APOLLO ACCIDENT

HEARING

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

ON

A REVIEW OF BACKGROUND INFORMATION AND SYSTEMS DECISIONS PRECEDING THE APOLLO ACCIDENT OF JANUARY 27, 1967

FEBRUARY 7, 1967

PART 1—WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE
74-521 WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 20 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota

MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

ALPHABETICAL LIST OF WITNESSES

APOLLO ACCIDENT

TUESDAY, FEBRUARY 7, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met in executive session, pursuant to notice, at 2:25 p.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Symington, Stennis, Young, Dodd, Cannon, Holland, Mondale, Smith, Hickenlooper, Curtis, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Craig Voorhees, Dr. Glen P. Wilson, and William Parker, professional staff members; Sam Bouchard, assistant chief clerk; Mary Rita Robbins, clerical assistant, and Howard Bray, press secretary to Senator Anderson.

[The following testimony was taken in executive session. The record was reviewed and the committee agreed without objection to its publication. Further, the National Aeronautics and Space Administration interposed no objection to its publication. Therefore, with the exception of minor editorial corrections, it is printed here in its entirety.]

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The hearing will come to order.

This is the first meeting between the National Aeronautics and Space Administration and the Senate Committee on Aeronautical and Space Sciences since the tragic accident which occurred on pad 34, Kennedy Space Center, on January 27, 1967. It is an executive session of the committee; therefore, only a majority of the members can authorize publication, in whole or part, of the testimony about to be taken.

Dr. Seamans, I hope you will take this opportunity to bring the committee up to date on the NASA investigation and to review the following:

1. The basic decision by NASA to use a pure oxygen atmosphere inside the Apollo command module and the safety procedures in effect during testing and operation.
2. Changes contemplated in the Apollo program as a result of the accident including changes in testing procedures, schedules and costs.

The first area will give the committee an opportunity to learn and develop the facts about pure oxygen atmospheres versus dual gas atmospheres.

With regard to the second area, we do not expect wholly definitiv answers at this time; but I would appreciate your discussing possibl or contemplated changes with the committee. As you know, ther is much public discussion about the effect of the accident on th program and I would hope you will set the record straight for th committee.

I want to emphasize to the witnesses that this committee does no want to interfere with the work of NASA's board of inquiry and, as w see it now, we will not. There are, however, many aspects of the acci dent and the Apollo program that can be discussed without hamperin the work of the board of inquiry and it is the responsibility of thi committee to develop the facts surrounding the accident and th impact of that accident on the Apollo program as swiftly as we ca

Suggested procedures and guidelines for the committee with respe to its handling of its review of the recent Apollo accident were issued t members February 1, 1967, and no adverse comment regarding the has been received. Therefore, the committee might consider that th guidelines are operative. I will place a copy of those procedures an guidelines in the record at the conclusion of my statement.

I have asked that the staff review the transcript of this hearing i conjunction with the members of the committee and NASA with th view to publishing it in its entirety or as much of it as possible at a early date. At the conclusion of this meeting today, or at anoth time, I will put that question to the committee for a vote as requir by the rules.

With the approval of the committee, the ranking minority memb and I will meet with the press, if the press desires, immediately aft this afternoon's hearing. Dr. Seamans and Dr. Mueller have agre to be available for that meeting.

(The procedures and guidelines for the committee referred to are follows:)

SUGGESTED PROCEDURES AND GUIDELINES FOR THE COMMITTEE DURING ITS REVI OF THE APOLLO ACCIDENT

1. The purpose of the Space Committee's inquiry with respect to the rec Apollo accident is—

(a) To establish the facts related to the accident.

(b) To insure that the formal NASA inquiry is conducted with compl objectivity.

(c) To establish the validity of any recommendations to prevent recurrence.

(d) To review such other aspects of NASA's stewardship of the Apo Program which may be necessary in order to accomplish the forego objectives.

2. The Committee's inquiry will in no way interfere with the proceedings of NASA Board of Inquiry.

3. The Committee will request that it be kept informed with respect to a interim findings or conclusions made by the Board of Inquiry during the progr of the Board's review.

4. While the Committee does not wish to inhibit any of its members from m ing personal statements in connection with the accident, any formal statem relative to the Committee's inquiry should be made by the Chairman and rank minority member.

5. The staff will keep advised of all developments, assemble data pertinent the accident, and identify areas of particular interest and/or controversy s

rounding the accident during the period that NASA's Board of Inquiry is conducting its investigation. During this period, however, the staff will in no way become involved in the Board's deliberations or interfere with the conduct of the Board's responsibility.

6. The Committee will request from NASA all reports of the Board of Inquiry and such other supporting data as may be necessary for the Committee to conduct its review.

7. Decisions on hearings, the substance thereof, and whether such hearings should be open or executive shall be held in abeyance pending developments in the NASA investigation and the nature of its findings.

The CHAIRMAN. Go right ahead, Dr. Seamans.

STATEMENTS OF DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NASA; DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR, OFFICE OF MANNED SPACE FLIGHT, NASA; DR. CHARLES A. BERRY, CHIEF OF CENTER MEDICAL PROGRAMS, MANNED SPACECRAFT CENTER, NASA; AND RICHARD S. JOHNSTON, CHIEF OF CREW SYSTEMS DIVISION, MANNED SPACECRAFT CENTER, NASA; ACCOMPANIED BY DALE H. MYERS, VICE PRESIDENT, SPACE AND INFORMATION DIVISION, AND APOLLO PROGRAM MANAGER, NORTH AMERICAN AVIATION, INC.; CHARLES D. FELTZ, DEPUTY APOLLO PROGRAM MANAGER, NORTH AMERICAN AVIATION, INC.; R. L. CALLAGHAN, OFFICE OF LEGISLATIVE AFFAIRS; ROBERT FREITAG, OFFICE OF MANNED SPACE FLIGHT; FRANK MAGLIATO, OFFICE OF EXECUTIVE SECRETARY AND JULIAN SCHEER, PUBLIC AFFAIRS OFFICE, NASA

Dr. SEAMANS. Mr. Chairman, members of the committee, I should like to introduce the discussion this afternoon by summarizing our policy on the review of accidents, by highlighting the events that have taken place since the occurrence of the accident on January 27, by outlining the procedures and actions of the Apollo 204 review board, and by laying out the approach we are taking in integrating the findings of the board and the recommendations of the Apollo program office into a pattern of decisions for the on-going program.

It is NASA policy to conduct thorough and detailed investigations of any serious accident or failure. This applies to our extensive program of ground testing as well as to flight operations—to aeronautical as well as space activities. We have established especially strict investigative and reporting procedures covering incidents of injury or death or significant damage to facilities or equipment. In certain cases, such as the Apollo 204 accident, the Office of the Administrator establishes a review board with board powers and responsibilities to investigate the circumstances and to recommend corrective or other action based upon the board's findings. As you know, it is this latter course that we have followed in the case of the Apollo 204 accident. I have available here copies of the management directive under which the present board was established.

The CHAIRMAN. Without objection, it will be placed in the record.

(The management directive above referred to follows:)

APRIL 14, 1966.

MANAGEMENT INSTRUCTION

Subject: Mission Failure Investigation Policy and Procedures.

1. PURPOSE

This Instruction establishes the policy and procedures for investigating and documenting the causes of all major mission failures which occur in the conduct of NASA space and aeronautical activities.

2. APPLICABILITY

This Instruction is applicable to NASA Headquarters and field installations.

3. DEFINITIONS

For the purpose of this Instruction, the following term shall apply: In general, a failure is defined as not achieving a major mission objective.

4. POLICY

a. It is NASA policy to investigate and document the causes of all major mission failures which occur in the conduct of its space and aeronautical activities and to take appropriate corrective actions as a result of the findings and recommendations.

b. The Deputy Administrator may conduct independent investigations of major failures in addition to those investigations required of the Officials-in-Charge of Headquarters Program Offices as set forth in paragraph 5a.

5. PROCEDURES

a. Officials-in-Charge of Headquarters Program Offices are responsible, within their assigned areas, for—

(1) Informing promptly the Deputy Administrator of each major failure and apprising him of the nature of the failure, status of investigations, and corrective or other actions which are or will be taken.

(2) Determining the causes or probable causes of all failures, taking corrective or other actions, and submitting written reports of such determinations and actions to the Deputy Administrator.

b. When the Deputy Administrator decides to conduct an independent investigation, he will—

(1) Establish a (name of project) Review Board, comprised of appropriate NASA officials;

(2) Define the specific responsibilities of each Board, encompassing such tasks as—

(a) Reviewing the findings, determinations and corrective or other actions which have been developed by contractors, field installations and the Official-in-Charge of cognizant Headquarters Program Office and presenting the Board's conclusions as to their adequacy to the Deputy Administrator.

(b) Reviewing the findings during the course of investigations with cognizant field installation and Headquarters officials.

(c) Recommending such additional steps (for example additional tests) as are considered desirable, to determine the technical and operational causes or probable causes of failure, and to obtain evidence of nontechnical contributing factors.

(d) Developing recommendations for corrective and other actions based on all information available to the Board.

(e) Documenting findings, determinations and recommendations for corrective or other actions and submitting such documentation to the Deputy Administrator.

c. Procedures for implementing the Board's recommendations shall be determined by the Deputy Administrator.

6. CANCELLATION

NASA Management Manual Instruction 4-1-7 (T.S. 760), March 24, 1964.

ROBERT C. SEAMANS, Jr.,
Deputy Administrator.

Dr. SEAMANS. At the time of the Apollo accident, the majority of the NASA and Apollo senior management were meeting with the combined group of the Gemini and Apollo executives. This 2-day meeting had been scheduled for January 27 and 28 to permit the senior members of the industrial organizations charged with the execution of the Apollo program to hear, firsthand, the experience, problems, and solutions that had been developed during the recently completed Gemini effort. This important management discussion continued on Saturday, January 28, although General Phillips, Dr. Gilruth, and Dr. Debus had left Friday evening for Cape Kennedy as soon as the extent of the accident became known to us in Washington.

IMMEDIATE STEPS TAKEN

Once at the cape, General Phillips took a number of immediate steps: He impounded all the data possibly relevant to the accident. This included the recorded test information, the spacecraft and launch vehicle, and such other records as were known to exist. This step was taken to assure that no information would be lost, changed, or released without being assessed in the light of other available data.

He established a careful security control over these data which has permitted the board to proceed smoothly with confidence that they have available for their review all the information pertinent to their work. General Phillips also examined the site of the accident, assured that all immediate safety precautions had been taken, and interviewed the eyewitnesses and test personnel in order to assess the contributions they could make to the work of the board and, if possible, obtain an indication as to the cause of the disaster. It was on the basis of these first impressions and actions, and without having had an opportunity to analyze the recorded data, that he reported on Saturday morning to the press those facts which he considered most pertinent to an understanding of the accident.

REVIEW BOARD SELECTED

During Friday evening, it was decided at NASA headquarters to establish a review board to report to the NASA Administrator. Dr. Floyd L. Thompson, the Director of the Langley Research Center, was selected as chairman. He accepted the assignment Saturday morning and agreed to fly immediately to the Kennedy Space Center. As a senior center director, he brings a wealth of experience and knowledge to this task.

Additional members of the board were selected during the day and their appointments were announced as they were made. The initial documentation establishing the board was developed during Saturday, January 28, and a copy of that memorandum is available for your information, which I shall be happy to submit for the record.

74-521—67——2

The CHAIRMAN. Without objection, it will be placed in the record.
(The memorandum referred to follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
Washington, D.C., January 28, 1967.

MEMORANDUM FOR THE APOLLO 204 REVIEW BOARD

1. The Apollo 204 Review Board is hereby established in accordance with NASA Management Instruction 8621.1, dated April 14, 1966, to investigate the Apollo 204 accident which resulted in the deaths of Lt. Col. Virgil I. Grissom, Lt. Col. Edward H. White and Lt. Cmdr. Roger B. Chaffee on Launch Complex 34, on January 27, 1967.
2. The Board will report to the Administrator of the National Aeronautics and Space Administration.
3. The following are hereby appointed to the Board:
   Dr. Floyd L. Thompson, Director, Langley Research Center, NASA, Chairman
   Lt. Col. Frank Borman, Astronaut, Manned Spacecraft Center, NASA
   Maxime Faget, Director, Engineering & Development, Manned Spacecraft Center, NASA
   E. Barton Geer, Associate Chief, Flight Vehicles & Systems Division, Langley Research Center, NASA
   George Jeffs, Chief Engineer, Apollo, North American Aviation, Inc.
   Dr. Frank A. Long, PSAC Member, Vice President for Research and Advanced Studies, Cornell University
   Col. Charles F. Strang, Chief of Missiles & Space Safety Division, Air Force Inspector General, Norton Air Force Base, California
   George C. White, Jr., Director, Reliability & Quality, Apollo Program Office, Headquarters, NASA
   John Williams, Director, Spacecraft Operations, Kennedy Space Center, NASA
4. George Malley, Chief Counsel, Langley Research Center, will serve as counsel to the Board.
5. The Board will—
   a. Review the circumstances surrounding the accident to establish the probable cause or causes of the accident, including review of the findings, corrective action, and recommendations being developed by the Program Offices, Field Centers, and contractors involved.
   b. Direct such further specific investigations as may be necessary.
   c. Report its findings relating to the cause of the accident to the Administrator as expeditiously as possible and release such information through the Office of Public Affairs.
   d. Consider the impact of the accident on all Apollo activities involving equipment preparation, testing, and flight operations.
   e. Consider all other factors relating to the accident, including design, procedures, organization, and management.
   f. Develop recommendations for corrective or other action based upon its findings and determinations.
   g. Document its findings, determinations, and recommendations and submit a final report to the Administrator which will not be released without his approval.
6. The Board may call upon any element of NASA for support, assistance, and information.

ROBERT C. SEAMANS, Jr.,
Deputy Administartor.

Dr. SEAMANS. After the initial meetings of the board, it was felt that some change in membership would be appropriate. Those changes, and expanded instruction to the chairman, were documented in a memorandum of February 3, which is also available here for submission to the committee.

The CHAIRMAN. Without objection, that will be included in the record.

(The memorandum of February 3, referred to, follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
Washington, D.C., February 3, 1967.

MEMORANDUM FOR THE APOLLO 204 REVIEW BOARD

1. The Apollo 204 Review Board was established on January 28, 1967, in accordance with NASA Management Instruction 8621.1, dated April 14, 1966, to investigate the Apollo accident which resulted in the deaths of Lt. Col. Virgil I. Grissom, Lt. Col. Edward H. White, and Lt. Comdr. Roger B. Chaffee on Launch Complex 34, on January 27, 1967. In order to reflect the current Board membership and to provide further guidance to the Chairman in the conduct of his duties, this memorandum supersedes that of January 28, 1967.

2. The Board will report to the Administrator of the National Aeronautics and Space Administration.

3. The Following are hereby appointed to the Board:

Dr. Floyd L. Thompson, Director, Langley Research Center, NASA, Chairman

Col. Frank Borman, Astronaut, Manned Spacecraft Center, NASA

Maxime Faget, Director, Engineering & Development, Manned Spacecraft Ctr., NASA

E. Barton Geer, Associate Chief, Flight Vehicles & Systems Division, Langley Research Center, NASA

Col. Charles F. Strang, Chief of Missiles & Space Safety Division, Air Force Inspector General, Norton Air Force Base, California

George C. White, Jr., Director, Reliability & Quality, Apollo Program Office, Headquarters, NASA

John Williams, Director, Spacecraft Operations, Kennedy Space Center, NASA

Dr. Robert W. Van Dolah, Research Director for the Explosive Research Center, Bureau of Mines, Department of Interior

4. George Malley, Chief Counsel, Langley Research Center, will serve as counsel to the Board.

5. The Board will—

a. Review the circumstances surrounding the accident to establish the probable cause or causes of the accident, including review of the findings, corrective action, and recommendations being developed by the Program Offices, Field Centers, and contractors involved.

b. Direct such further specific investigations as may be necessary.

c. Report its findings relating to the cause of the accident to the Administrator as expeditiously as possible and release such information through the Office of Public Affairs.

d. Consider the impact of the accident on all Apollo activities involving equipment preparation, testing, and flight operations.

e. Consider all other factors relating to the accident, including design, procedures, organization, and management.

f. Develop recommendations for corrective or other action based upon its findings and determinations.

g. Document its findings, determinations, and recommendations and submit a final report to the Administrator which will not be released without his approval.

6. The following amplifies and documents the verbal instructions given to the Chairman, January 28, 1967:

a. The Chairman shall establish such procedures for the organization and operation of the Board as he finds most effective; such procedures shall be part of the Board's records.

b. Board members shall be appointed or removed by the Deputy Administrator after consultation with the Chairman as necessary for the Board's effective action.

c. The Chairman may establish procedures to assure the execution of the Chairman's responsibility in his absence.

d. The Chairman shall appoint or designate such representatives, consultants, experts, liaison officers, observers, or other officials as required to support the activities of the Board. The Chairman shall define their duties and responsibilities as part of the Board's records.

e. The Chairman shall keep the Deputy Administrator advised periodically concerning the organization, procedures, and operations of the Board and its associated officials.

f. The Chairman shall assure that the counsel to the Board develops and maintains memoranda records covering areas of possible litigation.

7. The Board may call upon any element of NASA for support, assistance, and information.

ROBERT C. SEAMANS, Jr.
Deputy Administrator.

CAUSE NOT YET FOUND

Dr. SEAMANS. The board is charged with the specific task of establishing the probable cause or causes of the accident. As I have noted in my recent report to Mr. Webb, which has been submitted to this committee, the cause has not yet been found and is expected to require a detailed and painstaking evaluation of the physical evidence—that is, of the spacecraft and its support systems.

(The report to Mr. Webb referred to follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
Washington, D.C., February 3, 1967.

Memorandum to: Mr. James E. Webb, Administrator.
From: Robert C. Seamans, Jr., Deputy Administrator.
Subject: Report on Apollo 204 Review Board Discussions.

I spent yesterday at the Kennedy Space Center with the Apollo Review Board and other key personnel involved in the current investigation of the causes and circumstances of the Apollo 204 accident.

First, there has been no determination of the specific cause of the fire that resulted in the deaths of Lt. Colonel Grissom, Lt. Colonel White, and Lt. Commander Chaffee. The retracing of possible, and then of probable, chains of events in such an accident is a complex task that is demanding the complete attention of the Review Board headed by Dr. Floyd Thompson, of the assistants and consultants to the Board, and of many of the elements of government, industry, and universities involved in the Apollo program.

The Board is taking full advantage of the extensive taped data available as well as records made prior to the accident, the present condition of the spacecraft, and the reports of those involved in the test. All the physical evidence and data concerned with the test were impounded immediately following the accident. This was to assure that no pertinent information would be lost and that no actions would be taken except in the full context of all the data available.

As I have stated, the preliminary review of this information has not provided any direct indication of the origin of the fire; the preliminary analyses point to the conclusion that a clear identification of the source of ignition or of its possible source will depend upon detailed step-by-step examination of the entire spacecraft and its related test support equipment.

At present, the spacecraft is still mated to the unfueled launch vehicle at the pad. However, it is being prepared for removal to our industrial area where it will be disassembled and where experts in many technical and scientific areas can work with the physical evidence. Prior to disassembly of the damaged spacecraft, an undamaged and nearly identical (#014) spacecraft will be used to establish the conditions existing prior to the accident. The 014 spacecraft was flown from the North American plant in Califorina to Cape Kennedy on February 1.

The current plans are to go through a parallel, step-by-step disassembly process, first working on the undamaged vehicle and then repeating as closely as possible the procedure on the damaged vehicle.

In addition to analyses of recorded and physical data and equipment, the Board is defining a series of investigative tasks and is assigning these to teams for execution. For example, a team is charged with the chemical and spectrographic analysis of damaged elements aimed at identifying the propagative history of the fire. Another is working on relating the propagation history to the flammability characteristics of the spacecraft materials. Another is dealing with design analyses and experimental tests to help establish possible ignition sources. As work progresses and a pattern of information emerges, additional tasks, analyses, and reviews will undoubtedly be instituted by the Board.

From information now available to the Board, I had an opportunity to learn more about certain specific aspects of the simulated mission and the test sequence itself than we had previously had before us in a clearly related pattern.

At 6:31:03 pm EST the fire was first detected. The mission was holding at T-10 minutes. Up to this time there had been only minor difficulties with the equipment. The purpose of the hold was to provide an opportunity to improve the communications between the spacecraft and the ground crew.

Up to this time the cabin pressure, the cabin temperature, and the oxygen suit supply temperature were nominal. The oxygen rate of flow into the suits had shown an increase 4 seconds prior to this time but we have not been able to relate this to the accident.

Lt. Col. White was the only astronaut instrumented for heart rate and respiration. His heart rate had shown an increase 40 seconds prior to this time, but at 6:31:03 his heart was at the normal level for him when in a relaxed prone position.

The spacecraft was operating on external power. Earlier in the day, at 9:30 a.m. EST, the system for transfer from external (ground) power to simulated internal (spacecraft) power had been tested, and operated normally. The fuel cells in the service module were not in use, and the so-called internal power was being supplied by batteries having the same characteristics as the fuel cells but located external to the spacecraft. If the accident had not occurred, the transfer from external to simulated internal power would have taken place on resumption of the count.

> At the press conference on Saturday morning, Apollo Program Director S. C. Phillips was asked whether the spacecraft was on internal or external power when the fire occurred. At that time he did not realize that the spacecraft was still on external power since he had in mind primarily the eyewitness reports. Subsequent examination of the data has established the above power supply sequences. There is no evidence up to this time that the source of power whether simulated internal or external was related to the accident.

Lt. Colonel Grissom was the command pilot, sitting in the left seat; Lt. Colonel White, the senior pilot, sitting in the middle seat; and Lt. Commander Chaffee, the pilot, was in the right seat. In the event of emergency, the procedure is for the senior pilot (White) to reach high over his left shoulder to actuate the inner hatch release handle. The command pilot (Grissom), after lowering the center headrest, aids the senior pilot in lifting the inner hatch and removing it to the floor of the spacecraft. The main duty of the pilot (Chaffee) during this procedure is to maintain communication and assist in the removal of the inner hatch if needed. From the following data, you will note that the crew appeared to follow the correct procedure.

At 6:31:03, Pilot Chaffee reported that a fire existed in the spacecraft. At about this time Senior Pilot White's heart rate started to increase. At 6:31:04 the inertial platform in the capsule gave an indication of a small amount of motion which may have been caused by movement of the crew. At 6:31:05 the cabin temperature began to rise. At 6:31:09 Senior Pilot White repeated the previous report saying that there was a fire in the cockpit. At the same time the cabin pressure commenced to rise and a larger amount of motion was indicated by the inertial platform. This means that the crew were commencing their emergency egress procedure.

At 6:31:12, or nine seconds after the first indication of fire, the cabin temperature started to increase rapidly and pilot Chaffee reported that a bad fire existed in the cabin. Also at this time pilot Chaffee increased the illumination of the cabin lights and actuated the entry (internal) batteries. No other intelligible communications were received although some listeners believe there was one sharp cry of pain. Loss of radio signal occurred a few seconds later.

The oxygen supply to the astronaut suits, which had been holding nearly constant, pressure and temperature started to fluctuate at the time of signal loss. At 6:31:17 or fourteen seconds after the fire was first detected, the cabin pressure reached a level of approximately 29 psi and the cabin ruptured.

One and one-half minutes after the start of the fire, the ground power was switched off. Various command module systems continued to operate on the entry (internal) battery power until about 12:30 am EST on Saturday when the batteries ran down.

The official death certificates for all three crew members list the cause of death as asphyxiation due to smoke inhalation due to the fire.

I would like to emphasize that this report is based on preliminary information. This information has not as yet been extensively analyzed by the Apollo Review Board under Dr. Thompson. Since the data were recorded at a number of different stations, the time sequences may not be perfectly synchronized, possibly giving rise to errors of one or two seconds.

During my meetings with the Board a number of other items of information were discussed but I believe that the data I have outlined include all events having a significant bearing on an understanding of the accident.

ROBERT C. SEAMANS, JR.

DUTIES OF THE BOARD

Dr. SEAMANS. The board is charged with reporting its findings as to the cause of the accident as expeditiously as possible; it is further charged with developing recommendations for corrective or other actions based upon its findings and determinations. The final report, which I feel will take a considerable time to prepare, will be made available to the committee as requested in the chairman's letters of January 31.

In order to collect the relevant information, and to conduct the appropriate analyses and tests, the board's effort has been organized into a discrete number of tasks, each of which is to be performed by a task group made up of the appropriate Government and contractor personnel. Each panel is chaired by a NASA employee who is the most knowledgeable for the task. The board members act as panel monitors and points of contact with the board for those panels assigned to them.

In addition to the panels noted in my report to Mr. Webb, other panels are working in the areas of test procedures, witness statements, emergency procedures, and spacecraft disassembly activities. The board will continue to assign new tasks to the panels as the need becomes evident.

The board itself meets in both regular and executive session. In the regular sessions those consultants, panel members, and program officials that are appropriate are present to present their plans and schedules for forthcoming activity and to report upon the results attained to date. These daily meetings are held in a secure area and are carefully documented since they will form the basis of the board's final report. The board also meets in executive session so that matters requiring guidance to the panels from the board can be freely discussed and a responsible course of action developed, and also so that sensitive developments can be treated appropriately.

I would like to note that Col. Charles F. Strang, from the Safety Division of the Air Force Inspector General, is a full member of the board. Colonel Strang is an able and experienced officer and we are fortunate to have his talents available to us. At present, he will act for the chairman in the event Dr. Thompson is absent.

The Bureau of Mines of the Department of the Interior has provided us another board member—Dr. Robert Van Dolah, an expert in explosive research and fire propagation. Together with the team he has brought together, he represents a major asset in the identification of the source of ignition and the cause of the accident.

We have asigned a chief legal counsel to the board to advise it during its deliberations.

The Eastern Test Range of the U.S. Air Force is providing many important services during the investigation. They have provided a full-time representative to the board who is assisting in interviewing the many witnesses who may have information needed by the board. The board is also closely coordinated with the Air Force investigative board examining the Brooks space simulator accident. In addition, an Air Force observer associated with their manned flight effort is present at all regular meetings.

ALTERNATIVES CONSIDERED

In parallel with the board investigation and review, the NASA Manned Space Flight Program Office, headed by Dr. George Mueller, who is here today, is continuing its assigned responsibilities in the Apollo program. Under the procedures I have described, this Office retains a major responsibility in the collection and analysis of accident data for use in its own assessment of the accident and the possible corrective actions that it may be required to take.

Various alternatives are reviewed for technical and operational feasibility. The Program Office is reviewing the impact of these alternatives upon schedules, budgets, and manpower requirements. This effort in no way detracts from the support being provided the board, which has priority in terms of trained manpower or data analysis.

Alternatives that must be considered include the choice of cabin and suit atmospheres, means for improving accessibility into and out of the cabin during ground test, procedures for minimizing the possibility of fires, and approaches to extinguishing fires if they should occur. Such design and study effort are fundamental to the question of the tradeoffs that must be assessed as we go forward.

As you know, a majority of this effort is carried out by the industrial team supporting Apollo. Because of the number of people involved as these alternatives are examined and developed, it is not possible to assure that they will not become known outside of the agency and may even be reported as reflecting various categories of management decisions. We are doing all we can to release appropriate data as promptly as it can be properly verified and related to the main purpose of our effort—to understand what happened and the causes.

I wish to assure that no major decisions concerning the steps we may find it necessary to take have been made at this time. Mr. Webb, Dr. Mueller, and I will not make these decisions until the findings of the Board have been reported to the Administrator and we have had time to carefully consider all factors. NASA will provide authoritative information to this committee on any such decison prior to its announcement.

UNMANNED FLIGHTS TO CONTINUE

We have already advised this committee that we are continuing with the unmanned Apollo flight program on the schedule that was prepared before the 204 Apollo accident.

This refers to one flight on the uprated Saturn and two flights on the Saturn V.

We will not, however, undertake another manned flight or total systems simulation until we have ascertained to the best of our ability the conditions that have led to this accident, and until we are assured that all corrective and preventive measures available to us have been adequately analyzed and evaluated, and that appropriate actions have been taken. As we have consistently maintained in the past, the safety of our astronauts is and will be a prime consideration in all we do. Both President Kennedy and President Johnson have strongly supported us in this position, instructing us to "launch when ready, but *only* when ready."

We can assure this committee that we will press to meet specific flight targets only when we are assured of that readiness.

That completes my statement, Mr. Chairman.

The CHAIRMAN. Does the committee mind if we hold our questions and have Dr. Mueller's statement now?

Senator HOLLAND. Mr. Chairman, I shall yield to senior members, but I have one question I would like to ask when they are concluded.

The CHAIRMAN. Then we will have one more statement.

Dr. SEAMANS. Mr. Chairman, Dr. Berry was planning to make a detailed statement on the environmental control system, and Dr. Mueller was going to sum up our plans for the future.

Mr. GEHRIG. Whom do you want to go next?

Dr. SEAMANS. Dr. Berry.

The CHAIRMAN. Dr. Berry will go next, then.

You may ask your question now, Senator Holland.

Senator HOLLAND. Yes.

I notice in your statement, you indicate that contractor personnel are included in your board. Do you mean contractor personnel of the contractors who produced the space capsule that was involved in the accident?

Dr. SEAMANS. No; they are not included on the board, Senator Holland, but they are included in the effort to determine the cause and analyze the data. They are also included on our task force teams. These teams are preparing special information as requested by the board.

Senator HOLLAND. Are these contractor personnel from the contractors which produced the material that is in question or from other contractors?

Dr. SEAMANS. These are personnel from North American and other contractors who are involved in the Apollo program.

Senator HOLLAND. But solely from those involved in that program?

Dr. SEAMANS. Almost solely. We do have working with us as an adviser, Mr. Yardley from the McDonnell Co., because of his past experience.

Senator HOLLAND. Well, there is only one other question that occurs to me, Mr. Chairman.

I noticed that in a later part of the statement, you said that because of the inclusion of some contractor personnel, information might get out on some points which would not come from the board itself. Would you say that a little more fully?

Dr. SEAMANS. Yes. I did not mean to imply that contractor people were more or less reliable than Government people. I meant to imply that there are a very large number of people in this country who are preparing special information for the board and because of this, and because of the very great press interest, there may from time to time be information that appears to indicate that we have actually decided to adopt some of the alternatives we are investigating.

I want to assure the committee that this will not be so unless we have already discussed that possibility with the committee and indicated our plans to proceed with that particular alternative.

We are asking for your forbearance, Senator Holland, as you read the newspapers concerning what we are actually doing, and asking you to rely on information that is provided officially by NASA, either before this committee or in our press releases.

Senator HOLLAND. Well, I have implicit confidence in such NASA personnel as you will assign to this task, and I would take it from your statement that you think that there is some opportunity for matters to become public before they will have been passed upon by the board and before they are really official.

Dr. SEAMANS. Yes. Unfortunately, the experience of the past 10 days would indicate that this can and does happen.

Senator HOLLAND. Thank you, sir.

The CHAIRMAN. Dr. Berry?

BACKGROUND OF SPACECRAFT ATMOSPHERE

Dr. BERRY. Senator Anderson and members of the committee, I would like to review some of the background surrounding spacecraft atmosphere used in the U.S. manned space program.

The spacecraft atmosphere used in the U.S. manned space program has been based on extensive research and development covering the engineering, medical, and safety aspects of such a system. While the bulk of the research has been over the past 10 years, considerable work relating to the use of 100-percent oxygen in aircraft was done much earlier.

Work relating to single and multiple gas atmospheres has been done in the United States and abroad by government, university, and industrial investigators. Probably one of the most authoritative compilations of this research is contained in a four-part series on "The Selection of Space-Cabin Atmospheres," prepared for NASA by Dr. E. Roth of the Lovelace Foundation for Medical Education and Research, Albuquerque, N. Mex.[1]

GENERAL CONSIDERATIONS IN THE SELECTION OF SPACECRAFT ATMOSPHERE

Before discussing the specific aspects of the spacecraft atmospheres used in Mercury, Gemini, and Apollo, the general considerations relating to spacecraft atmosphere should be reviewed. There are many considerations in the selection of an atmosphere for manned spacecraft. The optimum atmosphere, from a physiological point of view, would be one which is identical with that here on earth, thus, removing any concern about variables in reviewing our flight data. However, practical engineering and physiological considerations relating to weight, volume, and possible decompression demand compromises in our selection of the actual atmosphere. Ideally, the atmosphere should represent an optimized mixture from the standpoint of physiologic support, system

[1] Pts. III and IV of this series have not yet been published.

reliability, ease of entering and leaving the environment for extravehicular work, and reduced combustion propagation characteristics.

The important physiological and engineering considerations in the practical choice of an atmosphere are as follows:

1. The most important consideration is the provision of sufficient oxygen content to support life and prevent hypoxia. The lower limit is determined by the desire to keep the partial pressure of oxygen as close as possible to the sea level equivalent of 21 percent of 1 atmosphere pressure.

Senator SYMINGTON. What is the technical meaning of hypoxia?

Dr. BERRY. That means a reduced amount of oxygen, Senator Symington. It is just a reduced amount of oxygen available to the body.

Senator SYMINGTON. Thank you.

Dr. BERRY. The amount of oxygen available to the body is determined by the partial pressure of oxygen in the lungs, as this is the only area where oxygen can enter the blood. When the environmental gas enters the air passages, it becomes saturated with water at body temperature—98° F. Upon reaching the lungs, the gas then equilibrates with the partial pressure of carbon dioxide in the lung blood vessels. In this manner the body eliminates metabolic CO_2. When determining the pressure of lung oxygen, the values for water, carbon dioxide, and any inert gas must be deducted from the total inspired gas pressure.

The primary objective in any atmosphere selection is to maintain the partial pressure of oxygen in the lungs as close as possible to that normally found on earth—104 millimeters Hg. This creates a requirement for a minimum oxygen partial pressure in a spacecraft atmosphere of approximately 3.5 pounds per square inch absolute.

If the partial pressure of oxygen in the lungs rises markedly above the normal earth level for long time periods, the increase can cause clinical symptoms due to the irritation of mucous membranes and may possibly affect the functioning of various enzyme systems. Oxygen is absorbed readily from temporarily occluded spaces such as the middle ear and sinuses. The severity is directly related to partial pressure of oxygen and duration of exposure. The possibility of oxygen toxicity then determines pressure exposure time limits.

2. Dysbarism or the effects on the body from reduced atmospheric pressure may produce symptoms ranging from bends—joint pain—to central nervous system involvement with collapse. This may be initiated by pressure decreases in a multigas system, or in transition from a normal atmosphere to a pure oxygen environment at reduced pressures. In order to prevent dysbarism, it is necessary to prebreathe 100-percent oxygen prior to reducing the pressure.

3. Occlusion of bronchi and absorption of trapped gas—oxygen—may lead to collapse of the air sacs—atelectasis. Respiratory distress may result with accompanying disturbances in gas exchange and blood oxygenation. In addition, atelectasis provides an ideal condition for the initiation of an infectious process—pneumonitis.

4. Crew comfort on a long mission which is significantly affected by continued suit operation in either a pressurized or unpressurized cabin. This consideration is also a function of confidence in cabin integrity and expected emergency decompression rates. Our experience in the 2-week Gemini VII flight demonstrated the advantages to the crew of being able to doff suits for extended periods of time. Outside of their

pressure suits, the Gemini VII crew were more comfortable, slept better, and were considerably more effective in their orbital duties.

5. Total operating pressure, which affects spacecraft structural design as well as dysbarism potential in event of spacecraft decompression in normal or emergency operations.

6. Space suit operating pressure which has significant effects on suit design, crew mobility in unpressurized cabin and extravehicular physiological stress levels. Suit pressure levels exceeding 3.5 pounds per square inch absolute result in increasingly severe space suit rigidity. Based on the experience obtained in Gemini extravehicular activity—EVA—it is clear that the suit forces, directly related to suit operating pressure, play a dominant role in the execution of EVA tasks. High pressure means high suit forces which result in lack of mobility and a high energy expenditure to accomplish even simple tasks.

7. Differences between cabin atmosphere and suit atmosphere constituents which could produce the possibility of the lack of sufficient oxygen, called hypoxia, in the event of minor system malfunction or interaction.

8. The hardware complexity of the environmental control system design which is a function of its atmosphere constituents. This extends to consideration of oxygen uses for purposes other than life support. For example, a single oxygen supply can be used to supply oxygen for both the fuel cells and the life support system. This was done for Gemini spacecrafts 7 through 12 and is the case for Apollo. This provides greater flexibility in the management of expendables by the crew and materially improves the mission reliability and safety in the presence of unexpected situations.

9. The reliability of measuring and controlling the partial pressures of constituent elements of a multigas system. More complex measurement and control systems must be used for a two-gas atmosphere as compared to simply controlling the pressure of an oxygen atmosphere. At the time of initial Apollo development, no multigas system suitable for space flight had even been demonstrated. A long development period which might have paced the entire program was avoided by drawing on the technology and experience gained in Mercury and Gemini using a 100-percent oxygen system.

SELECTION OF ATMOSPHERE FOR PROJECT MERCURY

The development of the Project Mercury spacecraft and its subsystems was initiated with a basic design philosophy of simplicity and utilization of the state-of-the-art technology.

The life sciences area was no exception to this general guide. The selection of the Mercury atmosphere was based largely on the experience generated in the aeromedical support of military high performance jet aircraft and the man-high balloon flights.

In the 1950's there was a general shift in aircraft breathing oxygen supplies away from diluter demand type oxygen systems—air and oxygen—to systems which employed 100-percent oxygen. The U.S. Navy, for example, in the mid-1950's, switched completely to a miniature oxygen regulator which provided only 100-percent oxygen to either a mask breathing system or for full pressure suit operation.

The general requirements for the Mercury environmental control systems were established for a 5 pounds per square inch absolute cabin pressure in which 100-percent oxygen would be provided for breathing. The selection of this atmosphere was basically a tradeoff between oxygen toxicity, hypoxia, spacecraft leakage, and weight. The following excerpt from a Mercury report summarizes the atmospheric selection discussion:

> In the development of the environmental system, simplicity of design was a very important consideration, primarily because of reliability requirements and also because of critical delivery requirements. In view of these requirements, a decision to use an artificial atmosphere composed of essentially 100 per cent oxygen rather than a more complex mixed gas system was made early in the program.
>
> Due to the O_2 environment in which man has always lived, his evolutionary processes have adapted him well to our atmospheric concentration. Man can tolerate some deviation from his natural environment and research has attempted to demonstrate these limits.
>
> It has been established that if a man is to breathe 100 per cent oxygen, his limits would be between 16,000 (412 mm.Hg) and 38,000 feet (155 mm.Hg) altitude depending upon the individual. The suitability of high oxygen concentrations at lower altitude has not been well established for extended periods of time. Since these are tolerances depending to a great extent upon individual differences for conservative operational purposes, we must reduce the range to limits which are approximately 20,000 (349 mm.Hg) to 33,000 (196 mm.Hg) feet altitude. This already narrows the possible pressure down to a 3 psi range.
>
> The total pressure required to keep most flight crew people out of the "bends"—susceptible altitude for at least up to a day is approximately 27,000 feet (258 mm.Hg). We are now in a range between 20,000 and 27,000 feet.
>
> Fire hazard becomes a more important consideration as the concentration of oxygen increases. The desire here would be to have as low a total pressure as possible. Since the minimum pressure desirable for the man is 258 mm.Hg or 27,000 feet, it was selected as the final capsule total pressure.
>
> This reduced pressure is very desirable because it avoids a high structural weight penalty for the capsule as well as minimizing leakage rates. The leakage rate becomes a very important item when replacement is from a stored supply.

Early in the Mercury program, a NASA Life Sciences Committee, chaired by Dr. W. R. Lovelace II, of the Lovelace Foundation for Medical Education and Research, Albuquerque, N. Mex., reviewed the medical requirements and approved the approach taken by the program.

MERCURY ENVIRONMENTAL CONTROL SYSTEM

The Mercury spacecraft environmental control system had a launch oxygen purge system. This system was so designed that when the spacecraft was launched, cabin gas was exhausted until an altitude of 27,000 feet—5 pounds per square inch absolute—was reached. At this altitude, the cabin relief valve sealed the cabin at this pressure. The launch purge supply worked as follows:

On the pad, air was present in the cabin. After launch, when the spacecraft passed 10,000 foot altitude, a flow of oxygen from a 1-pound supply was activated. This flow of oxygen enriched the cabin so that at 27,000 feet, the cabin composition was approximately 66-percent oxygen and 33-percent nitrogen.

LIFE SUPPORT SYSTEM TEST STARTED IN 1960

Manned tests on the life support system were started in April 1960. During the first test, the subject, Mr. North, of McDonnell, became unconscious due to hypoxia.

I would like to insert here that we are using the word, "hypoxia" rather than "anoxia," because it is the correct word, meaning a decrease in the amount of oxygen, and anoxia means a total lack of oxygen. We do not believe that occurred.

This incident occurred approximately 1 hour after the test. The cause of this failure was due to a nitrogen leak into the life support system suit loop. The nitrogen built up to a concentration where sufficient oxygen partial pressure was not available to maintain consciousness.

This initial failure was due to leaks in the instrumentation lines exterior to the space chamber and the suit loop system. Nine additional manned tests were subsequently conducted and the enclosed test summary from an official McDonnell report outlines subsequent problems in the maintenance of space suit oxygen partial pressure. This decrease in suit partial oxygen pressure was caused by negative delta pressure between the suit and cabin systems. In all of these and subsequent tests, oxygen partial pressure dropped in the space suit loop.

Based on these failures to maintain oxygen partial pressure levels at nearly 100 percent in the space suit loop, action was initiated to correct this situation. It was decided to remove the launch oxygen purge supply and provide a 100-percent cabin purge on the pad prior to launch. McDonnell Aircraft Corp. change No. 280(A) and 285 were issued. The following quotes are a summary of these changes:

280(A) Prelaunch Cabin Purge with Oxygen: Provide for purging the capsule with oxygen on the ground. Reason: To eliminate possibility of nitrogen concentration in the suit circuit. (Ground servicing change—improved system reliability). Effectivity: To support capsules Nos. 5, 7, 9 and up.

285 Removal of Launch-Purge Oxygen System: Remove launch-purge oxygen bottle assembly, tubing, purge valve, push-pull cable and attaching hardware. Reason: The capsule is purged on the pad thus eliminating the need for purging after launch. Effectivity: Capsule No. 10 and up.

The requirement for purging the cabin with pure oxygen at approximately 15 pounds per square inch during the prelaunch period of several hours has been continued for all manned spacecraft launched in this country. This same procedure has been used also on all manned spacecraft vacuum chamber tests in the Mercury, Gemini, and Apollo programs.

THE GEMINI ATMOSPHERIC HISTORY

The basic philosophy in the development of the Gemini spacecraft, its subsystems and operational plans were an extension of those developed in the Mercury project. The atmosphere selected was no exception. A 5 pounds per square inch absolute 100 percent oxygen environment was established for both the spacecraft cabin and space suit.

Efforts were taken to carefully screen materials used in the spacecraft to avoid inclusion of those items which would support combustion. Electrical systems were designed to provide protection from overload and subsequent sources of ignition. The spacecraft wiring insulation was changed to teflon to provide a vastly improved insulation material over that used in Project Mercury.

Special emphasis was taken to insulate wire bundles with teflon inserts on clamp retention points. Tests were conducted with total wire bundles to determine the effects of maximum electrical overloads. It was shown that no fires were produced, but in some cases there was insulation damage and wire rupture. Nonmetalic materials selected for Gemini were based on specification requirements of McDonnell Aircraft Report 6792.

Fire extinguishers were considered. Two general types were investigated—chemical or by inerting the combustible gas atmosphere. The chemical type was not considered practical for Gemini applications because it would not provide protection against fires in inaccessible locations such as behind the instrument panel.

Use of an inert gas extinguishing system coupled with an oxygen supply for the crew also was considered. Although gas inerting is much better than local type chemical extinguishers, from the fire standpoint, it does have certain disadvantages. It presents a crew safety hazard if the inert gas is advertently released when the crew is not protected with an oxygen supply.

Accordingly a fire extinguisher as such was not used in Gemini; instead, operational procedures were established in the event of fire while in orbit. These procedures include: deenergize main electrical buses, close the space suit plate, and decompress the cabin, isolate if possible the source of ignition and isolate if possible this electrical source, repressurize the cabin or prepare to reenter with the cabin decompressed. These procedures, of course, are applicable only if the crew is fully suited. If the crew had the helmet and gloves off at a time when smoke or fire is detected, it is recommended that they deenergize the main bus and common control bus, become fully suited, and follow the same procedure.

CAUSE OF ACCIDENT AS YET UNKNOWN

Senator SYMINGTON. Mr. Chairman, we were going to start at 3, and I have another hearing. Would it be in order to ask one question?

The CHAIRMAN. Go ahead, Senator Symington.

Senator SYMINGTON. Dr. Seamans, what do you think caused this accident?

Dr. SEAMANS. As yet, we have no way of knowing what started the accident.

Senator SYMINGTON. Thank you very much.

The CHAIRMAN. Dr. Berry, how much more do you have?

Dr. BERRY. About four more pages, I think, sir.

Senator YOUNG. May I ask a question?

The CHAIRMAN. Go ahead.

Senator YOUNG. Have you any opinion as to what caused this accident?

Dr. SEAMANS. Senator Young, I have been down to the Cape twice. I have been present at the board meetings. The board has not as yet found any indication of the cause of the fire.

ENVIRONMENTAL CONTROL SYSTEMS THE SAME IN MERCURY, GEMINI, AND APOLLO

Senator HOLLAND. Mr. Chairman, may I ask a question?

The CHAIRMAN. Yes.

Senator HOLLAND. I think I have understood you to say up to this time, Dr. Berry, that the environmental conditions inside this capsule at the time of the accident were the same as those that prevailed in Mercury and Gemini. Am I correct in that?

Dr. BERRY. Yes, sir.

Senator HOLLAND. Does that mean that the conditions were the same both as to the content of the oxygen and the pressure?

Dr. BERRY. Yes, sir. We have used this procedure since the beginning of the Mercury program.

Senator HOLLAND. And there is no change at this time?

Dr. BERRY. No, sir.

Senator HOLLAND. Thank you.

The CHAIRMAN. Go ahead.

APOLLO ATMOSPHERE SELECTION

Dr. BERRY. Apollo Atmospheric Selection. The original Apollo statement of work (August 2, 1961) specified a two-gas atmosphere composed of 50 percent oxygen and 50 percent nitrogen at a total pressure of 7 pounds per square inch absolute. This atmospheric composition was based on primarily physiological considerations. This physiological concern was primarily centered around the potential of pulmonary atelectasis—collapse of lung tissues. The potential of bends problems associated with the atmosphere and space suit operation at 3.7 pounds per square inch absolute was unknown at that time.

The Gemini project had selected a 5 pounds per square inch absolute 100 percent oxygen environment for use in these flights and accordingly a validation program was established to determine the human acceptability of this atmosphere for 14-day flights.

This test program was also design-initiated to resolve these physiological questions for both the Apollo and Gemini atmosphere selections—a 5 pounds per square inch absolutely 100 percent oxygen atmosphere was tentatively planned for the Gemini spacecraft at that time.

The program was carried out by the Republic Aviation Corp., Farmingdale, Long Island, N.Y., the U.S. Air Force School of Aviation Medicine, and the U.S. Navy Air Crew Equipment Laboratory under contract to NASA. The objective of these studies was to determine if exposure to a pure oxygen environment for extended periods of time would have detrimental effects on the health or performance of astronauts. A broad approach to the problems associated with pure oxygen at various barometric pressures in the absence of an inert gas was planned.

The overall test plans, objectives, medical protocols, et cetera, were reviewed and approved by a select committee of the National Academy of Sciences. Several meetings were held with these top specialists in atmospheric selection and controls to establish detailed test procedures.

The Republic Aviation Corp. contract was developed to study four groups of six subjects each exposed to 7.4 pounds per square inch absolute, 5 pounds per square inch absolute, and 3.8 pounds per square inch absolute pure oxygen as well as a control test at sea level conditions.

The U.S. Air Force School of Aviation carried out three investigations with the 100-percent oxygen 5 pounds per square inch absolute atmosphere in which six subjects were tests. These same tests were of 14-day and 30-day duration. In addition, a joint project involving the U.S. Navy Air Crew Equipment Laboratory and the U.S. Navy Aviation Medical Acceleration Laboratory was undertaken to study the combined effects on test subjects of acceleration and a 14-day exposure to a 100-percent-oxygen atmosphere at 5 pounds per square inch absolute.

Results of these three studies did indicate that, in general, the 5 pounds per square inch absolute 100 percent oxygen environment was well tolerated by all subjects for 14 days. The tests showed that a pre-oxygenation period of at least 3 hours was required to prevent bends in the event of a cabin decompression during or immediately following launch. Testing in the 5 pounds per square inch absolute 100 percent oxygen atmosphere indicated that it would not be a problem in the 2-week Apollo or Gemini missions.

During this period in the Apollo program, the lunar excursions module was approved as the lunar landing spacecraft. It was decided that since this was a 1-2-day spacecraft that a 5 pounds per square inch absolute cabin oxygen environment could be utilized to decrease spacecraft weight and increase system simplicity and reliability.

SINGLE GAS ATMOSPHERE

In July 1962 the question was raised as to why a single gas environment could not be considered for the command module. Based on preliminary results of the Gemini atmospheric validation program, it was stated that there was no apparent physiological reason for not changing to the single gas atmosphere. Accordingly, in August 1962, North American Aviation Corp. was directed to change to the single gas atmosphere.

Programs were established to screen materials for oxygen compatibility and special emphasis was made to install the electrical system and components to preclude sources of shorts which could cause ignition. The system design and operational philosophy followed that previously established for the Mercury project.

FLIGHT ATMOSPHERE FOR THE APOLLO APPLICATIONS PROGRAM

The Apollo applications program presently plans to use a 5 pounds per square inch absolute two gas atmosphere—69 percent oxygen, 31 percent nitrogen—only in the airlock module, S–IVB spent stage workshop, for planned mission durations in excess of 30 days. The 5 pounds per square inch absolute pressure level selected for the long duration missions was dictated by present Apollo pressure vessel capability and system compatibility considerations.

Present program plans continue the utilization of the standard Apollo pure oxygen environment in the command/service module and lunar modules which may be associated with the AAP missions. While the airlock module will have the capability for a two-gas system on the first AAP mission, present plans are to utilize the two-gas system for the second mission—up to 56 days. Pure oxygen atmosphere would be used on the first mission—up to 28 days.

The primary consideration in utilization of the two-gas system for long duration missions is a desire to avoid physiological uncertainties and the possibility of atelectasis.

FIRE HAZARDS IN THE SPACECRAFT ATMOSPHERE

The possibility of fire in any atmosphere has been understood throughout the program. In general, neither ignition temperature nor combustion rate is a strong function of oxygen partial pressure in the range from 3.5 pounds per square inch absolute to perhaps 7 pounds per square inch absolute.

However, at a fixed oxygen partial pressure, the propagation rate is a function of total pressure. Hence, for example, for a mixed gas with a constant 3.5 pounds per square inch absolute partial pressure, the combustion rate in a material such as cotton cloth could vary by as much as a factor of 5 from a total pressure of 3½ pounds per square inch to a total pressure of 16 pounds per square inch. In addition, the energy required to initiate combustion in materials may be significantly less in pure oxygen environments at pressure on the order of 1 atmosphere.

The approach to fire prevention is to prevent the initiation of combustion by attempting to remove all possible sources of ignition. Because these primarily involve heating of electrical or other components to temperatures approaching the ignition point of materials in the spacecraft, effort is directed toward assuring proper insulation, circuit design, and circuit protection to preclude excessive temperatures in the event of momentary system malfunctions. In addition, potentially flammable materials are removed from the immediate vicinity of electrical connectors and are spaced to prevent propagation of combustion.

Materials selected for use in the spacecraft cabin are carefully controlled. Both NASA and their contractors have carried out an extensive test program involving several hundred materials to determine their suitability for use in a pure oxygen atmosphere.

Investigations of the flammability characteristics of the materials used in the Apollo spacecraft were carried out by both the spacecraft contractors and various NASA laboratories. Each group has tested over 400 materials to determine their suitability for use in the spacecraft. From these tests and tests run for Mercury and Gemini, a list of acceptable materials has been established by a Material Review Board at Apollo Spacecraft Program Office.

Basically, these tests are designed to—

(*a*) select materials which have a sufficiently high ignition temperature to prevent the start of a serious fire—a material that evolves vapors which produce a visible flash at a temperature of 400° F. or shows evidence of charring, self-sustaining combustion or other sings of pyrolysis at a temperature of less than 450° shall be considered unacceptable—and,

(*b*) screen out undesirable materials in the habitable areas of the spacecraft which would enable an accidental fire to spread too fast before it can be brought under control—acceptable materials shall have combustion rates no greater than 0.5 inch per second.

Limited 0 g. aircraft testing has indicated that there may be a tendency for combustion in a low-pressure pure oxygen environment

74-521—67——4

at 0 g. to be self-limiting. This may occur because of the lack of natural convection to remove products of combustion which no longer contain oxygen from the vicinity of the flame source.

In orbit, fire on board the spacecraft could be extinguished by cabin depressurization. This mode of operation would of course require the crew be suited prior to the decompression period. The probability of fire was carefully evaluated and it was concluded from the Gemini VII flight that, for crew comfort and operational effectiveness in long-duration missions, their suits could be removed. This, however, established the requirement that suit-donning times be in the order of 5 to 10 minutes.

Attempts to design fire extinguishers for cabin deluge systems have not been particularly successful. The "fire pockets" between instrument panels and structures complicate the design of any effective fire-extinguishing system for spacecraft use.

In addition, there is the potential interaction with crew safety: that is, toxic fumes. The difficulty of timely detection of a fire and reliable operation of an extinguishing system must be carefully weighed against the potential dangers when considering such a system for spacecraft use. We have considered water deluge and nitrogen purge, as well as other chemical systems. Our studies in this area have been continuing but we have not at this time identified a satisfactory system.

TEST HOURS WITH 100-PERCENT OXYGEN

The use of oxygen in spacecraft testing and space suit evaluation programs for NASA-sponsored programs since 1960 has amassed a total of 20,756 hours. These test hours are fully documented and have been accomplished in support of the manned space flight program alone: 11,894 hours of systems testing have been completed; 914 hours of this total were conducted at sea level pressure or higher; 402 hours of manned testing at sea level pressure have been successfully accomplished without a fire or other major problem; 3,340 hours of manned testing which includes flight hours at 5-pounds-per-square-inch-absolute 100-percent oxygen have been logged to date; an additional 3,264 hours at 5-pounds-per-square-inch-absolute oxygen were logged in the Gemini-Apollo atmospheric validation program. The total time of space-suited operation using 100-percent oxygen is 9,341 hours.

From these numbers it is apparent that the 100-percent-oxygen environment has been fully tested and utilized with a high degree of safety throughout our testing programs.

SUMMARY REMARKS

In summary, the selection of a 100-percent-oxygen atmosphere for manned spacecraft has resulted from the careful consideration of all factors relating to crew safety and mission success. This choice has been based on extensive research which has included single- and multigas atmospheres with their attendant advantages and disadvantages.

The 100-percent-oxygen atmosphere has been used successfully in all U.S. manned flights to date and is considered suitable for missions of 30 days or less.

The CHAIRMAN. Gentlemen, I think we will start with some questions.

Dr. SEAMANS. Whatever you wish, Mr. Chairman.

APOLLO GOAL AS RELATED TO CHOICE OF ATMOSPHERE

Mr. GEHRIG. Dr. Berry, did the schedule for the Apollo program play any role in the decision to use a pure oxygen atmosphere as opposed to using a dual-gas system?

Dr. BERRY. I think this was considered, certainly, as to the availability of the systems that we had experience with. As I think I stated in the written statement, this was one of the considerations, to base it upon information that we had available to us at that time, and upon the hardware that we were familiar with as we went on to another program.

Mr. GEHRIG. Well, suppose that you did not have the goal of landing a man on the moon and returning him safely to earth by the end of this decade. Do you think that would have made any difference in the decision to use the pure oxygen system?

Dr. BERRY. I do not think that it would have. I really do not think that it would have at that time.

Mr. GEHRIG. Did the Apollo schedule play any role in making the decision to use pure oxygen at 16 pounds of pressure while testing on the ground or during operations while you are in the lower portion of the earth's atmosphere?

Dr. BERRY. No, sir. This decision was based upon our experience from the other programs and it was not related to any expediency whatever. I think it was a procedure that we were quite happy with. We had had good success with that procedure and had had no dysbarism develop in its use, and therefore felt it was a perfectly reliable procedure to use.

Mr. GEHRIG. So the primary reason for using 16-pounds-per-square-inch pure oxygen on the ground during testing, or I should say during operations while in the earth's atmosphere until you get to—what was it, 27,000 feet——

Dr. BERRY. 27,500.

Mr. GEHRIG (continuing). Was to eliminate the possibility that the astronauts would get what we call the bends?

Dr. BERRY. Yes, sir.

Mr. GEHRIG. How soon do the bends take hold after the pressure is reduced.

Dr. BERRY. Well, there are a number of incidents in aircraft experience which we will have to fall back on, because we have never had this occur, of course, in space operations to date because of our experience in prebreathing. The experiments you look at, chamber experiences and aircraft, will lead you to believe that the collapse I mentioned can occur, not just bends themselves; even bends can occur as rapidly as 5 minutes after the pressure is reduced.

The CHAIRMAN. Senator Smith?

Senator SMITH. Mr. Chairman, I have a couple of short statements that I would like to make.

The CHAIRMAN. Please go ahead, Senator Smith.

STATEMENT OF SENATOR SMITH

Senator SMITH. I want to express my appreciation for you gentlemen coming up here to tell us about the accident at a time which I am sure has been both busy and very trying for you. An accident that I would say has occurred after a most impressive space flight record from the standpoint of both safety and accomplishments, covering a period of almost 6 years.

I do want to reiterate the point made by the chairman in his prepared statement, that it is not our intention to interfere in any way with the board of inquiry's review of the accident. On the other hand, it has been reported by the press that NASA is seriously considering making certain changes in future manned Apollo spacecraft. If these reports are true, such changes would be of significant and immediate concern to this committee, since they might well affect the Apollo program scheduling and the fiscal year 1968 budget authorization requests.

I hope, gentlemen, that we can have a full discussion of these matters this afternoon.

DISCUSSION OF NASA'S COOPERATION WITH COMMITTEE

Now, Dr. Seamans, I am somewhat disturbed to find that I can apparently become more enlightened about certain aspects of the accident by reading my morning newspaper than I can by relying on the information provided directly from NASA. Although these have not been formal NASA press releases, their sole source is supposedly NASA officials, and the articles contain such minute detail that it is difficult to believe that they are not authentic.

A good example is the article appearing on page 1 of Saturday's Washington Post, entitled "Oxygen Mix To Feed Apollo Cabin in Tests." This article reports that NASA is taking steps to, and I quote, "bring about a major overhaul of the life support system that feeds pure oxygen into the Apollo living quarters. Henceforth, it is understood, the Apollo cabin will be filled with oxygen and nitrogen whenever it is on the ground or in the earth's atmosphere."

The article further reported that NASA has held a series of meetings at Cape Kennedy, Washington, and Houston, and that some 300 Apollo contractors have been asked by NASA to come up with proposals on how to acomplish this change, including estimates of time and cost.

You are familiar with this article, are you not, Dr. Seamans?

Dr. SEAMANS. Yes; I am, Senator Smith.

Senator SMITH. Is there any truth in the contents?

Dr. SEAMANS. The conclusions are not correct. This is the matter that I was addressing myself to in my statement. It is along the same lines as Senator Holland's question. I wanted to reassure this committee that we have not made a decision to go to a two-gas system for the ground preparation and liftoff period. We are, however, as I indicated in my statement, examining this as one alternative which we might wish to follow, because if we did follow this, we know it would have an impact on the fire propagation on the one hand, but it would introduce certain complexities on the other hand. At the time that the board findings are complete, we will then be able to review this as one alternative. At the time we can make a determination within NASA on our course of action, we will so inform the committee and discuss it in detail with you.

Senator SMITH. But do you not believe that a contemplated change of the magnitude referred to in this article should have been brought to the attention of the committee or its staff after the understanding that we have between Mr. Webb and the committee chairman?

Dr. SEAMANS. We are prepared today to have Dr. Mueller discuss with you certain of these major alternatives, and we will keep you and the committee and the staff informed of the various alternatives that we are analyzing.

Senator SMITH. Doctor, what I am getting at is that it is a little rough on a committee that is trying to cooperate in every way with you to have to read in the newspapers what you are considering doing or planning to do, especially after it has been understood that we would work together on that. Even if these plans are only in the discussion stage, it does not seem to me that this is the type of close cooperation that we would expect of NASA, particularly on the matter which the committee expressed a definite interest in.

A related matter, Dr. Seamans, concerns NASA's press release on Friday of your report to Mr. Webb, on the progress to date of the accident inquiry. Mr. Webb did kindly advise the chairman and myself by phone as to the report's contents. It seems to me that the actual press release document should have been made available to the committee and to the committee's staff simultaneously with the release to the press.

This report was not delivered to the committee staff director until noon of the following day, some 18 hours after its release to the press.

Were you aware of this delay in the release of your report to the committee? I think I should ask this of Mr. Webb, but he is not here.

Dr. SEAMANS. I regret that there was this delay, Senator Smith. I was informed of the delay before coming up here to this hearing.

Senator SMITH. I hope, Dr. Seamans, that these examples of communication are isolated ones and not indicative of the type of cooperation we are going to expect from you or can expect from NASA.

Mr. Chairman, I have some questions that I would like to ask, but that is a vote call, and I think perhaps I should wait.

Senator HOLLAND. Mr. Chairman, I think these are very important questions. I would like to have a repetition of the questions and answers when we get back from voting, because we are not able to stay and hear all of the answers now.

Similarly, I would like to withhold questions until we come back, if you do not mind, Senator Smith.

The CHAIRMAN. We will ask some questions now, because the votes might be pretty close together after a while.

Senator Brooke?

SOURCE OF IGNITION NOT DETERMINED

Senator BROOKE. I would like to ask a question before I leave, Mr. Chairman, for this vote.

The CHAIRMAN. Certainly.

Senator BROOKE. Dr. Seamans, after listening to the presentation by you and Dr. Berry, one might conclude that this unfortunate incident just could not have happened. In response to Senator Symington, you said that you had not determined just what the causes were at the present time. Have you narrowed it down? Do you have any possible causes that you feel could have been responsible for the incident?

Dr. SEAMANS. Senator Brooke, I am not aware of the source of the ignition. I talked to Dr. Thompson, who is the chairman of the board, this morning, so that I would be completely up to date before appearing before this committee.

He told me that the team of ignition specialists are carefully analyzing material that they are now taking out of the spacecraft, hoping in this way that they can determine the flow of the temperature and then trace it backward to find the point indirectly that caused the fire. So far, they have not been able to do so. However, we are still hopeful that we may be able to find the source, but it is conceivable that we will never know what initiated the fire.

The CHAIRMAN. Mr. Gehrig?

SATURN FLIGHT SCHEDULE

Mr. GEHRIG. Dr. Seamans and Dr. Mueller, I have a series of questions here, most of them, I think, can be answered very quickly, and probably would be more appropriately asked after your statement, Dr. Mueller. They are questions designed to get into the record some of the things we think are important. I will ask them of you now, since if we wait there might not be time.

The first question: Do we understand correctly, as indicated in your press release, that the Saturn V launch vehicle development flight schedule in the unmanned mode will be continued without change?

Dr. MUELLER. The basic schedule and the basic program will be continued on its presently scheduled dates. We are, of course, looking into those changes that can or should be incorporated as a result of our analysis of the causes of the fire in 204. So that I cannot say the schedule will go completely without change as far as the space vehicle is concerned, but it is not at this point in time immediately apparent that any change is required.

Mr. GEHRIG. How many unmanned Saturn V flights are scheduled and when are they scheduled to be launched?

Dr. MUELLER. There are at least two unmanned Saturn V flights The decision as to whether or not to man the third or subsequent Saturn V's will depend upon our flight experience and, in particular will depend upon both our experience with the spacecraft and its re entry heat shield and the experience with the launch vehicle; its per formance and operation.

Mr. GEHRIG. When are they scheduled to be launched, these two?

Dr. MUELLER. The first Saturn V is scheduled to be launched in th first half of this year, and the second Saturn V in the second half o this year.

Mr. GEHRIG. Do you think that any corrective measures necessary i the Apollo command module can be accomplished by the time that th first manned Saturn V flight is scheduled?

Dr. MUELLER. Any corrective measures that are required for fligh safety will be incorporated before the next manned flight, either o Saturn V or on the Saturn I.

Mr. GEHRIG. What we are trying to get is your best judgment now as to whether or not you think any corrective measures that might have to be made on the Apollo command module can be accomplished before you have the third Saturn V flight, which I believe is scheduled for some time late this year.

Dr. MUELLER. I cannot answer that in the absence of information from the Apollo 204 review board.

Mr. GEHRIG. Do you plan to make any changes in the present production, testing or delivery schedule of the S–IC stage?

Dr. MUELLER. No.

Mr. GEHRIG. The S–II stage?

Dr. MUELLER. No.

Mr. GEHRIG. S–IV B stage?

Dr. MUELLER. No.

Mr. GEHRIG. Was there any damage to either the S–IB or the S–IVB stage in the accident?

Dr. MUELLER. To this point in time, we have not identified any damage to the launch vehicle. Now, you recognize we have not yet disassembled the space vehicle.

Mr. GEHRIG. The launch vehicle?

Dr. MUELLER. That is right.

Dr. SEAMANS. Nor have we taken the spacecraft off the launch vehicle.

Mr. GEHRIG. Was there any damage to the pad itself, any extensive damage?

Dr. MUELLER. Not extensive.

Mr. GEHRIG. Do you have any follow-on uprated Saturn I vehicles on order; that is, in addition to the original 12, for the Apollo applications program, at this time?

Dr. MUELLER. No.

Dr. SEAMANS. We do, however, have some long-lead items on order for Saturn IB vehicles numbers from 13 to 16. That was included in our authorization for Fiscal 1967.

DAMAGE TO APOLLO SERVICE MODULE

Mr. GEHRIG. Was the Apollo 204 service module damaged in the accident?

Dr. MUELLER. Yes, there was damage. We have not been able to assess the degree of damage.

Mr. GEHRIG. I am sorry; I did not get that.

Dr. MUELLER. We have not been able to assess the amount of damage.

Mr. GEHRIG. But it is damaged? Is it very extensive, do you know at this time?

Dr. MUELLER. It appears to be a minimum amount of damage, but we will not know until we get into it.

RUSSIAN SPACECRAFT ATMOSPHERE

Mr. GEHRIG. It is understood that Russian spacecraft utilize a two-gas system. Could you comment, in view of the U.S. research in this area, on the Russian approach to spacecraft cabin atmospheric environments?

Dr. SEAMANS. Of course, I am not fully informed on the details of their environmental control system. I do know that it is a two-gas system. I know that in order to carry out their extravehicular activity, they provided an airlock, for denitrogenation, I presume. I understand that when Leonov went out into space, the pressure in his suit was higher than the suit pressure that we have used, and I believe this led to the fact that he had much less mobility than our astronauts have when they have been carrying out extravehicular activities.

Beyond that, I have nothing to add.

Dr. BERRY. I might just add a word, that their system is apparently a system which has a 1-atmosphere pressure, that it is an air system. We have not been able to determine exactly how they operate this system as a two-gas system, whether they replace a single gas or how they meter the gases and measure the pressures. We have indications that they had some method of reducing the suit pressure in Leonov's extravehicular activity.

He did denitrogenate by being on a 100-percent-oxygen system before he went extravehicular, and he did reduce the suit pressure before he went outside in order to get some mobility.

Mr. GEHRIG. Do we have some information from the Soviet Union of the biological effects on man of these various atmospheres? In other words, do we get very many Soviet reports on things like that, in this area?

Dr. BERRY. There have been a number of Soviet papers, and we have had a number of discussions with the Soviet group, but certainly not in any detail that would correspond to the type of atmosphere studies that I mentioned here today that we have done in our program. We have never exchanged any detailed information with them.

TWO-GAS SYSTEM

Mr. GEHRIG. As you stated, NASA is planning to use a two-gas system in the Apollo applications program. The Air Force will use a two-gas system in the MOL. Would you discuss just briefly why these newer U.S. manned space systems are going to a two-gas system?

Dr. SEAMANS. Let me just start in on that point by saying that we with our Apollo applications program, want to have a capability of extending our experience in space to periods well in excess of 1 month, out to as much as a year's time. As Dr. Berry indicated in his statement, for periods in excess of 1 month, there would be concern, medical concern, over possible physiological impairment if we were to proceed with the pure oxygen.

It is for this reason that we are planning to have the two-gas system in that part of the Apollo applications environment where the men will be located for protracted periods of time.

A similar reason exists for a two-gas system in the laboratory module for the Air Force's program.

However, I would like to emphasize that the Air Force is planning to use pure oxygen for the groundwork preparatory to liftoff and for that part of the mission that gets them into orbit. They will only go into the two-gas environment, I believe, upon attaining orbit.

Dr. MUELLER. They have been planning it. Just as we are re-examining the situation in the launch environment, so are they.

Dr. SEAMANS. They may, as a result of this experience, elect to change their plans.

Mr. GEHRIG. Is my understanding correct that the Air Force was planning to use a pure oxygen system in the Gemini capsule on the MOL program, but since the accident at Cape Kennedy and the accident at Brooks Air Force Base, they are now going to reconsider, or let us say, restudy?

Dr. SEAMANS. My understanding is that they have not made a firm decision to change this plan.

Mr. GEHRIG. They are restudying it in light of the accident?

Dr. SEAMANS. That is correct.

Mr. GEHRIG. But prior to that time, the decision had been made to use a pure oxygen system in the Gemini?

Dr. SEAMANS. That is correct.

EFFECTS OF PURE OXYGEN AFTER 30 DAYS

Dr. BERRY. Sir, I would like to amplify some of those statements about the medical reasons for being concerned about an atmosphere of 100-percent oxygen after 30 days. There are no very definite findings that one can point to at this time that says you cannot use a 100-percent oxygen environment after 30 days. We have test data with men through the 30-day period, there are some animal studies, and some very early indicators from some of our missions, just comfort items, concerning ears, nose, throat, things of this sort, that would make us more comfortable if we were to go to a two-gas system. But there are no definite things that you can now say absolutely happen to human beings that are limiting flight duration to 30 days as far as 100-percent oxygen environment is concerned.

SPREAD OF FIRE GREATER IN 100-PERCENT HIGH-PRESSURE OXYGEN

Mr. GEHRIG. Would going to a dual-gas atmosphere in a spacecraft eliminate the possibility of a severe flash fire such as occurred on pad 34?

Dr. MUELLER. You cannot eliminate the possibility of a fire as long as you have oxygen there in sufficient partial pressure to support life. The intensity of the fire, the rate of spreading the flame, would have been reduced in air, if the cabin had been filled with air.

Mr. GEHRIG. But you could still have had a fire?

Dr. MUELLER. Oh, yes, indeed.

Mr. GEHRIG. So, though you have not determined the specific cause of the accident, would you say that the pure oxygen environment contributed to the severity of the accident, the severity of the fire, I should say?

Dr. MUELLER. With our present state of knowledge, we would say that a fire would burn more rapidly in a 16-pounds-per-square-inch 100-percent-oxygen atmosphere than it would in a partial pressure atmosphere; yes.

Dr. SEAMANS. My understanding of the fire is that it spread more rapidly than it would have spread had there been a regular normal sea level atmosphere.

Dr. MUELLER. And considerably more rapidly.

Mr. GEHRIG. Fires have occurred previously in pure oxygen atmospheres, and also, I might say, in mixed atmospheres. How did these previous fires affect the Apollo test procedures?

Dr. SEAMANS. Dr. Mueller was going to include a discussion of this, I believe, in his statement.

Dr. MUELLER. I think we can either answer that now, or——

Mr. GEHRIG. If it is in the statement, Dr. Mueller, I think we might wait until the members of the committee get back from their vote.

NO CHANGES PLANNED IN S–IB AND S–IVB PRODUCTION

Do you plan to make changes in the present production, test or delivery schedules, for S–IB stage and the S–IVB stage of the uprated Saturn I launch vehicle?

Dr. MUELLER. No. There is no reason to do so at this time.

FLAMMABILITY OF MATERIALS IN OXYGEN

Mr. GEHRIG. As I understand your statement, Dr. Berry, there is a relationship between the amount of, the percent of, oxygen in the atmosphere, the pressure of the atmosphere, and the ignition point or the flammability of the materials inside the capsule. Would it be possible for you to provide for the record some data, say in the form of graphs, showing the relationship between oxygen content, the pressure of the capsule atmosphere, and the probability of ignition?

Dr. MUELLER. Yes.

Dr. SEAMANS. We will supply something for the record. I would like just to advise the committee that this, of course, depends on the materials in question, and it does vary, varies extensively from material to material.

(The information referred to above follows:)

In response to the request for data relating to ignition point and flammability of materials, the following information is supplied:

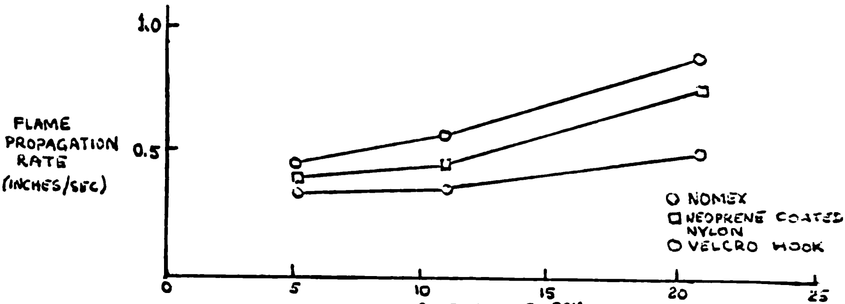


FIGURE 1.—Flame propagation rate as a function of pressure.

Figure 1 shows the change in flame propagation rate for several nonmetallic materials used in the spacecraft as a function of pressure. This is for a 100% oxygen atmosphere. Nomex is the material used for the space suit outer layer. Small patches of velcro are used to temporarily hold articles in place in the Zero-g environment. Neoprene coated nylon is the life raft material.

Figure 1 shows that there is not a significant increase in flame propagation rate for these materials in a pure oxygen atmosphere as we increase the pressure from 5 psia to 15 psia (one atmosphere).

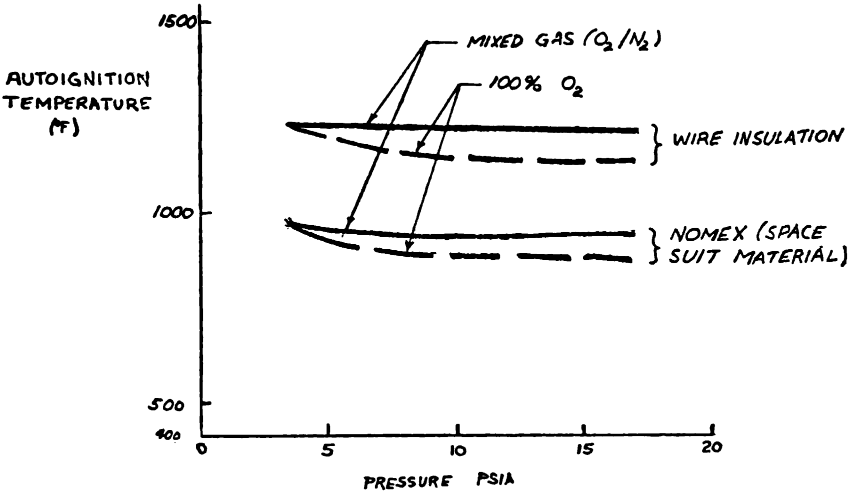


FIGURE 2.—Ignition temperature versus oxygen pressure and atmosphere composition.

Figure 2 shows the variation of autoignition temperature for two typical spacecraft materials for various pressures and for both a mixed gas atmosphere and 100% oxygen. It can be seen that there is relatively little variation in the ignition temperature in going from a mixed-gas atmosphere to the 100% oxygen atmosphere over a wide range of pressures.

EXPERIENCE WITH OTHER FIRES

Mr. GEHRIG. About 2 years ago, there was a fire here at Anacostia in the Navy's experimental diving unit. We understand that the atmosphere in the unit at the time of the fire was 28 percent oxygen and the rest of the atmosphere was half nitrogen and half helium, but it was at 40 pounds per square inch.

The description of the fire is similar to the description of the fire that happened at pad 34.

Dr. SEAMANS. You might like to hear from Mr. Johnston, who is familiar with that fire.

Mr. JOHNSTON. I do not have the exact number, but it is my recollection that the test unit was under either four or five atmospheres.

Mr. GEHRIG. It was 40 pounds per square inch, as we understand from the report of the board of inquiry.

Mr. JOHNSTON. Right. And, of course, at this higher pressure you have, of course, a lot more oxygen present in this unit. These were the circumstances of the Navy fire.

Dr. MUELLER. Mr. Gehrig, it might be worthwhile to have Mr. Johnston continue and talk about the fire experience we have had to date in our various programs, to answer your question.

The CHAIRMAN. Go ahead.

Mr. JOHNSTON. Sir, we have had, actually, three fires. I have a statement here, an outline of these three fires in our program.

On September 9, 1962, we had an accidental fire at the U.S. Air Force School of Aerospace Medicine. This was during our 100 percent, 5 pounds per square inch oxygen atmosphere validation program that Dr. Berry outlined. The fire started on the 13th day of a 14-day test. Two Air Force pilots were subjects for this test. Both were wearing full pressure suits at the time of the fire. The fire was initiated by an electrical defect in a psychometer display panel and was concentrated in the top half of the front area chamber.

Both subjects were hospitalized and thought to have suffered from moderate smoke inhalation. However, during the first night after the accident, one subject's vital capacity dropped alarmingly and his condition became critical. He was detained at the hospital for 2 weeks. Eventually, both subjects fully recovered and went back on active duty. It is certain that both men would have been more seriously injured had they not been wearing full pressure suits in a fully donned state.

In fact, the one man who had the smoke inhalation actually inadvertently opened his visor. That is how he was injured.

In November of 1962—actually, November 17, 1962—an accidental fire occurred at the U.S. Navy Air Crew Equipment Laboratory in Philadelphia. This again was part of NASA's program of atmosphere validation. The fire started on the 16th day of a 20-day program.

Three subjects had already completed their exposure to this total time in this atmosphere, combined with the acceleration runs, and had been removed from the chamber. At the time of the fire, there were three subjects and one flight surgeon in the chamber, all wearing pajamas. The fire started when one of the subjects attempted to replace a light bulb in an energized 24-volt light fixture similar to those found in commerical aircraft. Arcing occurred in back of the light and the subject attempted to smother the flame with a cotton towel, which immediately caught fire.

The fire rapidly spread to the subject's clothing. In further attemps to extinguish the flame, it spread, and, at least initially, from one subject to another by direct contact. All four subjects in this test were burned, two seriously. Most combustibles in the chamber were completely or partially burned.

Senator MONDALE. When did this take place?

Mr. JOHNSTON. These two fires occurred in September and November of 1962.

Senator MONDALE. Are these 100 percent pure oxygen?

Mr. JOHNSTON. Yes, sir. These were part of the atmosphere validation program Dr. Berry outlined. Both of these fires are attributed to test equipment problems.

The third fire that we should mention is the fire in an altitude chamber which was used to simulate the environment of the Apollo command module in which we were running the life cycle testing for the environmental control system.

This incident occurred at the facility of the AiResearch Manufacturing Division, Garrett Corp., Torrance, Calif., on April 28, 1966. We had completed 480 hours and 37 minutes of a scheduled 500-hour life cycle test.

The environmental control system and the test setup were severely damaged in this fire. These were unmanned tests. Since astronaut heat and humidity loads were simulated, and all damage was confined within the chamber, no personal injuries were encountered in this fire.

A board of inquiry was established to investigate this failure, and I can summarize quickly the conclusions of this board: the most probable cause of ignition of the fire was the failure of electrical heater tape which was installed as part of the test setup.

The environmental control system unit, while having some deficiencies during the run, was not the direct cause of the ignition of the fire.

Third, some of the ground test equipment and material used in the test setup were not suitable for application in the vacuum and 5 pounds per square inch, 100 percent oxygen environments. No adequate fire detection or extinguishing equipment was installed in the test setup.

From the standpoint of fire control, improvement in the selection of some materials used in the environmental control system and the Apollo command module could be made.

The command module electrical circuit and wiring which were inspected after this fire were found to be conservatively designed and generally provided appropriate normal overload protection. However, the board did cite that there was a potential fire hazard from arcing or direct short circuits.

Last, nothing developed in the investigation that would tend to jeopardize confidence in the then designed Gemini environmental control system.

Of course, this fire occurred while we were still in the middle of the Gemini space program and the investigation was made for applicability both to Gemini and Apollo programs.

This summarizes the three instances of fire that we have encountered in our program.

(The complete statement of Mr. Johnston follows:)

Fires in Testing Programs

In the course of various NASA testing programs in which 5 psia oxygen has been used, three fires were encountered. Briefly, the results of the fire investigation boards may be summarized as follows:

1. On September 9, 1962, an accidental fire occurred at the USAF School of Aerospace Medicine during a 100% oxygen 5 psia atmosphere validation test. The fire started on the thirteenth day of a fourteen day test. Two USAF pilots were subjects for the test. Both were wearing full-pressure suits at the time of the fire. The fire was initiated by an electrical defect in a psychomotor display panel and was concentrated in the top half, front area of the chamber. Both subjects were hospitalized and thought to have suffered only hypercapnia and moderate smoke inhalation; however, during the first night after the accident, one subject's vital capacity dropped alarmingly and his condition became critical. However, the pulmonary edema caused by smoke inhalation cleared rapidly and the subject's condition improved. He was detained at the hospital for two weeks. Both subjects fully recovered and went back on active duty. It is certain that both men would have been more seriously injured had they not been wearing their pressure suits in the fully-donned state.

2. On November 17, 1962, an accidental fire occurred at the U.S. Navy Air Crew Equipment Laboratory during another 100% oxygen, 5 psia atmosphere validation test funded by the NASA. The fire started on the sixteenth day of a twenty day program. Three subjects had already completed their exposure to this atmosphere, combined with acceleration, and had been removed from the chamber prior to the fire. At the time of the fire, there were three subjects and one flight surgeon in the chamber; all were wearing pajamas. The fire started when one of the subjects attempted to replace a light bulb in an energized 24 v d-c light fixture, similar to those found in commercial aircraft. Apparently, one of the wires in the fixture became disconnected, causing an arc-over. An arc or flame was observed in the fixture. An attempt was made to smother the flame with a cotton towel which immediately caught fire and the fire rapidly spread to the subjects' clothing. In further attempts to extinguish the fire, it

spread, at least initially, from one subject to another by direct contact. All four subjects were burned, two seriously. Most combustibles in the chamber were completely or partially burned.

3. A fire occurred in the altitude chamber used to simulate the interior environment of the Apollo Command Module in which the Apollo Environmental Control System (ECS) was undergoing a mission-duration qualification test. The incident occurred at the AiResearch Torrance Facility, Torrance, California, at approximately 2037 hours, PDT, on April 28, 1966; 480 hours and 37 minutes of a scheduled 500 hour test had been completed at this time. The ECS and the test set-up equipment were severely damaged. Since astronaut heat and humidity loads were simulated, and all damage was confined within the test chamber. no personal injuries were sustained.

Board conclusions can be summarized as follows:

The most probable cause of the ignition of the fire was a failure of electrical heater tape which was installed as part of the test set-up.

The Environmental Control System qualification unit (while having a number of component deficiencies during the test) was not the direct cause of the ignition of the fire.

Some of the ground test equipment and materials used in the test set-up were not suitable for application in the vacuum and 5 psia 100% oxygen environments. No adequate fire detection or extinguishing equipment was installed in the test fixture. No written emergency shutdown or fire procedures were provided to the test operators.

From the standpoint of fire control, improvement in the selection of some materials used in the Environmental Control System and Apollo Command Module could be made.

Command Module electrical circuits and wiring have been conservatively designed and generally provide appropriate normal overload protection; however, there is a potential fire hazard from arcing or direct short circuits.

There has been nothing developed in the investigation that would tend to jeopardize confidence in the presently-designed Gemini Environmental Control System.

DEGREE OF FIREPROOFING

Mr. GEHRIG. Mr. Johnston, could you discuss for the committee what the terms, "flammability," and "fireproofing," might mean in the different kinds of atmosphere? I am thinking here particularly of the fire you mentioned that occurred at the Air Crew Equipment Laboratory at the Naval Air Center, Philadelphia.

Here it says:

> The subject requested water but was told to snuff the fire out with a towel. The towel caught fire and blazed so vigorously that it set the man's clothing afire. An asbestos fire blanket was used to snuff out the clothing fire, but it, too, burst into flames.*

This suggests that, as applied to materials inside the spacecraft, the flammability characteristics change substantially in these different kinds of environments.

Mr. JOHNSTON. Yes, sir; your last point is true. I did not quite understand the rest of your question?

Mr. GEHRIG. What the record should show is that when we use the terms, "ignition," "flammability," or "fireproofing," these characteristics of materials change and things that we ordinarily think of as being fireproof—like an asbestos blanket—are not fireproof in a pure oxygen environment—the asbestos blanket burned.

Mr. JOHNSTON. This is true. In fact, there are very few things in an oxygen environment that, if heated to sufficient temperatures, cannot burn.

---

*NASA SP-48, "Space-Cabin Atmospheres," Part II—Fire and Blast Hazards, p. 100.

Mr. GEHRIG. This also means that the presence of unauthorized objects in a spacecraft can be a very dangerous thing and increase the probability of fire.

Dr. SEAMANS. That is true, and one of the jobs the review board has is to ascertain exactly what was in the AS-204 capsule prior to the fire. They will find out whether there are any items that were in there that were unauthorized.

Dr. MUELLER. Let me be real clear, though, that first you have to have an ignition source, something to heat the material up, regardless of what it is, to a point where it will actually catch on fire. It is not until you have a combination of an ignition source plus a material that will burn if that temperature is reached, that you have the fire.

Mr. GEHRIG. Yes, but is it not correct that the ignition characteristics of materials change as you change the oxygen content and the pressure?

Dr. MUELLER. They are dependent upon both the partial pressure of oxygen and the total pressure.

Dr. SEAMANS. The ignition temperature can change with these two variables.

Mr. GEHRIG. One of the staff members, Dr. Wilson, reminds me also that the time the materials have been in the pure oxygen environment—as they become saturated with oxygen—these characteristics change.

Dr. MUELLER. That, however, is a very weak relation and, in fact, some of the tests we have made indicate that there is relatively little change in materials with exposure to the pure oxygen environment.

Mr. GEHRIG. Well, the report I have here, which is a report—I believe this is a report mentioned by Dr. Berry, prepared for NASA by the Lovelace Foundation—says:

> It was felt that the blanket and the towel had been saturated with oxygen for 17 days and burned much more vigorously than could be expected under sea-level conditions.

Dr. MUELLER. Since the time of that report, we have actually made tests on materials with different times of exposure to pure oxygen atmosphere. There is a very weak coupling in this case.

If you would like, I believe that Mr. Johnston has some data.

Mr. JOHNSTON. Yes. Actually, there has been an Air Force study where they have exposed materials, spacecraft-type materials, to pure oxygen for 30-day exposure periods. We have also done this in our own laboratory to determine if ignition properties, burning rates, and so on, are altered by this exposure. This has been confirmed by both laboratories, that there is very little change in ignition properties.

I think those materials that have volatiles, such as organics, that could be evaporated off, you might possibly lower the ignition temperatures or, if you had water vapor present, where you could evaporate these off, perhaps the ignition temperature would be slightly raised. But for those things that did not contain volatiles, exposure for a 30-day period did not have this so-called soaking effect where the material was supersaturated with oxygen and the ignition characteristics were changed. This has been supported both in the Air Force statement and in our own laboratory.

The CHAIRMAN. I think we should have Dr. Mueller's statement as soon as we can.

Dr. MUELLER. Thank you.

If you would like, I could summarize the first part of my statement, having to do with the Apollo-Saturn-204 spacecraft. With your permission, I would submit the complete statement for the record and just summarize it.

The CHAIRMAN. No objection.

DESIGN CERTIFICATION REVIEW

Dr. MUELLER. Spacecraft 012, which is the spacecraft used in mission AS-204, began its structural buildup at North American Aviation, Downey, about August of 1964. By March of 1966, some 21 months later, it had completed its assembly process. It then had all the subsystems in place and began subsystem checkout. There are a series of reviews during the course of the checkout of the spacecraft. The first of these was held in June and was called the systems assessment review.

The next major review was a customer acceptance readiness review, following the integrated testing of the complete spacecraft which was held in August of 1966. Then, in order to assure that all of these reviews and others relating to testing and qualification programs were thorough and complete, there was a design certification review held by myself and our center directors, to be sure that everything in the design was safe for flight.

The spacecraft checkout continued down at the Cape through a series of altitude chamber tests, in which we did encounter some problems. The problems were associated with the environmental control sytsem, and those tests were delayed while a modified environmental control system was qualified and installed. We finally completed the testing in the altitude chamber with astronauts in place at the end of December of 1966.

We then mounted the spacecraft on the vehicle, and at that time it was in the final flight configuration. There were no changes made in the systems after its assembly on the stand.

Then the integrated tests began on the stand of the entire space vehicle, and this set of testing proceeded through until the time of the accident.

TESTS OF VARIOUS SPACECRAFT

Now, I thought it would be worthwhile to get some measure of the relative times involved in the checkout of our first manned Apollo spacecraft and those of Gemini and Mercury and to compare, for example, time spent in factory tests. On the Mercury, we spent about 7.8 weeks in factory tests; in Gemini, we spent about 16.3 weeks. Our experience on Apollo has been that we have spent about 20 weeks in factory tests and checkout.

In the case of KSC modification and hangar testing, we spent about 14.5 weeks on Mercury, about 9 weeks on Gemini, and then because of the problem with environmental control system, which accounted for about 11 additional weeks, we actually spent about 21 weeks on Apollo spacecraft 012.

On pad test and checkout, we had about 4 weeks on Mercury, about 4.5 weeks on Gemini, and a total of about 6 weeks on the Apollo. I only bring these out to illustrate the fact that we were not pressing too hard on the test and checkout of the vehicle.

The specific objectives of the "overall test plugs out" being conducted on January 27 were to verify for this particular vehicle, first, the compatibility and proper operation of all space vehicle and ground support equipment systems during a normal automatic firing sequence and flight sequences, with actual holddown release, electrical umbilical ejection, and firing of live ordnance in test chambers; second, to verify that there was no electrical interference at the time of umbilical disconnect; third, to check the computer flight routines; and fourth, to verify astronaut emergency egress procedures at the conclusion of the test. This was to have been unaided egress by the astronauts practicing escaping from the spacecraft itself.

On the 27th of January, the vehicle was powered up at 7:40 a.m., eastern standard time. After completing the verification tests of satisfactory system operations, the astronauts entered the command module at 1:19 p.m., eastern standard time with the count at T−2 hours, 25 minutes. Various communications difficulties delayed the count, and at 6:30 p.m., eastern standard time, the time of the accident, the count was in a hold at T−10, while additional communications problems were being resolved.

The accident occurred just as the countdown was to be resumed. This completes a very abbreviated review of the test history of the A-204 spacecraft.

(The complete prepared statement by Dr. Mueller follows:)

Development and Test of the AS-204 Apollo Spacecraft

Spacecraft 012, assigned to Mission AS-204, was structurally built at North American Aviation, Space & Information Systems Division, Downey, California between August 1964 and September 1965. Prior to subsystem buildup, each component was subjected to comprehensive acceptance tests. The subsystems were then assembled in the command and service modules between September of 1965 and March of 1966. Next, the assembled and mated spacecraft went through individual subsystem checkout to verify the functioning of the installed hardware.

Before integrated checkout of the spacecraft and its systems with and without the crew, a Systems Assessment Review was held at Downey on June 30, 1966. During this review, NASA and NAA reviewed the spacecraft systems for conformance to the specifications. Integrated testing of the complete spacecraft was conducted during a period between mid June and mid August, 1966. This involves verification of the proper operation of all the spacecraft systems, with crew participation, while performing all functions involved in various abort modes, followed by a mission sequence normal mission profile through command module-service module separation, using an external primary power source. Flight umbilical cable disconnect is simulated during this test. An engineering evaluation was conducted and some subsystems were re-evaluated after several hardware changes had been made. Another complete series of integrated tests was then conducted. This is characteristic of the deliberately paced Apollo testing program in which tests are repeated again and again until no unresolved anomalies remain.

Following integrated testing, the service module service propulsion system was calibrated and the earth landing and recovery systems installed. The environmental control system was checked out with the crew and crew equipment installed, and checked for fit and function.

The spacecraft and its test results received a critical review by NASA during the Customer Acceptance Readiness Review, held at Downey in August 1966. The spacecraft was then authorized for shipment to Kennedy Space Center and a Certificate of Flight Worthiness was issued. This document noted the open items and work to be accomplished at KSC.

For maximum confidence of proper design and testing, an additional Design Certification Review was conducted at NASA Headquarters September 26-28, 1966. This was a detailed review for the Associate Administrator of NASA for Manned Space Flight, and the Center Directors, to assure that the design of the total space vehicle met specifications and was acceptable for manned flight.

During the entire fabrication and test program leading toward launch of spacecraft 012, there were a number of Qualification Tests or Certification Test Requirements that were being completed on the most critical components in order to insure the adequacy of the spacecraft for manned flight. 442 individual tests were being evaluated and approximately 400 had been approved. The remainder would have been approved before flight. These tests are more severe than the component is expected to see in flight.

The command module was received at KSC on August 25th and the service module August 9th. The schedule at that time called for a period of about nine weeks of inspection, installation of flight components, calibration, system testing and altitude runs, prior to final mating with the launch vehicle at the pad.

Mating of the command module and service module in the Altitude Chamber occurred about the 1st of September followed by three weeks of intensive subsystem and system verification testing, functional checks and alignment. Each step in this testing follows a logical progression starting with low level subsystem testing, then integration to systems and preparation for all-up spacecraft testing in the Altitude Chamber. Altitude Chamber runs are performed with the flight crew in three phases: a manned sea level run to verify total spacecraft system operation; an unmanned altitude run to further verify operation including cabin environmental control, and finally, a manned altitude run to fully test the operation of all spacecraft systems in the manned configuration during a simulated mission.

During the first series of altitude runs, mechanical problems had been developing with the environmental control system in qualification testing that altitude tests were suspended until all known anomalies uncovered to date could be resolved, fixes made, and thorough testing accomplished at the vendor's facility prior to proceeding. Following the installation of qualified equipment, the altitude tests were fully accomplished at the end of December last year. Results of those altitude runs, which thoroughly simulate the mission in a typical environment, were entirely satisfactory, indicating that the spacecraft was ready to be moved to the pad and mated to the launch vehicle for testing as a space vehicle in preparation for launch.

Mating of the spacecraft to the launch vehicle completes the assembly of flight hardware, and ends the period of separate system and subsystem testing. From this point on, testing and simulations become increasingly more complete, using flight procedures, actual ground support equipment, timing, and hardware. The flight crew participates in each of the following major checkout events.

The checkout on the launch pad after mating involves approximately 100 NASA employees and 400 contractor personnel. These tests are directed by NASA test supervisors. The concept of operations is that of an integrated team in which the bulk of the work is carried out by the contractors under NASA supervision.

The first major testing of the total space vehicle occurs in the Overall Test Plugs In performed successfully on 25 January 1967. This test has as its objectives the vertification of the integrity and compatibility of the electronic, electrical, and mechanical space vehicle and ground support equipment systems while all launch vehicle and spacecraft systems are operating. It also verifies the functional capability to gimbal the service propulsion system engine at prescribed freqeuncies and amplitudes. The following launch vehicle functions are simulated: propellant loading, engine ignition, hold down release, umbilical cable ejection, swing arm retraction, lift off, retrorocket ignition, stage separation, ullage rocket ignition, second stage engine ignition and ullage rocket ejection. The spacecraft is checked for proper reaction control system firing and all instrumentation systems are operating. At no time during this test are the umbilical cables disconnected.

The Overall Test Plugs Out is designed to demonstrate space vehicle and instrumentation network capability in as near flight configuration as possible. System verification is performed after which an abbreviated terminal count is conducted, followed by a normal flight simulation test. The Mission Control Center at Houston monitors the flight simulation and sends radio control command signals. All communication and instrumentation systems are activated and proper measurements are monitored at appropriate ground stations. Flight umbilicals that would normally be disconnected for flight will be disconnected during this test.

The next major checkout milestone is the Flight Readiness Test which is performed to demonstrate space vehicle and launch complex capability and to perform a final systems verification in all modes prior to entering the launch count down. After all systems are verified, a terminal count sequence is conducted, followed by a Launch Escape System Abort Test and a Service Propulsion Abort Test. At completion of these abort runs a short count sequence is conducted through lift off, and a normal flight simulation is run. Umbilical connectors are not removed. Completion of this test verifies that the spacecraft ground support equipment configuration is ready for count down.

The Count Down Demonstration Test is the last major checkout milestone before launch and is performed to demonstrate the satisfactory time phasing of the normal sequence necessary to prepare the space vehicle for launch. This test lasts approximately 48 hours and simulated the count down sequence as closely as possible. Space vehicle, radio frequencies compatibility is verified in a count down configuration to demonstrate that the spacecraft pyrotechnic circuitry is not susceptible to radio frequency interference. All radio frequency systems on the space vehicle will be turned on in a predetermined sequence and simulated or monitored by the appropriate Eastern Test Range and Kennedy Space Center equipment. Prior to the above operational sequence, fuses will have been installed in place of all pyrotechnic items and the Master Event Sequencer Controller will be armed. At the conclusion of the radiation period, all radio frequency systems will be shut down in a predetermined sequence, and fuses will be examined to assure that none have blown. At the conclusion of these tests, the space vehicle is returned to flight configuration.

After loading fuel in the lauch vehicle and spacecraft, the terminal count is ready to commence. The Master Count Down consists of a series of tests and operations performed in a logical order which assure the space vehicle readiness for launch. Performance of the count down requires approximately 2 days and culminates in the launch of the Apollo/Saturn vehicle.

As a measure of the deliberately paced, meticulous testing and checkout of spacecraft 012, it is interesting to compare the time devoted to this effort to comparable test and checkout times for Mercury and Gemini. The table below illustrates this comparison for the spacecraft:

Weeks of test and checkout

	Mercury	Gemini	Apollo
Factory test	7.8	16.3	20
KSC modification and hangar test	14.5	9.0	[1] 21
Pad test and checkout	3.9	4.5	6
Total	31.2	29.8	[1] 47

[1] This includes approximately 11 weeks required to resolve problems concerned with the environmental control system and change out the environmental control unit.

The specific objectives of the Overall Test Plugs Out being conducted on January 27 were to verify for this particular vehicle:

1. compatibility and proper operation of all space vehicle and Ground Support Equipment systems during a normal automatic firing sequence and flight sequence with actual holddown release, electrical umbilical ejection and firing of live ordnance in test chambers.
2. no electrical interference at the time of umbilical disconnect.
3. computer flight routines.
4. astronaut emergency egress procedures at the conclusion of the test (unaided egress).

On 27 January the space vehicle was powered up at 7:42 a.m. EST. After completing verification tests of satisfactory system operation, the astronauts entered the command module at 1:19 p.m. EST with the count at T-2 hours 25 min. Various communications difficulties delayed the count. At 6:30 p.m. EST, the time of the accident, the count was in a hold at T-10 while additional communications problems were being resolved. The accident occurred just as the count down was to be resumed.

This completes the review of the test history of the AS-204 spacecraft. I would like now to turn to the impact of the accident on the Apollo program.

Dr. MUELLER. I would like to turn now to the impact of the accident on the Apollo program, if I may.

The CHAIRMAN. Proceed.

APOLLO PROGRAM DECISIONS

Dr. MUELLER. In addressing the question of the next steps to be taken in the Apollo program, I would like to make clear my own very deep concern over the tragic accident which took the lives of Grissom, White, and Chaffee. I, and every other person in the manned space flight organization, are and have been keenly aware of the risks inherent in manned space flight and have tried in every way that we knew to minimize those risks.

I know from talking to each crewmember that they were aware of the risks, accepted them and were proceeding with the program conscious that an accident could occur. Individually, and as an organization, we are dedicated to taking every step humanly possible to maintain the safety of the flight crews. But, having taken every precaution, we feel we must proceed with the program.

The planning of the Apollo flight program is based on providing not only the capability to capitalize on success but also the capacity to respond to problems. Flight missions have been assigned and planned so as to provide flexibility in the point of manning in the uprated Saturn I and Saturn V series and in the point of transfer between the two series. It is this planning which I believe will enable us to cope with the program impact of the AS–204 accident.

Thus, we have been able to make the decision to proceed with the launching of three unmanned Apollo flights which are presently scheduled in 1967.

AS–206 is an unmanned lunar module mission on an uprated Saturn I and is scheduled for the second quarter of this year. The mission provides a demonstration of propulsion and staging of the lunar module.

AS–501, the first launch of a Saturn V, is scheduled for the second quarter. It will fly a command and service module. AS–502, the second Saturn V launch is scheduled in the second half of the year. It will also fly a command and service module. Both the AS–501 and the AS–502 missions will be Saturn V launch vehicle development missions and will also include demonstration of the spacecraft heat shield at lunar return velocities.

Other significant decisions made since the accident are:

We are restricting manned testing in an environment containing high oxygen concentrations until such time as it is deemed safe to resume.

We are using Spacecraft 014 to support the accident investigation and have therefore shipped it to the Kennedy Space Center where it presently is in use.

We have put Spacecraft 008 back on test status at the Manned Spacecraft Center to support technical investigations arising from the accident.

We are proceeding at this time with all spacecraft manufacturing and checkout that do not involve checkout in an oxygen atmosphere in the spacecraft.

The major remaining issue is to decide what actions are required to prevent a recurrence of the AS–204 accident. It is clear that a decision as to the kind and extent of changes to be made in the Apollo spacecraft must await development of more facts about the accident.

We have not, at this time, made any decisions as to changes, but we are actively studying alternative system approaches and reviewing our past studies and decisions so that we will be able to move forward when the results of the board's investigation are available.

TRADEOFFS BEING STUDIED

Examples of tradeoff studies being reviewed at the present time are:

A. One-gas versus two-gas systems

This study considers the tradeoffs between the physiological considerations as evidenced in past laboratory and spacecraft tests, and reliability, weight and fire protection. One part of the study is considering the practicability of modifying the procedures and design so as to get away from the requirement for 16-pounds-per-square-inch oxygen environment in the spacecraft cabin during pad checkout and launch. Flame propagation studies will be reexamined to determine whether or not further steps can be taken to reduce fire hazard.

B. Emergency egress

The command module hatch design is being reviewed to reconsider the tradeoffs involving rapid hatch opening for safety on the pad versus reliability and safety, particularly the problem of accidental opening of the hatch in space.

C. Fire suppression and extinguishment

A reexamination of the quick vent or quick depressurization system of the spacecraft is being conducted relative to fire suppression and extinguishment. In addition, fire extinguishing techniques such as adding a nitrogen purge together with an appropriate oxygen system are being studied along with considerations of the time required for the astronauts to don their spacesuits under emergency conditions.

INSTRUCTIONS TO CENTERS

In the meantime, we have instructed our centers and contractors to proceed with Apollo work, using as an interim assumption that the first manned orbital flight will be a block II command module and service module on an uprated Saturn I. Objectives of this mission will be to demonstrate manned operations of the command and service modules, and to evaluate performance of the spacecraft in a low Earth orbital environment.

Since the operational life of these subsystems has not yet been demonstrated in flight, as we had planned, the first manned mission is open ended. By this we mean that the mission is laid out to consist of a series of decision points at which critical events occur. The decision points are separated by periods of continuing activity. Before and after each of these critical events, a complete review of vital systems, expendables and other aspects of mission status is made. Each review leads to a decision whether to proceed to the next period of continuing activity or return to Earth.

We have also told our centers and contractors to proceed on the assumption that the next succeeding manned orbital mission will be flown with command, service, and lunar modules on either the Saturn V launch vehicle or on a pair of uprated Saturn I launch vehicles, depending on progress in the Saturn V program.

In the event this mission is flown on the Saturn V launch vehicle, the objectives will be to verify the functional capability and operability of the command service module and the lunar module by manned operations and to obtain rendezvous and docking experience.

In the event a pair of uprated Saturn I launch vehicles is used, the manned command and service module will be launched into low Earth orbit on one uprated Saturn I. The second uprated Saturn I will carry the unmanned lunar module, launched about a day later. The objectives will be to achieve rendezvous and docking of the two vehicles in Earth orbit, followed by astronaut transfer to the lunar module and manned operation to verify its functional capability. The astronauts will return to the command module to conclude the flight with entry, splashdown, and recovery.

PROCEEDING AT A DELIBERATE PACE

In summary, we are proceeding at a deliberate pace on a program which permits the introduction of changes in an orderly manner. We are prepared to incorporate changes as they are defined by the Apollo program office and to implement the recommendations of the Apollo-204 review board. We will continue to review, identify, and implement means to assure crew safety. We will keep you informed of our progress.

Thank you very much.

The CHAIRMAN. Senator Cannon?

COMPLETE REPORT TO TAKE A MONTH OR SO

Senator CANNON. Do you have any estimate, timewise, as to when the board will be able to conclude its findings?

Dr. SEAMANS. I discussed this when I was with Dr. Thompson last week and again today, when I went over it with him on the phone. They now have blocked out all the tasks they think will be necessary in order to prepare the final report.

They have this in our regular PERT form so we can keep track, from the management standpoint, of all the jobs that need to be done. But because of the uncertainty in determining the actual cause of the ignition, we, of course, cannot state exactly how long it will take. That is the reason in my statement I indicated it may take a reasonably protracted period of time, on the order of a month or so, before we can complete the work.

ALTERNATIVES, COSTS, AND TIME DELAYS TO BE DETERMINED

Senator CANNON. Now, if you were to decide in favor of a two-gas system versus a one-gas, as Dr. Mueller has testified to, what are we talking about in terms of time and money?

Dr. MUELLER. We have had underway for some time a design study on two-gas systems, but we have not, at this point in time, carried out the planning required to identify either the time or the cost of the incorporation of a two-gas system into the Apollo program.

Dr. SEAMANS. This is part of the study of alternatives that our program office is carrying out in parallel with the work of the review board, so that at the time the review board completes their findings, it will be possible, then, to know the cost in terms of manpower, dollars, and technical feasibility of the various alternatives.

Senator CANNON. Well, do you have any rough idea, timewise? Are we talking about a year, or 2 years?

Dr. MUELLER. My own expectation is that we are talking of a period that would require somewhere between 6 months and a year for incorporation. That is just an educated guess. That is a two-gas system in orbit.

Now, in the case of two-gas system on the ground, there is a range of ways of accomplishing this. We are looking at a range that goes from a pure nitrogen atmosphere, for example, in the spacecraft with the astronauts on their own oxygen loops, to an air atmosphere and, of course, we are also considering the tradeoffs involved in these new systems and staying with the oxygen on the pad. In any event, in the case of the launch environment, I would expect the impact to be small.

For example, if we were to change to air on the launch pad so we had a two-gas system in the spacecraft itself, I would not anticipate an impact on the present schedule.

Senator CANNON. In other words, this would not resolve in a major redesign of the capsule itself?

Dr. MUELLER. That is correct, so that we really have two areas, the launch environment area and the space area. The inclusion of a two-gas atmosphere for operations in space does require more modification of the spacecraft and would take a longer time.

On the other hand, the incorporation of certain two-gas atmospheres on the ground would be essentially a procedural change.

Senator CANNON. I gather from your testimony here that the hazard in space would be considerably less because of the possibility of purging the oxygen from the capsule at that time?

Dr. MUELLER. That is correct.

SATURN V NOT YET FLOWN, BUT NO MAJOR PROBLEMS HAVE BEEN UNCOVERED

Senator CANNON. Now, Doctor, in your statement, you say:

> We have also told our centers and contractors to proceed on the assumption that the next succeeding manned orbital mission will be flown with command, service, and lunar modules on either the Saturn V launch vehicle or on a pair of uprated Saturn I launch vehicles, depending on progress in the Saturn V program.

Does that statement indicate that you are having some problems in the Saturn V program?

Dr. MUELLER. No; we have not yet flown one of the Saturn V's. Until we find out whether the careful ground testing we have done is, in fact, verified by the flight test, we will not know how soon we can man the Saturn V launch vehicles.

Senator CANNON. So far, you have run into no major problems then, in connection with the Saturn V?

Dr. MUELLER. So far, we have not encountered a major problem in the Saturn V program.

(We feel that we can find means of working around the difficulties imposed by the loss of the S-II test article during test at MTF and the failure of the S-IVB stage. While these are serious in terms of hardware scheduling, we feel we have no fundamental technical problem with the Saturn V and that this vehicle will meet its required performance and schedule milestones.)

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Curtis?

Senator CURTIS. I have no questions.

The CHAIRMAN. Senator Holland?

FURTHER DISCUSSION OF OXYGEN ATMOSPHERES

Senator HOLLAND. Dr. Berry, what are the percentages in the atmosphere on the ground at sea level, of oxygen and nitrogen?

Dr. BERRY. You mean, the percentages, sir, that pertain——

Senator HOLLAND. It is not fixed, as I understand it. It varies.

Dr. BERRY. Well, ordinarily, in the air that we breathe, as here in in this room, about 21 percent oxygen, and the bulk of the remainder, that is, the 79 percent, is nitrogen. You have a few trace gases with that, neon, argon, a few things like that. There is very little variance to that basic percentage makeup.

Senator HOLLAND. I notice that apparently, in your first consideration of the Apollo program, you were intending to use a dual-gas atmosphere, because this sentence appears:

Accordingly in August 1962, North American Aviation Corp. was directed to change to the single-gas atmosphere.

What was it that you intended to use prior to that time?

Dr. BERRY. Sir, I think it is two pages back, where it starts in the middle of the page, "Apollo Atmospheric Selection," it states that a 50-percent oxygen and 50-percent nitrogen atmosphere at a total pressure of 7 pounds per square inch was projected at that time to be used for Apollo. That was at a time when the Gemini's validation studies were not complete. As those became complete and that information was available to us and we were not concerned about the oxygen toxicity problem, then that atmosphere was changed and the direction was given to North American.

Senator HOLLAND. That was in August 1962?

Dr. BERRY. Yes, sir.

Senator HOLLAND. What were the dates, that have been testified to here by Dr. Mueller, of the two fires in the capsules?

Mr. JOHNSTON. September and November of 1962.

Senator HOLLAND. Were those fires in capsules where pure oxygen was being used?

Mr. JOHNSTON. Yes, sir. These were in space simulated chambers where we had 5 pounds per square inch pressure of pure oxygen. They were the same constituents, same composition as we have in earth orbit.

Dr. MUELLER. Senator Holland, these were not our Apollo space capsules.

Senator HOLLAND. But they were simulators, where the 5 pound pressure of pure oxygen was used and in which a man, or men protected by their spacesuits, were located?

Dr. BERRY. Yes, sir.

Senator HOLLAND. And in both instances, these fires presented serious hazards, from which, however, the men were able to escape, is that correct?

Mr. JOHNSTON. Yes, sir.

Dr. BERRY. Yes, sir.

Senator HOLLAND. At the time of those experiences, which followed very closely your decision to use a single-gas atmosphere, was there any further consideration of the question of using the dual-gas atmosphere, or did you think that the difficulties that you had run into were correctable, so that you could safely continue to use the single-gas pure oxygen?

Dr. BERRY. We felt, sir, that the failures that had occurred in the test chambers accounting for those two fires, were the result of test equipment and procedures that were used in those tests which were not things that would normally be used in a spacecraft environment, where the detailed checking procedures, equipment, electrical circuits, and so forth, would differ prior to using them with 100 percent oxygen in a spacecraft.

Senator HOLLAND. Have you already stated for the record with complete clarity what it was that occurred in those two cases that you thought brought about the fire?

Dr. BERRY. Yes, sir.

Dr. SEAMANS. I believe we have, a short while ago, Senator Holland.

Senator HOLLAND. And you think that all of the things which you think caused those fires were subtracted from the possibilities as to what could occur in the Apollo capsule?

Dr. BERRY. Yes, sir.

Dr. SEAMANS. Yes, sir; these were causes of ignition that were peculiar to the test equipment and were not equipment similar to those contained in the Apollo capsule.

Senator HOLLAND. You did not, then, feel that you should again consider the question of a dual-gas system?

CLARIFICATION OF OXYGEN SYSTEMS TESTING

Senator HOLLAND. All right.

There is a statement on the last page of your statement, Dr. Berry, that, to me at least, is not completely clear.

First, you say that 914 hours of this total were conducted at sea level pressure or higher. That is systems testing with 100 percent oxygen. Then you follow that statement by saying that 402 hours of manned testing at sea level pressure has been successfully accomplished without fire or other major problem.

The question is, what happened in the case of the other 512 hours which would make up the total of 914?

Dr. BERRY. Sir, those are different subjects. The first part, the 11,894 hours of systems testing, are not only manned tests. There are tests which do not have man involved, but are tests of equipment without the man and the loop in an oxygen situation.

Senator HOLLAND. That is true of the 914——

Dr. BERRY. Yes, sir.

Senator HOLLAND (continuing). And the 402?

Dr. BERRY. No, sir. The 402 were manned tests, but the 914 hours were the total conducted at sea level pressure or higher that were systems tests. Four hundred and two hours of manned tests at sea level pressure have been successfully accomplished, which is a separate group of hours.

Senator HOLLAND. I understand, and you say that last group was accomplished "without a fire or other major problem." Now, the question is is there any difference in that regard between the 402 and the 512. Was there any fire or major problem encountered in the 512 sea level, 100-percent oxygen tests?

Dr. BERRY. No, sir.

Senator HOLLAND. I think your statement should be very carefully restated, then, to make it very clear that in the 512 likewise, they were successfully accomplished without a fire or other major problem, though they were not manned, if that is the case.

Dr. BERRY. Yes, sir.

Dr. SEAMANS. That is the case, and you have a very good point.

Senator HOLLAND. I think it should be cleared up, because someone looking at this record later, and that is apt to occur, of course, might wonder what had happened.

Dr. SEAMANS. We will submit a table along with this text that will clarify these points. (See p. 53.)

Senator HOLLAND. And you are stating now that with the 512 which were successfully completed, as in the 402 which were manned, they were with 100 percent oxygen and they were completed without fire or other major problem?

Dr. SEAMANS. That is correct, Senator Holland.

Senator HOLLAND. All right. Thank you.

Senator CANNON (presiding). Have you completed, Senator Holland?

Senator HOLLAND. I am through; yes.

Senator CANNON. Senator Jordan?

NINETY SECONDS REQUIRED TO OPEN APOLLO HATCH

Senator JORDAN. Thank you, Mr. Chairman.

Dr. Mueller, in your statement, you are talking about examples of trade-off studies being reviewed. You give as examples, (A) one-gas versus two-gas systems: and (B) emergency egress. Under the "B," you say:

> The command module hatch design is being reviewed to reconsider the trade-offs involving rapid hatch opening for safety on the pad versus reliability and safety, particularly the problem of accidental opening of the hatch in space.

How long does it take to open the hatch that was in use in the event of disaster?

Mr. MUELLER. We have checked out the egress time and it is normally 90 seconds to open the hatch—there are actually three hatches—to open the three hatches for egress.

Senator JORDAN. What is involved here in opening the hatch? Are they a manual——

Dr. MUELLER. There is a manual release of the dogs that hold the inner hatch in, and there is a final manual opening of the hatches in the outer shell and the boost protective cover.

Senator JORDAN. Have you always used that design, that hatch design, in the capsules?

Dr. MUELLER. No, Senator Jordan. This is the first time that we have used this particular construction for a spacecraft capsule. The Apollo capsule has an inner pressure hull, as well as an outer shell that carries the structural loads of reentry, so that you actually have a two-layer cabin, if you will, and that necessitates the addition of an additional door.

Senator JORDAN. The hatch that—was it Gus Grissom that blew the hatch on splashdown?

Dr. MUELLER. Yes; on the Mercury.

Dr. SEAMANS. The Liberty Bell.

Senator JORDAN. That type of escape hatch, apparently, would operate almost instantly if it were energized, is that true?

Dr. MUELLER. That is true, and of course, it has the chance that you can operate it inadvertently in space.

Senator JORDAN. Is this what you mean by a trade-off, whether the adoption of that fast-opening escape hatch would be advantageous as against the danger of it occurring in flight?

Mr. MUELLER. Precisely.

Dr. SEAMANS. It happened inadvertently with the Liberty Bell on the surface of the water, as you understand, Senator Jordan. And we would not want that to happen in the capsule that was on its way to the moon, or at some very distant point from the earth.

Senator JORDAN. I can understand that, but as you say, you are exploring the possibilities of improving that emergency egress and still not sacrifice the safety that is required once you are in space. It seems to me there is a great avenue for research.

Dr. MUELLER. We are actively pursuing that at the present time.

Dr. SEAMANS. As a matter of fact, Senator Jordan, we were exploring the accessibility of the capsule prior to the time of the accident.

Senator JORDAN. And I want to get it clear in my own mind, this is the first time you have used this type of access, hatch access?

Dr. MUELLER. That is correct.

Senator JORDAN. Why did you discard the types of hatch access you had used prior to this time?

Dr. MUELLER. In the Apollo spacecraft, the heat shield surrounds the inner pressure cell. In the case of returning from the moon, you are traveling at a much higher velocity when you return to the earth. Therefore, both structural loads and the heat loads on this cabin shell, the outer shell, are higher. By using an inner pressure cell, we were able to isolate the heat shield and that structure from the supporting structure that surrounds the astronaut.

Senator JORDAN. It is a much more complicated problem, then, in the Apollo flight than it would be in a simple orbital mission?

Dr. MUELLER. Yes. We have something like four times as much energy to dissipate when returning from the moon as we do when returning from earth orbit.

Senator JORDAN. Thank you.

Senator CANNON. Senator Mondale?

MAY NEVER BE ABLE TO IDENTIFY CAUSE OF ACCIDENT

Senator MONDALE. I saw a picture the other day of the burned-out Apollo capsule. You indicate that your report will be ready, roughly, in a month, trying to identify——

Dr. SEAMANS. We cannot guarantee that it will be a month, but that is a goal we are shooting toward.

Senator MONDALE. I understand it was a rough estimate. Is there any fear here that you may be unable to identify?

Dr. SEAMANS. Yes; there is.

Senator MONDALE. Serious?

Dr. SEAMANS. That we may not be able to identify the cause of the fire?

Senator MONDALE. Yes.

Dr. SEAMANS. Yes, that is a possibility.

Senator MONDALE. Would your information indicate that it is a serious possibility?

Dr. SEAMANS. At the Cape last week, they were just commencing to take the parts out of the capsule, one by one, and to lay them out on a large floor area. The chemical and fire technicians and specialists were just starting their analysis, and it was not until today, when I had a report from Dr. Thompson, that he indicated that we now are starting to put the information together, but it is still too early to indicate what the cause of the fire was in the cabin.

Senator MONDALE. So that while we await this report, we should bear in mind that it is just possible that we may not be able to identify what caused it?

Dr. SEAMANS. Yes; that is absolutely correct.

RUSSIANS USE TWO-GAS SYSTEM

Senator MONDALE. Do the Russian space capsules operate on 100-percent pure oxygen?

Dr. SEAMANS. No; they have a two-gas system in their spacecraft.

Senator MONDALE. What is the mix in their two-gas system?

Dr. SEAMANS. We do not know exactly what the mixture is, but we believe they are operating pretty close to a pure air environment. That would be 21 percent oxygen, the remainder nitrogen, at atmospheric pressure.

Senator MONDALE. The flammability or combustibility of that upon ignition would be much less than 100-percent oxygen?

Dr. SEAMANS. Much less than 100-percent oxygen at sea level.

TRADEOFFS ALWAYS INVOLVED IN SELECTION

Senator MONDALE. Now, I am sure that you are painfully aware of the fact that many commentators, I would say classically represented by Walter Lippmann in this week's Newsweek, are claiming that in our effort to beat the Russians to the Moon, we are taking chances with the lives of our astronauts. I note in one of the statements here—I think yours—you indicated that both Presidents have instructed you to launch when ready, but only when ready. I gather from that that human lives come first.

And yet I would like to have an explanation of what is meant by Dr. Berry's testimony in point 9, when he says:

At the time of the initial Apollo development, no multigas system suitable for space flight had even been demonstrated. A long development period which might have paced the entire program was avoided by drawing on the technology and experience gained in Mercury and Gemini, using a 100 percent oxygen system.

In other words, by these words, "which might have paced the entire program," I understand what you are saying is that it might have slowed down the program, and "was avoided by drawing on the technology and experience," and so on. And there is one other statement on the next page—it says:

In the development of the environmental system, simplicity of design was a very important consideration, primarily because of reliability requirements and also because of critical delivery requirements. In view of these requirements, a decision to use an artificial atmosphere composed of essentially 100 percent of oxygen rather than a more complex mixed-gas system was made early in the program.

If I were to read that from a critical standpoint, I would say that what this means is because we had a "critical delivery requirement," meaning time as I understand it, we decided to use 100 percent oxygen rather than a more complex mixed system.

That, together, it seems to me, with the experience in 1962, provides at least enough fodder for those who wish to be critical of the efforts of NASA to ask whether we were not hurrying faster than was consistent with full safety for the astronauts.

I am being the devil's advocate here.

Dr. MUELLER. I understand.

Your second quotation was from the Mercury program. It had to do with the planning that went into that program.

Your first quotation was from some considerations associated with one-gas and two-gas systems in general, and in particular, in the case of the Apollo program, we had planned on use of the two-gas system. So such a statement or conclusion is not correct.

On the other hand, if you do look at the tradeoffs involved, there is a question as to whether the additional valves, the additional pressure indicators, associated with the two-gas system do not decrease the reliability and hence the chance for success or the chance of, again, a different kind of accident for the astronauts rather than improve it from going from a two-gas to a one-gas system. These kinds of tradeoffs, in terms of the reliability, and the survival of the astronauts in their environments, clearly have to be made and there are arguments in every case on both sides.

Senator MONDALE. Does the mixed gas alternative necessarily bring on a substantial increase in weight requirement?

Dr. MUELLER. It does not necessarily bring on a substantial increase in weight in terms of the weight of the spacecraft. Rather, it introduces an additional hazard to the lives of the astronauts, and the final decision is made on the basis of reducing the hazard to the life of the astronauts. So, in every single instance, we have always made our tradeoffs in favor of that which is most safe from the standpoint of the life of the astronauts. We have never, in my experience, done anything which would increase the astronauts' risk.

Senator MONDALE. So weight is not a factor in one system as against the other. It seems to me I have read that somewhere.

Dr. MUELLER. It is a factor in the tradeoffs, but it is not a factor——

Dr. SEAMANS. It is true that a two-gas system would weigh more.

Senator MONDALE. Substantially more?

Dr. MUELLER. Something in the order of 20 to 30 percent more.

EVERY EFFORT MADE TO MINIMIZE RISKS

Senator MONDALE. I do not know how you deal with this criticism. It seems to me it is a very serious charge.

Dr. MUELLER. It is a serious charge. It is, in my view, unfounded. As we have testified before this committee in years past, the Apollo program is probably the longest R. & D. program—well, is the longest R. & D. program that we have undertaken in this Nation. The actual time from the initiation to the completion of the program is longer than any other program than we have ever undertaken. You can compare that with aircraft development programs or other missile programs, or what have you. So that in a very real sense, the program was set up to take account of the complexity of the equipment that needed to be developed in order to carry out this mission. It has been paced at a deliberate pace so that it would in fact reasonably economically, but certainly safely, arrive at a set of equipment capable of carrying out the mission.

Dr. SEAMANS. Senator Mondale, I would like to reiterate what Dr. Mueller has said: "that that charge is completely unfounded; that before every one of our manned flights, as well as our ground test simulations, we have taken stock to be sure that there is nothing that has been left undone or that nothing has been done, that would in any way increase the risk to the astronauts; that they have been party to these decisions, part of the review process themselves, to be sure that this was the case.

Senator MONDALE. Thank you.

Senator CANNON. Have you finished, Senator Mondale?

Senator MONDALE. Yes.

FLAMMABILITY OF MATERIALS

Senator CANNON. Doctor, before I call on Senator Smith, I would like to ask you one question. You indicated here that you went to great lengths to provide insulation materials in the capsules, and material that would require a high point of flammability.

Dr. SEAMANS. A high temperature.

Senator CANNON. I would like to ask if all of those materials burned in the capsule in this instance?

Dr. SEAMANS. This is what they are still assessing. It might be better, really, to submit this for the record after the board has finished its review. However, there is a very large part of the capsule that is relatively untouched by the fire. Because of the intensity of the fire, there was a large amount of soot, but on cleaning up the inside of the cockpit, large sections of it were not badly damaged.

Senator CANNON. What about the life support items, including the suits and the covering for the pilots themselves?

Dr. SEAMANS. The suits in two cases were partially burned through. In the report that I submitted to Mr. Webb, I indicated that in the life support system that was operating the suits, oxygen maintained its temperature and flow rate until approximately 4 seconds after we had the last communication from Lieutenant Commander Chaffee. Then, at that time, it started to fluctuate. That undoubtedly was the time it burned through.

Senator CANNON. Senator Smith?

INSUFFICIENT EVIDENCE YET TO DETERMINE MODIFICATIONS

Senator SMITH. Dr. Seamans, you and the other officials have addressed yourself to the possible scheduling effects resulting from the accident. I have several questions concerning future manned and unmanned flights, which I think it would be well to ask, so that we are sure to have your views on the record. I realize that final determinations may have not been made by NASA and if this is the case please indicate this in your answer. Because of the lateness of the time and the vote going on right now, I would ask that these questions be placed in the record, Mr. Chairman, and have Dr. Seamans and his associates answer them for the record.

If I could have a copy so that I would not have to wait on them, I would like that.

Dr. SEAMANS. We will be happy to submit copies of them, both to you and to the committee.

Senator CANNON. Without objection, that will be done.

Senator SMITH. Do you plan a manned flight of a modified command module prior to the establishment of the probable cause of the accident?

Dr. SEAMANS. We have no plans at this time to carry out any specific modifications to the Apollo spacecraft since we do not have sufficient information upon which to base a decision. We will not conduct manned flights until we have the highest assurance of their safety and success.

As I have pointed out, we may not be able to pinpoint the single source of ignition involved with the 204 fire. In that case, we will be taking whatever steps are appropriate, based on the board's findings and the program office's recommendations, to assure that the Apollo system is as safe as we can make it. It is therefore possible that we may fly the Apollo without having been able to establish the cause of the fire. Even in that case, I believe that the care and skill with which the board and program office are conducting their investigations and reviews will provide the necessary assurance that such an accident cannot be repeated.

Senator SMITH. Do you believe the modifications to the command module will increase the weight to an extent that would exceed the capability of the launch vehicle system, thereby necessitating uprating of launch vehicle?

Dr. SEAMANS. No modifications have been decided upon at this time; therefore, we cannot estimate the weight factors that may be involved if changes are eventually made. However, I do not believe that any changes we may find necessary will be of the kind to increase weights beyond current launch vehicle capability.

Senator SMITH. Will the modification discussed in the Apollo command module necessitate any changes in the service module?

If so, what is the nature of the changes and how long will it take to make them?

Will it take a longer or shorter period than for the command module?

How much do you estimate these changes will cost?

Dr. SEAMANS. We cannot answer at this time since our investigation is not complete nor are our analyses of possible alternatives to the present spacecraft system design.

Senator SMITH. What impact has the accident had on the lunar module development?

Do you now anticipate changes and, if so, how long would it take to introduce them?

How much would this cost?

Dr. SEAMANS. The Apollo accident has not impacted the lunar module development up to this point.

As we have said, we are presently restudying the physiological, engineering, and safety tradeoffs involved in previous spacecraft design decisions. Although not anticipated now, it is possible that we will determine that changes should be made to the lunar module. Only then could we assess time and cost impact.

Senator SMITH. Would the proposed changes in the command module require facility modifications at launch complexes 34, 37, and 39?

If so, what is the nature of the change, how long would they take, and what would it cost?

Can the foregoing changes be made before the modified command module is ready or will the facilities be a controlling item?

Dr. SEAMANS. (See next answer.)

Senator SMITH. You are proposing modifications to launch complexes 34 and 37 in the fiscal year 1968 budget.

Would there be any merit in combining these with the modifications proposed as a result of the accident?

Dr. SEAMANS. Certain of the alternatives being examined could have an impact upon facilities, as in the case of the selection of different atmosphere or of wholly new test procedures. Study of the alternatives has not progressed to the point that any facilities estimate of extent, time, or cost can be made. If facilities modifications were required, we would want to carry these out as economically as possible, and would examine the budgetary impact before proceeding.

Senator SMITH. Overall flight schedule and cost: What is the estimated delay in the lunar landing, total estimated cost of the delay, and what are the major elements of cost involved as you now see it?

What is the impact on the fiscal year 1968 budget?

If corrective measures on the Apollo command module require 6 months, for example, does this mean the Apollo schedule will also be delayed 6 months?

If the Saturn V unmanned flights continue on its present schedule is there a possibility of recovering some of the time lost on the manned uprated Saturn I flights?

Dr. SEAMANS. We have no estimate as yet of the cost or schedule factors that may arise as a result of the Apollo 204 accident. When such estimates are developed, we will discuss them with the committee. However, it is certain that if modifications are required for astronaut safety, these will be incorporated prior to manned flight. Therefore, the time that corrective measures may require would have a direct relation to the launching of the next manned flights. Depending upon what these modifications might entail, it is possible that the program could meet its major milestones close to the original schedule; on the other hand, they might result in considerable delay in achieving a manned lunar landing. It is too early in the analysis of alternatives to identify the many factors that would be involved in developing hypothetical schedule revisions reflecting each of many possible sets of program decisions.

As we have often stated, the Apollo program is predicated on a success schedule and there are no margins of time or money in the program; any failure or accident will have direct impact on schedules and on hardware availability. This, in turn, can have a major cost impact, either in the current year or downstream. If hardware modifications are found to be required as a result of the accident, then additional costs may be involved, depending upon kind and extent of the work required. Until the ongoing reviews and analyses are further along, no estimate of the total budget impact can be made; however, it is already clear that we are diverting our manpower from work previously planned to tasks resulting from the accident, and this, if continued, could have a significant effect on eventual total cost and program accomplishment.

Until the board findings and analyses are completed, we cannot assess the time factors that would be involved in a redirection of the total program effort.

Senator CANNON. I understand that counsel has some questions that he would like to submit. If you will also submit the answers to these questions for the record?

Dr. SEAMANS. We will be very pleased to do so.

THREE FIRES IN 20,700 HOURS OF TESTING

Mr. GEHRIG. Dr. Berry, in your statement, you say that since 1960, NASA has amassed a total of 20,756 hours of testing, of manned testing in a pure oxygen atmosphere. Did NASA experience any fires during this more than 20,700 hours of testing?

Dr. BERRY. Yes. We had the three fires, and these are the ones that have been discussed previously by Mr. Johnston.

Mr. GEHRIG. Dr. Berry, would you provide for the record a table summarizing the first paragraph of the last page of your statement on testing in pure oxygen?

Dr. BERRY. The table referred to follows:

Pure oxygen atmosphere tests in hours (Mercury, Gemini, and Apollo)

	Sea level	Altitude	Total
Component and systems test (includes flight)	[1] 914	10,980	11,894
Suit operations (includes flight and manned systems test)	4,116	1,482	5,598
Atmosphere validation		3,264	3,264
Total, manned and unmanned test hours	5,030	15,726	20,756

[1] 402 hours manned and 512 hours unmanned.

Mr. GEHRIG. Dr. Seamans, do you expect the accident to have an impact on the fiscal year 1968 budget requirements?

Dr. SEAMANS. As we have often stated, the Apollo program is predicated on a success schedule and there are no margins of time or money in the program; any failure or accident will have direct impact on schedules and on hardware availability. This, in turn, can have a major cost impact, either in the current year or downstream. If hardware modifications are found to be required as a result of the accident, then additional costs may be involved, depending upon kind and extent of the work required. Until the ongoing reviews and analyses are further along, no estimate of the total budget impact can be made; however, it is already clear that we are diverting our manpower from work previously planned to tasks resulting from the accident, and this, if continued, could have a significant effect on eventual total cost and program accomplishment.

APOLLO SCHEDULE MAY NOT BE DELAYED

Mr. GEHRIG. If corrective measures on the Apollo command module require 6 months, for example, does this mean the Apollo schedule will also be delayed 6 months?

Dr. SEAMANS. Not necessarily. However, it is certain that if modifications are required for astronaut safety, these will be incorporated prior to manned flight. Therefore, the time that corrective measures may require would have a direct relation to the launching of the next manned flights. Depending upon what these modifications might entail, it is possible that the program could meet its major milestones close to the original schedule; on the other hand, they might result in considerable delay in achieving a manned lunar landing. It is too early in the analysis of alternatives to identify the many factors that would be involved in developing hypothetical schedule revisions reflecting each of many possible sets of program decisions.

Mr. GEHRIG. If the Saturn V unmanned flights continue on its present schedule, is there a possibility of recovering some of the time lost on the manned uprated Saturn I flights.

Dr. SEAMANS. Until the board findings and analyses are completed, we cannot assess the time factors that would be involved in a redirection of the total program effort.

NO UNUSUAL NUMBER OF TEST FAILURES

Mr. GEHRIG. It has been reported several times that the Apollo command module during development has been plagued by troubles. Several of the articles quote that there have been 20,000 changes logged in the 5 years the capsule has been under development. And would you want to comment on that statement? Is that an unusual number of changes to be logged during the development of such a complex piece of hardware.

Dr. SEAMANS. First, I would like to note that the development of the Apollo command module was not "plagued by troubles." It is a large and complex spacecraft. Also, because it is designed to go to the Moon and back, many of its specifications are more stringent than we have had for any other spacecraft. Considering these factors, the command module has not had proportionally more troubles prior to the accident than the Gemini or Mercury developments.

As to the news articles which quote the "20,000 changes" the capsule has had in the past 5 years, I believe the writers are referring to the press conference last December in Houston where the depth to which the test program has been carried was described in great technical detail. In that conference it was indicated that a total of some 20,000 failures have been logged in testing and retesting of the Apollo command and service modules and all associated ground equipment. These test failures included those at every level of system, subsystem, or component and covered every qualification, reliability, or other type of testing done within the total development program. Many of the tests resulted in changes, often in the ground equipment. Others resulted in procedural or specification changes.

In direct answer to the question, I would not consider that we have had an unusual number of either changes or test failures.

Senator CANNON. The committee will stand in recess until further notice, subject to the call of the Chair.

(Whereupon, at 4:40 p.m., the committee hearing recessed, subject to the call of the Chair.)

APPENDIX A

STATEMENTS BY THE CHAIRMAN AND THE RANKING MINORITY MEMBER ON THE APOLLO ACCIDENT

JANUARY 28, 1967.

SENATOR CLINTON P. ANDERSON ISSUED THE FOLLOWING STATEMENT THIS AFTERNOON

I have talked with Senator Smith, the ranking minority member of the Senate Space Committee, about the possibility of the committee conducting a full review of last night's Apollo tragedy. She feels, as I do, that this is essential and we would hope to do so after the NASA board of inquiry completes its investigation. We would, as we view it now, examine the proceedings of the board of inquiry—without hampering its work—and gather any additional information necessary to fulfill the committee's responsibilities.

JANUARY 31, 1967.

FLOOR STATEMENT BY SENATOR CLINTON P. ANDERSON, CHAIRMAN, AERONAUTICAL AND SPACE SCIENCES COMMITTEE

Mr. President, last Friday evening we had a tragic accident at Cape Kennedy in which three astronauts lost their lives. This is the first fatal accident involving Apollo hardware, although three astronauts had been killed previously in jet aircraft while assigned to the program.

The National Aeronautics and Space Administration has established a formal Board of Inquiry to review this accident in accordance with its established procedures. This investigation is now under way under the direction of Dr. Floyd Thompson, Director of the NASA Langley Research Center. Dr. Thompson is supported by technical experts from NASA Headquarters and field installations as well as by experts from other Government agencies, the industrial community, and the President's Science Advisory Committee.

In view of the nature of this tragedy and its potential impact on the national space program, as Chairman of the Committee on Aeronautical and Space Sciences, and with complete agreement with the ranking minority member, the senior Senator from Maine, we have decided it is essential that the Committee undertake a full review of this accident.

Our purpose will be to examine the facts surrounding the accident. We will, of course, be especially interested in the recommendations and actions taken to prevent a reoccurrence. The Committee will review other related aspects of NASA's stewardship of the Apollo program as may be necessary to accomplish the above objectives. Mr. Webb, Administrator of the National Aeronautics and Space Administration, has been advised of the Committee's intentions in this area.

I have directed the Committee staff to undertake such background study as may be appropriate at this time and to keep currently informed on the progress of the NASA inquiry, with the full understanding that these actions will not in any way impede the NASA formal inquiry. It is our judgment at this time that Committee hearings and other subsequent action by the Committee on this matter will be dependent on the findings of the NASA Board of Inquiry and Committee staff studies that I mentioned.

It is our purpose in undertaking this course of action that all aspects of this tragedy be assessed in an objective framework both with respect to its cause and to how it relates to the national space program and our effort to establish the preeminence of this nation in space.

In taking these actions, the Committee will fulfill its responsibilities to the United States Senate and to the American people.

FEBRUARY 6, 1967.

FROM THE OFFICE OF SENATOR CLINTON P. ANDERSON

Senator Clinton P. Anderson, D., N.M., chairman of the Aeronautical and Space Sciences Committee, announced today that the Committee will meet at 3 p.m. tomorrow in Executive Session to hear a preliminary report from NASA officials on the January 27 Apollo capsule fire that took the lives of three astronauts.

Anderson said the hearing is designed to bring Committee members up-to-date on the investigation by the NASA Board of Inquiry and on other matters related to the accident.

FEBRUARY 7, 1967.

FROM THE OFFICE OF SENATOR CLINTON P. ANDERSON

Senator Clinton P. Anderson, D., New Mexico, Chairman of the Senate Aeronautical and Space Sciences Committee, today issued the following statement:

The Committee this afternoon held its first meeting on the Apollo 204 accident at Launch Complex 34 at Cape Kennedy, January 27, 1967. As I stated on the Floor of the Senate, it is the purpose of the Committee's inquiry to assure that all aspects of this accident are objectively assessed, both with respect to its cause and how it relates to our effort to establish the preeminence of this nation in space.

We have, within the Committee, established the guideline that our inquiry will not interfere with the proceedings of the NASA Board of Inquiry. Today NASA has brought us up to date on its inquiry. However, there is nothing new to report regarding the incident or its probable cause beyond Dr. Seamans' February 3 report, which was made public. Further, it appears that identifying the cause will require much intensive study.

It is our judgment that the space program must continue and we reviewed with Dr. Seamans and Dr. Mueller their plans for moving ahead with the program, particularly we were exploring in detail the flight plans publicly announced by Dr. Mueller last Friday, the technical assessments of changes that might be required in Apollo hardware, and the impact on the lunar landing schedule and program cost.

It is clear that our unmanned Apollo programs can continue; however, scheduling of manned operations will await further review by NASA technical experts. Similarly, the long term impact on schedule and cost cannot be determined until the technical review is complete.

NASA will keep the Committee currently informed on the progress of its investigation and its technical review of Apollo hardware.

FEBRUARY 7, 1967.

FROM THE OFFICE OF SENATOR MARGARET CHASE SMITH, RANKING MINORITY MEMBER, SENATE COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

In view of the potential impact of the accident on the future of the national space program, I fully agree with Chairman Anderson that our Committee review the facts surrounding the accident.

I found today's hearings very constructive. Dr. Seamans and Dr. Mueller outlined for us the progress made to date by NASA's Board of Inquiry and discussed various possible effects with respect to scheduling and costs on the lunar program. However, no final decisions have been made at this time and, as indicated by the Chairman, a summarization of these matters were contained in NASA's press releases. With respect to changes in the spacecraft atmosphere environment we were advised that NASA is actively studying alternative system approaches but that any decisions as to changes must await the development of more facts about the accident.

I do think it would be well for all of us to place this accident in its proper perspective. One way this can be done is to remember that prior to this *one* accident NASA's space flight record has been most impressive from the standpoint of both accomplishments and safety covering a period of almost six years.

INDEX

○

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

TO

HEAR PRELIMINARY VIEWS AND RECOMMENDATIONS OF THE APOLLO 204 ACCIDENT REVIEW BOARD AND TO REVIEW NASA'S CURRENT PLANS FOR MODIFICATION OF APOLLO HARDWARE AND FLIGHT SCHEDULES

FEBRUARY 27, 1967

PART 2

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE

74-521 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 25 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota
MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

ALPHABETICAL LIST OF WITNESSES

LIST OF FIGURES

APOLLO ACCIDENT

MONDAY, FEBRUARY 27, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to notice, at 3:02 o'clock p.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Young, Dodd, Cannon, Holland, Mondale, Smith, Curtis, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everand H. Smith, Jr., Craig Voorhees, Dr. Glen P. Wilson, and William Parker, professional staff members; San Bouchard, assistant chief clerk; Donald H. Brennan, research assistant; Mary Rita Robbins, clerical assistant, and Howard Bray, press secretary to Senator Anderson.

STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The committee will be in order.

This is the second meeting of the committee with NASA to review the Apollo 204 accident which occurred on January 27, 1967. Today, Mr. James E. Webb, Dr. Robert C. Seamans, Jr., and Dr. George E. Mueller will discuss with the committee the interim findings of the Apollo 204 Review Board and advise the committee on decisions which have been made with respect to the future of the Apollo program because of the accident.

Mr. Webb, I understand Dr. Berry, who testified before us the last time (February 7, 1967), has a statement about the cause of the accidental death. Can he present that to us?

Mr. WEBB. Yes, sir, he has. If you will permit him to read it, Mr. Chairman, it is very short.

The CHAIRMAN. Go ahead, Dr. Berry.

STATEMENT ON CAUSE OF DEATH

Dr. BERRY. Mr. Chairman and committee, the death certificates stated the cause of death to be: Asphyxiation due to smoke inhalation due to fire.

Our continuing medical analysis of this accident, including the toxicology studies, now allows us to further refine the cause of asphyxiation as inhalation of carbon monoxide. A rapid buildup of carbon monoxide in the blood could result in unconsciousness in seconds and death very rapidly thereafter.

The pathological studies also confirm smoke inhalation.

The crew did have some thermal burns of second and third degree (involving all layers of the affected skin but without charring), but these were not of sufficient magnitude to cause death.

The CHAIRMAN. I appreciate that statement because people are asking many questions about what you achieved as the final result. I think that is a good statement.

I want you to leave it to your own discretion how you proceed. I think, Mr. Webb, you may make the first statement. Or Dr. Mueller. He is an old friend. We will be glad to have him.

Also, without objection, I will place in the record at this time biographies of the witnesses.

(The biographical sketch of Mr. Webb follows:)

JAMES E. WEBB, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

President Kennedy appointed James Edwin Webb Administrator of the National Aeronautics and Space Administration on February 14, 1961.

Mr. Webb is a member of the National Aeronautics and Space Council, the President's Advisory Committee on Supersonic Transport, and the Federal Council for Science and Techonology.

An attorney and business man, Mr. Webb has served in high governmental and industry positions. He has been active in aviation and education. He is a former Director of the Bureau of the Budget and a former Under Secretary of State. He has been a Vice President of the Sperry Gyroscope Co., New York City, Chairman of the Board of Directors of the Republic Supply Co., and a Director of Kerr-McGee Oil Industries, Inc.—both with headquarters in Oklahoma City, Okla.—and a Director of the McDonnell Aircraft Co., St. Louis, Mo.

In private life, Mr. Webb was a member of a number of government advisory boards, including the President's Committee to study the U.S. Military Assistance Program—popularly known as the "Draper Committee." He has been engaged in many public service programs related to his long-term interest in science.

Born Oct. 7, 1906, in Granville County, N.C., Mr. Webb graduated in 1928 from the University of North Carolina with a bachelor's degree in education. Later, he studied law at George Washington University, Washington, D.C., and was admitted to the District of Columbia Bar in 1936.

In the early 1930's, Mr. Webb became a U.S. Marine Corps Reserve Officer and pilot, and he currently holds a commission as a Lieutenant Colonel in the Marine Corps Reserve.

In 1936, he joined Sperry Gyroscope, serving for seven years as Personnel Director, Assistant to the President, Secretary and Treasurer, and Vice President.

Mr. Webb became an Assistant to the Under Secretary of the Treasury in 1946. Later that year, President Truman appointed him Director of the Bureau of the Budget, a position he held for three years. From 1949 to 1952, Mr. Webb served as Under Secretary of State in the Truman Administration. From 195[illegible] to 1958, Mr. Webb served as President of the Republic Supply Co., and became Chairman of the Board in 1958. Between 1952 and 1959, he engaged in a number of business activities, including banking, law, and the manufacturing of aircraft and accessories and oil equipment and supplies. He also served as General Chairman, Southwest Seminars in Public Responsibility, University of Oklahoma, Norman. From 1960 to 1963, Mr. Webb was a Trustee, National Center for Education in Politics, New York.

In 1959, Mr. Webb reduced his activity in business and returned to Washington where, until his appointment in NASA, he devoted much of his time to public service. Activities in which he continues to be active include:

Member, Cabinet Committee on Employment; President's Committee on Manpower, and the Visiting Committee, Graduate School of Public Administration, Harvard University; Trustee, Frontiers of Science Foundation of Oklahoma, Inc.; President and Chairman of the Board, Meridian House Foundation; National Member, Federal City Council, Washington, D.C.; Member, Board of Directors, Washington Planetarium and Space Center; Trustee, National Geographic Society; President, American Society for Public Administration, and Board of Governors, National Space Club.

Mr. Webb has been awarded the following honorary degrees: LL.D., from University of North Carolina, 1949, Syracuse University, 1950; Colorado College

1957; George Washington University, 1961; University of Florida, 1963; University of Delaware, 1963; University of Vermont, 1964; Duke University, 1966. Sc.D., from University of Notre Dame, 1961; Washington University, 1962 and New Mexico State University; University of Kansas City, 1962; Boston College, 1963; Missouri Valley College, 1964; University of Alabama, 1964; University of Miami, 1965; Brandeis University, 1965, and Ripon College, 1966. D.P.A. from Northeastern University, 1962. D.C.L. from University of Pittsburgh, 1963. Doctor of Humane Letters from Oklahoma City University, 1962, Nebraska Wesleyan University, 1965, Rose Polytechnic Institute, 1965. Doctor of Humanities from Wayne State University, 1965, and Doctor of Engineering, Rensselaer Polytechnic Institute, 1966.

Mr. Webb lives at 2800 36th St., NW., Washington, D.C., with his wife (the former Patsy Aiken Douglas). Son James Edwin, Jr., attends Princeton University. Daughter Sarah Gorham Webb attends Duke University.

(The biographical sketch of Dr. Seamans follows:)

DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. Robert C. Seamans, Jr., is Deputy Administrator of NASA, having been appointed by President Johnson and then sworn in on Dec. 21, 1965. He retains the responsibility for the general management of NASA on a day-to-day basis and serves as Acting Administrator in the absence of the Administrator.

Dr. Seamans occupied the top career post in NASA since joining the agency on Sept. 1, 1960, that of Associate Administrator. In that position he was responsible for the general management of NASA's research and development program and operations, which include field laboratories, research centers, rocket testing and launching facilities, and a worldwide network of tracking stations.

Prior to joining NASA, he was chief engineer of the Radio Corporation of America's Missile Electronics and Controls Division at Burlington, Mass.

Born Oct. 30, 1918, in Salem, Mass., he earned a B.S. degree at Harvard University in 1939. He earned his M.S. degree in 1942 and Sc. D degree in 1951 at the Massachusetts Institute of Technology, Cambridge, Mass.

Dr. Seamans has been active in the fields of missiles and aeronautics since 1941. From 1941 to 1955 he held teaching and project-management positions of increasing responsibility at M.I.T. These included: 1949 to 1955, Associate Professor of the Department of Aeronautical Engineering; 1950 to 1955, Chief Engineer of Project Meteor, and 1953 to 1955, Director of the Flight Control Laboratory.

He joined RCA in 1955 as Manager of the Airborne Systems Laboratory and Chief Systems Engineer of the Airborne Systems Department. In 1958, he became Chief Engineer of the Missile Electronics and Controls Division, supervising all scientific engineering and technical personnel in the division.

From 1948 to 1958 he served on technical committees of NASA's predecessor organization, the National Advisory Committee for Aeronautics. From 1957 to 1959 he served as a consultant to the Scientific Advisory Board of the Air Force, as a member from 1959 to 1962, and as associate advisor since Jan. 1, 1962.

Dr. Seamans is a member of Sigma Xi, the American Association for the Advancement of Science, American Astronautical Society, American Institute of Aeronautics and Astronautics, American Ordnance Association, American Society for Public Administration, Institute of Electrical and Electronics Engineers, American Academy of Arts and Sciences (Boston), and the National Space Club.

He has received the following awards: Naval Ordnance Development Award (1945); AIAA, Lawrence Sperry Award (1951); Godfrey L. Cabot Aviation Award (1965); NASA Distinguished Service Medal (1965).

He is married to the former Eugenia A. Merrill. They have five children and reside in Washington, D.C.

(The biographical sketch of Dr. Mueller follows:)

DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR, OFFICE OF MANNED SPACE FLIGHT, NASA

Dr. George E. Mueller (pronounced Miller) is associate administrator of the National Aeronautics and Space Administration for manned space flight. He assumed direction of NASA's manned space flight program on September 1, 1963.

Dr. Mueller was born in St. Louis, Mo., on July 16, 1918. He received a B.S. in electrical engineering from the Missouri School of Mines in 1939 and an M.S. in electrical engineering from Purdue University in 1940. He was awarded a Ph. D. in physics from Ohio State University in 1951.

Following graduation from Purdue, Dr. Mueller joined the Bell Telephone Laboratories where he conducted television and microwave measuring experiments. He pioneered there in the measurement of radio energy from the sun, in microwave propagation, and in the design of low-field magnetrons. While employed in Holmdel he continued graduate studies at Princeton University.

In 1946, Dr. Mueller joined the faculty of Ohio State University as assistant professor of electrical engineering. In 1952, he was appointed professor of electrical engineering. His research at OSU included the study and design of broadside and end-fire dielectric antennas, cathode emission, low field magnetrons, and traveling wave tubes. He designed and developed one of the first 6-millimeter traveling wave tubes and a scanning scintillometer for mapping radioactive iodine.

Before joining NASA, Dr. Mueller spent five years with Space Technology Laboratories, Inc., Redondo Beach, California, serving successively as Director of the Electronics Laboratories, Program Director of the "Able" Space Program, Vice President of Space Systems Management, and Vice President for Research and Development. In the last capacity, between 1962 and 1963, he had overall responsibility for the technical operations of the company.

While at Space Technology Laboratories, Dr. Mueller had overall responsibility for the design, development, and testing of the systems and components basic to the Atlas, Titan, Minuteman, and Thor ballistic missile program; for the development of the United States first successful space probe, Pioneer I; for several other space projects including Explorer VI and Pioneer V, and for the establishment of the U.S. Air Force SPAN satellite tracking network.

Dr. Mueller was one of the originators of the concept and design of the Telebit digital telemetery system. He holds seven patents in electrical engineering and is the author of more than 20 technical papers. With E. R. Spangler, he is the co-author of a book, "Communication Satellites."

Dr. Mueller is a fellow of the Institute of Electronic and Electrical Engineers, an associate fellow of the American Institute of Aeronautics and Astronautics, and a member of the American Physical Society. He is a member of Commission 6 (Radio Wave and Transmission of Information) in the International Scientific Radio Union and is active in national and international conferences on space communications and space technology.

Dr. Mueller, his wife, Maude, and his two daughters live in Washington, D.C.

STATEMENT OF JAMES E. WEBB, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NASA; DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR, OFFICE OF MANNED SPACE FLIGHT, NASA; AND DR. CHARLES A. BERRY, CHIEF OF CENTER MEDICAL PROGRAMS, MANNED SPACECRAFT CENTER, NASA

Mr. WEBB. Mr. Chairman, I would appreciate it if we could get into the record the statement by Dr. Mueller as to the actions we are now planning or have underway resulting from the work and recommendations of the Board. However, I believe, Mr. Chairman, since the previous record included only the first interim report by Dr. Seamans, you may want to include in the record the second and third interim reports which have been made and which were furnished to your committee. And I have four quick statements to make, if you permit me to proceed.

SECOND AND THIRD INTERIM REPORTS

The CHAIRMAN. Without objection, I am going to place in the record the second and third reports by Dr. Seamans on the Apollo 204 Review Board, and the statement Mr. Webb made at the time Dr. Seamans' third report was released.

(The second interim report referred to follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
OFFICE OF THE ADMINISTRATOR,
Washington, D.C., February 14, 1967.

Memorandum to: James E. Webb, Administrator.
From: Robert C. Seamans, Jr., Deputy Administrator.
Subject: Further report on Apollo 204 Review Board activities.

On February 10 I met with the Apollo 204 Review Board at KSC to discuss their progress in the investigation of the Apollo accident.

The Board now has 21 panels established and operating, each with a specific assigned task, each chaired by a Government employee, and each reporting to a specific Board member. A detailed Review Board activity schedule has been established and is reviewed daily to ensure that milestones are being met or that scheduled adjustments are made as early as necessary. This permits close coordination and integration of all the necessary activities, analyses, and studies.

In order to speed up the investigative effort, the Apollo 012 spacecraft is being mapped in detail, using a 3-dimensional coordinate system to which all physical spacecraft elements can be referred. Complete photographic coverage is being maintained, color film being preferred since it permits more ready identification of components and their condition. Each photograph is cross-referenced to the master grid.

The Board has implemented a data control system that permits a visual display, against a time-line background, of each step of the investigation. As spacecraft systems are examined and as their utilization in the 204 test is established, these are noted and color coded: at a glance, one can determine whether a system might have caused the accident or has proven to be non-contributory, and also whether a particular analysis is still underway or completed. This method of data control focuses on the critical areas requiring the greatest attention.

I reviewed at some length the work and procedures of the panel that is investigating the origin and propogation of the fire. While their work is far from complete, I am satisfied that the procedures they are following are well worked out. When this work is completed, it will give us as clear a view as can be obtained from the evidence. The panel has begun by examining each possible combustible within the spacecraft, its distribution and characteristics, and its proximity to each possible ignition source. Such combustibles include both solids and liquids. At each step of spacecraft disassembly, panel members are carefully removing both damaged and undamaged materials for microanalysis which, in turn, permits the identification of the material that was burned. This allows a reconstruction of the final location of all combustibles in the spacecraft and will point up irregularities in this distribution if any exist. The physical evidence thus far examined points to the following:

First, it appears the fire had considerable variation and directionality, since damage in the spacecraft indicates differences of intensity and timing. For example, an aluminum tubing handle has a hole burned through it indicating a temperature at that point of at least 1,400° F, while its nylon hinge within two inches of the melted spot is relatively undamaged indicating a temperature there of less than 500° F.

Second, there is evidence that the fire may have had more than one phase, but this is difficult to prove since the last phase would obscure the evidence of the earlier. One hypothesis, supported by the cabin pressure history, assumes a small, low-grade fire whose heat was at first largely absorbed by the spacecraft structure and that was burning at the time of the first crew report; that fire may have continued for as long as ten seconds. A more intense fire may have then developed, causing the rapid increase in cabin pressure. This fire was probably then extinguished by the depletion of oxygen.

Other peculiarities require further analysis. These deal with the ruptures in the spacecraft and the role of the fire in burning through into the space between the inner and outer hulls.

At this time, there has been no determination as to the source of the ignition itself.

Additional information relating to the progress of the accident has been identified and is being analyzed. A recording from an onboard bio-sensor that appears relatively undamaged is in the process of being read out at this time. Additional work to interpret all background sounds on a high fidelity recording obtained over the S-band link is being carried out in the hope of gaining further information on the course of the fire. I also reviewed with the physician who heads the medical analysis panel the condition of the personal effects, suits, and equipment of the crew as well as data available on their actions during the course of the accident. It is now clear that all three suits were burned through, though the extent of suit damage varies; the command pilot's received the greatest exposure to flame and the pilot's the least.

Spacecraft disassembly is proceeding with great care; for example, a false floor with plexiglass viewing ports has been installed to permit continued examination without the danger of disturbing physical evidence. Current plans are for the final removal of the spacecraft to the industrial area by the end of this week. Detailed plans for the continued disassembly of both the command module and service module are in preparation and will be reviewed and approved by the Board before further work is undertaken. It is important to note that no single spacecraft element is touched or removed for analysis without full Board approval and evaluation of its possible effect on any of the other on-going studies or analyses.

ROBERT C. SEAMANS, Jr.

(Mr. Webb's statement regarding the third interim report referred to follows:)

STATEMENT BY JAMES E. WEBB, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, FEBRUARY 25, 1967

NASA is releasing today a third interim report on the work of the Apollo 204 Review Board resulting from two days of meetings with the Board by Deputy Administrator Robert Seamans at Cape Kennedy. These meetings took place on February 23 and 24.

This statement and Dr. Seamans' third interim report have been reviewed with Chairman Clinton Anderson and Senior Minority Committee Member Senator Margaret Chase Smith and with Congressman George Miller. In continuation of the Senate Committee's review of the Apollo 204 accident, Senator Anderson has announced that the Senate Committee will hold an open hearing on the preliminary findings of the Board and actions to be taken by NASA at 3 p.m., Monday, February 27.

In addition to the information set forth by Dr. Seamans in his three interim reports, I have had the benefit of a review by three members of the Board—the Chairman, Dr. Floyd Thompson, Astronaut Frank Borman, and Department of Interior combustion expert Dr. Robert van Dolah. This included the preliminary views of the Board as to the most likely causes of ignition, the contributing factors in the rapid spread of the fire, the inadequacy of the means of emergency egress for the astronauts, and the need to recognize that all future such tests be classified as involving a higher level of hazard.

The following emerges from the preliminary views of the Board and the Board's preliminary recommendations:

(1) The risk of fire that could not be controlled or from which escape could not be made was considerably greater than was recognized when the procedures for the conduct of the test were established. Our experience with pure oxygen atmospheres included not only the successful Mercury and Gemini flights but a number of instances where a clearly positive source of ignition did not result in a fire. In one such instance an electric light bulb was shattered, exposing the incandescent element to the oxygen atmosphere without starting a fire.

(2) Our successful experience with pure oxygen atmospheres in Mercury and Gemini, our experience with the difficulty of storing and using hand-held equipment under zero-gravity conditions, and our experience with the difficulty of making sure before flight that no undiscovered items had been dropped or found their way into the complex maze of plumbing, wiring, and equipment in

the capsule, led us to place in the Apollo 204 capsule such items as Velcro pads to which frequently used items could be easily attached and removed, protective covers on wire bundles, nylon netting to prevent articles dropped in ground testing from being lost under or behind equipment in the capsule, and a pad or cushion on which, in the planned escape exercise, the hatch could be placed without damage to the hatch itself or to the equipment in the spacecraft. While most of these were constructed of low-combustion-potential material, they were not so arranged as to provide barriers to the spread of a fire. Tests conducted in an Apollo-type chamber since the accident have shown that an oxygen fire in the capsule will spread along the surface of Velcro and along the edges of nylon netting much faster than through the material itself.

(3) Soldered joints in piping carrying both oxygen and fluids were melted away, with resultant leakage contributing to the spread of the fire.

(4) The bursting of the capsule happened in such a way that the flames, as they rushed toward the rupture and exhausted through it, traveled over and around the astronauts' couches. Under these conditions, and with just a few seconds of time available, the astronauts could not reach the hatch and open it.

(5) This fire indicates that a number of items related to the design and performance of the environmental control unit will require the most careful examination and may require redesign.

Astronaut Borman, in commenting on his reactions to the conditions surrounding the Apollo 204 test and the subsequent knowledge he has gained as a result of serving on the Review Board, stated to Dr. Seamans, Dr. Thompson, and to me that he would not have been concerned to enter the capsule at the time Grissom, White and Chaffee did so for the test, and would not at that time have regarded the operation as involving substantial hazard. However, he stated that his work on the Board has convinced him that there were hazards present beyond the understanding of either NASA's engineers or astronauts. He believes the work of the Review Board will provide the knowledge and recommendations necessary to substantially minimize or eliminate them.

Dr. Thompson, Astronaut Borman, and Dr. van Dolah have returned to Cape Kennedy and are proceeding with the work of the Board. This will require several weeks to complete.

Chairman George Miller, of the House Committee on Science and Astronautics, has announced that as soon as the Board's work is complete, the Committee's Oversight Subcommittee, chaired by Congressman Olin Teague, will conduct a complete investigation of all factors related to the accident and NASA's actions to meet the conditions disclosed. Chairman Teague spent Friday and Saturday at Cape Kennedy with members of the Manned Space Flight Subcommittee, of which he is also Chairman, reviewing progress in the Apollo program. Dr. Seamans, Dr. George Mueller, and I will report further to him at 10 a.m., Monday, February 27.

(The third interim report referred to follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
OFFICE OF THE ADMINISTRATOR,
Washington, D.C., February 25, 1967.

Memorandum to: James E. Webb, Administrator.
From: Dr. Robert C. Seamans, Jr., Deputy Administrator.
Subject: Interim report of the Apollo 204 Review Board.

On February 22, 1967, I heard a presentation by the Apollo 204 Review Board at Kennedy Space Center of the significant information developed to date and of their tentative findings concerning the circumstances of the accident. The Board also discussed preliminary recommendations. These tentative findings and preliminary recommendations will serve as guides for those interim decisions to be made in the conduct of the Apollo Program prior to the completion of the Board report. I also reviewed the status of the investigation and of spacecraft disassembly, and followed up on items previously noted in earlier reports.

The spacecraft has been removed from the launch vehicle and is now housed in the industrial area. There detailed disassembly continues under careful supervision, each action being undertaken in response to a specific Board directive. This disassembly is far from complete, but a number of the major systems have been removed and are being checked for further verification of the part they played during the fire, the effect of fire on the equipment, and the evidence that analysis might add to the overall picture being built up of the accident. The heat shield has not yet been removed, nor has sufficient internal equipment to permit full view from inside of the entire pressure hull, and a large number of tests, checks and analysis are continuing at NASA, university, and industrial facilities around the country. At present, the Board has over 1,500 individuals, from nine government agencies and departments in addition to NASA, from thirty-one industrial groups, and from several universities, directly participating in the review and analysis. The Board currently estimates that its report will be completed by the end of March. The Board is developing procedures to assure that an orderly and rapid transition of the personnel under its control from the current accident investigation to redesign, qualification, and test effort where required can be made.

In my last report. I noted that an intact on-board biosensor recording was being analyzed for possible additional information; this analysis is now complete and provides little more than one second's additional information and duplicates data already examined that was available from the telemetry recorded during the test and subsequent accident. The S–band recording also mentioned in the previous report has been completely analyzed by the Bell Laboratories, including computer reconstruction and comparison, but no significant new information could be derived therefrom.

The Board has not identified the source of ignition at this time. Ignition sources that have been under review include possible *chemical reactions*, such as those in the on-board batteries or in the air purifier of the environmental control unit; possible *spontaneous combustion* of certain materials used in the spacecraft; and possible *electrical phenomena*, such as electro-static spark discharges, electrical arcing, or wiring overheating from shorts or malfunctions.

Examination of the environmental control unit lithium hydroxide and of the batteries indicates these were not the source of ignition. Tests of the combustible materials used in the spacecraft show that at least a 400°F temperature would be necessary for spontaneous combustion, and that no such materials could have been subjected to that temperature except by the malfunction of some other part of the spacecraft systems. An electrical malfunction is therefore regarded as the most likely source of ignition. While not wholly ruled out, electro-static discharge is deemed unlikely in that all reasonable concentrations of flammable vapors that could have been present in the spacecraft were not sensitive to this type of sparking ignition.

By the time it has completed its final report, the Board expects to have significantly narrowed the list of ignition sources that had a relatively high possibility of contributing to the initiation of the fire, but the possibility exists that no single source will ever be pinpointed.

A good deal of the work involved in tracing the history of the fire *after* ignition has been completed. The Board has considerable confidence in its present theory as to the initial location, propagation mechanisms, and phasing of the fire. This hypothesis, and some of the supporting evidence, is summarized as follows:

Present evidence indicates that the fire had three distinct phases. The fire originated in the left, or command pilot side, in the front corner of the spacecraft, near the floor. It probably burned for several seconds without being noticed by the crew or recorded on instrumentation. Because it was below the couch level it was not visible at this stage; because the crew was fully suited and breathing oxygen from the environmental control system rather than from the cabin, it was not smelled or heard. The left front corner shows the evidence of highest heat and longest duration of the fire, and the witnesses watching the television monitors place the first appearance of flame in that corner (the television camera was mounted outside the spacecraft, looking in through the window in the hatch). The first crew report of fire was at 6:31:04, EST, indicating the fire had become visible. Because the metal structure of the spacecraft absorbed the initial heat, the fire did not initially cause an increase in cabin pressure.

By 6:31:12, the fire had spread and become intense, igniting various materials along the left side of the cabin. Flames were hot and smoke-free, rising along the wall and spreading across the ceiling. The cabin shows heavy damage in this area but little smoke, indicating that the oxygen in the cabin had not been depleted at this time. The fire spread and fed on nylon netting (installed to prevent objects from floating into equipment crevices while in zero-g), Velcro fastening material (used to fasten equipment to the spacecraft interior), and the environmental control unit insulation. The cabin pressure began to rise rapidly at this time as the atmosphere became heated.

At approximately 6:31:19, the internal pressure had risen to an estimated 36 pounds per square inch and the sealed cabin ruptured. This first puncture of the pressure vessel was a long tear in the floor on the right, or pilot's, side of the cabin. With the high internal pressure released, cabin gases and flames flowed both over and under the couches toward and through the hole, moving from left to right. This was the second phase of the fire. Flames passed through the hole into the air space between the cabin pressure shell and the surrounding heat shield; these flames then escaped through access hatches in the heat shield and partially enveloped the outside of the spacecraft for a moment. The short duration, left-to-right, flame motion is evidenced by heavier damage on the left than right side of equipment and wiring on the floor, of the couches, and of the front panels.

With the rupture of the cabin and the rush of flame and gas outside, the oxygen content of the cabin atmosphere was quickly reduced and the fire smoked heavily, laying a film of soot on many interior surfaces. This third and final phase of the fire was also characterized by continued localized burning. The environmental control system uses a water/glycol coolant that leaked from burnt or burst pipes. Both high and low pressure oxygen lines were connected with solder joints that fail at temperatures below 400° F. The glycol mixture from the cooling system, acting as a fuel and supported by the flowing oxygen from the failed lines, caused continued hot burning in the left corner and melted a large hole in the floor there.

The Board noted that the underlying design approach in Apollo was to control the known risk of fire—on the pad or in orbit—by isolating and rendering safe all possible ignition sources. The experience in flight and in tests prior to the accident had suggested that the probability of a spacecraft fire was low. Continued alertness to the possibility of fire had become dulled by previous ground experience and six years of successful manned missions. Ground tests at the pad were classified as especially hazardous only when propellants or pyrotechnics were involved, and different procedures and safety precautions are taken in handling or working under such conditions. Potential ignition sources inside the spacecraft had been treated so as to be considered safe; neither the crews nor the test and development personnel felt the risk of spacecraft fire to be high. The Apollo 204 accident now proves this assumption to have been wrong.

The assumption of ignition source safety led to the use of several solid combustible materials within the spacecraft, including nylon and polyurethane foams. From the point of view of possible fire, these materials were distributed within the cabin without breaks specifically designed to help localize fire if it occurred.

The Board noted that, in the event of a fire emergency, the time and effort required to open the hatch was too long, and that pad emergency procedures were focused on propellant hazards and did not include provisions to meet spacecraft fires.

The principal preliminary recommendations of the Board are designed to assist the Administrator in making his decisions concerning the continuing Apollo program effort prior to completion of the Board review. These are:

> That combustible materials now used be replaced wherever possible with non-flammable materials, that non-metallic materials that *are* used be arranged to maintain fire breaks, that systems for oxygen or liquid combustibles be made fire resistant, and that full flammability tests be conducted with a mockup of the new configuration.
>
> That a more rapidly and more easily operated hatch be designed and installed.
>
> That on-the-pad emergency procedures be revised to recognize the possibility of cabin fire.

In addition, the Board has drawn attention to a number of components, subsystems, techniques, and practices which it feels can be improved to increase crew safety and mission reliability. These include findings on the environmental control system solder joints, location of wiring, electrical equipment qualification and design, and the developemnt of checkout procedures.

An important area of Board attention has been that of the cabin atmosphere. The atmosphere and pressure selected for the suit and the cabin, before launch and in orbit, have a very important relation to spacecraft design, hatch type, crew physiology, launch procedures, and mission capability. The Board did not recommend a change in the use of pure oxygen in the suit for either pre-launch or orbital operations. The Board did not recommend that cabin atmosphere for operations in space be changed from the currently planned 5 psi pure oxygen but did recommend that the trade-offs between one- and two-gas atmospheres be re-evaluated. The Board specifically recommended that pressurized oxygen no longer be used in pre-launch operations.

ROBERT C. SEAMANS, Jr.

The CHAIRMAN. Go right ahead.

STATEMENT BY MR. WEBB

Mr. WEBB. Now, Mr. Chairman, I have had, as you know, a review by the Chairman of the Board, Dr. Floyd Thompson, Astronaut Frank Borman, and Dr. Van Dolah, the combustion expert from the Department of the Interior, as well as the three interim reports by Dr. Seamans. My own view of the present situation in which we find ourselves is:

OUTLINES PRESENT SITUATION

(1) The risk of a fire that could not be controlled, or from which escape could not be made, was considerably greater than was recognized when the procedures for the conduct of the test were established.

(2) Our successful experience with pure oxygen atmospheres led us to place in the Apollo 204 capsule such items as Velcro pads to which frequently used items could be easily attached and removed, protective covers on wire bundles, nylon netting to prevent articles dropped in ground testing or in orbit from being lost under or behind equipment in the capsule, and a pad or cushion on which, in the planned escape exercise, the hatch would be placed to avoid damage to the hatch itself or to the equipment in the spacecraft. The Board finds that these articles did contribute to the rapid spread of the fire and the buildup of pressure in the capsule.

(3) Soldered joints in piping carrying both oxygen and fluids were melted away, with resultant leakage contributing to the spread of the fire.

(4) The bursting of the capsule happened in such a way that the flames, as they rushed toward the rupture and exhausted through it, traveled over and around the astronauts' couches.

MAY REQUIRE REDESIGN

And lastly, this fire indicates, from my review of these reports, that a number of items related to the design and performance of the environmental control unit will require the most careful examination and may require redesign.

Mr. Chairman, as Dr. Mueller proceeds, I hope you and the committee can keep in mind that an escape hatch designed to serve as a means of egress for astronauts on the ground could also serve as a great hazard during the much longer time these men are in space. We have a very real problem, as Dr. Mueller will indicate, in determining the best possible means to assure safety both on the ground and in space. And second, you have indicated a strong interest in the considerations that bear on the question of whether we use pure oxygen or a two-gas system, and so we have asked Dr. Berry to come up from Houston, which he did last night, in order to answer your questions with respect to the merits and problems we have in making our decisions as to the future.

So, if I may just add, the astronauts in their suits have to have pure oxygen if they are going to work outside in extravehicular activity, so we have, not just a simple question of whether we will have two gas systems in the spacecraft; in fact, we will have to have three systems if we go to the two-gas system. This is a very important matter that has not been well understood in some of the coverage of this accident.

If you would permit Dr. Mueller now to proceed with his report of the careful work we are doing, I would appreciate it.

The CHAIRMAN. If there is no objection, Dr. Mueller, you proceed.

Mr. MUELLER. Thank you, Mr. Chairman.

The CHAIRMAN. By the way, Doctor, your entire paper here will be included in the record?

Dr. MUELLER. Yes, sir.

The CHAIRMAN. Have you distributed these papers?

Mr. WEBB. Yes, sir. They have been distributed, Mr. Chairman.

STATEMENT BY DR. MUELLER

Dr. MUELLER. With your permission, I will proceed to read the paper.

Mr. Chairman and members of the committee, this is the second of NASA's formal presentations to the committee on the investigation of the tragic accident at Cape Kennedy on January 27, 1967. On February 7, Dr. Seamans, I and other witnesses testified on our understanding at that time of the fire in the Apollo AS-204 spacecraft, which took the lives of Astronauts Virgil Grissom, Edward White, and Roger Chaffee.

On Saturday, February 25, Mr. Webb and Dr. Seamans reviewed the present status of our understanding and actions underway with the chairman and the senior minority member of the committee. I am here today to report on the actions we are taking in the Apollo program as the result of the initial findings of the Apollo AS-204 Review Board.

APPROACH TO FIRE PREVENTION TO BE REVISED

The fire in the Apollo spacecraft cabin occurred under conditions and using procedures which had been verified by 7 years of manned spacecraft operational experience. Standards of design, manufacture, test, and operations which have been developed over the years had demonstrated that the possibility of a fire in the spacecraft cabin was remote. This background led to our considering this type of test as being nonhazardous. The fire proves the approach we had been using of preventing fires by preventing their ignition is inadequate. We are introducing, therefore, a three-prong approach to the prevention of fire in the future. (Fig. 1.) We will continue to minimize the possibility of ignition but will recognize that this possibility will always exist. We will take steps to limit and, insofar as possible, eliminate the chance of a fire propagating once it is started and finally we will arrange to minimize the consequences of a fire to the crew.

FIGURE 1

APPROACH

IGNITION

- REDUCE PROBABILITY - CANNOT ABSOLUTELY ELIMINATE
- AREAS OF INVESTIGATION
  - MATERIALS
  - ELECTRICAL
  - QUALITY

PROPAGATION

- SIGNIFICANTLY REDUCE - POSSIBLY ELIMINATE
- AREAS OF INVESTIGATION
  - MATERIALS
  - LAYOUT
  - CONFIGURATION CONTROL

CONSEQUENCE

- AFFECTED BY
  - MATERIALS
  - CREW PROTECTION
  - FIRE DETECTION
  - FIRE EXTINGUISHER
  - ESCAPE PROVISIONS
  - PROCEDURES

The Apollo organization of government, industry, and universities has devoted all of its applicable talent and resources to matters arising from the Apollo AS-204 fire since it occurred. In our work, we have given highest priority to supporting the Apollo AS-204 Review Board in its investigation. We have concurrently undertaken analyses and design studies with the objective of identifying such changes in design or procedures as are necessary to assure a satisfactory solution of the fire hazard problem.

LINE OF ACTION IN FIVE GENERAL AREAS

The work we are doing is in five general areas. (Fig. 2.) First, there is support of the Board in understanding the causes of the AS-204 fire and its propagation. We are simulating the various phases of the fire through materials test, boilerplate ground tests and special experiments. Third, we are reviewing the Apollo design and implementation in light of the knowledge we have gained from the fire. The fourth area is the conduct of those designs and analyses that will implement changes identified by the Board and by our own review, and finally, we will need to evaluate the new designs and the new procedures to be sure that they are sound.

FIGURE 2

LINE OF ACTION

- UNDERSTAND THE AS-204 FIRE
  - IGNITION SOURCES
    - ELECTRICAL SYSTEM
    - CHEMICAL REACTION
    - SPONTANEOUS COMBUSTION
    - STATIC DISCHARGE
  - FIRE PROPAGATION
- SIMULATE PHASES OF FIRE
  - MATERIAL TESTS
  - BOILER PLATE GROUND TESTS
  - SPECIAL EXPERIMENTS
- REVIEW APOLLO DESIGN AND IMPLEMENTATION IN LIGHT OF FIRE
- MAKE NECESSARY CHANGES
  - DESIGN
  - PROCEDURES
- EVALUATE REDESIGN
  - MATERIAL TESTS
  - BOILER PLATE GROUND TESTS
  - SPECIAL EXPERIMENTS

DESIGNING NEW HATCH

In particular, we are initiating actions to be responsive to each of the preliminary recommendations of the Apollo AS-204 Review Board. In this regard, we are taking steps to apply certain newly developed materials which are nonflammable in every possible place in the spacecraft. The nonmetallic materials will be arranged so as to maintain firebreaks and the systems that contain oxygen and liquid combustibles will be made more fire and heat resistant. This new cabin configuration will be verified by full boilerplate flame tests. A new hatch is now being designed. Emergency procedures throughout the program are being revised to recognize the possibility of cabin fire. A comprehensive review of the specification, design, and qualification, of spacecraft systems is underway. Studies of the tradeoffs between one- and two-gas atmospheres, as well as studies of means to implement the Board recommendation for the elimination of pure oxygen at atmospheric pressures in prelaunch operations, are underway. You recognize, I am sure, that it will take time to complete the review and carry

74-521 O—67—pt. 2——3

through the new designs to a point where proper decisions can be made. The work of the program is directed at a point where we can have sufficient information and test results to make the right set of decisions. Those sets of decisions will provide a sound basis upon which to continue the orderly execution of the Apollo program.

PROGRESS ON STUDIES AND DESIGN

Today I would like to describe the work and the progress of our studies and designs. In this presentation, I will cover our activities in reviewing the Apollo design as well as specific actions being taken in fire detection, fire extingushing, materials, cabin configuration, emergency egress, spacecraft atmospheres, and environmental control systems.

The CHAIRMAN. May I just say there, Doctor, that you have listed here some things you are doing. You say, "A comprehensive review of the specification, design, and qualification, of spacecraft systems is underway," and you say, "A new hatch is now being designed." I wish you would sort of stress these things you are doing so that the Nation may know about this new hatch being designed. You are doing it, you are on the way.

Dr. MUELLER. Yes, sir.

The CHAIRMAN. Pick up some of these as you go through.

Dr. MUELLER. I shall try to.

The CHAIRMAN. Thank you.

Dr. MUELLER. Now, in our review, the first item that I would like to cover are our procedures. (Fig. 3.)

FIGURE 3

APOLLO DESIGN AND IMPLEMENTATION

IN LIGHT OF AS-204 FIRE

- PROCEDURES
- ELECTRICAL SYSTEM REVIEW
- COMMUNICATIONS SYSTEM REVIEW
- SPECIFICATIONS AND QUALIFICATION
- QUALITY AND INSPECTION

REVIEW OF DESIGN AND IMPLEMENTATION

Our procedures have in the past required that each test to be conducted be reviewed from the safety standpoint. We will now insure that the review assume the possibility of fire in the spacecraft cabin and provide for careful identification of hazardous test conditions and establishment of appropriate emergency equipment, personnel procedures, and training.

We will tighten procedures and safeguards to insure that materials in the spacecraft cabin are controlled, recognizing the possibility of fire, and that the test configuration of the spacecraft fully take this possibility into account. Finally, we are taking steps to insure the early availability of procedures so that adequate reviews are carried out.

ELECTRICAL SYSTEM

In the electrical system area, a reevaluation of the electrical power system and cabling is underway to determine whether or not changes of cable design, fabrication, and routing will provide greater assurance of protection from damage and therefore improved assurance that we have done all that is practical to minimize potential ignition sources.

COMMUNICATIONS SYSTEM

In the area of the communications system, the AS-204 fire occurred while the checkout countdown was being held to rectify communications difficulties. While there is no indication that this was directly a factor in the fire, it is nevertheless important that the many interconnecting organizational elements be able to communicate efficiently at all times. We are therefore reviewing all circuits, interconnections, monitoring, and checkout procedures to determine whether or not changes are required to improve the total communications system.

SPECIFICATIONS AND QUALIFICATIONS

In the area of specifications and qualification, we expect to make changes to the spacecraft to reduce the hazard of fire. We are now reviewing both the specifications and the qualification requirements that apply to the spacecraft and its many components and subsystems to determine whether or not any changes are needed.

QUALITY AND INSPECTION

In the area of quality and inspection, workmanship and quality are as important, if not more important, to the reliability and safety of equipment as is the fundamental design. We believe we have maintained a vigorous and effective quality control and inspection program. The careful disassembly of the Apollo-204 spacecraft being accomplished under the direction of Apollo-204 Review Board provides a unique opportunity to determine whether or not there have been shortcomings in this area. We will follow this disassembly through step by step and take such actions as are indicated if quality and inspection deficiencies are found. I would like to say in each one of these areas that we have, I believe, exercised care in the past. I think that it is important to recognize that we are reviewing in the light of the 204 fire all those things that we have reviewed in the past.

FIRE DETECTION

Now, in the area of fire detection (fig. 4), the equipment with which to detect fire in space vehicles has always been a matter of interest; however, suitable detectors with adequate reliability have been difficult to develop. We have made some progress in our continuing development program and we are now evaluating those developments and also checking with other organizations to determine whether or not we can now incorporate suitable and reliable sensors into the Apollo spacecraft for fire detection purposes.

FIGURE 4

ACTIONS

FIRE DETECTION

- SYSTEM CONSIDERATIONS
- SUITABILITY AND RELIABILITY OF SENSORS

FIRE EXTINGUISHING

- CABIN DEPRESSURIZATION
- WATER SPRAY
- OTHER EXTINGUISHERS
- INERTING

FIRE EXTINGUISHING

In the area of fire extinguishing, much work has been done to develop equipment and techniques for extinguishing fires in space vehicles. Since the Apollo 204 fire, we have accelerated our work and have undertaken additional test programs.

The extinguishment methods under study and test include chemical extinguishing agents, dilution of the oxygen atmosphere with inert gases, cabin depressurization and water sprays.

In the fire extinguishment tests to date, it appears that chemical and inert gas extinguishers are ineffective. The gas streams from such extinguishers entrain sufficient oxygen from the spacecraft atmosphere to cause the fire to burn more vigorously rather than to be extinguished. This is true even for such chemicals as bromotrifluoromethane, one of the freons, which appears to be quite effective for aircraft fires.

The tests performed using inert gases such as nitrogen as a dilutant indicate that the turbulence caused by the introduction of the gas causes more rather than less intense burning.

The most effective fire extinguisher we have found to date is a water spray. On the other hand the detrimental effects of water on electrical equipment, together with complexity and weight considerations, make the usefulness of this system doubtful.

Additional tests are planned to determine combustion characteristics in simulated command module interiors. The command module for these tests will be a boilerplate spacecraft and will include tests with both present and modified interior arrangements.

SHOWS FILM ON FIRE TESTS

I have here a short film [1] that will show the progress of certain tests. The first of these is a measure of the propagation of flame. This is Velcro, the major constituent for holding and fastening we have in the spacecraft itself. If you look, you see the fire starting at the top and it travels quite rapidly. There is a very faint blue glow traveling down the face of the strip. When it reaches the bottom, you see the little flares that go down. When it reaches the bottom it will start burning from the bottom up.

Now, you see the slow propagation in the base material of the flame in the Velcro backing. These are the little hooks on the front that carry the flame so rapidly down the face of this thing.

Now, this is in 16 pounds pressure oxygen and the picture is slowed down by a factor of 17. So this actually occurs 17 times as fast as the picture.

In this particular kind of a test, the rate of propagation is about two and a half inches per second downward.

Now, here is a view of two of the materials we used in the spacecraft. Here we have a 3-foot horizontal and 3-foot vertical run of the material and it is ignited down at the bottom end. As you can see on the right, the Velcro properties burns rapidly; on the left, the shell net burns more slowly. Both of these are nylon and the rate of propagation goes along both horizontally and vertically at about this same speed, about two and a half inches or so per second.

This is another test in 16 pounds per square inch absolute atmosphere. You will notice that even though it rises more slowly, the fire in the net goes out before the Velcro fire has burned to completion.

These tests were made after the fire in our test system down at the Manned Spacecraft Center at Houston.

(Film stopped for questioning.)

[1] At this point a NASA film was shown entitled "Flame Propagation," MSC file role CL-67-354.

QUESTIONS BY SENATOR CURTIS

Senator CURTIS. Mr. Chairman, could I ask a few questions at that point?

The CHAIRMAN. Yes.

Senator CURTIS. Dr. Mueller. What in the spacecraft burned prior to the death of the three astronauts?

Dr. MUELLER. I beg your pardon?

Senator CURTIS. What in the spacecraft burned prior to the death of the three astronauts?

Dr. MUELLER. We do not have an accurate enough record of the precise events during the combustion to be able to identify for sure what the sequence of combustion of the materials was. We are reproducing at Houston a boilerplate mockup of the actual distribution of the flammable materials in the cabin and we will conduct tests which would permit us to simulate the fire as it occurred in Florida. Whether we will be able to identify the exact sequence of events, however, is not clear at this time.

Senator CURTIS. As between gases and tangible materials——

Dr. MUELLER. We did carefully examine the possibility of a gas being involved in the flame. I believe that our flame experts are convinced that the actual flame propogation and the initial phases of the fire were in the flammable nonmetallic materials that were on board the spacecraft in solid form.

Senator CURTIS. Thank you.

(Showing of film resumed.)

Dr. MUELLER. Now, returning to the film, we are looking at firefighting techniques, and here is the boilerplate that is used for these tests and we simulate inside the boilerplate mockup the flammability of materials and the ability to extinguish them.

Now, the example we are using is polyurethane and in this case we are trying the freon 1301 as a fire extinguisher on this flame. Incidentally, this test is in 5 pounds per square inch of pure oxygen.

You will note that pad of polyurethane foam is first ignited and then the fire extinguisher is placed on it. You will also notice that when the freon comes on, far from extinguishing the fire, it causes it to burst into flame and in effect scatters the material around the spacecraft.

There are a lot of tests. This is by no matter of means a definitive test. It just shows some of the problems involved in the development of a successful fire extinguishing method.

In this case we are dropping the pressure in the cabin and one of the most interesting things here is that it takes about a minute for the pressure to go down to about a half pound and the fire does not in this case, ever go out. You will see it gradually shrink, but actually at the lowest pressure we were able to achieve in the cabin, it continued to burn. This again is the 5 pounds per square inch area of pure oxygen.

We are now down to about——

(Film stopped for questioning.)

QUESTIONS BY SENATOR HOLLAND

Senator HOLLAND. May I ask a question, Mr. Chairman?

The CHAIRMAN. Senator Holland.

Senator HOLLAND. In the cases we have seen the pictures of, was the oxygen throughout the capsule and of a relatively uniform pressure throughout the capsule?

Dr. MUELLER. Yes, sir. In each case the oxygen pressure was maintained. In the last two cases, at 5 pounds per square inch and in the first two cases, at 16 pounds per square inch of pure oxygen. As the flame continues, a part of the oxygen is absorbed in the burning processes so that the percentage of oxygen does drop—but not appreciably—in these tests.

Senator HOLLAND. What is it that makes the base of the fire in those flames? Is there something particularly flammable there?

Dr. MUELLER. That is the polyurethane foam cushion material. It is a foam cushion that is widely used nowadays for cushions in air mattresses and stuff like that and which was used in the actual capsule for those pads on which the door was set when we were practicing with the door.

Senator HOLLAND. In other words, there was some of this particular material used where it could have been touched by and affected by the pure oxygen that was within the capsule?

Dr. MUELLER. Yes. And in fact, it was one of the major contributors to the flame in the fire in the 204.

Senator HOLLAND. Was it known before this accident occurred that this was flammable material and was being used inside the capsule?

Dr. MUELLER. Yes. It was known that it was flammable material; and yes, it was known it was used inside the capsule. I would point out that it was, however, tested and it is flammable after it is ignited. As with all the other materials we use in the spacecraft, the temperature has to go about 400° F. before it can be ignited.

Senator HOLLAND. Well, there are many materials within the spacecraft, though, that are not flammable, are there not?

Dr. MUELLER. There are many materials inside the spacecraft that are not flammable in that sense.

Senator HOLLAND. Thank you.

(Showing of film resumed.)

Dr. MUELLER (continuing from prepared statement). Now, as you notice here on the film, the fire is dying down. We are now at about the lowest pressure, about half a pound per square inch.

That was how far it went down and it did not go below that burning level.

Here we are mixing the oxygen with nitrogen so that it is a diluted atmosphere, evacuating oxygen and reaching about 14 percent oxygen at the end of the dilution.

We do have a rather carefully controlled set of holes designed to reduce the turbulence when letting the gaseous nitrogen in. You will find, however, when the gas comes in, even though the holes on the side next to the pad are shielded so that they do blow on the pad, there is a great deal of activity in the burning. And the general effect of having the nitrogen introduced is to increase the rate of burning rather than to decrease it.

Again, in this case, the fire finally was extinguished because it ran out of material to burn rather than because of diluting it with nitrogen. In other words, we were not able to reach an oxygen concentration at which the foam would not continue burning.

Incidentally, all of these tests have been conducted since the fire in the Apollo spacecraft.

Now we are trying to use the water to extinguish the flame. You will find if you look in the picture in the upper left hand corner that the nozzle is controllable from outside and you can see it moving into position for extinguishment of the flame. Even here, although this was the most effective of our fire extinguishing methods, it nevertheless took some considerable time and there was an initial flame as the water was used. Again, that is because you entrain oxygen, bring it down to the burning surface, and cause the flame to be fed, possibly, by introduction of the fire extinguishing material.

(End of film.)

QUESTION BY SENATOR CANNON

Senator CANNON. Mr. Chairman, may I ask a question at that point?

The CHAIRMAN. Senator Cannon.

Senator CANNON. Doctor, you indicated that all of these tests were performed since the unfortunate occurrence at the cape. Did you perform tests of this nature prior to the disaster?

Dr. MUELLER. Yes. There were a number of the tests on the flammability of materials working prior to the disaster. These happened to be particularly germane in certain areas that the Board has been interested in as to how one might have gone about extinguishing the fires. I think that, in general, in the case of fire extinguishment methods, we do not know a satisfactory way of extinguishing flames.

The CHAIRMAN. Mr. Gehrig has a question.

Mr. GEHRIG. Dr. Mueller, did I understand you correctly to say that Velcro and the nylon netting had a propagation rate of about 2½ inches per second?

Dr. MUELLER. Well, I would like to hasten to clarify the fact that the rate of propagation varies depending upon a lot of factors. The geometry of the sample, what the backing material is, and how it is located in the cabin: whether it is vertical, horizontal or what the convection current is. This is one of the less precise kinds of measurements. Relatively, it burns fast is the statement I would like to make.

Mr. GEHRIG. Dr. Berry when he appeared before the committee on February 7 said:

> Materials selected for use in the spacecraft cabin are carefully controlled.

And I will skip a few lines.

> Investigations of the flammability characteristics of the materials used in the Apollo spacecraft were carried out by both the spacecraft contractors and various NASA laboratories. * * * From these tests and the tests run for MERCURY and GEMINI, a list of acceptable materials has been established by a Material Review Board at the Apollo Spacecraft Program Office. Basically these tests were designed to * * * (*b*) screen out undesirable materials in the habitable

areas of the spacecraft which would enable an accidental fire to spread too fast before it can be brought under control—acceptable materials shall have a combustion rate of no greater than 0.5 inch per second.

Dr. MUELLER. That is correct.

Mr. GEHRIG. How did these materials get into the spacecraft if they had higher rates of burning?

Dr. MUELLER. Those tests and our specifications at that time related to 5 p.s.i.a. of oxygen. In this particular case we are talking about the burning rate in 16 p.s.i.a. of oxygen. Now——

Mr. GEHRIG. Is the burning rate of Velcro and the nylon netting less than one-half inch per second in 5 p.s.i. of pure oxygen?

Dr. MUELLER. The burning rate of the basic nylon material is less than one-half inch, or roughly one-half inch per second.

Now, again, Mr. Gehrig, I would like to emphasize that burning rates do vary depending on the conditions of the test. I am speaking of a particular standardized test.

Mr. GEHRIG. But in the 16 p.s.i. pure oxygen atmosphere, they do burn at 2½ inches per second. This was known prior to the accident?

Dr. MUELLER. Not at 16. Almost all the materials tests we made were at 5 p.s.i.a.

Now, we did have some testing, but that was relatively limited, at 16 p.s.i.a.

Senator CANNON. Mr. Chairman, I asked the doctor a question a moment ago to bring that out specifically. Dr. Mueller you said that you did perform tests of that nature prior to the accident.

Dr. MUELLER. Yes, sir.

Senator CANNON. Now, did you or did you not perform tests of the proposed materials under 16 p.s.i., prior to the accident?

Dr. MUELLER. We did perform some tests at 16 p.s.i. In particular, we did not perform tests at 16 p.s.i. with either the nylon net or the nylon Velcro. We did perform tests on those materials at 5 p.s.i.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Proceed.

FIRE EXTINGUISHING TESTS RESULTS

Mr. MUELLER (continuing from his prepared statement). The results of the many fire extinguishing tests run to date have not been encouraging. Additional effort is underway, however, and every possibility is being reexamined. Careful consideration must be given to the tradeoffs involved. The provision of a limited capability for fire extinguishment at the expense of reduced reliabiltiy and increase in the possibility of a toxic environment must be carefully weighed before any decision is possible.

EXHIBITS CABIN MATERIAL SAMPLES

Now, the next item on which we are working is that of cabin materials. I have some samples here, Mr. Chairman, that I would like to pass around, and I will talk about it in a little bit—as I come along to them I will point them out.

74-521 O—67—pt. 2——4

FIGURE 5

ACTIONS

MATERIALS

- SELECT NEW MATERIALS NOW UNDER DEVELOPMENT
  - RETAINING NETS
  - RESTRAINT STRAPS
  - COUCH COVERS
  - SPACESUITS
  - STOWAGE CONTAINERS
  - FASTENERS FOR USE IN ZERO "G"
  - PLUMBING INSULATION
- TEST AND QUALIFY NEW MATERIALS
  - NASA LABS
  - CONTRACTOR LABS
  - OTHERS

With regard to the materials used and contained in the spacecraft cabin (fig. 5), I would like to remind you why we attach so much significance to materials selection and control. We discussed this with you at the hearings on February 7, 1967; but to summarize, the argument goes like this:

For a fire to exist there must be an atmosphere containing sufficient oxygen to support combustion; there must be a source of ignition; and there must be combustible materials available to be ignited. As far as the atmosphere is concerned, an atmosphere which will support life will also support combustion. Therefore, the first answer to the fire-hazard problem must be fire prevention in terms of strict control of both potential ignition sources and combustible materials.

The fact is now clear that we will not be able to eliminate completely ignition sources in the cabin. We will continue to take every precaution to minimize possible ignition sources, but we cannot expect perfection. This means that the remaining technique of fire prevention—materials selection and the control of the geometry of their use—demands our utmost in care and attention.

SELECTION OF MATERIALS

Our objectives in the selection and use of materials are many.

First, we are reviewing the latest developments in material technology so as to replace potentially combustible materials with less flammable or nonflammable materials. Some needs can only be met using potentially flammable materials; the astronauts' food is an example. However, care must be taken that, at every opportunity, materials are selected which give us the most fire protection while still satisfying the basic need.

Second, we want to locate materials physically so as to inhibit ignition. (Fig. 6.) Ordinarily this requires that any potentially combustible materials be kept some distance away from possible ignition sources.

FIGURE 6

ACTIONS

CABIN CONFIGURATION

- ARRANGE MATERIALS TO INHIBIT IGNITION AND PROPAGATION

- FOOD STORED IN FIRE RESISTANT CONTAINERS

Third, we want to arrange materials to inhibit fire propagation. This is usually accomplished by assuring physical separation between small pieces of materials which might be potentially combustible.

Fourth, we want to store potentially flammable materials in fire resistant containers.

Fifth, we want to minimize the amount of potentially combustible materials exposed in the cabin at any one time, either on the ground or in flight.

Sixth, we want to exercise rigorous control over the introduction of materials into the cabin during manufacture and test. This includes both flight articles, such as the astronauts' space suits, and non-flight articles, such as test procedures books.

We believe we have exercised care in every one of these areas in the past. However, in light of the Apollo 204 accident, we are reviewing each area to make sure that we are doing everything that we should.

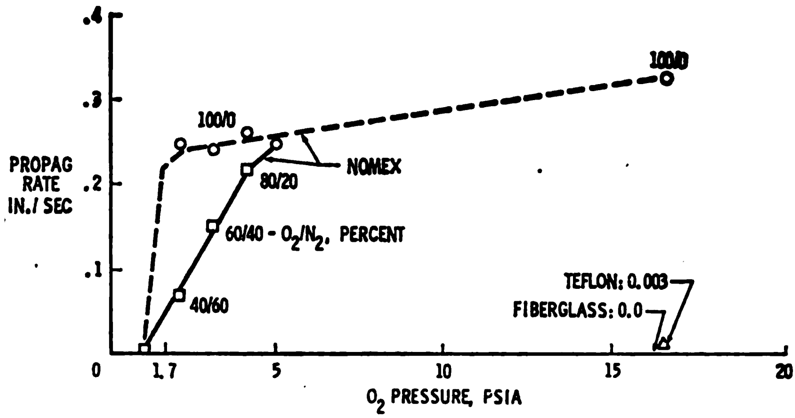
I would like to report in more detail on our status in the area of new materials.

In figure 7 we show the relative propagation rate of nomex, which is the material used in our spacesuits, and is a nylon material as compared with two new materials: teflon and fiberglass. As you can see, the rate of propagation of fire does vary with the partial pressure of oxygen and with a mixture of oxygen and nitrogen. The important point to make is that over the range of oxygen pressures in which we operate, the variation in propagation is only a factor of 2 or 3, while by going to a totally new material, such as Teflon, the propagation rate at the 5 p.s.i. pressure of pure oxygen—which we have used in our spacecraft cabins—is zero, as is that of fiberglass. Our approach, then, is one of selecting materials insofar as is possible which do not propagate flame in any atmosphere.

FIGURE 7

NASA-S-67-1045

COMBUSTION AS A FUNCTION OF O_2 TOTAL PRESSURE, O_2 PARTIAL PRESSURE, TYPE OF MATERIAL



We can divide the materials in the spacecraft cabin into a number of different classes, but I would like to discuss four with you today: fabrics, fasteners, films, and foams. (Fig. 8.)

FIGURE 8

FABRIC DEVELOPMENT

	ADVANTAGES	PROBLEMS OR DISADVANTAGES
• BETA FIBER	MELTING TEMP 1540°F DOES NOT BURN	FABRICATION TECHNIQUES ABRASION RESISTANCE
• TEFLON MATERIAL	MELTING TEMP 550°F SELF EXTINGUISHING	FABRICATION TECHNIQUES TOXICITY

In the case of fabrics, we are considering, among other materials, the use of Beta cloth, which is a new glass fiber cloth, to replace our current fabric material which melts in the range of 400° to 700° F., and will support combustion. The new fiber has a melting temperature of about 1,500° F., and does not burn. One of the problems with the new fiber is that making garments out of it requires the development of new fabrication techniques. At this point it appears promising. We believe that enough of it can be produced to meet our requirements and that the fabrication problems can be solved.

I might mention, also, that one of the problems with previous glass fibers has been the dermatological effects when the fabric is worn next to the skin. Preliminary tests of prototype clothing made with the new fiber appear promising in this respect also. I showed you the sock that has been made out of this fiberglass fiber.

Mr. WEBB. That is the one Senator Curtis has now. This little sock. That is fiberglass, Senator, of a new kind.

Senator CURTIS. This is what they are using now?

Mr. WEBB. No, sir; that is a brand new one.

Senator CURTIS. This is what you are using now?

Mr. WEBB. No. That is a new one also, better than the one we have now. Here is the one we are using now.

Dr. MUELLER. The material we are using now is this material here. A number of people have worn underclothing of the new material for some months without any adverse reaction.

Mr. WEBB. You understand, Senator, that fiberglass, as we have known it, tends to have little prickly protrusions that will cause skin irritation. This is a brand new type that can be worn as underwear without any adverse effect, and it will not burn. So I think the point is that we are looking at some completely new materials to avoid having any combustion potential materials in the spacecraft.

Senator CURTIS. How were those three astronauts dressed at the time of the fire?

Dr. MUELLER. They were dressed in spacesuits, and we have here some samples of that material. I will get to that in a moment, Senator.

Senator CURTIS. Thank you.

ABRASION RESISTANCE PROBLEM

Dr. MUELLER. A third problem with the Beta cloth, however, is that of abrasion resistance. Many of the applications, such as in the outer covering for a spacesuit, require a high order of resistance to abrasion and so far it has not been possible to develop a tight enough weave to provide adequate abrasion resistance in this cloth. A second fabric that is being evaluated and in which there have been some recent developments is that of teflon. Teflon has the advantage of being self-extinguishing in a 5-p.s.i. oxygen atmosphere. Because of its hardness and smoothness, new techniques for fabrication have to be developed before we can apply it. Also, in the thin cross sections required for nets and similar materials, we need to evaluate the possible toxicity when exposed to flame. From these new materials we are considering modifications to our buildup of spacecraft garment coverage. As you know, our basic spacesuit consists of many layers of cloth. This is our present lunar design and it has a number of layers of nylon, of insulating material, of reflecting material, and there is one particular layer that is particularly important: The nylon pressure bladder that forms the actual pressure covering that holds the gas pressure when the suit is pressurized. Then you have additional layers for backup to that layer, plus heat-insulating layers to prevent your losing heat while you are in the lunar environment, and then finally an outer covering which protects the whole from abrasion when you rub it.

Now, this buildup is characteristic of our present spacesuit. We do not have at the present time a satisfactory substitute for the inner nylon pressure suit garments, that is, the right combination of strength and impermeability, so that we need to have nylon as a main load-bearing element in the buildup of the spacesuit fabrics.

On the other hand, what we are trying to do is develop some outer layers of high-temperature-resistant cloth and some inner layers of the Beta cloth to provide for inner covering so that we can successfully contain any possible propagation of fire by protecting the flammable materials inside with nonflammable materials on both sides. So that is the approach we are using in the spacesuit today.

We do not feel——

Senator CURTIS. May I ask one question? Were all the garments on the three astronauts burned, destroyed?

Dr. MUELLER. No. They were partially burned in the course of the fire. In fact, they provided quite good protection until the very end of the fire period. As we have testified on February 7, the input and output loops in the suits maintained their integrity for most of the fire buildup period. There was severe burning of one suit and some burning of all suits but the pilot's suit was relatively untouched. We do feel that these——

The CHAIRMAN. Did you say this was—how much burning was that? Just below the knees?

Dr. MUELLER. Well, actually the burning did proceed further up and it varied between the layers of cloth. The outer layers burned further and the center layers did not burn up so far. I think that, generally speaking, the suit on the command pilot was burned quite severely.

COSTS IN CHANGING SUITS

The CHAIRMAN. Would there be much change in costs now, to get a different type of suit? Would there be a high cost of suits?

Dr. MUELLER. The suits are expensive, particularly the development costs for these suits are expensive, and there undoubtedly will be an increase in cost due to change in the fabrics and——

Senator HOLLAND. I could not understand that last statement. Will you repeat it, please, sir?

Dr. MUELLER. I said that the development of these suits is a costly endeavor and the changing of the fabric will require requalification and will increase the costs in this area.

The CHAIRMAN. About how much is a suit worth now? What does it cost?

Dr. MUELLER. Well, the actual cost of the suit after development was perhaps on the order of $25,000. That is not just the suit but also the equipment that goes with it.

We do feel that these two new materials can be developed and applied to meet most of the requirements for low or zero flammability materials in the spacecraft.

We are also considering new materials for fasteners. Some type of fastener must be available for crew convenience while operating in the weightless environment. Otherwise, it could be most cumbersome keeping everything "tied down". In the past, the fastener material has been nylon Velcro which supports combustion in a pure oxygen atmosphere. We are considering several possibilities for replacing this material. One is a steel Velcro, which has excellent fire protection properties, but has been judged to be too abrasive for our use when fabricated as a hook and pile fastener using the currently available techniques. Another material being considered is teflon. This material is self-extinguishing in terms of its burning characteristics, but fabrication techniques have not been developed. I have samples of both of these here. We do know, however, that using more conventional fasteners such as snaps and hooks and eyes will meet the need for fire resistant fasteners in the spacecraft. In the meantime we are continuing to explore the use of new materials for this application.

Films are used in the spacecraft cabin in the form of bags for containing food, for fecal collection, and for containing various small articles of equipment. Here again we are considering Teflon as a possible replacement material, but for this application the oxygen permeability of the material as a film must be verified. Other new materials are also being considered.

Foams are used for thermal insulation and for equipment protection inside the cabin. A high-density Teflon foam is available now. A low-density foam is preferred and is being developed. We are also investigating the availability and applicability of silicone foams. Our investigations in this area are promising, but some development work is undoubtedly required.

In summary, we do expect to be able to replace or protect all the very flammable materials in the spacecraft.

SPACECRAFT ATMOSPHERE

The next area in which we are working is in the area of spacecraft atmosphere. (Figs. 9 and 10.) We are continuing tradeoff studies on spacecraft atmosphere for each operational phase of the Apollo program. These studies include one—versus two—gas tradeoffs, evaluation of the prelaunch atmosphere, and a fire-resistant oxygen system.

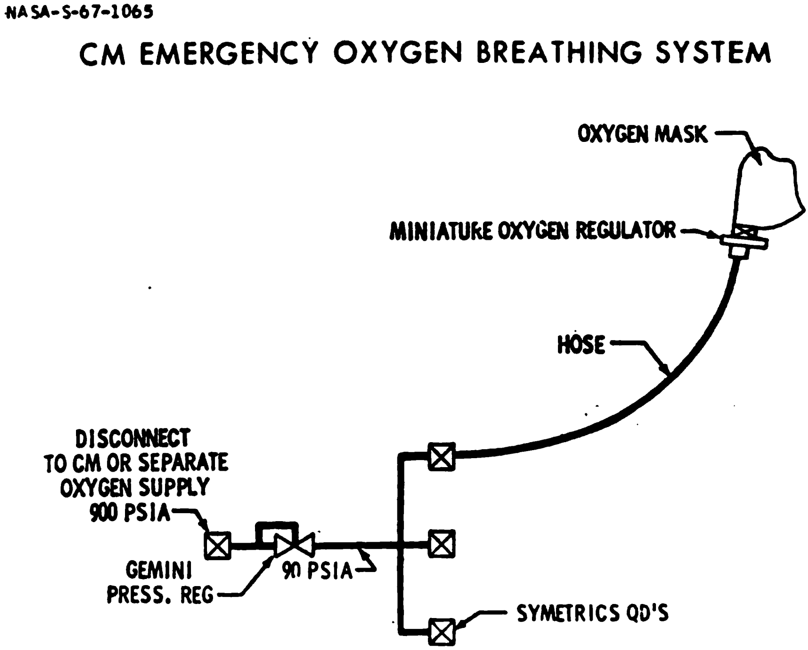
FIGURE 9

ACTIONS

SPACECRAFT ATMOSPHERE

- ONE VERSUS TWO GAS STUDIES
- EVALUATE WAYS TO MODIFY PRELAUNCH ATMOSPHERE
- FIRE RESISTANT OXYGEN SYSTEM

FIGURE 10



CABIN ATMOSPHERE WHILE ON PAD

With regard to the spacecraft atmosphere during pad checkout and launch operations, our tradeoff studies, which are still in process, are indicating that serious consideration should be given to the use of air in the cabin, with the crew on pure oxygen in the spacesuit loop, to improve safety.

Air, which contains 79 percent nitrogen, is attractive for the cabin atmosphere, because it greatly decreases the fire hazard while providing the capability to support life if there is a failure in the oxygen supply to the suit loop. This decrease in fire hazard, in conjunction with a reduction of cabin combustibles, improved egress capability, and the normal provisions for pad rescue and firefighting instituted during hazardous operations, will greatly reduce the crew risk during pad operations. A cabin atmosphere of pure nitrogen would further reduce the fire hazard but is not favored because it will not support life in case of a suit disconnect or other suit leak. During the prelaunch period, as a precaution against dysbarism (bends) after ascent, the suit loop would be held at slightly higher pressure than the cabin, and continuously monitored by gas sensors to assure complete denitrogenation of the crew at launch. Let me be clear that you understand we are studying this problem, that there are tradeoffs involved, that we are both worried about two effects. One is the lack of oxygen in the suit loop as we go up in altitude, if there should be a leak in that suit loop, and we are worried about the effect of nitrogen should we have to decompress the cabin suddenly during the launch phase itself. So it is not at all clear what the best and safest way to proceed in this area is.

We are studying the alternatives, however, which is one of the recommendations of the Apollo Review Board.

LAUNCH

During the launch phase, if we are using this mixed gas or air at launch, the cabin and suit loop would bleed down to space flight pressure. With the crew remaining on the suit loop, oxygen would then be supplied to the cabin to enrich its atmosphere. We are studying several alternative procedures for this enrichment. These include (1) cabin decompression, evacuating it to zero pressure and then followed by repressurization of oxygen, (2) partial decompression followed by oxygen replenishment, and (3) gradual enrichment by replenishment of normal cabin leakage with oxygen. These procedures offer tradeoffs, which are now being considered, between the system weight and the time which is required to achieve the desired atmosphere.

SPACE FLIGHT

During the flight itself, for the atmosphere in space flight, we continue to favor the choice of oxygen at 5 p.s.i.a. for the cabin and suit loop. We discussed this with you at the hearings on February 7, 1967. The factors which we are continuing to study include:

1. Pure oxygen eliminates the danger of dysbarism (bends) in case of sudden decompression.

2. Physiological considerations require that the partial pressure of oxygen be maintained no lower than the equivalent of 3.5 pounds per square inch absolute (p.s.i.a.) of 100 percent oxygen for life support, and no higher than the equivalent of 7.5 p.s.i.a. 100 percent oxygen for extended exposure to avoid toxicity.

3. An oxygen partial pressure somewhat higher than 3.5 p.s.i.a. equivalent is desirable to increase the margin of safety in event of cabin leak from micrometeoroid puncture or other cause.

4. A one-gas system is simpler than a multigas system, since it uses less components, requires no partial pressure gages, and thus offers greater reliability.

5. Pure oxygen in the pressure range required for life support presents a definite fire hazard. A physiologically acceptable two-gas system at a pressure within the present spacecraft structural limitation does not appear to offer a large reduction in fire hazard over a 5 p.s.i.a. pure oxygen atmosphere.

Our tradeoff studies continue to indicate that for missions of Apollo duration, within feasible limits of pressure for structures and space suits, and coupled with an intensive cabin materials selection process, the 5 p.s.i.a. oxygen atmosphere provides the highest overall crew safety. In continuing comparisons with candidate two-gas atmospheres, it appears to provide the best balance among fire hazard, system reliability, and physiological risks.

74-531 O—67—pt. 2——5

Senator HOLLAND. A question there, please, Mr. Chairman. You say within feasible——

Dr. MUELLER. Within feasible structural limits.

FLIGHTS UP TO 2 WEEKS

Senator HOLLAND. Are you speaking of limits for Apollo duration? Now, what do you mean? How long?

Dr. MUELLER. We are talking now of flights up to 2 weeks. When we get into flights of the length of a month or so, the physiological effect of long-term exposure to oxygen at 5 p.s.i. indicates that it is probably desirable to go to a two-gas system.

Senator HOLLAND. But you are not talking now about flights of a duration that were planned for this particular Apollo spacecraft.

Dr. MUELLER. That is correct.

The CHAIRMAN. Since you stopped, I want to ask a question. In a magazine of February 6, there is an article titled "Two-Gas Pros and Cons." It says:

> The original Apollo life support system which would have weighed 54 pounds more than it does now, had it been designed for a two-gas environmental, * * *.

Is that one of the reasons why you use a single-gas system?

Dr. MUELLER. No, sir. We did not select the single-gas versus the two-gas system on the basis of weight. We selected it on the basis of astronauts' safety.

(Dr. Mueller resumes giving his prepared statement.)

REENTRY

Dr. MUELLER. In the area of reentry our current planning is to retain the present practice of initiating reentry with 5 pounds per square inch oxygen atmosphere in the cabin. During reentry, atmospheric venting into the cabin begins as the command module descends below about 27,000 feet. Continuing dilution of the oxygen cabin atmosphere during descent will result in a 47-percent oxygen content at splashdown, and the postlanding ventilation system will quickly replace this with normal atmosphere. Initiation of reentry with the oxygen cabin atmosphere appears preferable to decompression or replacement of oxygen with an inert gas because it eliminates the risk of asphyxiation in event of trouble with the suit loop. We are currently reexamining the fire risks during the brief periods of high deceleration during reentry to see if the tradeoffs that we discussed above are affected.

A final point on spacecraft atmosphere: We are considering the usefulness to the crew of individual, fire-resistant emergency oxygen supplies and masks similar to those used in aircraft practice. It appears that such a system might provide additional protection for the crew in the event of fire.

EMERGENCY EGRESS

FIGURE 11

ACTIONS

EMERGENCY EGRESS

- RAPID OPENING HATCH
- PAD CONSIDERATIONS
- FLIGHT SAFETY CONSIDERATIONS
- RECOVERY CONSIDERATIONS

Now, in the area of emergency egress, we are proceeding with a complete review of the spacecraft design and procedures. (Fig. 11.) In this review we are including the study of rapid-opening hatches, modifications to the launch complex to improve egress, and the trade-offs between prelaunch safety and safety during flight and recovery. One of the most significant changes already in work is the redesign of the crew hatch. Our objective is to provide a hatch which permits safe and reliable operations under normal conditions while providing for rapid egress or rescue in the event of an emergency condition on the ground. Concurrently its reliability must be such that it will operate only when required. In other words, the emergency conditions must not be triggered by external heat, structural loads, or other mechanical or electrical operations.

SEVERAL HATCH CONCEPTS CONSIDERED

In the course of our review several hatch concepts have been considered. Before discussing some of the alternatives, I will briefly review the present hatch configuration. As discussed here on February 7, the requirements for return from the moon have dictated a different spacecraft design from that of Mercury and Gemini. Both structural and heat loads are substantially higher. Therefore, the Apollo heat shield surrounds the inner-pressure cell. Consequently, the present Apollo hatch is a multiple-hatch system consisting of a heat-shield hatch and an inner-pressure hatch. The heat-shield hatch is hinged and swings outward after being mechanically unlatched as a manual operation. The inner hatch is not hinged and opens inward. Internal pressure provides sealing loads on the inner hatch, thus resulting in a lightweight system.

Let me go back just a second and say this internal pressure not only provides the sealing load but prevents the inadvertent opening of the hatch in orbit and that, of course, is an important consideration in terms of flight safety.

Now, continuing the modification of the——

Mr. GEHRIG. Dr. Mueller, could I ask a question here as there is considerable interest in this? Is this why you pressurize at 16 psi on the ground during tests and before launch?

Dr. MUELLER. That is to check the spacecraft cabin itself for leakage so that there is a differential pressure of about a pound or pound and a half.

Mr. GEHRIG. And also to seal the hatch?

Dr. MUELLER. And it also seals the hatch.

Mr. GEHRIG. And the reason you used oxygen rather than air was because you successfully used oxygen in the Mercury and Gemini programs?

Dr. MUELLER. Yes; and it avoids any problem with leaks in the suit loop which, if continued over a period of time, would cause you to have too little oxygen so that the subject or the crew could suffer from lack of oxygen.

Senator HOLLAND. Mr. Chairman, may I ask a question? I believe you testified in your earlier appearance, Dr. Mueller, that the hatch used in the Mercury and Gemini flights were very much similar and very much quicker to open. I believe Grissom did open it at the time of his escape from the spacecraft when it sank into the Atlantic. Am I correct?

Dr. MUELLER. That is correct. I will discuss that——

Senator HOLLAND. How long a time was required for the opening of that very simple hatch?

Dr. MUELLER. In that case it opened in something of the order of a second after initiation and took a couple or 2 seconds to initiate.

Senator HOLLAND. And what is the comparison in length of time to open between that simple hatch and the hatch that was used in the Apollo craft which I understand is a double hatch?

Dr. MUELLER. The double hatch took about 90 seconds.

(I wish to make it clear that 90 seconds is the total time required to open the hatch and for all three crewmen to complete their egress.)

Senator HOLLAND. Thank you.

Senator MONDALE. Dr. Mueller——

The CHAIRMAN. Senator Mondale.

QUESTIONS ON HATCH OPENING

Senator MONDALE. There is some evidence that the stricken astronauts attempted to open the hatch; is there not?

Dr. MUELLER. Yes. They were proceeding with their emergency egress activities.

Senator MONDALE. What is the estimated, if you know, pressure inside the command module on the hatch at the time this attempt was made? What kind of pressure would be needed to open the door——

Dr. MUELLER. You mean——

Senator MONDALE (continuing). Of the hatch?

Dr. MUELLER. Well, the pressure inside was about a pound and a half. Of course, during the course of opening the hatch, you have to equalize the inner and outer pressures so that you have to decompress the cabin.

Senator MONDALE. There was tremendous pressure, as I understand it, within the capsule during the course of that fire.

Dr. MUELLER. It would not have been possible to remove the hatch until the cabin was equalized as to pressure.

Senator MONDALE. So would it have been physically possible for any one of these astronauts to have actually opened the inner door, considering the pressure that had built up during the fire, even if they had tried?

Dr. MUELLER. During the buildup of pressure where the final pressure reached 36 p.s.i., it would not have been physically possible.

Senator MONDALE. Is it possible, then, at the time they attempted to open the hatch that physically, in fact, it could not have been done because of the internal pressure?

Dr. MUELLER. Well, of course, you are talking about a period of a few seconds here.

Senator MONDALE. That is right.

Dr. MUELLER. And it is quite possible that at the time they could not.

Mr. WEBB. Let me say this.

Senator MONDALE. So, if I may just make——

Dr. MUELLER. As soon as the rupture in the vessel occurred, of course, the pressure dropped immediately down again.

Mr. WEBB. I think, Senator——

Senator MONDALE. If I can just make my point clear. So that it is entirely possible within this short period that the pressure within the cabin was so great that the Apollo inner hatch could not have been opened physically.

Dr. MUELLER. That is possible. On the other hand, there was not time to actually try it anyway, Senator Mondale.

Mr. WEBB. There is a handle by which the astronauts release the pressure in the capsule. In this case, Senator Mondale, that was not pulled. So in a sense the means of relieving the pressure inside was not actuated by the astronauts. I think this is also an important element here.

Dr. SEAMANS. But it is true that during this period the pressure inside went from 16 up to around 36 psi, with 14.8 psi outside. It was such that the force required to open the door built up as much as five or six times and it could not have been opened.

Senator MONDALE. That is the point I am trying to get at.

Mr. GEHRIG. Mr. Webb, may I ask one question? You say that there is a pressure handle that could be pulled to vent the capsule. Do you know if any attempt was made to vent the spacecraft from the inside?

Mr. WEBB. My understanding from the reports made by Dr. Seamans and by the preliminary reports made by Astronaut Borman, Dr. Thompson and Mr. van Dolah, is that no attempt was made to actuate that handle.

Mr. GEHRIG. That is part of the emergency procedure.

Dr. MUELLER. Yes; it is.

Mr. GEHRIG. Is it possible for a technician on the outside to open this vent to relieve the pressure?

Mr. WEBB. No.

CONSIDER THREE HATCH CONCEPTS

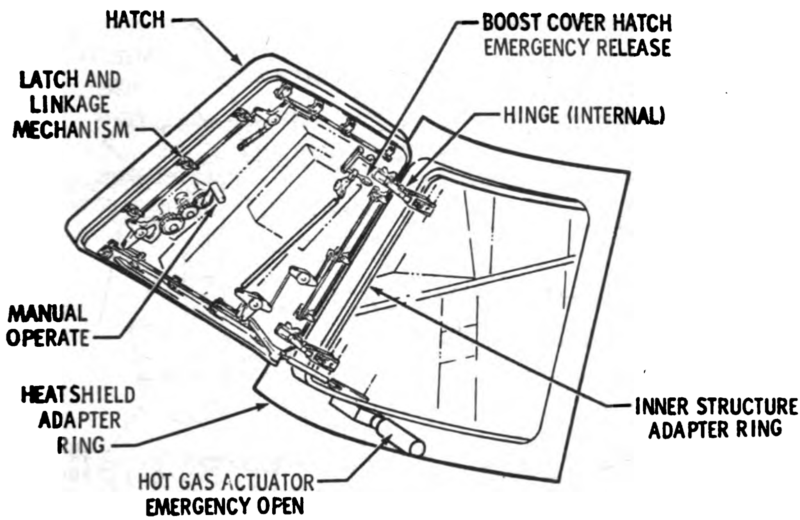
Dr. MUELLER (continuing with the statement). One concept we have examined involved minimum modification to the present two-hatch system. It utilizes a hot-gas generator system to release the heat-shield hatch and a Mercury-type "hatch within a hatch," for the inner hatch. The inner hatch is opened by a mild detonating cord which fractures the ring of bolts, thus providing an open-for-emergency egress. This system is complex and does not appear to satisfy both the normal mission requirements and the emergency egress needs.

A second concept was a three-man-size hatch to provide an opening large enough for simultaneous three-man egress. This concept presents the problem of a major spacecraft redesign because new load paths must be provided in the structure. Although the opening could be cut with a linear-shaped charge, such an operation may aggravate the emergency and, of course, represents a potentially dangerous failure point during flight and during water recovery. We all remember the dangerous situation that Grissom experienced on an early Mercury flight when the blowoff hatch of the capsule was inadvertently actuated when he was on the water. The spacecraft was lost in the Atlantic and Grissom barely escaped drowning.

FIGURE 12

NASA-S-67-965

UNIFIED HATCH



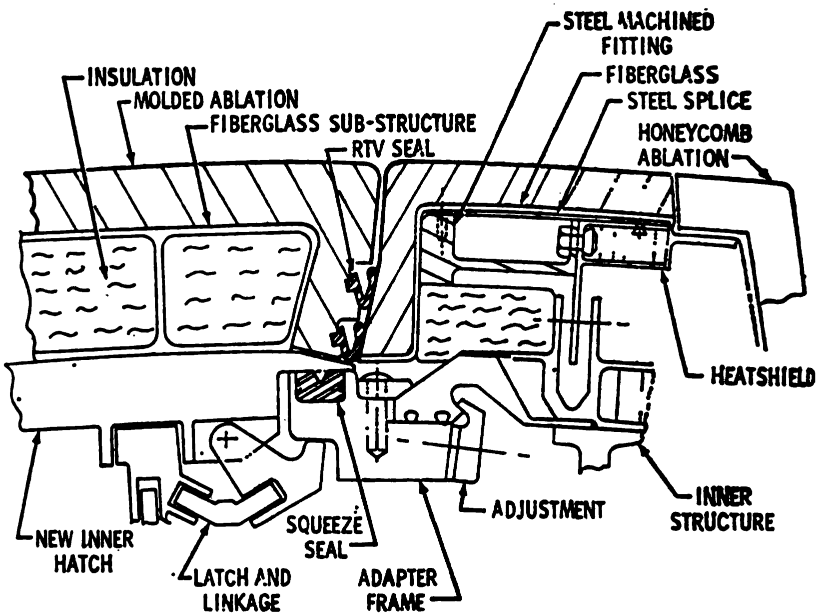
The third concept we have examined is the unified or integrated hatch system shown in figure 12. This system has been selected as the most promising, and detailed design work is underway. It is a single hatch which swings outward with a latch mechanism similar to that used on the present heat-shield hatch and on the Gemini hatch. It can be opened in about 2 seconds by pressure generated by a hot-gas actuator which is triggered by a percussion initiator. A manual mechanism is provided to open or close the hatch from either the inside or outside under normal operating conditions. It is a non-load-carrying hatch with a Gemini-type seal.

In carrying out this design, we are making use of the same type of hatch closure that was developed in the Gemini program. However, because of the two-shell structure, it is necessary to develop, as may be seen in figure 13, a means for sealing the heat-shield joint against reentry heat penetration under all possible conditions of relative motion of the outer heat-shield shell with respect to the inner-pressure shell. At the same time the inner-pressure-shell seal must be capable of multiple opening and closing for carrying out extravehicular activities in flight. The approach we have adopted is shown in the figure and has the advantage of being applicable with minor modifications to the present structure of the spacecraft.

FIGURE 13

NASA-S-67-982

UNIFIED HATCH



The redesigned hatch has been under consideration for extra vehicular activity for some time. It would have, of course, to be fully tested and qualified before manned flight. We are also reviewing the launch complex to identify changes that will be necessary to mate with the redesigned hatch and to insure that the emergency egress route permits as rapid movement of the crew as possible.

Senator HOLLAND. May I ask a question there? I am not clear. Do you mean that this redesigned hatch that you are mentioning would take the place of the double hatch or is it simply one of two hatches?

Dr. MUELLER. No, sir. It takes the place of both the inner and the outer hatch. It is a single hatch that takes the place of two.

Now, in any of these designs, you have got to recognize we are evaluating this design against the present design. In any of these designs you have tradeoffs and, in this particular case, we want to be very sure that we do not solve one problem and create several other problems because, particularly in this case, the relative motion of the inner and outer shells creates a problem in bonding the outer shell, outer hatch, to the inner.

Senator HOLLAND. Well, if that single hatch should prove to be the safest to be relied on, would that not cause a redesigning of the capsule entirely so as not to have a shell within a shell?

Dr. MUELLER. No, sir. Our design considerations indicate that we are safer in the overall design for the spacecraft to have the dual shell design, and if the single hatch is safer, it will be because we have found a way of making it work effectively with the two shells.

Senator HOLLAND. In other words, it would be attached to and part of both shells, is that it?

Dr. MUELLER. It actually is attached to the inner pressure shell and moves with respect to the outer shell but is sealed to the outer shell.

ENVIRONMENTAL CONTROL SYSTEM

The next area I would like to discuss is our environmental control system. (Fig. 14.) The environmental control system is being re-examined with emphasis on materials, failure modes, choice of fluids, and maintenance and servicing.

FIGURE 14

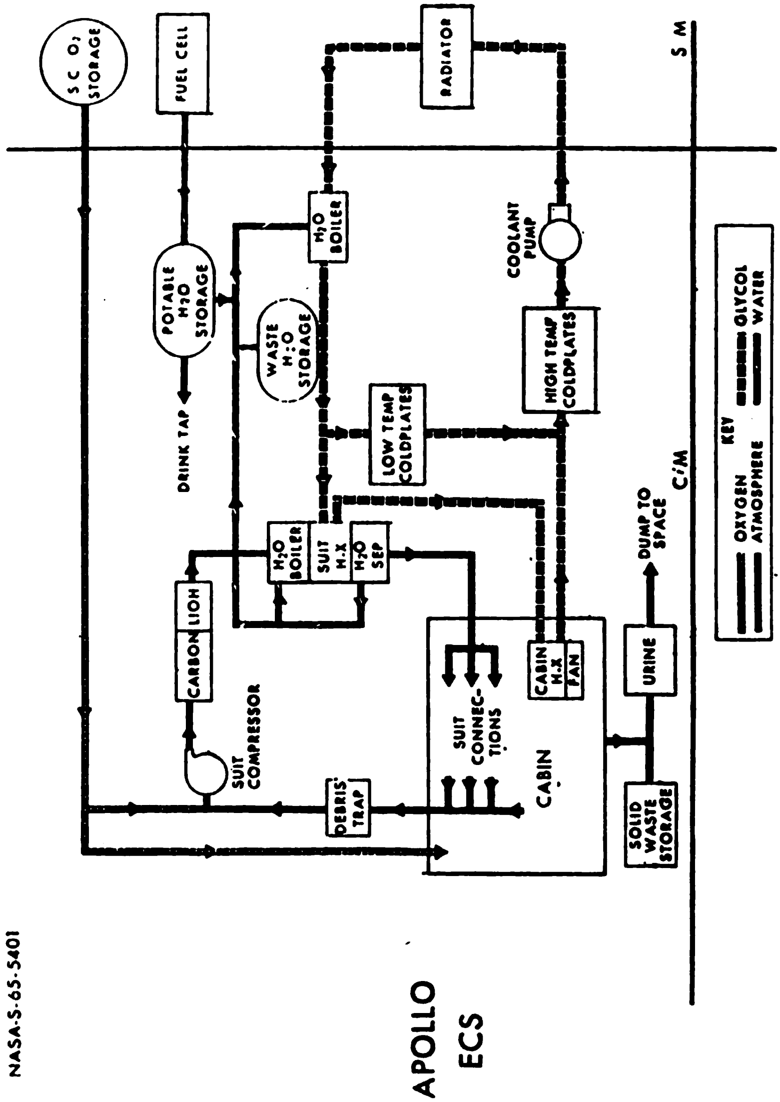
ACTIONS

ENVIRONMENTAL CONTROL SYSTEMS

- MATERIALS
- JOINTS IN PLUMBING
- FLUID CHOICE
- MAINTAINABILITY

Particular attention is being devoted to improving fire resistance by careful selection of (fig. 15) materials used and the types of plumbing connections with the aim of minimizing the potential of leakage or joint failure as well as improving the maintenance and servicing of the system. Changes being studied include the incorporation of improved mechanical or pressure joints, the relative merits of mechanical versus brazed joints, the feasibility of eliminating soldered joints, the relative merits of steel versus aluminum tubing.

FIGURE 15


S C O2 STORAGE
FUEL CELL
RADIATOR
S M
C/M
POTABLE H2O STORAGE
DRINK TAP
WASTE H2O STORAGE
H2O BOILER
COOLANT PUMP
HIGH TEMP COLDPLATES
LOW TEMP COLDPLATES
CARBON LIOH
H2O BOILER
SUIT H.X
H2O SEP
SUIT COMPRESSOR
DEBRIS TRAP
SUIT CONNEC-TIONS
CABIN
CABIN H.X FAN
URINE
DUMP TO SPACE
SOLID WASTE STORAGE
KEY
OXYGEN
ATMOSPHERE
GLYCOL
WATER
APOLLO ECS
NASA-S-65-5401

We are analyzing and conducting tradeoff studies to determine the feasibility of eliminating the present coolant fluid from the crew compartment. In this connection we are investigating other coolant fluids to determine if an alternate fluid with better fire resistance than water/glycol could be used. Of all the fluids considered—approximately 46—four have been selected as potential candidates. None of the alternate fluids have thermal characteristics comparable to water/glycol; however, three are considered non-combustible in air. Substitution of any of these coolant fluids will result in increased electrical power requirements, weight, increased water boiling during maximum heating, a new pump design, and verification testing.

A second approach is replacement of the glycol in the cabin by water while leaving the mixture of water and glycol in the service module. This can be accomplished by adding heat exchangers and additional pumps.

A third approach involves the examination of the flammability characteristics of other mixtures of water and glycol. In any event the thermal characteristics of the Apollo spacecraft are quite delicately balanced and care must be taken in evaluating tradeoff studies that any changes do not decrease the possibility of success, not only of the mission, but of the performance of the environmental control system, since the safety of the astronauts depends directly upon its successful operations.

Their safety depends on this last working for 2 full weeks under all phases of the flight and it is important that we have a system that is the best we can have.

Finally, the design of the environmental control system is being reviewed with a view to improving its maintainability and serviceability. In this regard the environmental control unit will be carefully examined to improve its ease of installation and removal.

SUMMARY AND OUTLOOK

As you have noted, there is intense activity in progress throughout the Apollo program organization to determine the specific actions required to correct conditions which could have contributed to the AS–204 fire. Engineering design, procurement, and fabrication are underway in many areas; in others we are still making studies to determine the best course of action to take.

As we have frequently stated before this committee, and as we surely all mean, crew safety is the principal consideration in scheduling manned space flight missions. We have never taken any step, either to save time or to save money, if that step would imperil the astronauts in any way. We will continue to be guided by this overriding principle. I would like to say one other word, and that is although we seem to be involved in a careful reexamination of every subsystem in the spacecraft, so far our examination has led us to believe that most, if not all, of the subsystems are correctly designed, and that the modifications that are required of the spacecraft will not affect the basic integrity of our program.

As stated in our testimony on February 7, we do plan to continue spacecraft manufacturing and checkout except that which involves checkout in pure-oxygen atmosphere in the spacecraft (fig. 16).

FIGURE 16

GROUND RULES

- BLOCK CONCEPT
- QUALIFICATION PROGRAM
- THERMAL VACUUM PROGRAM
- UNMANNED TESTS OF SAFETY OF FLIGHT ITEMS

We have a block concept in the Apollo program and we intend to stay with it. That means that we will introduce those things in the first block II spacecraft that we expect to have at the end of block II. The first block II spacecraft command and service module, No. 101, is the next spacecraft in the line at the North American Aviation plant at Downey, Calif. We plan to incorporate in spacecraft 101 all changes determined to be necessary as the result of the findings of the investigation of this accident.

SPACECRAFT SUBSYSTEMS ADEQUATE

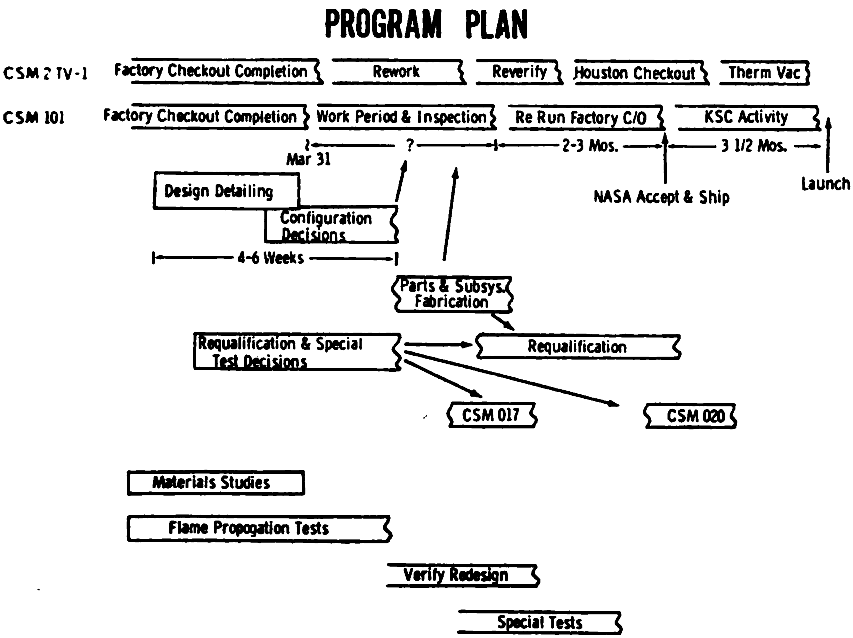
Meanwhile, we plan to continue the manufacturing and checkout of spacecraft 101, since the review thus far indicates that most of the spacecraft subsystems are adequate for safety; thus they will not require changes. We expect to gain valuable experience in this first use of the operational checkout procedures for block II spacecraft.

In parallel with this continued checkout of spacecraft 101 we will be carrying out the studies, tests, and designs which are described earlier in this report. We believe that in about 4 to 6 weeks, the results of such studies, tests, and designs, taken together with the findings and recommendations of the Apollo 204 Review Board will permit us to make decisions on specific configuration and procedural changes. These decisions and the designs so developed will then be the basis for fabrication of such parts and subsystems as may be required.

As the necessary parts and subsystems become available we will progress through a period of rework and inspection. Whatever changes may be involved will be made on spacecraft 101 (fig. 17).

How long this change implementation period will take cannot be determined at this time, but we expect to be able to make reasonable estimates early in April.

FIGURE 17



Following the change period, spacecrafe 101 will then again undergo checkout. With the experience gained in the current checkout we might expect this to proceed smoothly and to require from 2 to 3 months. Following checkout of spacecraft 101, we plan to conduct the normal contract acceptance readiness review. The spacecraft will then be shipped to the Kennedy Space Center where it will undergo approximately 4 months of preparation, test, and checkout prior to launch.

In parallel with the design and configuration decisions, we must also decide which items will require requalification and what special tests must be conducted. Involved here is the normal program function of allocating units to flight spacecraft versus ground test and qualification test. To perform any unmanned flight tests that we may determine to be necessary, we have two spacecraft, numbers 017 and 020, which are scheduled for the first two Saturn V flights. As reported on February 7, we are planning to conduct these unmanned flights this year—to flight test the launch vehicle, to evaluate the performance of the spacecraft heat shield, and to verify the spacecraft in orbital flight. These missions will afford the opportunity to flight test those changes that affect flight safety that may be made in procedures or hardware.

For ground test of spacecraft changes we have the 2TV–1, that is the thermal vacuum test article for Block II spacecraft. This test article, like spacecraft 101, is currently progressing through an initial series of operational checkout procedures. This article will be delivered to the Manned Spacecraft Center in Houston for the overall ground qualification of the Block II spacecraft. We plan that it will also be reworked and reverified before delivery to Houston for checkout and thermal vacuum tests. These tests will be required to be successfully completed prior to launch of a manned Block II spacecraft.

MANNED LAUNCH DELAY NOT KNOWN

This then is our current plan with respect to the Block II spacecraft. The impact on the first manned launch cannot be stated until we have determined the time required for rework and requalification.

FIGURE 18

ACTIONS

LUNAR MODULE

- EVALUATE IN LIGHT OF AS-204 FIRE
- CHANGE AS REQUIRED

It is quite possible that we will experience some impact also in our lunar module development program (fig. 18). We have deferred detailed consideration of the lunar module until a basic understanding of the Apollo 204 fire could be developed. We will reevaluate the lunar module program in the context of changes in the command module and expect to complete this review in the next 2 months. To support this effort which we will begin shortly, we have had several representatives of the lunar module contractor, Grumman, participating in our studies and design reviews on the command and service modules. More will be included as time goes on.

With respect to lunar module flight test, we plan, as reported to you on February 7, to carry out the unmanned flight this year on Apollo 206. This will be primarily a test of the propulsion systems in orbital flight. LTA-8, the lunar module thermal vacuum test article, will be available for ground test of any changes we may find necessary in the lunar module configuration.

In summary, then, we have a plan for the orderly accomplishment of required actions in the Apollo spacecraft program. We cannot at this time present a schedule of missions beyond the three unmanned launches planned for this year. Further definition of our schedules must await decisions yet to be made on the nature and extent of changes, which in turn will be based on the careful evaluation of the Board findings and recommendations as well as the studies and tests now in progress. We will include in our schedules the time necessary to conduct a thorough program of reverification and requalification of any changes. The general nature of our requalification will be similar to those we have conducted in the past, modified as appropriate to provide depth in selected areas based on what we have learned from the 204 fire and on what our analyses and tests indicate in the next few weeks. Our policy of full qualification prior to manned flight will remain unchanged.

With respect to the overall Apollo program effort we plan to maintain the present pace of effort in the many areas of current activity, such as launch vehicles, facilities, ground support software, training, and so forth. Much of our capability to cope with unforeseen difficulties is dependent on maintaining the planned rate of progress in all possible facets of the program. This carefully developed planning has enabled us to accommodate previous problems in both the Gemini and Apollo programs, and most importantly, maintains the flexibility that will enable us to schedule our flight operations as necessary to continue our progress in Apollo.

Thank you, Mr. Chairman.

HAZARDS NOT CLEARLY SEEN

Mr. WEBB. Mr. Chairman, as Dr. Seamans and I stated to you on Saturday, when we had concluded the preliminary review with Dr. Thompson, the Chairman of the Board, Col. Borman, and Dr. Van Dolah, Col. Borman stated that he would not have been concerned to enter the 204 Apollo capsule at the time Grissom, White, and Chaffee did enter it to start this test, and that he would not have felt on entering that capsule that he was going into a particularly hazardous situation. But he did state that as a result of serving on this Board and the one month of work the Board had done, he had learned a great deal more than he previously knew and that there were in fact hazards there that neither the NASA engineers nor the astronauts had previously seen clearly.

Mr. Chairman, also there has been question about testing of materials, and I believe it is fair to state that the materials in the capsule had been tested as to the point at which they would burn and the general level at which combustion would take place was about 400° minimum.

Now, this is about the same temperature at which the soldered joints in the tubing in the capsule would melt. So in essence, while we had not tested these particular materials in a fire, we had gone through very careful tests to make sure that it would take 400° or so to start them burning. And our whole plan was based on the prevention of the attainment of that much heat in the capsule.

Now, you did ask us on Saturday to make sure we could provide information on the one-gas two-gas system area, and Dr. Berry is here. He has come up from Houston in order to be sure we could answer the questions that you stated Saturday might be in the minds of the members of this committee. So we thank you very much, Mr. Chairman.

The CHAIRMAN. Dr. Berry, we are very glad to have you. We will have some questions probably after a while. Do you want to make a short statement on these things?

Mr. WEBB. He has not prepared a statement. He just got in this morning, Mr. Chairman. We had thought you thought the members of the committee might have questions and we wanted to be sure we would have people able to answer them.

COSTS AND TIME DELAY

The CHAIRMAN. I will begin with the questioning. Dr. Mueller. Fully recognizing that many of the suggested spacecraft changes are being considered and evaluated, could you make a judgment at this time as to estimated costs and time delay that will be necessary for some of the various alternatives under consideration?

Dr. MUELLER. Mr. Chairman, I do not believe that we can make a reasonable estimate at this time until we have had a chance to complete the tests and the design studies in order to find out just what needs to be done. So we do not at this point in time have an estimate of either the schedule impact as a whole nor the impact on the cost.

Mr. WEBB. Mr. Chairman, perhaps I could help a little with my own thinking on this matter.

In the 1967 budget, and in the 1968 budget as we will start submitting it to the House committee tomorrow, we have the funds to carry on what has been considered the normal forward thrust of this work.

Now, my guess is that the amount of work to overcome the difficulties that we find in the design of this equipment and in the testing procedures will not require, inosfar as I can see it right now, a request for supplemental funds in 1967 and may not require basic changes in the 1968 budget. I think the true impact of this will result from two factors.

First, can we, as a result of the disassembly of this very complex machine, which someone has said in a figure of speech was like putting an aircraft carrier or nuclear submarine into a package about three or four times as big as this table, can we as a result of the disassembly and study of the total equipment so change anything that requires change as to eliminate some of the testing up the road. It may be that the work we do to recover from this fire will permit us to make more rapid progress at some future time. That is an unknown factor at this time.

Second, the question of delay. If the program is delayed into the year 1970, the additional cost, I believe, will come in that year rather than in increases in 1967 and 1968, but this is a very preliminary estimate and given to help you have a framework within which to think about the problem of cost.

NEXT MANNED FLIGHT

The CHAIRMAN. Thank you.

When will the next manned flight be scheduled?

Dr. MUELLER. We would hope by sometime in April to be able to determine when the next flight could be scheduled.

The CHAIRMAN. What is the longest leadtime item as you now see it?

Dr. MUELLER. The longest lead item is probably the cabin door, although an equal contender is also the environmental control system and it depends upon the design changes that are required in both of those.

The CHAIRMAN. What is the longest overall program delay envisioned when considering that unmanned uprated Saturn I and Saturn V flights are scheduled to continue as originally planned?

Mr. WEBB. I think, Mr. Chairman, we could answer that a lot better a month from now when the Board has finished its work because the Board has now gotten to a point where it could give us preliminary findings but they must be refined through very, very careful work before undertaking to make any change in this system that must operate on the ground in one atmosphere, must operate in space in vacuum, and then come down on a flight from the Moon with a very large dissipation of energy, maybe four times what the Gemini had to dissipate—so it has got to operate under all of these conditions and we have to consider very, very carefully any change because while it may make it safer on the prelaunch testing, it may make it more dangerous on reentry.

So, I would hope you would give us about another month until the Board has finished its work to answer that.

The CHAIRMAN. If you give us another month, we will have other questions.

Mr. WEBB. Yes.

The CHAIRMAN. I am glad you answered the way you did. After a previous meeting I was asked about a delay. I said there might be a delay but probably only of 6 months. I now think it might be 6 or 10 months but it might be also very early and we are very glad to have you wait until you get a better answer.

Mr. WEBB. Mr. Chairman, I think you and the committee have found our group able to fly 20 men in 20 months in Gemini after having encountered very great difficulties in the early part of this program. Now, my own estimate is that this team which is a first-class team in industry and our own group and in the universities is going to find in the disassembly of this burned vehicle and the disassembly of the companion vehicle which was not burned a great deal of information that will permit them to have tremendous assurance in the product we put together after that process, and I would think the testing would not be delayed by unknowns to the same extent that testing has been delayed by unknowns discovered in previous testing.

I think we will know more as we start the testing than we have in previous testing periods. But again, I cannot guarantee that.

The CHAIRMAN. That was my final question, Mr. Webb.

Senator Smith?

STATEMENT OF SENATOR SMITH

Senator SMITH. Yes, Mr. Chairman.

Mr. Chairman, I think that Mr. Webb and his associates should be commended for presenting what appears to be a frank and objective analysis of the Review Board's findings concerning the probable causes of the accident and the steps that should be taken to minimize a recurrence.

PRAISES OBJECTIVE HANDLING OF INVESTIGATION

Admissions by Government administrators that operations can and should be improved are, unfortunately, seldom heard these days even in the presence of undeniable facts. It is for this reason particularly that NASA's objective handling of the accident investigation is commendable and has measurably strengthened my confidence in its management of our national space program.

I do have some questions, Mr. Chairman, for the purpose of getting a better understanding of the Board's report and the changes that are under consideration by NASA.

Mr. WEBB. May I thank Senator Smith for that statement. Senator Smith, we have tried to make absolutely sure that the best experts in and out of the Government would work on this problem. We are interested not in hiding any fact related to this accident but in finding the cause so that we can avoid any repetition of it or any increase in danger in endeavoring to overcome some of the hazards that may seem paramount at this time but which in fact may not be as grave hazards as some of the others that we will encounter further out in space and around the moon. So I do very much appreciate your statement.

FIRE-DETECTION EQUIPMENT

Senator SMITH. Thank you, Mr. Webb. Dr. Mueller, you indicated that the possibility of installing fire-detection equipment is being reinvestigated. Was there any reliable fire-detection system in existence on Apollo 204 before the fire, other than the television mounted outside the spacecraft which Dr. Seamans mentioned in his report?

Dr. MUELLER. No, ma'am. Nor have we in any of the equipment we have examined found a satisfactory fire-detection system at this point in time. We did look at that for those many years ago.

Senator SMITH. Who first detected the fire, the crew or those watching the television monitors; do you know?

Dr. MUELLER. It was almost simultaneous.

Senator SMITH. NASA has reported that the emergency egress time from inside the Apollo spacecraft is 90 seconds. What is the time required to open the hatch externally?

Dr. MUELLER. It takes about the same amount of time to open it from outside as it does from inside.

EMERGENCY RESCUE PROCEDURES

Senator SMITH. Were there specific emergency rescue procedures in existence prior to the fire which were to be followed by the on-pad test personnel?

Dr. MUELLER. In this case, the test in the closed cabin was not considered a hazardous test, so that there were not emergency procedures, nor emergency equipment in place. This was nonhazardous normal testing.

Mr. WEBB. No special equipment. There is always a level of equipment for handling emergencies in this testing area.

Senator SMITH. Well, were the on-pad personnel equipped with such items as fire-protective clothing, fire extinguishers, or oxygen masks?

Dr. MUELLER. They had masks, but the masks were designed to protect against the fumes from propellent spillages, and not from the smoke inhalation characteristic of a fire.

Senator SMITH. In the future will procedures require that such emergency fire equipment be available at the pad?

Dr. MUELLER. The equipment is available at the Cape and we are reexamining our procedures to determine just what is necessary and what can be used for emergencies of this sort.

Mr. WEBB. Senator Smith, there is no doubt that this kind of testing under this kind of pressure will be classified as a hazardous test just as the testing of the fuel boosters is a hazardous test in the future.

EMERGENCY ASSISTANCE

Senator SMITH. What emergency assistance was the pad personnel able to render in the Apollo 204 situation?

Mr. WEBB. Senator Smith, I would like to answer that by saying that the actions of every person in and around this capsule is being examined and recorded by the Review Board. We have not permitted those not associated with the work of the Board to intervene in this process. The Board has given us preliminary findings and preliminary recommendations primarily related to the things that we need to do in the future, so that we could meet the needs of this committee as expressed in the chairman's letter to us.

We have not endeavored to go into the detail of exactly what the personnel around the capsule did. That, is those of us sitting at this table. But that will be completely spelled out in the report of the Board.

I don't believe any one of us here knows the answer to that because we have not gone to question these people. The Board is doing that. Dr. Seamans made a preliminary review there and heard some of the panels, I believe; did you not?

Dr. SEAMANS. That is correct. There were 27 people up on that complex 34. They were, some of them, quite close to the spacecraft at the time of the fire. When the spacecraft ruptured and smoke and flame surrounded most of the spacecraft, they were thrown back away from it. As soon as they could, they got to the door and opened it, and about 5 minutes elapsed between the initiation of fire and the time that the door was opened.

The doctor was several levels below in the same complex and he was able to get there about a minute and a half after the door was opened.

I have checked this point further and now understand that medical personnel probably arrived from 3 to 5 minutes after the hatch was opened; definitive information will be in the Board's final report.

WRITTEN EMERGENCY PROCEDURES

Senator SMITH. Did I understand correctly, Mr. Webb, that there were no written emergency procedures to be followed by on-pad personnel at the time of the Apollo 204 test?

Mr. WEBB. Again, Senator Smith, I have been waiting for the record of the Board in this respect. We have announced we will conduct no tests of this kind out at Cape Kennedy or any other place until we have the report of this Board and decide on new procedures. So I have not asked this question, nor was it reported to me.

Now, maybe Dr. Mueller or Dr. Seamans might know the answer. I do not.

Dr. MUELLER. I would like to say just one word, and that is, "Yes," there are emergency procedures for many emergencies that are prepared and are practiced. In this particular case, since this particular test was not considered a hazardous test, emergency procedures for this particular test did not exist.

Senator SMITH. There are written emergency procedures, but not for this particular test?

Dr. MUELLER. Precisely.

Senator SMITH. Dr. Mueller, from your discussion in your statement, it appears that development of a fire extinguishment system is very difficult. Would this be a program control item or would you increase the fire prevention research to establish a sufficiently high degree of confidence and eventually fly without a fire extinguishment system?

Dr. MUELLER. We are pursuing both courses of action at the present time. We will make a decision as to whether or not to include a fire extinguishing system based upon the results of our tests and, in particular, we expect to create a mockup of the particular configuration that would be used in the Block II spacecraft with the materials that will be used in flight and see whether or not we can get the propagation of flame.

If we do not find a way of causing the spacecraft to burn, we will then probably conclude that fire extinguishing equipment is not essential.

Mr. WEBB. I think it is fair to say, Senator Smith, that there are no known completely reliable fire detection equipments for a closed system, whether submarine or airplane or this type of thing. You get many problems of false signals and the same applies in many cases to the extinguishment problem.

And the main consideration here, I think, is that if you have a fire, you have got very, very serious trouble on your hands and the extinguishment of it is not nearly so adequate a course of action as to prevent it, and as the Chairman of the Board said to me when we were considering the egress hatch and this question of fire extinguishment, there is no worse place to be in space than outside your spacecraft because the only way you can get back home is in the spacecraft, and if you are outside and it is burning, you are in very bad shape.

Senator SMITH. Thank you very much. You anticipated my questions.

Mr. WEBB. I am sorry, Senator.

The CHAIRMAN. Senator Dodd?

RESPONSIBILITY FOR INVESTIGATING FIRE

Senator DODD. I just have one question. I think it was on February 7 when we were told that there was a very serious fire that occurred, I believe, in April of 1966, in tests of the Apollo environmental control system.

What I want to know, if you can tell me, is, in view of that serious fire, what was done? What action was taken within the Agency to reassess the hazards? Who has this responsibility in the Agency?

Dr. MUELLER. This fire reported on here took place in the test center at the AiResearch Corp. on the west coast. It was a fire that was investigated by the contractor and by a task group from the Manned Spacecraft Center.

The responsibility for the evaluation of an accident of this sort rests with the contractor and is reviewed by the Manned Spacecraft Center, in this case, Mr. Johnson. This particular fire was a result of a failure in the ground-support equipment, the equipment that provides power and instrumentation readings to the environmental control. It did not involve—perhaps, unfortunately, it did not involve any of the environmental control unit hardware itself, and therefore the test disposal was that the ground-support equipment needed to be revised and improved, and that was done.

Dr. BERRY. May I add to that, too, as you know, we reported on three other fires that had occurred during testing in our atmosphere validation program, and in all of those instances exactly the same situation existed where it was ground-support equipment of some type, the sort of thing that would not be in a spacecraft, which was the item at fault, and therefore there was no action other than to realize again that the best thing is not to have a fire.

Senator DODD. Am I right in recalling that it related to a 100 percent oxygen environment?

Dr. MUELLER. That is correct.

Senator Dodd. Wouldn't that cause you to say we had better look out? This could happen inside. And that something ought to be done about that?

Dr. MUELLER. We did, and we very carefully examined what we knew to be the problem. We had, of course, in that case, nothing like the kind of a problem that we ran into with the 204. The fire itself was extinguished readily since the power went off and we didn't have anything like a flame.

Mr. WEBB. Senator Dodd, maybe I could add that in the 100 percent oxygen environment (if a combustible material is close) any source of ignition will create a fire. We have known this and this was not something that would necessarily have caused a red flag to be raised. The assumption has been from all of our testing, and our flights in Mercury and Gemini, that we had eliminated the sources of ignition in the capsule. Therefore, I think the alert as to the 100 percent oxygen was not driven home as a red flag.

FIRE SAFETY PROCEDURES TO CHANGE

Senator DODD. Well, I am not trying to badger you. I have heard Senator Smith ask—or she suggested that perhaps some procedures should be established for this type of test after that experience. I wonder if you had done that.

Dr. MUELLER. Well, I think, of course, in retrospect, it is always easy to say that one should have done something different.

Senator DODD. I know that.

Dr. MUELLER. In fact, however, we do carefully evaluate each such incident. We did, in fact, have a very carefully worked set of specifications, standards, for our materials. It was not through overlooking the problem that we arrived at the 204 accident. It was, rather, that our specifications simply did not take account of the actual event.

Mr. WEBB. And I think, Senator Dodd, it is very important to recognize that the Review Board is going to examine every single item surrounding the procedures, the accident, the actions of everyone, and potential sources of ignition, and I would hope that they will provide a better answer than we can give you today for your question because it is a crucial question.

Senator DODD. I hope so, too.

Dr. SEAMANS. But there is no question but what we should have been alerted to the fact that our procedures before this test were not adequate for this type emergency, this type hazard. We did not have the correct type of gas masks and firefighting equipment up in the complex, and this will be changed in the future.

Senator DODD. That is all I have.

The CHAIRMAN. Senator Curtis?

DURATION OF FIRE

Senator CURTIS. This may already be in the record, but I would like to ask it now. Do you know how long this fire lasted?

Dr. SEAMANS. It lasted about 20 seconds or so when we ran out of oxygen in the capsule, then smoldered in certain places for somewhat longer than that.

Senator CURTIS. Do you know how soon after it started, death occurred to the men in there?

Mr. WEBB. Dr. Berry, I think, can give you the best information on that.

Dr. BERRY. Well, Senator Curtis, we are not exactly sure of this. We lost any information we had in the way of telemetry giving us the electrocardiogram and heart rate. It appeared it was roughly 18 seconds after the initial onset, and we feel that there was unconsciousness at about that time within seconds, and we feel——

Senator CURTIS. How many seconds?

Dr. BERRY. Well, somewhere around 18 to 20 seconds.

Senator CURTIS. The fire only lasted 20 seconds.

Dr. BERRY. That is correct.

Senator CURTIS. Had there been an adequate gas mask, how long does it take to put on a gas mask?

Dr. BERRY. Well, even if they had had adequate gas masks which would have taken probably a minute or at least seconds, somewhere between 30 to 60 seconds, to throw on and get to the fire, there still would have been this 90-second period to open the hatch which has been referred to; therefore, I think we would have to say that they would not have had help from the outside in this instance.

Senator CURTIS. Twenty seconds is not very long.

Dr. BERRY. No, sir.

Senator CURTIS. And as soon as the carbon monoxide enters the body, unconsciousness begins, sets in.

Dr. BERRY. Well, it requires a very high level, sir, and the levels that we have obtained from the toxicology studies of blood and tissue led us to believe, obviously, that to produce that level, there had to be a very high level within the breathing atmosphere which they could get within that period of time. And it is going to take further study and analysis to try and determine exactly where this came from.

There are obviously investigations going on concerning other products that were also inhaled, because as any of the items burn in the spacecraft there are products produced which are also toxic, and we are continuing our investigations in toxicology to determine others that might be involved, but we feel there is no doubt that the carbon monoxide is the offender here.

Mr. WEBB. But the Senator's question is, Doesn't it affect—begin to affect the human being very rapidly, and the answer to that is, "Yes."

Dr. BERRY. Yes, sir.

Senator CURTIS. In other words, you come back to the proposition, what the answer has to be is, prevent fires.

Dr. BERRY. Yes, sir.

Senator CURTIS. Not, what to do about them after they happen.

Dr. BERRY. That is correct.

Mr. WEBB. I am sure of that. We must do all we can to prevent them. We must do all we can to shorten, to make sure they do not spread rapidly, so as to give more time to see what can be done about them.

Senator CURTIS. Yes.

Mr. WEBB. But in the end, space flight cannot take place successfully where there is a substantial risk of fire, in my opinion. We have to eliminate the possibility of fire.

Senator CURTIS. That is all, Mr. Chairman.

Mr. WEBB. Dr. Berry is supposed to differ with me a little bit here, or say a word. Would you permit him to do that, Mr. Chairman? I want to be sure we are accurate.

Dr. BERRY. I don't differ with Mr. Webb at all, but I would like to make the point that I think it is important that we realize we are never going to be able to completely eliminate the risk of fire as long as oxygen is available and we have this situation, and this situation is faced daily on the ground, in any medical situation where we have to provide oxygen for the human being to live. We use it in oxygen tents. We use it in operating rooms, and in all these situations there is a risk, and there always will be a risk, and our prime problem, of course, will be to see that that is as near zero as possible, but I don't think any of us can expect that it will be zero.

Mr. WEBB. That is a better answer, Senator, than I gave you.

Senator CURTIS. The point is, on the oxygen, though, if you have enough oxygen for the human being, you have enough for a fire.

Dr. BERRY. That is correct.

Senator CURTIS. And if you reduce it to the point where there is not enough for a fire, you do not have enough for a human being, is that correct?

Dr. BERRY. That is correct.

The CHAIRMAN. Mr. Gehrig wants to ask a question.

SOURCE OF CARBON MONOXIDE NOT KNOWN

Mr. GEHRIG. Dr. Berry, how did the carbon monoxide get into the astronaut environmental system to cause the asphyxiation?

Dr. BERRY. I really can't answer that at this point in time, Mr. Gehrig, because there are many sources, of course. Any time you burn objects you can produce very high levels of carbon monoxide and the exact source of this we are unable to determine at the present time.

We can't tell you, for instance, whether it came from heating up elements within the environmental control system or whether it came in from elements that were burned out in the cabin and came in after the suits were perforated. So, further investigation will have to answer this.

Mr. GEHRIG. Now, Dr. Seamans, in his second report, said that the suits of the astronauts were burned through. To what extent were they burned through, Dr. Berry. Would you say that the suits were consumed as has been reported elsewhere?

Dr. BERRY. No, sir; I would not. And the statement that I made at the beginning of the session in which I described burns follows along that same line. The suits were not totally consumed. There is a variance in the amount of suit that was consumed, as you go from the left couch to the right couch as it goes along with the fire, but the suits were not completely consumed.

The CHAIRMAN. Senator Cannon?

Senator CANNON. Thank you, Mr. Chairman.

NEW STANDARDS FOR COMBUSTIBLE MATERIALS

Dr. Mueller, from reading your discussion, one gets the impression that the standards for combustible materials established by the Apollo Review Board, as described to us before by Dr. Berry, were too low. I want to know whether or not that is a correct assumption or does that indicate that deviation from approved materials is responsible for increasing the severity of the action?

Dr. MUELLER. The materials review board did establish the standards for our materials, a set of specifications that in retrospect were too low. We were principally concerned with the ability of materials to stop fires rather than to sustain fires, and so our standards were set up to be sure that they would not participate in the ignition of the fire, and that was not adequate for assuring that they would not contribute later to the propagation.

Senator CANNON. We can assume, then, that you will establish standards much higher, then, when you get the results of the Board's study.

Dr. MUELLER. We are in the process of establishing a new set of standards and a new set of specifications that will avoid this in the future.

SPACECRAFT ATMOSPHERE

Senator CANNON. In your statement, you say:

> A physiologically acceptable two-gas system at a pressure within the present spacecraft structural limitation does not appear to offer a large reduction in fire hazard over a five psi pure oxygen atmosphere.

Before that you say:

Physiological considerations require that the partial pressure of oxygen be maintained no lower than the equivalent of three pounds per square inch of 100 per cent oxygen for life support.

Now, we understand that the MOL program will use a 5 p.s.i.a. atmosphere with a partial pressure of the 3.5 oxygen and 1.5 helium.

Now, do your statements mean that the MOL atmosphere just meets the physiological considerations of oxygen pressure and do not substantially reduce the fire hazard?

Dr. MUELLER. By "substantially reduce," if you mean by reducing the propagation more than a factor of two, that is correct. They will not substantially reduce the fire hazard by an order of magnitude.

Dr. SEAMANS. Could I say, Senator Cannon, having discussed this matter with the Department of Defense, it is my understanding that the selection of the two-gas system for the MOL was made on the same basis as our tentative selection of a two-gas system for Apollo Applications; namely, that for physiological reasons, pure oxygen is undesirable, or may be undesirable for periods of over 30 days, and that the Department of Defense did not make the selection of a two-gas system from consideration of fire potential.

Senator CANNON. Simply because of the length of them—possible length of the mission, is that it?

Dr. SEAMANS. That is correct.

Senator CANNON. And was there some particular reason for using the mix of oxygen and helium?

Dr. BERRY. Sir, there are a large number of arguments concerning mixed gas systems, whether you use as your dilutant nitrogen, helium, or neon, and there are many tradeoffs that can be considered in each of these.

I think that in the situation with helium, the best tradeoff that it offers you is a tradeoff as far as weight is concerned. It does offer you some weight advantages. Other than that, it does not offer any physiological advantage, and it does not offer any particular advantage over any other dilutant as far as fire is concerned.

TWO DIFFERENT TWO-GAS SYSTEMS

Senator CANNON. Well now, NASA is adopting a two-gas system at five p.s.i.a. for the S–IV workshop in the Apollo application program. Now, is this system identical with that to be used by the Air Force in the MOL program?

Dr. MUELLER. No, sir. It will use nitrogen as a dilutant, and in some respects it will be a simpler system than the Air Force is using.

Senator CANNON. A simpler system, did you say?

Dr. MUELLER. Yes, sir.

Senator CANNON. Does it have advantages over the other systems?

Dr. MUELLER. No. In this kind of development program, we would like to examine the relative merits, by practice, of various combinations. We feel that the use of nitrogen in this case would provide us with available points in experience in terms of cabin atmospheres for manned spacecraft in the future, and it is perhaps the most direct way to go for our kind of long-term exposure, since on the basis of physiological understanding, very long exposures to helium-oxygen mixture are not completely defined at the present time, whereas, we do know the long-term effects of oxygen-nitrogen.

You have to recognize in the Apollo application program, we are aiming toward the attainment of flight durations of up to a year.

Mr. WEBB. And the experience of the Air Force will be available to us, and vice versa, Senator Cannon, so the country gains the experience with both.

Senator Cannon. That was going to be my next question.

Mr. WEBB. I am sorry.

Senator CANNON. Is this being coordinated between you and the Air Force, the use of the two different systems?

Mr. WEBB. Yes, sir; completely.

Senator CANNON. And you feel that the advantages of using two identical systems would not outweigh the advantages that you can gain by using two different two-gas systems then?

Dr. MUELLER. More than that. I think we will both gain from the information that will be obtained. You recognize, Senator Cannon, that one of the things we are planning to test in the Apollo application program is part of the apparatus that the Air Force will be using in their environmental system.

Mr. WEBB. You could say, Senator Cannon, that they have a system to be used for their own needs. The S-IV-B is an experimental system aimed at using this empty hydrogen tank as a temporary shelter to experiment with quite a number of things.

Senator CANNON. Thank you.

The CHAIRMAN. Senator Jordan?

Senator JORDAN. Thank you, Mr. Chairman.

TEST IS NASA'S RESPONSIBILITY

Dr. Seamans, I think perhaps I shall direct this question to you. In a test such as the Apollo 204 test, what are the respective responsibilities of the contractor and of NASA? Do they have a joint responsibility in a test such as this, or whose responsibility is it?

Dr. SEAMANS. I might start by answering the question, and then refer to Dr. Mueller for the details.

The prime responsibility is NASA's. We must review the procedure prior to the test. We must in the final analysis take full responsibility for any accidents that occur.

However, we do delegate to the contractor the responsibility for a variety of tasks. These are spelled out ahead of time. And we do expect the contractor to think through possible difficulties that could arise in the test, and do insist that he advise us ahead of time when he believes that we are taking undue risks.

Dr. MUELLER. I don't think I can add any more to that except to say that the test conductor in this test, as in all tests, is a NASA person.

Senator JORDAN. Whose personnel manned the launch control center?

Dr. MUELLER. A mixture of NASA and contractor people.

Dr. SEAMANS. You might describe the test conductor.

Dr. MUELLER. The test conductor is a NASA man and he is in overall charge of carrying through the test. He is the one that determines when it is safe to go forward to the next step.

Senator JORDAN. The senior officer in charge of the Apollo 204 test is a NASA official?

Dr. MUELLER. That is correct.

Senator JORDAN. Where was he located?

Dr. MUELLER. He was located in the blockhouse at the test center.

Senator JORDAN. And whose personnel were on the launch service tower? Is that a blend of contractor personnel——

Dr. MUELLER. It was a blend of Government, contractor personnel, and involved some, if I recall correctly, seven NASA people and 20 contractor people.

TRADEOFFS REGARDING SINGLE HATCH

Senator JORDAN. I want to talk a little about the emergency egress hatch, Dr. Mueller. I believe you said that the one in use in Apollo 204 was one of multitype?

Dr. MUELLER. Was a dual.

Senator JORDAN. Dual type, requiring some 90 seconds to activate under favorable circumstances. I believe you mentioned——

The CHAIRMAN. You didn't indicate a sound. You nodded your head. Yes or no?

Dr. MUELLER. Yes.

The CHAIRMAN. Good.

Senator JORDAN. You are now studying a single hatch that will operate, I believe you said in 3 seconds, can be activated in 3 seconds.

Dr. MUELLER. That is correct, sir.

Senator JORDAN. And you are studying the tradeoffs. You mentioned a study of tradeoffs, the installation of this new single hatch with its obvious advantage of having very rapid emergency egress as against the present dual hatch requiring some 90 seconds.

Now, what are these tradeoffs that you were talking about?

Dr. MUELLER. Senator Jordan, it is very fine to have a hatch that opens in 3 seconds on the pad providing you don't have a fire in the capsule that will, when you open the hatch, cause flames to flare through that hatch door and across the couches. So that is one tradeoff area. Do you really improve the egress in terms of that particular emergency in this case?

Another tradeoff is, it is most uncomfortable to have a hatch that opens in 3 seconds when you are in orbit because that is far too rapid a decompression for the safety of the crew. And so we have to trade off, then, the safety of the crew for the hours that they are going to be in orbit against some cases where it might be advantageous to have a very rapid egress on the pad.

Dr. SEAMANS. Unless you can be sure in orbit that there are sufficient safeguards that you will not inadvertently open the door, and this means you have to have some arrangement with a double lock so that a person's elbow won't suddenly trip the mechanism and open the door.

Senator JORDAN. Yes. I would assume it would take two or three separate operations to activate even a fast-opening egress hatch that you are studying.

Dr. MUELLER. Yes, sir. Generally, at least, true.

Now, in addition to that, the third area of tradeoff, of course, is with respect to the heat shield itself on reentry. It is important that the hatch maintain its integrity during the whole of the reentry period and that is a third area of tradeoffs that has to be considered.

Senator JORDAN. I believe you suggested that it was not a part of the structure of the capsule, that you had engineered strength into the capsule without relying on this door to provide strength.

Dr. MUELLER. That is correct, but that door has to protect the inner structural shell that is there and from the heat of reentry itself, and therefore it has to maintain its integrity.

Mr. WEBB. The inner shell would burn if heat came out through the outer heat shield structure. So you, in a sense, have two shells, the inner vessel and outer vessel. The outer vessel doesn't give you any trouble until you start to come back, but there is an awful lot of heat when you come on in and if that comes in and the inner vessel will not contain it, it will burn through.

Senator JORDAN. I understand. This is why you went to the double shell when you had to go into the higher temperatures.

Dr. MUELLER. Exactly.

Senator JORDAN. Thank you.

The CHAIRMAN. Senator Holland.

SELECTION OF MATERIALS

Senator HOLLAND. Thank you, sir. I am particularly interested in page 86 of your statement, Dr. Mueller. To summarize it, you say that you wish to tell us why you attach such great significance to material selection and control inside the capsule. Then you remind us that there must be three things to make a fire, and that is sufficient oxygen, a source of ignition, and combustible materials.

And you say that as to the oxygen content, oxygen sufficient to support life is combustible, so you know in advance that you can't eliminate that factor. And as to a source of ignition, you know that there are going to be many chances for a spark or some other source of ignition, and that you can't eliminate that.

So you attempt to control it as close and carefully as you can. For that reason you seem to regard—and that is what I wanted to ask you—the selection or development and the geometric use and placement of materials that are either noncombustible or relatively noncombustible as your chief field of improvement.

Am I correct in that conclusion?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. I am correct.

All right. Now then, the next question is this: Who is charged under the organization and structure of NASA with the control of this field? The selection, the development, and the placement of materials within the cabin?

Dr. MUELLER. Senator Holland, I would like to answer that but first I would like to amplify just a little bit my previous answer. I think it is important to recognize that the philosophy with respect to the prevention of fires was developed as the result of our experience in the Mercury program where we made a conscious decision to go to a single-gas atmosphere.

At that time we made also a conscious decision that the way to prevent fires was to prevent ignition, prevent having them in the first place. So our total approach to the problem prior to this 204 accident has been one of minimizing the chance of having ignition of a fire and, in fact, that was the basic philosophy upon which the design, the specification and the development of materials, and selection of materials, and their use, was based.

Now, we did spend a great deal of trouble and effort in being sure the materials we used were not either self-flammable or flammable in the normal sense of things. And, for example, you found no cotton in the spacecraft itself which would not pass our flammability—material would not pass our flammability test.

With respect to the responsibility for the selection of the materials, there is a materials review board which is a part of our Manned Spacecraft Center, with responsibilities for the spacecraft. We have a similar materials review in our launch vehicle center, and again, we are equally concerned there with the selection and use of materials. And the overall standards are established by our people in the program office here in Washington.

Now, these standards in turn are reviewed by our safety office, so that there is a check and balance there. We do have offices for flight safety at Houston. We also have an office for safety here in Washington. So that the practices we are using are audited from time to time by our safety organizations.

RESPONSIBILITY FOR SELECTING MATERIALS

Senator HOLLAND. I am not finding fault with your approach to the matter at all, Doctor. In fact, I think it is a necessary approach. What I am trying to find out for this record, and to have the record show clearly, is just where in your organization is the responsibility, the ultimate responsibility, in the selection or the development of materials, or is that responsibility divided? If so, between whom?

And then in the placement of materials, so as to have materials that are even slightly flammable located so that the chance of their being ignited is reduced to the minimum.

Now, where is the responsible unit in your table of organization?

Dr. MUELLER. The program office, in particular for the spacecraft, it is the Apollo spacecraft program office which is responsible for the selection and location of materials.

Senator HOLLAND. Is there any responsibility vested in the contractor in this regard?

Dr. MUELLER. Insofar as he is responsible to the program office, yes, and there is a responsible program director in the contractor organization who is responsible for the total design, operation of the spacecraft.

Senator HOLLAND. Do we have a table of organization——

Dr. MUELLER. Yes, sir.

Senator HOLLAND (continuing). Of NASA, which can be found in the record at this time?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Does that table of organization show clearly where the responsibility is vested and, if vested in more than one place, how it is divided? I am talking about the selection or development or placement of materials within the cabin, which seems to be the most critical field of all in fire prevention.

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Does that—does your organizational plat show just where that authority is?

Dr. MUELLER. The authority is clearly established.

Mr. WEBB. Senator, our organization charts do not contain the entire protocol for materials selection and testing, but our total management system does, and there is in each case a single point of decision.

Now, where you get to a combination of a number of components and a number of subsystems into a system, there is a careful review board in each instance that meets with a very careful procedure laid out to examine every facet of the problem, and make a considered recommendation. That recommendation goes, in this case, to the program office. The Apollo manager is Gen. Samuel Phillips, and he will sign the final paper that says this is a satisfactory arrangement.

Senator HOLLAND. I realize that you have got a very complex structure necessarily. I wonder if it would be possible for you to, by a little thought, give us a written statement covering this question——

Mr. WEBB. Yes, sir.

Senator HOLLAND (continuing). Which I think is going to prove to be one of the important questions in this whole matter, just where the responsibility is, and we are not thinking in terms of the past. We are looking ahead.

Mr. WEBB. We will be glad to do that.

Senator HOLLAND. And will you do that, and supply it for the record?

Mr. WEBB. Yes, sir; we will.

(The material referred to follows:)

The Apollo Program Office in Washington has five subordinate program offices in the field: three program offices at Huntsville for the launch vehicles and large engines, one at Houston for the spacecraft, and one at Cape Kennedy for launch activities. The Apollo Program Director is responsible for the over-all management of the program; specifically, he is charged with development, test, and production of the spacecraft, launch vehicles and launch checkout equipment that are required to meet the Apollo objectives. The Program Managers at the manned space flight centers, under direction and through delegations, are responsible for carrying out assigned portions of the total program.

The Apollo Program Director establishes the over-all technical requirements and plans. Many control mechanisms are used. For instance, regarding materials, the Apollo Program Specification establishes over-all requirements for the spacecraft and launch vehicle. The Apollo Configuration Management Manual requires adherence to procedures concerning specifications and changes thereto. The Apollo Test Requirements document sets forth the qualification testing standards to meet specification requirements. Materials standards are delineated in the NASA Quality Publication. The Apollo Reliability and Quality Assurance Program Plan requires appropriate organizational levels to review and approve critical parts and materials. These documents set the management framework and establish operating responsibilities.

In the case of materials, the problems at the two development centers are different. At MSFC, for the launch vehicle, the Program Office utilizes the Materials Branch of the Propulsion and Vehicle Engineering Laboratory for technical assistance in the area of materials. At MSC, a material review board reports directly to the Apollo Spacecraft Program Office's Reliability, Quality and Test Division. Initially, the board (officially called "Appollo Waiver Board—Materials (Non-Metallic)") was concerned with developing specifications and lists of materials approved for spacecraft use. These specifications and lists were based on a variety of tests and on Mercury and Gemini experience. These specifications and approved lists then were incorporated as program requirements. The board continues to update this documentation and rule on requested exceptions to the established criteria.

An example of exceptions is the inclusion of Velcro in the spacecraft. This material was used extensively in Gemini because of the limited space and its suitability for securing objects in a zero-g environment. The board had Velcro tested in a 5 psia oxygen environment and noted there were conditions where its burning rate exceeded the one-half-inch per second criterion. Therefore, in the acceptable materials list, it is carried as acceptable provided it is no nearer than twelve inches to potential ignition sources. Compliance with this standard was specifically required in the case of spacecraft 012.

Senator HOLLAND. Thank you very much, Mr. Chairman.

The CHAIRMAN. One more question.

MATERIALS APPROVED BY BOARD

Mr. GEHRIG. Dr. Mueller, one question. Before a material can go into the Apollo Command Module, it must be approved by the Materials Review Board. Is that correct?

Dr. MUELLER. Yes, sir.

Mr. GEHRIG. Now, in the Apollo 204 Command Module, there were Velcro pads around the cabin. There were nylon sleeves around certain bundles of wire, as I understand it.

Dr. MUELLER. Teflon.

Mr. GEHRIG. As I understand it, the insulation on the wire is teflon, but from Mr. Webb's statement, over the teflon there were nylon protective sleeves put on. Isn't that correct?

Mr. WEBB. I am told I was mistaken in saying nylon, Mr. Gehrig, that the boots over the wire bundles were teflon. I had thought up until now they were nylon.

Mr. GEHRIG. But there was also a nylon netting in the bottom of the spacecraft.

Dr. MUELLER. There was——

Mr. GEHRIG. And there was this sponge material, these pads, to lay the hatch doors on.

Dr. MUELLER. That is correct.

Mr. GEHRIG. Were these materials approved by the Materials Review Board?

Dr. MUELLER. Yes, sir.

Mr. GEHRIG. They were approved to use inside the spacecraft?

Dr. MUELLER. Yes, sir, and they met the specifications for the control that we had in force at that time.

Mr. GEHRIG. Were they approved to use in the spacecraft at 16 pounds per square inch pure oxygen or 5 pounds per square inch?

Dr. MUELLER. Our specifications called for testing at 5 pounds per square inch.

Mr. GEHRIG. I see. So the Materials Review Board had approved the materials at 5 pounds per square inch.

Dr. MUELLER. That is correct.

Mr. GEHRIG. Where in the organization is it decided to put the nylon netting in and these pads, and the Velcro, and so forth? Is this something——

Dr. MUELLER. This, again, is a program office responsibility.

Mr. GEHRIG. Does the program office then pass on the use of these materials in the spacecraft?

Dr. MUELLER. That is correct.

Mr. WEBB. Mr. Chairman, could I say that Dr. Berry is needed very much back at Houston and wants to—has to leave here no later than 20 minutes to 6 if he is to make it. We can keep him as long as you wish. I thought maybe if members had questions of Dr. Berry particularly, we might take them so they wouldn't be denied that opportunity.

The CHAIRMAN. I am trying to get order in the questioning.

Mr. WEBB. Then we will keep him. We will just ask him to cancel his plane.

The CHAIRMAN. Senator Brooke.

Senator BROOKE. Dr. Mueller, was there anything that the astronauts could have done in that spacecraft to have avoided this accident?

Dr. MUELLER. Not that we know of.

Senator BROOKE. No equipment that they could have used?

Dr. MUELLER. Not to the best of our knowledge at this point in time.

Senator BROOKE. Now, you classified this as a nonhazardous test based upon the 7 years of manned spacecraft experience that you have had. Had you classified this as a hazardous test, what would you then have done? What precautions would you then have had that you did not have in the classification of the nonhazardous test?

Dr. MUELLER. In the case of our hazardous tests, we do provide for emergency equipment and for the procedures, and training to use that equipment with the spacecraft. I must say that in my judgment, even if this test had been classified as hazardous, we would not have been able to save the crew.

Senator BROOKE. It could not have been avoided even had it been so classified?

Dr. MUELLER. That is correct.

SPACECRAFT ON EXTERNAL POWER

Senator BROOKE. Is there a possibility that the spacecraft was drawing power from two sources, that is, externally and internally, at the time of this accident?

Dr. MUELLER. We have carefully reviewed at this point in time the sequence of switching. We have no evidence that the power source per se had an effect, was directly the cause of the fire.

Senator BROOKE. If this were the fact, would this have caused an overloading that could have caused the accident?

Dr. MUELLER. Well, to our knowledge, the electrical power supply system in the sense of supplying power did not—was not a factor.

Senator BROOKE. Not a factor. Would you agree with that, Dr. Seamans, that it was not a factor?

Dr. SEAMANS. Yes, Senator Brooke. I would agree it was not a factor. There was some confusion right after the accident—whether we were on internal or external power. Careful examination of the records showed that we were on external power, and that this was not a cause of the accident.

EXTENT OF DAMAGE

Senator BROOKE. Have you determined the extent of the damage to the Apollo 204 service module?

Dr. MUELLER. No. I have not had a record of the extent of damage. It is slight, however.

Senator BROOKE. Do you know the nature of it?

Dr. MUELLER. No, sir. It is a secondary flame impingement and I know of no real damage to the service module. Do you, Dr. Seamans?

Dr. SEAMANS. At the time that we were at Cape Kennedy last week, the command module had just recently been removed, and they were just starting to carefully inspect the service module. From my own observation I agree with what Dr. Mueller said, that there was a little bit of smoke and scarring on the outside, but I believe the damage is minimal.

Senator BROOKE. Would it be repairable, then?

Dr. SEAMANS. I believe it is definitely repairable.

Senator BROOKE. Would you care to estimate what the cost would be to repair it?

Dr. SEAMANS. No, I couldn't do that, but very minimal, I would say.

The CHAIRMAN. Do you have any questions of Dr. Berry? Do you have any questions?

Senator BROOKE. I have nothing further.

The CHAIRMAN. I think you can safely leave, Dr. Berry, if you want to.

Senator Mondale?

Senator MONDALE. First of all, I would like to applaud Dr. Mueller's statement, that the overriding principle of the Apollo efforts will be safety. I for one, would like to endorse that principle.

I think as much as we would like to beat the Russians to the Moon, that is your decision; I am glad to see it deeply imbedded in NASA policy not to let such a consideration have anything to do with the safety of our men.

SUCCESSFUL SERIES OF GEMINI FLIGHTS

We have just completed what would appear to be an exceedingly successful series of Gemini orbital experiences. As I understand it, by and large, the Gemini flights were on schedule, they were in many cases astoundingly successful. McDonnell Aircraft Corp. came within very close approximation of the contract amounts. They were very safe, and from everything I can tell, the quality controls and the rest were highly commendable.

We have yet to have a successful manned Apollo flight. We are already experiencing serious time delays. We have had overruns in the hundreds of millions of dollars. We have had five deaths.

Based upon this testimony today, there have been materials introduced into the capsule of questionable quality in terms of fire control.

DISCUSSION OF THE PHILLIPS REPORT

Is there anything to be learned in comparing the successful operation of the Gemini series with what we have already experienced thus far, and let me preface this by saying that I have been told, and I would like to have this set straight if I am wrong, that there was a report prepared for NASA by General Phillips, completed in mid or late 1965 which very seriously cricitized the the operation of the Apollo program for multi-million dollar overruns and for what was regarded as very serious inadequacies in terms of quality control.

This report, among other things, was so critical that it recommended the possibility of searching for a second source, and as I am told, recommended Douglas Aircraft.

Following the receipt of this report, the top leadership of NASA was sufficiently concerned that they actually discussed this matter with Douglas and had serious discussions with the present general contractor to try to revise and strengthen their operation in the light of these complaints.

Would you comment on that? Is there a Phillips report?

Dr. MUELLER. May I answer this by trying to place it in perspective.

Frank Borman and I were talking the other evening about the equipping of the Gemini VII spacecraft because at that time we had in operation the same set of standards, the same set of specifications, the same set of tests as we had used in the Mercury program.

I believe that the use of Velcro in Gemini VII was considerably greater than that in the Apollo 204. So that in terms of the application of our knowledge, we did fully use whatever knowledge we had gained about flammability and flame propagation in Gemini in the Apollo program.

With respect to the question concerning the relative performance of contractors in terms of carrying out the program, I remember my first experience before Congress was about 2 or 3 days after I arrived on this task here, finding that there was a special investigation of a report on the Mercury program which highlighted some of the quality control problems that we had experienced in the Mercury program.

And we had an investigation, in this case by the House, of that particular report.

I think that our experience, in fact, with this spacecraft has led us to believe that the Apollo 204, for example, was in fact a better quality article than the first Gemini spacecraft. That was the general opinion of the people that had worked on it down at the Cape when it came out.

Now, I think on the other hand, it is also fair to say, in the first article of any of these most complex equipments that we all learn, and we all have a great deal to learn. We have, after all, a Block II coming along after Block I, and we have incorporated into that those changes that we had learned from our experience in the Block I spacecraft.

I do not regard the performance of the contractors in the Apollo program as being any better or any worse than the performance of the contractors in the Gemini or in the Mercury program. We do have and prepare regularly reports on each of our contractors concerning their progress, and I am sure that General Phillips has on several occasions prepared reports on each of our contractors.

I do also recall that not all of them have been completely complimentary. On the other hand, I know of no gross overruns in the Apollo program, and we are tracking the budget and the expenditures that we had established for the program. I think you recognize that in any R. & D. program a considerable amount of management attention has to be paid to areas of weakness, both internally in NASA and externally in our contract structure.

We endeavor to create a system that highlights problems at an early enough time that appropriate action can be taken to solve them.

And, specifically, I know of no occasion when we thought of a second source, Douglas, on the Apollo.

Senator MONDALE. Is it your testimony that there was no such unusual General Phillips report? Is that rumor unfounded?

Dr. MUELLER. I know of no unusual General Phillips report. I do know that General Phillips has examined each of our contractors in the course of the program and, as a matter of fact, we have a yearly process of evaluating the contractors' structure, to be sure, and we do from time to time have special reviews of contractor problems.

I don't know of a specific report such as that.

Senator MONDALE. Was there a report in which General Phillips recommended looking for a second source?

Dr. MUELLER. I do not recall such a report.

Senator MONDALE. So that, basically, what I have incorporated in my question here by way of what has been reported to me, you regard to be inaccurate?

Mr. WEBB. Senator Mondale, I would like to say that we are using industry that has been accustomed to making large quantities of things like airplanes and various other components, to do research and development on very advanced systems from fuel cells to environmental control systems to a spacecraft to go to the moon, to land, and come home. We have had no contractor in this kind of work against which unfavorable reports have not been filed, and on the other hand, we have also found we could work out the problems with each one of them.

The cycle seems to be to get started, to run into a great many problems, to fold around with NASA, contractor, and other people the necessary effort to solve those problems, and then to emerge from the program with good results.

In the case of Gemini we had a very great deal of trouble in the beginning and we were more than 6 months behind, and yet the folding-around process produced an ability to move forward and finish on time, and to begin to get very thorough top management attention on this.

The conversion of people who have been doing other things to space work has been very painful in the case of engine manufacturers, in the case of spacecraft manufacturers, booster manufacturers, electronics manufacturers. It has been a very painful and difficult process but it is the only way the United States of America is going to operate in space.

REVIEW BOARD CONSULTANT INVITED TO JOIN NASA

Senator MONDALE. Do I understand that Mr. John Yardley, who was one of the key men on Gemini, will be shortly coming on the NASA staff?

Mr. WEBB. We do not know that. He is now working with the Board and he is an outstanding man and we would very much like to have him, but there is not——

Senator MONDALE. Has he been asked?

Mr. WEBB. I have asked Mr. McDonnell if he could be made available to us.

Senator MONDALE. Is that designed to bring his expertise and skill to bear on the Apollo program?

Mr. WEBB. It is designed to bring one of the best men in the country into the management team and it is exactly the same process we followed with respect to every occasion that we could find a good man that was ready to come in and work for a Government salary. I would say one of the difficulties is that in his present situation, his compensation is considerably beyond anything the Government will pay, and I would like to say one other thing, this is not a reflection on the people who have been the managers in this program, but we are now coming forward with an Apollo program that is easily 10 times, maybe 20 times as complex as the Gemini, and we are now in a position where the first articles are being delivered with very large testing programs ahead of us.

The testing program is designed to work out the bugs and if we could have 10 Yardleys we sure would be glad to take them.

Dr. SEAMANS. I wonder if I could just say an additional word, Mr. Chairman.

The CHAIRMAN. Go ahead.

GEMINI SUCCESSFUL BUT HAD PROBLEMS

Dr. SEAMANS. I would just like to say, Senator Mondale, that I agree with you that the Gemini program was successful. At the same time, it was not without its problems.

On quite a few of the flights we had really very great difficulty. We had thruster problems that sent one spacecraft into a high rate of spin, for example. I would also want to say that in our various status reviews we do look at the performance of each one of the contractors and I can remember discussing the possibility of a second source on parts of the Apollo. This was not directed at having the work go to Douglas, but we happened to believe that competition is a healthy thing and from time to time do review these possibilities in our status reviews.

Mr. WEBB. I want to add one other thing, since you have raised the question of contractor performance. There is nothing in the preliminary findings or recommendations of the Board that points to the cause of the Apollo 204 accident or fire as being generated by any contractor.

The CHAIRMAN. Senator Percy?

IGNITION SOURCE NOT KNOWN

Senator PERCY. If any of the three questions I am concerned with were asked this afternoon when I was out of the room, please let me know.

Dr. Seamans, in your statement on Saturday, you said that the fire probably burned for several seconds without being noticed. What materials and systems are located in the area where the initial burning apparently took place?

Dr. SEAMANS. We suspect that the fire started over in the lower left-hand side of the cabin underneath the level of the couch where the astronauts were located and that the netting that we have referred to, to catch objects that might have fallen, probably was ignited at that time, and that in turn spread, and the Velcro material also caught fire, and this served as a fuse that quickly took the fire around the spacecraft.

Mr. WEBB. The answer, I think, Senator Percy, is that the environmental control system is the largest single unit of equipment in this general area.

Dr. SEAMANS. We don't know what the ignition source was. We believe that it was some form of electrical short circuit or something of this sort, and it probably was located in the lower left-hand side of the cabin.

Senator PERCY. These materials, then, that are now being replaced were involved in the initial flame; is that correct?

Dr. MUELLER. Yes.

Mr. WEBB. Some of them that burned, Senator Percy, we clearly want to replace. Whether they were the first thing to burn, we are not sure.

Senator PERCY. And they would have contributed to the carbon monoxide that was inhaled and is the cause of death.

Mr. WEBB. Among other things; yes.

Senator PERCY. We all understand that the spacecraft itself is being modified considerably.

Do you anticipate any changes in the launch vehicle systems or the launching facilities?

Dr. SEAMANS. There is nothing at this time that points to the launch vehicle as a source of the difficulty, but we continually reevaluate all elements in the system and will do so with the launch vehicle, as well as with the spacecraft.

Dr. MUELLER. I might add that there may be changes in the pad itself as the result of this.

QUESTIONS ON DELAY IN PROGRAM

Senator PERCY. Lastly, Mr. Webb, I think the country would certainly absorb any delay in this program that would make the program a safer one and prevent any such future disaster. Is it possible for you to estimate how much of a delay now that it would be reasonable to expect we will have to absorb?

Mr. WEBB. Senator Percy, we did discuss this earlier, and my own view is that if we can find in the disassembly of the burned spacecraft and the disassembly of its companion Block I spacecraft, these two disassemblies taking place side by side for various purposes, not only all possible sources of ignition, but also any of the weaknesses that are incorporated, or points that we would raise questions about—and I am sure you understand as a manufacturer that when you look at a total system of the size and magnitude of this and you disassemble that system that has never been used, you learn a great deal about it just as you learn a great deal about any new engine that may even have been run a short period of time, when you disassemble it—my own view is that this process is going to eliminate all sources of weakness that we would feel were critical, and therefore we may be able to accelerate the schedule of flights to make up for this. We may be able. I hope so. This cannot be determined until this disassembly and other process is finished.

Now, second, I am sure you know also as a man with experience in the manufacturing industry that since this is Block I first delivered article and we are now only going to fly a Block II series, the changes are not going to go back and be made in the Block I.

We have stated already we will not fly men in Block I and the first planned flight will be Block II.

I think those two things may permit us to accelerate the schedule. If we don't we are going to have a delay that we cannot estimate until the Board has finished its work, filed its complete recommendations, and we have decided then what to do.

Part of that schedule of work will be related to the displacement within the spacecraft of any articles that can propagate a fire. We hope very much in our analysis we will eliminate any cause of ignition. We hope—we will take steps to minimize the possibility of propagation, even should a fire start. That is the process and I would say in about a month or 6 weeks we can tell you more about that.

Senator PERCY. Thank you very much.

Thank you, Mr. Chairman.

The CHAIRMAN. I think, Dr. Mueller, you may want someday to take a look at some information we have relative to this so-called Phillips report, and you might sometime discuss with the committee what he supposedly said about these things.

Senator CURTIS. Mr. Chairman, may I ask one question? How much——

The CHAIRMAN. Certainly.

Senator CURTIS. How many Apollo flights have there been, of course, that have been unmanned? How many——

Dr. MUELLER. There have been two of the Apollo Block I spacecraft thus far.

Senator CURTIS. What were they?

Dr. MUELLER. There are several boilerplates but in terms of spacecraft, there were the 201 and 202, AS-201 and AS-202.

Senator CURTIS. That is all.

Dr. MUELLER. Mr. Chairman, with respect to General Phillips' report——

The CHAIRMAN. Sam Phillips' report. It doesn't say General Phillips' report. Sam Phillips' report.

Dr. MUELLER. There are a number of reports that Sam Phillips has prepared from time to time on the status of the program. I cannot identify the one Senator Mondale was talking about.

The CHAIRMAN. This is February of 1965.

Dr. MUELLER. Well, in that time frame, we were examining all of our contractors.

The CHAIRMAN. I beg your pardon?

Mr. MUELLER. About once a year we go through and do an evaluation of the contractor's progress and——

The CHAIRMAN. He isn't so outraged but what he stays on the payroll, is he?

Dr. MULLER. Beg pardon?

Mr. WEBB. I didn't understand your question, Senator.

The CHAIRMAN. I simply say he isn't so outraged, and so upset, but what he stays on the payroll, is he?

APOLLO PROGRAM MANAGER

Mr. WEBB. He is still the program manager in the Apollo program.

The CHAIRMAN. He is a good man.

Mr. WEBB. An outstanding man that went through the whole Minuteman program for the Air Force and has done a very outstanding job here. I can say this, Senator Anderson. No contractor on a major project in this program is without adverse information in our files. None.

And one of our problems is to make sure that we can fly successfully, utilizing the American industrial system for 90 to 95 percent of our work. This is also a very great strength for this country. And I would say one other thing: I do not believe any Government organization could do as well as our contractors have done with these very complex problems

Senator MONDALE. Mr. Chairman, may I——

Dr. MUELLER. May I add one other thought to that? Also, I know of no contractor in our files who doesn't have some positively good things said about him. [Laughter.]

The CHAIRMAN. Now, you have opened up a big subject.

DISCUSSION OF PHILLIPS REPORT

Senator MONDALE. Mr. Chairman, do we have a copy of this February 19 report in the committee files, the so-called Phillips' report?

Mr. GEHRIG. No.

Senator MONDALE. Could we be supplied with a copy of that February 19 report?

Mr. WEBB. I would like to take that as a request, Senator Mondale, and examine it very carefully because, obviously, these companies are public companies. You have got many factors related to this and certain of these reports are regarded as of deep concern.

What we would be very happy to do is to make it available to the Comptroller General under any request that the committee or you would make to him. This provides a certain measure of control of these reports which I think permits you to get what you need but still under proper control. I just don't want to say yes until I see the full problem involved in that.

Dr. MUELLER. I am not even sure such a thing—February 19 report——

The CHAIRMAN. I think it was November.

Mr. WEBB. Whatever reports are of interest to this committee we are prepared to establish the proper procedure for them.

Senator MONDALE. What I am getting at is this allegation, this serious criticism made about this so-called Phillips report.

Mr. WEBB. Are you thinking of a report circulated by a former employee of the company recently, within the last 6 weeks?

Senator MONDALE. No, so-called Phillips' report came out mid or late 1965, conducted by NASA on the Apollo program.

Mr. WEBB. Let us look it up.

The CHAIRMAN. These circulations are radio stories, designed to have some comments.

Mr. Gehrig has a question.

Mr. GEHRIG. Dr. Mueller, to make sure the so-called Sam Phillips' report is put in proper perspective, General Phillips is in a sense the general manager of the Apollo program. Therefore, you would expect him to evaluate the contractor and make his thoughts known regarding the contractor to you and the Deputy Administrator and the Administrator.

Dr. MUELLER. Each of our contractors is periodically evaluated, yes.

Mr. GEHRIG. So this would be a management report, I would guess. I don't know. I have never seen the report, so I don't know. All I know is the name Sam Phillips' report that I have heard about.

Dr. MUELLER. But these are not generally reported in this form.

Mr. GEHRIG. He is expected to review the contractor and report?

Dr. MUELLER. We have contractors' regular reports in our management system. I assume that is not what Senator Mondale was referring to when he said something about a second source.

CONSULTANTS TO APOLLO REVIEW BOARD

Mr. GEHRIG. Another question. Mr. John Yardley was mentioned and you said he was assisting the Board but he is not a member of the Apollo 204 Review Board.

Mr. WEBB. No.

Dr. MUELLER. He is a consultant.

Mr. WEBB. One of the 1,500 people working with the Board in the examination of all of the factors related to this accident and the courses of action that should be taken as a result of it.

Mr. GEHRIG. How many consultants do you have for the Apollo 204 Review Board?

Dr. SEAMANS. We can submit that for the record. I don't know the exact number but it is a——

Mr. GEHRIG. Mr. Yardley is one of these consultants.

Dr. MUELLER. Let me say one of the most rewarding things about my contacts with American industry has been their willingness to do everything they could possibly do to further the space program. John Yardley was made available to the Board by McDonnell to help in every way he could to solve the problem of what we needed to do next. Other people have been made available from other companies.

We have a uniform response from every single member of the Apollo team, every single member of the Gemini team, a lot of people I really don't know, but they are responsible individuals in industry who really are willing to do everything they can to help this thing go. And now it isn't limited to this accident, however.

One of the real important considerations is that the people in industry have been willing to help one another to solve the problems that we have run into from time to time in the space program and they have been unstinting in their willingness to help.

Mr. GEHRIG. Dr. Seamans, would you furnish for the record a list of the consultants, not the 1,500 people——

Mr. WEBB. Mr. Gehrig, I would like very much to wait until this Board has finished its work. We have declined to open up for broad public consumption the total machinery of the Board. This is an impartial Board. We have done everything we could to meet your requirements by having Dr. Seamans go and meet with the Board and bring back interim reports.

We have tried to make sure we do not interfere or expose the Board improperly. We are going to stand before you with a full report of the Board, what its findings are, how it conducted its work, and it would seem to me that this list of consultants and the members and exactly what area people are working in could wait until that time.

Mr. GEHRIG. Well, that is perfectly all right. But the reason I asked for it is that the names of some of the people who are consultants on the Board and their areas of expertise are very well known, and others are not. I thought it would make the record complete to put the consultants in.

Mr. WEBB. We will be very glad to give it to you without interfering with the work of the Board which was the fundamental ground rule laid down by the chairman when he requested us to appear before the committee.

Mr. GEHRIG. Dr. Mueller, in your statement, you say:

> In particular, we are initiating actions to be responsible to each of the preliminary recommendations of the APOLLO AS-204 Review Board.

Would you put in the record at this point all of those preliminary recommendations?

Dr. MUELLER. I believe they are contained in the report of Dr. Seamans.

Mr. WEBB. No more complete statement can be made than the report written by Dr. Seamans and furnished to this committee, and which the chairman has put into the record at the beginning of this session.

Mr. GEHRIG. Does that contain all of the preliminary recommendations mentioned in Dr. Mueller's statement?

Dr. SEAMANS. I am going to say there are on pages 4 and 5 of this report to Mr. Webb a summary of eight findings and eight recommendations which do contain all of the major and significant preliminary findings and preliminary recommendations of the Board.

DISCUSSION ON IGNITION SOURCE

Mr. GEHRIG. Dr. Seamans and Dr. Mueller, there has been discussion about the ignition source and frequently when the ignition is discussed, it is discussed in terms of an arc or spark, or something like this.

Now, in the pure oxygen environment, do you need a spark or electrical arc, or something like this to initiate combustion?

Dr. MUELLER. No. Hot wire. Spontaneous combustion. You need the same kind of ignition source that you have in a fire in the house.

Mr. GEHRIG. Have you considered disassociation of oxygen atoms by electrical fields and the reformulation to form molecular oxygen giving off energy?

Dr. MUELLER. Well, yes; we considered many things, but it doesn't give up that kind of energy.

Mr. GEHRIG. I am told it gives up quite a bit of energy. For example, in the case of recombination of oxygen atoms in the presence of a catalyst to form molecular oxygen 119 kilocalories per mole is given off compared to 58 kilocalories for formation of water by hydrogen and oxygen.

Dr. MUELLER. A mole of oxygen is a very large amount of oxygen.

Mr. GEHRIG. Has this been considered?

Dr. SEAMANS. Let me just say, Mr. Gehrig, we have considered chemical reaction, spontaneous combustion, and a variety of electrical phenomena. We have been very grateful for the number of suggestions that have come into NASA.

These have all been referred to the Board and they are all being analyzed, and I cannot say whether this specific cause has been investigated. I believe it has. But this can very well be another suggestion that we will be happy to analyze.

Mr. GEHRIG. It seems to me, Dr. Mueller, that somewhere I saw a report or read a report that the Apollo command module is very carefully examined for the existence and the elimination of electrical fields. Isn't this correct, that in what you might call your electromagnetic analysis of the capsule you try to eliminate these fields?

Dr. MUELLER. Not eliminate them but at least understand and be sure they are not affecting the operation of the equipment.

Mr. GEHRIG. Well, shield against them, let's say.

Dr. MUELLER. The pressure vessel itself represents a shield against external electromagnetic radiation and it is immune to almost any amount of external radiation that might be present.

We have also looked rather carefully at whether or not the electrical discharge, lightning, or something, couldn't have caused the problem. There is no evidence to indicate that.

Mr. GEHRIG. It has been reported that the greatest damage seemed to have occurred where the lifeline from the launching pad entered the cabin.

That is, the Apollo 204 command module. Is that a correct statement?

Dr. MUELLER. Where is the lifeline?

Mr. GEHRIG. It said that the greatest damage seemed to have occurred where the lifeline from the launching pad entered the cabin.

Dr. MUELLER. What are you reading from, Mr. Gehrig? What are you reading from?

Dr. SEAMANS. What do you mean by the lifeline?

Mr. WEBB. We don't identify the term.

Mr. GEHRIG. There was a report made in the House that said that the greatest damage to the capsule had been in the area where the lifeline, I presume the oxygen line, where it entered the cabin.

I am trying to find out whether that is correct.

Dr. MUELLER. I believe what you are referring to is the environmental control unit, which is the life support system for the command module. It is a unit in the cabin on the lower left side of the command module and it, of course, provides all of the oxygen for the crew and for the cabin itself.

The greatest damage did occur in that area and in particular, it occurred in the area directly under the lithium hydroxide.

The CHAIRMAN. This ought to complete the hearing.

I do want to observe——

Senator HOLLAND. Mr. Chairman, may I ask a question? Will the committee, after it has seen the final report, have another hearing and have the presence of these skilled gentlemen to illuminate further questions for us?

The CHAIRMAN. We do plan that. We think it is going to be necessary to have a chance to read these statements, and so forth, and study them in some degree.

Thank you very, very much.

Mr. WEBB. Thank you, Mr. Chairman.

(Whereupon, at 5:50 p.m., the above hearing was adjourned, subject to the call of the Chair.)

INDEX

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

TO

HEAR MEMBERS OF THE APOLLO 204 REVIEW BOARD ON THEIR FINAL REPORT OF INVESTIGATION AND TO DISCUSS THE BOARD'S FINDINGS, DETERMINATIONS, AND RECOMMENDATIONS

APRIL 11, 1967

PART 3

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE

74-521 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota

MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

LIST OF FIGURES

LIST OF FIGURES—Continued

APOLLO ACCIDENT

TUESDAY, APRIL 11, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 10:05 o'clock a.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Young, Cannon, Mondale, Smith, Curtis, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Craig Voorhees, Dr. Glen P. Wilson, and William Parker, professional staff members; Donald H. Brennan, research assistant; Sam Bouchard, assistant chief clerk; Mary Rita Robbins, clerical assistant; and Howard Bray, press secretary to Senator Anderson.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The committee is meeting today in a continuation of its full review of the Apollo 204 accident. Previous to today's meeting the committee met on February 7 and February 27 to hear officials of NASA with respect to the manner in which the investigation of the fire was proceeding. The Apollo 204 Review Board submitted its report on Sunday, April 9, and the committee has asked that the Board members appear before it today in order that we may question the Board as to this report. The Board's report is voluminous and it is possible that the committee will wish to hear the Board again at a later date. This morning we will be especially interested in getting amplification of the Board's findings, determinations, and recommendations as they appear in part 6 of the report.

I want to express my personal belief that the Board has accomplished a difficult task and has submitted an honest and objective report. I know that the National Aeronautics and Space Administration has had a hard two and a half months. It is, quite obviously, easy to be a Monday morning quarterback. Yet, it is essential that we look at how the game was played so that the mistakes committed then need not be repeated. There would be little gained if we were to adopt a harsh approach, but we would be derelict in not asking fundamental questions—the kinds of questions that are on the minds of every American. We intend to do that. However, as the committee's professional staff has studied the entire report, I am not so sure that it is useful for the committee itself to spend a long period of time going over the great mass of detail embodied in the appendices.

The report is sharp in its criticism of some practices by the agency and the contractor. This committee regards such conditions as totally unacceptable. We must, therefore, know what NASA is doing and what it plans to do to assure to the maximum extent possible that they do not reoccur.

Beyond this tragedy and the investigations of how it was allowed to happen is the need to move ahead toward the Apollo goal. That is not an idle phrase. We have put lives and treasure into this program. Congress has accepted the value and importance of achieving the goal.

Dr. Thompson, chairman of the Board, has a statement to present to the committee. At the conclusion of Dr. Thompson's statement, if there is any member of the Board who wants to make a statement, the committee will be happy to hear him.

Senator Smith, do you have a statement?

OPENING STATEMENT BY SENATOR SMITH

Senator SMITH. Yes, Mr. Chairman. As you know, we have had only approximately two days to read and evaluate the very detailed and voluminous final report of the Apollo 204 Review Board. My first reaction is that the Board has been eminently successful in carrying out its primary mission—to investigate and report impartially and objectively on the probable causes and conditions which led to the Apollo spacecraft accident. I am sure this was neither an easy nor desirable task to undertake.

While the Board was not able to identify the specific cause of the accident, it has disclosed a number of serious deficiencies in the areas of safety, management, and engineering design and workmanship which may have contributed to the accident or the fatalities which occurred.

These conditions must be eliminated if we are to avoid such tragedy in the future and achieve any measure of success for the Apollo and later manned space programs.

Dr. Thompson and the other members of the Board can be of great help to the committee in this regard by giving us their valued opinions on how best we can identify the necessary corrective actions that should be taken to eliminate the deficiencies disclosed in their report.

The CHAIRMAN. Thank you, Senator Smith.

Dr. Thompson, the committee will be ready to hear your statement now.

STATEMENTS OF DR. FLOYD L. THOMPSON, CHAIRMAN OF THE APOLLO 204 REVIEW BOARD; ACCOMPANIED BY COL. FRANK BORMAN, ASTRONAUT, MANNED SPACECRAFT CENTER, NASA; DR. MAXIME A. FAGET, DIRECTOR, ENGINEERING AND DEVELOPMENT, MANNED SPACECRAFT CENTER, NASA; E. BARTON GEER, ASSOCIATE CHIEF, FLIGHT VEHICLES AND SYSTEMS DIVISION, LANGLEY RESEARCH CENTER, NASA; DR. ROBERT W. VAN DOLAH, RESEARCH DIRECTOR, EXPLOSIVE RESEARCH CENTER, BUREAU OF MINES, DEPARTMENT OF THE INTERIOR; COL. CHARLES F. STRANG, CHIEF OF MISSILES AND SPACE SAFETY DIVISION, AIR FORCE INSPECTOR GENERAL, NORTON AIR FORCE BASE, CALIF.; GEORGE C. WHITE, JR., DIRECTOR, RELIABILITY AND QUALITY, APOLLO PROGRAM OFFICE, HEADQUARTERS NASA; JOHN J. WILLIAMS, DIRECTOR, SPACECRAFT OPERATIONS, KENNEDY SPACE CENTER, NASA; AND BOARD COUNSEL GEORGE T. MALLEY, CHIEF COUNSEL, LANGLEY RESEARCH CENTER

(The biographies of Board members appear on page 261.)

Dr. THOMPSON. Thank you, sir.

INTRODUCES BOARD MEMBERS

Mr. Chairman, members of the committee, it is my honor to present to you the report of the Apollo 204 Review Board. Before I proceed with my brief statement concerning the Board's activities, I would like to introduce the members of the Apollo 204 Review Board, all of whom are with me today. The members of the Board are, besides myself:

Col. Frank Borman, astronaut, Manned Spacecraft Center, NASA; Dr. Maxime A. Faget, Director, Engineering and Development, Manned Spacecraft Center, NASA; Mr. E. Barton Geer, Associate Chief, Flight Vehicles and Systems Division, Langley Research Center, NASA; Dr. Robert W. Van Dolah, Research Director, Explosive Research Center, Bureau of Mines, Department of the Interior; Col. Charles F. Strang, Chief of Missiles and Space Safety Division, Air Force Inspector General, Norton Air Force Base, Calif.; Mr. George C. White, Jr., Director, Reliability and Quality, Apollo Program Office, headquarters, NASA; Mr. John J. Williams, Director, Spacecraft Operations, Kennedy Space Center, NASA; and Mr. George T. Malley, Chief Counsel, Langley Research Center, who is counsel for the Board. When I have completed my statement, I am going to have to ask for some assistance from certain members of the Board to present to you a fuller picture than I could present by myself, to round out my statement. I would like to call on Dr. Van Dolah to present a description of the accident and, following that, I will ask Dr. Faget to present, in summary form, some of the details of the investigation and analysis of anomalies and conclusions drawn therefrom, and then Colonel Borman will sum up with the presentation of the findings and determinations and recommendations of the Board.

The Apollo 204 Review Board was established by the Administrator, National Aeronautics and Space Administration, on January 27, 1967, confirmed by memoranda dated January 28, 1967, and February 3, 1967.

The Board was composed of eight members, including the Chairman. Six members were NASA personnel; one member was an officer from the Aerospace Safety Directorate of the Air Force Inspector General and one member was from the Bureau of Mines, Department of the Interior. A counsel was assigned to provide legal advice.

21 TASK PANELS ASSIST IN INVESTIGATION

Twenty-one task panels were formed, the majority of which were technically oriented to assist the Board in arriving at the probable cause of the accident, and in considering all other factors relating to the accident, including design, procedures, organization and management.

In addition, representatives, consultants and observers participated in general Board meetings and panel activities. These individuals assisted the panels and Board members in their area of expertise and responsibilities.

The established procedure for the Board was to convene a daily general session. During these meetings, plans and schedules were reviewed. Reports on previous actions were presented for approval of plans, schedules, and the determination of requirements for testing and analyses.

In addition, an executive session was held daily. Basic direction to all Board activities was developed and consummated during executive sessions. Plans, schedules and other investigating actions were formerly approved by the Board in this session.

INVESTIGATION PROCESS OUTLINED

An impounding process was implemented immediately after the accident. The launch complex, documents, historical records, and other relevant material were placed under the jurisdiction of the Apollo 204 Review Board.

The investigation techniques employed by the Board required the coordinated effort of numerous agencies. An overall master plan was developed to insure the investigation was accomplished systematically without disturbing evidence. This plan required a controlled disassembly of the spacecraft on a component or system basis with continual observation by appropriate panel personnel and photography before, during, and after the removal of each component. The technique of disassembly was validated in spacecraft 014 command module prior to the actual component removal from spacecraft 012 command module involved in the accident. During the disassembly, extreme caution was exercised to prevent disruption of adjacent areas. For example, a special false floor with removable 18-inch transparent squares was suspended from the existing couch strut fittings to provide access to the entire inside of the command module without disturbing evidence. This is shown in an enclosure of V–12 and I have a slide (figure 19) here to indicate what it looks like.

As components were removed they were identified and placed in a bonded area and made available for inspection. This is an enclosure, V–16, and is shown as another slide (figure 20).

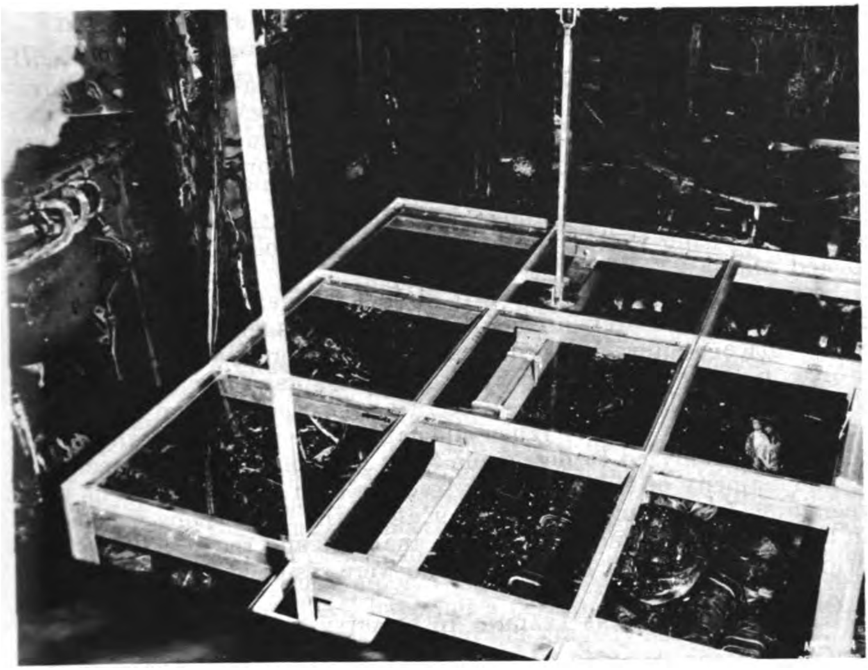


FIGURE 19

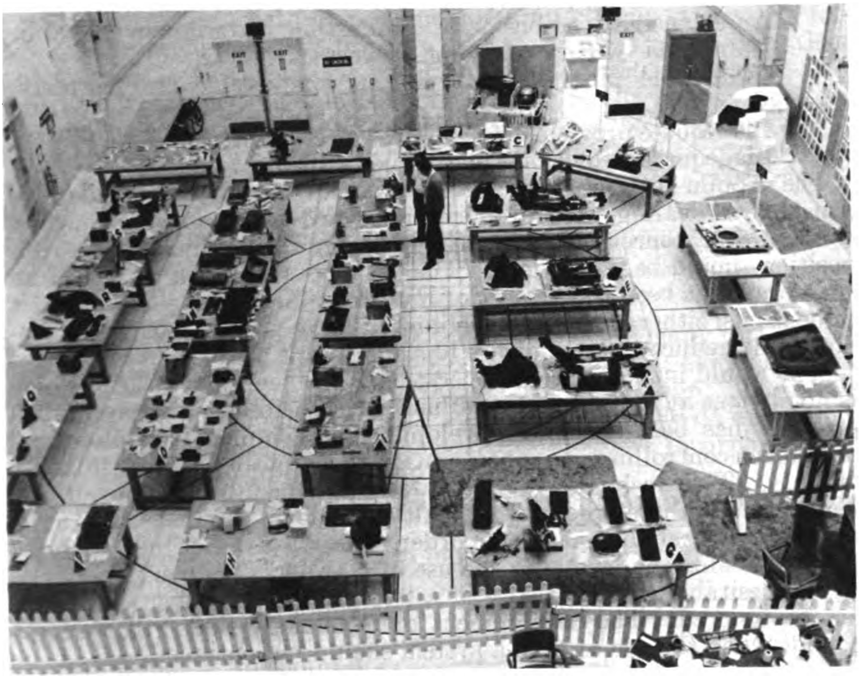


FIGURE 20

That is all the slides.

Components, systems and parts were studied inch-by-inch with magnifying glasses, and frequently parts were taken in the laboratory for microscopic or metallurgic analysis. Wire bundles were given particular attention and, after separation, the individual wires were examined under seven power magnification for sites of possible arcing.

Disassembly continued under controlled conditions until most systems and wiring were removed. This disassembly process was completed March 27, 1967.

Simultaneously with spacecraft disassembly, extensive testing and numerous analyses were accomplished by many agencies: that is, Kennedy Space Center, Manned Spacecraft Center, United States Air Force, Bell Telephone Laboratory, contractors, subcontractors and vendors. All telemetry data, spacecraft records and design documents were reviewed in detail. When anomalies were discovered, they were completely analyzed to determine their relationship to the accident.

The majority of tests and analyses have been completed. The tests remaining to be completed will not affect the conclusions arrived at in the report. Telemetry data, test analyses, and the actual physical evidence were studied by experts who were assigned to panels.

CONDITIONS LEADING TO DISASTER IDENTIFIED

Although the Board was not able to determine conclusively the specific initiator of the Apollo 204 fire, it has identified the conditions which led to the disaster. These conditions were—

A sealed cabin, pressurized with an oxygen atmosphere.

An extensive distribution of combustible materials in the cabin.

Vulnerable wiring carrying spacecraft power.

Vulnerable plumbing carrying a combustible and corrosive coolant.

Inadequate provisions for the crew to escape.

Inadequate provisions for rescue or medical assistance.

The Apollo program management has already made considerable progress in dealing with problems identified by this list. The first one, however, concerns a very difficult matter about which the Board's position should be made clear. The use of pure oxygen in American spacecraft has been the subject of much consideration. The use of a diluent gas, either nitrogen or helium, in large proportions would undoubtedly reduce the risk of fire to a significant degree. At the same time it would introduce other operational problems and risks. There is no obvious advantage of one diluent over the other, although much progress has been made in developing the complex technology required for controlling gas concentration to maintain a proper mixture reliably. This technology is still far from being fully developed. Furthermore, there are many difficult operational problems that must be solved in a reliable manner in order to decrease rather than increase the risks before undertaking the use of a two-gas system.

The desirable characteristics of a two-gas system, however, should not be ignored. The development of technology that will warrant confidence in the use of such a system should be continued.

The final report which was presented consists of the report itself and the appendices. The panel reports are the basis of the Board's report. The findings, determinations and recommendations of each panel were carefully considered by the entire Board and, after correlating the panels' reports, were restated by the Board in a composite manner.

FINDINGS FOLLOW OBJECTIVE REVIEW

Throughout its proceedings, the Board recognized the need for an impartial and totally objective review in order to arrive at its findings. The Board believes that this was accomplished.

The Board is very concerned that its description of the defects in the Apollo program that led to the condition existing at the time of the Apollo 204 accident might be interpreted as an indictment of the entire manned space flight program and a castigation of the many people associated with that program. Nothing is further from the Board's intent. The function of the Board has been to search for error in the largest and most complex research and development program ever undertaken. This report, rather than presenting a total picture of that program, is concerned with the deficiencies uncovered.

This Board has been greatly impressed by the integrity, candor and dedication of those people upon whom the Board relied in conducting this investigation. All have felt a personal loss in this accident, and all are determined that a comparable tragedy shall not recur.

In this review, the Board adhered to the principle that reliability of the Apollo command module and the entire system involved in its operation is a requirement common to both safety and mission success. Once the command module has left the earth's environment the occupants are totally dependent upon it for their safety. It follows that protection from fire as a hazard involves much more than quick egress. The latter has merit only during test periods on earth when the command module is being readied for its mission and not during the mission itself. The risk of fire must be faced; however, that risk is only one factor pertaining to the reliability of the command module that must receive adequate consideration. Design features and operating procedures that are intended to reduce the fire risk must not introduce other serious risks to mission success and safety.

PROBE DIRECTED AT FAULTS

Our review has been directed at faults, not at the many things that have been done well. Further, it has been directed at the spacecraft that was involved in the accident, that is, a block I design. The block II design was not studied in detail by this Board. We do know that some of the improvements we consider desirable are incorporated in the block II spacecraft design.

The CHAIRMAN. You indicated you would like to have Colonel Borman speak next?

Dr. THOMPSON. I would like to have Dr. Van Dolah describe something about the fire, please.

The CHAIRMAN. Dr. Van Dolah.

Dr. THOMPSON. Would you like to proceed with the findings and determinations at this point?

The CHAIRMAN. I want to do it the way you want to do it.

DESCRIPTION OF FIRE

Dr. THOMPSON. I would like to have Dr. Van Dolah describe the fire as it relates to giving you a more complete picture. Dr. Van Dolah.

Dr. VAN DOLAH. Mr. Chairman, I would like to stand over here if I can, because I have a lot of slides.

The CHAIRMAN. You proceed. You stand where you want.

Do you want to identify yourself, Doctor?

Dr. VAN DOLAH. Yes. Dr. Van Dolah, Bureau of Mines, Department of the Interior.

Mr. Chairman, Madam Senator, members of the committee, I would like to present a brief description of our investigation of the fire and give you a picture of how we think the fire progressed and what developed during the fire.

SPACECRAFT 014

In order to lay the groundwork for this discussion, I would like to show you the first slide (figure 21) which is a picture of spacecraft 014. This is a sister ship of spacecraft 012 that burned and was flown to Kennedy Space Center to provide an opportunity to study during the disassembly of the spacecraft itself.

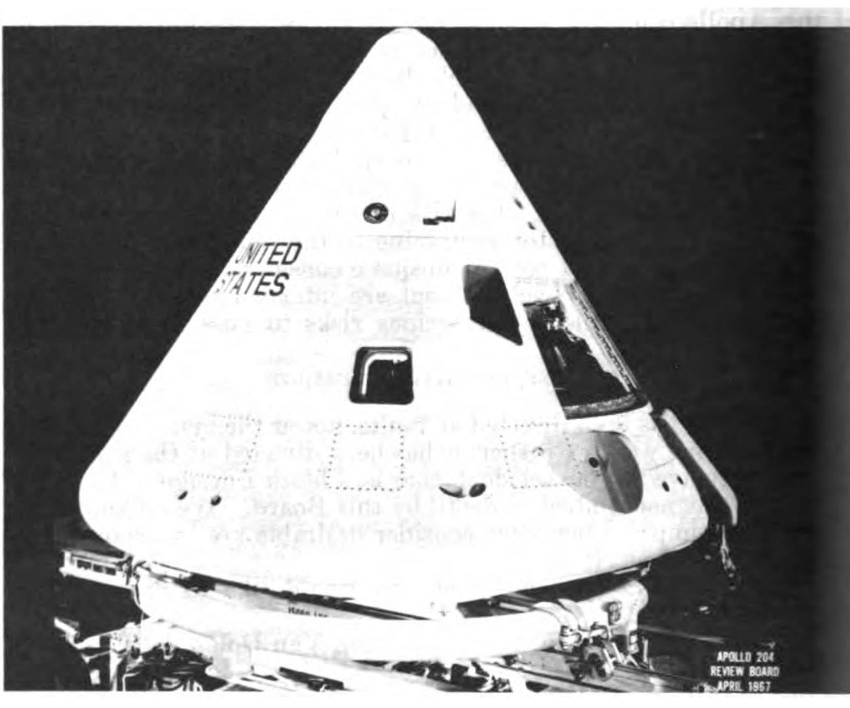


FIGURE 21

INTERIOR VIEW OF MOCK-UP

The next slide (figure 22) shows an interior view of a mock-up, that we also had for our use during the investigation. In this slide the couches are not in the command module in order to see more clearly the combustible materials that were present at the time of the fire.

At the bottom we have two rather large polyurethane—a foam plastic—pads that were there to protect the struts supporting the couches and the hatch during an emergency egress operation that was to be the final operation to be performed at the end of this test. We have in the forward bulkhead area large patches of Velcro. This is the hook and pile combination that is used to attach objects to keep them from floating around when in a zero G environment.

In this corner (pointing to right side) we have a Raschel net, more over in here (pointing to left side). This type of material is called a debris trap. This was to prevent objects floating in the zero G

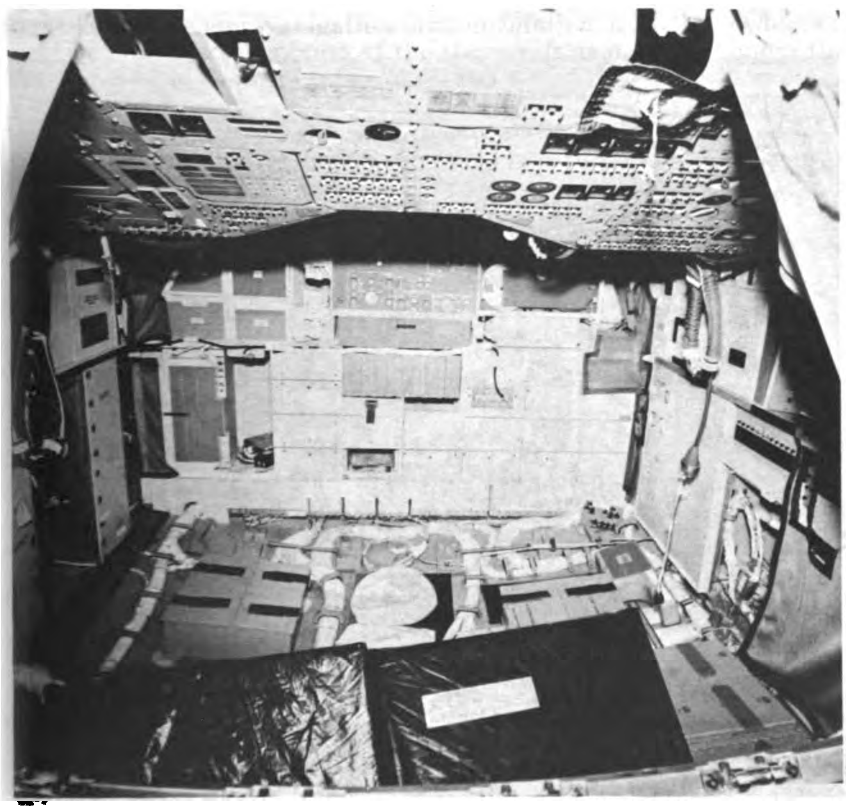


FIGURE 22

gravity from getting behind panels and into some of the plumbing and electrical fittings. We see that it continues along here (pointing). There was a large patch in this area. More continued around in the bulkhead under the hatch and we see more large patches over in this area (pointing to right side).

MOCK-UP WITH COUCHES IN PLACE

The next slide (figure 23) shows the same mock-up but this time with the couches in place. We see some of the additional combustible materials that were present. We have the removal of before flight tags. More importantly, we have sleeves of nylon that protected the oxygen umbilicals during test operations. These would be removed before flight. There are other objects in there, plastic zip tubing coming along here (pointing), covering control cables at the time of the fire there were checkout lists and other objects that would not be there during an actual flight.

Now, in the investigation of the origin and ultimately to seek the cause of the fire, one looks for the point at which the fire first broke out. Now, in a fire in an oxygen atmosphere, essentially a 100 percent oxy-

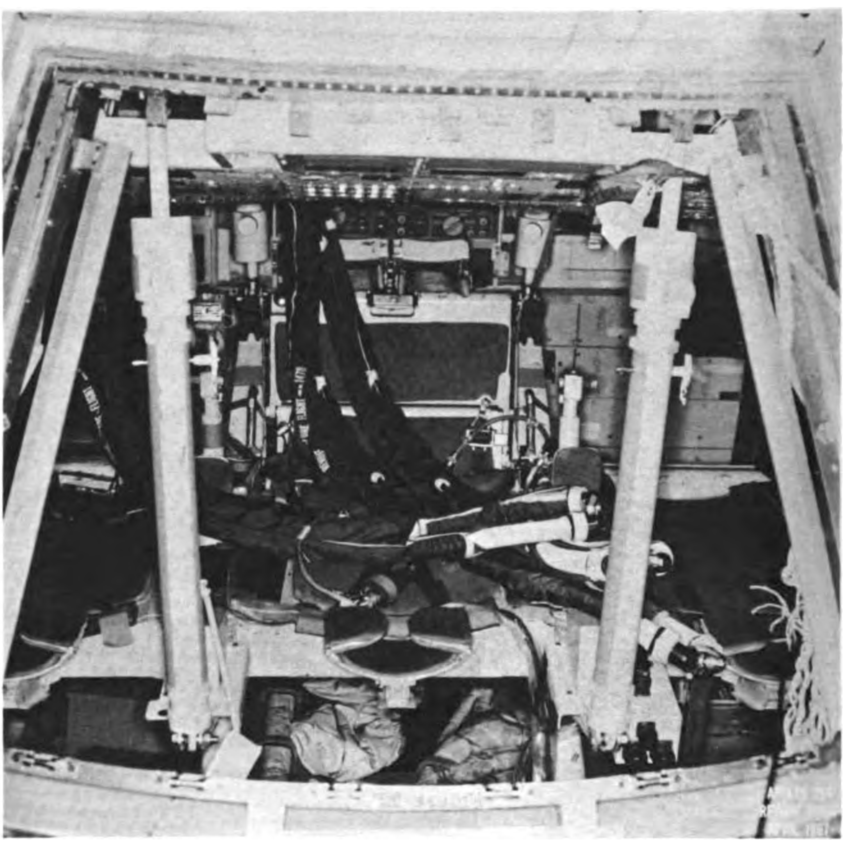


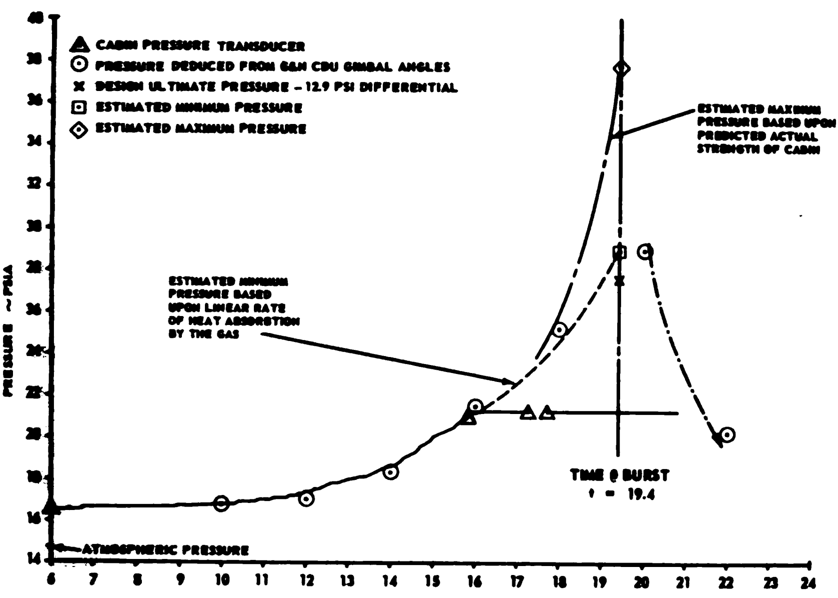
FIGURE 23

gen atmosphere, the first material to burn burns with a very white-hot, relatively non:•oting, flame. The combustibles tend to burn up in that area very completely.

In contrast, during the later stages of the fire, one has much sooting—the material does not burn completely—because of the depletion of oxygen. And so, in our first investigation of the command module, we looked for the areas of complete burning and areas of greatest sooting in order to separate the two stages—to find the point of origin of burning.

In order to discuss the fire, let me first bring in the one bit of evidence that we have as to the actual course of the fire (figure 24). The effective instrumentation that we had that indicated something about the course of the fire was pressure measurements of the cabin pressure. We see that beginning at 6 minutes after the 23:31 minutes and the first verbal report of the fire was at 4.7 seconds after 23 hours 31 minutes, GMT, the pressure begins to come up very slightly. It is not until about 12 seconds after the minute that the pressure begins to build up rather rapidly. At this point, about 16 seconds and at about 21 psi, the pressure transducer reached its limit of recording, and so indicated a constant pressure. But from the movement of the gimbals in the Guidance and Navigation instrumentation, a further deduction could be made of the motion of the spacecraft as it swelled under the influence of the pressure. It can be extrapolated to a minimum estimated burst pressure of about 29 psi up to a maximum of about 37 psi.

At this point the cabin ruptured. This is at 19 or 19.5 after the minute.



CABIN PRESSURE
ENCLOSURE 10-2

FIGURE 24

The fire now entered a second phase. It was relatively quiet burning up to this point. In the second phase during the outrush of gases, there was burning of the hull, and a great amount of burning in the areas outside the actual cabin. This was the period of greatest conflagration inside the command module, all combustible materials were set on fire. The oxygen was used up very rapidly, as well as escaping out the burst area. The pressure dropped very rapidly, perhaps coming down to atmospheric pressure at about 25 seconds after the minute, or only 5 or 6 seconds after the burst.

THIRD PHASE OF FIRE

At that point began the third phase of the fire, which was one of very rapid depletion of the oxygen, production of great amounts of carbon monoxide and of soot. The fire then went out probably in no more than about another 5 seconds.

START OF FIRE INVESTIGATION

Now, the next slide (figure 25) shows the beginning of our investigation. We looked first very carefully at this corner (forward right).

FIGURE 25

As I will describe it, I will be indicating the directions as viewed through the hatch. This is, then, the right forward area of the command module. We are looking at the forward bulkhead. This is the right side here. There was a battery connection panel in this area that was not in its proper location. It was out on the floor a few inches removed from the area where it would normally be bolted into place. Because there were exposed wires in this area, we were rather suspicious of it.

We see, however, that the Velcro patches here were not burned completely, up here (pointing) they were melted and not burned extensively. Over here, just melted material—some burning—of course, The Raschel knit that was in this area was mostly melted and much of it collected here and on the floor.

In contrast the next slide (figure 26) shows the opposite or left hand forward corner and we see that the patches of Velcro in this area are completely burned away. The roof, the aluminum structure here was very badly burned. The aluminum panels covering garment stowage areas were buckled. The evidence was of a very intense, very hot fire in this corner, the left forward corner, compared to the opposite corner.

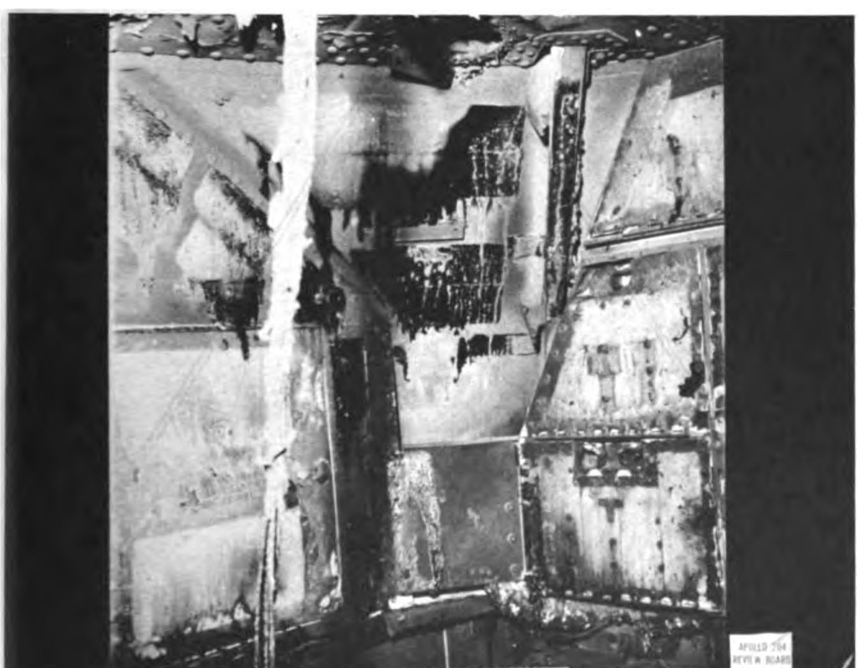


FIGURE 26

PORTRAYAL OF HOW FIRE STARTED

This said to us, then, that the fire began somewhere in this general vicinity. And the next slide (figure 27) shows a portrayal of how we think the fire started.

Somewhere in this area the fire began, probably some seconds before it was detected by the crew, and some seconds before the first verbal report of the fire. It spread rapidly in this area (pointing) and ignited the Raschel nylon material in this area, spread along the Velcro here (pointing) and along the net at the bottom, until it involved the large patch of Raschel net in this area.

Those two objects there are the cabin dump valves that had to be actuated in order to relieve the pressure from the cabin prior to egress. The hatch was pressure sealed. They were operating at 16.7 psi pressure, about 2 psi over atmospheric pressure. That pressure had to be relieved before the hatch could be opened. It is entirely possible that the fire in this area prevented the command pilot from actuating those dump valves, which would be the normal operation in an emergency egress. The valves were in fact, found in the closed position.

Now, I should remark that had these valves been actuated, it would have delayed the course of the fire perhaps only about 1 second. It would not have markedly changed the total event.

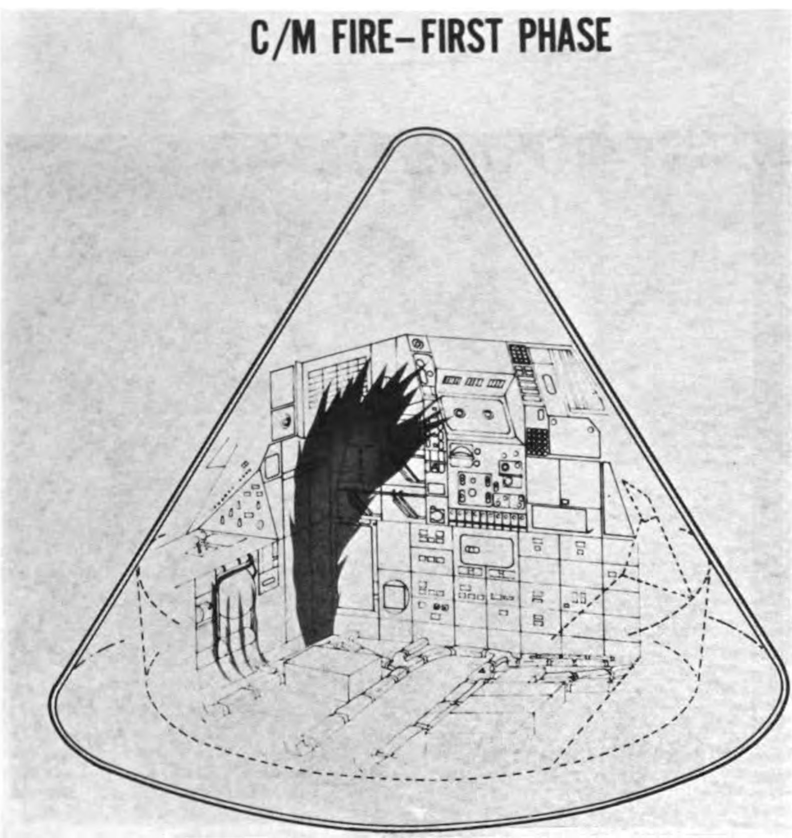


FIGURE 27

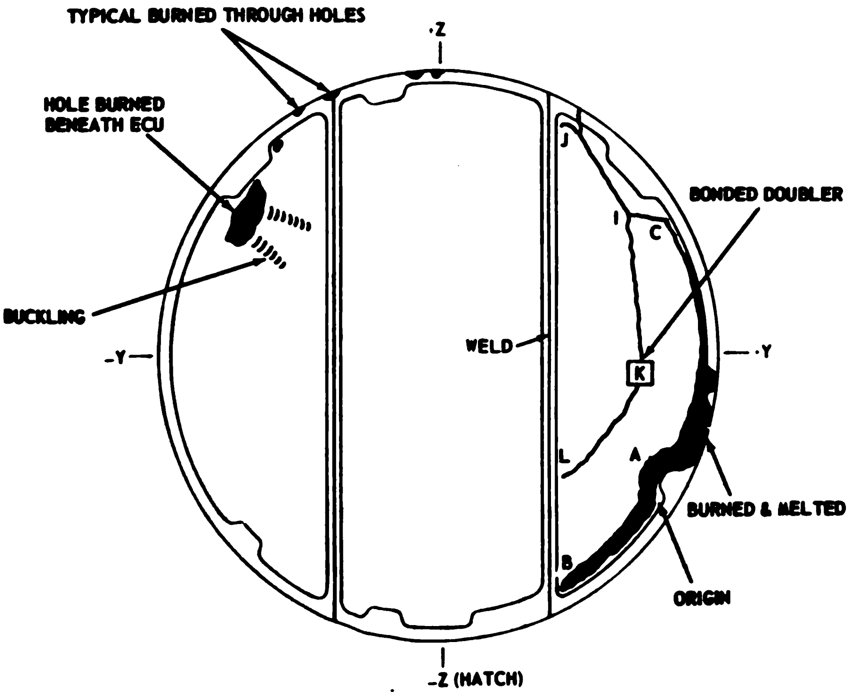
OUTER FACE SHEET OF BULKHEAD

The next slide (figure 28) shows the break as it was found when the heat shield was removed. We are now looking at the bottom of the command module. The break began here (pointing) and spread rapidly around to here where it branched up to that point and back around to this area. The break in this region (pointing), while perhaps only a half or three-quarters of an inch wide in the beginning, very rapidly enlarged by burning of the structure to create a large opening, causing the pressure to fall in the command module very rapidly.

There was a later break, still with some pressure on the cabin, in this area, a break in the inner face of the honeycombed structure and a small amount of burning outside at these points (pointing).

In this area there was a lingering fire after the main fire throughout the cabin went out. There was oxygen and combustible coolant being dumped in this area through broken lines.

Now, the result of this break and the outrush of gas through the break can be visualized in the next drawing (figure 29). We see that in this turbulent flow toward the break, the fire swept across the couches. There was, of course, some recirculation under the couches. This conflagration set everything on fire within the cabin and most of the burning occurred during this very short period of a few seconds.



OUTER FACE SHEET OF AFT BULKHEAD
ENCLOSURE 10-10

FIGURE 28

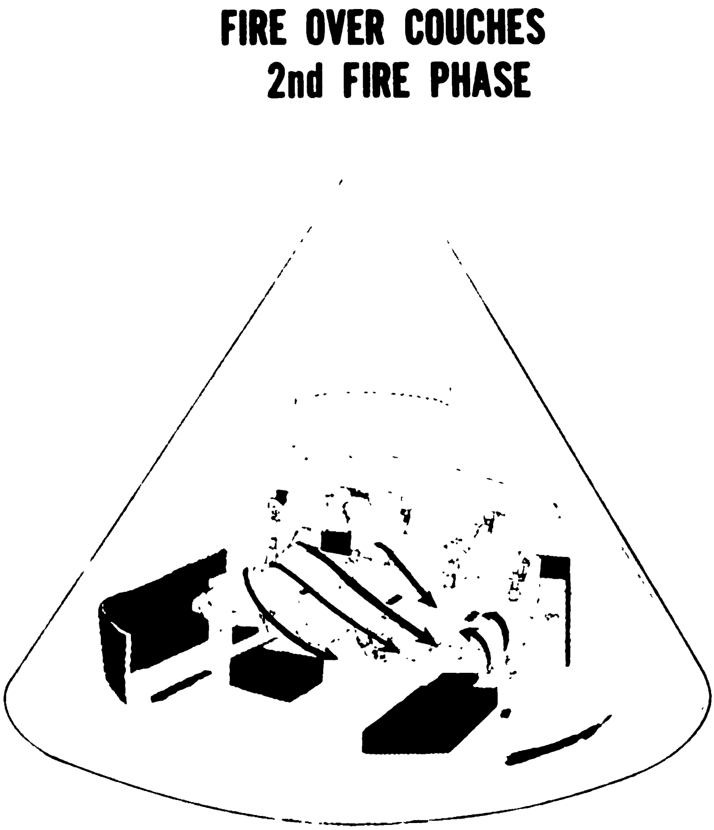


FIGURE 29

FIRE UNDER COUCHES

The next slide (figure 30) shows similarly that the fire progressed underneath the couches and along the forward equipment bay.

HELMET STOWAGE BAGS

The next slide (figure 31) shows two of the helmet stowage bags. These are made of nylon and would be used during flight to stow the helmets when the crew were unsuited. The flow swept around this stowage box and around over this way (pointing). One can see that there was substantial burning on this side and here (pointing), but only charring and browning of the nylon on the lee side of these stowage bags. Again, the fire swept around underneath the couches over to the break in this corner (pointing).

FIRE ON C/M FLOOR—2nd FIRE PHASE

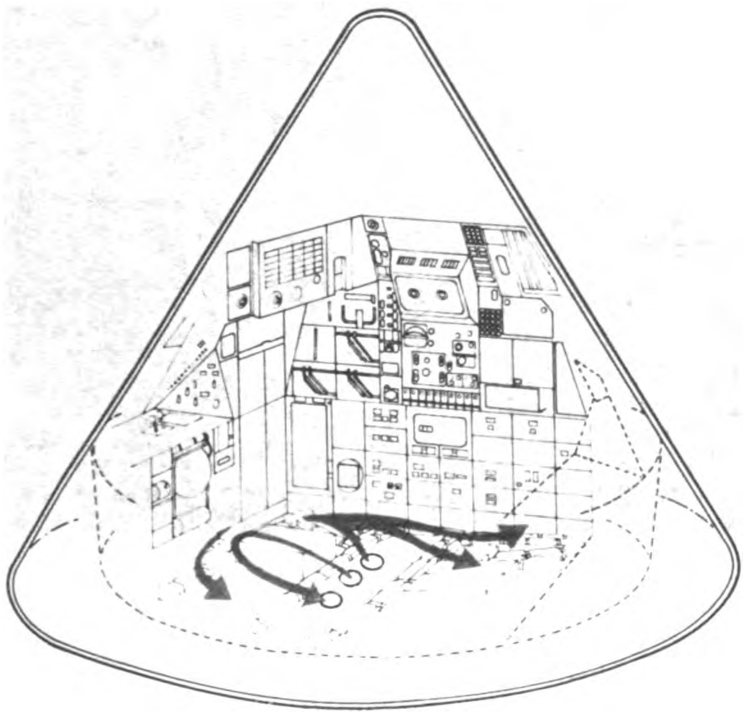


FIGURE 30

WIRING ALONG FLOOR

The next slide (figure 32) shows some wiring on the floor at the forward equipment bay. Again, we see that the burning is very great on this (left) side, relatively less on this (right) side. The Teflon sheets that were put on to protect the wires were only slightly damaged, again on the lee side of the floor. This is an aluminum tiedown strip and you can see that it is rather badly burned on the left-hand side and progressively less burned toward the right, again indicating the sweep of flame across in that direction.

As I said, the conflagration caused everything, or much of everything to be on fire at this point with a very rapid depletion of the oxygen. Thus the fire went out very rapidly and we now see the results of the final stages of the fire.

PATTERNS IN FINAL PHASES

Much soot is shown in the next slide (figure 33). Looking again at the forward equipment bay, we see sooting patterns of the final phases

FIGURE 31

of fire sweeping up in this direction (pointing), depositing soot in areas like this, but not depositing the soot in the shadows thrown by the handles. Again, you see that the destruction was relatively minor; burning was relatively minor in this area. Labels here were completely readable.

FINAL LINGERING STAGE

Now, there was a final lingering fire, as I said, in the lower forward portion of the cabin. The next slide (figure 34) shows this area. Here we have the carbon dioxide absorption units behind this door. This is a stainless steel tube here (pointing). These are stainless steel lines that were melted through. One sees a cable that burned away. There was a cable running along here up in this area (pointing) that was also melted.

One sees in this area a small stalactite of molten aluminum that had run down and frozen as it cooled.

This is the area of the suit heat exchanger of the loop supplying oxygen to the crew. It was covered by a very flammable foam plastic that burned away nearly completely and contributed very much to the violence of the fire.

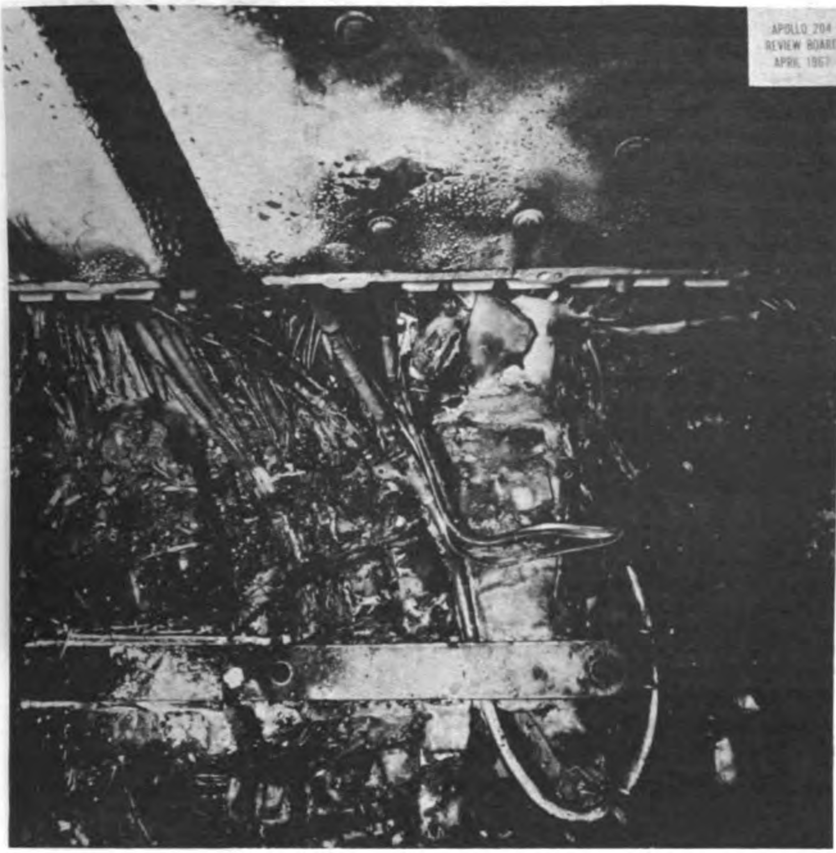


FIGURE 32

LINES PARTED FROM JOINTS

The next slide (figure 35) shows some of the other side of this same heat exchanger and we see here lines that parted at soldered joints. This one (pointing) is a hundred psi oxygen line, these two supplied 900 psi oxygen to the pressure-reducing valves going into the suit circuit. These lines had to part at the very end of the event because oxygen was being supplied into this region (pointing) to maintain this lingering fire for perhaps a minute or two, a rather short time after the total fire throughout the cabin was extinguished by lack of oxygen.

CLUE TO IGNITION SOURCE

We searched this corner, this left-hand forward corner, for areas that might give us a clue as to the specific ignition site. The next slide (figure 36) shows one area that we were particularly interested in. We found a cable down on the floor, a gas chromatograph cable that will be discussed briefly by Dr. Faget, which gave a spurious signal in the telemetry data. It was not connected to the gas chromatograph that would normally be in this area but there were two cameras and a hygrometer occupying this space.

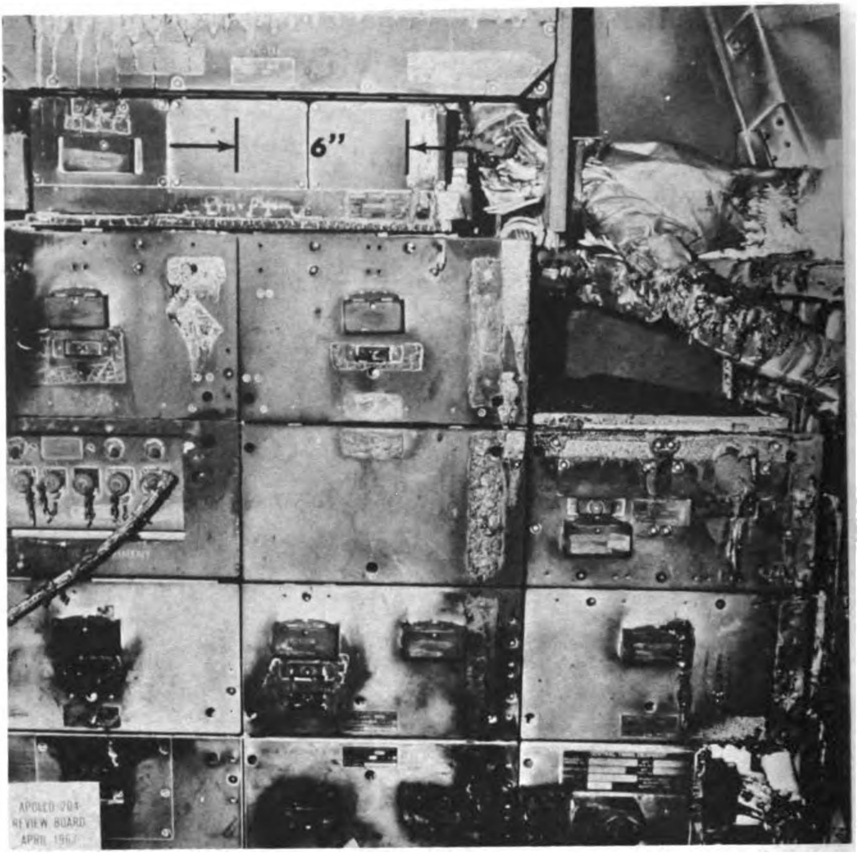


FIGURE 33

Figure 34

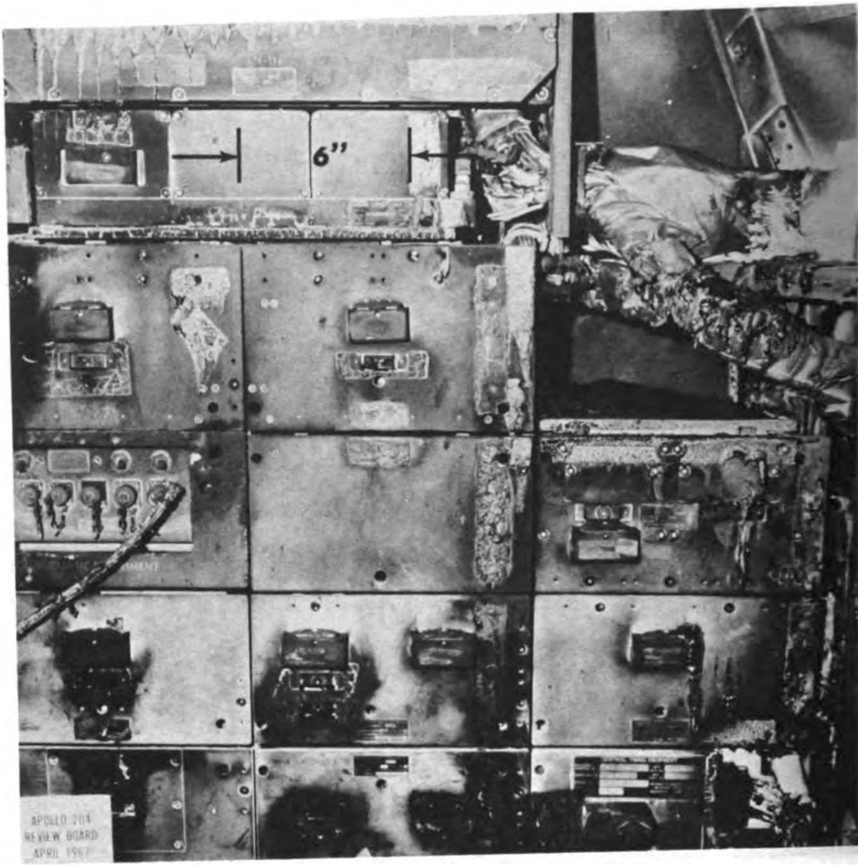


FIGURE 33

FIGURE 34

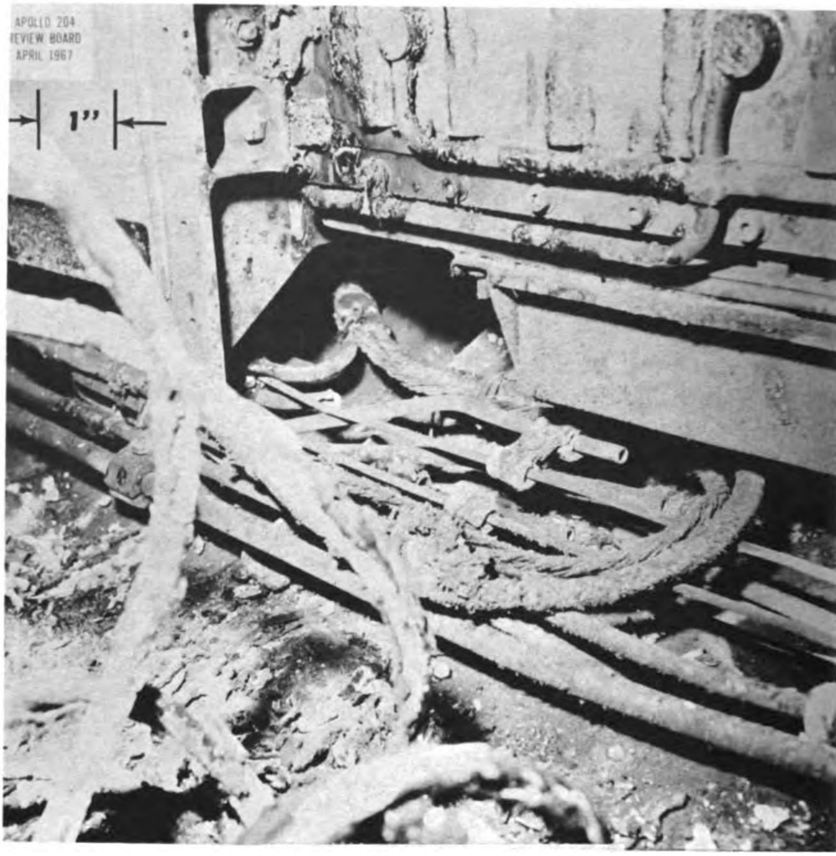


FIGURE 35

FIGURE 36

The cable was placed in this area (pointing) by the technician before the test began. It was found on the floor. Some of the power cables were burned—they showed arcing between leads—and so we were rather suspicious of them. They have since been exonerated.

There were other power leads in this area that also showed arcing between them, and these received a great deal of detailed study. Again, they were generally exonerated.

This is a kick plate that was installed as a modification to the spacecraft to protect terminals that were behind it. There was an arc crater found in this area and an arc spot on the wire that pressed against the plate, again an item that was of extreme suspicion to us. However, we find that this patch, this very large patch, of Velcro was mostly melted, somewhat burned, but still relatively intact, making us rather sure that this was not the first area to burn.

GAS CHROMATOGRAPH

The next slide (figure 37) shows a closeup of the connector to the gas chromatograph. It was powered and so it was sending a signal out to the data recording where the data was recorded. It was burned on both sides, indicating that it probably was burned on one side, then fell and was burned subsequently on the opposite side. It was burned completely on all sides.

FIGURE 37

KICK PLATE REMOVED

The next slide (figure 38) shows the kick plate removed now from the supporting brackets. It would normally be bolted from here to here (pointing) and right in this position was found a minute crater, and on the adjacent wires that pressed against it was found a similar crater. This was an extremely exciting clue but this was a nylon chafing guard along here (pointing) and most of the nylon was found to be intact at this point. It was melted, but it had not burned.

Experiments in the laboratory that duplicated an arcing to this point caused all of the nylon to be burned more or less completely, leaving only some soot.

AREA OF EXPLOSION

The next slide (figure 39) shows the other area that received a great deal of attention. This again is the carbon dioxide absorption unit. In here it was burst open by the explosion but all evidence indicates that the explosion came late in the event, after this rather massive

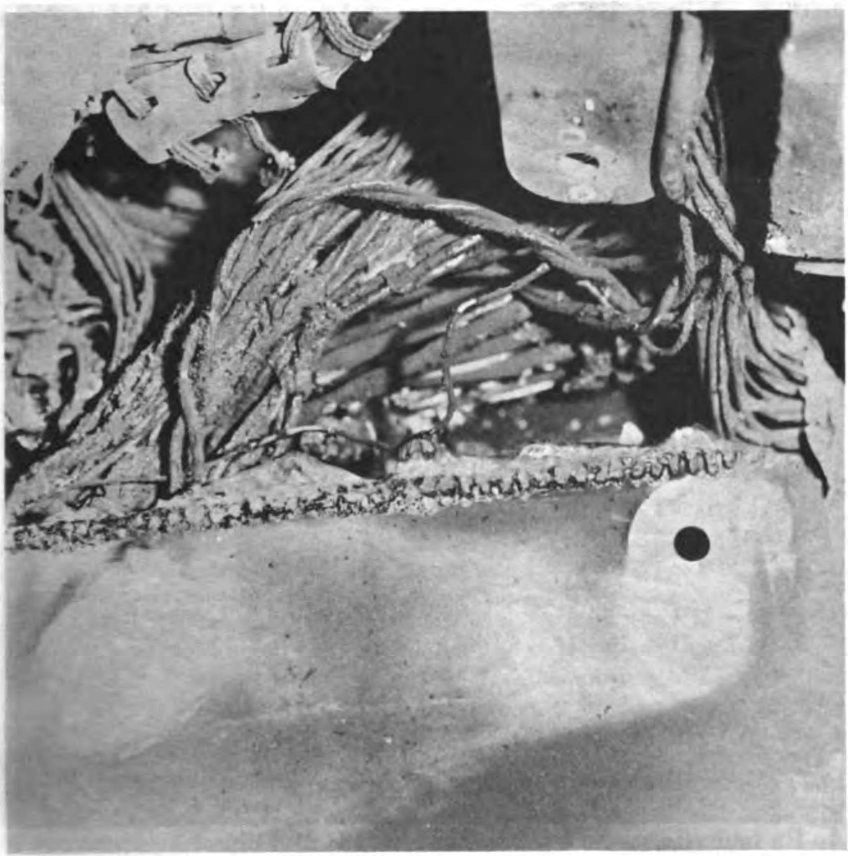


FIGURE 38

aluminum structure was heated sufficiently. You see stalactites again of what had been molten aluminum here (pointing). There is a large patch of aluminum, aluminum ingot, in this area (pointing). The lithium hydroxide that was used for the absorption unit was found under this molten material here.

These (pointing) are electrical cables that were burned through. This is the area which we think probably was the area of the cause of the fire. There were power leads going across the stainless steel tube, running up through this partition into this area. There is about 12 inches or so of those power leads that are gone, completely destroyed in the fire. Similarly, there was power into this area, this cable (pointing), and several inches of this cable were also completely destroyed. This is unfortunately the case with many fires—that the fire itself destroys the evidence of the cause of the fire—and so we cannot be completely positive as to the precise source and cause of the fire, but we are quite sure that it was in this area involving dc power cables, direct current power cables, in this area.

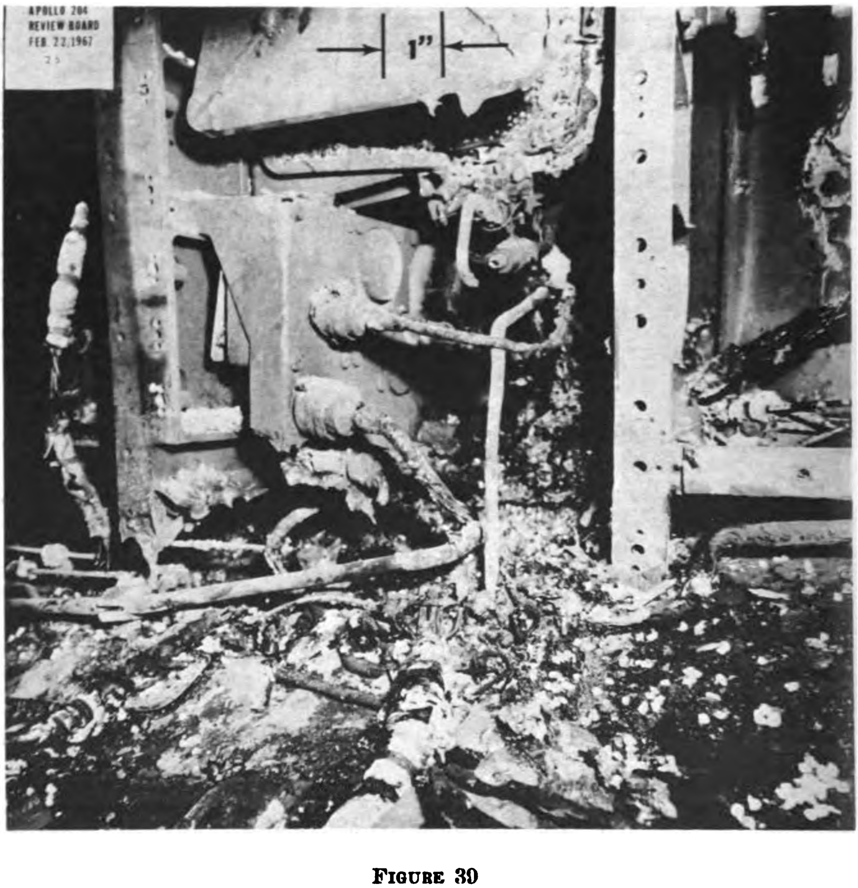


FIGURE 39

RECOGNIZED FIRE EXPERT

The CHAIRMAN. I do not mean to start questioning, but are you not considered the fire expert on this Board?

Dr. VAN DOLAH. Yes, sir.

The CHAIRMAN. You testify for yourself; you are regarded as an expert on the starting of fires and their ignition.

Dr. THOMPSON. Yes, sir.

The CHAIRMAN. How about consultation?

Dr. THOMPSON. Mr. Chairman, Dr. Van Dolah is a well-recognized fire expert assigned to the Board. He was assisted by other experts who acted as consultants to him, but he is fully qualified to comment on or answer questions.

The CHAIRMAN. I just wanted to state that for the record.

DESCRIPTION OF DATA ANALYSIS

Dr. THOMPSON. I would like to ask Dr. Faget to give you a little more insight into the—into our understanding of what went on. The tremendous amount of work that was done to analyze records, to give us an insight in what went on inside the spacecraft, and I think he can do it briefly enough so that it will not go too far afield. Dr. Faget was in charge of the analysis of data as far as the Board was concerned. He is the one who monitored that effort. Dr. Faget.

Dr. FAGET. Thank you, sir. I would like to refer you to pages 5–4 to 5–11 in the Board's main report and appendix D–18 for more detailed information on areas on which I am going to speak now.

OUTLINES INVESTIGATION APPROACH

The approach that we used in the investigation and analysis of the data to try to determine the ignition source were as follows: To begin with, there was extensive inspection and laboratory analysis of the physical evidence that remained after the fire. That is the hardware, the components that were removed from the spacecraft, the wiring in the spacecraft, and, of course, various other parts of the spacecraft.

Now, this evaluation was used together with the data that was reduced and analyzed. When I am talking about data, I am talking primarily about the data that was obtained during and subsequent to the time at which we think the fire started. This analysis was aided by a number of special tests that were conducted to provide a better understanding of the way this fire might have started or the way the fire may have developed in the spacecraft, and other tests that were carried out either to substantiate or to destroy hypotheses and postulations that were produced as to possible causes of the fire.

Immediately upon arrival of a number of system experts at Cape Kennedy, that night and the morning following the fire we initiated an extensive effort to reduce the data. This effort was carried on on a 24-hours-a-day basis for approximately the first week following the accident. I might add that at that time we essentially had all of the data reduced and we had time histories of all the measured data available for analysis. Subsequently more data reduction with a more intensive determination of the accuracy to better define the data as the analysis progressed. Also, further details or validation was required by those carrying out the analyses. This continued for a period of approximately three or four more weeks subsequent to the initial major effort.

INTEGRATION ANALYSIS PANEL

Now, I might explain that during the tests, approximately 400 different measurements were made and recorded. The majority of these were obtained from the spacecraft itself. The majority of the data obtained from the spacecraft is obtained by a PCM system. This is digital data. What I mean is that this data was sampled on one data channel, one data wave train. This wave train was capable of making approximately 6,400 measurements a second. These measurements were divided up among approximately 300 different items that were being measured. In other words, one item would be sampled in one instant. The next instant something else would be sampled. The various items being sampled were sampled at varying rates, the more important ones being sampled very rapidly, those that were not considered to vary rapidly during a test, not so often.

Sample rates were as fast as 200 times a second and as slow as once a second, depending on the particular measurements.

The primary effort on analysis of the data and the physical evidence was invested in panel 18, called the Integration Analysis Panel. All measured data and facts obtained from physical evidence and historical data obtained from the records that were thought to have bearing on the possible cause of the fire were fed from the other panels to panel 18. Panel 18 in turn analyzed all this information and reported twice weekly to the Review Board on the progress of their investigation. Later during the investigation period, it was found that once a week was sufficient in order to keep the Board up to date.

They divided their work up into separate items that were individually investigated and a total of 106 such investigations were carried out during the period. In addition to this, they submitted eight special reports to the Board to give the Board a better definition and a better understanding of how certain systems that were thought to be associated with the cause of fire were configured and how they were operating during the time of the test.

In addition to the more formal approach to finding the cause of the fire, a number of brainstorming sessions were introduced. In these brainstorming sessions informal discussions were carried out between the various panel members, members of the Board, and consultants in which various hypotheses were introduced. These in turn, if they appeared to have some basis of validity were made items of investigation and introduced in a formal manner into the investigation process.

SUMMARY OF TIME LINE

I would like to have the first slide at this time (fig. 40). I have summarized here the relevant time histories that we think are associated with either the cause of the fire or some effected of the fire. The period of time shown here starts approximately a minute before the crew reported the fire in the spacecraft and continues for a period of approximately 15 seconds thereafter. These relevant time lines include the data received from the gas chromatograph instrumentation lead.

SUMMARY OF RELEVANT TIME LINE

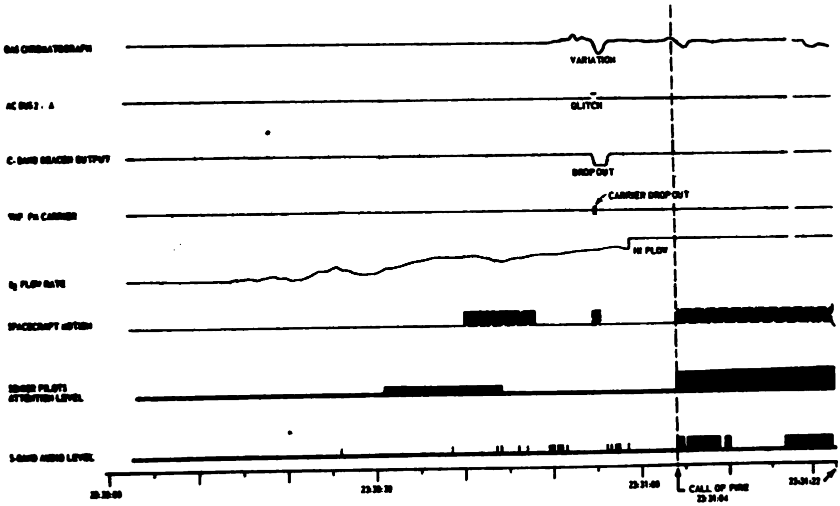


FIGURE 40

In order to clarify this data, it should be noted that there was no gas chromatograph installed during the test. However, the instrumentation lead was hooked into the data system. We also measured AC bus voltages, C-band beacon output, the telemetry carrier wave, the flow rate of the oxygen into the suit loop, various measurements of the spacecraft, motion measurements, biomedical measurements from the senior pilot, and also data from the audio communication channel, that is, the voice communication channel on S-band. These were all factors of consideration. Some of these I will discuss in detail later. Others I would like to talk about right now.

You will notice that at approximately 23:30:55, there are a number of variations that correlate with each other as to time. As a point of clarity, the data was reduced on the basis of Greenwich mean time and this time, eastern standard time, is 6:30 and 55 seconds. Five seconds before 6:31.

The gas chromatograph instrumentation showed changes in voltage output to the instrumentation system. Subsequent special tests and analyses have shown that this lead, although it was not attached to the gas chromatograph measuring equipment, did act as an antenna to the electric magnetic field within the spacecraft. What you see here we think is similar to the noise that you may get on your automobile radio if you do not have a good spark suppressor. In other words, ignition noise, sparking in your ignition system, could produce similar noise on your radio. So, we are seeing electro-magnetic interference showing up on this lead at this particular time. This is an indication that possibly arcing was occurring in the spacecraft at that instant.

As a point of complete consideration, other phemonena could also produce this. This is just the most likely thing that would produce those indications.

Similarly, at this time we noticed a slight increase in all three phases of the alternating current bus voltage. After a number of special tests, we think that this increase in bus voltage was a rebound from a dropout in the alternating bus voltage. The reason we do not see the drop but only see the rebound, or overshoot, is because this voltage was only measured once every tenth of a second. Special tests indicate that a dropout in AC bus voltage for as little as five one-thousands of a second could cause such a rebound. The odds of happening to make that measurement once every tenth of a second and catch that dropout, of course, would be very small. However, we have indications in the next two data time lines that strongly indicate we did indeed lose voltage on this AC–2 bus. These are to begin with a dropout or a loss in the power of the C-band beacon. This loss of power continued for a period of about two and a half seconds. Tests have indicated that if voltage is lost to the C-band beacon, protective circuitry on that equipment would not allow the beacon to start operating again for a period of two and a half seconds, similar to what we see here.

We also see an interruption of the VHF telemetry carrier at that time. This was also powered by this same voltage source. So, the conclusion is that we did indeed have an interruption of this power system.

POWER SYSTEM TESTS

In analyzing the power system we find that the AC–2 bus voltage is obtained through an inverter from one of the DC buses in the spacecraft. A number of special tests were conducted and we have ascertained that the most probable reason for loss of AC–2 bus voltage was a temporary loss, or a decrease in the power, on the direct current bus, which in turn powers the AC–2 bus through an inverter.

Other considerations shown are the O_2 flow rate. You will notice that sometime preceding the time in which we think there was this interruption in d.c. and a.c. power that there was an increase in flow rate to the suit circuit. We believe that this flow rate was caused by motion of the astronauts in the spacecraft. Evidence of this was obtained by listening to transcripts early in the test where the crew was heard to remark that if they make certain motions they could show indications of increased flow to the suit circuit. The fact that this flow rate goes to full scale toward the end of this time period, however, is most likely explained by one of the crew members opening his face plate. We have evidence of this in the audio level shown here, and I would like to talk about that later.

The senior pilot's attention level was derived from the biomedical indications. These were the EKG measurements in the form of an electrocardiogram. The senior pilot was the only one who was being instrumented—let me straighten that out—from which measurements were being obtained at this time. All three crew members were wearing biomedical harnesses but only the senior pilot's measurement system was attached to the recording system in the spacecraft and on the ground at this time. So, we only have his record. At this time period we notice a very small increase in the heart rate of the senior pilot. Our medical experts explain this as a slight increase in the attention level of the senior pilot or a very minor increase in his physical activity. There are indications that his heart rate was beginning to return to the previous base line or relaxed level after about 10 seconds, so that this increased attention level is only listed at the period of time shown on the slide.

However, at the instant of the call of fire, all of the instrumentation on the senior pilot indicated a very high state of excitement, starting at that instant.

SPACECRAFT MOTION

Could I have the next slide (fig. 41).

There were a number of indications of spacecraft motion that were obtained both before and after the fire. The first three labeled inner gimbal, middle gimbal and outer gimbal, relate to the gimbals that are supporting the inertially stabilized platform in the navigation system. These gimbals are driven by torquing motors in order to keep the platform stabilized. If the spacecraft moves, torquing signals are sent to these torquing motors in order to keep the platform steady during such motion.

We have indications of torquing signals going to the gimbal torquing motors at a time prior to the indications of the voltage transient. We also see some right at that particular instant. These indications of spacecraft motion are best interpreted as possible motion of the crew during this time period. The level of activity, though, is uncertain.

Following the period when fire was reported we also had strong signals of motion, not only from the inertial measuring unit that I talked about but also from a roll rate accelerometer in the stability and control system and on the launch vehicle we had motion indicated from the accelerometers that would react to pitch and yaw motion.

Finally, we had indications of some motion on the part of the command pilot from his live microphone. At a much earlier time during the test, it was determined that the press-to-talk switch that the com-

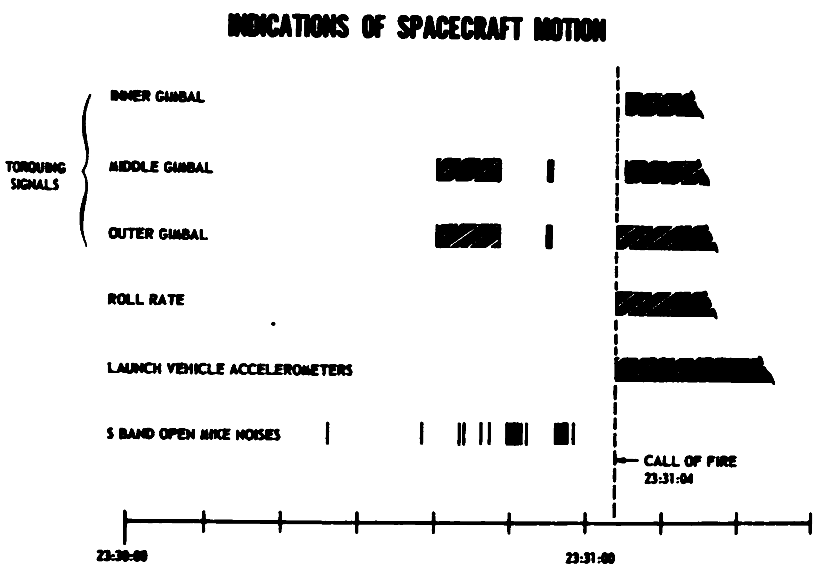


FIGURE 41

mand pilot would use in order to activate his microphone was in some manner or other grounded. We have determined that this grounding was in no way associated with the fire. However, it did keep his microphone alive so that breathing sounds, motion of his face within his helmet when he may brush the microphone, and anything he said would come out over the audio channel on S-band.

Now, at this time period preceding the call of fire we had indications of a number of tapping and brushing sounds similar to what you might hear—if you tap a microphone. We also have indications that he may have opened his faceplate. At an earlier time period during the test when he did open his faceplate certain other sounds were heard that were similar to the ones recorded at this time.

S-BAND VOICE CHANNEL

Let's go to the next slide (figure 42). What we see on this slide is a graphic representation of the audio level on the S-band voice communication channel. The first time period from 23:30:30 to about 23:31:02, a 30-second time period, shows more distinctly these brushing and tapping sounds which I talked about. The two transmissions shown below are on a much shorter time scale and they include approximately 8 seconds each. This live microphone, as I said, would pick up any noise emanating from within the pilot's helmet and trans-

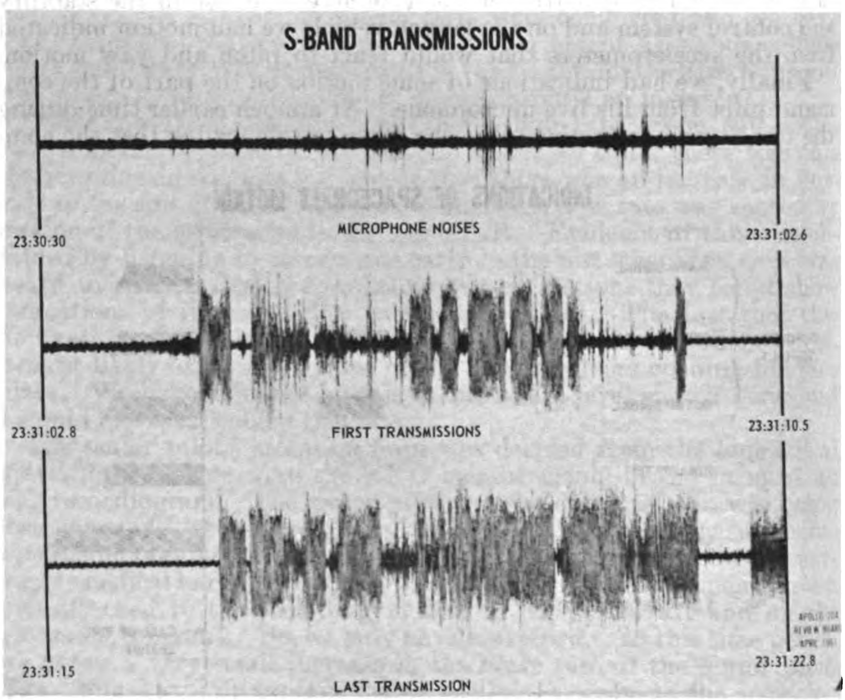


FIGURE 42

mit it over the air and we see indications of this right up to 23:31:04.7 when there was a very short exclamatory word which is best interpreted as the word "Hey". That was followed by much increased noise level. This high amplitude audio level is not voice but is an indication of noise coming over that live microphone. Then at this time period there are the words that are best interpreted as, "We've got a fire in the cockpit". This is followed by more noise and then the first part of a syllable that has been cut off that might sound like "Veh", like someone started to speak and was cut off, and, as a matter of fact, following this time period, this live microphone phenomena ceases and very little noise is indicated by the audio level shown. When listening to the tape recording, it sounds very quiet.

At about 23:31:17 there was a final voice transmission, and I might say that this transmission was much more garbled than the first one and there is a lot less certainty as to what was said. However, words like these may have been said. "We're fighting a bad fire. Let's get out. Open'er up."

There is another short period of silence and then this channel was lost completely and we had the noise of an open communication channel come on the tape.

Could I have the next slide. (Figure 43.)

POSSIBLE IGNITION SOURCES

- SPONTANEOUS COMBUSTION.
- ELECTROSTATIC SPARK DISCHARGE.
- CHEMICAL OR MECHANICAL ENERGY.
- SPACECRAFT'S ELECTRIC POWER

  ELECTRICALLY POWERED EQUIPMENT

  ELECTRICALLY OVERLOADED CONDUCTORS

  ELECTRIC ARCS

FIGURE 43

SEVERAL SOURCES INVESTIGATED

Now, in our investigation we not only considered electrical ignition sources, but a number of sources such as spontaneous ignition, electrostatic spark discharge, and energy from either chemical or mechanical means. These were investigated rather thoroughly and were eliminated as possible causes of the fire.

The spacecraft electrical power system could cause a fire by three typical means. First, through the electrically powered equipment. This was investigated in the following manner. Each piece of equipment on the spacecraft was removed from the spacecraft during the disassembly and made the subject of a particular investigation, first by the fire experts, and then if anything suspicious showed up, this investigation was continued by further investigations in the analysis and by circuit testing within the equipment.

All such equipment has been eliminated as a possible cause of the fire by this procedure.

Next, we considered electrically overloaded conductors. I might point out that this is the most normal way that fire starts in homes and in other places, using electric power. The conductor gets overheated. It melts or catches the insulation on fire and subsequently a fire starts.

In spacecraft 012, particular care had been taken to eliminate this as a possible fire starter by the following means. First, all power circuits were protected by circuit breakers or by fuses, and furthermore, we selected an insulation material that was very fire resistant. That is, Teflon. As a matter of fact, during the Gemini program we changed to Teflon insulation on the wire just to make that spacecraft more fire resistant.

BELIEVE ELECTRICAL ARC STARTED FIRE

Finally, as a possible source of ignition, we have electrical arcs. We believe that the fire was started by an electrical arc. The Teflon insulation used on the wire, although very fire resistant, in somewhat soft and is subject to cold flow phenomena. What this means is that if pressure is applied, mechanical pressure is put on that insulation, in time it will flow under this pressure and the insulation can be possibly defeated.

The CHAIRMAN. Before you go any further, did you just now say that this fire was started by an electric arc?

Dr. FAGET. We believe that that was the cause. The most likely cause.

The CHAIRMAN. The full report does not exactly state that, does it?

Dr. FAGET. Yes, it does, sir.

The CHAIRMAN. Go ahead.

Dr. FAGET. There were a number of electrical arcs that were found in the spacecraft. All of them that we have determined have been eliminated, all the evidence of electrical arcs that we saw in the spacecraft have been by one reason or another eliminated as the exact ignition source. However, there was one place that Dr. Van Dolah referred to where the wiring was so completely destroyed and where an adjacent structure had been destroyed that any electrical arc that would have occurred in this place, that is evidence of an electrical arc, would also have been destroyed.

The CHAIRMAN. The reason I interrupted you——

Dr. FAGET. Yes, sir.

The CHAIRMAN (continuing). I tried to read this report at some length and I did not find definite assertions. Did you now say flatly the fire was started by an electrical arc?

Dr. FAGET. No, sir. I said we believe the most possible cause was electrical arc. If I did not say that, I meant to say it, sir.

The CHAIRMAN. All right.

Dr. FAGET. Could I have the next slide.

LARGE WIRE BUNDLE

This slide (figure 44) is a photograph taken from spacecraft 014, the sister ship of spacecraft 012, it shows a large wire bundle running on the floor of the spacecraft. There are two branch bundles going

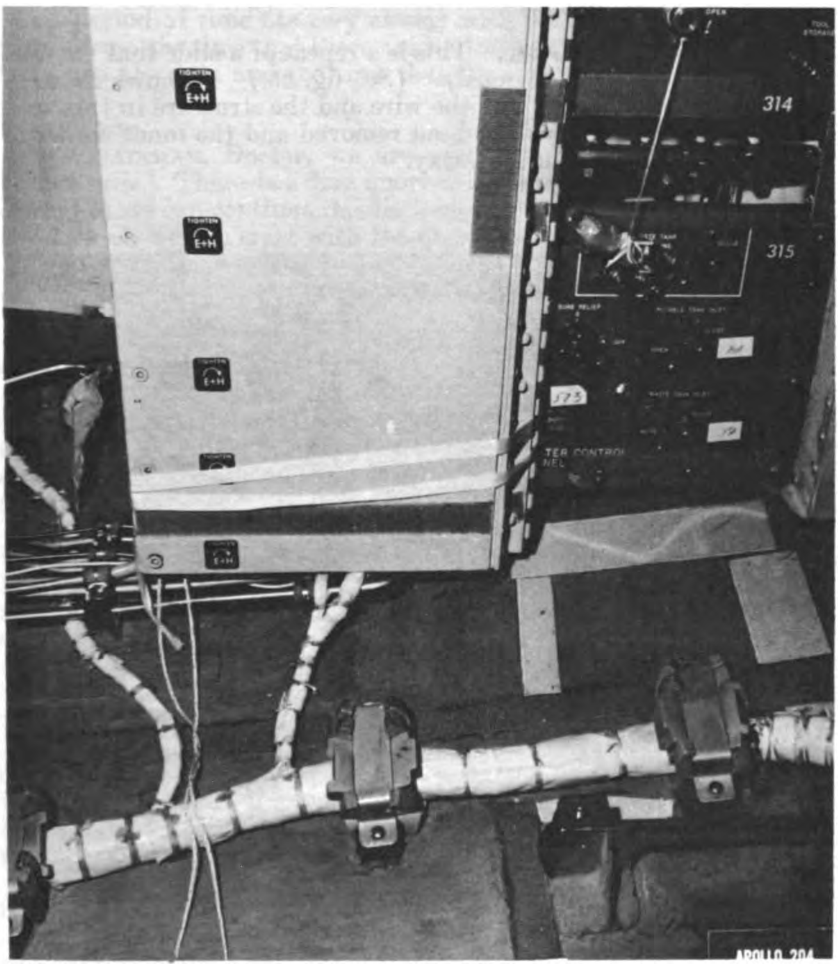


FIGURE 44

from this wire to the environmental control unit, one of them going underneath a number of lines (tubing) the other one is routed on top of the tubing and underneath the lithium hydroxide access door. This door is hinged on the right and is used to get access to the lithium hydroxide canisters which must be changed during the mission.

The way this wiring is so routed, it is potentially vulnerable to chafing or damage from this door.

Could I have the next slide.

ENLARGEMENT OF WIRE BUNDLE

This slide (fig. 45) is one that was taken of spacecraft 012. The graininess is because it is a blowup of this particular location. It shows a modification of the wire because of changed routing in the plumbing. The wire bundle shown was previously split. Now wires from both go over this stainless steel tube which is a waste management line.

This wire carries power to the two flow sensors. This is DC–A and DC–B power.

May I show the next slide. This is a repeat of a slide that Dr. Van Dolah had shown you previously. (See fig. 35.) It shows the massive destruction of the tubing, the wire and the structure in this area. I might mention the door has been removed and the inner corner of that door had also been burned away.

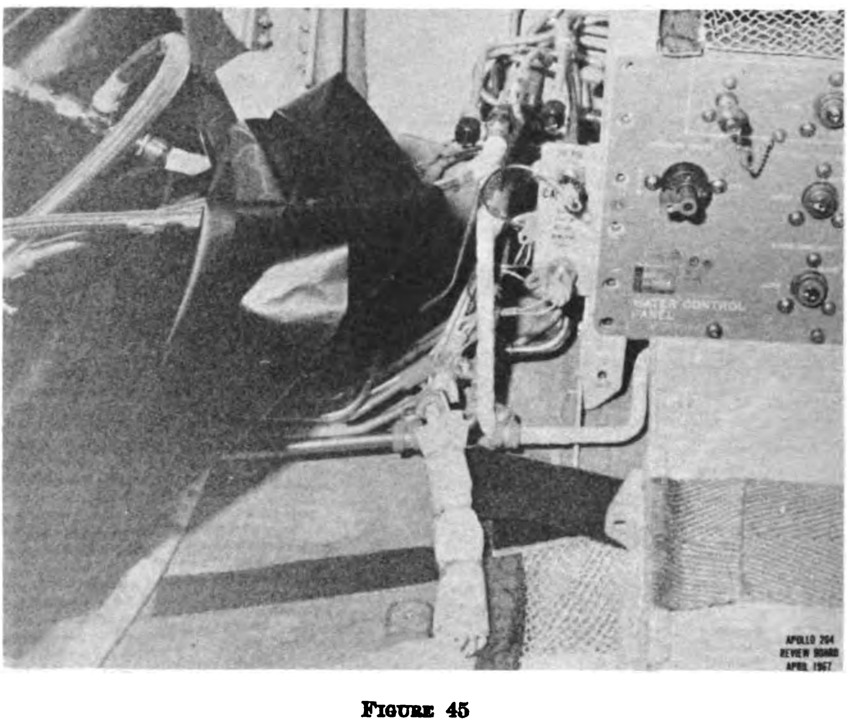


FIGURE 45

Likely areas in which this harness could have ignited the fire, of course, are near the door and up in the area behind the door.

Now, the reason we believe the fire started in this place is, first, from the physical evidence in the spacecraft—that is the firing patterns, the fact that all combustibles were completely burned away here, whereas in all other locations there is evidence of some of the combustibles melting rather than being burned away, indicating that the fire got to these other combustibles at a time period where oxygen was either completely depleted or partly depleted within the spacecraft.

Furthermore, we have investigated the arrangement of the combustibles in the spacecraft. There was a Raschel net, the debris trap net that ran horizontally along the floor in this area. We have carried out a special test in 16 and a half psi oxygen atmosphere, and ignited the net at the location of the harness and measured the time for the fire to travel to the corner, where it could communicate with a vertical Raschel net. And the total time from ignition to the time when that fire would come within the view of the astronauts was approximately 8 seconds.

This period of time fits very closely with the time difference of 9.7 seconds from the time that there are indications of an arc in the spacecraft from the data and the time that the spacecraft crew reported a fire.

Thank you.

The CHAIRMAN. Doctor, we are going to have to keep fighting quorum calls. There is a live quorum call now which we are trying to avoid so we can continue the discussion. If you can finish by about 12 o'clock so we can start with the questions, we would appreciate it.

SUMMARY OF BOARD'S FINDINGS

Dr. THOMPSON. I have Colonel Borman to sum up the findings; that would finish our presentation.

The CHAIRMAN. Thank you.

Colonel BORMAN. Mr. Chairman, Senator Smith, members of the committee, sir, I will present to you the findings and recommendations of the Board. You have them in part 6 of the Board's final report if you care to follow them at your desk.

May I have the first slide. (Fig. 46.) The first finding that the Board arrived at was that there was a momentary power failure at the 23:30:55 Greenwich mean time; evidence of several arcs was found in the post fire investigation; and that no single source of ignition was conclusively identified.

Next slide. (Fig. 47.) From this the Board determined that the most probable initiator was an electrical arc in the section between minus Y and plus Z spacecraft axes. The exact location best fitting the total available information is near the floor in the lower forward section of the left-hand equipment bay where the Environmental Control System instrumentation power wiring leads into the area between the Environmental Control Unit and the oxygen panel. No evidence was discovered that suggested sabotage.

The next (fig. 48) finding, (*a*) the command module contained many types and classes of combustible material in areas contiguous to possible ignition sources; (*b*) the test was conducted with 16.7 pounds per square inch absolute, 100 percent oxygen atmosphere.

1. FINDING:

A. THERE WAS A MOMENTARY POWER FAILURE AT 23:30:55 GMT.

B. EVIDENCE OF SEVERAL ARCS WAS FOUND IN THE POST FIRE INVESTIGATION.

C. NO SINGLE IGNITION SOURCE OF THE FIRE WAS CONCLUSIVELY IDENTIFIED.

FIGURE 46

DETERMINATION:

THE MOST PROBABLE INITIATOR WAS AN ELECTRICAL ARC IN THE SECTOR BETWEEN THE –Y AND ·Z SPACECRAFT AXES. THE EXACT LOCATION BEST FITTING THE TOTAL AVAILABLE INFORMATION IS NEAR THE FLOOR IN THE LOWER FORWARD SECTION OF THE LEFT-HAND EQUIPMENT BAY WHERE ENVIRON MENTAL CONTROL SYSTEM (ECS) INSTRUMENTATION POWER WIRING LEADS INTO THE AREA BETWEEN THE ENVIRONMENTAL CONTROL UNIT (ECU) AND THE OXYGEN PANEL. NO EVIDENCE WAS DISCOVERED THAT SUGGESTED SABOTAGE.

FIGURE 47

Next slide (fig. 49) determination, the test conditions were extremely hazardous.

Next slide (fig. 50) recommendation, the amount and location of the combustible materials in the command module be severely restricted and controlled. Restrict the amount and control their location.

Next slide. (Fig. 51.) Third finding. The rapid spread of the fire caused an increase in the pressure and temperature which resulted in a rupture of the command module and creation of a toxic atmosphere. Death of the crew was from axphyxia due to inhalation of toxic gases due to fire. A contributory cause of death was thermal burns.

Nonuniform distribution of carboxyhemoglobin was found by autopsy.

2. FINDING:

A. THE COMMAND MODULE CONTAINED MANY TYPES AND CLASSES OF COMBUSTIBLE MATERIAL IN AREAS CONTIGUOUS TO POSSIBLE IGNITION SOURCES.

B. THE TEST WAS CONDUCTED WITH A 16.7 POUNDS PER SQUARE INCH ABSOLUTE, 100 PERCENT OXYGEN ATMOSPHERE.

FIGURE 48

DETERMINATION:

THE TEST CONDITIONS WERE EXTREMELY HAZARDOUS.

FIGURE 49

RECOMMENDATION:

THE AMOUNT AND LOCATION OF COMBUSTIBLE MATERIALS IN THE COMMAND MODULE BE SEVERELY RESTRICTED AND CONTROLLED.

FIGURE 50

3. FINDING:

A. THE RAPID SPREAD OF FIRE CAUSED AN INCREASE IN PRESSURE AND TEMPERATURE WHICH RESULTED IN RUPTURE OF THE COMMAND MODULE AND CREATION OF A TOXIC ATMOSPHERE. DEATH OF THE CREW WAS FROM ASPHYXIA DUE TO INHALATION OF TOXIC GASES DUE TO FIRE. A CONTRIBUTORY CAUSE OF DEATH WAS THERMAL BURNS.

B. NON-UNIFORM DISTRIBUTION OF CARBOXYHEMOGLOBIN WAS FOUND BY AUTOPSY.

FIGURE 51

Next slide. (Fig. 52.) Medical opinion determined that unconsciousness occurred rapidly and death followed soon thereafter.

Next slide. (Fig. 53.) Finding: Due to internal pressure the command module inner hatch could not be opened prior to rupture of the command module. This is, of course, because of the fact that we had a sealed hatch that was designed to operate in orbit.

Next slide. (Fig. 54.) Determination: The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture.

DETERMINATION:

AUTOPSY DATA LEADS TO THE MEDICAL OPINION THAT UNCONSCIOUSNESS OCCURRED RAPIDLY AND THAT DEATH FOLLOWED SOON THEREAFTER.

FIGURE 52

4. FINDING:

DUE TO INTERNAL PRESSURE, THE COMMAND MODULE INNER HATCH COULD NOT BE OPENED PRIOR TO RUPTURE OF THE COMMAND MODULE.

FIGURE 53

DETERMINATION:

THE CREW WAS NEVER CAPABLE OF EFFECTING EMERGENCY EGRESS BECAUSE OF THE PRESSURIZATION BEFORE RUPTURE AND THEIR LOSS OF CONSCIOUSNESS SOON AFTER RUPTURE.

FIGURE 54

Next slide. (Fig. 55.) Recommendation: The Board recommends that the time required for egress of the crew be reduced and the operations necessary for egress be simplified.

Next slide. (Fig. 56.) Finding number five: Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous. Contingency preparations to permit escape or rescue of the crew from an internal command module fire were not made. (*a*) No procedures for this type of emergency have been established either for the crew or for the spacecraft pad work team, (*b*) the emergency equipment located in the white room and on

RECOMMENDATION:

THE TIME REQUIRED FOR EGRESS OF THE CREW BE REDUCED AND THE OPERATIONS NECESSARY FOR EGRESS BE SIMPLIFIED.

FIGURE 55

5. FINDING:

THOSE ORGANIZATIONS RESPONSIBLE FOR THE PLANNING, CONDUCT AND SAFETY OF THIS TEST FAILED TO IDENTIFY IT AS BEING HAZARDOUS. CONTINGENCY PREPARATIONS TO PERMIT ESCAPE OR RESCUE OF THE CREW FROM AN INTERNAL COMMAND MODULE FIRE WERE NOT MADE.

A. NO PROCEDURES FOR THIS TYPE OF EMERGENCY HAD BEEN ESTABLISHED EITHER FOR THE CREW OR FOR THE SPACECRAFT PAD WORK TEAM.

B. THE EMERGENCY EQUIPMENT LOCATED IN THE WHITE ROOM AND ON THE SPACECRAFT WORK LEVELS WAS NOT DESIGNED FOR THE SMOKE CONDITION RESULTING FROM A FIRE OF THIS NATURE.

C. EMERGENCY FIRE, RESCUE AND MEDICAL TEAMS WERE NOT IN ATTENDANCE.

D. BOTH THE SPACECRAFT WORK LEVELS AND THE UMBILICAL TOWER ACCESS ARM CONTAIN FEATURES SUCH AS STEPS, SLIDING DOORS AND SHARP TURNS IN THE EGRESS PATHS WHICH HINDER EMERGENCY OPERATIONS.

FIGURE 56

the spacecraft work levels was not designed for smoke conditions resulting from a fire of this nature, (*c*) emergency fire, rescue and medical teams were not in attendance, (*d*) both the spacecraft work levels and the umbilical tower access arm contain features such as steps, sliding doors, and sharp turns in the egress paths which hinder emergency operation.

Before leaving that I would like to point out that the key phrase here is that the test was not identified as being hazardous. Consequently, the deficiencies that we listed here in (*a*), (*b*), (*c*), and (*d*) resulted from the fact that the test was not identified as being hazardous.

Dr. THOMPSON. Colonel, this is—I do not believe you are really adding any comments.

Colonel BORMAN. Do you want me to go right on through?

Dr. THOMPSON. It is not necessary since the chairman and members of the committee have read the report. I think that you just stand on what is presented here.

Colonel BORMAN. Yes.

The CHAIRMAN. I agree with you. This is word for word.

Dr. THOMPSON. Yes. I do not think he plans to add much of anything to that, so we can let that stand as a sum up as written.

The CHAIRMAN. We will really put it in the report but—I hate to sort of cut you off.

Colonel BORMAN. No, sir, that is fine.

The CHAIRMAN. Do you have anything you want to say about this situation?

Colonel BORMAN. Well, sir, perhaps if we have discussion later on I will have an opportunity to comment.

(The remaining slides (figs. 57 to 76) in Colonel Borman's illustrated talk referred to above are as follows:)*

DETERMINATION:

ADEQUATE SAFETY PRECAUTIONS WERE NEITHER ESTABLISHED NOR

OBSERVED FOR THIS TEST.

FIGURE 57

*For convenience, part VI of the Board's report entitled "Board Findings, Determinations, and Recommendations" is printed in an appendix, see p. 267.

RECOMMENDATIONS:

A. MANAGEMENT CONTINUALLY MONITOR THE SAFETY OF ALL TEST OPERATIONS AND ASSURE THE ADEQUACY OF EMERGENCY PROCEDURES.

B. ALL EMERGENCY EQUIPMENT (BREATHING APPARATUS, PROTECTIVE CLOTHING, DELUGE SYSTEMS, ACCESS ARM, ETC.) BE REVIEWED FOR ADEQUACY

C. PERSONNEL TRAINING AND PRACTICE FOR EMERGENCY PROCEDURES BE GIVEN ON A REGULAR BASIS AND REVIEWED PRIOR TO THE CONDUCT OF A HAZARDOUS OPERATION.

D. SERVICE STRUCTURES AND UMBILICAL TOWERS BE MODIFIED TO FACILITATE EMERGENCY OPERATIONS.

FIGURE 58

6. FINDING:

FREQUENT INTERRUPTIONS AND FAILURES HAD BEEN EXPERIENCED IN THE OVERALL COMMUNICATION SYSTEM DURING THE OPERATIONS PRECEDING THE ACCIDENT.

FIGURE 59

DETERMINATION:

THE OVERALL COMMUNICATION SYSTEM WAS UNSATISFACTORY.

FIGURE 60

RECOMMENDATIONS:

A. THE GROUND COMMUNICATION SYSTEM BE IMPROVED TO ASSURE RELIABLE COMMUNICATIONS BETWEEN ALL TEST ELEMENTS AS SOON AS POSSIBLE AND BEFORE THE NEXT MANNED FLIGHT

B. A DETAILED DESIGN REVIEW BE CONDUCTED ON THE ENTIRE SPACECRAFT COMMUNICATION SYSTEM.

FIGURE 61

7. FINDING:

A. REVISIONS TO THE OPERATIONAL CHECKOUT PROCEDURE FOR THE TEST WERE ISSUED AT 5:30 PM EST JANUARY 26, 1967 (209 PAGES) AND 10:00 AM EST JANUARY 27, 1967 (4 PAGES).

B. DIFFERENCES EXISTED BETWEEN THE GROUND TEST PROCEDURES AND THE IN-FLIGHT CHECK LISTS.

FIGURE 62

DETERMINATION:

NEITHER THE REVISION NOR THE DIFFERENCES CONTRIBUTED TO THE ACCIDENT. THE LATE ISSUANCE OF THE REVISION, HOWEVER, PREVENTED TEST PERSONNEL FROM BECOMING ADEQUATELY FAMILIAR WITH THE TEST PROCEDURE PRIOR TO ITS USE.

FIGURE 63

74-521 O—67—pt. 3——4

RECOMMENDATIONS:

A. TEST PROCEDURES AND PILOT'S CHECKLISTS THAT REPRESENT THE ACTUAL COMMAND MODULE CONFIGURATION BE PUBLISHED IN FINAL FORM AND REVIEWED EARLY ENOUGH TO PERMIT ADEQUATE PREPARATION AND PARTICIPATION OF ALL TEST ORGANIZATIONS.

B. TIMELY DISTRIBUTION OF TEST PROCEDURES AND MAJOR CHANGES BE MADE A CONSTRAINT TO THE BEGINNING OF ANY TEST.

FIGURE 64

8. FINDING:

THE FIRE IN COMMAND MODULE 012 WAS SUBSEQUENTLY SIMULATED CLOSELY BY A TEST FIRE IN A FULL-SCALE MOCK-UP.

FIGURE 65

DETERMINATION:

FULL-SCALE MOCK-UP FIRE TESTS CAN BE USED TO GIVE A REALISTIC APPRAISAL OF FIRE RISKS IN FLIGHT-CONFIGURED SPACECRAFT.

FIGURE 66

RECOMMENDATION:

FULL-SCALE MOCK-UPS IN FLIGHT CONFIGURATION BE TESTED TO DETERMINE THE RISK OF FIRE.

FIGURE 67

9. FINDING:

THE COMMAND MODULE ENVIRONMENTAL CONTROL SYSTEM DESIGN PROVIDES A PURE OXYGEN ATMOSPHERE.

FIGURE 68

DETERMINATION:

THIS ATMOSPHERE PRESENTS SEVERE FIRE HAZARDS IF THE AMOUNT AND LOCATION OF COMBUSTIBLES IN THE COMMAND MODULE ARE NOT RESTRICTED AND CONTROLLED.

FIGURE 69

RECOMMENDATIONS:

A. THE FIRE SAFETY OF THE RECONFIGURED COMMAND MODULE BE ESTABLISHED BY FULL-SCALE MOCK-UP TESTS.

B. STUDIES OF THE USE OF A DILUENT GAS BE CONTINUED WITH PARTICULAR REFERENCE TO ASSESSING THE PROBLEMS OF GAS DETECTION AND CONTROL AND THE RISK OF ADDITIONAL OPERATIONS THAT WOULD BE REQUIRED IN THE USE OF A TWO GAS ATMOSPHERE.

FIGURE 70

10. FINDING:

DEFICIENCIES EXISTED IN COMMAND MODULE DESIGN, WORKMANSHIP AND QUALITY CONTROL, SUCH AS:

A. COMPONENTS OF THE ENVIRONMENTAL CONTROL SYSTEM INSTALLED IN COMMAND MODULE 012 HAD A HISTORY OF MANY REMOVALS AND OF TECHNICAL DIFFICULTIES INCLUDING REGULATOR FAILURES, LINE FAILURES AND ENVIRONMENTAL CONTROL UNIT FAILURES. THE DESIGN AND INSTALLATION FEATURES OF THE ENVIRONMENTAL CONTROL UNIT MAKES REMOVAL OR REPAIR DIFFICULT.

B. COOLANT LEAKAGE AT SOLDER JOINTS HAS BEEN A CHRONIC PROBLEM.

C. THE COOLANT IS BOTH CORROSIVE AND COMBUSTIBLE.

D. DEFICIENCIES IN DESIGN, MANUFACTURE, INSTALLATION, REWORK AND QUALITY CONTROL EXISTED IN THE ELECTRICAL WIRING.

E. NO VIBRATION TEST WAS MADE OF A FLIGHT-CONFIGURED SPACECRAFT.

F. SPACECRAFT DESIGN AND OPERATING PROCEDURES CURRENTLY REQUIRE THE DISCONNECTING OF ELECTRICAL CONNECTIONS WHILE POWERED.

G. NO DESIGN FEATURES FOR FIRE PROTECTION WERE INCORPORATED.

FIGURE 71

DETERMINATION:

THESE DEFICIENCIES CREATED AN UNNECESSARILY HAZARDOUS CONDITION AND THEIR CONTINUATION WOULD IMPERIL ANY FUTURE APOLLO OPERATIONS.

FIGURE 72

RECOMMENDATIONS:

A. AN IN-DEPTH REVIEW OF ALL ELEMENTS, COMPONENTS AND ASSEMBLIES OF THE ENVIRONMENTAL CONTROL SYSTEM BE CONDUCTED TO ASSURE ITS FUNCTIONAL AND STRUCTURAL INTEGRITY AND TO MINIMIZE ITS CONTRIBUTION TO FIRE RISK.

B. PRESENT DESIGN OF SOLDERED JOINTS IN PLUMBING BE MODIFIED TO INCREASE INTEGRITY OR THE JOINTS BE REPLACED WITH A MORE STRUCTURALLY RELIABLE CONFIGURATION

C. DELETERIOUS EFFECTS OF COOLANT LEAKAGE AND SPILLAGE BE ELIMINATED.

D. REVIEW OF SPECIFICATIONS BE CONDUCTED, 3-DIMENSIONAL JIGS BE USED IN MANUFACTURE OF WIRE BUNDLES AND RIGID INSPECTION AT ALL STAGES OF WIRING DESIGN, MANUFACTURE AND INSTALLATION BE ENFORCED.

E. VIBRATION TESTS BE CONDUCTED OF A FLIGHT-CONFIGURED SPACECRAFT.

F. THE NECESSITY FOR ELECTRICAL CONNECTIONS OR DISCONNECTIONS WITH POWER ON WITHIN THE CREW COMPARTMENT BE ELIMINATED

G. INVESTIGATION BE MADE OF THE MOST EFFECTIVE MEANS OF CONTROLLING AND EXTINGUISHING A SPACECRAFT FIRE. AUXILIARY BREATHING OXYGEN AND CREW PROTECTION FROM SMOKE AND TOXIC FUMES BE PROVIDED.

FIGURE 73

11. FINDING:

AN EXAMINATION OF OPERATING PRACTICES SHOWED THE FOLLOWING EXAMPLES OF PROBLEM AREAS:

A. THE NUMBER OF THE OPEN ITEMS AT THE TIME OF SHIPMENT OF THE COMMAND MODULE 012 WAS NOT KNOWN. THERE WERE 113 SIGNIFICANT ENGINEERING ORDERS NOT ACCOMPLISHED AT THE TIME COMMAND MODULE 012 WAS DELIVERED TO NASA; 623 ENGINEERING ORDERS WERE RELEASED SUBSEQUENT TO DELIVERY. OF THESE, 22 WERE RECENT RELEASES WHICH WERE NOT RECORDED IN CONFIGURATION RECORDS AT THE TIME OF THE ACCIDENT.

B. ESTABLISHED REQUIREMENTS WERE NOT FOLLOWED WITH REGARD TO THE PRE-TEST CONSTRAINTS LIST. THE LIST WAS NOT COMPLETED AND SIGNED BY DESIGNATED CONTRACTOR AND NASA PERSONNEL PRIOR TO THE TEST, EVEN THOUGH ORAL AGREEMENT TO PROCEED WAS REACHED.

C. FORMULATION OF AND CHANGES TO PRE-LAUNCH TEST REQUIREMENTS FOR THE APOLLO SPACECRAFT PROGRAM WERE UNRESPONSIVE TO CHANGING CONDITIONS.

D. NON-CERTIFIED EQUIPMENT ITEMS WERE INSTALLED IN THE COMMAND MODULE AT TIME OF TEST.

E. DISCREPANCIES EXISTED BETWEEN NAA AND NASA MSC SPECIFICATIONS REGARDING INCLUSION AND POSITIONING OF FLAMMABLE MATERIALS.

F. THE TEST SPECIFICATION WAS RELEASED IN AUGUST 1966 AND WAS NOT UPDATED TO INCLUDE ACCUMULATED CHANGES FROM RELEASE DATE TO DATE OF THE TEST.

FIGURE 74

DETERMINATION:

PROBLEMS OF PROGRAM MANAGEMENT AND RELATIONSHIPS BETWEEN CENTERS AND WITH THE CONTRACTOR HAVE LED IN SOME CASES TO INSUFFICIENT RESPONSE TO CHANGING PROGRAM REQUIREMENTS.

FIGURE 75

RECOMMENDATION:

EVERY EFFORT MUST BE MADE TO INSURE THE MAXIMUM CLARIFICATION AND UNDERSTANDING OF THE RESPONSIBILITIES OF ALL THE ORGANIZATIONS INVOLVED, THE OBJECTIVE BEING A FULLY COORDINATED AND EFFICIENT PROGRAM.

FIGURE 76

The CHAIRMAN. Are you ready to start the questioning now?

Dr. THOMPSON. Yes, sir.

BOARD HAD COMPLETE FREEDOM

The CHAIRMAN. I think in order to get around completely, we will give each person 10 minutes.

Dr. Thompson, did you feel as Chairman of the Board, that the Board has had complete freedom to carry out its responsibilities in the investigation of Apollo 204 fire?

Dr. THOMPSON. Yes, sir. I have been very much impressed with the cooperation and the candid, wholehearted support we have had from all people that we have had to ask for help from and who assisted us in this investigation.

The CHAIRMAN. Some people have been worried because this is an inside investigation, that you have not brought in a lot of outside experts. I think it has been done very well, but I just want to be sure that you, as the Chairman, were not hampered in your investigation.

Dr. THOMPSON. We certainly were not hampered in any way. We called upon the people who are most expert, most knowledgeable about this entire affair and they all cooperated in a very wholehearted manner.

The CHAIRMAN. Thank you. Do you know of any attempt by NASA or the spacecraft manufacturer to suppress any information which the Board regarded as pertinent?

Dr. THOMPSON. No, sir. Everyone, the contractor and all elements of NASA, contributed in a wholehearted manner to the requirements of this review.

The CHAIRMAN. Did the Board have adequate personnel, financing, and facilities to undertake the investigation in the depth deemed necessary?

Dr. THOMPSON. Yes, sir. There was very adequate support with a high priority. Wherever we put a demand, we got immediate and wholehearted support.

The CHAIRMAN. What is the status of the Apollo 204 Review Board? Has it completed its work? Have you disbanded or are going on for a while?

Dr. THOMPSON. Upon delivery of the report to the Administrator we are in recess subject to recall by me, the Chairman, until we are actually discharged by the Administrator. There is some unfinished business that has been referred to in investigations that I have said will not influence our findings, our opinions, as expressed here, but we do feel it necessary to wind up the affairs that will be incorporated in appendix G of the report.

The CHAIRMAN. It has been NASA's objective to design spacecraft and other hardware, and conduct operations with safety as the paramount concern. To what do you attribute the design and other deficiencies set forth in your report, which clearly indicate that the objective has not been obtained?

Dr. THOMPSON. Somehow or other in the process of the manufacture and quality control inspection, the results in certain areas that we have identified just have not come out as well as we think is actually required.

The CHAIRMAN. I think I am going to let the other members question. Senator Smith?

QUESTIONS IF DEFICIENCIES EXIST IN OTHER AREAS OF MANNED SPACECRAFT PROGRAM

Senator SMITH. Thank you, Mr. Chairman.

Dr. Thompson, the preface of the Review Board's report indicates that the report is not intended as representing a total picture of the manned spacecraft program. This is understandable since your investigation was directed toward uncovering specifics concerned with the accident. However, the Board did review NASA's management structure and the written procedures and operating practices for the Apollo program.

In light of this information, could we get your opinion as to whether the types of deficiencies disclosed for this one spacecraft may well exist in other areas of the manned spacecraft program?

Dr. THOMPSON. I think, Madam Senator, that the findings that we have may reflect certain areas that can well be improved, will require improvement, in matters that we have remarked on, particularly in the last two findings of our report. We think that in this very complex program, not all the objectives of management or desired by management have been achieved and I think we have identified those at least in a general way, and I fully expect that the Apollo Program Office, the directors, those responsible for the direction of the Apollo program will make use of this identification that we have provided to effect certain improvements. I do think they are quite important, relative to the future program, but I do think they are perhaps things you would find in or the general kind of things that you would find in any tremendously large undertaking. Any management has problems. We have identified some and, I think, it may be quite helpful to the Program Office in their efforts to correct the problems.

Senator SMITH. But, you would say there were some deficiencies in other areas of the program similar to some you found in this one?

Dr. THOMPSON. I think any program has deficiencies. We thought that there were certain ones that we should identify here that certainly the management should direct attention to.

ASKED IF PROBLEM RELATED TO TIGHT SCHEDULES

Senator SMITH. Dr. Thompson, the Board's report points out some serious deficiencies relating to design, workmanship, quality control, and failure to complete required engineering changes. In your opinion, are these deficiencies attributable in some measure to the tight schedules used for the program in order to assure a manned lunar landing in this decade?

Dr. THOMPSON. I cannot identify anything of that sort. A program of this kind has to have a very hard drive. It has to have built-in urgency in order to keep all the people properly motivated.

The thing that we directed our attention to was the other side of this tremendous project, that is, the orderliness that is required to see that this hard drive does not disregard some of the paperwork and those things that may be overlooked if there just is not sufficient attention paid to them.

I cannot conceive of a program of this nature that would offer a tradeoff between haste and the other orderly side of it. They have to be matched. You could not tell people to slow down because we are just going too fast here. I say you have just got to put the hard drive in both sides of this picture from where I sit.

Senator SMITH. Doctor, if the hard drive that you refer to is not responsible for these irregularities and deficiencies, then what would in your opinion, be the primary or underlying reason for such errors of omission and commission discussed in the Board's report?

Dr. THOMPSON. Well, I just think somehow or other they have not quite found out how to put all that order in. It is a very demanding task. This is a tremendously big program involving hundreds of thousands of people. Even the test itself, just the head count for the test itself showed 959 people on duty doing various tasks at that time. The organization of all that effort is a difficult management task but I do not see why it cannot be accomplished.

I think that an overview of it, as we have done, will identify areas that will provide a useful guide to improvements that ought to be made.

Senator SMITH. Well, of course, Dr. Thompson, we have to know in order to be able to correct the deficiencies and this is where I hope you and your associates may be helpful to us. I think it is very necessary for us to know just exactly what brought about these deficiencies—whether it was the tight schedules, the rush or negligence or some other reason—before we can go on to make the corrections. I am sure you understand what I have in mind.

Dr. THOMPSON. I do.

REQUESTS OPINION ON MANAGEMENT DEFICIENCIES

Senator SMITH. In several sections of the report the Board addresses itself to program management deficiencies and problems in the relationship between centers and with the contractor. I think it would be helpful to the committee if you would give us your opinion as to where in NASA's management structure the major deficiency lies with respect to the failure to recognize and correct the more serious deficiencies noted in the Board's report.

Dr. THOMPSON. The problem, as I see it, is in an evolving situation where so many people are involved and the necessity for employing so many people under, say, different centers.

There are three major groups involved in this program. There is the contractor. The contractor himself has groups at his plant and at the Cape. NASA has major groups at MSC and KSC. The difficult management problem of dealing with all those working relationships and laying out the areas of responsibility so that everyone is really fully coordinated is a tremendous task, and this has been subject to change over the recent years.

I feel that is the major factor in that.

Senator SMITH. Dr. Thompson, it may not be your responsibility to identify the areas of responsibility in the agency, however, you have been so close to this accident, you and your associates have gone into so many facets of it, and you have made numerous findings that it seems to me you could come up with the basic deficiencies or the area which is basically at fault in the management of the program. I presume that is what we have to find before we can go on with any corrections.

Dr. THOMPSON. Well, we have gone to a point, I think, of identifying areas. I think that we would get a little far afield if we try to tell how to recognize it. I think that perhaps we have done about as much as is appropriate, to our knowledge, at the moment in identifying the areas that we thought required attention and I believe it is more in the area of the program office to respond to just how the problems that we have identified can be effectively dealt with in the management.

Senator SMITH. We are all in this together, Dr. Thompson, and I have supported this program since its beginning, and I am sure we all want to see our space exploration plans and programs continue, and we want to see it successful.

I would like to get on the record your own feelings about whether there is a deficiency or inefficiency in the management of the space agency. It seems to me you could not help but come through with such a complete and wonderful report as you have provided without having some personal feelings about it.

Dr. THOMPSON. Well, I am afraid that my feelings, as far as I feel qualified to comment at this time, are pretty well expressed in the report. I think that it would be better to try to reach an understanding with the program office to see whether or not these things that we have identified as problems are being solved.

Now, we did not consider ourselves a board of management experts nor did we employ management experts to try to analyze the problem in detail, so I would be a little hesitant to pull off the top of my head at this point, statements beyond what we have already stated.

The CHAIRMAN. If you will yield to me, Senator Smith. Senator Smith asked a question asking you if you will give us your opinion as to where in NASA's management structure the major deficiency lies. In Dr. Seamans' letter of instructions to you he said:

> Consider all of the factors relating to the accident, including the design, procedures, organization, and management.

We really want to know if you have thought about this management question. You have been exposed to two and a half months of it. You have done a great job. Have you not had some feeling as to what this management problem has been?

Dr. THOMPSON. I think we identified certain problems. We said there was cumbersomeness in the operations relative to the conflicting management requirements of orderliness in dealing with a dynamic program, particularly, in the operations at the Cape where the MSC, the Manned Spacecraft Center, has the major responsibility, and when the spacecraft arrives at the Cape, the execution of that responsibility falls pretty much in the hands of another group.

Now, the working out of these areas of responsibility without impairing the necessary restraints as to cost and identification—clear delineation of the effect of any changes poses some rather difficult problems and I think that there is an area in this working relationship that can be improved to meet two conflicting requirements, flexibility, and yet not license to make changes.

Now, this is a difficult thing and, I think, quite a lot of what we directed our attention to and identified, was in that area. MSC at this stage is responsible for the spacecraft and yet it is another group, through delegation of responsibility, that is working on it. I think the lines are pretty well worked out. I do not think we saw any obvious flaws in the line of authority but there seems to be a lack of flexibility.

The CHAIRMAN. Doctor, you used charts showing the wiring as not very satisfactory. I helped with the long examination of the Navy Dapartment on the *Thresher*. At one point we found what we thought was a rather improper setup.

Have you not determined as yet anything about the propriety of these management problems and the product of them?

Dr. THOMPSON. Well, we have identified, I think, certainly certain items of workmanship that we were quite dissatisfied with and this is, say, a joint responsibility of NASA—I say a joint responsibility—of course, it is NASA's responsibility to get contractors responding, but workmanship certainly impresses us as being somewhat deficient and somehow or other it got through. I do not know that we are able to identify in detail. I think the Apollo program management will have a hard look at that.

Senator SMITH. Well, Dr. Thompson, in your finding 10, you recommend that—

Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

NASA and the industry are pretty big organizations. It would seem to me after all the efforts you have made that there would be some way for you and your people, with their variety of experience and background, could pinpoint the responsibility of either the positions or the levels where the problems exist.

Dr. THOMPSON. Well, I think we have identified, in our report, that there were certain processes that went ahead with more or less informal understandings rather than documented understandings. In a program as demanding as this, a certain amount of that is necessary. The remarks that we addressed ourselves to in that case were related to the fact that there seem to be rather too much informal understanding between the people involved at the time of the test rather than giving us the assurance that the written instructions required for all these people who are involved had been distributed to them long enough in advance, so that we are certain that everyone understood fully what the test group was doing. And, it is in this area where we felt that more attention to the, what I would call the orderliness of the project would be appropriate.

Senator SMITH. Well, Dr. Thompson, continuing with your finding 10, part D states:

Deficiencies in design, manufacture, installation, rework and quality control, existed in the electrical wiring.

Now, someone has to be responsible for that. I do not mean the individual involved, but some organizational unit must be specifically responsible for this work and do you mean to tell us that you cannot identify that area where the responsibility lies?

Dr. THOMPSON. Well——

REQUESTS STATEMENT OUTLINING PROBLEMS

Senator SMITH. Or if you could give us a statement on what has to be done to define those areas.

Dr. THOMPSON. The Apollo program office is organized in such a way as to attempt to deal with this. One of the members of the board is from the quality assurance area of responsibility, Mr. George White. I do not know whether he wants to comment on that.

Mr. WHITE. Yes, I would like to address myself to that question. The wiring problems that we have found in our investigation——

Senator SMITH. Will you identify yourself.

Mr. WHITE. I am George White, director of reliability and quality in the Apollo program office in Washington. These wiring deficiencies stem originally from a lack of adequate engineering information being passed on to the manufacturing people which in turn, means that in the inspection operation, rather than having the hardware compared with the engineering drawings and engineering requirements, it is compared with the inspector's knowledge of accepted practice.

Now, this sometimes leaves sort of a qualitative approach to things and there is not a firm set of criteria against which the inspector can judge.

The original responsibility here, of course, lies with the contractor, but NASA has inspectors on the spot who double check the contractor's inspection operation and, therefore, NASA must accept responsibility here, along with the contractor. In fact, the ultimate responsibility obviously is NASA's.

Does that answer your question on that, Senator?

Senator SMITH. Well, not wholly, no. Dr. Thompson said a few moments ago that he did not think he could come out from the top of his head with an opinion. I wonder, Doctor, if you would be willing to give this some specific thought. You know what I am after, and then give this committee the benefit of your thinking on it. I think we are relying a great deal on you and your associates and I personally will appreciate it if you can give me the benefit of your own personal thinking.

Dr. THOMPSON. Let me add one more thought to this. In my statement I pointed out that we had looked at the Block I design. Now, some of these deficiencies, particularly the wiring which has been the cause of great concern, we understand has been greatly improved in the Block II design. It has been recognized in the manufacturing process by the program office and the contractor and we have not examined—we have not looked over the Block II design, but our understanding is that this important question has been dealt with in an effective manner in the Block II design. So, in other words, it is a recognized problem that is being dealt with.

Senator SMITH. But, Block I spacecraft was to be flown by man, was it not?

Dr. THOMPSON. Sure, 012.

Senator SMITH. Should it not have been just as important before this happened as it is now?

Dr. THOMPSON. You are correct. Number 012 was a Block I spacecraft and that was the one that was to be flown.

Senator SMITH. What I am trying to get is, where the error was, where we slipped up in not having or taking every precaution before we had that test. I do not see why we would not have precautions in testing before flight.

Dr. THOMPSON. Well, I guess it is a matter of judgment that was made relative to that flight. Maybe I had better ask Colonel Borman. He was going to fly in a Block I spacecraft and he was prepared to go although knowing right much about this. I think we had better let him comment on that.

Colonel BORMAN. Yes. I think, Senator, we were very aware of the problem of fire in flight and we had adopted procedures primarily of venting the command module to a vacuum to eliminate the fire. We had done an extensive study on this before our Gemini 7 flight. However, I think that none of us were fully aware of the hazard that existed when you combine a pure oxygen atmosphere with the extensive distribution of combustibles and the likely source of ignition, and so this test, as I mentioned briefly during the findings and determinations, was not classified as hazardous.

I did not consider it as hazardous. I do not believe that anyone within the test organization or the program office considered it hazardous. And, this is the unfortunate trap through which we fell.

Senator SMITH. Well, Colonel, were you aware of the electrical deficiencies before you were appointed to the board?

Colonel BORMAN. Yes, Ma'am.

Senator SMITH. Mr. Chairman, I have other questions that I am quite anxious to ask, but if you would like to go around and then come back to me.

(The material referred to above follows:)

In my opinion, the overall organization structure of the Apollo program, both Government and Contractor, is sound. What I, personally, and the other Board members were concerned about were the procurement/inspection/checkout/acceptance processes of Apollo spacecraft at lower levels of management. I felt that this was a weakness within the structure that should be looked into by the top management of NASA. The accomplishment of this objective must face the difficulties of dealing with the dynamic requirements of a fast moving program. When you consider that two NASA Centers, Manned Spacecraft Center and Kennedy Spacecraft Center, and two Contractor facilities, North American Aviation, Downey and North American Aviation, Florida facility must, of necessity, coordinate the total effort, it is not difficult to discover areas where the administrative, engineering and operational procedures may show defects.

The Board described the management and organization of the Apollo program in Appendix E of its report to the Administrator, NASA. In its report, the Board set out in considerable detail the management and responsibility levels. However, no attempt was made to ascertain the actual working relationships as they currently exist between the various management levels. The Board did not consider itself to be charged with the responsibility of management analysis. Furthermore, if it had, the investigation would have taken several more months.

If any management level is to be charged with the failure to recognize and correct the deficiencies noted in the Board's report, it would be the design and layout engineering level. I pointed out in my testimony and it is a matter of record that the Board and I were seriously concerned with the electrical wiring and soldered joints. I specified the material to you in my testimony and referred you to page 6 of Appendix D-9 of the Report. I believe that when the wiring and plumbing joint problem is solved by the Apollo Program Office, coupled with the recommended reduction of flammable material, the reliability of the Apollo spacecraft will be increased to an acceptable level not only for safety, but for mission success.

The CHAIRMAN. Thank you.

Senator Cannon?

Senator CANNON. Thank you, Mr. Chairman.

RELATIONSHIP OF BOARD MEMBERS TO NASA

Doctor, I would like to review for a few moments with you the relationship of the various members of the Board to NASA—and I am not doing this from a critical standpoint—but I think it is well to know exactly what the relationship is.

Would you start with yourself and tell us what your relationship is to NASA and what it has been for the past several years.

Dr. THOMPSON. I am Director of the Langley Research Center of NASA. Our area of effort is in the research field. We report into headquarters through what is called the Office of Advanced Research and Technology. We do not have any direct connection with the Apollo program except in a supporting role as providing technology relative to this. This is technology developed by our research programs.

Now ——

Senator CANNON. And you have been with NASA yourself ever since NASA was first formed, have you not?

Dr. THOMPSON. Yes, sir. I have been ——

Senator CANNON. Now, as I understand it, if you consider the counsel not to be a member of the Board, six of the eight members are assigned to NASA and are employed by them, perhaps with the technical exception of Colonel Borman, who is assigned to them but is actually employed by the Air Force, I presume. Is that correct?

Dr. THOMPSON. Yes, sir.

Senator CANNON. And, what is Dr. Faget's relationship to NASA?

Dr. THOMPSON. Dr. Faget, will you describe your position at MSC, Manned Spacecraft Center.

Dr. FAGET. Yes. I am the Director of Engineering and Development.

The CHAIRMAN. I cannot hear you.

Dr. FAGET. I am the Director of Engineering and Development at Manned Spacecraft Center.

Senator CANNON. Does that mean that you had the responsibility for the general program of engineering and development for NASA?

Dr. FAGET. I have the general responsibility for providing engineering and development work as related to manned spacecraft; yes, sir.

Senator CANNON. And that included the capsule in this particular instance?

Dr. FAGET. That includes——

Senator CANNON. In the Apollo program?

Dr. FAGET. That includes all of the manned spacecraft program and Apollo as well, certainly.

Senator CANNON. And have you been with NASA since its inception?

Dr. FAGET. Yes, sir. I, like Dr. Thompson, was with NACA and have been with NASA since its inception.

Senator CANNON. Now, what about Mr. Geer?

Mr. GEER. I am E. Barton Geer. I am at the Langley Research Center and I am in engineering and design of flight vehicles and systems at Langley.

Senator CANNON. Now, is that completely disassociated with the space systems?

Mr. GEER. Yes. Manned space system; yes.

Senator CANNON. But, you are employed by NASA and have been for some period of time in your present assignment.

Mr. GEER. Yes, sir.

Senator CANNON. Dr. Thompson, were you ——

Dr. THOMPSON. I was trying to say he is one of my employees in one of the divisions at Langley.

Senator CANNON. And, Dr. Van Dolah, of course, is not connected with NASA, as I understand it, except as a member of this Board, and perhaps has assisted in advice on previous occasions.

Dr. VAN DOLAH. That is correct.

Senator CANNON. Colonel Strang, of course, is an Air Force officer and assigned to the IG Division out at Norton, is that correct?

Colonel STRANG. Yes, sir. Located at Norton, but under the Inspector General, Air, Washington.

Senator CANNON. And, you have no relationship to NASA as such, except as a member of the Board?

Colonel STRANG. Absolutely not.

Senator CANNON. What about Mr. White?

Mr. WHITE. I am director of reliability and quality in the Apollo program office here in Washington and in that position I am on the staff of General Phillips. He has five divisions in his organization which are "Operations, Test, Program Control, Systems Engineering, and Reliability and Quality." I am director of the reliability and quality division.

Senator CANNON. Would you say the matters involved here relate directly to reliability and quality in this particular instance?

Mr. WHITE. Yes, sir.

Senator CANNON. So, any finding of the Board, any adverse finding would reflect adversely on your office, would it not?

Mr. WHITE. I believe that is right.

Senator CANNON. And, what about Mr. John Williams?

Mr. WILLIAMS. I am director of the manned spacecraft operations at Kennedy Space Center.

Senator CANNON. How long have you been in that position, Mr. Williams?

Mr. WILLIAMS. I joined NASA in 1959.

Senator CANNON. You have been with NASA since its inception up to the present time?

Mr. WILLIAMS. Essentially since its inception.

Senator CANNON. And, you were directly related to the particular program here, is that correct?

Mr. WILLIAMS. Yes, sir.

Senator CANNON. And, Mr. Malley, while I presume he was not a member of the Board, he also is an employee of NASA and——

Dr. THOMPSON. At Langley. Chief counsel at Langley.

Senator CANNON. Getting back to Mr. Williams, you are directly involved in the spacecraft program and the operational program of the Apollo program, is that correct?

Mr. WILLIAMS. Yes.

Senator CANNON. Dr. Thompson, do you think the fact that six of the eight members of the Board are directly employed by or related to NASA would in any way tend to have the Board less critical of the actions that have been reviewed here than if it were an objective board from some other source? And, I am not saying that in a critical vein because I realize that to get people from the outside that are familiar with what is going on would be extremely difficult.

Dr. THOMPSON. Well, I feel that the people that I have had working on this Board have been very effective even to the point that Mr. George White perhaps criticized himself. Now, just what some other people would have done, I do not know. They could have been critical, I say—without knowing how to respond I do not believe I can tell that, but these people certainly have responded in a very effective manner and as you point out, they are knowledgeable which was a basic element of consideration, because we had to tie onto an existing system, a very complex system to pursue our review. So that I do not think our task suffered from the fact they were associated with it but I know it benefited very greatly because they were.

Senator CANNON. Now, you pointed out correctly, that they were critical but I am wondering if they might tend to be—the point I am concerned about is might they tend to be less critical than if they were from some other source?

Dr. THOMPSON. Well, I cannot tell, because I do not know who the other people would be.

DEFICIENCIES NOTED IN DESIGN REVIEW

Senator CANNON. Doctor, the report of the Apollo Review Board, Design Review Panel 9, states that independent design reviews were made by NASA and North American personnel during which numerous design deficiencies were noted. Now, I would like to ask you if that was the first design review that was ever made of the block I spacecraft by NASA personnel.

Mr. WHITE. The answer to that is "No," that there have been many design reviews conducted in the normal course of the program. Preliminary design reviews early in the design stage, and a critical design review when design is completed. There is a design certification review which had been completed on this spacecraft which is performed prior to every major change in the design of any particular element of the program.

For example, in this case, it was the first manned spacecraft, so we had a design certification review that was conducted by Dr. George Mueller and his Management Council, composed of the directors of the three centers involved. So, there had been numerous design reviews in the normal course of the program. This is our standard policy.

Senator CANNON. Why would you say that these design deficiencies were not noted previously, then, in these many design reviews?

Mr. WHITE. I believe probably the most significant thing here is that the deficiencies that we have found, particularly in the wiring installation, are detailed types of deficiencies concerned with routing and inadequate clearances and inadequate protection of wiring, which may not have actually been gone into. Design reviews have been devoted primarily to the more broad questions of design of subsystems, and capability of subsystems to do their jobs. And, in this sense perhaps the design review did miss some of these fine details which turned out to be very important.

Senator CANNON. Are you in effect, saying that nobody envisioned that you might have a fire and, therefore, you were looking at other things? Is that an oversimplification of it?

Mr. WHITE. Not exactly that, although the end result turned out to be that, yes.

PRESSURE DUMPING SYSTEM

Senator CANNON. Getting back to the technical part of this process—I would like to ask Colonel Borman—it has been stated here that the module could not be opened because of the pressures that built up. There is a pressure dumping system as was explained and I would like to ask you from your standpoint as a pilot, and as an operator, is that a quick release-type system that would be adequate for rapid dumping?

Colonel BORMAN. The system was not sufficient to dump the rapid build up of pressure that we experienced in this fire, sir. There was one dump valve, primarily designed for use again on orbit to expose the spacecraft interior to a vacuum. It was not adequate in the accident.

Senator CANNON. And, will that be one of the items that will have to be redesigned for a rapid dumping system?

Colonel BORMAN. In my opinion, yes, sir.

Senator CANNON. Now, Dr. Thompson, on page 8 of your statement, you say the majority of tests and analyses have been completed. The tests remaining to be completed will not affect the conclusions arrived at in the report.

If they will not affect the conclusions, why are you conducting other tests?

Dr. THOMPSON. We started a series of tests. The Board sponsored certain tests to pursue its review and those tests were not all completed at the time we considered that we had enough information to draw our conclusions from them.

However, the information being developed by those tests seems to be of sufficient interest so that we would like to have those tests completed and put into our final report in appendix G. So, they will have benefit to the future, although we do not depend on them for our determination at this time. They are technical matters that we thought ought to be completed.

Senator CANNON. And, may eventually affect redesign of the capsule in some other particulars.

Dr. THOMPSON. They will be useful in the future for those who are going to carry out the program and perhaps relative to redesign.

DISCUSSES WIRING CONDITIONS

Senator CANNON. Now, in your statement, you identified the conditions that led to the disaster and I would like you to explain, if you will, the third one where you say vulnerable wiring carrying spacecraft power. Do you relate there to wiring that is vulnerable under fire conditions or otherwise vulnerable wire?

Dr. THOMPSON. The vulnerable wire I think, was pretty well explained by the discussion here. I will interpret it this way: That there were certain wire bundles that were subject apparently to pressures that can ultimately result in failure of the insulation. Now, this insulation is very good from the fire standpoint. But, I believe it was noted that it has a characteristic for cold flow.

The cold flow that we referred to can be important if a wire bundle carrying power, presses on a sharp edge so that there is a fairly high amount of pressure on a point and it can be that under continual pressure it will break through, cut through insulation and make a short or fire. When wires with this type of insulation are installed, it is very important to see that their good characteristics are not offset by some disregard for this characteristic; and this is one of the principal things that we had in mind.

Senator CANNON. That is a well-known feature. That was known to you long before NASA was ever organized when you were related with its predecessor. Why is this matter found to be of particular importance at this point, when it is well known in the trade and has been for many years?

Dr. THOMPSON. The characteristics of this particular insulation, which is a new one, relatively new in the field, because of its fire resistance, is important. This particular type of insulation is very good from a flammability standpoint, but it does have this other characteristic that requires additional care in utilization of it.

74-521 O—67—pt. 3——5

RUSSIANS USE NITROGEN AND OXYGEN

Senator CANNON. Now, in your reference to the use of a, you call it a diluent gas——

Dr. THOMPSON. Yes, sir.

Senator CANNON. I would like to ask what is the Russian system? What do the Russians use?

Dr. THOMPSON. Col. Borman knows perhaps as much about that as anybody.

Colonel BORMAN. The Russians, to the best of my knowledge, sir, use a 14.7-pounds-per-square-inch atmosphere with essentially air. Nitrogen and oxygen.

Senator CANNON. Did they use that throughout the flight or just for ground?

Colonel BORMAN. No, sir. I believe they use it throughout the flight. This is based on discussions that I have had with Russian engineers when you and I met in Las Vegas the last time I saw you.

QUESTIONS NEED FOR TWO-GAS SYSTEM

Senator CANNON. And is the consideration now that we may go to diluent gas system on the ground and then to a pure oxygen system airborne? Is that what is now being considered?

Colonel BORMAN. Sir, I have, if I may, at least two hats when I testify. One as a Board member and one as a crewmember. I would like to answer that in my capacity as a crewmember, if you will.

Senator CANNON. Fine.

Colonel BORMAN. It would be my hope that the approach we take would be to remove the flammables from the spacecraft interior. Oxygen per se is not dangerous. It requires an ignition source, combustible materials and, of course, in an oxygen atmosphere you have a severely hazardous situation.

I would hope that we are able to remove enough of the combustibles, and to strategically locate those that remain, so that we can continue to use a hundred percent oxygen atmosphere.

The use of a two-gas system on the pad and then the resultant requirement to purge upon reaching operational altitude in my mind is very undesirable. This means that you would have to expose a command module to a vacuum almost immediately after insertion into orbit unless you were willing to stay in your suits for 4 to 5 days while the normal leakage bleeds off the nitrogen.

So I would hope that the management can find ways to remove—to replace many of the combustible materials, to strategically locate the others, and then to test the reconfigured spacecraft with a full-scale mockup such as we have recommended; and to prove that in this 16.7-pounds-per-square-inch oxygen with the new materials, regardless of where we might have an ignition source, we will not have the disaster that we had at Cape Kennedy.

CREW IS FINAL REVIEW BOARD ON MAKING FLIGHT

Senator CANNON. Now, is your judgment in that regard affected in any way by the time schedule in the Apollo program, the fact that if we went to a two-gas system it might delay the objective of the program?

Colonel BORMAN. Sir, I would be remiss if I did not admit that I am extremely anxious to meet the goals of this program. I am extremely—quite frankly, personally I am very anxious to make sure that, to see that we have an American lunar landing first. That is a personal desire.

However, never since I have been associated with NASA have I ever experienced any decision where a known detriment to crew safety was sacrificed to any operational requirement. And although I am willing to accept risk as I pointed out yesterday to the House committee, I am not willing personally to accept undue risk and I would not participate in any decision which I thought was expediting a program in an unsafe manner; and in the final analysis the crew is the real review board because if we do not like the way the spacecraft is configured, we don't have to get in.

Senator CANNON. And you would have no hesitancy if your recommendations were followed; you would have no hesitancy as a pilot yourself to proceed on that basis?

Colonel BORMAN. That is correct, sir.

Dr. THOMPSON. Could I add something on that point, Senator?

Senator CANNON. Yes, sir; you may.

COMPARES ONE-GAS AND TWO-GAS SYSTEMS

Dr. THOMPSON. I referred in my statement to the necessity for working out all the operations that would be associated with the two-gas system. Those problems have not been solved and whereas we have a very extensive record of reliable operation with oxygen, pure oxygen, in flight, we have no record that shows that we really know how to work with all these problems of diluent gas, identification of all the constituents in there, all the machinery or all the mechanisms that would be required to get out of the spacecraft and go into space; get out of the spacecraft and get on the moon, get back in.

Now, those problems are very considerable and as long as we are able to go along with this system that has proven to be so reliable until this last event; I think there is a pretty strong compulsion to stay with it.

Now, there are times I think if a craft is going to stay in space for long periods of time, it will probably be necessary to use a two-gas diluent system. But those problems, say, are not solved and I think we have to be very careful in trading off the unknowns of an unproven system for one identifiable item of risk in a well-proven system.

So that our feeling is that one of the most important things is to deal with matters as Colonel Borman has talked about, we have talked about getting rid of the sources of ignition, reducing the combustibles, making a greater use of materials that will not easily ignite, and otherwise reengineering the interior relative to this whole question of ignition and flammability rather than say we want to undertake a risk that we have not even properly assessed.

BOARD PERSONNEL DISCUSSED

Senator CANNON. Thank you, Doctor.

My time is about up. I would like to ask you just one final question relating back to my initial point.

There has been some criticism as you know that there are, or were too many NASA personnel and not enough outside experts on the Review Board.

What would have been the effect of bringing in more non-NASA experts in your judgment?

Dr. THOMPSON. In my opinion it would have been rather difficult. If Dr. Van Dolah does not mind my referring to his indoctrination into the system required to pursue a review of this magnitude without familiarity with it, I am sure he will agree that at times he became very impatient with the system because it seemed to get in the way of progress, but the system is the one thing, paperwork, the direction to people, is one of the major elements that makes a program like this possible, that makes it possible to organize efforts on a large scale with people on a 24-hour basis and a 7-day week basis and that system at times gets in the way of quick steps, but if we did not have people who were conversant with that, I am afraid we would have been very—would have felt frustrated and probably would have had a lot of trouble with them.

Senator CANNON. When you say "had a lot of trouble with them," do you mean just delaying your decisions or——

Dr. THOMPSON. I think it would——

Senator CANNON. Or impeding progress?

Dr. THOMPSON. I think they would have felt frustrated and felt dissatisfied with the lack of progress.

Senator CANNON. We are not concerned here with what the members might have felt. We are concerned with what the Board might find and might have found and what they can report to this committee and to the public.

Dr. THOMPSON. We acquired a great many experts to work with the Board. We canvassed the whole country and we got an extremely responsive effort from experts in all areas wherever we looked for help, and some volunteered their help and were very helpful, and I don't think, in any way, we suffered from lack of expertise in the areas that we pursued because the country as a whole seemed to be very, very interested in contributing anything that they could.

The heads of—well, the president of MIT, and the other colleges, offered to help and did contribute. We got help, expertness from the FAA, the CAB. We employed the expert assistance of the Naval Research, one of the Naval Research's most active people on fire. I don't see how we could have gotten much better help than we had.

Colonel BORMAN. Sir, don't you think really it is safe to say that regardless of who composed the Board, the findings and determinations and recommendations would probably not have been materially changed. Is that what you are getting at?

Senator CANNON. That is what I am trying to get at.

If that is your conclusion, I am very happy to have it, Colonel.

Do you agree with that, Doctor?

Dr. THOMPSON. I think that we were able to do an adequate job with the people that we had and with all the help that we got and I don't see how we could have much improved our capability.

Senator CANNON. And you had all the expert help you needed according to your testimony.

Dr. THOMPSON. Expert help from any source we asked for help, we got it.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Before Senator Curtis starts, will you please review the statements by panel No. 9—Design Review Panel—on page D-9-6 and give us some statement this afternoon because in that report the panel speaks of design deficiencies. It says: "Some areas of wiring exhibited what would be referred to as rat nests." I think those are pretty strong words and you might have something to say.

Senator Curtis?

BELIEVES FIRE DUE TO ERROR IN JUDGMENT

Senator CURTIS. Thank you, Mr. Chairman.

Did this fire occur because of a wrong decision or decisions made by our space scientists?

Dr. THOMPSON. I don't think it was a particular decision that caused it. I think it was a situation as has been pretty clearly described that resulted in it but I don't see any particular decision that caused it.

I don't see how we could identify it beyond what we have already described in that connection.

Senator CURTIS. What I want to know is this. Was the error or shortcoming, if there were such, in the field of scientific decision, of our space scientists, or was it in the area of executing what our space scientists said should be done?

Dr. THOMPSON. I think it was an error in judgment in identifying how great the risk was with what we saw there and as Colonel Borman has said, he knew about those things and the risk that apparently lay there had not revealed itself to the point that people thought it was too great to undertake the flight.

Senator CURTIS. Well, maybe I have not stated my question very well but what I am trying to get at is this. Was the plan scientifically wrong or was the shortcoming in executing the plan?

Dr. THOMPSON. There was nothing wrong with the plan that I know of.

As far as being scientifically wrong, I don't think there was anything wrong in that sense. It was simply the execution, detailed execution that resulted in this event.

Senator CURTIS. Do you concur in that, Colonel Borman?

Colonel BORMAN. Yes, sir.

Senator CURTIS. I believe you stated that you were aware of defects or problems in wiring prior to going on this board.

Colonel BORMAN. Yes, sir. I was on the backup crew for the sister ship to Spacecraft 012 and there were problems in wiring.

I must point out there are problems in the development of every vehicle.

Senator CURTIS. I understand.

Colonel BORMAN. And these were normal problems.

ASTRONAUT WOULD NOT HESITATE TO ENTER SPACECRAFT

Senator CURTIS. Now, would you have entered that spacecraft on this morning of the accident if your turn had been called?

Colonel BORMAN. Yes, sir. As a matter of fact,——

Senator CURTIS. Would you have had any hesitancy?

Colonel BORMAN. No, sir.

Senator CURTIS. And would you have been mindful of what you have just stated about criticism of some of the wiring?

Colonel BORMAN. No, sir; because in my opinion the people that were responsible for that spacecraft, including the crew, and the crew assumes a major interest in the reliability of the hardware, felt that the defects that had been noted throughout the development had been corrected and the spacecraft as it existed prior to this test was believed to be in good shape.

Senator CURTIS. Were there defects of workmanship?

Colonel BORMAN. There were, sir.

Senator CURTIS. Did they go beyond workmanship?

Colonel BORMAN. Defects in the design of the wire bundles, their routing, their construction, and in my opinion, a basic deficiency in the wiring, in the harnesses, that distribute electrical energy.

Senator CURTIS. Well, if you would have entered that spaceship that morning, would you have been motivated by a willingness for a risk taking?

Colonel BORMAN. No, sir. As I pointed out earlier, I am afraid that sometimes the newspapers and the magazines attest a great deal more of the silk scarf attitude to the astronauts than actually exists. I am willing to accept reasonable risks in pursuit of worthwhile goals but I am not willing to accept any undue risk.

Senator CURTIS. I understand.

Colonel BORMAN. So I would not have entered that spacecraft if I would have thought there was any danger of the disaster that occurred.

Senator CURTIS. In other words, while you were critical of some of the wiring, workmanship, and design, you were never critical to the point that you would say, "Well, I would not get in one of those"?

Colonel BORMAN. That is correct, sir.

FIRE LASTED 25 SECONDS

Senator CURTIS. How long did that fire last?

Colonel BORMAN. Dr. Van Dolah—excuse me, may I ask him?

Senator CURTIS. Yes, sir.

Dr. VAN DOLAH. It probably lasted only about 25 seconds, sir.

Senator CURTIS. Did the fire extend beyond the time that the astronauts died, do you think?

Dr. VAN DOLAH. Well, I might say that the fire presumably went out at about 30 seconds after the minute, some 25 seconds after we had the first report that there was a fire in the spacecraft.

The levels of carbon monoxide were very high at that time because of the deficiency of oxygen for the combustion.

I think that the medical testimony, medical evidence, medical opinion states that unconsciousness probably came in a matter of perhaps 30 seconds after the lethal quantities of carbon monoxide developed, 15 to 30 seconds, I believe, and that death followed a few minutes later.

Senator CURTIS. The fire was out, then, when they died?

Dr. VAN DOLAH. Yes, sir.

FAST OPENING HATCH MAY HAVE SAVED CREW

Senator CURTIS. Well, would it have made any difference what kind of an escape hatch there would have been?

Dr. VAN DOLAH. Yes, sir.

As I pointed out in the pressure record that we have of the fire, there was a period of many seconds, many in terms of the total event, perhaps 8 seconds or so before the fire began to be very vigorous. If there had been means for rapid dumping of the pressure and a hatch that could open in 2 or 3 seconds, I believe the crew could have escaped with only minor injuries at most.

Senator CURTIS. Are you prepared to say what kind of a hatch it should be, taking into account that the vehicle be in orbit?

Dr. VAN DOLAH. No, sir. I believe this gets beyond my expertise.

I think that it needs to be quick opening for certain emergencies but needs to have ample protection against accidential opening at times when you don't want it to open, but I believe this is something that others would be better prepared to discuss.

Dr. THOMPSON. Could I say something at this point, Senator?

A hatch design, redesign, was underway prior to this and I think that perhaps Colonel Borman can describe the situation a little bit better than I can relative to that.

Colonel BORMAN. Sir, the hatch that we had on the Apollo 012, Command Module 012, was an inward opening hatch that used the pressure of the spacecraft atmosphere to seal it, help seal it on orbit. It was a hatch that was not desirable for extra-vehicular activities. As a consequence of this, a redesigned hatch for Block II spacecraft was on the way at the time of the fire.

This hatch is being pursued actively now and all Block II spacecraft will have this new hatch. It is an outward opening hatch that will open in a matter of seconds.

Senator CURTIS. Now, if that hatch had been on the vehicle at the time of the accident, would they have escaped?

Colonel BORMAN. In my opinion, yes, sir.

Senator CURTIS. That is all, Mr. Chairman.

The CHAIRMAN. Senator Young?

Senator YOUNG. Thank you, Mr. Chairman.

At this time I have no questions.

The CHAIRMAN. Senator Jordan?

BOARD MEMBERSHIP WELL QUALIFIED

Senator JORDAN. Thank you, Mr. Chairman.

Going back to the line of questioning pursued by Senator Cannon, I am not altogether satisfied, Dr. Thompson, with some of the answers.

I want to go into this a little deeper.

You say in your statement the Apollo 204 Review Board was established by the Administrator of the National Aeronautics and Space Administration on January 27 and was confirmed by memorandums.

Now, we get appointments by the executive branch and confirmations by the Senate in some instances but I don't understand what confirmation by memorandums is.

Will you explain the memorandums and who issued the memorandums?

Dr. THOMPSON. Well, sir, I think this is a case where the paperwork had not quite caught up with the program, some of the same things we talk about in pursuit of this whole endeavor. The events move fast and I accepted the responsibility as Chairman and did not wait for the paperwork to catch up. I talked to Dr. Seamans as we went along, we formulated the course of action. The paperwork caught up with us as indicated by those two memorandums, although we had oral understanding, verbal directions as to what course we would follow.

Senator JORDAN. You have already testified that you believe the members of the Board, members of the panel, and certainly I am not doubting their competence, but you testified that perhaps they were the best qualified to make this in-house investigation.

Is that true?

Dr. THOMPSON. Well, I would say they were qualified to make it. I don't know whether they are best qualified. I think they did a very good job as far as I am concerned. They supported me.

Senator JORDAN. Do you believe that it was necessary to have on this team, making an investigation of itself, the director for reliability and quality of the Apollo program?

Dr. THOMPSON. It was very useful to have someone who was thoroughly conversant with that area on the Board as far as I was concerned and I did not detect in any way that he was withholding because he thought that he was criticizing himself in any way.

Senator JORDAN. Do you believe it would be absolutely essential to have a director of the whole spacecraft operation at Kennedy Space Center on the Board?

Dr. THOMPSON. I thought it was very essential because he was the most knowledgeable one. He certainly has contributed information no one else could have contributed to this Board as far as I can determine.

Senator JORDAN. But your research and the investigations have pointed up very clearly that there was sloppy work in many respects, has it not?

Dr. THOMPSON. I don't understand the question. Stoppage of work?

Senator JORDAN. Sloppy work. Sloppy is the adjective that has been used in describing it.

Dr. THOMPSON. I don't think we used that. I read that perhaps in the newspaper. There was work that we did not think was as good as it should be.

Senator JORDAN. But you think that the men who have those responsibilities in the program are thoroughly competent to make a judgment as to exactly what happened here and how best to remedy it, in the future?

Dr. THOMPSON. I think that we have identified the problems. I think that the action that has to be taken here ought to fall in the area of the program office with the things identified as we have seen them. They may find out things, too. My experience in managing projects is that a manager always has problems. They normally don't have to air them so much in public as these are. However, a manager has to manage and he always has problems and I think we have helped identify some of the problems that management has.

Senator JORDAN. Well, criticism has been leveled, Dr. Thompson, and I think will continue to be leveled, at the fact that the Board was predominantly staffed by members of NASA. As a matter of fact, staffed by the very people who had the responsibility for the execution of this part of the program. That is true, is it not?

Dr. THOMPSON. Yes. I think that that criticism will probably persist.

Senator JORDAN. And you think even so this particular Board could do a more objective job than could a board of independent status and background?

Dr. THOMPSON. My position is that we needed people who are very knowledgeable about the program to run this review.

Now, if we had had to get too many people who did not know how to do that, were not familiar with all the system, I think we would have had a very difficult job in moving as fast and effectively as we did.

CERTIFICATE OF FLIGHT WORTHINESS ISSUED

Senator JORDAN. The Board's report, states that in August 1966 a review of the spacecraft was conducted by NASA at the contractor's plant. Where was the contractor's plant?

Dr. THOMPSON. Downey, Calif.

Senator JORDAN. Afterward, NASA issued a certificate of flight worthiness and authorized the spacecraft to be shipped to Cape Kennedy.

The report further states that the certificate included a listing of open items and work to be accomplished at Kennedy, and one of the findings in the report states that there were 113 significant engineering orders not accomplished at the time the Command Module was delivered to NASA and yet it was given a certificate of flight worthiness at the point where it was manufactured in California.

Who would give it that certificate of flight worthiness at that point?

Dr. THOMPSON. The program manager for the Apollo Spacecraft program.

Senator JORDAN. Even though it had 113 significant orders not accomplished at that time?

Dr. THOMPSON. I think that this is a situation a program manager always has to face when it was not an off-the-shelf item. He made some judgments and he identified the number of open items and he made the judgment that it was time to ship in order to keep things moving properly.

Senator JORDAN. Is it usual to issue a certificate of acceptance when there are so many significant changes still to be made?

Dr. THOMPSON. There are a series of signoffs and I am not sure just—I am not at all certain that there is not always this element.

As a matter of fact, I am almost positive there is this element of lack of completion involved in this act. There has to be a judgment as to whether or not it is proper in view of that, whether the work properly should be accomplished during the next phase of the program.

Senator JORDAN. Were all these significant engineering changes eventually accomplished before initiation of manned testing of the spacecraft in the pure oxygen environment?

Dr. THOMPSON. John, do you not have the answer to that?

Mr. WILLIAMS. We had to do research. Anything that would affect the pure oxygen environment was accomplished prior to the first manned——

Senator JORDAN. A little louder, please.

Mr. WILLIAMS. Anything that would affect the spacecraft, 113 items, in a pure oxygen atmosphere had been accomplished prior to the altitude chamber run last October or November.

Dr. THOMPSON. Let me add one point.

Senator JORDAN. Yes, go ahead.

Dr. THOMPSON. The completion—the requirement for completion of all those items is judged in relation to what is being done at that particular time, too, though that does not mean that it is actually necessarily flight ready. Certain things could be left undone, at least conceivably they could be left undone and still not involve risk.

Senator JORDAN. Then it would follow that on the next page of your report you state that in December of that year the program director conducted a recertification review which closed out the majority of those open items, but would you define what is meant by "closed out"?

What do you mean when you say "closed out"?

Mr. WILLIAMS. Mr. White?

Mr. WHITE. An item is considered to be closed out when the deficiency has been corrected or it has been determined that it is not significant to the safety of the spacecraft. This involves an engineering review and signoff of a piece of paper that has this deficiency recorded on it.

While I have the microphone, here, if I may, I would like to make another statement with regard to this certificate of flight worthiness.

When the certificate is signed, it does include a list of exceptions, and it is considered normal practice that not every single one of these deficiencies must be corrected before shipment. They are listed and this list is transferred then to Cape Kennedy so that they are corrected at that point.

Senator JORDAN. Were any deficiencies listed with respect to the wiring?

Mr. WHITE. I believe there were. I can't specifically list them.

Senator JORDAN. And in your judgment they were corrected at Kennedy Space Center prior to this test?

Mr. WHITE. The deficiencies that were known to be dangerous, I would say, had been corrected.

We depend quite a bit on the tests that are conducted at the Cape which essentially operate all systems and do put power in all systems. Thereby we find whether or not there is a short or an open circuit or something of this sort.

The deficiencies of the nature of the wire routing, inadequate clearances, and lack of protection may not in all cases have been corrected.

Senator JORDAN. Had those safety precautions been taken with respect to this particular spacecraft prior to the test?

Mr. WHITE. What steps did you mean, Senator?

Senator JORDAN. The safety precautions of checking out the wiring and checking out the whole program for ——

Mr. WHITE. Yes.

Senator JORDAN. For safety?

Mr. WHITE. Yes, sir.

There had been other tests run. There had been tests run in the space chamber at Cape Kennedy, two manned tests and two unmanned tests, which did operate all systems satisfactorily.

We did not encounter any problems of the sort that occurred on the pad.

QUESTIONS CONDITION OF GAS MASKS

Senator JORDAN. Going to another matter, I had very little time to get through this voluminous report but I did note that certain individuals testified that the gas masks were either faulty or did not fit well enough to prevent leaks.

Is such equipment kept in a constant state of readiness and repair and have the personnel been trained in their use?

Dr. THOMPSON. Dr. Van Dolah?

Dr. VAN DOLAH. The majority of the gas masks that were available on the pad were masks that were designed to handle toxic fumes from the hypergolic propellants in that area.

They were not designed, with only four exceptions, to handle smoke and there is some question about whether the ones designed for smoke could actually handle the rather bad smoke conditions that existed at the time of the fire at the spacecraft level.

Senator JORDAN. The point is no one expected this kind of problem.

Dr. VAN DOLAH. That is correct.

Senator JORDAN (continuing). With this spacecraft at that time, is this right?

Dr. VAN DOLAH. That is correct, and I might go on to say that all of the personnel on the pad as far as I know were trained in the use of these masks. It was primarily the design of the mask itself.

Senator JORDAN. Thank you.

The CHAIRMAN. Does any other Senator have questions?

Senator Percy?

We will meet back here this afternoon at 2:30 instead of 2 o'clock, in this room rather than the room previously announced.

Senator Mondale?

WRENCH SOCKET FOUND IN SPACECRAFT

Senator MONDALE. Mr. Thompson, pictures of the probable source of the fire show a wrench socket.

Dr. THOMPSON. Yes, sir.

Colonel BORMAN. That is not the problem.

Senator MONDALE. The stories say it has nothing to do with the cause of the fire.

Was that wrench socket supposed to be there?

Dr. THOMPSON. No. I don't think it was.

Senator MONDALE. Isn't that rather illuminating evidence of lack of adequate attention to detail?

Dr. THOMPSON. It got left there. I am not too familiar with all the procedures that are followed to see that workmen don't lose tools and not recover them. I have heard of processes of shaking the spacecraft, and so forth, but having seen that there, it seems to be quite noteworthy that it had not been recovered.

QUESTIONS FLEXIBILITY OF MANAGEMENT WITHOUT LICENSE

Senator MONDALE. You indicated that you thought one of the management objectives of the program ought to be flexibility without license. To me that carried with it an implication that you had observed some evidence of license in the operation of the program.

Could you give us examples of what you had in mind when you made that statement?

Dr. THOMPSON. We did not observe the license.

We observed what we call the cumbersomeness of process.

Senator MONDALE. Could you give us an example?

Dr. THOMPSON. The problem in dealing with the changes in test programs at the Cape, I think that perhaps Mr. John Williams can describe some of the incidents to illustrate the point.

Mr. WILLIAMS. I think that the test program was outlined from the MSC to the Cape in the form of a GORP, a ground operations document. This is then answered by test outline and the change in GORP. A change in the GORP document requires a contract change. This goes back to the contractor and they put out the test specifications back down to the Cape, the OCP is implemented, and it is quite a long road, a long way to go to make changes in a particularly flexible program.

Senator MONDALE. Did you have any specifics in mind when you said the objective of the program from a management standpoint ought to be flexibility without license or were you speaking without a specific example?

Dr. THOMPSON. I addressed myself to the problem that is pretty well identified here I think in appendix D, page 7 of the report, which went into this in considerable detail and this is a difficult problem that I think has not quite been solved.

I think this is a problem that the management has got to try to figure out a procedure for introducing as well as they can. They cannot give up the controls but at the same time they have got a dynamic program going on and somehow or other it seems as though it would be possible to introduce a quicker response system to those dynamic requirements.

We are addressing ourselves to that problem. We have not arrived at specific recommendations to management, just how to do that.

I think that would require considerable study.

WIRING DEFICIENCIES

Senator MONDALE. Colonel Borman indicated the existence of what I think he described as a basic deficiency in wiring or basic deficiencies in wiring.

Did you identify whose responsibility or whose fault that was?

Colonel BORMAN. Yes, sir.

I believe that the responsibility for the—at least the initial design, was with the contractor.

Of course, the ultimate responsibility is NASA's because NASA has the requirement to approve the design, monitor the design and check on the workmanship involved.

So I think it is a shared responsibility.

COMBUSTIBLE MATERIALS

Senator MONDALE. What about the apparently excessive quantity of combustible materials present at the time of this fire? I think someone indicated nearly 70 pounds of combustible material of one kind or another was in that spacecraft.

As I understand it, there is a procedure by which before any materials can be introduced in the spacecraft, they have to be approved, for several reasons, and I assume one of the tests would be combustibility.

Were some of these materials of a combustible nature introduced into the spacecraft without complying with that procedure?

Colonel BORMAN. Yes, sir; some of them were. For instance, the pads that the hatch was to be rested on, you saw those black pads, they were not flight items. The configuration of the spacecraft is an evolving thing. When we finally get to the flight day, launch day, we have a spacecraft that would not have many of the combustibles in it that were in this particular spacecraft.

However, some of the specifications that NASA used for putting combustibles within the spacecraft were sufficiently or too permissive. Some of the equipment that we did not, or that we thought was relatively harmless if kept away from wires turned out to burn very readily.

Senator MONDALE. Did the Commission seek to establish responsibility for that failure to comply with regulations?

Colonel BORMAN. Well, sir, by the failure, you mean the putting in the——

Senator MONDALE. In other words, the fact that substantial quantities of combustible materials were in fact in the spacecraft contrary to procedures that were to be followed in such tests.

Did anybody seek to establish who was responsible for this oversight?

Colonel BORMAN. Yes, sir.

I believe that the responsibility—there were two different problems. One was the fact that for flight we had too many combustibles in the spacecraft.

Now, in some cases these combustibles were installed in violation of NASA specifications.

Senator MONDALE. By whom?

Colonel BORMAN. By the contractor, they are installed by the contractor but the——

Senator MONDALE. With the approval of the Program Office?

Colonel BORMAN. Yes, sir. In other cases the specifications were not rigid enough we know now, and it involved—involves the items that were in for this test only, the mats and the protective liners over the umbilical cords, they were all in and their presence was noted but the fact that they were in was not believed to present a hazard and so although they were properly noted and their presence was documented, they still were there.

VIBRATION TEST

Senator MONDALE. Mr. Thompson, according to reports, spacecraft 012 was delivered to the Cape without being vibration tested, is that correct?

Dr. THOMPSON. Yes, sir.

Senator MONDALE. How did that happen?

Why didn't that test take place?

Dr. THOMPSON. Well, as I understand it, a management decision was made to depend on the very rigid component testing—components had been subjected to a very rigid vibration test.

The thing that we commented on was that the entire spacecraft had not been subjected to an overall vibration test.

The management decision apparently was, as shown by the record, that they would go along with the flight test, unmanned flight test, and which would in their opinion constitute a measure of the capability for this spacecraft to withstand this vibration, and that was done.

Senator MONDALE. Weren't you critical of the fact that this had not been vibration tested?

Dr. THOMPSON. We were critical because the view that we have is that the best way to really find out whether a spacecraft of this type, now, not the one that will be man flown but a spacecraft of this type with all installations abroad, will stand the vibration that is experienced, particularly through the boost period, is to vibrate it and vibrate it at a certain level that gives a vibration level that is equal to the level that will be experienced during the launch period if it could be identified, and certainly it is shaped identified now, plus a factor of about 50 percent in time. That is a procedure that is used in most spacecraft.

Senator MONDALE. Did you seek to identify responsibility for this failure? In your——

Dr. THOMPSON. Failure to ——

Senator MONDALE. Failure to perform the vibration test of the spacecraft? Was any attempt made to assess——

Dr. THOMPSON. The program office. I don't know exactly who in the program manager's office but the decision was made to proceed that way.

Senator MONDALE. Would you say that—would it be fair to characterize your report as concluding that this spacecraft was not ready for flight? That it should have been vibration tested?

Dr. THOMPSON. Well, I would hesitate to say that it was not really ready for flight. It certainly is shown now by hindsight to have had risk in it that indicates it was not ready for flight.

The judgment there includes—all these things that have been done and relative to the particular vibration test, I think reliance was put on the flights that had been made. If I had been responsible at that point, whether I would have declared my own, as directing the program, that it was ready or not I don't know. I am not sure whether I would or would not.

I did think that this vibration test was a better assurance of the reliability of the spacecraft.

Colonel BORMAN. Sir, may I add something?

Dr. THOMPSON. Colonel Borman wants to add something.

Colonel BORMAN. I think if you would phrase the question, did the people that were concerned at the time feel that the spacecraft was ready for that test, to the best of their knowledge, the answer would be an unqualified "Yes".

I talked to Ed White shortly before. The crew thought they were over a lot of the problems and they were on the way. The night of the accident I talked to Wally Schirra who had just returned from running the test on a spacecraft and he was really dumfounded that the tragedy could have occurred because he had felt the spacecraft had evolved into a workable machine.

So I think if you put it in the time frame when the accident occurred, you have to say the people were satisfied.

CITES POLICY QUESTION

Senator MONDALE. Thank you, Colonel.

Mr. Chairman, if I may, I would like to make one observation here that I think is brought out by these questions.

It seems to me that this report is very sound in the technical and engineering field.

We get precise clearances as far as could humanly be determined after this tragedy and the destruction that followed the fire.

But it seems to me that our committee's responsibility is in the policy question, the management field. We should not try to compete with you in building a better spacecraft or being better pilots. Our basic question is whether it is being managed well, whether the policy approaches underlying the program are sound, and it seems to me in this particular field as distinguished from the engineering side that we are not getting the kind of hard answers that we need to do our job.

The CHAIRMAN. Well, I would think that Mr. Webb might be here on Thursday and we might ask him some questions at that time.

Senator Percy?

Senator PERCY. Colonel Borman, you mentioned before that you would not have hesitated on this fateful day to enter the spacecraft yourself knowing what you did at that time.

I now ask the obvious question.

Knowing what you know now, would you have refused to enter the spacecraft on that day?

Colonel BORMAN. Yes, sir.

CITES AREAS OF DEFICIENCY

Senator PERCY. Could you describe in lay terms the outstanding characteristics of the spacecraft that you feel now in retrospect were deficient?

Colonel BORMAN. Yes, sir. I think that the deficiencies that we have noted here, if I were to single them out, I think the first basic deficiency was in the fact that the test was not identified and classified as a hazardous test.

Now, this was a failure in the procedures and in management, if you will.

The second deficiency was we had combustibles, too many combustibles within the spacecraft contiguous to ignition sources and in a 16.7 pure oxygen atmosphere.

This was a deficiency.

The third basic deficiency was the fact that we had vulnerable wiring that provided the ignition source.

Senator PERCY. Do you feel that responsible management could have detected these with adequate testing, ahead of time?

Colonel BORMAN. Sir, the answer is "No," but if I may expound, this spacecraft had undergone 6½ hours of testing under the exact same conditions at the Cape without any problems involving arcs, sparks, or any sort of short circuits.

It had undergone 62.2 hours of testing in an oxygen environment without any of these difficulties. I think that in pointing out the deficiencies as we have done in a very frank manner we often overlook the fact that there is a great deal of effort to overcome and to pinpoint these.

Now, unfortunately we were not successful in this case.

Senator PERCY. Mr. Chairman, there is some doubt as to whether I can get back this afternoon.

Could I ask a question or two of Mr. Webb?

The CHAIRMAN. Excuse me.

Senator PERCY. Will Mr. Webb be speaking or testifying this afternoon?

The CHAIRMAN. He will not be testifying this afternoon.

I would prefer to wait for questions for Mr. Webb until he appears.

Senator PERCY. Would you prefer to hold those over until then?

The CHAIRMAN. If it is agreeable to you.

Senator PERCY. I will try to return if I can.

There is some doubt whether I can get back.

The CHAIRMAN. Thursday afternoon will be the time Mr. Webb testifies.

Senator PERCY. All right. Fine. I will hold off until then, Mr. Webb.

Thank you, sir. I have no further questions.

The CHAIRMAN. Any more questions?

Dr. THOMPSON. Mr. Chairman——

Senator PERCY. I will wait until Thursday.

The CHAIRMAN. Yes. Doctor?

COMPARING OF RATIO OF COMBUSTIBLES IN APOLLO AND GEMINI

Dr. THOMPSON. One point that has constantly come up here in a large amount of combustibles within the spacecraft, but in comparison with the previous spacecraft I think the ratio per man is about the same. That is, in other words, somewhere around 20 pounds, a little over 20 pounds per man, and I believe that in the Gemini—someone made the calculation for me the other day and showed that the Gemini—I think the spacecraft had about 20 pounds per man, too. This one has 70 which is a little over 20 pounds per man.

I thought it was a matter of interest to clarify the impression that it was a very large amount of combustible material, perhaps out of line with previous experience.

The CHAIRMAN. We will meet, then, at 2:30 again this afternoon in this room.

(Whereupon, at 1 p.m., the committee was recessed, to reconvene at 2:30 p.m., of the same day.)

AFTERNOON SESSION

(The hearing resumed in the afternoon at 2:30 o'clock with the same witnesses.)

The CHAIRMAN. Dr. Thompson, this morning in answer to one of my questions, to what would you attribute design and other deficiencies set forth in your report, you said somehow it—meaning quality—was not attained.

QUALITY RESPONSIBILITIES DISCUSSED

It seems to me that that is a function of management. If you set out to do something and you get a bad job, you do not blame the workmen. Do you blame these difficulties on management or the workers, these conditions?

Dr. THOMPSON. Well, it seems to me management to the extent that they did not manage to get the workmanship into it. Just where that falls is a little bit difficult to say. The process somehow or other did not arrive at good workmanship, and the element—that goes back to management—they failed to get it and in that sense I guess is where it lies.

The CHAIRMAN. In conducting your review did you have any difficulty in determining who was responsible for a particular activity?

Dr. THOMPSON. I do not think we did. We have a very good delineation of the organization and responsibilities. I think all those can be pretty well traced down through the information we have.

The CHAIRMAN. This responsibility——

Dr. THOMPSON. Appendix E deals in the matter of organization, line responsibility.

The CHAIRMAN. Well, was this matter of responsibility clearly defined, do you think?

Dr. THOMPSON. I think it is; yes, sir.

The CHAIRMAN. Were there any voids or duplications?

Dr. THOMPSON. We thought that the delineation of responsibilities was very well defined there. I would not say there were any voids that were apparent to us or unnecessary duplications.

The CHAIRMAN. Do you feel that there has been a division of responsibility which contributed to the fact that the desired quality levels were not achieved, for example, divisions of responsibility between the Manned Spacecraft Center and North American Aviation? Were they properly defined?

Dr. THOMPSON. I think that the relationship between MSC, yes, Manned Spacecraft Center, and North American were very well defined, yes, sir.

The CHAIRMAN. Do you feel that about—the same definition exists on Apollo as on Mercury?

Dr. THOMPSON. I am not too familiar with the exact definition that was used of responsibilities in Mercury. As far as I know—well, I really do not have anything to base an opinion on, I guess.

The CHAIRMAN. That is the best answer you can give me, Doctor, if that is the situation.

Dr. THOMPSON. Yes, sir.

The CHAIRMAN. In its finding No. 5, the Board referred to "Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous." Was there one specific organization responsible for establishing the practices for this test?

Dr. THOMPSON. Well, as to that it is a fairly complex matter that involves not only the line organization but the criteria that are used for defining hazardous operations, and they are different levels involved in those decisions.

Without a proper definition of criteria to clearly define what is hazardous and what is not, you cannot exactly blame a line organization for not imposing—for not having a good program when all they are doing is dealing with criteria that are not quite adequate to the situation so it is sort of a mixture of levels.

I think the reason we couch it in those terms is that there is a mixture of responsibilities required to really assess the criteria and then impose and direct the line organization and set up the proper organization to see that those criteria are properly applied.

It is a little bit more than just one aspect to it. So there is some combination of organizational elements involved, it is NASA and the contractor. The contractor is the main arm that implements the program. NASA has the responsibility to see that they do it, and hold them to it. It is not too easy to just say that this one element is responsible for any particular deficiency when there is a mixture of that kind. I think it needs a pretty general review to correct the situations that have been identified.

PRAISES SELECTION OF PANEL

The CHAIRMAN. This morning, Doctor, I had the impression that there were some questions which would indicate that the panel was not very well selected because of the employees and associates. I want to say I know how hard it is to do, having had a few years experience with atomic energy when they had an examination. I think it is a very good panel that got real good results, and I do not know where you could have gone to find that type of individual outside the organization.

I may be the only one, but I, for one, feel that the panel is well picked.

Dr. THOMPSON. Thank you, sir.

The CHAIRMAN. Thank you.

Was there any one specific organization responsible for establishing procedures for this test?

Dr. THOMPSON. The contractor is responsible for that. Whatever the contractor does had to be approved by NASA so that what the contractor does is subject to that approval, but then again going back to the criteria again, they also have probably somewhat a mixture of responsibility, although NASA always is in a position of ultimate responsibility for it.

What really need review are the criteria and a complete study of those things that are pertinent to an adequate safety program.

QUESTION OF OXYGEN

The CHAIRMAN. I was wondering, if a decision is to be reached about oxygen as the sole atmospheric gas, where would a nonscientific member of the committee such as I am, find out what the judgments might be? I would like to help get a clear decision on that question of oxygen.

It seems to me in looking at it that it is pretty complicated for a lay person to decide that.

Dr. THOMPSON. Well, I do not believe there is any subject that has been studied more than that particular thing.

The one we talked about is the one common in this room, that is nitrogen that is a common diluent for the oxygen, and there are advantages from a favorability standpoint of having air as is in this room.

However, another one that is discussed and considered, has been studied at great length, is helium, and helium has the possibilities of being a suitable diluent. Neither one of them escaped the danger of bends. If a person has this gas in his system and is subject to sudden depressurization, he gets the bends, and that is one of the hazards that goes along with a two-gas system.

Now, beyond that, as soon as you have a two-gas system, you have a mixture of gases in your spacecraft and then you must have, first of all, a means for identifying what you have there, the problem of identifying the mixture so that you know in fact that what the astronaut is getting is oxygen and in proper proportion, and not all nitrogen or all helium or all carbon monoxide or a disproportionate amount of those gases, is one of the problems.

A great deal of work has been done in developing the mechanisms, devices by which you can make the proper measurement. What you can do is—there are versions now that according to our recent studies are—I am talking about the Office of Advanced Research and Technology which has research programs in this area—show that there is great promise for means of, we think, for a flight-qualified instrument that will identify the amount of oxygen, the CO_2 and the water vapor. The amount of nitrogen can be identified as to just what is left, and a device of this kind, however, has to be worked out so it really is flight-qualified before you would want to trust or rely on it for a voyage to the moon or any other voyage far away from the earth.

The CHAIRMAN. Do you not have to do this same determination for the MOL?

Dr. THOMPSON. It certainly will have to be developed for the MOL if we are going to use it. I think they are using a two-gas system.

The CHAIRMAN. Some of the people who have to speculate have speculated that you had already decided—I am sorry—that the NASA organization has already decided on a one-gas system, and it makes it kind of hard.

I remember I asked a scientist how I could learn something about this. He said, "Well, you have to respect oxygen, you have to respect pure oxygen."

He said, Some people ignite a match by scratching it on a fingernail. You try that in pure oxygen and it will burn your arm off. I have not tried it.

Dr. THOMPSON. Oxygen has to combine with something else in order to make a complete combustion process. Oxygen by itself is a very useful gas. We all use it and we depend on it, but when it gets in close proximity with certain fuels or what we call fuels or combustible materials, they will then get in trouble, and it is the removal of those things that combine so readily with oxygen that is one of the basic elements of the improvement program that we are talking about.

This whole matter, however, as I say, has been—as a matter of fact, it is a subject of continuous study not only just because of the advantages of having a diluent gas from a flame standpoint but I think there is a pretty substantial body of thought that a man should remain for an indefinite period in an oxygen, pure oxygen, atmosphere. So that in longer duration flights, we would presumably have to have another two-gas system. However, the experience up until now, I believe, leads to a considerable confidence in up to perhaps 30 days of pure oxygen environment is suitable for the man, is not harmful to him. And the simplicity of it and the reliability of it from an operational standpoint is a very important factor in the continued use of it.

The thing to guard against is letting that pure oxygen get too close to things that will burn and then igniting them.

ELECTRICAL SYSTEM DEFICIENCIES

The CHAIRMAN. I asked this morning, and this afternoon you might want to finish your answer of the Board's finding No. 10, that deficiencies existed in the command module design, workmanship and quality control.

To what basic factor do you attribute these deficiencies in almost every aspect of the electrical system?

Dr. THOMPSON. I think we are going back pretty much to the things we have commented on earlier, that we just have not, some how or other, have not borne down enough on all the quality control machinery and have not borne down on the engineering that is necessary to the point that we have gotten what we want or should have out of this.

I can give you an example in the wiring; for example, the wiring that we see in this, particularly in this block I design, is not a very good exhibit of what we consider good wiring practice. What we think it shows is that there has not been a really adequate use of engineering before the wires were installed.

The wires—in order to avoid these problems of having wires go over sharp edges or get in front of doors that have to be opened and then have to go around elements of the vehicle in such a way as to avoid any abrasion or sharp bends—have to be engineered in a very careful way and should use three-dimensional forming to do that.

It is a pretty good engineering exercise to just lay out those wires as an engineering exercise. And this is the thing, I think, that is basically back of the faults that we see in this wiring.

The more wires were added, the conflicts were added, and then the wires were wedded up without just an engineering analysis of just where they should go and how they should be channeled around to avoid trouble of abrasion, how they should be channeled to avoid the danger of people stepping on them or misusing them after installing.

Fundamentally, I think this is what is back of what we have seen there, too much building without the real intensive use of engineering to formulate the design before allowing people to put wiring in.

30 MILES OF WIRE IN SPACECRAFT

I could add just a point perhaps about the wiring: There are according to the figures—I have, 30 miles of wire in a spacecraft, and there are 13,000 segments of wire. That 30 miles is cut up into 13,000 segments, and it does offer a fairly demanding exercise to engineer these wire bundles, 30 miles of wire in pieces so it does not get into some of these problems we see.

NO ESTIMATE ON DELAY OF GOAL

The CHAIRMAN. This question is purely related to your experience on the Board in this matter. You do not have to guess if you do not want to guess at it. What do you believe will be the impact of the accident on the national commitment to land men on the lunar surface and return them safely to earth by 1970? The goal President Kennedy set up where he said we will land a man on the moon and bring him back safely in this decade. Would you care to speculate what the results of that accident might be?

Dr. THOMPSON. Well, I have not tried to do the management exercise and to figure out how they are going to—what work is really necessary to deal with many of these questions we have brought up. We think it is necessary to deal with them, and I think they can all be solved. I do not think we have identified things that are of such fundamental nature that shows anything really wrong in the concept of this vehicle.

I think there are just a number of details that really require correction. Just how long it is going to take to do that is beyond the area of our effort. I think it will undoubtedly take a little longer than was originally anticipated but just how much that is I do not know.

The CHAIRMAN. We all seem to be guessing it might be 6 months or 12 months or 14 months and so forth. I think those have to be guesses, and I just wanted to know if you would guess.

Dr. THOMPSON. I would like to refrain from guessing. I would rather be able to estimate it, and I have not done that because that is a little beyond the area of our effort here, and I think it is more in the field of the program office. I think they are the ones who should make those estimates.

The CHAIRMAN. I have advanced it as a guess.

Senator Smith?

COMPARISON OF SPACECRAFT AND AIRPLANE DEVELOPMENT

Senator SMITH. Yes, Mr. Chairman.

Dr. Thompson, do any of the Board members have specific familiarity and experience with the development and manufacture of commercial and military aircraft?

Dr. THOMPSON. George, do you qualify for that?

Mr. WHITE. I have some experience, yes.

Dr. THOMPSON. Would you like Mr. George White to speak on this? He is familiar with this area.

Senator SMITH. I will address myself to Colonel Strang if you would rather I would.

Dr. THOMPSON. Colonel Strang is in the Office of Safety of the Air Force.

Senator SMITH. Why do I not address my questions to both of them.

Dr. THOMPSON. And see where you get the best response, maybe that is the best technique.

Senator SMITH. Although I recognize that the development and production of aircraft is not as complex as that for the Apollo spacecraft—it was my understanding that we were conducting the Apollo program in such a way as to assure the integrity of production. Could you tell us whether the types and number of deficiencies reported in the Board's report in the area of design, workmanship, and quality control is the type of engineering practice found in the production of commercial or military aircraft?

Mr. WHITE. It has been my experience, Senator Smith, that the type of deficiencies we have found are typical of the deficiencies that are normally found in an airplane development program.

I think one of the significant differences here is that in the case of an airplane development program there is usually one aircraft set aside as an experimental aircraft, at least one, many times three or even more, and these deficiencies are found and corrected in this first experimental aircraft. When the aircraft gets into production, things are usually on a routine basis so that the deficiencies are considerably less.

In our case it was almost tantamount to having the experimental aircraft, in this case the spacecraft, being our first manned spacecraft, so not all of the bugs had been worked out of the system.

Senator SMITH. Well, should they not have been worked out in the unmanned spacecraft?

Mr. WHITE. They were to quite a degree, but not completely.

Senator SMITH. Well, whose responsibility was that?

Mr. WHITE. Well, as I said, this morning—I do not know whether you were here at the time—the original responsibility for manufacturing and for these deficiencies lies with the contractor. However, NASA does have inspectors on the spot in the contractor's facility, and NASA does control the basic policies, so that the ultimate responsibility does lie with NASA.

Senator SMITH. Well, in the aircraft industry would a plane be flown with—and I read from your finding 10—"Deficiencies in design, manufacturing, installation, rework, and quality control existed in the electrical wiring." Would you have gone ahead with aircraft as you did with the space vehicle?

Mr. WHITE. I think for comparable types of deficiencies, yes, this has been done. There have been wiring problems in aircraft that are comparable to what we have had here.

Senator SMITH. Colonel Strang, would you have anything to add?

Colonel STRANG. The only thing I could add, Senator Smith, is that in the Air Force in the missile program we accepted exceptions to the missile system in the line of what Mr. White has just spoken of. They are well-documented so that both the Air Force and the contractor are well aware of what we accept with exceptions.

Senator SMITH. Would an airplane with 113 engineering changes to be made be certified for use for example?

Colonel STRANG. Senator Smith, my remarks were primarily for missiles. In the aircraft side of the house it would be a little different as far as I am concerned in that my experience has been around aircraft maintenance engineering. As you probably know, the Air Force has a team in the contractor's facility that accepts the airplane. The airplane is then delivered to the operational units. That is the area that I would come into; and usually the items of exception—from the experience I have had in the past—would be of a minor nature. Nothing ever to affect the safety of flight.

Senator SMITH. I am using the airplane industry because it is the closest type of program to spacecraft that I can think of.

Colonel STRANG. Yes, ma'am.

Senator SMITH. You may have—Dr. Thompson.

Dr. THOMPSON. Senator Smith, we do have on the Board an ex-test pilot. Maybe you would like to hear from him. Colonel Borman is an ex-test pilot, and maybe he has experience applicable to that situation.

Senator SMITH. Thank you for that Colonel Borman?

Colonel BORMAN. Yes, ma'am, I think just as a general comment it would be safe to say that the level of workmanship or the quality control and care of detail that we find in the spacecraft business is a whole order of magnitude higher than what we ordinarily experience in the aviation business, and this is with due reason, of course, because airplanes have an extended flight test program. You do not have the final dependence upon the system that you do in a spacecraft.

So I think based on my experience in both aviation and the space business that we find a much higher level of redundancy, of detailed engineering and of documentation of effort in the space business than we do in the airplane business.

Senator SMITH. As a layman, would there not be less chance of deficiencies in the case of the spacecraft?

Colonel BORMAN. Yes, ma'am. I think that, by and large, our experience with spacecraft has been phenomenal and the success we have had and in the fine engineering that we have experienced, including the disaster, I would say, by and large, we have gotten probably the best engineering effort and the best workmanship on any machine that has ever been built by man in our space program.

Senator SMITH. I agree with you, and in this tragedy I hope we do not lose sight of that very great accomplishment.

Colonel BORMAN. I hope we get better as a result of it. As a matter of fact, it would be a shame if we did not improve based upon what we have learned from this tragedy.

DISCUSSION OF DEFICIENCIES

Senator SMITH. The main body of the report represents a summary of the Board's findings and conclusions relating to the various areas of the investigation. I believe it would be helpful to the committee if the Board discussed examples of its findings which formed the basis for its conclusions in the following areas: One, the report states that the deficiencies existed in command module design, workmanship and quality control.

Would you please discuss some of the more serious deficiencies found in each of these areas and how they relate to the Board's statement that, and I quote, "These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operation"?

Two, the Board reports that differences existed between ground test procedures and the in-flight checklist. Would you also describe some of the more important differences and explain their significance?

That may be all too much in one question.

Dr. THOMPSON. In appendix D, 9–6, we discuss wiring. We also discuss the so-called ECS, environmental control system plumbing joints.

The wiring specifics, one, wiring of lower equipment bay was routed through narrow channels having 90-degree bends. This could cause mechanical stress on a Teflon installation. Somewhere in these areas was found damage to the sleeve which covered shielded wire. This is in line with what I was saying earlier, and it is particularly important to the use of Teflon insulated wire. Teflon insulation has a very good merit in that it is resistant to flame which is very important for wiring. It is a relatively soft material and has to be handled carefully as regards such things as an abrasion, bearing on sharp edges and so forth.

It goes on, there are several items there, there are items 1 to 6 there, that I think are rather specific and provide a specific basis for our findings.

Senator SMITH. Mr. Chairman, I would ask that the section of the report from which Dr. Thompson is reading be included as a part of his answer if that is agreeable to him.

Dr. THOMPSON. Yes.

The CHAIRMAN. Without objection, that will be done.

(The material referred to follows:)

During the wire inspection, the following design deficiencies were noted:

(1) The wiring in the Lower Equipment Bay (LEB) was routed through narrow channels having many 90 degree bends. This could cause mechanical stress on the Teflon insulation. Some wiring in these areas was found with damage to the sleeve which covers the shielded wire (Enclosure 9–4).

(2) Wire color coding practices were not always adhered to as evidenced by Enclosure 9–5.

(3) Some areas of wiring exhibited what would be referred to as "rats nests" because of the dense, disordered array of wiring. In some instances excessive lengths of wires were looped back and forth to take up the slack. Also, there were instances where wires appeared to have been threaded through bundles which added to the disorder (Enclosures 9–6, 9–7, 9–8, 9–9 and 9–10).

(4) A circuit breaker panel was pressed so close to a wire harness, that wiring indentions were left in the circuit-breaker potting (Enclosure 9–11).

(5) There were wires routed across and along oxygen and water/glycol lines.

(6) The floor wiring and some connectors in the LEB were not completely protected from damage by test personnel and the astronauts. This is evidenced by mashed 22-gauge wires found in some of the wire harnesses.

Dr. THOMPSON. The ECS, the environmental control system plumbing joints—now I make a distinction between ECU, the environmental control unit, and ECS, the environmental control system. The unit has to be connected in as a unit and then by plumbing, as I call it, tubes distribute the coolant and perform its functions of controlling the oxygen through connections to many lines within the spacecraft, so that the whole system is called ECS, and it is the plumbing, the joints, of that ECS that we have particular reference to, and their items 1 to 4, I believe the first one, the ECS design criteria, emphasizing minimum weight, resulted in the selection of aluminum piping with solder joints.

Design approach utilized the kind for the normal operating stresses but failed to account for the loads and stress had by handling it in installation.

Most of our criticism, I think, is summed up in an interpretation of that comment. Very well fabricated solder joints, not subject to anything but the loads which they were really designed to withstand, or the pressures in the line in the protected area, could very well stand up.

The facts of life are that in putting these things in and having them exposed to the problems or installation, other activities around the area, the movement of people, and subject to the vibration of the spacecraft, that the loads on those joints, the stresses on those joints, even though they might be very well made, would fail, because they just do not have the tolerance for abuse that is almost—some of them almost certainly get.

Now, the other thing that we worry about is that the integrity of the joints, its ability to withstand the environment, also depends on its being a very good one, and in our opinion it is hard to determine the quality of a solder joint on aluminum. I have seen some very good ones, and I have seen some that are not so good.

Opinion is that the joints should be improved in such a way as to provide, I would say, a great overstrength, assurance that even though abused, it is subject to the various things that are not really planned for, it will still retain its integrity, and that in essence is the feeling about the use of solder joints.

Senator SMITH. Would this be a design deficiency?

Dr. THOMPSON. I think this is a design deficiency. The collars that are used there provide such a short connection that it has certainly impressed us as being unable to withstand the abuse they would almost certainly get.

Senator SMITH. Now, shall I repeat the second part of the question?

Dr. THOMPSON. Yes, please.

DIFFERENCES IN GROUND TEST AND IN-FLIGHT PROCEDURES

Senator SMITH. Describe and explain the significance of some of the more important differences the Board found between ground test procedures and the in-flight checklist.

Dr. THOMPSON. Will you handle that?

Colonel BORMAN. Yes, ma'am; if I may. This was my area, I believe.

The differences that existed between the in-flight checklist and the operational procedure for this test were minimal. However, we put this in because we felt that any difference was significant. In fact the in-flight checklist is designed for a flight, for launch, and the test that was being run of course was not a launch or not a proposed flight, so there were some differences existing in switch positions between the checklist for flight which was used and the operational check procedure for this test.

We feel it is important that both the crew and the test personnel on the ground operate from the same piece of paper, and that is why the recommendation is in here.

INQUIRY ON BARON REPORT

Senator SMITH. I have just one more question in a couple of parts, Mr. Chairman.

There have been several newspaper reports that a Mr. Thomas Baron, a former employee of the Apollo spacecraft contractor, had rendered a report to both the spacecraft contractor and NASA pointing out several serious allegations concerned with poor quality assurance procedures and practices at Cape Kennedy. Did the Board read and evaluate Mr. Baron's report, Dr. Thompson?

Dr. THOMPSON. They did, at least some members of the Board, and the counsel read the report of Mr. Baron. There are two reports that he has written.

Senator SMITH. Then would you give us, give the committee, the Board's opinion of the validity of his allegations and whether or not there were any similarities between his allegations and the Board's findings?

Dr. THOMPSON. There was certain validity to some of the things that he stated. They were similar to some of the things which we have said. He was in the quality control office and saw some of the things going on in his view that he had—I think put him in a position to see some of the problems that are involved in the program.

He viewed the type of things that a quality control inspector would see in the position he had. I am not sure that he always knew what the final outcome was, how the matters that passed under his purview were actually handled.

In our opinion, after reading the report, we did not see that he was adding greatly to the knowledge we were getting from other sources, and it was generally somewhat vague as to just whether there was fault or whether he just saw things that were in process of being corrected.

Senator SMITH. Did any of the panels make a summary of Baron's report? I have not read the report thoroughly, but I am told that the Board does not include——

Dr. THOMPSON. I think—you read it, George. Did you read the full report?

Mr. WHITE. I did read it, but I have not prepared a summary of it.

Senator SMITH. There is no summary of it.

Mr. WHITE. No.

REQUESTS SUMMARY OF BARON REPORT

Senator SMITH. Dr. Thompson, would you be able to get a summary of Baron's report and give it to the committee?

Dr. THOMPSON. I will do that, yes, ma'am.

Senator SMITH. If you will, please.

Dr. THOMPSON. Yes.

(The summary submitted is as follows:)

During the course of the Apollo 204 Review Board investigation, a 58 page document called "An Apollo Report" was furnished to the Board by a Mr. Thomas R. Baron, a former North American Aviation, Inc. Quality Control Inspector and Receiving Inspection Clerk. This document was severely critical of North American Aviation's conduct of the Apollo project. Mr. Baron was requested to testify to the Board about his allegations which he did on February 7, 1967. In addition, he furnished a 275 page document entitled "The Baron Report." The testimony before the Board and the 275 page document reiterated and set out in more detail the allegations originally made against North American Aviation, Inc., in the 58 page document.

The criticisms levied by Mr. Baron at his former employer, North American Aviation, Inc., can be grouped into five (5) categories: (1) quality control.

(2) safety, (3) records and documentation, (4) personnel, and (5) operations. These allegations are summarized in the following:

1. *Quality control:*

Throughout the report, allegations are made of generally poor workmanship observed by Baron. Because of faulty quality control procedures, unacceptable workmanship was often missed by inspectors. When he himself observed defects which he was unwilling to pass, Baron would report these to his supervisors. The report details various instances where nothing was done to correct the deficiencies he noted. Specific samples of poor quality workmanship discussed in the report are faulty installation of spacecraft 012 heat shield; faulty installation of spacecraft 009 rendezvous window; poor workmanship in splicing on the quads; and unsatisfactory water glycol operations in ground support.

The report is also critical of test and inspection procedures, alleging that tests were frequently conducted by unqualified personnel using equipment not suited for the particular test being conducted. The failure of NASA personnel to participate in many of these tests and to maintain a general cognizance of the daily workings on the project has, in Baron's opinion, made such lax procedures possible.

2. *Safety:*

Baron alleges that the general level of safety on the project site was low. Lack of sufficient standards was a factor, which together with supervisory and employee carelessness contributed to the hazards he observed in the operations. Among the particular hazards he details are permitting smoking during and immediately after hazardous operations; conducting fuel operations to diesel power unit when oxidizer transfer unit operation was being conducted; leaving open drains at various levels of pad 34; absence of nets and chain rails to safeguard men working at different levels of the gantry; nonoperating elevators for emergency egress; falling objects endangering personnel on the ground; and operating of high pressure valves without proper protection.

3. *Records and documentation:*

In several areas, there are no procedures established for uniform record keeping. Where records are maintained, they vary from technicians notes to standard printed forms. Because of this lack of uniformity, it is possible to initiate relatively major alterations on the systems without these alterations ever being documented for future reference. An example of this situation is seen in the removal and replacement of parts in the coolant system without proper documentation. Where record keeping procedures are fairly well established, the procedures are often grossly inefficient. Parts distribution is an example of this inefficiency. Forms used for this are printed in two copies. One copy is torn off and thrown away without ever being used.

4. *Personnel:*

Personnel working on the project are shifted from one job to another before acquiring extensive familiarization with the particular project on which they are working. This prevents technicians from becoming "professional" and hinders their opportunities for advancement in the company.

Personnel control is generally poor; technicians at times standing around with nothing to do, while at other times, there was a lack of technicians for a given task. Work that should have been done by experienced mechanics was done by NASA Quality Control personnel and engineers would from time to time perform functions that the technicians should have been performing. Some phases of the work were improperly supervised, there being no qualified engineer on the project site.

These and several other personnel problems contributed to the lowering of morale among North American Aviation employees and a resultant reduction of efficiency.

5. *Operations:*

The Baron Report alleges a "lack of coordination between people in responsible positions" and a "lack of communication between almost everyone." More specifically he alleges a failure to provide official tie in periods for work; scheduling of work in areas so nearby as to cause almost certain contamination; and difficulty in determining whether meter calibrations are up-to-date.

CONSIDERED APOLLO SHIP SAFE AT TIME OF TEST

Senator SMITH. Mr. Chairman, I think Colonel Borman answered a question this morning, and I would like to ask it over and get it again on the record.

Colonel Borman, did you consider the Apollo spacecraft safe, safe enough for yourself to have gotten into it and why?

Colonel BORMAN. And what was the last part?

Senator SMITH. And why?

Colonel BORMAN. Yes, ma'am, I considered the command module 12 to be a safe vehicle at the time of the test. I was assigned as a backup crew commander for a sister ship to spacecraft 12, and although we had development problems and wiring problems and so on, you expect these things in the normal R. & D. program, and I can state that the crew from spacecraft 12 felt that the spacecraft was rounding into shape and both the prime crew and the backup crew were of the opinion that spacecraft 12 was a safe ship at the time they entered it for this test.

Senator SMITH. Thank you very much, Colonel. I thought I understood you correctly this morning, but I wanted to get it on the record again.

Colonel BORMAN. Yes, ma'am.

Senator SMITH. Thank you very much.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Young.

QUESTIONS ON HATCH DESIGNS

Senator YOUNG. Just a few questions, I believe.

According to the finding of the Board, the inner hatch could not be opened properly, and that the crew was never able to effect emergency egress because of pressurization and so forth, and then the Board made a recommendation that the time required for egress of the crew be reduced, and the operations necessary for egress be simplified.

Now, had thought been given to that before this tragedy occurred?

Dr. THOMPSON. I think Colonel Borman could better summarize that complete situation for you, sir.

Senator YOUNG. Yes.

Colonel BORMAN. Yes, sir; if I may.

At the time of the accident there was on the drawing boards a new hatch designed to open outward and to be hinged to the spacecraft. But the prime reason for the new design was to facilitate extravehicular activities on orbit. It was considered that for every conceivable hazard on the ground the present hatch or the hatch that was on board the spacecraft would suffice.

Now we know that it did not. But as we—as I have attempted to point out, the problem here was that we overlooked the possibility of an internal spacecraft fire.

Senator YOUNG. Yes, but, Colonel, before this tragedy occurred, it was not possible to open that from the outside, was it?

Colonel BORMAN. No, sir. You could open it from the outside. The problem is that the hatch is forced on to its latch by pressure within the spacecraft, and the pressure inside the spacecraft was 2 pounds per square inch higher than the atmospheric pressure. That does not seem like much, but over the area of the spacecraft that puts a force of about 2,400 pounds holding that hatch shut. So until you can get rid of the pressure within the spacecraft, you cannot open the hatch. And that was the problem.

Senator YOUNG. But the Board did make a finding that before the tragedy occurred there was failure to consider that the egress hatch was a hazardous situation.

Colonel BORMAN. That is correct, sir.

Senator YOUNG. Was that not negligence that the people failed to consider that hazardous before?

Colonel BORMAN. Sir, you could describe it as negligence. I would prefer to describe it, perhaps, as an oversight, since I feel that I share my full share of the blame for overlooking this problem.

I probably have had more experience or as much experience in similar test conditions as any man alive, and I certainly was not concerned about the particular situation that we had. So I agree with you, we were negligent, if you wish, but at least we had an oversight.

Senator YOUNG. Well, there was no intent, as a matter of fact, to use this new hatch design in the Apollo program, was there?

Colonel BORMAN. There was, yes, sir. It was being designed at the time for incorporation on the Apollo.

Senator YOUNG. For the Apollo application program.

Colonel BORMAN. No, sir; for the Apollo lunar program. But, you see, we had no plan for doing extravehicular activity on the Block I spacecraft. So we felt there was no requirement to incorporate this new hatch design on command module 12 because it would not be actuated on orbit.

QUESTIONS ON FUTURE EVALUATION OF FINDINGS

Senator YOUNG. Well, I think my next question should be directed to Dr. Thompson.

The Board having made findings, determinations, and recommendations, will the Board at some future time look at this matter again? Will the whole matter be evaluated to see whether all necessary actions have been taken on the Board's recommendations?

Dr. THOMPSON. Well, sir, I was hoping the Board would be able to go out of business here pretty soon. But we were charged with the responsibility by the Administrator for making this study and reporting to him, and we are currently in recess, holding ourselves together to finish up some of the reporting of tests in progress, and I have noted it will not influence our findings but they do need to be incorporated in the record, and I was hoping that having identified to the Administrator the things we found, that the discussion of whatever is done from here on would be—would fall to the lot of the program office, and I thought maybe the Board could then be dismissed and go back to our normal duties.

Senator YOUNG. Well now, important recommendations have been made to try to insure more safety for the crew. Will there not be some check made within a reasonable time as to whether all of those recommendations have been complied with? If so, when?

Dr. THOMPSON. I think it could be assured that the program office, the Administrator and the program office will report, will take this matter into consideration and take appropriate action, but it is not in the area of the responsibilities of this Board to see that the action is taken, as I understand our responsibilities.

Senator YOUNG. Well, maybe, Colonel Borman, maybe I should ask you this question: Since there are recommendations that the amount and the location of combustible materials be restricted in the future, that is in itself an admission, is it not, that there was laxity in permitting so much combustible material in the spacecraft?

Colonel BORMAN. Yes, sir; there were too many combustibles on board.

Senator YOUNG. Do you know personally whether thought had been given to the danger of that before?

Colonel BORMAN. Sir, we considered the danger of combustibles on board the spacecraft before our flight of Gemini 7, and we had done an extensive study of in-flight first. We were the first American crews to remove the spacesuits in flight, and when you fly without a spacesuit on, you lose the prime protection against fire when you are in orbit, which is to depressurize the cabin, so we were very particular in looking into means of controlling fires during flight.

We did not consider this problem sufficiently for test on the ground.

Senator YOUNG. But now hindsight shows that there really was negligence in connection with that.

Colonel BORMAN. Well, as I said before, sir, I guess you could call it negligence. We had over 3,000 hours of experience testing in a hundred percent oxygen. I believe it is in the record. I am sure it is over 3,000 hours. As you may or may not know, sir, when I fly, when I flew up here from Houston, I was using 100 percent oxygen all the way on my airplane, the T-38 that we fly. I am afraid that we overlooked the potential hazard of combustibles, pure oxygen and an ignition source.

COMMUNICATIONS SYSTEM

Senator YOUNG. Did you yourself at times prior to this tragedy consider that the overall communications system was unsatisfactory, was not adequate?

Colonel BORMAN. Sir, I was not involved in testing an Apollo spacecraft at the Cape. We had a different communications system for Gemini and it was adequate. But according to all the testimony that we had and the records of the tests, the present ground communications system at Cape Kennedy was inadequate.

Senator YOUNG. Do you know whether Dr. Thompson and others knew of that fact beforehand? Was it considered by you before this tragedy occurred that the overall communications system was not adequate or was somewhat unsatisfactory?

Dr. THOMPSON. No, sir. I learned about all this when I was assigned the responsibility as Chairman of this Board. I am stationed normally at Langley Research Center, and I was not—I am not familiar with all the operations at KSC. I am much more familiar than I was at the end of January.

Senator YOUNG. Well, are you able to expand on this determination for the committee, particularly with respect to why there was not provided a satisfactory communications system before this tragedy occurred? Can anyone answer that question fully?

Colonel BORMAN. Sir, if I may, I can tell the reason for it anyway. The spacecraft uses a four-wire system; the ground communications system at Cape Kennedy is a two-wire system. This results in the requirements for what we call voice-operated relays to transmit messages from the spacecraft to the various organizations.

Now, if these relays are all set to actuate at the proper level, the system works fine. The problem is in getting them all set to the proper level, and this communications system, although I must point, sir, that we found that it did not contribute to the accident, it nevertheless made the test difficult. They were holding at the time of the accident for a communications problem, as you may have read. So the Board said that one of our recommendations was that before the next manned flight we fix it.

Senator YOUNG. Yes.

Now, thank you Colonel, for your opinion on that. But do you know what organizations were responsible for the design, the building, and the operation of the communications system which you now know was not adequate?

Colonel BORMAN. I believe it would be the Kennedy Spacecraft Center, sir.

Senator YOUNG. Is that——

Colonel BORMAN. I am not sure, but I would say that is who it was.

Senator YOUNG. And you surely believe that should be corrected?

Colonel BORMAN. I certainly do, sir.

Senator YOUNG. As quickly as possible?

Colonel BORMAN. Yes, sir.

Senator YOUNG. Thank you. No further questions.

The CHAIRMAN. Senator Brooke.

SPACECRAFT SAFETY

Senator BROOKE. Colonel Borman, if I understood you correctly, in answer to Senator Smith's question, you said that in your opinion this spacecraft was safe at the time, and yet after reading the Board's findings it is inconceivable to me that you could make such a statement that the spacecraft was safe at the time. Is this statement based upon your beliefs prior to this accident or do you still believe the spacecraft was safe?

Colonel BORMAN. Sir, I am certain that I can say now the spacecraft was extremely unsafe. I believe what the message I meant to imply was that at the time all the people associated and responsible for testing, flying, building, and piloting the spacecraft truly believed it was safe to undergo the test itself which was being conducted at the time, and my opinion is based on many hours in a sister ship that I spent in checking, in testing of a sister ship.

Senator BROOKE. But one of the things that is included in the report was that the coolant leakage was a chronic problem.

Colonel BORMAN. That is correct, sir.

Senator BROOKE. And apparently this was known by you and by members of the spacecraft prior to this unfortunate accident.

Colonel BORMAN. That is correct, sir, and the last coolant leak that was discovered at Cape Kennedy was a leak of about five drops of coolant that was unexplained, and as a result of this leak of just five drops the entire environmental control unit was sent back to the contractor, the launch date was slipped, and every effort was made to make sure that the leaks had been understood and corrected.

So these things that were problems along the way, we thought, had been corrected.

Senator BROOKE. But you knew that the coolant was combustible.

Colonel BORMAN. Sir, it is combustible, but it is extremely difficult to ignite.

Senator BROOKE. And you felt that it was—the fact that it was combustible did not necessitate the changing of the coolant.

Colonel BORMAN. That is correct, because, you see, the coolant is contained of course in plumbing, and hopefully if you do not have leaks, and if you have no ignition source, you will not have a fire.

Senator BROOKE. But you did not know about the joints and that you did have leakage.

Colonel BORMAN. Yes, sir.

Senator BROOKE. You recommended correction of that.

Colonel BORMAN. Yes, sir.

MANAGEMENT ASPECT OF PROGRAM

Senator BROOKE. Now, prior to this Board's report you had hearings, the committee had hearings, and if we were to believe what was said by those who appeared before us, the accident could not have occurred because everything was right, a hundred percent pure oxygen was right and everything else was right.

Now, of course, the Board, having made in-depth study, has obviously found some mistakes and some errors and some conditions that need rectifying.

Did the Board go in depth into the management aspect of the program?

Colonel BORMAN. No, sir, I do not believe so. I believe Dr. Thompson should answer that.

Dr. THOMPSON. We went into management to the extent that it impacted the things that were involved in our review; that is, as I was trying to visualize it one day, I said we started from inside and worked out. We did not look at management and then concentrate on an area of deficiency. We looked at an accident, something that had gone wrong, and then looked outward from that to see if there were management aspects of the operation that seemed to have impact on it. And to that extent we did look into certain management problems.

Senator BROOKE. If management had been proper, could not these findings that were relative to mistakes and errors in this spacecraft have been found prior to this accident and corrected?

Dr. THOMPSON. Well, we did not find any direct connection between the accident—the management and this accident. We saw things that we thought needed to be improved in the management as we looked into this problem. But I do not think any management is perfect on the point that there might not be something wrong somewhere.

The assurance of quality, I think, left something to be desired, but we have gone into that in considerable detail here, I think, in identifying those areas; to the extent that those areas reflect management, I suppose we are criticizing management.

I do not know exactly how to be more definitive about it though than we have in the statements we have made on it.

The assurance of quality is certainly a NASA responsibility, and we tried to impose on the contractor the direction and control, whatever it is, that will insure that the quality is, in fact, built into the spacecraft, and somehow or other that result did not come out exactly right.

DISCUSS EVENTS PRIOR TO FIRE

Senator BROOKE. Now, Dr. Thompson, your Board has not been able to actually pinpoint the cause of this accident, is that correct?

Dr. THOMPSON. We have established a most probable cause, and we have established conditions that support that kind of thing as being almost certainly the cause, but we are not certain that we have put our finger on the exact thing that ignited that fire.

Senator BROOKE. In your opinion, if the recommendations that are contained in this report were carried out, is it true that this accident would not have occurred?

Dr. THOMPSON. Yes, sir; that is the intent of our recommendations which is to remove the probability of fire, and we think that by following the recommendations that we have made and certainly a great deal of progress is already being made that we know of in that direction, that the probability of fire will be reduced to a very low level.

Senator BROOKE. Of course, hindsight is always easier than foresight. But assuming that these matters could have been found out previously, then is it not the responsibility of someone or some organization to have done what this Board did prior to this accident, and corrected these things which would have avoided this accident?

Dr. THOMPSON. Well, the stimulation has been very great here to go into a depth that, perhaps, has not been followed before. I think we probably have gone into greater depth than some of the reviews that have been made up until now and, of course, we have usurped a lot of manpower. We have had an overriding priority on all manpower to try to support this thing. So I do not think that the Agency would like to support this kind of review very often.

Senator BROOKE. This manpower could have been mustered previously, could it not, for an important operation such as this?

Dr. THOMPSON. It could have if the need had been identified in the way it was here.

Senator BROOKE. There was no question about shortage of manpower, shortage of equipment, in preparation for this operation?

Dr. THOMPSON. Well, in managing a program I think there is a shortage of manpower to do all the things. We have interfered with the ordinary use of manpower in a rather drastic way. So we have diverted manpower from their normal duties in a pretty extensive fashion.

Senator BROOKE. That is all, Mr. Chairman.

Dr. THOMPSON. Could I add one more point about this?

The CHAIRMAN. Yes.

Dr. THOMPSON. In dealing with the fire, the assessment of fire, I think we, perhaps, made some mention of this earlier or it is implied in the record, that we have stimulated here a very important advance in the understanding of the risk of fire by this review.

74-531 O—67—pt. 3——7

Prior to this review the understanding of flammability of materials was dependent to a large extent on tests in laboratories of small specimens arranged in different ways, some horizontal, burning horizontal, some vertical, some upward and some vertically downward, even 45 degrees, samples of materials with various kinds of nap on them, and on a variety of results which were obtained, and there was no real standardized method for deciding on flammability of materials.

What has been achieved here is a utilization of a mockup over at the Command Spacecraft Center to get, I think probably for the first time, a reliable index of the flammability of materials for real useful application to this problem.

At MSC, the Manned Spacecraft Center, they immediately constructed a boilerplate model mockup of this vehicle arranged in such a way that it could simulate the vehicle rather carefully as regards the arrangements of combustible materials in it.

The first exercise was the attempt at duplication of the actual accident, and I think in two attempts, the first one was not arranged quite right—well, the simulation was not quite what it should have been—and the next one, the arrangement of the vehicle was very similar as regards combustibility of materials, the arrangement of combustible materials, and a very adequate simulation of the combustibility problem was achieved.

Now, this goes way beyond the use of just samples of materials. An overriding factor is: How are they arranged? How is nylon knit? Is it coarsely knit or is it finely knit? Does it have a fuzzy edge? How is it arranged as far as continuity is concerned? And all those factors, factors of the geometric arrangement, and the nature of the weaving are very important factors.

The important result has been achieved that a system or a method of testing and evaluation has been developed that will be extremely useful in qualifying the vehicles for future flight use.

This simulator will be used to evaluate the improved arrangement and selection of materials so that there can be a very good evaluation of what the flammability risk is and the extent to which it has been reduced, and I think it is a very important achievement that, as I say, has been stimulated here by the start of this review.

The CHAIRMAN. I think that is true, Doctor. We had a hearing about these materials, and the Senator from Illinois examined the material, as we all did, and I think a very important contribution has been made by it.

I did not mean to interrupt you, Senator.

Senator BROOKE. Dr. Thompson, aside from the flammability of materials, take, for instance, the training of the launch pad crews for emergency training. This particular operation was not classified as hazardous, I understand.

Now, presumably, you will go through this stage again or this phase again.

Would it be classified hazardous the next time and, if so, why would it be classified hazardous?

Dr. THOMPSON. Well, I feel pretty sure it will be classified as hazardous. But the criteria that were used, that were in existence at the time of the test, did not automatically classify it as hazardous because those criteria apply to the use of hypergolic fuels in the spacecraft, and the application of the criteria simply that were in use did not identify this as its operation. I am sure those rules will be changed.

The same spacecraft, in the vacuum chamber, was classified as a hazardous operation because it was in a vacuum chamber at KSC.

Senator BROOKE. That is all.

The CHAIRMAN. Senator Cannon.

MATERIALS PANEL BOARD

Senator CANNON. Thank you, Mr. Chairman.

Doctor, the Materials Work Panel stated that several inadequacies were found in materials control, control of flammable materials installation was exercised by several organizations which tended to act independently.

Now, from a systems management standpoint, what organization should have been responsible for establishing and monitoring such controls?

Dr. THOMPSON. Well, the Apollo program office had the responsibility for that, and then the execution of the installation is in the hands of the contractor, and then the inspection, I think, is in the hands of MSC.

I think this is the basis for the several organizations, and the way this works out is that there are certain criteria, guidelines, used for installation for these materials dependent on their sensitivity to ignition, as to how close they should be placed particularly relative to possible ignition points.

Our understanding is this: that the contractor's guidelines that he developed and used in the installation were checked by MSC walk-through inspections at various stages, and I think this is the basis for this evaluation.

The MSC criteria that were used in that walk-through inspection had been identified as being more rigorous than the criteria used by the contractor, and when a walk-through inspection was made at the plant, the application of that more rigorous guideline resulted in the removal of a substantial amount of material because of its proximity to what were thought to be possibly ignition points or wire models, I believe, are the main criteria.

Later on during the course of the progress of the completion of this vehicle and in getting it ready for flight, other materials, flammable materials, might have been added, and a walk-through inspection, another walk-through inspection, which according to our understanding would have used the same criteria that the Manned Spacecraft Center used, would have been employed at that time.

That walk-through inspection was to have taken place within a few days, I think only a day or so after this accident. It had not taken place. It had not been accomplished prior to the accident, and I believe this application of different criteria arrived at in this way is the basis for that statement.

Senator CANNON. From a systems management standpoint shouldn't there have been one organization responsible, directly responsible, to tie these loose ends together?

Dr. THOMPSON. I think there is room for improvement in that respect; yes, sir.

Senator CANNON. In view of the leakage problems experienced in the environmental control system in Spacecraft 012 prior to the accident, did the Board find any evidence that joint redesign or other corrective action was underway to correct the deficiency?

Dr. THOMPSON. In the joints we did not.

QUESTIONS ON REDESIGN

Senator CANNON. Wasn't that a failure from a management standpoint, with the history of leakage that had been indicated?

Dr. THOMPSON. As far as we know that design had been accepted, and it was not subject to redesign. There was apparently a different idea of what is appropriate. We differ with the program office on that score.

Senator CANNON. And you recommend now that there be a redesign, this is part of your recommendation?

Dr. THOMPSON. We recommend that there be a redesign to the extent at least of applying much greater strength at those joints to give it redundancy necessary to stand abuse.

Senator CANNON. Now, in finding No. 11 reference is made to "open items," and "engineering orders not accomplished."

What is the significance of these findings to good engineering, manufacturing, and quality control practices?

Dr. THOMPSON. Well, I think this is a matter of judgment.

As to how many open items are appropriate, there are always open items, there are bound to be some. But our view of the situation was that there were probably more than would represent what we considered a proper situation. We thought there were more of those than were consistent with what there should be.

Senator CANNON. In your judgment, what accounts for this number of discrepancies in operating practice in the spacecraft program?

Dr. THOMPSON. I think that Mr. Williams should answer.

Mr. WILLIAMS. I think you will find a lot of significant engineering orders were open at the time of delivery down at the Kennedy Space Center and 623 engineering orders were released subsequent to the delivery.

Senator CANNON. How many was that?

Mr. WILLIAMS. 623 engineering orders. I think the only thing here is that the spacecraft was continuing to be designed, or the engineering orders, at least, were putting improvements and changes into the spacecraft as it was going through the test at the Cape.

I think that is the significance of the 22 orders not on the books yet. There was a timelag between the release of engineering orders at Downey, and incorporation into orders down at the Cape.

Senator CANNON. Would you anticipate as the program goes along that you would continue to have discrepancies develop; that is, as your experimentation progresses?

Mr. WILLIAMS. No, sir. This is the first manned spacecraft, and you would assume that you would get several engineering changes, and so forth, along the way during the testing program. I think the number should decrease.

Senator CANNON. The number should decrease, but you would be constantly getting new ones, would you not?

Mr. WILLIAMS. Getting new ones?

Senator CANNON. Yes, having new items developed that you would find required them to be changed.

Mr. WILLIAMS. I do not follow.

Senator CANNON. Perhaps I would prefer to ask Colonel Borman that as a test pilot. Isn't it usual to find discrepancies develop as you go along in a testing program?

Mr. WILLIAMS. Oh, sure.

Senator CANNON. And you find new items occurring that were not initially on the list as old items are corrected?

Mr. WILLIAMS. Yes, sir.

Colonel BORMAN. Yes, sir. I think Mr. Williams just misunderstood your question.

Senator CANNON. I see.

In finding No. 8 you recommend tests with full-scale mockups and flight configuration to determine the risk of fire.

Did the Board consider that good engineering practice would have specified such tests prior to the accident?

Dr. THOMPSON. The fire hazard has been completely reassessed as a result of this, and I do not think that we would have acquired a new value in the scheme of things and, as I think I indicated, the important development of a very good scheme for properly evaluating the fire risk or the flammability, has been a development that we think should be really applied to any future programs, and that mockup scheme should be utilized, and I am sure that they plan to utilize it to qualify what new engineering approaches to this problem are employed. So that we would not have said this before the fire.

Senator CANNON. But you feel that it would be good practice to follow?

Dr. THOMPSON. We feel it is an extremely valuable addition to the whole technology of conducting proper qualification tests.

ASTRONAUT EAGER TO MAKE FLIGHTS

Senator CANNON. I would like to direct a series of questions here to Colonel Borman, and I presume that you will be in command of the next flight, is that certain now, in view of the reorganization? [Laughter.]

Colonel BORMAN. As a matter of fact, I may be back in the Air Force. [Laughter.]

Colonel BORMAN. No, sir. I was assigned to the third manned flight, sir, and since I have been at Cape Kennedy since the 28th of January, I understand that some of the crews have been realined, but I hope that I will be flying one of the earlier flights.

Senator CANNON. Let me ask you these questions in the context of either your membership on the Board or as a pilot and a potential commander of one of the Apollo flights.

Colonel BORMAN. Yes, sir.

Senator CANNON. Referring to page 9 of the doctor's statement, assuming that item 2, an extensive distribution of combustible materials in the cabin is corrected, as has been described here today; assuming that the wiring deficiencies from a vulnerability standpoint have been corrected; assuming that the vulnerability of the plumbing items have been corrected, as they were described here; assuming that the hatch is redesigned to provide for a rapid-crew escape, and that provisions are made on a standby basis for rescue or medical assistance, would you then be willing to assume position of command in that capsule with the sealed cabin pressurized with the oxygen atmosphere?

Colonel BORMAN. I would be willing and eager to, sir.

Senator CANNON. Now, relating specifically to the other findings of the Board, of course, finding No. 1 presumably relates to the cause of the arcing.

In No. 2, do you feel if the recommendation of the Board is followed with respect to finding No. 2, that that would provide adequate safeguards from the standpoint of combustible material there?

Colonel BORMAN. Yes, sir; if we go the additional step that Dr. Thompson has just recommended, and that we check out the reconfigured spacecraft with the full mockup test.

ESCAPE POSSIBLE WITH NEW HATCH

Senator CANNON. I take it that, of course, finding No. 3 just related to the causes, and would you consider that finding No. 3 would be adequately taken care of if you have the redesign of the hatch and the rapid egress available?

Colonel BORMAN. Sir, it is my opinion, and I believe it is shared by the other members of the Board, that had we had the new hatch installed on this command module the crew would have escaped, so I would say, "Yes."

Senator CANNON. In that connection, will there be a provision, a redesign provision, for a rapid dumping of pressure other than just the removal of the hatch?

Colonel BORMAN. Yes. It is my understanding—of course, I believe you should address this to the Program Office, sir. I do, from the knowledge that I have, believe that this is being incorporated also. It is certainly important.

Senator CANNON. Of course, if that were true that would take care of finding No. 4; would it not?

Colonel BORMAN. Yes, sir.

Of course, if we get the new hatch the rapid dumping of the pressure will lose its significance on the ground, but we would still like to have it in the air.

Senator CANNON. You would like to be able to dump the pressure in the air?

Colonel BORMAN. I should not say in the air, I should say in orbit, sir.

Senator CANNON. In space.

Colonel BORMAN. Yes, sir.

Senator CANNON. Now, finding No. 5, of course, I think it has been well identified as being a hazardous condition, so there would be no need for any further identification in that area.

On finding No. 6, I take it that it does not actually relate to the cause, as to this type of occurrence again, but simply better procedure; is that correct?

Colonel BORMAN. That is correct, sir.

Senator CANNON. And finding No. 7 likewise did not contribute to the cause of the accident in this instance, and you would assume that that would not contribute to a future accident.

Colonel BORMAN. Yes, sir. I would also hope that it does not happen again. I do not like to get changes in the test procedure the night before we are supposed to run the test.

Senator CANNON. Finding No. 8, I think, requires no comment there in view of your comments already on the full-scale mockup.

I believe also you have commented on No. 9 there accordingly.

Do you have any further comments with respect to finding No. 10, Colonel Borman, insofar as you are concerned as a pilot?

Colonel BORMAN. Sir, the only finding part of No. 10 we have not touched on is 10g, "No design features for fire protection were incorporated." By this we mean there were no auxiliary, or one of the implications is, there were no auxiliary oxygen masks to protect the crew in the event of a toxic atmosphere on orbit, and I would hope that this recommendation will be heeded by the Program Office also.

Senator CANNON. The recommendation being that investigation be made of the most effective means of controlling and extinguishing a spacecraft fire and also to consider that auxiliary breathing oxygen be provided to protect from smoke and toxic fumes.

Colonel BORMAN. Yes, sir.

Senator CANNON. Are there any matters that, in connection with finding No. 11, that you think should be commented on from your standpoint?

Colonel BORMAN. No, sir.

Senator CANNON. Thank you very much, Mr. Chairman. That concludes the questions I have.

The CHAIRMAN. Do you have anything else, Senator Young?

Senator YOUNG. Yes.

UNIFIED HATCH PREFERRED

Colonel Borman, you deserve our gratitude for your frank answers to questions, and I compliment you on being very, very knowledgeable in this subject, and, therefore, I am directing a question to you. From testimony at our previous hearings, it is unclear to me and there seems to be some confusion about the status of this redesigned hatch, and I believe you can clear up this uncertainty.

Now, I know that Dr. Mueller on February 27 stated that consideration was being given to three different hatch concepts: One—you will find it on pages 98 and 99 of that hearing, you are familiar with it—one, the present two-hatch system; a second was the three-man sized hatch to provide an opening large enough for simultaneous three-man egress, and then there was this third concept that he told about.

Now, he said that NASA is evaluating these three concepts, but you indicated in your testimony, Colonel, that a decision had been made prior to the time this tragedy occurred.

Now, will you please clarify that for me?

Colonel BORMAN. Sir, it was my understanding that the decision—at least perhaps a decision had not been made by Dr. Mueller, but I believe that I am safe in saying that the decision among the flight crew, at least indicating the desirability of the unified hatch, had been agreed upon prior to this accident, and I believe, sir, that this is the type of hatch that is now being designed, the one that is shown on page 99 of your Apollo accident hearings, part 2.

Senator YOUNG. Well, here again Dr. Mueller stated that "We are evaluating this design against the present design," and so has a decision already been made to put the new hatch on block II spacecraft?

Colonel BORMAN. It is my information, sir, that, yes, it has been made, and it will be the unified hatch.

The CHAIRMAN. What is the basis of your information?

Senator YOUNG. Yes.

Colonel BORMAN. The basis of my information is informants that——

The CHAIRMAN. The information we have is it was not.

Colonel BORMAN. Sir, the basis of my information is by contact that I maintain with my fellow flight crew people and people in the Apollo office that are dealing with this problem daily. We have members of our organization that are interested in this, and that have been following the developments of it, sir.

The CHAIRMAN. Would not Dr. Mueller have to be brought into this somewhere?

Colonel BORMAN. I am sure he will have to approve it, but I think he has already done so. I believe it would be better for you to ask him, though all I can tell you, it is my understanding.

The CHAIRMAN. We did ask him.

Colonel BORMAN. Yes, sir; but you asked him on February 27. I think perhaps he will tell you, if you ask him tomorrow, that it is being—I hope he will confirm what I have just mentioned here. [Laughter.]

The CHAIRMAN. I realize you have hopes.

Colonel BORMAN. I have my hopes, but I also have my sources of information, sir.

Senator YOUNG. But it appears there is a discrepancy at the present time, is that not right?

Colonel BORMAN. I think, sir, that perhaps when Dr. Mueller testified before you, that he was still considering them, and perhaps I was premature in saying that I was—the other two hatches, in my opinion, were so out of the question that I immediately settled on the one that we have here.

Senator YOUNG. Well, we may be impressed by your view and agree with you, but apparently if a decision has already been made to put that new hatch on this spacecraft, if that has been made, when is it going to be done?

Colonel BORMAN. Sir, it is my understanding that it will be available the latter part of this year. And may I just suggest, I would like to be able to tell you exactly, but this is really in the area of the program office, sir, and everything I am telling you is just information I picked up through communication with Houston.

Senator YOUNG. Yes; but we really cannot rely definitely on this except that it is your understanding, based on your information, is that not right?

Colonel BORMAN. Yes, sir.

Senator YOUNG. Because there is a discrepancy as the record now stands, is that not correct?

Colonel BORMAN. I think there is a discrepancy in that I testified that it was my belief that at the time of this accident, a unified hatch was on the design board, and Dr. Mueller said at the time of the accident there were three different approaches being considered.

Senator YOUNG. That are presently being considered?

Colonel BORMAN. Yes, sir; and I guess I had considered them rapidly and settled on one that I felt was proper.

Senator YOUNG. But you have been too optimistic.

Colonel BORMAN. I may have been mistaken, but I would be willing to wager if I could.

The CHAIRMAN. No bet.

Senator BROOKE. Mr. Chairman.

The CHAIRMAN. Senator Brooke.

FLIGHT CREW SATISFIED SPACECRAFT SAFE FOR TEST

Senator BROOKE. Colonel Borman, I would think that the flight crews, having worked with the spacecraft, make recommendations that programing would listen to and utilize.

Now, you knew the flight crew intimately. Had at any time any member of the flight crew ever brought to your attention anything concerning that spacecraft which they felt could have been rectified or should have been rectified which was not done prior to this accident?

Colonel BORMAN. No, sir. I might add that never in my experience with NASA—I have been almost 5 years now at Houston, never in this time period, in my experience, have I ever seen in any instance any item that was identified as affecting crew safety overlooked, turned down, or relegated to a lower priority for any reason whatsoever, and in this case unfortunately we did not identify the hazards.

But the hazards that have been identified have never been diluted for any reason that I know of, sir.

Senator BROOKE. To the best of your knowledge none of the mistakes which have been found by this Board were ever mentioned by members of the space crew.

Colonel BORMAN. Well, yes, sir. There is—we knew about the coolant leaks, we knew about the trouble with the ECU, we knew about the wire problems, but, as I pointed out, there was a continuing vigorous effort to correct these items, and we had hoped and believed that the action was sufficient and adequate.

Senator BROOKE. This crew believed that everything that could have been done at that time had been done.

Colonel BORMAN. Sir, I think I can say that at the time they entered the spacecraft, they were satisfied that they had a spacecraft that was not only adequate but safe for the test that they were performing.

ALARM SYSTEM NOT WORTHWHILE

Senator BROOKE. Will the new spacecraft have an alarm system?

Colonel BORMAN. Sir, the old one had an alarm. We had an extensive caution and warning system. We do not have a reliable means of picking up fire detection. Fire detection is in its infancy, and we do not have that, and I would not propose that we install one.

Senator BROOKE. You do not propose to install one.

Colonel BORMAN. No, sir.

Senator BROOKE. Why?

Colonel BORMAN. Because of my experience in the aviation business where they have sometimes caused more troubles than they are worth.

I just do not believe that if we do the other things that we have recommended that they will be required for this item.

Senator BROOKE. Would you agree with that, Dr. Thompson?

Dr. THOMPSON. I agree with that. I am afraid if you put in a system, it might not see the fire, we might not know where it is going to occur, and I doubt that we know enough about where it is going to occur to properly sound an alarm that would be effective. If we did, we would fix that place so that the fire did not occur, and my understanding of fire alarm systems is that—like Colonel Borman's is—they might be much more hazardous than they are safe.

Senator BROOKE. The second reason would obviously be sound, but the first reason of course we did not know in this instance what could have happened so that would not necessarily be a justifiable and valid reason for not having a fire alarm; is it, Dr. Thompson?

Dr. THOMPSON. Well——

Senator BROOKE. If you feel it is going to be hazardous.

Dr. THOMPSON. I think it would be a very difficult problem to have an alarm that would provide a useful purpose arranged in such a manner that would give any reasonable additional assurance to reliability of the vehicle, and I would be willing to be convinced if I saw one, but I would be very skeptical. It would be very hard to prove to me that the system was not just another gadget that perhaps was more risky than it was safe.

Senator BROOKE. No further questions.

The CHAIRMAN. Mr. Gehrig has some questions.

Mr. GEHRIG. Dr. Van Dolah, the fire occurred in three phases, is that correct?

Dr. VAN DOLAH. Yes, sir; we have described it.

THREE PHASES OF FIRE

Mr. GEHRIG. Would you put into the record a chronology of the fire giving each of the three phases, the duration of the phase, and what characterized that phase?

Dr. VAN DOLAH. Yes, sir.

Mr. GEHRIG. If you can just furnish that for the record, it would be fine.

Dr. VAN DOLAH. All right, fine.

(The information referred to follows:)

First phase approximately 21:30:55 to approximately 21:31:19—relatively slow burning—intensely hot flames.

Second phase approximately 21:31:19 to approximately 21:31:25—turbulent burning—violent conflagration.

Third phase approximately 21:31:25 to approximately 21:31:30—rapid decrease in oxygen, rapid increase in soot and carbon monoxide.

Mr. GEHRIG. At what time did the third phase of the fire start?

Dr. VAN DOLAH. The third phase started at the time that the cabin atmosphere returned to atmospheric pressure, which we estimate to be about 25 seconds after the minute, that is 23:31:25.

Mr. GEHRIG. At what time did the third stage end?

Dr. VAN DOLAH. Well, again, as it can only be estimated; but we again estimate it to have lasted about 5 seconds so that it would end at 30 seconds after the minute.

Mr. GEHRIG. Dr. Thompson, panel 11, the Medical Analysis Panel, determined that the suit of the command pilot failed prior to the rupture of the pressure vessel which occurred at 23:31:19 G.m.t., as I understand it. In other words, at 19 seconds after the minute. Do you agree with that?

Dr. THOMPSON. I agree with the findings that have been determined by them; yes, sir.

Mr. GEHRIG. And the origin and the propagation of the fire estimates are that significant levels of carbon monoxide were present in the spacecraft atmosphere by 23:31:30, 30 seconds after the minute. Or 11 seconds later after the rupture.

Dr. THOMPSON. Yes, sir.

Mr. GEHRIG. Since one suit had failed, these gases are introduced into all of the suit loops, as I understand it; is that correct?

Dr. THOMPSON. Yes, sir.

Mr. GEHRIG. And therefore the crew was exposed to a lethal atmosphere right after the first suit failed. What is the best determination as to when the crewmembers lost consciousness?

Dr. THOMPSON. I think it is written in the record. I cannot recall the figures.

Mr. GEHRIG. As I read the report, the medical panel estimates that consciousness was lost between 15 and 30 seconds after the first suit failed.

Dr. VAN DOLAH. That is correct.

Mr. GEHRIG. And since the first suit failed prior to the cabin rupture at 23:31:19, that means that the medical panel estimated that unconsciousness did not occur until 23:31:34, which would be after the fire occurred. Is that correct? And perhaps not as late as 23:31:49.

Dr. VAN DOLAH. I do not think that is quite correct; no, sir. There is no precise knowledge as to when the first suit failed. We only know it failed prior to the burst of the cabin which occurred about 19 seconds after 23:31. But that suit could have failed many seconds before that, sir.

Mr. GEHRIG. What time did the fire start? As I understand, it started at about 23:31:04.7—no, I am sorry.

Dr. VAN DOLAH. That was the beginning.

Mr. GEHRIG. 04.7.

Dr. VAN DOLAH. That was the beginning the first verbal report of fire, sir.

Mr. GEHRIG. But it could not have started you think before 23:30:50.

Dr. VAN DOLAH. We do not know when it started.

Mr. GEHRIG. You have no estimate at all of when the fire started.

Colonel BORMAN. Yes, we estimated it started——

Mr. GEHRIG. You estimate it started at that time.

Dr. VAN DOLAH. Yes, sir.

TIME OF DEATHS DISCUSSED

Mr. GEHRIG. Did the medical analysis make any determination as to the time that death occurred?

Dr. THOMPSON. Medical opinion?

Mr. GEHRIG. Yes.

Dr. VAN DOLAH. The estimate is that chances——

Dr. THOMPSON. I think at this point it would be very well to have Dr. Berry, who is—who just walked in the room here, testify.

Mr. GEHRIG. Was Dr. Berry a member of the medical panel?

Dr. THOMPSON. He is head of the medical group. He heads up the medical group that we had on our panel and is very conversant with this whole matter; and we have relied very heavily and, as a matter of fact, our position has been established by the people who worked for Dr. Berry, who are on our panel with the assistance of Dr. Berry.

Mr. GEHRIG. I think the committee would prefer to hear Dr. Berry another time, Dr. Thompson. We would prefer to have the Board's views now.

What I am trying to establish is the sequence of events. As I understand it, the medical assistance panel did not make a determination as to the time death occurred. They only made a determination—an estimated—as to when unconsciousness occurred.

Colonel BORMAN. We have it right here, sir. I think on D 11–8, the determination, right above No. 15, gives you the best estimate of that. It is estimated that the time consciousness was lost was between 15 and 30 seconds after the first suit failed. "Chances of, resuscitation decreased rapidly thereafter and were irrevocably lost within 4 minutes."

Mr. GEHRIG. Dr. Thompson, does the Board feel, that is, is it the judgment of the Board, that death occurred before the fire was extinguished or before the fire ended?

Dr. THOMPSON. I think about the same time. This comes about the same time the fire ended but while they were in a very lethal atmosphere of carbon monoxide, the termination of the fire ended up with a chamberful of a high concentration of carbon monoxide.

Mr. GEHRIG. It would cause unconsciousness.

Colonel BORMAN. The hatch was not removed until about 4 minutes, 36 seconds. Your survival would be minimal.

Mr. GEHRIG. Is it reasonable that the——

Colonel BORMAN. Thirty-six, excuse me.

Mr. GEHRIG. I am sorry, 36 what?

Colonel BORMAN. Thirty-six seconds.

The CHAIRMAN. Would you start back your sentence and repeat it?

Colonel BORMAN. Yes, sir. The hatch was removed 4 minutes and 36 seconds after the crew report of fire, and it was the opinion of the best medical advice that we can have, that we have had, that the crew was beyond revival at that time.

Mr. GEHRIG. But then one can reason if there had been proper emergency procedures established for the ground support people outside they would have been able to remove the hatch within 90 seconds that perhaps some crew members could have been saved.

Colonel BORMAN. I think this is conjecture. You certainly would have to have some feeling, I think, for the intensity of the fire and the toxicity of the atmosphere.

From talking to the witnesses who were on the pad at that time, it was a very violent reaction. There was an intensely toxic atmosphere around the outside of the spacecraft, heavy smoke, and the efforts at rescue were severely impeded not only by the lack of equipment but by just the sheer lack of visibility.

Mr. GEHRIG. So if the proper equipment had been available, they could have worked on the hatch door.

Colonel BORMAN. That is correct.

DISCUSS TESTS PRIOR TO FLIGHT

Mr. GEHRIG. How many manned tests are run on the pad before there is a manned Apollo spacecraft flight?

Mr. WILLIAMS. If you will take a look at the test program, you run a detailed systems test first and then an electrical mate test between the launch vehicle and the spacecraft and then an integrated test with the launch vehicle and the plugs-out test followed by FRT test, flight readiness test, which is followed by servicing of the spacecraft on the launch pad.

Mr. GEHRIG. So how many manned tests are there? I do not know if I caught it, five or six.

Mr. WILLIAMS. About five or six.

Mr. GEHRIG. What test number was being run on January 27 when the accident occurred?

Mr. WILLIAMS. 0021, the plugs-out test.

Mr. GEHRIG. And had manned tests been run on the pad with the spacecraft prior to this test?

Mr. WILLIAMS. Yes, sir. The detailed systems test, the electrical mate test, and the integrated test with the launch vehicle.

Mr. GEHRIG. With men in the spacecraft.

Mr. WILLIAMS. With men in the spacecraft.

Mr. GEHRIG. During any of these prior tests, was the spacecraft—was the spacecraft pressurized with 100 percent pure oxygen at 16.7 psi?

Mr. WILLIAMS. No, sir; not on the pad. It was pressurized with roughly 16 pounds in the altitude chamber four different times.

Mr. GEHRIG. So January 27 was the first time that the Apollo spacecraft was pressurized on the pad with 100 percent pure oxygen.

Mr. WILLIAMS. On the pad, that is right.

Mr. GEHRIG. Mr. Chairman, may I suggest that we put into the record some organization charts that we have used here of the Office of Manned Space Flight, the Manned Spacecraft Center, the Marshall Space Flight Center, and the Kennedy Space Center, and I would also recommend that the Board put in the record at this point an organizational chart of the North American Aviation Co.

The CHAIRMAN. Without objection.

(The charts (see figs. 77–86) referred to follow:)

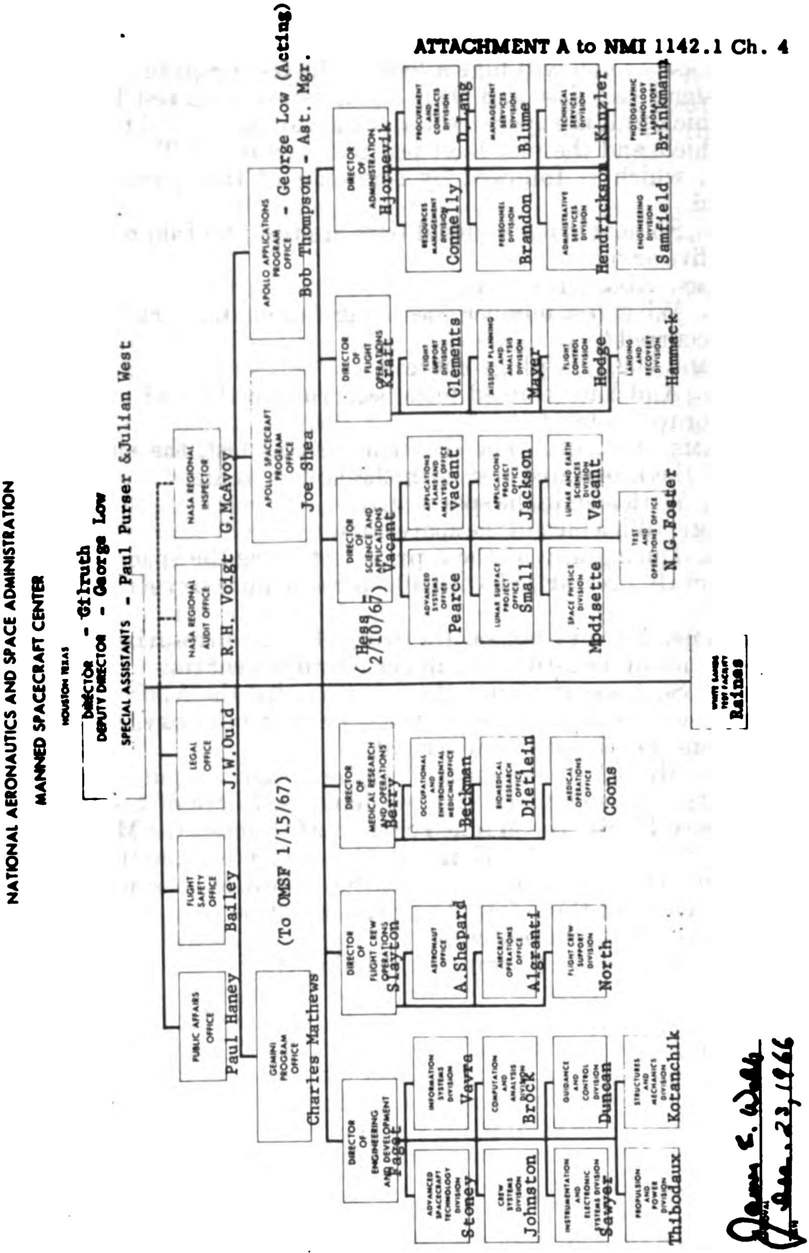
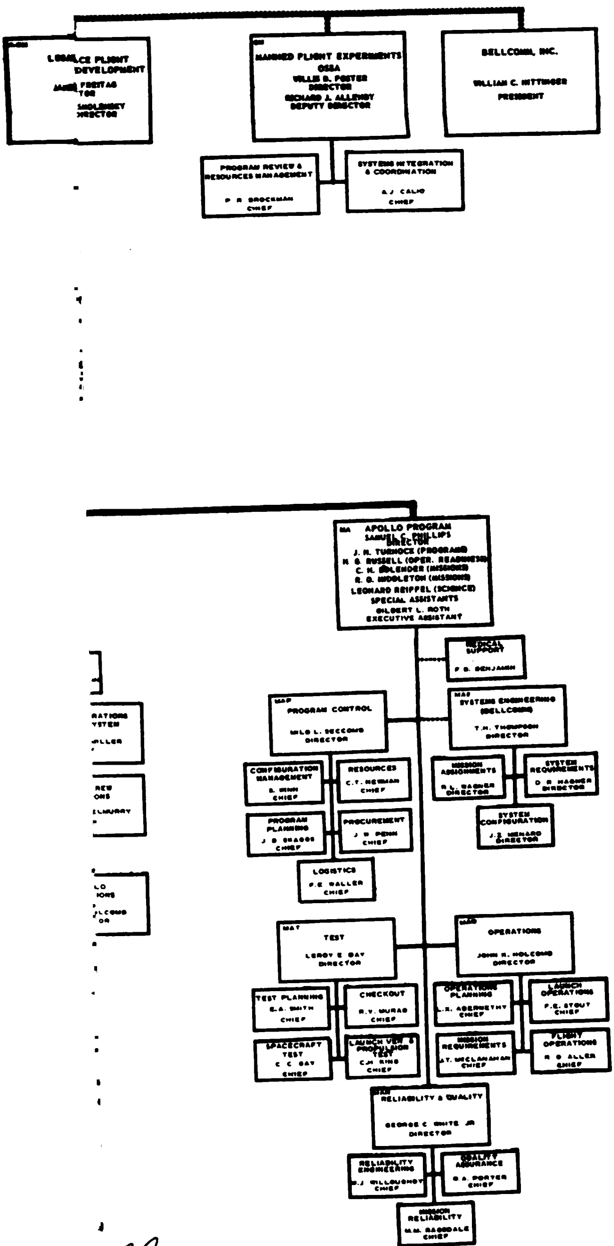

ATTACHMENT A to NMI 1142.1 Ch. 4
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON TEXAS
DIRECTOR - Gilruth
DEPUTY DIRECTOR - George Low
SPECIAL ASSISTANTS - Paul Purser &Julian West
PUBLIC AFFAIRS OFFICE
Paul Haney
FLIGHT SAFETY OFFICE
Bailey
LEGAL OFFICE
J.W.Ould
NASA REGIONAL AUDIT OFFICE
R.H. Voigt
NASA REGIONAL INSPECTOR
G.McAvoy
GEMINI PROGRAM OFFICE
Charles Mathews
(To OMSF 1/15/67)
APOLLO SPACECRAFT PROGRAM OFFICE
Joe Shea
APOLLO APPLICATIONS PROGRAM OFFICE
- George Low (Acting)
Bob Thompson - Ast. Mgr.
DIRECTOR OF ENGINEERING AND DEVELOPMENT
Faget
ADVANCED SPACECRAFT TECHNOLOGY DIVISION
Stoney
INFORMATION SYSTEMS DIVISION
Vavra
CREW SYSTEMS DIVISION
Johnston
COMPUTATION AND ANALYSIS DIVISION
Brock
INSTRUMENTATION AND ELECTRONIC SYSTEMS DIVISION
Sawyer
GUIDANCE AND CONTROL DIVISION
Duncan
PROPULSION AND POWER DIVISION
Thibodaux
STRUCTURES AND MECHANICS DIVISION
Kotanchik
DIRECTOR OF FLIGHT CREW OPERATIONS
Slayton
ASTRONAUT OFFICE
A. Shepard
AIRCRAFT OPERATIONS OFFICE
Algranti
FLIGHT CREW SUPPORT DIVISION
North
DIRECTOR OF MEDICAL RESEARCH AND OPERATIONS
Berry
OCCUPATIONAL AND ENVIRONMENTAL MEDICINE OFFICE
Beckman
BIOMEDICAL RESEARCH OFFICE
Dierlein
MEDICAL OPERATIONS OFFICE
Coons
WHITE SANDS TEST FACILITY
Raines
DIRECTOR OF SCIENCE AND APPLICATIONS
Vacant
(Hess 2/10/67)
ADVANCED SYSTEMS OFFICE
Pearce
APPLICATIONS PLANS AND ANALYSIS OFFICE
Vacant
LUNAR SURFACE PROJECT OFFICE
Small
APPLICATIONS PROJECT OFFICE
Jackson
SPACE PHYSICS DIVISION
Modisette
LUNAR AND EARTH SCIENCES DIVISION
Vacant
TEST AND OPERATIONS OFFICE
N.G.Foster
DIRECTOR OF FLIGHT OPERATIONS
Kraft
FLIGHT SUPPORT DIVISION
Clements
MISSION PLANNING AND ANALYSIS DIVISION
Mayer
FLIGHT CONTROL DIVISION
Hodge
LANDING AND RECOVERY DIVISION
Hammack
DIRECTOR OF ADMINISTRATION
Hjornevik
RESOURCES MANAGEMENT DIVISION
Connelly
PROCUREMENT AND CONTRACTS DIVISION
D. Lang
PERSONNEL DIVISION
Brandon
MANAGEMENT SERVICES DIVISION
Blume
ADMINISTRATIVE SERVICES DIVISION
Hendrickson
TECHNICAL SERVICES DIVISION
Kinzler
ENGINEERING DIVISION
Samfield
PHOTOGRAPHIC TECHNOLOGY LABORATORY
Brinkmann
James E. Webb
Dec. 23, 1966

FIGURE 78



...D SPACE FLIGHT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

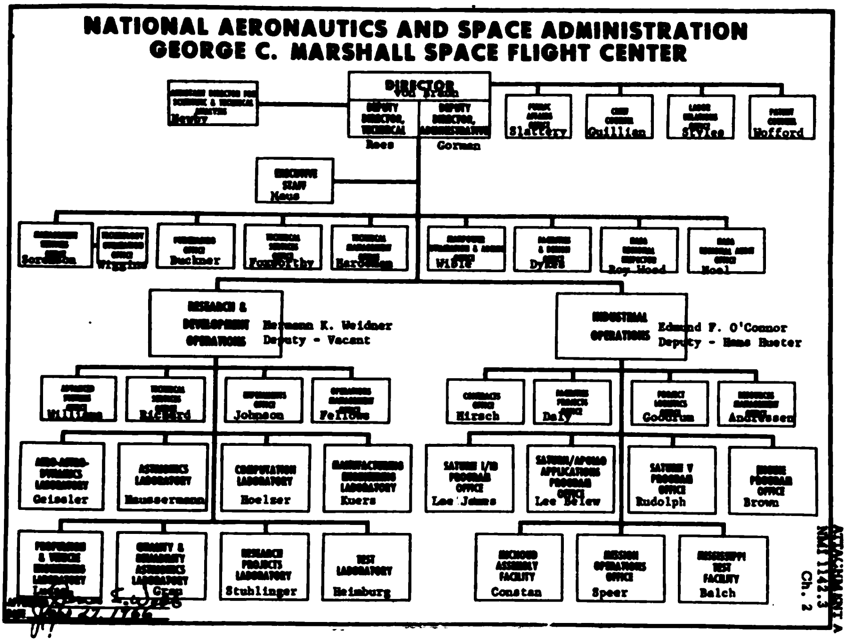


FIGURE 79

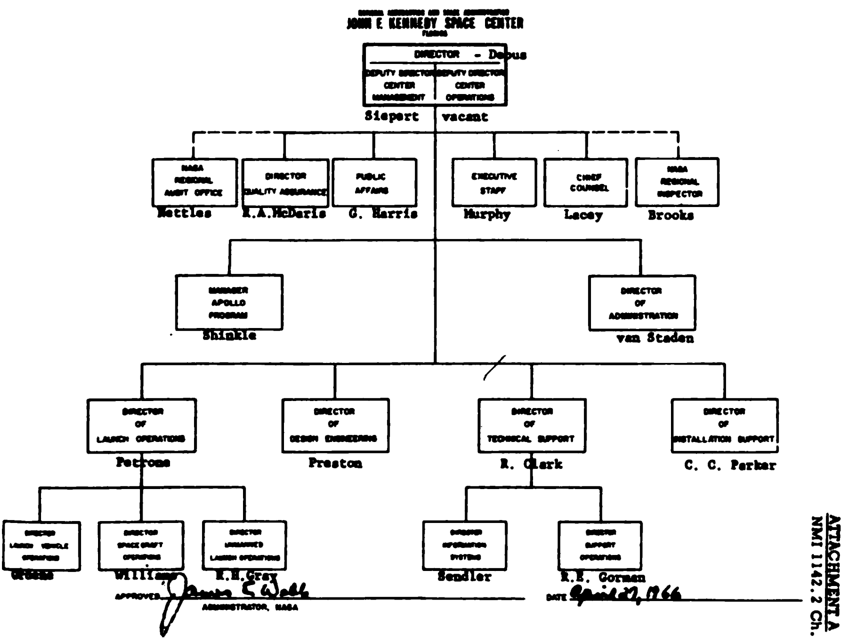


FIGURE 80

(The material on North American Aviation referred to was submitted as follows:)

Transmitted herewith is the North American Aviation, Inc. organizational structure together with a brief narrative of the organization and management of the Apollo Command and Service Module Program.

DIRECTION AND CONTROL OF APOLLO COMMAND-SERVICE MODULE (CSM) PROGRAM

I. ORGANIZATION AND MANAGEMENT OF APOLLO CSM PROGRAM

North American Aviation (NAA), by the nature of its organization and the policy of its management, makes available to the customer the full resources of the company in support of the Apollo CSM Program. Program management has been assigned to direct and control the Program to satisfy customer technical, schedule, and cost requirements.

A. Corporation

The Space and Information Systems Division (S&ID), which is responsible for the Apollo CSM and Saturn II Programs is one of seven NAA operating divisions supported by corporation administrative organizations. Each division is headed by a division president who is also a vice president of the corporation responsible to NAA President, J. L. Atwood. Mr. Atwood is also Chairman of NAA's Board of Directors. The corporation establishes and administers the broad policies which constitute the framework within which each operating division functions. Chart "X" shows the NAA corporate organization.

B. S&ID

S&ID is headed by Division President, H. A. Storms. This division is responsible for the Apollo CSM and Saturn II Programs which are being carried out under separate program managers. The Apollo CSM Program is directed by Apollo CSM Program Manager and S&ID Vice President, D. D. Myers, who is responsible to both NASA and Division President, H. A. Storms. Advanced Programs Development, and Research, Engineering and Test furnish special technical support as needed. Other S&ID functions provide administrative support—Chart "Z" shows the S&ID organization.

C. Apollo CSM

As shown in Chart "L," the Apollo CSM Program Manager, D. D. Myers, is assisted by Deputy Program Manager, C. H. Feltz, and four Assistant Program Managers. Directors of four functional areas report directly to the Program Manager. The Director of Quality and Reliability Assurance is responsible to the Program Manager in technical matters although reporting administratively to the S&ID Director of Quality and Reliability Assurance. The Director of Apollo CSM Operations, Florida, J. L. Pearce, is responsible to the Apollo CSM Program Manager although he reports administratively to the NAA General Manager of the Florida Facility, W. S. Ford. This organizational plan gives the Apollo CSM Program Manager direct control and responsibility over all phases of the Program including all subcontracting, which is administered by Apollo Material.

D. Florida facility

The overall Florida Facility organization is shown in Chart "Q," and the Apollo CSM Florida organization, in Chart "E." The Apollo CSM Florida Director, J. L. Pearce is supported by three managers, the Chief Project Engineer, R. W. Pyle, and the Technical Support Chief, R. E. Fransen. The three managers have separate areas of responsibility: Test Operations, J. M. Moore; Test Sites, R. E. Barton; and Quality and Reliability Assurance, J. L. Hansel. Very close liaison and control between Downey and Florida Apollo CSM operations is maintained.

II. PROGRAM HARDWARE RESPONSIBILITY

S&ID is responsible, with NASA concurrence, for the overall development, design, manufacture, and test of Apollo CSM hardware.

A. Spacecraft configuration

The Apollo CSM configuration is shown in Chart ZZ. S&ID is responsible for the command and service modules, the launch escape system, the spacecraft/lunar module adapter, and most subsystems pertaining to these modules. S&ID is responsible for coordinating the physical and operating interfaces of these modules and systems with the Associated Contractors (shown in Chart LC), and NASA.

B. Ground support equipment (GSE)

NAA supplies GSE as directed by NASA to support Apollo CSM test and checkout operations at all test sites. This GSE consists of checkout equipment, auxiliary equipment, servicing, and handling equipment. NAA is responsible for the design, manufacture, and checkout of this GSE.

C. Subsystems

The following Apollo CSM subsystems and modules are being produced inhouse at NAA:

Subsystem or Module and Division.—
Command and Service Modules (Complete): S&ID;
SLA (Complete): S&ID;
Launch Escape System Structure: Los Angeles Division;
Sequencer System: Autonetics; and
Command Module Reaction Control System: Rocketdyne.

Units that are made at other NAA divisions are designed, manufactured, and tested under S&ID supervision and control.

D. Subcontractors

Major and minor subcontractors are selected with NASA concurrence by S&ID, and are under S&ID surveillance. The subsystems they fabricate are designed, manufactured, and tested under S&ID supervision and control. Chart R shows the Apollo CSM major subcontractors and the systems for which each is responsible.

E. Suppliers

S&ID buys hardware for the Apollo CSM Program directly from over 12,000 first tier suppliers of which 9,000 represent small business; and the remainder, large business. All such hardware must be bought from S&ID approved sources and the hardware must be certified and tested as required to meet applicable specifications. Suppliers of these first tier suppliers represent many thousands of additional firms.

III. PROGRAM CONTROL PROCEDURES

A. The baseline for NASA and NAA management of the program is contained in the contract. The particular control baselines are the technical, master end item and specific end item specifications, the contract plans, and contract change notices which become incorporated into the baselines by specification and supplemental agreements. The controlling plans are the Manufacturing Plan, the Quality Control Plan, the Configuration Management Plan, the Ground Operations Requirement Plan and the Reliability Plan.

B. Control Tools—Cost, Schedule and Quality. Program control procedures are implemented only after formal Joint NASA/NAA interface agreements. These interfaces consist of contractual, technical and schedule meetings and documentation. Contractual direction is given by NASA to NAA through (bilateral) Supplemental Agreements and Contract Specification Change Notices and through (unilateral, by NASA) Contract Change Authorizations. Technical direction is given by NASA through Program Management Meetings, letters and wires to the NAA contracting officer and in formal reviews and Interface Control Documents. Formal joint reviews are Preliminary and Critical Design Reviews (PDR's and CDR's), First Article Configuration Inspection (FACI), Customer Acceptance Readiness Reviews (CARR) and Flight Readiness Reviews (FRR).

Through the S&ID Apollo CSM Program Manager's Office, control is exercised over CSM program costs, schedule and quality. The control media include the following:

1. *Cost Control* is provided primarily through Joint NASA/NAA negotiated and approved "work packages" with individual work package managers assigned to control costs, schedule achievements and quality. The choice of work package breakdown structure has enabled individual cost control of functional elements within S&ID as well as major subcontractors which supply CSM subsystems. NASA, NAA division and corporate policies assure proper make or buy decisions, subcontractor bid selection and the like.

2. *Schedule Control*, is provided by use of a "Master Development Schedule," a formal schedule change system, a PERT reporting system of scheduled milestones and formal critical problem reports. Major schedule changes receive concurrence of the NASA Program Manager prior to NAA implementation. The selection of schedule milestones, monitored by PERT are also identified in the cost control work packages, yielding an integrated cost/schedule measuring device.

3. *Control of Quality* is provided by (a) jointly approved hardware qualification test-selection, criteria, test surveillance and test report approval, (b) Joint NASA/NAA mandatory inspection point assignments and surveillance, and (c) step-by-step inspections (NASA/NAA) through manufacture, checkout and prelaunch operations. A failure reporting system assures follow-up on potentially discrepant hardware. Control of subcontractor quality is provided in a similar fashion, with NAA and NASA approvals obtained as described in paragraph E.

C. *Management Control Documents*—Management control documents for Apollo CSM hardware exist at both the program level and at the first-line level of NAA S&ID management. The top documents serve to record design and product certification and flight readiness. These are the jointly approved minutes of PDR, CDR, FACI, CARR, Design Certification Review (DCR) and FRR.

The first-line level management control documents are:

1. *Design*—Master Change Records (MCR), drawings, process specifications, interface control documents and measurement lists.
2. *Manufacturing*—Fabrication and inspection record tickets, planning tickets, tool orders and parts replacement requests.
3. *Material (Purchasing)*—Purchase order, purchase order change notice and specification control documents.
4. *Test and Operations*—Operational test plan, operational checkout procedure, not satisfactory report, test preparation sheet, development test procedure.
5. *Quality and Reliability Assurance*—Inspection test instructions, material review disposition and quality control specifications.

D. *Configuration Management*—Configuration Management is practiced through compliance with the NASA Apollo Configuration Management Manual and NAA Division Policies as implemented by the Apollo CSM Change Control Board, chaired by the Assistant Program Manager. Configuration changes with major program impact are resolved at Joint Change Control Board meetings between the NASA and S&ID Program Managers.

Changes imposed on program baselines originate from both NASA and NAA. NASA directed changes are processed by Contracts through the Change Control Board for preparation of proposals. In-house changes are processed by the Apollo CSM chief project engineer also through the Board for evaluation and direction. Change control documentation is in the form of a Master Change Record (MCR) which defines the change and is the basis of an order to the functional departments to provide cost and schedule information for necessary evaluation, prior to final implementation. The MCR can be used, as above, to determine details of a change prior to implementation; however for urgent changes the purpose of the MCR is to initiate action, which is accomplished upon MCR approval by Program Management for "Release to Production".

Configuration records are maintained in mechanized records of released engineering drawings and specifications. These records provide indentured drawing lists, parts lists and alpha-numeric parts or drawing lists. The manufacturing planning system assures drawings and engineering order (E.O.) compliance utilizing Fabrication and Inspection Records (FAIR) and a Change Verification Record (CVR) for each end item. The FAIR provides both fabrication instructions and inspection verification; the CVR provides E.O. records and verification of compliance.

During Downey, Houston and Florida testing, a Test and Inspection Record (TAIR) system provides identical configuration and inspection information.

E. Subcontractor control baselines consist of (a) approved design specifications, drawings, components, qualification test plans and reports, acceptance test plans, critical process specifications, and component failure histories. A FACI is conducted for complex (major) procurements by S&ID with a NASA audit. Other procurements are subjected to FACI at NAA, utilizing subcontractor data. All baselines are re-verified to NASA at the SC 101 (Block II lunar capable vehicle) FACI.

Conformance of the subcontractors is controlled by "freezing" component changes at FACI, strict part number control, identification and reidentification. source or receiving inspection to formally approved drawings and baselines and component repair or overhaul, controlled to the configuration specified in the approved baseline.

Changes are justifiable only for NASA or NAA requirements modifications; failure in qualification, during production or in operational tests; or for significant cost reduction. Change controls parallel the NASA–S&ID change control procedures. This method of subcontractor control is in effect at such major subcontractors as Honeywell, AiResearch, Beech and Pratt & Whitney.

F. Field Site Control—Apollo CSM Program Field Site efforts with activities at Florida, MSC–Houston, White Sands, New Mexico and El Centro, California, are managed as are similar efforts in Downey. The management differences are caused by the fact that hardware at field sites has usually been transferred to NASA-owned, and also is governed by NASA field site management procedures, rather than NAA or NASA–MSC.

Hardware flow through the field site is controlled by the Ground Operations Requirement Plan (GORP) contractual document, as modified by operational changes and deviations approved by the NASA–KSC or other field site change board.

Hardware changes evolving from NASA and NAA sources, identified previously are processed through the Downey system for incorporation in a similar manner to other changes.

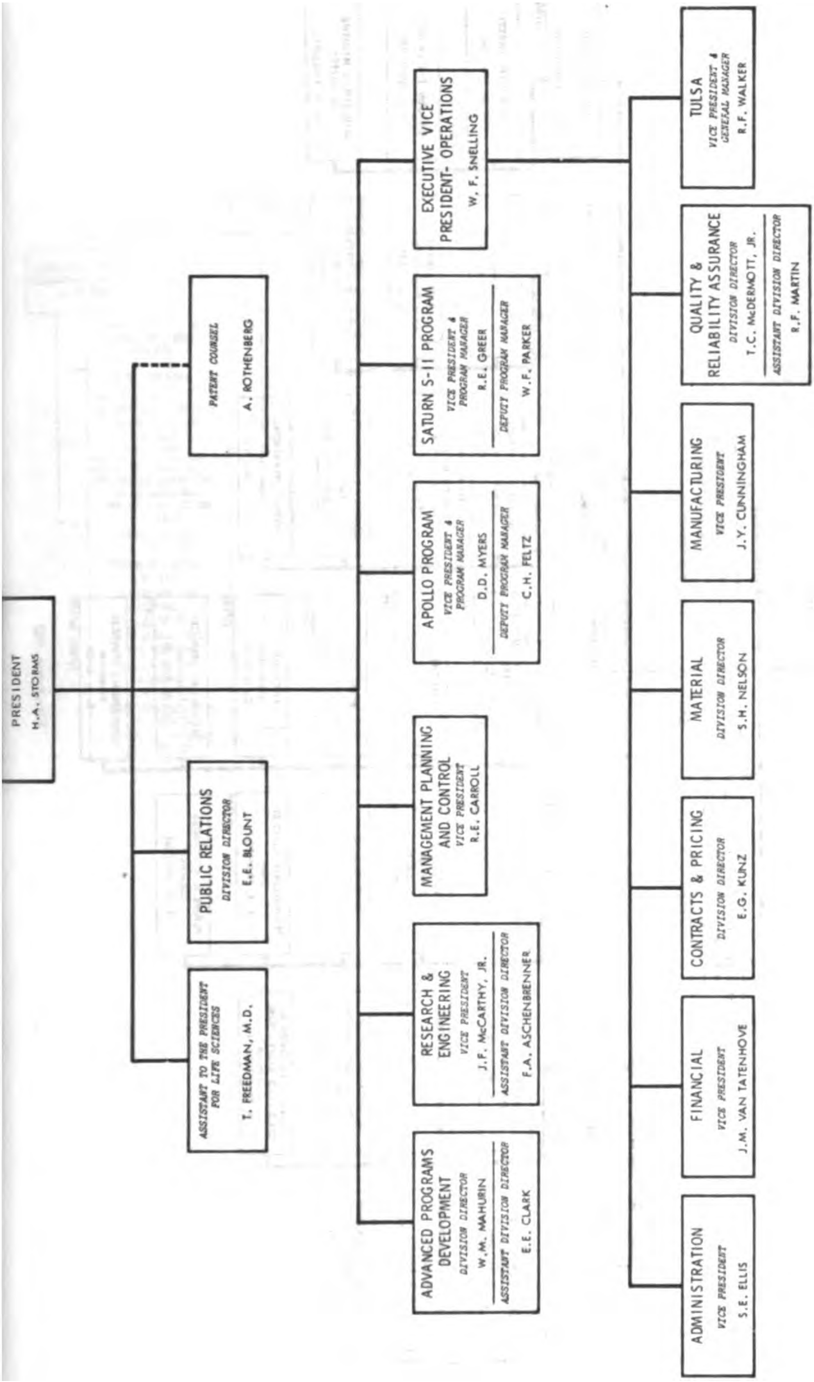

PRESIDENT
H.A. STORMS
PATENT COUNSEL
A. ROTHENBERG
PUBLIC RELATIONS
DIVISION DIRECTOR
E.E. BLOUNT
ASSISTANT TO THE PRESIDENT FOR LIFE SCIENCES
T. FREEDMAN, M.D.
EXECUTIVE VICE PRESIDENT- OPERATIONS
W. F. SNELLING
SATURN S-II PROGRAM
VICE PRESIDENT & PROGRAM MANAGER
R.E. GREER
DEPUTY PROGRAM MANAGER
W.F. PARKER
APOLLO PROGRAM
VICE PRESIDENT & PROGRAM MANAGER
D.D. MYERS
DEPUTY PROGRAM MANAGER
C.H. FELTZ
MANAGEMENT PLANNING AND CONTROL
VICE PRESIDENT
R.E. CARROLL
RESEARCH & ENGINEERING
VICE PRESIDENT
J.F. McCARTHY, JR.
ASSISTANT DIVISION DIRECTOR
F.A. ASCHENBRENNER
ADVANCED PROGRAMS DEVELOPMENT
DIVISION DIRECTOR
W.M. MAHURIN
ASSISTANT DIVISION DIRECTOR
E.E. CLARK
TULSA
VICE PRESIDENT & GENERAL MANAGER
R.F. WALKER
QUALITY & RELIABILITY ASSURANCE
DIVISION DIRECTOR
T.C. McDERMOTT, JR.
ASSISTANT DIVISION DIRECTOR
R.F. MARTIN
MANUFACTURING
VICE PRESIDENT
J.Y. CUNNINGHAM
MATERIAL
DIVISION DIRECTOR
S.H. NELSON
CONTRACTS & PRICING
DIVISION DIRECTOR
E.G. KUNZ
FINANCIAL
VICE PRESIDENT
J.M. VAN TATENHOVE
ADMINISTRATION
VICE PRESIDENT
S.E. ELLIS

FIGURE 81

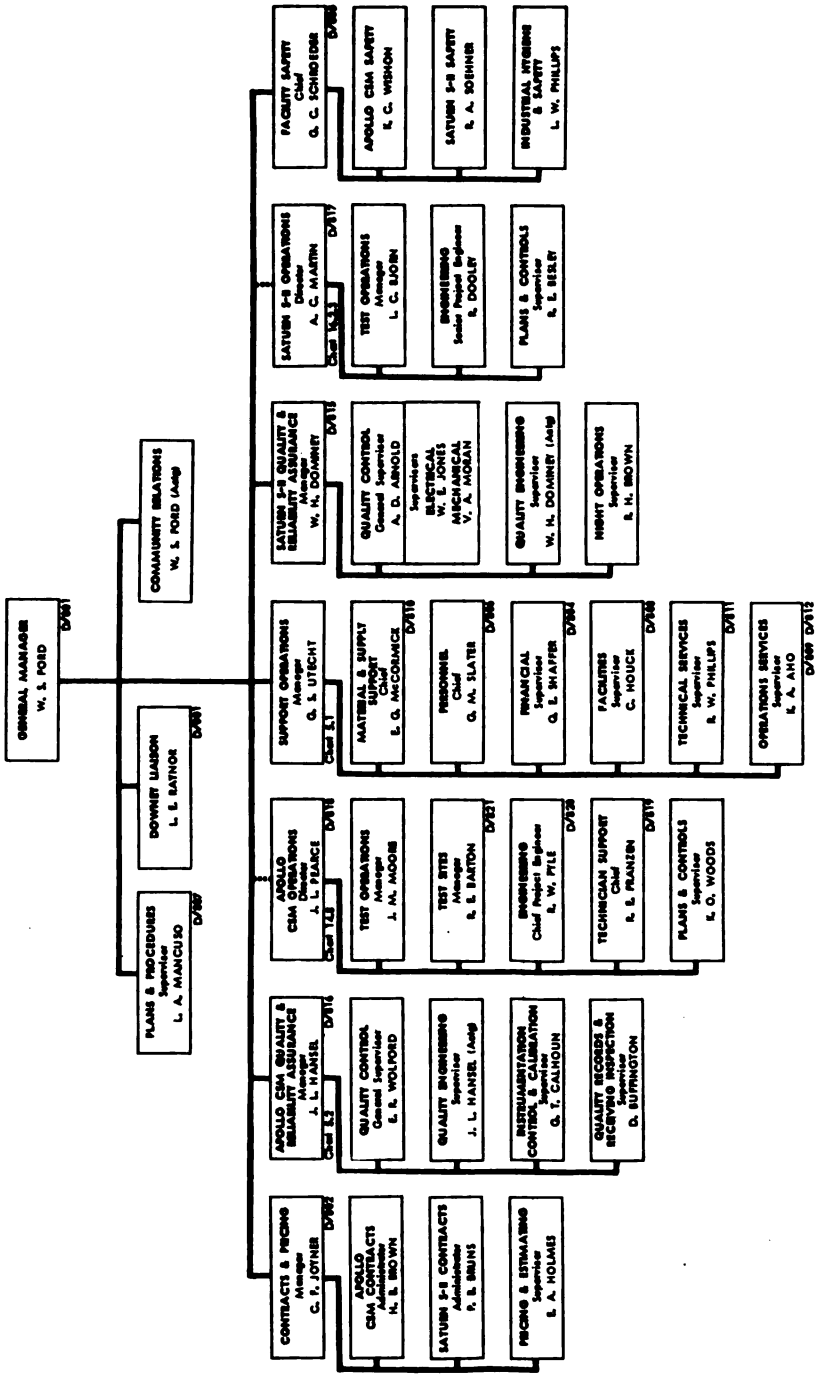

GENERAL MANAGER W. S. FORD D/801
COMMUNITY RELATIONS W. S. FORD (Actg)
DOWNEY LIAISON L. E. RATNOR D/801
PLANS & PROCEDURES Supervisor L. A. MANCUSO D/807
CONTRACTS & PRICING Manager C. F. JOYNER D/802
APOLLO CSM CONTRACTS Administrator H. E. BROWN
SATURN S-II CONTRACTS Administrator P. E. BRUNS
PRICING & ESTIMATING Supervisor E. A. HOLMES
APOLLO CSM QUALITY & RELIABILITY ASSURANCE Manager J. L. HANSEL D/816
QUALITY CONTROL General Supervisor E. R. WOLFORD
QUALITY ENGINEERING Supervisor J. L. HANSEL (Actg)
INSTRUMENTATION CONTROL & CALIBRATION Supervisor G. T. CALHOUN
QUALITY RECORDS & RECEIVING INSPECTION Supervisor D. BUFFINGTON
APOLLO CSM OPERATIONS Director J. L. PEARCE D/818
TEST OPERATIONS Manager J. M. MOORE
TEST SITES Manager R. E. BARTON D/821
ENGINEERING Chief Project Engineer R. W. PYLE D/820
TECHNICIAN SUPPORT Chief R. E. FRANZEN D/819
PLANS & CONTROLS Supervisor K. O. WOODS
SUPPORT OPERATIONS Manager G. S. UTECHT
MATERIAL & SUPPLY SUPPORT Chief E. G. McCORMICK D/810
PERSONNEL Chief G. M. SLATER D/805
FINANCIAL Supervisor G. E. SHAFFER D/804
FACILITIES Supervisor C. HOUCK D/808
TECHNICAL SERVICES Supervisor R. W. PHILLIPS D/811
OPERATIONS SERVICES Supervisor K. A. AHO D/809 D/812
SATURN S-II QUALITY & RELIABILITY ASSURANCE Manager W. H. DOMINEY D/815
QUALITY CONTROL General Supervisor A. D. ARNOLD
Supervisors ELECTRICAL W. E. JONES MECHANICAL V. A. MORAN
QUALITY ENGINEERING Supervisor W. H. DOMINEY (Actg)
NIGHT OPERATIONS Supervisor R. H. BROWN
SATURN S-II OPERATIONS Director A. C. MARTIN D/817
TEST OPERATIONS Manager L. C. SJORN
ENGINEERING Senior Project Engineer R. DOOLEY
PLANS & CONTROLS Supervisor R. E. BESLEY
FACILITY SAFETY Chief G. C. SCHROEDER
APOLLO CSM SAFETY K. C. WISHON
SATURN S-II SAFETY R. A. SOEHNER
INDUSTRIAL HYGIENE & SAFETY L. W. PHILLIPS

FIGURE 82

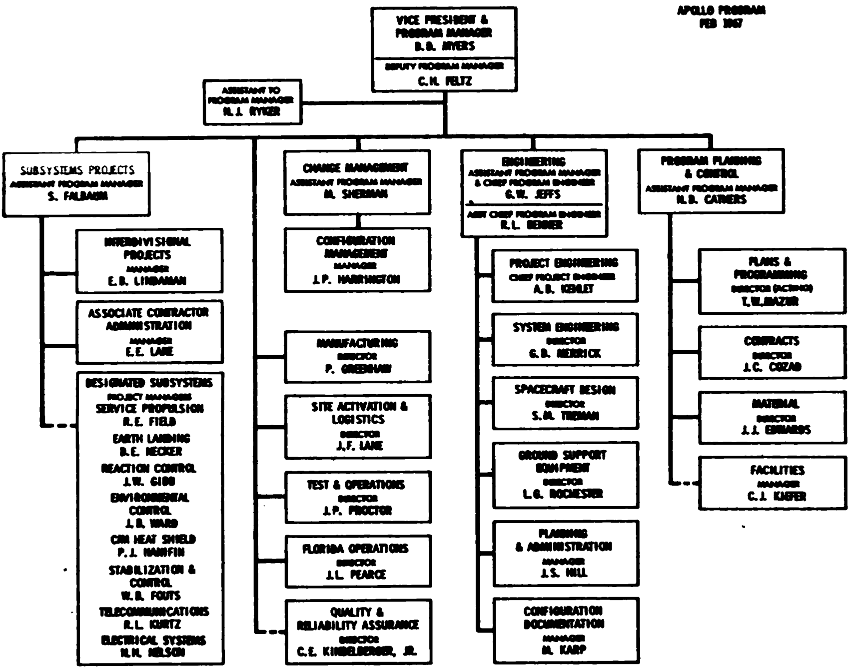

APOLLO PROGRAM
FEB 1967
VICE PRESIDENT & PROGRAM MANAGER
D. D. MYERS
DEPUTY PROGRAM MANAGER
C. H. FELTZ
ASSISTANT TO PROGRAM MANAGER
H. J. RYKER
SUBSYSTEMS PROJECTS
ASSISTANT PROGRAM MANAGER
S. FALBAUM
CHANGE MANAGEMENT
ASSISTANT PROGRAM MANAGER
M. SHERMAN
ENGINEERING
ASSISTANT PROGRAM MANAGER & CHIEF PROGRAM ENGINEER
G. W. JEFFS
ASST CHIEF PROGRAM ENGINEER
R. L. BENNER
PROGRAM PLANNING & CONTROL
ASSISTANT PROGRAM MANAGER
H. B. CATHERS
INTERDIVISIONAL PROJECTS
MANAGER
E. B. LINDAMAN
ASSOCIATE CONTRACTOR ADMINISTRATION
MANAGER
E. E. LANE
DESIGNATED SUBSYSTEMS
PROJECT MANAGERS
SERVICE PROPULSION
R. E. FIELD
EARTH LANDING
D. E. HECKER
REACTION CONTROL
J. W. GIBB
ENVIRONMENTAL CONTROL
J. B. WARD
CM HEAT SHIELD
P. J. HANIFIN
STABILIZATION & CONTROL
W. B. FOUTS
TELECOMMUNICATIONS
R. L. KURTZ
ELECTRICAL SYSTEMS
N. N. NELSON
CONFIGURATION MANAGEMENT
MANAGER
J. P. HARRINGTON
MANUFACTURING
DIRECTOR
P. GREENSHAW
SITE ACTIVATION & LOGISTICS
DIRECTOR
J. F. LANE
TEST & OPERATIONS
DIRECTOR
J. P. PROCTOR
FLORIDA OPERATIONS
DIRECTOR
J. L. PEARCE
QUALITY & RELIABILITY ASSURANCE
DIRECTOR
C. E. KINDELBERGER, JR.
PROJECT ENGINEERING
CHIEF PROJECT ENGINEER
A. B. KEHLET
SYSTEM ENGINEERING
DIRECTOR
G. D. MERRICK
SPACECRAFT DESIGN
DIRECTOR
S. M. TREMAN
GROUND SUPPORT EQUIPMENT
DIRECTOR
L. G. ROCHESTER
PLANNING & ADMINISTRATION
MANAGER
J. S. HILL
CONFIGURATION DOCUMENTATION
MANAGER
M. KARP
PLANS & PROGRAMMING
DIRECTOR (ACTING)
T. W. MAZUR
CONTRACTS
DIRECTOR
J. C. COZAD
MATERIAL
DIRECTOR
J. J. EDWARDS
FACILITIES
MANAGER
C. J. KIEFER

FIGURE 83

17AP86788

APOLLO ASSOCIATE CONTRACTORS

MIT	GUID & NAV EQUIP. - TECH MGMT
AC ELECTRONICS	GUID & NAV EQUIP. - MFG
CHRYSLER	S-I
BOEING	S-IC
NAA S&ID	S-II
DOUGLAS	S-IV & S-IVB
GENERAL ELECTRIC	ACCEPTANCE CHECKOUT EQUIP.
GRUMMAN	LUNAR MODULE
HAMILTON STANDARD	SPACESUIT & PORTABLE EQUIP.

FIGURE 84

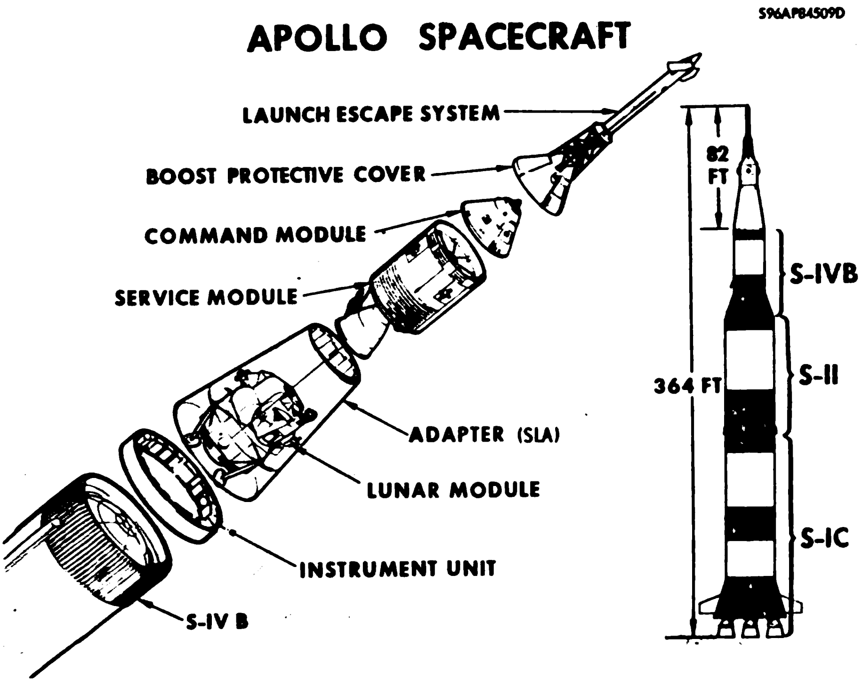

S96AP84509D
APOLLO SPACECRAFT
LAUNCH ESCAPE SYSTEM
BOOST PROTECTIVE COVER
COMMAND MODULE
SERVICE MODULE
ADAPTER (SLA)
LUNAR MODULE
INSTRUMENT UNIT
S-IV B
82 FT
364 FT
S-IVB
S-II
S-IC

FIGURE 85

APOLLO MAJOR SUBCONTRACTORS

SUBSYSTEM	SUBCONTRACTOR
SERVICE MODULE PROPULSION MOTOR	AEROJET-GENERAL CORPORATION
CM HEATSHIELD BRAZED STRUCTURE PANELS	AERONCA MFG CORPORATION
ABLATIVE HEATSHIELD	AVCO CORPORATION, RESEARCH & ADVANCED DEVELOPMENT DIVISION
SUPER CRITICAL GAS STORAGE	BEECH AIRCRAFT CORPORATION
COMMUNICATIONS AND DATA	COLLINS RADIO COMPANY
ENVIRONMENTAL CONTROL	GARRETT CORPORATION, AIRESEARCH MFG. DIVISION
MISSION SIMULATOR TRAINER	GENERAL PRECISION, INC. LINK DIVISION
STABILIZATION AND CONTROL	HONEYWELL
LAUNCH ESCAPE AND PITCH CONTROL MOTORS	LOCKHEED PROPULSION COMPANY
REACTION CONTROL MOTORS (SERVICE MODULE)	THE MARQUARDT CORPORATION
EARTH LANDING	NORTHROP CORPORATION, VENTURA DIVISION
ESCAPE TOWER JETTISON MOTOR	THIOKOL CHEMICAL CORPORATION, ELKTON DIVISION
FUEL CELL	PRATT & WHITNEY AIRCRAFT, DIVISION OF UNITED AIRCRAFT CORPORATION

FIGURE 86

NASA-CONTRACTOR AND STRUCTURE QUESTIONED

Mr. GEHRIG. Dr. Thompson, the chairman asked a question early this afternoon as to whether or not the Board felt that there was a division of responsibility which contributed to the fact that desired quality levels were not achieved. For example, divisions of responsibility between the Manned Spacecraft Center and North American Aviation, et cetera, that were not properly defined. As I understood your answer, you said that the Board had found these—the gist of your answer was that there were not divisions of responsibility, but that does not seem to be the same as your determination under finding No. 11, and I wonder if you can speak to that determination and amplify this for the committee.

Dr. THOMPSON. The problem, I think, that we have identified is more the interface between MSC and KSC. As the spacecraft is moved from the custody of Downey, the contractor, under MSC control, cognizance, to Kennedy, KSC, where in effect another group of NASA employees take over but still under the control of MSC, and I think that in the development of working interfaces there of MSC retaining the control over the spacecraft as far as design changes in things that affect the cost are concerned, or changes to the spacecraft, that there is some—a problem of cumbersomeness or what was defined to us as cumbersomeness, that relates to working out in an effective way those relationships. This is, I think, as close as I can come to, or is about as well as I really understand the problem.

We heard quite a lot of talk about this in our considerations here, and I believe that it is the development in this evolving area that is not yet perhaps resolved. All the interface of the NASA organization working with another set of contractors, another contractor group, too.

Now, North American has 8,000 employees at Downey and something like a thousand at KSC, so the spacecraft moves from one group of people to another but—two different groups, in effect, with the necessity for actual control remaining always at MSC, and I think that the problems are the interface problems that have not been sufficiently smoothed out to deal with the flexibilities required, or the quick response that is required with the necessity for actual restraint, and I do not believe that I can go much farther than that.

Mr. GEHRIG. So that there are some management problems. There are some management problems, in this area.

Dr. THOMPSON. There are management problems in every program I have ever seen and this is one that probably is not fully resolved yet. The lines of organization seem to define these things to a point that it does not appear in the line organizations.

Mr. GEHRIG. Mr. Chairman, those are all the questions that I have.

The CHAIRMAN. We will go back again. We want to see if there are additional questions.

Senator Curtis?

SAFETY GIVEN TOP CONSIDERATION

Senator CURTIS. Just one question, and I am sorry I had to be out. If this has been covered, why, I will not go over it again.

Colonel Borman, this morning I asked you about the fact that you had objections to the wiring before you went on this Board. Did you express those objections to anyone?

Colonel BORMAN. Sir, I believe you asked me if I knew of deficiencies in the wiring, and I said yes, I did. The deficiencies were continually being corrected, and they were known, and they were modified, and as far as I know at the time of this test the wiring was accepted.

Senator CURTIS. In other words, you are referring to some deficiencies that were known and——

Colonel BORMAN. And had been fixed.

Senator CURTIS. And when it was mentioned they were taken care of.

Colonel BORMAN. Yes, sir.

Senator CURTIS. So you were not referring to some deficiencies that, after they became known, were neglected.

Colonel BORMAN. No, sir.

Senator CURTIS. Do you know of anything in the space program where such a thing prevailed?

Colonel BORMAN. Sir, while you were out I mentioned to Senator Brooke that I know of no instance in my 5 years with NASA when there has been ever any compromise when a question of crew safety was involved in any respect—time, schedule, money, and everything—everything was sacrified to provide a safe vehicle.

Senator CURTIS. Did you ever receive any rejection of questions or inquiries about something? Was there freedom to express a concern about something that ought to be improved?

Colonel BORMAN. Yes, sir; I think speaking again as a flight crewmember, this is, in my opinion is, one of the very great assets of NASA as an organization. The opinions, the considerations, and sometimes even the desires of the flight crew are always listened to and very often heeded. We have a very willing and able access to every level of management.

Senator CURTIS. Well, I will not pursue it any further, and I am pleased that Senator Brooke did follow through, because I was afraid this morning we may have left a record that to some would indicate that you were aware of some deficiencies that somebody failed to take care of.

Colonel BORMAN. I am sorry I left you with that impression.

Senator CURTIS. No; I think it was the questioning that would have left that.

BOARD UNANIMOUS IN FINDINGS

The CHAIRMAN. Dr. Thompson, we know that each member of the Apollo 204 Review Board has formally signed the Board's report indicating concurrence in the findings included therein. However, I think it would be well that the record show that this committee has been assured that no Board member has any reservation concerning any aspect of the report or any of the findings and recommendations.

Therefore, if any member has any such reservation, would he please stand up, identify himself, and state what part of the report he wishes to have qualified insofar as he is concerned?

You have to speak now or forever hold your peace.

Dr. THOMPSON. I am not surprised at the result of that, because I thought we did have concurrence.

The CHAIRMAN. I thought so, too.

Senator Cannon?

Senator CANNON. Thank you, Mr. Chairman.

Dr. VAN DOLAH, I want to make sure I understood your testimony correctly. You say that in your opinion had there been an adequate dump system and a quick opening hatch, that the crew could have escaped alive in this instance.

Dr. VAN DOLAH. Yes, sir; that is correct.

Senator CANNON. I would like to ask you whether or not in your judgment as a fire expert if the recommendations of the Board are taken here with respect to combustibles, and the vulnerable wiring system and the vulnerable plumbing that have been identified here have been correct, and a quick-opening hatch has been provided, do you believe that there will be any likelihood of a loss of any further crewmembers in this program as a result of fire in the capsule?

Dr. VAN DOLAH. No, sir; I do not.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Any further questions?

Thank you very much. This has been a very useful hearing. We are going to keep the record open in case additional questions come up. If we do have questions which you have not answered, they will be submitted to you for your reply. When we recess today, we will reconvene Thursday, April 13, at 2 p.m. in room 235 of the Old Senate Office Building. We will meet Thursday in this room here, Thursday at 2 o'clock. (The meeting place was later changed to room S-126.)

Thank you very much Doctor, and all the members of your Board. You have done a very fine job.

Dr. THOMPSON. Thank you, sir.

(Whereupon, at 4:25 p.m., the committee recessed, to reconvene at 2 p.m., Thursday, April 13, 1967).

(The biographies of Board members are as follows:)

DR. FLOYD LAVERNE THOMPSON

Dr. Floyd LaVerne Thompson is Director, Langley Research Center, National Aeronautics and Space Administration, Hampton, Virginia. He plans and directs research designed to provide the science and technology for a variety of important aeronautical and space programs, including the national effort to land a man on the moon and safely return him to earth. He guided research leading to a number of programs of world importance including Project Mercury, the concept of erectable space vehicles which led to the development of the world's first passive communications satellite, and the first solid fueled launch vehicle to propel a satellite into orbit.

Dr. Thompson was born in Salem, Michigan, November 25, 1898; graduated from high school in Salem in 1917 and served the following four years in the United States Navy. After his war service, he entered University of Michigan and was awarded a B.S. Degree in Aeronautical Engineering in June 1926.

He began his science career July 8, 1926, as a member of the staff of the Langley Research Center of the former National Advisory Committee for Aeronautics, nucleus of the National Aeronautics and Space Administration. Starting as an aeronautical engineer in the Flight Research Division, he progressed through various assignments to Chief of Research in 1945. He was appointed Associate Director in charge of all research September 14, 1952, and in May 1960, became Director of the Center. In addition to his duties as Langley Director, Dr.

Thompson completed a two-year period of service as Chairman of the Policy Planning Board at NASA Headquarters, Washington, D.C.

He is the author or co-author of 20 technical reports based on research he conducted. He has lectured and participated in a number of technical conferences conducted by NASA, the American Institute of Aeronautics and Astronautics, the Society of Automotive Engineers and many other professional organizations. Dr. Thompson was elected in 1949 as a Fellow of the American Institute of Aeronautics and Astronautics. He is a member of the American Association for the Advancement of Science.

Dr. Thompson was cited by the University of Michigan in 1953 as a distinguished alumnus in recognition of his outstanding career in the flight sciences and honored him again in June 1963 by awarding him the honorary degree of Doctor of Science. The College of William and Mary awarded him the honorary degree of Doctor of Science in June 1963.

In May 1963, the President of the United States presented the NASA Medal for Outstanding Leadership to Dr. Thompson at ceremonies at the White House. He was honored by the NASA "for his outstanding leadership of the scientists and engineers who were responsible for the original technical concepts and who comprised the nucleus of the development team for the space flight missions of the United States in Project Mercury."

Active in civic affairs in Hampton, Virginia, and surrounding communities, Dr. Thompson is a member of the Hampton Rotary Club and the Board of Trustees of the Dixie Hospital. He is an honorary member of the Board of Directors of the Virginia Peninsula Chamber of Commerce, a trustee of The War Memorial Museum of Virginia, and an honorary life member of the Engineers' Club of the Virginia Peninsula.

Dr. Thompson lives at 94 Alleghany Road, Hampton, with his wife—the former Jean Geggie of Hampton. They have three daughters.

CHARLES F. STRANG, COLONEL, USAF

Colonel Charles F. Strang is Chief, Missile and Space Safety Division, Directorate of Aerospace Safety, Deputy Inspector General for Inspection and Safety, Headquarters, United States Air Force. In this and prior assignments, Colonel Strang has obtained extensive experience in aircraft and missile accident investigation. He was alternate President of the Air Force Board which investigated the Titan II Missile Accident of August 1965 at Little Rock Air Force Base, Arkansas.

Colonel Strang entered the United States Air Force in January 1940. He was commissioned a Second Lieutenant in March 1943 after graduation from Officer Candidate School, Miami Beach, Florida. He has served in various staff and management positions in the fields of aircraft and missile maintenance engineering and materiel. These assignments included: Chief of Maintenance, 7th Bombardment Wing, Carswell Air Force Base, Texas; Director of Materiel, 72d Bombardment Wing, Ramey Air Force Base, Puerto Rico; Deputy Director of Weapon Systems, Headquarters, 13th Strategic Missile Division, Francis E. Warren Air Force Base, Cheyenne, Wyoming; and Chief of Weapons Maintenance Management, Directorate of Materiel, Headquarters, Strategic Air Command, Omaha, Nebraska.

Colonel Strang has been awarded the Legion of Merit, the Air Force Commendation Medal with Oakleaf Cluster, the Army Commendation Medal and other Service Medals. He has served in South America, Puerto Rico and Europe.

Colonel Strang was born in Philadelphia, Pennsylvania, in 1918. He completed high school at Havertown, Pennsylvania and attended Texas Christian and Florida State Universities. In 1956, he graduated from the Air Force Command and Staff College at Maxwell Air Force Base, Alabama. He is a 1965 graduate of the Industrial College of the Armed Forces, Washington, D.C.

Colonel Strang is married to the former Mildred Irene Wells of Benton, Illinois. They have two daughters and a son. Daughter Charlene is married to Mr. R. James Mitchell of Lincoln, Nebraska. Their son, Charles II, who attends San Bernardino College, and daughter, Karen Sue, reside with the Colonel and Mrs. Strang in Redlands, California.

E. BARTON GEER

Mr. E. Barton Geer has been Associate Chief of the Flight Vehicle and Systems Division, Langley Research Center, Hampton, Virginia, since 1961. He is responsible for directing and reviewing the design and development work of the three Branches of this Division covering mechanical, structural, dynamic analysis, reliability, qualification testing of spacecraft systems and subsystems. Included are considerations of thermal balance, life support, cryogenics, hypergolic, hydrogen peroxide and cold gas control systems, deployment devices, structures, dynamic vehicles and reentry and orbiting payloads.

Mr. Geer was born April 28, 1919, in Rockwell, Iowa. He attended Iowa public schools and received his Bachelor of Science Degree in Mechanical Engineering from Iowa State College in 1942, at which time he joined the Langley Research Center. From 1942 to 1950, Mr. Geer designed and developed vacuum systems, high pressure air systems, air dryers, refrigeration systems and heat exchangers. In 1950, Mr. Geer became Group Leader of the Mechanical Engineering Group and he held this position for six years. In 1956, Mr. Geer was made Head of the Systems Engineering Section, supervising twenty-five specialists and engineers in the field of thermodynamic pressure and fluid systems. In addition, he directed the detail design of the 9 foot x 6 foot Thermal Structures air storage and supervised investigation of materials and design methods for obtaining air temperatures up to 5,000 F.

In 1960, Mr. Geer was made Branch Head of Systems Engineering Branch, consisting of 60 specialists and engineers working on systems and controls. In January 1964, Mr. Geer was named Chairman of the Scout Vehicle Design Environmental and Quality Control Committee which consisted of ten members to review the relationship among design, environment, quality control, testing and operations on the reliability of the total Scout Vehicle System. In September 1964, he was appointed Chairman of the structural, mechanical, electrical and pyrotechnic committee to review the related systems of the Pegasus Project. In 1965, Mr. Geer was appointed Chairman of a committee to review the systems, reliability and operational status of the Explorer Injun IV spacecraft. On Project Fire, he participated in the design and flight reviews of the spacecraft and directed the design and review of the tracking telespectrograph. On the Lunar Orbiter Spacecraft, Mr. Geer participated in all the Preliminary and Critical Design reviews.

He is married to the former Iris J. Carr of Fertile, Iowa, and they live at 3203 Matoaka Road, Hampton, Virgina. They have two daughters, Diane and Cheryl.

Mr. Geer is active in Civic and Church work. He is a registered professional engineer in the State of Virginia and is a member of the Engineers' Club of the Virginia Peninsula.

FRANK BORMAN, COLONEL, USAF, NASA ASTRONAUT

Colonel Frank Borman was assigned as Commander of the third manned Apollo flight. He was Commander on the fourteen-day Gemini VII mission.

Colonel Borman entered the Air Force in June 1950 after graduation from West Point. He received his pilots' wings in 1951. From 1951 to 1956 he was assigned to various fighter squadrons in the United States and the Philippine Islands.

Colonel Borman became an assistant professor of thermodynamics and fluid mechanics at the United States Military Academy in 1957. In 1960 he graduated from the USAF Aerospace Research Pilots School. He remained there as an instructor until 1962 when he was selected by NASA as an astronaut. Colonel Borman served as back-up command pilot for the Gemini IV mission prior to flying on Gemini VII. He has accumulated over 5200 hours flying time, including 4300 hours in jet aircraft.

Colonel Borman has been awarded the NASA Exception Service Medal and the Air Force Command Astronaut Wings. He also received the 1966 American Astronautical Flight Achievement Award and the 1966 Air Force Association David C. Shilling Flight Trophy. He was corecipient of the 1966 Harman International Aviation Trophy.

Colonel Borman was born in Gary, Indiana on March 14, 1928, and was raised in Tucson, Arizona. He graduated from Tucson High School in 1946, the United States Military Academy in 1950 and received a Master of Science Degree (Aeronautical Engineer) from the California Institute of Technology in 1957.

Colonel Borman is married to the former Susan Bugbee of Tucson, Arizona. The Borman's have two sons, Frederick, age 15 and Edwin, age 13.

GEORGE C. WHITE, JR.

George C. White, Jr., is Director, Apollo Reliability and Quality in the Apollo Program Office, NASA Headquarters. Prior to his appointment to this position in November 1966, he was Chief, Spacecraft and Launch Vehicle Test Performance in the Apollo Test Division since December 1963. He had joined NASA in February 1963 as Chief, Command and Service Module Development.

During the period from October 1953 to February 1963, Mr. White had been with Fairchild Aircraft (now Fairchild-Hiller) in Advanced Design, Engineering Management and Program Management on the WS–123A Goose Missile and the SD–5 Surveillance Drone.

Six years, beginning in October 1947, were spent with NACA, Langley Research Center, in mechanical and structural design of rocket powered research models and special projects in the helicopter and airplane fields.

Mr. White had resigned from the Curtiss-Wright Corporation, Buffalo, New York in December 1945 to organize and manage the Dansaire Corporation where he was responsible for design, manufacture and flight test of a three place personal aircraft. He had, previous to this, been in structures engineering at Curtiss-Wright for six years, and in manufacturing at Curtiss-Wright and Piper Aircraft for a total of four years, having started at Piper in 1935.

Mr. White was born in West Grove, Pennsylvania in 1914. He received a B.S. Degree in Aeronautical Engineering from Tri-State College, Angola, Indiana, in 1937. He is married to the former Marcia C. McOmber of Bradford, Pennsylvania and they have two daughters now in college. They reside in Rockville, Maryland, where they are both active in the Rockville Presbyterian Church. Mr. White is a Registered Professional Engineer and an Associate Fellow in the AIAA and he holds a Commercial Pilot's License.

DR. ROBERT WAYNE VAN DOLAH

Dr. Robert Wayne Van Dolah is Research Director, Explosive Research Center, Bureau of Mines, U.S. Department of Interior, Pittsburgh, Pennsylvania. In this position which he has occupied over twelve years, he plans and directs research in the fields of combustion, explosions and explosives. In addition to the programs supported by direct appropriation, he directs investigations related to a variety of space, military and private industry problems in the field of combustion and explosions. He has provided consultative service to military agencies on a number of occasions. He has participated in several accident investigations involving fire and explosions.

Prior to joining the Bureau of Mines in 1954, Dr. Van Dolah was head of the Organic Chemistry Branch and then head of the Chemistry Division at the U.S. Naval Ordnance Test Station beginning in 1946. In those positions he planned and directed research on the chemistry of propellants and fuels and their combustion characteristics. Before that he served first as assistant to the Scientific Director and later as research Chemist and Group Leader of the William S. Merrell Company, Cincinnati, Ohio.

Dr. Van Dolah was born in Cheyenne, Wyoming, February 1, 1919. He received a Bachelor of Arts Degree in Chemistry from Whitman College, Walla Walla, Washington, in 1940 and a Ph.D. in Organic Chemistry from the Ohio State University, Columbus, Ohio, in 1943. He is a member of the honorary societies: Phi Beta Kappa, Phi Lambda Upsilon and Sigma Xi; and of the professional societies: American Chemical Society, American Association for the Advancement of Science (Fellow), Combustion Institute, American Institute of Aeronautics and Astronautics (Senior Member). He is on the Board of Directors of the National Fire Protection Association.

Dr. Van Dolah is author or co-author of 97 publications and three patents. He is very active in committee work in areas relating to fire and explosions including being Chairman of National Fire Protection Association Committee on Chemicals and Explosives, the Working Group on Hazards, Committee on Safety Criteria of the Interagency Chemical Rocket Propulsion Group. He is a member of American Chemical Society Committee on Chemical Safety and of numerous other committees. In July 1965, he received the Department of Interior Distinguished Service Award.

Dr. Van Dolah lives at 202 Cherokee Road, Upper St. Clair Township (Pittsburgh), Pennsylvania, with his wife, the former Elizabeth M. Becker of Portland, Oregon. They have one daughter in college and two sons in high school.

JOHN J. WILLIAMS

John J. Williams, Director, Spacecraft Operations, John F. Kennedy Space Center, is responsible to the Director of Launch Operations for the management and technical integration of KSC operations related to preparation, checkout and flight readiness of manned spacecraft.

Since joining the National aeronautics and Space Administration in 1959, Mr. Williams was the Head of Capsule Systems Branch during the Mercury Program and was the Assistant Manager for Gemini, MSC-Florida Operations until he was moved to his current position in December 1964.

From 1954 to 1959 he was employed by the U.S. Air Force as an electronic engineer in the Directorate of Test Engineering, Air Force Missile Test Center, Florida. He was responsible for the evaluation of various missile prelaunch and flight tests.

From 1951 to 1954 Mr. Williams was employed as an electronic engineer in the Technical Systems Laboratory, Air Force Missile Test Center, Fla., where he was engaged in ground instrumentation and antenna fabrication and testing.

Mr. Williams was employed as an electronic engineer by the U.S. Air Force at Wright Patterson Air Force Base, Dayton, Ohio. He engaged in the development of a cooling system for electronic devices at extremely high altitudes and in the miniaturization of airborne power supplies.

Mr. Williams, a native of New Orleans, Louisiana, graduated from high school in 1944. He served in the U.S. Navy during World War II as an electronic technician and upon his discharge from service entered Louisiana State University. He graduated in 1949, receiving a Bachelor of Science Degree in Electrical Engineering.

Mr. Williams and his organization won many honors, receiving the Group Achievement Award in 1966 for contribution to the success of the Gemini VII, VI Launch Operations and to the success of Project Gemini. In 1966 Dr. Seamans presented him the Outstanding Leadership medal for his work in Manned Space Programs.

He now lives in Eau Gallie, Florida, with his wife, Peggy; daughters, Barbara and Jo Ann; and son Michael.

DR. MAXIME A. FAGET

Dr. Maxime A. Faget has been the Director of Engineering and Development, Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas, since February 1962. He is responsible for technical support of the Gemini and Apollo manned space flight programs and advanced studies into space systems. As a NASA member of the Polaris Missile Steering Task Group, he contributed to the design of that Navy missile. Dr. Faget served on the Steering Committee which helped the NASA Administrator make Project Mercury policy decisions.

Dr. Faget was born at Stann Creek, British Honduras, August 26, 1921. He attended San Francisco, California, Junior College and received a Bachelor of Science degree in Mechanical Engineering from Louisiana State University. He served three years as a naval officer during World War II.

Dr. Faget joined the staff of Langley Research Center, NASA, in 1946 as a research scientist. He worked in the Pilotless Aircraft Research Division; later was named head of the Performance Aerodynamics Branch. He conceived and proposed the development of a one-man spacecraft, later used in Project Mercury. Dr. Faget was one of the original group of 35, assigned as a nucleus of the Space Task Group to carry out the Mercury project.

Dr. Faget has authored and co-authored numerous technical papers on aerodynamics, rocketry, high-speed bomb ejection, reentry theory, heat transfer, and aircraft performance. He is co-author of a textbook, "Engineering Design and Operation of Spacecraft," and is author of a book entitled, "Manned Space Flight." Dr. Faget holds joint patents on the "Aerial Capsule Emergency Separation Device" (escape tower), the "Survival Couch," the "Mercury Capsule," and a "Mach Number Indicator."

Dr. Faget is a member of the following: Tau Beta Pi, National Engineering Honor Society; Omicron Delta Kappa, National Leadership Honor Society; International Academy of Astronautics of the International Astronautical Federation. He is an Associate Fellow, American Institute of Aeronautics and Astronautics.

Dr. Faget was presented the Arthur S. Fleming Award in 1960. He was presented the Golden Plate Award in 1961 by the Academy of Achievement. In 1963 he was awarded the NASA Medal for Outstanding Leadership and in 1965 he was presented the Award of Loyola. Dr. Faget was honored by the University of Pittsburgh, March 1966 by awarding him the Honorary Degree of Doctor of Engineering. Dr. Faget served as visiting Professor teaching graduate level courses at the Louisiana State University, Rice University and the University of Houston.

Dr. Faget is married to the former Nancy Carastro of Philadelphia, Pennsylvania. They reside with their 3 daughters—Ann Lee, Carol Lee and Nanette, and son, Guy, at Dickinson, Texas.

GEORGE T. MALLEY
Counsel to the Board

Born April 24, 1913, Rochester, New York. Attended public and parochial schools in Rochester and received A.B. Degree from the University of Rochester, and L.L.B. Degree from Cornell University, Ithaca, New York.

Member of the New York Bar.

Attorney, Office of General Counsel, Department of the Navy—1950 to 1959.

Chief Counsel, Langley Research Center, National Aeronautics and Space Administration, 1959 to present.

Retired Naval Research Officer—Active duty World War II—1939 to 1946, chiefly in South Pacific serving on various types of ships.

Married to Sally E. Wren, 2 step-sons, resident of Newport News, Virginia.

APPENDIX

PART VI. BOARD FINDINGS, DETERMINATIONS, AND RECOMMENDATIONS

In this Review, the Board adhered to the principle that reliability of the Command Module and the entire system involved in its operation is a requirement common to both safety and mission success. Once the Command Module has left the earth's environment the occupants are totally dependent upon it for their safety. It follows that protection from fire as a hazard involves much more than quick egress. The latter has merit only during test periods on earth when the Command Module is being readied for its mission and not during the mission itself. The risk of fire must be faced; however, that risk is only one factor pertaining to the reliability of the Command Module that must receive adequate consideration. Design features and operating procedures that are intended to reduce the fire risk must not introduce other serious risks to mission success and safety.

1. Finding

(*a*) There was a momentary power failure at 23:30:55 GMT.
(*b*) Evidence of several arcs was found in the post fire investigation.
(*c*) No single ignition source of the fire was conclusively identified.

Determination.—The most probable initiator was an electrical arc in the sector between the —Y and +Z spacecraft axes. The exact location best fitting the total available information is near the floor in the lower forward section of the left-hand equipment bay where Environmental Control System (ECS) instrumentation power wiring leads into the area between the Environmental Control Unit (ECU) and the oxygen panel. No evidence was discovered that suggested sabotage.

2. Finding

(*a*) The Command Module contained many types and classes of combustible material in areas contiguous to possible ignition sources.
(*b*) The test was conducted with a 16.7 pounds per square inch absolute, 100 percent oxygen atmosphere.

Determination.—The test conditions were extremely hazardous.

Recommendation.—The amount and location of combustible materials in the Command Module must be severely restricted and controlled.

3. Finding

(*a*) The rapid spread of fire caused an increase in pressure and temperature which resulted in rupture of the Command Module and creation of a toxic atmosphere. Death of the crew was from asphyxia due to inhalation of toxic gases due to fire. A contributory cause of death was thermal burns.
(*b*) Non-uniform distribution of carboxyhemoglobin was found by autopsy.

Determination.—Autopsy data leads to the medical opinion that unconsciousness occurred rapidly and that death followed soon thereafter.

4. Finding

Due to internal pressure, the Command Module inner hatch could not be opened prior to rupture of the Command Module.

Determination.—The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture.

Recommendation.—The time required for egress of the crew be reduced and the operations necessary for egress be simplified.

5. Finding

Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous. Contingency preparations to permit

74-521 O—67—pt. 3——9

escape or rescue of the crew from an internal Command Module fire were not made.

(*a*) No procedures for this type of emergency had been established either for the crew or for the spacecraft pad work team.

(*b*) The emergency equipment located in the White Room and on the spacecraft work levels was not designed for the smoke condition resulting from a fire of this nature.

(*c*) Emergency fire, rescue and medical teams were not in attendance.

(*d*) Both the spacecraft work levels and the umbilical tower access arm contain features such as steps, sliding doors and sharp turns in the egress paths which hinder emergency operations.

Determination.—Adequate safety precautions were neither established nor observed for this test.

Recommendations.—(*a*) Management continually monitor the safety of all test operations and assure the adequacy of emergency procedures.

(*b*) All emergency equipment (breathing apparatus, protective clothing, deluge systems, access arm, etc.) be reviewed for adequacy.

(*c*) Personnel training and practice for emergency procedures be given on a regular basis and reviewed prior to the conduct of a hazardous operation.

(*d*) Service structures and umbilical towers be modified to facilitate emergency operations.

6. *Finding*

Frequent interruptions and failures had been experienced in the overall communication system during the operations preceding the accident.

Determination.—The overall communication system was unsatisfactory.

Recommendations.—(*a*) The Ground Communication System be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.

(*b*) A detailed design review be conducted on the entire spacecraft communication system.

7. *Finding*

(*a*) Revisions to the Operational Checkout Procedure for the test were issued at 5:30 pm EST January 26, 1967 (209 pages) and 10:00 am EST January 27, 1967 (4 pages).

(*b*) Differences existed between the Ground Test Procedures and the In-Flight Check Lists.

Determination.—Neither the revision nor the differences contributed to the accident. The late issuance of the revision, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

Recommendations.—(*a*) Test Procedures and Pilot's Checklists that represent the actual Command Module configuration be published in final form and reviewed early enough to permit adequate preparation and participation of all test organization.

(*b*) Timely distribution of test procedures and major changes be made a constraint to the beginning of any test.

8. *Finding*

The fire in Command Module 012 was subsequently simulated closely by a test fire in a full-scale mock-up.

Determination.—Full-scale mock-up fire tests can be used to give a realistic appraisal of fire risks in flight-configured spacecraft.

Recommendation.—Full-scale mock-ups in flight configuration be tested to determine the risk of fire.

9. *Finding*

The Command Module Environmental Control System design provides a pure oxygen atmosphere.

Determination.—This atmosphere presents severe fire hazards if the amount and location of combustibles in the Command Module are not restricted and controlled.

Recommendations.—(*a*) The fire safety of the reconfigured Command Module be established by full-scale mock-up tests.

(*b*) Studies of the use of a diluent gas be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two gas atmosphere.

10. Finding

Deficiencies existed in Command Module design, workmanship and quality control, such as:

(*a*) Components of the Environmental Control System installed in Command Module 012 had a history of many removals and of technical difficulties including regulator failures, line failures and Environmental Control Unit failures. The design and installation features of the Environmental Control Unit makes removal or repair difficult.

(*b*) Coolant leakage at solder joints has been a chronic problem.

(*c*) The coolant is both corrosive and combustible.

(*d*) Deficiencies in design, manufacture, installation, rework and quality control existed in the electrical wiring.

(*e*) No vibration test was made of a complete flight-configured spacecraft.

(*f*) Spacecraft design and operating procedures currently require the disconnecting of electrical connections while powered.

(*g*) No design features for fire protection were incorporated.

Determination.—These deficiencies created an unnecessarily hazardous condition and their continnation would imperil any future Apollo operations.

Recommendations.—(*a*) An in-depth review of all elements, components and assemblies of the Environmental Control System be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.

(*b*) Present design of soldered joints in plumbing be modified to increase integrity or the joints be replaced with a more structurally reliable configuration.

(*c*) Deleterious effects of coolant leakage and spillage be eliminated.

(*d*) Review of specifications be conducted, 3-dimensional jigs be used in manufacture of wire bundles and rigid inspection at all stages of wiring design, manufacture and installation be enforced.

(*e*) Vibration tests be conducted of a flight-configured spacecraft.

(*f*) The necessity for electrical connections or disconnections with power on within the crew compartment be eliminated.

(*g*) Investigation be made of the most effective means of controlling and extinguishing a spacecraft fire. Auxiliary breathing oxygen and crew protection from smoke and toxic fumes be provided.

11. Finding

An examination of operating practices showed the following examples of problem areas:

(*a*) The number of the open items at the time of shipment of the Command Module 012 was not known. There were 113 significant Engineering Orders not accomplished at the time Command Module 012 was delivered to NASA; 623 Engineering Orders were released subsequent to delivery. Of these, 22 were recent releases which were not recorded in configuration records at the time of the accident.

(*b*) Established requirements were not followed with regard to the pre-test constraints list. The list was not completed and signed by designated contractor and NASA personnel prior to the test, even though oral agreement to proceed was reached.

(*c*) Formulation of and changes to pre-launch test requirements for the Apollo spacecraft program were unresponsive to changing conditions.

(*d*) Non-certified equipment items were installed in the Command Module at time of test.

(*e*) Discrepancies existed between NAA and NASA MSC specifications regarding inclusion and positioning of flammable materials.

(*f*) The test specification was released in August 1966 and was not updated to include accumulated changes from release date to date of the test.

Determination.—Problems of program management and relationships between Centers and with the contractor have led in some cases to insufficient response to changing program requirements.

Recommendation.—Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

INDEX

O

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES
UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

TO

HEAR TESTIMONY FROM OFFICIALS OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION REGARDING CORRECTIVE MEASURES OF THE APOLLO 204 REVIEW BOARD FINDINGS AND TO REVIEW PLANS FOR CHANGES IN PROGRAM COSTS AND SCHEDULES

APRIL 13 AND 17, 1967

PART 4

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE
74-521 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 35 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota
MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

LIST OF FIGURES

APOLLO ACCIDENT

THURSDAY, APRIL 13, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 2 p.m., in room S-126, the Capitol Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Smith, Young, Cannon, Holland, Mondale, Curtis, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Dr. Glen P. Wilson, Craig Voorhees and William Parker, professional staff members; Sam Bouchard, assistant chief clerk; Donald H. Brennan, research assistant; Mary Rita Robbins and Rhea Bruno, clerical assistants; and Howard Bray, press secretary to Senator Anderson.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The committee is conducting today its fourth hearing in connection with its review of the circumstances surrounding the Apollo 204 accident. To respond to the committee's questions, we have Dr. Robert Seamans, Deputy Administrator of NASA, and Dr. George Mueller, Associate Administrator, Office of Manned Space Flight, NASA, together with Gen. Samuel C. Phillips, Apollo program director, Dr. Charles Berry, chief of medical programs, Manned Spacecraft Center, and other NASA officials.

With the filing of the Apollo 204 Review Board's very comprehensive report, I would hope that today the committee can receive the Space Administration's views and judgments on the adequacy and completeness of the Board's review, findings, and recommendations and to the extent feasible at this early date, an outline of the corrective measures taken or to be taken as a result of the Board's findings and the expected impact such changes will have on the Apollo program costs and schedules.

Before proceeding with Dr. Seamans' statement, I believe Senator Smith has a statement.

OPENING STATEMENT BY SENATOR SMITH

Senator SMITH. Mr. Chairman, I would like to say briefly—last Sunday, when you, Mr. Chairman, announced that this committee will continue its review of the Apollo accident, you stated that the review will, and I quote, "* * * continue to be conducted responsibly and carefully." I know you did not use those words lightly. This committee has always been guided by the principle that each proposed space exploration program be carefully reviewed and scrutinized before receiving our recommendation for authorization. I believe the record will clearly show that the committee's chosen method of operation has been the correct one. The United States has in a relatively few years reached an unprecedented preeminence in space. NASA and its team of industrial contractors have demonstrated remarkable success with its Mercury and Gemini manned flights and with its many unmanned exploration programs as well. It is notable, too, that each of these programs was conducted with full public disclosure. In my view, all Americans can be justifiably proud of this record.

On Tuesday, this committee heard testimony on the final report of the Apollo 204 Review Board, which was charged with investigating the spacecraft accident at Cape Kennedy. While the Board was not able to identify the specific cause of the accident, its findings disclose a number of deficiencies concerned with engineering design, workmanship, test procedures, and practices. There is no question, Mr. Chairman, but that the conditions which permitted these deficiencies to occur must be eliminated. However, I am fully confident that the skilled and dedicated people, both within NASA and its contractor organizations, who have been so eminently successful in prior programs, can correct the problems identified by the Board.

I hope, therefore, that Dr. Seamans and his associates, who are to testify today, will outline for the committee the specific corrective actions needed to get the Apollo program back on a successful track. I would expect these corrective actions to involve not only engineering design and workmanship, but a strengthening in the management area as well, to assure that this complex program receives the degree of surveillance and control necessary to prevent a recurrence of this tragedy.

If such improvements are made, I have no doubt that the American people will continue to support this great space effort that has been so successful in the past, and can continue to be even more so in the future.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Smith.

Dr. Seamans.

STATEMENT OF DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NASA; ACCOMPANIED BY DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR, OFFICE OF MANNED SPACE FLIGHT, NASA; DR. CHARLES A. BERRY, CHIEF OF CENTER MEDICAL PROGRAMS, MANNED SPACECRAFT CENTER, NASA; AND GEN. SAMUEL C. PHILLIPS, APOLLO PROGRAM DIRECTOR

Dr. SEAMANS. Mr. Chairman and members of the committee, the report of the Apollo 204 Review Board has been available for 4 days—since noontime Sunday, April 9. The Board has already appeared before this committee and before the House Oversight Committee to discuss their findings and recommendations. From their report and the statements made in testimony before the Senate and House committees, it appears that:

(1) The fire was probably initiated by an electrical arc generated when the insulation on a power cable failed, most probably due to chafing against a door on the environmental control unit.

(2) Nylon netting near the arc was ignited. Nylon netting, Velcro patches, and other flammable materials were installed in the cabin in such a manner that they served as a fuse, spreading the fire in the pure oxygen, 16-pounds-per-square-inch, atmosphere quickly around the inside of the cabin.

(3) The test underway at the time of the accident was not deemed hazardous by those responsible, and consequently there was no means for rapid egress of the crew, nor was firefighting equipment available on the pad to deal effectively with this type emergency.

The Board was asked not only to establish the probable cause of the accident but also to consider the impact of the accident on all Apollo activities involving equipment preparation, testing, and flight operations and to develop recommendations for corrective action. Therefore, many of the factors discussed in the report did not contribute to the accident, but are nonetheless important for management considerations.

The report, dealing with the most complex of our development projects, represents in my judgment, an honest and straight forward engineering audit of the Block I spacecraft. The report provides specific guidance for technical studies, evaluations, and changes that need to be undertaken in relation to the Block II spacecraft, test procedures, and the next manned flight. In summary, I accept the Board's report as an important document for NASA management decisionmaking.

AREA FOR IMPROVEMENTS LISTED

I feel the Board has carefully and well discharged the difficult task laid upon it. We have now the task before us of implementing those recommendations appropriate to the revised program, of identifying further actions we must take outside of the Board review, and of placing the program back on a firm operating schedule. I can speak in general to our decisions: We will revise and improve the design, fabrication, and inspection of spacecraft electrical cabling. We will change current nonmetallic materials to reduce flammability. We will improve accessibility to the spacecraft interior. We will establish different criteria defining hazards and the precautions to be taken when they are present. We will introduce more clarity, more flexibility, or more rigor—as necessary—in our operating, test, and management procedures.

Neither Dr. Mueller nor I are prepared today to discuss in detail the actions that NASA will take based on these findings and recommendations. These decisions must be based on a thorough evaluation of the 3,000-page report of the Apollo Review Board and also on the Apollo Program Office design and trade-off studies that have been conducted concurrently with the Board's activities.

However, we are prepared today to discuss the management structure and processes that have been developed in the Apollo program with particular attention to their relation to the operations at the time of the accident. Before Dr. Mueller commences this discussion, I would like to make a few remarks about the conduct of large development projects of this type.

NEED STRONG BUILT-IN DISCIPLINE

A development project is characterized by both newness and change. Development, by definition, involves new techniques, new concepts, new materials and components, and untried operations that are focused on accomplishing an objective never before achieved. A development project, as it progresses, will be subject to change. In fact, it must be designed and directed from the start with inherent ability to accept useful change, since the process of development itself is successful only if it identifies the best solutions from among the alternatives at each step and then incorporates these into the evolving project.

There must also be strong discipline built into the technical requirements, schedules, and management. Otherwise, components will not integrate one with another; one development activity may unduly delay many others; funds may not be distributed according to need; and management decisions can suffer for lack of improperly used information systems.

At the start of a development, the principal tasks center on the definition of the work packages and the organization of the teams that will carry them out. Past experience is a valid guide in terms of principles, even if the details of development are unrepeatable and dynamic, which they are. The guidelines that I can draw from the experience of large scale developments, most of which have occurred since the Second World War, are few but clear:

DESCRIBES GUIDELINES FOR LARGE PROJECT

First, the objective itself must be feasible in a reasonable time span—the mission must not require advances among its critical elements that are beyond the state of existing technology. At the same time, the length of the forward stride, the degree of progress achieved in the development, is measured by the quality of the solutions to new problems, not by the number of "off-the-shelf" answers and production equipments that are applied. In the case of Apollo, the careful studies by industry and Government that were carried out between 1959 and 1961 and substantiated by experience in Mercury, Gemini, and Apollo to date, do not lead me to believe that the development of the manned lunar landing capability—and all that this entails—is too demanding of our present technology.

Second, in a large project the activities must be clearly defined for each of the organizations involved so that each of the organizational groups clearly understands its responsibilities, measured in terms of technical achievement, budget, and schedule. It must be recognized that in the development process, the responsibility for a piece of equipment may change hands from contractor to Government, or from engineering department to manufacturer's division, to test operations; but at no time should the responsibility be ambiguous because of the shift. The corollary is the requirement that management and direction of these activities have the discipline to integrate the product of the many teams and at the same time, the flexibility to revise its planning, schedules, budgets, and controls to accommodate necessary changes and unforeseen problems.

Third, engineering and design must be at the highest level of competence, aimed at high reliability and possible modifications, and not aimed at large production runs. Trained technicians are required to insure that all components, subsystems and assemblies are executed well and in accordance with the best practices available. Inspection and quality control must assure that the workmanship satisfies the engineering requirements. It should be recognized that reliability cannot be built into a badly engineered design. However, a good design will not be effective unless it is manufactured according to carefully prescribed drawings and specifications. All equipments must be appropriately tested under critical environmental conditions with procedures carefully established for all participants. In some cases, only type, or one of a kind, tests are required; whereas in other equipments, it is desirable, that all such equipments be tested before use—proof test.

Fourth, as I have already stressed, there must be a fundamental recognition of, and provision for, change. A development team grows in experience and maturity as it works toward its objectives; it is the solution to problems while learning to communicate and work together that goes with it that makes a team effective and of greater value than the simple sum of the individuals it comprises. A design must be tested before confidence is established, and the design must be tolerant of changes that test results prove necessary. To give a specific simple example, cable runs must be protected so that removal and reinstallation of equipment will not chafe the insulation eventually causing short circuits or arcs.

OUTLINES PROCESS OF DEVELOPMENT

With these four points in mind, it can be seen that development is not a simple, straight-lined, sequential, orderly process; it is highly complex and iterative. A possible analogy is to imagine the development process to be shaped like a pyramid.

There are the many individual building blocks of the project at inception, forming the base of the pyramid. Then at higher levels in the pyramid components are assembled into subsystems and then into systems and then integrated, near the apex of the pyramid, into mission hardware and operations. Each block must fit tightly with the next on its own level and on the levels above and below to insure that the entire task has been defined and that no element is missing. The second, or subsystem, tier is smaller in number of blocks, but each now is of greater complexity and the constraints of assuring proper "fit" becomes increasingly important. As the tiers get smaller the constraints increase, and the flexibility and tradeoff problems are more severe. At the top, then, is the completed system that is ready to be committed to the objective.

As knowledge is gained concerning the capabilities of the hardware, as this knowledge is refined and validated by testing, an overall confidence level is established and the focus becomes stronger on problem areas requiring specific attention. It is not enough to be certain that each design at the base of the pyramid is good, that each element operates to specification; there must be assurance that all the systems will operate together and in harmony.

In this process, the function of technical specifications and operatings procedures are critical, since they define the tasks to be done and the relations both between the elements of hardware and of the organization—both the contractors' and the Government's. It is important to note here that these organizations are not monolithic, but are composed of many entities that must develop between themselves working relationships that are sound and distinctions of responsibility that are meaningful. Both specifications and procedures, as well as the elements that are subject to them, must respond to change, to evolution, in the conduct of development.

IMPACT ON PROGRAM NOT YET KNOWN

Turning again to the Apollo Review Board report, I would like to emphasize that these investigations centered on Apollo Spacecraft 012, a Block I spacecraft. The Block II spacecraft was initiated several years ago to incorporate features required for lunar rendezvous and docking and also to permit design changes felt to be necessary as a result of the Block I experience. Block II is further up the development pyramid than Block I and now will be used for all Apollo manned flights.

We are not in a position at this time to decide upon the schedules and objectives for the next manned flight in detail, or for the succeeding Apollo missions. We have not assessed the downstream cost or schedule parameters affected by the Apollo 204 accident and by the responses we shall make. We plan to make our decisions sequentially and carefully, assessing the impact and relationship of each to the total Apollo program structure. It will be a matter of weeks before the pattern of decisions and actions can be translated with confidence into a new program and program management plan.

The report of the Apollo 204 Review Board has pinpointed potential design, engineering, fabrication, and procedural problems. The program office, in its own assessment, is developing its recommendations both in light of the report and of its own project responsibility.

STRENGTHENED SPACE PROGRAM SEEN

Nothing in the report or in the program assessment to date suggests that the fundamental concept and design of the Apollo system are other than sound, or that the basic management structure is faulty. However, the fact of the accident itself is proof of imperfection and fallibility; the Board has carried out its charge of identifying, where possible, the areas where improvement can be made. We intend to make improvements, where required, and to establish confidence in the overall system by complete testing before committing it to manned flight.

We have allowed a serious accident to occur, but from this experience we will derive a strengthened space program that more nearly reflects the aspirations of our country.

Now, Mr. Chairman, Dr. Mueller is prepared to present to this committee a discussion of the organization, procedures, and practices that have been established to provide the discipline and the flexibility required in the conduct of the Apollo development program.

The CHAIRMAN. Thank you, Dr. Seamans. I think I should say to the people here that Mr. Webb will not testify here today.

It seems also, Dr. Seamans—you have given us a good lecture about how to build a pyramid, but we are very much interested in the accident at Cape Kennedy, and we hope your staff will give us quite a bit of information on that.

Senator HOLLAND. Mr. Chairman, at what stage will we be allowed to address questions to Dr. Seamans?

The CHAIRMAN. We can do it either way.

Senator HOLLAND. I would be glad to accept any ruling the Chair would make.

The CHAIRMAN. I would like to have all of their statements and then begin the questions.

STATEMENT OF DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR, OFFICE OF MANNED SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. MUELLER. Mr. Chairman, if I may have the first viewgraph (fig. 87). Unfortunately I was not able to prepare a statement. I testified yesterday before the House Oversight Subcommittee.

The CHAIRMAN. I am not worried at all about it.

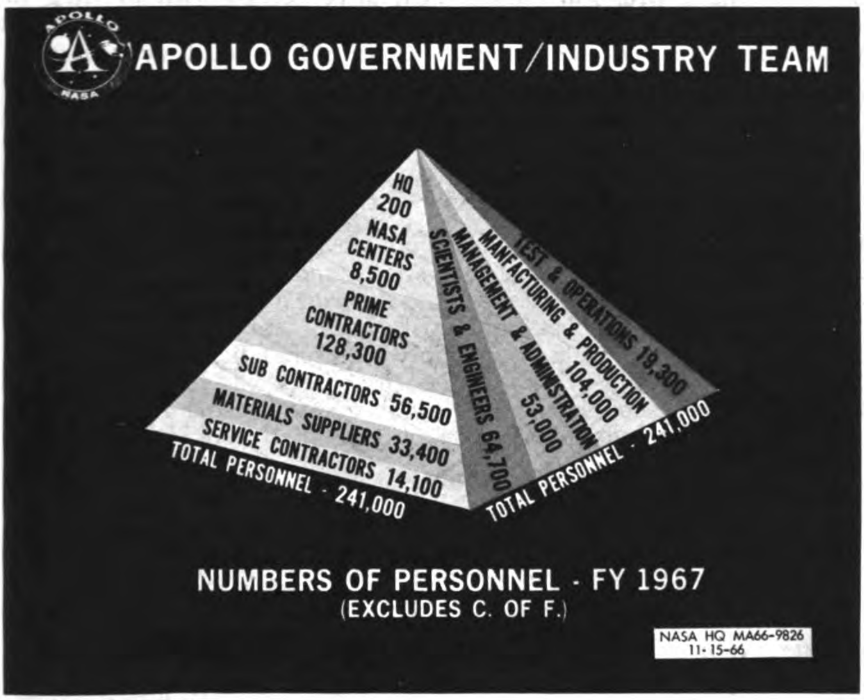


FIGURE 87

DESCRIBES GOVERNMENT-INDUSTRY TEAM

Dr. MUELLER. I apologize for starting with a pyramid. This is a different pyramid, however. It is a pyramid that talks to the people involved in the program, because ultimately, in any program, no matter what its scope, it is the people that are doing the work, and how they communicate with one another that determines the progress and the success or failure of the program.

Beginning at the bottom we have some 14,000 service contractors associated with the Apollo program. This is about the number we have on board today.

There are 33,400 material suppliers, 56,500 subcontracting people, 128,000 people in the prime contractor's plant, and some 8,500 people in the NASA centers.

Now, it is this organization which carries out the tests and operations of the equipment, the manufacturing and production, the management and administration, and the engineering design.

Going to the next slide—(fig. 88)—that is the organization.

APOLLO PROGRAM MANAGEMENT

The Apollo program management is concerned with making the efforts of these people effective, pulling their efforts together into

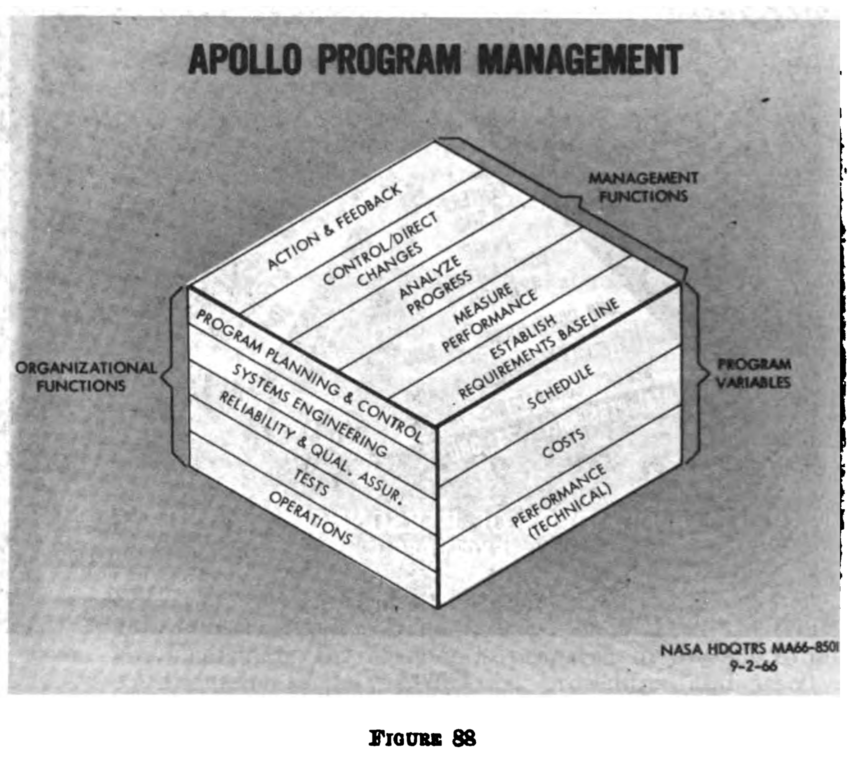


FIGURE 88

a focus which provides the communications, the checks and balances that make possible the conduct of a program, a program that is the largest single R. & D. program we as a nation have ever undertaken.

In particular, there are certain functional organizational elements of program planning and control, systems engineering, reliability and quality assurance, tests, and operations. And these functions are throughout the NASA structure, and down through the contractor plants themselves. Those lines run all the way down through the structure, and they provide lines of communication through which it is possible at any time to determine the status of any one of the numerous subsystems that make up this total program package.

Looked at another way, we must control the variables in the program. Those are the technical performance, the costs, and the scheduling, so that we cut through, then, to obtain that control by means of the functional organizations. And we have certain management tools that we use, involving action and feed-back nets, the control and direction of changes, analysis of progress, the measurement of performance, and the requirements that we establish and a base line.

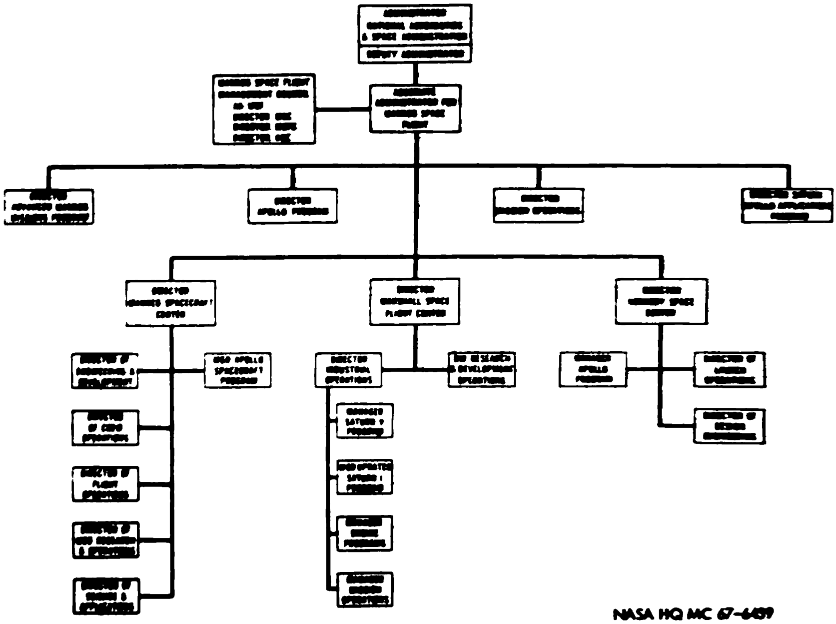
SPACE AGENCY STRUCTURE

Now, using these tools, this management system, which is no more than a tool that permits people to work effectively toward a common objective, we have established an organization, and the organization begins with Mr. Webb and Dr. Seamans here in Washington. (Fig. 89.) I report to them. And I have, for establishing the policy for the manned space flight program as a whole, myself and the three center directors—Dr. Von Braun, Dr. Gilruth, and Dr. Debus—who do establish the policy within the framework, and within which we carry out the manned space flight program.

There are program offices in Washington, in particular General Phillips is the head of our Apollo program office here in Washington, D.C. As we go down through today's testimony, we will look at two of our three centers. One is the Manned Spacecraft Center in Houston, Tex., and under Dr. Gilruth that center is responsible for the development of the Apollo spacecraft itself. Then we will look at the Kennedy Space Center. That center is responsible for the final test and check-out of the Apollo space vehicle before it enters upon the flight mission.

RELATIONSHIPS OF SUBSYSTEM MANAGERS

Now, turning to the next slide (fig. 90), you will see how Dr. Gilruth's organization is broken down in order to carry out this function of managing development of the Apollo spacecraft. In particular, we have an Apollo spacecraft program office manager, Dr. George Low, who has the responsibility for all aspects of the development, the scheduling, the design, the test, the operation of the space-



NASA HQ MC 67-6489
4-13-67

FIGURE 89

craft. He uses, however, the total resources of the center, and brings them to bear through the utilization of subsystem managers that are located in the Engineering Directorate of the Houston Manned Spacecraft Center. And in particular, he has subsystem managers that are responsible for the communications system, for the guidance and control system, the propulsion systems, the thermal protection, and so on.

This is the organization that is responsible for the spacecraft.

Let's see how we actually define for that whole structure what it is we want to have built, and how it is we want to go about testing and flying the spacecraft.

SPECIFICATION PROGRAM

This is done by means of specifications (fig. 91).

It begins with a master Apollo program specification, which is prepared and controlled here in Washington.

Beneath that specification there are specifications for each of the major elements of the program. There is a specification for the spacecraft, for the launch vehicle, and for the facilities.

EXAMPLE OF RELATIONSHIPS OF SUBSYSTEM MANAGERS

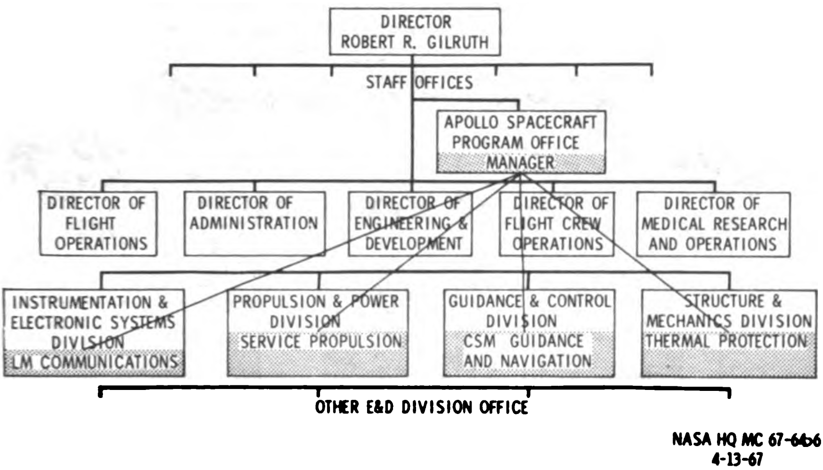


FIGURE 90

If we go down one more step in the spacecraft, the spacecraft itself is made up of a number of systems, or subsystems, and so there are a set of system specs. The spacecraft specification is an overall document, prepared by the manned spacecraft center. The systems specifications are prepared by the contractors, but are approved by the manned spacecraft center. They are a giant document.

The contract end item specifications are prepared by the contractors. They are reviewed and verified by MSC and they define the actual hardware and the actual tests, in order to make a flight qualified subsystem.

So that is the framework upon which the design is based.

APOLLO SPACECRAFT PROGRAM OFFICE

In order for these end items, which are the boxes that go into the Apollo spacecraft, as well as the Apollo spacecraft as a whole, to be controlled, we have established a set of subsystem project managers (fig. 92), so that each one of these subsystems is of a manageable size, of a size that a man can understand and be responsible for. He is in effect, then, responsible for both the technical performance, design, the construction, the manufacture of this device. He is also responsible for the scheduling, for when it is to be completed, and he is responsible for what it is going to cost.

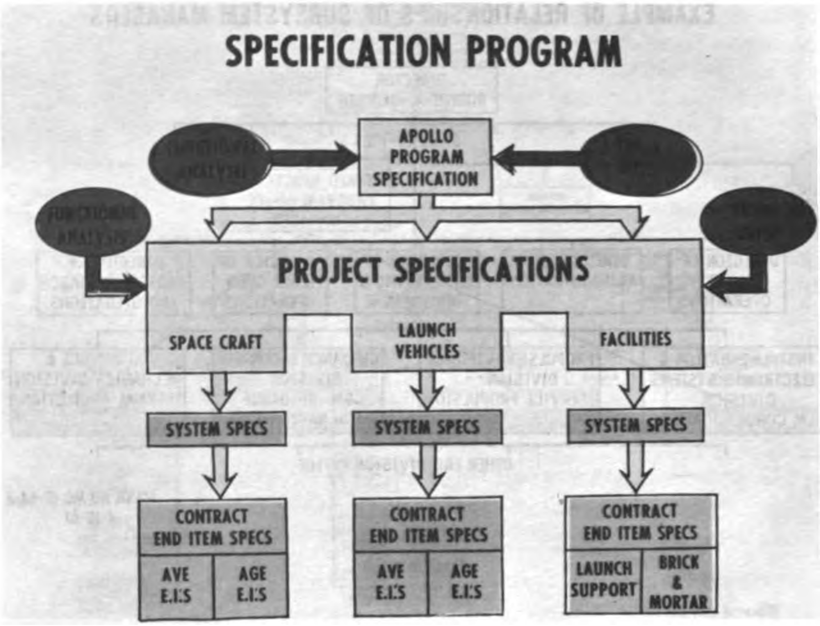


FIGURE 91

And these subsystem managers involve structures. I might say a word about how many of them there are. There are something like 52 subsystem managers at MSC, and because of the much larger number of elements of the space vehicle itself, there are 115 subsystem managers at the Kennedy Space Center.

This provides us with a means for keeping tab on each one of the major elements of the Apollo spacecraft.

I would call your attention to one of these—the structure's subsystem manager, as an example. He is responsible for all aspects of the structure. He in turn would be responsible for the design of the hatch that we use on the Apollo spacecraft.

You go down here, and you will find that there is a person who is responsible for communications in the Apollo spacecraft. And this subsystem manager, then, is responsible for the spacecraft communication system.

And you will find here a man under this structure that says fuel cells, and under that man you will find not only fuel cells, but also the electrical power distribution system.

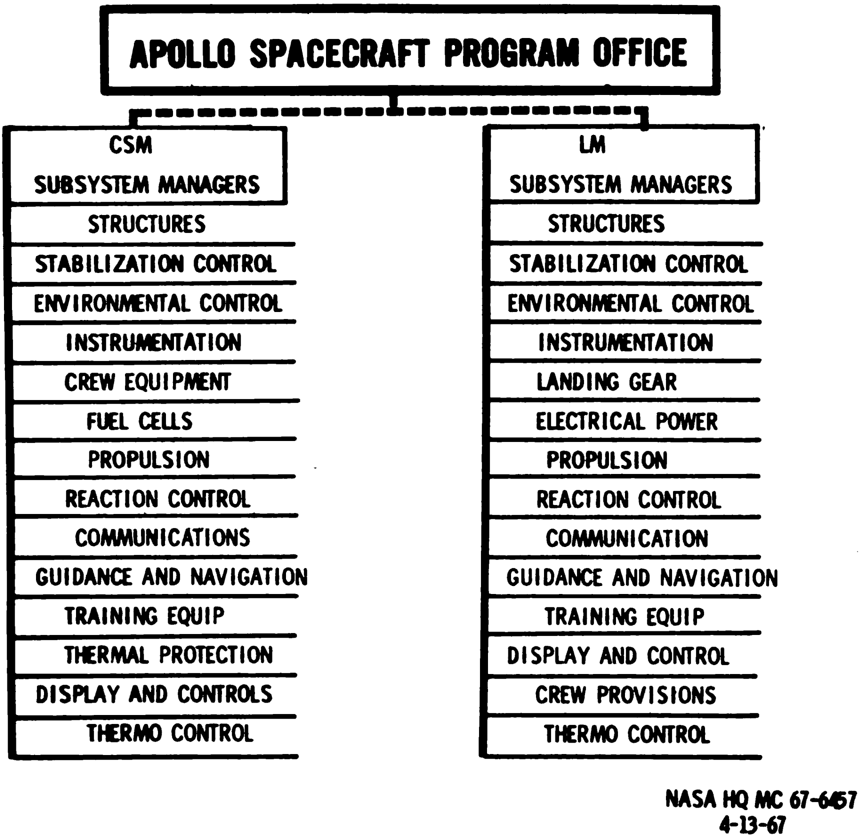


FIGURE 92

So here we can pinpoint the responsibility to particular individuals in the organization who are responsible for their particular subsystems.

They are not alone in this operation, of course. There are proper controls and proper checks and balances. They report to the Apollo spacecraft program office for direction and for the integration of their efforts to be sure that when we put the subsystem together, they do in fact work as a total system.

NASA-CONTRACTOR RELATIONSHIPS

Now, if we turn to the next slide, I would like to say a word about Contractor-NASA management relations (fig. 93).

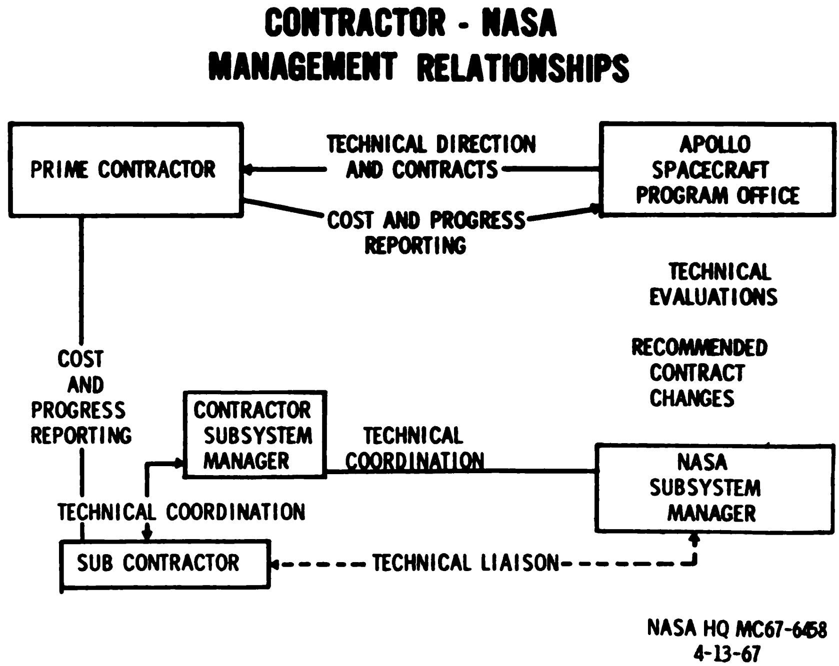


FIGURE 93

Ultimately you realize the actual design, the construction, the manufacture, the tests, and the preparation for launch, are carried out by our contractor structures. You realize that some 95 percent of the people in the Apollo program are people in private American industry. About 5 percent of the people are actually in our NASA centers, and actually manage the program. I think the number is now about 8 percent.

So the bulk of the work, of the production of these spacecraft, for example, is done by people in private industry.

In order to establish the proper set of relationships, between the Government and the prime contractors, between the Government and the prime contractor's subcontractors, we have established the Apollo spacecraft program office, which does have technical direction and contract direction over North American Aviation, which is responsible for the development and manufacture of the spacecraft, and the testing, and the flight of the spacecraft itself.

In turn, the prime contractor reports back to the Apollo spacecraft program office as to its cost, as to its progress, its technical performance, and so on—a set of management controls that provide the proper set of working relationships.

Now, the NASA subsystem manager provides direction through the Apollo spacecraft program office over to the prime contractor, so all formal direction to the prime contractor comes from a single source, that is the Apollo spacecraft program office, and ultimately the Apollo spacecraft program manager.

In order to provide the kind of communications, the kind of understanding that is necessary on the part of the people actually building the subsystems, the subsystems manager serves an important function in technical coordination with his counterpart in the prime contractor organization, who also has subsystem managers. And so there is a direct communication between these two people who in turn provide the direction to the subcontractor.

Most of the work done is in order to be sure that the subcontractor understands how his subsystem is going to fit into the Apollo spacecraft, and he has to understand what it is supposed to do, which the specification tells him—has to understand how it interfaces with the other elements of the spacecraft, and that is what the interfaces specification does for him. But these are dynamic instruments. They do change, as he finds better ways of doing things, as we find we can improve the overall operations of the spacecraft by changing some part of the system.

There is a communications channel that provides for a short line of communication so that changes and implications of the program can be developed and brought to bear as early as possible.

APOLLO REVIEW PROCESS

That is the management structure that we use for actually carrying out the development, manufacture, test, and flight.

Now, if we can turn to the next slide (fig. 94), we can see both how we do the process of building the spacecraft, and also the kind of reviews that take place in order to make sure it is the best possible spacecraft that we can arrive at and we have the best possible subsystem we can have.

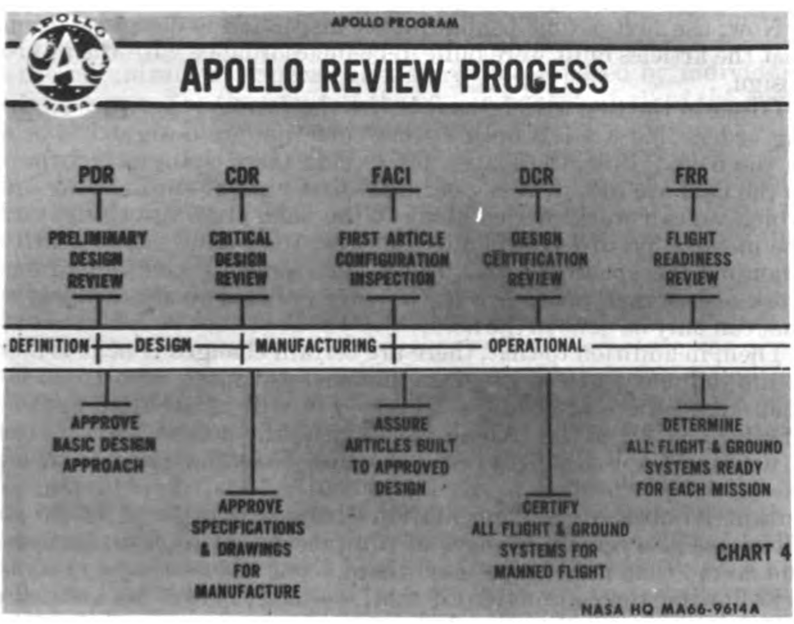


FIGURE 94

I have shown here the basic review process for the spacecraft as a whole. Underneath this is another review process that leads up to each one of these that involves a similar set of checkpoints, or reviews of what the equipment is in the subsystems.

Now, the first thing we have is a preliminary design review. And what that does, we have provided the manufacturer with the specification, he has designed the equipment in a preliminary form, he has the concepts, he knows how it is going to be built, and then it is reviewed by NASA management, the program office, the subsystem engineers, and by the contractor management, the contractor subsystem engineers, the contractor system engineers.

At that point, the design is committed for final design prior to manufacturing.

At the end of the design process, and before it actually goes into manufacturing, there is a critical design review to be sure that the actual design meets the specifications, and that the drawings are ready for manufacture.

Then it goes into manufacturing. This is another element—the first two of these is carried out by engineering in the manufacturer's plant with communications with and work with the engineering organizations in NASA.

Then this design is passed to manufacturing for the actual manufacturing process. We build the spacecraft in the factory, and we then look at it to be sure that it is in fact ready for release to the field.

Now, during the process of manufacturing, you also have factory tests, and the factory test involves a thorough test of every subsystem, and every system as an integrated system, so that by the time it leaves the factory it is in fact in a flight-ready condition.

Now, the first article configuration inspection is designed to insure that the articles built were built to be in accordance with the approved design.

Often in the first article, as it leaves the factory, there are engineering orders that are left open at that time that are designed to be done in the field. Now, the reason for having these changes incorporated in the field are of two varieties. The first kind of engineering orders, which we call work carried along to the field, are those things such as the installation of pyrotechnics that have to be done in the field. For example, the spacecraft 012, there were some 70 items of orders, of work orders that went with it, that were related to the kind of work that can only be done in the field.

Then, in addition to that, there are certain changes that it is deemed in the judgment of the program management most wise to do in the field. And there are certain things—you will recall that in the case of 012, and all of the Apollo spacecraft, the actual vacuum testing is done at Cape Kennedy. So the first time the spacecraft sees a vacuum is down at Cape Kennedy, and associated with that are a certain number of instrumentation changes that need to be made. There are also certain changes of equipment that have to be installed and so on, that need to be done there.

Following the completion of that, we have, before we commit any vehicle to manned flight, a design certification review.

That review consists of a review of all the failures, of all the discrepancies, by the subsystem managers throughout the program, and a judgment on the part of each one of those that is, in turn, verified by their supervisor that these failures have successfully been worked off, that the design is sound, and that it is safe for manned flight.

That design certification review actually is carried out by the total program office, and the program office in that case reports to our management counsel, which is the Design Certification Review Board. At that point, we—and I mean by that Werner and Bob and Kurt and I—sit down and go through each one of these subsystems, and ask the most penetrating questions we can of each subsystem manager as to the readiness of his particular design, the particular implementation of that design, to be ready for flight.

FLIGHT READINESS REVIEW

Finally, there is before the flight itself a flight readiness review, which is the last check before flight. It is carried out by the program office, and it determines that all flight and ground systems are ready for each mission.

Before I leave it, I would like to point out that at the very beginning of this process is the establishment of the specifications. And as we see in the Apollo spacecraft 012 accident, there was one thing that more than anything else led to that accident, and that was the establishment of a specification—and actually that specification was established in the Mercury days—which specified the materials to be used in the spacecraft cabin, and the disposition of those materials, where you put them in the cabin. That is the specification that originated in the days of Mercury. And that specification was rigidly adhered to throughout Mercury, Gemini, and Apollo, up to 012.

Now, that particular specification had as its basis, for the formulation, the best engineering judgment of the people that we had throughout the organization. Specifications are not prepared by individuals, but are prepared as the result of the best judgment of all of the people who understand the problems related to that particular specification.

Now, I might digress for just a second here, because it is important to our later discussion of the accident—it takes three things to have a fire anywhere, one is oxygen, a second is some form of fuel, and the third is an ignition source, something to start the fire; those three things are required to have a fire.

In particular, the philosophy, the basic practice that we established—in the Mercury, Gemini, and Apollo programs has been to avoid an ignition source—to so design and manufacture the spacecraft that there was not an ignition source, and then the second fall-back position was to say that we would not have any flammable materials near enough to an ignition source to cause the flame to propagate, to be able to start the fire in the flammable materials.

The third factor, in implementing that policy, we used the best materials that we had available at the time, to minimize the ability of these materials to burn. And that specification has changed from time to time. I might point that in Mercury we were using a wire insulation that was a polyolefin type of insulation, and when we got to Gemini, they had developed the techniques and means of building Teflon wire insulation, and we switched in Gemini on our manned flights to the Teflon insulation, which has very much more fire-resistant qualities than the polyolefins.

We have in every case as we have learned how to use new materials, where we could protect against fire, recognized those materials, and applied them. Because we had used such care, we established standards and criteria for the selection and disposition of materials, and for the control of ignition sources, which we felt in the best judgment of not only the people directly involved, but every review group that did look at those specifications, we felt would protect us against fire in the cabin—we did not consider this test any more hazardous than the other tests that were carried out. And in searching through the records, I find no instance wherein Mercury, Gemini, or Apollo, were the actual test of the spacecraft with a hundred percent oxygen at either ground level or altitude was labeled extremely hazardous.

I will say some more about why that is the case a little later. But I thought it would be well to bring it in specification.

The design, the manufacture, and so on, in terms of the material selection for inside the cabin was determined by the definition.

MANUFACTURER'S QUALITY CONTROL

Now, the other thing that is not included in this particular chart is the fact that at each stage of manufacturing, there is an organization that works in parallel, consisting of manufacturer's quality control people, who inspect each operation as it is completed, to be sure that the subsystem, or the system, or the wiring, or whatever it is—whenever that operation is completed, he inspects it to be sure it meets sound manufacturing practices, and that it meets the design requirements established by the designers.

So he checks the implementation of the manufacturing process against the design to be sure that it meets those design requirements—both with respect to workmanship, and with respect to the fact that it does in fact do what the designer said.

So that is the quality control function. And that occurs every time an item is completed. It occurs before a component is delivered to the subcontractor who is building a subsystem, before the subsystem is delivered to the prime contractor, and so on up the chain.

That is how we insure that the work being done by the workmen on the line is being done according to the engineering requirements that were established earlier.

Superimposed on the manufacturer's quality control people are a set of NASA, or at least Government inspectors, who verify that the quality control people in the contractor's plant are doing the things that they should do.

They again verify this against the standards that were established by the engineering department in the first instance.

I think that completes how we manufacture and deliver a spacecraft.

Now, turning to how we test a spacecraft, and check it out before launch, I will dwell on only one facet of the operation down at Cape Kennedy.

Cape Kennedy, as you know is directed by Dr. Kurt Debus, and the actual checkout of the space vehicle is under the direction of Colonel Petrone who has had a long period of experience with the development—the checkout and test and development of the checkout equipment for spacecraft and launch vehicles.

Reporting to Colonel Petrone is the director of launch vehicle operations, a director of spacecraft operations.

I will talk about the functions of the director of spacecraft operations a little bit later. But it is in this area that the test and checkout of the spacecraft is carried out, and there are the supporting quality control people under the director of technical support who in fact verify that any work that is done on the spacecraft is done according to the specifications and requirements of the manufacturers. So the quality control at the Cape is also carried out by an independent organization.

OUTLINES TEST PROCESS

Now, turning to the actual test process itself (fig. 95), how one goes through the steps of preparing a spacecraft for launching, it actually begins with test of the components themselves, before they are delivered by the vendors to the manufacturer of the subsystems.

These components have been carefully and specially tested, and have a special test history, which is maintained, which covers their development and manufacturing, so that we can have traceability, we can trace back the actual components that are used in each one of the subsystems that are a part of the Apollo program. These are major components, something that is of a size that can be numbered.

The next level of testing, then, is the subsystem testing, and each subsystem is tested, it is vibrated, it is subjected to a whole series, first of qualification tests, and then once it is qualified, to a set of acceptances, so that every subsystem, before it is delivered to the spacecraft, has gone through an environment which is at least as severe as it will ever encounter during flight or operation in space.

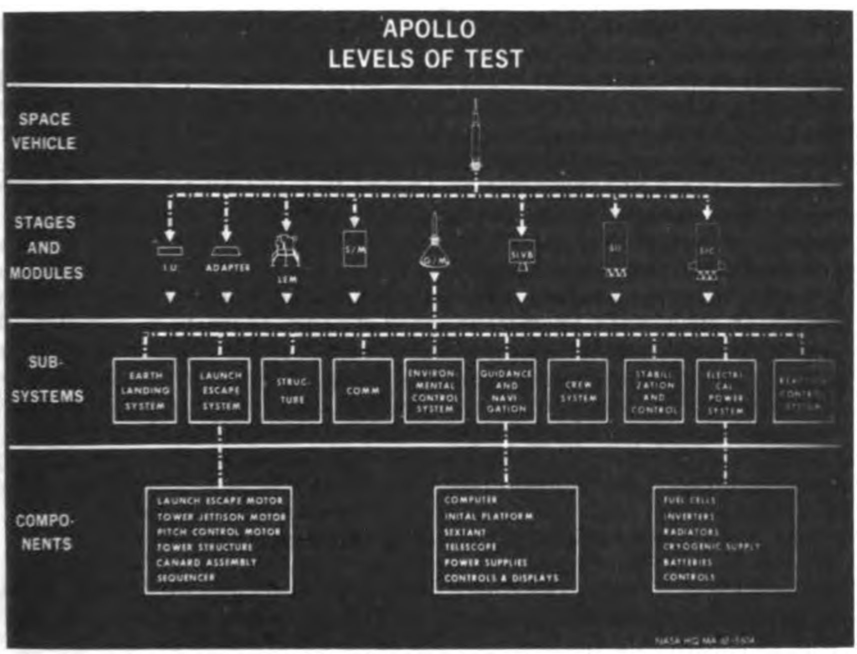


FIGURE 95

Once these subsystems are assembled together in a spacecraft, at the prime contractor's plant, that entire spacecraft, then, is tested, checked out, to be sure that all of the subsystems work together according to the way the design was established in the first instance.

We actually build an entire spacecraft, with a set of flight subsystems that are then subjected to a set of qualification tests. That spacecraft is taken down to KSC, and it is operated in a vacuum. The astronauts actually operate it as though it were going to be in space, to make sure, by as realistic a simulation as we can on the ground, that we have in fact a spacecraft that can carry out the flight mission.

Each subsequent spacecraft is tested as an individual unit before it leaves the factory, and is delivered to Cape Kennedy. At Cape Kennedy, it goes through a second test of checkouts. It goes through the vacuum chamber there; every subsystem is checked, and the system as a whole is checked to be sure it is operating in a vacuum according to design specifications.

Following that, it is mounted on the launch vehicle and is given an integrated space vehicle test to be sure that it is in fact ready for flight.

The "plugs-out" test is the second to the last major test that occurs before the launch of a space vehicle. This plugs-out test verifies that the spacecraft will operate on its own internal power in the way that it is designed to be operated in space, insofar as possible we duplicate all of the steps that we will carry through on the day of launch to be sure that every system that is necessary for the launch and flight of the spacecraft is working according to our design.

That was the point in the test and checkout where 012 was at the time of the accident.

I think it is important to recognize that the spacecraft 012 and the launch vehicle 204 were the first pair of models to be carrying men in the Apollo program. As a consequence, there were many things that we were learning in terms of development of the procedures for bringing men into the system, for learning how to best carry out the testing procedures, how to interrelate the men and what they had to do in the cabin to the test and checkout crew on the ground that had to make the total space vehicle ready for flight.

This is the KSC organization (figure 96) and I have tried to pinpoint the elements that are responsible in the various organization elements.

I might add one other thing.

In the test organization itself—that is in the Apollo—under the director of spacecraft operations, at Kennedy, there is a director of North American Aviation, and each of the other contractors that have a major module in the system, which is responsible for developing the test procedures, and for being sure that these test procedures meet the requirements of the program office, to verify that the test, when they are conducted, will meet the specifications that were established by the program office for that test.

PROCESS FOR DETERMINING HAZARDOUS TEST

This is a test systems engineer in the North American organization. It is this man who is responsible for that particular system testing, who is responsible for the establishment of whether or not a test is

FIGURE 96

hazardous. He is the first man who says, "This test is hazardous, or it is not."

Now, in judging whether a test is hazardous or not, he uses a set of criteria that are established by the Safety Office at Cape Kennedy. These criteria are reviewed by the Program Office, both at Cape Kennedy, at the Manned Spacecraft Center, at Marshall Space Flight Center, and in Washington. These criteria establish the conditions that have to ascertain when a test is judged to be hazardous.

Following the development of the test procedures, and the definition of the character of the test, a NASA test systems engineer reviews and approves this test procedure. Then this test procedure is submitted to the test conductor, who either accepts it or rejects it, and he is the final review of whether any test is ready to be run.

In parallel with that, and with an overriding control of the test are the astronauts. Since they actually fly the vehicle, they have the prerogative of deciding before any test is run, of which they are a part, as to whether or not they judge that test to be hazardous, whether or not they judge that test ready to be run at that time. So they, in effect, have the final control over whether a test is run or whether it is hazardous or not.

VIEWS ON BOARD'S FINDINGS

Turning to the Board's findings, determinations, and recommendations, Mr. Chairman, I might say just a few words of my view, if you will, on these findings and recommendations, if that would be suitable.

The CHAIRMAN. Go ahead.

Dr. MUELLER. The thing I would like to do is to say that first of all we did not, of course, participate as a program office with the Board itself. So that these findings and determinations are as new to us as they are to you. And although we supported the Board by having our people work with the Board during this period of time, we did not have an early recognition of what they are. So that I have to say that we have not had a chance to go through in detail the findings and recommendations and determinations of the Board at this time. But we have had an opportunity to go through the Board's findings and recommendations; we have not had a chance to go through and understand the implications of the various panel reports.

DIVIDES FINDINGS INTO TWO PARTS

Now, I think we can divide the findings into two parts. The one set of findings have to do with the accident itself, and describe the findings of the Board with respect to the accident and its determination and recommendations as to what can be done to avoid this kind of an accident in the future.

In this area, it is my opinion that—let me say to begin with that I believe that the Board has done a thorough objective and complete job of looking at every facet of the Block I spacecraft, and the 012 spacecraft in particular, and has assessed all of its deficiencies, and all the problems that one could find in carrying that through.

Now, all of the results, though, are generally applicable—some are definite to particular aspects of the 012 spacecraft.

The CHAIRMAN. Doctor, you said, "in my opinion." Have you divorced yourself from NASA's opinion?

Dr. MUELLER. No, sir. I believe that is also the opinion of NASA. I was adding my opinion to the opinion of management.

The CHAIRMAN. We would rather have your opinion and make sure NASA agrees with it also.

Dr. MUELLER. Now, if we look at those findings that relate to the accident, you will find, as Dr. Seamans has said, that there is a central problem which we did not recognize, and in which we were wrong, a central problem which was the selection and the location of materials in the spacecraft. If we had had a different set of specifications, if we had had a more rigorous control of the material selection, and of their disposition, I do not believe that any of the consequences of the accident we had would have occurred.

Senator HOLLAND. You mean with reference to the flammability?

Dr. MUELLER. That is right. I am talking about the nonmetallic materials in the cabin.

Now, there is a secondary problem, though, and that was the quality, the workmanship, and the design of the electrical wiring system. And it is clear that without an ignition source, the Board has pinpointed the electrical wire system as being the most probable source of the ignition for the fire—we would not have had the fire. Now, because of the long history of the Mercury and Gemini program, using this particular set of specifications, which represent an engineering judgment on the part of a number of people, we did not label the test as hazardous. Having not labeled it as "hazardous," the various other consequences of not having the proper people available resulted. So that all of the other consequences in the determinations and findings are really a result of the fact that this was not labeled a "hazardous test." That deals directly with the accident.

The CHAIRMAN. That is a vote. I suppose we might as well go now.

(At this point a short recess was taken to allow Members to respond to a rollcall vote in the Senate Chamber.)

The CHAIRMAN. You go ahead, Dr. Mueller.

Dr. MUELLER. The Board found that the most probable cause of the fire was an arc in an electrical circuit and they identified the region in which the arc was taking place as being the lower left-hand forward part of the equipment, lower equipment bay.

Now, I know that you have seen pictures of this before, so I will not dwell on that except to say that in relation to that, and looking at the last finding, the Board also found that there were deficiencies, not mistakes but deficiencies in design of the electrical wiring harness. There were deficiencies in the quality of that harness. There were deficiencies in manufacturing and there were deficiencies in the quality control and, therefore, they felt that that might have been contributory to the accident itself. However, since it was impossible to find the actual place where this arc occurred, there is no firm evidence that a particular deficiency was the cause. Now, basically the findings of the board in this relate to the Block I spacecraft. We had recognized that there were design deficiencies, engineering design deficiencies, in the writing of the Block I spacecraft and we had taken steps in the Block II design to improve the manufacturing process, to improve the cable layout, to improve the ability to build a harness and use it without having as many changes as were necessarily incorporated in the Block I wiring harness. Much of the criticism related to two things. One, the fact that we had used a two-dimensional jig; that is, we laid the wiring out on a flat jig and then built it up. The second was that we had had numerous changes in the wiring harness as we developed it and found different places to make measurements. In the development of spacecraft we had to introduce wires in order to carry those things.

Now, that wiring harness, incidentally, had been carefully reviewed by the quality control people at North American, had been reviewed again very carefully and completely before the spacecraft went into the vacuum chamber at Cape Kennedy and each of these review groups which involved not just the quality control people, but also the engineers, et cetera, had concluded that this harness, although it had deficiencies, was nevertheless safe for manned flight. And, it was on the basis of these reviews that we in fact, certified that this particular design was safe for manned flight.

DISCUSSION ON COMBUSTIBLE MATERIALS

Now, the next finding of the Board has to do with the amount and location of the combustible materials in the command module, and here, as I said, we did have control of all of the material in the command module. We have gone back and checked that. A socket wrench that was found inside the wiring harness, we were able to trace back to the fact that that it must have been placed there sometime between October 21 and November 3, I think. Due to some work that was done in the digital control assembly—that is nowhere near the fire itself—we were able to trace back that that socket wrench had been there and were able, therefore, to determine which workmen were working on the thing at that time.

Now, with respect to the combustible materials, as I say, that was a basic flaw in our engineering judgment and I can only relate that to the fact that if you will recall, in the early days of the development of aircraft, you did find on occasion that wings failed. I remember the Martin 202, for example, in its early design, and operations, had a series of wings that failed. They failed because of fatigue stress in the main member of the wing. It had gone through very careful design and very careful testing. Everything had been done right and yet the wings fell off. As a consequence of that, the airplane people learned how to design wings that did not fatigue but it took an accident before one could learn that you had made the wrong judgment about the design of the wing. Well, in a very real sense in this case we made the wrong judgment. It was not made lightly. It was made very carefully. It was reversed a number of times but nevertheless it was a wrong judgment about the location and distribution and the kind of materials in the spacecraft capsule.

We do agree with the Board's conclusion that we ought to change and establish more rigid specifications for the flammable materials. We are taking steps to replace those with materials that either are nonflammable or at least burn very slowly, and in particular the Teflon wire is an example of where we had taken advantage of technology as it existed in the design and development of the Apollo spacecraft. We have now found that the Beta cloth, the fiberglass cloth, has become available in a form that permit you to wear it as underwear. This is a major breakthrough in the technology of fiberglass which is permitting us to make many of the interior nonmetallic things out of fiberglass, and that is essentially noncombustible. We do have within our grasp the materials that we can use to eliminate once and for all that particular fire problem.

PLAN FULL-SCALE MOCKUP FIRE TESTS

We did learn one other thing which is in a later finding of the Board from the accident itself, and that is we learned that we should have carried out full-scale mockup tests of fire replicas, mockups of the spacecraft in such a fashion that we could carry out in replica of the burning that would take place inside a spacecraft. The boiler plate testing, so-called, to do this was developed down at MSC. It was suggested to the Board and supported the Board in reproducing the details of the accident. We plan to make full-scale mockup fire tests of every spacecraft cabin in the future. We believe that we can be sure that the changes we introduce then in materials, and their location, can be verified that they will be safe from fire. We are sure, as sure as we can be, that this particular fire hazard will not continue to be a problem in the space program.

Now, another finding had to do with the hatch and the hatch design, and the Board recommended that the time required for egress be reduced and the operations necessary for egress be simplified. We have, as I reported to this committee a month ago, been in the process of designing a hatch to replace the hatches in the Block I command module. We have under design, we now have mockup, we have a working model, if you will, of a new hatch which is a single hatch that opens outward.

PLAN RAPID ESCAPE HATCH

The present hatch on the Block I spacecraft, the hatch which contributed to the problem we had, was designed for operation in space. That hatch was designed to allow the internal pressure to hold the hatch shut so that you could not inadvertently open it in space, so that the internal cabin pressure would in fact, seal the hatch to prevent it from leaking. Now, there is in many of these designs a tradeoff between the best things in flight and the best things on the ground, and in particular the hatch that we designed to be safe for flight turned out to require some 90 seconds to leave the cabin, and 90 seconds sounds like a short time, but if you have a fire in the cabin it turns out to be too long.

The new hatch is designed, based upon our experience in Gemini. It uses much the same kind of mechanism that we used in the Gemini hatch to hold it in place. It is capable of being opened in somewhere between 2 and 5 seconds. It does permit the crews to leave the spacecraft in between something like 15 and 20 seconds. So that the new hatch will in fact, provide for rapid egress on the ground.

We have taken those precautions that we feel are necessary to avoid the inadvertent opening of the hatch in space. We have, in some small amount, increased the hazard of operations in space by going to an opening outward hatch. We feel that we have not increased that appreciably and we feel that we have improved both the usefulness of the hatch for extravehicular activity in space and the usefulness of the hatch for egress and ingress on the ground.

PREPARATIONS FOR EMERGENCIES

Now, another major finding has to do with our preparations for an emergency. As I said before, since we had not identified this test as hazardous, we did not have in attendance fire crews, emergency crews, doctors, the whole group of people that are normally present during those tests which we classify as hazardous.

You may be interested that there are some 115 test procedures that are carried out on the Apollo spacecraft at Cape Kennedy and of these, some 50 are labeled as hazardous. They are hazardous because of the presence of pressure on our pressure vessels or pyrotechnics or something like this. This particular test was not labeled as hazardous because none of these things were present.

I think that the one area that has—that is not really related to the present accident that the report covers, and you have got to recognize that the report looked very carefully at the whole implementation of the Block I spacecraft and the management that led up to it and sought possibilities for any future accident, and so the findings, for example, on the communications system and the recommendation that we review the system design of the spacecraft and the ground communications system to assure better communications, was not directly related to the accident.

We, however, have completed a design review of the communications system on the Block II spacecraft since that is the next spacecraft we plan to fly manned, and the Block II spacecraft had, in fact, incorporated all of the findings of the Communications Board. So, the Block II spacecraft was designed properly and really it consisted of relocating and changing slightly two switches in the system, as the total changes that were required in going from Block I to Block II communications.

Now, the ground system is a more complex system. This is the same system that we used in Gemini, in Mercury and we have used in all of our ballistic missile programs. However, the one thing that is associated with the Apollo space vehicle is the fact that it is a more complex vehicle and that we do in fact have more people involved in the checkout. There are some 925 people involved in checking out the Apollo 204, that were involved in checking out and testing Apollo 204 in this plugs-out test. Now, 725 of them, I believe, were at Cape Kennedy and the rest were at the Mission Control Center in Houston. The communications have grown, then, as the size of the spacecraft and number of functions have grown, and the system that we had in use at Cape Kennedy was, as nearly as I can tell from the review that has gone this far, overloaded and what we are doing is making changes that will permit that system to in fact, operate properly.

CHECKOUT PROCEDURES

Now, another finding which again did not have a direct influence on the accident was a finding by the Board that we had allowed insufficient time for the verification of the checkout procedures, for the development and the use of the checkout procedures by the test crew. We have carefully reviewed that. We agree with the finding that in fact, the test procedures were not revised at as early a date as they should have been.

Now, interestingly enough, the policy and requirements for the development of these test procedures do in fact, require that an adequate time be provided prior to a test for the completed procedures. There was a lack of discipline and a lack of rigor in the application of these policies. We are, of course, taking steps to be sure that does not happen again in the future.

WILL HAVE RIGID QUALITY CONTROL

Finally, findings 10 and 11 represent a set of findings which describe certain design deficiencies, certain operating deficiencies, which are germane to the Block I spacecraft. We have gone through these and we find that the Block II spacecraft has corrected or will correct, in all but one or two cases has corrected the design, the manufacturing deficiencies that are outlined here. We are taking steps to introduce a more rigorous application of the procedures for quality control. We looked back at the quality—at the management system for quality control that has been developed and we have had a very careful review of that by a number of outside people as well as by the Board. You will find that the procedures are good and are as good as can be developed. We find that the actual implementation of these procedures at the working level has been impeded by several things. And we are taking steps to establish more rigid set of standards, more rigid description of good workmanship, and are taking steps to be sure that the inspectors do in fact, interpret these standards on the conservative side instead of on the unconservative side.

I believe, Mr. Chairman, that that completes my review of the accident and the Board's findings and determinations in a summary form.

The CHAIRMAN. Will there be other presentations?

Dr. MUELLER. No, sir.

The CHAIRMAN. We can start questioning?

Dr. MUELLER. Yes, sir.

The CHAIRMAN. Dr. Seamans, do you agree, completely or in part, with the findings, determinations, and recommendations of the Apollo 204 Review Board?

BOARD RESULTS PULL NO PUNCHES

Dr. SEAMANS. As I indicated in my statement, Mr. Chairman, I agree in large part with the findings. I believe that one must differentiate between those findings that are directed at the accident and its cause and those findings that are more general in nature. I believe that we must very carefully review all of the findings and recommendations and that we will act on a large percentage of them as they recommend.

The CHAIRMAN. Are you personally satisfied as to the objective of the Board's work?

Dr. SEAMANS. I am absolutely satisfied with their objectivity. The results that they came up with pull no punches as far as anyone could possibly tell.

The CHAIRMAN. There has been some criticism that there were too many NASA personnel and too few outside experts on the Review Board. Why were there not more non-NASA people on the Board?

Dr. SEAMANS. Well, I was one of those directly involved in selecting the Board membership. We picked the best man that we knew of to chair the Board; namely, Dr. Thompson. We then picked people who could provide the right degree of leadership and knowledge to help him. We found that we lacked in NASA anyone really familiar with the details of fire and investigation of fire, so we went outside to the Department of the Interior, Bureau of Mines, to pick Dr. Van Dolah. We also found that we in NASA had not had the experience with such large-scale investigations and we were fortunate to get Colonel Strang from the Air Force, who had just finished a responsible assignment for the investigation of the Little Rock accident and came and was able to materially assist in the procedural aspects.

However, the detailed knowledge of the individuals in NASA was absolutely indispensable for the rest of the Board membership in our view.

STATUS OF REVIEW BOARD

The CHAIRMAN. What is the status of that Apollo 204 Review Board? Has it completed its work? When will it be disbanded?

Dr. SEAMANS. The 204 Review Board have essentially finished their work. However, there are still a few studies outstanding where we are investigating certain equipments that came out of the capsule. Until that work is completed, we are keeping the Board in force so that they will have a chance to review these studies. However, these will not affect the overall findings and determinations.

MOON LANDING GOAL NOT CERTAIN

The CHAIRMAN. I want to try to keep my questions limited, but in the intervening period since the last hearing, have you formed a judgment as to the impact of the accident on our ability to effect lunar landing before the end of this decade?

Dr. SEAMANS. We are, of course, reviewing this matter in depth. We are not prepared to present to you today a revised schedule for the next launchings nor for the totality of the Apollo-Saturn program for lunar landings. It is our view that this delay will cause a delay in the first Apollo flight of up to a years' time. That is, the very earliest that we could have the next Apollo flight will be the end of this year and more likely it will be this winter. This, in turn, will tend to delay subsequent flights.

However, we have gained a very large amount of information as a result of this which can, if we use it properly, and we intend to, assist in reaching our goal. It is our view that, and my view, that there will now be more of the Apollo-Saturn V flights outside of the period in this decade and that our chances for the lunar landing in this decade are somewhat less.

The CHAIRMAN. Dr. Mueller, we all have great confidence in you. What do you believe will be the impact of the accident on the national commitment to land men on the lunar surface and return them safely to earth by 1970?

Dr. MUELLER. Mr. Chairman, I think that obviously the accident has impacted our ability to fly men early. I think that we have not yet fully assessed the consequences of the accident. It is possible, as Dr. Seamans has said, that we may gain enough information from the very careful review of the accident itself and the consequences would be of looking in depth into all of the subsystems of the Apollo spacecraft that we will minimize that impact.

In particular, I am encouraged by the fact that 89 of the 90 subsystems in the Apollo spacecraft were found by the Board after careful review to be satisfactory not only from the standpoint of the fire, but from the standpoint of their application to future flight hardware. So, we are talking about a very small part of the total spacecraft components as related to the accident. My own view is that it is still possible to carry out the manned lunar landing within this decade.

The CHAIRMAN. Senator Smith?

REQUESTS SPECIFICS FOR DEFICIENCIES

Senator SMITH. Yes, Mr. Chairman.

Dr. Seamans, the Apollo 204 Review Board sets forth several deficiencies in design, manufacturing, workmanship and quality control. From your experience in research and development and engineering and manufacturing, to what do you attribute these deficiencies? If you would just speak to that generally now, and, if you wish, give us a more comprehensive statement as to specifics for the record, I would appreciate it very much.

Dr. SEAMANS. Just, then, summarizing my ideas on this, because it is a——

Senator SMITH. Yes.

Dr. SEAMANS. A very complex and a very important matter, I would say, that in any program such as this, where there are so many people, there is required an extensive period of training and familiarization of those involved. And, this learning process goes right down to the technicians who are working on the bench. We found in the past that we in NASA, have had to run training schools for technicians to teach them how to solder. Soldering is not an easy matter when the joint must be absolutely firm even under conditions of extreme vibration and heat.

I would say that we had not, or I would say specifically, that North American did not address themselves sufficiently to the problem of training their personnel. They did not provide sufficient supervision of their personnel and they did not provide adequate inspection of the work that was done. However, as a result of a hard hitting record by Dr. Mueller and General Phillips that went back a number of years the contractor's effort is very definitely improving, but it takes time to build up this competence.

TRAGEDY NOT DUE TO TIGHT SCHEDULES

Senator SMITH. Dr. Seamans, as I recall in answer to my question about tight schedules having to do with the tragedy, Dr. Thompson, and other members of the Board, said that they believed it was not due to tight schedules. In other words, it was not because NASA was in a hurry.

Dr. SEAMANS. I, myself, would agree with that. I do not think that the scheduling caused faulty workmanship. I think there was ample time to do a good workmanlike job.

PLANS FOR CORRECTIVE ACTION

Senator SMITH. Dr. Seamans, we appreciate that Apollo 204 Review Board has just released its report. However, aside from the hatch, the environmental control system, and other hardware modifications, what corrective action do you as a top management official propose, to prevent a recurrence of the deficiencies in engineering, design, manufacturing, workmanship, and quality controls listed in the report? Have you initiated any corrective action up to date?

Dr. SEAMANS. There are, as you indicate, those matters that will require attention that are of technical or operational nature, such as the hatch, such as the amount of flammable material in the cabin, and such as the possible problem resulting from the tubing and the manner in which it is soldered together. These, of course, we will address ourselves to specifically and in depth.

In addition we must, of course, look at the total management organizational structure. We believe, just as we believe that the design is basically sound, that the organization is sound. However, we will look carefully at the whole method of inspection and quality control, both with regard to how the contractor is carrying out his work and his responsibility for inspection. We will also look at the manner in which the Government team is carrying out inspection, and this team includes not only NASA personnel but also includes Department of Defense personnel who do the major share of our inspections. We will look at the manner in which our requirements and specifications are given to the inspectors to see whether they are clear as to what is mandatory and what is not mandatory. We will also look at the reporting chain in quality assurance. For example, in Houston, we have right now the quality assurance unit reporting to the project manager. We may find it wise to take this out of the project chain and have this a separate functional unit reporting to the director of the center as we now have at Huntsville.

We will also look carefully at the management relationship between the contractor in Houston and the contractor at the Cape and particularly between Houston Manned Spacecraft Center and the operation at the Cape and to be sure that there is no ambiguity as to who is responsible at each instant of time as material flows from the contractor to the Cape.

Senator SMITH. Well, Dr. Seamans, in the fourth point of your statement, with respect to change, you give one example and I read, "to give a specific simple example, cable runs must be protected so that removal and reinstallation of equipment will not chafe the insulation eventually causing short circuits or arcs."

As a layman, that seems pretty simple to me. I think that would be done in an ordinary radio. Why was it not done in this case?

Dr. SEAMANS. The matter seems simple and in every single case it is simple, but when looking at the totality of equipment inside the capsule, I guess roughly equivalent to the kinds and functions that you have inside of a 707, the packaging problem is very difficult. There is a tendency in order to include everything in the capsule to somewhat pile elements one on top of another. It takes very good design, very imaginative people, and oftentimes some extra space to design the elements so that each one fits in reasonably, independent of the other. We had a lot of difficulty in Mercury with this. When we had a failure, we had to take out three parts to get at the faulty part.

Gemini was greatly improved because all the components were around the outside and readily accessible. We could not do this in Apollo because of the heat shield problem. We are, as we say, inside the egg in this situation where it is hard to get access to the elements. I think, for example, that we must do a better job and I believe from what I know that the Block II is a much improved design in this regard.

Senator SMITH. I would like to read for the record, Dr. Seamans, from the report of Panel 9 of the Review Board: "during the wire inspection the following design deficiencies were noted." Finding No. 3 states "some areas of wiring exhibited what would be referred to as 'rats' nests' because of the dense disordered array of wiring. In some instances, excessive lengths of wires were looped back and forth to take up the slack. Also there were instances where wires appeared to have been threaded through bundles which added to the disorder," and so on.

There are other similar statements with respect to the wiring.

Now, going back to Dr. Mueller's statement, Dr. Mueller, I think I understood you to say that there were nearly 500 inspectors in the Apollo program at the Cape?

Dr. MUELLER. There were 950 people involved in the test of the 012, AS-204. And 725 of them were at Cape Kennedy working on that test when the accident occurred.

Senator SMITH. Now, for the life of me, I just do not understand why, with all those people, whose responsibility was to carry on very careful inspection, how a wrench socket could have been left undetected in the capsule from October or November, I believe you stated, to January 27, the date of the accident.

Dr. MUELLER. Madam, that particular socket, when you saw it in the picture, they had opened up the trough in which this cable was placed so that you can pull the wire bundles apart. They have taken that spacecraft apart piece by piece. I do not understand why the inspector did not see the socket when the closeout was made. And, I cannot explain why people do not see things when they have not sometimes.

But, on the other hand, I must say that once it was closed out you could not see it from outside.

QUESTIONS ON LINE OF ORGANIZATION

Senator SMITH. Well, Dr. Mueller, from your statement this afternoon, your description of NASA's lines of organization and the procedure that is followed, is very interesting and I think very valuable for the record. According to the plan that you outlined, everything was perfect but apparently that was on paper and not in being. In your statement of what happens in the Apollo program, you explained the lines of responsibilities at the Center level, among Centers and between MSC and contractors. You did not go back and explain the flow of directives and information from and to headquarters.

My question is—and this you may be supplied for the record in the interests of time, Mr. Chairman—where do the directives or instructions come from? For instance, do you issue instructions directly to the MSC director or to the Apollo program manager?

Dr. MUELLER. The Apollo program manager is responsible for the Apollo program. General Phillips will send a directive through the center director to the Apollo spacecraft program manager, for example, at Houston. In turn, depending upon what the directive says, the Apollo program manager directs the contractor, the prime contractor. The prime contractor in turn directs the subcontractors. Now, there is a chain going back up which consists of a thorough reporting system. Every discrepancy, for example, in the wiring, every failure in equipment, is, in fact, recorded and a record of that is sent back to the Manned Spacecraft Center and in turn sent, compiled there and at least in headquarters we see all of the major trends and the particular instances of note.

Senator SMITH. What I am trying to get at is, who watches whom? Does the director of the Manned Spacecraft Center have line responsibility, for instance, for Apollo?

Dr. SEAMANS. Yes.

Senator SMITH. Full responsibility?

Dr. SEAMANS. For the Apollo spacecraft.

Senator SMITH. And, does he have full authority, too?

Dr. SEAMANS. Yes.

Senator SMITH. He has full authority.

Dr. SEAMANS. Yes. Subject to whatever review that is normal with responsibility and authority.

Senator SMITH. Now, did I understand you correctly when you said that the Apollo program manager, for instance, has about 30 separate subsystem managers reporting to him? What does he do with those reports? Do they stop there or do they go to the next higher line of authority, or do they go to you?

Dr. SEAMANS. Eventually, these subsystem managers will report at regular—at determined intervals to not only myself, but also to the three Center directors. The level of reporting varies from time to time, and in particular at any time we buy off a design for manned space flight, every subsystem manager reports to the four of us.

Senator SMITH. Well, you say that——

GENERAL PHILLIPS OUTLINES AUTHORITY PROCESS

The CHAIRMAN. I wonder, General Phillips, do you have any comment? Are you not that person they were talking about?

General PHILLIPS. Yes; I am the Apollo program director and have been now since the fall of 1964. I was assigned to NASA in January of 1964 in the capacity of the deputy Apollo program director and assigned the job of director in October of 1964.

In response to Senator Smith's question, the program managers in the three centers send reports to me and to the staff that I have here in Washington on, for example, the subject of failure reports which are a part of the quality cycle. These are sent in detail by the contractors to the center program officers where the details of contract direction are accomplished, and in the case of quality discrepancies, for example, they are sent on up to my office in summary form and one of the things that I and my staff do is keep careful track of the trends, take action when the trends are not right or the numbers of discrepancies are too high, and in addition, through frequent contact with the people in the field, including the contractors, try to keep close cognizance over the progress and the status of the work in the field.

Senator SMITH. Well, General Phillips, you say that reports go both to you and to MSC director. Now, my question is, who acts? Is there a diffused authority?

General PHILLIPS. Senator Smith, I think it is quite clear, the responsibility for the total program, the total Apollo program, has been assigned to me. That involves the Apollo spacecraft which is the responsibility of the Manned Spacecraft Center at Houston, the Saturn launch vehicles which are the responsibility of the Marshall Spaceflight Center at Huntsville, and the launching facilities and associated checkout and test operations which are clearly the responsibility of the Kennedy Space Center at the Cape. Now, in the case of the two development centers, Houston and Marshall, they execute directly with industry, the contractor, the development of the equipment that we require. These contracts are based on the specifications for the total Apollo system, which are my responsibility and which are developed in my office. The detailed responsibility for the detailed development of that equipment resides at the appropriate center in the field and that is a clear line of authority.

In turn, in the case of the spacecraft, the Manned Spacecraft Center deals through their contractors with their several contractors. In the case of Apollo spacecraft, it is the North American Corp. So, the line of responsibility, I think, is quite clear. The line of reporting back is also quite clear.

Senator SMITH. Well, now, Mr. Chairman, I have a request for information to be inserted in the record. I will just outline my request briefly and Dr. Mueller, Dr. Seamans, and General Phillips can give us their best thinking on it. Would you describe the lines of responsibility and authority on the Apollo program as they emanate from your office, Dr. Mueller, for the design and development of the spacecraft, for quality control, and for the testing of the total system at the Kennedy Space Center, as they relate to each of the following positions: the Apollo Program Director, the Manned Spacecraft Center Director, the Apollo Program Manager, the Kennedy Space Center Director, the Director of Launching Operations, the Director of Spacecraft Operations and the Director of Reliability and Quality. In addition, please tell us whether the Apollo Program Manager at MSC is responsible for all Apollo activity at the Center or only for the spacecraft? Could you describe also the management interfaces between MSC, KSC, and the contractor.

I think, Mr. Chairman, that will be very helpful for the record.

Dr. MUELLER. We will do so.

The CHAIRMAN. Will you supply it, then, and make certain that copies get to Senator Smith quickly.

Senator SMITH. Thank you.

(The information supplied for the record follows:)

The Associate Administrator for Manned Space Flight (AA/MSF) is responsible for the *overall* management and direction of all Manned Space Flight programs as defined and approved by the Administrator. He is also responsible for directing launch and flight operations through completion of each mission within a program. He provides policy guidance and direction to the Directors of three Manned Space Flight Centers (MSFC, MSC and KSC), the Apollo Program Director and the OMSF Mission Operations Director.

MSF Management Council

The OMSF Management Council, consisting of the AA/MSF, Dr. G. Mueller as Chairman and the Directors of each of the Manned Space Flight Centers, Dr. Von Braun (MSFC), Dr. Gilruth (MSC) and Dr. Debus (KSC) establishes policy guidelines and plans for the Apollo program.

The Council ensures that policy, progress and performance goals are being met, that technical problems are being dealt with properly and that adequate resources are available for the successful conduct of the program. The Council also acts as the Design Certification Board for examining the design of the total Apollo mission complex for proof of development maturity prior to each manned flight of a new configuration. It assesses (1) the design of the Space Vehicle for flight worthiness and manned flight safety, and (2) the design of the Launch Complex, the Mission Control Center, Manned Space Flight Network and Launch Instrumentation for manned Apollo missions. A Mission Design Certification Document, executed by the MSF Management Council serves as the approval authority for proceeding with specific flight missions designated for manned flight.

Apollo Program Director

The AA/MSF has assigned the responsibility for all aspects of the Apollo Program to General Phillips, the Apollo Program Director, and has delegated him the authority for overall planning and schedules, budgets and cost control, systems engineering, design, development, test, and performance evaluation necessary to ensure the achievement of program objectives. This includes the mission descriptions, technical requirements, program specification, and reliability and quality standards. He is the NASA official authority for issuing Apollo Program Directives and imposing Apollo Program requirements on Field Centers. His line of communication for direction of program affairs at each of the MSF Centers is to the Apollo Program Manager within the respective Center. General Phillips operates within the MSF Management Council guidelines and approved plans and discusses with the Council each month his program plans, known and potential problem areas, and a comprehensive assessment of program status and outlook toward approved performance, cost and schedule requirements.

Director of Reliability and Quality Assurance

Within General Phillips' Apollo Program Office is the Directorate of Reliability and Quality under Mr. G. White, Jr. General Phillips has assigned Mr. White the responsibility for establishing Quality Assurance requirements, policies and standards, and administering them at the program level. (The Quality and inspection programs are established in accordance with the provisions of NASA Publications NPC 200–1A, 200–2 and 200–3 as appropriate.) The Director also establishes levels of reporting for quality assurance activities. A major responsibility of this directorate is to evaluate progress in achieving quality program objectives and to initiate corrective action where it is required to improve the effectiveness of the Quality function throughout the Apollo Program.

Center organizations for Apollo

The AA/MSF has assigned the development of the Apollo Spacecraft and related ground support equipment and support of manned space flight missions to Dr. R. Gilruth, the Director of the Manned Spacecraft Center at Houston, Texas. He is responsible for development, production, checkout and technical integrity of all assigned Apollo hardware and software. His organization manages Spacecraft contractors' activities in each of these functions. He retains this responsibility through all phases of activity, regardless of location of the hardware or software, from inception to program completion. He is also delegated the authority for Apollo flight operations and flight crew operations. The AA/MSF has assigned the responsibility for Apollo Launch Operations, facilities and Common Ground Support Equipment to Dr. Kurt Debus, the Director, Kennedy Space Center (KSC). He to, retains this assignment through all phases of activity, regardless of location of hardware or software, from inception to completion of the program.

Each Center Director assigns responsibility and delegates sufficient authority to his designated Apollo Program Manager to effectively manage his portion of the program.

Apollo Program Managers

The Apollo Program Managers at each MSF Center report organizationally to their respective Center Directors, but are responsive to program direction from the Apollo Program Director under overall direction of the Program Management Council. Each Apollo Program Manager is delegated the authority for overall coordination, planning and direction of all aspects of the Apollo Projects assigned to his Center Director. This includes effective technical performance, cost and schedule management. He is required to establish project development plans, project specifications and subsidiary specifications, test and operating plans, mission descriptions and reliability and quality procedures consistent with and responsive to the direction and guidelines provided by Headquarters, NASA, OMSF and the Apollo Program Director.

Apollo Spacecraft Program Manager (MSC)

At the Manned Spacecraft Center in Houston, Texas the Apollo Spacecraft Manager, Mr. George Low, formerly Dr. Shea, reports directly to the Center Director Dr. Gilruth, and is responsible for the planning, coordination, and direction of all aspects of the Apollo Spacecraft Program. This includes the supervision of industrial contractors within the scope of the contract and the direction and coordination with other elements of MSC or NASA Headquarters which are assigned parts of the program. Specific responsibilities include:

(a) Development of the Apollo Spacecraft Program resources and scheduling plans, their integration and development into an overall program development plan and the control of the implementation of this plan.

(b) Serving as the primary point of coordination and control of systems design, specification, and development for the Apollo Spacecraft Program.

(c) Development or approval of spacecraft subsystems design requirements, the performance of tradeoff studies, the definition and control of all interfaces between spacecraft subsystems and the spacecraft, interfaces between other related program elements, and the development and maintenance of all crew safety requirements.

(d) Management of the detailed planning, implementation, and reporting of results for each major flight and integrated systems ground test.

(e) Coordination and development of the test program plan, the development of the mission directive documents, the determination of instrumentation and measurement lists and requirements, the determination of engineering data acquisition and reduction requirements, the establishment of detailed schedules, and the determination of the adequacy of checkout procedures for each major flight and integrated systems ground test.

(f) Development and standardization of requirements for reliability and quality assurance and the reliability apportionment between various elements of the Apollo spacecraft.

(g) Management of contractor and subcontractor reliability and quality control efforts and the coordination of the inspection efforts of cognizant Government inspection organizations.

(h) Development of the basic design of the lunar landing mission and the development of criteria for the training of the spacecraft crew for the lunar landing mission.

The Apollo Spacecraft Manager's responsibilities are generally limited to the management of the Spacecraft program. While he is not directly responsible for other MSC activities, such as Flight Crew Operations and Flight Operations, he does play a key role in the technical and management interfaces between the Spacecraft itself and these other closely related activities. The total management and coordination of all these MSC activities, of course, is the responsibility of Dr. Gilruth, the MSC Director.

Management interfaces between MSC, KSC, NAA

The basic management relationship between MSC, KSC and the Apollo spacecraft contractor is described in a documented agreement signed by Dr. Gilruth (MSC) and Dr. Debus (KSC) the major points of which are listed below:

1. MSC shall be responsible for the determination and control of the configuration of the spacecraft and all spacecraft contractor-supplied GSE, including ACE. MSC shall be responsible for approval of all changes in configuration.

2. MSC shall establish overall checkout standards and plans. These standards and plans shall set the broad parameters for checkout and inspection for all spacecraft checkout and inspection for all spacecraft checkout from the factory through Cape checkout. MSC shall establish detailed factory checkout procedures; KSC shall review and advise MSC on these procedures. KSC shall develop Cape checkout plans for review and approval by MSC as a part of the overall spacecraft checkout plan; KSC shall develop detailed checkout procedures for MSC review and concurrence. No checkout procedures shall be adopted which are not concurred in by MSC.

3. MSC shall conduct technical reviews, inspection, and checkout acceptance activities at the spacecraft contractors' plants; KSC shall provide checkout personnel to serve as observers and advisors; KSC shall conduct detailed Cape checkout of spacecraft, securing MSC approval of necessary performance and checkout procedure waivers or inspection deviations; KSC shall conduct the actual countdown and launch activities. This includes direction of those MSC spacecraft contractor personnel engaged in preflight checkout activities at the Cape.

4. MSC shall provide to KSC performance data, systems or subsystems specifications, or test results which are needed or requested by KSC.

5. MSC shall provide data requirements for format and/or reduction requirements for pre-mission, real-time mission, real-time mission support, or post-mission evaluation.

6. MSC shall determine the disposition and place of failure analysis of all

failed components after removal from the spacecraft; KSC shall conduct failure analyses as requested by MSC and make recommendations for corrective action as applicable.

7. MSC shall retain responsibility for all astronaut activities; KSC shall provide necessary housing and logistical support as required.

8. MSC shall prepare all on-board experiments which are intimately associated with the astronauts; KSC shall prepare those experiments intimately associated with the spacecraft.

9. KSC shall participate as a Board Member of the Acceptance Review Board in conducting formal pre-delivery reviews of spacecraft at the contractors' plants and on the MSC Spacecraft Readiness Review Board; MSC shall participate as a Board Member in launch readiness reviews and shall participate in preflight and post-launch debriefings of launch crews conducted by KSC. MSC shall conduct necessary post-mission tests of spacecraft.

10. MSC shall establish minimum readiness specifications or lift-off rules for spacecraft systems; KSC shall conduct necessary integrated space vehicle checkouts.

11. KSC shall provide MSC such administrative and housekeeping support for personnel assigned to the MSC Resident Offices as may be necessary.

Apollo Program Manager (KSC)

The KSC Apollo Program Manager is directly responsible to the Center Director and is responsive to program direction from the Apollo Program Director under overall direction of the Program Management Council. The KSC Apollo Program Manager is responsible for:

1. Official interface with other Manned Space Flight Centers and Office of Manned Space Flight.

2. Formulation of subsidiary specification, test and operating plans, mission description, program reliability and QA procedures and operating plans.

3. Translate requirements and schedules received from the Apollo Program Director and forward to line organizations for development into detailed plans.

4. Receive, review, validate and integrate plans for individual operating Directorates into KSC Apollo Program plans.

5. At a program commitment level, coordinate, monitor and track the execution of requirements and utilization of funds against approved plans, schedules and resources.

6. Approve the scope and changes in scope in the work of stage and spacecraft contractors.

7. Assure that the scope or change in scope of support contractors are consistent with Apollo Program requirements.

8. Maintain surveillance of stage and spacecraft contractors activities to assure optimum balance in performance, schedules, and cost.

9. Review development plans for KSC designed or furnished equipment and facilities. Assure performance and design criteria is proper and acceptable with all activities involved and are consistent with Apollo Program guidelines and available resources.

Director of Launch Operations

The Director of Launch Operations reports directly to the Center Director and is responsible for:

1. Management and technical direction of preflight operations and integration, checkout, and launch of all Apollo space vehicles at KSC and ETR.

2. Installation, checkout, modification, maintenance and operation of all GSE provided as used by launch vehicle and spacecraft contractors.

3. Initiates, supervises and coordinates the preparation of preflight launch operations test plans and is responsible for the execution of them.

4. Assists the Kennedy Space Center Apollo Program Manager in his negotiating with, and receiving approval of, the cognizant development Centers concerning test and operational sequences, and methods and standards.

5. In accordance with program requirements received from the KSC Apollo Program Manager, develops operational support and resource requirements needed to execute the assigned mission within approved schedules and/or funding limitations.

6. Oversees the management of specific contractor efforts as appropriate to their mission, insure consistency, coordination and effective management.

7. Chair the Apollo Launch Operations Committee (ALOC).

Director, Spacecraft Operations

The Director, Spacecraft Operations, is responsible to the Director of Launch Operations for:

1. All operations and technical management functions relating to spacecraft contractors within the jurisdiction of KSC.
2. Management and technical integration of all KSC operations related to preparation, integration modification, checkout and flight readiness of manned spacecraft.
3. Installation, checkout modification, maintenance, and operation of all GSE provided or used by the spacecraft contractors.
4. Develop operational support requirements for manned spacecraft checkout and launch at KSC.
5. Establish a uniform and consistent program within the Directorate for configuration management, reliability, QA, logistics, and systems engineering based on the prescribed guidelines.
6. Review and approve (jointly) spacecraft test requirements.
7. Review and approve detailed spacecraft operational checkout plans and procedures.
8. Accept spacecraft test results.
9. Operational direction authority of spacecraft during the conduct of tests and checkout. Assure the coordination, consistency, and effectiveness of the spacecraft contractors during the KSC operational phase.
10. Develop detailed spacecraft checkout schedules prior to electrical SC/LC mate consistent with the overall milestones developed by the Apollo Program Manager.
11. Implement MSC approved spacecraft and GSE configuration changes. Certify changes are implemented per blueprint.
12. Assure the quality of contractor work performed at KSC.

The CHAIRMAN. Senator Cannon?

QUESTIONS ON SPECIFICATIONS

Senator CANNON. Thank you, Mr. Chairman.

Dr. Mueller, you stated to us that in order to have a fire, such as we had here, it was necessary to have oxygen, fuel, and an ignition source, and that the wiring was suspected as the ignition source in this instance. You gave us a very fine instructional course in quality control and so forth.

I would like to ask whether or not in this instance, the wiring problems would be related to that of quality control or would be related to that of improper specifications.

Dr. MUELLER. In most of the problems, particularly referring back to Senator Smith's finding in one of the appendices, were related to the engineering design of the wire layouts and in particular to the fact that the place on which they built up the wiring harnesses was not the same as the place where they were located when they were in the spacecraft. It was a poor design practice. It has been recognized and it has been changed.

The part of the problem, of course, in terms of the snarl of wires that was described, does not affect the basic operation of the circuits. They worked functionally quite well. They, however, do not look good and they also provide pressure points which can cause failure of the insulation.

Senator CANNON. Now, would the poor design be a result of improper specifications in that instance?

Dr. MUELLER. Well, it would be a specification established at the end item specification level and it was a poor specification in the first instance. It was not specific enough to require the designer to avoid that.

Senator CANNON. So that you have really poor specification or improper specification and quality control to a degree both involved, then, in that situation.

Dr. MUELLER. Senator Cannon, I think that General Phillips would argue with that, that the specification generally does not go to the detail of defining how the cable wiring is run. The specification would, however, require, for example, a three-dimensional jig to be used in the design. So it depends on what level of detail in the specification that you are discussing here. I would say that the principal problem is that of the design rather than the specification.

The CHAIRMAN. I think we had better stop.

Dr. MUELLER. They are both, however, produced by the contractor.

The CHAIRMAN. There is a rollcall vote.

(A short recess was taken to allow Members to respond to the rollcall vote.)

The CHAIRMAN. Senator Cannon?

Senator CANNON. Thank you, Mr. Chairman.

Dr. Mueller, what I am trying to get at is, in what particular area of responsibility this situation occurred and you say it was bad—faulty engineering. Well, was it faulty from the specification side of it as to what the contractor was told to do or was it faulty on the part of the contractor and, if so, was it faulty on the part of the supervisory people in not finding it in their inspection process?

Dr. MUELLER. Let me pinpoint it. Both the specifications for the wiring and the manufacturing of the wiring cable and the inspection to be sure it meets the requirements of the design and manufacture are a responsibility of North American, North American Aviation Co., in the case of the Apollo spacecraft. NASA reviews the specifications. It reviews the designs and approves them. And it reviews and checks on and monitors the quality function. So that in every case NASA has reviewed and/or approved this thing at each stage. But the basic responsibility is the contractor.

Dr. SEAMANS. Senator Cannon, could I just add a little bit to that.

Senator CANNON. Yes, sir.

Dr. SEAMANS. At this particular design point, you had a steel tube and a cable going over it and just above that a cabinet with a door on it, and the cable was held by the pipe in close proximity to this door.

Now, this is not a good design situation, but in development work from time to time, you get into these situations. So at that point the inspection department, quality control department, at North American should have seen the possibility of chafing and they should have put chafing guards in there, but they never noticed the deficiency.

Senator CANNON. All right. Now, let us go to the question next of combustibles. Now, was this, then, in the area of improper specifications or was this again, in the area of improper design and quality control?

Dr. MUELLER. This was clearly in the area of improper specifications. They were specifications developed over a period of time. They were NASA specifications. They had been reviewed by the various contractors involved and their safety organizations over a period of time, but they were basically improper specifications resulting from a lack of knowledge about the engineering problems, real problems associated with the material selection and distribution of the capsule.

Senator CANNON. And the contractor in that instance, had just done simply what he was told to do, is that correct?

Dr. MUELLER. Well, essentially, yes.

Senator CANNON. Now, let us turn to the third area, that of the escape hatch. Again, was this a matter of improper specifications, because of the deliberately different type of design—will you address yourself to that, Doctor?

Dr. MUELLER. I do not believe there was anything fundamentally wrong with either the specifications, the design, the manufacturing, or the concept of the hatch system. If there was a problem, it was associated with the tradeoff between operations in space and operations on the ground, but it in turn, really goes back to the experience and the specification on materials because of that specification and our experience with it, we did not feel that a fire inside the spacecraft cabin was really a possibility and, therefore, we had not considered it as a hazard. And, consequently, the hatch was designed to maximize the safety in space.

Senator CANNON. All right. Now, with the redesign, then, of the hatch that you have described here, is this going to increase hazards in other areas? For example, in space?

Dr. MUELLER. It will very slightly increase the hazard while you are inside the spacecraft. It will, however, increase the facility, the extravehicular activity, and, therefore, decrease the risk of extravehicular activity. On balance, I do not believe that it will change.

NEW HATCH PRESENTS NO HEALTH HAZARD

Senator CANNON. Dr. Berry, I would like to ask you if you think that the redesign of the hatch is going to increase appreciably the hazard to the men from the medical standpoint.

Dr. BERRY. No, sir; Senator Cannon. We have been concerned, as the crew has also, about the extravehicular activity with this hatch and that was why a hatch design had been underway for a long period of time, for the Block II spacecraft. I think that you always have to make tradeoffs in things like this and that is one of the things that we are all involved in constantly, trying to evaluate and make sure that you are not compromising man's safety, and I really do not think that this hatch will do that. I think it will add to his safety in the overall operation. As Dr. Mueller has said and, I think we have to continue to look at every single thing so we do try and make sure it does not compromise man's safety. I do not think we have.

Senator CANNON. Dr. Mueller, the materials work panel stated that several inadequacies were found in materials control, such as control of flammable materials installation, and that this control was exercised by several organizations which tended to act independently. Now, from a systems management standpoint, what organization should have been responsible for establishing and monitoring such control?

Dr. MUELLER. The Apollo Spacecraft Program Control Office.

Senator CANNON. The what?

Dr. MUELLER. Apollo Spacecraft Program Office.

Senator CANNON. Now, did NASA review and approve the contractor's specifications with respect to the wiring and the combustibles that you referred to?

Dr. MUELLER. With respect to the wiring, yes. With respect to the combustibles, the contractor had a different set of specifications that evidence developed internally. We imposed the NASA MSC specifications on him by direction. The spacecraft 012 in fact, met the NASA specifications. I would point out that the difference was involved in incorporating this particular specification into the contract rather than with respect to the implementation of the materials control and selection and distribution.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Brooke?

GENERAL PHILLIPS ASKED TO REVIEW CONTRACTOR WORK

Senator BROOKE. Dr. Seamans, you made certain statements which I interpreted to mean that you believe that North American had been guilty of some misfeasance or negligence. At any time, did you consider replacing North American?

Dr. SEAMANS. I did not mean to imply malfeasance.

Senator BROOKE. Misfeasance.

Dr. SEAMANS. I am sorry. Misfeasance.

Senator BROOKE. Not malfeasance.

Dr. SEAMANS. I misunderstood you. But, what I did mean to imply was that in my view there has not always been at North American sufficient dedication, either to the engineering design or to the workmanship on the job. This was a matter that was of extreme importance to us as we recognized it several years ago and it was for that reason that we asked General Phillips to put together a team to very carefully review all the detailed work going on at North American. This he did, with the full cooperation of North American. He put together information that was very hard hitting. It did get the North American management's attention. He has followed up on that and there has been marked improvement at North American during the past year and a half or so.

However, it should not have been necessary for the Government to take this type of strenuous action.

DISCUSSION OF GENERAL PHILLIPS' REPORT

Senator BROOKE. May I ask General Phillips, did you recommend after your inquiry or investigation that North American be replaced by another contractor?

General PHILLIPS. No, sir; I did not.

Senator BROOKE. You never made such a report?

General PHILLIPS. I never made such a recommendation. In other words, Senator Brooke, your question was whether I recommended that North American be replaced by another contractor. My answer was that I did not recommend replacing North American by another contractor.

Senator BROOKE. Dr. Seamans, did you ever receive a recommendation from any source that North American be replaced by another contractor?

Dr. SEAMANS. Not to the best of my knowledge. I do not remember such a recommendation. I will say that in connection with another division of North American, the Rocketdyne Division, there was concern several years ago, I believe about 2 or 3 years ago, with regard to the engine program. They were having difficulty with the J–2 engine and at that time I asked the program office, Dr. Mueller, and General Phillips, to consider the possibility not of canceling the North American contract, but of considering a second source for that engine. They looked into this and did not recommend that we do so and the J–2 engine has proven to be to date a high-quality engine.

Senator BROOKE. You said that General Phillips' report was a hard-hitting report, if I remember your words. Did you, at any time, consider that the report warranted replacement or cancellation of the contract with North American?

Dr. SEAMANS. I did not at the time that I reviewed the findings of this task force. However, I was reserving judgment until such time as we could see whether the North American trend was in the appropriate direction and it did turn out that the improvement was such that I never discussed with Mr. Webb a possibility of changing contractors.

Senator BROOKE. You did discuss it?

Dr. SEAMANS. I did not.

Senator BROOKE. You did not discuss it.

Dr. SEAMANS. Never; we had not in my mind, reached that serious a situation.

Senator BROOKE. Apparently there had been a sufficient number of problems for you to consider appointment of a task force to study problems involved in North American. It must have been of a very serious nature to warrant the appointment of such a task force under General Phillips, was it not?

Dr. SEAMANS. I would like to say that this is not the only task force of this type, that we have used in the program. We have reviewed other activities. This was not incidentally—this was a matter that Dr. Mueller and General Phillips instigated. It was not something that I demanded they do. This was something they felt appropriate to the occasion. They can discuss this further with you if you like.

Senator BROOKE. Who had the authority to cancel the contract with North American? Who does have this authority?

Dr. SEAMANS. Well, this is such a serious matter that it would never be done without very careful review and very full consideration by the Administrator, and so I would say that Mr. Webb has this authority.

Senator BROOKE. Ultimately, the authority is vested in Mr. Webb and you make recommendations; is that about the size of it?

Dr. SEAMANS. That is correct.

Senator BROOKE. With Dr. Mueller and General Phillips and others?

Dr. SEAMANS. Neither General Phillips nor Dr. Mueller nor I would have the prerogative to make a change of this magnitude on our own responsibility.

Senator BROOKE. What was the date of your report, General Phillips?

OUTLINES PHILLIPS REPORT IN DETAIL

General PHILLIPS. Senator Brooke, there has been a fair amount of discussion as I am well aware of this so-called report. I would like to be sure we understand what we are talking about.

The CHAIRMAN. Speak louder, will you?

General PHILLIPS. Yes, sir. The task force which I had with me out at North American in the late fall of 1965 made a verbal report to Dr. Mueller and Mr. Atwood and their respective staffs on the 19th of December. Now, this was a verbal briefing and in that sense was a verbal report of the work that I had done and the recommendations that I was making.

Now, in the course of our work with North American in the fall of 1965, the company was quite cooperative, which is one of the important elements of a good program team organization, and in the course of our work we made considerable notes and were, in fact, working in the direction of being able to put together or compile these notes into report form. In other words, into a formal document kind of report.

It did not seem to me to be worth the effort to go ahead and finalize as a formal documented report that effort. In other words, it is a fair amount of paperwork and the main value was accomplished by the work—working together with the contractor, by the verbal discussion of the conclusions and recommendations, so it was my judgment that the value of the paper was mainly to turn it over to the company as a set of notes. I did so on the 19th of December, handed it to Mr. Atwood under cover of a letter that I signed to him, dated the 19th of December.

Now, I called that collection of paper which originally had been headed to become a report the notes of my survey team. Now, that is the set of facts, then, that tries to put the word "report" in the proper context.

Senator BROOKE. That is the only report that you rendered on this subject?

General PHILLIPS. It was not. My final recommendation on that 19th of December was that the company respond in the early spring with the actions they had taken on the points that I had made. I and my team spent a fair amount of time with North American up into the spring working with them and they with us to help solve the problems, to enable better program progress. In the middle part of April of 1966 my team reassembled and spent almost a week going back over the same ground that we had been over in the late fall.

On the 22d of April 1966 I again gave a verbal report to Dr. Mueller and to Mr. Atwood and their respective staffs, and this, too, then, was a verbal report.

Senator BROOKE. And, was that the final report you made? Relative to North American?

General PHILLIPS. The final recommendation I made on that occasion was that the progress that had been made on the problems I had identified was proper. The company had been cooperative and responsive. The progress that had been made was such as to give me reasonable confidence that we were on the way to having the problems that I had identified earlier solved properly. So, I recommended that that phase of our activity be terminated and that the normal set of the contract relationships carry on from there. That recommendation was accepted and that terminated that phase of survey activity.

Senator BROOKE. Do you have a copy of the notes that you submitted to Mr. Atwood on December 19, 1965, and a copy of the notes you submitted on April 26, 1966, which constituted your report?

General PHILLIPS. Copies of the briefing charts that I used on both occasions and a copy of the letter that I gave to Mr. Atwood and the notes that were appended are in my file.

Senator BROOKE. And the nature of your findings and recommendations.

PHILLIPS FINDINGS SUPPLIED TO REVIEW BOARD

Dr. MUELLER. May I add while General Phillips is looking at that, that these notes, the reports thereof, were supplied to the Board, Review Board for the 204 accident and were reviewed by that Board with respect to whatever findings they might have led to both with respect to the accident and any other phase of the operation.

Senator BROOKE. Are you satisfied, Dr. Mueller, then, that none of the findings by General Phillips and his task force were such that they could have been the cause of this accident at all?

Dr. MUELLER. We have carefully reviewed the findings and to the depth that we have gone, it is clear that the Phillips report or notes or what have you, the reports I heard, did not have an effect on the accident, did not lead to the accident and were not related to the accident.

Senator BROOKE. Could I have the nature of that, General Phillips, if you have found them?

DETAILS OF PHILLIPS REVIEW

General PHILLIPS. Senator Brooke, I and the task force that worked with North American during the period I have indicated, looked into the following areas. First of all, the overall program management, involving the corporate officers and the management of the Space and Information Division of North American, and of their project management within S. & I.D. I know you are aware that that division has two major contracts in the Apollo program, one, for the Apollo Command Service Module and one for the S–II stage which is the second stage of the Saturn V and those two contracts are with the Manned Spacecraft Center at Houston and the Marshall Spacecraft Center respectively.

Now, in the functional areas that are involved in doing the program, we went into program control, engineering, manufacturing, contracting, and quality control.

Now, to summarize the essence, if you will, of the recommendations that I made, I felt that the top management of both the corporation and the division were not giving sufficient attention to the details of the direction and execution of these contracts and recommended more attention from that level of management to the details of their problems and progress. I felt that the authority of the two program managers in that division was really too diffuse to enable them to harness all the resources they had to bring to bear to get our job done and recommended that they strengthen the project organization and pull parts of the functional organization together under the more direct authority of the program managers, respective program managers.

In the functional area of planning and control which to me is one of the essential fundamentals in accomplishing a program, that is where the details of the planning, the details of the costing, are made and the basis on which a great deal of the contractor's efforts are really organized. I felt here that they had not gone nearly far enough to make a work structure breakdown or what we have come more recently to call work packages clearly defined so that there were clearly stated jobs to be done which could be clearly assigned in the appropriate places in the organization.

I felt that they were not doing enough in integrating the total program planning. There were planning groups in several places but I was critical of the manner in which they were bringing all the planning together so that the total job could be properly understood and directed and I was critical also of what I call the visibility that program management had and their ability to understand the details of the progress and be able then to focus energy and resources to solve the problems.

Now, with respect to engineering, I was critical of the ability of the engineering organization as had been demonstrated in the months preceding my visit to meet their engineering release schedules. I was critical of the fact that our block II design which has been referred to here today, was falling behind schedule and I felt there was no reason why it should be behind schedule if it was properly addressed by the management of the engineering organization.

We were having fairly serious technical problems with the S–II, the S–II stage, which have been since overcome. These were—a couple of examples are the insulation which at that time was a considerable problem in engineering, and there were problems also with the structure which have since been overcome.

I was critical of the changed control that was being exercised and made recommendations for tighter control of engineering changes. We were critical of their test operations with respect to the timely development of the procedures which tell the test engineers the steps to go through.

With respect to manufacturing, I concluded that part of their problem in manufacturing had its origins in the engineering department and I think that is fairly obvious. The late design releases give manufacturing a problem. I was critical of the way in which manufacturing was divided between the program organization and the central manufacturing activities and recommended some organizational changes which the company did respond to and make. We were critical of the behind schedule position of some of the components and subsystems and of the practices that were being followed in managing certain subcontracts and in expediting some of the materials, and here, too, as in all the cases I have been enumerating, the company worked very closely with me and my team and were very cooperative and responsive to these recommendations in the main.

I was critical in manufacturing of what I considered the effectiveness of supervision. The equipment that we get, of course, is the result of work of individual humans and the skill with which they do their work is where good products start. And, if the skills are not all that one wants, then in being terms of numbers of people that have to do this work, then the importance of supervision is greater.

And finally, in regard to manufacturing, I was critical of the efficiency of the work force. In other words, the work per man-hour, if you will.

With respect to contracting, we were critical and made recommendations with respect to the timely submission of contract proposals, contract proposals on which negotiations could be carried out between our contract negotiators and the company.

I was critical also of the protracted negotiations that had become more or less the way of business between our respective contracting organizations and recommended that actions be taken to improve our ability together to negotiate contracts and changes to contracts in a more timely fashion.

With respect to quality control, I made recommendations that trend data be used more effectively by management to identify whether the quality of workmanship was as good as it should be. I was critical that our Government inspectors were finding what I considered to be too many discrepancies over and above those that the company inspectors identified.

I felt that the quality control organization was not being fully effective in carrying out their inspection function and in identifying discrepancies.

Finally, with respect to overall management, it was my conclusion that the division could do a better job of both managing and carrying out both of these large programs with less total people being charged against these contracts that were then being used, and recommended that if efficiencies in the several areas that I discussed were introduced, that the manpower could drop down somewhat, and I think the later events showed that to be correct.

Now, that is a summary of the high points, if you will, of the recommendations. I would like to repeat that the company was cooperative with me and my task force in the entire period. It was to our mutual advantage to identify problems that were hindering our ability together to get the equipment properly designed, properly built, tested, and ready to operate. They were completely responsive to the recommendations that I made. And in the main I had a reasonably good confidence in the spring of 1966 that the implementation of the recommendations in all these areas was proper and that the program was in tremendously better shape at that point in time than it had been several months earlier.

Now, I would like to comment that there has been discussion of the—let me stop there because I am taking more time perhaps than I should.

SURVEY PLACES APPROVAL ON PROGRESS OUTLOOK

Senator Brooke. Well, in view of the seriousness of your findings and your criticisms, General Phillips, why did you not recommend to Dr. Seamans and to Mr. Webb that North American be replaced by a new contractor?

General Phillips. Well, Senator Brooke, the fundamental reason is that the progress in overcoming these problems I judged to be entirely satisfactory in the intervening period.

Senator Brooke. I am speaking of December 1965. Did you feel they could be overcome?

General Phillips. Yes.

Senator Brooke. And in April of 1966 you felt that in the main, to use your language, they had been overcome?

General PHILLIPS. Had either been overcome or the outlook for progress was entirely satisfactory.

Senator BROOKE. And was that the most recent supervision or investigation that you made or your task force made with this company?

General PHILLIPS. It was the last of the so-called task force visits, Senator BROOKE. I have visited North American myself as all others, most of the other contractors, fairly frequently since that time.

Senator BROOKE. But I understand from what Dr. Mueller said that this was almost a continuing sort of thing, that you had many task forces and that you kept pretty much abreast of what the contractor was doing all the time. Am I wrong in that?

Dr. MUELLER. Senator Brooke, may I explain that we do conduct management surveys of all of our prime contractors on a periodic basis. Not very often, however, does General Phillips himself create a task force for doing it. General Phillips and I do periodically visit contractors. Generally our visits are to the contractors who are having more problems than other contractors but I have managed to visit every prime contractor on the program something like once a year and in many cases much more frequently.

Now, a major management survey, however, has been conducted of the sort that General Phillips has described and is one that really cuts across several centers' responsibilities, and since we have defined the responsibilities of the center level, we normally have the management surveys made by center-level people and they report to General Phillips and myself as to the results of that survey.

Senator BROOKE. And NASA was satisfied with the work of North American as of April 1966, is that correct?

Dr. MUELLER. I would say that we were satisfied with the work of North American as we were with the average contractor we have. In other words, they weren't better than or worse as a prospect.

Senator BROOKE. Are we looking for no better than or no worse than? Is that our standard measurement?

Dr. MUELLER. Senator Brooke, I have a great faith and great admiration for American industry. My feeling is when I say that is average, that is an outstanding compliment to our industrial system.

QUESTIONS ON CHANGES IN BLOCKS I AND II SPACECRAFTS

Senator BROOKE. Your "C" is comparable to an "A," is that correct? Two brief questions, if I may.

Dr. Seamans, you said the Block II spacecraft was initiated several years ago to incorporate features required for lunar rendezvous and docking and also to permit design changes felt to be necessary as a result of their Block I experience.

Now, why were not these features included or incorporated in Block I? Was it too late to incorporate the improved features that you found in Block II into Block I?

Dr. SEAMANS. Let me say a word and then I would like Dr. Mueller to discuss that a little further. We were far enough along with the Block I that it would have been difficult to make, for example, major changes in cable runs or anything of this sort because it would have meant tearing capsules apart and rebuilding them, when starting with a new set of spacecraft which we call a new block, you can introduce, if you will, into this new block all the experience that we gained by virtue of the work we had done on the first block. That is the intent of the sentence as I wrote it.

Dr. MUELLER. I would like to say a word about it and that is that we do have a practice and a concept that if we make changes, major changes in any of our modules, that we do that on a block basis. If we do not do this, then we would find ourselves with every spacecraft being different from the next one.

We have made a very strong effort to create a situation where we did, in fact, build spacecraft to a common design and common basis. Now, there were changes necessary in going from Block I spacecraft to Block II. These were principally in the area of implementing our ability to carry out the lunar orbit rendezvous mode of operation. We felt that the design of the spacecraft was safe and was capable of carrying out the mission that we had assigned to it. But we did not feel that we would improve either the safety or the probability of the mission success by retrofitting those changes that we had put into Block II.

Senator BROOKE. But if you do discover new changes that could improve a program you have already in operation, you certainly are flexible enough to incorporate those new changes, certainly safety changes, aren't you?

Dr. SEAMANS. That obviously depends on the need for the change and the extent of the change, and if it truly involved the safety of the crew, then the change would be made, regardless of the extent of the cost or the schedule. Very often there are situations that arise where the people involved see that an improvement could be made that would give us greater performance in some area.

They would like to make the change, but General Phillips has to hold the line and not permit everybody on a permissive basis to do everything they want. But at the time you make a block change, all these matters can be considered.

Senator BROOKE. I was just going along with you following you in your statement, that paragraph.

"We will improve accessibility of the spacecraft. We will change current nonmetallic materials. We will revise and improve the design fabrication. We will establish different criteria of the," and so forth.

I couldn't help but wonder why you didn't do some of these things.

Dr. SEAMANS. Well, I think, Senator Brooke, we have discussed most of the items. As Dr. Mueller has indicated, we in NASA did not appreciate the fire hazard. There was a great desire to have the Velcro and other materials in there to assist the crew. And so this material was used and it was used in such a way that there were no fire breaks between the various patches.

We now know obviously from our experience that this was a mistake. We made a mistake in this regard and we will not use, no matter how much anyone insists, this kind of a spacecraft interior in the future.

CHANGES RECOMMENDED BY ASTRONAUTS

Senator BROOKE. One final question, Dr. Seamans. Forgive me, Senator.

Did you ever have any report of any changes recommended by the astronauts themselves which were not acted upon by NASA for improvement of the spacecraft?

Dr. SEAMANS. I myself did not but I would have to refer it to Dr. Mueller and General Phillips.

Dr. MUELLER. There are two classes of changes that the astronauts recommend. One class is those related to safety. I know of no recommendation——

Senator BROOKE. I am primarily interested in safety.

Dr. MUELLER. That was associated with flight safety that was ever turned down.

Senator BROOKE. Do you have a record of recommendations that the astronauts themselves made pertaining to safety of the spacecraft?

Dr. MUELLER. Yes, I am sure we do because their changes are handled in the same fashion as all other changes. They go through our change control board and are acted on there. So we can provide you with a record of those changes that the astronauts or the flight crew division have recommended.

Senator BROOKE. And you are sure that none of those recommended changes were ever rejected by NASA.

Dr. MUELLER. I am certain of that. I have talked to the astronauts themselves and they will agree, do agree.

(The information supplied for the record follows:)

The following is a statement made by Astronaut Donald K. Slayton on the subject of Flight Crew Interface with MSF Organization:

"I understand there has been some interest in how the flight crew interfaces with the rest of the organization in terms of inputs and developments and design of the spacecraft, checkout, et cetera. I thought I might run through this very briefly so everyone understands this basic concept.

As you are probably aware of, we have had astronauts assigned to follow specific spacecraft subsystems throughout the program, starting with Mercury, on into Gemini and Apollo. In addition to that, we have a crew of support engineers assigned that work directly with the flight crew in terms of crew station layout, checklist, flight plans and this sort of thing. They are essentially the right hand in the flight crew in these areas.

Then, of course, the assigned flight crews as they are assigned to missions work directly with the program office, the people checking out the spacecraft, from the time that they are assigned on to flight date. I think we were all involved in the basic Apollo concept at the time it was decided to go the lunar orbit rendezvous mode versus earth orbit. We were involved in the hardware. We have been involved in the specifications review, the design reviews that have followed this and we have what we call Delta CDR's, which are critical design reviews, at the various phases as the program progresses. We have had membership on these boards and our people have participated in these reviews. We have mock-ups that supplement these reviews. We have a CARR which is a Customer Acceptance Readiness Review.

In the case of spacecraft 12 I was a member of that board. Wally and the 12 crew were part of the review on that spacecraft. We had a design certification review on the spacecraft which again I was present at along with a couple of our other people. We did not reach the Flight Readiness Review which is the final review to establish flight readiness for the spacecraft.

In round numbers the flight crew has been involved in all stages of Apollo design, development and operation from day number one. We have a procedure to implement changes which is through a subsystem management assigned through our flight crew support division. Any changes that the crew wishes to get into the spacecraft goes through the subsystem management.

I reviewed our records for the past year and we recommended 45 changes to spacecraft 12, 39 were implemented, which is about 89 percent, the additional six were implemented at a later date for later spacecraft not for that specific spacecraft. Most of these were of a relatively minor nature.

Our channel of appeal, of course, if the crew is unable to get changes is a letter prepared for my signature to go to the Apollo program management and we normally resolve it at that level. If the crew can't get it in at that level, we have Dr. Gilruth's office, which is open at all times, and we are able to make requests for changes at this point. We have never gone through that channel. We have always resolved our differences at the director level or the program manager level.

I think that is about all I have to say. If there was any interest in some of the changes that the crew have been involved in, we can tell you about them from the time we came into the Mercury program. Al Shepard flew with little portholes. We requested the picture window which is somewhat of an exaggeration, but it was somewhat better than what we had. This was implemented. I think we can safely say there has never been a crew request for anything remotely resembling crew safety that has not been implemented.—" . . ."

TOTAL COST OF APOLLO SPACECRAFT

The CHAIRMAN. I think some figures might well be put in the record, Senator Brooke. You have raised some good questions.

What is the total cost of the contract for the Apollo spacecraft with North American Space and Information Systems Division? How much? \$2½ billion?

Dr. MUELLER. It is about that much, Senator.

The CHAIRMAN. \$2.2 billion.

Dr. MUELLER. I don't happen to have the numbers.

The CHAIRMAN. Will you supply that for the record?

Dr. MUELLER. Yes, sir.

(The information supplied for the record follows:)

As of March 31, 1967, the funding of NASA Contract NAS 9-150 with North American Aviation for the Command and Service Modules, the Lunar Module Adapter and support services related to the Command and Service Modules totaled \$2.456 billion. The present contract is in the process of being extended through completion of the Apollo program.

The CHAIRMAN. What is the total cost of all of the contracts on the Apollo program with North American Aviation?

Dr. MUELLER. Roughly a third of our total contract in the Apollo program. It is roughly, then, about \$5 billion or \$6 billion.

OUTLINES PROCEDURE FOR CHANGING CONTRACTORS

The CHAIRMAN. Dr. Seamans, what is involved in changing contractors on a program of this size?

Dr. SEAMANS. Changing contractors is a tremendous undertaking because the organization involved, let's say North American, is complex. It involves taking into account both the spacecraft and the S-II stage: I guess the order of 20,000 people, with maybe half this number on the spacecraft. They in turn, North American, have many, many subcontracts and suppliers. A change of contractor would involve changing every one of these contracts, and would very severely change the schedule and our ability to move ahead on the program.

APOLLO CONTRACT REPRESENTS 25 PERCENT OF NASA BUDGET

The CHAIRMAN. What kind of a contract does the National Aeronautics and Space Agency have with North American Aviation Space Division for the development of the Apollo spacecraft? Wasn't there a change to an incentive fee arrangement from a cost-plus-fixed-fee-type?

Dr. SEAMANS. We had originally a cost plus fixed fee for the main part of the program on the spacecraft. We then went to a cost-plus-incentive fee.

I would like General Phillips, if you might permit him, to discuss this in more detail.

General PHILLIPS. The incentive contract was effective in October of 1965.

The CHAIRMAN. Was effective at that time.

Has NASA ever evaluated North American Aviation which has three major parts of the Apollo program—the spacecraft, the S–II stage and the F–1 and J–2 engines—to determine if that company may have stretched its technical and managerial capability too far?

Dr. SEAMANS. I believe that on each one of these procurement decisions, we were going to the best designer and manufacturer that was available in this country. Each one of these decisions was made on the basis of a competitive negotiation.

The CHAIRMAN. But you have three big pieces of the program in there, haven't you?

Dr. SEAMANS. There is no question but that North American has a very large proportion of the NASA program. In total they represent about 25 percent of the total of the NASA budget.

The CHAIRMAN. Senator Holland.

DISCUSSION ON FLAMMABLE MATERIALS

Senator HOLLAND. Thank you, Mr. Chairman.

I shall confine my questions entirely to the matter of flammable material in the cabin because it seems to me that has become a principal field for the future and it may be the principal field for examination of what happened at Cape Kennedy.

I ask first, Mr. Chairman, that there be included in the record the part of the statement of Dr. Mueller at a former hearing contained on page 86 of that hearing, that is, the February 27 hearing, beginning at the middle of the page and going down to the heading "Selection of Materials."

The CHAIRMAN. Without objection that will be done.

(The information follows:)

With regard to the materials used and contained in the spacecraft cabin, I would like to remind you why we attach so much significance to materials selection and control. We discussed this with you at the hearings on February 7, 1967; but to summarize, the argument goes like this:

For fire to exist there must be an atmosphere containing sufficient oxygen to support combustion; there must be a source of ignition; and there must be combustible materials available to be ignited. As far as the atmosphere is concerned, an atmosphere which will support life will also support combustion. Therefore, the first answer to the fire-hazard problem must be fire prevention in terms of strict control of both potential ignition sources and combustible materials.

The fact is now clear that we will not be able to eliminate completely ignition sources in the cabin. We will continue to take every precaution to minimize possible ignition sources, but we cannot expect perfection. This means that the remaining technique of fire prevention—materials selection and the control of the geometry of their use—demands our utmost in care and attention.

Senator HOLLAND. And I note two very important statements, at least they seem such to me, in that statement. The first is this. Dr. Mueller says:

The fact is now clear that we will not be able to eliminate completely ignition sources in the cabin.

Is that still your opinion?

Dr. MUELLER. Yes, sir

Senator HOLLAND [reading].

We will continue to take every precaution to minimize possible ignition sources, but we cannot expect perfection.

Now, those two sentences taken together mean that although you are going to do everything possible to eliminate sparks, ignition sources, you realize that you cannot completely eliminate them.

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Then you finish with this statement:

This means that the remaining technique of fire prevention—materials selection and the control of the geometry of their use—demands our utmost in care and attention.

Dr. MUELLER. Yes, sir.

Senator HOLLAND. You are still of that feeling?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. That the real task in explaining this terrible tragedy and also in making sure that the possibilities for the future are made sounder lies in that field.

Dr. MUELLER. Yes, sir.

Senator HOLLAND. All right.

Now, Mr. Chairman, I ask that the statements from that same record beginning at page 120 with the heading "Selection of Materials" and continuing to page 123 to the heading of "Materials Approved by the Board" also be included in the hearing record.

The CHAIRMAN. Without objection, that will be done.

(The information follows:)

SELECTION OF MATERIALS

Senator HOLLAND. Thank you, sir. I am particularly interested in page 86 of your statement, Dr. Mueller. To summarize it, you say that you wish to tell us why you attach such great significance to material selection and control inside the capsule. Then you remind us that there must be three things to make a fire, and that is sufficient oxygen, a source of ignition, and combustible materials.

And you say that as to the oxygen content, oxygen sufficient to support life is combustible, so you know in advance that you can't eliminate that factor. And as to a source of ignition, you know that there are going to be many chances for a spark or some other source of ignition, and that you can't eliminate that.

So you attempt to control it as close and carefully as you can. For that reason you seem to regard—and that is what I wanted to ask you—the selection or development and the geometric use and placement of materials that are either noncombustible or relatively noncombustible as your chief field of improvement.

Am I correct in that conclusion?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. I am correct.

All right. Now then, the next question is this: Who is charged under the organization and structure of NASA with the control of this field? The selection, the development, and the placement of materials within the cabin?

Dr. MUELLER. Senator Holland, I would like to answer that but first I would like to amplify just a little bit my previous answer. I think it is important to recognize that the philosophy with respect to the prevention of fires was developed as the result of our experience in the Mercury program where we made a conscious decision to go to a single-gas atmosphere.

At that time we made also a conscious decision that the way to prevent fires was to prevent ignition, prevent having them in the first place. So our total approach to the problem prior to this 204 accident has been one of minimizing the chance of having ignition of a fire and, in fact, that was the basic philosophy upon which the design, the specification and the development of materials, and selection of materials, and their use, was based.

Now, we did spend a great deal of trouble and effort in being sure the materials we used were not either self-flammable or flammable in the normal sense of things. And, for example, you found no cotton in the spacecraft itself which would not pass our flammability—material would not pass our flammability test.

With respect to the responsibility for the selection of the materials, there is a materials review board which is a part of our Manned Spacecraft Center, with responsibilities for the spacecraft. We have a similar materials review in our launch vehicle center, and again, we are equally concerned there with the selection and use of materials. And the overall standards are established by our people in the program office here in Washington.

Now, these standards in turn are reviewed by our safety office, so that there is a check and balance there. We do have offices for flight safety at Houston. We also have an office for safety here in Washington. So that the practices we are using are audited from time to time by our safety organizations.

RESPONSIBILITY FOR SELECTING MATERIALS

Senator HOLLAND. I am not finding fault with your approach to the matter at all, Doctor. In fact, I think it is a necessary approach. What I am trying to find out for this record, and to have the record show clearly, is just where in your organization is the responsibility, the ultimate responsibility, in the selection or the development of materials, or is that responsibility divided? If so, between whom?

And then in the placement of materials, so as to have materials that are even slightly flammable located so that the chance of their being ignited is reduced to the minimum.

Now, where is the responsible unit in your table of organization?

Dr. MUELLER. The program office, in particular for the spacecraft, it is the Apollo spacecraft program office which is responsible for the selection and location of materials.

Senator HOLLAND. Is there any responsibility vested in the contractor in this regard?

Dr. MUELLER. Insofar as he is responsible to the program office, yes, and there is a responsible program director in the contractor organization who is responsible for the total design, operation of the spacecraft.

Senator HOLLAND. Do we have a table of organization——

Dr. MUELLER. Yes, sir.

Senator HOLLAND (continuing). Of NASA, which can be found in the record at this time?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Does that table of organization show clearly where the responsibility is vested and, if vested in more than one place, how it is divided? I am talking about the selection or development or placement of materials within the cabin, which seems to be the most critical field of all in fire prevention.

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Does that—does your organizational plat show just where that authority is?

Dr. MUELLER. The authority is clearly established.

Mr. WEBB. Senator, our organization charts do not contain the entire protocol for materials selection and testing, but our total management system does, and there is in each case a single point of decision.

Now, where you get to a combination of a number of components and a number of subsystems into a system, there is a careful review board in each instance that meets with a very careful procedure laid out to examine every facet of the problem, and make a considered recommendation. That recommendation goes, in this case, to the program office. The Apollo manager is Gen. Samuel Phillips, and he will sign the final paper that says this is a satisfactory arrangement.

Senator HOLLAND. I realize that you have got a very complex structure necessarily. I wonder if it would be possible for you to, by a little thought, give us a written statement covering this question——

Mr. WEBB. Yes sir.

Senator HOLLAND (continuing). Which I think is going to prove to be one of the important questions in this whole matter, just where the responsibility is, and we are not thinking in terms of the past. We are looking ahead.

Mr. WEBB. We will be glad to do that.

Senator HOLLAND. And will you do that, and supply it for the record?

Mr. WEBB. Yes, sir; we will.

(The material referred to follows:)

"The Apollo Program Office in Washington has five subordinate program offices in the field: three program offices at Huntsville for the launch vehicles and large engines, one at Houston for the spacecraft, and one at Cape Kennedy for launch activities. The Apollo Program Director is responsible for the over-all management of the program; specifically, he is charged with development, test, and production of the spacecraft, launch vehicles and launch checkout equipment that are required to meet the Apollo objectives. The Program Managers at the manned space flight centers, under direction and through delegations, are responsible for carrying out assigned portions of the total program.

"The Apollo Program Director establishes the over-all technical requirements and plans. Many control mechanisms are used. For instance, regarding materials, the Apollo Program Specification establishes over-all requirements for the spacecraft and launch vehicle. The Apollo Configuration Management Manual requires adherence to procedures concerning specifications and changes thereto. The Apollo Test Requirements document sets forth the qualification testing standards to meet specification requirements. Materials standards are delineated in the NASA Quality Publication. The Apollo Reliability and Quality Assurance Program Plan requires appropriate organizational levels to review and approve critical parts and materials. These documents set the management framework and establish operating responsibilities.

"In the case of materials, the problems at the two development centers are different. At MSFC, for the launch vehicle, the Program Office utilizes the Materials Branch of the Propulsion and Vehicle Engineering Laboratory for technical assistance in the area of materials. At MSC, a material review board reports directly to the Apollo Spacecraft Program Office's Reliability, Quality and Test Division. Initially, the board (officially called "Apollo Waiver Board—Materials (Non-Metallic)") was concerned with developing specifications and lists of materials approved for spacecraft use. These specifications and lists were based on a variety of tests and on Mercury and Gemini experience. These specifications and approved lists then were incorporated as program requirements. The board continues to update this documentation and rule on requested exceptions to the established criteria.

"An example of exceptions is the inclusion of Velcro in the spacecraft. This material was used extensively in Gemini because of the limited space and its suitability for securing objects in a zero-g environment. The board had Velcro tested in a 5 psia oxygen environment and noted there were conditions where its burning rate exceeded the one-half-inch per second criterion. Therefore, in the acceptable materials list, it is carried as acceptable provided it is no nearer than twelve inches to potential ignition sources. Compliance with this standard was specifically required in the case of spacecraft 012."

Senator HOLLAND. Thank you very much, Mr. Chairman.

Now, Dr. Mueller, I note in your statement here one sentence that seems to me to indicate that this decision to rely principally upon the check of flammability of materials to be used within the space capsule was a decision reached recently because I note you make this statement:

> I think it is important to recognize that the philosophy with respect to the prevention of fires was developed as the result of our experience in the Mercury program where we made a conscious decision to go to a single-gas atmosphere.
>
> At that time we made also a conscious decision that the way to prevent fires was to prevent ignition, prevent having them in the first place.

And then this next sentence which I think is the most important:

> So our total approach to the problem prior to this 204 accident has been one of minimizing the chance of having ignition of a fire and, in fact, that was the

basic philosophy upon which the design, the specification and the development of materials, and selection of materials, and their use, was based.

At what stage did you cease to rely upon that total approach that was the minimizing of the chance of ignition and come to the decision that the principal thing was to control the flammability of the materials and the arrangement of the materials within the space capsule? When did you reach that decision?

Dr. MUELLER. As a result of the experience of the 204 fire and as a consequence of the development of the capability to test flame propagation in full-scale boilerplates, we came to that decision. Shortly before our last meeting, Senator Holland.

Senator HOLLAND. Then, as a matter of fact, one great change in policy has already been made as the result of the 204 tragedy and that is that you are ceasing to rely upon ability to prevent ignition and looking instead to your principal source of control, coupled with doing everything you can to control ignition, principal source of control will be the specification and development of materials and selection of materials and their use in the space capsule?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. All right. Now, I want to call attention in closing to the memorandum filed in the record of the early hearing by Mr. Webb, and I assume it was prepared by yourself, wasn't it, Dr. Mueller? Or by whom was it prepared?

Dr. MUELLER. I would have to know——

Senator HOLLAND. Having to do with the question of the chain of responsibility in approving the materials to be used as to their flammability and also as to the geometric placement within the space capsule.

Dr. MUELLER. That was prepared by my organization.

Senator HOLLAND. You prepared the memorandum?

Dr. MUELLER. Yes.

Senator HOLLAND. I have read that memorandum several times and very carefully and I don't think it makes a clear case of where the real responsibility is.

Now, can you say anything at this time that will make it clearer than that memorandum does as to who has the ultimate responsibility in this field of selection of materials from the standpoint of getting the least flammable that you can that will fulfill the necessary purposes, and from the standpoint of geometric placement of these materials in the space capsule? Who has the ultimate responsibility?

Dr. MUELLER. The development of specifications for the location and the selection of materials is, as I said earlier, a joint responsibility which is developed using our best engineer talents to develop those specifications.

Now, the selection of the materials to meet those specifications is a responsibility of the Crew Systems Division, which is a division of the Engineering and Development Directorate of the Manned Spacecraft Center.

Senator HOLLAND. Well, now, Dr. Mueller, I hope that you will reexamine this statement to which I have referred and which has been placed in the record now and the statement which you have just made because I think it can be made much clearer than both of those statements do make it as to what is the chain of command and where the ultimate responsibility lies, and I am not trying to fix the responsibility for something in the past. I am trying to fix responsibility for the development that lies ahead of us because it seems to me that everything you have said and everything Dr. Seamans has said today makes very clear that this question of the flammability of materials used in the space capsule has become the principal question, not only in the review but in the planning for the future. Are you in accord with that?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. Well, I ask that you do review again this statement and add to it anything that you think will clarify it because I have not been able by reading several times to make it clear to myself where the real responsibility lies. And the succession of responsibility is an important matter as we move ahead.

Now, one more question.

Referring to the second of the five general decisions of which you speak in your prepared statement, Dr. Seamans, you don't number them but it is the second of five:

> We will change current nonmetallic materials to reduce flammability.

We understand that that is part of the program, but has there been any change in the chain of command, the fixation of responsibility, from the time when you admit there is a change in objective because you have stated that from the time when you decided that you couldn't rely again on the decision that the way to prevent fires was to prevent ignition, so that "our total approach to the problem prior to this 204 accident has been one of minimizing the chance of having ignition of a fire." Have you made any change in fixation of responsibility following that change in your objectives by which you have made this question of flammability of materials the principal field which you are examining?

Dr. SEAMANS. I would like to say that it is a principal field. I listed other items in my statement that I feel are also principal and important items. However, I think you are correct, that this is a matter that we did not fully appreciate. We were wrong in the criteria that we were using. The Crew Systems Division which is responsible for the specific materials is working on criteria that is supplied to them. I don't believe that it is necessary to make an organizational change. It is necessary to change these criteria, and Dr. Mueller can discuss with you the specific actions that he will take to put this into effect. However, I can assure you that we will not have in any future spacecraft the same inner lining of flammable material in the capsule that we had in 012.

Senator HOLLAND. Well, I have correctly and exactly quoted the statement of Dr. Mueller in his former appearance and as I understand those statements they are very clear to the effect that this field, the field of control of the materials, putting in less flammable materials and putting them in places where they will be less vulnerable, has become your principal field of securing additional safety in the space capsule. Dr. Mueller, is that correct or not?

Dr. MUELLER. Yes, sir.

Senator HOLLAND. All right. I thank you.

Thank you, Mr. Chairman.

(The material supplied for the record follows:)

Under the guidelines established by NASA, NAA is responsible for the selection, evaluation and qualification of the materials used in the Apollo spacecraft. The program office issued a document in May of 1966 which established uniform criteria for the selection on non-metallic materials in the crew compartment, MSC-A-D-66-3, "Procedures and Requirements for the Evaluation of Apollo Crew Bay Materials".

To obtain maximum utilization of existing data the program office compiled and published lists of acceptable and unacceptable materials. This list titled MSC-A-D-66-4, "Acceptable and Unacceptable Non-Metallic Materials for Crew Bay Use" was first published in June of 1966 and updated approximately once a month.

NAA incorporated the above documents into their specification MC 999-0058 which established the criteria for control of non-metallic materials in the crew compartment. Contractual implementation of these MSC specifications is currently underway.

The CHAIRMAN. Senator Mondale?

RENEWS REQUEST FOR PHILLIPS NOTES

Senator MONDALE. I may have missed this while I was out. Did anybody ask that you produce a copy of your famous notes?

Dr. SEAMANS. No, sir; they did not, Senator Mondale.

Senator MONDALE. I would like to renew that, if I may. You recall my request last February 27 that we be supplied with a copy.

What is the position as with respect to that request?

Dr. SEAMANS. The position—my position or the position of NASA—I guess they are not necessarily synonomous—is that this review was to be effective, detailed, directed toward difficulties, hard hitting, and this is exactly what General Phillips and his task force did. It was effective because it really got down to the very bedrock of the problems that they saw as they reviewed North American.

However, for a relationship to be effective between Government and contractor, there must be mutual confidence and if on every occasion that there is either a minor or a major review this is going to be exposed in all of its detail, it will soon erode the confidence that is so necessary.

So I cannot sit here as a lawyer—I am not a lawyer—and give you the ramifications of this but I can tell you as one who has been involved in development that the release of this report would seriously impair our ability to prosecute work in the future.

Senator MONDALE. To whom has this report been supplied?

Dr. SEAMANS. I missed that, Senator.

Senator MONDALE. To whom have copies of this report been supplied?

Dr. SEAMANS. I think perhaps General Phillips might answer that or Dr. Mueller.

Dr. MUELLER. It has been supplied to the contractor, to certain individuals within NASA who participated in the report or had need of its knowledge. It has been supplied to the Apollo 204 Review Board for their review to see if it could have had any possible bearing on the accident.

Senator MONDALE. Anyone else?

Dr. MUELLER. Not to my knowledge.

Senator MONDALE. Has the House committee or anyone in the House committee been supplied a copy?

Dr. MUELLER. They have not.

Senator MONDALE. I think the problem here, if I may just make a brief statement, is that the Apollo report, the Board report, was a magnificent document in the engineering field. I think it was one of candor. I think it was a no-holds-barred report. I find it wholly satisfying on the engineering details as related to the accident, but I think the matter that has to concern us in this committee and concern the Congress is the question of whether this was an accident which is just that and could occur with any program of this kind or whether it may indicate deeper problems which ought to be the concern of Congress.

I am not interested in knowing enough about building spacecraft so that I can build one in my backyard, but I do think I have responsibility to know enough about the questions of management, contractor performance, and quality control, so that I can pass judgment on this question of whether there are fundamental issues that need to be dealt with.

I know of no better way of doing this than to be informed of the basic crucial issues confronted in management and NASA and then compare what is known with what was done. That is what bothers me with the question of the Phillips report. I believe this was a fundamental searching analysis of the performance of the contractor and the very problems we should be concerned with. It was followed by the steps which NASA took to seek to correct them. And I think it is the sort of information that we must have to responsibly discharge our duties.

GENERAL PHILLIPS REVIEW HELPFUL

I must say in that regard I think today's review by General Phillips was helpful. I think this is the fullest public explanation of the famous report that has been given thus far. I think it has been helpful and I am encouraged by your conclusion that you are satisfied that the essence of that report has been dealt with and that the present relationship with North American is on a sound responsible basis. But this whole management policy does trouble me. Quality control does trouble me and I just want to be candid about it.

PRAISES REVIEW BOARD WORK

The CHAIRMAN. Any further questions? Dr. Seamans, I believe that your board of review on this accident did an excellent job and that they presented you with an honest and objective report. I think it is remarkable that we have a system—that you have an agency—that can produce a report that is so critical of yourselves. We are very much aware that the Apollo 204 Review Board's job was to look for errors—and they did a good job of that.

The board itself stressed before the committee that they were concerned that their work would be looked upon as an indictment of the entire manned space flight program and a castigation of the many people associated with that program. This they said was not their intent. They emphasized that their report does not present a total picture of the Apollo program, and made note of the fact that they were greatly impressed with the integrity, candor and dedication of the people upon whom the board relied when conducting their investigation. We know that many of those people were NASA and contractor people closely associated with the program and who must assume some of the responsibility. Nevertheless, it appears that none shrank from their duty.

This committee is very much aware that there is much that is good in our manned space flight program. If there wasn't you could not have had two programs like Mercury and Gemini so fraught with risk yet with no loss of life.

It is essential of course that the committee study the accident and ask the "hard" questions—the kind of questions that are on the minds of every American. This we are doing. The committee regards the deficient conditions and practices found by the board as totally unacceptable. We must know what you are going to do to assure to the maximum extent possible that deficiencies do not recur.

Having done all that, I think it is important that having had this tragedy and the investigation of how it was allowed to happen, we now move ahead toward the Apollo goal. The Congress and the people have accepted the value and the importance of achieving the manned lunar landing and have supported the program with the Nation's resources—both in lives and treasure. It is up to you gentlemen to supply the management necessary for the program to achieve its goal.

We will try to close up as soon as we can in the next day or two. I think Mr. Webb will be here to testify.

I, for one, thank you for your patience, your tolerance, and your good nature.

The committee will be adjourned.

(Whereupon, at 5:25 p.m. the committee adjourned subject to the call of the Chair.)

(Questions submitted by the chairman to Dr. Seamans and answers supplied for the record are as follows:)

SPACE PROGRAM CONTRACTOR

Question 1: Dr. Seamans, I asked whether NASA had ever evaluated whether North American may have stretched their technical and managerial capability to cope with these very demanding problems. You answered that NASA selected what you considered to be the best technical team. However, one of General Phillips' critiques of North American was that top management did not spend enough time on the spacecraft program.

Would you amplify your response, considering General Phillips' statement?

Answer: I feel we selected the best technical team that bid and that the design of the spacecraft is a sound one. However, a technical team requires top level management direction. As General Phillips pointed out, he felt more management attention should have been given to the project at North American Aviation. We have had and are continuing discussions with NAA in an effort to strengthen the management.

Question 2: Since the contract with North American is an incentive type contract, do you think that there is a relationship between the type of contract and the cause of the accident?

Answer: The Cost-Plus-Incentive-Fee contract which was in effect with North American prior to the accident was not a contributing cause to the accident since the incentive provisions encouraged high quality standards by payment of increased fee for meeting rigid performance requirements.

Therefore, North American had to checkout carefully each CSM with a series of tests at the factory prior to delivery to NASA with the knowledge that any deficiencies could be extremely costly from the incentive fee standpoint. The incentive contract thus had the effect of placing a financial reward on good quality or a penalty on poor quality where under a Cost-Plus-Fixed-Fee contract only the reputation of the contractor would be at stake.

Question 3: Dr. Seamans, the Apollo program has been described as the largest and most complex program ever undertaken by man. In your judgment how does the complexity of the program bear on this accident?

Answer: The Apollo spacecraft system represents a complexity parallel to that of a commercial jet aircraft, but required to operate in an even more hostile environment and packaged in a much smaller volume. The more complex and tightly packaged a system is, the larger the number of potential failures which must be identified and guarded against by rigor in design, manufacture, and test. The Apollo 204 accident was probably initiated by a spark between a cable and the door of the environmental control unit. Close tolerances were caused by the limited space for ducting, cabling and equipment in this part of the spacecraft.

However, the propagation of the fire was not related to complexity since the given problem was the amount of distribution of combustible material in the cabin.

Question 4: Dr. Seamans, regarding the Board's second determination "The test conditions were extremely hazardous," why, in your judgment did NASA and the contractors fail to recognize such a condition?

Answer: The initial determination of whether or not a procedure contains a hazardous operation is the responsibility of the originator of the procedure, i.e., the systems engineer. This determination is based upon criteria outlined in the basic KSC Safety Manual and in the appropriate Apollo Pre-flight Operations Procedure. This latter document is a joint KSC-Contractor document, directive in nature, and is authenticated by both the contractor and KSC. Propellant loading, ordnance and explosives handling, high powered electromagnetic radiation, ionizing radiation, photographic operations and accoustic levels are some of the hazardous criteria defined in the KSC Safety Manual.

Neither the KSC Safety Manual nor the governing Apollo Pre-flight Operations Procedure classified spacecraft testing with the hatch closed in an oxygen environment as being hazardous. Our lack of a complete appreciation of the nature of a fire in the spacecraft based on the steps taken to control ignition sources and to qualify materials for spacecraft use, together with the experience of Mercury and Gemini, led us to conclude that the possibility of a spacecraft fire was remote.

On the day of the accident, it was planned to conduct a full scale emergency egress training exercise involving the trained emergency egress team. They were not on station at the time of the accident because the test being conducted had not been declared hazardous, although they were to have been there for the emergency egress training exercise.

The extremely rapid rate of propagation of the fire in the spacecraft makes it unlikely that the outcome of the accident would have been different even if the procedure had been declared hazardous and the emergency egress team had been on station. This is indicated by a lack of evidence that the flight crew were able to initiate the first emergency escape procedures, or activating the cabin pressure dump valve.

APOLLO COSTS IN RELATION TO ACCIDENT

Question 5: Dr. Seamans, at our previous meeting Mr. Webb indicated he did not believe increased funds would be required in FY 1968 as a result of the Apollo 204 accident.

What is your current best estimate of fund requirements for the Apollo program in FY 1968?

If there is no impact in FY 1968, do you foresee an increase in the cost of the program in FY 1969 or FY 1970 as a result of the accident? If so, would you discuss this?

Answer: Mr. Webb has indicated that by May 9, 1967, we will be in a position to discuss the impact of the AS-204 accident on the funding and progress of the Apollo program. We are currently analyzing the Board report and the actions we are taking with these questions in mind.

(Questions submitted by the chairman to General Phillips and answers supplied for the record are as follows:)

COMMUNICATIONS SYSTEMS

Question 1: General Phillips, in Finding No. 6 the Board determined that the overall communications system was unsatisfactory.

a. Why were the technical personnel unable to provide a satisfactory communications system?

b. What organizations were responsible for design, building and operation of the communications system?

Answer: (a) It is true that a number of interruptions had been experienced in the communication system during the portion of the Plugs Out Test preceding the accident. However, the only failure encountered was an open microphone in the command pilot's voice circuit.

The tape recordings show that 34 interruptions of conversations occurred. These resulted from the design characteristics of the voice-operated switches used to interconnect the 2-wire intercom system at LCC–34 and MSOB with the 4-wire system interconnecting the sites.

The voice (VHF and USB) communications systems of the spacecraft operated very well until the failure in the command pilot's audio system about an hour before the accident. This transmitted a continuous signal from the spacecraft, which locked up voice operated circuits in the ground system used by the command pilot and prevented its use for communication to the spacecraft.

To resolve this problem, it was decided that ground personnel would use the VHF link for communicating to the spacecraft, thus permitting the test to continue.

Difficulty was also experienced with the Astro communicators (CAST) panel in the LCC–34 because of inadvertent coupling between the voice circuits used by the astronauts.

Overall performance of the communications system was not satisfactory. We have been conducting extensive tests of this system and we are carefully reviewing the findings of the Board to determine how best to modify the system to correct these problems.

(b) The ground portion of the communications system external to the spacecraft was designed by the Directorate of Design Engineering at the Kennedy Space Center, a line organization whose Director reports directly to the Center Director, Dr. Debus. The system was built under contract by the same organization. The communications system is operated and maintained by the Director of Support Operations, who reports directly to the Director of Technical Support.

The Spacecraft Communications system was designed and built under the cognizance of the Engineering and Development Directorate at the Manned Spacecraft Center, a line organization whose Director reports directly to the Center Director, Dr. Gilruth. For this activity personnel with the Engineering and Development Directorate are responsible to the Apollo Spacecraft Program Manager for development of the communications system to given specifications. The spacecraft communications system is operated by the respective Apollo flight crew members.

Question 2: General Phillips, in Finding No. 10 the Board states that deficiencies existed in command module design, workmanship and quality control.

To what basic factor do you attribute these deficiencies in almost every aspect of the electrical system?

Answer: It is important that in reviewing Finding No. 10 of the Board these deficiencies be looked at carefully and placed in context.

There are two systems that are called into question. They are the environmental control system and the wiring of the spacecraft, i.e., the electrical distribution system. To place this in context you will find that there was also a thorough analysis made of the other 88 subsystems that make up the spacecraft. None of these other 88 subsystems were found to have a fault that was either connected with or would be associated with future problems concerning mission success, or the safety of the astronauts. So what we are really addressing are two of a total of 90 subsystems that make up the entire spacecraft.

These deficiencies in design can be traced to criteria which changed in the course of the program. These criteria continued to evolve after the design had been started and in some instances changed after release of design to manufacturing. Some significant examples of changing criteria that resulted in design deficiencies to the electrical system were:

1. As a result of Mercury experience, the environmental-seal concept was introduced which changed the packaging design of the electronic equipment.

2. A thorough analysis of the in-flight maintenance concept, on which the initial design was based, caused us for reasons of flight safety to favor built-in redundancy after design completion on Block I spacecraft.

3. The requirements for in-flight scientific experiments were added after designs were released to manufacture and test.

4. Additional development and operational instrumentation requirements were introduced after the wiring design was released and in manufacture or test.

5. The design of displays and controls was based on requirements established by a flight-crew group. Subsequently, minor changes were made to meet requirements of the assigned flight crew.

We had recognized that there were design deficiencies in the wiring of the Block I spacecraft and we had taken steps in the Block II design to improve the manufacturing process, to improve the cable layout, to improve the ability to build a harness and use it without changes. So these were not unknown deficiencies uncovered by the Board.

As had been stated throughout the review of the AS-204 accident the spacecraft had passed each technical review, shown on the chart, except the Flight Readiness Review which follows the tests that were being conducted at the time the accident occurred.

Throughout, management and engineering had deemed that the deficiencies would not be hazardous for manned flight.

There is a review process established for Apollo which carefully considers the design manufacturing and operational stature of the program throughout each phase. As shown on the attached chart (MA 66-9614A, 12-30-66) these reviews are held at key program phasing points and include technical and management personnel from NASA and the contractors. As an example the Design Certification Review Board is chaired by Dr. Mueller and includes Dr. von Braun, Dr. Gilruth and Dr. Debus as members.

CABIN ATMOSPHERE

Question 3: General Phillips, has NASA completed its study of the cabin atmosphere in the Apollo spacecraft for use during future ground test operations? If so, what is the principal consideration underlying the decision to use this approach?

What cabin atmosphere will be used in the Apollo spacecraft in orbit and what are the underlying considerations for this decision?

What is the status of the 2-gas atmosphere for the Apollo spacecraft which also was being restudied?

Answer: No decision has been made concerning the cabin atmosphere to be used during ground test operations. We are continuing our trade off studies of using air in the cabin while on the pad vs the requirement to depressurize in space. The study is considering utilization of air in the cabin and pure oxygen in the suits for astronaut breathing. There are major considerations involved, one is the danger of nitrogen in the air leaking into and contaminating the suit oxygen circuit. Any significant amount of nitrogen in the suit would nullify the benefits of having pre-breathed pure oxygen and could result, in addition to the hazard of decompression, in crew hypoxia during the launch phase due to the dilution of the oxygen. Another consideration is of an operational nature. Use of air in the cabin prior to launch requires that the crew remain fully suited until the cabin can be completely purged of air (to eliminate nitrogen) and replenish with pure oxygen. This adds a number of operations which the crew must perform at a time when they are already very busy. As I said, they must remain fully suited during this busy schedule. These considerations will require further study and testing.

We still plan to use pure oxygen at 5 psia in the cabin, after orbit has been achieved, because of this systems overall simplicity and reliability, and also it is considered that the physiological advantages outweight the disadvantages. As has been brought out in previous testimony, it is not considered that a 2-gas atmosphere, at the reduced pressure required, really provides sufficient improvement in safety to outweight its other disadvantages.

Question 4: General Phillips, what is the impact of your engineering studies on the lunar module?

Will this module have to be modified as a result of the accident? If so, briefly what are the principal modifications and what are the estimated time and fund requirements to accomplish these modifications?

Answer: The AS-204 fire has caused us to examine the design and test procedures for the Lunar Module (LM) to determine what changes must be made, if any, to assure that adequate fire protection exists for both ground tests and flight operations.

We are presently engaged in a detailed review of the Lunar Module design, covering such areas as materials, the environmental control system, electrical power system, fire detection and extinguishing systems, rapid cabin egress capability, and preflight and flight operational procedures.

Since all studies have not yet been completed, we cannot ascribe an exact time requirement to decide on these modifications. However present estimates are that the Lunar Module modification can be accomplished without further impacting our program schedule.

Funding requirements for the Lunar Module modifications can only be determined after all changes have been identified.

(The following question was submitted by Senator Smith and the answer supplied for the record is:)

Dr. Seamans, how much of the responsibility for this accident do you think lies with the spacecraft contractor?

Answer.

Until we have fully analyzed the report and completed our reviews of our own procedures and of the fundamental government contractor relationships involved, it will be difficult to make an assessment of responsibility. As Mr. Webb stated, in a few weeks, we will complete our analysis and will be in a much better position to assess the impact and the corrective actions to be taken to prevent a reoccurrence.

(The following questions submitted by the committee to Dr. Mueller and answers supplied for the record are as follows:)

SPACECRAFT HATCH DESIGN

Question 1: You spoke about the subsystem managers who report to the Apollo Program manager and, particularly you mentioned the subsystem manager who is responsible for the hatch design. Is this subsystem manager also responsible for selecting the kind of hatch that goes on the spacecraft?

Answer: No, the subsystem manager is not responsible for selecting the kind of hatch that goes on the spacecraft. This decision was made by the Program Manager and concurred in by various other levels of management including the Design Certification Review Board which is made up of the Management Council. The subsystem manager's responsibility is for evaluating the hatch, recommending approval/disapproval and/or changes to the program manager and for assuring that the design meets the requirements of the program.

Question 2: Who decided that 90 seconds was a satisfactory period of time for opening the hatch? (What position in the program?)

Answer: The original design of the Apollo hatch involved a pyrotechnically actuated, rapid opening latching mechanism. Following the inadvertent actuation of the hatch on "Liberty Bell 7" (Mercury spacecraft), the Apollo hatch design was reviewed. A decision was subsequently made by the Apollo Spacecraft Program Manager to change the design to that which was used on spacecraft 012. This decision was supported by the management of the Manned Spacecraft Center.

Question 3: Has a new hatch design been selected? Will this design be incorporated in the first manned Apollo spacecraft to fly? Will any unmanned flight tests of this new hatch design be required.

Answer: A new hatch is being designed for incorporation in the spacecraft and it is presently planned to test the concept for thermal compatibility on S/C 017 and to have the hatch installed in S/C 020 in order to flight test the new design. The new hatch will then be installed on S/C 101 for the first manned flight. S/C 017 and 020 are, of course, unmanned.

Question 4: When will the first flight be made?

Answer: The unmanned flight test of the new hatch is planned late this year.

Question 5: What is the estimated cost of the hatch modification?

Answer: Since the hatch modification design has not been completed we have no estimated cost of the modification.

APOLLO PROGRAM MANAGER

Question 6: Dr. Mueller, in your statement you spoke of the test conductor at the Kennedy Space Center. Who is that? Is that the Apollo program manager or the director of Launch Operations or who?

Answer: The Test Conductor being referred to is the Spacecraft Chief Test Conductor, a member of the test team at the Kennedy Space Center under the direction of Colonel R. Petrone, the Director of Launch Operations, KSC and the Launch Director for the AS-204 test.

The Spacecraft Chief Test Conductor's location in the test team is as follows:

Launch Director

Launch Operations Manager

Space Vehicle Test Supervisor

Spacecraft Chief Test Conductor

FIGURE 97

He is responsible to the Space Vehicle Test Supervisor for the overall conduct of spacecraft operations by the Command Service Module Test Conductor and the Lunar Module Test Conductor (when applicable). This responsibility includes overall surveillance and direction of the CSM and Lunar Module Test Teams (NASA and Contractor personnel) during testing and checkout operations.

Question 7: Dr. Mueller, in your discussion of the management of the Apollo program you referred frequently to the Apollo Program Manager at the Manned Spacecraft Center. What are the respective responsibilities on the Apollo program of the Apollo Program Manager at that Center and of the director of that Center?

Is the Apollo Program Manager at the Manned Spacecraft Center responsible for all aspects of the Apollo program at that Center or just the spacecraft since he is in the spacecraft office?

Would you discuss the same relationships and responsibilities and authorities for the Apollo Program Manager and the Director of the Kennedy Space Center?

Answer: For the Apollo Program at the Manned Spacecraft Center, Houston, Texas:

The AA/MSF has assigned the development of the Apollo Spacecraft and related ground support equipment and support of manned space flight missions to Dr. R. Gilruth, the Director of the Manned Spacecraft Center at Houston, Texas. He is responsible for development, production, checkout and technical integrity of all assigned Apollo hardware and software. His organization manages Spacecraft contractors' activities in each of these functions. He retains this responsibility through all phases of activity, regardless of location of the hardware or software, from inception to program completion. He is also delegated the authority for Apollo flight operations and flight crew operations.

At the Manned Spacecraft Center the Apollo Spacecraft Program Manager, formerly, Dr. Shea, reports directly to the Center Director, Dr. Gilruth, and is responsive to program direction from the Apollo Program Director, General Phillips, under the overall direction of the Program Management Council. He is responsible for the planning, coordination, and direction of all aspects of the Apollo Spacecraft Program. This includes the supervision of industrial contractors within the scope of the contract and the direction and coordination with other elements of MSC or NASA Headquarters which are assigned parts of the program.

The Apollo Spacecraft Manager's responsibilities are generally limited to the management of the Spacecraft program. While he is not directly responsible for other MSC activities, such as Flight Crew Operations and Flight Operations, he does play a key role in the technical and management interfaces between the Spacecraft itself and these other closely related activities. The total management and coordination of all these MSC activities, of course, is the responsibility of Dr. Gilruth, the MSC Director.

The specific duties of the Apollo Spacecraft Program Manager include:

(*a*) Development of the Apollo Spacecraft Program resources and scheduling plans, their integration and development into an overall program development plan and the control of the implementation of this plan.

(*b*) Serving as the primary point of coordination and control of systems design, specification, and development for the Apollo Spacecraft Program.

(*c*) Development or approval of spacecraft subsystems design requirements, the performance of tradeoff studies, the definition and control of all interfaces between spacecraft subsystems and the spacecraft, interfaces between other related program elements, and the development and maintenance of all crew safety requirements.

(*d*) Management of the detailed planning, implementation, and reporting of results for each major flight and integrated systems ground test.

(*f*) Development and standardization of requirements for reliability and quality assurance and the reliability apportionment between various elements of the Apollo spacecraft.

(*g*) Management of contractor and subcontractor reliability and quality control efforts and the coordination of the inspection efforts of cognizant Government inspection organizations.

(*h*) Development of the basic design of the lunar landing mission and the development of criteria for the training of the spacecraft crew for the lunar landing mission.

For the Apollo Program at the Kennedy Space Center, Florida:

The AA/MSF has assigned the responsibility for Apollo Launch Operations, Facilities and Common Ground Support Equipment to Dr. Kurt Debus, the Director, Kennedy Space Center (KSC), Florida. He is responsible for development and construction of facilities to checkout and launch Apollo spacecraft, launch vehicles and launch facilities—for providing support services at Cape Kennedy Air Force Station and Kennedy Space Center, NASA. His organization manages contractor activities as appropriate in each of these functions. He retains this assignment through all phases of activity from inception to program completion.

At the Kennedy Space Center, the Apollo Program Manager, General J. Shinkle, reports directly to the Center Director, Dr. Debus and is responsive to program direction from the Apollo Program Director, General Phillips under the overall direction of the Program Management Council. He functions as the central point for management of all Apollo Program activities for which the KSC is responsible. He is the primary and official point of interface for the Apollo Program functions with other MSF Centers. He maintains a continuous overall surveillance of the stage and spacecraft contractors at KSC but is not accountable for giving all directions to the contractors. All technical instructions to the contractor within the scope of the contract flow through line organizations. His specific duties include:

(*a*) Official interface with other Manned Space Flight Centers and Office of Manned Space Flight.

(*b*) Formulation of subsidiary specification, test and operating plans, mission description, program reliability and QA procedures and operating plans.

(*c*) Translate requirements and schedules received from the Apollo Program Director and forward to line organizations for development into detailed plans.

(*d*) Receive, review, validate and integrate plans for individual operating directorates into KSC Apollo Program plans.

(*e*) At a program commitment level, coordinate, monitor and track the execution of requirements and utilization of funds against approved plans, schedules and resources.

(*f*) Approve the scope and changes in scope in the work of stage and spacecraft contractors.

(*g*) Assure that the scope or change in scope of support contractors are consistent with Apollo Program requirements.

(*h*) Maintain surveillance of stage and spacecraft contractors activities to assure optimum balance in performance, schedules, and cost.

(*i*) Review development plans for KSC designed or furnished equipment and facilities. Assure performance and design criteria is proper and acceptable with all activities involved and are consistent with Apollo Program guidelines and available resources.

Question 8: Dr. Mueller, with all the reviews built into the system, how do you account for the deficiencies found by the Board?

Answer: See answer 2 from General Phillips.

SATURN I FLIGHT SCHEDULE

Question 9: Dr. Mueller, when is the next unmanned up-rated Saturn I flight scheduled?

When is the first manned up-rated Saturn I flight scheduled?

When is the first unmanned Saturn V flight scheduled?

When is the first manned Saturn V flight scheduled?

Answer: The next unmanned Uprated Saturn I flight (using SA-204 launch vehicle and unmanned Lunar Module LM-1) is scheduled for the second half of Calendar Year 1967.

The next manned flight will use the Uprated Saturn I launch vehicle and a Block II CSM. Until a detailed schedule impact assessment of the changes that will be made to the spacecraft as a result of the accident is completed, no firm schedule commitment can be made. Based on a preliminary assessment, it is felt that the first manned flight will either be late this year or in the first half of next year.

The first unmanned Saturn V flight—AS-501 (using Saturn V launch vehicle SA-501 and unmanned Block I Spacecraft CSM-017) is scheduled for the third quarter Calendar Year 1967.

The first manned Saturn V flight has not been scheduled. The manning of the Saturn V launch vehicle will be dependent on:

A successful unmanned Saturn V flight program that demonstrates that the Saturn V launch vehicle can be safely manned.

A successful Uprated Saturn I manned flight program.

Question 10: Dr. Mueller, the report of the Apollo Review Board Design Review Panel 9 states that the Board had independent design reviews made by NASA and North American personnel during which numerous design deficiencies were noted.

NASA had held design reviews. Why were those deficiencies not noted previously?

Answer: See answer 2 from General Phillips.

(Questions submitted by the committee to General Phillips and answers supplied by him for the record are as follows:)

CERTIFICATE OF FLIGHT WORTHINESS

Question 1: General Phillips, on page 1, part 4, of the Board's report, it states that in August 1966 a review of the spacecraft was conducted by NASA at the contractor's plant. Afterwards NASA issued a certificate of flight worthiness and authorized the spacecraft to be shipped to Cape Kennedy. The report also states that the certificate included a listing of open items and work to be completed at KSC. One of the findings in the Board's report states that there were 113 significant orders not accomplished at the time the command module was delivered to NASA.

Is it usual to issue a certificate of acceptance when there are so many significant changes still to be made? Were all the significant engineering changes eventually accomplished before initiation of manned testing of the spacecraft in a pure oxygen environment?

Answer: Often in the first article, as it leaves the factory, there are engineering orders (EO's) that are left open at that time that are to be accomplished in the field. For example, on spacecraft 012, there were some seventy EO's that were related to the kind of work that only can be done in the field. Then in addition to that, since this spacecraft was to undergo actual vacuum testing at KSC, certain instrumentation EO's were associated with this test. There are also certain changes of equipment that have to be installed at KSC. With this background, it is not unusual to issue a certificate of acceptance with known outstanding changes.

Question 2: General Phillips, in your judgment why did the management of the Apollo program fail to recognize that this test during which the accident occurred was an "extremely hazardous" operation?

Answer: Test procedures that involve hazardous operations are reviewed and approved by the contractors' and KSC Safety Offices. The initial determination of whether or not a procedure contains a hazardous operation is the responsibility of the originator of the procedure, i.e., the systems engineer. This determination is based upon a predetermined set of criteria that is outlined in the basic KSC Safety Manual and in the appropriate Apollo Pre-flight Operations Procedure. This latter document is a joint KSC-Contractor document, directive in nature, and is authenticated by both the contractor and KSC. Propellant loading, ordnance and explosives handling, high powered electromagnetic radiation. ionizing radiation, photographic operations and accoustic levels are some of the hazardous criteria defined in the KSC Safety Manual.

Neither the KSC Safety Manual nor the governing Apollo Pre-flight Operations Procedure classified spacecraft testing with the hatch closed in an oxygen environment as being hazardous. Our lack of a complete appreciation of the nature of a fire in the spacecraft led us to conclude that such a situation was an extremely remote possibility.

On the day of the accident, it was planned to conduct a full scale emergency egress training exercise involving the trained emergency egress team. They were not on station at the time of the accident because the test being conducted had not been declared hazardous, although they were to have been there for the emergency egress training exercise.

Because of the extremely rapid rate of propagation of the fire in the spacecraft, it is unlikely if the outcome of the accident would have been any different irrespective of whether or not the procedure would have been declared hazardous and the emergency egress team would have been on station. This is indicated by a lack of evidence that the flight crew initiated any of the emergency escape procedures, the first of which is to activate the cabin pressure dump valve.

Question 3: General Phillips, during our last hearing, weaknesses in the solder joints of the environmental control system plumbing were discussed.

Have you completed your restudy of this system and determined what changes are necessary? If so, what is the nature of the changes?

How much time will be required to incorporate the new design into the Apollo spacecraft?

Do you have an estimate of the cost of these changes?

Answer: Basically we believe that the soldered joints in the ECS system are of sound design and will be retained in general. The changes to be made include the high pressure oxygen supply system piping which will be changed from aluminum to stainless steel in order to provide increased system integrity once a fire has been initiated. Exposed piping will be better protected against physical damage and some critical oxygen controls will be modified to improve their accessibility for emergency operation.

Several piping changes are being made to improve the strength and reliability of soldered joints in aluminum piping and to enhance the ability to remove and replace certain components for test or inspection.

Work is continuing on methods for improved leak detection for the water-ethylene glycol coolant fluid. Improved corrosion inhibitors are also being investigated.

Question 4: General Phillips, in view of the leakage problems (6 instances identified) experienced in the environmental control system in Spacecraft 012 prior to the accident, did NASA have any joint redesign or other corrective action underway to correct the deficiency? Do you have any now?

Answer: In general, the leakage problem associated with the ECS system have occurred with either mechanical type fasteners or with soldered joints.

It is expected that the leakage problems associated with the mechanical type of connection can be effectively eliminated by the use of compressible metal washers, and by tightening them to a greater-than-minimum allowable torque.

A significant number of the leakage problems associated with soldered joints are believed to have been connected with either removal and reinstallation of mechanical fasteners or with inadvertent abuse of exposed solder joints. In order to minimize these problems, adhesively applied doublers to armor these joints are being developed which will provide additional joint strength. Tests of the doublers and the standard North American solder joints are more than adequate for mission-level requirements, provided residual installation stresses in the joints are avoided, and that the doublers will provide a large margin of safety to exposed or stressed joints.

In addition to the doublers, flame-proof protective structural covers are provided over joints and tubing subject to inadvertent abuse either in construction or in flight.

APOLLO ACCIDENT

MONDAY, APRIL 17, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 2 p.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Stennis, Symington, Young, Cannon, Holland, Smith, Hickenlooper, Curtis, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Dr. Glen P. Wilson, Craig Voorhees, and William Parker, professional staff members; Sam Bouchard, assistant chief clerk; Donald H. Brennan, research assistant; Mary Rita Robbins, clerical assistant; Eilene Galloway, special consultant; Howard Bray, assistant to Senator Anderson.

The CHAIRMAN. The committee will come to order.

STATEMENT BY SENATOR ANDERSON

Today the committee is continuing its review of the Apollo 204 accident. We have with us today the Administrator of NASA, Mr. James E. Webb.

Mr. Webb, it is my understanding that you do not have a prepared statement, but that you will make a few comments before submitting to questions by the committee.

I believe that Senator Smith has a statement to make at this point.

Senator SMITH. Yes, Mr. Chairman. Thank you.

STATEMENT BY SENATOR SMITH

We have now had 4 days of testimony and discussion on the Apollo accident.

We have heard from the Review Board on the results of the investigation and we have discussed the accident with those officials of NASA directly concerned with carrying out the Apollo lunar program.

I believe it is, therefore, appropriate that Mr. Webb is appearing before the committee at this time to summarize his views on the board's findings and recommendations, his plans to implement the necessary corrective action, and his best estimate at this time concerning the impact of the accident on program costs and schedules.

As I have stated previously, Mr. Chairman, this *one* accident should be kept in its proper perspective. I believe this message bears repeating. We should not lose sight of the fact that our manned space flights have been remarkably successful over a 6-year history, and has gained for us a preeminence in space many thought was not possible in so short a time.

Nevertheless, I expect NASA to do everything in its power to avoid a recurrence of this tragedy, and I know, Mr. Chairman, that our committee intends to maintain close surveillance over the program to insure that this is done.

I, for one, have every confidence that if the necessary corrective actions are taken, the program can again get back on a successful track.

The CHAIRMAN. Thank you.

STATEMENT OF HON. JAMES E. WEBB, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NASA; AND DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR FOR MANNED SPACE FLIGHT, NASA

Mr. WEBB. Thank you, Mr. Chairman. Let me express my appreciation to Senator Smith for her confidence.

I believe also that we can do all of the things that she has stressed as important.

Mr. Chairman, I had understood that you wished to ask me questions. I do not have a prepared statement. I will be very glad to refer to some of the things that Senator Smith has indicated an interest in her statement, if that is your desire.

The CHAIRMAN. Thank you.

INVESTIGATION MOST EXHAUSTIVE EVER DONE

Mr. WEBB. First of all, with respect to the work of the board, I think it is very important that we remember three things: This board has done as exhaustive an examination of a very complex situation as this Nation or any other nation has ever done. No investigation in history has had the same careful attention to detail, the same running of tests concurrently with the examination of the evidence of what happened in the Apollo 204 capsule, and the same relationship of both what happened in the accident and the results of these tests to recommendations for future action.

Let me say also, Mr. Chairman, that if anyone still feels that the board was not independent, I hope they will go back and read the report of the board, because I think it will be seen that this board took its responsibility very, very seriously. It did as thorough a job as I believe could be done under all the circumstances considering this most difficult task of operating out into space without in-front equipment.

I think the board further did a rather remarkable thing in publishing the minutes of its own meetings to indicate to all interested how it had arrived at its decisions and how it dealt with the recommendations of its various panels.

FAILURE TO RECOGNIZE HAZARD

Now, the second thing, Mr. Chairman, I would like to say is that the Board itself pointed out in its report that it was calling attention to those items which had come through a number of years of development in the building of manned spacecraft, the testing of them, and the flying of them. It said that its purpose was to call attention to that area of error, of a failure to recognize hazard, of the surrounding circumstances of this one spacecraft, Apollo 204, the spacecraft that we have called in the Apollo series 012, and not to the early days of the program. The program went through a number of important developmental concepts on into the Block I—of which this was the only one to be flown—and the development has now proceeded on into the Block II.

The Board did not deal with the Block II spacecraft of which the first unit is now under test at North American Aviation. This unit incorporates many of the things which we have learned, and which will be modified to incorporate all of the things that we believe are essential to accomplish those things that Senator Smith has specified as our national objectives. These will be done before a man is asked to fly in it.

Everything necessary to establish the best possible conditions for success on the first flight will be done, and the men who are asked to fly will have full and complete opportunity to state whether they wish to fly or do not wish to fly.

DESCRIBES WORK PACKAGE PROCESS

Now, the third thing about the report of the Board, Mr. Chairman, that I think is very, very important to recognize is that in the period since 1961, with a group of contractors that includes the best corporations in the aerospace and electronics industry of this Nation, together with the governmental agencies and other industrial companies, we have had to go through a learning process which has now, within the last relatively short time, perhaps of 6 months, as an effective period, brought us to a point that we can identify what we call "work package management." This enables us to identify a unit of work, then designate the manpower required to do it, determine the time required to accomplish the work with the degree of accuracy and care and perfection that must be built into the product of that work package. We can then incorporate that unit into a management system that gives management visibility at the same time it gives the foremen and the workmen on the job knowledge of what is to be done in very advanced areas of research.

The Apollo 204 spacecraft was not built under these conditions. The conditions under which it was built were a part of the learning process that has brought us to the system of management that I have just described.

Now, it seems to me very important to recognize that no corporation which has had a large and important segment of this very advanced research and development work has been able to move into it without this same learning period.

The best corporations in the United States have had to go through this learning period. I am going to reserve judgment in this field on North American until we have had about the 2 weeks that I mentioned to you that we will need to come to definitive conclusions with respect to our relationships with that company and with our schedules. My view today is that the main difference that we are now involved in is not the problem of the learning process but rather the rapidity with which we can move from the learning process into a stable relationship that takes full advantage of this work package type of operation. We in NASA have chosen to pioneer this method which is being applied in our program to all of our large contractors—in one degree or another—to prove out the value of the system.

This is not a static kind of management system. It is, indeed, an experiment within which the Government has put out to industry about 90 to 95 percent of the work, and has developed in its own laboratories the technical and other capabilities to engage in the learning process along with these corporations.

Now, neither these corporations nor NASA are perfect. We have moved a long way up the learning curve in this process by which we believe the best of the institutions of our society can be involved. We have many difficulties now, and will find them with other contractors in other programs as we move toward the final test and flight of some of, undoubtedly, the most complex equipment the human race has ever undertaken to build and to put into operation. We are shortly to fly unmanned the Lunar Module, and this year we expect to fly two Saturn V's. These will be unmanned, and will be designed to test the heat shield on the unmanned Apollo spacecraft by going up to a very high altitude and then driving the spacecraft back into the earth's atmosphere at about the same speed they would attain when returning from the moon.

There is no way that I or any other man alive today can tell you that these flights will succeed.

The Saturn V is a very large and complex machine. When fueled, it has the rough equivalent power of an atom bomb, a small atomic bomb, and yet we must fuel it and launch it automatically, with no human being within 3 miles except the three astronauts riding in the nose. This is not a light undertaking, Mr. Chairman.

In the entire process, from design through the selection of materials, through the testing procedures, through the participation and the launch, the American industrial partners of the Government are involved in every stage, and the test of this Nation in the space program, in my view, is whether this system involving this method of operation can succeed.

Another test, as a part of that task, is whether we can observe failure and take ourselves up and move ahead.

We are going to have failures, and my deepest regret is that our first fatal failure in space flight equipment where men are involved in equipment to fly, was on the pad, and in and under conditions that should have been classified as hazardous, and that they were not so classified.

SPACE TRANSPORTATION SYSTEM

It seems to me, Mr. Chairman, that in this country, we have the capability to build a transportation system to the moon or anywhere between here and the moon, and develop a capability to operate out that far with men.

It seems to me further that it would be hard today by hindsight to develop a better list of contractors or a better way of getting this work done if we mean to develop this kind of ability in space and utilize the capability that this will give this Nation for a long time to come.

I only hope that out of the tragic experience that occurred on January 27, we can learn not only about the combustibility of materials, but how to conduct tests in a flight configured spacecraft or one very nearly flight configured so as to know what the hazard is, and take all necessary precautions against it. I also hope that we can preserve the incentives for the workmen in the factory, the supervisors of those workmen, the engineers, the designers, and management required to work in these very advanced fields of technology.

We, in NASA, are prepared to do our best to continue to work in this direction. We do have problems in every single area that I have touched on, whether it has to do with the contractual relationships, the introduction of incentive features into contracts for work package management of research and development, or in the determining of a proper incentive to pay a contractor for performance in orbit around the earth.

None of us yet know very much about how to make these work best for this Nation.

Thank you, Mr. Chairman.

I believe I have not answered her question, though, with respect to time. May I have one more minute?

The CHAIRMAN. Please.

WILL REPORT BACK ON ACCIDENT IN 2 WEEKS

Mr. WEBB. My best estimate is that within 2 weeks time we will have thoroughly analyzed the report of the Apollo 204 Board and that large stack of appendices and supporting documentation which they have furnished to you and to us. We will also have analyzed our own internal documentation and records from our Apollo program office, and will have had discussions with the various contractors and subcontractors involved. We will have made some estimates as to the relationship of our future program to the 1968 budget that you will be considering then, and be able to give you our best judgment as to when we think we can fly the first of the Block II spacecraft, spacecraft No. 101.

I would hope you would give us a chance to do that work, because without that kind of work we are not going to have a very firm basis on which to move ahead in the future.

Thank you, Mr Chairman.

The CHAIRMAN. We will be happy to give you that time.

What sort of a time schedule is that?

Mr. WEBB. About 2 weeks' time, Mr. Chairman, in which we will come back before you, give you the benefit of our work, tell you what we propose to do, unless someone has got some better ideas or can tell us better ways to do it. In other words, we will be prepared to tell you how we expect to proceed, subject to any instructions you care to give us.

The CHAIRMAN. I hope to ask very few questions. But you are talking about a better list of contractors, and I do think it would be well to comment at a later date or today on the size of the North American package, with the command module, the service module, the LEM adapter, the S–II stage, and all of the J–2 and F–1 engines. It is a pretty big order for one industrial corporation.

Mr. WEBB. Yes, sir. The total under contract, Mr. Chairman, is about $3.3 billion to this company, and this will mean something between $5 and $6 billion in the entire Apollo program, as I recall it. I can look it up for you now or I can furnish it for the record.

The CHAIRMAN. Furnish it for the record. We would like to know what size package it is.

(The information referred to follows:)

The total cumulative obligations for the North American Aviation Apollo contract of March 31, 1967, is $4.835 billion.

The CHAIRMAN. Senator Smith?

QUESTIONS WHETHER ACCIDENT DUE TO TIGHT SCHEDULES

Senator SMITH. Yes, Mr. Chairman.

Thank you, Mr. Webb, for your kindness with reference to my statement.

As I recall, in answer to my question about tight schedules having to do with the tragedy, Dr. Thompson and other members of the Board said that they believed it was not due to tight schedules. In other words, it was not because NASA was in a hurry.

Would you give the committee your views on this same question.

Mr. WEBB. Yes, Senator Smith.

My view is that we have developed a hard-driving effort to build a capability in an area that requires advances in every scientific discipline from the use of energy to very advanced use of material and systems engineering and, at the same time, to prove this capability with flights that reach out as far as the moon carrying human beings. We have had to have a hard-driving program to do it.

We have had to make many changes in the program due to knowledge that we gained, and due to incorporating in the newer system designs those things we learned from our tests; we have had to put in place something like $2.5 billion of concrete and steel and environmental testing facilities and simulators on the ground, and in all of that, with a hard-driving program, we have not put schedule above either safety or reasonable precautions with unmanned tests.

I think that the schedule has been a coordinating and integrating tool of management to get on with the job, just as landing on the moon gives us a concrete, specific objective, either you get there and get back or you do not. I mean there is no way you can say you did if you did not do it. That is the same kind of function we have with the schedule, except that we do not commit as ultimately we will on the flights to the moon.

So it has been a coordinating plan, a very important part of our work. It pulled together the work of 20,000 contractors and over 400,000 men and women in the total NASA program, and over 300,000 men and women in over 12,000 factories in the manned program; without a schedule you cannot do that. But it has not taken precedence over the other things that are important.

OUTLINES METHOD OF CHOOSING CONTRACTOR

Senator SMITH. Mr. Webb, there has been a great deal of speculation as to the ability of the spacecraft contractor to do a satisfactory job. Much of this speculation stems from the reviews and findings of your own staff.

Could you and would you tell us how the spacecraft contractor was chosen. Was it by competitive bid, chosen by an evaluation board or just how did it happen?

Mr. WEBB. Senator Smith, at the time the decision was made to land on the moon in this decade, there were many different proposals as to how to do it, such as the Government arsenal type of operation. One American company wrote me a letter and said if we would just give them the contract they would do the whole job, and NASA would not have to bother about it, just give them the contract and they would do it.

We chose to go into very careful design studies. We expanded studies that had been started in 1959 by the Eisenhower administration. Out of all of the knowledge of these studies we chose 12 contractors to request proposals from. We were asking the contractor to take all of this knowledge, design equipment that would do the job, and then build early models and test them and participate with us in the launching and the flight.

Now, this required, of course, early efforts some of which were completely successful, some of which were not. Development involves a perfection of design with a feedback to the contractor of all we were learning in the other programs from Mercury and Gemini and Surveyor and Apollo and Ranger. We had a lot of projects under way.

It also involved a feedback into this process of how the flight equipment would fit in with this roughly $1.8 billion of ground testing and launching equipment that we were building for manned space flight.

Of the 12 companies that were in a position to have the most important knowledge, and of which three had been given study contracts to develop information that could be used by the Government and all bidders, we received, if I recall it, six bids—I will have to correct that. It was either five or six. I believe it was six.

Now, we had a Source Evaluation Board that was told "take these proposals, look them over carefully, relate them to the information the Government has from all sources, and select the method that you believe, as a Source Evaluation Board, will differentiate one from the other. You select the method that you think is appropriate and apply the method that you have chosen and come in and report to the three senior officers of NASA."

They took a considerable time to do this. If I recall correctly about 200 people were involved. The Source Evaluation Board did come in, and Dr. Dryden, Dr. Seamans and I questioned them at great length, and the work that they had done gave us a very good fix on the capability of those six companies.

Now, after the board reported to the three of us, we retired to another room with the head of our procurement section, with our senior attorney who understood the requirement of the procurement law for competitive range factors, with the person concerned with small business set-asides and with Dr. Gilruth, who was the head of our manned space flight operation, who would have to operate under the contract, and who would be responsible for the Government's work in supervising the contract.

SOURCE EVALUATION BOARD

Senator SMITH. Mr. Webb, may I interrupt right there? Was North American the first choice of the Source Evaluation Board?

MR. WEBB. Yes. It was the recommended company, and in this discussion that I was referring to there was a unanimous recommendation to me from Dr. Gilruth, Dr. Dryden, who is now dead, Dr. Seamans who is here today—the three of them—recommended that North American be chosen, not for the contract, Senator Smith, but for negotiation to determine whether we could establish a basis of a contract. (Note additional testimony in part 6.)

North American was so chosen, and an announcement was made, and we proceeded to negotiate. And I may say, Senator Smith, that since there has been a good deal of discussion about this matter I have taken occasion to ask the men that I have been able to locate, who served on that Source Evaluation Board, if they at any time in the Board had any doubt that Dr. Dryden, Dr. Seamans and I, had made the correct selection based on their work, and no one of them has ever raised a question that we applied the facts that they had so carefully worked up to make the right decision.

ACCIDENT IN RELATION TO CONTRACTOR'S FEE

Senator SMITH. The contract with the Space Information Systems Division of North American Aviation, incorporated a cost-plus-incentive-fee contract, and testimony before the committee has been that the contractor is responsible in some measure for the deficiencies in spacecraft 012 found by the Apollo 204 Review Board.

How significant a consideration will the accident be in determining the contractor's fee?

Mr. WEBB. Well, first, let me clarify the situation with respect to the contract.

I believe General Phillips was going to give some other information when the hearing on Thursday went forward rather rapidly, and what I believe to be an important element did not get into the record; namely, that after going through the learning period and the use of work packages in the spring of 1966, we then were to start negotiation on a follow-on contract on July 1. Proposals were to be submitted by the company on July 1 for a contract that would follow on the expiration of the then existing incentive contract that would expire December 3, 1966.

It turned out that the company requested an extension in the submission of its proposals. That was granted.

The proposals came in on September 15, and they did not appear to NASA to incorporate all of the work that we had been doing together to move toward the work package system of management. We were concerned that without this type of management that we had found effective elsewhere with other companies, that we would not get the fullest effort of that company. We feel the same about other companies.

So in the interim period between September 15 and December 3, we were not able to do all the work, to reduce this proposal to the kind of work packages that would have been acceptable to NASA and also acceptable to the contractor.

You have to have an agreement here. This is a negotiation and not an order from a Federal Government agency and, therefore, on December 3 we reverted to a letter contract.

We had the option under the existing incentive contract to extend the time under a letter contract which, as you know, carries a considerably lower margin of profit for the company.

Since December 3 we have been under this contract arrangement.

I would like to point out though, just to make sure there is no misunderstanding, negotiations did proceed, and the most important issues between North American and the National Aeronautics and Space Administration were resolved by December 28. There were four not-too-important issues left on December 28, and all of us felt, who were involved in it, that it would be possible to resolve those while the lawyers and accountants and others were doing the work necessary to get a signed agreement. These things require considerable review.

When the fire came and the Apollo tragedy on 204 came, it was generally agreed by North American and ourselves that we had better wait to see just what the situation was as the investigation clarified the situation before proceeding.

I have today talked to Mr. Atwood of North American. He assures me that within something like a week he will be prepared to present fully and completely the company's position with respect to the problems of reducing the letter contract of December 3, and the meeting of the minds that took place on December 28, to a definitive incentive contract that will, in fact, carry forward the work-package type of management that we were seeking.

There is one other factor, Senator Smith, that is very important, in my opinion. The improved performance represented in the period between April and the general September 15–October-November period of negotiation has continued into January and into February.

I have, today, looked at the manpower figures and the performance of North American shows a continued improvement in lowered cost, a continued improvement in reduction of the number of deficiencies found by inspectors, and the results that we have found elsewhere that would accrue from a properly designed incentive contract.

I believe that is the best statement I could make to you as to the situation with respect to the contract.

Senator SMITH. Are you saying that you do not have an incentive contract at the present time?

Mr. WEBB. It is very hard to make quite that clear a statement because the work that was going forward under the incentive contract prior to December 3 was carried under a contractual arrangement that let the incentives remain after the contract terminated until the test of whether or not the company had earned the incentives took place.

So certain of the work that is covered by the incentive features of the previously existing contract is yet to be done, and the incentive features yet to be applied.

There is one other little complexity here that I think we should recognize, and that is that this is a very large and involved contract with many, many details that require very careful understanding and cannot be simplified or oversimplified.

The point is that the contract that existed up to December 3 was extended by letter contract under provisions of the previously existing contract, and I think it takes a good deal of careful thought to say precisely whether or not some features of the previously existing contract in addition to the exercise of this option continue to exist.

Mr. Atwood has assured me that he wishes to cooperate 100 percent in finding an answer to and having a meeting of the minds on—the total relationships—and then reducing that to an incentive contract, and I am sure that he is working as hard on this as the NASA officials are doing.

I believe you asked a question also about the incentives that apply on the 012.

Senator SMITH. Yes.

Mr. WEBB. The provision on that spacecraft called for some 600 incentive points which are worth about $50,000 per point if fully earned out by the contractor.

My recollection is that something like $1.5 million or so were earned by the contractor and paid to him prior to the time this spacecraft was shipped from Downey, Calif., to Cape Kennedy.

I believe that there are still something like 143 points yet to be determined. These points would have earned for the contractor incentives had 204 flown successfully and thereby proved out the work of the contractor.

This is a matter that will require adjustment and, as you can see, by multiplying $50,000 by this number, that you have between $6 and $7 million of incentives involved in this kind of a determination between the Government and the North American Co.

Senator SMITH. Mr. Webb, the contractor is working on a straight fee now and not an incentive contract. If NASA concludes that the accident should be given significant consideration in determining the contractor's fee, will North American be as interested in an incentive contract?

Mr. WEBB. I believe that North American Aviation is more interested in an incentive contract at this point than anybody in the U.S. Government, and that is saying a lot, because I believe Dr. Seamans, Dr. Mueller, and I are about as interested in that as anybody can be.

I believe there is going to be a clear meeting of the minds that will take all of the learning process we have gone through in the last several years and put it into an effective arrangement that will give the Government all, and I hope more than all, that it might expect from any industrial contractor.

Senator SMITH. Mr. Chairman, I am sure the committee will want to follow these negotiations very carefully, and I think probably Mr. Webb and his associates will be willing to keep us advised.

Mr. WEBB. Senator Smith, I have stated today, and will state again, that we do not expect to proceed with definitive arrangements without coming before this committee and informing you as to what the situation is and what we expect to do about it, and receiving any advice that you can give us.

Senator SMITH. Thank you very much. That is all.

The CHAIRMAN. Senator Young?

QUESTIONS ON JUDGMENT PRIOR TO ACCIDENT

Senator YOUNG. Thank you, Mr. Chairman.

Mr. Webb, in answer to a question from Senator Smith, you admitted there was poor judgment on the part of NASA officials in not considering the situation on the pad as hazardous prior to this tragedy.

Mr. WEBB. Senator Young, I guess in hindsight you could say poor judgment. I can only say that everyone who dealt with this somehow did not have a built-in ring in their minds to say this is a hazardous thing. You can call this poor judgment.

All I can say is some of the ablest people in the world who had had experience with pure oxygen, as test pilots, and had been through medical concern for the prolonged use of pure oxygen, and the astronauts who had to fly and risk their lives, somehow, for some reason that is very hard to understand today, did not believe this was hazardous enough to make it necessary to get together all of the equipment and people that would have been required had it been classified as hazardous tests.

This was a mistake, I prefer to use the word mistake, rather than poor judgment.

Senator YOUNG. Yes. But my use of the words "poor judgment" are merely repeating a statement you yourself made in answering Senator Smith's question.

Mr. WEBB. Well, I would be glad to be on the record with a combination of poor judgment and failure to recognize the true hazard in what we were doing.

Senator YOUNG. But there was negligence on the part of North American, was there not?

Mr. WEBB. I do not know how you could call what they did negligence unless you take it that the management of a company is negligent unless it does everything to make its full and complete organization work 100 percent without mistakes.

I do not feel that this is negligence. I notice from the record that Senator Brooke used the word "misfeasance" and Dr. Seamans said to me, "I am not a lawyer. I know malfeasance but what is misfeasance?"

I think we have got this problem of misfeasance, malfeasance, negligence. I have not found anyone here who would not have given anything they had to prevent what happened, and I do not know that negligence is the right word.

Senator YOUNG. We are not arguing that. But negligence on the part of North American could certainly consist of not doing some things and not taking some precautions that they should have exercised in the ordinary care they should have taken, is that correct?

Mr. WEBB. They did not do all the things that they should have done in the state of knowledge that existed prior to the fire, and they certainly did not do all the things that we now know should have been done, and I can say the same thing for those of us in the National Aeronautics and Space Agency, and I can say the same thing for almost every airplane pilot that flies an experimental new airplane.

Senator YOUNG. Well, I, as a former trial lawyer, would say that North American was guilty of negligence.

Now, Mr. Webb, your Agency has made, and is making, a thorough investigation of this tragedy. That is not completed as yet, as I understand.

Mr. Webb. The Board has made its report, Senator Young. We are holding them together pending the examination of all factors in the NASA management system which they did not consider. They considered the things surrounding the accident. We are considering the total range of things related to the management of this large project.

COST OF INVESTIGATION

Senator Young. All right. Have you, Administrator Webb, made an estimate of the total dollar cost of your complete investigation of this accident, including the value of the time of all your people assigned to assist the Board of Review?

Mr. Webb. Senator Young, I do no have a tabulated estimate broken down in detail, but I have thought about this very much, and where I have come out is that we have in the 1967 budget funds to pay a substantial number of both NASA and contractor people. That number is about 70,000 people less than we had at the beginning of the year, and is now going down at the rate of about 5,000 a month as our contractors pass the peak in things like Gemini and the construction program phaseout.

I believe within the number of man-hours that can be put in our Agency and in our contractors in fiscal 1967, and the man-hours that the President is requesting in the 1968 budget, the budget that you will take up tomorrow, it will be possible to do the work necessary to get ready to fly again, and I hope it can be done in time to fly block II spacecraft No. 101 in the year 1967 or certainly early 1968.

If, in fact, Senator Young, we have learned more than we would have learned in a comparable period of time through the tests of combustibility which we have conducted as a result of this investigation; if we have, in fact, convinced everybody associated with this program that this work package incentive type of research and development management is the only way to go, to have complete visibility and control and accurate estimates as to the future, and then can tie incentives to this that will really be effective in American industry, I would suspect, I would believe, I have a strong feeling of belief, that by the end of 1969 we will not be very far behind where we would have been if this total combination of Government, industry, and universities had had to learn this hard lesson in another way at another time.

I think that this hard experience has given us some hard lessons, and so I would say that there is no way that anyone can tell you today that there is going to be an increased cost or delay in the schedule when it comes to the flight to the moon. It is certainly going to involve a delay with respect to the first time we fly a man because we would have already had a manned flight if 204 had flown successfully.

Senator Young. Will you be able, Mr. Webb, 2 weeks from now to answer that question more accurately as to dollar costs of the total investigation of this accident?

Mr. Webb. I will, Senator Young. There is not a person involved in this program who is not working all hours.

I left my office at 12:30 last night after a planeload of people got up here from Houston, and we spent 4 hours together.

This is what is going on, and we have got an able-bodied team, as I said to the House, and we are going to be in a position to come before you and state what we think and what our estimates are authoritatively, probably in public, insofar as the speculation about that is concerned; I would hope you would give us a chance to do that rather than to assume that we cannot do it.

Senator YOUNG. Do you agree that you will be able to do that with some degree of accuracy——

Mr. WEBB. Yes, sir.

Senator YOUNG (continuing). Two weeks from now?

Mr. WEBB. Yes, sir. I think we can give you the facts as we see them, and can bracket the amount of, shall I say, possibility that they may be slightly one way or the other from that figure.

Senator YOUNG. And you will do that within 2 weeks from now?

Mr. WEBB. Yes, sir; I hope to do it. If it is 2 weeks and 1 day, Senator, I hope you won't chop my head off. I cannot tell you precisely, but I have talked to Mr. Atwood today. He is the largest contractor involved here. I do believe that the work going forward to fly the first unmanned LM is now going forward with Grumman, and with the S–IVB and this is proceeding.

I think that we very likely, for the first flight, are not going to change the one-gas pure oxygen atmosphere, but are going to eliminate the risk another way.

I think we will be putting into the equipment on the pad and, to some extent in the spacecraft, the opportunity to change our minds in that regard if we need to. In other words, we will have the capability for two gases. But I think we will proceed, until we have gotten further up the road, with a one-gas system.

I think all of that will be pretty clear in our minds, and in that case we will not have to make major redesign of the environmental control unit. This kind of thing we will be able to tell you within 2 weeks.

Senator YOUNG. Now, Mr. Webb, assuming that probably at this moment you would be unable to give this committee any accurate estimate of the cost in money of this terrible tragedy, do you think that you will be able to provide that information by 2 weeks from now or if not by that time, will you please provide that information to the committee just as soon as you possibly can?

Mr. WEBB. Well, now, Senator, let me have one minute on that subject, if you will, please.

First of all, our management system and those things that assist the ablest human minds we have, like computers and methods of analysis and methods of management, are also positioned that they can be applied to the toughest problems in order to get them behind us.

We always face the question—whether you are in critical analysis or whatever it is—you tend to focus your best ability on the hardest problem.

Now, thus far, the disassembly of the 014 alongside of the 012 has focused our ablest minds on the best equipment and the best systems of analysis on the toughest problems we have to solve to get to the moon in this decade.

Now, my view is that we will solve those questions and we will fly, and I hope we will fly this year. If that flight should be more successful than it possibly could have been otherwise, then we are likely in this process to eliminate a risk of another failure somewhere up the line, and if that turns out to be true, I believe that the cost of getting to the moon will not be beyond those estimates that we have already given you, and which we will update in the authorization hearings.

Senator Smith has asked us every year, to give you the runout costs and we are prepared to give you the runout costs if we can under the direction of the President. If they change we will come and tell you they will change.

Senator YOUNG. No further questions at this time, Mr. Chairman.

The CHAIRMAN. At a previous meeting Senator Percy tried to question Mr. Webb, and we had to suspend. So I will call on Senator Percy.

Mr. WEBB. I was here, Senator.

The CHAIRMAN. Senator Percy?

SPEED IN RELATION TO SAFETY

Senator PERCY. If my senior colleagues would prefer, I will be glad to yield to them.

The CHAIRMAN. Senator Percy?

Senator PERCY. Mr. Webb, I would like to put my questions in the context of one who has had a great deal of admiration for the leadership that this program has had.

We have all been thrilled with the progress that has been made. We started out way behind. Yet we have caught up with a degree of sophistication we did not think was possible. This progress has been due to the dedicated way that your team has worked for the national objectives enunciated by our President. The complete cooperation and the use of every single resource we had available to us through our free enterprise private system have been exemplary.

Mr. WEBB. We used the best there was, Senator Percy. It is not perfect in either Government or industry, but it is the best we have, and it is getting better.

Senator PERCY. I have great admiration for that.

I think in the spirit of Senator Smith's comments, our questioning is not one of interrogation to embarrass in any way, but to see if we can add one iota of intelligence and knowledge in carrying the program forward in a way that will preclude any such recurrences of this in the future.

One part of it, I think, is involved in the speed with which we are operating.

On February 27, during earlier hearings I asked the following question:

> I think the country will certainly absorb any delay in this program that would make the program a safer one and prevent any such future disasters. Is it possible for you to estimate how much of a delay now that would be reasonable to expect that we should absorb?

And you said, in part:

> My own view is that this process is going to eliminate all sources of weakness that we would feel were critical and, therefore, we may be able to accelerate the schedule of flights to make up for this. We may be able, I hope so—this cannot be determined until this disassembly in the other process is finished.

Do I understand now that in the light of the past several months of reflection and analysis that certainly there is not going to be a speedup, though you still maintain that there may not be a delay from the original schedule?

Mr. WEBB. Senator Percy, more than most people who vote on legislation, you understand how to put a work force together, and that speed is determined by the effectiveness of the man-hours of work you put in, the efficiency with which they work, and the accuracy with which they are directed to the right purpose, and the ability to determine whether or not they have, in fact, accomplished an efficient piece of equipment that will operate without a failure.

Now, we in the whole NASA program are down to about 350,000 people. We are constantly increasing our efficiency.

In North American the work force is going down by something like 200 men per month in the carrying out of the workload that is not declining at anything like that rate.

I would say in answer to your question that the true determinant of our future will not necessarily be in the Block II spacecraft, of which 101 will be the first to fly.

Of the 90 major subsystems in that spacecraft we have already gone over them very, very carefully, and have determined that 88 of them are as good as we know how to do it at the present state of the art, and I do not think we are going to change them unless we are directed to or funds to move forward with them are not provided.

With respect to the other two, I think we will make some changes, but I do not think they will be of such a nature as to force delay. I do not think they will be the pacing items in the program.

Now, with respect to the procedures that a company can use in this improved Block II spacecraft, with the wiring made on three-dimensional jigs, not two-dimension jigs which, as you know, make a vast difference in this kind of manufacturing, and even though the kind of insulation that we will be using on the wiring is of the same kind that we had in the previous spacecraft, but thinner because we have found that we actually can use this more effectively and move the wires into the proper configurations in the jigs better with thinner insulation, and have a more reliable spacecraft. Now, all of that I think is going forward, and I think you are going to be satisfied when we tell you 2 weeks from now what we are going to do.

The pacing item is going to be, in my view, these big boosters. The Saturn V booster is—it has the equivalent power of 6,000 Boeing 707 airplanes, that is airplanes at cruising speed power, and each engine consumes 3 tons of fuel per second. We burn 2,300 tons in two and a half minutes through those five engines, and accelerate 6 million pounds from zero to 5,000 miles an hour burning liquid hydrogen.

This is a massive undertaking, and because the program was reoriented due to the concern over the level of expenditures, it has been operated at about a half billion dollars a year less than we planned it, less than would have been the most efficient and desirable way to operate.

Now, we have gone to all of the systems tests. The first Saturn V that flies is going to fly complete, first stage, second stage, third, service-and-command module, spacecraft-and-escape tower, all on one machine. Every unit will have been tested on the ground, and the escape tower in flight, and the capsule would have been dropped from airplanes, and so forth, but the basic booster structure, the first and second stage, will never have flown.

Now, I do not believe there is a man alive who can tell you or me that those first two flights are going to fully succeed. If they fail we have got a real job to find out why they failed.

If they succeed, we are well on our way because I believe the spacecraft will be ready to ride on those boosters as soon as they are ready to fly. Does that help a little bit?

Senator PERCY. Well, it helps a little bit. [Laughter.]

Mr. WEBB. I cannot tell you whether the Saturn V is going to fly. Dr. Von Braun has flown successfully every Saturn we have launched. The first two Saturn-Apollo 1-B flights were successful.

On the first guided trip we went 18,000 miles. We went 18,000 miles with the payload without updating guidance information from the ground. We automatically reentered the earth's atmosphere; at the proper time exited from the earth's atmosphere, and went another thousand miles, and reentered after going 19,000 miles; where we start out with a single message, and the guidance system was set for 194 miles, and it landed 204 miles from where we expected it to land. This is a tremendous achievement.

Many things in life are victims of the hidden flaw, and there may be a hidden flaw in the Saturn V. But, we have done everything we could to find it.

DECISIONS GUIDED BY POLICY

Senator PERCY. Maybe I can get at it this way: I think it would be important for all of us to know who it is in the management, who makes the management decisions which balance the need for speed in the program against the safety of the crews involved.

There are three statements that I could give you: First, that we all know President Kennedy said we are going to land a man on the moon in this decade.

Board Chairman Thompson testified last Tuesday that the only haste involved was the sense of urgency necessary to keep everyone on their toes and keep the program moving along at a motivated fashion.

Colonel Borman stated on Tuesday that he would prefer the United States to land a man on the moon before the Russians.

Now, maybe I could put the question in the simple terms: As a matter of policy are we actually in a race with the Russians to land a man on the moon, and who makes that determination of balancing out speed and the urgency of speed with safety of our crews?

Mr. WEBB. You have correctly stated, Senator Percy, the fact that decisions are guided by policy. The policy has been never to sacrifice the safety of astronauts or a major risk of success on a major test for speed. This has been the policy.

It has been implemented well, but there have been exceptions, and I would say that the decisions at many levels down the line are made under this policy, under the supervision with respect to the boosters of Dr. Wernher von Braun and recommendations of contractors, and by giving instructions to contractors.

With respect to the spacecraft, decisions are made by Dr. Robert Gilruth and his associates at the Manned Spacecraft Center; with respect to launch, they have been made by Dr. Debus and his associates at Cape Kennedy.

While it is true that a number of people must acquiesce to proceed with a major matter, any one of them can stop it. Dr. Debus can stop a launch; the test director can stop a launch, and the only direction I ever received from President Kennedy or President Johnson has been "go when you are ready and don't go until you are ready." That is the only instruction I have ever received.

This was one of the matters at issue in some of the Mercury flights, if you may remember.

Senator PERCY. So really the decision is left very much in your hands.

Mr. WEBB. There is no political element in the decision, if that is what you are asking. The decision is to proceed effectively; to do it as safely as you can do this kind of thing; to build up the confidence of the country through the employment of universities and industries, rather than just government installations; and to develop a capability with new technology to operate in this unlimited medium.

I would say with respect to the Russians though that we, I believe, in the end, will regret that we did not operate at about a half billion dollar level higher than we have. I think we would have had a more efficient program.

I think we would not now be facing about 2 years in which they will be flying spacecraft larger even than the kind that we can fly if we fully succeed in the 101 and Saturn system.

I think, further than that, they will be exploiting us at a time when this Nation would be well advised to demonstrate that it is there when it comes to judging the technological balance of power among nations. We are faced with that possibility.

Now, I have stated unambiguously many times that we had constructed a machine that could operate under policy with a foot on the brake or a foot on the throttle, and we expected to be guided by policy, and we have never come up here asking for a sum, a supplemental appropriation, except in one instance where there was an authorization. It went over to the next year, and the President used that authority as a part of his next year's budget, just as he is this year using the $60 million that he held back out of this program last year to fund part of this program.

We always have said that we will do our best with the President and Budget Director. We do our best with you, and then we operate under what you provide because we believe that you should make the policy decisions.

APPRAISAL OF BOARD'S FINDINGS

Senator PERCY. A brief question which you might just reply with a "yes" or "no" answer: Are you satisfied with the report of the board, and that the charges of errors, mistakes, and inadequate precautions and procedures, inadequacies and deficiencies in workmanship and quality control are warranted?

Mr. WEBB. Senator Percy, the board has done an outstanding job. I cannot answer that yes or no. If I have to say "No" I will say "No."

The board has not stated correctly a full and fair appraisal of the system under which this work is being done. It has done a thorough job of investigating one accident, of pointing how it happened and the conditions under which it happened, and pointing to the things that we need to do, many of which were already under way.

So I would not like to leave the implication that the material written in those books you received—and there is an awful lot of writing in those books—can be taken as a guide to the reality of this program; in my view it cannot.

DEFINES INDEPENDENT INVESTIGATION

Senator PERCY. In paragraph 5(b) of the April 14, 1966, NASA instructions on mission failures, what does the term "independent investigation" mean? I was particularly interested in going back over all of NASA's instructions to try to find out what procedures have been established, and I have found very few omissions. I found tremendous detail in the procedures that were established.

But I stumbled on this one because I could not figure out what an independent investigation meant. Does it mean the Deputy Director has required an investigation independent of the Program Office?

Mr. WEBB. No, sir.

Senator PERCY. Independent of persons related to the circumstances of a particular accident, or independent of NASA and its subcontractors involved in the incident under investigation?

Mr. WEBB. It means independent, Senator Percy, in the same manner as the Source Evaluation Board which I explained to Senator Smith.

The Source Evaluation Board is protected from influences of any kind. We do not tell who the members of it are. We do not permit U.S. Senators or Chambers of Commerce to contact the Board. We want them to choose their method of evaluation, to apply it and to report and to be subjected to careful-examination by the senior officers of the agency.

In the case of this Board, we did not want the Board constrained by any feeling that they were stepping on anybody's toes, that they could not get the resources to conduct tests; that they were independent in terms of their judgment and the resources to apply that judgment as to how to do the job they were given to do, and to report fearlessly, fully, with a complete sense of independence.

That, I believe, they did, and I do not agree with anyone who says that the most competent people in the country cannot be put together by an agency to do this kind of a job.

If you are looking for something like a court of equity, where a lot of judgment is involved, that involves not quantifiable things, you may look for what you might say is non-NASA people for this kind of investigation.

But no board not composed as this one was, with extremely able men, with full competence and a dedicated sense of responsibility, could do this job.

We wanted to make sure that the independence, that competence was brought fully into play for the benefit of this Nation, and I think if you have a little trouble with that word "independent," the end result of that report speaks for itself. It is a good report.

Senator PERCY. I agree with that. I think this is an exceedingly thorough report and very objective and critical.

The only reason I ask the question is to see if we cannot learn from present and past for the future.

Mr. WEBB. Let me say this: When that Board decided to report, I gave careful instructions to Dr. Mueller not to go down there and get any advance indication of the report. I did not want them——

Senator PERCY. I know that.

Mr. WEBB (continuing). Insofar as my own office is concerned, produce the report with all the documents, and I will give it to the press and send it to the Congress instantly. I will not stop the reading. This is one of the elements of independence.

Senator PERCY. I agree with all that, Mr. Webb.

But my point is this: Consider the amount of time that you and your associates have spent defending to the House and the Senate the makeup of that Board, even considering the competence of the Board and the thoroughness of the report, and your confidence in the reliability of the Board. Would it not have still been better in retrospect, and would it not be better in future investigating of anything, to have more outside members, just as an independent financial audit?

It is better to have an outside independent auditor, even though he may not be as competent to deal with the intimate details of an organization. His determinations have that stamp of outside independence that this report, no matter how we justify its thoroughness, can never have so long as most of the people—in fact every member of it—were Government employees. There was not a single soul absolutely independent from influence, we rely, rather, on the absolute integrity of those men which I do not question for a moment.

Mr. WEBB. Their integrity and their professional and technical competence—we deal, Senator Percy, in organized facts and not in organized prejudice.

Now, it seems to me that somebody else has got to decide whether or not we have done a proper job of investigating this accident. Maybe we should not have used the word "independent." Maybe we should have found a better word than that.

But I do not think quality of performance on the production of a report in which I and my associates can have confidence, and in which when we come to you with our proposals to go forward under a situation that could cost you a billion dollars if what we propose does not work—I think you want the best facts organized as to this so that you can make a decision, and if that involves some exposure to those who wish to use organized prejudice instead of organized facts that is a risk, I believe, we have to run.

PROCEDURES USED TO IDENTIFY HAZARDS

Senator PERCY. Mr. Webb, on the nature of the decision made by the contractor, panel 13 investigated the procedures presently used to identify hazards, and to document emergency procedures.

As I understand it, the contractor makes the initial determination of whether or not a test is hazardous?

Mr. WEBB. This is under the policy, you see, of placing on the contractor rather than to build Government competence, competence to tell the contractor what to do, the full responsibility for producing something that will not be hazardous and will fly. We do not just say he will do anything he wants, but we make him address himself to the question, and I believe this is a good policy.

Senator PERCY. I found a great deal of detailed procedure for NASA to follow when the contractor said it was hazardous. I found a lack of detail when it was a nonhazardous determination. I would like to know what the NASA procedure is for reviewing the contractor's determination as to whether it is a hazardous or nonhazardous situation, again not for the benefit of looking back for blame or mistakes or errors, but for the sake of plugging a loophole we possibly might have in the procedures.

Mr. WEBB. This is an area in that tremendously complex system that you have seen in this report which, I believe, we need to improve. We are initiating work in this direction now. We are going to report to you in 2 weeks' time that we are making improvements there that I believe you will be satisfied with.

We will be creating a different type of examination which, I think, will be more effective.

But I will say to you, sir, it will not be 100 percent as long as human beings are involved in it. It will be better than we have had and as good as we know how to do now, and will give it to you fully and completely in 2 weeks.

Senator PERCY. 99.44 percent will be acceptable.

Just finally, Colonel Borman said if he knew then what he knows now, of course, he would not have entered that spacecraft as an astronaut.

Is there any other thing that you can think of, Mr. Webb, that can contribute to our understanding as to why it was that we were able quickly to determine what did go wrong after it happened, but we were not able to determine or did not determine it before it went wrong?

Mr. WEBB. Senator Percy, I think that you must bear in mind that the original ideas of how to construct a machine that could transport a man to the moon, carrying with him an environment that would permit him to live and do useful work, had to be tested out. There were many ideas.

We had to begin to sift them, to focus on them, to build machines, to test those ideas as embodied in hardware, to eliminate those that did not work, say, in environmental control systems, to constantly study and close in on this problem.

Now, the 012 was preceded by very careful examinations and tests on the earlier models up through 019, and then it was decided that although we had already agreed to go to a Block II model, and to do our work out in orbit around the earth, the main part of our work and outward to the moon with Block II, we could gain a great deal of information and gain it much earlier if we made at least one flight with the Block I, and from that decision came the procedures under which we did decide to fly Block I.

I should say that, perhaps, we would today look very, very carefully as to whether what we would gain, the time we would save from flying men in Block I, would be a proper decision.

I am inclined to think we would consider very, very carefully whether we should not have made the first manned flight in Block II. That to me is, perhaps, more important than some of the discussion that goes around about an ignition source and how much combustibles.

Senator Percy, it only took 4 ounces of combustible material to produce the pressure that exploded that capsule. Four ounces, that is all.

Now, it is pretty hard to eliminate all the hazards from a situation where combustion of 4 ounces will produce the pressure that will rupture the capsule.

These equipments are designed to do a specialized task very efficiently, and they do not have much tolerance for off-design conditions.

Senator PERCY. Thank you, Mr. Webb, very much indeed.

Mr. Chairman, thank you.

The CHAIRMAN. Senator Cannon.

QUESTIONS ON CORRECTIVE ACTION

Senator CANNON. Thank you, Mr. Chairman.

Mr. Webb, after studying the Apollo 204 Review Board's report, to what do you attribute the deficiencies found by the Board?

Mr. WEBB. Senator Cannon, we have agreed to examine the full work of this Board, all the documentation, including that that you have seen in the appendices and all of the documentation and records and personnel.

As I have said, we have been meeting day and night with this. The group from Houston came up last night. I would much prefer to answer this when I can give you the result of an exhaustive study where nothing yet remains to be done. I believe my answer would be better.

I would say there the conclusions of the Board itself, that somehow our success in Mercury and in Gemini had been translated into a feeling that the real risk on that pad was not in the spacecraft but in the booster, that the minute you fuel up that booster you have got a tremendous risk.

Up to that time the risk is so much smaller that you just do not address your mind to it. The mind gets sort of staggered at the risk of a fueled booster with a man near it. I think, perhaps, this is the best answer I can give you at this time.

Senator CANNON. Do you propose to report to us at some time in the future as to what you attribute the deficiencies to?

Mr. WEBB. Yes, sir. I will be glad to do that at the time we come back with the full report.

Senator CANNON. Now, to correct the deficiencies that are pointed up, do you foresee any changes in the organizational structure and management of NASA?

Mr. WEBB. Yes, sir; I do, and we will report those to you.

Certainly with respect to the organization of safety and quality control, some of the questions that relate to the insistence that procedures for tests will be available certain lengths of time ahead of time, there will be some necessary organizational changes. And I think, Senator Cannon, again just as we have been engaged in a learning process with American industry and with this business of rocketry, we have been engaged in the learning process as to the proper time when you transfer responsibility for the booster from Marshall Spaceflight Center to the Cape. That had taken place.

We were in the process of making that transfer on the spacecraft at the time this accident occurred. We were caught right in the middle of applying what we had learned to a new and better organization of the work, and I think that we will be able to show you that, to proceed on with what we had already started, and to do it better than we would have done it because of the tremendous impact of this which will give some assurance.

Senator CANNON. And you have already initiated corrective action?

Mr. WEBB. We are initiating the procedural actions and things of this kind. With respect to all other matters we expect to come before you and give you our views and tell you what we propose to do so that you will have an opportunity to react to them. We are not waiting though with respect to test procedures and matters of this kind.

Senator CANNON. Since this incident there was announced a reorganization, if you prefer to call it that, of the pilot crews, the flight crews. Was that related at all to the accident or any of the matters relating to the investigation?

Mr. WEBB. Well, it was related to the fact that we had had an accident and knew we were not going to fly again soon, and what we wanted to do was to clear the decks of the crew assignment, and to put the men to work in the place they could work most efficiently for the next 6 or 9 months.

But it was not related to any evaluation of the men themselves and their qualifications for flight. We want to choose the crew for the next flight on the basis of the men best qualified to go near the time of the flight, and not to feel committed to a specific crew as of this time.

QUESTIONS ON PERSONNEL REDUCTIONS

Senator CANNON. Earlier in the program you have mentioned that we had 20,000 contractors and 400,000 employees working in the program. You restated that today, and later indicated that there is a reduction of about 5,000 people a month in the program.

I am wondering what our current on-board situation is with respect to contractors and with respect to employees in the NASA program.

Mr. WEBB. In the total NASA program we have 35,000 roughly, I would have to give you the exact number, civil service employees in our installations and test facilities. We did go up to a high point of 420,000 men and women working in industrial plants.

We have dropped off about 70,000 to where we are now approximately at 350,000, and we are on the way downward so that at the end of fiscal year 1968, that is the budget period we will be presenting to you tomorrow, we will be down to approximately 300,000 or, perhaps, slightly under depending on the progress we can make.

Of the people who have been reduced, Senator Cannon, about 20,000 are in the construction field. Our facilities are either in place or rapidly being completed, so our construction force has dropped from 40,000 to 20,000. I would like a chance to correct those a little more precisely, but they are not far wrong.

Senator CANNON. For a long period of time NASA was recruiting specialized people. Are you still in that situation or have you met all of your recruitment needs for highly specialized people?

Mr. WEBB. I would like to answer that by saying that we were able, as the program built up, to employ the essential needs of very skilled and able people. They came to work for us for considerably less than they could earn elsewhere.

We filled them out with young graduates from college who got their work experience and training and opportunity to get advanced degrees with us. That attracted them.

Now we are having trouble holding both groups of people to some extent. We are not suffering terribly, but our turnover has increased substantially.

DISCUSSION OF APOLLO CONTRACT

Senator CANNON. There was a considerable amount of discussion last week about the investigation that NASA made of North American, and Dr. Seamans was asked whether or not he had ever recommended that the contract be canceled.

Let me ask if at any time you considered cancellation of North American's contract.

Mr. WEBB. Senator Cannon, is it wise to make that kind of a statement in a public hearing? You are getting into the kind of detail that whatever the situation may have been at one time or another, I have stated the current conditions are that Mr. Atwood and I are determined to find a relationship on which we can go forward together or find it is not possible to do so, and we are going to tell you within 2 weeks what we propose to do.

I will be glad to answer the question if you insist on it, but I would prefer not to start the precedent of answering that kind of detail because it does affect the rights of many people not in this room.

Senator CANNON. I thought you might prefer the opportunity to answer it in view of the fact that both Dr. Mueller and Dr. Seamans were asked the question last week and answered it for the record, and I thought, perhaps, you might want to go on the record on it.

But I will leave that up to you.

Mr. WEBB. Senator Cannon, these men are wonderful associates but the ultimate responsibility rests with me, and what I have thought of in terms of how to get the work done, I would prefer not to answer. But if you insist I will answer.

The CHAIRMAN. Senator Cannon, there is a vote on the Hartke amendment. This is a very good time to recess. We will be back in about 5 or 10 minutes.

Mr. WEBB. Yes, sir.

(Short recess.)

The CHAIRMAN. Senator Cannon.

LISTS REASONS FOR USING OXYGEN

Senator CANNON. Thank you, Mr. Chairman.

Mr. Webb, in your answer to Senator Young you stated that you did not believe you would change the pure oxygen gas but would eliminate the hazard in another way. What is the alternative approach that you propose to use?

Mr. WEBB. Well, first of all, Senator Cannon, I was trying to make sure that there was an understanding that we selected the pure oxygen approach for some very solid reasons, that there are risks attendant on changing from it, particularly on launch and what Borman called "on" orbit, I would say "in" orbit or in space, there are very real advantages in work out and around the moon, and there are some advantages on reentry.

Now, one of the very real problems of going to a two-gas system is the amount of inflation that you must have to get the proper partial pressure of oxygen within the lungs to support life, and this means that if you go out into the vacuum of space for extra vehicular activity you have to have a space suit that is blown up tighter, with more pressure inside and that affects the amount of work that you can do.

However, we do not want to make this decision for all time. Our whole policy in these matters is to do the best we can, but to try to provide for changes if we find that there is a need for change.

We have built extra capacity into our Vertical Assembly Building so that we can put in a nuclear stage. We have 70 feet clearance in that building; so our decision with respect to the nuclear change means that we could do it without increasing the height of the building.

Now, as for the possible use of a two-gas system on the pad prior to launch, with the needs of the capsule in orbit, the transition to a full oxygen atmosphere will be provided.

I was giving you my own estimate that as of this time I doubt myself that we will do that. But we will not preclude the possibility, and we won't wind up some time later with the inability to do it if it turns out to be wise. I think this is what I was trying to convey.

QUESTIONS ON 1968 BUDGET PROPOSAL

Senator CANNON. Now, a little earlier you stated you were going to be up tomorrow with your 1968 budget request proposal to us.

I would like to ask whether or not the 1968 proposal is at the level that was envisioned prior to this accident or whether or not it has been changed as a result of the accident.

Mr. WEBB. Senator Cannon, I know of no way to present to this committee the large and complex problem of funding the ongoing programs that are in our agency, and then giving you the facts you need to consider the Apollo Applications at some $452 million for 1968.

The Voyager, which is a start toward landing on Mars in 1973, and the development of a nuclear upper stage to replace the S–IVB so that we can approximately double the Saturn V capability for certain missions except within the framework that the President has submitted to you—he has sent a supplemental covering the nuclear rocket which involves $50 million extra for the NERVA II engine.

I believe that this committee and NASA can work together to get the right answer to these questions within the framework of the President's 1968 budget without change, and then I believe if changes are necessary we can work together, as we have in the past, through reprograming actions later when we know more than we know today.

Senator CANNON. A little earlier you made the statement if we had had a little higher level of funding, about a half billion dollars per year, you thought we could have had a more efficient program. I believe it was the year before last that I asked you specifically whether you thought that we could do better if we speeded up the program or if we slowed it down and, at that time, you stated that it would be more expensive if we slowed down, and would be more expensive if we speeded it up—I am paraphrasing your answer—you thought we were proceeding at about the optimum level.

Would you reconcile that answer given to me then with your statement made here earlier today?

Mr. WEBB. Senator, if you have the report there, I believe—I am going from memory—you will find I said at that time—you see, we planned this program and put it in motion in 1961. We planned to go up to between $5¾ and $6 billion and then taper off.

Now, the program got up as high as $5¼ billion and began to drop off, and I believe your question came within the period that Congress for 2 years in a row had established this rough five and a quarter, $5.1 billion level as the one at which it would support the program, and the President accepted that. He just did not keep sending up $5¾ billion, $5½ billion.

Now, the year before the testimony you are referring to, I believe Senator Anderson made a very strong and vigorous effort to get the program up to around $5½ billion. My recollection is that we were asking for $5.43 billion—something of that kind. So I believe you will find that the reconciliation relates to the time at which I made that statement, not to the other.

The total effect of 5 years work, 6 years work, I believe, is that we have added between $2 and $3 billion to the cost of doing the same amount of work. We are about 2 years behind where we could have been as a nation—I am not in any way saying that we have not all done the best we could. I have done the best I could, and I am sure Members of the Senate and Members of the House have done the best they could, and the President, too.

But I believe that the facts show or will show when ultimate history is written that we could have been ahead, and I do believe that it is very likely to be that very period when the Russians are flying bigger things than we can for a couple of years, and that the optimum level for doing what this Nation needed would have been better at five and three quarters and dropping off fairly rapidly after that. We could then have a decision as to what we did after that, what we used this equipment for once we had established the capability to build it and fly it.

Senator CANNON. Thank you, Mr. Chairman. Those are all the questions I have.

I want to commend Mr. Webb and also Dr. Mueller and Dr. Seamans for the very forthright statements and position that they have taken here with the committee with respect to this very unfortunate accident. I think that you all have been very forthright with the committee and I appreciate it, for one.

Mr. WEBB. Senator, Cannon, Mr. Chairman, let me just say one thing about the question he asked me as to my thoughts with respect to changing contractors, and so forth.

I think it is incumbent on all of us in these proceedings to recognize that much of what we do will determine how effective the whole system will operate in the future.

Now, if it is possible to preserve enough of the close, confidential working relationships so that the best knowledge we gain, and we have the largest exposure to all the problems of all the contractors, and we have, perhaps, broadly, the most broadly based total technical competence in the Nation, if that can be applied to the work of any one contractor to help him move in step with the others, we should proceed to do it.

I hesitate very much to do anything here, whether it is producing documents or giving my thoughts about a contractor that sets such a precedent that we cannot continue to do this work in a confidential way, and get on with the job.

Now, any procedure this committee establishes to receive this information in a nonpublic way and decides itself what part of it it wants to make public will be all right with me. I will give you everything I have.

But I do not want to leave the impression that my request to Senator Cannon not to press this question is related to anything except my feeling that I must act responsibly to preserve the capability of the system we have constructed here. That is the factor that enters my judgment in making that request not to press that question.

The CHAIRMAN. Senator Curtis.

QUESTIONS ON CHANGE IN SPACE LAW

Senator CURTIS. Thank you, Mr. Chairman.

Preceding my question I do want to say this: that everything that has been said or written about this accident that occurred on January 27, isn't that the right date——

Mr. WEBB. Yes, sir.

Senator CURTIS (continuing). Has really been hindsight.

I would call attention for the record to the fact that not only did NASA and the contractors proceed in an unknown area, something new, but that the Congress, as the legislative body, likewise was proceeding in an unknown area.

When the Congress and the committees thereof undertake to legislate on taxation or transportation, military affairs, aviation, almost anything else, they can turn to members in their own body who have been highly experienced in this, or we can all turn to outside individuals in whom we have confidence who have had years of experience.

This has not been true in establishing the legislative policy for our space program.

I have spent quite a bit of my time in the Congress in hearings of various investigations. I want to say that I am very much impressed with these hearings over the fact that I have found no evidence of anything being held back, and I commend NASA for its candor and forthrightness.

Do you have in mind any change in the law that ought to be made, and I am confining my question to matters other than budget?

Mr. WEBB. Does that include the annual authorization process, Senator Curtis?

Senator CURTIS. Yes.

Mr. WEBB. When you say you would preclude the budget——

Senator CURTIS. I do not want to get into discussions about the amount of the budget.

Mr. WEBB. Yes, sir.

Senator CURTIS. But I mean the laws the Congress has passed setting up the agency, the requirements, everything involved in the operation which is done in conformity to a statute.

Mr. WEBB. Senator Curtis, I am deeply grateful for your expression of the feeling that NASA, as a part of the executive branch, has endeavored to give you what you need here in this committee to act responsibly as a legislator. I am very grateful for that statement because that is what we have tried to do.

Now, it seems to me when we get into programs that have long lead times with respect to astronomical observatories which are going to be in orbit and refueled and being used time after time, with astronauts going up to them and setting them up with telescopes or with some new idea that an astronomer develops, and then when we have to go to the university campus to get outstanding graduates, their students, to commit 8 years of their lives to doing the scientific work that permits the proper use of these telescopes, it would seem to me that we should consider some form of authorization on a project like Voyager that does not leave it subject to the process of an annual authorization.

I think the annual appropriation is consonant with our whole system of reviewing the work of the Government by the representatives of the people, and I could think of no better way to do it.

I would hope that as time goes on, and we have moved toward these things that I have mentioned on the university campuses, where I assure you there will be 8-year lead times for the scientists and graduate students as well as for Government agencies and contractors, and as we then move into another field which offers almost unlimited promise; namely, the use of this new technology of the rocket to master and use the space environment, that we can work out some means by which responsible bodies like yourselves can devote your time to determining something of what has happened in the past, as you are doing here today, rather than to always be dealing with what we tell you we think we can do at some time in the future, which is the inherent nature of the annual authorization project.

I think oversight or feedback from operations by which to judge an annual appropriation may be more productive of strong technological power for this Nation in all the disciplines we deal with, and in this new field of technology.

VIEWS ON AUTHORIZATION PROCEDURE

Senator CURTIS. What you are saying then is you favor some longer leadtime in authorizations.

Mr. WEBB. Yes, sir; and a careful examination as frequently as you want to do it as to what progress we are making toward the goal set in the authorization, with utilization of the funding that is provided on an annual basis.

Senator CURTIS. Wouldn't you say, however, that thus far, appearing for an annual authorization has been good for NASA, and it certainly has been a source of education to the committees, and, in turn, to the country? Don't you believe that?

Mr. WEBB. I would, Senator Curtis, I would strongly endorse that view, and it may be good for another year or two. But at some point we need a little more stability to the authorization process and a little more time for the committees of the Congress to examine what actually happened rather than to spend so much time on what we think will happen if you provide a certain level of authorization.

Senator CURTIS. Yes.

The CHAIRMAN. Will the Senator from Nebraska yield there?

Senator CURTIS. I will be happy to yield.

The CHAIRMAN. Are you trying to say the annual appropriation act which is before the Appropriations Committee is necessary but the authorization is not necessary?

Mr. WEBB. I would hope that the authorization could be considered in some form that would go beyond 1 year, Senator Anderson.

You know very well, from your long experience, that you have provided us with no-year funds, and this is a very important part of the process by which we work together. So I am completely in agreement that what we have done together up to now has been good. I don't believe it could have been improved on in terms of education, acceptance and providing the power for the country.

If you look ahead for 10 or 15 years though an annual authorization and detail of these large programs is a process that may not be the most productive use of our time.

I want to get a feedback from what we do examine so that we can judge the future by what happened in the past, and we have not quite had that process in the authorizing committees in the Senate and the House, in my humble opinion, sir.

The CHAIRMAN. I want to say that I disagree with you. But that is all right. I sometimes feel the authorization goes as far as the appropriation, and this might be somehow tied to it in some degree. But I wanted to be sure that you understood that I thought the annual authorization was necessary.

Mr. WEBB. I think the annual authorization imposes a burden on time that could be better utilized. But again that is just my view.

May I say one other thing?

The CHAIRMAN. What would Congress do with all the rest of the departments that have the same thing, with the military and all the other annual authorizations before appropriations?

Mr. WEBB. Senator Anderson, as we move into these large technological programs with very long leadtimes, we are going to have to learn to marry public policy with great technical excellence and some interface between the two that is better than we have today if we are going to develop and use the power that will make the future of this Nation secure, in my opinion. I think that is really what I am saying.

The CHAIRMAN. Sometimes people get a divorce under the same circumstances.

Mr. WEBB. Yes, sir; and frequently the power that came from the marriage dissipates with the divorce, too.

Can I just answer Senator Curtis one more thing?

We do have some problems with respect to legislation affecting the acceptance of long-range risk, and there are certain elements of legislation that will be coming to you with a Presidential recommendation from the Bureau of the Budget that you will get a chance at.

But basically I have no other suggestion with respect to changes in the law. I think it is a good law, Senator Curtis.

Senator CURTIS. I see.

FAVORS PRESENT AUTHORIZATION PROCEDURE

Senator HOLLAND. Mr. Chairman, may I make one comment?

As the chairman knows, I sit on this committee, which is the legislative committee, and on the Appropriations Subcommittee which hears the appropriations for the Space Agency.

My observation would be this: That the matter of the authorization hearings goes much deeper into the detail of the subject matter and affords a text, a body of information, to the Appropriations Subcommittee and to the full Appropriations Committee not otherwise available to us.

I would respectfully, but very seriously, differ from the Administrator in his feeling that we could dispense with the annual authorization, because the Appropriations Subcommittee jurisdiction is over about 19, as I recall, of these independent agencies, and it simply does not have the time to go into the 2- or 3-day hearings on authorization. These authorizing hearings give the facts annually which the Appropriations Committee needs to have and has available in printed records when it reaches the appropriation procedure.

I approve of what the distinguished chairman has to say, and that is without any feeling at all toward the Administrator because we are all trying to go in the same direction and accomplish the same results.

These facts determined here cannot be available to the Appropriations Committee any other way, and I would very seriously disapprove our doing away with the authorization procedure.

The CHAIRMAN. I feel that my 25 years taught me that lesson, and I am glad to have your view.

Go ahead.

Senator CURTIS. I did not know what the response would be from any source when I asked the question.

Mr. WEBB. Senator, you have to remember that I started in this legislative process here when Mr. Hoover was President. I was a clerk to the Rules Committee, and I have had to look at how the administrative side of these things worked.

Now, the chairman has also, as Secretary of Agriculture, had all of this problem, too. We just happen to differ in our approach to it.

Senator CURTIS. Well, frankly, I think this, that probably we have to work out something with a little longer planning and lead-time which can to quite a degree be relied upon because of the long-range nature of the programs. At the same time, we should hold to the annual authorization. I think what we have to have is a combination of the two.

Now, one more question about the need for legislation.

Can you think of anything in connection with this accident that better legislation or a change in the legislation might be helpful in lessening the chance of it happening?

Mr. WEBB. No, sir; with the exclusion that you mentioned earlier, I cannot.

I would want to say this, Senator Curtis: Many people tend to compare NASA's operations with those of the military services.

I would like to point out that the military services are required to be a ready force and also develop the tools to which they will apply that force. They do a great deal of development work. They find that, as the years go by, and basic research feeds an on-going front of scientific knowledge and technology springs from that and new designs for tools, machines, technologies, out of that, then new machines have to have research in support of development. That is our function in NASA, for many purposes, for the communications satellite arena, whether it is military or civilian, for the resource survey type of things that the Agriculture and Interior Departments are interested in, for the meteorological and weather things that those services are interested in. I think it is very, very important to recognize that there is a great advantage in our not having to be a ready force because then we can do the job, the specialized job, for which we are set up, and we can consider the needs of those who have to be a ready force.

Now, this bears on the question of whether these various suggestions for an inspector general of NASA, and so forth, might be an improvement over what we have.

I think certainly there is room for difference of opinion as to whether the investigation we have conducted produced the best result that could possibly have been produced.

Senator CURTIS. Let me ask you, would you need a law to have an inspector general?

Mr. WEBB. No, sir; we would not.

Senator CURTIS. And the organization that has been set up has not been dictated by statute, has it?

Mr. WEBB. No, sir; it has not.

We have had more freedom in that regard than any Government agency that I know of, much to the advantage of the program.

Senator CURTIS. Yes.

I do not want to take too much of the committee's time, but I do want to ask, is it also true that in this very complex field, a field the consequences of which are enormous, that public acceptance of the program is an absolute necessity?

Mr. WEBB. Yes, sir.

Senator CURTIS. And it is the type of program that does not bring tangible monetary benefits or anything of that sort to the rank and file of our citizens immediately?

Mr. WEBB. It has the importance——

Senator CURTIS. And, therefore, it only comes about as they understand what is taking place and what our objectives are?

Mr. WEBB. And see the second and third order effects, Senator, as well as the first order effects.

QUESTIONS PAD ACTIVITIES PRIOR TO ACCIDENT

Senator CURTIS. Yes. I want to ask this question: Was there anything taking place on that pad on January 27 that had not taken place before? Was there any process, was there anything——

Mr. WEBB. No, sir. The spacecraft had been subjected to 16.7 pounds of pure oxygen atmosphere internal pressure both manned and unmanned prior to that test through which these men lost their lives.

It had also been in vacuum chambers under test at the vacuum—the pressure we use in space, 5 pounds per square inch.

It was connected with the total communications system of the Cape, however, in the same manner that it would have been on a launch.

This was the first of the spacecraft that we expected to launch with men in it. It was the first time we were slowly building up all of the competence to get to the top of the pyramid and launch.

So although in terms of the men in it, of the equipment in it, of the atmospheric pressure, of the use of the equipment in the spacecraft, of the training, nothing was different. But it was, in fact, connected with the total communications system of the Cape, and we were in the process of shaking this down and learning how to work out all the bugs so that we could launch. In that regard it was different.

Could I ask Dr. Mueller this—I want to be sure I am not giving you the wrong answer—is this the right answer? It is the right answer, he said.

Senator CURTIS. I want to make sure that the only new process that was going on that day was, or the new feature of the process was, the fact that the communications were connected.

Mr. WEBB. Would you let Dr. Mueller answer? Let me just say one word.

Senator CURTIS. I do not want to put words in his mouth.

Mr. WEBB. No. You see, when we put this spacecraft in a vacuum chamber or in another test facility, not on the launch pad on the Cape, we connected it up with power, and we connect it with simulated communications systems that run into the mission control center and elsewhere. But these are simulated.

Now, you put it on top of the booster on the pad, you are working toward launch, and you are connected with the real system, you see, and this is the major difference, as I see it.

George?

Dr. MUELLER. Actually, the communications systems are the same in both cases. The one thing that is different on the pad is that we are bringing in the communications systems that have to do with the launch vehicle as well as the spacecraft. So far as the spacecraft is concerned it had seen all of these before. But this is the first time that it has been tested with men on the launch pad with a 16 pounds per square inch oxygen atmosphere, and the first time the total communications had been put together.

Senator CURTIS. And you had never tested it with men before?

Dr. MUELLER. Not that day.

Senator CURTIS. Not before that day.

Dr. MUELLER. Not before that day.

Mr. WEBB. It had been tested for longer periods of time than the men were in it prior to that day, with men in it prior to that day.

Senator CURTIS. Now, what was new that day?

Dr. MUELLER. There was not anything really new that day.

Mr. WEBB. Except the fact that we had a point of ignition that started a fire.

Dr. MUELLER. That is right.

Mr. WEBB. And we were having troubles with the total communications system at the Cape as we made the first connection between the capsule through the booster with that system.

Senator CURTIS. Well now, that first connection of the communications system that you are talking about, was it through that that the fire occurred?

Mr. WEBB. No, sir; not at all. It only delayed the conduct of the test and showed us we had certain deficiencies and trouble in the communications system. It was in no way, that we have been able to discover, related to the ignition point of the fire or the fact that the fire spread.

This came from arcing and from the existence of combustibles in the spacecraft that we will not put there again when men are in it.

Senator CURTIS. In other words, what you were doing on that pad on that day consisted of things that had been done before on the pad with the exception of your communications system and those new activities had no relation to the fire; is that correct?

Mr. WEBB. I think that is true. But I must add one other exception, Senator Curtis.

There were two pads on the floor of the spacecraft that were there so that when the men were to practice an emergency exit from the spacecraft at the end of the flight they could take the hatch and drop it down against those pads because the emergency exit test requires them to get out in a hurry.

We did not want to damage the spacecraft or the hatch, so we put two pads on the bottom, and the idea was that these men would release the hatch, drop it down against these pads and get out as quickly as they could.

Now, those pads contributed to the fire. They would not have been there in flight. They were not there on the previous times when we tested this spacecraft with 16.7 pounds of oxygen and with men in it.

Senator CURTIS. The pads had nothing to do with the origin of the fire?

MR. WEBB. No, sir. Well, but they had to do with the spread of the fire.

Senator CURTIS. I see.

Mr. WEBB. And they provided fuel for the fire, and the fire might not have been fatal if those and other combustible materials had not been there. They might have had time to get out, and there might have been time to release the pressure and stop the fire if the pads had not been there.

Senator CURTIS. Now, by pads you are referring to the launch pad?

Mr. WEBB. No, sir. I am referring to two little things like pillows.

Senator CURTIS. Inside?

Mr. WEBB. Inside; yes, sir; something that would cushion—when you take a hatch down and put it down as fast as you can, you can damage it against some other part, and you can damage the spacecraft.

So we wanted sort of a shock absorber, something that this could rest on, like a pillow without damaging anything.

Senator CURTIS. And they had never been in there before?

Mr. WEBB. They had not been there—I am not sure about that.

Dr. MUELLER. They had been there before, Senator Curtis, but not in that location with a 16-per-square-inch oxygen atmosphere.

Senator CURTIS. Then this leads to my final question: Was there anything that had occurred prior to January 27 which would have caused prudent men who were scientifically trained in the space sciences to feel that there was an unusual danger on January 27?

Mr. WEBB. Senator Curtis, the only way I know how to answer that is that prudent men like Frank Borman, who was on the backup crew for the next one, did not feel that there was the danger there. I am sure a prudent man today would not do it.

Senator CURTIS. My question was not too well stated.

As I understand your answers, practically everything was being done that day had been done before.

Mr. WEBB. This is true, sir.

Senator CURTIS. That is all.

The CHAIRMAN. Senator Symington.

DISCUSSION OF OTHER ACCIDENTS IN SPACE PROGRAM

Senator SYMINGTON. Thank you, Mr. Chairman.

Mr. Director, when did NASA start as an agency?

Mr. WEBB. In late 1958, I believe, November or so.

Senator SYMINGTON. How many people have you working in the Agency now?

Mr. WEBB. In all of our installations, approximately 35,000.

Senator SYMINGTON. Is this the first serious accident involving loss of life that you have had?

Mr. WEBB. No, sir. It is in a manned spacecraft. We lost some men when a rocket that was being tested on a spin table went off and burned three men. I believe all three died, and we lost three astronauts, as you know, in airplane crashes.

We have a large operation. Men have been lost in the construction program. Some were electrocuted on cranes that touched high-tension wires, but all of this is very much a common experience with all who have conducted this kind of a program in various parts of American life.

We lost test pilots, too, as you know, Senator Symington.

Senator SYMINGTON. I am not talking about those. About the men who died in St. Louis—accidents of that character. You lost three men on a launching pad. How many men have you lost in the actual operation of the agency?

Mr. WEBB. Yes, sir. But we lost an airplane that was checking out the range that, I believe, had six men on it several years ago.

Senator, we have had loss of life, and I have never known a program like this that has not.

Senator SYMINGTON. I am only asking for the facts.

Anybody who makes or has made anything knows that you always produce some improper articles.

We have a couple of cars, I have one, my wife one, and both of us have had letters from manufacturers saying certain parts were wrong. Anybody who has ever had any industrial experience knows you cannot make everything right all the time. The president of the company cannot watch over the shoulder of every welder. You say you have 35,000 people.

Was there any special heat put on you to put out the product quicker which you feel in any way resulted in this accident, or any other accidents you have had?

Mr. WEBB. No, sir, Senator Symington. We have never had an instruction from either President Kennedy or President Johnson except to launch when we were ready and not to launch until we were ready. There has never been a political ingredient established to guide us in these matters.

Senator SYMINGTON. I have had the privilege of being connected with what one might call permanent government organizations as against new government organizations, departments. And, at times, especially in starting up a new organization, you have problems incident to getting personnel, do you not?

Mr. WEBB. Yes, sir.

Senator SYMINGTON. The more technology involved as a requirement in people you want to work for you, the more difficult it is, especially in government, to obtain exactly the right people; is that a fair statement?

Mr. WEBB. It is, Senator Symington. The further you get up into the technology areas of very advanced technology, the more disparity there is in the pay.

Senator SYMINGTON. And you and Dr. Seamans have done your best to get the best people you could to do the work?

Mr. WEBB. We have, Senator Symington.

Senator SYMINGTON. Down at the Cape, which not too long ago was a spit of sand, you have built a great technological establishment. You have a lot of people down there. Some are happy, some not so happy, for many reasons; as examples, the amount of pay, the fact somebody was promoted over them, the fact their talents, at least in their opinion, are not being recognized. This is always true when you are building up rapidly an operation of this character, either in private business or government; is it not?

Mr. WEBB. Yes, sir.

Senator SYMINGTON. Sometimes those people express their sympathies to you and sometimes they express them to the outside, do they not?

Mr. WEBB. Yes, sir.

Senator SYMINGTON. Have you any evidence that people have been passing stories around so as to accentuate the problems incident to this tragedy?

Mr. WEBB. I would like not to answer that question, Senator Symington.

Senator SYMINGTON. Well, Mr. Chairman, I would have the record show that the Director and I have never discussed this matter before. I wondered, inasmuch as there has been such heavy criticism of this the very first accident of its kind. There will be other accidents, and I am glad to hear there has not been any pressure on him either from the Administration or the Congress.

The program has been extraordinarily successful up until this unfortunate accident, and I want to express my confidence in the Director and Dr. Seamans, also my hope that in the future they will have as little trouble as they have had in the past.

One other question: You are not in any race to get the moon; are you?

Mr. WEBB. We are in a fast-paced program, Senator Symington, to do the work, to develop the capability of landing on the moon and get back as rapidly as we reasonably can with the resources, but not what I would call a race.

It may be that we decided not to have this race a year or two ago insofar as the Russians are concerned.

Senator SYMINGTON. You could not promote the morale of your organization if you said, every morning "Let us all be sure we are going to be behind the Russians in getting to the moon"?

Mr. WEBB. No, sir. There are lots of people that do not want to be behind them, including Frank Borman who spoke here. But in my view, those views have not driven us to things that should not have been done in this program.

Senator SYMINGTON. It would be natural for you to say, "Let us do it as well as we can as fast as we can, and thereby save as much money as we can, and hope to get there first." That would be a normal action of management, would it not?

Mr. WEBB. Yes. But I would not sacrifice the first two for the third, which is to get there first.

Senator SYMINGTON. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Jordan.

QUESTIONS ON DUAL RESPONSIBILITY

Senator JORDAN. Thank you, Mr. Chairman.

Mr. Director, up until January 27 NASA's safety record had been very good, as you have recounted here in answer to Senator Symington and others.

It seems to me that a further rehash of events and circumstances that culminated in that 204 Apollo tragedy are meaningless except as they contribute to the prevention of accidents in our future space efforts.

There are one or two points I would like to clear up here because I am not just sure of what the testimony has been.

My first question is this: At what point does contractor liability cease and NASA responsibility take over, and is there a vague area of dual responsibility?

Mr. WEBB. Senator Jordan, it is not a vague area. In these areas of very advanced research and development, NASA's responsibility, the U.S. Government's responsibility, is complete.

We try to pass as much of that to the contractors as we can. They have an obligation to do the very best they can, but in terms of, say, financial liability, things of this kind, the Government has had to assume the risk of success or failure in these very advanced projects.

Now, on fixed-price contracts, things of this kind, this depends on the contractual arrangements. We do not have a large number of those, and we do have certain pressures of contractor liability in the sense that we have driven as hard as we could to get incentive contracts, and this applies even to base support contracts where there is a rating by the Government of the contractor as frequently as once a month, with then a meeting to determine whether the contractor agrees or disagrees, and with the payment to the contractor under an incentive or a penalty placed on him based on this rating.

So there is some question of what you mean by liability. But in terms of financial liability for the loss of a vehicle, things of this kind, it is clearly the Government.

Senator JORDAN. Clearly the Government?

Mr. WEBB. Yes, sir.

Senator JORDAN. So the liability of the contractor ceases upon delivery to you and acceptance by you of the object, the spacecraft?

Mr. WEBB. No, sir; no, sir.

Senator Jordan, one of the most imaginative and forward-looking features of our program is that we have worked out ways and means to keep the contractor continuously involved until the vehicle is in orbit.

Senator JORDAN. Successful flight.

Mr. WEBB. The contract is for work from the first manufacture and design through the test, on through assembly, on through launch, and his men are right there when this decision is made, do we launch or do we not launch, and his people have to sign off, they have to take their part of the responsibility.

If the vehicle succeeds some of them will be paid according to the amount of time the vehicle works in orbit. So we keep them continuously involved just as long as we possibly can.

Senator JORDAN. Some of these incentive payments will be forfeited by reason of failure of this vehicle?

Mr. WEBB. Yes, sir; although this, in my view, for reasons of equity and inability precisely to determine mathematical ratios should be worked out in an overall settlement between North American and ourselves.

We must revise our schedules. We must consider very carefully how we proceed with the spacecraft 101, the first model of the Block II, and the extent to which we are prepared to insure costs between now and the time that first manned vehicle will be launched.

So I think there are so many complexities here, it would be better to try to work them out in some kind of an overall settlement or relationship or renegotiation, which we expect to endeavor to do, and then to report back to this committee and give you an opportunity to advise us before we put it into final effect.

So there will be penalties, in my opinion, but I would prefer not to be too precise about them, dependent on this overall workout of the many problems involved.

Senator JORDAN. Thank you.

Mr. WEBB. And again this is a preliminary view, Senator. I have not seen all the evidence yet. I mean I am giving you now maybe my thoughts rather than a promise, except for the fact that whatever we work out we will be coming back to you to get your advice.

TRADEOFFS OF NEW ESCAPE HATCH

Senator JORDAN. I see. Thank you.

On another matter, a point was made by one witness here about a week ago, a member of the Board from the Department of Interior, that had the new escape hatch been installed in this spacecraft it might have been possible for these three astronauts to escape.

This brings up a question, and I understand that an improved escape hatch is in being.

Mr. WEBB. It is almost through its design. We will test it, we will make a decision, we will let you know what we think we should do 2 weeks from now as to putting it into production for the 101.

I think George Mueller has practically made up his mind. I have not yet made a final decision insofar as my responsibility is concerned.

Senator JORDAN. And is there any likelihood that with the acceptance of this improved escape hatch, we might be trading off the safety of astronauts in orbit for the safety of astronauts on the pad?

Mr. WEBB. Senator Jordan, I think it goes to another matter that must be incorporated in this discussion.

The improved hatch was under design considerably before this accident. But for the reason that we needed a better means to egress and ingress in space because we must be able to operate outside the spacecraft where we are dependent for success on joining two spacecrafts in orbit and where, if anything goes wrong, one of the ways to try to get it fixed and save the mission is to send the men outside to make a correction or to do something that cannot be done from inside the spacecraft. So the main purpose of our previous work, the work that has been going on, has been to permit us to operate in orbit.

Now, if we have to have it to operate in orbit anyway, I think the fact that it may be less completely secure, from possible decompression of the spacecraft in space would have to be taken as a part of the extra benefit of being able to operate more readily outside the spacecraft in space.

Senator JORDAN. But you will report on that to us later?

Mr. WEBB. Yes, Sir.

But I would like to make sure you understand that the fact we started on this design some time ago was not for the safety on the pad so much as to perfect our operations in space.

Senator JORDAN. I see. Thank you.

One final question, Mr. Director; are you satisfied now that full cognizance has been taken of every conceivable factor that may have contributed to the Apollo tragedy, to the end that future space efforts will not be encumbered by this single tragic failure on the pad?

Mr. WEBB. No, sir. That is the point at which I hope to arrive when I come back 2 weeks from now.

Senator Jordan, I have decided last night, after a long and detailed examination of quite a lot of records, that I would establish what I would call an Administrator's Review Panel. This Panel will pull together not only the documentation that the Board used, but all material that we have in NASA, including that in the General Counsel's office, those problems that relate to the legal relationships here, and have that Panel responsible for presenting to Dr. Seamans, Dr. Mueller, and me those things that we should use as three responsible men working toward a decision that we can then report to you so you can give us your advice.

I have established that Panel, but not in writing as yet. I will do that the first time I have a chance to write the proper letters and memorandums.

It seems to me that we need in NASA a means by which, at the level that the three men here at the table have to operate on these large decisions, a mechanism for an orderly presentation of all facts that we should consider.

Now, Dr. Mueller, I am sure, believes, and I believe, that he, as the head of the program, will give me a responsible recommendation that will take into account those things that you have mentioned.

I want to see not only what he has from the program office but what all of our people have.

I would like to see from our Office of Industry Affairs—the Assistant Administrator for this office will chair this Panel—all they know about all contractors rather than just those in the manned spaceflight program.

So this is the procedure we expect to use to arrive at the point that we can come back to you two weeks from now.

Senator JORDAN. Thank you for your frank answers. I appreciate your cooperation.

Mr. WEBB. Thank you, sir.
The CHAIRMAN. Senator Holland.

CONTROL OF FLAMMABLE ARTICLES

Senator HOLLAND. Thank you, Mr. Chairman.

Mr. Webb, at their testimony before this committee last week, Dr. Seamans and Dr. Mueller, following up testimony given by one or both of them at the earlier hearing, made it quite clear that at or just prior to the time of this test on January 27, the total concern—I believe that was the word that they used with reference to the prevention of fire inside the spacecraft—was to prevent the ignition, but that their decision since the accident had been that ignition failures could not be completely or perfectly avoided. There might be a spark anyhow, and that the subject of greatest attention should be the flammability of the objects and the geometrical arrangement of those objects within the spacecraft.

Mr. WEBB. Senator Holland, I believe that I would put the emphasis somewhat differently, and I believe maybe they meant to do that.

I think, first of all, we must continue to take the most extreme and rigid care to prevent a point of ignition under any circumstances.

Now, second, we must supplement that care with both control and arrangement of any flammable articles, and we must do all we can to develop new articles like beta cloth that will not burn under any conditions. I think that is the way I would state it.

Senator HOLLAND. Well, I think that is an understandable way to state it, and I suspect that members of this committee might have made the same decision made by you gentlemen in view of the successful termination of the manned Mercury missions and the Gemini missions, which were also manned, with full strength oxygen, although under somewhat different pressure, and with somewhat the same furnishings within the capsule.

Mr. WEBB. I hope you would have been wiser than we were, Senator.

Senator HOLLAND. Well, I would hope so, but I can easily see that success in those several missions—how many were there, manned missions—seven all told?

Mr. WEBB. No, sir; more. We flew in the Gemini program 20 men in 20 months, and we flew six men in the Mercury program, including two suborbital flights, so there were 26 individuals who went into space in the combination of those two programs.

Senator HOLLAND. Well, that was enough to make reasonable people feel that, perhaps, the answer had been reached. Certainly I found no fault with that decision having been made at that time, although I share your feeling that we would have wished that it could have been otherwise.

But you were trying to exercise all possible care.

Mr. WEBB. Thank you, Senator.

Let me give you an illustration of what is involved here.

In the Mercury program we had a minimum of weight. We could not put switches in the circuits for the communications system, so an astronaut, if he wanted to plug in the communications system simply plugged it in. It was live. I mean, there was no switch in the circuit.

Now, this worked well. We thought it has worked well in Mercury and we will move to Gemini.

We did, and we never had the slightest trouble with it. But we are now putting switches in the Block II Apollo.

Now we are putting switches in every one of these circuits so we will not plug in either instrumentation or communication equipment from an astronaut into a live circuit. We will have a switch that will turn the circuit off.

Senator HOLLAND. I understood from the testimony of these gentlemen the other day that some of the safety measures that provide better internal arrangements, and some that provided less flammable material, were already reflected in the Block II spacecraft.

Mr. WEBB. Yes, sir; and they were before the fire.

But Senator, you must bear in mind that a switch inserted in the circuit can itself cause trouble, so we have some real problems in that regard.

Senator HOLLAND. Well, I so understand it, and I think I understood these witnesses to testify the other day that except for the changes by way of improvements already built into the Block II, that you would not be able to disassemble Block II, and put in other changes that you might discover as a result of the accident. Does that still remain the case?

Mr. WEBB. Senator, I believe it is a slight difference—it is slightly different than that.

Senator HOLLAND. I wish you would state it just exactly the way it is.

Mr. WEBB. Yes, sir.

The first model, spacecraft number 101, which is the first of the Block II series, has been fabricated, has gone through the assembly process, is now under test, and we have kept it in the testing process in the period since the fire.

Now, we are benefitting from this testing experience. We are relating the condition of the spacecraft and the result of these tests to what we have learned from this examination, and will take steps to incorporate in Block II, including this first model, all the things that we have learned that we feel are necessary for a safe flight because we do expect to fly that No. 101 as the first manned flight.

Senator HOLLAND. You do not expect to send men up in any Apollo capsule that does not have every additional protective and security measure that you will have discovered as a result of the accident to 204?

Mr. WEBB. Senator, we will put in there every measure calculated to make it a safe mission. I should say that there is going to be an area of judgment here where certain things can be done which may add to safety at one point in the flight and not to another, or may for one reason or another not be incorporated.

In other words, you simply cannot put in one of these spacecraft everything somebody thinks will make it a little safer. It is a very delicate operation to make a machine that can go to the moon and land and get back, and you have to be very, very careful about adding to a system that we have built up over a period of years and where thousands of people have made their best contribution to it.

Now, if we are sure that something will add to the safety we will certainly put it in. We will not put in everything that somebody suggests.

ASTRONAUTS HAVE RIGHT TO DECLINE FLIGHT

Senator HOLLAND. I am glad you have accentuated during this hearing one thing that I do not think has been made sufficiently clear, at least to the public, and that is that the astronauts themselves, whose lives are at stake and who have become, of course, highly trained specialists in this particular field, I might even say highly trained scientists in this particular science, have always the right to say "No."

Mr. WEBB. Absolutely, an inviolate right, Senator.

Senator HOLLAND. And while that does not take from the seriousness of this accident, it does make us realize that the very men who knew better than anyone else that their lives were at stake not only every moment in flight but also at many stages on the on-earth preparation for flight, that they must have felt secure or they would have objected at the time that they were asked to make this test in January at the Kennedy Center.

Mr. WEBB. It adds a stern discipline to all nonastronauts also, Senator, not to come up to a point where an astronaut will say, "I am not prepared to fly that spacecraft."

Senator HOLLAND. I understand so, but I want us to understand, and I want the country to understand, that the astronauts themselves do have this right, that you encourage them to exercise it, and that unless they have felt that every precaution of which they know has been taken that they would be very foolish to risk their lives, particularly in a test of this kind not in flight.

Now, I was impressed particularly with your use of the words "confidence of the country" in your first statement.

You recognize the fact that not only the confidence of the men with whom you work, and not only the confidence of the committees of Congress and of both Houses of Congress, but that the confidence of the country must be a factor to be always recognized by you as the responsible administrators of this great program, and I was glad to note your use of that term.

Your meant, I hope, that you regarded the creation and the maintenance and retention of public confidence as one of the ends which had to be subserved as you moved forward in this program.

Mr. WEBB. I do, Senator.

I should like to point out to you, sir, that when Senator Symington asked me if I had any evidence of people who, for one reason or another, liked to put into circulation information, and I preferred not to answer, there is no way that you can have universal confidence in any public official that I know, but we have tried to so conduct ourselves as to deserve that confidence. Insofar as I am concerned, I do not expect to engage in activities just for the purpose of trying to generate confidence. I hope that the decision that we made, as soon as I came into this organization, that we would try to talk about things when they came out of the pipeline and not when we put them in, can be preserved.

Senator HOLLAND. Well, speaking only as one Senator who is sometimes inclined to be a little bit suspicious, maybe that is my professional training, I have very great, I have very great, I have unlimited, confidence, insofar as you can have confidence in human beings, in yourself, in Dr. Seamans and Dr. Mueller, and the other chief administrators in your program.

Mr. WEBB. I would like to thank you, Senator for all three of us, and many others.

Senator HOLLAND. I just hope that on your part you have that complete confidence in the members of the committees of the two Houses in our desire to further this tremendously important program in every way that we can reasonably further and support it. I hope that you haven't because I think mutuality in this matter is necessary.

Mr. WEBB. I have it, Senator, and I believe I had demonstrated it by coming to you with the fullest and frankest kind of information, including the presentation to you of the full and complete record of the Board, with all appendixes at the same moment I received it and read it. If I did not believe that you would judge this kind of material with the greatest of care and responsibility I would have had the gravest concern. I never gave it a moment's thought because I was certain that was the right thing to do.

Senator HOLLAND. Well, I thank you, and I want to close on just one note, maybe because I have got a little more grey hair than some of the rest of you. I do not want to see any of you people be so deeply concerned, so overanxious about this matter, that that might impose upon your health, your nerves, your objectivity or your calmness, because I think that those factors are going to be completely necessary to the working out of this problem in such a way that you are going to retain that public confidence which you know is supremely necessary in this matter.

Mr. WEBB. Thank you, Senator.

Senator HOLLAND. I have been a little fearful that maybe these long hours, maybe this tremendous pressure—and I think I have an idea how tremendous it has been—might sometimes have made you feel that you could forget that you are human beings with nerves and strength that can be overstrained. My only comment right now would be that this is a long pull, and that I hope that you chief executives in this matter will retain the calmness and the poise and objectivity which I think is a complete necessity, and I would hope and believe that you will, and I certainly will continue my feeling of confidence so long as that is the case.

Thank you very much.

Mr. WEBB. Thank you, Senator.

Let me say that I deeply appreciate that. I appreciate your personal concern.

There have been some of our men who have spent too many hours, and we have had to insist that they stop that and get a little rest. That does not apply to the three men at this table, and I believe that the three of us will be able to maintain a sense of balance and continue to merit your confidence.

QUESTIONS ON SAFE COMPLETION OF APOLLO PROGRAM

Senator HOLLAND. One more question or comment if I might make it, Mr. Chairman.

You know, coming from the state that I do, I get, perhaps, as many reactions from the public as does any Senator, and I have gotten very many reactions of various types, particularly from the central Florida area which is closer to this matter geographically than any of the rest of us.

74-521 O—67—pt. 4——8

I would like to see in your budget presentation and in your own planning and in your own assignment of your most capable personnel every accentuation possible in the solution of this problem, and your moving ahead to where you feel it is safe again to have manned flights in the Apollo program and a deceleration of the post-Apollo program.

I think that would be an element in the making of even a greater confidence on the part of the public, and I just drop that out because I strongly feel it as the result of numerous reactions I have had from Florida. They feel the big job right now is to get over this hump and to get this Apollo program back on the completely safe or as nearly completely safe basis as human ingenuity can make it, with every emphasis placed upon that rather than with a diversion of energy, thinking, and scientific skill at this stage into too great a degree in the post-Apollo program.

Mr. WEBB. Senator, I must say one word there. If we increase our layoff rate from 5,000 men a month to 10,000 and do not prepare to keep the production lines of Saturns going there is not going to be any space program. The post-Apollo funding is largely to keep on the job people making big boosters and those who will be prepared to learn from the Block II Apollo whether or not that is the spacecraft we want for the post-Apollo systems, and whether we can spend relatively limited amounts of money to take advantage of flights that may not be required to do the Apollo mission.

I do not see how we can place a lower priority on the post-Apollo for 1968 than on the Apollo itself. I do not see it.

Senator HOLLAND. Well, you spoke of public confidence, and I am simply passing on to you as one confederate to another, because that is the way I feel about this matter, the reaction that has come to me. And I think that the interest now is centralized and concentrated entirely on getting over the hump, and I hope that the attitude of NASA not only at this hearing but at the appropriation hearings which are coming up, will reflect that same attitude because it is rather important, and that is all I shall say. I do not expect you to take my advice, but I expect you to consider it.

Mr. WEBB. Senator, I do not think I am going to take it because Dr. Mueller has just said that if you followed that line the Apollo program itself would involve an additional element of risk that will not be in it if we go forward with the Apollo Applications Program.

It will decrease the safety of the Apollo program.

Senator HOLLAND. That would mean you would be stopping things that are directly contributing to the Apollo program, and I have not even remotely suggested that. I have suggested that you accentuate those things that contribute to the Apollo program, and that you deemphasize those things which do not contribute to it.

Mr. WEBB. Let me explain what I mean by that.

Unless you fly a certain amount you cannot maintain your proficiency to fly, and if we limit our work here to only the flights that can come out of the Apollo program and do not take advantage of a relatively level effort of launching four small Saturns and four large ones a year we will not have as much assurance of safety on each launch as we will have if we do that.

So this is what I mean; you cannot just launch a rocket once a year and maintain the competence to do it, so the Apollo Application fits in with the other and maintains the competence so that all of it works better.

Senator HOLLAND. If you would just simply make completely clear to the committees of Congress and to the public that everything you are asking for is something that, in your view, will contribute to the safe completion of the Apollo project you will be carrying out the suggestion that I have made.

Mr. WEBB. I will certainly follow that, Senator. Thank you.

The CHAIRMAN. Senator Brooke.

QUESTIONS ON APOLLO CONTRACTOR

Senator BROOKE. Mr. Webb, I applaud you and the members of NASA candor with which you have answered the questions which have been asked you by members of the committee.

I had the opportunity to ask Dr. Seamans and General Phillips pertaining to a task force report concerned with North American. I do not know whether you were in the hearing room at the time.

Mr. WEBB. No, sir. I was appearing before the Appropriations Committee trying to get the 1968 budget approved.

Senator BROOKE. Yes, that is right. I do recall that now.

Dr. Seamans said the procedure would be for him to make a recommendation to you relative to replacement of the contractor, but he had never thought it advisable even with the report that was rendered by General Phillips to make such a recommendation, and General Phillips, upon questioning, was asked to give the nature of his findings in his report, and he did so.

Now, my question to you, sir, at any time did you consider the replacement of North American as a contractor in the Apollo program?

Mr. WEBB. Senator Brooke, I was asked that question when you were out of the room by Senator Cannon, but in a slightly different form. He said "Did you ever think of this," I believe he said, and I requested him not to press me on that matter.

The reason that I made that request is that we are dealing here with a new way for a governmental agency to spend 90 and 95 percent of its resources outside the Government involving the best we have in industry and, in essence, working together in a learning process.

Every major contractor that we have had operating in space, and certainly all of those who are involved in the large systems for manned space flight from Mercury through Gemini through Apollo, through the booster stages have had to go through a learning process through which they found that to work with space systems was different from working with aeronautical systems or with any other kind of systems they ever worked with.

I pointed out that the real issue was not whether we had to go through that learning process that we have not been able to find a substitute for, but whether we could convert the knowledge gained in the early learning process to an effective system of management based on work packages through which the Government and the contractor could then efficiently utilize the knowledge gained during the learning process.

Now, in that regard there are substantial differences between companies. There are substantial differences between divisions of one company with respect; first to the learning process, second with the ability to translate that knowledge into an effective and efficient system of management which gives you visibility—responsible knowledge of how to estimate the costs and things of this kind.

Now, in that process, any senior administrative person undoubtedly has thoughts about whether or not he could do better elsewhere, and so forth. I do not believe the protection of this system which has given us the benefits it has is one of my small responsibilities. I think it is one of my largest, and I am very anxious not to do anything that makes it hard to work intimately, directly, confidentially with these different companies in order to go through these two processes, the learning process and the translation of that into a capability the country can count on.

So I would hope you would not press me whether or not I have considered this. You know these gentlemen have not recommended it to me.

QUESTIONS ON CONTRACTORS AVAILABLE FOR SPACE WORK

Senator BROOKE. Mr. Webb, let me ask you a quick three questions and see if you can give me three quick, brief answers.

Number one, how many contractors are available to you for this spacecraft work?

Mr. WEBB. There have been in these larger requests for proposals anywhere from 20 down to 4, 5 or 6, generally in that range. But there are not a large number of companies capable of doing this kind of work.

Senator BROOKE. How many are capable of doing this work, in your opinion?

Mr. WEBB. Are you thinking of the Apollo Command and Service Module?

Senator BROOKE. Yes.

Mr. WEBB. I would say no more than a dozen, and most likely four would include the most competent. Is that a reasonable statement, George?

The CHAIRMAN. We have a vote on. Do not confer too long.

Mr. WEBB. Dr. Mueller expands the list a little. He says 20 might be able to do it and ten might be considered competent.

Senator BROOKE. How many have bid on it?

Mr. WEBB. Six companies bid on the Apollo. I believe there were 5 or 6. I will have to look at—5, Dr. Seamans tells me.

Senator BROOKE. And are you compelled to take the lowest bidder?

Mr. WEBB. No, sir.

Senator BROOKE. How much leverage do you have in this regard?

Mr. WEBB. It depends on whether you are speaking of legal or whether you are speaking of practical latitude.

Now, we have a Source Evaluation Board. They go into everything and report fully to Dr. Seamans, Dr. Dryden when he was alive, and to me. We make this selection with the advice of the person who has to be responsible for the contract. In this case the Source Evaluation Board did give its preference to North American. There was a unanimous recommendation to me from Dr. Seamans, Dr. Gilruth and Dr. Dryden that that was the company that was likely to do the best job and should be selected for negotiation.

Senator BROOKE. Mr. Chairman, I notice we have to go for a vote. But is it the intention of the Chair to call the contractor in for these hearings at all?

The CHAIRMAN. We have not as yet decided on that. It needs to be discussed.

Senator BROOKE. May I suggest to the Chair, because we are conducting an investigation in which we are calling NASA, and NASA officials primarily and, of course, a great deal of this program was left to the contractor, the contractor had great responsibility in the program, that many of the questions that I would like to ask cannot be fairly or justly asked of NASA, and should more appropriately be asked of the contractor.

The CHAIRMAN. We have 7 days of hearings on the budget and we will try to get into that.

Senator BROOKE. May I recommend to the Chairman that we do ask the contractor to come in.

The CHAIRMAN. We will try to get it done.

Before we close, Senator Smith had a question here.

INCENTIVE CONTRACTS

Senator SMITH. Going back to my question on incentive contracts, my reason for asking the question was because of NASA's release dated January 21, 1966, which stated:

> The National Aeronautics and Space Administration converted one of its major contracts today from a cost plus fixed fee type to a cost plus incentive fee agreement.

However, the release further stated—

> The conversion covers the contract period from October 1965 to December 3, 1966.

Thus, the cost-plus incentive fee agreement did not cover the time of the accident, January 27, 1967, and we understand that negotiations were going on at that time.

Mr. Chairman, I ask that the entire release No. 66-15 be placed in the record at this point.

The CHAIRMAN. Without objection, that will be done.

(The release referred to follows:)

APOLLO SPACECRAFT MAJOR CONTRACT IS CONVERTED

The National Aeronautics and Space Administration converted one of its major contracts today from a cost-plus-fixed-fee type to a cost-plus-incentive-fee agreement.

With the North American Aviation Space and Information Systems Division, Downey, Calif., the contract is for development of the Apollo spacecraft Command and Service Modules and the adapter which houses the Lunar Excursion Module.

The conversion covers the contract period from October 1965 to Dec. 3, 1966. Estimated cost is $671,300,000. Additional negotiations will be held for subsequent periods.

The contract provides profit incentives for outstanding performance, cost control, and timely delivery as well as potential profit reductions when performance, cost and schedule requirements are not met.

North American was selected by NASA in November 1961 to develop the Command and Service Modules of the spacecraft for the Project Apollo manned Moon exploration program. The work includes manufacture of the spacecraft, LEM adapter, spare parts, ground support equipment and extensive ground testing. Cost of the work, including the new agreement, is $2.2 billion.

The Apollo mission calls for three astronauts to be in the Command Module when the spacecraft is launched from Cape Kennedy, Fla. and when they return to Earth. The Service Module, unmanned throughout the mission, contains the main propulsion system for operations in space and other equipment to support the Command Module.

A third segment of the spacecraft, the Lunar Excursion Module, is being developed for NASA by the Grumman Aircraft Engineering Corp., Bethpage, N.Y. When the three-module vehicle is orbiting the Moon two astronauts will enter the LEM from the Command Module, detach the LEM from the mother ship and descend to the lunar surface.

The spacecraft development contracts are managed by NASA's Manned Spacecraft Center, Houston.

Senator SMITH. Is this a normal procedure not to arrive at an agreement on such an important provision as an incentive fee until after part of the work is already completed? You may answer for the record if you wish.

(The answer follows:)

Under normal conditions agreement on incentive fee provisions would have been reached prior to the scheduled effective date of the new incentive contract. Accordingly, extensive negotiations were conducted between NASA and NAA prior to the expiration of the October 1965 to December 3, 1966 incentive increment; however, full agreement was not reached. After December 3, 1966 negotiations proceeded with the intent that incentive provisions based on continued cost, schedule, and performance objectives would be made retroactive to the previous incentive expiration date. In this way, the advantages of an incentive arrangement were maintained despite the fact that final agreement had not been reached. Tentative agreement had been reached prior to the accident of January 27, 1967; however, the contract had not been signed at that time. Due to the accident, the incentive concept has been under intensive review in order to assure proper motivation affecting reliability, quality, performance and cost.

The CHAIRMAN. Mr. Gehrig has some questions.

Mr. GEHRIG. Mr. Webb, so that the record may be absolutely clear, are you personally satisfied as to the objectivity of the Board's work?

(The answer follows:)

I am completely satisfied with the objectivity of the Board's work. I believe that anyone who has read the report with its supporting documentation, and who heard their testimony before this Committee would be confident that this Board approached its work objectively and independently. I think they did an outstanding job under very difficult conditions.

Mr. GEHRIG. Earlier in the hearing, Senator Curtis asked a question as to whether or not there were any firsts, whether any operations were occurring for the first time during the accident which occurred on January 27.

As I understand it, all of the operations had taken place earlier either on the pad or in the simulator.

But January 27 was the first time the spacecraft on the pad was pressurized with 16.7 pounds per square inch pure oxygen with the men in the spacecraft; is that correct?

(The answer follows:)

Yes, this was the first time spacecraft 012 was manned with 16.7 PSI pure oxygen on the pad. However, it should be pointed out that the manned spacecraft with 16.7 PSI pure oxygen was subjected to several tests in the altitude chamber at KSC. There were no "firsts" other than the fact that this was the first time we were running that particular test.

Mr. GEHRIG. Mr. Webb, there has been much discussion about the schedule for the Apollo program, and statements have been made that the Apollo program is a crash program and should be placed on what some call a sound, practical, deadline-free basis.

Earlier in your discussion you mentioned the usefulness of the schedule as a management tool.

Dr. Thompson, in his appearance before the committee, said about the schedule:

A program of this kind has to have a very hard drive. It has to have built-in urgency in order to keep all the people properly motivated.

Would you please address yourself to the importance of a sound but tough schedule to accomplish a program of this magnitude.

(The answer follows:)

The thread that ties a development program together is its schedule. This describes the effort that each element of the program must expend in relation to all the elements in order to achieve the program objective. The more complex the program (the greater its diversity), the more carefully must the basic schedule be developed so that the program can move forward with disciplined balance and flexibility. A schedule that is too lax is wasteful and the solution of problems is not pursued with vigor; a schedule that is too tight will have a similar result because the schedule cannot be met no matter what effort is made. Whenever a schedule slips, the funding requirements rise because the effort must be maintained for a longer period of time rather than phasing down.

The Apollo schedule falls between the cases cited above. With emphasis upon realism in scheduling we have been able to invoke discipline within the program and because of this have maintained the positive motivation of the various program elements. This has resulted in a determined effort, when problems have arisen, to find alternate or different means of accomplishing the objectives. An example of this is the AS-501 Launch Vehicle. The S-II Stage was pacing the delivery of this launch vehicle to KSC. Rather than delay the delivery of all the other stages to KSC and therefore the start of checkout at KSC, a plan was developed whereby the other stages could be delivered to KSC and an "S-II Spacer" used in lieu of the flight S-II Stage until it was available. To have delayed all the stage deliveries to KSC until the S-II arrived would have impacted the entire program. By using the spacer, we were able to save time and spread the checkout period over a greater period than if we had waited for the S-II.

In summary, a positive attitude toward achieving realistic schedule commitments develops the discipline and motivation that let us reach our objectives. The Apollo effort is not a "crash" program. The programs on which we embarked with the full support of the Congress in 1961 were geared to objectives which could be accomplished with technology that was clearly attainable in a time frame that was reasonable. The funding requested by the President was at every step far short of what would have been required for an all-out "crash" program.

Mr. GEHRIG. Dr. Mueller, since the lunar module has some of the same systems in it that are used in the command module, and is a spacecraft in which men will ride in space, what is the impact of the accident on the lunar module development and production?

(The answer follows:)

The AS-204 fire has caused us to examine the design and test procedures for the Lunar Module (LM) as well. We are carrying out these reviews now and the impact on the lunar module development and production has not yet been determined.

As you may know, we plan to fly the first Lunar Module, LM-1, unmanned on the SA-204 launch vehicle. In view of the fact that LM-1 is unmanned, there appears to be no reason for making any significant system changes as a result of the AS-204 fire. Beyond this, we will have to wait for the results from our reviews before we can assess the impact on the LM program.

The CHAIRMAN. Mr. Gehrig, will you read my closing statement.

Mr. GEHRIG. This is the chairman's closing statement.

NASA ASKED TO REPORT BACK

The committee, in its meeting last Thursday and today, has heard NASA's comments on the report of the Apollo 204 Review Board, NASA's analysis of deficiencies noted by the Board, and the agency's plans for remedying the various deficiencies noted by such Board.

I believe it is the feeling of the committee that the Board made an objective, as well as very penetrating review of the spacecraft program in determining the probable cause of the Apollo 204 fire. In so doing, some rather pointed deficiencies have been identified and recommendations for corrective action set forth.

The committee appreciates that NASA management already has initiated searching examination of the spacecraft program, and it realizes that it will take some time to identify the most appropriate corrective action and to initiate such action. At the same time, the committee has the duty to follow through on its inquiry. Therefore, it is requesting NASA to appear before the committee not later than May 9 to give the committee (1) a detailed report of NASA's action on the recommendations listed in part VI of the report of the Apollo 204 Review Board, and (2) the agency's best estimate of the schedule for resuming the manned flight program.

The hearing is recessed, subject to the call of the Chair.

Mr. WEBB. Thank you very much.

(Whereupon, at 4:50 p.m., the committee adjourned subject to call of the Chair.)

(The biographical sketch of General Phillips follows:)

MAJOR GENERAL SAMUEL C. PHILLIPS, USAF

Major General Samuel C. Phillips, Director of the United States Apollo Lunar Landing Program, has spent more than half of his military career in the research and development field. He is on detached service from the U.S. Air Force to the National Aeronautics and Space Administration in his present duties.

He was born in Arizona in 1921 and moved to Cheyenne, Wyoming, at an early age. He attended public schools, graduating from Cheyenne High School in 1938. He graduated from the University of Wyoming in 1942 with a Bachelor of Science degree in electrical engineering and a Presidential appointment as a Second Lieutenant of infantry in the Regular Army. After graduating, he was transferred to the Air Corps and earned his pilot's wings in 1943. Wartime duties included two combat tours in England with the 364th Fighter Group of the 8th Air Force. He earned the Distinguished Flying Cross and Oak Leaf Cluster, Air Medal with seven Oak Leaf Clusters, and Croix de Guerre.

After the war, General Phillips, then a Major, remained in Europe, assigned to theater headquarters, Frankfurt, Germany, until July 1947. His meritorious service during this period earned him the Army Commendation Ribbon.

An assignment as Director of Operations, 1st AACS Wing, Langley AFB, Virginia, was shortened by General Phillips' selection for graduate training at the University of Michigan, where he studied from 1948 to 1950 and received his Master of Science degree in electrical engineering, specializing in electronics.

Following his graduation in February 1950, he joined the Engineering Division of the Air Materiel Command at Wright-Patterson AFB, Ohio, and remained there in research and development work for six years, with the exception of three months in Eniwetok as an electronics officer on Operation Greenhouse in 1951, and three months at the Air Command and Staff School, Maxwell AFB, Alabama, also in 1951. While assigned at Wright-Patterson AFB, he served as Director of Operations at the Armament Laboratory; B-52 Project Officer; and Chief of the Air Defense Missile Division, working on such missiles as Falcon and Bomarc.

In June 1956, General Phillips returned to England as Chief of Logistics for Strategic Air Command's 7th Air Division. There he participated in writing the international agreement with Great Britain on use of the Thor IRBM. Later, as 7th Air Division Director of Materiel, his duties included assisting in the completion of Thor IRBM installations for turnover to the RAF for which he was awarded the Legion of Merit.

He returned to the United States in 1959 and was assigned to the Ballistic Missiles Division of the Air Research and Development Command, in Los Angeles, as Director of the Minuteman program. He was nominated for promotion to Brigadier General in April 1961. He served as Director of that program until August 1963. During this period, Air Force reorganizations occurred resulting in the Minuteman Program Office being a part of the Ballistic Systems Division of the Air Force Systems Command.

In June 1963, the University of Wyoming conferred on him the Honorary Degree of Doctor of Laws.

In August 1963, he was made Vice Commander of the Ballistic Systems Division.

In January 1964, General Phillips moved to Washington to become the Deputy Director of the Apollo Program. In February 1964, he was nominated for promotion to Major General. In October 1964, he was appointed Director of the Apollo Program.

General Phillips calls Cheyenne, Wyoming, his permanent home. His Mother, two brothers, and a sister reside there. His wife, the former Betty Anne Brown, is also from Cheyenne. They have three daughters—Dana, Janie, and Kathleen.

General Phillips is a member of the Kappa Sigma Fraternity and the Institute of Electrical and Electronic Engineers.

INDEX

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

TO HEAR OFFICIALS OF NORTH AMERICAN AVIATION, INC., PRIME CONTRACTOR TO NASA IN THE APOLLO PROGRAM

MAY 4, 1967

PART 5

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE

74-521 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 45 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota
MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

LIST OF FIGURES

APOLLO ACCIDENT

THURSDAY, MAY 4, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL
AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 2:30 p.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Symington, Stennis, Young, Cannon, Holland, Mondale, Smith, Curtis, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Dr. Glen P. Wilson, Craig Voorhees, and William Parker, professional staff members; Sam Bouchard, assistant chief clerk; Donald H. Brennan, research assistant; and Mary Rita Robbins, clerical assistant.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The committee will come to order.

The committee is meeting today to continue its review of the Apollo 204 accident on January 27, 1967, that took the lives of three astronauts at the Kennedy Space Center. Our principal witness today is Mr. J. L. Atwood, President and Chairman of the Board of North American Aviation, Inc., prime contractor to the National Aeronautics and Space Administration for the Apollo spacecraft, the service module, the S–II stage, and the F–1 and J–2 engines.

The committee has previously heard from the Apollo 204 Review Board of which Dr. Floyd Thompson, Director of the NASA Langley Research Center, is Chairman; and Mr. Webb, Administrator of NASA; his deputy, Dr. Seamans; and other NASA officials.

In view of the extensive involvement of North American Aviation in the Apollo program and its prime responsibility for the spacecraft, the Committee decided that it should ask Mr. Atwood to appear and present his views on:

(1) the report of the Apollo 204 Review Board.

(2) the role and responsibilities of North American in the design, engineering and testing of the Apollo spacecraft; and

(3) what actions North American has taken or plans to take with respect to its management, design, workmanship and quality control of the Apollo spacecraft.

Mr. Atwood, you may proceed.

STATEMENT OF J. L. ATWOOD, PRESIDENT OF NORTH AMERICAN AVIATION, INC., ACCOMPANIED BY DALE D. MYERS, VICE PRESIDENT OF THE SPACE DIVISION

Mr. ATWOOD. Thank you, Mr. Chairman. I am J. L. Atwood and I am president and chairman of North American Aviation. I am accompanied by Dale D. Myers, who is a vice president of the space division and program manager of the Apollo command and service modules and the spacecraft lunar module adapter. After my statement, Mr. Myers will assist me in answering questions.

I wish to assure the committee of North American's complete cooperation in your inquiry.

North American has cooperated fully with the Apollo 204 Review Board. Since its report was made public on April 9, we have had time to study it and believe it represents a professional and thorough investigation. North American's comments on the Board's findings have been incorporated in a memorandum, copies of which have already been made available to this committee.

We share the responsibility. We do urge, however, that the deficiencies cited in the Board report, whether directed to North American or NASA be viewed in the perspective of the standards involved. In assessing the findings, it must be recognized that in space work the standards are and must be extremely high. Literally, perfection is the goal. Not only do we accept these standards, we have in many areas led the way in establishing them. We are resolved to exert every effort to meet them in every particular.

NEW HATCH WILL OPEN IN FIVE SECONDS

North American has been devoting extensive technical and management effort, in close cooperation with NASA, to develop appropriate changes in the spacecraft and the related test procedures. While this work is not finished, and final determinations must be made by NASA, we will mention a few of these changes. One is the design of a new outward opening command module hatch which will open in less than five seconds. We have already manufactured a working model of this hatch and its design is being proven.

The method of manufacture and installation of wiring and tubing in the Block II spacecraft included substantial improvements over that in Block I. We are now providing for additional protection for both the wiring and the tubing in the form of metal covers and protection of joints. The use of a three-dimensional jig in the fabrication of wire harnesses for the Block II spacecraft had been previously implemented and has substantially aided in the installation of wire harnesses in the Block II spacecraft.

As to the amount and location of nonmetallic materials in the spacecraft, we are working with NASA to expand the methods of testing of materials at a component and subsystem level as they are configured for installation in the spacecraft. We fully support the recommendation of the Board that full-scale mock-up fire tests be conducted.

These changes are important but should not cause us to lose sight of the remarkable progress which has been made to date in what the Board called the "most complex research and development program ever undertaken." The Board made it clear that its report was not intended to present a total picture of that program. The Board expressed its concern that the report might be interpreted as a criticism of the entire manned space flight program and of the many people associated with it. I share that concern. North American believes it would be a disservice to the many thousands of dedicated people who have contributed to this complex project not to remind the committee of the accomplishments which have been achieved. It should not be forgotten that a great part of the effort on this program has already been completed. I have confidence that these accomplishments form a solid basis for moving forward to successful completion of the program.

13 SUCCESSFUL TEST LAUNCHES

Among these accomplishments have been 13 test launches, all of which have been completed successfully. They included two launches of unmanned spacecraft using S–IB launch vehicles. These tests, together with various ground tests, have proved the soundness of the basic design through demonstration of:

The spacecraft structural integrity;

The launch escape system;

The earth-landing system;

The ability of the heat shields to withstand the reentry environment; and

The integration of these and other sophisticated systems in the spacecraft.

In addition, two manned tests of the environmental control system have verified the capability of that system under simulated spaceflight conditions including a period in excess of that expected in a lunar mission.

I would like to add that North American's other efforts in the Apollo Program are proceeding satisfactorily. Tests of the Saturn II vehicle have confirmed the design and integrity of the structure. Both the F–1 and J–2 engines have been fully qualified. The J–2 engine has performed perfectly in three flights of the Saturn IB launch vehicle, and has been successfully cluster-fired for full durations in ground tests of the Saturn S–II stage. The F–1 engines have been successfully fired in clusters, and are ready for the first flight of the Saturn V vehicle.

While there have indeed been accomplishments which should not be overshadowed in reaching an objective assessment of the program, there have also been problems. There have been technical problems as well as managerial problems.

Toward the end of 1965 program conditions, as they then existed, reflected the fact that the mission criteria had been evolving toward their final form. Until these criteria became stabilized it was extremely difficult to achieve full control and visibility of North American's basic design and development effort. At the same time, we had been going through a rapid buildup in manpower. These conditions were important factors affecting our ability to put to most efficient use our capabilities. It must be recognized that problems of this kind are encountered in almost all large, complex developmental programs.

TASK FORCE HEADED BY GENERAL PHILLIPS

It was about this time when these problems were reaching their peak that Dr. Mueller discussed with me the desirability of NASA organizing a team to take a hard look at North American's operations, I was very glad to accept his suggestion.

Shortly thereafter, a task force headed by General Phillips did conduct a survey. General Phillips and his task force briefed me and my associates in December 1965 on his findings and recommendations. Between December 1965 and April 1966 North American took appropriate action where we felt that the result would improve management and program performance. In April the task force reviewed our progress and expressed general satisfaction with it.

An inherent part of a developmental program is problem solving. As we recognize problems we devote our best resources and skills to their solution. More important, we try to anticipate problems which might arise and to take preventive action. I cannot say that there will not continue to be some problems as we go forward. But I am confident that we have the capability and the dedication to successfully meet such contingencies.

While I believe the Apollo program stands on a strong foundation and that much has been accomplished, we have recognized that because the program is a complex one it requires constant attention and a balancing of the management skills as it moves into various phases.

I believe that there are gathered within North American outstanding resources and skills for carrying out large systems programs. Coupled with this capability is a team of excellent subcontractors which represents a fine body of technical and management competence. We have recognized that we must draw from all the resources available to the company those capabilities which can best match the needs of the program.

In addition we have frequently drawn on special abilities and skills which may be found outside the company and will do so in the future. I am confident that we can direct these skills and resources, as we have on other complex programs which North American has successfully performed, to meet the current and future challenges of the Apollo program.

MANAGEMENT AND ORGANIZATIONAL CHANGES

Based on a careful review of all of our program operations, we are making a number of management and organizational changes. These changes are designed to strengthen the application of skills which are required to move the program forward and to meet the challenges of the requirements ahead. Among these actions are the designation of a new president and a new executive vice president of our space division who are both men with the experience and skills especially required at this time. Other key organizational alinements and appointments are also being made or planned. These changes will lend further strength to the program.

In addition to the actions which we are taking within North American, there have been discussions between the Administrator and myself concerning the overall working relationships between North

American and NASA. These discussions have been held in the light of independent and frank examinations by North American and NASA of their own operations, procedures and requirements. The areas which we have been reviewing include: the means by which improved visibility of the management effectiveness and program control will be available to both North American and NASA on a coordinated basis: the establishment of clearer and more specific objectives and measurement techniques with respect to program performance; greater use of periodic surveys and audits of program progress and performance by competent review teams; use of sharper incentives and penalties in contract relationships to focus maximum attention on those aspects of the program which are key to its successful execution.

North American is determined, in concert with NASA, to take every step required to move the program forward successfully. I believe we have a firm basis on which to build future success, and I am confident that we can effectively accomplish the lunar mission in this decade.

Before concluding, I want to say all of us at North American have felt a very sharp sense of grief over the loss of the three American astronauts, in the tragedy of the 204 accident. Many of us viewed them not only as professional colleagues but as personal friends.

It was a terrible shock to us all.

The CHAIRMAN. Mr. Atwood, a great many people are asking what will the reorganization of your company do. Will you explain why you brought Mr. Bergen in at this time?

Mr. ATWOOD. Mr. Bergen—I am sorry, Mr. Chairman. I must have missed a word.

The CHAIRMAN. I am trying to find out why you turned to the Martin Company for this capability.

Mr. ATWOOD. He resigned from the Martin Company before we had discussed employing him at North American. But I have known him long and favorably. And when I approached him, he was interested in coming with the company. We worked out a satisfactory employment arrangement, and he is now with us.

NORTH AMERICAN COMMENTS ON REVIEW BOARD FINDINGS

The CHAIRMAN. In your statement you say that the Apollo 204 Review Board's report "represents a professional and thorough investigation." Does North American Aviation generally concur on the findings, determinations, and recommendations of the Board?

Mr. ATWOOD. Did you say do we concur with the findings and recommendations? Generally concur, yes, sir.

The CHAIRMAN. Do you disagree with any specific finding or recommendation or determination?

Mr. ATWOOD. We have submitted to this committee a detailed discussion of our views on the findings. We generally concur. I believe I would ask Mr. Myers to point out anything he thinks might be covered.

The CHAIRMAN. Mr. Myers.

Mr. MYERS. There are in our memo in answer to the summary report that was submitted to the House Committee, some specifics within the report where we disagreed with the amount of emphasis that was put on particular parts of the report. We disagreed at that time with the word "chronic" leakage of solder joints. We disagreed with, I think, the general need in terms of the value of a vibration test of an all-up spacecraft. The panel report was very specific in pointing out the differences in philosophy as to the need for vibration testing of an all-up spacecraft. The final Board report recommended that an all-up spacecraft be vibrated. And we felt that the amount that you get out of such a test has some question as to the amount of money that has to go into such a test. In other words, it is a very expensive test to bring off, and we think there is some question as to the value that you get out of those results.

The CHAIRMAN. In your statement, you mention a memorandum of North American's comments on the Board's findings. This, as I understand it was prepared for the subcommittee on NASA oversight of the House Committee on Science and Astronautics. Will you submit a similar memorandum for the record of this hearing, giving the views of North American Aviation on each of the Apollo 204 Review Board's findings?

Mr. ATWOOD. We have already filed it with your staff, Mr. Chairman.

The CHAIRMAN. Thank you.

(The memorandum referred to appears on page 452.)

The CHAIRMAN. You state that the standards of space work are and must be extremely high and perfection must be the goal.

I would like you to speak as to why it apparently was not achieved.

CONTINUOUS EFFORT TOWARD GOAL OF PERFECTION

Mr. MYERS. Could I speak to that?

I think all through the program, Mr. Chairman, there has been a continuous effort on the part of NASA and North American to reach toward this goal of perfection. The many programs that are introduced into the activities for motivation of the employees are evidence of the attempts on the part of North American and NASA to further improve all activities that are involved in reaching for this goal.

The "PRIDE" Program developed by North American has been used, I think, quite effectively in motivating people towards this goal. There have been other programs in the country. Subcontractors, for example—many of them have used the Zero Defects Program as a goal for their people to shoot for.

In this striving for perfection. there are also many elements of the program that from the initiation of the program NASA brought into their methods and operating procedures which have been incorporated in our plans and have been expressed through our subcontractors as extra means of defending, cross-checking, double-checking, that we have in fact done the best that every human being can do in reaching for this goal.

I think that the typical examples of this are the techniques used by North American in fabrication and the assembly—fabrication and inspection requirements, documentation, that takes the engineering drawing and describes in detail for the process of fabrication and inspection all of the steps that the personnel must go through in this particular application.

For example, we define in these documents any special materials that are to be used. We define whether that material must be traceable or not, and many, of course, of our materials are traceable back to the original source, so that we can follow up on problems, and determine the cause of any particular problem that may show up.

We define the requirements for the type of person that will be used for the fabrication process.

We have a very extensive training program that involves the qualification of people through a training course for a particular process or assembly technique. And these people are called out on this manufacturing requirement when it is necessary in critical cases to have a man that has had specific training in a particular area—called out on this document.

We work with our inspection people in defining the points of inspection that will be used during the fabrication process.

All these things are pre-planned to give us the ability from a management point of view as to what is being accomplished in a particular fabrication process. And because of our preplanning, it brings qualified and trained people into those processes that are used.

I find another example of our reach for perfection is in the process of soldering wires. Early in the program we defined with NASA the detailed specifications required for wire soldering in the Apollo program. I believe you will find that those criteria requirements are far beyond those that have been used in past programs. And in the definition of those requirements to the worker that is actually going to be doing the work, we prepared a very fine manual that described to the workman in photographic form a good solder joint compared to a bad solder joint, and described in detail to him the techniques that he should use in soldering wire.

That particular manual that was developed for that purpose has been used extensively throughout North American and its subcontractors, and has been brought by NASA into some of their other activities in the program. We think it is one of the examples of this continued reach for perfection.

The CHAIRMAN. I want to give members of the committee an opportunity to question extensively. I may have more questions later. Senator Smith.

STAFF MEMORANDUM ON GENERAL ELECTRIC REPORT

Senator SMITH. Thank you, Mr. Chairman.

Mr. Atwood, an article in yesterday's New York Times by John Nobel Wilfred states that last month the General Electric Co. submitted a confidential report to NASA on the Apollo spacecraft. Apparently there are some significant omissions in this press article. And to make the record clear on the GE report, Mr. Chairman, I would like to insert in the record a staff memorandum evaluating General Electric's effort which led to its report.

The CHAIRMAN. Without objection, that will be done.
(The memorandum referred to follows:)

MAY 4, 1967.

Memorandum to: Senator Anderson.
From: James J. Gehrig.
Subject: General Electric Spacecraft Operations Reliability and Quality Problem Report, dated April 3, 1967.

This report was prepared by a General Electric quality and reliability group engaged in Apollo quality and reliability assessment as a part of the General Electric prime contract with NASA for integration, checkout and reliability of the spacecraft. General Electric was selected for this work on February 9, 1962, and one of its principal functions has been the design and fabrication of the automatic checkout equipment for the Apollo spacecraft, the service module and the lunar module.

The quality assessment and reliability group was established as a part of the General Electric checkout and reliability function in February 1966, and reports to the Manager of Spacecraft Operations, Kennedy Space Center. The group consists of one supervisor, nine engineers and two data clerks. This group is charged with monitoring reliability engineering activities for NASA and specifically to review, as a part of this function, failure and discrepancy reports for all spacecraft contractors on a daily basis. These contractors are North American Aviation (command and service module), Grumman (lunar module), and AC Electronics (guidance and navigation system). It is to be emphasized that this group reviews for NASA the discrepancy reports and does not perform physical inspections of equipment. The group also has a subsidiary function as an arm of the NASA Manager of Spacecraft Operations to prepare discrepant report control data for the flight readiness review for each Apollo launch.

Although this group has been functioning in the above described capacity since February 1966, all reports were previously on an informal close-working relationship basis with NASA. The April 3, 1967, report is the first formal report and the Committee staff is advised by Mr. George White, Apollo Director of Reliability and Quality, NASA Headquarters, that this report was formalized because of the increasing interest in this area. NASA has under consideration the continuation of this report on a formal basis in the future. In fact, it probably will be issued periodically. Inasmuch as this document was an internal NASA quality management report, North American Aviation was not included on the distribution list.

The material in this report primarily relates to spacecraft 017, which was scheduled to fly on the first Saturn V flight with a primary spacecraft mission to check the heat shield capability of the spacecraft on a simulated lunar return. The data, as indicated above, is that which is extracted from reports filed by the responsible contractors and NASA inspectors.

Mr. White advised that this report is a product of a formally established group assigned to monitor quality and reliability activities for NASA and that this group was not formed as a result of the accident. This approach of having an independent group review defect reports is not unusual in government-industry operations. Mr. White advised also that since this is an ongoing internal NASA function, the report was not formally released by NASA and he does not know personally how the information reached the press.

In closing, I think it is important to re-emphasize that this report which the Committee staff has reviewed is merely a recitation of discrepancies extracted from the quality defect reporting system and the status of each item so that NASA does have control of each item which is open at any point in time. General Electric has not made any physical inspection for their own part and this specific report does not contain any summary evaluations or judgments as to relative quality levels of the contractors' operations at the Kennedy Space Center.

COMMENTS ON PHILLIPS REPORT

Senator SMITH. Mr. Atwood, the summary of General Phillips' report states that by April 1966 North American had made substantial progress to correct the noted deficiencies, and that North American was also advised of certain areas where greater effort was still required.

Would you tell us what additional areas these were?

And I would ask, Mr. Chairman, if Mr. Atwood would be permitted expand on this at his convenience, when the transcript comes back.

Mr. Atwood. You mean verbally, Senator Smith, at this time?

Senator Smith. Yes. I think it would be well for you to make some tatement on that.

The Chairman. Also, if you want to amplify your statement later, ou can do so, for the record.

Mr. Atwood. I would like to speak to this. And then I would like o ask Mr. Myers to amplify my remarks on this subject.

The reference to the Phillips report is a matter of definition. I elieve that General Phillips clarified this matter before your comnittee, and I concur with his clarification.

In the period before December 1965 we were in a rapid build-up of ctivity. The subsystems had all been ordered. The qualification of hese subsystems has been going on at a very rapid rate. And by that mean rather of complete torture tests of everything that went in the pacecraft were required. So that the vibration, temperature, the opering cycle, the off limit conditions, would all be simulated in accordnce with specification.

At the same time, of course, we were bringing the engineering of he structure of the spacecraft, its heat shield—its entire mechanizaion—to a point of utilization in the first complete test spacecraft.

Now, this was a peaking period of effort in many ways. It was a period of rapid engineering action. There were changes coming from very major subsystem supplier, there were changes coming from our own fit and function activity which we follow very carefully with our ngineering detailed drawings. And during that late fall, about October, we began to notice, of course, the difficulty in getting our milestone on schedules accomplished as we had hoped to do.

A little later on, Dr. Mueller phoned me and said he noticed that we were having indications of milestone slippages, problems in——

Senator Smith. Mr. Chairman, may I interrupt right there—Mr. Atwood, what I wanted was just a brief statement at this time on the areas referred to where greater corrective effort was called for, and then the longer background statement for the record. I think that would be the interest here.

Mr. Atwood. You would rather we furnish the background statement in written form, Senator?

Senator Smith. Yes, I think that would save time.

Mr. Atwood. Well, let me make it very brief, then.

Dr. Mueller called me and suggested that a NASA review team come to North American. I welcomed this suggestion, feeling that it would really improve communication, and it would help us to enhance our program. So they sent a series of teams in. I think there were five or six areas covered. They went through our operations of engineering, manufacturing, quality control, program control and procurement subcontracting. I believe those are the principal ones. And they gave us a briefing on their recommendations and suggestions and findings.

We reviewed—we of course went into whatever detail we could to get all the information that they had on these subjects. And then we established, from company-wide sources groups of individuals to take the best advantage they could of these suggestions, and to make al possible improvements.

Now, we did this and worked very diligently on that. It was agree that General Phillips and his team captains would come back in Apri review the progress that was being made.

They did come back in April, and I believe General Phillips tol you that he considered satisfactory progress towards the objective was being made. And he decided that he did not have to renew hi review team action at that time, but kept in touch with progres through all kinds of management reports and the usual communica tion data.

Senator SMITH. Mr. Atwood, I want to be sure that you provide fo the record the full information as to the deficiencies that needed cor rection after the Phillips review. So if you will be sure that you ge that into the transcript after you get it back, because that was m question, and I think the background can go along if you wish it.

(The information supplied appears on page 438.)

NORTH AMERICAN STATEMENT ON PHILLIPS REPORT

Senator SMITH. Now, Mr. Chairman, I would like to request tha Mr. Atwood submit to the committee a statement of the North Ameri can Aviation Company with respect to those findings and conclusion of the Phillips report which it considers unfair and unjustified, to gether with its reasons for exceptions taken to these findings, and statement as to what action it has taken with respect to those finding and conclusions it considered fair and justified.

Now, this will require a lengthy statement, Mr. Chairman. In th interests of time, and trying to help the afternoon along, I would lik Mr. Atwood to make the full statement for the record. If he wants to I would be glad to have him make just a brief statement now. But would not want to take the time for a full statement.

The CHAIRMAN. If you would provide the committee with a ful statement, Mr. Atwood; you may give such comments as you desir now, and send the full statement within a week, if you could.

Mr. ATWOOD. Senator Smith, and Mr. Chairman, we certainly wil do that.

(The information submitted appears on page 438.)

DISCUSSION ON FAST OPENING HATCH

Senator SMITH. In North American's comments on the Board' findings, reference is made to the spacecraft hatch, Mr. Atwood, an I quote:

> At one point North American did propose a hatch which could be opene quickly by use of explosive charges which was intended for crew egress wit parachutes prior to landing operations. This course was not followed becaus it was considered by NASA that the risk which would be created by an inad vertent opening of the hatch would outweigh the benefits.

Did you agree with NASA's decision at that time, that a quicl opening hatch would offer more problems than benefits?

Mr. MYERS. Yes, we did.

Senator SMITH. Then apparently your position has changed.

What additional facts are at your disposal now that you did not have then?

Mr. MYERS. We had at that time a requirement for the quick opening for the egress of the astronauts during parachute descent. And in the design studies that we made with NASA at that time, it was pointed out that the explosive devices could cause debris within the cabin which could cause damage to the personnel.

At the same time, there was an analysis that indicated that there could be problems with an inadvertent deployment of the hatch in space, and the fears of that occurring, or the possibility of that occurring, led us all to agree that we should not go that way.

Senator SMITH. Would it be reasonable to suppose that NASA must also have considered using the use of a quick-opening hatch since such a hatch was used on the Gemini spacecraft?

Mr. MYERS. I am sure that considerations of this sort were given by NASA.

Senator SMITH. Would it not be fair to say that North American probably made thousands of suggestions to NASA during the course of design and development of the spacecraft?

Mr. MYERS. Yes.

Senator SMITH. Were there any suggestions made by North American that NASA did not adopt, but which you strongly felt should have been adopted for success or safety of the mission?

Mr. MYERS. There are many trade-offs that we go through with NASA in these studies. We have a continuing system engineering activity with NASA in the trade-off of various factors that deal with safety. I think there are no cases where we would disagree with the conclusions of NASA as drawn.

Mr. ATWOOD. Senator, I could only add that I feel that if there is any fundamental disagreement, I have not heard about it, and we would have made some representations. I did not get any word of it.

Senator SMITH. What, then, is your reason for specifically noting the suggestion on the quick opening hatch? Is it because this is one of the changes being made on the basis of the Board's findings?

Mr. MYERS. It is that the Board had recommended the quick opening hatch. I think we all recognize that the technique that was used in that study is not the technique that we should be using now.

There has been with the NASA an advance in technology that has developed this single opening door, a single hatch that opens outward, and that hatch design has really come about because of the results of the tests of Spacecraft 011, where we were able to define, through flight tests, the capability of what we call passive thermal protection, where there is a gap in the ablative heat shield that blocks plasma flow in a manner which allows us then to design a hatch which becomes a one piece hatch outward opening. Without this technology from the Spacecraft 011 flight, we would have a difficult time having great confidence in that type of design.

Senator SMITH. Then the type of hatch that you originally suggested was not feasible to adopt?

Mr. MYERS. It would have been feasible with the addition of debris traps to stop any inward explosive action, we believe, but the recent technology has helped tremendously in the design of a quick opening hatch which is compatible with the double shell construction of the Apollo Spacecraft. It is a much better design.

Senator SMITH. Thank you very much, Mr. Chairman. That is all for the present.

The CHAIRMAN. Senator Symington?

Senator SYMINGTON. Thank you, Mr. Chairman.

I have no questions to ask Mr. Atwood at this time, Mr. Chairman. Very glad to see him.

The CHAIRMAN. Senator Jordan?

QUESTIONS ON RESPONSIBILITY

Senator JORDAN. Yes. Thank you, Mr. Chairman.

Mr. Atwood, at what point does the responsibility of the contractor cease and the responsibility of NASA take over?

Mr. ATWOOD. Senator Jordan, this is a very difficult thing to define. We design the spacecraft, and we have the design approved by NASA. Changes are jointly worked out, which are approved by NASA. And as far as the actual design of the spacecraft is concerned, I would have to say that it must be considered acceptable, insofar as design is concerned, when NASA has reviewed all the drawings, examined the spacecraft, and accepted it.

Our obligation runs pretty deep—to design in accordance with the very best techniques available to us, and the very best knowledge that we can command.

But in the design process, I believe that design, review and approval makes the design a jointly acceptable one, sir.

Senator JORDAN. Then at the time of the testing, of simulated flight, the day of the fatal accident, was it a joint responsibility of both the contractor and NASA to see that safety precautions were taken?

Mr. ATWOOD. We would consider it is a joint responsibility, and it was our responsibility really, in that we could not possibly avoid feeling responsible for detecting anything that might contribute to lack of safety. We would so conduct ourselves in reporting.

The actual testing of the spacecraft is of course not under the contractor as test conductor. We provide engineers and we provide workers to carry out continuing work in the test area. The test conductor is a NASA official.

Could you add anything to that?

Mr. MYERS. I think you, Senator, are referring to the definition of a hazardous test.

Senator JORDAN. Yes.

Mr. MYERS. I think as previously testified, we have a responsibility to define those tests which are hazardous. There were 104 different tests outlines that were included for the tests of Spacecraft 012, and 54 of them had been defined as hazardous in accordance with the criteria which is established by the NASA. We had consulted with them in the development of that criteria. That criteria as published did not cite full oxygen tests as a hazardous test. And we all are fully aware that in retrospect it should have been.

Senator JORDAN. Whose decision was it, if anyone's, that the tests on that day was not dangerous from the fire standpoint, hazardous from fire?

Mr. MYERS. Well, I guess you would have to say as a decision the fact it was not called hazardous was in effect a definition or a decision that that was not a fire hazardous condition.

Senator JORDAN. This was a joint decision?

Mr. MYERS. Well, that came from the criteria that is established in the safety criteria of the NASA range safety criteria. In other words, those criteria did not call out a full oxygen test as a hazardous test.

Senator JORDAN. So no precautions were taken by anyone inasmuch as the pre-agreed criteria did not call for fire protection in this particular test.

Mr. MYERS. I believe that is correct.

Senator JORDAN. That is all I have right now.

The CHAIRMAN. Senator Cannon?

THREE CONTRIBUTING FACTORS TO TRAGEDY

Senator CANNON. Thank you, Mr. Chairman.

Mr. Atwood, it seems to me you have put your finger on the three key things that were apparently contributing factors to this great tragedy. First, the new outward opening command module hatch, which you say you have now designed, and you have already addressed yourself to. Secondly, you say you are providing for additional protection for both the wiring and the tubing in the form of metal covers and protection of the joints. Why was this not done in the first instance?

Mr. ATWOOD. Senator Cannon, I think I will ask Mr. Myers to answer that. It is a design consideration.

Mr. MYERS. Actually, the command module for Spacecraft 012, in the Block I configuration, did at one time have wire harness channels designed into it. At the time of the design of Block I, we had the electronics equipment mounted on one side of the spacecraft, and the umbilical that leads these wires to the service module mounted on the other side of the spacecraft. As is sometimes the case in design problems, this was a necessity because we needed the weight on the one side of the command module to give us the proper lift to drag ratio for landing, and we needed the wires on the other side of the spacecraft, coming out of the spacecraft, to the booster, because that was the leeside of the spacecraft as far as heat is concerned, and was at a lower heat level than the other side of the spacecraft.

The technology again has moved forward, and in the Block II spacecraft we have the umbilical where the wires come out of the spacecraft on the same side that the electronics equipment is.

The point I am making here is that on Block I the wires had to run from one side of the spacecraft to the other. We had, as I said, originally some protective channels for that wire to run through. With the change in the configuration of the spacecraft as it evolved, and with the additional changes that came out of our various tests, the wire runs were brought to a position where we were having difficulty running all the wires in the wire runs we had. So the decision then,

74-521 O—67—pt. 5——8

from the standpoint of the protection was that we had protective covers over the wire harnesses during the fabrication process, and after installation of the couches, the protective covers were removed because the wire harnesses were protected by the couches themselves.

The wire harnesses were also protected with teflon wrap to further decrease the amount of damage that could occur to them.

In Block II, with the umbilical on the other side of the command module, we are able to have much less wire runs in the cabin area, and are able to close off all these with metal containers for completely protected wire harnesses.

Senator CANNON. Wouldn't it have been possible to have left the covers on the wires underneath the couches?

Mr. MYERS. I think so, although I have a problem here, and I would have to get a specific answer for you.

We had fiber glass covers at that time, and there is a problem with fiber glass particles floating in the cabin. So I will have to get an answer for the record.

Senator CANNON. If you could supply that. I realize we are looking back in hindsight now, and perhaps that you had placed primary emphasis on the problem of chafing or damaging to the wire structures, rather than the thought of a possible arcing that might start a fire.

Is that correct?

Is that a fair statement?

Mr. MYERS. Well, of course the chafing protection is to keep from having the possible arcing of the wires.

(The information referred to follows:)

Originally hard fiberglass covers were to be utilized to cover certain wire harnesses in exposed areas on the Command Module floor of the Block I spacecraft. It was later determined that securing hard covers to the flexible Command Module floor presented very difficult fabrication problems. In addition, the wire harnesses, due to engineering changes, were growing in diameter and therefore the attachment points could not be located precisely. Various factors were considered in reviewing and assessing the problem. Among these were: weight considerations, conditions which would be experienced within the spacecraft during flight and the degree of protection afforded by the unitized couch. As a result of this review, the decision was made to use a substitute cover over the wire harnesses. The substituted cover on Spacecraft 012 and subsequent Block I spacecraft consisted of Teflon wrap over the harnesses. In Block II spacecraft, it is possible to use metal covers because of the relocation of wire harnesses along the sides of the Command Modules.

Senator CANNON. Now, when you make the changes here that Mr. Atwood referred to; namely, that you are providing for additional protection in the form of metal covers and protection of joints, is this going to eliminate the possibility of arcing as a hazard in the forthcoming module?

Mr. MYERS. I think it will certainly help tremendously. I think the problem that we have here is that we have got to recognize with 20 miles of wire, and the amount of work that goes on during fabrication, that there can be some time in some spacecraft another arc. The actions that are being taken by NASA and ourselves are to be absolutely sure that no arc can, in combination with the oxygen atmosphere, and in combination with the materials that we have in the spacecraft, ever cause a spreading fire or any case where any arc can actually start a fire within the spacecraft itself. That is being accomplished by this very extensive substitution of materials that are essentially fireproof, and by major reductions in the amount of material within the cabin itself.

Senator CANNON. Now, that leads to the third point that Mr. Atwood covered. You are working with NASA to expand the methods of testing materials at a component and subsystem level as they are configured for installation in the spacecraft, and that would cover of course the amount and location of materials.

Mr. MYERS. Yes.

Senator CANNON. Does that include the experimentation with new materials that NASA demonstrated here to the Committee some time ago?

Mr. MYERS. Yes, it does.

We have a joint team of NASA and North American people at our plant right now going through all the materials that are located within the spacecraft, and identifying substitutes in terms of new materials in some cases or the elimination of some of the functions of materials previously used.

We are also combining within metal containers some of the materials so that we essentially have firebreaks between any material and any other material.

The testing is going on now mainly at NASA, and some at our plant, but a fairly extensive program with NASA and some other subcontractors, on these various materials, to the new criteria which we are all confident will eliminate the possibility of fire.

Those tests are to the level of components, or small pieces of material, and then in combination with other materials. For example, a wire bundle with Teflon wrap with Beta cloth wire ties. That is a combination of materials that will be tested to give us what I call subsystem tests.

And then finally verification and full demonstration of the lack of possibility of a fire through the total system tests that NASA will run down at Houston, where we will put all the materials together in a mockup, I guess you woud call it, and actually attempt, through instigation of possible fire sources, to see if there can be any fire.

We believe that will give us final proof that we have no fire problem.

COMMENTS ON GENERAL ELECTRIC REPORT

Senator CANNON. Mr. Atwood, Senator Smith referred to an article in the New York Times yesterday and said—requested permission to submit for the record a staff memorandum on that matter. (See p. 400.)

I would like to ask you for your comments—first, whether or not you are familiar with this so-called GE report, and, secondly, if you are, if you would give us your comments.

I am referring now to the item in the New York Times dated Wednesday, May 3, entitled "GE Study Lists Host of Serious Flaws in Apollo." And an article of similar content from the Evening Star of Wednesday, May 3, it says, "GE Report Tells of Poor Apollo Work."

Would you respond to that? Are you familiar with that report, or those articles, Mr. Atwood?

Mr. ATWOOD. Yes, Senator Cannon, I have familiarized myself in the last 24 hours of course.

General Electric does have a technical responsibility at the Cape, and they compile various data and make this sort of thing known from time to time.

The data they use are a compilation of North American inspection reports. And I would like Mr. Myers, who has had time to look into it a little more completely, to give you a little more detail.

Senator CANNON. All right.

Mr. MYERS. Well, this data—the data in the report is known to us. We have not previously received it in this form. This is part of our normal process of our feedback of quality information into our system for correction of anything that we find out of line.

So it is nothing new to us as far as detailed data is concerned. I think some of the words that are used in the report itself are worth some explanation—at least as they are reported in the newspaper articles.

There was a comment about the lack of the installation of ablative material within three holes in the command module heat shield. Since the report is written for the technical people within NASA, I think we all know those holes were previously designed for instrumentation runs in the heat shield. They are actually holes drilled through the heat shield for instrumentation, to pick up the heat of the heat shield itself during its reentry. The way it is worded it could be interpreted as if somebody had punched a hole in the heat shield or something of that sort.

The actual fact is that RTV insulation, the ablative insulation, in those small holes, drilled through the heat shield, was accomplished in the last week of December during the assembly of the heat shield—excuse me—during the assembly of the command module and service module, which was the first thing done down at the Cape.

The other actions that are called out in the report are actions which were open as of December 31. And when I say open, they are items which are reported by the Cape out of our inspection data and NASA's inspection data as what they call unsatisfactory reports.

And they can be unsatisfactory reports either in paperwork or in hardware. And those things are fed back into our system through Houston. They deal with not only North American equipment, but associated contractors equipment also.

So the Houston folks divided these various unsatisfactory reports up, and send them out to the various companies that are involved with particular equipment.

We then have a thirty-day response time to get an answer into the record for just what action we are taking to correct this unsatisfactory condition.

As I say, those action items that are listed in that report are known to us, and are either closed out now or are in work for closeout.

Senator CANNON. Now, were these items discovered independently by GE, or were they discovered from your own inspection records—your own company's records?

Mr. MYERS. Oh, they are from our own records.

Senator CANNON. They are from your own records?

Mr. MYERS. Yes.

Senator CANNON. Because it does not lead one to believe that from the newspaper article.

Mr. MYERS. Of course, as I say, we have not been receiving that type of report. It has been considered, I am sure, by NASA as an internal NASA report. And I think the NASA people are fully cognizant of the role that GE plays in gathering contractor's data for summarizing for management review purposes.

There is another part of that report that I think I should comment on.

There was a comment that there has been up to that time 1,300 discrepancy reports, a thing that NASA calls "DRs" that we use in the field, on spacecraft 017. I think it is worth noting here that after the accident North American and NASA got together to review again the inspection criteria that are used for inspection and acceptance of the spacecraft.

And we. working together with NASA, developed a much more objective inspection criteria.

The word "objective" here means to define for the inspector specific detailed standards that he can measure without being subjective. And to give you an example of that, the military standards, and background we have used in the program, have called out wire ties such that slack does not develop in a cable.

In other words, if you have a group of wires together, you want to tie the wire bundle so that you do not have pulling in the cable as it goes.

This, over a period of time, has developed as a criteria within North American to generally call for wire ties to be placed every 4 inches.

In our review with NASA, on being more objective for the inspector, as to what he ought to be measuring to, we agreed to make it on 2-inch bundles, 4 inches plus or minus a half an inch.

So he has something to measure to when he is doing his inspection.

That criterion in itself developed a certain number of these squawks which under the more general functional standards that we had had in the past were not considered detrimental at all to the performance of the spacecraft.

I think along with this we all have become maybe a little more subjective as far as inspection is concerned since the fire, too. And we are all reaching for even the details of where is a wire tied on a bundle, to have something definitive for the inspectors to use as a standard.

Senator CANNON. Well, now, when you say that these discrepancies were all known to you, that they were taken from your records, did you, at the time they became known to you, initiate corrective action on all of them?

Mr. MYERS. Yes, we had initiated corrective action on all of them.

Senator CANNON. And you say they were known to you in December, is that right?

Did I understand you correctly?

Mr. MYERS. The report actually calls out two types of information.

One is open items as of December 31, and the open items are those which we had already taken action on, but which were not closed to the satisfaction of NASA and ourselves. In fact in many cases we had submitted a report on the action we were taking, and in some cases we did not have an agreement with the NASA, and we were back to the showers to work out more detail that would satisfy NASA that we were taking the proper action on a particular item.

The other piece of the report, are on items that had come up since December 31.

Senator CANNON. And had some of the items actually been corrected as of December 31?

Mr. MYERS. Yes, many had been corrected as of December 31.

Senator CANNON. Now, this newspaper article says—

> The reported flaws included damaged parts, corroded valves, leaky pipes, and three small holes in the capsules heat shield that the document said could have catastrophic implications during the vehicle's return through the atmosphere to a splash down.

Was it intended that that vehicle would be flown with those holes in it, in that condition?

Mr. MYERS. No; it was not intended that it be flown in that condition.

The open item that was listed there was closed the last week of December. We had corrected the open item—open item means an open item on the books that has not been worked off yet. In this particular item, which was an instrumentation hole in the heat shield, the ablative material was filled in during the last week of December.

And there was certainly no intention of flying without that.

Senator CANNON. That was filled in before this report was ever finalized, is that right?

Mr. MYERS. I believe it was.

At least before the date of that report.

Senator CANNON. Mr. Chairman, I wonder if we might ask that if they have any further comments that they would care to elaborate on for the record in response to this article or report, that could be supplied for the record?

The CHAIRMAN. I think it would be interesting if you give us a sample of some of the reports and then have an analysis of what you have done.

Senator HOLLAND. Mr. Chairman, it is not clear to me at least whether or not the General Electric report has been made available to them, or is it just an inside NASA report?

Mr. MYERS. It was made available to us yesterday.

Senator HOLLAND. Yesterday?

Mr. MYERS. Yes.

The CHAIRMAN. How could you correct them when you did not know what they were?

Mr. MYERS. Oh, no. All the data is in our system. So it is more a matter of the wording in the report that I think we would object to.

Because all the data that is in that report has come from North American records, and were a part of our normal system of corrective action.

The CHAIRMAN. We have the report here, Senator Holland. It states it was prepared from NASA and North American Company documents.

Senator HOLLAND. Mr. Chairman, I understood that we had it. I understood that NASA had it. But I also understood, both heretofore and from what has been stated by the witness today, that there was an internal report of General Electric to NASA.

And the question was solely to bring out the question of the fact as to whether that report had been made available. As I understand it, it was made available yesterday to North American Aviation.

The CHAIRMAN. What happened in the meantime?

Wasn't it prepared a long time ago?

Mr. MYERS. It is my understanding it is dated December 31—April 3—excuse me.

The report is dated April 3 of this year, and apparently it is a quarterly report. But it is made up of data we already had available within our own corrective action system.

The CHAIRMAN. Is it true that the report is dated April 3, 1967, and it was not made available to your company until yesterday?

Mr. MYERS. That is my understanding.

The CHAIRMAN. You say it is an understanding.

Is there somebody who knows whether it was or was not?

What about the company?

Does the company know whether it was or was not available?

Mr. MYERS. We obtained the report from the NASA KSC personnel in the last 48 hours.

The CHAIRMAN. This report was prepared some time ago, it is dated April 3. It is an internal report as far as NASA is concerned. But should not the report have been sent to you at the time it was prepared?

Mr. ATWOOD. Mr. Chairman, may I see if I cannot explain?

The CHAIRMAN. It sounds like a very mystifying situation. If I was to say to a member of this staff, "Please give me certain documents," and a month later he said they are internal documents—I would say, "What about it?"

Mr. ATWOOD. General Electric's duty is apparently to compile this report from data obtained from the contractors at the Cape. We were one of those contractors, and they took our inspection data and wrote the report. The words and comments are theirs. The data on which the report is based are ours.

I believe that is the basis of the report. When it goes to the NASA distribution center, we would then receive from NASA appropriate extracts for our comment. And as Mr. Myers pointed out, some of the comments would go to other contractors, because they provided the equipment.

The CHAIRMAN. The comments relating to North American should be given to you, shouldn't they?

Mr. ATWOOD. Apparently there are some equipments that are not built by us. And the reports would be sent to other companies.

Mr. MYERS. I mentioned earlier——

The CHAIRMAN. The portions relating to North American Aviation should be sent to you?

Mr. MYERS. Those portions dealing with North American Aviation are already sent to us in the form of an unsatisfactory report which goes through Houston to us. This report, in itself, with the editorializing that is involved there, is an internal NASA Report, but all of the data on which that report is based must come through normal channels to us, as far as the specification of the unsatisfactory condition.

The CHAIRMAN. Since this was an internal report, there may be some restrictions on its distribution. I hope I do not violate any "secrets" when I say one item deals with contamination. Now, the report lists its status as "open." Has it been corrected by now?

Mr. MYERS. Some of the actions have not yet been completely satisfactorily closed. And some cases we may have submitted an answer to them for correction, for what we consider to be the correction, and they would like to have another—NASA may have another direction they want us to go to correct that particular item, in which case they would not agree to close that action item. So, there would be some where in all cases we are taking action on them—there are some which are not yet closed.

The CHAIRMAN. The first line reads: "The cause of these discrepancies was identified as workmanship." You would want to correct that workmanship, wouldn't you, as soon as you heard about it?

Mr. MYERS. Yes, sir.

The CHAIRMAN. How long would it take to get that accomplished with NASA?

Mr. MYERS. I am sure that action is already being taken.

The CHAIRMAN. Well, it says "open". Does that mean closed?

Mr. MYERS. No, it means open, meaning that we have not had a satisfactory conclusion by NASA that they agree with the written answer that we have given to them on the particular item.

Mr. GEHRIG. As of what date?

Mr. MYERS. I guess as of April 3.

Mr. GEHRIG. I thought you said December 31st before.

Mr. MYERS. December 31st—are you talking about the one on the heat shield here specifically?

The CHAIRMAN. I was trying to stay away from classified material.

Mr. MYERS. This is not a classified document.

Were we talking there of the heat shield itself?

The CHAIRMAN. It has not been circulated, I guess. Has this been published in the newspapers? People ask us questions about this report, and we cannot answer very well. Has this report been given to the public, or have others examined it?

Senator CANNON. I think it's quite obvious it has been available to the public in the newspapers, Mr. Chairman.

The CHAIRMAN. They had it earlier than the committee.

Mr. MYERS. Mr. Chairman, I think I understand the point here. Those items were—that are listed as open—were open as of December 31.

The CHAIRMAN. And how would we find out if they have been closed?

Mr. MYERS. I can supply for the record whether they have been closed since that time.

The CHAIRMAN. 1300 of them?

Mr. MYERS. You talk of the 1300 discrepancies on Spacecraft 17? Those are continuously being worked off, and we now have plans to have them all worked off by—well, we will be back in a position to test the spacecraft by the end of May.

The CHAIRMAN. Thank you very much.
(The material supplied for the record follows:)

The spacecraft Operations Reliability and Quality Problem Report dated April 3, 1967, prepared by General Electric, was not the result of an independent inspection of spacecraft but was merely a compilation of information generated by NASA and North American under an established system for problem identification and corrective action.

A review of this document did not reflect any new or unknown problems, and correction of all of the items listed in the report had previously been planned.

As noted in the report itself, 42% of the items listed had been closed prior to issuance of the report. Since that time, all but 15% of the listed items have been closed. Of the 15% still open, planned action is being taken, and they are all scheduled to be closed by early June 1967.

Senator CANNON. Now you have me confused.

Where did this initial list of discrepancies come from? Did this come from your records, from NASA Inspectors, or did it come from GE Inspectors?

Mr. MYERS. It came from a combination of North American Inspectors and NASA Inspectors. The data is then compiled out of those records by GE.

Senator CANNON. GE just simply examines your records, and made no independent inspection to come up with their list of discrepancies. And these discrepancies were known to you, and you were in the process of writing them off, or working them off.

Mr. MYERS. That's right.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. One reason that I asked about it is that we understand that the NASA did discuss this with the press. I just wish they would send some of this information to the Committee sometimes.

Senator Brooke.

ACTIVITIES OF NORTH AMERICAN IN APOLLO PROGRAM

Senator BROOKE. Mr. Atwood, in 1965, prior to November 22, had it come to your attention that NASA was dissatisfied with North American's performance, both as to engineering and to the design, manufacture, and quality control?

Mr. ATWOOD. Senator Brooke, not in an organized way as it was in December of 1965. Yes, we have many, many interchanges with them. The basis of our arrangement is a continual criticism, an attempt to improve everything in connection with this major program.

There is a major effort to save money, of course, where it can be done. There is a major effort on engineering design, to save weight and improve procedures.

Yes, I would have to say that I have been conscious from the very first days of the program of—doing better because of criticism; yes, sir.

Senator BROOKE. Specifically, were you not told the delays that North American was engaging in were very costly, and in some instances tripling the cost?

Mr. ATWOOD. Our estimates have been, of course, very hard to arrive at, Senator, in that the scope of the work, the nature of the lunar craft has been very hard to define—particularly in advance of that period of time.

74-521 O—67—pt. 5——4

As we have gone further ahead, we have come to better and better definition of the design, the work.

I will say, and I believe I'm right—that since a year prior to November 1965, and up to this time, our expenditures have been very close to the amounts of money that were agreed on for that period of time.

Now, we have not necessarily accomplished the work we wanted to accomplish. But that was not because of money—but the difference has not been great.

Would you amplify my remarks in detail?

Mr. MYERS. I would like to go back to a period of 1964, May until December of '64, when we went through what I call a major program definition for the Block II Program, and at the same time NASA went over all of the activities that were required for completion of the Block I Program.

Beyond that time we built into 1965 a very stable definition of the funding requirements and from that time on we have been extremely close in terms of funds.

The peak activity in 1965, late '65, led to the Phillips review of our activities, and our own review of the program activities, which was the result of a very large peaking of the testing activities in the program in terms of qualifications, flight tests of vehicles from White Sands, the beginning of the vacuum chamber operation down at the Cape—excuse me—down at Houston—and the early various boilerplates and test vehicles that we flew down at the Cape.

All of this——

Senator BROOKE. Mr. Myers, if I may interrupt you. Are you basing the deficiencies entirely upon the peaking of activities?

Mr. MYERS. The deficiencies in terms of the schedule effects were, we believe, certainly influenced very heavily by the peaking factor.

Senator BROOKE. Not the deficiencies in design?

Mr. MYERS. The deficiencies in design that were criticized by the Phillips Report generally were in the area of systems engineering, and this was in terms of picking up requirements established by the NASA and going through the trade-offs that would lead to a specific design change to meet that requirement.

Senator BROOKE. Mr. Atwood stated that there had been some discussions with NASA relative to the efficiency of North American. Apparently there had been some deterioration which would have provoked a task force being assigned by NASA to make a study of North American efficiency.

Would you agree with that?

Mr. ATWOOD. Well, certainly there was room for concern. And this is an enormously big project. And it involved a large review. I guess it has probably been our experience that in most development programs there comes a time when some sort of review and performance assessment is carried out by the customer. This one was, of course, a very comprehensive and very complete one because, as has been pointed out before your committee, it is perhaps the biggest systems engineering problem ever undertaken. Certainly it did indicate some difficulties.

Senator BROOKE. Mr. Atwood, I believe General Phillips' task force commenced this work November 22, 1965. Now, you said that in December you received—I want to quote you correctly from your report —you said, "General Phillips and his Task Force briefed me and my associates in December, 1965, on his findings and recommendations."

Did General Phillips not submit to you a written report of his findings and recommendations?

Mr. ATWOOD. General Phillips gave us the access to the notes of all his teams, and they were in a variety of forms. The team on engineering had several sections, and they had put together their observations, in various sheets and various forms. The same with Procurement, Manufacturing, and Quality Control.

We were certainly given access to these notes and minutes and we did use them as a guide in our review and in our followup.

LETTER FROM GENERAL PHILLIPS

Senator BROOKE. Well, Mr. Chairman, I don't know whether this is a matter of record, but it is certainly widely distributed—a letter which you received on December 19, 1965, from General Phillips. The letter was addressed to you and referred to you as "Dear Lee," and it stated very plainly grave concern by General Phillips, and presumably the task force, of his findings as a result of his investigation which was conducted from November 22d to approximately December 19th. Is that not correct?

Mr. ATWOOD. Yes, sir.

Senator BROOKE. And you received a copy of that letter, did you not?

Mr. ATWOOD. Yes, sir; I certainly did.

Senator BROOKE. And that letter also incorporated the report of the NASA review team findings; isn't that correct?

Mr. ATWOOD. No, I don't think that the letter did—I mean the letter of transmission did. We were given access to all the briefing charts and principal notes. But—what the letter intended to convey, I think, was a transmission of findings of the survey committee to the company, so that I would know that we had access to all the data they had accumulated.

Senator BROOKE. Let me refresh your recollection. One paragraph states—

> Enclosed are ten copies of the notes which we filed on the basis of our visits. They include details not discussed in our briefing and are provided for your consideration and use.

So you did receive those, did you not?

Mr. ATWOOD. I am sure we did.

Senator BROOKE. And what action, if any, did North American take as a result of having received this letter and report?

Mr. ATWOOD. Actually, if I may backtrack just a moment—when this group was organized to come in, as I said, I welcomed them in their effort because I felt it would be a tremendously valuable tool to have, and we would have the benefit of their findings.

Immediately upon the completion of their work, and our access to these notes, we formed several teams, company-wide groups of people, to establish actions to implement essentially all the recommendations that we had gotten from the Phillips Review Board.

We formed a group of people from engineering, for instance. We had a chairman, and he was able to draw on engineers from other divisions of the company, as well as the space division. We in effect helped the division either reorganize or regroup to put in as nearly as we could actions which were in consonance with these recommendations. We did it in manufacturing, we did it in quality control, we did it in procurement, we did it in purchasing. We certainly did the same thing in the matter of program control and reporting.

Senator BROOKE. Well, you have just recently reorganized the space division, have you not?

Mr. ATWOOD. We have changed the top management of the space division, Senator.

Senator BROOKE. But you did not change the top management after the receipt of the Phillips Report in 1965?

Mr. ATWOOD. No. We sent in quite a number of people, however. We sent in our chief engineer and the systems engineer. We sent in a new chief inspector. We sent in a new manufacturing director, or factory manager. And we redoubled our surveillance from corporate headquarters to attempt to improve performance at every level.

There are several more people that were sent in, and some replacements were made. The same head of the division, however, was carrying on. I felt that he was a qualified man in every way and was at the time the best we could provide.

Senator BROOKE. And you were satisfied that you had done everything that you could do in order to comply with the recommendations of the Phillips Report?

Mr. ATWOOD. Senator, we tried very, very hard. I did put a tremendous amount of emphasis on it. And it was a very effective effort, in my opinion.

I believe the remarks of General Phillips indicate that he felt that there was response, there was action, there was effectiveness. And I believe that, too.

Senator BROOKE. You are talking about General Phillips' remarks at what time, now?

Mr. ATWOOD. I was reading the Senate transcript, in this last two-week period.

Senator BROOKE. Well, at that time General Phillips said, "I could not find a substantive basis for confidence in future performance."

Did he then find a substantive basis for confidence in your performance in 1966?

Mr. ATWOOD. As I understand it, he certainly indicated in April of 1966 that——

Senator BROOKE. That he did find it.

Mr. ATWOOD. He indicated that to us.

LARGEST NASA CONTRACTOR

Senator BROOKE. Now, in 1965 North American was number one, so far as contracts awarded by NASA is concerned; is that correct?

Mr. ATWOOD. I believe so.

Senator BROOKE. And in 1966 North American was also number one so far as contracts with NASA?

Mr. ATWOOD. Yes, Senator.

Senator Brooke. And do you find this rather astounding in view f the difficulties that were incurred in 1965?

Mr. Atwood. No, sir; I honestly don't. I feel that the difficulties we xperienced in these projects were perhaps unusually severe. But I id feel that we took exceedingly effective action to overcome these roblems, and in view of the difficulty of the project, and the many, nany supporting factors we had to rely on, that we were making not nly an effective effort, but we had every reason to expect it would be atisfactory.

Senator Brooke. Did you feel that the Phillips report was fair and echnically, technologically correct, his findings, and in his recommendations, or do you find differences—when I say you, I mean did North American find differences of opinion insofar as some of the indings and recommendations were concerned?

Mr. Atwood. Senator Brooke, I cannot speak in great detail on this, but I will say this: In these notes and memorandums there were probably—in fact undoubtedly—some things that were recommended or suggestions for which other solutions might be preferable.

The sole purpose of this review was to look for difficulty, error or less than maximum efficiency. And so we did not see any parts of their review that reflected comments of commendation or anything like that at all. There were many things, of course. I would like to say whatever errors are properly chargeable to North American, we certainly are responsible. But I would like to at this time point out that there have been millions and millions of man-hours applied by the most highly skilled people, of great integrity, and the degree of deficiency has been very, very small. I would like to say that I appreciate the work of these people in North American, in our subcontractors, and in NASA. I do want them to know that I feel that they deserve some recognition for their loyalty and persistence. I do accept what is properly my responsibility for any deficiencies.

WORKED CLOSE WITH ASTRONAUTS

Senator Brooke. Well, Mr. Atwood, certainly no one challenges the dedication of the men that have worked on the program.

On the other hand, we cannot merely look at the successes of the program when we are trying to find out the causes of deficiencies in the program and trying to correct those causes and prevent them in the future.

I am sure you are certainly in agreement and in accord with that statement.

I would like to ask you if at any time, to your knowledge, General Phillips or any of the astronauts visited North American and reviewed the work that was being done on the Apollo spacecraft?

Mr. Atwood. Yes, of course. I asked one of the team leaders to come and spend as much time as he could with us, and sit with me when I was working on some of these constructive activities. He did come. He was very helpful.

Senator Brooke. Did he make recommendations?

Mr. Atwood. He had made them, and he helped me in implementing some of them.

Senator BROOKE. What were the nature of his recommendations, if you recall?

Mr. ATWOOD. In this particular case, they were in the program control area. He had good ideas, and we wanted to benefit from them, and fortunately were able to, through his courtesy and that of NASA. I guess I might not have completely answered your question before, Senator. But I think we tried to comply with essentially all the suggestions that were made. And even if they felt there might be other ways that were better, we went as far as we could to comply with the suggestions of the NASA Team.

Senator BROOKE. The last question that I asked you had to do with whether or not you had received recommendations from astronauts in the program, and whether or not you had accepted or rejected these recommendations and the nature of them, if you know.

Mr. ATWOOD. I believe Mr. Myers can answer that.

Mr. MYERS. We worked very closely with the astronauts and their suggestions and recommendations are considered by ourselves and NASA as pretty powerful inputs to the program, and in most cases they are accepted. I think in cases where they are not, they are generally reviewed by the NASA Program Manager and the astronauts, where they reach agreements. But I would say in most cases the astronauts are a pretty strong unit.

Senator BROOKE. I am speaking specifically of the Apollo spacecraft.

Mr. MYERS. That's what I'm speaking of here.

Senator BROOKE. And you do not recall any recommendations being rejected by North American which were made by any of the astronauts?

Mr. MYERS. I'm not aware of any. I worked very closely with the astronauts on the spacecraft.

COMPLETE COMPANY INVESTIGATION UNDERTAKEN

Senator BROOKE. Now, Mr. Myers, might I ask you this question? I know that the Board has not been able to find the actual cause of this disaster. They have given proximate causes. No one has wanted to name names or place responsibility on individuals. I certainly commend that, and I can understand it.

On the other hand, it seems important that you would want to find out where along the supervision, supervisory and management line, mistakes were made.

Can you go back, for example, and take for instance where this wrench was left in the capsule inadvertently and find out who left the wrench there, what supervision was made of the capsule after this was done, whose responsibility it was to supervise and make this control study, and right on up the line to top management, to find out where management was faulty or guilty of misfeasance—certainly not of malfeasance, but guilty of misfeasance, along the managerial line. Was that done?

Mr. MYERS. It is in process right now. We have a complete investigation concerning the conditions that you stated, which covers the identification of how it got into it, what time, the person that's involved, the supervision, the procedures that are involved, and methods of improvement, either in terms of supervision of the techniques of further insuring that tools are not able to get into the spacecraft and stay there.

Senator BROOKE. So a tester who maybe did not make the test or something of that sort could be found out?

Mr. MYERS. Yes. We certainly intend to have a full understanding of this.

Now, I have looked at the procedures we have used in the past on this, and we have had some very stringent controls on the technique of checking tools in and out of the spacecraft. So the record should be there in this investigation to define exactly how it happens.

Senator BROOKE. Of course, we understand in dealing with human beings you have error. But you would not expect it all along the line. For instance, if the wrench was left—somebody along the line who had the responsibility should have found it—and this same thing about the——

Mr. MYERS. I was extremely surprised that that did happen, in fact, because we had reviewed those procedures just a couple of months before that was revealed.

Senator BROOKE. And you say an investigation is presently under way?

Mr. MYERS. Yes.

Senator BROOKE. And this committee will be given the benefit of what your findings are—not names, but what your findings are so far as control is concerned, management.

Mr. MYERS. You want that submitted for the record?

Senator BROOKE. Yes.

Mr. MYERS. Okay, fine.

Senator BROOKE. Mr. Chairman, I would like to see that submitted to the committee for our record, a report of the investigation currently being conducted, from the initial stage to top management, without necessarily naming the names.

The CHAIRMAN. That will be done.

(The material follows:)

North American has conducted a review of its procedures concerning access to Spacecraft 012 during pre-launch operation, and the procedures for controlling materials and tools taken into the spacecraft.

An Apollo Pre-Flight Operations Procedure (APOP) had been issued covering access control of test and work areas. The Apollo Pre-Flight Operations Procedure was a joint North American/NASA procedure which was coordinated by the Procedures Unit of the North American Space Division, Florida Facility, and by Procedures Control, NASA Spacecraft Operations, and was approved by the Director of Apollo Command and Service Module (CSM) Operations, North American Space Division, Florida Facility, and by the NASA Manager, Test and Operations Information Office. The section of the APOP relating to the control of North American tools states that employees requiring admission to the spacecraft must sign in on the Ingress and Egress Log (I&E Log); must surrender to the monitor of this log all personal effects on his person; and must reference on the log the applicable work authorization document. An Ingress and Egress Monitor appointed by the North American Quality Control Supervisor was required to log all material and tools each entering employee carried into the spacecraft and to account for any material or tools removed from the spacecraft.

The APOP also contained detailed instructions with respect to materials or tools accidentally lost in the spacecraft. In addition to the APOP covering access control to the spacecraft, North American had, in September 1966, established a tool control procedure for tools assigned to Spacecraft 012 under which the tools would be controlled by a "Tool Box Monitor". Under this procedure, all spacecraft tools were identified by special markings and were listed by part number and placed in a tool box on the work stand at the Command Module. This tool box was put into use on September 30, 1966, together with the Tool Log identifying the contents. It was the responsibility of the Tool Box Monitor to insure accountability for all the tools at any given time and it was required that each tool be logged in and out. In addition, each Technician to whom a tool had been assigned was required to be cleared of all tools accountable to him, and the Monitor was instructed to account for all contents of the tool box at the beginning of his shift. The Tool Box Monitors were furnished by either the Quality Control Organization or the Apollo Technician organization.

A review of the logs shows that the procedures and instructions were not being fully implemented in practice. Specifically, the records do not show the date on which the ¼" wrench socket was left in the spacecraft or the identity of the person who left it.

Under the procedures in effect during the applicable period when the wrench socket could have been left in the spacecraft, North American Assistant Supervisors directly responsible for the employees working at the spacecraft work stations were responsible for maintenance of the Ingress and Egress Logs and the Tool Box Log. In the case of the Monitors from the Quality Control organization, they reported through a Supervisor to a General Supervisor who, in turn, reported to the Quality and Reliability Assurance Manager, who reports to the General Manager of the Florida Facility. The General Manager was responsible to the Executive Vice President of the Space Division. In the case of Monitors from the Technician Support Group, they reported through a Supervisor to a General Supervisor who reported to the Technician Support Chief. He reported to the Director of Florida Operations. The Director reported to the Apollo Program Manager who is directly responsible to the President of the Space Division.

North American is installing a system under which individual separate organizational departments maintain and monitor the Ingress and Egress Log and the Tool Box Log. A rigid monitoring system is in effect and additional reviews and sign-off of the logs by higher level supervision at the conclusion of each shift has been instituted.

In addition, new tool box containers have been provided with specific shaped pockets or retainers for each tool normally required for use in the spacecraft. Each pocket or retainer is identified by the part number and serial number of the applicable tool. The tool box is maintained in a manner whereby visual inspection of the pockets or retainers will confirm that tools are either present or charged out. Visual inspection of the tool box and a review of the Tool Box Log is performed at the end of each work shift.

It should be noted that the report of Panel 5 of the Apollo 204 Review Board states that "none of the instrumentation in the Lower Equipment Bay Area is considered to be a primary ignition source of the fire". This was the area in which the wrench socket was found.

Senator BROOKE. No further questions.

The CHAIRMAN. Senator Brooke, you asked a very good question at the hearing a while back. General Phillips gave a very good summary of the findings and recommendations of his task force review. If you do not mind, I would like to ask unanimous consent to have that placed in the record at this point. That is pages 354 to 359.

(The material referred to follows:)

Now, to summarize the essence, if you will, of the recommendations that I made, I felt that the top management of both the corporation and the division were not giving sufficient attention to the details of the direction and execution of these contracts and recommended more attention from that level of management to the details of their problems and progress. I felt that the authority of the two program managers in that division was really too diffuse to enable them to harness all the resources they had to bring to bear to get our job done and recommended that they strengthen the project organization and pull parts of the functional organization together under the more direct authority of the program managers, respective program managers.

In the functional area of planning and control which to me is one of the essential fundamentals in accomplishing a program, that is where the details of the planning, the details of the costing, are made and the basis on which a great deal of the contractor's efforts are really organized. I felt here that they had not gone nearly far enough to make a work structure breakdown or what we have come more recently to call work packages clearly defined so that there were clearly stated jobs to be done which could be clearly assigned in the appropriate places in the organization.

I felt that they were not doing enough in integrating the total program planning. There were planning groups in several places but I was critical of the manner in which they were bringing all the planning together so that the total job could be properly understood and directed and I was critical also of what I call the visibility that program management had and their ability to understand the details of the progress and be able then to focus energy and resources to solve the problems.

Now, with respect to engineering, I was critical of the ability of the engineering organization as had been demonstrated in the months preceding my visit to meet their engineering release schedules. I was critical of the fact that our block II design which has been referred to here today, was falling behind schedule and I felt there was no reason why it should be behind schedule if it was properly addressed by the management of the engineering organization.

We were having fairly serious technical problems with the S–II, the S–II stage, which have been since overcome. These were—a couple of examples are the insulation which at that time was a considerable problem in engineering, and there were problems also with the structure which have since been overcome.

I was critical of the changed control that was being exercised and made recommendations for tighter control of engineering changes. We were critical of their test operations with respect to the timely development of the procedures which tell the test engineers the steps to go through.

With respect to manufacturing, I concluded that part of their problem in manufacturing had its origins in the engineering department and I think that is fairly obvious. The late design releases give manufacturing a problem. I was critical of the way in which manufacturing was divided between the program organization and the central manufacturing activities and recommended some organizational changes which the company did respond to and make. We were critical of the behind schedule position of some of the components and subsystems and of the practices that were being followed in managing certain subcontracts and in expediting some of the materials, and here, too, as in all the cases I have been enumerating, the company worked very closely with me and my team and were very cooperative and responsive to these recommendations in the main.

I was critical in manufacturing of what I considered the effectiveness of supervision. The equipment that we get, of course, is the result of work of individual humans and the skill with which they do their work is where good products start. And, if the skills are not all that one wants, then in being terms of numbers of people that have to do this work, then the importance of supervisions is greater.

And finally, in regard to manufacturing, I was critical of the efficiency of the work force. In other words, the work per man-hour, if you will.

With respect to contracting, we were critical and made recommendations with respect to the timely submission of contract proposals, contract proposals on which negotiations could be carried out between our contract negotiators and the company.

I was critical also of the protracted negotiations that had become more or less the way of business between our respective contracting organizations and recommended that actions be taken to improve our ability together to negotiate contracts and changes to contracts in a more timely fashion.

With respect to quality control, I made recommendations that trend data be used more effectively by management to identify whether the quality of workmanship was as good as it should be. I was critical that our Government inspectors were finding what I considered to be too many discrepancies over and above those that the company inspectors identified.

I felt that the quality control organization was not being fully effective in carrying out their inspection function and in identifying discrepancies.

Finally, with respect to overall management, it was my conclusion that the division could do a better job of both managing and carrying out both of these large programs with less total people being charged against these contracts that were then being used, and recommended that if efficiencies in the several areas that I discussed were introduced, that the manpower could drop down somewhat, and I think the later events showed that to be correct.

Now, that is a summary of the high points, if you will, of the recommendations. I would like to repeat that the company was cooperative with me and my task force in the entire period. It was to our mutual advantage to identify problems that were hindering our ability together to get the equipment properly designed, properly built, tested, and ready to operate. They were completely responsive to the recommendations that I made. And in the main I had a reasonably good confidence in the spring of 1966 that the implementation of the recommendations in all these areas was proper and that the program was in tremendously better shape at that point in time than it had been several months earlier.

The CHAIRMAN. Senator Holland.

MORE DETAILS ON GENERAL ELECTRIC REPORT

Senator HOLLAND. Thank you, Mr. Chairman.

Mr. Chairman, I think in the first instance that we have been talking about two different reports, two very different reports, from their objectives, and I think it would be well to clear up for the record just what these reports are.

At first, therefore, I want to make some comments with reference to the General Electric Spacecraft Operations Reliability and Quality Problems Report dated April 3, 1967.

The staff of our committee has made a very able résumé of that report, and I am going to read certain sentences from it, and I ask Mr. Atwood and Mr. Myers to follow, and if there are any corrections or additions that they wish to make, I invite them to do so. But I think these sentences explain clearly what the nature of this General Electric report is:[1]

> The quality assessment and reliability group was established as a part of the General Electric checkout and reliability function in February 1966, and reports to the manager of spacecraft operations, Kennedy Space Center. The group consists of one supervisor, nine engineers and two data clerks. This group is charged with monitoring reliability engineering activities for NASA and specifically to review, as a part of this function, failure and discrepancy reports for all spacecraft contractors on a daily basis.

Now, the second quotation:

> It is to be emphasized that this group reviews for NASA the discrepancy reports and does not perform physical inspection of equipment. The group also has a subsidiary function as an arm of the NASA manager of spacecraft operations to prepare discrepant report control data for the flight readiness review for each Apollo launch.

The third part that I quote is this:

> Although this group has been functioning in the above described capacity since February 1966, all reports were previously on an informal, close working relationship basis with NASA. The April 3, 1967 report is the first formal report, and the committee staff is advised by Mr. George White, Apollo director of reliability and quality, NASA Headquarters, that this report was formalized because of the increasing interest in this area. NASA has under consideration the continuation of this report on a formal basis in the future.

---

[1] See p. 400 for full text of staff memorandum.

The next quotation:

Mr. White advised that this report is a product of a formally established group assigned to monitor quality and reliability activities, and that this group was not formed as a result of the accident.

And the last quotation:

Mr. White advised also that since this is an ongoing, internal NASA function, the report was not formally released by NASA, and he does not know personally how the information reached the press.

It seems to me that those quotations from the very able staff résumé clearly show what the nature of this report was, and I want to ask Mr. Atwood and Mr. Myers if they are in accord with the summary statements which I have read, which clearly show what was the nature of the General Electric team function, and of their report.

Mr. MYERS. That is a correct series of quotes for the definition of their activities.

Senator HOLLAND. This internal report, dated April 3, did not reach you people until the last 48 hours. You have already testified to that.

Mr. MYERS. That is correct.

MORE DETAILS ON PHILLIPS REPORT

Senator HOLLAND. All right.

Now, with reference to the other report, which is quite a different matter, which is the General Phillips report—my understanding is that the General Phillips Task Force was appointed by NASA in late 1965 and made the report of its findings and recommendations in December 1965.

Is that your understanding?

Mr. ATWOOD. Yes, Senator.

Senator HOLLAND. Now, you state in your testimony that between December 1965 and April 1966 North American took appropriate action "where we felt that the result would improve management and program performance. In April the Task Force reviewed our progress and expressed general satisfaction with it."

Was that general satisfaction stated in a letter, or in a formal way?

Mr. ATWOOD. I don't think so, Senator. I think it was expressed in informal briefings.

Senator HOLLAND. Who appeared for the General Phillips task force to discuss the matter with you in April following the report of the preceding December?

Mr. ATWOOD. Well, I don't remember in all. There was, of course, General Phillips. I think generally he had the captains of various task teams there. I believe there was Mr. Kuba and of course Dr. Shea, who is the program manager, and people of that kind. There must have been six or eight of them. They came back. It was verbal, as I remember it. I don't recall any in writing. Do you?

Mr. MYERS. They did cover each of the areas of deficiencies that had been reported in December, and they had reviewed the answers we had put together for improvement of the actions that were involved and gave us a read-out at that time.

Mr. ATWOOD. Senator, I would not want you to think that we interpreted their visit or their review with us as complete satisfaction or having completely mastered the tremendous program and be completely satisfied. This was not the case at all. I believe they felt that procedurally, organizationally, and from the standpoint of control that we had or were getting adequate means to handle the management of the program. I think they felt that all of our activities were improving in quality.

I do know that we had been able to make substantial reductions in manpower through getting on top of the engineering load, improving our scheduling of changes, and many other things that we were able to do as a result of this joint survey.

Senator HOLLAND. There was no written statement made in April of '66, comparable to the written listing of discrepancies and defects and criticisms contained in the letter of December '65?

Mr. ATWOOD. Well, there may have been. I don't know that any were transmitted to us. Do you?

Mr. MYERS. There were briefing charts used in that.

Senator HOLLAND. What?

Mr. MYERS. There were briefing charts used, as I remember.

Mr. ATWOOD. Yes. We must have gotten copies of the briefing charts. They would be only poster-type presentations which would list topics and be a prompting device for the speaker.

Senator HOLLAND. Are those briefing charts available?

Mr. ATWOOD. I don't know, sir, whether they are or not.

Senator HOLLAND. I ask that a search be made and if they are available, that they be delivered to the staff for study as a basis for possible later discussion.

One more question on this point.

Mr. ATWOOD. Senator——

Senator HOLLAND.. Has there been any formal——

The CHAIRMAN. Senator, I think Mr. Atwood has another comment.

Senator HOLLAND. I am sorry.

Mr. ATWOOD. Senator, I greatly prefer if you would ask NASA for whatever they used to talk to us in April.

Senator HOLLAND. We will ask NASA for everything that we think they may have. But if you have these briefing reports—and you indicated that you think you have—I suggest that you do deliver them to our staff for consideration. We are just as willing to get our information from you as we are from NASA.

Mr. ATWOOD. Senator, we will look at our files and see if we have them.

Senator HOLLAND. Thank you.

Now, the next question is—was there any formal or written statement made by the Phillips task force at all following December 1965 and following April 1966, which you have?

Mr. ATWOOD. We, of course, have, as I said before—and I am sure we still have—copies of the memoranda, briefing charts, all the data which they allowed us to see in connection with their review.

Senator HOLLAND. Well, the reason for my question is this. You have already stated that you do not want to create the impression that the Phillips task force stated in April 1966 that they were satisfied completely with what you had done following their letter of December 1965. You have stated that, have you not?

Mr. Atwood. Yes, sir.

Senator Holland. Now, if there have been later statements in which they have stated more complete satisfaction, or even complete satisfaction, we would like to see them.

The point of my question, the point of my suggestion is this.

If there were continuing disagreements between you and the Phillips task force, as shown either by briefs or by formal letters, we would like to see them. If there were any later expressions of satisfaction, either partial or complete, by the Phillips task force, we would like to have them for the record.

The point is not clearly left for the record unless you show everything that is of importance that was transacted between yourself and the Phillips task force after the date of December 1965 on which you learned of the criticisms they had and the many discrepancies of which they complained.

I think that for your own sake and for NASA's sake, and for the information of this committee, the fullest search should be made of your records and the fullest statement made to this committee as to any agreement reached between you and the Phillips task force, or any continuing disagreements, so that the committee may have the whole situation clearly in the record.

Mr. Atwood. Well, Senator, as I have understood, this was a very informal effort, and it is my understanding that after April they relied on their own program manager's office to follow continued improvement in the various fields they had mentioned to us. The program manager is really the responsible NASA officer so far as the spacecraft is concerned, or were concerned. And it is my understanding that he was relied on to follow the continued progress we were making.

Do you have anything to add, Mr. Myers?

Mr. Myers. Well——

Senator Holland. You have not stated, though, whether there were any later meetings in which fuller satisfaction was expressed by the Phillips task force, or whether there were continuing disagreements showing that they were not satisfied with what you had done.

Mr. Atwood. Senator, I will be glad to search our records and see if there is anything that is appropriate.

(The material supplied for the record follows:)

North American's records do not reveal any further meetings with the General Phillips review team after April 1966.

COMMITTEE WILL SEEK REPORT ON REGULAR BASIS

Senator Holland. Now, Mr. Chairman, there is one other thing I would like to say.

If the report of April 3 by General Electric was the first formal report, and if there is a question as to whether they are to make later written reports, I strongly hope that the chairman will insist that regular reports be made, because here we have a situation with reference to the Phillips task force which shows that while conferences continue, there is no record we can see and rely upon as to just what complaints of the Phillips task force were satisfied, and what were not satisfied, or whether there were continuing disagreements and arguments on the subject matter.

It seems to me that the regular written reports in this critical field are appropriate. And that is what I suggest, that we insist upon that as to the General Electric reliability team.

The CHAIRMAN. The chairman will try to get those on a regular basis. If he cannot, he will report back to the committee.

Senator HOLLAND. I thank the chairman.

The CHAIRMAN. Senator Curtis?

NO RECOMMENDATIONS OVERLOOKED

Senator CURTIS. Thank you, Mr. Chairman.

Mr. Atwood, I have gone over your statement and listened to as many of the inquiries as possible. Regrettably, I did not get in on all of them.

I have this question.

Were there any findings or recommendations of the Phillips Report or a report of any other group, individual, team or office, which went unheeded and which in any way contributed to the accident now under investigation?

Mr. ATWOOD. Senator Curtis, I do not think so. I would like to defer to my colleague and see if he has any such opinion.

Mr. MYERS. No, I don't think there has been any that we have left unheeded that would have anything to do with the accident.

Senator CURTIS. Were there any that were disputed and therefore not followed that in any way contributed to the accident? I'm not limiting this to the Phillips Report. I mean any report recommendation from any group, team, individual, task force, office.

Mr. MYERS. I am certainly not aware of any, Senator.

Senator CURTIS. None relating to any kind of hatch?

Mr. MYERS. No.

Senator CURTIS. Or in reference to flammable materials inside the spacecraft?

Mr. MYERS. No.

Senator CURTIS. Or reference to wiring?

Mr. MYERS. No.

Senator CURTIS. Or inspections?

Mr. MYERS. No.

Senator CURTIS. In other words, your position is that in response to all findings and recommendations by any group, the reference to all the phases of the program, that those findings and recommendations were followed and not disregarded, unless upon further study the recommendation was not valid.

Mr. MYERS. Yes—the answer is yes. I would like to qualify slightly.

Senator CURTIS. I would be happy to have you do so.

Mr. MYERS. I would like to refer to the Phillips Review of 1965 in the Board report, and any other major reviews that we have had with the management of NASA in things that I am aware of.

Now, there are thousands and thousands of people in this program. There may have been comments made or small meetings held some place that might have had some reference that could by our judgment now be related to the combination of circumstances that led to this accident. But I am not aware of it, Senator.

Senator CURTIS. Did any inspection group or team, task force, ever make any allegation of general laxness or carelessness?

Mr. ATWOOD. I don't know whether any such thing was ever reported or not. I know when you report discrepancies, you fix them. This has to be done. I believe Mr. Myers comments would go to the point that any known discrepancy in any known inspection would be fixed.

Senator CURTIS. I realize the wide latitude in the question—a general allegation of laxness or carelessness. Such an allegation would always be easy to make, and the less competence you have the easier it would be to make. But for the record, I wanted to ask the question.

I think that's all, Mr. Chairman.

The CHAIRMAN. When you look through the testimony, if you decide you should have made some other remarks, you can call it to our attention. Because with the wide scope of the questions we are dealing in here, it could be your answer might need amplification.

Senator CURTIS. Mr. Chairman, you are referring that if something comes to their mind later.

The CHAIRMAN. Certainly.

Senator Mondale.

BASIC OBJECTIONS OF PHILLIPS REVIEW CLEARED UP

Senator MONDALE. Mr. Atwood, I missed part of your testimony because I had to make a quorum call. But I take it it is now established that you did receive a copy of a letter with an attached report signed by Mr. Phillips dated December 19, 1965.

Mr. ATWOOD. Certainly.

Senator MONDALE. Is it your testimony that North American has cleared up all of the basic objections set forth in that report and had done so by April, 1966?

Mr. ATWOOD. In responding to Senator Holland, I tried to make it clear that we had tried to acomplish just that, tried very hard. I could not, of course, state that we had succeeded, nor that General Phillips so indicated in his meeting with us. But he did state, as I recall, that we had made a great deal of progress, many improvements, that the program was improving rapidly, the manpower situation was improving, and engineering was returning to schedule, and I believe that methods of reporting program progress were generally satisfactory. But he did not, I am sure——

Senator MONDALE. Was this report brought to your personal attention as president of North American at the time of its receipt?

Mr. ATWOOD. You mean the Phillips report?

Senator MONDALE. Yes.

Mr. ATWOOD. Oh yes, I was involved in every bit of that, and the call from Dr. Mueller until—well, I'm still involved in that.

MANAGEMENT CHANGES DISCUSSED

Senator MONDALE. The last few days there have been public reports to which you refer in your testimony of a basic shakeup in the management of the North American space efforts. One of the columnists who deals in this field, in the Post, commented this morning that the changes in North American's management "appear to reflect some of the criticisms made in the Phillips report". Would you regard that as a fair conclusion?

Mr. ATWOOD. No, sir. Although we did make many management changes after the Review Boards were there, we removed some. But actually this Phillips review program was 17 months ago, and pretty much passed out of the active category in April, and the program manager was carrying on. So it has been over a year since we have had anything to do with it in an active sense.

Senator MONDALE. Are you planning any other basic personnel changes or organizational changes in your space efforts?

Mr. ATWOOD. Yes, sir, we are. And I am able to mention two or three right now.

We have obtained the services of Mr. Hello, formerly of the Martin Co., who served as the program manager on their Gemini since its inception. They had the booster for Gemini. We were able to get him to come, and we are putting him in charge of our operation at Cape Kennedy. We feel he is an experienced and capable and very effective man.

In addition, we have obtained the services of Mr. G. T. Willey, not as a full time employee, but as a consultant. He has worked for Martin all of his career, too, and has retired. But he has been active in charge of the company's launch operations for the Titan and Gemini programs down there. So he will be of considerable assistance to us.

Another man that is being transferred to the division, Space Division, is P. R. Vogt, and he is Vice President and Assistant to the President for Quality—Product Quality. He has been with North American Aviation for 20 years and has been Chief Engineer of our Rocketdyne Division.

So I mention those three. And we are probably going to have some others.

Senator MONDALE. Has North American been approached by NASA about the possibility of having McDonnell Aircraft personnel inspect North American's space vehicles before they leave North American?

Mr. ATWOOD. No, sir. I have not heard of it, anyway.

Senator MONDALE. Is nothing being explored along those lines, to your knowledge?

Mr. ATWOOD. No. But I would say this: If any inspectors can improve our quality, I would welcome them. And if they could be used in this role, I would appreciate it.

QUESTIONS ON PRESENT APOLLO SPACECRAFT

Senator MONDALE. The present Apollo spacecraft, now in the process of preparation for the un-manned test flight later this year, and the subject of the GE study that has been discussed extensively here today, contained the many flaws and difficulties that have been outlined. Did North American regard this spacecraft to be flight ready when it left the factory?

Mr. ATWOOD. Senator, it had been through all the checkout, and through all the inspection and acceptance at the plant. I want Mr.

Myers to speak for this. But I would like to say that this was designed as a manned space craft unit, and was adapted to an unmanned automatically controlled spacecraft. The wiring—Spacecraft 17 is the number—the wiring was augmented about 70 percent over the basic wiring system that would go with the basic configuration. This wire was added overlaid, and appliqued, into the wiring harness of Spacecraft 17.

Yes, we thought it was ready for flight, and it had been through all the functional tests to so qualify it.

I would like now for Mr. Myers to explain his view of why the discrepancies—such numerous discrepancies, primarily on wiring, were reported at the Cape.

Mr. MYERS. First I would like to point out that when we check out a spacecraft and do its final inspection, we have in that checkout checked every wire, every circuit, every switch, every place electrons can go in the spacecraft. The spacecraft met the criteria of inspection that had been applied previously to Spacecraft 011. If you recall, Spacecraft 011 was also an unmanned flight, and also had added to it by splicing into the main wire harnesses a mission control programmer which we called the "mechanical man" that does the programming to the very strict and rigorous requirements of these unmanned space flights.

Spacecraft 011 was completed successfully.

The same criteria for inspection was applied to Spacecraft 017 before it was shipped to the Cape.

After it reached the Field, it had a receiving inspection which revealed about 74 discrepancies, and then after the fire we worked with NASA to develop a new criteria which was objective, specifically giving the inspectors a standard to which to inspect—more specifically measurable.

Now, that inspection criteria was applied in the middle of a work period, and normally inspections are performed, or at least the inspection discrepancy reports are written after work periods are complete and the technicians have removed themselves from the space capsule and the inspectors go in and inspect. This time we were not able to close out all of the activities that we had. We wanted to get on to this new criteria of inspection, and in the process we developed through this very objective and more detailed inspection criteria many discrepancy reports which have nothing to do with the actual capability of the spacecraft.

Now, in the process of this inspection there were some items found which were, if left alone, and no longer checked during the further checkout of the Spacecraft, and no longer found by other means—would have been listed as hazardous to the flight of the spacecraft. But we do have continued inspection and continued checkout of the spacecraft where all the wires again are checked, prior to launch, and we believe we would have found those, and we would have had a successful flight with the ship.

Senator MONDALE. In the original Phillips Report, one of the criticisms made was in the nature of the quality control was such that the spacecraft would be certified for approval by North American, but then NASA inspectors would uncover hosts of inadequacies. Is it your testimony that that problem has been corrected, and that despite this GE study, that an adequacy system of quality control has been established?

Mr. MYERS. We had a fairly major change in our quality control organization 1965–66 time period, and did a lot of work with NASA in the definition of the method of describing a discrepancy. We had differences in the details of how you note what is a discrepancy, and how many discrepancies are noted. We clarified that so there we have a system that is common with NASA's system, and we do continue to do a closeout inspection by North American personnel, followed by a NASA inspection. I don't think we have—we have rarely had a case where there are not a few discrepancies noted by the NASA inspectors after we have completed our inspection.

Senator MONDALE. I admit I find it difficult to visualize the magnitude of technical problems that you are confronting. But this GE report, among other things, indicated that a timing device costing $100,000 was delivered and it could not keep time. Isn't that the sort of thing that is worthy of detail quality control? This may not be accurate. It said it was supposed to run for 8 days and it ran for 4 minutes and 4½ seconds. At the second test it gained time, or it failed altogether. Maybe this is not North American's responsibility. But how——

Mr. MYERS. It is my understanding—and as I said, I have had just a few hours to check on this, on the item specifically in the report—but it is my understanding that the clock, which is—and by the way, I question the cost noted there—but the clock was overtorqued in the installation, and a procedure has been written to correct that overtorqued condition.

Senator MONDALE. Is there a difference between the approach of North American in terms of having a space capsule ready for what they call flight readiness, and the approach of McDonnell? Do you have a different standard for determining flight readiness than McDonnell Aircraft?

Mr. MYERS. I am not aware in detail of the specific procedures that are gone through in getting ready for the flight readiness review in the Gemini Program, but as I understand it, they are essentially the same as far as the technique is concerned. It involves the understanding of every failure that has occurred during the qualification, during acceptance testing of the equipment, during the installation, and during the checkout of that equipment in the spacecraft, and the specific answer that is satisfactorily agreed to between NASA and ourselves on every one of those items. That's the way we do it on the CSM. I understand that is what they do on the Gemini.

Senator MONDALE. No further questions, Mr. Chairman.

The CHAIRMAN. Senator Percy.

THREE DIMENSIONAL JIG BOARD

Senator PERCY. Mr. Atwood, in your statement, you talk about the method of manufacture and installation of wiring and tubing in the Block II Spacecraft. You indicate that a three dimensional jig has been used in the fabrication of wire harness for the Block II Spacecraft that is a significant improvement to the construction of the Block II Spacecraft. Apparently these jigs were not used in the Block I. Isn't it true that this was used, this technique and method was used in the Gemini Spacecraft?

Mr. Atwood. Could we allow Mr. Myers to speak to that?

Mr. Myers. Yes, it is my understanding that the Gemini did use a three dimensional jig board. At the time we were designing the Block I, we had a number of individual wire harnesses that were separately built on flat jig boards. A decision was made at that time that flat jig boards would be satisfactory for limited length wire harnesses. In the process of designing the Block II we actually reduced the number of connectors that are used in the wire harness, and by that means we actually increased the length of the various wire harnesses in Block II and concluded that we should use this three dimensional wire harness in that case.

There is an improvement therefore in decreasing the number of connectors that are used and therefore the improved reliability of Block II.

Senator Percy. If there is a proven technique in Gemini which has been eminently successful in every aspect of it, wouldn't it have been wise to have used it in Block I? You now decided to go back and use that technique in Block II.

Mr. Myers. Well, I think the decision that was made recognizing the three dimensional jigboards in Gemini was based on wire harness lengths for Block I.

Mr. Atwood. Senator, I can only add that it depends on a number of things. The three dimensional jig, of which we have a picture here—you might pass it around—is an installation aid more than a basic wire harness system. It's an installation aid. You can only twist wires or bend wires so far—depending on the size and the length. And I don't really know, but I am sure that the flat jigboard design and the length of the wires used were considered satisfactory for installation on a spacecraft at the time.

CHANGE IN MANAGEMENT WILL HELP

Senator Percy. Could I ask you about your management changes, Mr. Atwood. I ask this with a background of some experience in having had to change occasionally management setups.

In your statement you indicate the designation of a new president and vice president, implying that their skills are "especially required at this time." Was this special requirement generated by the accident? What special skills does this new team possess that were not possessed by the old team that has now been replaced and then will their skills strengthen the program, as you say?

Mr. Atwood. Of course we didn't have Mr. Bergen available to us before this. But I do feel that his experience as president of the Martin Company which has handled the Titan booster for Gemini, and many other programs, qualifies him to a greater extent than the man that previously headed this division.

I feel that Mr. Storms, who was head of this division for 6 years, a very brilliant and accomplished engineer, has accomplished many things. I feel that we will make more progress with Mr. Bergen because I think he has more capabilities for the situation in which we find ourselves now, and I believe those capabilities included a better understanding of NASA's operations and methods, a perhaps broader perspective of organization and motivation of personnel, and certain other managerial skills that have been developed by his company which I think can be transferred effectively to our operation.

Senator PERCY. You feel this new team possesses such skills, that if they had been in charge of this program from the inception we might not have had this accident?

Mr. ATWOOD. This is very hard to say, Senator Percy. I certainly did not expect perfection in anybody's administration. I don't mean to represent to you and to the committee that new management will eliminate all our problems. This is a tremendously difficult program, by far the most difficult we've ever seen. And yet I do think that this change in management will help. We had felt very fortunate to get Mr. Bergen where he could move in and take this work.

Senator PERCY. I think your report, Mr. Atwood, is very clear and concise. One part of it I stumbled over. It's a question of terminology, I am afraid.

In your statement you indicate that in 1965, "It was extremely difficult to achieve full control and visibility of North American's basic design and development effort." And later you indicate the necessity now to review the means by which improved visibility of the management effectiveness in program control will be available to both North American and NASA.

Would you explain the meaning of the term "visibility"? It's a term with which I'm not familiar.

Mr. ATWOOD. Senator, I will try, and I think my colleague may be able to give you more on that.

We have here a great many concurrent activities, and many, many companies. There is the design and development, procurement—design, development, qualification and testing of environmental control system—and in most of these things we buy from subcontractors or suppliers. We also buy the fuel cells from United Aircraft. And we are responsible for the coordination of all that work—to know the progress that's being made, the schedule, the expenditure involved. And it makes a real problem to come out even on schedule, technical qualifications, money and program progress.

What we mean by that is ability to see at various levels how various things are coming along and to take timely action when we see something failing to meet a schedule or a test criterion or in any way falling behind the parade. And so we call it visibility. It is primarily just a management system reporting progress, key milestones, and expenditures that go with them. That would be my primary definition of visibility.

Dale, do you have any more?

Senator PERCY. Is there any implication here that management could not determine the effectiveness of its efforts at all if it really went out to try to find out what the situation was?

Mr. ATWOOD. Well, yes—if what we call visibility were not good, this is true.

Mr. MYERS. After the Phillips survey, we set up a vice president in charge of program control reporting to the president of the division whose job it was to develop standardized methods of reporting to higher management. I am not sure I would say more detail, I think

I would say more succinct important information relating to the progress in program and relating to the elements of the quality and performance, schedules and costs of the program.

I believe the comments that are made here are just reaching furthei again for further information presented properly at all levels of management to give them the greatest possible insight into all problems.

Senator PERCY. In your statement you suggest that the primary failure to identify the hazards was NASA's, since they omitted the necessary criteria from their guidelines—I know that Senator Jordan has questioned you on one phase of this.

Referring to your own memorandum and comments on finding number five, which you supplied to the committee would you define for us or refer us to provisions spelling out the responsibility of North American for safety in conjunction with the contracts which you are performing for NASA.

Mr. MYERS. I think, Senator, the response North American made is fully definitive. The problem that was involved for all of us was not recognizing oxygen testing as a hazardous condition. The hazardous condition criteria called out on a range safety memorandum published by NASA and used as the criteria for choosing those tests that are by that definition hazardous. And I think we all feel now, in retrospect, that we all missed the point on what was hazardous.

Mr. ATWOOD. Senator, you notice our engineers looked at the criteria, made the recommendation. We stated here—with the benefit of hindsight it is evident that the criteria were not directed to the potential risk of spacecraft 012. We recognize that North American might well have questioned them, even though it did not have the primary responsibility for determining the criteria.

Senator PERCY. In that same section you say "we recognize that North American might well have questioned them, even though it did not have the primary responsibility." Wouldn't you perhaps modify that now to say you should have questioned them—rather than might well have questioned them? And in a future relationship shouldn't a closer look be taken at this aspect of the program to pinpoint responsibility?

Mr. ATWOOD. Senator, I am sure that all criteria will be doubly and triply questioned. We certainly will consider it our duty.

Senator PERCY. Lastly, Mr. Chairman, it seems that probably the most significant management deficiency disclosed was a lack of an effective system to identify, eliminate or control potential hazards. What action has North American taken to assure for both ground tests and space flights an adequate analysis of all the potential hazards have been made?

Mr. MYERS. We have a team of NASA people stationed at North American to do just that. We have a team made up of top system-oriented engineering and quality people from MSC, headed by Colonel Borman, that is in residence with us for the review of materials, the hatch design, the electrical system, and all of the activities that deal with hazard, and the changes that are coming into the spacecraft.

Senator PERCY. Thank you very much.

Senator BROOKE. Mr. Chairman?

The CHAIRMAN. Senator Brooke?

CONTRACT CANCELLATION NOT CONSIDERED

Senator BROOKE. Two quick questions.

Mr. Atwood, number one, at any time in 1965 or 1966 did Mr. Webb discuss cancellation of the contract with you?

Mr. ATWOOD. Senator Brooke, I do not remember any such occasion or even any indication that it was being considered.

Senator BROOKE. At any time?

Mr. ATWOOD. No, sir.

Senator BROOKE. Number two, did your staff study the report made by the Phillips task force and compare it with a report made by the board of review in order to determine whether there was any similarity in the findings of the Phillips task force and the findings of the board of review which was, of course, after the Apollo incident?

Mr. ATWOOD. I do not think we have had a systematic comparison item-by-item, Senator. I don't know of any suggestion or recommendation that would in itself have prevented—would have obviously prevented this accident. I believe——

Senator BROOKE. I am not saying that might have caused the accident exactly. What I am asking is did you examine the two reports to determine whether findings made by the Phillips task force had been corrected prior to the Apollo incident, and thus not contained in the report of the board of review?

Mr. ATWOOD. I have not been able to get any information that would help to answer that question. I would say that most of the Phillips review had to do with procedures, organization and systems and methods of procurement, and I am sure that nothing involved in those notes had any reference to anything that would in itself pinpoint this type of accident.

Now, I am going to defer to my colleague and see if he knows of anything to add.

Mr. MYERS. No, I don't have anything to add.

Senator BROOKE. Your answer, Mr. Myers?

Mr. MYERS. I have nothing to add to that.

Senator BROOKE. Then is your answer, Mr. Myers, the same as Mr. Atwood's—that you did not find any findings of the Review Board which were similar to the findings of the Phillips Task Force?

Mr. ATWOOD. Well, I think——

Senator BROOKE. Specifically I'm trying to get at, Mr. Myers—the Phillips Report—let me make is as clear as I can. The Phillips Report made certain findings and recommendations. The Phillips Report was in 1965.

Mr. MYERS. I'm with you now.

Senator BROOKE. The NASA Review Board, so-called, findings were after the Apollo accident. Now, I'm asking you—did there appear in the Review Board findings anything that had been pointed out to you in the Phillips findings which you had not corrected?

Mr. MYERS. There were, I would say, similarities in the area of the deficiencies spelled out in the two areas. Now, since the time of the Phillips Report I would like to point out for the record that we have had a very complete review of the trends of our discrepancies as a function of time, and we have had major improvements in the decrease in discrepancies, which is an indication of each workman doing his job a little better as time has gone on. And I think the reference in the Board Report has that similar tone, but our records would indicate there have been major improvements in that area since the time of the Phillips Report.

Senator BROOKE. Of course the Phillips Report was in 1965 and the Review Report was in 1967. Now, in that interim period, did not North American have sufficient time to correct all of the deficiencies pointed out by the Phillips Task Force?

Mr. ATWOOD. Well, Senator, certainly we made every effort to eliminate all discrepancies. The question as to whether any discrepancy caused the fire is still moot.

Senator BROOKE. I'm not trying to place the blame for the fire. I'm merely trying to find out more about management at North American.

Mr. ATWOOD. I believe the only similarity might be that in both instances criticisms were made of the remaining or existing questions of the quality of the work. That would be a similarity, a general similarity. It is the only way I can define it.

Senator BROOKE. Mr. Myers, you say there were similarities in deficiencies.

Mr. MYERS. Yes.

Senator BROOKE. And you have no explanation as to why these deficiencies were not corrected between 1965 and 1967 with the exception that it does take time——

Mr. ATWOOD. I feel sure they were not the same deficiencies. This is a matter of inspection and the standards Mr. Myers spoke to. We have done everything with the inspectors we have, the workmen we have, and with NASA's supervision, to try to eliminate them all, sir.

Senator BROOKE. Thank you. No further questions.

The CHAIRMAN. I have one item that sort of bothers me. What was General Phillips' position?

Mr. ATWOOD. General Phillips, as I understand, is still an Air Force officer. He is now director of the Apollo program for NASA.

MORE QUESTIONS ON PHILLIPS FINDINGS

The CHAIRMAN. At all times during the entire period he was the Apollo Program Director, wasn't he?

Mr. ATWOOD. Yes, sir.

The CHAIRMAN. If he found all these deficiencies, what did he do to correct it, as far as your company is concerned?

Mr. ATWOOD. Are you thinking of this General Electric report, Mr. Chairman?

The CHAIRMAN. No, I'm talking about General Phillips. Regarding all of these defects, and all of these troubles, and all these errors, what did he do to correct them?

Mr. ATWOOD. He tried very hard to improve quality and all other characteristics of the work. He has had a quality control organization—that is NASA has a quality control organization within its headquarters, and at each center, and at each major manufacturer's plant.

The CHAIRMAN. He had this long list of things needing correction in what you called the Phillips report. When he tried to cor them, was he stopped by your company?

Mr. ATWOOD. Oh, no, sir.

The CHAIRMAN. If you didn't stop him, who did?

Mr. ATWOOD. Senator, no one stopped anybody from trying to m sure that everything was as perfect as we could make it. I k he tried very hard. He emphasized the problems very hard. He his own inspectors, and of course we had ours.

The CHAIRMAN. I regard General Phillips very, very highly. I th he tried to correct these things, as you folks also did.

This equipment out there that he was talking about was on line, wasn't it? Your Spacecraft 012?

Mr. ATWOOD. Yes, sir, it was on the line at Downey.

The CHAIRMAN. I spent a little time visiting with the Atomic E ergy Commission at various times. They have a system of check and I am going to send you a question about this which I hope y will answer at some later date.

Now, I note your company was awarded the Apollo command a service module development and the S–II stage development with 2 months of each other. Do you feel in retrospect that you had avai able the management and technical capability to handle these tw launch programs simultaneously, particularly when both could be ex pected to contain some large technical problems?

Mr. ATWOOD. We should have had, and I do think we did have The two projects were different.

The CHAIRMAN. You made some changes in your organization, in the management structure. Will you send us now a record of the organization chart of the corporation and the Space Division, giving the names of responsible people?

Mr. ATWOOD. Yes, sir.

(The charts referred to are figures 98 and 99 which follow.)

The CHAIRMAN. Senator Smith.

QUESTIONS SUBMITTED FOR PHILLIPS REPORT SUMMARY

Senator SMITH. Mr. Chairman, earlier in the afternoon I asked Mr. Atwood to supply for the record a statement with respect to the findings and the conclusions of the Phillips report and related information.

That you may have a clearer understanding when doing that, Mr. Atwood, I would like to read a sample of two or three questions that I have in mind, and then supply, Mr. Chairman, for the record a number of questions that are not to be answered individually, but answered in the statement that I asked for, if that would be all right with the committee.

The CHAIRMAN. That will be done.

Senator SMITH. For instance, Mr. Atwood, General Phillips in appearing before the committee and discussing the so-called Phillips Report said, "Now to summarize the essence, if you will, of the recommendations that I made, I felt that the top management of both the corporation and the division were not giving sufficient attention to the details of the direction and execution of these contracts and recom-

4

i
t

s
h
h

h

l

e
a
v

s
2
a
l
p

T

t
g
t

M
t
i

A
I
n
a
w

p
R
m
co
th

mended more attention from that level of management to the details of their problems and progress."

That's a very critical assessment of North American management on these two contracts for the spacecraft in the S-2 stage, and I think it would be useful if we could have your views in the statement that I have referred to, Mr. Atwood.

General Phillips also testified that—"I was critical of the change control that was being exercised and made recommendation for tighter control of engineering changes. We were critical of their test operations with respect to the timely development of the procedures which tell the test engineers the steps to go through."

In the statement it would be well if you could give us something of the steps that you have taken to control the engineering changes and assure the timely development of test procedures.

I will read one more and supply the others.

General Phillips further testified:

"In the functional area of planning and control * * * I felt here that they had not gone nearly far enough to make a work structure breakdown or what we have come more recently to call work packages clearly defined so that there were clearly stated jobs to be done which could be clearly assigned in the appropriate places in the organization."

In your statement, you might give us an idea of the improvements that have been made of the area of planning and control.

I will provide for the record a number of other questions similar to those, Mr. Atwood, that you might touch upon in making your statement for the record.

Thank you, Mr. Chairman.

The CHAIRMAN. Those will be included.

(The questions referred to by Senator Smith are as follows:)

1. General Phillips testified before the Committee that in December 1965 he thought that the authority of the two program managers (on the Apollo command and service modules and the S-11 stage) in the division was too diffuse to enable them to harness all the resources they had to bring to bear to get the job done and he recommended that you strengthen the project organization and pull parts of the functional organization together under the more direct authority of the respective program managers.

Did you realine the authority of the program managers and change the project organization so that the organization could pull together under the authority of the program managers? (Perhaps you would like to put some charts in the record at this point showing before and after organizations.)

2. General Phillips further testified that:

"I felt that they were not doing enough in integrating the total program planning. There were planning groups in several places but I was critical of the manner in which they were bringing all the planning together so that the total job could be properly understood and directed and I was critical also of what I call the visibility that program management had and their ability to understand the details of the progress and be able then to focus energy and resources to solve the problems."

What have you done to improve the integration of the total program planning?

3. General Phillips was also critical of the ability of the engineering organization to meet engineering release schedules and because the Block II design was falling behind schedule for no reason that he could see. He believed there was no reason for it to be falling behind schedule if it was properly addressed by the management of the engineering organization.

What steps has North American taken to improve the ability of the engineering organization in these areas?

4. General Phillips was also critical of the efficiency of the work force in manufacturing.

Have you improved the amount of work you get per man hour?

5. General Phillips was also critical of manufacturing. He testified that:

"We were critical of the behind schedule position of some of the components and subsystems and of the practices that were being followed in managing certain subcontracts and in expediting some of the materials, and here, too, as in all the cases I have been enumerating, the company worked very closely with me and my team and were very cooperative and responsive to these recommendations in the main."

Have you gotten those components and subsystems back on schedule or have you taken steps to bring them back on schedule?

Have you taken the appropriate steps to change your practices in managing subcontracts and to expedite some of the materials?

6. General Phillips was also critical of the effectiveness of supervision in manufacturing.

What steps have been taken to improve this supervision since without good supervision you cannot get good products?

7. General Phillips was critical of contracting and particularly the contracting negotiations which he said "had become more or less the way of business between our respective contracting organizations," and he recommended that actions be taken to improve the ability of North American and NASA together to negotiate contracts and changes to contracts in a more timely fashion.

What have you done along these lines?

8. General Phillips was critical of the quality control at North American and made recommendations "that trend data be used effectively by management to identify whether the quality of workmanship was as good as it should be."

What steps have you taken to use trend data more effectively?

9. General Phillips also testified that "our government inspectors are finding what I consider to be too many discrepancies over and above those that the company inspectors identified."

What steps has North American taken to correct this criticism by General Phillips.

Finally, with respect to quality control, General Phillips said:

"I felt that the quality control organization was not being fully effective in carrying out their inspection function and in identifying discrepancies."

10. What has North American done to improve the effectiveness of the quality control organization?

(The answers supplied for Senator Smith's questions referred to above and on p. 402 are as follows:)

As requested by the Committee, North American amplifies herein its comments on the summary which was presented by NASA with respect to the review made by the survey team headed by General Phillips.

North American indicated in the earlier testimony some of the conditions which contributed to the problems identified by the NASA review. These conditions were in a real sense inherent, given the size, complexity and evolutionary nature of the development necessary to achieve the lunar mission objectives. A significant consideration was that the mission and performance criteria under which the Apollo CSM and Saturn S-II were being designed and developed continued to evolve based on knowledge and experience being gained by NASA and North American. This caused frequent and almost continuing changes in the detailed specifications and the associated engineering, test, manufacturing, quality control and other program activities. By the fall of 1965 the cumulative impact of the problems being experienced was having a significant effect on the achievement of program milestones.

North American welcomed the NASA Review Team in order to receive the benefit of their views on identifying specific program problems and recommending solutions.

Although North American in some instances took exception to the findings and recommendations of the review team, these were not stressed. It was recognized that in the main, while there might be differences of opinion as to emphasis, the problem areas identified were real. North American, therefore, directed its efforts to responsive action. The Company did not wish to detract from the importance of the review team's views, but was concerned that its concentration on problems would obscure a good understanding of their causes. Successful accomplishment of the program objectives required this mutual understanding, which would include recognizing that stable schedule, cost, and performance conditions were heavily dependent upon clearly defined mission criteria and specifications, tight control of changes, and close and effective working relationships between North American and NASA.

As part of North American's responsive action to the review, Mr. Atwood formed an Action Group consisting of himself, the President of the Space Division, and selected top corporate executives.

This group was directed by Mr. Atwood to make a thorough assessment of actions already taken, and those planned to be taken, by the Company in monitoring and improving program performance. In the conduct of this reevaluation, the group made a thorough analysis of the review notes, examined the conditions referred to, and implemented necessary actions on each item.

The corporate executives on the Action Group in turn formed teams, drawing on qualified personnel throughout the corporation to take actions within their respective areas of responsibility. They worked in close cooperation with Space Division management, Apollo CSM, and Saturn S–II Stage program management, supervision at all levels in Space Division within their functional areas, and with each other.

Subsequent to the NASA assessment in April 1966 of North American actions taken or initiated, the corporate executives concerned continued to work closely with Space Division program and functional management in following up on all actions prescribed. NASA was kept advised of program performance and progress through regular North American-NASA program management channels of communication.

North American believes that its response to the Phillips review showed an understanding of and effective plans to attack vigorously and promptly, in careful detail and in an orderly manner, the problem areas reflected. The actions taken looked to significant improvements in program planning and control, better application of the total corporate resources including, in particular, the resources available in the General Offices, attention to the problem of program management with emphasis on defining and strengthening the role of the Program Managers, and organizational and other improvements in the Engineering, Manufacturing, Quality Assurance, and Reliability areas. Particular emphasis was placed on achieving maximum divisional and corporate program visibility and control. Both accompanying and following these changes, a number of important organizational and personnel shifts were made, designed to assist in accomplishing objectives.

The review team was specifically concerned with six areas, as described to the Committee. North American's further comments and actions taken with respect to these areas are summarized below.

ORGANIZATION AND MANNING

Organization changes and consolidations were effected to: strengthen the authority and control of the Program Managers; provide greater concentration of effort through consolidation of closely related functions under single management; strengthen Space Division central guidance and surveillance; shorten channels of communication; and increase efficiency of operations.

The authority and control exercised by Program Managers were greatly strengthened. Among the actions taken were: separation of the Test Operations and Engineering Reliability Functions from the central Test and Quality Assurance organization and transfer to the Program organizations; transfer of the Structural Fabrication function from central Manufacturing to the Apollo CSM Program; and issuance of new directives which clearly and unequivocally set forth the authority of Program Managers to provide program direction by defining the tasks to be performed, assigning the tasks, authorizing budgets and schedules for each task, measuring performance against plan, and directing any necessary corrective actions.

Actions also were taken to improve division central operations support of the programs. Among the more significant actions taken were: the transfer of non-space oriented activities to other North American operating divisions; the consolidation of all non-Program Engineering activities; and the establishment of the Quality and Reliability Assurance functions which were previously a part of the disbanded central Test and Quality Assurance organization as a new central Quality and Reliability organization, reporting to the Executive Vice President-Operations. In addition, in order to assure continued improvement in program planning and control and to provide improved visibility into the programs for the Space Division President, a new Division office of Vice President-Management Planning and Controls was established.

Reassignments of key personnel were made to increase efficiency of operations by capitalizing on specific and outstanding skills and capabilities available throughout North American. Some examples of these actions were:

Assignment of a new Program Manager to the Saturn S–II Program

Assignment of new Chief Engineers for both Programs

Assignment from another division of an executive to head the new central Quality and Reliability Assurance organization.

Assignment of a new Assistant Program Manager for Program Control in the S–II Program.

Continuing emphasis has been placed since on maintaining effective organization alignments responsive to changing program requirements. Key personnel changes have continued to be made based on frequent management reviews and assessments.

During the period December 1965 to April 1966, both Programs' manpower peak requirements had been experienced. Completion of early phases of the program and increasing stabilization of engineering design were key factors in diminishing manpower requirements. These factors, coupled with organizational realignments and greater efficiency, permitted significant manpower reductions.

In April 1966 Space Division's Southern California organizational components had a total headcount of 28,000. The Division established headcount targets for its Southern California elements of 25,000 by July 1966 and 22,000 by December 1966. Both of these goals were achieved. By early May 1967 the headcount had been reduced to less than 20,000. The total employment at the Space Division at all locations was 34,300 in April 1966 and in early May 1967 it was 26,300.

North American's current corporate (General Offices) organization charts and Space Division organization charts in effect at the time of the NASA review, immediately following that review, and as of the current date, are attached. (See foldin, opposite p. 436.)

PROGRAM PLANNING AND CONTROL

At the inception of the Apollo CSM and Saturn S–II contracts, Program Planning and Control organizations were established by each Program to assist the respective Program Managers in program planning and in control of cost, schedule, and technical performance. The prime tools for this operation were the Master Program Schedule, the Master PERT Network, development Program Plans, and Program Budgets.

In cooperation with the NASA survey team, and with corporate office guidance, both Programs initiated a new system of work package management. New Division procedures were written, as well as definitive Program implementing instructions. A formal work breakdown structure was developed for each Program, with management responsibility and budget assigned for each major element. Within each element, definitive tasks were identified and scheduled. In-process task milestones were identified and keyed to work package milestones, which, in turn, were identifiable to the Master Schedule and PERT networks. This gave each Program Manager an integrated planning and control system, and gave performing supervision definitive task statements, budgets, and schedules against which performance could be measured. This capability existed not only for internal program functions, but for work performed by central support organizations, other North American divisions, and subcontractors as well. Continuing evaluation of the work task structures had identified areas for further improvement.

To improve engineering visibility, the Master PERT Networks were expanded to encompass more engineering activities, and mechanized "Engineering Product Plans" were expanded on both Programs to schedule and track engineering outputs against user need dates. Weekly print-outs of these reports enabled management to apply corrective action where needed to support the Programs. In addition, the critical problem resolution system was expanded to further expedite the identification and resolution of significant technical, production and quality problems.

For greater integration of program planning, expanded requirements were applied to the establishment, revision, and maintenance of master schedules, maintenance of congruity between the functional and task schedules and PERT events, and reporting of schedule status on controlled milestones. A series of training sessions were held to insure that concerned personnel understood and carried out these improvements. Program Schedule Manuals containing this information are continuously maintained on both Programs.

Concurrent with the establishment of work package management, improved cost control systems, covering work-in-process and labor hours, as well as more detailed reporting on material costs, were implemented against the work package budgets. This provided improved visibility into cost versus budget for specific tasks, and against specific milestones. At the same time, tighter change control procedures were instituted and emphasis placed on schedule and cost impact analysis.

With assistance from the corporate office, a new management reporting system was established in January 1966, which tiered upward from the task supervisor level through the Manager level to the functional Directors and the Program Manager, summarized, as appropriate, to each level, but with detailed data available as required. Emphasis was placed on reporting cost and schedule against plan, supplemented with functional manpower reporting, as well as other appropriate performance indices. Subordinate level reports and backup data are reviewed at weekly Program Reviews by the Division President. This data is also reviewed and validated continuously by the Division's new Management Planning and Controls organization, and their summary and assessment of Program status forwarded monthly for the review and analysis by corporate Executive Management.

Development and refinement of Program Planning and Control Systems has continued, directed primarily toward further mechanized processing of data to improve both its depth and timeliness.

CONTRACTING, PRICING, SUBCONTRACTING, AND PURCHASING

Proposal and negotiation backlogs relating to changes have been kept at a reasonable level by means of systematically focused attention on the part of both North American and NASA. This effort included a process for continuing intensive review of backlog status by North American and NASA personnel who had been made individually responsible for the expedited reduction of such backlogs. Higher North American and NASA management has been kept regularly apprised of backlog status. In consequence of this process backlogs have been markedly reduced.

All Apollo CSM Block II major subcontracts have been definitized on an incentive or fixed-price contract basis. The last of the major subcontracts on the Saturn S-II Program had been definitized approximately six months prior to the completion of the NASA review in December 1965.

North American considers it has demonstrated the willingness to undertake program work on a multiple incentive basis, believing that the incentive form of contracting can provide an effective means of motivating the contractor in a manner which will be most beneficial to the requirements of the Government.

The effective and expeditious negotiations of contracts is dependent upon many elements in the case of programs as large and complex as the Apollo CSM and Saturn S-II. There have been difficulties in the negotiation process in the past which can be attributed to various causes, but North American considers that fundamentally the problem has been one of achieving clear understandings as to requirements and the means of fulfilling them. Continuing effort is being devoted within North American and between North American and NASA to achieve these basic understandings. Based on discussions which have been held between NASA and North American, including discussions at senior management levels, North American believes that those remaining areas which need further clarification can be resolved soon and that the major contract negotiations which remain to be undertaken will be effectively consummated.

ENGINEERING

Continuing improvements in identification of and accountability for engineering output have been achieved. The program Engineering organizations were strengthened to include program-oriented activities previously performed by the central Engineering functions, and to accentuate the system engineering, project engineering, and configuration management disciplines.

Significant changes in key Engineering personnel on both programs were designed to strengthen both management and technical capability. The Project Engineering and System Engineering organizations in each program were streamlined and their functions more clearly delineated. Key people were added to the System Engineering and Project Engineering operations, and a more rigorous system of design review and evaluation was instituted, together with the establishment of performance requirements.

Additional detailed actions have been taken with respect to timely development of test procedures. The individual test procedure requirements expressed in Process Specifications were included in the Engineering Product Plan. Coordination of scheduled requirements with respect to preparation of detailed test procedures has been accomplished. Both the engineering testing requirements plan and the detailed test procedure plans of the testing department are coordinated to support the test schedule.

Planning related to engineering releases, engineering support of program schedules, and engineering product plans improved. All planned engineering products, such as drawings, specifications and interface documents are identified in these product plans and scheduled down to the organizational unit level. These products are statused so that deviations to plan are identified in sufficient time for action to be taken. The Product Plans are continuously reviewed and modified to accommodate those program changes which are processed through the Change Control Board.

Studies of engineering scheduling resulted in requirements for expanding the number of detailed engineering schedule milestones in order to establish improved planning and control. Between November 1965 and April 1966, the number of these milestones in the Apollo CSM and Saturn S–II schedule networks were increased significantly. As an example, between September and December 1965 the behind-schedule Apollo CSM Block II engineering products in the Product Plan (each of which releases one or more engineering drawings or specifications) rose from 120 to 285. This rise was attributed to some late definition of these products and to engineering changes. Concentrated engineering effort brought this total down to 20 delinquencies by the first of February 1966. During February, March, and April, the delinquencies were on the order of 20 to 50 and since mid-April have been below the level of 25. Similar actions and improvements were accomplished in Block I CSM engineering activities.

The Apollo CSM Block II Critical Design Review, originally scheduled for June 1965, slipped six months primarily because of the late definition of criteria for the Block II spacecraft, and was conducted in December 1965. By a concentrated engineering and manufacturing effort, all but one week of the impact on spacecraft fabrication was recovered by April 1966.

Continuous in-depth screening of change requests by North American and NASA to eliminate nonmandatory changes has resulted in a marked reduction in change activity. However, considerable change activity still exists and will continue to exist as it does throughout every development program.

Internal Space Division procedures concerning configuration management were revised to better support the configuration management needs of the two Programs. Simplification and improvement in the mechanized configuration accounting system continues.

MANUFACTURING AND QUALITY

During 1965 late engineering releases and engineering change activities imposed a heavy requirement on the manufacturing work force in follow-up and material expediting activities. The completion of the early phases of the program and the efforts on the part of the Engineering, Manufacturing, and Material departments in the latter part of 1965 and the first quarter of 1966 resulted in drastically reducing parts and material shortages. Subsequent activities in the mechanization of various production order and parts activities have yielded even further improvements. Except for the environmental control unit, major subsystems have been on schedule, and the behind-schedule condition, overall, of components has been improved significantly.

Important steps were taken on both Programs to improve the flow of design information from Engineering to Manufacturing and to better assess the impact of both design releases and design changes, as well as to implement effective fabrication and installation plans to accommodate these unusual problems. The key to improving this flow, initiated in late 1965, was the increased emphasis on the Engineering Product Plan and the keying of the required release dates in the plan to the Manufacturing Master Index Schedule.

This effort continued through 1966, resulting in the continuation of marked improvement in the schedule status of work-in-process production orders.

Engineering formed a Manufacturing and Test Support section to assist the engineering/manufacturing liaison for rapid problem solving. Improved automated production control methods have been implemented to control manufacturing orders, tooling orders, material requisitions, and storage requirements. Rapid data feedback to management from these systems permits timely preventive and corrective action.

Overall Space Division work measurement indications show that a general 10% increase in work force effectiveness was attained from January 1966 through April 1967, with a marked reduction in the work force being realized during the same period.

Additionally, internal North American actions to improve supervision indicated a need for changes in organizational structure and reassignment of duties and responsibilities. Organizational realignments have permitted the line supervisor to be freed to spend maximum time in carrying out the work plan.

Manufacturing supervisors are continually measured by the group performance of those employees who report to them. The ability of each supervisor to meet the daily work plan and the unit cost and scheduled objectives while maintaining high quality is reflected in trend charts. The effectiveness of manpower utilization in his function is recorded and charted.

The bonding technique utilized in the Command Module is the result of technical processes which were under development. The successful conclusion in mid-1966 of these developments has provided the process which is currently being utilized effectively. North American has led the aerospace industry in the development of welding techniques. Nevertheless, the requirement to weld the special aluminum alloy used in the Command Module produced a number of technical problems. Through the incorporation of improved tooling, better control of the parts and environment of the weld, successful production of welds has been achieved.

The welding problem on the Saturn S-II was primarily one of extreme size of structure and extremely small tolerances of the assembled hardware. Fabrication development has been a joint effort by both NASA and NAA. The present welding technique is good, but improvement is still being pursued by the joint team.

The proof of the manufacturing process is reflected in the quality of its final product. North American has been continuing its efforts to achieve the highest standards of quality performance through careful selection, indoctrination and motivation of individual employees, as well as by providing rigorous training for these employees to enhance their individual accomplishments. Each new phase of the work process in this program requires the development of new technical skills and certification of employees who work upon items of the spacecraft. Motivation for all technical and supervisory personnel is aimed at bringing to the employee an awareness of the effect of his work on the spacecraft quality. Rigorous quality control procedures are utilized, and an error analysis data system has been implemented to provide timely information on defects to operating supervision and technicians as a tool in improving workmanship and reducing error.

In addition to organization changes, improved techniques in the recording and utilization of quality trend data were implemented. Quality trend data display was expanded throughout the Manufacturing area. Weekly meetings are held between program Quality and Reliability Assurance and Manufacturing to review and analyze trends, problems and corrective actions; specific quality problems are presented daily to the Program Manager and weekly to the Space Division President; material review procedures have been examined and revised.

Further strengthening of the Quality function has been accomplished by expansion of the on-the-job employee qualification program to supplement the formal skills certification program to more adequately assure that the individuals concerned possess the specific skills required for the job. Implementation of the "resident quality engineer" concept in which quality engineers are assigned (in addition to quality inspection personnel) to Manufacturing and Test departments to provide in-process surveillance and rapid detection and resolution of quality problems has proven effective.

Effectiveness in the use of quality control trend data has been improved by having computerized inspection data analyzed weekly and reported to each Manufacturing department leadman or station. Charts are included, showing the weekly trend of the total Manufacturing department. Within the Manufacturing departments, wall charts are maintained to provide easy reference to trend data. To identify repetitive defect conditions, major and repetitive defects are flagged weekly for analysis leading to preventive or corrective action. The daily inspection sheets are analyzed each day for immediate identification of problem areas. Apollo CSM and Saturn S–II Manufacturing analyze repetitive defect data and initiate, in conjunction with Quality Control, corrective actions. In selected departments control limits and other statistical measures are routinely applied to department and area data.

Establishment of a joint Quality Assessment Team has enhanced the cooperative effort between North American and NASA in the identification of quality problems and the initiation of corrective actions. North American and NASA Quality Assurance management conduct monthly briefings to report program quality problems, quality activities, and quality trends. Personnel from NASA Centers and Headquarters, and North American General Offices attend the meetings as required, as do Quality Assurance personnel from major subcontractors and other participating North American divisions.

* * * * * * *

North American is and has been thoroughly dedicated to the effective management and execution of the Apollo CSM and S–II Programs. Top management of the Corporation has sought, on the one hand, to assure that sufficient authority and resources would be available to the Division management and, on the other hand, to devote corporate top management attention to furnishing support, guidance and, where necessary, direction to Space Division management.

It is recognized that management effectiveness in terms of program progress is best measured by dedication and attention to specific elements of program operations. It is these specifics which are being reemphasized vigorously.

The President of the Corporation has taken many actions to insure that the skills and resources available to the key corporate executives are applied as effectively as possible. Additionally, new program reporting requirements and systems were initiated in early 1966 to assure that corporate executive management was closely informed, in meaningful ways, of program progress and problems. This improved management information flow was designed so that corporate top management would be able to apply prompt support and take corrective action as indicated.

The CHAIRMAN. Mr. Gehrig?

SPACECRAFT ON PRODUCTION LINE AT TIME OF REVIEW

Mr. GEHRIG. Mr. Atwood, where was the Apollo Spacecraft 012 at the time of the General Phillips review?

Mr. ATWOOD. At the time General Phillips visited the plant it was in Downey. I don't remember what stage it was in.

Mr. MYERS. It was in the final stages of fabrication prior to checkout.

Mr. GEHRIG. So the spacecraft in which the fire occurred was on the production line at the time he made this review of North American.

Mr. MYERS. That's right.

Mr. GEHRIG. Since the findings, the General Phillips review relate to the period during which the Spacecraft 012 was on the line being developed, was a reexamination made of this spacecraft to determine whether it required redesign or rework?

Mr. MYERS. The General Phillips report did not deal with the specifics of the design, but the activities that we took with respect to our management certainly did apply to Spacecraft 012.

Mr. GEHRIG. But these activities of management certainly were the management that was responsible for this spacecraft and the S–II stage.

Mr. MYERS. I think the point I'm trying to make here is that all of the items that dealt with, for example, the shortening of spans of control in our quality control, method of management of the information coming from quality control, all were applied to Spacecraft 012—that came out of the Phillips report—all were applied to Spacecraft 012 before it was delivered.

Mr. GEHRIG. Now, the Apollo 204 Review Board, in their review of the accident they were reviewing the Apollo Spacecraft 012. This is the spacecraft they studied?

Mr. MYERS. Yes.

Mr. GEHRIG. So it was not surprising that many of the things the Apollo 204 Review Board found were similar to the things that General Phillips remarked on. They were looking at the same period of time essentially, were they not?

Mr. ATWOOD. Well, if you think that the Phillips recommendation was improving inspection procedures, which of course was the essence of their quality control comment, the group's comment, 012 certainly had the benefit of many improved quality control and inspection procedures that were applicable. And it was inspected many times in this period.

Mr. GEHRIG. When was the Apollo 012 spacecraft shipped to the Cape?

Mr. MYERS. In August of 1966.

DISCUSS REVIEW BOARD FINDING NO. 10

Mr. GEHRIG. The Apollo 204 Review Board, in its report, in Finding No. 10, said:

> Deficiencies exist in command module design, workmanship and quality control.

North American Aviation, Inc., is responsible for the design, workmanship, and quality control of the command module, it is not?

Mr. ATWOOD. Yes.

Mr. GEHRIG. Do you agree with the board's finding?

Mr. ATWOOD. Which number is that again?

Mr. GEHRIG. Finding No. 10.

Mr. ATWOOD. Yes.

Mr. GEHRIG. Did you say yes, Mr. Atwood?

Mr. ATWOOD. Well, yes. We have given our comments. We certainly do agree that when they found deficiencies, they certainly were there.

Mr. GEHRIG. What has North American done to correct these deficiencies? And if you would like to make a comment now, and then amplify it in a statement for the record, that would be fine.

Mr. ATWOOD. Well, I think perhaps it would be well to add to the record. Suffice it to say, we are doing everything humanly possible to emphasize the importance of quality control, quality in detail workmanship, and the portion of inspection, detection of any defects and deficiencies. This is emphasized in both our work and I am sure equally in the NASA inspection ranks. But we can augment this with some more information, which we will do.

(The material referred to follows:)

As North American has indicated in its memorandum response to the Findings, Determinations and Recommendations of the Report of the Apollo 204 Review Board, copies of which were filed with the Committee, the deficiencies covered by the Board in Finding No. 10 related only to certain specific areas of the wiring and to the Environmental Control System. North American's detailed response to each of the specific areas was set forth in that memorandum.

The following are the improvements or corrective actions which had been taken, or are planned, for Block II spacecraft. It should be noted that most of the actions relate to improvements in existing procedures, and cover areas in the Board Report which were not in fact deficiencies.

Finding No. 10a related to the Environmental Control System. In the Block II spacecraft the Environmental Control Unit, which is a principal portion of the Environmental Control System, has been repackaged for easier installation, accessibility and maintenance. In addition it is planned that some of the tests which were formerly conducted in the spacecraft will be conducted at the subcontractor's plant, thereby reducing the number of removals from the spacecraft.

Finding No. 10b relates to coolant leakage at solder joints. The tubing which carries the coolant has been extensively reviewed in the Block II spacecraft care has been taken to eliminate stress in solder joints. In certain areas, where it has been considered appropriate, brazed or mechanically jointed stainless steel tubing will be substituted for solder jointed aluminum tubing. Tubing which was exposed to the space craft interior will be protected by metal covers both during manufacture as well as in the final flight configuration, and "armoring" and shielding has been designed to strengthen and protect joints in susceptible areas. Wherever possible, joints will be eliminated by combining several segments into longer runs of tubing without joints.

Finding No. 10c referred to the water-glycol coolant itself. As pointed out above under Finding No. 10b, the actions being taken with respect to both the tubing and the elimination or protection of solder joints should eliminate problems resulting from coolant leakage. In the event the coolant is leaked or spilled, a new process for cleaning the affected areas has been developed, as has a chemical test to identify any residue from the inhibitor.

Finding No. 10d covers electrical wiring. Since the date of the accident, a NASA/Industry team of specialists has reviewed the wiring specifications of the Block II spacecraft and has agreed with the design approach taken on Block II by North American. The following improvements from the wiring practices used in the Block I spacecraft are applied in the Block II electrical wiring:

1. Three-dimensional jigs are used to fabricate the cables so that the finished bundles can be fitted into the spacecraft without stress or strain.

2. In the Block II spacecraft design, the umbilical which connects the Command Module to the Service Module has been relocated so that it is now close to the major electrical equipment, thus obviating the need for wire bundles to be routed completely across the spacecraft floor.

3. More extensive support will be provided for the wire bundles, and metal covers will be installed to protect wiring from possible damage during manufacture, installation and test, as well as in flight.

4. The number of inspections has been increased to insure that spacecraft wiring conforms to all criteria. The Mandatory Inspection Point plan in use has been increased to require additional mandatory inspection of wiring at specified points in the manufacturing, installation and test processes before additional work proceeds.

5. Receiving Inspection procedures have been strengthened and expanded, and the number of sampling tests and electrical tests of dielectric strength and insulation resistance have been increased. Wire suppliers have been resurveyed and additional in-process inspections have been included at suppliers' plants. To supplement previous sampling tests at the suppliers' plants, we have added North American resident inspectors who will participate full time in the acceptance testing of wire to be used in the spacecraft.

6. Block II wire harnesses contain additional flexibility for changes, and spare wires have been provided to allow for "splice areas" to provide for ease of incorporating changes.

7. A spacecraft manager and team have been formed for each spacecraft. This team will stay with the spacecraft through the manufacturing, checkout and pre-launch activities and will work with the flight crews.

8. A number of process specifications with respect to wire fabrication and assembly have been grouped together into a single process specification for the general instruction of wire harness technicians and inspectors.

9. A procedure for installing changes in blocks, rather than individually, has been instituted, and such changes will be demonstrated on a wiring mock-up prior to installation.

Findings No. 10e relates to vibration test of a completed flight configuration spacecraft. An acoustic vibration test of a production line Block II spacecraft in flight configuration is to be completed at the Manned Spacecraft Center prior to the next manned flight. This test will determine the vibration levels within the spacecraft at each subsystem location, providing an additional assurance that the qualification and acceptance testing of the subsystems already carried out reflects the vibration conditions expected to be encountered during flight. Such testing will also further verify the integrity of the interconnections, both electrical and mechanical, between the various spacecraft systems and the subsystems.

Finding No. 10f relates to the disconnecting of electrical connections while powered. The Block II spacecraft design already incorporates switches that eliminate the necessity for electrical connections or disconnections of cables while energized within the crew compartment. No design or connector changes to the Block II system will therefore be required.

Finding No. 10g is directed to design features for fire protection. As NASA representatives have recently testified, a number of agents have been tested as possible candidates for extinguishing spacecraft fires. These included solids, gases and liquid. It currently appears that water is the most effective fire extinguishing agent that can be used, although additional investigations of other substances are continuing. These investigations are in addition to the plans for the elimination, or placement, of combustible materials within the spacecraft, and the other actions which are being taken to limit the possibility of an ignition source.

Mr. GEHRIG. I have one other question here which goes to the review board finding number 10, which I will put in the record, and you can answer it for the record.

North American's comments on the review board's finding number 10 which related to certain deficiencies in the Environmental Control System (ECS) state that—

The basic cause of these problems, as discussed in the Panel Report, was that the criteria which established the requirements for North American's design continued to evolve after the design had been started and in fact continued after release of the design to manufacture.

Why wasn't the ECS redesigned so as to conform with the revised criteria?

Was the failure to redesign the ECS because it was necessary to meet project time schedules?

Answer: The Environmental Control System (ECS) was redesigned to conform with the revised criteria. The ECS criteria have been revised, not all at once as a single set of revisions, but as a continuous series of changes since the beginning of the program, as the environmental control requirements have been better understood. Each time these criteria have been revised, whether by NASA or North American, the ECS system has been redesigned to conform to the revisions. The frequency and extent of the changes in the ECS has been greater than other systems, partially because it is the system most sensitive to the deep space and circumlunar environment and to mission planning. No compromise in any modifications to the ECS has ever been made because of time schedules.

DISCUSS REVIEW BOARD FINDING NO. 11

Mr. GEHRIG. Now, the Apollo 204 Review Board determination under Finding No. 11 is—

Problems of program and relationships between Centers and with the contractor have led in some cases to insufficient response to changing program requirements.

Do you agree with this determination?

Mr. ATWOOD. It is a tremendously big organization, Mr. Gehrig. I am not aware of the relationship factors—I certainly realize the size of the organization—the size has contributed to the difficulty of such communications. Perhaps Mr. Myers would like to say something.

Mr. MYERS. We are aware of actions within NASA and actions of ours on streamlining some of the procedures, so there can be quicker response to these activities.

Mr. GEHRIG. Well, is North American satisfied with the definition of the interfaces between the company, NASA headquarters, and various centers, and the other contractors on the program now?

Mr. MYERS. I think they generally are. I think in some cases there is a better definition that could be brought about within the program. I think some of these have been focused—attention has been focused on them during this period, and there are actions going on in this area.

Mr. GEHRIG. The Apollo 204 Review Board recommendation under Finding eleven was—

Every effort must be made to insure the maximum clarification and understanding of responsibilities of all organizations involved, the objective being a fully coordinated and efficient program.

Now, in your judgment have you made progress since the accident to more clearly define these interfaces that we are discussing?

Mr. MYERS. Yes. We have had several meetings with George Low and Dr. Gilruth on this activity, and at my level we are actively pursuing definition of responsibilities which in most cases are a matter of detail clarification, not major changes in responsibilities.

Mr. GEHRIG. You are satisfied at the present time with the delineation of authority between these various organizations?

Mr. MYERS. We have made some recommendations concerning the responsibilities and authorities between the centers and headquarters with respect to definition of program plans and definitions of inspection techniques.

DUTIES OF GENERAL PHILLIPS DISCUSSED

Senator BROOKE. Mr. Gehrig, would you yield at this point?

Mr. Chairman, you asked a question as to what did General Phillips do. It is not quite clear as to where one responsibility begins and the other one ends. Now it might not be fair to ask Mr. Atwood and Mr. Myers, but certainly NASA ought to present us with the clear distinction of the responsibilities. I am not quite sure what General Phillips, for instance, could have done. Could General Phillips have said you must do A, B, C, D, and North American had to do it—what would the results have been? Is there a joint responsibility here?

This is a very fuzzy area, at least in my mind, Mr. Chairman. And when you ask that question of Mr. Atwood, as to what General Phillips did, it came to my mind what could General Phillips do other than perform his duty as a task force leader and make his findings and recommendations. Did he have the power and authority to pursue them, and to insist that they be corrected?

The CHAIRMAN. He was the Apollo Program Director.

Did you have to take instructions from him?

Mr. ATWOOD. Of course he is the Program Director. As far as we are concerned, he could give orders.

The CHAIRMAN. I think probably we better ask NASA to get us that information. That is a very good point, Senator Brooke. Thank you very much.

Mr. GEHRIG. Mr. Myers, going back, you said you made some recommendations on how these interfaces between the various organizations might be improved. Suppose your recommendations are not accepted? Are you satisfied with the delineation of responsibility and authority?

Mr. MYERS. Well, I know that NASA is actively pursuing the ideas right now. I think I would have to wait and see what the results of the NASA actions are. I am quite sure personally that I am going to be satisfied with them, because I think that General Phillips is very actively involved in this, and I have a tremendous amount of respect for him and his ability to organize these activities.

Mr. GEHRIG. So at the present time you think there must be some changes made, and you are waiting to see what the changes will be.

Mr. MYERS. And am working with NASA on some of these changes.

Mr. GEHRIG. In the report of the Review Board to this committee, the Board noted that there was a problem in coordinating the activities of the contractor personnel and the NASA personnel.

Now, when you define these interfaces, do you think this problem will be satisfied?

Mr. MYERS. Do you have it by the finding?

Mr. GEHRIG. I think the Board discussed this, before the committee, that there were some problems in coordination between NASA and the contractor personnel. My question is after you realigned the responsibilities and authority between the organizations, do you think the coordination will be better?

Mr. MYERS. There are always problems of coordination. It's part of the business of the management to keep those to an absolute minimum. The activities that were going on between ourselves and the Cape people I think in general were very good. There were exceptions with respect to coordination that was not completed. I do expect the action is being taken by NASA to improve that, and we are certainly doing everything we can from the management standpoint to improve it too.

IMPROVED REPORTING SYSTEM

Mr. GEHRIG. Dr. Thompson, when he appeared before the committee, as Chairman of the Apollo 204 Review Board, said in his opinion there were too many informal understandings about work to be performed and functions to be carried out. What would you have to say about this problem and have any steps been taken to make this relationship more formal? I think there is some indication of this in the General Phillips review of North American, in that there was apparently never any formal report submitted. The word "informal" has been used several times in relation to this.

Mr. MYERS. We do have a formal reporting system from our Cape operation to myself and our management. With this new change in organization at the Cape, I believe there will be even further stiffening of those formal relationships.

Mr. GEHRIG. You think that the relationship will become more formal?

Mr. MYERS. Yes, I do believe they will.

Mr. ATWOOD. Of course in speaking of the Phillips Review, it was exceedingly informal, but it was intended for a variety of things—thought provoking action, recommendations, criticism, anything that would be useful in our self-analysis, as well as in the analysis of the task force team. I should think informally there is a most effective way of doing that sort of work, Mr. Gehrig.

Mr. GEHRIG. Mr. Chairman, I have four additional questions which I would suggest we put in the record and Mr. Atwood and Mr. Myers can answer for the record.

Mr. CHAIRMAN. Without objection, that will be done.

(Questions submitted by Mr. Gehrig and answers submitted by Mr. Atwood for the record are as follows:)

13 TEST LAUNCHES LISTED

Question 1. Mr. Atwood, in your statement you mention 13 test launches successfully completed.

Would you furnish for the record a list of these launches; what was tested on each launch; and what was achieved?

Answer. The following is a list of the thirteen (13) test launches successfully completed in the Apollo-CSM program:

November 7, 1963: Boilerplate 6. Pad Abort: Test the launch escape system's ability to work in emergency before launch while on the pad.

May 13, 1964: Boilerplate 12. Transonic abort test: Utilizing Little Joe II which simulates a Saturn V in trouble in high stress, high speed region.

May 28, 1964: Boilerplate 13. Proved spacecraft compatibility with Saturn I space vehicle. Went into earth orbit (SA–6).

September 18, 1964: Boilerplate 15. Determine space vehicle launch exit environment on Saturn I (SA–7).

December 8, 1964: Boilerplate 23. High Q abort test to verify launch escape, earth landing systems and canard subsystems (Little Joe II).

February 16, 1965: Boilerplate 16. Pegasus Micrometeoroid Detection Satellite—an Apollo test spacecraft housed and protected the Pegasus payload until reaching orbit where Apollo Command Module was jettisoned, permitting the satellite to deploy (SA–9).

May 19, 1965: Boilerplate 22. Planned high-altitude launch escape system test to determine performance of launch escape vehicle canard subsystem, and to demonstrate orientation of launch escape vehicle (Little Joe II). Partially successful (Boost vehicle guidance malfunctioned causing premature low-altitude abort. Apollo systems functioned perfectly, pulling command module away from debris and lowering it safely to earth).

May 25, 1965: Boilerplate 26. Second Pegasus Meteoroid Detection Satellite . . . an Apollo test spacecraft housed and protected the Pegasus payload until reaching orbit where Apollo Command Module was jettisoned permitting the satellite to deploy (SA–8).

June 29, 1965: Boilerplate 23A. Pad Abort: Second test of the launch escape system's ability to work in emergency before launch and while still on the pad atop a Saturn. The canards, boost protective cover, jettisonable apex cover and dual reefed drogue chutes were all tested satisfactorily.

July 30, 1965: Boilerplate 9A. Third Pegasus Meteoroid Detection Satellite . . . an Apollo test spacecraft housed and protected the Pegasus payload until reaching orbit where Apollo Command Module was jettisoned, permitting the satellite to deploy (SA-10).

January 20, 1966: Spacecraft 002. Final abort test utilizing actual spacecraft to test escape in high tumbling region. This completed the abort test phase, qualifying the astronaut escape system for manned flights (Little Joe II).

February 26, 1966: Spacecraft 009. First flight of unmanned Apollo spacecraft to test command module's ability to withstand reentry temperatures; determine command module adequacy for manned entry from low orbit; test command and service module's reaction control engines; test service module engine firing and restart. This was also first flight of the Saturn 1B (A-201). Flight was successful.

August 25, 1966: Spacecraft 011. Second flight of unmanned Apollo spacecraft to test command module's ability to withstand reentry temperatures under high heat load. Flight was successful.

LIST REASONS FOR CHANGING DIVISION NAME

Question 2. Mr. Atwood, why did you change the name of the division from the Space and Information Systems Division to the Space Division?

Answer. The Company changed the name of the Space and Information Systems Division to the Space Division to emphasize that the main thrust and effort of that division is space work. The information systems activities of the division had already been transferred to other divisions of the Company.

Copies of charts of the Company and of the Space Division showing the names and positions of the management have been submitted.

RESPONSIBILITY FOR IDENTIFYING HAZARDS

Question 3. Mr. Atwood, in the North American statement on the Board's findings, you state that NASA had the Kennedy Space Center furnish criteria identifying a hazardous test operation. This did not include manned testing in 100 percent oxygen environment at 16 p.s.i.

As a contractor to NASA with certain design and test responsibilities, do you believe that you have an obligation to adhere strictly to the criteria furnished by NASA for such tests or do you feel you have a broader responsibility to identify and provide for other hazards which might originate from the test conditions?

Answer. North American certainly feels a broad responsibility, to the full limit of its resources, to identify and protect against hazards which might originate from test conditions. We recognize that the NASA listed criteria reflect the results of experience at any given time, and that such a listing is subject to change in light of new factors or additional experience.

INSPECTION PROCEDURES OUTLINED

Question 4. Mr. Atwood, there have been many newspaper reports in the last few months concerning a variety of alleged shortcomings in the way that the Apollo spacecraft was handled after it reached Cape Kennedy. Would you describe for the committee just what the procedures are at North American for inspecting the spacecraft, for determining what corrections must be made, and how these corrections are carried out?

Answer. After they reach Cape Kennedy, all spacecraft are inspected at key points in the pre-launch checkout sequence. These inspections are detailed and are designed to detect discrepancies in all systems and equipment. Inspection points verify that equipment integrity has been maintained, that the configuration of the spacecraft is proper for testing, and that all previous detected discrepancies have been corrected. A "shakedown" inspection is an inspection of the equipment and the area in which the equipment is located to look for damaged wires, damaged tubing, safety of wiring, proper torquing, cable stress and clearance, contaminants and debris. These inspections are conducted jointly by North American and NASA inspection personnel. They are as follows:

1. Receiving Inspection—C/M, S/M, Launch Escape System and SLA (Spacecraft LM Adapter).

2. The Service Module interior prior to installation of the four reaction control system modular assemblies.

3. The top of the Service Module prior to mating the Command Module.

4. A complete exterior shakedown inspection of the CSM prior to mating with the SLA.

5. A complete crew compartment shakedown inspection prior to crew ingress for the altitude chamber test.

6. A complete crew compartment shakedown inspection after completion of the altitude test and prior to removal of the CSM from the altitude chamber for movement to the launch complex.

7. A complete shakedown inspection of the crew compartment and C/M exterior prior to crew ingress for the flight readiness test.

8. A complete crew compartment shakedown prior to crew ingress for the launch countdown. This is performed after all precountdown operations.

In addition to the above, all work and activity in the C/M interior is monitored full time by North American and NASA inspection personnel. This would include modification, equipment installations/removals, rework, cleaning, pretest preparations, and connections/disconnections of electrical connectors and plumbing. Prior to the installation of equipment the technician notifies the inspector of the work to be accomplished and he must receive an "okay to install" from both North American and NASA inspection. When this is granted, it signifies that the inspectors have examined all equipment in that area to assure compliance with engineering drawings and specifications. The inspectors also inspect conformance to acceptable work standards, and are responsible to check all wiring, plumbing, contaminants, adequacy of safety wiring, etc. Upon completion of the installation, North American and NASA inspectors reinspect the area in detail.

The CHAIRMAN. Mr. Atwood, Mr. Myers, I am sorry we have to terminate this at this time. We are having some trouble on the floor of the Senate. I thank you very much. I know you are hard-working, conscientious people. We have a great deal of respect for you. We are very happy to have had you here today.

Mr. ATWOOD. Thank you very much, Mr. Chairman.

The CHAIRMAN. At this time, the committee will stand in recess until 10 o'clock next Tuesday morning.

(Whereupon, at 4:50 p.m., the committee was recessed to reconvene at 10 a.m., Tuesday, May 9, 1967.)

(The memorandum referred to on p. 398 follows:)

MEMORANDUM FOR COMMITTEE ON SCIENCE AND ASTRONAUTICS SUBCOMMITTEE ON NASA OVERSIGHT, OF THE HOUSE OF REPRESENTATIVES

This memorandum sets forth the comments of North American Aviation, Inc. on the Findings, Determinations and Recommendations of the Report of the Apollo 204 Review Board.

The comments follow the same numbering system used by the Board in its Findings, Determinations and Recommendations.

Before making specific comments, North American believes it important to underscore the concern expressed by the Board in its Preface that its Report might be interpreted as a criticism of the entire manned space flight program and of the many people associated with it. The Board made it clear that this was not its intent, pointing out that it was dealing with the "most complex research and development program ever undertaken" and that the Report was not intended to present a total picture of the program.

The Board did find deficiencies, and North American accepts its share of responsibility. There have been problems in the developmental phase which led to the difficulties described in the Board Report. We believe the Board has done an excellent job of searching these out and describing them fully. In assessing the Findings, it must be recognized, however, that in space work the standards are and must be extremely high. We have always sought improvements and are continually striving for the goal of perfection.

The Apollo Program is indeed a complex program. Great progress has been made and many outstanding accomplishments have been achieved. Until the time of the accident, the spacecraft and their subsystems had a highly successful series of ground tests to qualify them for manned flight and there have so far been 13 flight tests of Command and Service Module systems, all of them successful.

We believe it would be a disservice to the many thousands of dedicated people who have contributed to this great project not to remind the Committee of past accomplishments and to express the confidence which North American has that the Apollo Command and Service Module Program is sound, and that a solid basis exists for moving forward to a successful completion.

FINDING NO. 1

North American concurs with this Finding and with the Determination as to the most probable initiator. We have noted the other nine possible ignition sources, and on the basis of our participation in the conduct of tests and analyses, concur with the Findings that the most probable initiator was an electrical arc in the sector between —Y and +Z spacecraft axes.

FINDING NO. 2a

North American concurs with Finding 2a that the amount and location of combustible materials in the Command Module must be severely restricted and controlled.

The Mercury and Gemini materials (nonmetallic) testing was limited to testing for toxicity and outgassing, and did not include spark ignition testing. Therefore, North American initiated the development in 1963 of criteria for testing the ignition point of individual materials in an oxygen environment. These criteria were incorporated into a North American specification which was reviewed with NASA. The criteria used by North American in this testing was "no ignition below 400° F. in 14.7 psi, 100% oxygen environment with spark impingement".

Possible materials for use in the spacecraft were divided into functional and chemical classes and 178 materials representing worst case samples of these classes were tested. Of the materials tested, 22 materials and those associated by chemical classification were rejected. The approximately 1800 organic materials used in the spacecraft were all measured against the established criteria and the results of testing. Limited utilization of materials that did not meet these criteria was made on the basis: (a) that a small quantity was used, or (b) that there was a minimum exposed surface area, and (c) that there was no adjacent ignition source, or (d) that the material was protected from a potential ignition source.

Notwithstanding this emphasis on the potential problems created by combustibles in the spacecraft, it can be seen in retrospect that attention was principally directed to individual testing of the material. What was not fully understood by either North American or NASA was the importance of considering the fire potential of combustibles in a system of all materials taken together in the position which they would occupy in the spacecraft and in the environment of the spacecraft.

FINDING NO. 2b

North American concurs with Finding No. 2b and the Determination and Recommendation. However, see Finding No. 5 for our comments on "hazardous test".

North American has recommended that NASA conduct a feasibility study as to the use of air in the Command Module on the launch pad instead of 100% oxygen. It is recognized that there are a number of considerations involved which must be evaluated, such as the design of suits and the repressurization of the spacecraft with oxygen while in orbit.

FINDING NO. 3

North American concurs.

FINDING NO. 4

North American concurs. The Command Module inner hatch was designed with emphasis on reliability and crew operation during space flight. A maximum allowable cabin leak rate of 0.2 pounds of oxygen per hour resulted in a design utilizing internal pressure to assist in sealing the hatch. An important safety factor provided by this design was the prevention of inadvertent opening of the hatch in flight. It was decided by NASA that the hatch should permit a 90 second egress time at pressures up to .5 p.s.i. above ambient. The hatch on Spacecraft 012 met this requirement. It was fully recognized that in the event of an emergency, egress could not be accomplished until the cabin was depressurized, which was to be accomplished by use of a cabin pressure relief valve operated manually by the crew, and post-landing vent valves for venting cabin pressure after landing.

In reaching the final decision on the design of the inner hatch, many factors were considered, including the need for crew safety during lengthy space flights. As pointed out by the Board in its introduction to the Findings, once the Command Module has left the earth's environment, the occupants are totally dependent upon it for their safety, and design features that are intended to reduce the fire risk must not introduce other serious risks to mission success and safety. A wide range of considerations did in fact enter into the trade-off studies in the design of the spacecraft. At one point, North American did propose a hatch which could be opened quickly by use of explosive charges, which was intended for crew egress with parachutes prior to landing operations. This course was not followed because it was considered by NASA that the risk which would be created by an inadvertent opening of the hatch would outweigh the benefits.

North American concurs with the Recommendation of the Board to reduce the required egress time and is working with NASA on a new hatch design to implement this Recommendation. The new hatch includes a clearance around the heat shield which can now be accomplished as a result of flight test data from Spacecraft 011 that verifies safety during reentry when gaps are included in the ablator.

FINDING NO. 5

North American concurs with this Finding and Recommendation. We wish to point out. however, as noted in the report of Panel No. 13, that North American's responsibility for identifying hazardous tasks in the preparation of Operational Checkout Procedures is based upon compliance with the guidelines and criteria established in the NASA documents defining the overall safety program at the Kennedy Space Center which includes the procedures concerning the generating and approval of hazardous test documents. These guidelines and criteria had evolved out of previous spacecraft and missile program experience. In identifying "hazardous" operations, the documents are focused on those tests involving fueled vehicles, hypergolic propellants, cryogenic systems, high pressure tanks, live pyrotechnics or altitude chamber tests. It can be seen that these criteria did not lead to the identification of the spacecraft 012 test as a "hazardous" test. With the benefit of hindsight, it is evident that the criteria were not directed to the potential risk involved in the Spacecraft 012 test. We recognize that North American might well have questioned them even though it did not have the primary responsibility for determining the criteria.

The balance of this Finding dealing with the matter of contingency preparation to permit escape or rescue of the crew relates to NASA responsibilities.

FINDING NO. 6

North American concurs with the Determination and Recommendation, subject to the following comment. It is understood that the communications system problems discussed in this Finding are concerned almost entirely with the Ground Communications System, which was not the responsibility of North American. The Spacecraft Communication System operated satisfactorily, with the minor exception of an open microphone condition which did not affect the quality or intensity of communications. We are investigating the open microphone problem. but feel that the Spacecraft Communication System is an effective system, and it did not contribute to the accident.

FINDING NO. 7

North American concurs with this Finding. However, Finding 7b requires some clarification. The Ground Test Procedures, in the form of Operational Checkout Procedures, were compatible with the In-Flight Checklists at the time the revision was made. Thereafter, further changes occurred in the In-Flight Checklists at the request of NASA. The few variations which existed between the two at the time of the initiation of the test have been reviewed and are considered to be minor in nature and in no way contributed to the accident.

However, with respect to the statement that test personnel were not adequately familiar with the test procedure, it should be pointed out that all North American test engineers were familiar with the revised procedure at the time of the accident of Spacecraft 012.

North American has already discussed with NASA the need for establishing a period of time, such as ten days prior to the start of a test, to finalize all changes to the In-Flight Checklists, and the need to establish a two-day lead time prior to a test for distribution of test procedures.

FINDING NO. 8

North American concurs. Full-scale mock-up fire tests are essential to the program from a systems point of view. It should not be the only basis for testing, however, but should be supplemented by testing at a component and/or subsystem level of materials applications as configured for installation in the spacecraft and tested in the environment to which the spacecraft is exposed during ground tests and flights.

FINDING NO. 9

That part of this item dealing with combustibles and full-scale mock-up tests has been previously commented on.

With respect to the balance of this item, North American concurs in the necessity of conducting studies of the use of a diluent gas, and had previously proposed in 1963 that it be authorized to conduct studies of this kind.

FINDING NO. 10

In the Board Report and in the underlying Report (Panel No. 9) the discussion of design, workmanship and quality control relate only to certain specific areas of the wiring and to the Environmental Control System. North American recognizes the problems which did exist in the wiring and the Environmental Control System. The basic cause of these problems, as discussed in the Panel Report, was that the criteria which established the requirements for North American's design continued to evolve after the design had been started and in fact continued after release of the design to manufacture. We do not believe that a basis exists for construing this Finding as an indictment of the overall design, workmanship and quality control of the Command Module.

FINDING NO. 10a

Environmental Control Systems (ECS) for spacecraft application must meet very demanding performance requirements and are extremely complex. The ECS systems for all previous manned spacecraft programs have experienced developmental problems, the resolution of which was difficult and time-consuming. In the Apollo Program, the requirements both for earth orbit and for deep space operations impose new and more difficult requirements than previously. In developing this system, the developmental subcontractor (the same subcontractor who developed the ECS systems for the Mercury and Gemini Programs) has encountered problems.

Many of the problems were encountered late in the subcontractor's development program. The solution to these problems required modifications to the equipment installed in Spacecraft 012 which required removal and replacement of components in the assembled condition. The Environmental Control System for future missions was being improved to permit easier installation and maintenance. In addition, the improvements will allow some of the tests, which were formerly conducted in the spacecraft, to be conducted at the manufacturer's plant, thereby reducing the number of removals from the spacecraft.

We concur with the Recommendation for a review of the ECS, and NASA and North American have conducted such a review. We are confident that the corrective measures taken will resolve the problems.

FINDING NO. 10b

North American does not concur that coolant leakage at solder joints has been a "chronic" problem, although there has been some leakage. At the time the decision was made to use solder joints one of the considerations was to use aluminum tubing in order to save weight. The most reliable way known to join aluminum tubing was by soldering, taking into account experience and data which had been accumulated in aircraft and other space programs with respect to the use of welds or B nuts. Solder joints have a safety factor of 20 times that of normal working pressure. Care had been taken to eliminate stress in solder joints. It has been found that after installation the tubes can be stressed by external sources causing "creep" which might result in small leaks. "Armoring" and shielding are being designed to strengthen and protect joints in susceptible areas.

FINDING NO. 10c

North American believes that a major change involving testing and selection of a new coolant is not required in view of the very minor combustible properties of the coolant. As the underlying Panel Finding points out, no evidence of deleterious corrosion or corrosion products was noted in examination of test hardware and in post-flight examination of Spacecraft 011.

We believe that armoring and shielding of the solder joints will meet the Board's Recommendation.

FINDING NO. 10d

In order to properly respond to this Finding, which is general in nature, it is appropriate to consider the specific Findings made by the underlying Panel Report (Panel 9) with respect to Spacecraft 012.

As to the cited design deficiencies in wiring:

(1) (The wiring in the lower equipment bay was routed through narrow channels having many 90 degree bends.)

The design of the wiring in the lower equipment bay was dictated by the "modular concept" approach that was used for the equipment. The channel design, as such, is a standard practice that is followed for the modular concept, and the 90 degree bends are necessary due to the compact design. The bends are within the minimum design tolerance (4 times the diameter of the individual wire) and the corners of the channels are insulated to provide additional protection for the wiring around these bends. Recent test data on teflon cold flow characteristics is resulting in further protection of bends and other pressure points. The reported damage to the protective sleeving which covers the shield on the wire in these areas is not detrimental to the wiring insulation or the circuit functional integrity.

(2) (Wire color coding practices were not always adhered to as evidenced by the enclosed photograph.)

This is an erroneous Finding. Multiple conductor cables are identified with a cable identification number. Individual wires within the cable are color coded while they remain in cable form. Once the cable terminates and branches out as individual conductors, then the connected individual conductors are identified by individual wire numbers and the color coding is no longer applicable. Some instrumentation components purchased, or delivered to us by NASA, have colored wire. The specifications allow them to be used as delivered.

(3) (Some areas of wiring showed a dense, disordered array.)

This Finding refers to appearance and not to the functional integrity of the wire. It must be recognized that all of the wiring that connects to the Service Module must leave the Command Module structure at a single location to eliminate the need for more than one umbilical. These wires, of necessity, come from all areas of the Command Module. The original installation of the wiring to these feed-through connectors was orderly but due to changes which were ordered after the original installation, disarray did occur in some areas.

This Finding also notes instances of wires being looped back and forth to take up the slack. This is a valid wiring practice. In some cases excessive lengths of wire had to be stored or looped back into the bundle because they were to calibrated resistances for the instrumentation functions, and the instrumentation would be affected if these wires were not to the calibrated lengths. In other cases due to changes which were ordered, equipment was relocated, thereby leaving lengths which could either have been cut and spliced or looped. It was considered that looping was as fully acceptable a practice as cutting and splicing.

There is no evidence that the disarray, which resulted from the conditions described above, affected the integrity of the wiring or in any way attributed to the accident.

(4) (A circuit breaker panel was pressed close to a wire harness.)

The original design provided sufficient tolerance between close-out panels and wire harnesses behind the panels so that touching would not occur. Our techicians were instructed not to close out panels if there were obstructions or :her indications that the wire harnesses may touch the panel. Although there ; no indication of shorting or arcing in this panel, or any evidence that it con-ibuted to the accident, it did indicate insufficient clearances of the wiring fter panel installation.

(5) (There were wires routed across and along oxygen and water-glycol nes.)

Routing of wires along hard lines is acceptable with secured clearance of one-alf inch between wires and the hard lines. This is a standard and acceptable esign practice.

(6) (The floor wiring and some connectors in the LEB were not completely rotected from damage by test personnel and the astronauts.)

The design of the wire harnesses routing and protection in the Block I crew ompartment was based upon certain constraints imposed by the combination f weight, lift to drag ratio, entry thermal protection for the umbilical connec-ion, and the importance of these factors on safety and reliability in reentry.

The unitized couch provides natural protection during flight and manned round testing for that portion of the wire harness under the couch. Moreover, hile the spacecraft is in orbit there are no weight loads imposed by the stronauts.

The basic protection for the wire harness was tough anti-chafing teflon wrap. n addition, during the manufacture and checkout of the spacecraft, protective evices in the form of work floors and thick padding were used. In the Block II pacecraft it was possible, because of a relocation of the umbilical, to shorten he wire harness runs and locate them around the sides of the floor where hey are protected by metal covers.

As to the cited deficiencies in manufacturing and quality control:

(1) (Lack of attention during manufacturing and/or rework is evidenced by oreign objects found in the spacecraft harness.)

Two instances are cited by Panel 9 of foreign objects in the spacecraft har-iesses. There are no indications, however, in the Board Report that these two oreign objects are anything but isolated instances. Such instances indicate, iowever, the great importance of maintaining the highest standards of quality f workmanship and inspection. North American has recognized that the stand-ırds which it has followed in its other programs would, adequate though they nay have been for those programs, have to be brought as close to perfection as ›ossible for manned space work. North American's objective, therefore, has een to seek improvements both in the procedures for workmanship and inspection ınd in the means of insuring compliance with them.

Improved methods of tracking and retrieving tools and equipment that could ›ossibly be left in the spacecraft are being instituted and a Planned Change }rouping Method has been implemented to accumulate and package changes to e installed at specified periods of the manufacturing and test cycles. These ackages of changes are mocked-up, accumulated, and approved and delivered ıt a scheduled time along with a sequential quality control approved procedure.

(2) (Some wiring did not have identification tags.)

Some wiring did not have identification tags, but it should be pointed out hat this was not an omission. By specification, multiple conductor cables or vires carry identification tags. All single conductor wires are numbered. So ar as we can determine, there is no evidence that identification tags were not ısed at all terminating ends. These methods of identification are very satis-actory.

(3) and (4) (Two Hughes connectors were found to be broken or chipped.)

This condition on these two connectors might have been caused by improper nstallation, but they could have chipped from thermal shock and sooted dur-ng the fire. There is no evidence in the Board Report that indicates that the onnectors were not functioning properly or contributed to the accident.

As to Recommendation 10d, North American had been fabricating wire har-ıesses by three-dimensional method since March 1966. In the manufacture of vire harnesses for Block II spacecraft North American utilizes three-dimen-sional jigs which accurately represent a dimensionally correct spacecraft and ıssures that the harnesses will be built exactly to that configuration. Specifica-tions and drawings have been reviewed and in Block II are verified by com-puter and design reviews. As Panel Findings have noted, Block II wire har-nesses contain flexibility for change and spare wires have been provided to allow for "splice areas" which provides for ease of incorporating changes with least disruption to the basic harness either functionally or in appearance.

FINDING NO. 10e

As the underlying Panel Report (Panel 2) has pointed out, the vibration levels for qualification testing of components were originally established on the basis of data from other programs. These data were used to define a spectrum of flight vibration levels which would be expected along each axis of the spacecraft throughout a frequency range of 20 to 2000 cycles per second. The components were qualified by subjecting them to a random vibration within this frequency range at the expected flight level. The length of these tests, 15 minutes along each axis, was several times the expected duration of vibratory excitation during atmospheric flight. Some component vibration tests were conducted using an electromagnetic shaker and the remaining components were tested with acoustic excitation.

Unmanned Spacecraft 009 and 011 were actual flight vehicles which, during their suborbital flights, were exposed to boost, orbital and entry vibration conditions. Their primary mission was to qualify the spacecraft for manned flight, complementing an extensive ground acoustic vibration test program which was conducted on representative portions of the entire spacecraft and its subsystems.

North American did conduct vibration acceptance tests on Spacecraft 009 and, based upon the results, agreed with NASA to stop such tests. Structural vibration tests were conducted on Spacecraft 004, and acoustic tests were conducted on a 180 degree sector of the Service Module.

Because of previous tests of flight configured spacecraft and because of the rigorous qualification and acceptance vibration tests conducted on subsystems, our view is that vibration testing of a Block II spacecraft is not of significant value.

FINDING NO. 10f

With one exception the spacecraft design and operating procedures do not require the disconnecting of electrical connections while powered. The one exception was the "cobra cable", which is the cable by which the crew connects to the spacecraft communication and biomedical systems. Special design precautions were taken with respect to this cable. These included limiting the current to a value of 25 to 100 milliamperes by resistors in the circuit leading to the cables. In addition, the electrical connection is broken prior to disengagement of the protective shell, thus preventing exposure to external material. The safe operation of this cable is evidenced by the Panel Report which stated that in a simulated separation test neither arc nor ignition was produced. We are, however, studying the possibility of providing a switch to de-energize the cable prior to disconnection.

FINDING NO. 10g

Preliminary studies for fire protection in the form of fire-fighting equipment were made by North American in 1965 and reviewed by NASA. This effort was not pursued since it did not appear that feasible fire-fighting protection could be designed and installed in the spacecraft. As NASA has explained, additional study and tests are planned to determine whether technology can be developed to permit the design of effective fire-fighting equipment.

FINDING NO. 11a

North American concurs that not all open items were listed in the DD250 shipping document that accompanied the spacecraft at the time of shipment. However, a revised DD250 was prepared by North American and accepted by NASA on September 27, 1966, which documented officially the shipped configuration.

During the preparation of Spacecraft 012 for shipment from Downey, North American had agreed with NASA to include at Downey many items previously planned for field site installation. Revised planning documents were issued calling for the incorporation at Downey of as much of this effort as possible prior to shipment.

Additional emphasis is being placed on compliance with our procedure for a 24-hour cut-off time prior to shipment for turn-in of records of work not completed. This situation related solely to the formalities of timely completion of paperwork, and there is no evidence that it contributed in any way to the accident.

FINDING NO. 11b

North American concurs. Because of the dynamic nature of the test program, ertain paperwork formalities were not followed. A pretest constraints list for his test was prepared, however, and NASA and North American Test Conductors id not complete the formality of signing the document. A real-time update of he constraints to the test was made by a daily coordination meeting held by the peration Engineers for NASA and attended by NASA and North American ystems Engineers. "The Daily Status Report, SC 012" was used to establish he original constraints list and new items that became constraints were scheduled for work during these meetings. On the morning of January 27, 1967, items rere signed off of the original constraints list, and oral agreement was reached etween NASA and North American that no new constraints had been disovered that were not on the original list. There is no evidence to indicate that he absence of the appropriate formalities contributed to the accident.

FINDING NO. 11C

It is our understanding that NASA has taken action to resolve this situation. 'his action will aid the definition of the responsibilities of the organizations nvolved.

FINDING NO. 11d

Of the 829 equipment items required to be certified for the Command Module, nly four were not completely certified (i.e., had not completed qualification esting) at the time of the accident. In accordance with NASA requirements, hese four items would have been certified prior to flight of the spacecraft. 'aking into account the degree of qualification test accomplished on these items, t was considered that these items were suitable for pad testing. Insofar as we an determine from the Board Report, there has been no evidence that any of hese four items related in any way to the cause of the accident. The certificaion or qualification testing achieved on the Apollo Program surpasses that chieved on any other manned spacecraft program at a comparable time in the levelopment program.

FINDING NO. 11e

North American recognizes that discrepancies did exist between specifications rhich were included into the contract with NASA and a new specification rhich NASA was generating for use with all contractors. The North American pecification was developed in late 1962 and early 1963 (and imposed on all f our subcontractors) to limit the use of flammable materials in the Comnand Module. North American and NASA engineers conducted a "walk through" f Spacecraft 008 and 012 to review the use and placement of materials. Another "walk through" was planned for Spacecraft 012 prior to launch. Neither f the specifications, however, provided for the system testing of materials which s now considered necessary for a full understanding of the hazard potential.

FINDING NO. 11f

North American concurs with this Finding. The Operational Checkout Proedure implementing the specification was prepared at Kennedy Space Center y North American personnel. As changes were required in the test requirements, Downey engineers were sent to Kennedy Space Center to provide engineering ssistance in the rewrite of the Operational Checkout Procedure. The changing est requirements of the test specification in many instances was brought about ecause of constraints in the field such as ground support equipment or facilities roblems or refinement of test procedures. While the test specification was not pdated, the Operational Checkout Procedure actually represented the latest onfiguration of the test specification as affected by changes. We have already nstituted action to clarify our specification requirements and procedures on Block II and remedy this problem.

As to the Recommendation under this item, North American concurs that every ffort must be made to ensure maximum clarification and understanding of the esponsibilities of all the organizations involved in the Apollo Program. It is a program of immense complexity and requires the highest degree of organizaional skill, both within the Government and industry, to effectively coordinate the efforts of the hundreds of thousands of people who are engaged in Apollo work.

INDEX

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

ON

NASA'S REPORT ON ITS IMPLEMENTATIONS OF THE APOLLO 204 REVIEW BOARD RECOMMENDATIONS, TOGETHER WITH REVISED COST ESTIMATES AND SCHEDULES FOR THE APOLLO PROGRAM

MAY 9, 1967

PART 6

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE
74-521 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 30 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota

MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

TABLES

LIST OF FIGURES

APOLLO ACCIDENT

TUESDAY, MAY 9, 1967

U.S. SENATE,
COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES,
Washington, D.C.

The committee met, pursuant to recess, at 10:10 a.m., in room 235, Old Senate Office Building, Senator Clinton P. Anderson (chairman) presiding.

Present: Senators Anderson, Young, Cannon, Mondale, Smith, Jordan, Brooke, and Percy.

Also present: James J. Gehrig, staff director; Everard H. Smith, Jr., Dr. Glen P. Wilson, Craig Voorhees, and William Parker, professional staff members; Sam Bouchard, assistant chief clerk; Donald H. Brennan, research assistant; Mary Rita Robbins and Patricia Robinson clerical assistants.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. The committee will be in order.

First of all, I want to state that Mr. Webb has written me a very substantial letter giving comments on what has developed on the so-called Phillips report and other things. I have not yet released the letter to the press. But Mr. Webb has agreed that it may be given out.

I want the committee members to glance at it and see whether or not it should be given out.

Mr. Webb, do you have any more copies?

Mr. WEBB. We have sent for some copies, Senator. I was not aware of your desire to submit it to the press, so I gave you only enough copies for your use in the committee. We have now sent for additional copies.

The CHAIRMAN. Do you have any objections to distributing it to the press?

Mr. WEBB. No. sir; that is your decision, Senator.

The CHAIRMAN. I do not see how we can discuss these things and not permit the press to look at the letter. I really feel that the full letter ought to be given to members of the press, as well as members of the committee. They have not received it. This is not an item that has been locked up for a long period of time. We were discussing it at a late hour yesterday afternoon, and this is the first time I have had an opportunity to consider it.

(The letter referred to appears on page 496.)

I want to take complete responsibility for not having the complete Phillips document for members of the committee. I have not yet seen it and I think it is probably improper for us to question you on many things in the report at this time. The manufacturing process, the whole operation of North American, is reviewed in the full report, and I think we ought to take a great deal of care that we do not by our questioning on this report, hurt the space program.

I would like to say to the members of the committee that I wish I could produce copies of the report for all of you. I think it ought to be done on the decision of the committee, not that of the chairman. But we will turn our attention for the moment to reading through the four-page letter of the Administrator and the number of interesting statements therein.

I think that the best thing to do is proceed with your statement, Mr. Webb. Before you do that, however, I think it would be well for me to state that we have before us today Mr. James E. Webb, Administrator of NASA, accompanied by Dr. Robert Seamans, Deputy Administrator, and Dr. George Mueller, Associate Administrator for Manned Space Flight.

These witnesses will review the actions taken by the National Aeronautics and Space Administration for moving the Apollo program ahead after the Apollo 204 accident.

They will review the actions taken on the deficiencies identified by the Apollo 204 Review Board and describe the actions they have taken with respect to the recommendations of that Board. They will discuss the changes to spacecraft and facilities required as a result of the accident. Finally, they will discuss the impact of these actions on the manned and unmanned flight schedules, on the cost of the program, and on our ability to achieve a manned lunar landing and safe return to Earth within this decade.

All right, Mr. Webb. You go ahead.

STATEMENTS OF JAMES E. WEBB, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; ACCOMPANIED BY DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR; DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR FOR MANNED SPACE FLIGHT; AND MAJ. GEN. SAMUEL C. PHILLIPS, APOLLO PROGRAM DIRECTOR

Mr. WEBB. Mr. Chairman, before I begin my statement, I would like to make one comment on your remarks, if I may. I believe certainly that the conduct and particularly the results of the agencies like NASA, achieved with public funds, must be thoroughly scrutinized by those responsible committees in the Congress. I am very concerned about a situation that arises when we go to a contractor like the General Electric Co. and ask them to summarize from the records of a large number of contractors, current troubles with mechanical and electronic equipment which must be cured before we commit it to flight and on which our ultimate judgment must rest as to whether we commit it to flight at one time or another. If, every time we have such a summary of work done before we are to fly equipment, and this is put into the newspapers, I do not believe that we will have a successful space program. I think the ultimate result will be some kind of a closure of the industrial system that is now very open with respect to the things that are important and on which it can be judged.

Now, Mr. Chairman——

The CHAIRMAN. Before you start with your prepared statement, I want you to realize that it is not easy on the committee either. There are a great many people who would like to see the Phillips report in toto. I am not sure whether we would want that or not. If we do want it—we will have discussion with the committee on that. But you can understand that people are tremendously interested in this whole situation and ought to have the facts if any help can be given from those facts.

Mr. WEBB. I agree, Mr. Chairman. Again, I would only comment that if documents are extracted from governmental or private industry files through a process of sale of documents or bribery to purloin documents, and then are thrown into the public arena, this will destroy the system on which our success is built. This committee and this agency must give the most careful consideration to where we go from here, and I think my letter speaks for itself with respect to this report.

The CHAIRMAN. I think I envision the report in another capacity. But obviously, the committee has to ask questions that might involve the comprehensive files of the company. If we do, we can do so by a vote of the committee and by consultation with all the members of it. I would like very much to be able just to say that these are the complete reports. I recognize, also, that sometimes that is not too desirable. I have had a little experience with security in the Joint Committee on Atomic Energy. But I have suggested that these things be opened up as far as possible. I hope you will not be too impatient with us if we want to examine them at some time.

Mr. WEBB. My request is only that it be done in a thoroughly responsible way, Senator.

Mr. Chairman, members of the committee, on April 17, at the close of your hearing we were instructed to appear today to give a detailed report on all action recommendations in part 6 of the Apollo 204 Review Board Report and our best estimate of the schedule for resuming the manned flight program.

In response, we have developed a plan under which the first man-rated Apollo Block II spacecraft will be delivered to Cape Kennedy late this year and launched 3 months later.

FIRST APOLLO FLIGHTCREW ANNOUNCED

Dr. Mueller is here to present this plan. The crew for the first flight will be Capt. Walter M. Schirra, USN; Mr. Walter Cunningham; Maj. Donn F. Eisele, USAF; and backup crew will be Lt. Col. Thomas P. Stafford, USAF; Comdr. John W. Young, USN; Comdr. Eugene A. Cernan, USN.

The CHAIRMAN. Would you stop there?

Mr. WEBB. Yes, sir.

The CHAIRMAN. I think members of the committee may want to ask questions earlier than we have permitted sometimes. I want to say to the committee that the members may interrupt as they wish. I prefer to have it without interruption, but if any of the members have questions they want to ask, and a few may decide they want to inquire early, they may do that, if they wish.

Mr. WEBB. I will do that any time you say I may.

I would like to say that Captain Schirra is on his way to the Downey plant of North American today to start a detailed, day-by-day, month-by-month association with Block II Spacecraft No. 101. He will be the command pilot on this spacecraft, and with the completion of a successful flight in that spacecraft, he will then become the only man anywhere who has flown three generations of spacecraft; Mercury, Gemini, and Apollo. I think everyone knows that he was not only successful, outstandingly successful, in the Mercury as a pilot and as an engineer in preparation for the flight, but also did the remarkable job of achieving the first rendezvous between two manned spacecraft traveling at 18,000 miles per hour around the Earth.

I would like to say also that Colonel Stafford has that remarkable capability to use his mind, a pencil, and a piece of paper and achieve almost as rapid calculation as a computer can do. These two commanders, the main crew commander and the backup crew commander, are outstanding men with great experience, and they will be working closely and intimately with every change that is made in the spacecraft as it gets ready to fly. They will not fly unless they are ready to fly.

May I say also that Astronaut Frank Borman, whom you have heard, after service on the 204 Review Board, is now in California. He will be there for about 2 months as the chairman of the engineering group that will determine the changes to be made in the 101 Spacecraft, and thereby let it become the standard for the Block II series. He is the NASA——

The CHAIRMAN. May I interrupt again to say that the statement that I made earlier was with full recognition of the announcement of this crew? If members want to ask questions about what qualifications they must have, what they plan to do, who this man is, it is appropriate for them to do it.

Mr. WEBB. Yes, sir. I would like to point out that Frank Borman as the senior NASA person on the Board to pass on the changes to be made in the spacecraft, brings to this job not only the experience of 14 days in orbit in Gemini—the longest flight ever made but also his experience on the Review Board. I believe he will have as much interest as any human being could have in making sure that the changes that are agreed to and put into the spacecraft will make it fly successfully.

Mr. Chairman, we have also prepared an overall program and financial plan for our manned space flight activities. Dr. Seamans will present this.

APOLLO BLOCK II WILL USE 100 PERCENT OXYGEN

The Apollo Block II will use a 100-percent oxygen atmosphere, but the use of noncombustible and fire-resistant materials will minimize the risk of fire. In oxygen piping, stainless steel will replace aluminum lines that previously were joined with solder. For fluid lines, aluminum will be retained, with special protection for soldered joints in from 15 to 20 of the most vulnerable locations. Improved methods of assuring strength of soldered and mechanical joints will be introduced. These mechanical joints are the B-nuts of which the committee heard reference in the report of the Board. Wiring runs will be shortened and protected.

Since the Apollo 204 accident, more than 100 flame propagation tests have been run. A whole new body of knowledge as to the causes and propagation characteristics of fire, useful in many areas beyond the field of aeronautics and space, has been developed. The Apollo Block II will take advantage of this new knowledge and the risk of fire will be held to the lowest level possible.

MOON GOAL POSSIBLE WITHOUT BUDGET INCREASE

We can carry out this plan within the funds now available for fiscal year 1967 and those in NASA's budget request for fiscal year 1968.

We are confident that the results of the first Block II Apollo flights will justify moving rapidly to follow-on flights, thus overcoming some of the effects of the present delay.

Under our plan, the 11th of the 15 Saturn V flights in the program will take place toward the end of calendar year 1969. If the lunar landing can be accomplished on that flight, or an earlier one, the landing will be made in this decade and the total cost up to that point will be within the $22 billion 700 million estimate of runout costs supplied to your committee last year. This means that the last four of the 15 Saturn V flights will then occur in calendar year 1970 and their costs absorbed in the Apollo Applications program.

If the lunar landing cannot be accomplished until after the 11th Saturn V flight, then the costs of one or more of the four 1970 Saturn V launches will be added to the above Apollo runout costs, and would mean an increase of between $200 and $500 million.

To assure maximum progress and efficiency, we will make a number of changes in the organization of NASA's field centers and in the pattern of Apollo contracting.

CONTRACTING CHANGES LISTED

Dr. Mueller will describe the NASA changes as he comes to that item in the recommendations of the 204 Review Board. The changes in the contracting pattern involve:

1. The Apollo Block II design will be standardized and negotiations will be initiated with North American Aviation for the manufacture, test, and delivery of these standard Block II Apollo spacecraft. The new agreement will provide strong incentives for a maximum contractor effort to achieve the best in meeting performance, cost, and time requirements. It will provide means to give both North American and NASA unambiguous and timely management information so that the status of the work will be known at all times.

2. Negotiations will be initiated with the Boeing Co. to extend Boeing's present contract responsibility for the integration of the first, second, and third stages of the Saturn V to include also the integration into this system of the Apollo Command and Service Module and the Lunar Module. Boeing officials have indicated they are prepared to enter into such negotiations promptly.

3. In addition to these arrangements with North American and Boeing, a third contractor will be selected to make all modifications to standard Apollo vehicles which may be required for their use in the Apollo Applications program. Such a procedure has worked well

in other programs requiring variations from standard articles for multiple use. The Agena program is a good example. Selection of this contractor will be accomplished by competitive negotiation with the best qualified companies. These will not be limited to, but will include, Lockheed Aircraft Corp., the Martin Co., and McDonnell-Douglas Corp.

4. Other forms of contractor assistance to the systems management, checkout and test procedures required in Apollo have been generously offered by a number of outstanding aerospace companies, including Aerojet-General, General Electric, Lockheed, Martin-Marietta, McDonnell-Douglas, and RCA. As we complete the above-mentioned main elements of our revised contractual pattern, we may find it advantageous to utilize some of these or other contractors for specialized supplemental functions.

Mr. Chairman, with your permission, I should now like to call on Dr. George Mueller, Associate Administrator for Manned Space Flight, to present the actions we expect to take on each of the recommendations of the Apollo 204 Review Board. Dr. Robert Seamans will then be prepared to present the full plan for our Office of Manned Space Flight.

STATEMENT OF DR. GEORGE E. MUELLER, ASSOCIATE ADMINISTRATOR FOR MANNED SPACE FLIGHT, NASA

Dr. MUELLER. Mr. Chairman and members of the Committee, today I will cover three basic topics: First, I will describe the specific actions to be taken in relation to each of the Apollo 204 Board recommendations; second, I will highlight some of the additional actions to be taken that are not related to the Board's recommendations but that are desirable and appropriate in terms of the first manned flight of a Block II spacecraft; and third, I will summarize the planned steps leading to the first manned Apollo flight.

ACTIONS RELATING TO BOARD RECOMMENDATIONS

For clarity and completeness, I will cite each Board recommendation individually and then describe the NASA actions that relate thereto.

The Board recommended that: The amount and location of combustible materials in the Command Module must be severely restricted and controlled.

I will treat this matter under three categories—selection, substitution, and stowage of nonmetallic materials.

SELECTION

The criteria for use of nonmetallic materials for manned spacecraft operations, both in ground and in flight, are:

To minimize possibility of ignition through material selection and placement.

To so place nonmetallic materials that any fire that does occur will be restricted to a small and definable area.

To so limit the weight of nonmetallic materials used in the cabin that its burning cannot increase cabin pressure or temperature to the point of damaging the spacecraft.

To protect the crew from the effects of potential fires.

To choose materials that, if burned, do not produce toxic fumes that could injure the crew.

Based upon the various uses to which nonmetallic materials may be put in the spacecraft cabin, a comprehensive set of guidelines has been developed to serve as the basis for the selection of new materials. Initial selection in terms of the guidelines will be made by the spacecraft contractor and approved by the spacecraft project manager at MSC. After a series of sequential tests, culminating in full-scale mockup testing, there will be sufficient information to make specific final selections and to specify in detail which material will be used for each application.

SUMMARY OF CLASSIFICATION AND SELECTION GUIDELINES
FOR NON-METALLIC CABIN MATERIALS

CATEGORY	USAGE & APPLICATION OF MATERIALS	EXAMPLES	PRINCIPAL FLAMMABILITY CRITERIA FOR ACCEPTANCE
A	Major Crew Compartment Materials	Debris Net, Paints Space Suit Outer Layer, Insulation, Wiring Insulation	Self-extinguishing in 16.5 psia oxygen.
B	Less Used Materials in Crew Compartment	Name Plates, Instrument Knobs, Molded Fasteners, Stencil Paint/Ink	No Propagation to adjacent items. Burn without dripping or sparking. Pressure rise less than 2.5 psi in cabin or equivalent.
C	Space Suit Loop Materials	Hoses, Helmets, Inner Garment, Couplings	Self-extinguishing in 19 psia oxygen.
D	High Pressure Oxygen System	Filters, Valve Seats, Seals Pressure Bladders	Fire point 450° F in 16.5 psia oxygen. No friction or impact ignition.
E	Inside Hermetically Sealed Containers	Electrical Wiring Wire Wraps/Potting	Container shall not rupture in 16.5 psia oxygen inside and worst case short.
F	Inside Vented Containers	Foam Padding, Food Packages, Wiring, Survival Equipment	Fire point 450°F in 16.5 psia oxygen. Internal fire must be contained until extinguishment (in 16.5 psia oxygen). Vented gases not capable of fire propagation.
G	Non-Flight Equipment	Plastic Bags Carry-on Cables	Self-extinguishing in air. Requirements "A" - "F" in O_2 testing.

NASA HQ MA67-6969
5-8-67

FIGURE 100

The attached (fig. 100) summarizes the categorization and flammability acceptance goals for nonmetallic materials. It is necessary to point out that the acceptance goals are extremely difficult to meet in some cases since it may be impossible to find materials, even metallic ones, that are in fact self-extinguishing once ignited.

SUBSTITUTION

Final recommendations on substitutions are not complete, but figure 101 provides an indication of the items that must be changed and

SPACECRAFT EQUIPMENT MATERIAL SUBSTITUTION

ITEM	ORIGINAL MATERIAL	SUBSTITIUTE MATERIAL
SLEEP RESTRAINT	NYLON	BETA FIBER
HOSE COVERS		
RESTRAINT HARNESS		
FOOD CONTAINERS		
EQUIPMENT BAGS		BETA/TEFLON
COUCH PADS	NYLON/RUBBER	
FOOD BAGS	POLYETHYLENE	KEL-F (TEFLON)
DEBRIS TRAP	NYLON NETTING	BETA OR METAL
WINDOW SHADE	MYLAR	METAL
INSULATION	SILICON RUBBER	FIBER GLASS/TEFLON
VELCRO FASTNERS	NYLON	(UNDER DEVELOPMENT) BETA/PBI/TEFLON

NASA HQ MA67-6191
4-11-67

FIGURE 101

the class of material that can be used to reduce flammability. Figure 102 summarizes the characteristics of some of the new materials now to be used.

NEW NONMETALLIC MATERIALS
CHARACTERISTICS & APPLICATIONS

MATERIAL	SERVICE TEMPERATURE RANGE	FIRE RESISTANCE IN 100% OXYGEN	ABRASION & WEAR RESISTANCE	SEWING	FUNCTIONAL APPLICATION
BETA-FIBER	− 250°F TO + 1200°F	NON-FLAMMABLE	FAIR (WITH LUBRICANT)	FAIR	• FABRIC • WEBBING • TAPES • BRAIDED • MAT • FELT • FILTER • INSULATION
TEFLON-FIBER	− 450°F TO + 550°F	GOOD (SELF-EXTINGUISHING IF IGNITION SOURCE REMOVED)	GOOD	GOOD	• FABRIC • WEBBING • TAPES • BRAIDED • MAT • FELT • FILTER • INSULATION
QUARTZ-FIBER	TO + 1400°F	NON-FLAMMABLE	FAIR	DIFFICULT (BRITTLE)	• FABRIC • MAT • THREAD
POLYBENZIMIDAZOLE	TO + 600°F	FAIR	GOOD	GOOD	• FABRIC • WEBBING • BRAIDED • MAT

NASA HQ MA67-6134
4-11-67

FIGURE 102

We do have available some samples of these materials on cards that we can pass out to the members of the committee.

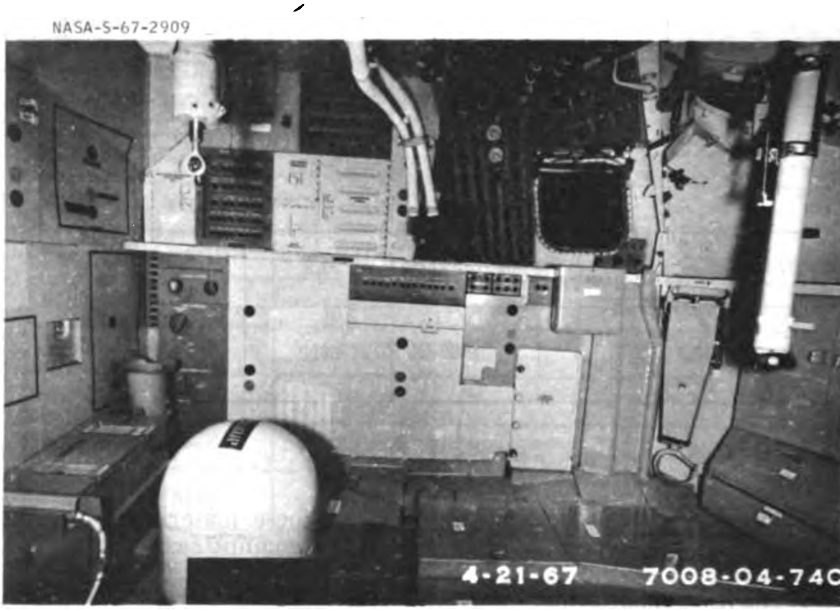
One example of the changes to be made is the substitution of new materials in the spacesuits.

I have here an example of the spacesuit itself and the new configuration, the outer covering being the Beta cloth. Current spacesuits are basically nylon inner and outer layers surrounding an airtight, pressurized bladder made of chloroprene. No substitute has been found for the chloroprene bladder, and it is therefore necessary to insure that both the inner and outer layers surrounding the bladder provide isolation of the chloroprene from a potential fire. A combination of nonflammable Teflon and Beta fabrics can provide this isolation, thereby rendering the suit virtually fireproof. In addition, underwear and flight coveralls can be manufactured from Beta cloth. The work in this area has already been put to use by the Air Force which plans to use Beta cloth suits for their personnel in space applications as well as for space simulation in ground test operations.

Associated with the suit changes, four of the nonmetallic materials used in the environmental control system suit loop will be replaced with fiberglass, Beta cloth, or metal.

STOWAGE

There will be always some potentially flammable materials on board the spacecraft, such as food, which must be protected by fireproof containers. The specifications for such containers require that, if a fire occurs inside, the container is not to rupture nor is the fire to be able to propagate outside of the sealed stowage. Mockups of such new containers have been completed and meet the required specifications. Figure 103 shows some examples of new stowage containers for hel-



REDESIGNED APOLLO COMMAND MODULE INTERIOR

FIGURE 103

mets, spacesuits, and similar equipment implaced in the spacecraft mockup.

In summary, the basic problem of materials in relation to fire hazard is to be met by removing bulk combustibles such as nylon netting and Velcro, by replacing these and other flammable materials with new ones selected under more stringent guidelines associated with a detailed test program, by stowage of necessary flammables in fireproof containers, and by the requirement that a full-scale flammability test of the spacecraft interior in flight configuration be satisfactorily concluded prior to the next manned flight. The new criteria, specifications, guidelines, and tests are applicable to all manned spacecraft in the program.

NEW HATCH DESIGNED

The Board recommended that: The time required for egress of the crew be reduced and the operations necessary for egress be simplified.

This area has two facets, modifications to the spacecraft and changes to the launch facility.

A new hatch (fig. 104) has been designed for the spacecraft. This provides a single, outward-opening, quick-release hatch that replaces the separate pressure and heat shield hatches of earlier designs. This hatch can be manually released from either within or without the spacecraft. The hatch sealing approach is similar to that successfully used in Gemini. For increased safety, the hatch is spring, rather than explosively, assisted in opening, requiring positive action either by the flight crew or the ground crew and thus guarding against inadvertent opening. In addition, the hatch incorporates a locking device for operation in space. A schematic of the hatch design is illustrated here in Figure 104.

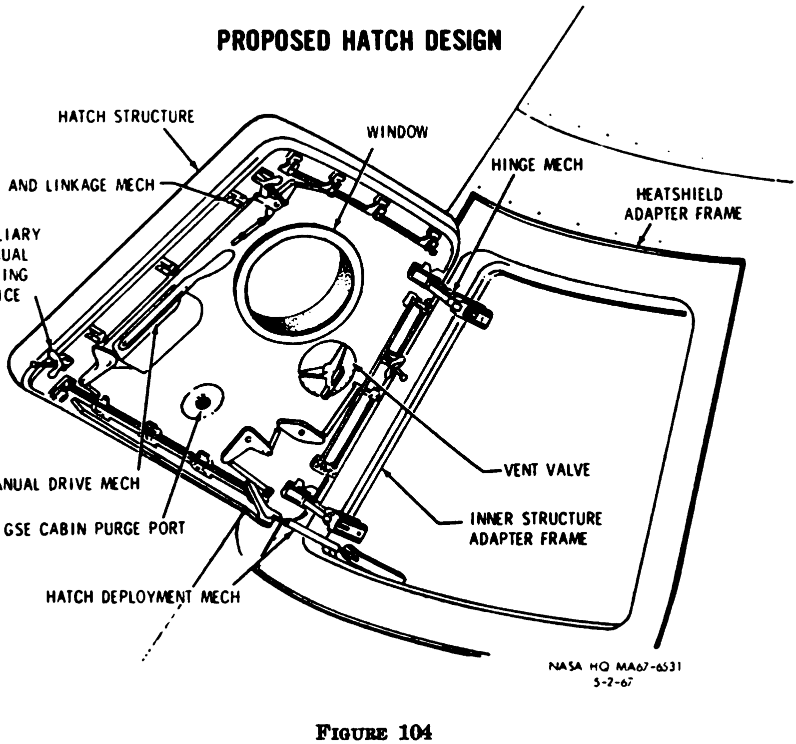


FIGURE 104

Ground and flight tests are necessary to qualify the new hatch to assure its effective operation, integrity in the vibration environment encountered during launch and reentry, compatibility with crew requirements including EVA, and integrity during reentry heating.

These tests are to be conducted on ground test articles, on the thermal vacuum model, and on unmanned Saturn V heat shield qualification flights.

FACILITIES

In order to accommodate the new hatch and to simplify the egress of the crew, a number of facility changes will be introduced. Principal among these changes is redesign of the adaptor hood which fits against the spacecraft and joins it to the "white room" located in the access arm of the launch facility, and modifications to speed up the repositioning of the access arm and white room against the Command Module in the event of an emergency prior to launch but after the access arm has been withdrawn. In addition, the steps, protuberances, one-way doors and angles in the path the astronauts would take upon leaving the spacecraft in an emergency are to be eliminated, and improved white room ventilation and lighting to cope with the possibility of smoke is to be provided.

FLIGHT SAFETY OFFICE ESTABLISHED

The Board recommended that: Management continually monitor the safety of all test operations and assure the adequacy of emergency procedures.

Within the manned space flight organization, a new office of flight safety will be established. This office will report directly to the Associate Administrator for Manned Space Flight, working under the guidelines and standards established by the NASA Safety Office. This new office is to become the focal point within the Office of Manned Space Flight for continuing review and evaluation of safety provisions in all areas of manned space flight activity. A draft of the management instruction establishing this office is in "The Manned Space Flight Report of Actions Taken as a Result of the AS-204 Accident" which has been filed with the committee. That is this report here, Mr. Chairman. In addition, the safety offices at each field center will report directly to the Director of that Center, thus assuring continuing high-level management awareness of, and participation in, the flight safety effort. As a further check, the NASA Safety Office is responsible for assessing the overall safety programs.

Each safety office is proceeding with detailed reviews of all manned test and checkout procedures to identify possible hazards and to develop revised safety precautions where required. In particular, the safety office at the Kennedy Space Center is being enlarged and the scope of its activities increased. Launch pad personnel are being given increased training in areas of possible emergency, including use of a spacecraft mockup for rescue training. All test procedures are being reviewed and revised where necessary to include emergency instructions. Responsible pad personnel meet weekly at each launch complex to review the activities of the past week and to prepare plans for upcoming activities that integrate improvements found possible in procedures and operations.

The Board recommended that: All emergency equipment (breathing apparatus, protective clothing, deluge systems, access arm, et cetera) be reviewed for adequacy.

The equipment for use by emergency crews and spacecraft technicians has been reviewed. Additional gas masks are being provided and more fire hoses are being added to the access arm. Protective clothing for the ground crews in the event of fire has been ordered and fire retardant materials have been substituted for flammable ones in the access arm and environmental chamber. Additional warning horns and lights and improved communications are being installed.

The Board recommended that: Personnel training and practice for emergency procedures be given on a regular basis and reviewed prior to the conduct of the hazardous operation.

In addition to the training and drills discussed earlier, emergency procedures will be reviewed by the safety organization prior to any hazardous operation. In the case of manned spacecraft operations, the crew will practice egress under simulated emergency conditions prior to participation in the test itself.

The Board further recommended that: Service structures in the umbilical towers be modified to facilitate emergency operations.

The CHAIRMAN. You do not want this report made a part of the record, do you? Or do you? [1]

Dr. MUELLER. If the chairman would like, it would be an appropriate thing to include, because it provides the details of the actions I am summarizing here.

The CHAIRMAN. Without objection it will be admitted.

There are a number of inclusions for the record totaling several hundred pages, but we will let it go.[2]

Mr. WEBB. Mr. Chairman, may I make a comment there? There is no way that you can deal with the complexity of the work of 400,000 men and women in making machines that are going to land men on the Moon and bring them back home without getting into a great deal of detail. We are trying to provide the detail. I do not know the extent to which the record should include it.

The CHAIRMAN. We have indicated we will put it in the record. I do hope that there will be limited requests for it, because it is pretty bulky already.

Dr. MUELLER. As already noted, the access arm and white room are to be appropriately modified prior to the next manned operation in order to increase the capability of quick response to many different possible emergency conditions.

COMMUNICATIONS SYSTEMS CHANGES

The Board recommended that: The ground communication system be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.

A review of the ground communication system has indicated that, by limiting the number of individuals able to communicate over critical loops to those with a specific need to be tied together on the circuit, the present overload will be significantly reduced. In addition, minor

[1] "Manned Space Flight Report: Actions Taken As a Result of the AS-204 Accident," NASA, Washington, D.C. This appears as app. 1 in a separate section with other related materials in pt. 7 of the Apollo Accident Hearings.

[2] The information referred to is printed as app. 2 and 3 in pt. 7 of the Apollo Accident Hearings and are entitled: "Summary of Actions Taken on the Findings and Determinations of the AS-204 Review Board Panels" and "Manned Space Flight Report Block II Spacecraft."

design changes in such areas as the voice-operated switches, together with improved operational procedures, will assure reliable operation of the current system. The addition of a four-wire, full duplex link connecting the crew on board the spacecraft directly to the Mission Control Center at Houston, to the test conductor in the blockhouse and to the Spacecraft Checkout Station at Kennedy Space Center will insure uninterrupted two-way voice communications among these critical elements.

The Board recommended that: A detailed design review be conducted of the entire spacecraft communication system.

The Block II spacecraft communication system has been reexamined in detail and has been revalidated. It has been determined that no further changes are required in this system. The problems of concern to the Board in the Block I system are already corrected in the Block II system by the inclusion of diodes that isolate certain circuits from each other and thereby prevent the "hot mike" problem, and the redesign of crew umbilicals (cobra cables) to replace the earlier design which caused difficulties during the prelaunch test.

The Board recommended that: Test procedures and pilots checklists that represent the actual command module configuration be published in final form and reviewed early enough to permit adequate preparation and participation of all test organizations and that timely distribution of test procedures and major changes be made a constraint to beginning any tests.

We have issued a new test directive which establishes that all procedures are to be distributed at least 1 month prior to the test operation itself and careful controls restrict the number of changes and the period in which they can be made. For example, written revisions must be approved, available, and distributed no less than 48 hours prior to a test. Pretest conferences of all key members of the test team are then held before the test to insure that the hardware configuration, the documentation, and the test procedures are compatible. In the case of manned tests, a representative of the flightcrew will approve the test and checkout procedures in order to insure that flight procedures and ground test procedures are compatible. Changes to procedures can only be made with the specific approval of the authorized representative of the center director.

In the conduct of test operations themselves, it is necessary to have the flexibility to permit real time changes or deviations; this authority is restricted to specific individuals designated by their center directors. After each test, formal review and followup procedures require the recording of any deficiencies noted during the test, the evaluation of necessary changes in procedure and plans, and the reporting of actions taken.

Detailed work implementing this basic outline is underway in both the development and test organizations and will be fully completed and exercised before the fall of this year.

NEW TESTING CONCEPT DEVELOPED

The Board recommended that: Full-scale mockups in flight configuration be tested to determine the risk of fire and that the fire safety of the reconfigured command module be established by full-scale mockup tests.

In the course of the Board's investigation, a significant new research and testing concept has been developed. This is the use of boilerplate or mockup spacecraft, with all flammables in place in which an ignition can be deliberately initiated in an atmosphere reflecting that of the condition being simulated. Over the past months, such full-scale mockup tests have been run, both in simulation of the Apollo 204 fire itself and with various of the new materials being evaluated as replacements and substitutes for those previously in use. Figure 105

FULL SCALE BOILER PLATE

COMMAND MODULE FLAMMABILITY TESTING

	STATUS		MATERIALS		ATMOSPHERE		PRESSURE-PSIA			
TEST	COMPLETE	PLANNED	S/C-012	NEW	OXYGEN	AIR	5	6.2	14.7	16.5
1	X		PARTIAL SIMULATION		X					X
2	X		X		X					X
3	X		X		X		X			
4	X			X		X			X	
5	X			X	X		X			
6	X		X		X					X
7	X			X	X			X		
8	PARTIAL COMPLETION			PARTIAL SIMULATION	X					X

NASA HQ MA 67-6189(a) rev. 5-8-67

FIGURE 105

summarizes the testing completed to date. Note that these tests are being run at various cabin pressures, both with air and with pure oxygen. As testing continues and as prospective materials are accepted or rejected, ever-increasing assurance can be developed that the final spacecraft interior will be as fire-safe as possible. Prior to the next manned spacecraft operations on the pad, final mockup tests will be run. All the materials proposed to be used, located as they would be in either the test or the flight configuration, will be installed in a boilerplate spacecraft and deliberately ignited under the atmospheric conditions chosen for test and flight. The results of these boilerplate tests will determine whether or not it is safe to proceed with the next step of manned operation in the new spacecraft configuration.

OPTIONS ON THE USE OF OXYGEN

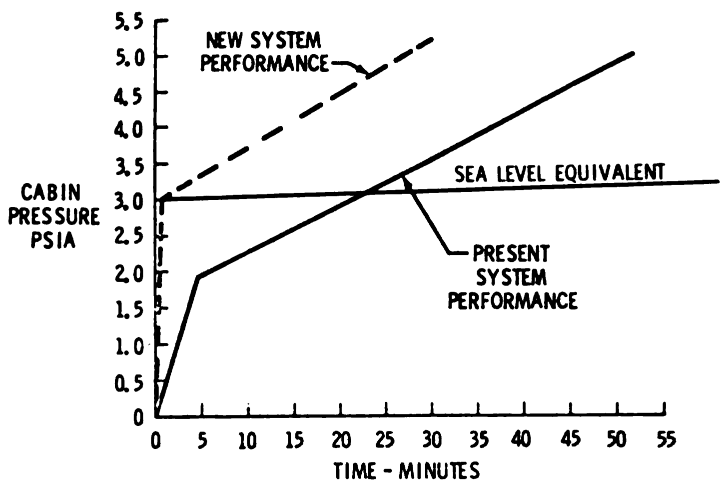
The Board recommended that: Studies of the use of a dilutent gas to be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two-gas atmosphere.

A five psia, 100-percent oxygen atmosphere in the spacecraft cabin combines the greatest opportunity for mission success with safety for manned operations in space. For manned test operations on the ground, the previously used atmosphere of 16.5 psia of pure oxygen will continue to be used unless the boilerplate fire safety tests to be conducted with the new materials and the new configurations indicate that a significant fire hazard would exist under these conditions.

In order to provide an option to the use of oxygen on the pad in the event of an inability to find adequate fire-safe materials, the changes required to permit the use of air as a cabin atmosphere with oxygen in the crew's suit loop are being made. If air is used on the pad, it is necessary to insure that nitrogen not be allowed to leak into and collect within the suit circuit. A positive pressure system will be installed to keep the suit pressure above that of the cabin at all times. Again, if air is used on the pad, it is necessary to provide for venting air from the cabin when in space and then rapidly repressurizing the cabin with oxygen first to the safe limits for the crew and then to the five psia operational pressure level. Early spacecraft will provide this repressurization capability through the use of an additional onboard container of pressurized oxygen; later spacecraft will have this capacity built in to the environmental control system. The figure 106 indicates the performance of the modified system in comparison with that of the

NASA-S-67-2892

RAPID CM REPRESSURATION



CHANGE TO PROVIDE RAPID CABIN REPRESSURIZATION REQUIRED DUE TO:

- CABIN DEPRESSURIZATION AND REPRESSURIZATION REQUIRED AFTER LAUNCH WITH AIR AS THE CM PRELAUNCH ENVIRONMENT
- REQUIREMENT FOR ROUTINE EVA CAPABILITY

NASA HQ M67-7981
5/10/67

FIGURE 106

current design. This change, in addition to permitting the air-on-the-pad option, improves the Apollo systems capability for extravehicular operations in space.

ENVIRONMENTAL CONTROL SYSTEM

The Board recommended that: An in-depth review of all elements, components, and assemblies of the environmental control system be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.

The environmental control system provides the basic life support functions for the crew, being the source of the oxygen they breathe and the means of controlling and regulating the temperature of the spacecraft they inhabit. The heart of the system is the environmental control unit, which has been repackaged in the Block II spacecraft for easier accessibility and maintenance. This repackaging makes the unit easier to repair, adjust or replace than was the earlier model. This Block II design has been reviewed in depth and we have concluded that the basic design and operating mode of the system will not be changed. The coolant, and inhibited water/glycol mixture, will be retained. Tests have indicated that there is no improved coolant mixture that would reduce fire hazards or the corrosive potential of the coolant if spilled on wiring bundles and not properly cleaned up. Ignition tests of the present coolant have proved that it cannot ignite until most of the water component has evaporated. Tests at temperatures of up to 2,200° F. have not resulted in burning through aluminum tubing filled with water/glycol and therefore neither the coolant selection nor the use of aluminum plumbing for its routing through the spacecraft can be considered contributors to a fire risk unless extremely high temperatures have already been reached. Neither the coolant nor the aluminum tubing that carries it are to be changed.

The system will be improved by changing insulation and filter materials in accordance with the new guidelines mentioned earlier and by replacing, within the cabin, solder-jointed aluminum oxygen lines with brazed or mechanically jointed stainless steel tubing. Aluminum will continue to be used for oxygen lines inside the environmental control unit itself. The piping, both for coolant and for oxygen, that was exposed to the spacecraft interior in the Block II design, will be protected by metal covers both during manufacture to prevent accidental damage during the later installation of equipment as well as in the final flight configuration. Figure 107 shows these new protective panels and covers installed in an approved mockup spacecraft.

DESIGN OF SOLDERED JOINTS

The Board recommended that: Present design of soldered joints in plumbing be modified to increase integrity or the joints be replaced with more structurally reliable configuration.

I do have some samples of these soldered joints, Mr. Chairman, that I would like to pass around. They represent both the actual soldered joint itself and the joint that is protected by additional armor.

After replacement of the soldered oxygen lines with brazed steel, the only soldered joints in the plumbing system are those carrying the

NASA-S-67-2907

FIGURE 107

water/glycol coolant. A careful review of the methods of joining tubing carrying liquids under pressure has determined the soldered joint to be acceptable and safe as long as it is not subjected to abuse, twisting or compression. Therefore, all exposed soldered joints are to be armored by the addition of a strong structural collar that will prevent tension or torsion from being transferred to the joint itself. In addition, where possible, joints will be eliminated by combining several segments into longer runs of tubing without joints. As noted earlier, all exposed plumbing is further protected by metal covers that prevent inadvertent damage during assembly, test, or flight operations.

COOLANT LEAKAGE AND SPILLAGE

The Board recommended that: Deleterious effects of coolant leakage and spillage be eliminated.

The use of self-sealing quick-disconnect fittings for those joints which must be occasionally parted for normal maintenance will substantially reduce or eliminate the incidence of leaks and spills.

In the event coolant is leaked or spilled, a new process for cleaning the wetted areas has been developed, as has a chemical test to identify any residue from the inhibitor. The present documentation process identifying coolant spills, cleanup actions, and subsequent inspections is reliable and effective.

WIRE SPECIFICATIONS

The Board recommended that: Review of specifications be conducted, three-dimensional jigs be used in the manufacture of wire bundles and rigid inspection at all stages of wiring design, manufacture and installation be enforced.

The Block II wiring specifications have been reviewed by a joint team including personnel from NASA, Lockheed Aircraft Co., Douglas Aircraft Co., the Federal Aviation Administration, the Air Force, and North American Aviation; no major deficiencies in the Block II specifications were identified.

Whereas in the Block I spacecraft the wiring bundles were assembled on a flat surface and then installed in the spacecraft, the Block II wiring bundles are being assembled on three-dimensional jigs that minimize the possibility of undue stress occurring in the wiring during installation.

We do have over here a set of pictures of the three-dimensional jig (exhibit in committee room).

Furthermore, the Block II spacecraft umbilical connection is located quite differently than it was on the Block I. The umbilical connection, now being close to the major electrical equipment of the spacecraft, obviates the need for many of the wire bundles that in the Block I configuration had to be run across the floor.

The same protective metal covers discussed in connection with the environmental control system plumbing will serve to protect all interior spacecraft exposed wiring during manufacture, test, and flight operations (see fig. 107). To insure quality workmanship and adherence to standards, additional electrical testing, and mandatory inspections at each phase of manufacture or after modifications have been instituted.

PLANS FOR VIBRATION TESTS

The Board recommended that: Vibration tests be conducted of a flight-configured spacecraft.

An acoustic vibration test of a production line Block II spacecraft in flight configuration is to be completed at the Manned Spacecraft Center prior to the next manned flight. This test will determine the vibration levels within the spacecraft at each subsystem location, thereby providing an additional assurance that the qualification and acceptance testing of the subsystems already carried out does, in fact, reflect the vibration conditions expected to be encountered during flight of the complete spacecraft system. Such testing also verifies the integrity of the interconnections, both electrical and mechanical, between the various spacecraft systems and subsystems. Tanks and plumbing will be under pressure during vibration testing.

The Board recommended that: The necessity for electrical connections or disconnections with power on within the crew compartment be eliminated.

The Block II design already incorporates switches that eliminate the necessity for electrical connections or disconnections of cables while energized within the crew compartment. No redesign or connector changes to the Block II system are required.

SPACECRAFT FIRE CONTROL

The Board recommended that: Investigation be made of the most effective means of controlling and extinguishing a spacecraft fire. Auxiliary breathing oxygen and crew protection from smoke and toxic fumes be provided.

The basic means of controlling fire within the spacecraft is through the selection of nonflammable materials where possible and through the placement of those flammable materials which must be carried on board in such a pattern that any fire that might occur would remain localized and small.

Many agents have been tested as possible candidates for extinguishing spacecraft fires. Solids, gasses, and liquids have all been tested and after careful study it has been determined that water is the most effective fire extinguishing agent that can be used. A hose and nozzle system will be incorporated in the Block II spacecraft, drawing water from the basic pressurized spacecraft water supply. In addition, investigations are continuing on the possible use of aqueous gells, either in blanket or in pressurized forms, for onboard firefighting.

Aircraft-type oxygen masks connected to the environmental control system will be added to provide crew protection from smoke or toxic fumes in the event of spacecraft fire. The new spacesuits mentioned earlier will have fire resistant outer and inner layers and the flight coveralls will be of nonflammable fiber.

ORGANIZATIONAL RESPONSIBILITIES OUTLINED

The Board recommended that: Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

In carrying out its investigation, the Board found instances where the documentation of responsibilities between organizational elements differed from the operating practices in force, instances where that documentation was either out of date or not sufficiently specific, and instances where documentation was not readily available to all parties involved. The management review carried out by the Apollo program office since the accident has noted no areas requiring major management or organizational change but has identified the need for compilation of directives and agreements to insure clarity of understanding. For example, a new consolidated program directive has been drafted to replace and consolidate previous individual directives and intercenter agreements. This directive clearly defines the roles and relationship among the NASA Centers carrying major responsibility for manned missions. By removing possible ambiguities in the assignment of responsibilities between centers, this approach reinforces configuration control requirements and control of waivers and deviations. In addition, transfer of contractual responsibility for spacecraft checkout from MSC to KSC, has been identified as advantageous to improved working relationships at the Kennedy Space Center.

In addition, as mentioned earlier a complete review of test and checkout procedures and practices was instituted immediately after the accident. The results of the review are incorporated in a revised program directive on the preparation of test and checkout plans and procedures at Kennedy Space Center. This directive was issued on April 18, 1967. A copy of this directive which defines responsibilities and required actions is attached to the report filed supporting my statement. The key points of the revised directive are to assure uniform practices throughout the manned space flight organization and to define the level at which action decisions are to be made.

In summary, the development organizations—the Manned Spacecraft Center for the spacecraft and service module and the Marshall Space Flight Center for the launch vehicle—define the specific test and checkout requirements for the hardware systems for which they are responsible. These organizations provide the test specifications and the criteria upon which to judge whether or not the test, in fact, has been adequately performed. Standardized formats simplify the process of documentation. The requirements and specifications are provided to the Kennedy Space Center for months prior to the delivery of the flight hardware.

The test, checkout and launch organization is the Kennedy Space Center and based upon the requirements from the development Centers, Kennedy prepares test and checkout plans and procedures. These plans and procedures are based upon those at the factory or test site that were used in the earlier testing of the same hardware. The test and checkout plans and procedures are then reviewed by the Development Center and, if necessary, are revised to assure that their requirements are met.

In addition, all procedures are independently reviewed and approved by the safety and quality organizations as an additional check and balance in terms of identifying and isolating possible hazards.

Other management actions include the documentation of test and checkout functions and the establishment of the flight safety office mentioned earlier. Continuing management analysis and clarification of organizational interfaces is a necessary element in the administration of large programs. As the program matures and changes, so must the organization and the interorganizational and intraorganizational relationships. The effort to insure clear understanding of responsibilities has been constant in the past and will continue during the life of the program.

SUMMARY OF ACTIONS TAKEN

The CHAIRMAN. Before you go on, I have something here called the Summary of Actions Taken on the Findings and Determinations of the AS 204 Accident Review Board Panels. What is this?

Dr. MUELLER. There were a set of Panel reports in appendix D, to the Summary Report of the Apollo AS 204 Board. In that set of appendixed Panel reports were a set of findings and recommendations. That report you have there, Mr. Chairman, details the actions we have taken with respect to each one of these findings and recommendations that were not covered in the main Board report. We have assigned responsible action individuals to every single finding and determination in the appendixes, as well as in the main Board report.

The CHAIRMAN. This will not be necessary to be put in the record?

Dr. MUELLER. At your pleasure, Mr. Chairman.

The CHAIRMAN. We will leave it open. I think we may put it in the appendix as part of the record and just hope that people will be able to get a boy who is strong enough to carry this material.

Mr. WEBB. They amount to subsidiary recommendations, below the level of main Board recommendations, together with our actions thereon, Mr. Chairman.

The CHAIRMAN. I think that should be very important to our files. Maybe we will include it.[3]

May I also say, Mr. Webb, that copies of the letter you wrote to me are now available up here. Whatever action we take, I want to make sure that the working newspaper staff has copies.

I believe the committee members are all equipped, and I do not want to cause any trouble but I think we ought to distribute it at this time. Since it does bear on discussions we are now having we will put this in the record at the appropriate place—wherever it is decided it should go.

Mr. WEBB. Yes, sir; Mr. Chairman.

OTHER APOLLO SPACECRAFT CHANGES

Dr. MUELLER. Moving now to the second of the three topics, I would like to discuss briefly some additional changes that we feel are appropriate to make in the spacecraft prior to the first manned flight. Some of these are developmental changes that were in the process of being defined prior to the accident, others are adjustments made necessary by the changes already discussed above in relation to the Board's report, and still others result from the very detailed reviews and analyses carried out by the Apollo program office in seeking real and meaningful improvement of the spacecraft in terms of safety and mission capability. For example, a part of the R. & D. instrumentation to have been flown in spacecraft 012, the first planned Apollo manned flight, will now be flown in spacecraft 101, the first of the Block II series.

Examples of minor changes are the relocation of the ECS controls for easier access by the crew, modifications of the crew couches to simplify entrance and exit to the spacecraft.

Our continuing design review has found, for example, that an error during the ground checkout could possibly cause the inverter motor to malfunction; a small change now prevents this motor from being locked out. Experience with Gemini thrusters and the problems they encountered has led to the inclusion of new filters to prevent possible contaminants from holding the valves open. In the event of an abort from the pad, certain wind conditions have been identified that could result in the spacecraft landing on or near the beach instead of in the water as desirable; a modification of the timer which sequences the reaction control fuel system now permits longer controlled flight away from the shore in the event of a pad abort.

[3] See app. 2 in pt. 7 of the Apollo accident hearings.

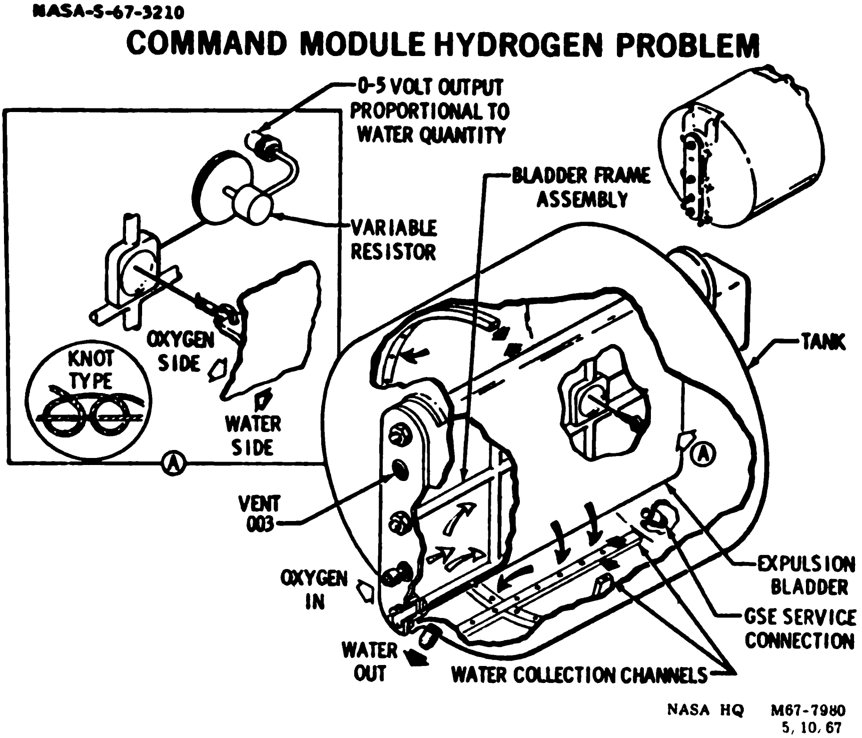


FIGURE 108

Perhaps the best example of the care and attention to detail which has gone into the program office review of possible safety features for the next manned space flight is the analysis of the command module's water system. A schematic of this system is shown on figure 108. In this system the water produced by the fuel cell in the course of operation, and which serves as the potable water supply for the crew, flows into a cylindrical tank. Inside the tank is a small bladder pressurized with oxygen. The force of the expanding bladder against the surrounding water is used to provide a positive, pressurized water flow to the crew even in zero g. Inside the oxygen-pressurized bladder is a small electrical device that permits measuring the amount of water in the tank, which is proportional to the inward or outward movement of the bladder wall. In the investigation of all potential ignition sources, the potentiometer inside the bladder was examined in light of every possible condition to determine if it could be considered a hazard.

Now the water flowing from the hydrogen powered fuel cell into the collection tank carries with it hydrogen in solution. This hydrogen, it was postulated, could possibly permeate and eventually pass through the watertight bladder and thereby mix with the pressurizing oxygen within. Were this to continue until the unlikely concentration of 4 percent by volume of hydrogen was reached, an explosion could occur. A simple but ingenious redesign of the unit now makes this impossible; by permitting a very small flow of oxygen through the bladder, thereby venting the excess hydrogen to space, the buildup of a potentially explosive mixture is avoided.

STEPS TOWARD THE FIRST MANNED APOLLO MISSION

I would now like to turn to the third topic of my discussion, that of the steps necessary before the next manned flight operations.

The ground test program for the Block II Command and Service Module has qualified the spacecraft through such means as aircraft drop tests, propulsion tests, structural tests and crew compatibility tests. We will perform vibration tests, and thermal vacuum tests before clearing for manned flight. In addition, the new hatch design is to be tested on the unmanned Saturn V missions planned for this fall. The command module fire test in the boilerplate spacecraft must be successfully completed. The various units and systems being changed must be requalified. Finally, all approved changes and modifications must be incorporated into the flight spacecraft and then it must be tested both at the Downey plant and at the Kennedy Space Center.

The delivery of the first Block II flight spacecraft is expected toward the end of this calendar year, some 6 months later than previously planned. A 3- to 4-month checkout period at the cape is necessary, including the following major events: The command and service module will be mated; and the combined systems test will be run. There will then be the first manned test at sea-level conditions, followed by unmanned test in the altitude chamber; the last of the vacuum chamber tests will be with the spacecraft manned and the chamber simulating the changing environmental condition from launch to orbit. The spacecraft will then be moved to the pad and mated to the launch vehicle, where further tests will continue. The last tests are the manned plugs in and plugs out tests and finally the countdown demonstration test. As Mr. Webb indicated toward the end of the first quarter of calendar 1968, we expect to be prepared to fly the Block II spacecraft, the first of the manned Apollo series, in an open-ended mission of up to 2 weeks in Earth orbit to verify the combined performance of the spacecraft and the crew in accomplishing one of the major milestones leading to the eventual objective of the manned lunar landing and return.

Dr. Seamans will now outline the required changes to the manned space flight program and the effects this will have on the fiscal years 1967 and 1968 budgets.

EXPECT DELAY OF 1 YEAR IN FIRST MANNED FLIGHT

The CHAIRMAN. A great many people have asked about how much delay there might be in the Apollo program, and whether you can have the first flight in a year or a few weeks. You are now testifying that within 6 months, this will be tried?

Dr. MUELLER. The delay in the flight of the first Block II spacecraft is on the order of 6 months. The delay of the first manned flight of the Apollo program is on the order of a year.

The CHAIRMAN. Mr. Webb, you testified that there will be extra costs, but you will not ask for a special budget because of the accident.

Mr. WEBB. That is true, Mr. Chairman. Another statement needs to be added, namely, that we expect to come out of this rearrangement with an improved spacecraft and booster system. Two large Saturn flights should be behind us later this year and this will permit us to move more rapidly from the smaller Saturns to the big Saturns for manned flights. We would then have the flight experience of the extra spacecraft equipment by calendar year 1969, and therefore, make the lunar landing by number 11 of the 15 big Saturns. If we do that, the overall run-out costs for a lunar landing will not be beyond the $22.7 billion we have indicated to you heretofore, and the budget for 1967 and 1968 will not need to be increased by a supplemental request.

The CHAIRMAN. Thank you very much. I think members might want to ask you questions about that, but as I understand it you will not have to ask for additional budget.

Mr. WEBB. Mr. Chairman, I must point out that the plans we are presenting can only be implemented by negotiation with a number of contractors where large amounts of work are involved. We expect to start those negotiations, and our estimate is that we can accomplish what we have said to you. But the contractors must agree to contracts, and we will proceed with very active negotiations as soon as we are through with these hearings.

The CHAIRMAN. I grant that. I am merely trying to find out the answers to the two questions that come most frequently to my office: How long will this be delayed? How much more will it cost? Dr. Mueller says it is unnecessary for it to be delayed if you have some good luck. We are hopeful that you will have good luck. You assess now that it may not need to have any extra cost.

Mr. WEBB. Mr. Chairman, Dr. Mueller, General Phillips, and others have hoped to fly earlier than the last quarter of 1969. They had hoped to fly Saturn V No. 11 earlier in 1969. What we are saying is that we now are about two Saturn V flights behind where we would have been if we had not had this accident.

The CHAIRMAN. I compliment you on that, because that is one question about which the American people are very anxious.

Senator Smith?

TOTAL COSTS OF LUNAR LANDING PROGRAM

Senator SMITH. Mr. Chairman, I have a question along that line that might be well to get in here.

Mr. Webb, in your statement, you indicate that if your plan to accomplish the lunar landing by the 11th Saturn V flight is successful, the total cost of the lunar landing program will be within the $22.7 billion estimate provided this committee last year. Is this not the same as saying the costs have already increased?

Mr. WEBB. Senator Smith, it depends on whether we can get such a good spacecraft out of the work we have done including utilizing the knowledge that we have about problems of controlling fire and things of this kind, that we can move more rapidly. We could move earlier from the small Saturn that exercises this equipment around the Earth to the big Saturn that has the capability to go to the Moon and thus exercise the entire system earlier than we might otherwise have done. The run-out costs depend more on the amount of time than any other factors involved.

I think what I am saying is maybe the opposite of what you indicated. I am saying that it may be that we will extrude four Saturn V's into Apollo Applications and absorb their costs in that program.

Senator Smith, you know that the committee has been very anxious to get both the Voyager and the Apollo Applications separated from Apollo. In fact, we are now making that clear line of distinction, by separating these costs and giving you run-out costs of the lunar landing.

Senator SMITH. Mr. Webb, the $22.7 billion figure given to the committee last year included costs for all 15 Saturn flights. My understanding is that you do this because the Apollo Applications program has not yet been approved to absorb the costs of unused vehicles and spacecrafts, and not because you expected to use all the Saturn V vehicles for the Apollo program.

Am I not correct in that?

Dr. MUELLER. Senator, may I answer that?

Senator SMITH. Yes, Dr. Mueller.

Dr. MUELLER. The $22.7 billion did include 15 Saturn V's and 12 uprated Saturn I's. The estimated run-out costs that we have here increases by $400 to $500 million primarily as a result of the stretch-out in the Apollo Saturn V launch schedule. This then says that the comparable figure this year would be $23.1 to $23.2 billion for the entire program as we have evolved it here.

We do, of course, hope that we will be able to carry through the manned lunar landing before the end of 1969, and I do believe that this is a reasonable possibility.

Mr. WEBB. And may I say one other thing, Senator Smith? I put in my statement today the indication of the costs after the point of lunar landing in order to make it clear exactly what we are doing. It would have been very difficult to make a comparison that would have been precisely accurate with the others.

Senator SMITH. But it was not comparable to the figure that we got last year, was it? Did you not indicate last year that if you could assign unused vehicles to the follow-on Apollo Applications program, the total Apollo costs would be about $20 billion and $22.7 billion if all hardware is assigned to the Apollo program?

Mr. WEBB. You are right about the figure submitted last year, absolutely. Our updated Apollo cost estimate last year was $22.7 billion.

Senator SMITH. Mr. Chairman, I would ask that Mr. Webb provide for the record a statement showing, on a comparable basis, the estimates supplied last year and the new revised cost estimates. In this statement, please adjust for all costs now assigned to the Apollo Applications program, if you will, for the record.

Mr. WEBB. Senator Smith, would you like that at this time or would you prefer that we go through our negotiations and clearly indicate what the costs of this revised contracting pattern are, also?

Senator SMITH. Well, you brought it up. I will leave the timing to you. I just want it to be part of the record.

Mr. WEBB. Thank you very much.

Senator SMITH. Thank you.

(The information referred to follows:)

Last year NASA estimated the cost of the manned lunar landing program at $22.718 billion. This estimate included the 12 Uprated Saturn I and 15 Saturn V launch vehicles in the mainline Apollo Program, as well as the associate spacecraft, facilities, and operations costs. As indicated in the testimony, our current comparable estimate is $23.190 billion, which includes the impact of program and schedule changes resulting from the Apollo 204 accident and, like last year's estimates, assumes that all the mainline Apollo hardware will be used to accomplish the manned lunar landing and return. The increase is largely due to the effect of stretching out the Saturn V launch schedule, since four of the fifteen Apollo Saturn V launches are now scheduled during calendar year 1970.

If successful flight experience allows us to move rapidly to the Saturn V manned missions and to achieve the national goal of manned lunar landing and return within this decade, the unused Apollo space vehicle hardware and an appropriate share of the operational expenses can be allocated to the Apollo Applications Program. This program, which is pending Congressional approval, is designed to capitalize on the extensive skills, technology, and facilities that have been developed in the Apollo Program since 1961.

The table provided below compares last year's estimate of $22.718 billion with the current estimate of $23.190 billion.

[In billions of dollars]

	As reported in fiscal year 1967 Senate authorization hearings	Current estimate
Spacecraft	6.642	7.127
Launch vehicles	8.941	8.886
Engine development	1.053	.878
Operations support	1.077	1.223
Subtotal manned space flight R. & D	17.713	18.114
Tracking and data acquisition	.730	.743
Facilities	1.773	1.830
Installation operations	2.502	2.503
Total	22.718	23.190

Mr. WEBB. Do you want Dr. Seamans to proceed now, Mr. Chairman?

The CHAIRMAN. Yes, go ahead Dr. Seamans.

STATEMENT OF DR. ROBERT C. SEAMANS, JR., DEPUTY ADMINISTRATOR, NASA

Dr. SEAMANS. Mr. Chairman and members of the committee, when I was before you on April 26 at a Senate hearing, I was able to announce that we had successfully launched, as part of the Italian-United States cooperative program, the San Marco II. I am happy to report that this satellite is working and giving valuable scientific data.

I am also happy to announce that the Ariel III, a United Kingdom-United States cooperative program, led to a successful launching on May 5, and this satellite is working properly.

NEW ACCURACY ACHIEVED

I am also happy to announce that the Lunar Orbiter IV, which was launched on May 4, has been placed in orbit around the Moon. The perilune was supposed to be, or expected to be, 2,701 kilometers; it came out 2,706. The apolune was supposed to be 6,111; it is 6,111.4 kilometers.

The inclination angle was supposed to be 85.5, and it is 85.48. The period was supposed to be 720; it came out 721 minutes.

Mr. WEBB. An astonishing accuracy, never before achieved, Mr. Chairman.

PROGRAM PLANNING FOR MANNED SPACE EXPLORATION

Dr. SEAMANS. Program planning for manned space exploration, taking into account the Apollo 204 accident and its impact upon costs, schedules, and goals, must balance the many critical considerations of priority, industrial capability, mission feasibility, crew safety, and long-term objectives and implications.

The development of a manned space capability which began with the Mercury and Gemini projects continues in Apollo and Apollo Applications. The lunar landing demonstration is the objective of the Apollo program initiated in 1961. The Apollo Applications program, recommended for authorization this year will use, for a variety of important objectives, the systems, the facilities, the personnel, and the experience developed in achieving the basic Apollo objectives.

Before we commit a manned system to a lunar mission, we must have reached a point in hardware development and human experience that provides the highest possible confidence level in the safety and success of that attempt. We see, in the Apollo program, a number of basic steps which must be surmounted to reach that level:

Development of the Command and Service Module (CSM) and of the uprated Saturn I launch vehicle, including unmanned and manned flight tests.

Development of the Lunar Module (LM), including unmanned flight testing on the uprated Saturn I.

Development of the Saturn V launch vehicle, including unmanned flight testing.

Unmanned testing of the Apollo heat shield at lunar reentry speeds.

Manned operations in earth orbit with the CSM and LM using either the uprated Saturn I or the Saturn V.

Manned lunar mission simulation with the complete CSM–LM system in each orbit, but with highly elliptical orbits going out to 4,000 or 5,000 miles.

DISCUSSION OF LETTER AND ATTACHMENTS

The CHAIRMAN. Dr. Seamans, may I interrupt to ask a question about the letter?

In your letter of May 8, Mr. Webb, you say on page 4:

> At the end of your executive session, it will be my purpose to gather up the materials referred to above and return them to NASA files, unless the committee takes action to the contrary.

No material has yet been distributed to the committee?

Mr. WEBB. No, sir.

The CHAIRMAN. All these materials (indicating the letter with enclosures) are all right?

Mr. WEBB. I am offering to produce the information for the committee in executive session, and allow you then to decide how to use it most effectively for the committee's purposes.

The CHAIRMAN. I thank you very much, but this material does not in any way conflict with that, does it?

Mr. WEBB. No, sir. You mean the attachments to the letters as examples?

The CHAIRMAN. Yes. Can that be——

Mr. WEBB. It can. I would say some of it is slightly marginal due to the references, but I am satisfied that this is something that should be done, under the circumstances.

Mr. Chairman, there is one other matter, though. My letter to you was not intended to clearly specify all that North American has done. I would like a chance to read into the record about two pages of comment on that at some proper point this morning, since you are releasing the letter.

The CHAIRMAN. I will be glad to have it. I just want to be sure that the people who are here with copies do not bring back the manuscripts.[4]

Mr. WEBB. Absolutely not.

The CHAIRMAN. Thank you.

Dr. Seamans, I am sorry I interrupted you.

Dr. SEAMANS. In order to phase the many activities that are involved in these steps into a coherent plan susceptible to successful execution, we have established fundamental ground rules for the Apollo program: Flight mission objectives are preplanned and sequential; these missions remain fixed while the allocation of flight systems can be flexible; each flight is open-ended, meaning that because of the absence of an arbitrary predetermined number of orbits, the maximum return can be achieved with agreed constraints, arrived at prior to the launch; third, the flight systems used in early missions must be as nearly like the final lunar mission configuration as possible; and fourth, for each major phase of flight activity, there should be the maximum flexibility in terms of flight hardware availability and ultimate mission modes.

Mr. Chairman, in the interest of time, I would like to place in the record the next section of this statement. This next section goes as far as page 9, which talks about Apollo scheduling. This next section discussed in some detail the three major elements of the program—the unmanned flight test missions, the first manned orbiter flights, and the succeeding missions leading to the lunar landing.

The CHAIRMAN. Is there any objection to that procedure?

(No response.)

The CHAIRMAN. We will do it that way, then.

---

[4] The letter and attachments followed by Mr. Webb's comments appear on p. 496.

(The unread portion of Dr. Seamans' statement follows:)

APOLLO PROGRAM PLANS

Dr. SEAMANS. We can examine the status and prospects of Apollo flight activity in terms of three major elements: the unmanned flight test missions, the first manned orbital flight, and the succeeding sequence of missions leading to the lunar landing.

UNMANNED FLIGHT TESTS

The uprated Saturn I launch vehicle has been successfully flown three times and is considered ready for manned flights. Two of those flights carried unmanned Block I Command and Service Modules, whose performance satisfactorily completed development requirements for Apollo Earth orbital CSM operations.

The Lunar Module (LM) has not yet been flight tested because of delays in the manufacture and checkout of the first LM; such a test is planned this fall on an uprated Saturn I (AS–204). The test will prove the LM propulsion system in space, under environmental conditions that cannot be readily simulated in ground facilities. The Saturn 204 vehicle was not damaged in the accident of January 27, 1967, and is the last uprated Saturn I that carries full R. & D. instrumentation.

The first Saturn V is scheduled for launch this fall, carrying an unmanned Block I Command Module protected by the Block II, or lunar capability, heat shield. This flight test has two purposes—first, to begin qualification of the launch vehicle, facilities, and procedures; second, to proof test the heat shield under the reentry conditions expected during return from the Moon. At the same time, this heat shield test will serve to qualify the heat shield sealing concept for the hatch to be used on the next manned flight. The second Saturn V, carrying a similar payload and scheduled for this winter, will repeat the mission to qualify the launch vehicle and heat shield.

FIRST MANNED ORBITAL MISSION

The first Block II CSM (101) is expected to be delivered late this calendar year with all the spacecraft mandatory changes resulting from the accident and program office reviews incorporated and the affected subsystems requalified. The checkout period at the Kennedy Space Center will proceed in parallel with the mandatory thermal vacuum, vibration, and flammability tests of the new configuration at the Manned Spacecraft Center.

The launch vehicle planned is an uprated Saturn I (AS–205). The flight mission objectives are open ended: After the first six orbits, individual planned decision points are reached that determine whether to terminate or continue the flight; the mission could continue for as long as 10 days.

The current plan calls for this mission to be launched toward the end of the first quarter of calendar year 1968. In the event that the performance of the several major systems to be tested by inflight operation does not meet the required levels, repeats of this mission can be scheduled on available uprated Saturn I vehicles as soon as the next Block II CSM's are delivered and checked out.

Once the objective of verifying expected crew and CSM performance in Earth orbit has been met, it is planned to proceed to the next phase of manned flight activity.

SUCCEEDING MISSIONS

The next major step is to begin the development and verification of the flight operations that are required for lunar missions. In this phase, the CSM and LM are operated together and separately in various modes. This is the first opportunity for manned operations with the LM. These missions are accomplished in Earth orbit at altitudes of less than 300 nautical miles to allow return to Earth in minimum time in the event of emergency, using either the reaction control or main propulsion systems. The key operational procedures to be developed in these missions include separation of the LM and CSM; rendezvous and docking of the two spacecraft; crew transfers between the CSM and LM, both through the CSM tunnel and by extravehicular means; tests of spacecraft propulsion and guidance while docked to the LM; and LM operation and simulated descent.

In the event that the Saturn V is considered man rated by the time we are ready to carry out the CSM–LM operations flights, we plan to move the mainline Apollo effort directly over from the uprated Saturn I to the Saturn V. This would have the benefit of developing experience with the total flight system eventually designed for the lunar landing at the earliest time possible. On the other hand, if the availability of the Saturn V is delayed for any reason, these CSM–LM operations missions will be carried out on dual uprated Saturn I flights, with one vehicle placing the unmanned LM and the other the manned CSM into orbit. After the CSM has completed its rendezvous with the LM, the mission would proceed in the same manner as if it had been initially launched on the Saturn V. The flexibility of using uprated Saturn I or Saturn V vehicles to continue development flights has been and continues to be a major asset to the Apollo program; this provides assurance that flight operations can continue despite problems that might occur in the launch vehicle.

In the event that the two unmanned Saturn V flights mentioned earlier are successful, and that the first manned Block II CSM flight has met its objectives, it is planned to carry out a CSM–LM operations mission on the third Saturn V in the spring of 1968.

This mission can be repeated as necessary to meet its objectives on either dual uprated Saturn I or single Saturn V launches.

Following the conclusions of the CSM–LM operations phase, we would begin missions to simulate in Earth orbit the complete lunar landing and return sequence. This mission requires the Saturn V launch vehicle and cannot be conducted with uprated Saturn I vehicles because of payload weight. The upper stage of the Saturn V injects the spacecraft into a highly elliptical Earth orbit with an apogee of some 4,000 nautical miles. This simulates insertion into the lunar trajectory and permits the development of navigation and midcourse correction functions. After several orbits, the spacecraft return to a low Earth orbit and simulate a manned lunar landing: Two crewmembers enter the docked LM, separate from the CSM, simulate landing maneuvers, separate from the LM descent stage and return to the orbit of the CSM in the LM ascent stage. After rendezvous, redocking, and crew reentry to the CSM, the ascent stage is jettisoned and the CSM returns to Earth. In this way a complete lunar mission, including the length of time for each event, can be simulated. This mission will be repeated as required to develop the experience and confidence necessary to undertake the actual lunar landing mission.

The lunar landing missions themselves will be open ended. Reviews of the status of the system will be conducted at various points throughout the flights to determine whether to proceed or to take an alternate return path to Earth. Only when every man and system is performing properly will the final landing be permitted. Crew safety will remain the overriding consideration in this pattern of mission decision.

APOLLO SCHEDULING

Dr. SEAMANS. The actual scheduling of the Apollo flight missions after the first manned CSM flights will reflect the degree of success or difficulty encountered in the conduct of each mission. Production of flight systems is being planned to take advantage of sequential success and to provide flexibility and continued progress in the event of development problems. While the first Block II spacecraft has yet to be delivered, we feel today that we can plan on production, test, and checkout for flight availability of some five spacecraft in 1968 and up to eight more in 1969. The production and test capabilities of both industry and the Government are sufficient to meet these requirements. It is planned that all Block II Apollo spacecraft will be fully qualified for lunar missions and that no configuration changes due to the AAP will be introduced during manufacture. This will simplify the task of the spacecraft contractor, improve system reliability, and develop experience and confidence in the final lunar system as early as possible.

After the first manned Block II flight on the uprated Saturn I in 1968, we plan three to four manned Saturn V missions or, alternately up to three dual Saturn I missions if the larger vehicle is not ready. In 1969, it is reasonable to plan up to six Saturn V missions.

During 1968 and 1969 this plan projects nine manned Saturn V missions with up to three dual uprated Saturn I missions as backup for the early operations phase in the event of Saturn V delays. The last four Saturn V launch vehicles from the original Apollo block of 15, will be available in 1970, as Mr. Webb has aready indicated.

It is theoretically possible that each phase of the buildup to a manned lunar landing capability will be executed perfectly the first time; that no problems will arise in the production, test, and checkout of either the launch vehicles or the spacecraft; and that every element of the program will dovetail with every other. This, of course, is the quality of performance that we set as goals for ourselves, but practical experience indicates that, while we can often exceed conservative assumptions of progress, we cannot expect perfection. It is this practicality that has developed the guidelines stressing flexibility alternate mission planning, and system redundancy.

I believe that a lunar landing before 1970 remains possible. Th impact of the Apollo 204 accident has been to reduce that probability not eliminate it. NASA plans to provide the Apollo program orga nization the authority, the assistance, and the flexibility required to move forward once more in an orderly pattern of progress. Additional industrial support will be provided. What is needed now is the decision to proceed to incorporate the system changes that enhance safety and reliability and to fly the Apollo and to meet the Nation's space objectives.

I would like now to discuss briefly the revisions we are considering for the Apollo Applications program.

APOLLO APPLICATIONS PROGRAM

First, I believe it is wise to reaffirm one of the important Apollo Applications program elements—the continued availability of the Saturn launch vehicles for space activities beyond the initial production in support of the Apollo mainline activity. The fiscal year 1968 AAP plan provides for continuation of both the Saturn V and the uprated Saturn I production at a rate permitting four flights of each per year. There are no reasons to change this plan—the rate of delivery is scaled to the most economical level we have identified, and termination of either or both production capabilities would leave this Nation short of major space boosters at a time when the Soviet Union is showing evidence of increasing its strength in this field.

Second, I believe that the fundamental concept of the AAP—to capitalize upon a developed capability rather than start a whole new developmental effort until more experience is gained—is sound. Through the AAP we will identify what are the goals and rewards that mastery of the space environment can offer—and at what cost and for what returns.

The impact of the Apollo 204 accident, together with current assessment of readiness dates for the orbital workshop and the Apollo Solar Telescope experiments, lead to a slightly different organization of program elements than that projected at the time of the fiscal year 1968 budget.

One result of the accident has been the decision to include in mainline Apollo Earth orbital flights only those experiments relating directly to the eventual lunar mission. This leaves a number of scientific and technological experiments which have been approved and are under development without a spacecraft assignment. Another result has been the need to reconsider the use of the Apollo prime spacecraft contractor for experiment integration and spacecraft modification required by the individual AAP missions; in order to avoid diversions from the mainline task, the spacecraft contractor will concentrate on the task of providing reliable standard lunar-configured spacecraft. A third result has been the requirement to retain for a longer period the uprated Saturn I launch vehicles for possible mainline Apollo Applications. Under earlier plans these might have become excess to mainline needs at an earlier date, thereby permitting their allocation to AAP.

In order to reduce the burden of diversity otherwise borne by the mainline Apollo spacecraft contractor, it appears reasonable to plan on selecting an entirely separate industrial organization to support the Apollo Applications program effort. This new industry team would be responsible for the integration of Apollo Applications program experiments with the standard Apollo spacecraft, as well as the necessary engineering, design, development, test, and spacecraft modifications.

The mission planning for AAP that has been underway for several years is inherently sound and does does not change under the circumstances of the 204 accident. The basic concept of orbital storage and reuse of manned space systems remains at the heart of the Earth orbit program, continuing scientific and applications missions with the development of long duration (up to 1 year) mission capability. The plan to increase stay time on the lunar surface through the landing of unmanned supply and shelter systems remains valid. The investigation of the utility of manned systems in synchronous orbit is still attractive, especially for astronomical and meteorological observations.

Detailed mission planning for early AAP missions must be based on certain assumptions; I wish to make these clear so that the relationship of the AAP to the mainline Apollo is not ambiguous.

In 1968 and 1969 the source of flight hardware for AAP is the Apollo mainline program; flight availability of systems funded under AAP does not begin until 1969 for the uprated Saturn I and 1970 for the spacecraft and Saturn V. Depending upon the progress of Apollo, some flight hardware may become excess to the mainline effort. For example, early Apollo success is moving from the uprated Saturn I to the Saturn V could release up to seven of the Saturn I launch vehicles for AAP missions in 1968 and 1969. At the same time, a lower rate of Apollo utilization of spacecraft after completion of the Command Service Module-Lunar Module operations phase could release standard lunar mission spacecraft for alternate missions in Earth orbit. It is not possible to predict with accuracy today which of the many programs alternatives is the most likely, but it is clear that appropriate AAP payloads should continue to be developed to take advantage of either the success expected in Apollo or the option for orbital AAP missions if delays are encountered in the Apollo Saturn V schedule.

In the event that spacecraft availability alone becomes a pacing item for AAP because of Apollo priorities, it is possible to alleviate such a constraint through the reuse of previously flown spacecraft. Studies have been completed on the feasibility of this approach and appear encouraging. It is planned to turn over one or two of the first Apollo Earth orbital Command Modules after they have completed their assigned missions in orbit to the AAP organization for refurbishing. This work could be undertaken by the new AAP industrial team charged with experiment integration; it is not planned to add such a task to the workload of the basic spacecraft production organization. Refurbished spacecraft, then, could be available in 1969 to support AAP flights without interference and in parallel with Apollo missions. If this approach is successful and cost-effective, it would be expanded to extend program accomplishment at reduced costs.

A representative AAP mission schedule, then, assuming steady progress and success with the mainline Saturn V program, would include a 2-week scientific mission late in 1968; the first orbital workshop and telescopic mount flights in 1969; the first synchronous orbit mission in 1970; and extended lunar exploration in 1970–71.

BUDGET IMPACT

The program planning I have described has the flexibility to meet both adversity or success; however, it depends upon full support of the fiscal year 1968 budget request, as Mr. Webb indicated. NASA will not request a supplemental appropriation in fiscal year 1968; the impact of the accident will be absorbed within the total budget plan as presently before the Congress. I would like now to discuss our plans in this regard.

First, the immediate problem is how to absorb the added costs in fiscal year 1967 and fiscal year 1968. Our review of the Apollo budget indicates the following increases over the combined fiscal year 1967 operating plan and fiscal year 1968 request:

The required materials changes and flammability testing for the new spacecraft configuration are estimated at about $5 million.

The design and incorporation of equipment changes and modifications in the Block II spacecraft are estimated at some $40 million.

The development of new spacesuits is estimated at some $8 million.

The rescheduling of spacecraft, both CSM and LM, deliveries, is estimated at some $17 million.

The modifications to the launch facilities are estimated at some $5 million.

In total, then, about $75 million of additional costs through fiscal year 1968 have been identified to date. Offsetting reductions of $25 million in fund requirements, stemming from the lower than planned level of mission operations, have been established, of which $15 million relates to less launch preparation and $10 million to fewer recovery operations. At this time, it appears that the operations of the incentive contracts in the Saturn V program will make up the remainder of the deficit; namely, $50 million. I wish to stress again that these are estimates at this time and are subject to revision as the individual contractual actions are taken.

The AAP budget plan for fiscal year 1968 has also been reviewed in the light of schedule and program changes. The major increase arises from the plan for AAP experiment integration and engineering. This effort is expected to cost about $55 million to initiate in fiscal year 1968. A corresponding decrease, however, will be applied to the funds earlier planned for follow-on spacecraft procurement and mission-peculiar modifications.

SUMMARY OF ACCIDENT IMPACT ON PROGRAM

To highlight the discussion of the impact of the Apollo 204 accident:

It has reduced but not eliminated the probability of a manned lunar landing attempt in this decade.

It has delayed the earliest targets for major AAP missions.

It has created changes in fiscal year 1967 and 1968 cost estimates which we are determined to absorb within the current budget request.

Above all, the accident has had an impact on the NASA organization and the industrial teams it directs. We are determined to make the changes and run the tests and accomplish the missions we have planned since 1961. We are determined to find effective means of adjusting workloads, within the framework of the total job to be done, to reflect the capacity of each element in the organization for accomplishment. We have confidence in our technical and administrative teams, both in Government and in industry. But that is not sufficient; unless the Congress, representing the people of the Nation, has this confidence as well as fully support this endeavor, the work and the sacrifice of the past will be abandoned and the objectives of manned space exploration cannot be achieved.

LETTER AND ATTACHMENTS LISTED

Mr. WEBB. Mr. Chairman, if I could have 2 minutes now to read the statement that I think should accompany the letter and be placed in the record at the same point as the letter, I have it ready.

The CHAIRMAN. You may do so.

(The letter and attachments previously referred to and Mr. Webb's summary statement to the letter are as follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
Washington, D.C., May 8, 1967.

HON. CLINTON P. ANDERSON,
U.S. Senate,
Washington, D.C.

DEAR MR. CHAIRMAN: I am deeply troubled by your statement to me last Saturday that members of the Committee are not satisfied with our testimony on NASA's actions in follow-up of the deficiencies found by the management review team headed by General Phillips at North American Aviation in 1965. Your statement that members of the Committee believe NASA is endeavoring to put a disproportionate part of the blame for the Apollo 204 accident on North American Aviation and avoid its proper acceptance of blame troubles me even more.

On April 13, 1967, General Phillips testified before your Committee and summarized the actions of his team and the responses made by North American Aviation during the following several months. He answered all questions that were asked. The Oversight Subcommittee of the House Committee on Science and Astronautics, because it had not pressed this line of questioning, immediately asked for a summary of the team report, which was furnished to Chairman Teague on April 15, 1967, and publicly released by him.

Over the past six years, NASA has placed contracts with American industry for more than 22 billion dollars of work. To do this kind of advanced aeronautical and space research and build flight hardware, American industry has had to introduce new, very difficult fabrication and test capabilities. It has had to learn to use new management systems. In this process, NASA has provided a technical interface and technical monitoring function as an addition to the normal or standard process of contract monitoring, much of which is performed for us by the Department of Defense contract administration service. In cases where contractors have encountered serious technical or management difficulties, it has been our policy to assist them to develop strengths they did not have and to utilize our knowledge of the factors which brought success to one contractor to help others take advantage of this experience. We and most of our contractors have cooperated fully in approaching problems in whatever manner was best calculated to solve them and get on with the work, rather than to try to fix blame. At the same time, we have had to find new ways to reward efficiency and penalize poor performance. We and our contractors have placed a high premium on self-analysis and self-criticism, as painful as it has had to be in many cases.

The plain fact is that our U.S. industrial system has in the past generally made its profits from large-scale production and the initial learning period on complex space development projects has not had the incentive of anticipated profits from large production orders. However, after six years, the process we have developed is in its final stages and demonstrating efficiency in most companies with large contract obligations to NASA.

In Apollo, we are very near to a flight demonstration of all the equipment that will prove that six large companies could take contracts for major segments and that the resulting vehicle provides for this country the space capability we have needed since the USSR flew Sputnik in 1957 and Gagarin in 1961. In the Saturn V Apollo system, Boeing makes the first stage, North American the second, Douglas the third, International Business Machines the instrumentation unit, Grumman the lunar excursion module, and North American the command and service module. The General Electric Company provides the automated checkout equipment. Even the smallest of these projects runs into tens or hundreds of millions of dollars.

Almost without exception each company has encountered serious difficulties at one time or another. Many NASA management review teams have had to work with prime or sub-contractors to move the work ahead. The end result is going to be success for Apollo, but it is going to be much harder to achieve if every detail of every difficulty is now to be put on the public record as a failure of either the contractor or NASA.

It is a hard fact of life in this kind of research and development that success cannot be achieved without a certain amount of experimentation in design to find the limits that can be safely reached. This means a high initial rate of failure on inspection and test, and consequent redesign. We are still in or near many areas of the unknown.

As I have pondered the meaning of your statements to me on Saturday, I have tried to think of ways through which the Committee could reestablish the confidence in NASA it formerly had and in the system we are using. I have tried to find some way this could be done without violating the basic commitments we have made to individuals and companies to regard information given as confidential and also without having the Committee undertake the enormous task of forming a judgment about at least a sample of the management review criticisms we have recorded with respect to every major unit in the program.

With the pressure of time to get the program moving, now that we have established a basic plan which will bring us to the next manned flight at an early date, which we will be presenting to your Committee tomorrow, May 9, and with the limited investment of time which the Committee is able to make in understanding the complexities which alone permit valid judgments, I can think of nothing better than to request an executive session of the Committee, to which I would bring General Phillips and all the members of the review team which made the study of North American Aviation in December of 1965. In such major matters, it is our practice to include on a management review team a knowledgeable senior person from outside NASA. In this case, the member was General G. F. Keeling of the Air Force Systems Command. The NASA members, other than General Phillips, are Dr. J. F. Shea, Dr. E. F. M. Rees, and General E. F. O'Connor.

In such an executive session, this group can lay on the table all of the documentation which it used in its analysis of the situation at NAA and the six volumes of responses made by North American. These responses show the actions taken by North American between December 1965 and April 1966. In an executive session, General Phillips and other appropriate officials will also be prepared to present and answer questions on the actions taken by both North American and NASA in the 1966–1967 period following the April reviews. Statements of most of these actions will be referenced to the management review team materials. Examples are enclosed in order that you may see that NASA and NAA have continued to take vigorous action in the period since the management review.

To answer the questions you have raised, there is no way to exclude from the documentation we are prepared to present in executive session such business confidential data on North American as indirect cost rates, burden rates, direct and indirect employees, general and administrative expenses, bidding expense, independent research and development expense, and other similar information. This material falls within the purview of section 1905 of Title 18, United States Code, which means that the Committee must restrict this information to use by Committee members.

At the end of your executive session, it will be my purpose to gather up the materials referred to above and return them to NASA files, unless the Committee takes action to the contrary.

Through the expenditure of about 25 billion dollars over the last six years, NASA has brought the efforts of over 400,000 men and women working in American laboratories and factories into the development of the space capabilities our nation needs. Our success is shown by the fact that we are now laying off from this work force 5,000 workers per month. We have utilized the American industrial system flexibly and in ways that have added vast new strengths that have permeated practically every segment of our national economy. We have created within NASA's developmental centers such as Huntsville, Houston, and Cape Kennedy, an ability to work with contractors to do new and almost impossible tasks. To make public every detail of the difficulties we have encountered out of the context of the total program efforts involved will do grave injustice to many individuals in private life and many outstanding industrial units, and undoubtedly will destroy our ability to continue this system on the cooperative basis essential to its success. However, after you have inspected the attached materials and we have answered your questions in executive session, that decision must become the responsibility of the Committee. I can only give you my judgment as to what is in the best interests of the country.

Because time is so short, I am sending you sufficient copies of this letter to permit distribution to the members of the Committee should that be considered desirable.

Sincerely yours,

JAMES E. WEBB, *Administrator.*

[The attached statements summarize and reference those actions taken by North American Aviation on problems identified during the NASA review conducted during the period November 22–December 6, 1965.]

ORGANIZATION AND MANNING

References:

NASA Review Team Notes
Section IV.C, pages 9 and 10, 2nd paragraph (Manning)
Section IV.C, pages 9, 10 and 11 (Organization)
Section IV.D, page 11, 2nd paragraph (Organization)
Section IV.F, paragraph 1, page 13 (Organization)
Appendix I, page 2, 2nd paragraph and page 13, 2nd paragraph (Organization)
Appendix IV, paragraphs 6 and 7, page 6, and paragraphs 1 and 2, page 7 (Organization)
Appendix V, Findings No. 1 and 2 (Organization)
Section IV.B, pages 8 and 9 (Corporate Interest)
Appendix II, page 12, last sentence, paragraph 6 (Corporate Interest)
Section IV.J, page 17, paragraph 1 (Responsibility and Initiative)

Problems

The Space and Information Division (now the Space Division) was overmanned and the S–II and CSM programs could be done, and done better by fewer total people, properly organized, with particular emphasis on achieving more competence in key management and technical positions. The Engineering, Manufacturing, Quality and Program Control functions were too diversely spread and in too many layers throughout the S&ID organization to contribute effectively to the requirements of our programs. A lack of clear line of authority and accountability for program results by the CSM and S–II program managers in S&ID was noted. Further, there was a lack of proper attention and support by the corporate office of NAA to these two programs of high national priority.

NAA action

The Central Engineering organization was consolidated and streamlined to concentrate engineering talent to the requirements of our two programs. Similar action was taken in Manufacturing, Quality and Program Control to insure maximum support to the program organization. Non-space work was transferred out of the Division allowing the Division President to more fully concentrate his attention to our programs. A Division Planning and Control organization was established to insure that all elements of the Division were working and being controlled to a single integrated plan. Reassignments of certain key personnel were made to strengthen the organization where we felt it was weak. A significant increase in corporate level attention and participation in our programs at S&ID was effected. Many of these actions were in addition to and in further response to changes that had been recommended and brought about by NASA Center management actions taken with NAA prior to the December 1965 Review.

NASA assessment

The actions taken by NAA resulted in a stronger and more streamlined organization. The realignments and consolidation of functions brought a greater concentration of S&ID resources directly to bear on the needs of CSM and S-II programs. It is significant that NAA was able to improve the total effectiveness of their organization while showing a definite downward trend in total manpower applied to the two programs. This reduction was accomplished in an orderly manner, based on the real needs of the programs.

PROGRAM PLANNING AND CONTROL

References:

NASA Review Team Notes
Section II.A.1, pages 2 & 3 (Meeting Schedule and Cost Commitments)
Section II.A.2, page 3 (Meeting Schedule and Cost Commitments)
Section II.B.1, page 4 (Meeting Schedule and Cost Commitments)
Section II.B.2, page 4 (Meeting Schedule and Cost Commitments)
Section III.A., page 5 (Meeting Schedule and Cost Commitments)
Section III.A, page 6, second sentence starting with "leave little basis" to end of paragraph (Meeting Schedule and Cost Commitments)
Section III.B, pages 6 & 7 (Meeting Schedule and Cost Commitments)
Section IV.A, page 8 (Meeting Schedule and Cost Commitments)
Appendix I, pages 1 & 2, "Summary", 1st & 2nd paragraphs (Program Planning & Control—General)
Appendix II, page 12, last sentence, paragraph 6 (Program Planning & Control—General)
Section IV.J, page 17, paragraph 2 (Work Package Management, Schedule/Resource Management)
Appendix I, page 14, 17th paragraph (Work Package Management, Schedule/Resource Management)
Appendix II, page 18, "Performance and the Estimating Cycle" (Work Package Management, Schedule/Resource Management)
Section IV.D, pages 11 and 12, 4th paragraph, "Management Reports" (Program Planning and Control—Management Reports)
Section IV.J, page 18, 5th paragraph (Program Planning and Control—Management Reports)
Appendix I, pages 1 and 2, "Summary", 8th paragraph (Program Planning & Control—Management Reports)
Appendix I, page 14, 2nd, 8th and 9th paragraphs (Program Planning and Control—Management Reports)
Appendix I, pages 29–34 (Program Planning and Control—Management Reports)
Section IV.D, page 11; and page 12, 2nd paragraph, "Schedules" (Program Planning and Control—Scheduling)
Appendix I, pages 1–2, "Summary", 5th paragraph (Program Planning & Control—Scheduling)
Appendix I, pages 10–14 (Program Planning & Control—Scheduling)
Section IV.D, page 11; and page 12, 3rd paragraph, "Budgeting System" (Program Planning & Control—Budgeting)
Appendix I, pages 1–2, "Summary", 6th paragraph (Program Planning & Control—Budgeting)
Appendix I, pages 26–28, except 4th & 5th paragraphs on page 26, and 1st & 2nd full paragraphs on page 28 (Program Planning & Control—Budgeting)
Appendix II, page 7, 2nd paragraph (Program Planning and Control—Budgeting)
Appendix II, page 9, 2nd sentence, 1st paragraph (Program Planning and Control—Budgeting)
Section IV.C, page 10, 2nd paragraph (Program Manager Control of Program Manpower)
Section IV.J, page 17, paragraphs 3 & 4 (Management of Problems)
Section IV.J, page 18, paragraph 6 (Management Systems)
Appendix I, pages 35–38 (Management Systems)
Appendix II, page 17, "The Grass Roots Estimate and Its Review" (Review of Efforts vs Work Requirement)

Problem

Several significant inadequacies were found in the area of program management. Work tasks were inadequately defined and scheduled; there were several different rather than a single integrated set of program and operating schedules and, largely as a result of these conditions, budget and cost control was deficient. There was a serious lack of visibility, at all levels of NAA management, on how the CSM and S-II programs were progressing, where the real problems were and what was being done to correct these problems. In many respects NASA management visibility in these programs at NAA was considered to be better than that of the contractor.

NAA Action

One of the actions taken by NAA was to establish a disciplined, integrated planning and control system throughout S&ID, an important element of which is a system of work package management which not only defines project work and individual responsibility for that work, but also provides a much improved basis for cost estimating and cost control. A system of work package management had been in use at NAA in 1964 but the contractor subsequently changed its work planning and control system and the effectiveness of the work package management system was lost. Concurrent with the implementation of this integrating planning and control system, improved methods of providing each level of management with an assessment of program status, problems and outlook were implemented to enable NAA to better measure the progress of work against the plans and to identify problems and act on them in a timely manner.

NASA Assessment

Much effort has been applied to defining meaningful work packages in both programs and to establishing effective means for their management through work package managers who are responsible and accountable for schedule, performance, and cost results. Progress is satisfactory and substantial pay-off is expected. Tighter management of SWA's (Support Work Authorizations) has been implemented as part of the work package approach and it is intended that closer management of IDWA's (Inter-Departmental Work Authorizations) will also be implemented. Since IDWA's are a significant part of program costs this effort should be expedited.

CONTRACTING, PRICING, SUB-CONTRACTING, AND PURCHASING

References:

NASA Review Team Notes, Section II.A.2, page 3 (S-II and CSM Cost Forecasting)
Section II.B.2, page 4 (S-II and CSM Cost Forecasting)
Section III.A, page 6 (S-II and CSM Cost Forecasting)
Appendix VI, pages 5, 6, 10 and figures 10 and 11 (S-II and CSM Cost Forecasting)
Section IV.D, page 12 (Work Task Definition)
Appendix II.2, page 6, "Performance and the Estimating Cycle" (Work Task Definition)
Section IV.G, pages 14 and 15 (Division Management Review—"Grass Roots" Estimates)
Appendix II, "The 'Grass Roots' Estimate and its Review" and "Performance and the Estimating Cycle." Also various comments in Appendix II (Division Management Review "Grass Roots" Estimates)
Page 18 (SII Backlog of Undefinitized Changes)
Appendix II, page 14 "Definitization of Changes" (SII Backlog of Undefinitized Changes)
Appendix II "Definitization of Subcontractors (Lack of Block II Definition—Apollo Major and Minor Subcontractors)
Appendix II.A.6, page 12 (except last sentence thereof). (Corporate Influence)
Appendix II, last paragraph of page 11 (Spares Estimating)
Appendix II, pages 3 and 4 (Manufacturing Estimates—C&SM)
Appendix II "Estimating of Engineering Materials"; Material Budgets (Engineering Material Estimates)

Problems

Many of the deficiencies we found in these areas trace back to the deficiencies in organization and program planning and control. Inadequate task definition, lack of integrated planning and control, poor status visibility and lack of strong program management organization all contributed to inaccurate cost estimates and ack of planning and disciplined follow through to insure prompt definitization of contracts and change orders. These problems were reflected in lengthy negotiation delays with both NASA and subcontractors.

NAA Action

Work package management methods to be developed and implemented on both programs as soon as possible. Development of cost/work accomplishment assessment techniques were initiated and implemented to support the cost, schedule, performance relationship and requirements. Definitize subcontracts to achieve, on a case-by-case basis, appropriate balance of cost rate, delivery schedule, follow-on order time and other factors as pertinent. Implement change order definitization so that it receives proper attention by NAA/MSC.

NASA Assessments

The improvements in program planning and control and the strengthening of the program management organization provided a basis for improvement in contracting, pricing, subcontracting and purchasing. Standards and controls were improved in these areas within S&ID and we were beginning to see results in definitization of subcontracts and a significant increase in the effectiveness of the purchasing function.

The trend of improvement noted in the management of the CSM program confirmed the soundness of the incentive features of the CSM contract, which became effective in October 1965. A major problem still existed, however, regarding conversion of the S-II contract to an incentive basis. Continued efforts during 1965 to reach a program position where we could negotiate such an incentive contract were unsuccessful.

ENGINEERING

References:

NASA Review Team Notes, Appendix III, page 29 (Planning, S-II Qual Test)
Section IV.F.2, page 13 (Systems Engineering Process)
Appendix III, pages 4, 7 and 8 (Systems Engineering Process)
Pages 3, 4 and 5 (Technical Risk Identification)
Appendix VI, page 9 (Technical Risk Identification)
Appendix III, pages 3, 4, 17 and 18 (Design Reviews)
Appendix III, page 20, lines 2-4; page 19; page 20 (Definition of Ground Support Equipment (GSE) Reqmts.)
Appendix I, page 47, lines 11-13 (Definition of Ground Support Equipment (GSE) Reqmts.)
Appendix III, pages 3 and 27 (Proc. Specs. Oper. C/O Proc.)
Appendix I, page 6, Question No. 17 (Control of Central Research and Engineering Effort)
Appendix I, Attachment 5, pages 23-25 (Control of Central Research and Engineering Effort)
Section IV.F.3, page 13 (Visibility on Intermediate Progress on Engineering Releases)
Appendix I, pages 21 and 22 (Incompatibilities Between Engineering Release and User Need Dates)
Appendix I, Attachment 5, pages 23 and 25 (SWA's, IDWA's and WTR's)
Appendix III, Section III.B, page 22 (SWA's, IDWA's and WTR's)
Appendix I, page 20 (Engineering Planning and Cost Estimating)
Appendix III, page 10 (Engineering Planning and Cost Estimating)
Appendix I, page 22 (Verification of Future Release Commitments)
Appendix I, pages 22 and 30 (Application of PERT)
Appendix III, pages 13, 14, 15 and 26 (Configuration Management—Apollo CSM)
Appendix III, page 24 (Conf. Mgt. Policies and Procedures)
Page 13 ("As Designed"/"As Built" Data (Comparison))
Appendix I, pages 20 and 22 ("As Designed"/"As Built" Data (Comparison))
Appendix III, pages 3, 11, 12 and 25 ("As Designed"/"As Built" Data (Comparison))
Section II, page 3, paragraph II.A.3 (Technical Performance—Saturn S-II)
Section III, page 5, paragraph III.A (Technical Performance—Saturn S-II)
Section II, page 5, paragraph II.B.3 (Technical Performance—Apollo CSM)

Problems

We found four major deficiencies in S&ID engineering. The way in which work was decided between the central engineering organization and the program managers organization caused inefficiencies and made it difficult to identify and place accountability for required engineering outputs. In the case of the CSM, for example, engineering planning did exist at the lower levels of the organization but there was inadequate visibility and control of the work of the many engineering groups by higher levels of supervision and management. As a result, sufficient engineering effort was not being applied to the Block II spacecraft design, and Block II engineering releases and program schedule fell behind. An inadequate system engineering job was being done in the process of developing engineering design releases from NASA stage requirements. The engineering planning and output was not supporting program schedules. Procedures for configuration management, as agreed to by NAA and NASA were not being adhered to by the engineering organizations.

NAA action

The consolidation of the engineering effort to more directly respond to the Program Managers' requirements and the improvement in defining and scheduling engineering tasks had significantly improved the timeliness and quality of the engineering for both the CSM and S-II.

NASA assessment

The better identification of engineering tasks and more direct control of S&ID engineering resources by the CSM and S-II Program Manager strengthened project engineering and enabled these managers to do a better job of systems engineering by being in an improved position to control the individual design tasks to meet the system performance requirements stated by NASA. Significant progress was noted toward meeting the configuration management requirements established by NASA through more disciplined use of configuration control boards for decision making on engineering changes.

RELIABILITY AND QUALITY ASSURANCE AND MANUFACTURING

Reliability and Quality Assurance References:
- NASA Review Team Notes
- Appendix V, Finding No. 6, pages 16–17, Item I (Corporate Audit of Quality Assurance Activities at S&ID)
- Appendix V, Finding No. 9, pages 16–17, Item I (Apollo CSM and Saturn S–II Stage Quality Program Plans)
- Appendix V, Finding No. 7, pages 16–17, Item I (Subcontractor Control for R&QA)
- Appendix V, Finding No. 4, pages 16–17, Item I (Management Visibility and Control—Quality Assurance)
- Appendix V, Finding No. 3 (Apollo Design Reviews)
- Appendix V, Finding No. 5 (Modeling Techniques)
- Appendix V, Finding No. 8 (Reliability Communications)
- Appendix I, Page 41 (Contractual Coverage)
- Appendix I, Page 41 (Logistics Requirements Plan)
- Appendix I, Page 42 (Maintenance Plan)
- Appendix I, Page 43 (Maintenance Analysis)
- Appendix I, Pages 43 and 44 (Maintenance Manuals)
- Appendix I, Pages 44 and 45 (Modification Kits)
- Appendix I, Page 45 (KSC Maintenance Plan)
- Appendix I, Pages 45 and 46 (Manufacturing Process Specification vs. Site-Generated Detailed Operating Procedures)
- Appendix I, Page 46 (Use of Material Review to Effect Repairs in Field)
- Appendix I, Page 46 (Identification and Requisitioning of Parts)
- Appendix I, Page 47 (Identification of Scheduled Maintenance Actions)
- Appendix I, Page 47 (Bulk Item Procurement)
- Attachment "D" (Communications Between NASA Centers and NAA)
- Section IV.E, Pages 12 and 13 (Review of Space Parts, Tooling and Test Equipment Status)
- Appendix I, Page 2 (Review of Spare Parts, Tooling and Test Equipment Status)
- Appendix I, Page 48 (Review of Spare Parts, Tooling and Test Equipment Status)
- Appendix V, Finding No. 10 (PRIDE Program—Employee Motivation)

Manufacturing References:

NASA Review Team Notes
Section H, page 16 (Overtime and Work Measurement)
Section H, page 16 (Incomplete Hardware)
Section H, page 16 (Certification of As Built Configuration)
Appendix III, page 25 (Certification of As Built Configuration)
Section H, page 15 (Workmanship)
Appendix I, Attachment 11, pages 72 and 73 (IDWA Policies and Procedures)
Appendix I, Attachment 11, page 73 (IDWA Off-Loading)
Appendix IV, page 6, paragraphs 1, 2, and 5 (General Offices Surveys)
Appendix IV, page 8, paragraphs 3, 4 and 5 (Reassignment of S–II Manufacturing Director)
Appendix IV, page 8, paragraphs 6 & 7; page 9, paragraphs 1 & 2 (Response Time)

These two areas will be discussed together since they are so related in terms of the quality of manufacturing workmanship and the effectiveness of the disciplines established to get the required level of quality in the delivered product.

Problems

Difficulties that resulted in rejection and rework were being experienced in the S–II program in manufacturing processes for bonding and welding, similar to earlier problems in spacecraft airframe fabrication.

Several of the problems found in manufacturing stemmed from the lack of proper support from engineering. Late or incomplete engineering, for example, had a direct impact on manufacturing's ability to meet their commitments to the program.

NAA had implemented stronger material control and parts expediting and manufacturing supervision had improved. These actions contributed to the general efficiency of the work force.

In December 1965 Quality was not meeting NASA standards. This was evidenced by the large number of discrepancies discovered by both NAA and NASA inspectors and "corrections" type engineering orders issued by engineering. We found that quality trend data was not being used effectively by NAA management to measure performance and pinpoint and correct quality problems at the sources.

NAA actions—Manufacturing

Following a survey of S–II manufacturing, action was taken to provide for more parallel operations in order to aid in S–II schedule recovery. In January 1966, a survey of parts control, blueprint control, change control, work breakdown, work planning, methods of communication, and response time for parts support was made on Apollo and Central manufacturing. A supplemental survey of manufacturing manpower utilization was made and a review on manufacturing organization and staffing is being made for all manufacturing departments at the Space Division. Responsibility for Apollo structural Assembly was transferred and made a responsibility of the Apollo Program Manufacturing Director.

The organization and staffing survey team specifically reviewed the organizational responsibilities and physical location of design, test, procurement, and fabrication of Apollo and Saturn GSE and made recommendations to management.

Each superintendent was reminded of his responsibilities when overtime is worked to: (a) assure that regular supervision is present, (b) make sure that spot overtime is being worked only in those areas which are critical bottlenecks preventing programs from moving forward, and (c) ascertain that extended overtime or work week, where it is being applied, is necessary. The responsibility for good workmanship starts with management standards, motivation and training, and is effected by individually responsible workers. Increased efforts to improve training and personnel motivation were applied.

In addition to revising the implementing instructions to accentuate the program office responsibility for assuring that the IDWA schedule supports the program master schedule, periodic checks were made to assure full implementation of this responsibility.

NAA actions—quality

The first of a group of special corrective action teams were established to concentrate on those specific areas where the quality trend data reflected the need for corrective action. Special and periodic reports regarding their activities will be made to both program and division management.

The position of the Program Quality Control Manager was elevated to Program Quality and Reliability Assurance Director and a new position description prepared defining his responsibility and authority for directing quality program activities.

The use of quality trend and indicator charts was expanded throughout the manufacturing area.

Quality Assurance engineers and Laboratory personnel were assigned to specific manufacturing areas to evaluate process and product quality problems and improve the timeliness of corrective action. In the Saturn S–II and Apollo CSM assembly and checkout areas, these Quality Assurance engineers report directly to the Program Quality and Reliability Assurance Directors.

A more formalized program for corporate and divisional audits has been established.

NAA actions—reliability

NAA has established Apollo CSM Reliability as being responsible for the scheduling, agenda preparation and visibility of design review activity.

To provide improvement in the exchange of information between the Saturn S–II and Apollo CSM Reliability Programs, a formal monthly review program has been implemented in consonance with the NASA recommendation.

NAA actions—logistics

NAA has contributed considerable effort to the formulation and review of logistics plans for both the Apollo CSM and Saturn S–II for all sites involved.

NAA has consolidated the logistics and test effort on the Saturn S–II by alignment of the Florida, Mississippi and California Test Operations and the Logistics and Test Support organization under the direction of an Assistant Program Manager. A similar arrangement will be established for the Apollo CSM including Florida, White Sands, Houston and California Test Operations, and the Apollo CSM Logistics and Test Support organization.

NASA assessment

Difficulties were still being experienced in the S–II in April 1966 although some improvements were noted.

The improvements made in engineering, including more timely releases and engineering support on the factory floor, resulted in increased effectiveness in manufacturing.

A major organizations change which provided stronger Quality organization support to the manufacturing and test organization and to the CSM and S–II program managers had been accomplished by April 1966. Program management attention to quality trend data, as a measure of performance, had increased.

The net effect of all these actions by NAA was improved adherence to Quality Assurance disciplines, and improving workmanship as evidenced by a downward trend, from December 1965 to April 1966, in the discrepancy rate.

MR. WEBB'S COMMENTS ON LETTER

Mr. WEBB. Mr. Chairman, this is a quick summary chronology of the activities of the management review team headed by General Phillips.

Early in the Apollo Command and Service Module and S–II stage programs, the performance requirements, key milestones, and cost plans were agreed upon by NASA and North American and formed the basis for negotiated cost-plus fixed fee contracts between the Government and North American Aviation, Inc. As the programs progressed, we experienced a trend of slippages in key milestone accomplishments, shortcomings in equipment performance, and increasing costs.

By the fall of 1965, it was apparent that the rate of progress in both the Command and Service Modules and the S–II programs at the Space and Information Systems Division of North American Aviation were not sufficient to meet the requirements of the Apollo program. It appeared that both projects would diverge even further from planned technical, cost, and schedule achievement despite the efforts of the two cognizant manned space flight centers, unless immediate remedial action was taken. We therefore undertook a high-level review of the contractor's obligations, with a view to reexamining the reasons for past and current difficulties so that necessary corrective actions could be identified and taken to improve program position as rapidly as possible and provide greater assurance that future technical costs and schedule goals could be met or bettered.

The scope of the review included an examination of the North American corporate organization and its relationship to and influence on the activities of the Space and Information Systems Division. The internal activities and management effectiveness of S. & I.D. were examined in depth as to: program planning and control; contracting, pricing, subcontracting, purchasing; engineering; manufacturing; and reliability and quality assurance.

The members of the NASA review team were specifically chosen for their competence in large research and development program management experience with S. & I.D. and their intimate knowledge of the Command and Service Module and the S–II programs.

The S. & I.D. and North American Aviation corporate offices were informed of our plans for this review on October 27, 1965. The review was conducted from November 22 through December 6, 1965, at North American Aviation. The review team made its initial report in a verbal briefing to Dr. Mueller and North American management on December 19, 1965, at which time the contractor was provided extensive documentation in the form of notes which elaborated on the findings of the review team. Upon receipt of the NASA review team notes, Mr. Atwood formed a Survey Action Group to make a thorough assessment of actions already taken and those planned to be taken by North American Aviation in monitoring and improving program performance, and, in the light of the reevaluation, to make a thorough analysis of the notes and views of the Board as well as examination of the conditions referred to and implementation of necessary action.

North American Aviation's response, dated January 31, 1966, to the December 19, 1965, review was received by NASA for review and action. This response was examined in detail by the review team and in the ensuing 2½ months both the contractor and NASA personnel engaged in continuing efforts to bring the programs under better control and to improve the overall cost, schedule, and technical performance picture.

The NASA review team reassembled at the contractor's plant from April 22 to 27, 1966, to evaluate North American Aviation's progress in correcting the deficiencies found by NASA and to assess the current situation and outlook. It was determined at that time that the contractor had undertaken major efforts to bring the program into a position which would meet the Apollo program requirements in all areas. Specifically: corporate leadership was brought into play and participated actively in fixing Space and Information Systems Division programs; actions to improve were beginning to show results in schedule performance, but costs were still a major problem; personnel changes in the key jobs were considered to be good ones; program management was making its weight felt in S. & I.D.—there was a strong interest in program accomplishment at all levels; there was still further potential for streamlining the organization and more drastic manpower reductions could be made without program impact.

In the period following April 1966, the NASA team, along with our counterparts in North American Aviation, continued to move forward in constant betterment of the overall program. NASA-contractor meetings have been conducted at all levels from the Apollo executives to the individual engineers and designers. These have continued to provide direct exchange of technical and managerial information pertinent to meeting of program requirements.

And, Mr. Chairman, I would like to add this one observation: It would not be possible today to present to you a program through which the United States can recover from the Apollo 204 accident and do a lunar landing within this decade, if the work done by North American was all of the poor quality that it has been represented in some quarters to be. This work, in a large area, is good and we expect to fly if we can maintain the support of this committee and others to give us a chance to do so. The astronauts who are going to fly will be living with the equipment day by day, and will have the ultimate decision as to whether they will enter the spacecraft and take off for the Moon.

Thank you, Mr. Chairman.

SEARCHING EXAMINATION OF SPACE PROGRAM

The CHAIRMAN. I want to thank you for this reply.

As I said at our last meeting with Mr. Webb, we appreciate that NASA has made a searching examination of the spacecraft program: we realize that it will take some time to identify the most appropriate corrective action and initiate such action. At the same time, the committee has a duty to follow through. Therefore, we requested that NASA appear before the committee on this date, May 9, to give the committee, (1) a detailed report against all action recommendations listed in part VI of the Apollo 204 Review Board's report, and, (2) the agency's best estimate of its schedule for resuming the manned flight program.

I want to say I think you have done a very good job of that. Dr. Mueller went down it point by point. We find this was helpful to the committee. He has been very competent and we appreciate it a great deal.

In your discussion of the Apollo Applications program, Dr. Seamans, are you suggesting that some parts of the Apollo Applications program are important to the Apollo program in the sense of the Apollo program's being able to achieve its objective?

Dr. SEAMANS. Mr Chairman, we have laid out the main-line Apollo effort in such a way that in each step, we are gathering information, we are testing our hardware, we are training crews, and we are gaining experience from the past. We are obtaining scientific data between here and the Moon and around the Moon to carry out this mission.

The Apollo Applications program is not directed toward this main-line endeavor, but rather gains from this main-line effort. However, I want to say that having the development teams in being for the Apollo Applications program does provide a very important resource in the event we should have difficulties on the main-line Apollo effort. In that sense the Apollo Applications program, we feel, is important not only in its own right, but as a back-up and support for Apollo itself.

The CHAIRMAN. Senator Smith?

Senator PERCY. Mr. Chairman, could I ask one question?

The CHAIRMAN. Senator Percy.

Senator PERCY. In this $22 billion of contracts that have been placed for NASA in this program, some have been placed under fixed price contracts, some under cost-plus. There are incentive payments that have been provided.

Has the NASA management given consideration to penalty clauses which is a common occurrence in some types of contracts, where performance does not live up to standards, schedules have not been met, or accidents occur which cause a tremendous setback, as this program has been set back, considering just the amount of time you have spent in committee hearings since it occurred? What are the pros and cons of the feasibility of a penalty clause in these very large contracts?

Dr. SEAMANS. Senator Percy, what you say is correct; we do have some fixed price contracts. These are primarily for facilities that can be completely defined, where we put together a bid package with definite specifications and where the decision can be based on the factor of price. In such cases, naturally, if the contractor cannot deliver within price, he must continue until he finishes the job. He is responsible for completing the job within that price.

Some other parts of the program, particularly during the preliminary design phase, cannot be sufficiently well-defined for anything but a cost-plus contract, and it would be inadvisable, we believe, for the Government to enter into any kind of contract other than cost-plus. However, when we get to the major fabrication, hardware for the spacecraft, and the launch vehicle, we believe that we have things well enough established that we can provide what we call an incentive contract, which has within it, if you will, penalties for failure. We define the target cost, the target schedules and the performance that we must receive, and achievement of these goals gives the contractor nominal or target fee. However, if the contractor does not measure up in any one of these three areas, then he receives less fee and in that eventuality, he is losing his profit in such a way that he is at least partially paying for whatever loss is involved—costs, schedule, or performance.

Mr. WEBB. And Senator Percy, it would be a grave mistake to think of the program only in terms of the setback from one major accident. I would like to point out that as of yesterday, 98 percent of all spin-stabilized and unstabilized spacecraft launched since the start of NASA have worked. Eleven out of the last group of deep-space missions have been successful, if we count the Lunar Orbiter which went into orbit last night, as successful. We will get the pictures back in a day or two, and I feel sure it will be successful. Of 26 Scout vehicles launched, 25 have succeeded. Of 48 Deltas, 44 have succeeded. Of the Thor Agenas, seven have been launched and all seven worked. All operational Centaurs—that is, three—have succeeded.

So, it seems to me that we have had some successes including those of Gemini, where we made up time, and, in fact, did a better job than anyone could have projected. So, we must balance off the failures with the outstanding success that advanced us rapidly in areas where the system of contracting and the spending of this money with American industry did a good job.

Senator PERCY. I do not dispute that at all. But back to the question of penalties, in what way has North American been penalized from the financial standpoint or otherwise for the partial responsibility that it had for this accident, other then the obvious agony that its management went through in this room and in their own minds over the past many months?

Dr. SEAMANS. Senator Percy, at the time of the accident, the work that was being done on the 204 Spacecraft was under an incentive arrangement. With the Block I spacecraft, we had laid out a series of goals for each one of the spacecraft, including the 204. They had completed some of the work and earned some of the fee for that work, but some of it was related to final checkout on the Cape, actual placement into orbit, and satisfactory operation in orbit. They will, of course, not receive the full amount of the fee related to that.

Because we didn't use the spacecraft in orbit, we still have to negotiate with them the details of the fee adjustment. But they will, in the sense that I have indicated, receive a penalty for not achieving the full objective that we had defined with them.

Senator PERCY. Do you have any estimate as to what that might amount to?

Mr. WEBB. Dr. Mueller estimates several million dollars.

Senator SMITH. Mr. Chairman?

The CHAIRMAN. Senator Smith.

SOURCE EVALUATION BOARD

Senator SMITH. Mr. Webb, I think you will recall that when you were here last, on April 17 I asked questions with respect to the selection of North American for the award of the Apollo spacecraft program. My question was: Was North American the first choice of the Source Evaluation Board, and your reply was "Yes." As you know, there has been some speculation that at one point in the process of the source evaluation procedures, Martin appeared to be in the lead for getting the award. Questions have been raised as to why Martin did not get the award.

Mr. Chairman, I want to proceed with certain questions on this if I may.

The CHAIRMAN. Yes, proceed.

Senator SMITH. What were the factors upon which it was agreed that the award should be based primarily on technical information, Mr Webb?

Mr. WEBB. Senator Smith, my answer to your question was related, as I recall, to source selection, and the source selection was made by Dr. Dryden, Dr. Seamans, and myself on the recommendation of Dr. Gilruth, the Director of the program, and after a full hearing of the Source Evaluation Board. The Board considered the technical qualifications of the various contractors who were submitting proposals, considered the various facilities proposed and the design proposals—that is, the quality of the specific design proposals included in the written proposals to us. In addition, the Board considered the business factors relating to the management capability of each company, its subcontracting system, its pricing system, and the estimate of the cost to the Government of proceeding with any one of the contractors. Those were the main factors which the Source Evaluation Board used in making its presentation to those of us who had to make the selection.

Senator SMITH. And your answer yes, when I asked if North American was the first choice of the Source Evaluation Board, is correct, is it not?

Mr. WEBB. I thought you said Source Selection Board.

Senator SMITH. I am sorry, Source Evaluation Board.

Mr. WEBB. No. North American, at one point or another in the process of analysis, was not first in one or another of those areas which were assigned for initial analysis to a number of panels (of the Board) and considered, as I mentioned to you before in answer to your question, considered carefully by almost 200 people—I believe the exact number is 190. The end result of the evaluation procedure which the Board selected and applied itself was North American as the second choice in terms of the sum of the numerical scores of this Board.

I think it is only fair, Senator Smith, to point out that the responsibility of Dr. Dryden, Dr. Seamans, and myself, as well as of Dr. Gilruth, was to examine the work of the Board and how it made its own evaluations, as well as to select a contractor. In our oral hearings on the scoring of this Board, which lasted quite a number of hours, we went into great depth; and the fact became very clear that the North American Aviation proposal, in the scoring by the Board, had lost points unduly because the company had not participated in the studies paid for by the Government which included work toward possible designs for an Apollo spacecraft. These studies had started back as far as 1959 in various areas. We chose, as a matter of judgment—Dr. Gilruth, Dr. Dryden, Dr. Seamans, and myself—to reevaluate the capability of the company in the light of this fact. In reevaluation we examined very carefully those factors which indicated experience and capability in developing high-performance manned flight systems.

Second, I think it is quite important to recognize that the record of North American up to that time, and, in fact, its proposal, reflected a consistent pattern of low-cost, high-quality engineering production. And there was a cost factor of something like two or more when compared with (1) the technical capability offered, (2) the resources offered and (3) the personnel offered and many other things. So, in effect, we were examining the proposals of North American and Martin in the final selection. The other proposals were eliminated by the work of the Source Evaluation Board.

May I say one other thing, Senator Smith? One of the things that is extremely important to recognize is that the X-15 aircraft is a man-operated air-to-space and reentry vehicle that goes up to about 60 miles and is controlled above the earth's atmosphere with reaction jets of the kind we had to learn to use in space. North American had done an outstanding job in the design and development of the X-15. This has been one of the most successful programs we have ever had. It gave us the knowledge on which Mercury and many other of our programs were based, including our unmanned programs, and Dr. Gilruth, Dr. Seamans, Dr. Dryden, and I felt that this experience had not been fully taken into account. The Board had tended to equate all activities of each company in evaluating company experience rather than to segregate them into specific divisions and with the specific persons that were proposed to the Government.

Senator SMITH. Mr. Webb, I was not questioning your authority to change the recommendation of the Source Evaluation Board. I was only trying to have the record straight in this particular instance.

I asked the question, and I thought you said that North American was second. Was that right?

Mr. WEBB. They were second in the numerical evaluation which the Board reported, but when we questioned the members of the Board with respect to, first, the method they had chosen to evaluate the various proposals; second, the actions they had taken to apply their own methods; and third, what they had found, we discovered that they had inadequately, in the judgment of all four of us, applied their numerical equations or numerical ratios to the element of experience. The experience element we felt was particularly pertinent was in the area of high-performance systems involving man such as the X-15. We therefore made a correction of what we believed to be an error in the numerical ratings of the Board; or shall I say evaluations of the Board.

Senator Smith, we have let these boards be relatively free in using adjectives, but we have always reached through the adjectives and based our final determination on numbers.

Senator SMITH. Is it right for me to assume that the primary factor on which this agreement came was technical information, then?

Mr. WEBB. Technical evaluation, Senator Smith. It was the evaluation of Dr. Gilruth, Dr. Seamans, Dr. Dryden, and myself that the capability offered by North American to do the job should be explored through negotiations. I think it is important to recognize that when you have a final type of runoff between two companies, you choose one to test whether you can get a contract that the Government is prepared to go forward with. So, we selected North American for negotiation and, in the negotiation process, did determine to award them a contract.

The complete and final determination of whether or not North American would be awarded the work came only after the negotiation with them was successful. So, the process is not complete until there is this negotiation. The second contractor, in effect, is available for negotiation should it be desired by the Government in the event negotiation with the first contractor is not successful.

Senator SMITH. Briefly, if you will, and then expand for the record if you prefer, what constitutes primarily the factors of technical information? You may want to get that in the record.

Mr. WEBB. We will do that.

Senator SMITH. Also give me the difference between technical approach and technical qualification, if you will.

Mr. WEBB. We will do that.

(The material referred to follows:)

I believe the below material on technical evaluation will cover the area referred to in the two questions that relate to technical information obtained from contractors in requesting their proposals and the difference between technical approach and technical qualification.

The primary factors making up the technical evaluation were technical pproach and technical qualifications. Briefly stated, technical approach is how contractor proposes to do a job and technical qualifications are the resources e has to apply in terms of facilities, personnel, experience and "know-how") do the job.

More specifically, the technical approach in the proposals for the Apollo pacecraft was to present an engineering proposal covering the spacecraft with s associated ground support equipment and ground operational system to atisfy the requirements of the procurement, which included detail design of he modules, integration of the complete spacecraft, manufacturing of the odules, and operational support of the spacecraft. This engineering proposal ras to be in sufficient technical detail to demonstrate both the bidder's undertanding of the problems and his engineering, manufacturing, and operational kills. The bidder was also required to discuss the state-of-the-art of the systems roposed, the research and development programs required, and their adaptiveess to orderly technical growth and improvement. Areas considered in evaluatng this part of the proposal were systems integration; propulsion; flight mehanics including aerodynamics, trajectory analysis, and guidance and control; tructures, materials, and heating; human factors including crew considerations, raining and crew participation, and radiation; instrumentation and communicaions; on-board spacecraft systems including auxiliary power supplies, environental control systems, landing and recovery, and mechanical systems; ground perational support systems and operations; technical development plan; eliability; and manufacturing.

The areas considered under technical qualifications were experience in deeloping major systems of an advanced technology nature involving both ground nd flight systems, facilities and equipment suitable for the development of ystems of an advanced nature, experience and capability of personnel, and he strength of the technical organization and its capability for technical anagement.

Senator SMITH. Is it true, then, that on the basis of technical inormation, the Source Evaluation Board rated Martin very slightly etter than North American? I am speaking about the source——

Mr. WEBB. Senator Smith, you are bringing me into an area that think should be considered in executive session, because there are egal requirements to the effect that when you obtain cost and proprieary business information about companies through Government activy, you have certain restrictions on the use and release of such infornation. I would much prefer to see you examine this in executive ession and then decide what questions you wish to ask in public. I elieve that you would find this would permit you to accomplish anyhing that you feel you need to, but without asking me to try to make decision on the spot as to what might fall within the provision of he statute and what might not.

Senator SMITH. Mr. Webb, you would have no objection for me to sk the questions in this hearing, would you?

Mr. WEBB. No, and for the record I will supply what I can.

(The following additional material was submitted for the record y Mr. Webb.)

The Apollo Spacecraft Source Evaluation Board was composed of technical nd business experts, and at the start of its work made a number of assumpions as to which factors of technical and business experience it considered best o use as a basis for arriving at numerical ratings of the proposals. The Source valuation Board presented to the source selection officials composed of Drs. ryden, Seamans, and myself, a number of detailed and summary tables of atings with supporting data. In the totals the Martin Company was rated 9 and NAA 6.6.

One of the duties of the selection officials was to cross-examine the board embers to determine if the assumptions used were proper and showed a full nderstanding of the factors which should show differences of significant kinds and degrees, and to discover if the board considered all proper factors and weighted them reasonably. Upon close questioning of this board, during its explanation of the factors it had used and ratings it had reported Dr. Seamans, Dr. Dryden, and I became convinced that the board had failed to differentiate between the companies as a whole and the specific divisions of the companies proposed to do the work in building the spacecraft. The board had arrived at its rating for experience on the basis of considering all relevant work on a company-wide basis, so that a company was given points for work completed by a division which would have no responsibility for building the command and service module. Our cross-examination of the board also brought out that while the board had given a higher rating for technical approach to the Martin Company, its participation in feasibility studies of the Apollo system under contract with NASA accounted for some part of this. A recomputation of the Source Evaluation Board's numerical ratings was made to test the validity of a revised set of experience criteria. On this basis, in the combined areas of experience and technical approach, North American Aviation rated ahead of Martin. We compared the factors in this revised numerical rating against those submitted by the board with the result that we were unanimous in our judgment that in these areas North American Aviation should be selected.

Senator SMITH. I think perhaps the chairman and I may be aware of the answers, but I think the American public are the ones that we are trying to get answers for.

I will ask my questions. If you will answer them for the record, if you wish, and then we will take——

Mr. WEBB. I would be very happy to furnish answers to questions which I feel the law might not permit me to place in the record and then let the chairman and you decide the extent to which you wish to put them in the public record. I will answer for the record all other questions.

Senator SMITH. Is it true that in the breakdown of technical information into the two subfactors of technical approach and technical qualification in adjusted indices, that while Martin was slightly ahead of North American on technical approach, in contrast, North American was rated nearly twice as good as Martin?

Mr. WEBB. My answer for the record is:

I believe you refer to the adjustment Dr. Seamans, Dr. Dryden and I made in the Board's rating for the experience factor which was one of four equally rated subfactors under the primary factor of technical qualifications. In evaluating experience, the Board ratings for Martin and North American were approximately a one-to-one ratio based upon an evaluation of all projects the companies had accomplished in several divisions and not just the division proposed by the companies to do Apollo. Since the project would profit primarily from the experience in the division of the company which would do Apollo, the rating was recomputed excluding Titan, Vanguard, Pershing and Viking for Martin and excluding A3J, AJ2, F-86, T-39, FJ-1, and AJ3 for North American. The ratings on this basis then became slightly less than two-to-one in favor of North American.

Senator SMITH. The next question, Mr. Chairman.

In the final analysis, Mr. Webb, is it true that while the Source Evaluation Board rated Martin slightly ahead of North American on technical information—approximately 3.5 percent better—that in sharp contrast, North American had the lowest proposed cost and was about 30 to 40 percent lower than Martin? In other words, is it true that the North American superiority on cost over Martin, percentagewise, was approximately 10 times as great as the Source Evaluation Board's technical information rating of Martin over North American?

Mr. WEBB. My answer for the record is:

I believe you refer to the technical evaluation by the Board. The Board included under its technical evaluation the primary factors of technical approach and technical qualifications. It had rated North American slightly superior to Martin on technical qualifications and Martin superior to North American on technical approach. The combination of these ratings gave an overall technical evaluation rating for Martin slightly over North American. Percentagewise, the Martin numerical rating of the technical evaluation was 3.4 percent higher than the rating assigned to North American, or approximately the 3.5 percent which you stated. It is also true, that North American had the lowest proposed cost and its adjusted cost as calculated by the Source Evaluation Board was reported to Dr. Dryden, Dr. Seamans and me as some 25 percent below Martin's adjusted cost. Stated differently, the Martin adjusted cost was 34 percent greater than North American's adjusted cost.

Senator SMITH. Was then the cost factor one of the controlling factors in the unanimous decision that Dr. Dryden, Dr. Seamans, and you, with Dr. Gilruth, reached to select North American over Martin?

Mr. WEBB. It was an important factor, the fact that North American did propose the lowest cost.

Senator SMITH. What were the principal factors in your decision to select North American over Martin?

Mr. WEBB. We will answer that.

(The material referred to follows:)

The principal factors in the selection of North American over Martin have been essentially covered. In summary they were:

a. In North American, experience in the specific division which would perform under the contract was greater and the specific persons proposed to do the work were judged to be better qualified than those in the division Martin offered to do the work. In judgment, North American had greater technical competence.

b. North American submitted the lowest cost proposal and the company had the best record for low-cost, high-quality engineering production.

DISCUSS NASA GUIDELINES FOR INFORMING COMMITTEE

Senator SMITH. Mr. Chairman, I have two or three more questions. Perhaps I had better ask them now.

Mr. Webb, Dr. Seamans had testified that in the fall of 1966 he was concerned with North American performance and that it was decided to establish a task force under General Phillips. Mr. Webb, did you share the concern of Dr. Seamans?

Mr. WEBB. Yes, indeed, and the year, I believe, Senator Smith, was 1965. We all shared this concern, both in North American Aviation, Inc. and in NASA, as to whether we could do the work necessary to keep this program on schedule.

Senator SMITH. Well, shortly after General Phillips completed his review, you, Dr. Seamans and Dr. Mueller testified before this committee on the 1967 authorization. At that time, in answer to questions, Dr. Mueller indicated satisfaction on compliance with program requirements.

Why was not the seriousness of the situation regarding the multibillion dollar contracts at North American made known to the committee. Or, if not specifically during the hearings, should not the chairman and other members of the committee have been briefed on this situation?

Mr. WEBB. Could you give me the date of that testimony, Senator Smith?

Senator SMITH. I do not have it with me.

Mr. WEBB. Certainly, we should keep you informed, and, Senator Smith, I believe we have testified here that all of these large contractors have had many problems.

We have not undertaken to make statements about the problems if we thought they could be solved and we could move ahead with the work. Where we encountered a situation that we did not believe could be worked out, we certainly would have indicated it to you.

On the other hand, I think it is quite important to recognize that we are dealing with a very large program and that we have taken it as our responsibility to work with American industry to produce the equipment and fly. We have not felt it necessary nor wise to spell out difficulties that we thought could be overcome, especially when we were giving you our best judgment and authoritative schedules that we expected to meet.

Senator SMITH. The date of that hearing, Mr. Webb, for the record, I am informed, is March 1, 1967.

Mr. WEBB. March 1, 1967?

Senator SMITH. 1966, I am sorry.

Mr. WEBB. Dr Mueller says he would like to say a word on that.

Senator SMITH. Yes, Doctor.

Dr. MUELLER. Senator Smith, at that time, there was very real progress being made by North American in overcoming the difficulties that General Phillips and his review team had found, and we had every evidence that they would in fact be successful in meeting the needs of the program. Now, part of the development of any program is the maintenance of the forward progress of the people themselves, the attitude of the people. It is important in any program, to be sure, that we do not pinpoint blame to any contractor or to any individual without real cause. I believe they were making at that time—taking all the steps that could be taken to satisfactorily bring the program forward.

Senator SMITH. Dr. Mueller, I am sure the chairman would see you any time a situation of this kind comes up. To show the seriousness that General Phillips had about this, he reportedly stated the following after his review in December 1965, and I quote:

"The conclusions expressed in our briefings and notes are critical. Even with due consideration of hopeful signs, I could not find a substantive basis for confidence in future performance."

I would ask, Mr. Webb and Dr. Mueller and Dr. Seamans, Do you have any guidelines as to when serious situations are to be brought to the attention of this committee?

Mr. WEBB. I do not know that we have, Senator Smith. We have tried to work as closely with this committee as we could. We have stated to you what we thought we could do. I believe we have delivered the goods in these programs and schedules when it came to flights. The problem of getting a massive amount of work done at the base of a pyramid, of closing in on the capability to launch at the top of the pyramid, is not a matter that we have felt it necessary to come in and discuss with the committee. Our judgment and our reports to the committee have been based on our expected performance against the schedules that we have asked you to appropriate the funds for.

Senator SMITH. I will ask you one more question in this line, Mr. Webb.

Are there any similar situations with other NASA contracts that the committee should know about?

Mr. WEBB. There are similar serious situations, and have been, in the development of every major unit that we have had. What we have in this combination of industry, universities, and Government laboratories is the capability to overcome the difficulties. The difficulties are related to the problems of going to the Moon and coming back.

We right now have a number of extremely serious situations, but we also believe we can ovecome them and fly. They are no more difficult than those we faced over the last 5 or 6 years, maybe less difficult.

Senator SMITH. Do you think they are serious enough to have any effect on the program?

Mr. WEBB. Senator Smith, I believe they will be overcome, and I believe that our testing program will give us a good deal of information on this during the coming months. I think we will know whether they have been overcome when we fly the first two Saturn V's with the all-up systems test concept that we had to develop when the program had to be revised some years ago. I believe the unmanned Lunar Module flight will be a success—that is coming this summer. Now, if they are not, then we will have a very serious situation that we and the committee may have to examine. I believe my statements in previous years' hearings have been that we were operating on a success schedule and that you could tell whether we were in trouble or not by seeing whether the flight succeeded. I think that is still true.

I hesitate very much to speak in public about the difficulties of an individual company or an individual division of a company when I believe they will overcome the difficulties. If I felt it was necessary to help the company overcome them, I would speak without the slightest hesitation. But I think it may make overcoming problems more difficult. The problems of this week are never the problems of next week. It is a constant series of a large number of problems; as each one is solved another one emerges. In the end, you get to the point that you have enough confidence to launch the equipment.

Senator SMITH. Well, Mr. Chairman, it seems to me that it was certainly NASA's responsibility to bring the North American situation to the attention of this committee at the time General Phillips completed his review. These contracts represent about 25 percent of NASA's budget. This does not necessarily mean that the detailed report had to be provided to the committee, but we should have been apprised of the situation early enough, since it directly affects the budget authorization request and the overall progress of the program.

I think, Mr. Chairman, this involves a communication problem between NASA and the committee that must be corrected for the future, and this was the reason I asked my question about guidelines.

Mr. Webb, I wish you would give that a little consideration. Will you?

Mr. WEBB. I certainly will, Senator.

Senator SMITH. I, as one member of the committee, want to be helpful rather than not, and I would hope we could have a little better communication in the future on the serious problems that you have in case we might be able to help.

Mr. Chairman, I have two or three other questions that I would like to have read into the record and answered for the record, if you please.

The CHAIRMAN. Without objection, that will be done.

(Senator Smith requested that the following questions be answered for the record:)

QUESTIONS ON NEGOTIATIONS WITH OTHER CONTRACTORS

1. Mr. Webb, in your statement you indicate that the Boeing Co. will be used to integrate the Apollo command and service module and the lunar excursion module in the Apollo program.

Would you briefly explain what Boeing's efforts will be for this work and what prompted this decision at this late period in the program?

Answer. The Boeing Company, being the manufacturer of the first stage of the Saturn V launch vehicle on which all other stages have to rest and depend, currently has a systems integration contract for the Saturn V launch vehicle. This contract provides for the decisions with respect to the interfaces between the various stages of the launch vehicle (first, second and third stages and the instrument unit) to monitor these interfaces to make sure that the whole system will work as a unit and will successfully fly. The intent now is to extend the Boeing responsibility to include not only the launch vehicle portion of the system but to also include the total payload, that is, the command and service modules and the lunar excursion module.

Regarding the timing of the decision to bring Boeing in for this integration function, our original plan was to have North American Aviation perform this integration of the payload systems, since they had the largest part of the spacecraft. We never did let the contract to them because we were not satisfied that they were prepared to take over this function. We were considering whether or not we could develop this capability in our field centers, i.e., in our in-house laboratories, but we have decided since the fire to ask the Boeing Company to do it.

2. In your statement you also indicate that a third contractor will be selected to make all modifications to standard Apollo vehicles which will be required for use in the Apollo Applications programs.

Would Boeing have been selected for this modification work if they were not chosen for the integration of the Apollo CSM?

Answer. I indicated in my statement that NASA will call in McDonnell-Douglas, Martin, and Lockheed for negotiations on this work. We are not limited, however, to these three companies and, indeed, both Boeing and General Electric have so far indicated that they would like to be considered as a possible source. We are not quite sure at this time exactly how we will proceed.

3. Dr. Seamans, in your statement you itemize the estimated $70 million of additional cost resulting from the new operating plan.

Have you included in this estimate the additional cost of assigning a separate integration contractor, Boeing, for the command and service module?

Answer. The cost for this new Boeing activity is not included in the $75 million of additional costs spelled out in the statement. It is NASA's intent, however, to fund this activity out of the Apollo program and to do so within the current 1967 budget and the 1968 budget request as provided to Congress. The answer, of course, will not be available until contract negotiations have been completed at which time we will be in a position to know the scope and estimated cost of this new activity.

FIRST MANNED ORBITAL MISSION

4. Dr. Seamans, in your statement you indicate that the first manned orbital mission will be made with the first Block II spacecraft having all the changes resulting from the accident.

Does this mean that the new quick egress hatch will be flown for the first time as a manned mission?

If this is so, are we giving enough consideration to the safety factors involved?

Answer. Ground and flight tests are necessary to qualify the new hatch to assure its effective operation, integrity in the vibration environment encountered during launch and re-entry, compatibility with crew requirements including EVA, and integrity during re-entry heating. These tests are to be conducted on ground test articles, on the thermal vacuum model, and on unmanned Saturn V heat shield qualification flights.

The ground test program for the Block II command and service module has qualified the spacecraft through such means as aircraft drop tests, propulsion tests, structural tests and crew compatibility tests. We will perform vibration tests, and thermal vacuum tests before clearing for manned flight. In addition, the new hatch design is to be tested on the unmanned Saturn V missions planned for this fall.

The CHAIRMAN. Senator Cannon?

BACKUP CREW NAMED FOR FIRST APOLLO FLIGHT

Senator CANNON. Thank you, Mr. Chairman.

Mr. Webb, I would like to associate myself with Senator Smith's remarks. I would be very hopeful that you would take it upon yourself to inform the committee if similar situations or situations of any great magnitude come up so that at least we would be advised of what was happening. And as Senator Smith said, we want to be helpful if we can, but we cannot be if we do not learn about these things until after they are accomplished fact.

Mr. Webb, some little time ago you made the announcement that all of the astronauts were being taken off their previously assigned crews and duties and now you are reinstating the crew for the first Apollo flight. The crew that you have selected now is the same crew that was the backup crew for the initial program flight, is that correct?

Dr. MUELLER. That is correct.

APOLLO BLOCK II DESIGN TO BE STANDARDIZED

Senator CANNON. I thought it might be well to make that clear for the record.

Now, Mr. Webb, in describing the changes in the contracting pattern you say that the Apollo Block II design will be standardized and the negotiations will be initiated with North American Aviation for the manufacture, test, and delivery of these standard Block II Apollo spacecraft.

First, I would like to ask you whether or not this design was standardized previous to this time and, if not, why not, so that you will explain clearly for the record why there is a change in your procedure in that regard at the present time.

Mr. WEBB. Senator Cannon, we learned a great deal from the 204 accident and fire. We have conducted over 100 flammability experiments that have given us a large amount of knowledge. The tremendous amount of work done by Dr. Thompson and the Apollo 204 Review Board is being taken into account, and all of that now comes into play to enable us to make a standard Block II vehicle, incorporating all the changes that we presently feel we need.

We also have the experience of the Block I learning process, so that we now standardize the Block II design and do not permit changes at the North American factory in this standard article.

Heretofore, we considered having capsules coming through the line, modified on the basis of an anticipated success which would then permit us to use that capsule for an alternate mission. We have now decided to follow the process that the Agena program found so successful. We and the Air Force were both using Agenas off the same production line. We found it was considerable trouble to modify them on the production line. We finally worked out a process where every single one of them came through in a standard configuration and each of us, NASA and the Air Force, modified the stage to suit our needs after it came off the line. We have decided this is the way to proceed with the Block II.

Senator CANNON. That decision was made only since the accident?

Mr. WEBB. Yes, sir.

PLANS NEGOTIATIONS TO EXTEND BOEING'S CONTRACT

Senator CANNON. In item No. 2, you say negotiations will be initiated with the Boeing Co. to extend Boeing's present contract responsibility for the integration of the first, second, and third stages of the Saturn V, to include also the integration of this system into the Command and Service Module and the Lunar Excursion Module.

I would like to ask you first whether or not that was a change and, if it was a change, what was the specific change, and what was the necessity for it?

Mr. WEBB. The change, Senator Cannon, relates to the fact that the Boeing Co., being the manufacturer of the first stage of the Saturn V on which all other stages have to rest and depend, now has the contract to provide for decisions with respect to the interfaces, to monitor the interfaces to make sure that the whole system of the first, second, and third stages do work as a unit and will successfully fly. Due to the success they have had in this work and their capability and our desire to have not only NASA examining the whole structure and making sure we are ready to fly, we have asked the Boeing Co. if they would extend that activity to include also the payload, which is in three units.

They now, on the basis of their previous experience, are being asked, in effect, to certify that the whole unit, vehicle and payload, does function together, is compatible, and is ready for flight. This gives us an additional, capable organization to examine all factors necessary to success and help us form a judgment at the time we have to fire up the engines and take off from the Earth.

Senator CANNON. Did any contractor have that responsibility prior to this time or was that simply NASA's own responsibility?

Mr. WEBB. No, sir; in the early stages of our planning, we expected to have North American integrate the total payload since they had the largest part of the spacecraft. We never let the contract to them because we were not satisfied that the time had come that they were prepared to do this. We were considering whether or not we could build enough capability in our own Centers to do it, and we have decided since the fire to ask the Boeing Co. to do it. So the contract for this was never let to anyone.

Senator CANNON. Will that appreciably increase your costs in that regard?

Mr. WEBB. It may decrease the cost if it turns out that you get a much better article. Of course, the cost of the Boeing Co.'s operations will have to be borne against the program. So I just cannot answer your question. My judgment is we will get more than the money we spend in value from this arrangement.

Senator CANNON. Now, your third point, you say that, in addition to these arrangements with North American and Boeing, a third contractor will be selected to make all modifications to standard Apollo vehicles which may be required for their use in the Apollo Applications program. What was the previous arrangement?

Mr. WEBB. The previous arrangement was that we would place work orders on North American to prepare each spacecraft coming through the production line for its most likely use on launch. We have now decided to standardize and have them produce only the standard article, rather than to take work orders for modifications.

General Phillips has made a very strong point that his responsibility for seeing that this lunar landing takes place successfully in this decade depends on a clear, unambiguous workload in the North American plant for standard articles with no dissipation of energy or ambiguity with respect to that task. This must be a clear, specific, direct task and he must be in a position to command the use of those standard articles until he certifies he does not need them. At that point we will take them, determine other uses for them and have another contractor modify them.

QUESTIONS ON FLIGHT SAFETY OFFICE

Senator CANNON. Dr. Mueller, with respect to your statement on the Office of Flight Safety, how does this office differ from the functions of the present 90-man flight safety office at the Manned Spacecraft Center?

Dr. MUELLER. We are providing an overview and a policy-establishing organization in our office here in Washington to tie together the activities of the flight safety office of the Manned Spacecraft Center, the flight safety office that will be established at the Marshall Space Flight Center and the flight safety office at Cape Kennedy, so we will now have an integrated, uniform flight safety approach. And we have broadened the responsibility of these offices to review all of our test procedures.

Senator CANNON. What will their relationship be to the present flight safety office?

Dr. MUELLER. The flight safety office at MSC will continue its role and be strengthened with some additional people in order to accomplish the review.

COST OF EQUIPMENT CHANGES

Senator CANNON. Dr. Seamans, I want to compliment you, first, on your statement of accomplishments, your summary of accomplishments, that you gave to the committee when you started your statement. I think that is very impressive, and you should be commended on it.

Could you tell us what the major cost elements are that make up the $40 million estimated for equipment changes and modifications? That is on the Apollo estimate now.

Dr. SEAMANS. Could we supply that for the record, Senator Cannon?

Senator CANNON. Yes, if you would.

(The information referred to follows:)

The $40 million is an estimate of the cost of the changes for the Command and Service Module and the Lunar Module. This estimate covers a large number of specific modifications to the sub-systems and components which have not, as yet, been negotiated with the contractors. The major specific modifications to be made are as follows:

(1) All cabin materials have been reviewed for flammability characteristics and appropriate changes will be made. This will include both substitution of new materials and re-arrangement of materials to inhibit fire propagation.

(2) A manually operated, quick release, one-piece hatch will replace the hatch used on Apollo 204.

(3) The spacecraft communications systems will be improved.

(4) The option to use air in ground tests, rather than pure oxygen, will be provided by modifications to the Environmental Control System. The plumbing required for the oxygen lines will also be improved. Fire hazards in the ECS system will also be either removed or protected.

(5) A number of other changes intended to provide increased fire protection and enhanced reliability are also included.

COMMAND AND SERVICE MODULE COSTS

Senator CANNON. I have a number of questions here that you may want to answer for the record. Those that you desire to answer now, you may answer at this time.

What are the factors that create the $17 million cost increase in the rescheduling of the Command and Service Module and the lunar module delivery?

Dr. SEAMANS. This relates to operations and recovery, which breaks out at this time into $4 million in 1967 and $6 million in 1968, plus launch preparation activities at Kennedy, which breaks out into $5 million in 1967 and $10 million in 1968.

Senator CANNON. Well, that totals more than the $17 million that you mentioned.

Dr. SEAMANS. Again, if I might, may I look into this more carefully and supply it for the record.

(The information referred to follows:)

The additional $17 million is an estimate of the net effect on costs in fiscal years 1967 and 1968 of the adjustments to manufacturing, assembly, system installation and checkout activity at spacecraft contractor plants which results from the schedule adjustments relating to the 204 accident. In FY 1967 some production effort is being deferred to incorporate new hardware modifications which results in some reduction in cost. These reductions will be more than offset however in FY 1968 since flight spacecraft will not be completed as early as planned and will be in process in the plants for a longer period of time, and the decrease in contractor cost rates will not materialize as rapidly as planned in formulation of the FY 1968 budget request.

Senator CANNON. You proposed $43.3 million in the fiscal year 1968 budget to purchase two Command and Service Modules and long-leadtime items for three more. Do we understand that you will not initiate these procurements now but will divert these funds to other procurements in the Apollo Applications program or elsewhere in the Apollo program?

Dr. MUELLER. Certain of the funds will be shifted in this application. As a matter of fact, in this particular instance, though, we will continue to use those long-leadtime funds for the purchase of spacecraft for the Apollo Applications program, Senator Cannon, and in this respect the Apollo Applications program is providing for alternate spacecraft that could be used in the Apollo program in the event we had to, so that we are maintaining a production of the Command and Service Modules on a continuing basis.

Now, in particular, though some funds are being reprogramed, particularly those that were associated with the modification of the Command and Service Module at North American, and they will be reprogramed into the funds required for carrying out the modification of the spacecraft by this new third contract.

Senator CANNON. Now, you mentioned reusing the Command Modules for the Apollo Applications program. Does that mean that you do not plan new procurement of Command Modules at this time, or what exactly do you mean?

Dr. MUELLER. No, sir, what we are doing is refurbishing certain selected ones of the Command and Service Module. This will cut down the number we will have to buy if this is successful.

On the other hand, it will not mean that we can continue to refly these on a continuing basis. In addition to that, of course, we will have to build new Service Modules for each flight, because those are not recovered. So although it represents a significant potential savings, it does not eliminate the need for a continuing production of Spacecraft and Service Modules.

FUNDS FOR SPACECRAFT MODIFICATIONS

Senator CANNON. Now, in your fiscal year 1968 budget request, you asked for $91.3 million for spacecraft modifications. Do you now plan to initiate these modifications, or do you propose to divert those funds?

Dr. MUELLER. We expect to initiate those modifications. They will, however, be expended through this new contract.

Senator CANNON. And in your 1968 budget, you proposed $140.7 million for Apollo Applications experiments. Now, would you clarify your statement regarding the increase for Apollo Applications experiment integration and engineering estimated at about $55 million?

Dr. MUELLER. Well, with respect to the experiment budget, this is a decrease. Some of the experiments are delayed in their implementation because of the new schedule for Apollo Applications.

The integration support for this experiment, though, is carried in the refurbishment and modification contractors budget and there will be, because of the introduction of a scientific payload satellite in the latter half of 1968, funds required for the integration of the experiments. These experiments were at one time going to be flown in the mainline Apollo program that because of the Block I accident have had to be transferred to Apollo Applications.

Senator CANNON. Does that mean that you will spend part of that $55 million, then, in addition to the $140 million originally proposed?

Dr. MUELLER. The $140 million was just for the development of the experiments. The $55 million picks up items from the space vehicle modifications, from a reduction in the funding required for Command and Service Module procurements, because, again, the actual time we have to obligate funds has been delayed, and by a reduction in the experiments themselves.

So that we have from those three categories provided the funds for this new refurbishment modification contract.

SOVIETS SHOW EVIDENCE OF INCREASING BOOSTER CAPABILITY

Senator CANNON. Now, Dr. Seamans, in your statement, you said there are no reasons to change this plan; that is, going on from Apollo Applications. "The rate of delivery is scheduled at the most economical level we have identified and termination of either or both production capabilities would leave this Nation short of major space boosters at a time when the Soviet Union is showing evidence of increasing its strength in this field."

Would you tell us what the evidence is that the Soviet Union is increasing its strength in this field?

Dr. SEAMANS. This is a matter we have discussed before this committee this year, referring here to the new booster that the Soviets have demonstrated with their Proton spacecraft. This spacecraft weighs in the order of, we believe, 25,000 to 30,000 pounds and we understand from what we know of this booster that with proper staging, it could deliver a payload into orbit of the order of 40,000 or 50,000 pounds. That is in excess of the uprated Saturn.

It is on the basis of this clear demonstration that the Soviets are moving ahead with their booster technology that I made this statement.

Senator CANNON. Do we know what size and type of booster they used on their recent flight, the shot that resulted in the accident, and also what the command module consisted of?

Dr. SEAMANS. I do not believe we do have authoritative information on this. Our understanding is that this was a smaller module—that is, not up in the 20,000 to 30,000 pound class, but was more of the size of their previous manned spacecraft and that they used the same booster they had used on previous manned flights.

Senator CANNON. And was it a module believed to be similar to those that had been in use recently, or was that a different type module, if you know?

Dr. SEAMANS. I think perhaps, Senator Cannon, further discussion of this might be in a restricted session.

ASKS NASA TO KEEP COMMITTEE INFORMED

Senator CANNON. Mr. Chairman, one further thing to Mr. Webb.

Mr. Webb, getting back to Senator Smith's point, I would hope that if you do have at this time any current problems of the magnitude and type that were covered in the Phillips report, you would call those to the attention of the committee in executive session, if need be.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Jordan?

Senator JORDAN. Thank you, Mr. Chairman.

Mr. Webb, Dr. Seamans, Dr. Mueller, I shall not take too long here because the time is growing late and we all have things to do.

Mr. Webb, we have operated this program on a very tight budget back through the years and especially fiscal year 1967 and looking forward into fiscal year 1968, have we not?

Mr. WEBB. Yes, sir.

Senator JORDAN. In your statement on the first page, you say that—you give us something of a time schedule for the Apollo Block II stating it will be delivered late this year and launched 3 months later. By "late this year," what do you mean?

Mr. WEBB. I mean December, perhaps even late December, Senator Jordan.

Senator JORDAN. Then launching 3 months later would put us into the early spring, well along into the spring?

Mr. WEBB. Yes, sir.

Senator JORDAN. In the actual time elapsed between the tragic accident and the launching of the Block II, it will be somewhat over a year?

Mr. WEBB. Yes, sir, but I think we should bear in mind that we wanted to get flight experience with Block I in order to do a good deal of work on Block II, to confirm the work to be done. So we probably are not set back by that amount. It might be nearer 6 months in terms of the actual prove-out in the flight of Block II.

Senator JORDAN. I see. Well, then I am a little puzzled when you say on page 2—and it was repeated also by Dr. Seamans—that we can carry out this plan within the funds now available for fiscal 1967 and those in NASA's budget request for fiscal year 1968.

Dr. Seamans has enumerated some specific items amounting to $70 or $75 million that will have to be made up in various ways. But I am a little surprised that you can stay on target within that limit for fiscal year 1967 and 1968.

How much of this program are we going ahead with? How much of the Apollo program are we rolling ahead into Apollo Applications?

Mr. WEBB. Would you allow Dr. Mueller to answer that?

Senator JORDAN. Yes.

Dr. MUELLER. Senator Jordan, the source of the funds, we have not intermingled Apollo and Apollo Applications funds at this point in time, nor are we proposing to do so. The Apollo program is living within its fiscal 1967 and fiscal 1968 budget primarily because of two things: One, the actual buildup of operational support personnel at Cape Kennedy is less than we had otherwise planned, and, we do have appreciable savings in the order of $20 million in the combination of fiscal 1967 and fiscal 1968 fundings.

The other major area where additional funds are becoming available is from our experience with the operation of the incentive contracts on the Saturn V vehicle itself, where we have been realizing appreciable savings.

Of course, if we run into difficulties in the course of the development of Saturn V, these savings could disappear. But at this point in time our best indications are that we will actually underwrite slightly the funds we have established for the Saturn V launch vehicle.

That makes up the remainder of the $70 million in the 2-year period that Dr. Seamans discussed.

PLAN SELECTION OF NEW CONTRACTOR TO SUPPORT AAP EFFORT

Senator JORDAN. Thank you.

Dr. Seamans, you said on page 13 of your statement that in order to reduce the burden of diversity otherwise borne by the present Apollo spacecraft contractor, it appears reasonable to plan on selecting an entirely separate industrial organization to support the AAP effort. This new industry team would be responsible for the integration of AAP experiments with the standard Apollo spacecraft as well as the necessary engineering, design, development, test, and spacecraft modifications.

Is this a change of plan?

Dr. SEAMANS. This is not a plan, Senator Jordan, that we had prior to the Apollo accident. This is a plan that has resulted from our careful review of the responsibilities of the various organizational groups, including our contractors, and also taking into account our in-house responsibilities. There may be several contractors for these tasks.

We felt that a selection of an additional contractor would do two important things: It would permit the North American Co., which has the responsibility for making the hardware for the Apollo program, to concentrate on that mainline effort, and at the same time give us the opportunity to modify spacecraft coming off the line or to refurbish used spacecraft with a second team who would be concerned only with the modifications, experiments, and special objectives, both scientific and technical, of the Apollo Applications program. So this seemed like a good division of responsibility.

As Mr. Webb indicated, we have had extremely good success on the Agena program with this concept of a modification center. It is a concept that was used in World War II with aircraft to standardize them and then make changes.

So we believe this will permit us to move ahead as expeditiously as possible on the lunar landing program and also satisfy the needs of the Apollo Applications program.

Senator JORDAN. You have made a policy decision to use another contractor. You have not selected that contractor?

Dr. SEAMANS. No. As Mr. Webb indicated, this would, if circumstances permit, be carried out as a competitive negotiation; that is, we would send out a request for proposals, proposals would come in from interested companies, and they would be evaluated.

We would have a source evaluation board and go through that process, according to our present procurement plans.

QUESTIONS ON GROUND SAFETY-FLIGHT SAFETY IN RELATION TO NEW HATCH

Senator JORDAN. Now, you have made a number of changes in the capsule and in the equipment going into the capsule. You have made substantial changes in the design and construction of the escape hatch.

Earlier testimony discussed that at some length. I believe we were told that the reason the escape hatch was designed the way it was in Apollo 204 capsule was for security in flight.

Now, my question to you is: With this new escape hatch which will be a component part of Block II, are we trading off safety of astronauts in flight for safety of astronauts in test operations on the ground?

Mr. WEBB. Senator Jordan, before that is answered, let me go back to Dr. Seamans' question. He was describing the process that we would go through if there is enough time to pursue this process. How much time will be available depends somewhat on when Congress finishes with the budget and also the success of our negotiations with North American and Boeing as I have indicated.

We have, to shorten the time requirement on occasions, called in all contractors that we knew had a capability, discussed with them the availability of that capability at that particular time—whether or not they were loaded with contracts, whether or not they could actually do this work, whether they had an interest—and then made a sole-source selection after this kind of fairly thorough but informed investigation of their capabilities.

We have indicated in my statement that we will call in McDonnell-Douglas, North American, and Lockheed for those negotiations, and I notified those companies yesterday by telephone that we did expect to call them in.

So in the interest of making the program move, I think we would not like to stand 100 percent on the standard process here.

Could Dr. Mueller give the answer to the question?

Excuse me. I am informed that I said North American. The companies that we are going to call in are Lockheed, Martin, and McDonnell-Douglas.

The CHAIRMAN. Not Boeing?

Mr. WEBB. We did not plan to call in Boeing, but, Senator, I made the telephone calls to the presidents of these companies. I find there is a very considerable interest in this procurement. Both General Electric and Boeing have indicated they would like to be considered as a possible source. So we are not quite sure exactly how we will proceed.

The CHAIRMAN. I am not trying to change your decision. I just thought at one time that I heard the name of Boeing mentioned by you.

Mr. WEBB. We had not thought that they would wish to compete for this business. But they indicated yesterday they did not wish to be excluded from it. Now, in the end, they may not. I am not able to say today.

Dr. MUELLER. With respect to the hatch and its design, it is certainly true that one has to make tradeoffs with respect to safety in the design of the hatch for a spacecraft. The tradeoffs involve the means of getting into and out of the spacecraft versus the possibility of an inadvertent opening of the hatch door, which could occur in the case of the outward-opening hatch that we are proposing to build into the Apollo Command Module.

After a careful review of the design, our experience on the Gemini program with this particular design concept, and a review of the requirements for extravehicular activity which are a basic part of the Apollo program, we decided that this particular hatch was the safest overall approach that we could use. So we adopted it, but primarily not for the problem of fire safety. We expect to solve that through the change of materials in the cabin and the other changes we are introducing but principally because on balance the tradeoff in terms of the ease of extravehicular activity is in favor of this particular hatch design.

STRESSES SAFETY OF ASTRONAUTS

Senator JORDAN. Thank you.

In your summary, Dr. Seamans, you said to highlight the discussion of the impact of the Apollo 204 accident, No. 1, it has reduced but not eliminated the probability of a manned lunar landing attempt in this decade.

Secondly, it has delayed the earliest targets for major Apollo Applications program missions; third, it has created changes in fiscal year 1967–68 cost estimates which we are determined to absorb within the current budget request.

Now, I commend you for your frugality, but I just want the record to show that this Senator is interested primarily in the safety of these astronauts. If it ever comes to a tradeoff of safety of astronauts against the extension of time or the expenditure of more dollars, I want to be recorded as being for the safety-first part of it.

Mr. WEBB. I think, Senator Jordan, our policy has been never to try to absorb costs at the expense of the safety of the flight personnel, whether it is in the space program or the flight program. You know, we do a great deal of test flying in airplanes as well as in flight in space. What we are trying to say there, I think, is that we are going to drive as hard a bargain for service with the whole system of contractors and our own in-house capabilities as possible so that we will not have to ask for additional funds.

For another few weeks, while we go through this process of negotiation, no one can tell precisely what the costs will be. But the determination to save those funds is more related to the process of finalizing this plan, which involves a substantial number of millions of dollars and estimates of contractors, with costs in all manufacturing plants in this country going up, as you know, through inflationary and other processes at work in the country.

So the determination is not to absorb it at the expense of flight safety, but rather to do our very best to get the work done within the money now available to us.

Senator JORDAN. And within the time limits which you set?

Mr. WEBB. Yes, sir, but if anything has to give, it will be the time, Senator.

Senator JORDAN. I appreciate that, and I agree with you most heartily.

Mr. WEBB. Thank you, Senator.

The CHAIRMAN. Senator Brooke left. He had some questions. I think we will come back. I would like to provide an opportunity for Senator Brooke to ask his questions.

Mr. WEBB. This afternoon, Senator?

The CHAIRMAN. No, we will find time tomorrow or some other day.

Mr. WEBB. I have promised to go to the House committee at 10 a.m. tomorrow because they have a very substantial interest in this program, also.

The CHAIRMAN. All right, 7 o'clock tomorrow morning? [Laughter.]

Mr. WEBB. Yes, sir. Or this afternoon or tonight.

The CHAIRMAN. Senator Mondale?

DISCUSSION OF PHILLIPS REPORT

Senator MONDALE. Thank you, Mr. Chairman.

I wish to warmly endorse the issue raised by Senator Smith, because as far as I am personally concerned, it is central to the function which this committee and the Congress must perform in relation to the Nation's space efforts. I think the key question is whether we are going to be limited to information which NASA wants us to have or whether we will be provided with the critical information such as the Phillips report which clearly and candidly describes the condition of the space program, not only the success but the difficulties.

I think the experience we have had with the Phillips report is very instructve. On February 27 I asked for a copy of the Phillips report. The response was one of uncertainty as to whether there was such a report. Later on the same question was asked in the House committee, and this document that we now know as a report was referred to by NASA as a series of notes. When the president of North American was asked for a copy of the Phillips report, he said, "I have heard it mentioned, but General Phillips has not given us a copy of any report," and this misleading response was permitted to be uncorrected in the record.

We find ourselves in the position where the Phillips report is now available to the Congress, but it was not provided upon formal request of committee but was obtained through the underground.

The CHAIRMAN. I just want to be sure you are talking about the Phillips report. So far as I know, it has not been made available to Congress.

Senator MONDALE. I have a copy, Mr. Chairman, that I got through the underground.

The CHAIRMAN. You have a copy of a document that was compiled on the basis of the Phillips report as I understand it. You have a document like that [indicating]; I understand the report is one like that [indicating again].

Senator MONDALE. I am not strong enough to carry it, Mr. Chairman. I have 20 pages here.

In any event——

The CHAIRMAN. Are you referring to the disclosure——

Senator MONDALE. Mr. Chairman, I am referring to a series of documents with a covering letter dated December 19, 1965, directed to President Atwood, of North American Aviation, signed by General Phillips, with an attached NASA review report to which were, in addition, attached several feet of documents.

We now know that this is a searching, candid, revealing document which reveals fundamental policy questions, fundamental questions of management. Yet it seems to me that NASA's response, a proper request by a member of this committee, was not responded to, and I wonder if NASA believed it acceptable and proper that this significant report, so fundamental to the space effort, should be obtained only in that fashion?

Mr. WEBB. I will respond to that, Senator Mondale, if you wish.

First of all, we have worked with American industry together through two learning processes, one on the hardware, one on the ability to manage research and development where there was no large-scale production. Our decision has been to have candid and frank reviews, with full cooperation of the contractor and a full and frank presentation by both NASA and contractor personnel to NASA and contractor executives at the end.

It has not been our policy to try to summarize a large amount of data of this kind, because the actions to be taken by the contractor and our monitoring of his success in taking those actions is related to the detailed sections of the review findings and not to an overall criticism.

I, myself, when you asked the question, of course knew of difficulties we had had with North American as we have had with other companies, as I expressed it on that occasion. I did not know that our practice of confining the discussion with the contractor to the specific items that needed correction had also produced an overall strong admonition by General Phillips to the managers of North American with respect to the total operation of the company, although I knew that was a matter at issue.

Now, Senator Mondale, my answers to your questions were as candid as they could be and just as candid as the information available to Dr. Mueller and myself made it possible to be.

I think you are centering on the question of one critical report when the important thing is what happened after that. The process has produced a successful train of improvements in North American which have continued beyond the final board review in April of 1966, which I have commented on here and placed in the record to indicate that the management of North American did get busy and did do a great many things. Then I have indicated that there are matters we will present in executive session that bring that record up to date, showing that North American has constantly improved and that the work package system of management, as incorporated by them at as rapid a rate as they could, has produced a far better system in the factory and has permitted us to give you a program that makes a lunar landing still possible in this decade.

So I think the issue is how the whole system works and not whether one report or one statement will be put on the public record which tends not to give the true picture of what is happening. We are prepared to give you a full and frank statement of all that takes place.

I am not prepared at this time, out of executive session, to present material which can be taken out of context and used to defeat a major forward-thrusting successful effort that now has 350,000 people in it.

I think this is as grave an issue for you and other members of this committee as it is for me. If we have to put in the record every summary of every deficiency on a spacecraft we expect to fly 3 months from now, every day or every week or every month, you are never going to fly that spacecraft, Senator Mondale.

Senator Mondale. Well, I think we do have some problems of balance here. I think the Phillips report is the sort of information that we should have if we are going to do our job here in the Congress. And I think, as Senator Smith has suggested, there is a policy question here. and I hope we can explore it more fully.

Mr. Webb. Then, Senator Mondale, I would suggest that you consider whether the statute restricts you as well as me with respect to the revelation of proprietary information, because there is a statute that restricts you, if you receive this information in the course of your official duty.

The CHAIRMAN. May I interrupt and say we shall just put the statute in the record. I do not quite agree with what you said. A great many lawyers do agree. I am not a lawyer, so I can disagree.

Mr. WEBB. This is the interpretation of my lawyer, Mr. Chairman.

The CHAIRMAN. I appreciate that.

Without objection, it will be placed in the record.

(Title 18, United States Code, Section 1905 "Crimes and Criminal Procedure," follows:)

§ *1905. Disclosure of confidential information generally*

Whoever, being an officer or employee of the United States or of any department or agency thereof, publishes, divulges, discloses, or makes known in any manner or to any extent not authorized by law any information coming to him in the course of his employment or official duties or by reason of any examination or investigation made by, or return, report or record made to or filed with, such department or agency or officer or employee thereof, which information concerns or relates to the trade secrets, processes, operations, style of work, or apparatus, or to the identity, confidential statistical data, amount or source of any income, profits, losses, or expenditures of any person, firm, partnership, corporation, or association; or permits any income return or copy thereof or any book containing any abstract or particulars thereof to be seen or examined by any person except as provided by law; shall be fined not more than $1000, or imprisoned not more than one year, or both; and shall be removed from office or employment. (June 25, 1948, ch. 645, 62 Stat. 791.)

DISCUSSION OF GENERAL ELECTRIC REPORT

Senator MONDALE. In the New York Times a few days ago, as you remember, there was an article by John Wilford reporting on a GE study listing a series of flaws in the Apollo spacecraft being prepared for the unmanned test flight later this year. I was unaware that General Electric was under contract to do this kind of oversight.

Would you describe what their role is in preparing these reports?

Mr. WEBB. This was not an oversight role, Senator Mondale. We are short of certain capabilities. We have a lot of contractors. We contracted with General Electric to utilize its experience to prepare a summary from the records of the contractors as to every deficiency shown that must be overcome before we commit this vehicle to flight. They did prepare such a summary for our management purposes with the other contractors, as well as North American, to give us a full and complete picture of that report.

Senator MONDALE. Was either the Senate or the House committee advised of this function which GE performs?

Mr. WEBB. No, sir; not that I can recall.

Senator MONDALE. At the last hearing with President Atwood, Senator Holland of Florida recommended, I think, in a very wise suggestion, that this committee request NASA to provide copies of these ongoing deficiency reports to the committees, or at least to this committee, so that we might be periodically advised of the frank and candid situation with respect to these matters.

Do you have any objection to——

Mr. WEBB. Yes, sir; I have a strong objection to this, because we have 20,000 contractors, subcontractors and suppliers. We have a tremendous on-going amount of work. No one of these reports is the determining factor as to whether this country is going to succeed on any one flight. They are only a part of the total process which I doubt seriously the members of this committee can take the time to fully understand in relation to those reports.

I think that this will destroy the system that is now giving us success. It will kill the goose that has laid the golden eggs.

I would like to suggest that you consider what you really need to do your work and we will provide it, rather than have you say that you want to look at everything we need to do our work in the executive branch.

Senator MONDALE. How can we request information which is candid and frank if we do not know of its existence?

Mr. WEBB. This is a problem I think we do have to address a great deal of attention to.

ASKS IF NASA HAS OTHER REPORTS

Senator MONDALE. Are there any other reports of a substantial and critical nature other than the Phillips report and the Apollo 204 report and possibly the GE report of which we are not now aware?

Mr. WEBB. Yes, a very large number, Senator Mondale. You would only be able to carry them in a truck, there are so many.

Senator MONDALE. Was one of them prepared by a Capt. Roderick Middleton and issued near or about the time of the 204 disaster?

Dr. MUELLER. The only report I am aware of involving Captain Middleton is one on quality, a quality audit by a quality audit team headed by Captain Middleton and including a number of other members of our NASA staff. This team reviewed the implementation of our quality management system.

The conclusion was that the system was basically sound but that there needed to be improvement in the implementation, and this essentially agrees with the conclusions of the Apollo 204 Review Board.

Mr. WEBB. And Dr. Mueller has stated in his statement this morning the steps we are taking within NASA to provide those improvements.

Senator MONDALE. Was this report by Captain Middleton issued prior to the 204 disaster or after?

Dr. MUELLER. It was issued after the 204 disaster.

Senator MONDALE. Was there an earlier, more critical one issued by him prior to the 204 disaster?

Dr. MUELLER. Not to my knowledge.

Senator MONDALE. If there is one, could I be advised of it?

Dr. MUELLER. Yes.

The CHAIRMAN. The only reason I questioned the report a while ago, Senator, was that I had asked Mr. Webb if he had a set of these and about what it was in shape or volume. I will not try to testify on what he said, but I think he put up his hands about like that for the preliminary and that much for the entire thing [indicating].

Is that right?

Mr. WEBB. That is right. I think it would be very, very unfair for legislators to start reading critical reports without understanding what responsible companies have done to overcome the difficulties referred to.

The CHAIRMAN. Did you offer to make any such report available to any committee?

Mr. WEBB. No, sir; I have offered it to this committee in executive session and to no other committee.

Senator MONDALE. I have no further questions.

Mr. WEBB. I may have to change that statement as of tomorrow, Mr. Chairman, in view of what has happened here today.

The CHAIRMAN. I only want to say that the members of the committee can meet and discuss this if they wish. I would not want to ask for improper information, but anything that we want in executive session, it can be done. Is that correct?

Mr. WEBB. Yes, sir. But I do want to modify my statement to this extent: I offered it in the full context of the situation it pertains to, not as an individual item. I believe the responsibility of the committee is to examine the total situation and understand the true nature of it. It is within that context that I wrote my letter.

The CHAIRMAN. I am trying to make sure that Senator Mondale, or any other member, gets what he needs to explain why the material is not there.

Mr. WEBB. I am trying to keep him from being misled by thinking that one report really tells all the truth about these matters.

Senator MONDALE. I think, Mr. Webb, you are exactly correct when you say that we have a duty to take critical comments in context and that that is not a simple or an unburdensome responsibility in something as vast as the space program. I agree and I accept that responsibility.

But I think what we have ended up with thus far is a situation where we read most of the critical comments that are known to those of you who head the program through the newspapers and not here. I think this is unwise, I do not think the policy is working satisfactorily, and I wish we could come to an understanding for fuller and more candid disclosure, not alone of the success and some of the embarrassments, but also the profound and difficult questions with which you must grapple.

I think we might be of more help to you than you think.

Senator CANNON. Mr. Chairman, further on that, I am really confused now, because my recollection of this so-called Phillips report is that when General Phillips testified before this committee he said he did not make any official report, that he had a group of notes made as a result of his study with the committee, and that, based on those notes, he briefed the members of the North American administration.

The CHAIRMAN. Let me read the statement he made. I hope this is the right one. I do not mean to pick out something wrong.

He said:

> It did not seem to me to be worth the effort to go ahead and finalize as a formal documented report that effort. In other words, it is a fair amount of paperwork and the main value was accomplished by working together with the contractor, by the verbal discussion of the conclusions and recommendations, so it was my judgment that the value of the paper was mainly to turn it over to the company as a set of notes, I did so, he says, on the 19th of December * * *"

He did have a set of notes and he——

Mr. WEBB. Mr. Chairman, General Phillips is here. While I myself have stated that it is not the policy to produce opinion summaries in these matters so much as it is to produce for the company the things that will enable them to make the corrections necessary, in this case General Phillips did summarize, I guess, his very strong views with respect, to the actions that the company should take.

I think he wanted very much to get the full attention of the corporate executives with respect to doing the job that was required.

But he is here. Maybe he should speak for himself.

General PHILLIPS. Mr. Chairman, you have accurately read the testimony that I gave in the last hearing. It said that the paper which was being prepared by the review group was compiled as a set of notes and transmitted to the president of North American with my letter of the 19th of December.

The paper which was transmitted as a set of notes, as the letter indicates itself, was being prepared in previous weeks, intending ultimately to be a report.

It was my decision, as the letter to Mr. Atwood indicated, and my testimony in the last hearing, that the effort required to formalize all of that draft paper into a formal document and report would not be worth the effort and that the purposes of the work with North American had been served in communicating and that the notes would serve that purpose.

So the draft paper in some places carries the word "report," but it was not a formal report.

Senator MONDALE. Would the Senator yield?

Senator CANNON. Yes.

Senator MONDALE. Are we not really just in a semantic waltz here? The fact is that there was a note, a report, a document that was critical and searching and fundamental in character. That is what I want; whether you call it a report or what you call it, that is what we were getting at. That is what NASA knew we were getting at; that is what we could not get.

I do not care what you call it. That is the sort of information I think we should have.

Mr. WEBB. I will respond to you, Senator Mondale, by saying that I decided not to try to provide one letter or one summary, that you call a report and which did have the word "report" on it, apart from the rest of the Phillips material.

I think we would have been subject to more criticism had we provided it, than we would with respect to maintaining the position that we have maintained.

The CHAIRMAN. General Phillips, were you employed by NASA during the time between January 1964 and the date of the accident?

General PHILLIPS. I reported to duty in NASA on January 15, 1964, and have been on duty with NASA since that time.

The CHAIRMAN. You are now the Apollo Program Director?

General PHILLIPS. I am now the Apollo Program Director, sir.

The CHAIRMAN. Did you prepare a report on all these actions being discussed or do you have neither——

General PHILLIPS. I am sorry, Mr. Chairman.

The CHAIRMAN. I probably phrased the question poorly. I mean did you ever prepare a report which you sent to North American on things of that nature, or do you have a series of notes, just attached one after another, in the file? What is the character of this paper?

General PHILLIPS. The character of the paper that has been referred to as a report was the transmittal under a letter which I signed, addressed to the president of North American, dated December 19, 1965, of a compilation of material which had originally been prepared—intended to be a report, and was a collection of notes transmitted on that date to him.

The CHAIRMAN. Have you attempted to conceal that fact?

General PHILLIPS. I have not, sir.

The CHAIRMAN. Thank you.

Senator Young?

Senator YOUNG. And that collection of notes, General, that you transmitted at that time, you labeled as a report, did you not?

General PHILLIPS. My letter to Mr. Atwood refers to an attachment which is a set of notes from the review team. The letter which I signed refers to an attachment as a set of notes.

Senator YOUNG. And that is termed a report, is it not?

General PHILLIPS. That is what has come to be called a report. I think in some respects, as Senator Mondale has indicated, it is a matter of semantics at this point.

Senator YOUNG. Well, did you not say that on one occasion, did you not use the word "report," that you were submitting a report?

General PHILLIPS. I do not recall saying so, Senator Young. My letter to Mr. Atwood clearly refers to an attachment as a set of notes.

Mr. WEBB. Senator Young, you have asked certain legal questions. I think it is a very interesting fact that under the law there may well be a substantial difference between a compilation of notes and the other documents in terms of the company's proprietary information and revelation of data and things of this kind.

I do not know the full answer to this. But the status of this kind of document is not very clear.

Senator YOUNG. Well, as a former trial lawyer, I know that the lawyers for NASA might refer to something in one manner and other lawyers refer to it in another manner and other lawyers reach a different conclusion.

You know that also, do you not?

Mr. WEBB. Yes, sir; I do Senator.

QUESTIONS ON FLAMMABLE MATERIALS

Senator YOUNG. Now, Dr. Mueller, is it not a fact that— now I am referring to your testimony, for example, on page 4—you say that, referring to flammable materials and then the recommendation, there should be stowage of necessary flammables in fireproof containers. Well, the facts are, are they not, that those flammable materials, had ordinary care been exercised, would have been inclosed in fireproof containers from the start?

Dr. MUELLER. Senator Young, we had a set of criteria and a set of specifications upon which material for inclusion in the spacecraft cabin were selected. That set of criteria did not require the storage of such materials, as food, in a fireproof container.

We did, however, store them in such a fashion that fire propagation from point to point was not considered to be a hazard.

Senator YOUNG. But since the time of the tragedy and the examination made following that, was it not determined that ordinary care should really have required the storage in fireproof containers?

Dr. MUELLER. Senator Young, since the accident, we have adopted a posture of extraordinary care and the sets of specifications and the criteria, the guidelines with which we are working, are designed to avoid any possibility of a future accident.

I would say that we had exercised more than ordinary care in every aspect of the development of the Block I spacecraft and that we have taken steps which are extraordinary in their nature as compared to past practices in any other comparable situation.

I think you ought to recognize that the basic design and development of aircraft, for example, does not require the storage of foodstuffs, for example, in fireproof containers.

Senator YOUNG. Well, the committee also has a grave responsibility here and is it not a fact that the North American people, in not having fireproof containers, might be considered to have failed to exercise ordinary care?

Dr. MUELLER. No, sir; I do not believe so.

Senator YOUNG. Well, anyway, you do not mean to say, do you, that by now requiring flammable materials to be put in fireproof containers, that this should be classified as extraordinary care, rather than just ordinary care?

Dr. MUELLER. Sir, we are doing everything that we can think of to avoid a similar accident in the future. We have taken extraordinary steps to assure that. One of the things that we did learn, although I have no knowledge that the combustibles, for example, foodstuffs on board, contributing to the fire, but we have learned a great deal and we are taking steps to avoid any possibility of such a thing in the future.

Senator YOUNG. Well, it appears to me that proper thought had not been exercised; in other words, ordinary care had not been exercised on the part of North American in permitting the egress of the crew in an emergency on the ground.

Dr. MUELLER. Senator Young, that was that tradeoff that we were discussing earlier. The tradeoff that we made at the time of the design of the Block I and Block II spacecraft in favor of being safe in space as compared to the increase, to some extent, of the risk on the ground.

Senator YOUNG. Well, as a matter of fact, if your prime contractor and your officials had been extremely vigilant, it probably would not have been necessary to exercise any so-called tradeoff, is that not a fact?

Dr. MUELLER. No, sir.

Senator YOUNG. That was not determined, was it, before this accident occurred?

Dr. MUELLER. The tradeoff was very carefully considered in terms of the hatch before the accident and has been considered very carefully after the accident. In fact one has always to balance the risks in one of these programs. There is no way of guaranteeing that every risk can be avoided. I do not think that we have eliminated risk from the program.

Mr. WEBB. Senator, I think one very important element here is that we have found in rocketry when something works, it should be used again. We inevitably encounter unknown difficulties when we change. The experience with Mercury and Gemini was basically what we were following here. By hindsight, we should have penetrated more deeply into these questions. But we were using a procedure that had worked for us.

Senator YOUNG. Well, Dr. Mueller, on page 7 of your statement, you said the equipment used by emergency crews and spacecraft technicians has been reviewed. Now, you are referring to the fact that since this tragedy, that has been reviewed.

That is correct; is it not?

Dr. MUELLER. Yes.

Senator YOUNG. Now, as it turns out, it was very unfortunate that that was not reviewed some months ago, before the tragedy; is that not true?

Dr. MUELLER. It is true that a review in anticipation of a fire on the launch pad was not made. However, there was a review, and a careful review, of the equipment on the launch pad in the light of the test procedures expected and in the light of the hazards expected. So that the problem there was the same one that we had with the fire itself, and that is that we did not anticipate that fire.

Senator YOUNG. It appears to me, Dr. Mueller, that there was negligence on the part of North American, on the parts of prime contractors, that contributed to or caused this tragedy. But I am not going to pursue my questioning further at 1:15 p.m., when we have been in session all this time. But I feel that this committee has a responsibility to pursue the matter to determine whether there was negligence on the part of the prime contractor and whether there was inattention on the part of NASA officials, and I think we will do that.

The CHAIRMAN. I probably should announce now that we will adjourn, but I do not want to do it. Senator Brooke is here and we are very anxious to have him ask questions.

Mr. WEBB. Could we have a 2-minute break, Mr. Chairman?

The CHAIRMAN. Yes, we shall take a 5-minute break.

(Recess.)

The CHAIRMAN. Senator Brooke?

QUESTIONS ON NASA'S AUTHORITY TO ENFORCE RECOMMENDATIONS

Senator BROOKE. Mr. Webb, when Mr. Atwood, the chairman of North American, was before the committee last week, the question was asked as to what NASA did to encourage or enforce the recommendations which came from the Phillips task force and there was some doubt as to the authority of NASA in this regard. I have asked for and received from NASA a contract with North American, manned and service module system contract, NAS 9-150, with which I am sure you are familiar, in an effort to determine what provisions of the contract granted what authority to NASA under the circumstances, and it is a very voluminous document. I refer you to page 69 of that contract, article 20, visits to contractor and its subcontractor plants, and this provision, I would assume, is included in other contracts with North American and other contractors.

Mr. WEBB. I do not have the contract before me, Senator Brooke, but in all of these matters, we have retained for the Government the right to inspect, the right to be present, the right to get right at the problem of getting the work done and to participate actively to make sure that the changes necessary in equipment are in fact made before we commit the equipment to flight. So I am sure it is in all of our major Apollo contracts.

Senator BROOKE. Well, now, on this service module system, you had the authority, the right to visit the contractor's and the subcontractor's plant or plants at any reasonable time during the performance of this contract for the purpose of making any necessary inspections or obtaining any program-related information. Prior notification of such visits is to be given to the principal contractor's personnel to minimize interference with normal operation at such plant or plants.

Now, so far as North American is concerned, to your knowledge, was this option, this authority, exercised by NASA during the work done on Apollo spacecraft?

Mr. WEBB. Yes, sir; it was. There was a very intimate and continuing relationship between NASA and North American people. Maybe you would like Dr. Mueller or General Phillips to comment on that, because they were the responsible officials in connection with this contract.

Senator BROOKE. Now, I am not referring to the task force which General Phillips headed. I am talking about the routine inspections which I presume were conducted by NASA periodically in order to avoid the deficiencies which General Phillips ultimately reported.

Mr. WEBB. Yes; but it is important to recognize that General Phillips is the continuing, day-to-day program manager of this effort, of which this contract is a part. So his responsibility is complete, pervasive, and continuous. This particular management review team which he headed and which went out in December of 1965 was extraordinary, an extraordinary effort to overcome difficulties that had accumulated. But his responsibility is continuous.

Senator BROOKE. Then General Phillips must have known about these deficiencies which he found at North American during the course of his study on November 22, I believe, of 1965, when he commenced it, until the first part of December 1965. General Phillips must have known or should have known that these deficiencies did exist. Is that true?

Dr. MUELLER. Senator Brooke, you understand that there is a branch of the spacecraft program office at North American Aviation in residence there. There are also inspectors, quality engineers, and contract administration people furnished by the Department of Defense who actually work on the monitoring of the contract. The actual management of this particular contract is the responsibility of the Manned Spacecraft Center and in particular, of the spacecraft program manager at the Manned Spacecraft Center which at that time was Dr. Shea. We do have a management system, a reporting system that provides visibility to us here in Washington, to General Phillips on a continuing basis, and to the rest of us on a periodic basis, of the progress each of our contractors makes in the program. We have essentially exercised this contractual provision of advising the contractor on a continuing basis, then, by various elements of the NASA organization.

Senator BROOKE. Dr. Mueller, what is difficult for me to understand is how these accumulated deficiencies existed when there were periodic inspections made under the supervision of General Phillips. Now that Mr. Webb has said that General Phillips had the overall responsibility to make periodic inspections under the terms of this contract, then it would seem to me that had these inspections been made with the degree of efficiency that we would expect of General Phillips, of course, you would not have had the accumulated deficiencies which the task force found in its investigation from November to December of 1965.

Dr. MUELLER. Senator Brooke, may I try to answer that, because it becomes an important part of the management of these programs. In particular, there was visibility that progress was not being made on a day-to-day basis. Each day, the work that needed to be done that day was not being accomplished and we do manage and do keep track of this progress on each of our contractors. Now, on the other hand, the contractor is responsible for the delivery of the spacecraft. We, in turn, are monitoring these activities. We are not, however, directly responsible for supervising his everyday's work. That is his problem and his job. It is essential that the contractor have some freedom to perform his task without over-supervision by the Government. That contract does provide essentially for the contractor to have the proper amount of freedom to accomplish the objectives of the program.

Senator BROOKE. That I can understand, Dr. Mueller, and would you answer this question: How frequent are these periodic inspections that General Phillips performs? I can understand from what you said that NASA is not going to be there on a daily basis, perhaps even a weekly basis. I would like to know how frequently these periodic inspections were held?

Frankly, when I read the letter which General Phillips addressed to Mr. Atwood, it appeared to me that General Phillips was somewhat shocked by the conditions that his task force had found during the conduct of their investigation. If you tell me that General Phillips was making periodic inspections, it would appear to me that General Phillips would have been forewarned, that he was well aware that these conditions were going on in North American when these conditions could not conceivably have come about overnight.

Mr. WEBB. Let me say one word here, Senator Brooke. I think it is quite important for you to recognize that we do not rely on that provision of the contract for our inspections in the sense that we are inspecting work. We rely on the clauses of the contract that give us a specific right to inspect for quality control, for reliability, and for monitoring the testing of the contractor and the test results. The procedures established pursuant to these contract provisions are designed to inform us and the contractor whether the equipment will meet the requirements for the next stage of manufacture.

The right to visit, the right to inspect, is obtained so that we can bring in others to aid us if we have problems with associating the contractor's equipment with some other equipment; it is not basically that contract provision we rely on to make sure that the contractor does his job. In 1965, we saw the contractor building up a large work force, trying to get spacecraft designed, trying to train people to do all of the work, and struggling very, very hard to build up a large organization that would ultimately build flightworthy spacecraft. The early spacecraft were not planned to be flightworthy spacecraft. They were to be various items for tests—building up to the point that you had enough competence to build a flightworthy spacecraft. As we saw the contractors struggling with these problems, we saw them beginning to fall behind. At a point in time, we could not see how they could work out of their difficulties. They were slipping further behind. Therefore, we had to take action. We were aware of the continuing state of the work and of the problems.

DISCUSSION OF PHILLIPS REPORT

Senator BROOKE. Mr. Webb, that is informative, and I thank you, but it is not responsive, frankly. Maybe I should ask this of General Phillips, since he was in charge of the task force and he also made the periodic inspections.

General Phillips, did I misinterpret your letter to Mr. Atwood? Were you not shocked or did you have prior knowledge that these deficiencies were building?

General PHILLIPS. I had prior knowledge that these deficiencies were building and that is the reason I put together a task force to spend the time at the plant necessary to go into detail to find out what were the underlying problems that were affecting progress.

I think that one of the points we are missing here is the fundamental program management process that has to go on between government and industry. We have built in the NASA Apollo program, I think, a good organization that is designed well to carry out the job. The job is a very large one so there are three large NASA field centers involved in the direction and execution of the major parts of the equipment development and the preparation of facilities for launching. In the case of the spacecraft, the Manned Spacecraft Center at Houston is responsible for the day-to-day direction and the day-to-day management of the contract activities with the space craft contractor and consequently, is responsible for keeping me informed on a daily and weekly basis of the process and problems. That process was working well.

We have in addition a resident office located in each of our major plants that reports to the particular manager concerned. So there is a resident office and has been for some years at the Downey plant of North American. They, in turn, report on a daily and weekly basis to the spacecraft program office at Houston.

There is a pattern of monthly meetings where the progress of the project is reviewed by the spacecraft program manager with the contractor. It is my practice to travel as much as I can and to visit all of our major plants fairly frequently. I have visited the North American plant in California, in the 3 years that I have been in this program, eight to 12 times a year, depending on the general situation. It was in the fall of 1965 that the general situation was not developing as rapidly as far as progress is concerned as I thought necessary to insure the solid progress of the program. Our work with the contractor in that fall and in the succeeding spring satisfied me that the fundamental problems that were hindering progress recently were being satisfactorily taken care of. I think events up through the balance of 1966 indicated that that was so, because to use my words, the program was turning a corner and we were starting to get our equipment into shape to fly.

Senator BROOKE. General Phillips, let me first say that I personally am very much impressed by your report and by your letter to Mr. Atwood and by your recommendations. Certainly my questions are not intended in any way to question your ability or your dedication as far as this program is concerned. But I wish you would direct your remarks to the question that I did raise as to how the degree of deficiency which prompted you to recommend and to form a task force and resulted in such startling findings as were made by your task force were able to develop if the regular procedures for inspection—not perhaps at your level, but at other levels—the workings between NASA and North American, were properly conducted?

General PHILLIPS. I have said it was my view in the fall of 1965 that it was necessary to make an extraordinary effort to find out what it was that was underlying, that was causing difficulty in getting the progress we required. It was not my judgment alone, but that of our organization, including the management at the Manned Spacecraft Center and at the Marshall Space Flight Center, which has the responsibility for the S–II stage, and of my superior, Dr. Mueller, that an extraordinary effort was required to try to look below the surface and see if we could find out what it was that required perhaps extra ordinary attention and effort to insure more rapid progress in the months ahead than we seemed to be making in the summer and fall of that year. So it was a recognition, not by me alone, but of the responsible management organization, that more than the normal effort was required. We were aware that we had a problem and more than normal attention and effort was required, in our judgment, to get at the problems and get moving with the program.

Senator BROOKE. General Phillips, again, that is informative, but I respectfully suggest it is not responsive. Do you or can you say where the work or the inspection was not properly done which allowed this buildup of deficiencies which prompted this task force formation?

General PHILLIPS. Senator Brooke, I believe that our organization was doing its work well.

Senator BROOKE. That NASA was doing its work well?

General PHILLIPS. Yes, and that is why we were able, at the levels involved, to achieve the requisite corrections and progress.

Senator BROOKE. Would you change the procedure now, looking at it from hindsight, for inspection?

General PHILLIPS. I do not believe so.

Senator BROOKE. You do not believe so?

General PHILLIPS. It was not inspection, Senator, that was the problem in my view.

Senator BROOKE. Well, quality control, as well as inspection, would you change that procedure now, from hindsight? Could it have been avoided? Could these deficiencies which built up to the point that you felt that drastic action should be taken in November of 1965 be avoided with better inspection methods and techniques?

General PHILLIPS. I believe that our inspection organization and techniques are adequate and satisfactory.

Another point that I think——

Senator BROOKE. Then we could have the same conditions existing in 1967 that existed in 1965?

General PHILLIPS. My point is that we knew we had a problem. We went out and studied that problem and took action and the contractor cooperated fully and took action in response to our recommendations.

Senator BROOKE. But when you took action, it had already reached the crisis stage, almost, had it not?

What action was taken prior to this time, the time that you reached what I have described as the crisis stage? What action was taken prior to that time in correcting things regularly so as to avoid this necessity of a combat task force type of operation?

General PHILLIPS. Senator Brooke, I do not regard the situation in December as a crisis. I think that is an overstatement.

Senator BROOKE. I think you could stop there, General Phillips. Your language is of a crisis nature, I would suggest, unless you just write very strongly. I do not want to characterize your language, but it was very strong language; and it seemingly was obviously sent from a man who had very strong convictions that something was wrong and needed correction and you wanted to see it done, for which I have applauded you.

Now, I do not think you ought to soften that language. You would not change that letter, would you?

General PHILLIPS. No, sir.

Senator BROOKE. You meant it then and you mean it now. Is that right?

General PHILLIPS. It was accurate at that time and I would not change it.

QUESTIONS ON TERMINATION OF CONTRACT

Senator BROOKE. Mr. Webb, there is no place in the contract that I find that provides for termination of the contract. How is a contract terminated?

Mr. WEBB. It is in the contract. You can terminate for convenience of the Government and for default on the part of the contractor.

Senator BROOKE. Can you terminate for cause?

Mr. WEBB. Yes.

Senator BROOKE. The Government can terminate with North American at any time they find their work was not up to standard?

Mr. WEBB. If that turned out to be in the best interest of the Government. It had the power to terminate.

Senator BROOKE. That is what I am asking.

Mr. WEBB. Yes, sir; the power existed to terminate this contract from the first day it was signed.

Senator BROOKE. Is that power vested in you as head of NASA?

Mr. WEBB. Yes.

Senator BROOKE. And you did not feel, after the Phillips report, that you should terminate that contract?

Mr. WEBB. No, sir; I did not. I felt that this company was trying hard to get on with the things that needed to be done. The trend of many, many inspection results was not being followed as carefully as it should have been by North American management, in my opinion. We directed their attention through these strong actions to the fact that the trend was going in the wrong direction. They put strong efforts in and got the trend moving in the other way.

Senator BROOKE. Even the dedication of the company was questioned, was it not? It was more than trends that you speak of now?

Mr. WEBB. The dedication to follow the trend and get the job done was not sufficient. I have never believed that the dedication of the company to get the job done was not there.

I do want to say one thing that is very important, Senator Brooke. In these recent negotiations over the last week that I have had with the best companies in the United States, they have each one of them asked in his mind, what reports by General Phillips did they have on the Minuteman? Two companies told me they had reports in their files worse than the ones they had seen in the paper about North American. The process of getting this work done is extremely difficult.

Senator BROOKE. You made that point and I have heard Mr. Atwood say this and I have heard you say it, that work was coming in so fast—I do not want to misquote Mr. Atwood, but he gave me, at least, the impression, Mr. Chairman, that work was coming in so fast that these deficiencies were understandable if not unavoidable. Well, it seems to me, if I may finish, that if the work was coming in faster than North American could take it, then they should have, as most companies would do under those circumstances, say "I just cannot take any more work, you perhaps ought to give the contract to another company, we are overburdened, we do not have the personnel, we do not have the scientists, we do not have the technicians, do not have the mechanics, do not have the supervisors," whatever else they were lacking. It seems to me that this is not an acceptable excuse for the deficiencies found in North American merely to say that we are moving at such a fast pace that we did not have time to do this thing correctly. If they did not have time, they should have stopped. If they did not stop, they should have said to you as the head of NASA, give this next contract someplace else. North American was No. 1 in 1965, No. 1 in 1966 and it is No. 1 in 1967 in so far as contracts awarded by NASA are concerned. And we are talking about big money, there is no doubt about that, as I am sure you are aware.

It seems very difficult for me to understand how, when you knew about all these deficiencies and lack of dedication, et cetera, and I shall not go into them, well, I think condemning in some of the language that I have used, even though I have used the word "crisis" it seems to me that perhaps contracts would not have been awarded to the degree or the extent that they were in 1966 and 1967. That brings me to my next question.

When were these contracts awarded?

Mr. WEBB. Senator Brooke, the work in 1966–67 is follow-on work on very large systems.

Senator BROOKE. So the contracts were awarded sometime in the past?

Mr. WEBB. Yes, sir; and they have developed the engineering, the capability, the jigs, the fixtures, the factory capability, and the test facilities.

Senator BROOKE. Are you saying that when we appropriate money now for fiscal 1968, this money has already been spent and we are just paying off the bills?

Mr. WEBB. No, sir.

Senator BROOKE. Suppose we did not appropriate this money. Would you then not be able to enter into a contract?

Mr. WEBB. We simply would not be able to continue the work under the existing contract.

Senator BROOKE. But the contract is already in existence.

Mr. WEBB. This is again a matter that will have to be negotiated out with respect to this changed pattern that I have stated here today.

The thing, I think, that is very important is if North American had not responded after the December 1965 operation, we would then have proceeded to either cancel the contract or find some other way to get the work done. It was their response that led us to continue and the record has been better ever since, Senator Brooke.

COMPARES FINDINGS OF PHILLIPS TASK FORCE AND APOLLO REVIEW BOARD

Senator BROOKE. Mr. Webb, I went very closely over the findings of the Phillips task force and compared those findings with the findings of the Apollo Review Board. In some instances—and I shall not go over all of them; they are very lengthy, Mr. Chairman—but in some instances, too many instances in my humble opinion, the same findings that were made by General Phillips' task force were made by the Apollo Review Board, which indicates to me that these conditions had not been corrected from the time that General Phillips reported on them, which was in December of 1965, until the Apollo Review Board made its findings in 1967, more than 2 years.

Now could you explain that?

Mr. WEBB. Would you permit Dr. Mueller to?

Senator BROOKE. Certainly.

Dr. MUELLER. Senator Brooke, I think that one of the basic problems that is associated with any document is a clear understanding of what is behind it. In particular, there are continuing problems in any program, the actual person soldering a wire, learning how to do it every time exactly the same and perfectly. It is this learning process that is the heart of the research and development process itself.

Now, if you go back to those reports, if you compare word for word, you will find that there are quality defects involved in the spacecraft. There was that socket wrench, you will remember. That was a quality goof. That was not the same quality goof that occurred or was picked up by the Phillips group. As a matter of fact, we were able to trace back where that socket wrench came from. It came from a new group down at the Cape who were carrying out some maintenance work on this particular spacecraft in October or November of 1966—a different group, a new group learning how to do the work.

The problem is that these documents are snapshots at a particular time across the program. The snapshots of the Apollo Review Board show one set of things that happened across the whole of that Block I spacecraft down at the Cape. Another snapshot was what Sam Phillips' group took across this whole Command and Service Module and the S–II stage.

In detail, those things are different. They are new people learning how to do the job at each of our locations. You will find, as we go through this process of building up equipment, that each company and each individual has had to learn how. Down at the end of this vast group of 300,000 people, there is someone who is soldering wires and he has to learn how to solder properly and the inspector has to learn how to catch the problem if he does not solder it properly. What you are seeing here, in the eyes of the Board, is a different view, the view primarily of the Cape activities that followed a year later, the activities that Sam Phillips was reviewing out at the manufacturer's plant.

Senator BROOKE. Then I take it that your answer that the similarity in deficiencies found in the two reports is not valid. Is that correct?

Dr. MUELLER. My answer is that they are referring to different times, different places, and are not, therefore, related on a one-for-one basis. They describe phenomena that are similar.

Senator BROOKE. And you believe that North American has corrected all of the deficiences that were found by the Phillips review or task force in 1965?

Dr. MUELLER. It is my belief that they have done a remarkable job of improving their operations. I do not think that they or any other of our contractors have corrected all the deficiencies in the production of this rather complex order. You only have to look at some of our experiences in other parts of the program to realize that.

Senator BROOKE. And you are satisfied with the progress that they are making in correcting the deficiencies that were found by the Apollo Review Board?

Dr. MUELLER. We believe that they are taking the appropriate steps that will assure us of safety in the future.

Mr. WEBB. And they have undertaken, Senator Brooke, to make quite substantial changes in the way they provide visibility for themselves and for us in any future work as we negotiate the future arrangements. They have undertaken this very clearly as a deep and dedicated action on the part of the officials of that company.

Senator BROOKE. Just for the record, what citation of the clause provides for termination of the contract? Do you have it?

Mr. WEBB. I do not. We can give it to you before——

The CHAIRMAN. Title XVIII, section 1905.

Senator BROOKE. The chairman has supplied it.

I thank you, Mr. Chairman.

(See p. 544.)

Senator BROOKE. Mr. Webb, can you answer, if you have any way of knowing, how much additional money was used because of the deficiencies part of the contract?

Mr. WEBB. I do not think we have a way of knowing this precisely, Senator Brooke; I really do not.

Senator BROOKE. Let me pinpoint the question. For example, in General Phillips' report, there was a reference to hardware being turned out with thousands of hours still left for total completion, which meant that some money had to be spent in completing this hardware. Now, was this additional money that NASA had to spend, or was the contractor charged for this, or how have you handled it so far as the financial transactions are concerned? Generally, when the product has not been up to the standards established by NASA?

Dr. MUELLER. Senator Brooke, this particular work was being done under an incentive contract. Under these contract provisions, the contractor was penalized for not producing either on schedule or within the cost budget or within the performance limitations that we have established. In fact, the contractor was penalized for failing to meet the goals that we have set.

Mr. WEBB. But I think, Senator Brooke, also, the question is whether the work is to be done at Downey or after it is shipped to the Cape. Part of this statement that you just read results from our desire to get the work done at Downey before it comes to the Cape. The work would have had to have been paid for in either place. We think it could have been done more efficiently at the plant and wanted it done there to avoid congestion at the Cape.

Senator BROOKE. More efficiently and less expensively also?

Mr. WEBB. Yes, sir.

Senator BROOKE. What was the penalty?

Dr. MUELLER. This was in fee and I do not have the exact figures, Senator Brooke. In fact, we are in the process of negotiation.

Senator BROOKE. Is it a percentage of the contract price or the cost price of a particular product?

Dr. MUELLER. It is a percentage of the fee that he can earn.

The CHAIRMAN. Senator Brooke, I was in error in my answer when you asked for the citation. It will go in the record.

Senator BROOKE. I complimented you too soon.

The CHAIRMAN. You surely did.

Senator BROOKE. Would you give us the citation?

Mr. WEBB. Yes, sir.

(The citation referred to follows:)

The Termination clause for contract NAS 9-150 between the National Aeronautics and Space Administration and North American Aviation, Inc. for the command and service module was incorporated into that document by reference from the Basic Agreement between that company and this agency, NAS w-302. It was the standard Termination clause from NASA Procurement Regulation 8.702, in effect at the time Basic Agreement NAS w-302 was negotiated, and was made a part of the contract in Article III (a) of NAS 9-150.

NORTH AMERICAN PRIDE PROGRAM

Senator BROOKE. Apparently, North American was in error itself when it instituted its PRIDE program. When was that PRIDE program instituted? Do you know, General Phillips?

General PHILLIPS. The PRIDE program was in operation when I came into this program in January of 1964. How much before that they instituted it, I really do not recall.

Senator BROOKE. And you were critical of the PRIDE program also?

General PHILLIPS. I was.

Senator BROOKE. Only because it was not getting the desired results?

General PHILLIPS. I felt that the PRIDE program, which was a North American innovation of their own to motivate good work, was fundamentally a sound program and that with management support and with the exploiting of the potential of that program, it could help produce results. The company agreed and got behind it and it did start to work a lot better.

Senator BROOKE. Is it still in progress at the present time?

General PHILLIPS. It is.

Senator BROOKE. I have one final question of General Phillips.

After you sent your letter to Mr. Atwood, did you have a meeting with Mr. Atwood at which time you discussed your findings and recommendations?

General PHILLIPS. I met with Dr. Mueller and Mr. Atwood and there were other members of both organizations present on the 19th of December and we discussed—I gave them a briefing, as did other members of my team, on what we found and what we recommended be done. That was one meeting.

Senator BROOKE. That is the date of your letter to——

General PHILLIPS. It was on that date, sir.

Senator BROOKE. The same date?

General PHILLIPS. Yes, sir; the 19th of December. I have met subsequently with Mr. Atwood on a number of occasions. In my previous testimony, I indicated another formal meeting, where I and other members of my team met with Mr. Atwood and Dr. Mueller again on April 22, as I recall. So those are two formal meetings. But I have met with Mr. Atwood on more occasions than that.

Mr. WEBB. There was a formal review between the 22d and 27th of April, over a period of time, in which a full presentation was given by the company as to the progress it was making. This was represented by the six volumes that the Chairman indicated the size of. The company did cover fully all the things they had done in the meantime, Senator Brooke.

Senator BROOKE. I was primarily interested in that December 19 meeting which you say you were present at, Mr. Atwood and other members of your staff were present. And you did discuss the recommendations and your findings at that time?

General PHILLIPS. Yes.

Senator BROOKE. I have no further questions.

The CHAIRMAN. Mr. Gehrig has a great many questions which I have asked him to present to you.

Mr. Webb, will you carefully consider Mr. Gehrig's questions and put your answers to them in the record?

Mr. WEBB. Yes, sir.

(Questions submitted by Mr. Gehrig and answers supplied by Mr. Webb for the record are as follows:)

QUESTIONS ON CONTRACT NEGOTIATIONS

Question 1. Mr. Webb, in your statement you say that the Boeing Co. will be given responsibility for the integration of the Apollo Command and Service Module and the Lunar Module to the Saturn V launch vehicle.

Who was to have the responsibility for this prior to this arrangement with Boeing?

Answer. The Boeing Company, being responsible for the first stage of the Saturn V launch vehicle, has had the systems integration function for the launch vehicle (first, second and third stages and the instrument unit) portion of the Saturn V/Apollo system. Original planning called for a similar responsibility to be given to North American Aviation for the spacecraft portion (command module, service module, lunar module and spacecraft/LM adapter) of the total system, since they have contractual responsibility for the major portion of these systems. We never did let the contract go to them because we were not satisfied that they were prepared to take over this function. We were considering whether or not we could develop this capability in our field centers, i.e., in our in-house laboratories, but we have decided since the fire to ask the Boeing Company to do it.

Question 2. Mr. Webb, in your statement you say a third contractor will be selected to make all modifications to standard Apollo vehicles.

Does this include both launch vehicles and spacecraft?

Answer. No. This is only for the spacecraft.

Question 3. Mr. Webb, at the time of the Apollo 204 accident you had a letter contract with North American for the Command and Service Modules, but you were negotiating a definitive contract.

Is that negotiation complete?

When will there be a definitive contract between North American and NASA for the Command and Service Modules?

How will the accident affect the incentive provisions of the contract?

Answer. It is true that at the time of the Apollo 204 accident North American was providing command and service modules under a letter extension to a cost-plus-incentive-fee contract most of the features of which had expired on December 3, 1966. The accident halted negotiations which were underway for a contract modification to extend the CPIF contract from December 3, 1966, to to the end of the program.

Negotiations will be initiated shortly to close out the existing contractual arrangement and to enter into an agreement for standard command and service modules required in the Apollo/Saturn manned lunar landing program. Until these negotiations are completed we cannot answer when there will be a new definitive agreement between North American and NASA for the command and service modules; nor can we answer to what extent the accident will affect the incentive provisions of the contract.

QUESTIONS ON CHANGES FOLLOWING ACCIDENT

Question 4. Dr. Mueller, what changes in the Lunar Module are planned as a result of the Apollo 204 accident?

How much time is required to accomplish these changes and what is the cost impact of the changes?

It is understood that the Lunar Module program is now behind schedule.

Is this slippage due to the accident or to other causes? If the latter, what are the reasons for the slippage?

Answer. 1. The first Lunar Module, LM–1, is presently undergoing factory test and checkout at the contractor's plant prior to delivery to Cape Kennedy for a flight on an uprated Saturn I. LM–1 will be flown unmanned to demonstrate the propulsion systems and the flight control systems of the lunar module prior to manned flight. Since this is an unmanned vehicle, it will never be exposed to a pure oxygen atmosphere; instead, air will be used in the cabin for all ground checkout and for flight. In view of the fact that this vehicle is unmanned and will never be exposed to an oxygen atmosphere, only those changes necessary for safety of the checkout and launch crews has been made to this vehicle to allow the earliest possible flight date.

The subsystems that will be demonstrated during this flight are:

a. Descent propulsion system.
b. Ascent propulsion system.
c. Reaction control subsystem.
d. Primary guidance and navigation system.
e. Control electronics system.
f. Communications systems.

The safety of the systems to be utilized on this vehicle will have been demonstrated during the ground development and qualification tests which will be conducted prior to the time of this flight.

2. Another lunar module, LTA–8, (the LM thermal vacuum ground test article), is in the process of being tested at the factory prior to delivery to the Manned Spacecraft Center for thermal vacuum testing in support of the first manned LM flight. The specific changes being made to this vehicle as a result of this review resulting from the 204 accident are as follows:

a. *Mechanical:*

(1) Hatch—Replace the forward hatch with a ground test hatch which can provide an open crew egress path in 10 seconds or less.

(2) Pressure Relief—Provide a means for rapid equalization of cabin and chamber pressures.

b. *Electrical:*

(1) Ground Test Wiring—Inspect and modify all wiring associated with ground test heaters and supplemental instrumentation required for thermal vacuum testing to assure flight quality fabrication and installation.

(2) Power Interlocks—Remove all non-critical power, including heaters and special instrumentation, whenever emergency chamber repressurization is activated. Provisions shall be made to assure voice communications and cabin lighting under these conditions.

(3) Electrical Connectors—Assure that design and procedures are such that all power is removed from electrical connectors before making or breakng.

c. *Non-Metallic Materials:*

(1) Nylon Debris Netting—Do not install.

(2) Polycarbonate Shields—Do not install.

(3) Nylon Velcro—Do not install.

(4) Cable Lacing—Replace harness lacing with non-flammable spot ties when required.

(5) Potting—Determine accepability of potting materials. Cover with fireproof material or replace, as required.

(6) Window Glare Shields—Do not install.

(7) Glycol—Document glycol spill history. Reclean spill areas to assure no residue.

(8) Thermal Blankets—Add inner H-film layer on blankets not having it.

(9) Stowage Bags—Replace nylon bags with acceptable material.

(10) Binding Tape—Replace nylon tape with acceptable material.

(11) Restraint Harness—Replace Dacron harness with acceptable material.

(12) ECS Wicking Material—Replace plastic foam in water separator and heat exchanger with acceptable material.

(13) Splice Sealant—Investigate flammability of splices as installed. Cover with fireproof material or replace, as necessary.

(14) Panel Overlays—Investigate flammability of panel overlays as installed.

After incorporation of these changes, LTA-8 will be subjected to a thorough thermal vacuum test program at the Manned Spacecraft Center to demonstrate the adequacy of the lunar module systems to function in a thermal vacuum environment, allow an evaluation of the overall vehicle thermal balance for different operating conditions, and develop detailed procedures to be used during the checkout of flight vehicles at Cape Kennedy.

3. A Design Review of the entire lunar module is being conducted to determine its adequacy of meeting its mission requirements and in particular, to assure that adequate fire protection exists for both ground tests and flight operations. The areas being reviewed are similar to those being reviewed for the command module, namely:

a. Spacecraft materials.
b. The environmental control system.
c. Electrical power system.
d. Fire extinguishing systems.
e. Adequacy of rapid cabin egress capability (for ground tests).
f. Spacecraft communications systems; and
g. Preflight and flight operational procedures.

In addition to conducting these studies on the lunar module, the results of all similar studies and ultimate changes for the command and service module will be reviewed for their applicability to the lunar module. As a result of that review conducted to date, many of the changes being made to the LTA-8 are being made to the flight LM's. As the conclusion of the LM design review, all those modifications appropriate to the lunar module will be incorporated and the adequacy of these modifications to produce satisfactory flammability characteristics will be demonstrated by the conduct of tests on a boilerplate replica of the crew compartment with the interior materials installed. The contractor has been instructed to design and fabricate the vehicle required for this test.

B. Time required and cost impact required to accomplish these changes is expected to be about two weeks for LM-1 and 3 and 4 months on LTA-8 and the early manned vehicles, with the impact gradually diminishing to a minimum of two weeks on the last two vehicles delivered.

The $40 Million is an estimate of the cost of the changes for the Command and Service Module and the Lunar Module. This estimate covers a large number of specific modifications to sub-systems and components which have not, as yet, been negotiated with the contractors. The major specific modifications to be made are as follows:

(1) All cabin materials have been reviewed for flammability characteristics and appropriate changes will be made. This will include both substitution of new materials and re-arrangement of materials to inhibit fire propagation.

(2) A manually operated, quick release, one-piece hatch will replace the hatch used on Apollo 204.

(3) The spacecraft communications systems will be improved.

(4) The option to use air in ground tests, rather than pure oxygen, will be provided by modifications to the Environmental Control System. The plumbing required for the oxygen lines will also be improved. Fire hazards in the ECS system will also be either removed or protected.

(5) A number of other changes intended to provide increased fire protection and enhanced reliability are also included.

C. Other Program impact: Although there is a LM program impact resulting from changes required due to the 204 accident, as documented in paragraph 2, there was some schedule degradation in the LM program at the time of the accident. In the case of LM-1, this schedule delay could be as much as 6 months. This schedule degradation is attributable to first article delivery problems which are usually experienced on complex R&D programs such as:

a. Development of test and checkout procedures together with that personnel training necessary to accomplish these procedures efficiently,

b. Development testing of propulsion and environment control system components.

Question 5. Dr. Mueller, have you accepted and acted on all of the recommendations of the Apollo 204 Review Board?

Answer. My prepared statement detailed the actions taken or in process by NASA on each of the 204 Board recommendations.

Question 6. Dr. Mueller, on page 2 you speak of materials "that are in fact self-extinguishing once ignited."

Would you discuss a little bit more fully what is meant by the phrase, "self-extinguishing once ignited"?

Answer: All non-metallic materials for use in the spacecraft cabin must not spontaneously ignite at temperatures below 450°F. Thus, combustion can occur only if there is a coincidence of an ignition source and a combustible material. One of the goals of the material selection process is to select materials which will not propagate a fire if ignited and which will not continue to burn once the ignition source is removed. The term "self-extinguishing once ignited" means simply that if ignition occurs, a fire in the material will not propagate but will go out of its own accord once the ignition source is removed. Teflon of moderate thickness is an example of a self-extinguishing material even in an oxygen environment.

Question 7. Dr. Mueller, in your statement you say:

"Initial selection in terms of guidelines (for nonmetallic materials used in the spacecraft) will be made by the spacecraft contractor and approved by the spacecraft project manager at MSC."

Is the spacecraft project manager referred to here the same as the Apollo program manager at that center?

Who is that?

Answer. Yes, the individual referred to is the Apollo Program Manager at MSC. He is Mr. George M. Low.

Question 8. Dr. Mueller, in your paper you discuss the new hatch for the Block II spacecraft.

What is the estimated egress time of the 3-man crew?

Answer. The estimated egress time of the three man crew is approximately 45 seconds. This number, of course, is dependent on the training of the crew and the type of test under study. For a well trained crew participating in a fast egress test, the time to egress can be substantially less than this and perhaps as low as 25-30 seconds.

RESPONSIBILITY FOR ACCEPTABLE CONTRACT PERFORMANCE

Question 9. General Phillips, from testimony before this committee it appears that contract performance by North American Aviation on the spacecraft was deteriorating for possibly 18 months before you began your review in late 1965. Was the Manned Spacecraft Center responsible for assuring acceptable contract performance? If not, who was?

What action had been taken prior to the Phillips study to correct the deficiencies?

Who took this action, and why was it not effective?

When were you first formally advised that North American was deficient in contract performance in several areas in the development and production of the Apollo spacecraft?

Did MSC request headquarters assistance in upgrading North American's performance at this time?

Did you consider that MSC had done a competent job of administering contract performance and had exhausted all remedies available to it before requesting headquarters assistance?

Why was MSC unable to obtain the desired level of performance from the spacecraft contractor, North American Aviation?

Are you now satisfied with North American's performance on the spacecraft contract?

Answer. Yes, the Manned Spacecraft Center was responsible for assuring acceptable performance under the contract with North American Aviation for the command and service module and for drawing in other NASA offices to help as needed. The Apollo Spacecraft Program Office at MSC was the office of that center directly concerned with such performance.

The program offices at the Marshall Space Flight Center (on the SII Stage) and the Manned Spacecraft Center (on the CSM) had been acting to assure acceptable contract performance at the Space and Information Division of North American Aviation since the inception of the program. The various functional elements of these centers had taken such action to correct deficiencies as were appropriate to their areas of responsibility; including actions on matters indicated as needing attention at the many regular design, financial, and management reviews. In addition special actions were taken concerning problem areas. While these actions often produced results, it became apparent in the fall of 1965 that rather than a series of isolated matters, the problems were symptomatic of management deficiencies inherent in the North American structure. The two centers were capable of coping with the functional problems; however, because in this instance corporate management deficiencies were involved, overlapping two programs, it was necessary for the cognizant NASA Headquarters office to join with the two center offices to deal directly with the contractor.

Under the management's reporting system of the Apollo program, information regarding the contractor's performance is continually furnished to the Headquarters Apollo Program Office by the centers involved in administering the contract. In the summer and fall of 1965, based on our continuing analysis of these reports, we saw that the problems being experienced by North American regarding increased manpower, increasing costs and schedule slippage were not being satisfactorily resolved by NAA management. Therefore, there was no single specific time when I was formally advised of these deficiencies but these deficiencies became apparent through our analysis of the information received through the normal reporting systems from the two centers.

As I stated in the above paragraph there was no single formal notification as such of the deficiencies in the contractor's performance; and there was no specific formal request by MSC for assistance. The decision to organize the task team evolved out of discussions between the Headquarters Apollo Program Office and the Houston Manned Spacecraft Center and the Marshall Space Flight Center at Huntsville. The management at MSC, therefore, agreed with the analysis of the NAA deficiencies and participated in the decision to organize a team to look into the problems of the spacecraft and those of the SII stage.

In my view, MSC had done a competent job in administering the contract, but the net results of its efforts on the very difficult technical and management problems involved, and the conduct of the work by NAA, were not satisfactory from the standpoint of progress in accomplishing the objectives of the program. The efforts of the center could not in any case be fully effective until the deficiencies in the North American management structure were corrected.

The Headquarters Apollo Program Office is not fully satisfied at the present time with North American's performance on the spacecraft contract, but the trend of improvements such as the recent management changes in its new Space Division and increased responsiveness to its obligations to NASA give confidence that the program objectives can be accomplished. We will have a more firm basis for judgment as we measure the progress made in accomplishing the changes necessary to manufacture and test the Block II spacecraft; and as we proceed with the negotiations that will establish whether NAA has a clear understanding of what NASA will require in the future.

FIRST SATURN V LAUNCH

Question 10. Dr. Seamans, you say, "The first Saturn V is scheduled for launch this fall." This flight was scheduled earlier to take place this spring.

Why was it delayed?

Answer. The primary reason for the delay of the first Saturn V launch was the Apollo 204 fire.

As a result of the Apollo 204 fire, new, more rigorous criteria were developed for the CSM 017 (the spacecraft for the first Saturn V flight) inspection. Inspections by both the contractor and NASA, and rework required to correct the deficiencies revealed by these inspections, were the main cause for the delay of this launch.

Question 11. Dr. Seamans, on page 495 you have identified $75 million of additional costs to the Apollo program through fiscal year 1968. You have indicated that $25 million of this will be made up from a lower than planned level of mission operations.

Would you please explain for the committee in a little more detail where it is you expect to make up the unaccounted for $50 million?

Answer. During recent months launch vehicle contractors have made excellent progress in production and checkout of the various stages and have demonstrated an ability to control costs so as to achieve or surpass the objectives established in our incentive contracts. A careful review of the current status of the launch vehicle effort leads us to believe that we may be able to accomplish this portion of the program with FY 1968 funding requirements approximately $50 million below the amounts contained in the budget, although the margin for unforeseen problems will be reduced.

Question 12. Dr. Seamans, on page 490 of your statement, you refer to the next Block II Command and Service Module being delivered and checked out.

When is the second Block II Command and Service Module scheduled for delivery?

Answer. The scheduled delivery of the second Block II flight CSM as presently planned is March 1968, or approximately 3 months subsequent to the first Block II flight CSM.

COMMENDS NASA'S PRESENTATION TO COMMITTEE

The CHAIRMAN. I want to commend Administrator Webb for the specific proposals which he has presented to the Senate Space Committee and made to the public.

He has announced a crew for the next manned flight.

He has announced, after considerable discussion, that the Apollo Block II will use noncombustible and fireproof material to the greatest possible degree. He also makes clear that the Apollo Block II uses a 100-percent oxygen atmosphere. There will be debate and discussions about this, but somebody has had to settle it, and I am happy that Administrator Webb—with his staff—has made a decision. The 100-percent oxygen atmosphere, which is highly dangerous and hazardous, can apparently be handled once the vehicle is in flight.

All the way through he has in his statement assured the American people. He plans to continue to use aluminum fluid lines at some places and watch the matter of soldering. At other places aluminum lines will be replaced by stainless steel, and I am certain that there will be a careful testing before they are actually in flight. The wiring lines will he has to learn how to solder properly and the inspector has to learn how to catch the problem if he does not solder it properly. What you are seeing here, in the eyes of the Board, is a different view, the view primarily of the Cape activities that followed a year later, the activities that Sam Phillips was reviewing out at the manufacturer's plant.

Senator BROOKE. Then I take it that your answer that the similarity in deficiencies found in the two reports is not valid. Is that correct?

Dr. MUELLER. My answer is that they are referring to different times, different places, and are not, therefore, related on a one-for-one basis. They describe phenomena that are similar.

Senator BROOKE. And you believe that North American has corrected all of the deficiences that were found by the Phillips review or task force in 1965?

Dr. MUELLER. It is my belief that they have done a remarkable job of improving their operations. I do not think that they or any other of our contractors have corrected all the deficiencies in the production of this rather complex order. You only have to look at some of our experiences in other parts of the program to realize that.

Senator BROOKE. And you are satisfied with the progress that they are making in correcting the deficiencies that were found by the Apollo Review Board?

Dr. MUELLER. We believe that they are taking the appropriate steps that will assure us of safety in the future.

Mr. WEBB. And they have undertaken, Senator Brooke, to make quite substantial changes in the way they provide visibility for themselves and for us in any future work as we negotiate the future arrangements. They have undertaken this very clearly as a deep and dedicated action on the part of the officials of that company.

Senator BROOKE. Just for the record, what citation of the clause provides for termination of the contract? Do you have it?

Mr. WEBB. I do not. We can give it to you before——

The CHAIRMAN. Title XVIII, section 1905.

Senator BROOKE. The chairman has supplied it.

I thank you, Mr. Chairman.

(See p. 544.)

Senator BROOKE. Mr. Webb, can you answer, if you have any way of knowing, how much additional money was used because of the deficiencies part of the contract?

Mr. WEBB. I do not think we have a way of knowing this precisely, Senator Brooke; I really do not.

Senator BROOKE. Let me pinpoint the question. For example, in General Phillips' report, there was a reference to hardware being turned out with thousands of hours still left for total completion, which meant that some money had to be spent in completing this hardware. Now, was this additional money that NASA had to spend, or was the contractor charged for this, or how have you handled it so far as the financial transactions are concerned? Generally, when the product has not been up to the standards established by NASA?

Dr. MUELLER. Senator Brooke, this particular work was being done under an incentive contract. Under these contract provisions, the contractor was penalized for not producing either on schedule or within the cost budget or within the performance limitations that we have

INDEX

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

APPENDICES 1, 2, AND 3 CONTAINING INFORMATION RELATING TO THE ACTIONS TAKEN ON THE FINDINGS AND DETERMINATIONS OF THE REVIEW BOARD PANELS; AND MANNED SPACE FLIGHT REPORTS ON BLOCK II SPACECRAFT CHANGES AND ACTIONS TAKEN AS A RESULT OF THE ACCIDENT

PART 7

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE

74-621 O WASHINGTON : 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price $1.00

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota

MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

APPENDIX 1—MANNED SPACE FLIGHT REPORT ACTIONS TAKEN AS A RESULT OF THE AS-204 ACCIDENT

(T) Technical report with added technical details.

(T) Technical report with added technical details.

SECTION IV

SECTION V

(T) Technical report with added technical details.

(T) Technical report with added technical details.

(T) Technical report with added technical details.

APPENDIX 3—MANNED SPACEFLIGHT REPORT—BLOCK II SPACECRAFT

LIST OF FIGURES

TABLES

APOLLO ACCIDENT

APPENDIX 1

Manned Space Flight

Report

Actions Taken as a Result

of the AS-204 Accident

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.

Section I

SPACECRAFT MATERIALS

INTRODUCTION

The Apollo 204 Review Board recommended that the amount and location of combustible materials in the Command Module be severely restricted and controlled.

Knowledge gained as a result of the fire and in subsequent testing has led to a significant change in the approach to selection and placement of materials in the Command Module. This change to previous practice is more significant than any other single change resulting from the investigation.

Prior to the accident, the primary emphasis of the materials control program had been directed toward the prevention of ignition. The materials used in the cabin were in most cases identical to those used in Gemini and were chosen from the materials available when the Apollo Spacecraft was designed. In retrospect, it is apparent that they were not adequately fire resistant. Considering the recent advancements in fire resistant materials, the emphasis has now been shifted to the more exacting objective of insuring that if ignition does occur, the resulting fire cannot spread throughout the spacecraft. Confined in one area, a fire will be fuel limited and can be easily suppressed. In addition, of course, the extent of potential damage to the spacecraft and crew will be much less, enabling successful crew-egress or other action to be initiated, if necessary.

The AS-204 fire investigation revealed that improvements must be made in the following areas: (1) procedures for selection and testing of the crewbay nonmetallic materials, (2) reduction in the quantity of combustibles in the cabin to the absolute minimum, (3) stowage in fireproof containers of those combustible materials which must be retained, (4) placement of nonmetallic materials throughout the spacecraft to inhibit fire ignition or propagation, and (5) improved fire protection for crew clothing. The following progress has been made in these areas.

NONMETALLIC MATERIALS CRITERIA

Nonmetallic materials criteria have been established to control the risk of fire in all manned spacecraft operations ground and flight. These criteria are:

1. The possibility of ignition shall be minimized through conservative electrical design, material placement, material selection, etc.
2. Any fire shall be restricted to a definable area.
3. The rate and magnitude of pressure and temperature increase resulting from combustion shall not result in loss of structural integrity.
4. The crew shall be protected from the effects of potential fires.
5. Toxic fumes and temperatures resulting from combustion shall not result in incapacitation or injury to the crew.

MATERIALS USAGE CATEGORIES

In order to establish a systematic plan for material control which is oriented toward fire containment, the cabin materials have been classified by usage. This enables more specific tailoring of the test program to the particular material and application, so that the requirements placed upon the material are appropriate and sufficient. Accordingly, the most stringent requirements are placed upon those items needed for use throughout the cabin, such as the space suits, couches, and interior cabin paint. Control of other materials that are used only in small quantity (such as name plates, instrument knobs, and small fasteners) will be maintained through separation from similar items and from potential electrical ignition sources. Materials not required for general use (such as life vests) will be stored protectively inside fire resistant containers. Further material categories pertain to specialized applications in areas such as: (1) the high pressure oxygen system (for example, inside the suit loop), (2) inside components that are hermetically-sealed to protect electrical wiring and accessories, or (3) nonflight items (such as test procedures books).

Each of these categories has its own set of test guidelines, which are summarized in table 1. These guidelines are more stringent than any previously used for the selection of materials. Using these guidelines, we are now screening materials presently in the spacecraft and new materials for substitute use in the spacecraft.

During the last three months, we have carried out an extensive test program to identify materials appropriate for use in each usage category. These tests, in addition to providing data for use by the AS–204 Accident Review Board, have evaluated the effectivity of new, less flammable materials for use in spacecraft cabins. A description of this test program will next be given, paying particular attention to those aspects which are most significant in terms of materials selection and operational planning.

MATERIALS TEST PROGRAM

The materials test effort has been of two types. Extensive data has been gathered on the pertinent flammability parameters of individual materials and components through additional laboratory sample testing. Concurrently, full-scale boilerplate spacecraft testing has been carried out to observe the interaction of materials during a fire in a simulated spacecraft configuration and environment. The full-scale testing is a necessary adjunct to the laboratory testing in that it insures that the group effect of the materials has been accurately predicted from the test data on the individual materials.

The two parameters which serve to characterize the flammability potential of a material in a given atmosphere are combustion rate and ignition temperature. Combustion rate in air or oxygen-rich mixtures is normally measured either as the time required to consume a sample or the speed of flame travel over the surface. The ignition temperature is the lowest temperature at which the vapors from the surface of a material when mixed with air or oxygen in the environment and exposed to an ignition source will continue to burn after ignition.

An important aspect of recent testing has been the evaluation of combustion rates and ignition temperature in atmospheres of varying oxygen partial pressures. Previously, samples had primarily been tested in the nominal spacecraft flight environment of 5 psia pure oxygen, with only partial testing done at higher pressures. Testing is now including air and oxygen pressures up to 16.5 psia, with some materials intended for use in the oxygen system or suit loop being tested at even higher pressures as consistent with their intended applications. From this testing, the potential improvement in fire prevention and control due to changes in cabin materials and atmospheres can be examined. It is possible at this time to describe the general nature of our findings.

First, it has been generally found that ignition temperature is not strongly dependent on oxygen partial pressure, or on the presence of inert gas. Recent tests repeated on many of the Apollo cabin materials, which were originally tested for ignition up to 400° F. in 5 psia pure oxygen, have indicated that no significant reduction of ignition temperature results when the atmosphere is changed to 16 psia pure oxygen.

Combustion rate, on the other hand, depends more critically upon oxygen partial pressure. Most materials, such as nylon, burn faster in 16.5 psia oxygen than in air at the same pressure. Several new materials which will be described shortly, however, do not burn in pure oxygen at any pressure. The use of such nonflammable materials, therefore, can greatly reduce the first hazard in the spacecraft for any atmosphere.

Laboratory testing

As of May 5, 1967, 2,298 laboratory test specimens of nonmetallic materials had been prepared from 544 samples; 1,254 of these specimens were in test and 1,044 had completed testing. The nature and results of this testing are described in the technical report titled, "Special Tests" (see p. 566). Only the main points will be discussed here.

The most significant finding has been with regard to the dramatic improvement in fire resistant properties available in recently developed materials, such as glass Beta cloth and Teflon. The flammability test results of some of these candilate replacement materials are summarized in figure 109. For comparison, figure 110 shows that the combustion rates at various oxygen pressures of Teflon and

FLAMMABILITY TESTING OF NON-METALLIC MATERIALS IN OXYGEN

SPECIMEN DESCRIPTION	AVERAGE PROPAGATION RATE INCHES/SEC. O_2 PSIA	FLASH & FIRE POINT °F-O_2 PSIA	AUTOGENOUS IGNITION °F-O_2 PSIA	REMARKS
BETA CLOTH	DOES NOT BURN	DOES NOT IGNITE	DOES NOT IGNITE	MELTS AT 1550° F
TEFLON				
a.	.030 "/SEC 16.5	900°F 14.7	NONE	CABLE SHEATHING
b.	.009 "/SEC 16.5	900°F 14.7	NONE	THIN SHEET
c.	.003 "/SEC 16.5	900°F 14.7	NONE	CLOTH
d.	SELF-EXTINGUISHING	900°F 14.7	NONE	.010 THICK SHEET
FIBER GLASS	DOES NOT BURN	DOES NOT IGNITE	DOES NOT IGNITE	MELTS AT 1550°F

NOTES: PROPAGATION RATE - THE SPEED AT WHICH FLAME MOVES DOWNWARD ON A VERTICALLY MOUNTED SPECIMEN WHEN IGNITED AT THE TOP.

FLASH & FIRE POINT - FLASH POINT IS THE TEMPERATURE AT WHICH A HEATER MATERIAL CAN BE IGNITED BY A SPARK BUT WILL NOT SUSTAIN COMBUSTION. FIRE POINT IS THE TEMPERATURE AT WHICH A HEATED MATERIAL CAN BE IGNITED BY A SPARK AND CONTINUE TO BURN.

AUTOGENOUS IGNITION POINT - THAT TEMPERATURE AT WHICH A HEATED MATERIAL WILL BURST INTO FLAMES WITHOUT AN EXTERNAL SOURCE OF ENERGY.

NASA HQ MA67-5182a
5-8-67

FIGURE 109

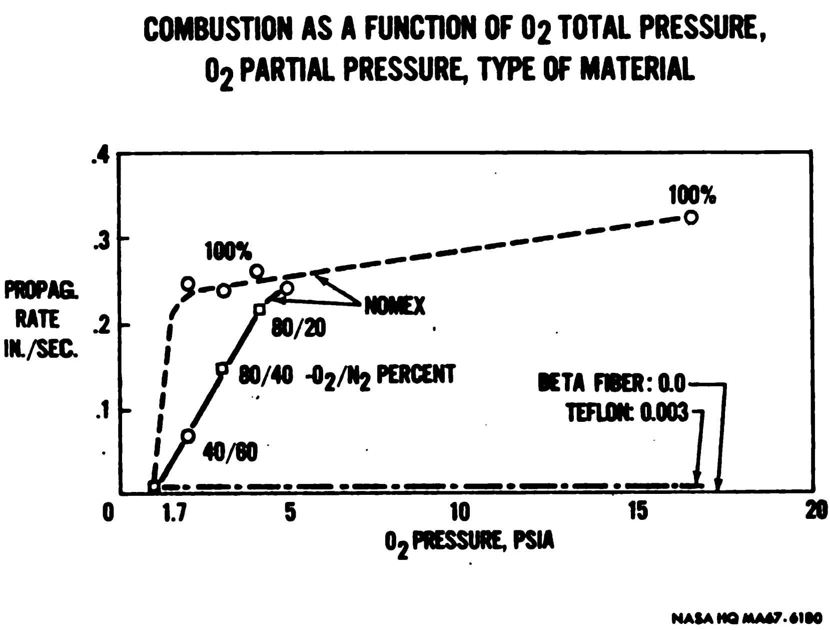


FIGURE 110

Beta fiber fall below those of Nomex, a nylon previously used in the outer spacesuit layer. Through this and other testing, it has become evident that the spacecraft fire hazard can be considerably reduced by replacement of present materials with these new materials. The most prominent new materials will be described later.

The materials utilized in conjunction with the electrical wiring are of particular interest. Since the previous control philosophy emphasized the prevention of ignition, the materials used near the electrical wiring proved to have been well chosen. Typical spacecraft wire bundles were tested in an oxygen environment at 6.2 pounds per square inch. The wire bundles, about two inches in diameter, were tied together with nylon over Teflon tape or silicone rubber clamps. One wire in each bundle was overloaded electrically until the wire melted. Insulation on wires in the bundle adjacent to the hot wire suffered some localized damage or burning but in no instance was the entire wire bundle ignited and destroyed.

Boilerplate command module flammability tests

The gross flammability effects of nonmetallic materials have been investigated by the use of steel boilerplate Command Modules with simulated interiors. Fires were deliberately started in order to obtain information on the mode, rate and scope of fire propagation. The materials tested included those typical of spacecraft 012 as well as the less flammable replacement materials under consideration. These tests were conducted with oxygen and air at different pressure levels, as described in the technical report, page 579, "Command Module Mockup Fire Tests."

Two of these tests at the Manned Spacecraft Center were quite significant in enlarging our understanding of the relationship of the materials to a fire's intensity and rate of propagation. In the first, the materials in the interior of the test vehicle were configured to simulate spacecraft 012 at the time of the accident. A fire was started and the failure of the cabin structure and rupture of the oxygen line were simulated. The mode and extent of propagation of the fire was similar to that postulated for spacecraft 012 on the basis of the post-accident investigation. The shapes of the pressure-time curves of the test and of the spacecraft 012 accident were quite similar. Damage to the interior of the test vehicle was extensive.

Another test was conducted to determine the characteristics of a fire in a Command Module when new less-flammable materials were used and the cabin atmosphere was air at 14.7 pounds per square inch. Four ignition points were used because it was not expected that the fire would propagate with new materials and the air atmosphere. This expectation was confirmed in that damage at each ignition point was negligible, the flame did not propagate, and the cabin pressure rise was also negligible.

These tests demonstrated that in an oxygen atmosphere at 16.5 pounds per square inch the nonmetallic materials used in spacecraft 012 had a high rate of fire propagation and the extent of damage was large. The same materials in an oxygen atmosphere of 5 pounds per square inch demonstrated a substantially reduced rate of fire propagation and damage. Fire damage was negligible in Command Module tests in which less flammable materials were substituted for the spacecraft 012 nonmetallic materials with cabin atmospheres of air at 14.7 pounds per square inch and oxygen at 5 pounds per square inch.

Thus, the use of less flammable materials can significantly reduce the damage due to an ignition. When the material selections are complete and a new materials configuration has been defined, it will be tested in the boilerplate Command Module at the highest oxygen pressure to which it will be exposed during program operations.

NEW MATERIALS DEVELOPMENT

The prime factor enabling an improved selection of materials for spacecraft cabin use is the recent advancements in the development of materials and textiles. Now available are fabrics, films, and other materials with fire resistances which are greatly improved over that of the materials available early in the Apollo Program. These new materials include glass Beta-fiber products, fluorocarbons, and other high temperature fibers. An effort is now underway to assemble all available information on these new materials and a handbook is being prepared for circulation to all Apollo contractors to insure maximum utilization of these materials.

One of the most promising materials is known as Beta fiber. It is a very fine glass filament, approximately 3.8 microns in diameter, which can be used to weave fabrics, webbings, tapes, and braids; and can also be used to make mats, felts, filter materials, and insulation material. Beta fiber, because it is a glass, silicon dioxide, has a useful service temperature up to 1200° F., depending upon the construction, and melts at 1550° F., but does not burn.

Beta fabrics can be made extremely soft and flexible and, unlike Fiberglass cloths, do not cause skin irritation. Generally, articles woven from glass have an inherently poor wear and abrasion resistance, in addition to being more difficult to sew. These shortcomings can be reduced to an acceptable level, however, by the addition of finishes which serve as a lubricant between the glass filaments. Finishes are now available which do not increase the flammability of the Beta material. An example is the Owens Corning No. 4190-D cloth now under development for use on the space suit and other spacecraft applications.

The history of the development of Beta fabrics represents the type of progress that has been made in the materials area since the onset of the Apollo Program. Pilot-plant production of Beta filament was started in 1962, and in 1963 limited production of certain fiber sizes was started. In 1964, experimental-type Beta fabrics were introduced into the industry, and late that year, NASA initiated procurement action to develop a flame-proof constant-wear garment made of Beta fiber, with the contract let early in 1965. Meanwhile, the first commercially available fabric production was started in 1965, and in mid 1966 the first full-scale production of Beta fabrics was started in one plant. In their continuing effort, NASA in 1966 conducted animal and human testing to determine the dermatological effects of long-term wear. The tests showed that the lastest Beta fabric did not cause skin irritation as did earlier Beta fabrics; however, resistance to long-term wear or abrasion was considered marginal. In early 1967, NASA initiated a follow-on contract to improve the abrasion resistance or durability of Beta fabric, and in February the use of Beta fabrics in space suits was initiated.

Teflon is another material available for relatively general use. Consisting of long carbon chains having all available bonds completely saturated by fluorine, it is the most chemically resistant fiber known. It can be woven into fabrics, webbing, straps, tapes, and braids in addition to being made into mats, felts, film, insulation, and filter material. It has a useful service temperature range from −450° F. to +550° F., and is superior to Beta for sewing. Though the fibers have lower breaking strength, Teflon fabric, due to its elongation, is stronger than glass, as well as being superior to Beta fabric in wear and abrasion resistance.

Quartz fiber represents another possible high temperature material. Composed of 100-percent silica, it has a high softening point, in the range of 1500° to 1670° C., and an extremely low coefficient of thermal expansion, which imparts a high thermal-shock resistance. Quartz fiber has a good mechanical strength, excellent electrical properties, and is nonflammable in a pure oxygen environment, but has the disadvantage of being more brittle than glass fabric and more difficult to sew.

Polybenzimidazole is a recently developed fiber for use in the temperature range of 600° to 900° F. Its rate of combustion in pure oxygen is approximately half that of nylon, and the fiber is much superior to glass or quartz in wear, abrasion resistance, and sewing properties.

Relatively detailed descriptions of these candidate replacement materials have been given due to the importance attached to such substitutions. This point cannot be over emphasized. It is felt that no other change can be made in spacecraft equipment or procedures which can overshadow the increased safety afforded by these new materials. As mentioned before, testing has shown that the use of these newly developed fabrics and materials in the Command Module will greatly reduce the possibility of fire propagation.

MATERIAL CHANGES

Space suit

The Apollo space suit serves to illustrate the manner in which these new materials will be used. The space suit materials are now being changed to

FIGURE 111

eliminate as much nylon as possible. Shown in a cross-sectional drawing of the new space suit (figure 111), the outer cover-layer will be made more fire resistant by using two layers of Beta fabric with a layer of nickel H film between. The next layers of the suit which provide the pressure integrity will be nylon and chloroprene-coated nylon. These layers will not be changed at this time because effective substitutes are not available, and changes will not be made which reduce our confidence that the suit can hold pressure in space. The fire resistant inner and outer layers provide effective protection for this internal layer. The suit inner comfort layer will be a Teflon fabric, and the space suit underwear will be made of Beta fabric. Bioinstrumentation signal conditioners and wiring will be encased in a Teflon jacket to provide additional protection.

Other space suit components, such as the communications cap, are also being changed to Beta fabric to enhance crew safety. Certain items, such as the liquid-cooled garment and the urine-collection device, will not be changed because of the low potential for fire problems and the unavailability of suitable replacement materials. Some additional qualification tests will be required as a result of the material changes.

Nylon fasteners

A replacement material for the nylon Velcro fasteners is also being developed. Because of its extensive use in the cabin and relatively high rate of flame propagation in a 16 psia oxygen environment, this material contributed greatly to the rapid spread of the fire throughout the 012 Command Module. Since these fasteners are of great convenience to the crewmen to secure frequently needed items in the weightless environment, efforts have been made to develop less flammable substitutes. A candidate replacement is shown in figure 112. Beta-fiber tapes are used in place of nylon tapes. The hook, which grabs the pile, is made of polybenzimidazole (PBI) and the pile is made of Teflon or PBI. Small samples of this new Velcro have been made and show great promise.

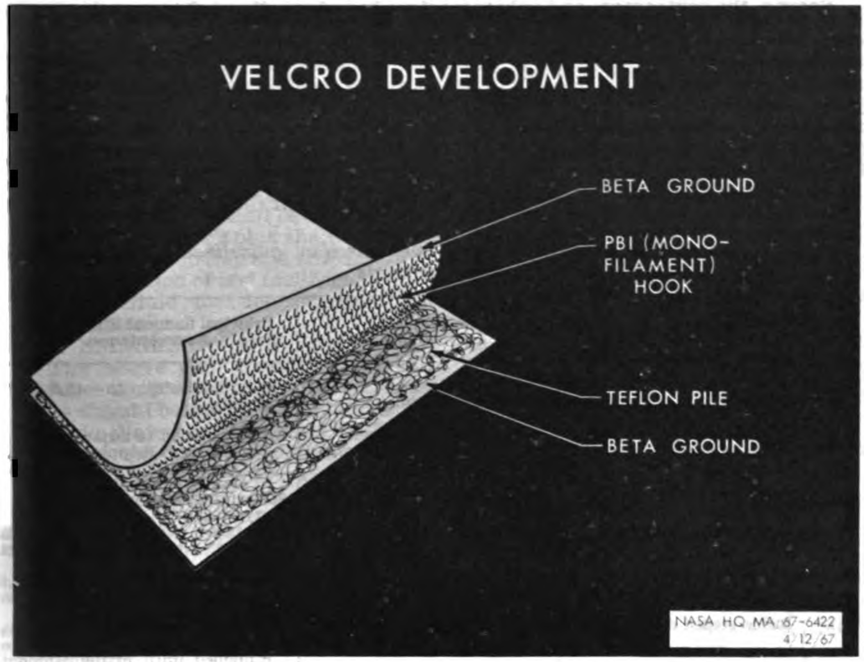


FIGURE 112

Crew provisions materials

The crew provisions have also been examined in terms of their fire resistance. An example of the type of changes which are envisioned here is given by the food bags. The current food bags utilize an outer cover made of polyethylene, which supports combustion, and so will be stored in metal containers within the spacecraft. The food itself, of course, is flammable. This is an example of some flammable materials which cannot be removed. Improved safety could be achieved by the substitution of a nonflammable outer layer, however, and the Apollo food contractor has been assigned the task of developing a suitable substitute. Currently it appears that a Teflon or Kel-f outer layer will be used. Prototypes will be delivered for test and evaluation, and future flight food will be packaged in such fire-resistant bags. Other film bags, used in the spacecraft for waste and stowage, will be changed in a similar manner.

These few examples indicate the type of effort which is being directed toward the replacement of combustible materials in the spacecraft. This is being given the highest priority, as mentioned before, and the replacement program will be conscientiously carried out within the framework of our revised materials usage program.

IMPLEMENTATION GUIDELINES

It is, of course, imperative that procedures and controls be set up to implement the intended materials usage program. Following is a summary of the features of the program to highlight the actions being taken to control the usage of materials in the cabin of the spacecraft.

First, revised criteria and guidelines have been established for the selection and application of materials in the spacecraft cabin. These guidelines, classified in terms of material usage, are those summarized in table 1. The selected materials will be approved by the Spacecraft Project manager. Final confirmation of the selected materials and their utilization will be verified in full-scale Boilerplate CSM testing prior to use in manned tests. The classification and selection of materials will then be implemented into appropriate specifications.

Second, the contractors and subcontractors have been directed to use these new materials selection guidelines.

Third, a management system is being implemented with the contractors to identify and report materials usage.

Fourth, particular attention is being paid to the means of controlling the type of materials and the procedures used to test against our new criteria, to identify deviations and to provide technical rationale on all waivers to the criteria. As can be understood, slight differences in material composition or test procedures could lead to misleading results. Controls must insure that the materials used are indeed the same as the ones that were tested and that the tests are meaningful.

TABLE 1.—*Summary of classification and selection guidelines for nonmetallic cabin materials*

Category	Usage and application of materials	Examples	Principal flammability criteria for acceptance
A	Major crew compartment materials.	Debris net, paints, space suit outer layer, insulation, wiring insulation.	Self-extinguishing in 16.5 psia oxygen.
B	Less used materials in crew compartment.	Name plates, instrument knobs, molded fasteners, stencil paint/ink.	No propagation to adjacent items. Burn without dripping or sparking. Pressure rise less than 2.5 psi in cabin or equivalent.
C	Space suit loop materials....	Hoses, helmets, inner garment, couplings.	Self-extinguishing in 19 psia oxygen.
D	High pressure oxygen system.	Filters, valve seats, seals pressure bladders.	Fire point 450° F. in 16.5 psia oxygen. No friction or impact ignition.
E	Inside hermetically sealed containers.	Electrical wiring wire wraps/potting.	Container shall not rupture in 16.5 psia oxygen inside and worst case short.
F	Inside vented containers....	Foam padding, food packages, wiring, survival equipment.	Fire point 450° F. in 16.5 psia oxygen. Internal fire must be contained until extinguishment (in 16.5 psia oxygen). Vented gases not capable of fire propagation.
G	Nonflight equipment........	Plastic bags carry-on cables....	Self-extinguishing in air. Requirements "A"-"F" in O_2 testing.

Fifth, the Manned Spacecraft Center is expanding its data management to provide current materials approval and waiver status, test data, and supporting documentation.

Sixth, an active materials information interchange system is being created by the Manned Spacecraft Center and major contractors to assure that the current information is available and used to select materials for spacecraft. The integrated materials lists and development of a materials handbook represent effort in this area.

Finally, efforts devoted to inspection and assurance activities are being increased to insure that deviations and potential problem areas are identified in time for program management to take effective action.

CONTRACT CHANGE AUTHORIZATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, MANNED SPACECRAFT CENTER, HOUSTON, TEX.

Date:
Contract No.: NAS 9–150
COA No.:
Master Serial No.:

NORTH AMERICAN AVIATION, INC.,
Space and Information Systems Division,
Downey, Calif.

GENTLEMEN: Pursuant to the provisions of the clause of the above numbered contract entitled "CHANGES" and other applicable provisions of said contract, you are hereby directed to proceed with the implementation of the changes specified herein and the preparation of a firm contract change proposal.

The Contractor shall implement the General Fire Control Criteria as specified in paragraph III of Attachment 1 "Nonmetallic Materials Selection Criteria" dated April 10, 1967. The categories specified in paragraph IV of the attachment will be utilized as guidelines for the selection of nonmetallic materials. The Contractor shall recommend a detailed plan for analysis, application testing, selection, and approval of nonmetallic materials so as to assure that all potentially combustible applications are identified and controlled. In addition, the Contractor shall recommend any design and/or material changes necessary to meet this criteria. Those shown in "Plan of Action covering Substitute Materials for Presentation" shall be implemented immediately.

The Contractor's plan shall detail the following:

1. Detailed listing and schedule of all tests.
2. Definition of test facilities.
3. Schedule for determination and categorization of all material and/or applications.
4. Submittal for MSC approval of a plan for continuing control of materials.

The above plan should be developed for an implementation which does not involve major redesign without reducing the effectiveness of the criteria. The plan should be submitted no later than May 15, 1967.

This change is effective on CSM 2TV-1, 101 and subsequent.

Except as hereby modified, all terms, covenants and conditions of said contract as heretofore modified or amended shall remain in full force and effect.

THE UNITED STATES OF AMERICA
By ____________________________

[Attachment 1]

APRIL 10, 1967.

NONMETALLIC MATERIALS SELECTION CRITERIA

I. PURPOSE

The purpose of this document is to establish usage criteria and test requirements for nonmetallic materials in the Apollo spacecraft.

II. SCOPE

The scope of this specification covers: (1) Materials exposed to the crew compartment atmosphere; (2) Materials exposed to the suit loop oxygen atmosphere; (3) Materials used in high pressure oxygen systems; (4) Materials used in hermetically sealed containers in the spacecraft atmosphere; (5) Materials used in vented containers in the spacecraft atmosphere; (6) Materials used in closed hatch, power-on tests; and (7) Materials used in uninhabited portions of the spacecraft. Criteria shall apply to all spacecraft equipment needs during manned test and flight. The materials selected for use shall meet the requirements of this document and those documents referenced herein.

III. GENERAL FIRE CONTROL CRITERIA

A. The possibility of ignition shall be minimized through proper electrical design, material placement, material selection, etc.

B. Any fire shall be restricted to a definable area.

C. The rate and magnitude of pressure and temperature increase resulting from combustion shall not result in loss of structural integrity.

D. The crew shall be protected from the effects of potential fires.

E. Toxic fumes and temperatures resulting from combustion shall not result in incapacitation or injury to the crew.

IV. CATEGORY OF MATERIALS

Materials shall be categorized primarily by functional application and spatial distribution. This criteria also defines material toxicity and flammability characteristics as well as design, and test requirements for each category.

A. CATEGORY A—MAJOR EXPOSED MATERIALS

This category shall include the material applications that are unlimited with respect to quantity, proximity to ignition sources or exposure to oxygen and are used over wide areas of the spacecraft. To prevent flame propagation, these materials must be self-extinguishing as defined below.

1. Functional description

Materials performing the following functions shall be subject to the requirements of this category:

a. Debris traps or nets.
b. Outer space suit materials.
c. Couch cushions.
d. Webbing and harness.
e. Spacecraft electrical wire bundles and accessories.
f. Other functions shall be considered subject to these requirements if a propagation pattern is identified.

2. Material property requirements

a. Combustion rate: Self-extinguishing in 16.5 psia oxygen (MSC–A–D–66–3) when ignited at the bottom of the test specimen.
b. Fire point: Test not required.
c. Odor and carbon monoxide (CO): MSC–A–D–66–3.
d. Total organics: MSC–A–D–66–3.
e. Electrical wiring overload test: MSC–A–D–66–3, appendix A.
f. Connector, potting and conformal coating electrical overload test: MSC–A–D–66–3, appendix B.

B. CATEGORY B—SPECIAL APPLICATIONS AND MINOR EXPOSED MATERIALS

This category includes those material applications in the spacecraft arranged in discrete locations and exposed to the cabin atmosphere. The specific amount and arrangement of materials at any discrete location shall be limited so as to prevent pressure and temperature increases from exceeding allowable limits as a result of combustion. Also the type of material and/or installation arrangement shall be such that the fire cannot spread to any other discrete location in the pressure vessel.

1. Functional description

Those materials located and contained as described above and performing the following functions shall be subject to these criteria:

a. Electrical connectors including inserts, potting compounds, shell, and mounds.
b. Electrical components including terminal boards, conformal coatings, and potting compounds.
c. Instrument panels including control knobs, dial faces, luminescent panels, panel fronts, paints and coatings, and potting compounds.
d. Batteries including associated equipment.
e. Miscellaneous materials:
(1) Discretely isolated shock absorber materials.
(2) Discretely isolated thermal insulation materials.
(3) Plastic sheets.
(4) Nonmetallic films and containers.
(5) Tapes.
(6) Seals and/or sealants.
(7) Paint.
(8) Adhesives.
(9) Lubricants.
f. Other material applications—All material applications not included in other categories shall be considered subject to these criteria and requirements.

2. Materials property and application requirements

a. Combustion rate: The combustion rate measured downward shall not exceed 0.3 inch per second when tested at 16.5 psia as outlined (MSC–A–D–66–3). There shall be no spark, sputter, drip, or transfer of solid mass during burning.

b. Fire point: Greater than 450° with spark in 16.5 psia oxygen (MSC-A-D-66-3).
c. Odor and carbon monoxide: MSC-A-D-66-3).
d. Total organics: MSC-A-D-66-3.
e. Connector, potting, and conformal coating electrical overload test: MSC-A-D-66-3, appendix B.
f. Test requirements of applied configuration: Materials in this category shall be subjected to special tests to demonstrate that fire control criteria are met in the applied configuration. The Contractor shall identify applications to be tested and the specific test configuration, ignition sources, test conditions, and acceptance criteria for each test:

(1) *Test selection criteria*.—Tests of "worst case" configurations of each generic class of equipment shall be conducted to verify acceptability. The Contractor shall furnish analysis to support this selection.

(2) *Test configuration*.—The equipment tested shall be identical to the flight article. All potential propagation paths shall be simulated. Geometric and spatial proximity to spacecraft panels and enclosures shall be simulated.

(3) *Ignition source*.—A standard hot wire ignition source shall be used. It shall be placed at the most combustible material in the test. Sufficient energy shall be supplied to ignite the configuration or assure that it will not ignite in actual service.

(4) *Test conditions*.—All tests shall be conducted in 16.5 psia oxygen atmosphere with an ambient temperature of 75±5. The test set-up shall simulate the ventilation condition available to the test specimen in the flight condition. The total volume of the test chamber shall be identical to that of the applicable crew compartment.

(5) *Acceptance criteria*.—The pressure rise during the test shall not exceed 2.5 psi. There shall be no propagation of the fire to adjacent equipment. There shall be no sputter, drip, or release of hot particles. The atmosphere of the test chamber shall be monitored by chromatographic or spectrographic techniques to determine the nature of combustion products.

g. Installation protection: The following methods are among those that may be evaluated to provide nonpropagating configuration of materials in category B. The configuration shall still be subject to the test requirements of paragraph *f*.

(1) Installation of nonflammable covers, panels, or other fire breaks over or between adjacent combustible materials.
(2) Reduction in potting, conformal coating, and paint quantities.
(3) Covering the flammable material with an inorganic coating or other appropriate fire inhibitor.
(4) Covering material with aluminum foil or teflon sleeving.
(5) Covering flammable material with noncombustible foams.

C. CATEGORY C—SUIT LOOP MATERIALS

This category shall include those materials used in the suit loop (less than 20 psia oxygen).

1. Functional description

Materials within the ECS suit loop and interior of space suit such as hoses, helmets, flex joints, couplings, valve seals and seals including regulators and check valves, and inner garment materials, shall be subject to these requirements.
Suit loop wiring and electrical components such as biomed/communications, harnesses, signal conditioners, connectors, transducers, wetness sensor. and thermo-couples, shall also be included.

2. Material property requirements

a. Combustion rate: Self-extinguishing (upward) in 19.0 psia oxygen (MSC-A-D-66-3).
b. Fire point: No test required.
c. Total organic: MSC-A-D-66-3.
d. Odor and carbon monoxide: MSC-A-D-66-3.
c. Electrical wiring overload test: MSC-A-D-66-3, appendix A.
f. Connector, potting, and conformal coating, electrical overload test: MSC-A-D-66-3, appendix B.

3. Design requirements

The requirements for combustion rate shall be applicable to all materials in this category except those wherein no ignition source is possible. The Contractor shall specifically identify these materials with appropriate analytical rationale.

D. CATEGORY D—MATERIALS APPLICATIONS IN HIGH PRESSURE OXYGEN SYSTEM

This category shall include those materials used in greater than 20 psia oxygen systems. Materials shall have prior use history in oxygen service with no fire or explosion experience.

1. Functional description

Materials for such applications as filters, seals, valve seats, and pressure bladders, shall be covered by this criteria.

2. Material property requirements

a. Combustion characteristics: No test required.
b. Fire point: Greater than 450° F. with spark in 16.5 psia oxygen.
c. Odor and CO: MSC–A–D–66–3.
d. Total organic: MSC–A–D–66–3.
c. Friction and impact ignition: Materials shall not ignite when tested to the requirements of Appendix D, MSC–A–D–66–3.

E. CATEGORY E—MATERIAL APPLICATIONS IN HERMETICALLY SEALED CONTAINERS

This category shall include those material applications inside hermetically sealed containers (with inert gas, air, and/or potting with no method of receiving or replenishing a supply of oxygen).

1. Functional description

Applications such as electrical wiring, tie wraps, potting compounds, and electronic components shall be subject to these criteria.

2. Material application requirements

The sealed container shall not rupture as a result of internal temperature or pressure increases caused by internal electrical malfunction. Verification by test that a worst case configuration meets this criteria shall be required. Rationale shall be furnished to support the selected test configuration:

a. Test selection criteria.—Tests of representative worst case configurations of hermetically sealed containers containing ignition or heat sources shall be conducted to verify acceptability. The Contractor shall provide analysis to support the selection of test configuration.

b. Test configuration.—The equipment tested shall be identical to the flight article.

c. Ignition source.—The ignition or heat source shall be that expected in normal operation. Overload shall be applied to failure.

d. Test conditions.—Tests shall be conducted in 16.5 psia oxygen atmosphere with a container temperature of 145 ± 5° F.

c. Acceptance criteria.—The hermetically sealed container shall not rupture or exceed design leakage requirements as a result of this test.

F. CATEGORY F—MATERIALS IN VENTED CONTAINERS

This category shall include those materials used inside unsealed containers with or without an internal ignition source. The containers shall allow over-pressure to be vented and preclude ready access of fresh oxygen so that a fire inside will be self-extinguishing. Removal of materials from containers shall be permitted for operational use only.

1. Functional description

Applications shall include foams, food bags, survival equipment, personal equipment, printed circuit boards, wiring, potting compounds, and electronic components.

2. Material property requirements

a. Combustion rate: No test required.
b. Fire point: Greater than 450° F. with spark in 16.5 psia oxygen, for material in containers (MSC–A–D–66–3).

c. Odor and CO: MSC–A–D–66–3.
d. Total organic: MSC–A–D–66–3.
e. Test requirements: Materials in this category shall be subjected to special tests to demonstrate that fire control criteria are met.

(1) *Test selection criteria.*—Tests of configurations representative of each generic class of equipment shall be conducted to verify acceptability. The Contractor shall furnish analysis to support the selection of test configurations.

(2) *Test configuration.*—The configuration tested shall be representative of the flight article.

(3) *Ignition source.*—A standard hot wire ignition source shall be used. It shall be placed at the most combustible material in the test configuration. Sufficient energy shall be supplied to ignite the configuration or assure that it will not ignite in actual service.

(4) *Test conditions.*—All tests shall be conducted in 16.5 psia oxygen atmosphere with a container temperature of 145 ± 5° F.

(5) *Acceptance criteria.*—The vented container shall contain an internal fire or heat source until extinguished. No flaming particles or flame shall be emitted. The vented gas shall not be capable of igniting adjacent combustible materials. The atmosphere shall be monitored by chromatographic or spectrographic techniques to determine nature of combustion products.

(6) *Installation protection.*—Design approach which may be considered to provide acceptable configurations include filling the internal volume of the container with nonflammable material or material which prevents or impedes oxygen access.

G. CATEGORY G—MATERIAL APPLICATIONS IN NONFLIGHT EQUIPMENT

This category shall include those materials used in nonflight equipment during closed hatch, power-on tests.

Materials used in manned oxygen atmosphere tests must meet applicable category A through F tests and requirements.

1. Functional description

Applications shall include "Remove Before Flight" flags, plastic bags, plastic tape, carry-on GSE, and associated cables.

2. Material property requirements

a. Combustion characteristics: Self-extinguishing in air.
b. Fire point: No test required.
c. Odor and carbon monoxide: MSC–A–D–66–3.
d. Total organic: MSC–A–D–66–3.

H. CATEGORY H—MATERIALS IN UNINHABITED PORTIONS OF THE SPACECRAFT

The material applications included in this category shall be those in uninhabited portions of the spacecraft simultaneously exposed to ignition sources and an atmosphere which will support combustion.

1. Functional description

Applications shall include insulation blankets, protective covers, wire bundles and harness, tape, conformal coating, and encapsulents.

2. Materials property requirements

a. Combustion rate: Self-extinguishing in air.
b. Fire point: No test required.
c. Odor and carbon monoxide: No test required.
d. Total organics: No test required.
e. Installation protection: The usage of materials which do not meet these requirements is restricted to an inert atmosphere when potential ignition sources are present, i.e., during power-on tests.
f. Electrical wiring overload test (in air) MSC–A–D–66–3, appendix A.
g. Connector, potting and conformal coating electrical overload test (in air) MSC–A–D–66–3, appendix B.

SPECIAL TESTS (T)

NASA APOLLO PROGRAM WORKING PAPER NO. 1272

MANNED SPACECRAFT CENTER, HOUSTON, TEX,

April 6, 1967

SUMMARY

In addition to the investigations reported individually, the following special tests related to the Spacecraft 012 accident were performed:

1. Materials tests:
   (a) Combustion (flame propagation) rate.
   (b) Flash and fire point.
   (c) Autogenous ignition.
2. Wire bundle ignition by electrical overload.
3. Burning of foam insulation or oxygen and water-glycol tubing.
4. Corner flammability and ignition.
5. Circuit-breaker conformal coating.
6. Electro-luminescent panels.

In the materials tests the flammability characteristics indicated above were determined for spacecraft nonmetallic materials in an atmosphere of oxygen at 16.5 pounds per square inch absolute pressure. Previous data in an oxygen atmosphere were obtained almost wholly in an oxygen atmosphere at 5 pounds per square inch absolute.

In large wire bundles, the electrical overloading of one wire to melting temperature caused minor damage.

Burning of the Uralane foam insulation on aluminum tubing containing oxygen at 600 pounds per square inch or water-glycol at 45 pounds per square inch, which represent Apollo command module conditions, did not cause failure of the tubing.

The corner flammability and ignition tests provided information on a possible mode of ignition and of propagation of a fire out of the corner of the junction of the left hand equipment bay (LHEB) and the lower equipment bay (LEB).

An electrical overload ignited the silicone conformal coating on the back surfaces of circuit breakers. However, if the overload current passes through the circuit breaker, the breaker will open and prevent damage to the circuit.

INTRODUCTION

Various special tests were performed in support of the investigation of the Spacecraft 012 accident by the AS-204 Review Board. Also, tests were performed on spacecraft components and nonmetallic materials toward the objective of reducing or eliminating fire hazards. The special tests include the following:

1. Materials tests:
   (a) Combustion (flame propagation) rate.
   (b) Flash and fire point.
   (c) Autogenous ignition.
2. Wire bundle ignition by electrical overload.
3. Burning of foam insulation on oxygen and water-glycol tubing.
4. Corner flammability and ignition.
5. Circuit-breaker conformal coating.
6. Electro-luminescent panels.

MATERIALS TESTS

Various tests related to the flammability of the nonmetallic materials in the Spacecraft 012 crew compartment were conducted. These tests were requested by the AS-204 Review Board or by the Manned Spacecraft Center (MSC) Materials Waiver Board and include:

1. Combustion (flame propagation) rate.
2. Flash and fire point.
3. Autogenous ignition.

These tests were performed, generally, in an oxygen atmosphere at a pressure of 16.5 pounds per square inch absolute. Heretofore, tests of spacecraft materials in an oxygen atmosphere had been performed almost exclusively at a pressure of 5 pounds per square inch absolute. The tests were performed at the Manned Spacecraft Center and at the White Sands Test Facility. Standardized procedures were followed by all test groups in order that test results would be correlatable. The tests which were performed were primarily screening tests to provide relative rating of materials in specific characteristics.

TESTS

Combustion rate.—The combustion rate was determined for a flame moving downward in a vertical plane. Test samples 2 inches wide by 5 inches high were ignited at the top (2-inch) edge by means of a "hot wire." The use of a downward propagation rate aids in obtaining reproducible results and constitutes a reference for screening materials.

Flash and fire point.—Flash and fire point determinations were made by use of a spark greater than 15 millijoules at a distance of 0.03 inch from the surface of the specimen.

Autogenous ignition.—Autogenous ignition was attempted by heating the specimen by means of a hot plate in an oxygen atmosphere.

Status of materials test program.—As of March 31, 1967, 533 tests have been completed in this program.

RESULTS

The results of the materials test completed to date are summarized in table 2. From this table, the following significant items are noted for the materials tested:

1. The polyurethane and Uralane foams have very high flame propagation rates—in excess of 10 inches per second.
2. Nylon in its various forms (Velcro, Trilock, Raschel net) has high propagation rates.
3. No autogenous ignition occurred for any of the specimens below the specification limit of 400° F., at which most tests were terminated. For tests above 400° F., melting and smoking of the material were observed, but ignition did not occur.
4. None of the materials ignited at temperatures to 400° F. when ignition was attempted by electric spark (except one material, Rayon terry cloth, which ignited at 325° F.).

ADDITIONAL TESTS

Tests on additional Spacecraft 012 materials will be conducted and tests on new, less flammable materials will be conducted in air and in oxygen at pressures of 6.2 and 16.5 pounds per square inch absolute.

Wire Bundle Ignition Tests

Wire bundles with flammable ties and clamps were tested in an oxygen atmosphere of 6.2 pounds per square inch absolute. In each bundle, approximately 2 inches in diameter, one wire on the bundle surface was overloaded electrically until the wire melted. The ignition and burning of the flammable materials were recorded on motion picture film.

The wire bundle for test 1 contained Nomex (nylon) ties over Teflon tape. The overloaded wire carried a maximum of 100 amperes at 25 volts for 17 seconds.

In test 2, a wire bundle with Nomex (nylon) ties and silicone rubber clamps was used. The overloaded wire carried a maximum of 75 amperes at 28 volts for 15 seconds.

The test setup for the wire bundle tests is shown in figure 113. One half the length of each bundle was horizontal and the remaining half was vertical to determine differences, if any in horizontal and vertical fire propagation rates.

FIGURE 113

RESULTS

Test 1.—The electrically overloaded wire ignited several ties in both horizontal and vertical portions of the cable. Some ties burned completely around the bundle and some burned only at the heated wire and then extinguished. The insulation on the wires adjacent to the hot wire or to the ties which burned suffered negligible damage.

Test 2.—The electrically overloaded wire ignited one silicone rubber-covered clamp on the horizontal portion of the cable. The outer surface of this clamp burned out but the fire extinguished without significant damage to the wire insulation.

CONCLUSION

For the large wire bundles tested, burning of Nomex ties spaced at about 3 inches or greater, or burning of a silicone clamp caused minor damage to the wire insulation.

ADDITIONAL TESTS

Tests of wire bundles with other tie and clamp materials will be performed.

BURNING OF FOAM INSULATION ON OXYGEN AND WATER-GLYCOL TUBING

Because oxygen and water-glycol lines ruptured during the Spacecraft 012 fire, four tests were conducted in order to determine whether a Uralane-oxygen fire would burn through typical Environmental Control Unit (ECU) piping containing flowing oxygen at 100 and 600 pounds per square inch and flowing RS-89a (water-glycol with inhibitors) at 45 pounds per square inch.

TEST ARTICLES

The test articles consist of 12-inch lengths of ¼-inch and ⅜-inch-diameter aluminum and stainless steel tube bent in a horseshoe configuration. Each test article, with the exception of the oxygen flow tube in test 4, was coated with a ⅜-inch-thick covering of Uralane foam.

TEST APPARATUS AND CONDITIONS

Each test was conducted in a 14-inch diameter by 16-inch long aluminum flammability chamber. Oxygen flow of 0.1 cubic foot per minute, or about one-tenth of the chamber volume, was introduced into the chamber through a ¼-inch stainless steel tube extending 15 inches past the chamber bulkhead. Chamber pressure was maintained by a bleed valve while the maximum chamber pressure was controlled by a pressure-relief valve.

The oxygen flow rates were orifice-controlled, with the test flow orifice located downstream of the test article and the limiting flow orifice located upstream of the test article. Orifice pressures were monitored by pressure transducers located immediately upstream and downstream of the limiting flow orifice. Oxygen chamber flow and test article flow were provided by a common connection to a single K-bottle.

Ignition of the test article was accomplished by feeding 10 amperes dc through a double-wrap of 20-gage Nichrome wire around the test article. Ignition was started on the oxygen flow-tube foam in each test with the exception of test 4. Test 4 used a 1-inch by 1-inch by 6-inch block of Uralane foam in the bottom of the chamber to start ignition. The temperature of the burn was monitored by a chromel-alumel thermocouple embedded in the foam insulation of the test article.

All of the apparatus for each test was located exterior to the chamber bulkhead with the exception of the test articles and the thermocouple and ignition wiring.

TEST PROCEDURE

The chamber was first evacuated with a vacuum pump. The pump was then removed and the oxygen supply turned on. The chamber bleed valve and the oxygen pressure regulator were adjusted until the chamber pressure and the test flow orifice pressure were maintained at the proper values. The nitrogen supply to the water-glycol container was turned on and the container was pressurized to 45 pounds per square inch. (Water-glycol flow rate had been previously established.) The countdown was initiated, and at T minus 15 seconds, the oxygen flow was turned on. At T minus 2 seconds the high speed camera was turned on, and at T minus 0 seconds the water-glycol flow and igniter voltage were activated. The test conclusion was determined by either a nominal time interval of T plus 30 seconds or a burn-through of the water-glycol line. (Burn-through of the water-glycol line would be characterized by a sharp increase in flow rate.)

RESULTS

All test articles remained intact for the duration of each test. In each test, the foam insulation on the oxygen tubing was consumed at a faster rate than the water-glycol insulation. With the exception of test 1, the water-glycol flow was maintained for approximately 25 seconds of test duration. In test 1, the water-glycol flow was expended before ignition of the Uralane foam. This resulted in nitrogen flow through the test article for the duration of the test. Tests are summarized in table 8. Fire-induced rupture or burn-through was not observed in any of the tests conducted.

ADDITIONAL TESTS

Tests similar to the above will be performed on tubing containing soldered joints.

CORNER FLAMMABILITY AND IGNITION TESTS

Although the exact cause and location of initiation of the Spacecraft 012 fire is not known at this time, interest is focused on the region at the juncture of the left-hand equipment bay and the forward lower equipment bay as a possible location. In particular, it was noted that an aluminum panel at the bottom of the lower equipment bay adjacent to the corner appeared to have been struck at the lower right corner by an electrical arc. The location of the arc strike was about ⅜-inch from the end of a nylon chafing strip attached to the bottom edge of the aluminum panel and about ⅛ inch from adhesive material which extended beyond the end of the nylon chafing strip. This chafing strip was intended to protect electrical wires which passed under the bottom edge of the panel. Two tests were performed to provide information on flammability and ignition in this corner region: the corner flammability test and the corner ignition test.

OBJECTIVES OF TESTS

The specific objectives of the tests were as follows:

1. The corner flammability test was performed to determine whether a fire ignited in the chafing strip could propagate to nearby materials.
2. The corner ignition test was performed to determine if an electric arc created at the location of the arc strike found on the panel in Spacecraft 012 could ignite the nearby nylon chafing strip.

TESTS

The corner flammability test setup is shown in figure 114. The nonmetallic materials include Raschel net (nylon) and Velcro (nylon) arranged to simulate the installation of these materials in Spacecraft 012. The aluminum panel with the chafing strip is at the lower portion of the right vertical panel. The electrical wires which supplied power to the hot wire by means of which the nylon strip was ignited are shown attached to the panel at the nylon chafing strip. This test was performed in a steel boilerplate command module in oxygen at 16.5 pounds per square inch absolute.

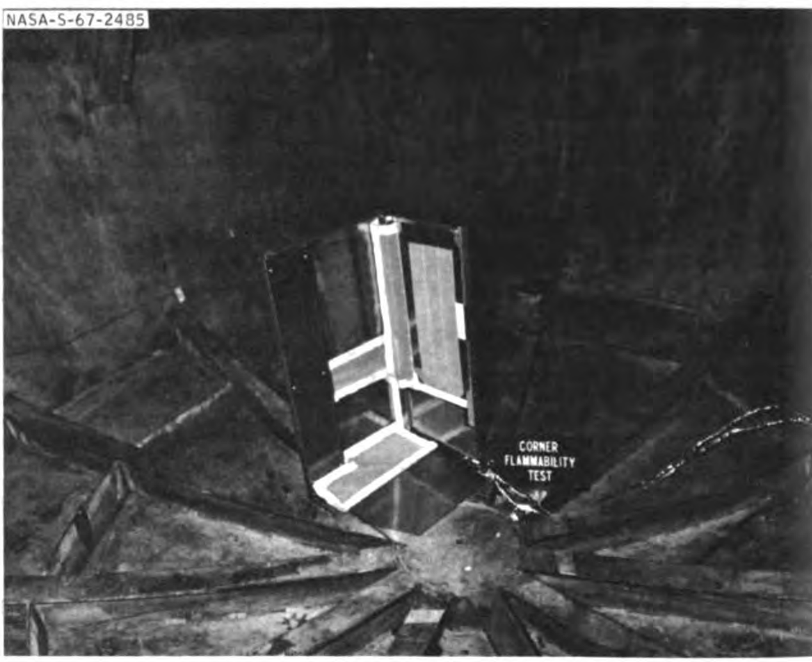


FIGURE 114

The corner ignition test was performed only with the aluminum panel with the chafing strip attached. The test was performed in a small chamber in an atmosphere of oxygen at 16.5 pounds per square inch absolute. A 20-gage (spacecraft size) wire was placed so as to pass over the corner of the panel at ⅜-inch from the chafing strip. This wire was part of a simulated spacecraft circuit. The wire was then placed in tension so as to cause the corner of the panel to penetrate the insulation of the simulated spacecraft wire.

RESULTS

In the corner flammability test, the fire deliberately ignited in the chafing strip propagated along the full length of the strip. This fire ignited Velcro placed horizontally (see fig. 114) on the structure above the panel with the chafing strip. That is, the fire "jumped the gap" of approximately 7 inches between the chafing strip and the combustible material above the panel. The fire then propagated throughout the remainder of the simulated corner.

In the corner ignition test, the insulation on the wire which passed over the corner of the aluminum panel was penetrated very quickly, an arc occurred without ignition, then a second arc occurred and all of the nylon chafing strip burned.

CONCLUSIONS

When the nylon chafing strip on the panel described was ignited, the fire propagated to other materials.

An electric arc at the location described ignited the nylon chafing strip.

CLOSING PRECAUTION

It is desired to emphasize that these corner flammability and ignition tests are not claimed to depict the cause of the Spacecraft 012 fire. The appearance of the panel with the chafing strip was not the same after these tests as the panel from Spacecraft 012. The nylon chafing strip on the spacecraft panel was melted but was not burned completely, whereas the chafing strip on the test panel was burned completely and only soot remained on the panel. Additional investigation is required.

Circuit Breaker Conformal Coating

The back portions of circuit breakers and switches on control panels contain many wire connections. All bare copper metal of the wires and attachment points on the circuit breakers and switches are coated with a silicone rubber coating (called a conformal coating) for purposes of insulation and sealing. Tests are now in progress to evaluate the fire hazard of this conformal coating.

PRELIMINARY RESULTS

Results of the first tests indicate the following:

1. If the electrical overload passes through a "correctly sized" circuit breaker, the breaker will operate and prevent ignition of the coating material.
2. A fire in the coating material deliberately created by by-passing the circuit breaker spreads to the adjacent circuit breakers and burns all of the coating on all of the breakers. In addition, the circuit breaker bodies, which were composed of a nonmetallic material, burned.

CONCLUDING REMARK

It is emphasized that the above results are based on preliminary tests. The test configuration did not represent completely the spacecraft installation, in that oxygen supply to the back of the panel in the spacecraft is limited by the enclosure of the panel, whereas in these preliminary tests the oxygen supply was not limited. Additional tests will provide more complete information and, if necessary, will be conducted to devise a means of minimizing the hazard associated with this coating.

Electro-Luminescent Panels

Tests are planned to investigate the hazard, if any, associated with the use of electro-luminescent panels on spacecraft control panels. These tests will be conducted as soon as preparations are complete.

74-521 O—67—pt. 7——3

TABLE 2.—*Materials tests summary*

[Atmosphere was oxygen at 16.5 pounds per square inch absolute]

No.	Date	Type test	Material	Results from samples			Average	Remarks
				1	2	3		
1	Feb. 2, 1967	Propagation rate, in./sec	Velcro hook, white with adhesive back.	0.71 in./sec	1.04 in./sec	0.83 in./sec	0.86 in./sec	Propagation in vertical plane downward.
2	do	do	Velcro pile, white with adhesive back.	0.49 in./sec	0.42 in./sec	0.42 in./sec	0.44 in./sec	Do.
3	do	do	Velcro pile, blue	2.77 in./sec			2.77 in./sec	Do.
4	do	do	Velcro hook, blue	0.723 in./sec			0.73 in./sec	Do.
5	do	do	Velcro hook, blue with adhesive back.		0.76 in./sec	0.93 in./sec	0.84 in./sec	Do.
6	Feb. 3, 1967	do	Velcro pile, blue with adhesive back.	2.08 in./sec	2.78 in./sec	1.67 in./sec	2.18 in./sec	Do.
7	do	do	Trilok	1.73 in./sec	2.0 in./sec	1.67 in./sec	1.80 in./sec	Do.
8	Feb. 2, 1967	do	Velcro hook, white	0.67 in./sec			0.69 in./sec	Do.
9	Feb. 3, 1967	do	Raschel net	1.38 in./sec	0.681 in./sec	0.833 in./sec	0.95 in./sec	Do.
10	do	do	Polyurethane foam with velostat cove cover.	0.926 in./sec	0.982 in./sec	0.926 in./sec	0.94 in./sec	Do.
11	do	do	Polyurethane foam	(1)	(1)	(1)	(1)	Do.
12	Feb. 4, 1967	do	Teflon cable sheathing type E7A.	Not obtained	0.032 in./sec	0.029 in./sec	0.030 in./sec	Flame not self-sustaining.
13	do	do	Rubberized horse hair, green.	5.17 in./sec	2.5 in./sec	2.38 in./sec	3.0 in./sec	Propagation in vertical plane downward.
14	do	do	Rubberized horse hair, gray	2.78 in./sec	3.33 in./sec	2.5 in./sec	2.9 in./sec	Do.
15	Feb. 7, 1967	Autogenous ignition	Velostat 3 specimens	No ignition	No ignition	No ignition		No ignition to 400° F.
16	do	do	Uralane 577-1 3 specimens	do	do	do		Do.
17	do	do	Raschel net, blue	do				Do.
18	Feb. 8, 1967	do	Silicone rubber silastic rubber clamp.	do	No ignition	No ignition		Do.
19	Feb. 7, 1967	do	Uralane 577-1 plus ethylene glycol.	Charred no ignition.	Charred no ignition.	Charred no ignition.		Do.
20	Feb. 9, 1967	do	Trilock	Melted				
21	do	do	Trilock plus MEK wash	Melted, smoked				Do.
22	Feb. 11, 1967	do	Trilock plus MEK wash	Ignited 867° F	Ignited 723° F	Ignited 727° F	706° F	No ignition to 595° F.

23	Feb. 15, 1967	Combustion rate	White cloth No. 14-0112-02	4.00 in./sec	4.26 in./sec	4.86 in./sec	4.37 in./sec	
24	do	do	Blue Velcro pile	0.825 in./sec	0.785 in./sec	1.02 in./sec	0.877 in./sec	
25	do	do	2 in. hook No. 65 white fastener.	0.77 in./sec	0.67 in./sec	0.94 in./sec	0.79 in./sec	
26	do	do	White Velcro hook		0.549 in./sec	0.61 in./sec	0.58 in./sec	
27	Feb. 16, 1967	do	Rubberized horsehair	2.5 in./sec	3.04 in./sec	1.6 in./sec	2.39 in./sec	
28	do	do	Nylon cloth MIL-C-7219B	0.421 in./sec	0.32 in./sec	0.390 in./sec	0.377 in./sec	
29	do	do	Holland cloth MIL-C-17564	0.398 in./sec	0.405 in./sec	0.428 in./sec	0.407	
30	Feb. 13, 1967	TGA flash and fire point	Grease silicone DC33	667° F	732° F	695° F	698° F	
31	Feb. 15, 1967	Autogenous ignition	Velostat	Melting at 267° F.	Melting at 207° F.	Melting at 257° F.		No ignition.
32	Feb. 13, 1967	do	Raschel net	No ignition	No ignition			Some discoloration test No. 1 to 770° F., test No. 2 to 400° F.
33	do	do	Raschel net with water-glycol RS-89-a.	(2)	(2)	(2)	(2)	Tested to 400° F.
34	Feb. 17, 1967	Combustion rate	Velcro hook, blue	0.69 in./sec	0.66 in./sec	0.66 in./sec	0.67 in./sec	
35	do	do	Velcro pile, white	2.0 in./sec	1.90 in./sec	2.0 in./sec	1.97 in./sec	
36	do	do	Fastener 2 in. pile	2.42 in./sec	2.5 in./sec	2.56 in./sec	2.47 in./sec	
37	do	do	Teflon sheet	None	None	None		
38	do	do	Polyethylene storage bag	0.80 in./sec	1.02 in./sec	0.864 in./sec	0.894 in./sec	
39	do	do	Nylon fastener 2 in. hook, blue.	0.635 in./sec	0.616 in./sec	0.722 in./sec	0.658 in./sec	
40	do	do	Nylon cloth ruck sack	0.458 in./sec	0.377 in./sec	0.358 in./sec	0.398 in./sec	
41	do	do	Nylon neoprene, yellow	0.371 in./sec	0.508 in./sec	0.400 in./sec	0.426 in./sec	
42	Feb. 28, 1967	do	Nylon window shade	0.696 in./sec	0.820 in./sec	0.744 in./sec	0.753 in./sec	
43	do	do	Mylar polyester film, type A, gray.	0.605 in./sec		0.6075 in./sec	0.6062 in./sec	
44	do	do	Velcro hook, blue with adhesive back.	0.616 in./sec	0.631 in./sec	0.608 in./sec	0.618 in./sec	
45	do	do	Nylon webbing MIL-W-4088E.	0.376 in./sec	0.337 in./sec	0.32 in./sec	0.348 in./sec	
46	do	do	100-percent nylon pile fastener.	1.775 in./sec	2.16 in./sec	2.225 in./sec	2.053 in./sec	
47	do	do	Tape GT-300	3.92 in./sec	3.12 in./sec	3.05 in./sec	3.36 in./sec	
48	do	do	Projection film PF-M4	0.596 in./sec	0.523 in./sec	0.601 in./sec	0.573 in./sec	
49	do	Combustion rate sheet	Polyethylene MIL-P-22035	0.147	0.110		0.129	
50	do	Combustion rate	Velcro hook and pile sewn together, green, pile.	2.699	2.564	2.352	2.538	Samples in series; to be rerun.
51	do	do	Velcro hook and pile sewn together, green, hook.	0.624	0.636	0.683	0.648	Do.
52	do	do	Polyurethane foam	20.0 in./sec	24.7 in./sec	25.0 in./sec	23.2 in./sec	Flash time; sample to be rerun.
53	Mar. 1, 1967	do	Mylar electrical tape	1.50 in./sec	1.58 in./sec	1.43 in./sec	1.51 in./sec	
54	do	do	Cloth tape	0.339 in./sec	0.332 in./sec	0.348 in./sec	0.339 in./sec	
55	do	do	Thermofit rigid polyolefin, clear.	0.485 in./sec	0.61 in./sec	0.466 in./sec	0.521 in./sec	

See footnotes at end of table, p. 577.

TABLE 2.—*Materials tests summary*—Continued

No.	Date	Type test	Material	Results from samples 1	Results from samples 2	Results from samples 3	Average	Remarks
56	Mar. 1, 1967	Flash and fire point	Rayon-polynosic terry cloth	325° F fire point	No fire to 400° F	390° F fire point		
57	do	do	Teflon sheet	No fire to 400° F	do	No fire to 400° F		
58	do	do	Blue Velcro hook	do	320° F fire point	do		
59	do	do	Holland cloth	do	No fire to 400° F	do		
60	do	do	Nylon coated with Velcro neoprene.	do	do	do		
61	do	do	Secondary stowage bag, polyethelene.	do	do	do		
62	do	do	White Velcro hook	do	do	do		
63	do	do	White Velcro pile	do	do	do		
64	do	do	Light blue Velcro hook	do	do	do		
65	do	do	Medium blue Velcro pile	do	do	do		
66	do	do	Nylon cloth, sage green	do	do	do		
67	do	do	Thermofit rigid polyolefin, clear.	do	do	do		
68	do	do	Nylon window shade	do	do	do		
69	do	do	Projection film PF-M4	do	do	do		
70	do	do	Mylar polyester film, type A, clear.	do	do	do		
71	do	do	Glass tape, 1 in., selvage edge.	do	do	do		
72	do	do	Butyl rubber	do	do	do		
73	do	do	Mylar electrican tape	do	do	do		
74	do	do	Epoxy sleeving	do	do	do		
75	do	do	Mystic tape	do	do	do		
76	Mar. 9, 1967	Combustion rate	Mylar type A clear polyester film.	0.70 in./sec	0.598 in./sec	0.66 in./sec	0.653 in./sec	
77	do	do	Mystic tape	1.95 in./sec	1.51 in./sec	1.33 in./sec	1.59 in./sec	
78	Mar. 16, 1967	Flash and fire point	Nylon cloth MIL-C-7219C	No fire to 370° F.	No fire to 400° F.	No fire to 400° F.		
79	do	do	Nylon webbing MIL-W-4088E.	No fire to 400° F.	do			
80	do	do	Mylar polyester film 750GA	do	do	No fire to 400° F.		
81	do	Combustion rate	Glass tape 1 in., selvage edge.	No burn	No burn	No burn		
82	do	do	Butyl rubber	0.120 in./sec	0.154 in./sec	0.122 in./sec	0.132 in./sec	
83	Mar. 14, 1967	do	Epoxy sleeving	0.176 in./sec	0.156 in./sec	0.181 in./sec	0.171 in./sec	

84	Mar. 16, 1967	do	SLP-13 sheet	2.53 in./sec.	2.94 in./sec.	2.37 in./sec.	3.61 in./sec.
85	do	do	Aclar 33-C	(3)	(3)	(3)	
86	do	do	Polyamile yarn	3.24 in./sec.	4.0 in./sec.	3.46 in./sec.	3.57 in./sec.
87	do	do	3M tape No. 474	0.559 in./sec.	0.534 in./sec.	0.515 in./sec.	0.536 in./sec.
88	do	do	Rubberized cloth MIL-I-23926.	0.32 in./sec.	0.308 in./sec.	0.308 in./sec.	0.312 in./sec.
89	Mar. 24, 1967	do	Nylon webbing MIL-W-4088E, Ty. I.	0.2017 in./sec.	0.1430 in./sec.	0.1247 in./sec.	0.1565 in./sec.
90	do	do	Nylon tape MIL-T-5038C, Ty. III.	0.236 in./sec.	0.328 in./sec.	0.236 in./sec.	0.233 in./sec.
91	do	do	Lexan polycarbonate sheet LP 393.	0.056 in./sec.	0.044 in./sec.	0.057 in./sec.	0.052 in./sec.
92	do	do	Nylon tape 101 EN 675	0.108 in./sec.	0.111 in./sec.	0.110 in./sec.	0.110 in./sec.
93	do	do	Teflon sheet AMS 3651	0.009 in./sec.	0.009 in./sec.	0.009 in./sec.	0.009 in./sec.
94	do	do	Trilock with tricot trim	0.133 in./sec.	0.145 in./sec.	0.127 in./sec.	0.135 in./sec.
95	do	do	Polyethylene film LP 378	0.579 in./sec.	0.416 in./sec.	0.556 in./sec.	0.517 in./sec.
96	do	do	Tetra flurol AMS 3650	0.0218 in./sec.	0.0125 in./sec.		0.114 in./sec.
97	do	do	Mylar sheet	0.451 in./sec.	0.470 in./sec.	0.396 in./sec.	0.439 in./sec.
98	do	do	Paper towel	5.52 in./sec.	6.56 in./sec.	5.25 in./sec.	0.578 in./sec.
99	do	do	Black linen	0.493 in./sec.	0.441 in./sec.	0.442 in./sec.	0.459 in./sec.
100	do	do	Brass zipper on nylon	0.500 in./sec.	0.357 in./sec.	0.400 in./sec.	0.429 in./sec.
101	do	do	Nylon webbing MIL-W-4088D, Ty. I.	0.187 in./sec.	0.208 in./sec.	0.216 in./sec.	0.204 in./sec.
102	do	do	Adhesive transfer tape, 3M No. 465.	0.438 in./sec.	0.420 in./sec.	0.441 in./sec.	0.433 in./sec.
103	do	do	Rubber tube GE 565	0.122 in./sec.	0.108 in./sec.	0.125 in./sec.	0.118 in./sec.
104	do	do	Foam scott 100 PPI	10.0 in./sec.	10.6 in./sec.	10.6 in./sec.	10.4 in./sec.
105	do	do	Nylon webbing P1184	0.172 in./sec.	0.254 in./sec.	0.242 in./sec.	0.223 in./sec.
106	do	do	ASTM rubber AMS 3334	0.136 in/sec.	0.138 in./sec.	0.126 in./sec.	0.133 in./sec.
107	do	do	Silastic tubing No. 52272	0.176 in./sec.	0.146 in./sec.	0.166 in./sec.	0.163 in./sec.
108	do	do	Polyethylene sheet P5466	0.126 in./sec.	0.179 in./sec.	0.111 in./sec.	0.139 in./sec.
109	do	do	10AF photographic sponge	10.0 in./sec.	9.27 in./sec.	10.6 in./sec.	9.96 in./sec.
110	do	do	Constant-wear garment	26.6 in./sec.	24.6 in./sec.	25.1 in./sec.	25.4 in./sec.
111	do	do	Bladder cloth-holland backed.	0.547 in./sec.	0.600 in./sec.	0.58 in./sec.	0.516 in./sec.
112	do	do	Nylon cloth-neoprene coated.	0.186 in./sec.	0.193 in./sec.	0.197 in./sec.	0.192 in./sec.
113	do	do	Nomek cloth P5995	0.281 in./sec.	0.286 in./sec.	0.199 in./sec.	0.255 in./sec.
114	do	do	White broad cloth P-5975	0.406 in./sec.	0.387 in./sec.	0.400 in./sec.	0.398 in./sec.
115	do	do	Perlon marquisette cloth	0.804 in./sec.	0.800 in./sec.	0.888 in./sec.	0.831 in./sec.
116	do	do	Polypenco nylon MIL-D-46060.	0.117 in./sec.	0.105 in./sec.	0.136 in./sec.	0.119 in./sec.
117	do	do	Marking foil KT-26	1.09 in./sec		1.00 in/sec.	1.05 in./sec.
118	do	do	Marking foil KT-29	1.12 in./sec.	10.955 in./sec.	0.945 in./sec.	1.007 in./sec.
119	do	do	Marking foil K-39	1.01 in./sec.	1.05 in./sec.	1.02 in./sec.	1.03 in./sec.
120	do	do	Marking foil K-36	1.09 in./sec.	0.96 in./sec.	1.17 in./sec.	1.07 in./sec.
121	do	do	Electrical tape 3M No. 64	0.271 in./sec.	0.236 in./sec.	0.261 in./sec.	0.256 in./sec.

See footnotes at end of table, p. 577.

TABLE 2.—*Materials tests summary*—Continued

No.	Date	Type test	Material	Results from samples			Average	Remarks
				1	2	3		
122	Mar. 24, 1967	Combustion rate	Clear sheet s/p-6	1.21 in./sec	1.38 in./sec	1.28 in./sec	1.29 in./sec	
123	do	do	Electrical tape 3M No. 61	0.248 in./sec	0.179 in./sec	0.156 in./sec	0.194 in./sec	
124	do	do	Electrical tape 3M No. 38	0.450 in./sec	0.463 in./sec	0.503 in./sec	0.472 in./sec	
125	do	do	Electrical tape 3M No. 28	0.705 in./sec	0.571 in./sec	0.615 in./sec	0.631 in./sec	
126	do	do	Cohrlastic silicone sponge	0.180 in./sec	0.179 in./sec	0.181 in./sec	0.180 in./sec	
127	do	do	Transfer tape 3M No. 667	0.833 in./sec	0.860 in./sec	0.754 in./sec	0.816 in./sec	
128	do	do	Acetate electric cloth tape		0.697 in./sec	0.672 in./sec	0.685 in./sec	
129	do	do	Pressure sensitive tape 3M No. 666.	0.501 in./sec	0.495 in./sec	0.613 in./sec	0.539 in./sec	
130	do	do	Polyester film 3M No. 54	0.501 in./sec	0.496 in./sec	0.613 in./sec	0.539 in./sec	
131	do	do	Thermosetting tape 3M No. 56.	1.15 in./sec	1.18 in./sec	1.18 in./sec	1.17 in./sec	
132	do	do	Flurocarbon film tape 3M No. 60.	0.598 in./sec	0.888 in./sec	0.615 in./sec	0.701 in./sec	Recommended retest.
133	do	do	Rubatex foam R-431-N	1.00 in./sec	1.00 in./sec	0.941 in./sec	0.981 in./sec	
134	do	do	Rubatex foam R-411-N	3.16 in./sec	3.316 in./sec	3.23 in./sec	3.232 in./sec	
135	do	do	Nylon tape MIL-T-5038C Ty. II.	0.740 in./sec	0.425 in./sec	0.336 in./sec	0.501 in./sec	Do.
136	do	do	Nylon tape MIL-T-5038C, Ty. III.	0.498 in./sec	0.381 in./sec	0.530 in./sec	0.469 in./sec	
137	do	do	Nylon cloth type M1-A	0.556 in./sec	0.561 in./sec	0.627 in./sec	0.581 in./sec	
138	do	do	Nylon tape MIL-T-5038, Ty. III.	0.367 in./sec	0.354 in./sec	0.341 in./sec	0.355 in./sec	
139	do	do	Preshrunk webbing No. 8947.	0.146 in./sec	0.121 in./sec	0.182 in./sec	0.149 in./sec.	
140	do	do	Webbing No. 7408	0.241 in./sec	0.380 in./sec	0.312 in./sec	0.311 in./sec	
141	do	do	Nylon tape MIL-T-8363A, Ty. III.	0. 200 in./sec	0.200 in./sec	0.208 in./sec	0.203 in./sec	
142	do	do	Stretch nylon A3583	0.514 in./sec	0.625 in./sec	0.527 in./sec	0.555 in./sec	
143	do	do	Waxed nylon tape A6820/17A.	2.28 in./sec	2.16 in./sec	1.77 in./sec	2.07 in./sec	
144	do	do	Waxed nylon tape A6820/17B.	1.50 in./sec	1.64 in./sec	1.45 in./sec	1.53 in./sec	
145	do	do	Silicone elastomer No. 420-615.	0.210 in./sec	0.275 in./sec	0.233 in./sec	0.242 in./sec	

146	Mar. 28, 1967	do	Silastic material P5455	0.299 in./sec	0.328 in./sec	0.328 in./sec	0.318 in./sec
147	do	do	White tape P600	0.265 in./sec	0.273 in./sec	0.226 in./sec	0.255 in./sec
148	do	do	Silicone rubber sheet LSAR No. 5724.	0.047 in./sec	0.046 in./sec	0.051 in./sec	0.048 in./sec
149	do	do	Single beaded tape P3242	0.242 in./sec	0.205 in./sec	0.226 in./sec	0.238 in./sec
150	do	do	Silicone rubber sponge AMS53195.	0.103 in./sec	0.103 in./sec	0.116 in./sec	0.107 in./sec
151	do	do	Sponge strip MBO-130-041	0.606 in./sec	0.610 in./sec	0.514 in./sec	0.577 in./sec
152	do	do	Polyurethane foam No. 1360.	3.00 in./sec	2.05 in./sec	2.19 in./sec	2.41 in./sec
153	do	do	Nylon mesh P1310	0.882 in./sec	0.704 in./sec	0.978 in./sec	0.855 in./sec
154	do	do	Asbestos cloth P710	0.122 in./sec	0.133 in./sec	0.125 in./sec	0.127 in./sec
155	do	do	Knitted cotton cloth P7084	31.6 in./sec	20.6 in./sec		26.1 in./sec
156	do	do	Cork sheet LC-800	0.267 in./sec	0.287 in./sec	0.297 in./sec	0.654 in./sec
157	do	do	Cotton cloth P739	0.635 in./sec	0.688 in./sec	0.640 in./sec	0.654 in./sec
158	do	do	Neoprene sponge P3113	2.00 in./sec	2.00 in./sec	1.81 in./sec	0.194 in./sec
159	do	do	White elastic tape P331	0.325 in./sec	.330 in./sec	0.329 in./sec	0.328 in./sec
160	do	do	Knitted cloth P-5709	10.0 in./sec	11.9 in./sec	9.52 in./sec	10.47 in./sec
161	do	do	Cotton cloth P-5079	22.8 in./sec	20.0 in./sec	22.2 in./sec	21.7 in./sec
162	do	do	Nylon cloth P731	0.857 in./sec	0.016 in./sec	0.111 in./sec	0.995 in./sec
163	do	do	Nylon taffeta P1266	1.481 in./sec	1.215 in./sec	1.090 in./sec	1.262 in./sec
164	do	do	Stockwell rubber P.O. 650	0.531 in./sec	0.348 in./sec	0.350 in./sec	0.409 in./sec
165	do	do	Polyurethane sponge P5477	12.50 in./sec	10.909 in./sec	11.111 in./sec	11.507 in./sec
166	do	do	Neoprene squares A502	0.188 in./sec	0.198 in./sec	0.199 in./sec	0.195 in./sec
167	do	do	Electrical tape 3M No. 56	4.70 in./sec	4.26 in./sec	4.32 in./sec	4.43 in./sec
168	do	do	Polyethylene bag P6094	1.48 in./sec	1.03 in./sec	0.869 in./sec	1.126 in./sec
169	do	do	Impregnated nylon cloth P2277.	0.845 in./sec	0.808 in./sec	0.898 in./sec	0.850 in./sec
170	do	do	Nylon cloth P728	0.837 in./sec	0.917 in./sec	0.926 in./sec	0.927 in./sec
171	do	do	Sponge backed nylon cloth P3457.	20.0 in./sec	25.0 in./sec	18.2 in./sec	21.1 in./sec
172	do	do	Ribbon P1387	0.708 in./sec	0.455 in./sec	0.423 in./sec	0.529 in./sec
173	do	do	Zanzibar mesh P4893	3.20 in./sec	3.47 in./sec	4.21 in./sec	3.36 in./sec
174	do	do	Nylon bladder cloth P711	0.487 in./sec	0.458 in./sec	0.482 in./sec	0.476 in./sec
175	do	do	Nylon ripstop cloth P1807	0.344 in./sec	0.333 in./sec	0.348 in./sec	0.342 in./sec
176	do	do	Trilock mesh P3458	0.156 in./sec	0.178 in./sec	0.250 in./sec	0.195 in./sec

[1] On all 3 samples flame propagation was too fast for visual timing.
[2] No ignition, slight discoloration.
[3] Combustion unsustained.

TABLE 3.—*Summary of conditions and results of tests on burning of tubing insulation*

Test No.	Test article		Upstream test flow orifice pressure, psig	Oxygen flow rates		Chamber pressure, psia	Water-glycol flow, lb/hr	Maximum recorded burn temperature, F.
	Oxygen	Water-glycol		Limiting lb/hr	Test flow lb/hr			
1	¼-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	⅜-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	90	10.93	1.32	Set-16.5 Max-23.8	705	1050
2	¼-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	¼-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	580	15.18	4.36	Set-15.5 Max-26.5	165	1785
3	¼-inch diameter x 0.020 wall; 304 stainless steel; foam covered.	¼-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	580	15.18	4.36	Set-15.8 Max-25.0	167	2180
4	¼-inch diameter x 0.035 wall; 6061-T6 Al; no foam cover.	¼-inch diameter x 0.035 wall; 6061-T6 Al; foam covered.	94	11.38	1.87	Set-16.0 Max-27.2	149	1925

Command Module Mockup Fire Tests (t)

NASA APOLLO PROGRAM WORKING PAPER NO. 1280

Manned Spacecraft Center, Houston, Tex.

April 3, 1967

Summary

In order to simulate the Spacecraft 012 and to provide a reference for Block II spacecraft work in the substitution of new, less flammable materials, the flammability of nonmetallic materials in the Apollo command module was investigated by igniting these combustibles in full-scale mockups of the interiors of command modules. Steel boilerplate command modules were used as test vehicles. The configurations of nonmetallic materials employed in the tests included that of Spacecraft 012 and those proposed for Block II Apollo command modules; atmospheres included oxygen at several pressures and air at normal sea-level pressure (14.7 pounds per square inch absolute). The nonmetallic material was ignited at a location which was suspected as the place of initiation of the Spacecraft 012 fire and at other locations. Data were obtained on the mode, rate, and scope of fire propagation; pressures, temperatures; and atmosphere compositions in the command modules.

In an oxygen environment at 16.5 pounds per square inch and with nonmetallic materials as used in Spacecraft 012, the rate of fire propagation was high and the extent of damage was large. In an oxygen atmosphere at 5 pounds per square inch absolute, the rate of propagation and the extent of damage were significantly decreased. The decrease in propagation rate with decrease of oxygen pressure has also been observed in tests of isolated materials samples, but the magnitude of this decrease was much greater for the full-scale mockup tests.

Negligible fire damage resulted when new, less flammable materials were substituted for Spacecraft 012 materials and ignition was made in air at atmospheric pressure. From results of these full-scale tests and individual materials tests, it is believed that by substitution of less flammable materials, the rate of propagation and extent of damage by fires can be reduced to negligible magnitudes. Also, it is believed that such fires can be readily extinguished by relatively simple methods such as the use of water or water-gel sprays.

Introduction

In order to provide the AS–204 Review Board with information on the mode, rate, and scope of propagation of the fire in the AS–204 command module (Spacecraft 012), the event was simulated in a steel boilerplate command module fitted with nonmetallic materials as used in Spacecraft 012.

Because less flammable materials will be substituted in Block II spacecraft for the nonmetallic materials of Spacecraft 012 and because the cabin atmosphere in ground tests on the launch pad may be air, it was deemed necessary to evaluate the new materials in similar full-scale tests in the boilerplate command modules with both oxygen and air atmospheres. The purpose of this report is to present the results of tests to date.

Objectives of Tests

The objectives of the tests were related to the configuration of materials and the atmospheres employed, as follows:

1. For the Spacecraft 012 materials configuration, the tests were designed to provide the AS–204 Review Board with information to support the Board investigation and to provide a reference for comparison of performance when new materials are used.

2. For new materials, the tests were designed to provide a basis for determining the reduction in flammability and fire hazard which could be achieved by use of new materials of lower flammability.

3. The tests were also designed to indicate the effect of pressure and atmosphere composition on the fire hazard associated with materials configurations as used in Spacecraft 012 and as proposed for use in Block II spacecraft.

TEST PROGRAM

The program of command module mockup tests is as follows:

COMPLETED TESTS

Test:*	*Configuration*
1A	Spacecraft 012 materials (partial simulation); oxygen at 16.5 pounds per square inch absolute.
2B	Spacecraft 012 materials (essentially complete simulation); oxygen at 16.5 pounds per square inch absolute.
3C	Spacecraft 012 materials (essentially complete simulation); oxygen at 5 pounds per square inch absolute.
4B	New materials; air at normal sea-level pressure, 14.7 pounds per square inch absolute.
5B	New materials; oxygen at 5 pounds per square inch absolute.

*The letters designate which of the three boilerplate test vehicles were used.

FUTURE TESTS

Test 2B will be repeated but with more complete simulation of spacecraft 012 nonmetallic materials. The atmosphere will be oxygen at a pressure of 16.5 pounds per square inch absolute.

Also, tests will be made in an oxygen atmosphere at 6.2 pounds per square inch absolute utilizing the best possible selection of low-flammability materials in a fire-minimization installation. These tests will include fire extinguishment by methods currently in development for spacecraft use.

TEST DESCRIPTION

In each boilerplate command module, the nonmetallic materials were placed with locations, surface areas, and masses appropriate to the test configuration. Ignition was performed at the desired location by means of a hot wire in a highly flammable material placed adjacent to a spacecraft combustible material. Motion pictures, pressure and temperature time histories, and gas samples were obtained. In each test, the cabin fan and the cabin pressure relief valve were functioning. The following paragraphs are additional explanatory comments on specific tests.

Test 1A was a preliminary test with only partial simulation of the Spacecraft 012 interior. This test will not be discussed further because subsequent tests are more meaningful.

In test 2B the materials configuration was a more complete simulation of Spacecraft 012 materials than was the simulation in test 1A. For example, the nonmetallic materials in test 2B (see table 4) duplicated more than 90 percent by weight of the visible, apparently combustible materials of Spacecraft 012. Details, such as control panels, were not duplicated in this mockup. Failure of the Spacecraft 012 pressure cabin and rupture of the oxygen line in the cabin were simulated. Ignition was made at point 1 shown in figure 115. This location is in the area in which the fire of Spacecraft 012 may have been initiated.

The nonmetallic materials employed in test 3C (see table 5) represented the flight configuration of Spacecraft 012. As shown by comparison of table 4 and 5, the major changes in materials in test 3C from test 2B are the addition of procedures books and deletion of Urathane foam pads. Failure of the Spacecraft 012 pressurized cabin structure and rupture of the oxygen line were not simulated in this test. Ignition was made at point 1 shown in figure 115.

In test 4B, new, less flammable materials (table 6) were substituted for the corresponding materials of Spacecraft 012. For example, the Raschel net (nylon) of Spacecraft 012 was replaced by Teflon cloth, and the Nomex (nylon) material of the space suit was replaced by Beta cloth (fiber glass). Other substitutions are shown by a comparison of table 5 and 6. Tables 5 and 6 also indicate

TABLE 4.—*Nonmetallic materials in mockup test 2B*

Item:	Weight (pounds)[1]
Nylon Velcro	6.35
Nylon Trilock and Raschel net couchpads	6.29
Uralane form insulation	4.74
Urathane foam pads	4.53
Procedures books	4.39
Raschel net	3.44
Nomex suit simulation	2.19
Nomex helmet bags	1.88
Nylon restraint straps	1.86
Silicone pads under wire bundle clamps	1.38
Nylon life vest harness	1.36
Nylon oxygen supply line covers	1.28
Miscellaneous	1.58
Total	41.27

[1] Teflon wire insulation, approximately 40 pounds, not included in above weights.

TABLE 5.—*Nonmetallic materials in mockup test 3C*

Item:	Weight (pounds)[1]
Procedures books	21.42
Nylon Trilock and Raschel net couchpads	6.29
Nylon Velcro	4.90
Nylon bags and tissue	4.86
Raschel net	3.44
Uralane foam insulation	2.77
Nylon life vest harness	2.75
Nylon sleeping bags	2.64
Nomex outersuit simulation	2.25
Nylon stowage bag	1.91
Nomex helmet bag	1.81
Nylon restraint straps	1.53
Silicone pads under wire bundle clamps	1.38
Nylon litter bags	1.33
Miscellaneous	4.12
Total	63.40

[1] Teflon wire insulation, approximately 40 pounds, not included in above weights.

TABLE 6.—*Nonmetallic materials in mockup test 4B*

Item:	Weight (pounds)[1]
Procedures books	21.42
Teflon couch pads	20.19
Beta cloth bag and Neoprene-coated nylon liferaft	13.09
Beta cloth outersuit with Neoprene bladder	6.57
Beta cloth life vest and Neoprene-coated nylon life vests	5.18
Teflon bags with paper tissue	5.00
Fiber glass insulation	4.07
Teflon net	3.77
Beta cloth stowage bag	3.74
Thermal and meteoroid protective garment bag	2.76
Beta cloth helmet bags	2.49
Teflon sleeping bags	1.61
Silicone pads under wire bundle clamps	1.38
Teflon and Beta cloth restraint straps	1.16
Teflon bioassembly	1.10
Beta cloth stowage bag	1.10
Beta cloth suit bag	1.00
Miscellaneous	1.61
Total	97.19

[1] Teflon wire insulation, approximately 40 pounds, not included in above weights.

that a weight increase results from replacement materials as used in Spacecraft 012 with less flammable materials. Details, such as control panels, were not simulated. The atmosphere was air at 14.7 pounds per square inch absolute. Ignition was made at points 1, 2, 3, and 4, successively (see fig. 115). Four ignition points, in contrast to one ignition point of preceding tests, were chosen because it was not expected that a large fire from one ignition point would result.

Test 5B was an exploratory test with partial use of less flammable, but not optimum, materials. This test will be repeated in the future when the new materials to be used in Block II spacecraft are identified and optimized.

Test Results

Pressure time histories, temperature time histories at various locations, and gas samples were obtained. Additional results obtained from specific tests are discussed in the following paragraphs.

TEST 2B

The mode and extent of propagation of the fire observed in this test were similar to those postulated for Spacecraft 012 on the basis of postaccident examination of the spacecraft. "Before and after" views of command module mockup 2B are presented for selected locations in figures 116 through 128. Figures 116 and 117 show the left couch before and after the test. The fire damage is very severe. Figures 118 and 119 show similar before-and-after views of the center couch, and figures 120 and 121 of the right couch. The fire damage decreases somewhat in severity from left to center to right couch. A similar decrease was observed in Spacecraft 012. The fire damage under the couches is illustrated in the "before and after" photographs of figures 122 through 128. Figure 126 also shows the opening in the "floor" (aft bulkhead) of the command module which simulated the rupture of the pressure-cabin structure.

The pressure time history for the cabin atmosphere in this test is shown in figure 129. Although complete data on pressures in Spacecraft 012 during the fire were not available, an extrapolation of partial data resulted in a pressure time history like that shown in figure 129. The peak pressure in Spacecraft 012 when the cabin ruptured is estimated to have been between 32 and 37 pounds per square inch absolute. The peak pressure in test 2B was designed to occur at 37 pounds per square inch absolute by opening a valve which permitted flow through the simulated cabin rupture (fig. 126). Temperature time histories of the metal footrests and headrests on each of the three couches are presented in figures 130 through 132 for test 2B. It will be noted that temperatures decrease from left to center to right couch. This decrease is consistent with the fire damage observed on the couches. Comparable temperature data for Spacecraft 012 are not available.

The composition of the atmosphere in the command module was determined from gas samples taken at intervals. The composition at 25 seconds after ignition, just prior to peak pressure, is presented in table 7. The atmosphere at ignition contained 92 percent oxygen, which is the same as that which was present in Spacecraft 012 at the time of the accident.

A significant mode of propagation of the fire was observed in that "explosions" of polyurethane foam and dripping liquid of burning nylon created new fire nuclei at some distances from the sources of the burning particles.

TABLE 7.—*Composition of atmosphere in test 2B at 25 seconds after ignition*

Constituent:	*Percent*
Carbon dioxide	72
Oxygen	12
Nitrogen	14
Carbon monoxide	2

TEST 3C

The fire damage to the interior of the command module in test 3C—Spacecraft 012 materials (flight configuration) and oxygen at 5 pounds per square inch absolute pressure—was substantially less than that which occurred in test 2B in which the pressure was 16.5 pounds per square inch absolute. The damage is illustrated by means of "before and after" views (figs. 133 through 141). Figures 133 and 134 show the damage to the left couch. Although the damage is considerable, it is nevertheless much less severe than that which occurred in test 2B. The damage to the center couch, shown by comparison of figures 185 and 186, is negligible. The right couch was undamaged and only the "before" view is therefore shown (fig. 187). Similar comparisons of damage under the couches are shown in figures 188 through 141. In general, the damage was confined to the left third of the crew compartment—the left-hand equipment bay (LHEB), left couch, and area under left couch.

At a pressure of 5 pounds per square inch absolute the oxygen in the boilerplate command module weighed approximately 8 pounds. Some of this oxygen was lost when the cabin vent valve opened at approximately 6 pounds per square inch absolute, the maximum pressure attained during the test. In this test the fire extinguished at approximately 2.5 minutes after ignition (see table 8).

TABLE 8.—*Composition of atmosphere in test 3C*

Time, sec.	Carbon dioxide	Oxygen	Nitrogen	Argon
T−10		90.0	10.0	
T+44	4.9	83.1	11.7	0.3
T+82	11.7	73.8	14.3	.3
T+68	15.7	71.1	12.8	.3
T+124	27.8	58.2	13.6	.3

TEST 4B

Less flammable materials (table 6) and an air atmosphere were employed in test 4B. As mentioned previously, ignition was made at four points successively. The ignition consisted of a small block of polyurethane foam in which a Nichrome wire was heated electrically. The combination of low-flammability and air atmosphere resulted in negligible damage at each of the four ignition points. Each ignition point and the damage at that point are shown in before-and-after views in figures 143 through 149. Figure 142 shows ignition point 1, which was at the lower edge of the Teflon cloth on the left-hand equipment bay. This Teflon replaced the Raschel net of Spacecraft 012. The flash bulb shown in this figure provides a timing signal. Figure 143 illustrates the damage which occurred at ignition point 1: A circular area approximately 6 inches in diameter was burned in the Teflon cloth. Similar minor damage is shown at ignition point 2, the thermal garment bag under the left couch, and at ignition point 3, on the center couch adjacent to a life vest cover and a simulated suit outerlayer. The materials of the thermal garment bag, the life vest cover, and the suit outerlayer were Beta cloth (fiber glass). Ignition point 4 was adjacent to the Beta cloth cover of a life raft in a closed metal compartment. This ignition point is shown in figure 148, and the damage which resulted after the fire in the closed compartment is shown in figure 149.

The fire at each ignition point self-extinguished some time after the ignitor polyurethane foam burned. Each of these fires were of such small magnitude that it could have been readily extinguished by relatively simple fire extinguishment means (see table 9).

TABLE 9.—*Composition of atmosphere in test 4B*

Time	Oxygen	Nitrogen	Argon
Before test	21.11	77.87	1.01
After test	21.02	77.97	1.01

CONCLUSIONS

1. In an oxygen atmosphere at 16.5 pounds per square inch absolute and with visible apparently combustible nonmetallic materials as used in Spacecraft 012, the rate of the fire propagation was high and the extent of damage was large. The results of the test in this configuration (test 2B) provided the AS-204 Review Board with significant information.

2. In an oxygen atmosphere at 5 pounds per square inch absolute and with nonmetallic materials as used in Spacecraft 012, the rate of fire propagation and the extent of damage were substantially less than in an oxygen atmosphere at 16.5 pounds per square inch.

3. Fire damage was negligible in a command module in which less flammable materials were substituted for Spacecraft 012 materials and the atmosphere was air at 14.7 pounds per square inch.

From the results of these mockup tests and of individual materials tests, it is believed that fire propagation and damage will be negligible in Apollo command modules in which materials optimized for minimum flammability are used. Such fires can be readily extinguished by relatively simple fire extinguishment systems.

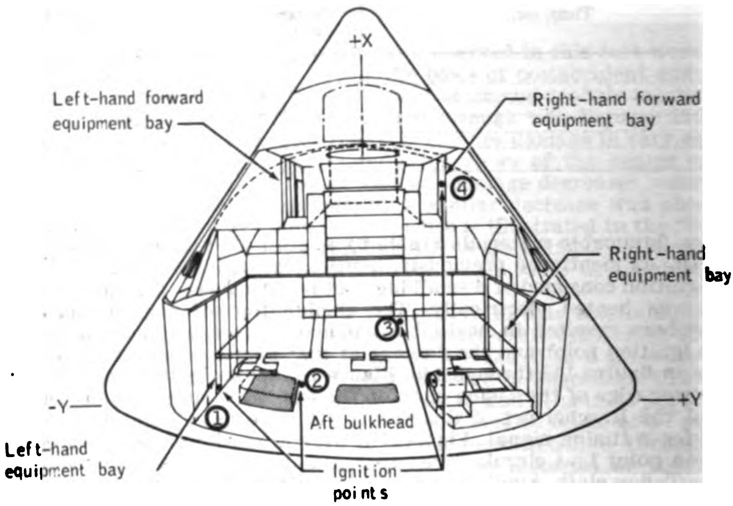


FIGURE 115

FIGURE 116

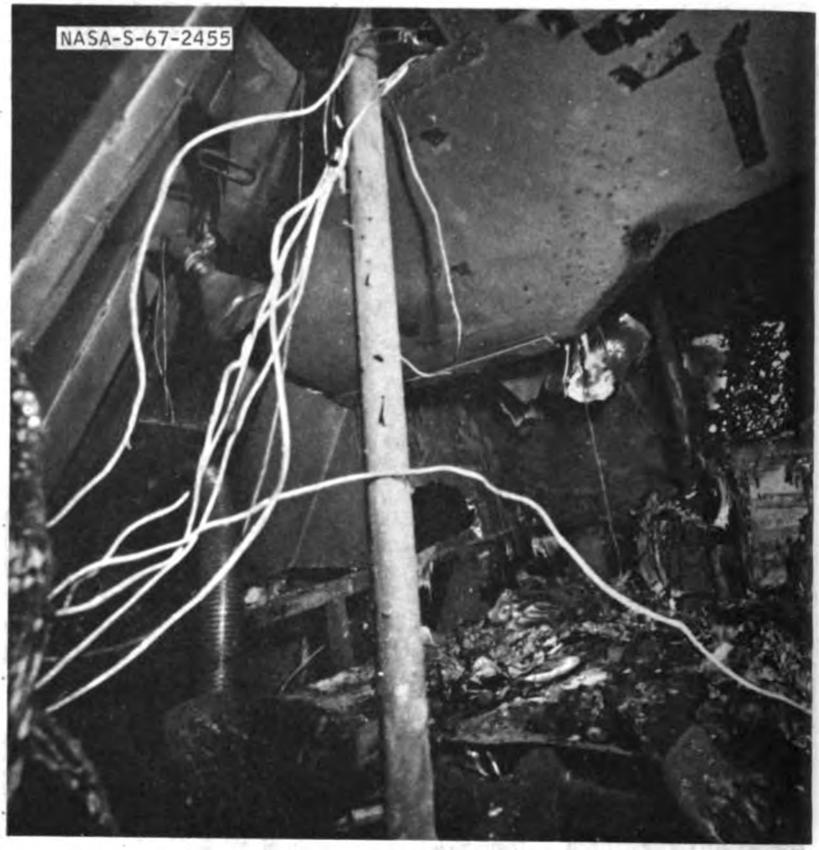


FIGURE 117

FIGURE 118

FIGURE 119

FIGURE 120

FIGURE 121

Figure 122

FIGURE 117

FIGURE 118

FIGURE 119

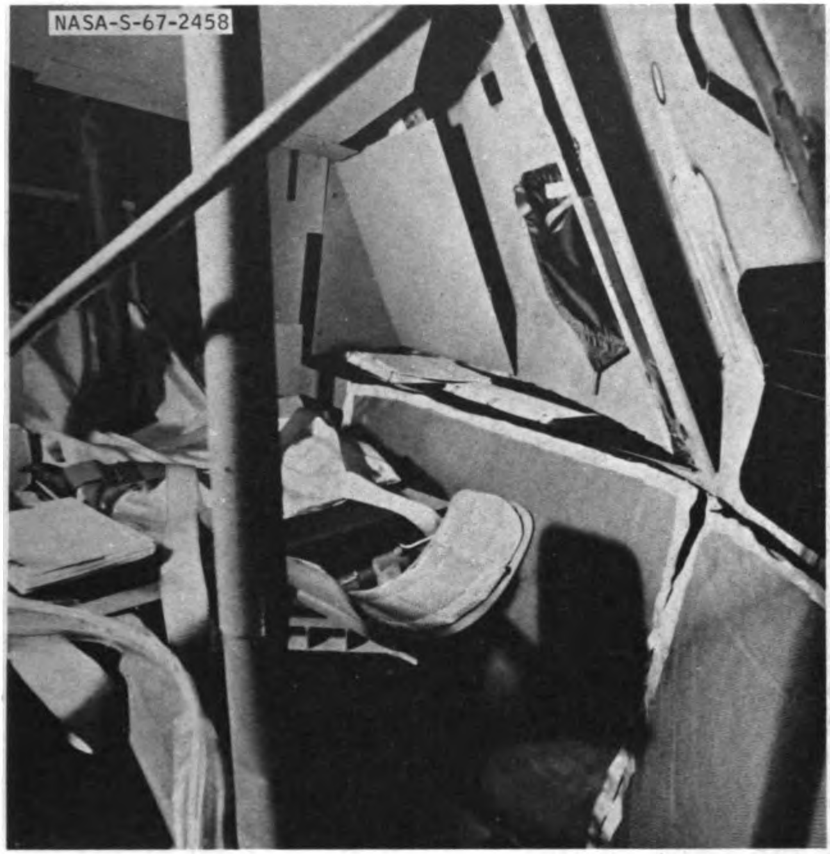


FIGURE 120

FIGURE 117

FIGURE 118

FIGURE 119

FIGURE 120

FIGURE 119

FIGURE 120

FIGURE 121

FIGURE 122

FIGURE 123

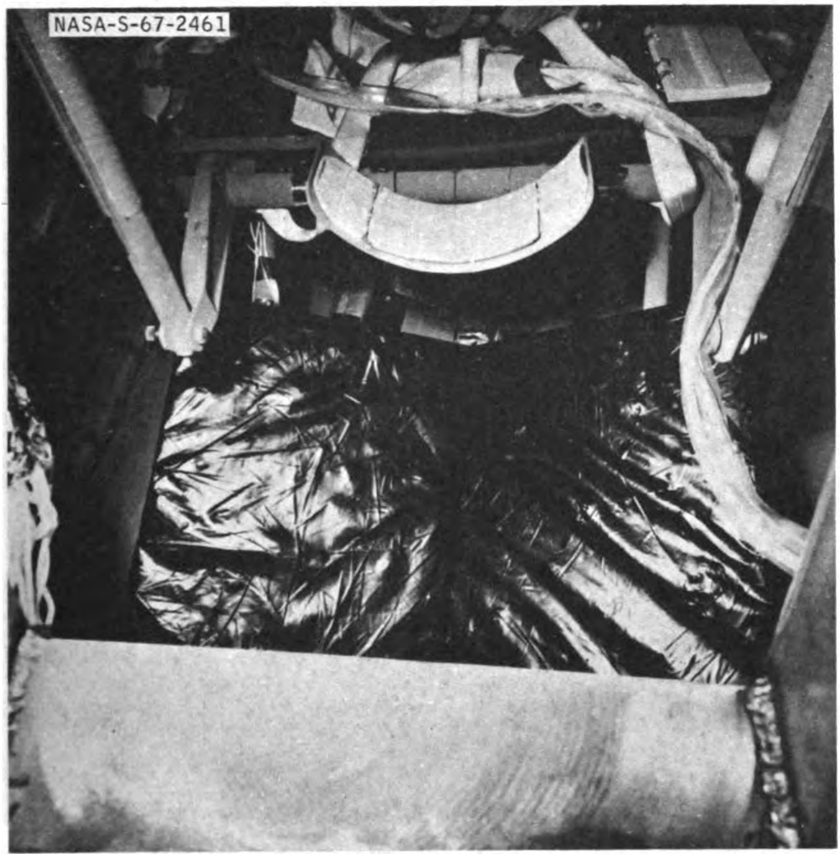


FIGURE 124

FIGURE 125

FIGURE 126

FIGURE 127

FIGURE 128

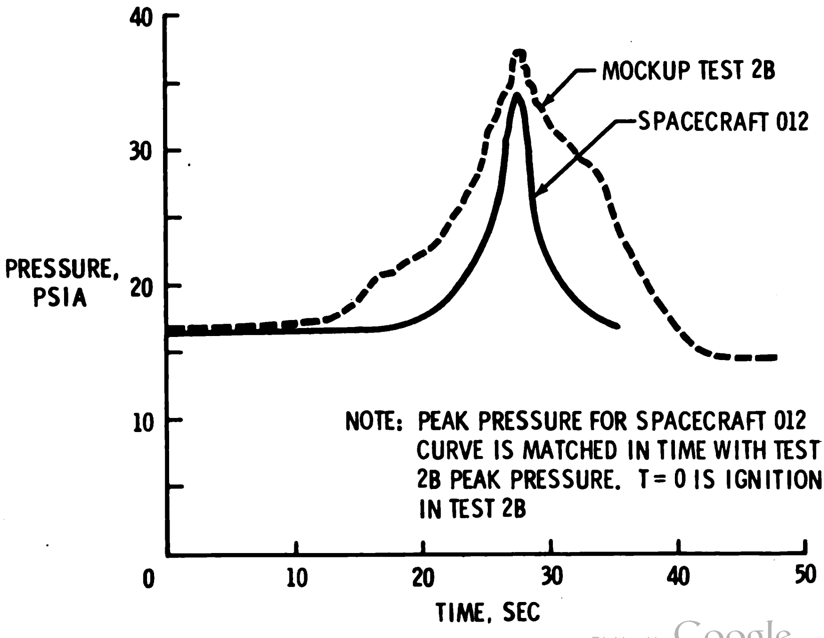


FIGURE 129

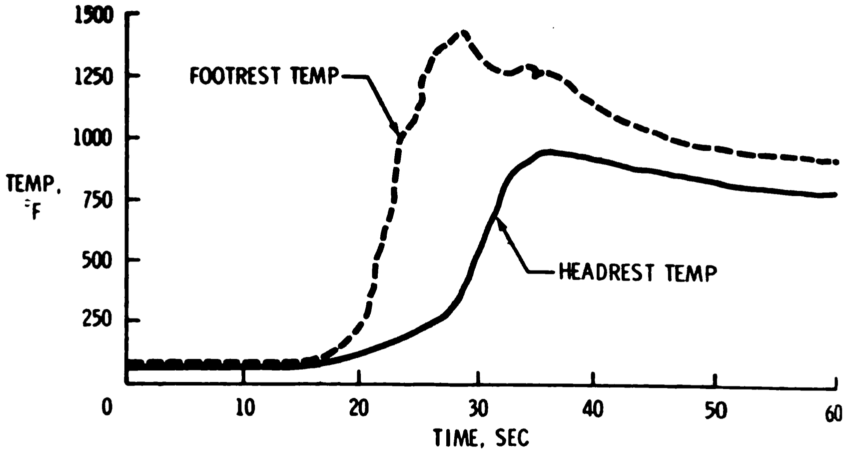


FIGURE 130

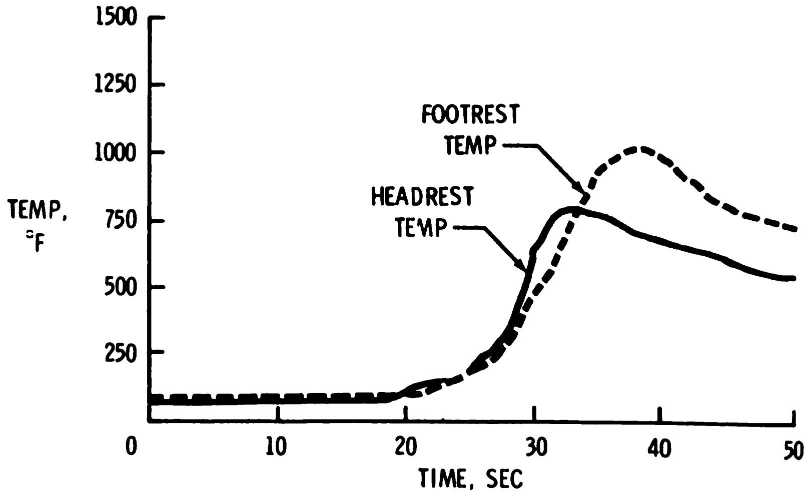


FIGURE 131

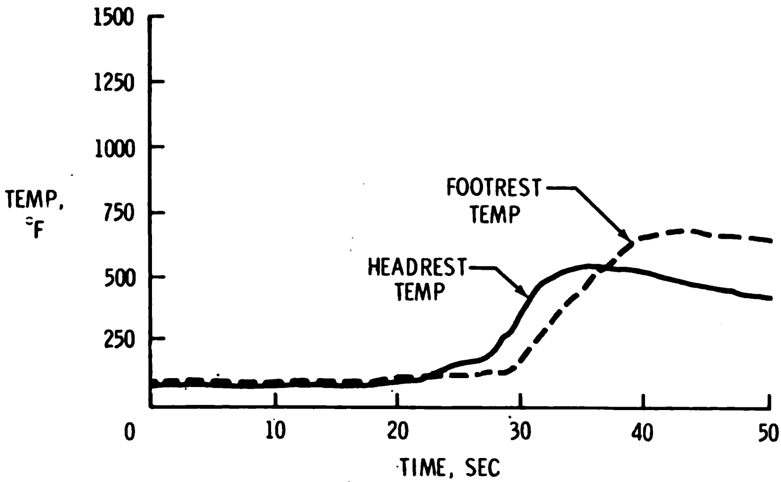


FIGURE 132

FIGURE 133

FIGURE 184

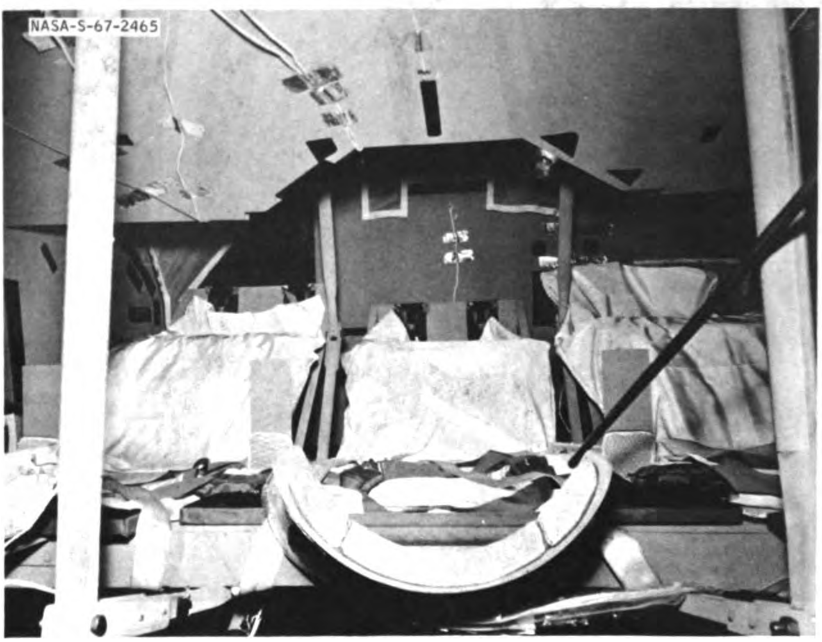


FIGURE 185

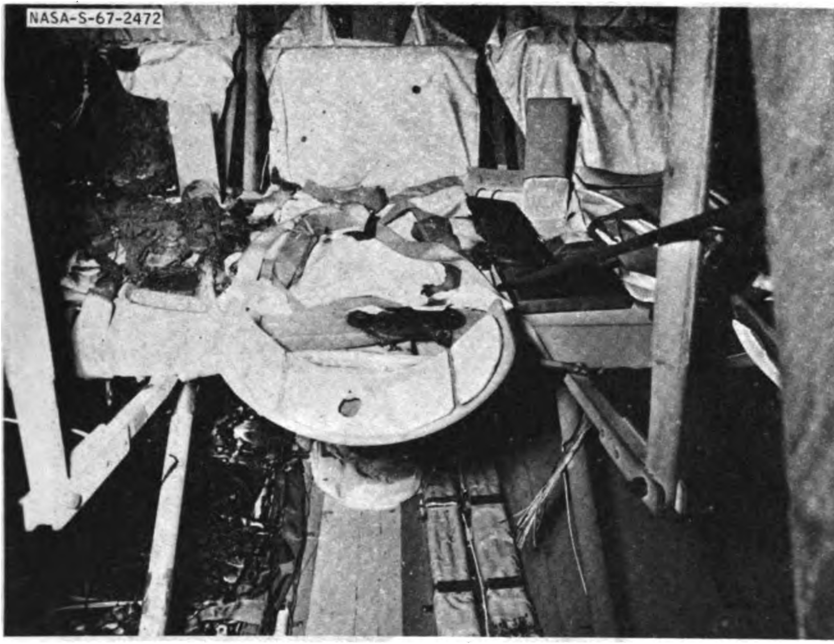


FIGURE 136

FIGURE 137

FIGURE 138

FIGURE 139

FIGURE 140

FIGURE 141

FIGURE 142

FIGURE 143

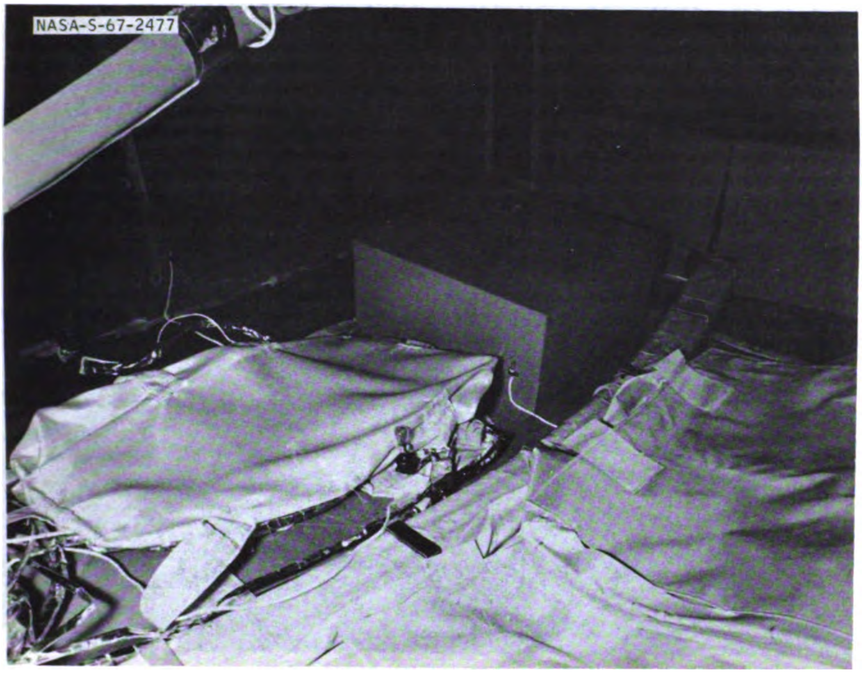


FIGURE 144

FIGURE 145

FIGURE 146

FIGURE 147

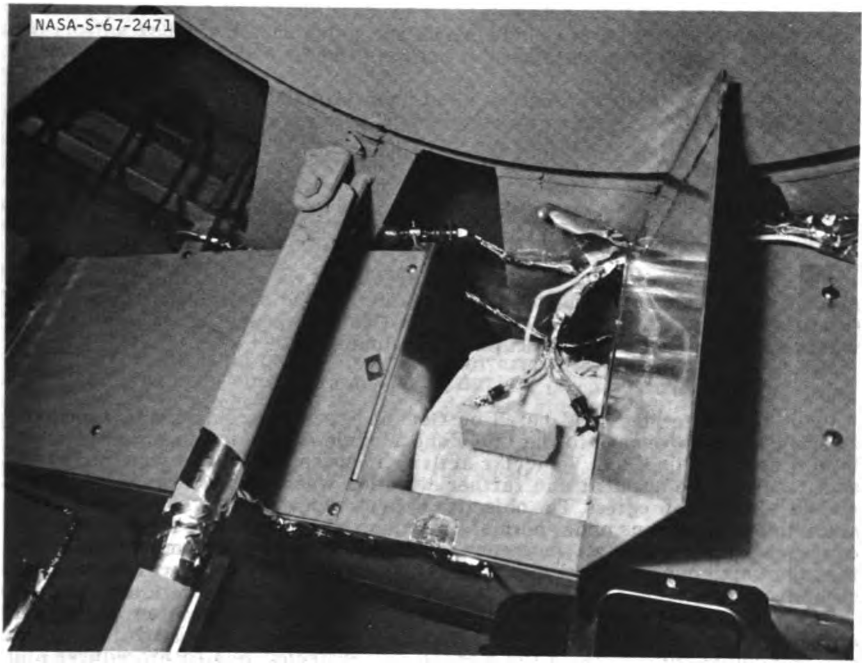


FIGURE 148

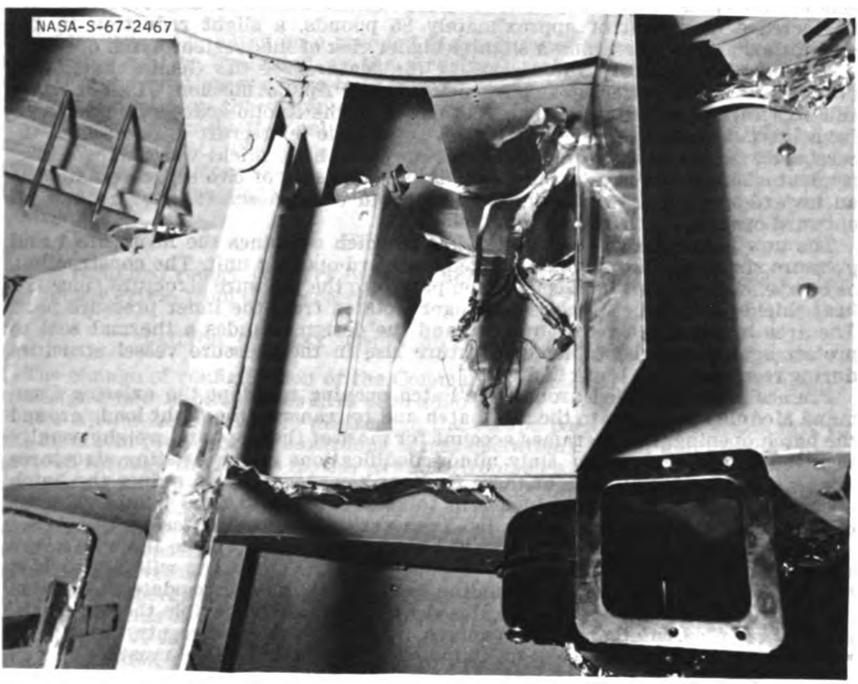


FIGURE 149

Section II

EMERGENCY EGRESS

An intense examination has been conducted of the Command Module and ground facilities design and of the procedures which affect emergency egress from the spacecraft. The tradeoffs involved in emergency egress on the pad versus safety in space have been carefully evaluated.

HATCH REDESIGN

Prior to the accident and based on Gemini experience, NASA had been considering an improvement to the Command Module side hatch in order to make it more suitable for Extra Vehicular Activity in space. This effort was intensified as a result of the accident and further attention was directed toward pre-flight and post-flight crew egress. The objective is to provide a hatch which permits safe and reliable operations under normal conditions while providing for rapid egress or rescue in the event of an emergency on the ground. The design must also insure that the hatch cannot be falsely triggered by external heat, structural loads or other operations.

The preliminary design of a new quick-opening hatch has been completed, and a mockup review has been held at the contractor's plant. NASA engineers and astronauts have operated the mockup, demonstrated related procedures and have suggested some minor refinements which are being included in the final design. The new design offers operational improvements in normal preflight, space flight, and post landing use as well as in providing the fastest possible emergency crew egress capability. The major penalties for these improvements are an increase in weight of approximately 85 pounds, a slight reduction in the size of the hatch opening, and a slightly higher risk of inadvertent hatch opening.

The new hatch incorporates some of the features of the Gemini hatch but differs due to the different requirements of the Apollo mission. High thermal and structural loads that will be experienced by the Apollo spacecraft on return from the moon were factors that led to the Apollo spacecraft design which incorporates an inner pressure vessel and an outer heat shield which move independent of one another. The old hatch design consisted of two separate hatches: an inward-opening hatch on the inside to hold the spacecraft pressure and an outward-opening hatch in the heat shield.

The new hatch design is a unified hatch which combines the heat shield and pressure structure into a single, hinged, outward-opening unit. The construction, of course, introduces a heat conduction path into the pressure structure since the heat shield part of the hatch is no longer isolated from the inner pressure part. The area involved is small, however, and the design includes a thermal seal to protect against unacceptable temperature rise in the pressure vessel structure during reentry from a lunar flight.

Frames must be added around the hatch opening to adapt the existing Command Module structures to the new hatch and to transmit the flight loads around the hatch opening. These frames account for most of the 85 pound weight penalty involved in the new design. Only minor modifications to the existing structures are required for installation of these frames; however, they do reduce the hatch opening approximately three inches in total width and in total height. The acceptability of the reduced opening has been verified in mockup tests.

When closed, the hatch will be locked by its mechanism to the inner pressure vessel and will float with respect to the outer shell. A small gap will be provided between the hatch and the surrounding heat shield to accommodate the motion of the two shells. This gap will be closed with two sets of flexible thermal seals, such as are used on other small openings, in order to prevent reentry heat penetration. The inner seal between the hatch and the pressure vessel must, of course, hold the pressure with a minimum of leakage and must be capable of opening and closing reliably for carrying out Extra Vehicular Activities in space. The same type of rubber seal which was used in Gemini to meet these requirements will be used on Apollo.

The proposed new hatch also contains a window to provide crew visibility both in flight and on the ground. This window provides an additional means of monitoring the activities of the crew during any hazardous testing, and of course, lets the flight crew see any ground crewmen who could be standing in front of the hatch. On designated missions, it will be possible to replace the window assembly with a small airlock so scientific experiments can be exposed to space without depressurizing the spacecraft.

One of the tradeoffs of much concern to NASA is the requirement for quick opening of the hatch in an emergency versus the possibility of an inadvertent opening which would expose an unsuited crew to the vacuum of space. During an Appollo mission the crew plans to be working without their spacesuits for long periods of time. The present hatch opens inward and is sealed by cabin pressure so there is no possibility of an inadvertent opening. The proposed unified hatch will open outward and will be held in place against the cabin pressure by a set of latches. The latches, which are almost identical to those used in Gemini, are a self-locking, overcenter design and can be released only by a manual drive assembly. The latches provide adequate mechanical advantage to permit a crewman to unlatch and open the hatch in spite of internal pressures.

OPERATION OF PROPOSED HATCH

When the hatch is closed, the latches will operate to seal the hatch against the inner frame. In order to open the hatch, either the right-hand or center crewman simply reaches over his shoulder and operates the handle. This releases the latches in less than five seconds. During ground tests the hatch will be opened automatically. Operation of the spacecraft hatch will also push away the Boost Protective Cover hatch when it is installed for launch. In case there is a need to enter from the outside, either on the ground or in space, a handle is provided which will unlock the latches and release the door.

TEST

Before using the hatch on a manned flight, it must be thoroughly tested. The new hatch will be evaluated on the structural test spacecraft. Flotation tests will be rerun and crew egress tests will be conducted to demonstrate the capability to operate on the water after a landing from space. The new hatch will also be installed in the thermal vacuum ground test vehicle, 2TV-1, before testing begins on it at MSC. The thermal seal portion of the new hatch will be tested on the unmanned mission AS-501. It is also planned to verify the new hatch concept in a test on the unmanned mission AS-502.

ADDITIONAL DATA

The technical report (p. 611) provides additional technical details concerning emergency egress from the spacecraft.

LAUNCH COMPLEX DESIGN CHANGES FOR RAPID EGRESS

The change of configuration of the Command Module hatch makes it necessary to design a new Apollo Access Arm hood adapter.

The Apollo Access Arm is utilized as the escape path from the spacecraft to the umbilical tower for all hazardous egress operations. Flight and ground crews proceed through the Apollo Access Arm Environmental Chamber to the umbilical tower as the first step in the egress operation. Any difficulty experienced in this phase of operation may endanger the total hazardous egress operation. Consequently, the egress capability of the existing Apollo Access Arm was reevaluated to assure compatibility of design with intended operation. This reevaluation resulted in several design changes which will improve the egress capability.

Previous operating procedures provided for retraction of the Apollo Access Arm at T minus 30 minutes. Approximately 49 seconds was required for extension and remate of the Apollo Access Arm with the Command Module from the retracted position with the previous configuration. This time was compatible with the previous Command Module hatch opening time.

The mechanism of the Apollo Access Arm will be modified to permit retraction to a park position after Command Module closeout. From this park position, the Apollo Access Arm can remate with the Command Module within approximately 12 seconds with the hatch in any position between full open and closed. This will provide an egress path through the Apollo Access Arm, across the umbilical tower to the egress elevator. Positioning of the Apollo Access Arm in the park position will still allow utilization of the Launch Escape System abort capability.

OTHER LAUNCH COMPLEX IMPROVEMENTS

Additional improvements will provide a larger egress path by removing or covering protrusions and elminating some steps along the path. These changes will reduce the time for egress operations either in the aided or unaided mode.

Double swinging doors will replace the two present Apollo Access Arm doors to assure capability for rapid movement in either direction.

Control of fire

Improvements are also being made in fire fighting and fire suppression capabilities. Dense smoke concentration in the environmental chamber is a major deterrent to any rescue or emergency egress effort. To enhance the capability for removal of smoke of toxic fumes in the Apollo Access Arm Environmental Chamber, a positive ventilation system will be provided. This modification will provide additional safety for egressing crew members. It will be used in conjunction with the existing Command Module conditioned air supply to provide air circulation in the Command Module and Environmental Chamber if needed.

Lighting

Additional lighting will be provided in the hood adapter of the Apollo Access Arm to improve illumination at the Command Module hatch area. An automatic, battery-powered backup lighting system was considered. This concept was discarded because of the high weight and low output of such units. However, portable battery-powered backup lighting will be provided at strategic locations. Additional hood adapter lighting, connected to the critical power source, will assure continuous power during egress operations. The existing power supply in the Apollo Access Arm Environmental Chamber will be supplied from the critical power bus. These changes will provide reliable backup systems since critical power is automatically switched to another source in the event of a power failure in the primary source.

Materials

All materials in the Environmental Chamber and along the egress path were examined for flammability characteristics. A few changes are required. KSC designers are taking advantage of the recent MSC materials studies in the selection of fire retardant materials.

New fire resistant bellows for the Environmental Chamber will be provided. These new bellows will be made of fiberglass cloth coated with silicone which will withstand temperatures of 500° F. continuous and 2,000° F. for ninety seconds. Although not flammable, it was determined that the paint inside the Environmental Chamber would produce smoke at a relatively high temperature (500°–600° F.); consequently, the interior will be coated with a higher temperature paint to preclude the generation of smoke.

CABIN EGRESS (T)

NASA APOLLO PROGRAM WORKING PAPER NO. 1217

MANNED SPACECRAFT CENTER, HOUSTON, TEX.

April 3, 1967

SUMMARY

A detailed preliminary design of a single outward-opening hatch to replace the existing two-piece command module hatch system has been completed. The design uses existing materials and manufacturing processes. Critical components in the hatch design are similar to design concepts which have already been successfully employed on the Gemini and Apollo spacecraft. Compatibility with the already manufactured command modules can be assured by the use of add-on adapter frames which convert the existing hatch opening to the new design. The ground and flight test requirements for qualification have been identified and a program using existing command module test articles has been defined.

The new design can provide operational improvements in normal preflight, space flight, and postlanding use as well as insuring the fastest possible emergency crew egress capability. The major penalties associated with the new hatch design are a weight increase of approximately 85 pounds, a reduction in the size of the hatch opening, and a higher probability of inadvertent hatch opening. The command module has adequate design margins to accommodate the weight and hatch size penalties. Protection against inadvertent opening is provided by the over-center latch design. The design, analyses, and program planning which have been accomplished assure that the new design could be implemented with minimum developmental risk.

INTRODUCTION

A design effort to simplify the operation of the Apollo command module hatch was initiated late in 1966 as a result of the extravehicular activity experiences in the Gemini program and testing of the command module hatch in an aircraft simulating the space-flight zero-gravity environment. This activity was primarily directed at achieving a hatch design suitable for space flight utilization (extravehicular activity). As a result of the Apollo 204 accident of January 27, 1967 this effort was intensified and emphasis placed on emergency crew egress as well as space flight utilization. A number of conceptual designs were considered. After a comparison of the more promising concepts, a design, identified as the "unified hatch" during the conceptual phase, was selected for further study. The preliminary design was completed, a development test plan was defined, and a mockup review was conducted. This report describes the design, its operation, and the development test program required to qualify the design for manned ground testing and space flight.

HATCH DESIGN

The selected hatch concept replaces the present two-piece command module hatch system (outward-opening heat shield hatch and inward-opening pressure hatch) with an outward opening single hatch and two adapter frames for the conversion of the presently built structure to the new hatch. Figure 150 depicts the conceptual design identifying the major components.

HATCH STRUCTURE

The hatch structure is a laminated unit consisting of three layers bonded together. The inner layer is a machined aluminum structure which seals the cabin and has been designed to withstand the pressure loads encountered during the mission. The center layer is a fiber glass substructure which is filled with insulation and provides thermal isolation between the aluminum structure and the outer heat shield layer. The outer layer is an ablative-type heat shield and is identical to that employed on the major portion of the command module. A typical cross section through the hatch edge is shown in figure 151. Thermal analysis of the performance of this construction assures that the design provides adequate entry heat protection. The standard command module thermal criteria of 600° F. at the ablator-to-substructure bond line and 200° F. at touchdown for the aluminum structure are not exceeded, as shown in figure 152. The hatch construction falls within the existing technology and uses standard materials and manufacturing processes employed on the command module.

The command module primary (pressure) and heat shield structures move relative to each other under thermal loading and require that a gap be provided between the hatch heat shield (which is attached to the hatch structure) and the surrounding crew compartment heat shield. The gap is sized for the maximum relative motion which may be encountered. Flexible thermal seals are attached to the hatch periphery to close the gap and seal the entry thermal flux from the aluminum primary structure. Two seals, either of which is capable of providing the required protection, are provided for redundancy. Analysis has indicated that these seals will remain well within their temperature limits during entry from the lunar mission as shown by figure 153. Additional confidence is gained by their similarity to seals used on other heat shield joints which have been successfully tested on AS-202 (Spacecraft 011).

A large viewing window is mounted in the center of the hatch. Figure 154 shows the cross-section installation. The window consists of a frame, two pressure panes, a heat shield pane, and a micrometeoroid pane. The design is the same as that employed for other windows on the Block II command module. This design, except for the micrometeoroid pane, has been successfully flight tested on several vehicles including missions AS-201 (Spacecraft 009) and AS-202 (Spacecraft 011). The micrometeoroid pane has been added to the Block II command module as additional protection against the micrometeoroid environment of the lunar landing mission. On designated mission, it will be possible to replace the window assembly with a small airlock to permit the conducting of certain types of scientific experiments without depressurizing the crew cabin.

ADAPTER FRAMES

Two adapter frames are provided to modify the existing command module heat shield and pressure structures for accepting the hatch. The major portion of the approximately 85-pound weight penalty for the new hatch installation is in these frames which are designed to provide structural continuity for transmitting the primary structural loads around the hatch opening without transmitting tension or compression loads to the hatch. This concept does not require structurally interlocking the hatch and frames in the tangential direction and permits the provisioning of adequate allowances for structural and thermal deformations without impairing hatch operation. A heat resistant steel outer frame is mechanically attached to the existing heat shield substructure. Modifications to the existing heat shields are limited to the machining of the existing frame to remove the tongue and groove and the local removal of the ablator. The steel frame is bolted and/or riveted to the steel substructure, and molded ablator is then bonded and bolted to the exterior surface and edge of the frame. Figure 155 shows cross sections of the existing heat shield and the modified heat shield. The materials and manufacturing processes are consistent with the existing heat shield construction and do not require the development of new technology.

A machined aluminum inner frame is bolted and sealed to the existing pressure hatch frame. It contains the seal for the new hatch and transmits the primary body loads around the hatch opening. The only modification to the existing structure is the addition of bolts at the bottom edge. Figure 156 shows a typical cross section through the inner frame. The adapter frame is machined to mate the existing structure using numerically controlled milling machines in the same manner as the previous pressure hatch frames. The pressure seal design and materials are the same as those successfully employed for the Gemini hatch seal.

The installation of this frame reduces the clear opening available for ingress and egress from that which was previously provided by the two-hatch system. This reduction is necessary to provide a seal for the outward-opening hatch and to provide the required structural strength in the frame. Minimum hatch size requirements are established by the space-flight extravehicular activity requirements when the crewman is wearing a pressurized space suit and portable life support system (back-pack) and by the emergency crew egress considerations. The reduced hatch opening is shown in figure 157. Its acceptability has been demonstrated by the use of mockups at MSC and North American Aviation.

Hatch Mechanism

A mechanism is mounted to the hatch structure for locking the hatch to the surrounding frame to seal the command module cabin. The mechanism consists of an operating lever and drive assembly, latches and drive linkage, hinges and door deployment mechanism, and the boost protective cover actuator assembly. Major elements of the hatch mechanism are identified in figure 150.

Internal and external operating levers are provided to permit rapid manual locking and unlocking of the latches through a gear box and the connecting drive linkages. The internal lever is located over the shoulders of the center and right-hand crewmen and may be operated by either crewman lying in his couch. The lever is ratcheted and will require only two or three strokes to fully operate the latches. The external operating lever permits latch operation by either the ground crew or an extravehicular flight crewman. The latches and drive linkages provide a hatch lock for pressure loads and for sealing the cabin. These latches employ an overcenter self-locking design similar to those successfully employed on the Gemini hatch and the Block II command module heat shield hatch. They are larger than the latches used on Gemini and are sized by conservative preliminary analysis of the hatch growth and distortion due to the temperature changes encountered during use of the hatch for space flight extravehicular activities.

The hinges and door deployment mechanism provide support and restraint for the hatch when the latches are unlocked. They permit the hatch to open approximately 100 degrees and lock the hatch in the open position. Manual release of the deployment mechanism lock is required to close the hatch. The hinges are designed as four-bar linkages and are identical in concept to the hinges previously developed for the Block II heat shield hatch, the only difference being size and the detailed attachment to the hatch frame.

The hinge kinematics permit the hatch to move radially outboard until the hatch clears the heat shield frame and then rotate to the open position. Since the hatch motion at seal contact is in a radial direction, the effects of any hatch distortion are minimized and equally shared by opposing latches.

A boost protective cover actuator assembly will be provided and will be operated by the hatch operating levers and gear box. This assembly will provide a plunger type of motion through the hatch to unlock the boost protective cover hatch mechanism. The actuator is not depicted, as its location and design are not defined. A similar function was mechanized through the Blocks I and II heat shield hatches and had been successfully ground and flight tested.

Auxiliary closing devices will be provided to permit closing and retaining the hatch in the event of a failure such as a jammed mechanism or excessive thermal warpage during space flight hatch use. These provisions are basically three bolts and wing nuts which may be attached between the hatch and inner adapter frame and manually tightened to secure the hatch in place. They will retain the hatch suitable for entry heat protection and limited postlanding water integrity but will not necessarily be adequate to allow cabin pressurization. A conceptual representation of these provisions is shown in figure 158.

Boost Protective Cover Hatch

The requirements for a boost protective cover have been re-examined to determine whether the boost protective cover could be eliminated or whether a different design approach should be employed. This has resulted in a tentative decision to retain the existing design. Primary reasons for retention of the boost protective cover concept are to protect the heat shield thermal control coating and windows during boost and to save effective spacecraft weight by jettisoning the heat protection required for boost. The thermal control coating assist the environmental control system in maintaining spacecraft temperature control and limits the temperature extremes of the heat shield during spaceflight thereby eliminating an ablator cracking problem. A hatch is provided in the boost protective cover to correspond with the command module hatch and is installed at cabin closeout (approximately T minus 30 minutes) during the final countdown. The boost protective cover, including its hatch, is jettisoned by the launch escape system after ignition of the second stage of the launch vehicle.

The boost protective cover hatch design is being modified for compatibility with the new command module hatch. It is similar to the previous design which has been successfully developed and tested. Modifications are limited to the relocation of the latch drive mechanism and the addition of an integral external operation lanyard, a window, and provisions for operation of the command module hatch mechanism without requiring removal of the boost protective cover hatch. A conceptual representation of the hatch is included in figure 159.

The boost protective cover hatch will not impede crew egress, as it will be unlocked by the operation of the command module hatch mechanism and opened as the command module hatch is opened.

Hatch Operation

The selected hatch design provides simple manual operation for normal crew ingress and egress, emergency crew egress, or the rescue of an incapacitated flight crew. Hatch operation will normally occur only after the cabin pressure has been equalized to the surrounding atmosphere. For emergency egress, however, it is not necessary to equalize the pressures. The crewmen can simply reach above his shoulder and engage and operate the lever to release the hatch. The outward opening hatch will automatically relieve any cabin pressures above the surrounding atmosphere. External ground support equipment to aid hatch opening will be attached for altitude chamber and launch pad preflight testing. This equipment will effectively counterbalance the hatch weight and open an unlatched hatch. External ground support energy absorption will be provided to attenuate the hatch opening energy for cases of high internal pressure.

Crew procedures for emergency egress will be defined so that the right-hand crewman releases the hatch and it is opened by the external aids while the center crewman is preparing to egress from the cabin. The hatch will require approximately 5 seconds and will be fully open by the time the center crewman has released his restraint harness and space suit umbilicals. This concept will accomplish hatch opening in parallel time with other egress procedures and insures the fastest possible egress time. If the right-hand crewman is incapacitated, the center crewman can, of course, open the hatch. During the preliminary design phase, consideration was given to the use of an emergency pyrotechnic actuator to unlatch and open the hatch. It could not, however, reduce the egress time and had the disadvantage of possible inadvertent hatch opening; therefore, it has not been included in the design. These procedures have been reviewed using the mockup at the contractors plant. Figures 160, 161, 162, and 163 are photographs of the mockup.

Hatch Test Program

An extensive ground and flight test program would be required to qualify the new hatch design for manned flight. The major elements of a test program to accomplish this qualification are described in the following notes.

GROUND TESTING

Spacecraft 004.—Spacecraft 004, a Block I command module used for structural testing, will be modified by the installation of the command module and boost protective cover assemblies. Basic mechanism and seal qualification will be accomplished on this spacecraft and include seal leakage, latch operation and cycling, strength at elevated temperature, and emergency opening. Verification of emergency opening at the differential pressure extremes will be accomplished since it is a constraint to manned ground testing in a closed command module.

Spacecraft 2S-2.—A hatch assembly will be installed on Spacecraft 2S-2, the Block II command module static loads test article. Ultimate pressure and abort static loads tests, the critical conditions for the primary and heat shield structures, will be performed on this spacecraft. These tests will verify the capability of the inner and outer adapter frames to transmit the structural loads around the hatch opening.

Spacecraft 007A.—Spacecraft 007A, the Block II postlanding and egress verification command module, will have a hatch installed to make it suitable for manned testing. As a schedule expedient, it will be used for vibro-acoustic testing to verify compatibility of the hatch design with the launch environment. After completion of the vibro-acoustic testing, this spacecraft will be used for postlanding and egress verification.

Spacecraft 2TV-1.—Spacecraft 2TV-1 will be modified by the installation of a hatch assembly. The installation will provide an emergency egress capability during manned thermal-vacuum testing at MSC. Hatch operation will be tested in the simulated space-flight thermal-vacuum environment to determine the effects of thermally induced dimensional changes on hatch opening and closing. Maximum differential temperature and cold and hot soak conditions will be included in this testing.

Zero-gravity testing.—The zero-gravity test fixture will be modified and utilized to verify crewman operation of the hatch in a zero-gravity environment and for crew training. A KC-135 will be used for simulated zero gravity and water tank neutral buoyancy.

FLIGHT TESTING

Mission AS-501.—Spacecraft 017 will be modified by replacing the hatch window with an instrumented test panel. This panel will contain simulations of the flexible thermal seals and gaps between the hatch and surrounding heat shield. Successful completion of this test will qualify the seals, which are the critical element of the heat protection, for the entry heating environment which will be experienced in the Earth's atmosphere at the completion of the lunar mission.

Mission AS-502.—Spacecraft 020 will have a complete hatch assembly installed and will qualify the hatch for the flight environments.

CONCLUSIONS

The feasibility of replacing the existing command module two-hatch configuration with a single outward-opening hatch has been firmly established by the preliminary design effort. This concept provides operational improvements for normal preflight, space-flight, and postlanding use, as well as crew emergency egress. The major penalties for this concept are an increase in command module weight of approximately 85 pounds, a reduction in the hatch opening, and an increased probability of inadvertent hatch opening. The command module design has adequate margins to accommodate the increased weight and the reduction in hatch size has been found to be acceptable. Protection against inadvertent hatch opening can be provided by using overcenter latches which can be released only through the manual drive assembly. The outward-opening feature, combined with the mechanical advantage of the overcenter latches, can enable manual hatch opening for large differential pressures.

The detailed design can be developed such that no new materials or manufacturing processes are required and that the existing technologies are applicable. The latches, hinges, pressure seal, thermal seals, and heat shield are either identical or similar to designs which have been successfully used on the Gemini and Apollo spacecraft. The design, analyses, and program planning which have been accomplished to date assure that the design described in this report could be successfully employed as the command module hatch.

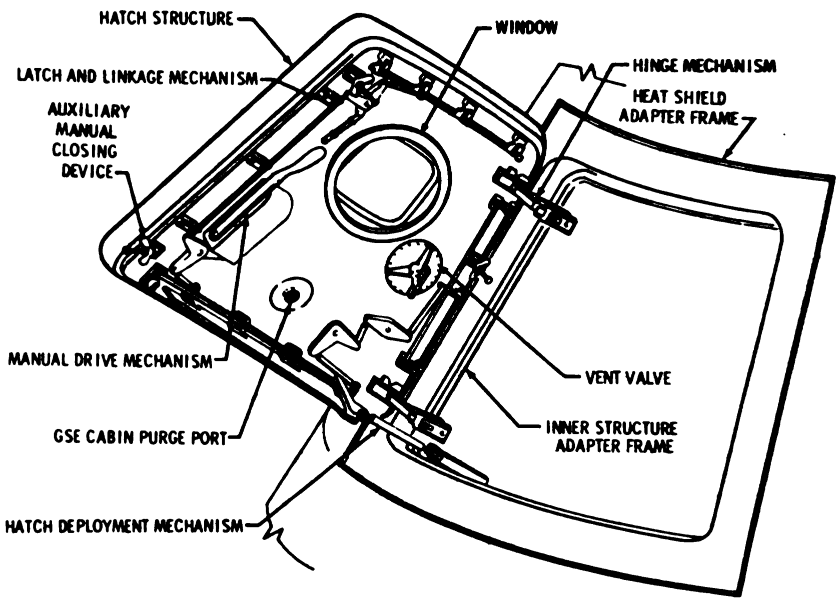


FIGURE 150

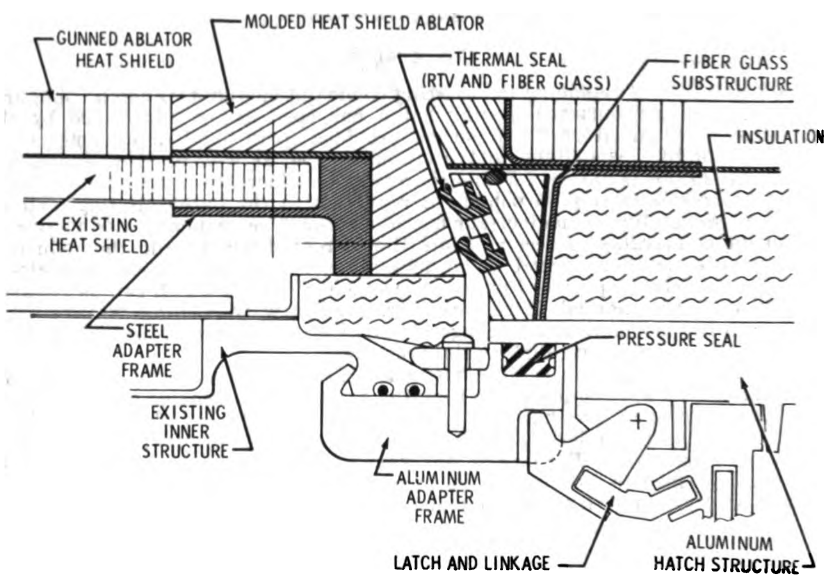


FIGURE 151

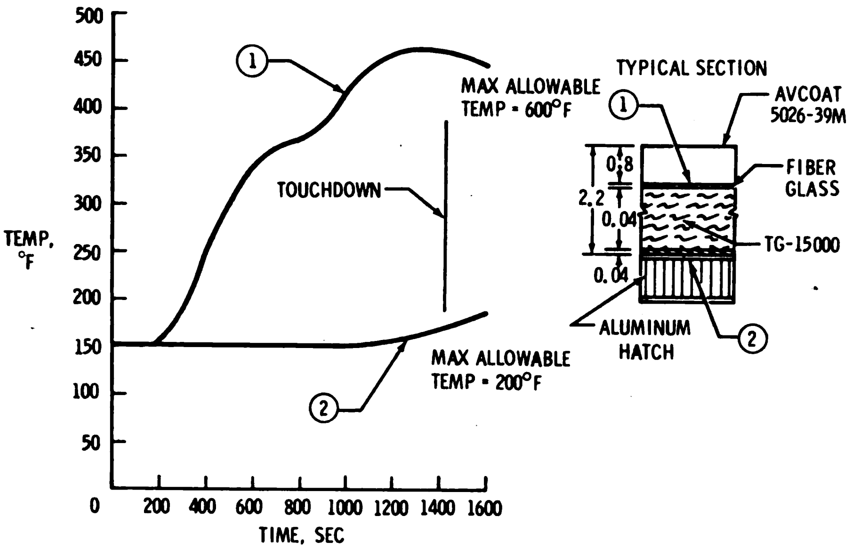


FIGURE 152

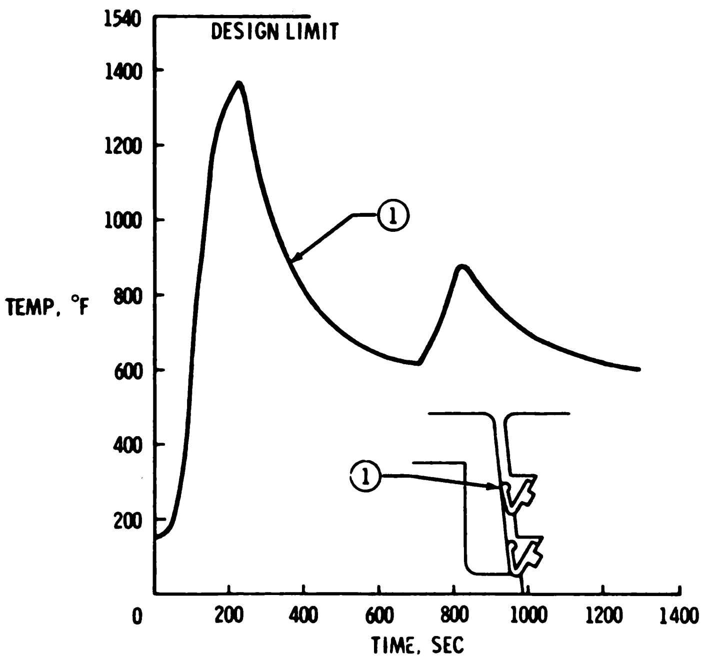


FIGURE 153

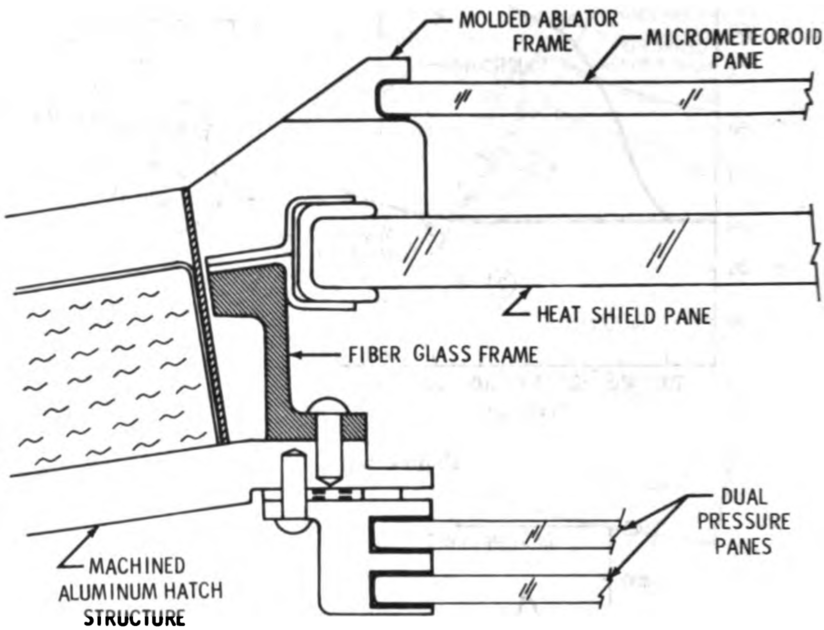


FIGURE 154

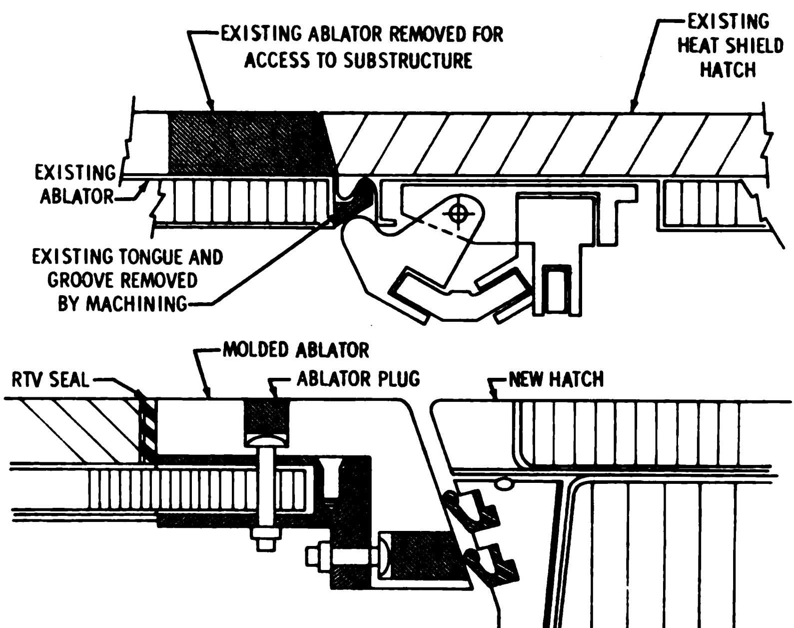


FIGURE 155

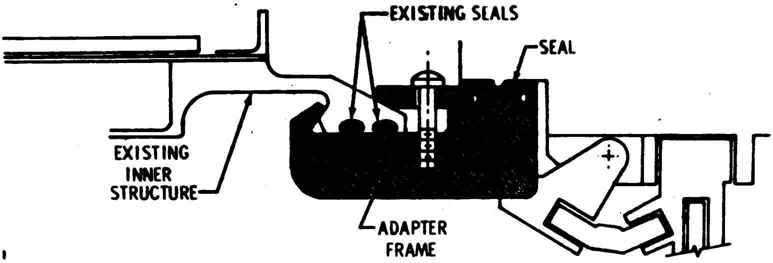


FIGURE 156

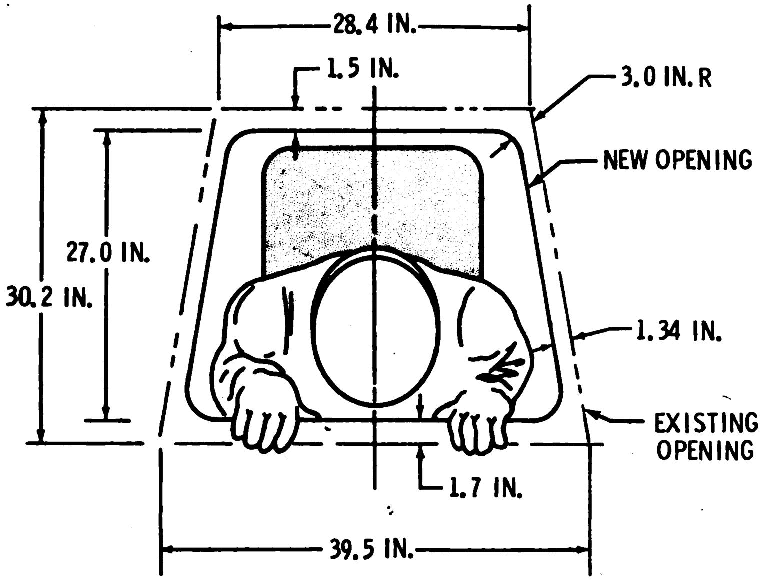


FIGURE 157

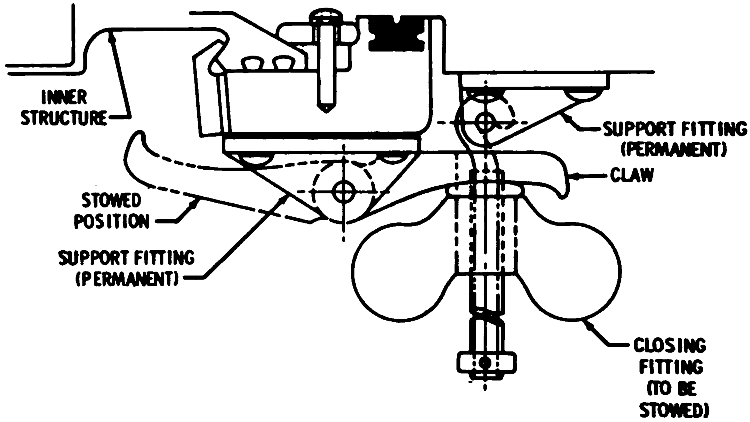


FIGURE 158

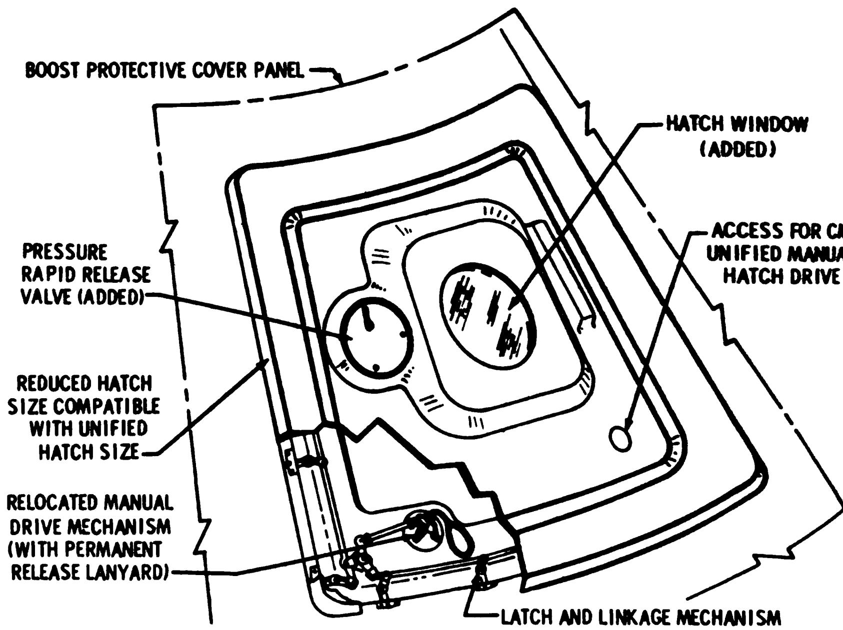


FIGURE 159

FIGURE 160

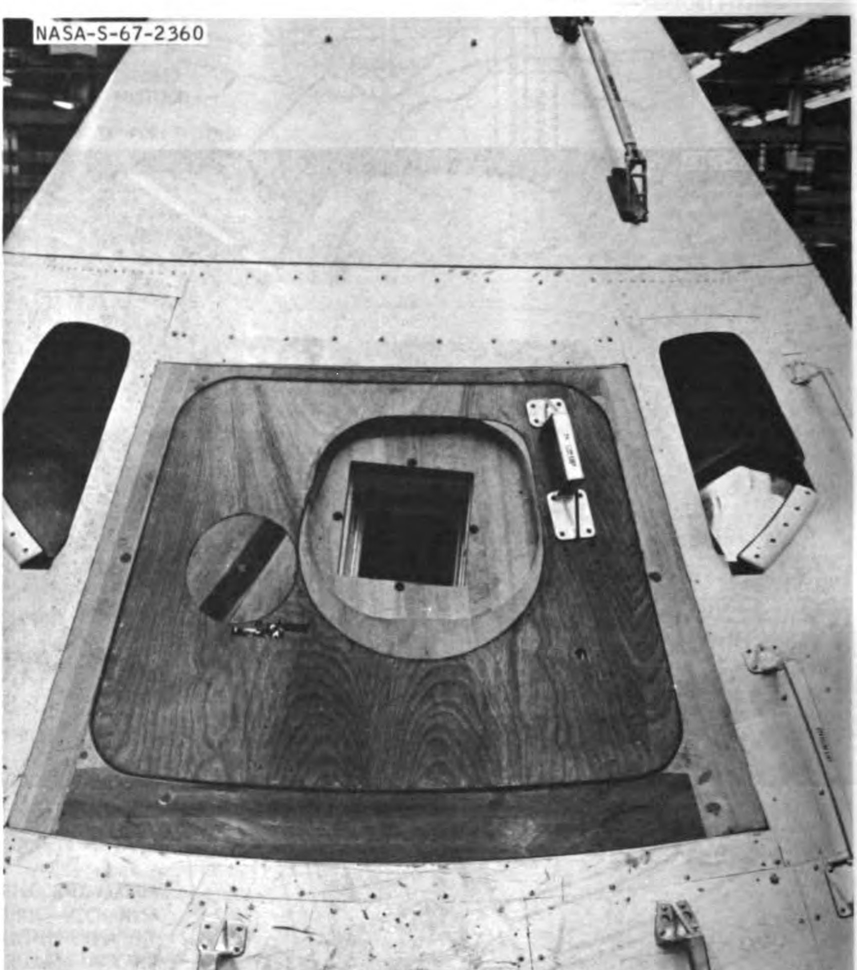


FIGURE 161

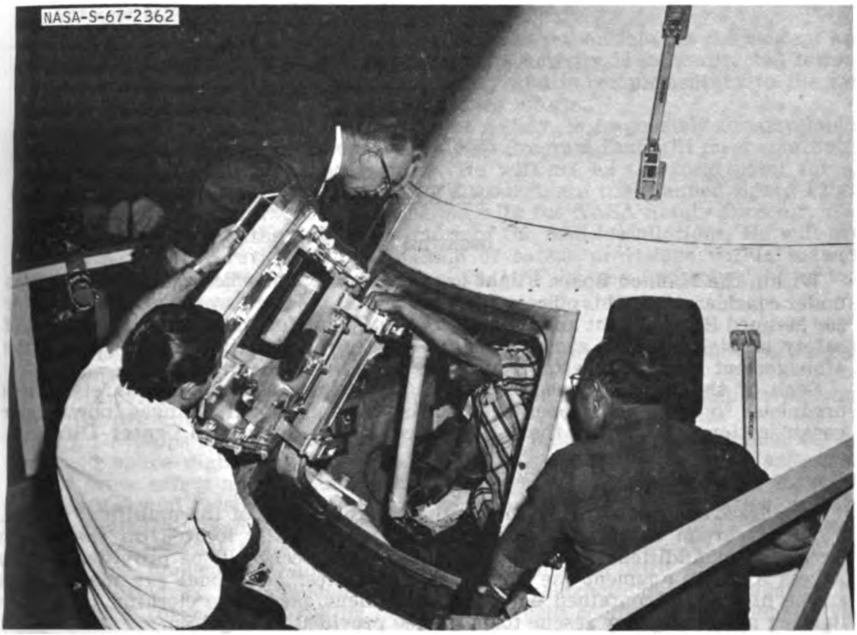


FIGURE 162

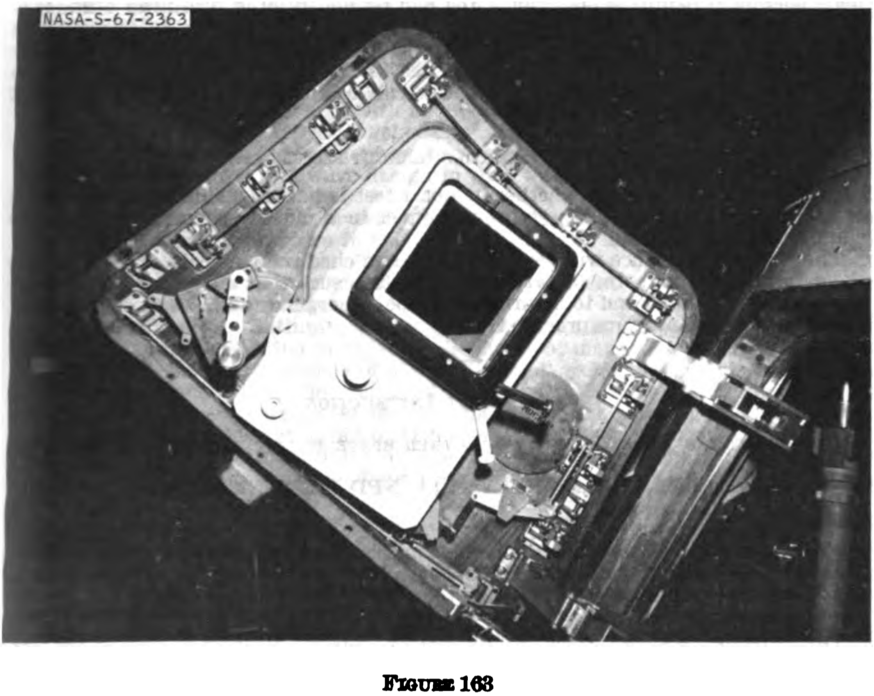


FIGURE 163

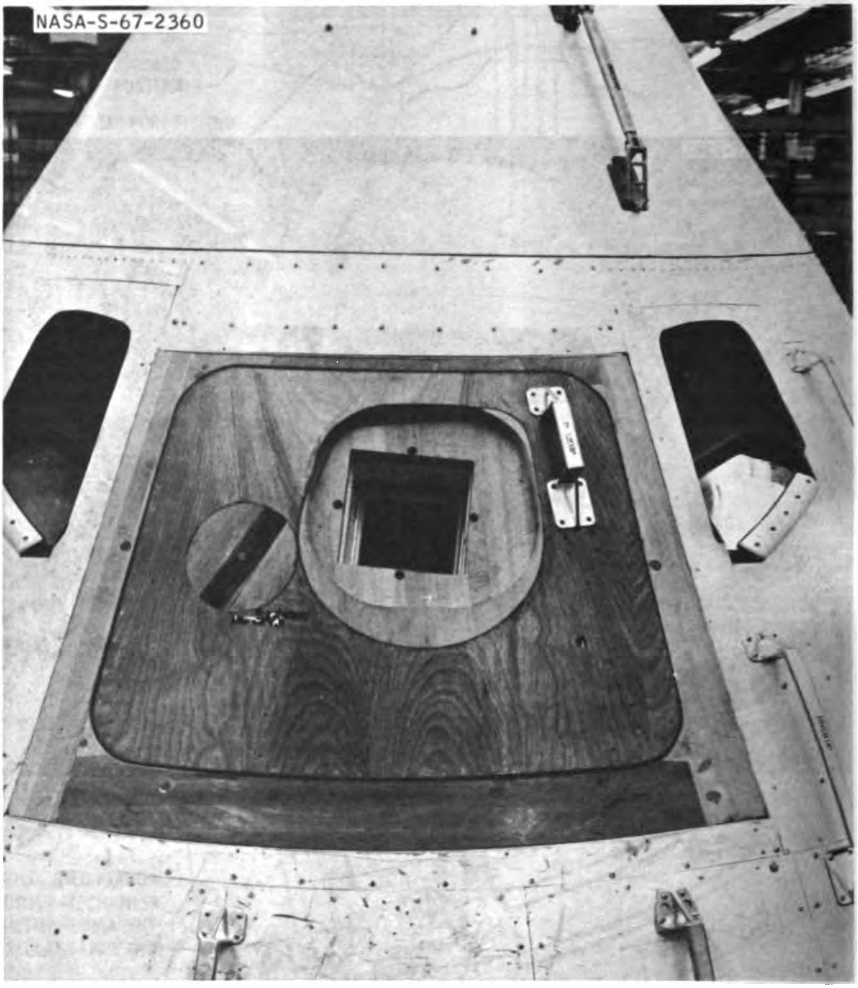


FIGURE 161

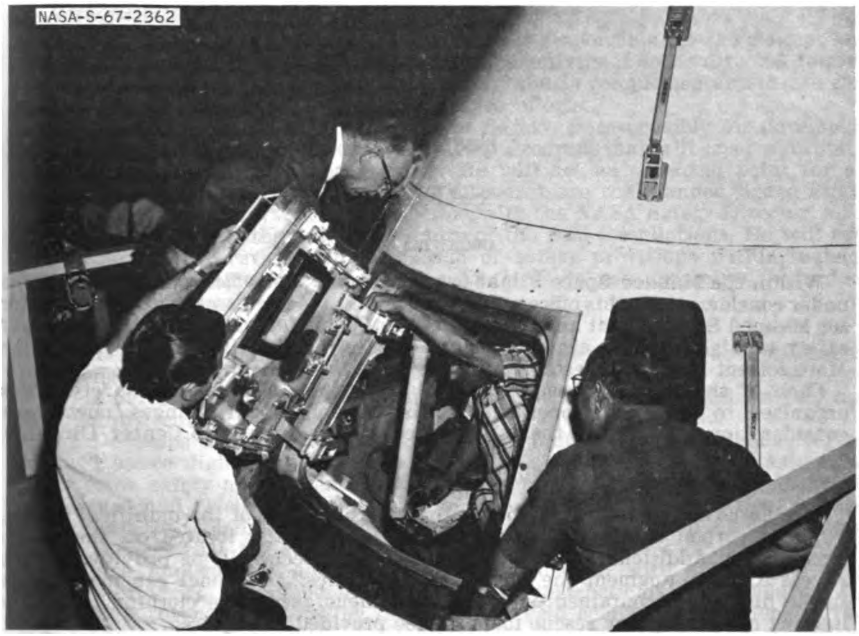


Figure 162

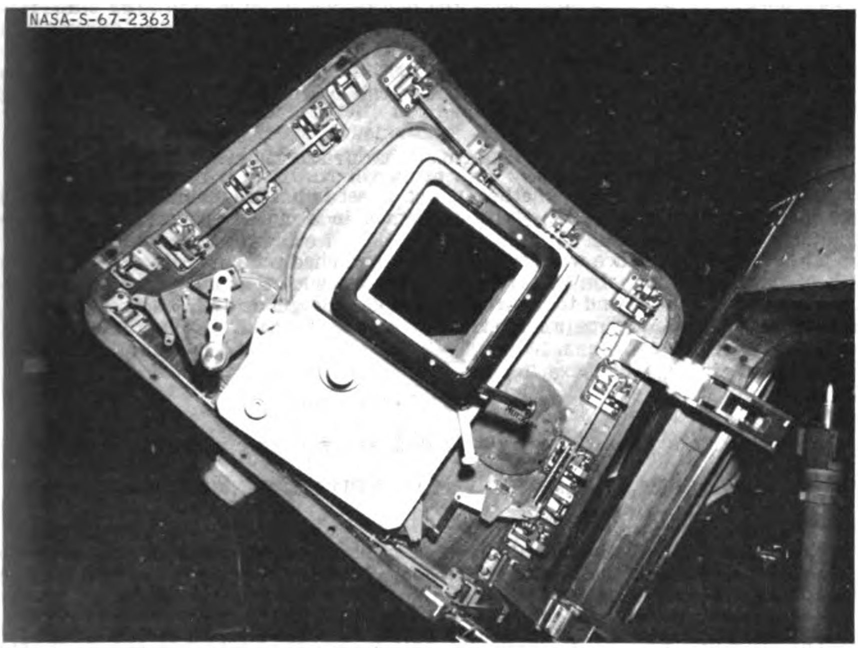


Figure 163

Section III

SAFETY

ORGANIZATION

Within the Manned Space Flight organization, a new office of Flight Safety is under consideration. This office will report directly to the Associate Administrator for Manned Space Flight and will be the focal point for continuous evaluation of safety provisions in all areas of manned space flight activities. A draft of the Management Instruction establishing this office is seen below.

Each of the three Manned Space Flight Centers already has safety offices organized to meet their operating needs. Organizational changes now under consideration will require that these offices report directly to Center Directors.

EMERGENCY EQUIPMENT

Fire hoses are already available at the working levels of the umbilical towers. Portable carbon dioxide extinguishers are strategically located on the Apollo Access Arm. Additional strategically placed hose reels will be provided on the Access Arms to augment the fire fighting facilities. Additional gas masks with smoke filters, self-contained breathing equipment, protective clothing, auxiliary lighting and emergency rescue tools will be provided as required.

PREPARATION OF PERSONNEL FOR EMERGENCIES

New criteria have been established at KSC for determining those additional test team personnel requiring emergency and pad rescue training. Training standards for all types of personnel and an individual certification program to ensure such training are being developed. A spacecraft mockup will be provided at KSC for training of rescue and operational personnel. The mockup will contain new hatch provisions and will be movable so that it can be installed in the altitude test chamber for training exercises.

REVIEW OF TEST AND CHECKOUT PROCEDURES

Criteria for determining whether or not a test is hazardous have been revised to insure that test operations with personnel in a closed spacecraft cabin are classified as hazardous.

The KSC Safety Office will review all test and checkout procedures to evaluate them from the standpoint of safety hazards to insure that adequate safety precautions are included and to insure that proper emergency and rescue equipment, personnel and training are provided.

MANAGEMENT INSTRUCTION

FUNCTIONS AND AUTHORITY—MANNED SPACE FLIGHT SAFETY OFFICE

Ref: NMI 1710.1A, NMI 1711.1A, NPD 1711.2, NMI 1136.8A

1. Purpose

This instruction establishes the responsibility, functions, and authority of the Manned Space Flight Safety Office. It does not affect any of the authorities or functional responsibilities assigned to the NASA Safety Director.

2. Organizational location

The Director, Manned Space Flight Safety, reports directly to the Associate Administrator for Manned Space Flight (AA/MSF). He receives administrative support from the Director, Mission Operations, and guidance for overall safety policy from the NASA Safety Director (AA for Administration).

3. Responsibility

(*a*) The Manned Space Flight Safety Office is responsible for the concept and execution of manned flight systems safety. Its activity is to be directed toward the development of total system flight safety and is complementary to the system reliability and system quality assurance efforts.

(*b*) The Director, Manned Space Flight Safety, is responsible for developing and executing a Manned Space Flight Safety Program that will meet continuing requirements for manned flight safety. He will act as the focal point for all system and flight safety matters and will coordinate the Manned Space Flight Safety Program by working in conjunction with the NASA Safety Director, MSF Program Offices, and the Safety Directors of the field installations. He will provide a continuing review and evaluation of safety provisions within manned space flight programs and report to the AA/MSF on any unresolved hazardous or unsafe practices and conditions.

4. Functions

The Director, Manned Space Flight Safety, performs the following specific functions:

(*a*) Advises the AA/MSF on all matters involving manned flight safety and accident prevention.

(*b*) Develops and documents safety policy, standards, and guidelines for all manned space flight programs. These standards will encompass all aspects of flight crew safety and the entire life cycle of manned flight systems, including conceptual and feasibility studies, design, manufacture, transportation, storage, flight plan, test planning, checkout procedure, and launch and flight missions.

(*c*) Insures that the standards and policies issued by the NASA Safety Director are implemented and, if necessary, augmented with appropriate MSF safety standards. The implementation of these instructions and standards will be effected through the existing program and field center organizational structure.

(*d*) Insures the inclusion of safety standards and related requirements in contractual clauses as directed by the NASA Safety Director.

(*e*) Provides guidance to MSF Program Offices in system safety for proposed manned space flight programs during the definition phase to insure inclusion of system safety provisions.

(*f*) Reviews, approves, and monitors the manned flight system safety plans developed by MSF Program Offices to describe the program requirements and objectives.

(*g*) Audits the compliance with manned flight safety standards in all manned space flight programs and MSF field center activities.

(*h*) Insures that independent system safety analyses are completed by MSF Program Offices for hardware design in time to support design reviews and certification boards.

(*i*) Develops accident investigation and reporting plans, procedures, and diagnostic analyses for use in the event of manned flight system anomalies, in accordance with the referenced Instructions.

(*j*) Participates as *ex officio* member on accident investigation boards for MSF-developed flight hardware.

(*k*) Provides a continuity of accident investigation experiences and insures pertinent data utilization in appropriate phases of manned space flight activities.

(*l*) Maintains surveillance of all incidents or accidents involving flight hardware and insures that the results of those investigations which affect manned flight safety are incorporated into all manned flight systems as appropriate.

(*m*) Provides for the rapid distribution of accident/incident causes and corrective action data identified by the investigation, throughout the program and all other manned space flight programs, for use as applicable in accident prevention.

(*n*) Insures a continuing assessment of the projected emergencies and risks associated with all manned flights and develops requirements for emergency systems to meet residual risks beyond the capability of the basic system.

(*o*) Insures that adequate attention is focused on the requirements for manned flight emergency systems and their timely development.

(*p*) Effects proper liaison with other governmental agencies in matters concerning manned flight safety and acts as MSF representative in joint DOD/NASA manned flight systems safety activities.

(q) Establishes awareness of the latest advances in the state-of-the-art of manned flight safety management and technical methodologies and the relative advantages and merits of each new technique developed. Insures, where appropriate, the incorporation of new techniques in the various manned space flight programs.

5. Scope of authority

The Director, Manned Space Flight Safety, in the exercise of his functions and responsibilities, is authorized to take such action as is necessary within the limitations established by the AA/MSF or by applicable law or NASA regulations. He is authorized to redelegate to personnel under his jurisdiction such of his functions and authority as he may consider necessary and which are not specifically restricted to him.

6. Relationship with other officials

In performing the functions assigned to him, the Director, Manned Space Flight Safety, will recognize the responsibility and authority of field centers and program officials and will insure that actions taken or instructions issued by him are properly coordinated with other offices and divisions having joint interests. In the operation of all system and flight safety activities the Director, Manned Space Flight Safety, will initiate and promote relationships among the field centers that will give the Manned Space Flight Safety Program appropriate emphasis and priority.

GEORGE E. MUELLER,
Associate Administrator for Manned Space Flight.

Section IV

COMMUNICATIONS

Voice communications difficulties were experienced by the spacecraft crew and ground test personnel during the AS-204 test. The test was delayed by two holds for communication problems. The report of the Apollo 204 Review Board states that none of the communications problems appear to have had a direct bearing on the fire. However, the Board determined that the overall communications system was unsatisfactory and made two recommendations:

1. The Ground Communications System be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight.
2. A detailed design review be conducted on the entire spacecraft communication system.

SYSTEM DESCRIPTION

The prelaunch tests and the launch of Apollo space vehicles are coordinated over an extensive voice communication network which interconnects the communications system aboard the spacecraft with the ground intercommunications system. The required number of voice loops in the ground Operational Intercommunication System is large (over 40 in the AS-204 tests) and several hundred people are involved both at Cape Kennedy and at the Manned Spacecraft Center at Houston. These personnel must have access to the voice circuits to direct and coordinate their work.

As the time for the actual or simulated launch approaches, the mission activity is concentrated on a small number of voice channels. At this time almost all the test personnel switch to these few channels and impose a peak load on the voice communication system. In previous missions, it was only at these times of peak loading that some complaints of faint or noisy voice signals were made. Design work to identify changes needed to correct these shortcomings was initiated late last year and plans were being developed to make the necessary changes.

REPORTED PROBLEMS

The difficulties which were reported during the checkout on January 27 can be summarized as:

1. Poor intelligibility, distortion, and word interruption.
2. Undesired voice and other interference on some circuits.
3. Occasional inability to obtain contact with some offsite locations.
4. Retransmission of voice from the spacecraft to the ground network and back to the spacecraft when certain switching combinations were used on the astronauts' communication panel in the blockhouse.
5. A failure in the Command Pilot's microphone circuit which caused his microphone to transmit continuously. This failure prevented voice transmission back to the spacecraft on any link to which the Command Pilot was connected.
6. The crew communications umbilicals were considered to be too cumbersome.

INVESTIGATION OF SYSTEM

In February, the Apollo 204 Review Board conducted a simulation test of the communication system to provide information on the causes of the problems encountered during the checkout. It was found that:

1. Weak voice reception noted by some users was caused by both variations in signal level adjustments and circuit length.
2. Restricted bandwidths reduced the quality of some voice channels.
3. The interruption of messages were caused by voice operated switches required to permit the 2-wire systems to interface with the 4-wire systems.

4. The inability of certain users to contact other users can be ascribed to the locking character of the voice-operated switching systems which permitted voice transmission in only one direction.
5. The noise and unwanted signals observed were ascribed to a variety of causes.
6. The design of the astronaut communications console in the blockhouse of Launch Complex 34 permitted undesired crosstalk from one communication loop to another.
7. The continuous transmission by the microphone at the Command Pilot's position was caused by a circuit failure which resulted in power being continuously applied to the microphone amplifier.
8. Two-way voice communications could be restored by abnormal adjustment of the voice operated switching system in spite of the continuous transmission from the spacecraft. This indicated that the switching system was performing in a normal manner.

IMPROVEMENT OF GROUND COMMUNICATIONS

In order to correct the voice communications difficulties encountered during the AS-204 test, changes to the ground intercommunications system and the procedures for its use will be made. These changes fall into three categories:
1. Reduction of the number of stations on those critical loops which are now being overloaded during peak periods.
2. Introduction of some design changes to assure reliable operation of the present circuits and equipment.
3. Addition of four wire intercommunications equipment to provide full duplex links among the flight crew, the Blockhouse, the Spacecraft Checkout station, and the Houston Mission Control Center.

CHANGES TO GROUND COMMUNICATIONS EQUIPMENT

The following changes are now being designed. They will be incorporated prior to the next manned flight:
1. Modify the astronaut communication consoles in the Launch Complexes to eliminate the undesired coupling between the voice communication links and to provide full duplex communication to the spacecraft over the umbilical cable without the use of voice operated (VOX) devices.
2. Delete the locking feature on all push-talk microphones and remove all loud speakers in areas where the acoustic coupling with an open microphone could cause undesired feedback.
3. Modify the input to the operational intercommunication system from the unified S-Band (USB) station on Merritt Island so that the proper voice signal levels and noise levels are maintained.
4. Provide additional central testing facilities at KSC to permit continuous circuit quality monitoring. The implementation of this testing has already been started and will be expedited. This capability will include test locations at each major facility and will facilitate failure detection, analysis and repair.
5. Reduce the use of voice operated (VOX) devices in the KSC intercommunications system. Such devices can operate satisfactorily as previous usage at KSC has shown, but they do have limitations and require careful attention.
6. Augment the present ground intercommunications System with 4-wire full duplex stations, utilizing the present cable plant, to interconnect the spacecraft, blockhouse, spacecraft checkout station, and the Houston Mission Control Center.

CHANGES TO PROCEDURES

In addition to equipment changes, the following changes in procedures will be made:
1. More extensive inspection and verification tests of the communication system will be made before all major space vehicle tests. This will insure that connections, levels and other adjustments are within tolerance.
2. Throughout all major space vehicles tests, communication systems engineers with knowledge of the entire voice system will be on duty.
3. Continuous recordings of critical voice communication loops during major tests will be obtained.
4. A more comprehensive method of controlling the configuration of and the access to the voice circuits will be instituted.

REVIEW OF SPACECRAFT COMMUNICATIONS SYSTEM

The design and performance of the spacecraft communications system were reviewed in February and March of 1967 as recommended by the Apollo 204 Review Board. This review concluded that those features of the spacecraft communications system which were not entirely satisfactory in the AS-204 vehicle (which involved Block I Apollo Spacecraft 012) have already been corrected in the Block II Apollo Spacecraft design. Changes to the Block II Apollo Spacecraft system are, therefore, not required.

ONBOARD TELEVISION MONITORING

The feasibility of using television to view the crew during all hazardous tests was also examined.

Consideration was given to the use of external cameras to look through the spacecraft windows, and the use of the spacecraft flight camera and television system. The use of external cameras was considered the poorer of the two approaches because of the large stresses on the umbilical tower access arm and because the emplacement of the boost protective cover would prevent monitoring the total test. Also, the spacecraft camera was found to have a capability to view all three astronauts from an available mounting location. Since adequate spacecraft ground interfaces already exist and the only new item required for the spacecraft is a mounting bracket, the decision has been made to use the onboard television camera for monitoring the cabin interior during hazardous prelaunch test and checkout operations.

ADDITIONAL DATA

Following is a technical report which discusses in detail the review of the Spacecraft Communications System.

SPACECRAFT COMMUNICATIONS ANALYSIS (T)

NASA APOLLO PROGRAM WORKING PAPER NO. 1261

MANNED SPACECRAFT CENTER, HOUSTON, TEX.

April 5, 1967

SUMMARY

As a result of communications difficulties experienced during the AS–204 pad test, an analysis was made of the spacecraft voice communication system performance.

The total voice system consisted of the spacecraft VHF/AM transmitter/receiver, unified S-band equipment, audio center, crew umbilical, and headsets.

The spacecraft-to-ground communication system includes equipment required for voice transmission and reception. At least part of the voice communication system would be in operation during all phases of a mission. The following list summarizes voice communication capabilities of Spacecraft 012:

1. Spacecraft intercommunications between crewmen (duplex)
2. Hardline voice communications to the Launch Control Center via the Service Module Umbilical during the prelaunch period (simplex)
3. Radio voice communications with the Manned Space Flight Network: (*a*) S-band (duplex); (*b*) VHF/AM (simplex)

The findings and recommendations of this review are based on analysis of the spacecraft PCM data and voice tapes. The voice tapes were the major sources of information and were available from the Blockhouse at Launch Complex 34, the operational instrumentation system in the acceptance checkout equipment, the Mission Control Center at Cape Kennedy VHF/AM station, and the RF monitoring communications station in the Manned Spacecraft Operations Building (MOLC). The tape from the Manned Spacecraft Operations Building was used most, primarily because it contained the only spacecraft S-band voice and the most noise-free VHF/AM voice.

In general, the quality of the voice radiated from the spacecraft was good (i.e. low distortion and good signal-to-noise levels). Only two significant problem areas were noted, as follows:

1. Propagation of the "hot mike" problem (a constantly keyed condition of the command pilot audio center) to the other audio centers, for certain switch positions.
2. The cumbersome characteristics of the crew umbilicals.

No specific malfunction was determined which would have caused the "hot mike" condition; however, possible causes are discussed in a special section of this report.

Both of these problem areas are rectified by the present Block II design.

An investigation of the feasibility of a television monitoring capability during all hazardous testing was made, which was completely independent of the communications analysis. Consideration was given to the use of external cameras looking through the spacecraft windows, and the use of the spacecraft flight camera and television system. It was determined that the spacecraft camera and television system is the better choice. Details of this investigation are described in Appendix A of this report, see page 632.

INTRODUCTION

Severe voice communications difficulties were experienced by the spacecraft crew and ground test personnel during the AS 204 Plugs-Out Test (OCP–0021). The test was delayed by two holds for communications problems and cancellation of the test was considered due to these problems. As a result, an investigation was made of the system performance, independent of the search for the cause of the accident.

The report includes (1) a discussion of findings relating to spacecraft communications subsystems performance and problems, as determined from voice tapes and telemetry data, or special tests made to the subsystem and (2) determinations relative to the problem areas. Specific attention is given to "hot mike" condition, its effect and probable causes. Appendix B contains a description of the spacecraft subsystems considered (i.e., headsets, crew umbilical assembly, audio centers, VHF/AM transmitter/receiver, and the unified S-band equipment).

SYMBOLS

ACE	Acceptance Checkout Equipment (spacecraft).
AGC	Automatic Gain Control.
CAST	Communications Astronaut.
CSTC	Spacecraft Test Conductor, Blockhouse 34.
GMT	Greenwich Mean Time.
LC–34	Launch Complex 34.
LCC	Launch Control Center.
LOS	Loss of Signal.
MCC–K	Mission Control Center—Cape Kennedy.
MDAS	Medical Data Acquisition System.
MOLC	Mission Open-Loop Communications Laboratory.
MSFN	Manned Space Flight Network.
OIS	Operational Intercommunications System.
PCM	Pulse Code Modulation.
PTT	Push-to-Talk.
REC	Receive.
S/C	Spacecraft.
SCMD	Spacecraft Commander.
S/N	Signal to Noise.
SPLT	Spacecraft Pilot.
SSRP	Spacecraft Senior Pilot.
T/R	Transmit/Receive.
USBE	Unified S–Band Equipment.
USM	Service Module Umbilical.
VHF	Very High Frequency.
VHF/AM	Very High Frequency/Amplitude Modulation.

METHOD OF ANALYSIS AND RESULTS

In the analysis of the spacecraft voice communications (see fig. 164) the results are based on analysis of the spacecraft PCM data, visual inspections of equipment, X-ray photographs, and voice tapes. The voice tapes were the major sources of information, and were available from: the Blockhouse, Launch Complex 34; ACE–OIS; MCC–K; and MOLC. The MOLC tape was used most, primarily because it contained the only spacecraft S-band voice and the most noise-free VHF/AM voice.

The best data that were available for the evaluation of the communications subsystem were the MOLC voice tape and PCM measurements of receiver AGC, transmitter power output, and static phase error from the unified S-band. Post-accident inspection, X-rays, and some special tests were used to verify the findings.

The headsets, torso harnesses, noise suppressors, pressure garment assembly, electrical adapter, cobra cable, tee-adapter, audio centers, VHF/AM transmitter-receiver, and unified S-band equipment were all considered as a subsystem, and each was considered separately. Except for the "hot mike" anomaly, all were determined to have performed well throughout the whole test to loss of signal (LOS).

"HOT MIKE" ANOMALY

The constant-keying "hot mike" condition is traceable to the command pilot's communication system. The "hot mike" condition as used in this report means that (1) the microphone amplifier in the audio center has received a ground which energized the amplifier electronics, and (2) the S-band audio gate received a ground which energized the gate and allowed the audio center output to modulate the S-band transmitter. These two conditions are normally effected by a crewman pressing his PTT button on the cobra cable (when in the PTT position) or, in the command pilot's position, pressing his hand controller PTT button. The PTT button, in addition to the above, provides a ground for the VHF/AM transmitter keying relay through the audio control panel VHF/AM T/R select switch (see fig. 165). The VHF/AM T/R switches are interconnected, which would cause a ground to be transferred between all positions in VHF/AM T/R mode. The logic detail is shown in figure 166.

Data analysis indicated that the "hot mike" condition began about one hour and 15 minutes before the accident.

Various troubleshooting exercises were performed by the astronauts in an attempt to determine the cause of the "hot mike". The audio centers were switched to various modes of operation (i.e., S-band only, VHF, and intercommunication); the cobra cables were exchanged between the command pilot and senior pilot; the spare cobra cable was substituted and the command pilot changed from his normal connector to the emergency connector, using the senior pilot's audio center. However, the S-band MOLC voice tape indicated that the "hot mike" condition in the command pilot position continued to at least the first transmission of the accident.

The actual cause of the "hot mike" condition is not known. Possible causes are as follows:

1. The Velcro strap could have been connected across the command pilot's cobra cable PTT button. This is a normal design function capability; however, it is very unlikely because of the long troubleshooting exercise, and two cobra cables exhibited the same problem.

2. The hand controller PTT button could have stuck down. This appears to be a possibility because of the post-test results on the translation hand controller. (The button stuck down on the fifth activation of the functional test.) However, the troubleshooting exercise should have discovered this condition.

3. A ground could have existed somewhere in the command pilot's PTT control circuitry (see fig. 166).

4. A diode short could have existed in the audio center. There is a steering diode in the audio gates which normally allows the selection of "Receive Only" or transmit/receive. If in a receive function (panel selection) and the steering diode shorts, then the transmit audio gate function is automatically enabled. During the "hot mike" troubleshooting exercise, the astronauts discussed and turned off the VHF and Intercom switches; however, during this time the S-band T/R switch was never mentioned. It could be assumed that the S/band T/R switch was never taken out of the T/R position, which, with the steering diode shorted, would produce the "hot mike" anomaly. However, post-incident ohmmeter tests indicate that the diode was good.

5. There are multipoint failures which could have caused the "hot mike" anomaly; however, such failures are considered unlikely.

Concluding Remarks

An assessment of the Block II design reveals that the aforementioned problem areas are corrected by the present design. In the Block II configuration, steering diodes are provided to isolate the keying control circuits of the three audio control centers, which should prevent the propagation of the "hot mike" problem. A switch is provided for the selection of normal or emergency connection through alternate audio centers instead of the emergency connector arrangement; a switch is provided in place of the sleep adapter; and the noise eliminator circuit is moved to the helmets. These changes will improve the umbilical design. No further design changes are required as a result of the investigation.

Appendix A

Onboard Television Monitoring

The feasibility of using television to view the crew during all hazardous tests was investigated.

Consideration was given to the use of external cameras to look through the spacecraft windows, and the use of the spacecraft flight camera and television

ne two
s arm,
ı, and
.e win-
ı capa-
n, and
would
launch

ch can
e used

nt and
h orbit

is just
ner of
lisplay
onauts

ertain

s, and
rovide

to five

ate in
wman
of two
tained
ion.
audio
ee fig.
, PGA
llation
audio
Two

e mis-
n this
M and
s con-
switch

of the
muni-
tions.
sition
unica-
Their
PTT

ORM
er, in

whic
ceive
to m
by a
posit
butt
VHF
T/R
whic
T/R
Da
and
Va
temp
to va
the
the
norn
cent
cond
miss
Th
as f
1.
cobr
it is
cable
2.
be a
troll
How
3.
trol
4.
diod
or t
diod
Duri
turn
T/R
swit
shor
mete
5.
anon

Ar
lem
steer
audi
prob
necti
arra
elim
bilic
vesti

Th
was
Co
spac

system. The use of external cameras was considered the poorer of the two approaches because of the large stresses on the umbilical tower access arm, due to the weight of commercial cameras and long moment arm, and because the implacement of the boost protective cover would cover the windows for part of the test. Also, the spacecraft camera was found to have a capability to view all three astronauts from an available mounting location, and adequate spacecraft/ground interfaces already exist. The only new item would be design of a mounting bracket for the Block II camera to withstand launch and/or pad abort stresses.

The spacecraft/ground interfaces consist of the hardline umbilical, which can be used most of the time, and the S-band FM transmitter, which can be used during plug-out tests.

The spacecraft camera is designed to withstand the launch environment and could be used during all of the prelaunch tests. It can be carried into earth orbit in the mounted position, if a proper mount is provided.

It was determined that the location best suited for the view required is just under the main display console (in either the right-hand or left-hand corner of the spacecraft) on a ledge over the equipment located under the main display console. In this position the camera will not be in the way of the astronauts and will provide a proper view.

Some filtering may be required to prevent damage to the vidicon by certain (bright) cabin lighting.

Because of the desire to view the operation during these hazardous tests, and the relative ease of implementating this capability, it was decided to provide the television monitoring capability.

Appendix B

SPACECRAFT SYSTEM DESCRIPTION

The description of the voice communication subsystem is divided into five parts.

Headsets—All spacecraft voice communications originate and terminate in the crewman's personal communication assemblies (headsets). Each crewman has a headset located in the space suit helmet. Each helmet is comprised of two independently operating earphones and two microphones with self-contained preamplifiers. The headsets are used for all voice transmission and reception.

Crew umbilical assembly—Each crewman's headset is connected to the audio center (A/C) equipment by a separate electrical umbilical assembly (see fig. 165) consisting of a cobra cable and associated adapters (tee-adapter, PGA adapter, and noise suppressor). A sleep adapter is also available for installation in place of the noise suppressor. When installed, all functions except the audio warning signal are carried through the umbilical assembly and returned. Two adapters are stowed in the spacecraft. In addition to the audio circuits, each of the three cobra cables contain wiring for the operational biomedical sensors in the spacesuits and the push-to-talk (PTT) control circuitry. The PTT control circuitry consists of a pushbutton type PTT key and a PTT/CW selector switch. With the PTT/CW selector switch in the PTT position, the PTT key permits manual control of voice transmission by the appropriate transmitter and mike amplifier circuit in the audio center module.

The PTT mode was designed to be used during the launch phase of the mission when high noise levels would preclude usage of the VOX circuitry. In this mode, the PTT key will enable the microphone amplifier and the VHF/AM and S-band transmitters, if the crewmen have their attendant control switches configured properly. The audio center power switch and the cobra cable mode switch should be in PTT position during this mode.

The CW mode was also designed to be used during the high-noise levels of the launch phase. In this mode, however, the VHF and S-band down-voice communications links are not enabled. This gives PTT-controlled intercommunications. The audio center power switch would also be in the PTT position. This position was to be used for both the emergency (USBE) and the PTT intercommunications functions. PTT keys are also located on the translation controllers. Their function duplicates that of the PTT key with the PTT/CW selector in the PTT position of the cobra cable.

The head of each cobra cable has two electrical connectors, marked NORM and EMER. Normally, the connector marked NORM will be used; however, in the event of failure in one of the A/C modules, the affected crewman may connect the cable from his space suit to the connector marked EMER. This will connect his audio circuits to another A/C module and allow the same module to be shared by two crewmen.

A strap has been added to the cobra cable so the PTT button can be held in the ON position if desired. This was intended for orbital use only. This would allow a continuous intercom if the audio center (MDC–13, –23, –26) POWER switch is in the PTT position.

The pressure garment assembly (PGA) electrical adapters are normally connected between the space suit and the noise suppressor adapter (see fig. 165). The purpose is to provide a quick-disconnect electrical cable from the space suit to the rest of the umbilical assembly.

The noise suppressor adapters are normally connected between the cobra cable and PGA electrical adapter (see fig. 165). This adapter was designed to pass normal voice signals and to minimize ambient space suit air noises.

The tee-adapters are normally installed between the spacecraft panels and the cobra cables. The purpose is to provide an electrical output from the operational biomedical sensors in the space suits to the Medical Data Acquisition System (MDAS). The voice communications and control circuitry are straight-through in the tee-adapter.

Audio center equipment.—The A/C equipment (see fig. 167) consists of three separate identical modules located in a single electronics package in the lower equipment bay. Each module is controlled independently by its own control panel and supplied with 28-volt-dc power through separate circuit breakers. The three control panels, MD–26, –13 and –23, are located in stations 1, 2, and 3, respectively. Each of the astronaut's headsets, containing two microphones and two microphone amplifiers, and two independently operating earphones, is connected to one of the A/C modules by a cobra cable. Thus, each astronaut has a separate headset, audio center module, and audio control panel to provide him with individual control of voice transmission and reception (see fig. 164).

Each A/C module contains a microphone amplifier, voice-operated transmitter (VOX) circuitry, an earphone amplifier, and various signal attenuation, switching, and isolation circuits. The earphone and microphone amplifiers amplify the voice signals to and from the headset. The VOX circuitry is a voice-operated keying circuit that supplies a ground return path necessary for activating the microphone amplifier and the transmitter keying relay in the high frequency (HF) transceiver, and the power control relay in the operating voice recorder.

Audio signals are provided to and from the HF transceiver equipment, VHF/AM transmitter-receiver equipment, USBE via the premodulation processor (PMP) and the intercom bus.

The intercom bus is common to all three modules and provides for the hard-line communications between crewmen and with the LCC.

Each audio control panel (see fig. 164) has three thumbwheel-type potentiometer controls: a VOX SENS control for adjusting the sensitivity of the VOX circuit, an INTERCOM BALANCE control for decreasing the level of the audio signals received from the RF equipment relative to that received from the intercom bus, and a VOLUME control for changing the overall level of all audio signals to the earphones. Each channel in the A/C modules also contains sidetone circuitry which enables a crewman to monitor his own transmission.

VHF/AM transmitter-receiver equipment—The VHF/AM transmitter-receiver equipment (see fig. 164) provides the primary means for inflight voice communications with the MSFN. It is contained in the same electronics package as the VHF recovery beacon equipment in the lower equipment bay. Two modes of operation are possible: simplex and duplex. The simplex mode will normally be utilized.

The transmitter operates at 296.8 megacycles in both operational modes. The receiver contains two "front ends." The receive-1 front end operates at 296.8 megacycles and is used for simplex operations. For duplex operations, the receive-2 front end, which operates at 259.7 megacycles, is selected.

The VHF/AM transmitter-receiver is controlled by the VHF/AM controls on MDC-20. The T/R/OFF/REC switch activates the transmitter and receiver when in the T/R position; the REC position activates the receiver alone; the OFF position removes power from both. Simplex or duplex operation is selected by placing the RCVR switch to 1 or 2, respectively. The thumbwheel-type SQUELCH control can be rotated up or down to increase or decrease the sensitivity of the squelch gate.

Audio to and from the VHF/AM is controlled by the VHF/AM T/R/OFF/REC switch on MDC–13, –23, –26. Voice transmission is possible when this switch is at T/R, the POWER switch is at PTT, the cobra cable PTT/CW switch is at PTT, and the PTT key is pressed. The POWER switch can also be at VOX; however, actual keying of the VHF/AM must be via the PTT circuit (see fig. 166).

Unified S-Band equipment—The USBE (see fig. 164) consists of a receiver, transmitter, and power supply contained in a single electronics package in the lower equipment bay. Although primarily designed for deep-space communications, the USBE was to be tested on the AS–204 mission and used as backup for inflight voice communications, tracking and ranging, transmission of PCM data, and reception of up-data. The USBE also provides the only means for transmission of spacecraft television, except for the hardline.

The USBE receiver is a phase-tracking receiver that accepts a 2106.4-megacycle, phase-modulated RF signal containing the up-data and up-voice subcarriers, and a pseudo-random noise (PRN) code when ranging is desired. This signal is supplied to the receiver via the diplexer in the S-band power amplifier equipment and presented to two separate detectors: the loop phase detector and the ranging phase detector. In the ranging phase detector, the 9.531-megacycle intermediate frequency (IF) is detected; and the 70-kilocycle up-data and 30-kilocycle up-voice subcarriers are extracted, amplified, and routed to the up-data and up-voice discriminators in the PMP equipment. Also, when operating in a ranging mode, the PRN ranging signal is derived, filtered, and routed to the USBE transmitter as a modulating signal input to the phase modulator. In the loop phase detector, the 9.531-megacycle IF signal is detected by comparing it with the loop reference frequency. The resulting dc output is used to control the frequency of the 19.0625-megacycle voltage-controlled oscillator (VCO). The output of the VCO is used as the reference frequency for receiver circuits as well as for the transmitter. The receiver is also provided with automatic gain control (AGC) and antenna selector circuitry which automatically selects the proper SCIN antenna when the S-BAND ANTENNA switch is in the AUTO position. When the receiver is not phase-tracking an RF signal (unlocked), the AGC voltage approaches zero, allowing maximum gain which results in a high voice level. A "mute" capability for this noise was provided on spacecraft 012 by using the S-band mode select switch on Panel 23 (pilot position).

The USBE transmitter is capable of transmitting a 2287.5-megacycle signal, either phase-modulated (PM) or frequency-modulated (FM). In the PM mode, the initial transmitter frequency is obtained from one of two sources—the VCO in the phase-locked USBE receiver, or the auxiliary oscillator in the transmitter. When operating in the FM mode, the VCO or auxiliary oscillator initial frequency is not multiplied and used directly but is used to control the frequency of a third oscillator, the FM VCO. The FM VCO is the source for the frequency-modulated 2287.5-megacycle signal.

Output mode and frequency source are controlled by the S-BAND group of switches MDC–20. The VOICE and EMERG switches, contained in this group, also have an effect on PMP operation, thus insuring compatability between USBE and PMP modes. All data to be transmitted by the USBE are supplied by the PMP. Normally, the initial transmitter frequency is obtained from the receiver VCO. In case of failure of the VCO or S-band power amplifier (PA) equipment, the auxiliary oscillator can be selected. This is done by moving the OSC switch from PRIM to SEC (with the RNG/RNG ONLY switch at the normal, center position) or by placing the EMERG switch to VOICE. If the latter is done, the PMP will provide a voice modulating signal directly to the auxiliary oscillator.

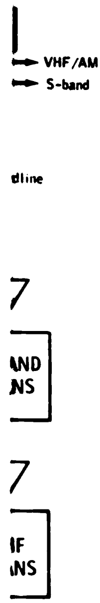
With all three S-band VOICE switches and the S-band EMERG switch set at their center positions, the USBE transmits a phase-modulated signal containing PCM, TLM, and voice data from the PMP. Setting the RNG/RNG ONLY switch to RNG enables the PRN ranging code but eliminates the PCM TLM portion of the PM input from the PMP. This mode is used to increase the strength of the PRN ranging code received by the MSFN. The other two S-band VOICE switches are the TAPE and the TV switches. For PM operation, both of these switches must be at their center, off, position. Setting either of them to any other position changes the USBE mode to FM for increased band-width and selects the FM–1 output of the PMP. Thus, these four switches (the three VOICE switches and the EMERG switch) are used to establish the operational mode. Only one switch at a time may be placed to any position other than center for proper operation of the USBE PMP. For further description of PMP i puts refer to the discussion of the PMP equipment.

The USBE is activated by the S-band XPONDER/XPONDER PWR AI switch. Setting this switch to XPONDER or XPONDER PWR AMPL energ a relay that applies 115 volts ac to the USBE power supply, which prov plus 15 volts dc and minus 15 volts dc outputs to the USBE transmitter receiver. The RF output of the USBE transmitter is fed to power amplifier eq ment. Here, the signal is either bypassed directly to the S-band ANTE switch or amplified and then fed to the S-band ANTENNA switch.

The S-band power amplifier equipment (see fig. 164) is used to amplify RF output from the USBE transmitter when additional signal strength is quired for adequate reception of the S-band signal by the MSFN. It con of a diplexer, a traveling-wave tube for amplification, power supplies, and necessary switching relays and control circuitry. The S-band PA is conta in a single electronics package located in the lower equipment bay.

All received and transmitted S-band signals pass through the S-band diplexer. The 2106.4-megacycle S-band carrier received by the spacecraft en the S-band PA diplexer from the S-band antenna equipment. The diplexer pa the signal straight through to the USBE receiver. The 2287.5-megacycle ou signal from the USBE transmitter enters the S-band PA, where it is ei bypassed directly to the diplexer and out to the S-band antenna equipmen amplified first and then fed to the diplexer. There are three power ampl modes of operation—bypass low power, and high power.

Two of the S-band switches on MDC–20 are used to control the S-band po amplifier. Setting the XPONDER/XPONDER PWR AMPL switch to the XP DER PWR AMPL position energizes the USBE power supply and applies 3-p 115-volt-ac power to the S-band PA through relay K1 in the circuit utiliz box. This also activates the 90-second time-delay relay in the S-band PA. U initial application of power, only the low-voltage power supply is energ which applies power to the traveling-wave tube heater. After 90 seconds, RF signal from the USBE transmitter is switched from the bypass circu the amplifier circuit, and 3-phase, 115-volt-ac power is applied to either the power or high power section of the high-voltage power supply, which sup the correct operating voltages to the remaining elements of the traveling-w tube. Selection of the low power (LOW) or high power (HIGH) mode is trolled by the S-band power amplifier HIGH/LOW switch.


VHF/AM
S-band
dline
7
AND
NS
7
IF
NS

for pro|
puts ref
The U
switch.
a relay
plus 15
receiver
ment. E
switch (
The S
RF outp
quired 1
of a dip
necessar
in a sin
All re
diplexer
the S-ba
the sign
signal f
bypassed
amplifie
modes o
Two o
amplifie
DER PV
115-volt-
box. Thi
initial a
which a
RF sign
the amp
power o
the corr
tube. Se
trolled b

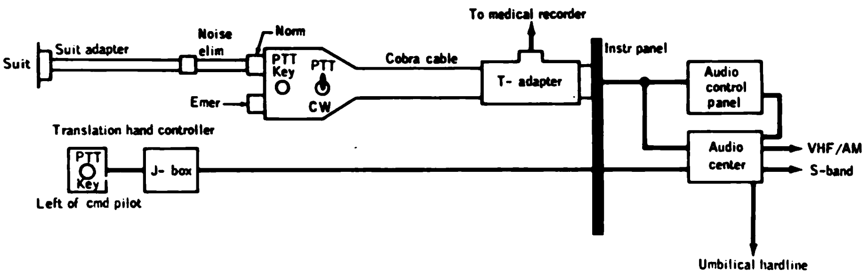


FIGURE 165

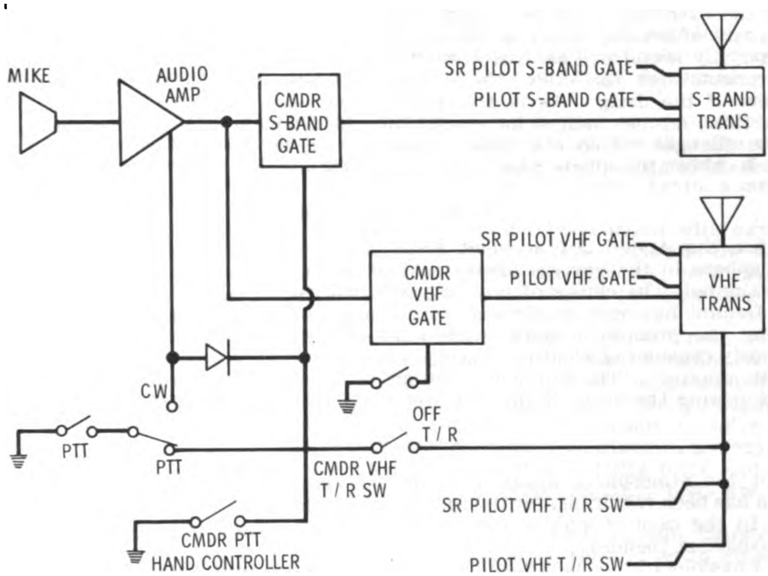


FIGURE 166

Section V

ENVIRONMENTAL CONTROL SYSTEM

The Environmental Control System controls the atmosphere for the crew in the cabin and in their space suits and provides thermal control for the crew and equipment in the spacecraft. Other life support functions such as waste and water management are also provided by the system. The design of the system, as in Mercury and Gemini, contains a separate pressure suit loop so that the astronauts can be isolated from the cabin. Experience over the past six years of manned space flight has demonstrated that the design of the ECS is basically sound and safe. However, since this system is essential for a livable environment for the crew, the accident investigation has led to a complete review of the design. As is always the case when a design is reviewed at a later time, minor changes have been identified which will improve the system.

The changes which are under consideration in the ECS relate to the prelaunch cabin atmosphere and to the implementation of the design.

Cabin Atmosphere

Since the Apollo 204 accident studies regarding the selection of the cabin atmosphere in the various operational phases of the Apollo mission have been re-evaluated. The choice of pure oxygen at 5 psi such as was used on Mercury and Gemini has been reaffirmed. Initial studies indicated that air in the cabin during the prelaunch phase with pure oxygen in the space loop should be seriously considered. Continued study has clarified advantages and disadvantages of this approach. The following sections contain discussions of the cabin atmosphere during the space flight and prelaunch phases of a mission.

SPACE FLIGHT

For the atmosphere in space flight, the choice of oxygen at 5 psia for the cabin has been reaffirmed for the following reasons:

1. In the case of sudden decompression, pure oxygen eliminates the danger of dysbarism (bends).
2. Physiological considerations require that the partial pressure of oxygen be at least 3.5 psia to support life and no more than 7.5 psia to avoid toxicity during extended exposure.
3. An oxygen partial pressure above 3.5 psia increases the margin of safety in case of a cabin leak.
4. A one-gas system is simpler than a multigas system, and thus offers greater reliability.
5. A physiologically acceptable two-gas system at a pressure within the present spacecraft structural limitation does not offer a large reduction in fire hazard over a 5 psia pure oxygen atmosphere.
6. Six years of experience in the Mercury and Gemini programs has resulted in a system with characteristics which we know with confidence.

For missions of Apollo duration, within feasible pressure limits for structures and space suits, and coupled with cabin materials now being selected, the 5 psia oxygen atmosphere provides the highest overall crew safety during space flight.

PRELAUNCH

For manned test and prelaunch operations in the ground, the previously used atmosphere of 16.5 psia pure oxygen will continue to be used unless the boilerplate fire safety tests to be conducted with the new materials in the cabin indicate that an unacceptable fire hazard would exist under these conditions.

Air is an alternative for the prelaunch cabin atmosphere because of the reduced fire hazard and the ability to support life in the cabin if there is a failure in the oxygen supply to the space suits. Pure nitrogen in the cabin would further reduce the fire hazard but is considered unacceptable because nitrogen will not support life in case of a suit disconnect or suit loop failure.

In order to use air to pressurize the cabin during prelaunch activities, the suit loop must be isolated from the cabin to avoid the risk of getting nitrogen into the suits. The presence of nitrogen can lead to hypoxia, as occurred in an early Mercury ground test or, to the risk of bends, due to nitrogen in the blood. A system will be added to bleed oxygen into the suit loop to ensure that the suits are kept at a higher pressure than the cabin and sensors will be provided to detect any failure which might allow leakage into the suit loop.

During the launch phase, the cabin and suit loop will bleed down to the 5 psia space flight pressure. If air is used in the cabin, the air would be at essentially standard composition, that is, about 21 percent oxygen, and would not support life at the reduced pressure in orbit. To provide a safe cabin atmosphere in which the crew can work, the air must be replaced with oxygen upon reaching orbit. There are three alternatives which must be considered:

1. The air can gradually be replaced with oxygen as a replacement for cabin leakage. This approach provides the greatest savings in oxygen supplies, but it exposes the crew to the discomfort of wearing a suit and the risk of pressure suit failure for several days. In addition, a positive means of determining the composition of the atmosphere is necessary.

2. Partial depressurization and then repressurization with oxygen can be accomplished in a series of steps. This approach may reduce the time the crew spends in pressurized suits while offering some protection in the event of suit loop failure; however, it results in the highest usage of oxygen. Again, a means of determining atmospheric composition is necessary.

3. The cabin can be completely depressurized and repressurized with oxygen in a two-step operation. This method will reduce the oxygen expenditure when compared to the second approach and will minimize the time the crew spends in pressurized suits. However, it results in maximum risk in the event the suit loop pressure is lost during the operation.

These procedures offer tradeoffs which need to be demonstrated in tests which are now planned. It is important to reemphasize the fact that changing from a method which has been safe and successful during many years of manned space flight is not done without intensive thought and testing. No possible danger to the crew during the entire mission can be overlooked in a desire to solve the immediate problem. Thus, at this time we are planning to continue to use oxygen subject to confirmation by the full-scale boilerplate flammability tests, and are providing the option to use air on the pad if these flammability tests are not successful.

Additional changes in the cabin atmosphere system are to provide individual oxygen masks for the crew. These masks are similar to those used in aircraft but will also provide protection for the eyes. Provisions are being made for an additional dump valve in the hatch to make it possible to depressurize more rapidly than in the previous design and an additional oxygen surge tank will be placed in the system to shorten the time required to repressurize the cabin. Finally, the oxygen system aluminum plumbing containing solder joints will be replaced with steel lines which can be brazed.

THERMAL CONTROL LOOP

Because of the variation of environments experienced on an Apollo mission, such as during high velocity flight through the atmosphere, coast in space, and finally, entry into the earth's atmosphere, the thermal control system must cope with a wide range of conditions. The Apollo system uses a water glycol coolant loop to absorb heat from the crew and equipment; and a system of water boilers in the Command Module, and space radiators in the Service Module, to collect and reject this heat. This system must be carefully balanced to provide proper heat flow during all phases of the mission. In particular, on the Block II spacecraft the radiators and the coolant fluid are very carefully matched to achieve the desired performance. Experience on Mercury, Gemini and Block I Apollo spacecraft has led to the development of an efficient stable system.

An extensive study of coolant fluids was conducted in making the original selection of water glycol. Since the Apollo 204 accident, more than 40 possible substitute coolant fluids have been reevaluated for use in the Apollo system and none were acceptable.

Also considered was a dual loop system which would use pure water in the Command Module and water glycol in the Service Module. Although such a system would avoid the need to redesign the radiator system to accommodate a new coolant, it would substantially reduce the reliability of the system because additional pumps, heat exchangers, valves and controls would be needed. Since thermal control is a very necessary part of the system, no changes will be made which reduce reliability.

While studies of replacements for water glycol were being conducted, test experience with water glycol was also reexamined. Numerous ignition tests of water glycol mixtures in an oxygen atmosphere using sparks, hot plates and open flames have been conducted but have not succeeded in igniting the fluid until almost all the water in the mixture was evaporated. Thus, water glycol is difficult to ignite and in a number of tests, was an effective extinguisher. In fact, water glycol is somewhat less flammable than the Gemini coolant, Coolanol 15.

Aluminum tubing filled with water glycol has been heated in special laboratory tests and no failures were experienced. The maximum recorded temperatures during these tests were between 1050 and 2200 degrees Fahrenheit. The coolant fluid provides a heat sink which protects the lines and joints at high temperatures. These tests and the results of the Apollo 204 investigation indicate that water glycol contributes to a fire only after major damage has already occurred from extremely high temperatures.

Tests do indicate, however, that the corrosion inhibitor added to the water glycol can leave an undesirable residue if allowed to leak and dry. It is, of course, necessary to use an inhibitor, and the present one, type II, was selected, after an intensive search, as the best available for the system.

It should be emphasized that the inhibited water glycol is not a problem unless it leaks or is spilled in the proximity of an ignition source. Steps are being taken to make the coolant system essentially leakproof and thus minimize this concern.

The primary source of leaks in the coolant system has been from mechanical fittings. The Block II spacecraft incorporates soft metal washers in these fittings to prevent leaks. In addition, improved torqueing procedures have been implemented. An occasional leak on the Block II spacecraft has been from solder joints in water glycol lines which have been inadvertently abused. Extensive tests of these joints have been conducted with the conclusion that the solder joints are satisfactory if properly made and not subjected to stress or damage. In the Block II spacecraft, the plumbing lines are different from the Block I in that stress relief has been built in to avoid stressing solder joints when mechanical fittings are tightened. Armor will be added to those exposed joints which could be damaged during testing or flight. In addition solder joints will be eliminated where possible by combining line segments. Covers are also being added over all exposed plumbing to provide additional protection. These steps will effectively eliminate leakage from solder joints.

Spillage of water glycol has occurred during coolant system maintenance, particularly when the Environmental Control Unit has had to be removed for repairs. Self sealing quick disconnects had already been incorporated in the fourth Block II spacecraft and will now be retrofitted into all of the Block II spacecraft to facilitate maintenance. The quick disconnects will close off the coolant lines when they are opened and will prevent any glycol spillage.

A process has been developed to clean up, without leaving a residue, any water glycol spills that cannot be prevented. In addition, chemical tests have been developed to make sure that no residue remains after the cleaning operation. These tests will ensure that all leaks and spills are properly cleaned.

Thus, better protection of the plumbing, the addition of quick disconnects and better methods of cleaning up spilled fluid will effectively solve the coolant problems which are of concern.

SUMMARY

In summary, the following changes will be made in the Environmental Control System:

1. Provide an option to use either oxygen or air during ground test operations.
2. Provide rapid depressurization and repressurization capability.
3. Provide individual oxygen mask systems for use by the crew.

As far as the implementation of the design is concerned, these changes are planned in the cabin:

1. Armor water glycol joints which are exposed.
2. Replace those aluminum oxygen lines which have solder joints with stainless steel.
3. Provide protective covers for all exposed plumbing.
4. Make necessary materials changes.
5. Relocate controls requiring quick access by the crew.

ADDITIONAL DATA

The following Technical Report provides details of the reviews, studies, and tests of the Environmental Control System.

Environmental Control System (t)

NASA APOLLO PROGRAM WORKING PAPER NO. 1221

Manned Spacecraft Center, Houston, Tex.

April 3, 1967

Summary

As a result of the AS-204 incident, the Apollo Command Module has been reviewed. The Environmental Control System has been a part of this review. It is proposed to alter the system to:

1. Reduce the fire hazard associated with operations at high ambient pressures and improve the repressurization performance.
2. Improve the integrity and protect the oxygen system plumbing.
3. Improve the integrity and protect the thermal control system plumbing (water-glycol fluid).
4. Provide an emergency oxygen mask breathing system for postlaunch emergencies.

In addition studies are proposed to improve the inhibitor used in the water-glycol coolant fluid and provide an additive which has a detectable odor to assist in low level leak detection.

Introduction

The Apollo CSM Environmental Control System has been the subject of a detailed review with respect to the AS-204 incident. This report contains the pertinent information concerning the review.

The overall design and performance of the system is assessed and changes are considered in (1) the atmospheric composition during specific mission phases; (2) the design, integrity, and protection of the oxygen plumbing; (3) the design of certain crew controls with respect to function and accessibility; (4) the system performance during the depressurization/repressurization mode of operation; (5) the design, integrity, and protection of thermal control circuit plumbing; and (6) the composition of the coolant fluid used in the thermal control circuit. In addition, an emergency breathing system is considered. The subject of nonmetallic materials used in the construction of the system, and the hazards associated with their use and application are covered in a separate report.

Appendix I contains a description of the Apollo Block II environmental system.

Appendix II contains an outline of the detailed procedures used to check for system leakage in ECS joints.

Spacecraft Atmosphere Selection

INTRODUCTION

This section discusses the engineering and physiological considerations used in selecting spacecraft atmospheres, the historical aspects and validation programs which have been conducted, and the recommended prelaunch and flight procedural changes proposed as a result of the AS-204 incident.

A 100-percent oxygen atmosphere at 5 pounds per square inch absolute remains the gaseous environment of choice inflight for missions planned through Apollo.

The principal characteristics to be considered in selecting an atmosphere for supporting life are pressure and composition. Any life-supporting atmosphere must contain an adequate amount of oxygen for sustaining life. The ideal atmosphere is generally felt to be one which is identical in composition and pressure with that on Earth between sea level and 5,000 feet altitude (14.7 to 12.2 pounds per square inch absolute; 21 percent oxygen, 79 percent nitrogen). The provision of such an ideal atmosphere would aid in achieving the overall goal of approximating all possible environmental variables which exist on Earth in order to assess better the effects of those variables which are unique to space flight—in particular, weightlessness.

ATMOSPHERE SELECTION PARAMETERS

The variables which determine the design envelope of the gaseous environment for manned enclosures are the total pressure and the partial pressures of oxygen, inert gases, water vapor, and toxic gases (essentially, carbon dioxide) that make up its composition. The discussion which follows will address itself essentially to the limiting conditions for total pressure, partial pressure of oxygen, and partial pressure of the prime inert (diluent) gas under consideration.

Total pressure.—Physiological considerations: Physiologically, total pressure is not the most important consideration in the selection of an atmosphere capable of sustaining life. The sum of the partial pressures of the various constituents equals the total pressure, and the properties of the complete mixture are determined by the proportions and properties of the constituents. The choice, therefore, of the most suitable atmosphere for use in manned spacecraft is the result of carefully considering the limiting conditions imposed by the acceptable range of values for each constituent gas, as well as for the resultant mixture. It is, therefore, understandable that a particular atmosphere selection is optimal only for a given set of spacecraft and operational mission parameters (see ref. 1, p. 695.)

The upper limit for total pressure, assuming that the only constraint is physiological, is arbitrarily fixed at the ideal of one atmosphere (14.7 pounds per square inch). The composition (neglecting trace gases) at this pressure consistent with physiological well-being is 21 percent oxygen (3 pounds per square inch partial pressure) and 79 percent nitrogen (11.7 pounds per square inch partial pressure). This limit can be shifted to a 5,000-foot equivalent (12.2 pounds per square inch total pressure) without changing composition or requiring acclimatization for acceptable crew performance. However, further reduction in total pressure, assuming no acclimatization by the crew, will require changing the composition (i.e., enriching the mixture with oxygen), as will be subsequently discussed.

Minimum total pressure is fixed by the physiological requirement for adequate oxygen to maintain an acceptable level of blood saturation (above 95 percent). The addendum explains in detail the physiological considerations which must be taken into account in order to insure that the inspired gas in a selected atmosphere provides adequate oxygen to sustain life processes.

The addition of an inert gas will require a proportionate increase in total pressure to the extent that the partial pressure of oxygen in the lungs is maintained at not less than approximately 2 pounds per square inch (104 millimeters of mercury).

In considering total environmental pressure, the phenomenon of ebullism must be mentioned in the interest of completeness. Ebullism is the vaporization of body fluids which occurs at extremely low total pressures. It is not, however, a consideration in establishing total spacecraft pressure, since long before this stake is reached, any given atmosphere is incapable of supporting life.

Engineering consideration: Engineering constraints are solely responsible for the upper limitation in spacecraft pressurization. These constraints include the following:

1. Structural strength of the spacecraft.
2. Leakage rate.
3. Atmospheric supply.
4. Ventilation power requirements.
5. Pressurized suit mobility.

Numbers 1, 2, 3, and 5 all result in spacecraft weight penalties which increase as pressure is increased. The ventilation power penalty increases as the pressure is decreased.

With respect to pressurized suit mobility, the state-of-the-art in suit development requires operation in a pressurized suit mode at a total pressure not exceeding approximately 4 pounds per square inch (in a vacuum environment) in order to avoid excessive metabolic energy expenditures with the associated penalties for biothermal control, condensation collection, and increased consumption of oxygen, food, and water.

Hazardous events considerations: Final determination of the lower bound for total pressure is generally based on providing an adequate margin of safety for appropriate crew action (for example, donning pressure suits) in the event of an unexpected cabin decompression such as from micrometeoroid penetrations.

Hazardous events having a relationship with total pressure are fire and blast (overpressure) effects. In general, with the partial pressure of oxygen held constant, the burning rate of a fire will be reduced as total pressure is increased (i.e., partial pressure of inert gas is increased), and the blast hazards will increase as total pressure is increased.

Composition.—The composition of the atmosphere refers to the proportions or partial pressures of the gaseous constituents of the atmosphere. The major constraints which fix the limits of partial pressure of each constituent are essentially physiological in nature.

To permit a more systematic study of the requirements for atmospheric composition, a number of feasible candidate atmospheres have been selected for comparison purposes.

The candidate atmospheres are:

1. Pure oxygen at a pressure of 5 pounds per square inch absolute.
2. Sixty-nine percent oxygen, thirty-one percent diluent gas, with a total pressure of 7 pounds per square inch absolute.
3. Pure oxygen at a pressure of 3.7 pounds per square inch, absolute (suited mode).

Physiological considerations: The physiological disturbances which may occur as a result of conditions of atmospheric composition and partial pressures of the constituents are:

1. Hypoxia (inadequate oxygenation)
2. Hyperoxia (excessive oxygenation)
3. Atelectasis (collapse the air sacs of the lungs)
4. Dysbarism (decompression sickness or "bends")

A fifth category, inert gas narcosis, is not considered in this report, since this effect requires inert gas pressure in excess of values currently considered feasible for space flight.

The potential states of hypoxia and hyperoxia establish the lower and upper limits respectively for the partial pressure of oxygen in the space vehicle enclosure.

Because oxygen is absorbed readily by body tissues, earache and reduction in total aerating capacity of the lungs may result when oxygen is absorbed from temporarily occluded cavities of the middle ear and lung alveoli (air sacs of the lung). The pulmonary condition, called atelectasis (collapse of the air sacs of the lung), is aggravated by exposure to increased gravity loads. Provision of an inert diluent gas in the atmosphere provides protection against atelectasis.

Dysbarism or "decompression sickness" (bends) is a general term which includes all the physiologic effects occasioned by reductions in barometric pressure independent of any hypoxic effects. The causes of dysbarism are the expansion of existing gases within the body cavities and the formation of gas bubbles, principally nitrogen, in body tissues and fluids. An adult breathing sea-level air has approximately one liter of nitrogen dissolved in tissue fluids. During ascent to altitude, tissues and fluids become supersaturated and nitrogen is evolved from solution as gaseous bubbles, which, depending on their quantity and location, produce the major symptoms of dysbarism. These symptoms are classified as "bends" when produced by bubbles located in the connective tissue in and about joints and muscles, and are referred to as "chokes" when such bubbles accumulate in the pulmonary circulation. In addition to these manifestations of dysbarism, the evolved gases can produce mild to severe symptoms involving the nervous system in a variety of patterns, depending on the anatomical location of the bubbles.

The only preventive measure effective against dysbarism is denitrogenation (removal of nitrogen from the body) before ascent to a higher altitude. Denitrogenation is accomplished most rapidly by breathing pure oxygen as ambient pressure. Individual susceptibility to dysbarism varies widely in a given population and even within a given individual as a function of time. Such factors as age, increased body fat, and excercise not only increase the incidence of symptoms at a given altitude, but also lower the threshold altitude at which these symptoms may appear. Investigations are currently being conducted to establish the preoxygenation time at sea level required to prevent dysbarism following sudden decompression to suit operating pressure (3.7 psia nominal) should the spacecraft cabin fail to pressurize. Although this program is not complete, it would appear that 3 to 4 hours of preoxygenation will be required.

Engineering considerations: Most of the engineering considerations related to atmosphere selection previously discussed are concerned with total pressure requirements. There are, however, several aspects of spacecraft design which are specifically related to atmosphere composition; these aspects are:

1. Sensing.
2. Control.
3. Reliability.

For single-gas systems (i.e., pure oxygen), adequate sensing and control are based on total pressure regulation. This approach, plus the addition of simple redundancy in critical areas, provides maximum reliability. For mixed atmospheres, it is essential to sense and control the proportions of the atmospheric constituents as well as total pressure. Reliable partial pressure sensors which are suitable for flights exceeding 30 days are still under development. The principal problem inherent in the most promising sensor is that of degradation in sensitivity over a relatively short period of time. In addition the complexity of controlling the amount of each gaseous constituent introduced into the cabin and the feasibility of providing essential redundancy makes it very difficult to meet reliability objectives required for mixed gas systems.

Hazardous events consideration: The four types of hazardous events which usually influence atmopshere selection are:

1. Asphyxiation.
2. Fire.
3. Blast.
4. Rapid Decompression.

Asphyxiation may result from various system failures leading to excessive production of suffocating particles or toxic gases, or from failure of the pressure integrity of the pressure suit or suit circuit, or the presence of excessive diluent.

Roth summarizes (ref. 2, p. 695) the multifaceted nature of fire risk assessment as follows:

1. A reduction in total pressure may result in a reduction of flash points of volatile liquids and an increase in arcing of electrical contacts.
2. An increase in the partial pressure of oxygen virtually always increases the fire hazard.
3. An increase in the partial pressure of the diluent gas with a fixed partial pressure of oxygen reduces the fire risk.

Pure oxygen in the pressure range required for life support presents a definite fire hazard. On the other hand, a physiologically acceptable two-gas system at a pressure compatible with spacecraft structural limitations does not appear to offer a large reduction in fire hazard over a 5 psia pure oxygen atmosphere. In general, atmospheres which support life will also of necessity support combustion.

In summary, the principal determinants of total pressure limits are engineering constraints (maximum) and the need for adequate oxygen (minimum). The principal considerations which determine the composition of the spacecraft atmosphere are the physiological risks of hypoxia, decompression sickness, and atelectasis and the difficulty in developing an atmosphere control system which will meet established reliability objectives. The risks of decompression sickness and hypoxia inherent in a mixed gas atmosphere are considered more serious than the risks of fire and atelectasis inherent in a pure oxygen atmosphere for the relatively short flight regimes of Apollo.

It is felt, however, that certain design and procedural changes can be made and additional precautions taken during the prelaunch and flight phases which will further minimize the risks to crew safety.

HISTORICAL ASPECTS

Projects Mercury and Gemini.—The atmospheres used or planned for use during the prelaunch and flight phases of the various manned space flight programs have been previously documented (ref. 3 and 7, p. 695); therefore, only the salient historical features will be outlined.

Selection of the pure oxygen atmosphere for flight in the Mercury and Gemini programs was dictated by the requirement for a high reliability system with minimum weight and volume. The final choice was based on experience gained through manned balloon and aircraft flights with similar systems in the late 1950's. The Mercury selection was evaluated for its physiological implications and was subsequently approved by the NASA Life Sciences Committee, chaired by Dr. W. R. Lovelace II.

Mercury flights served to validate the use of the 5 pounds per square inch absolute pure oxygen atmosphere for the initial short-term Gemini flights. Insufficient data were available on the physiological effects of a 14-day exposure to this environment, and MSC therefore initiated a test program in early 1962 in order to insure validation of the proposed atmosphere prior to flight. Based on these initial data, it was concluded that there were no physiological objections to the use of a 5 pounds per square inch absolute, 100-percent oxygen atmosphere for flights not exceeding 14 days in duration.

The cabin atmosphere initially planned for Mercury during the prelaunch phase was air. During launch, this 14.7 pounds per square inch absolute atmosphere was to bleed down to 5 pounds per square inch absolute and was to be simultaneously enriched to a level of 66 percent oxygen. The replacement of cabin gas leakage with oxygen would further enrich the atmosphere.

Tests subsequently conducted at McDonnell Aircraft Corporation resulted in several incidents of hypoxia (oxygen deficiency due to low oxygen partial pressure) in test subjects when nitrogen in the cabin gas leaked into and diluted the oxygen in the suit circuit. Following these test failures, the prelaunch atmosphere was changed to 100 percent oxygen at 15 pounds per square inch.

Project Apollo.—The initial choice for the Apollo command module atmosphere was a 7 pounds per square inch absolute 50–50 percent oxygen-nitrogen mixture with an oxygen partial pressure of 180 to 200 millimeters of mercury. The rationale behind this choice was based principally on the possibility of pulmonary atelectasis (collapse of lung air sacs) resulting from long-term breathing of pure oxygen, particularly at reduced total pressures. It was felt that limiting total pressure to 7 pounds per square inch absolute would permit emergency operations in a 3.5 pounds per square inch absolute, 100-percent oxygen suit loop with a minimal risk of dysbarism ("bends"). Studies were then initiated to validate this choice.

In June 1962, North American Aviation was advised that the command module atmosphere would be 100-percent oxygen at 5 pounds per square inch absolute. This change was dictated by the simplicity and reliability of the one-gas system, lunar module compatibility considerations, and favorable results of the referenced Gemini tests. As in the previous Mercury and Gemini programs, 100-percent oxygen purge of the cabin was planned for the prelaunch phase.

Parallel activities of Gemini and Apollo permitted use of the same test results to validate the atmospheres for both programs (ref. 5 and 6, p. 695). The overall test program was completed in November 1963 and the 5 pounds per square inch absolute, 100-percent oxygen atmosphere validated for a 30-day period. The NASA position was reviewed in 1963 and 1965 and previous decisions were reaffirmed. Additional chamber tests conducted during this period established that there were no physiological reasons for altering this decision.

Soviet spacecraft atmosphere.—It should be noted here that the Soviets have utilized a slightly oxygen enriched air at 760 ± 20 millimeters of mercury. The reasons stated for this choice were to minimize fire risk and to normalize all variables possible in order to evaluate more precisely the psychological effects of the weightless environment.

In order to minimize the risk of dysbarism, it has been necessary for the Soviets to utilize a suit pressure of approximately 7.5 pounds per square inch absolute. Although some evidence exists indicating that the Soviet cosmonaut could modulate suit pressure to provide increased mobility. it appears that this choice of operating pressure has placed rather severe constraints on suit development and extravehicular activity.

APOLLO PROCEDURAL AND ENGINEERING CHANGES

Proposed launch pad phase changes.—In order to reduce the spacecraft fire hazard during launch pad operations, proposed spacecraft systems changes will permit the use of air in the cabin while retaining oxygen in the suit circuit during manned operations. A firm decision to use air in the cabin during the launch pad phase has not yet been made; however, systems modifications and designs are being made to permit this procedure to be evaluated and incorporated into flight spacecraft. The feasibility of this proposed change will be demonstrated by appropriate testing prior to actual operational use. Further, this feasibility is predicated upon fulfilling the physiological requirements outlined below. Air with its high nitrogen content will not be permitted to enter the suit circuit. The suit circuit will be maintained at a pressure slightly greater than cabin pressure to prevent air inleakage (see fig. 168). This slightly elevated pressure will not prevent or deter egress in any way because the suit umbilicals (hoses) can be detached quickly for unencumbered egress.

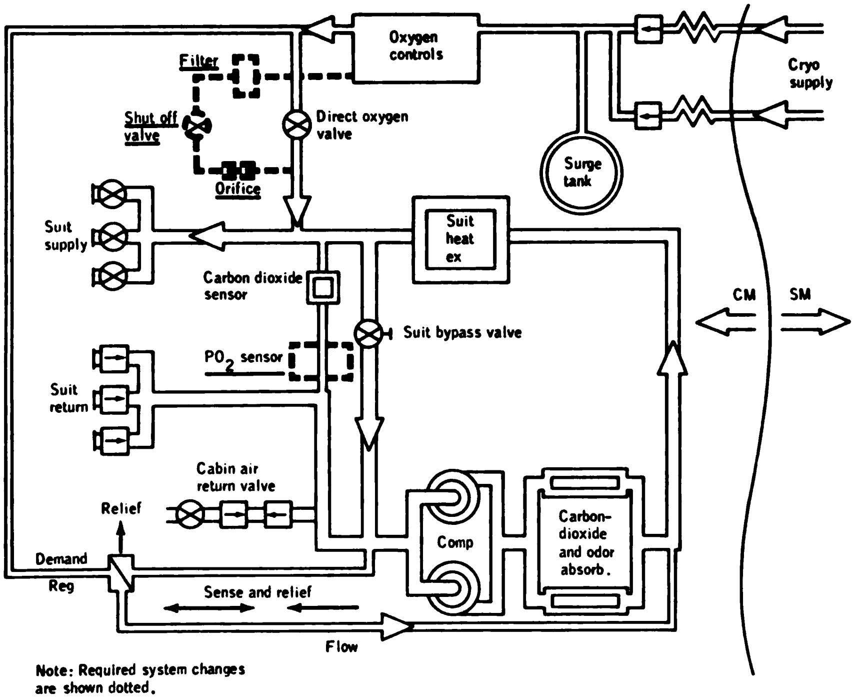


FIGURE 168

The use of air during the prelaunch phase as a fire deterrent may have an impact on current preoxygenation procedures since the presence of nitrogen in the spacecraft makes it mandatory for the crewman to prebreathe oxygen within the suit circuit isolated from the spacecraft cabin gas environment. Any violation or contamination of this isolated circuit by inert gas would compromise decompression protection. In space missions which involve the use of a mixed-gas atmosphere (69–31 percent oxygen-nitrogen at 5 pounds per square inch absolute), crewman will be required to denitrogenate prior to any planned EVA. Studies are presently underway to establish the duration of the denitrogenation period. In addition, investigations have been initiated concerning the effects of repeated planned decompressions.

The final cabin leakage check will be performed by pressurizing the cabin. This procedure requires 20 minutes maximum and will be performed with the cabin pressure 3.0 to 3.5 pounds per square inch above ambient pressure. The suit circuit will be maintained slightly above cabin pressure, and it will contain only oxygen. Any hazards are minimized by keeping the duration of the over-pressurization period short, while maintaining the suit pressure slightly above cabin pressure, so as to insure only out-leakage of gas from the suit circuit. Verification of cabin integrity has been required on all spacecraft. The proposed change in the present Apollo procedure is to perform this check with air rather that with oxygen. Following the leak check, the pressure is reduced to ambient (see fig. 169). All components subjected to the elevated pressures have been qualified by test to be satisfactory in safety and performance for this environment.

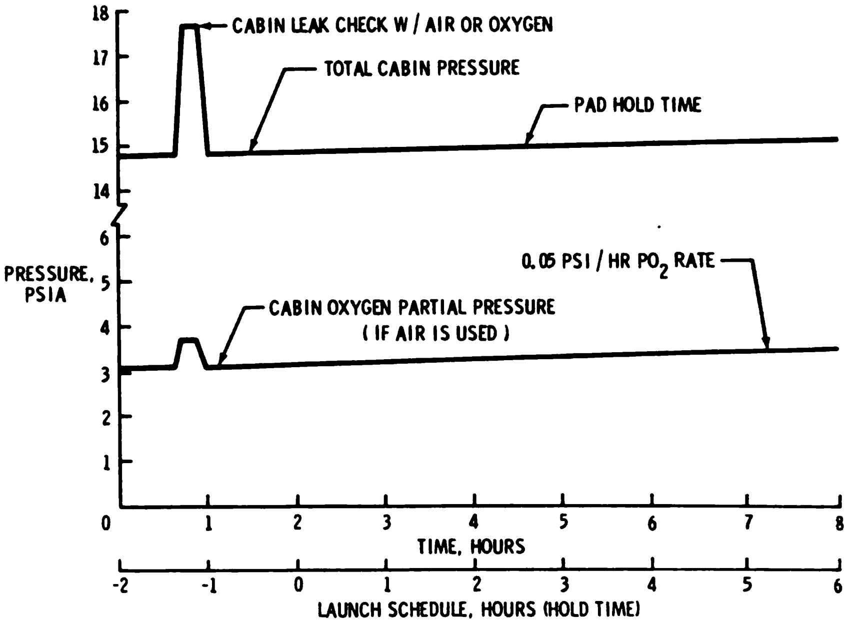


FIGURE 169

The suit must remain closed to prevent the inflow of air (since it contains nitrogen). The introduction of nitrogen into the suit circuit would be hazardous because of the possibility of dysbarism and/or hypoxia when cabin pressure is reduced during launch, as previously noted.

Physiological impact.—The use of air instead of pure oxygen in the spacecraft during the prelaunch phase, while potentially reducing the fire hazard, poses no physiological problems as long as the crew is maintained on pure oxygen completely isolated from the spacecraft atmosphere, and as long as their prescribed denitrogenation procedure is not compromised. Adequate protection against dysbarism (with the use of air in the spacecraft), however, is predicated on maintaining the integrity of the pure oxygen suit circuit.

The purpose of maintaining the crew in a pure oxygen suit environment is to insure maximum protection against decompression hazards (dysbarism) in flight—a mission abort situation. On the other hand, any very prolonged prelaunch "holds" would result in exposure of the crew to this hyperoxic (100 percent oxygen, 15 or more pounds per square inch absolute) environment which is potentially toxic. The use of 100 percent oxygen in high performance jet aircraft at sea-level pressures is standard operating procedure.

Oxygen monitoring.—If air is used in the cabin, an oxygen partial pressure sensor is required in order to monitor the status of oxygen within the suit circuit. This operational instrumentation will require monitoring by ground and flight crews during all phases until the cabin air is vented and replaced with oxygen. Phases which will be particularly critical will be during cabin leak checks, and during the orbital phase when the cabin is being vented and refilled. Other instrumentation is currently provided which will show that the suit circuit is being maintained at slightly greater than cabin pressure. This makes the oxygen partial pressure sensor not flight critical.

Launch and orbit phase proposed changes.—As the spacecraft ascends to higher altitudes, the air is automatically released from the cabin until the cabin pressure is constant at 5.6 to 6.2 pounds per square inch absolute. The suit circuit follows the cabin pressure automatically by venting 100 percent oxygen into the cabin. It should be noted that although the suit circuit vents 100 percent oxygen into the cabin, the volume of oxygen involved is very small due to the relatively small suit loop volume. Thus, the air in the cabin remains at virtually standard composition. At this reduced pressure, there is not sufficient oxygen in the cabin to support life. The only significant changes in operations are the confinement and isolation in suits and the requirement for the sensor to detect any reduction in the suit circuit oxygen partial pressure. When orbit is achieved, the cabin pressure will bleed down from the relief valve setting of 6.2 to 5.6 pounds per square inch, due to leakage. The suit circuit will automatically vent to the cabin to maintain a constant differential pressure which will be positive with respect to the cabin. This is favorable from an air in-leakage consideration. Cabin pressure may bleed down to 5.0 pounds per square inch (nominal), at which time the cabin pressure regulator (an inflow value) will automatically meter in oxygen to maintain 5.0 pounds per square inch (see fig. 170).

Normally, the gas change operation is a manual two-step depressurization. A lever is pulled to decompress (dump) the cabin to 3.0 pounds per square inch, then replaced to its normal position to stop the dump. This provides a final momentary verification that the suit circuit has full integrity. Under these conditions, the suits will be slightly inflated (suit pressure will be at 3.75 pounds per square inch, when cabin pressure falls below 3.75 pounds per square inch), allowing maximum mobility if there should be a problem.

Following verification of suit circuit integrity, the cabin dump is completed by manual actuation of the lever, and the cabin is then repressurized with oxygen. Two modes of repressurization are available, one being a current change. The present repressurization is slow because of flow restrictors in the oxygen supply lines to protect the cryogenic source from a high withdrawal rate. Approximately one hour is required to repressurize the cabin in this mode. The proposed change provides an additional oxygen source (surge tank) which can supply at a high rate to reestablish cabin pressure to a safe level in approximately two

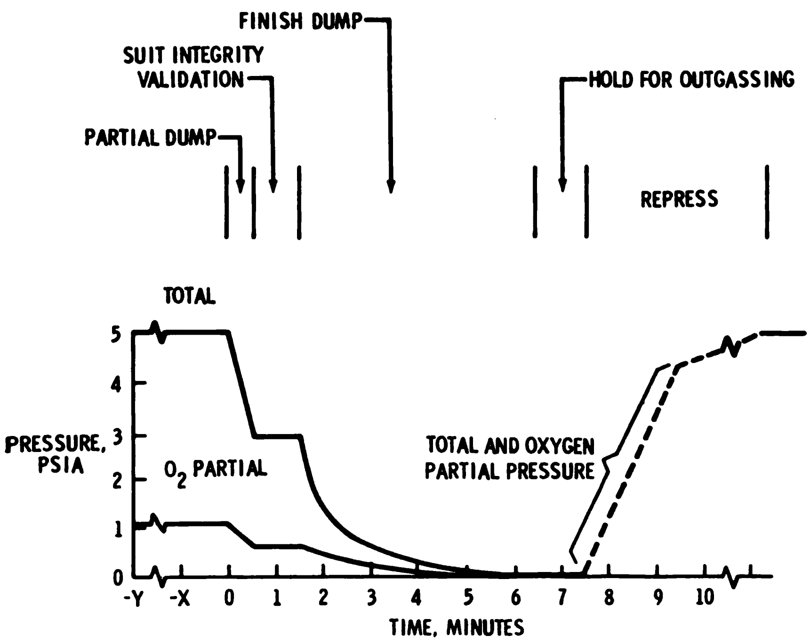


Figure 1-3. - Cabin and oxygen partial pressures for reestablishment of 100 percent cabin environment following use of air on pad.

FIGURE 170

minutes (see fig. 171). The remainder of the pressurization will be at the slow rate with no risk, and the crew can proceed with other activities as required. This fast repressurization mode must be manually selected. The additional surge tank will refill slowly from the cryogenic supply so that repeated use will be limited to several hour intervals. The crew will remain confined to suits until this repressurization supply pressure is re-established (approximately one hour) to guard against a subsequent emergency. From this point in the mission, the atmospheres and procedures remain unchanged.

Special operations such as extravehicular activity (EVA) or lunar module docking and pressurization will be performed as before. As in the past, the cabin must be depressurized after the crew is suited for EVA. The crewmembers to be extravehicular must transfer to the Portable Life Support System (PLSS) and remove umbilicals from the ECS prior to complete depressurization to perform final checks. The remaining crewmember is supported by the ECS. Cabin depressurizations and repressurizations are provided in substantially the same manner as previously described.

Entry phase.—Preparations for entry will include the crew donning of pressure suits and "buttoning up" in the suit circuit. Verification of the integrity of the suit circuit is performed by elevating the suit pressure to check for leaks. Entry is performed while the crew remain suited, but the suits are not inflated. If there should be a fault in the cabin pressure vessel and subsequent loss in cabin pressure, the suits will automatically retain their pressure. The entry mode imposes high thermal stresses on the cabin structure, and therefore the suit mode is a preplanned backup, since donning suits during entry is impossible.

As the spacecraft enters higher pressure ambient air, the cabin pressure controls automatically vent air inward to prevent crushing due to the ambient pressure buildup. The suit circuit pressure controls admit more oxygen to permit the suits to follow cabin pressure, preventing the suits from collapsing on the men. At touchdown, the cabin will contain oxygen-enriched air at the prevailing ambient total pressure, and the suit circuit will contain oxygen at the same pressure. The partial pressure of oxygen in the cabin will be 6.85 pounds per square inch, or less than 4 pounds per square inch above normal air and less than 2 pounds per square inch above routine flight. This enriched air presents no hazard and has been used repeatedly in previous spacecraft.

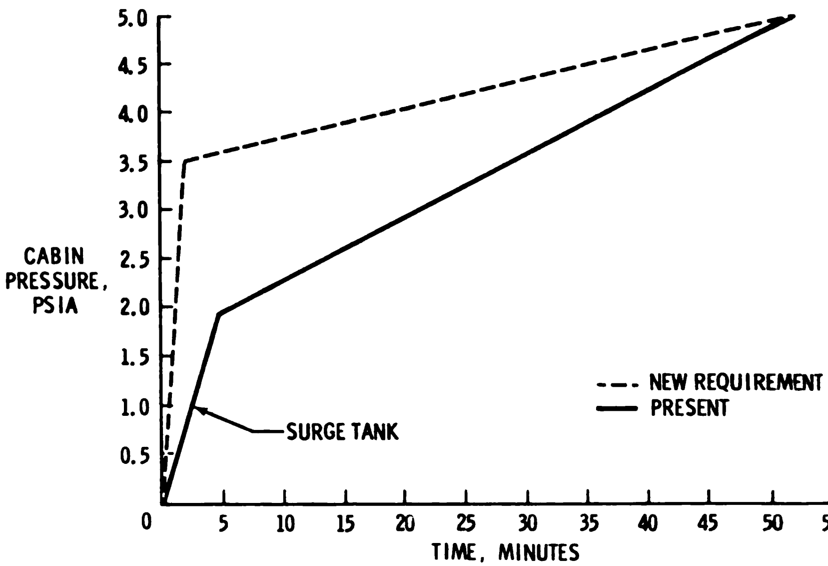


FIGURE 171

Chamber operations.—Chamber testing with manned spacecraft will be performed with atmosphere supplies duplicating those to be used during flight vehicle operations. All equipment checkouts prior to actual test runs will be performed using air as both cabin and suit circuit gas, except when the checkout requires a man in the suit circuit. In those cases, air will be used in the cabin and oxygen in the suit circuit, duplicating pad atmospheres and procedures.

Unmanned test runs in altitude chambers will not provide a duplication of flight vehicle atmospheres because of the manual operations required to dump the residual air from the cabin and backfil with oxygen. It is an unacceptable compromise to the system to provide remotely activated valves to perform these functions. Unmanned chamber testing will of necessity be conducted with 100 percent oxygen in both cabin and suit circuits. The use of oxygen in this case has the added advantage of demonstrating that all spacecraft systems are safe to operate when exposed to 100 percent oxygen at sea level pressure, giving added assurance of safety at the reduced oxygen pressures that will be used for manned testing and manned flights.

Changes required.—The implementation of the proposed use of air in the cabin at launch will require equipment modifications to insure that nitrogen will not be introduced into the suit circuit. This requires the addition of a flow control valve (or modification of an existing design, filter and flow control orifice. Procedural changes (flight and ground) must be documented and verified to insure that complexities do not prove too cumbersome and that conflicts in requirements are not encountered. Since oxygen must be maintained in the suit circuit, a sensor system must be incorporated into the design providing the capability of monitoring the partial pressure oxygen. Specifications must be revised and the suit return valve made leakproof so as to prevent inleakage of air. Additional oxygen must be budgeted to replace the air which will be vented from the cabin.

ATMOSPHERES BEYOND APOLLO

Recommendations concerning the choice of atmospheres for prolonged space missions have been made by the 1966 Woods Hole summer study group organized by the Space Science Board of the National Research Council, and by the Medical Advisory Council, Office of Manned Space Flight, NASA Headquarters (addendum A). The recommendations contained in these were that 100 percent, 5 pounds per square inch absolute is physiologically acceptable for use during space flights not exceeding 30 days. The use of this atmosphere for longer space flights (over 30 days) made, day-for-day ground-based validation of the oxygen atmosphere mandatory—a prohibitively expensive requirement. For flights in excess of 30 days, a two-gas system was recommended, notwithstanding the fact that the introduction of an inert gas increases the risk of dysbarism and complicates the engineering of the life-support system. The use of the two-gas system was justified principally on physiological grounds: to prevent or reduce the risk of atelectasis.

ADDENDUM A

PHYSIOLOGICAL CONSIDERATIONS ESTABLISHING THE OPTIMUM PARTIAL PRESSURE OF OXYGEN IN A MIXTURE OF RESPIRABLE GASES

Figure 172 is a graphic presentation of the relation of oxygen partial pressure to percentage saturation of human blood with oxygen. It is obvious that when the oxygen pressures are above approximately 60 millimeters of oxygen, an increase in pressure serves to increase the blood oxygen saturation only a small amount. Below about 50 millimeters of mercury oxygen pressure, a relatively small decrease serves to unsaturate the hemoglobin molecule rather precipitously. Three curves are shown, with the center curve (B) describing the case when the acidity of the blood plasma is 7.4 pH units, a condition considered normal for human blood.

Atmospheric air at sea level pressure contains approximately 21 percent oxygen by volume. When air is inspired into the trachea, it is immediately saturated with water vapor by contact with the moist lining of the respiratory tract. Assuming that dry air had been inspired at a pressure of 760 millimeters of mercury, the addition of moisture to the trachea air lowers the total pressure of the other gases (nitrogen and oxygen) so that their combined pressures total 713 millimeters of mercury. The vapor pressure of water at body temperatures is 47 millimeters of mercury. Therefore, 760—47=713.

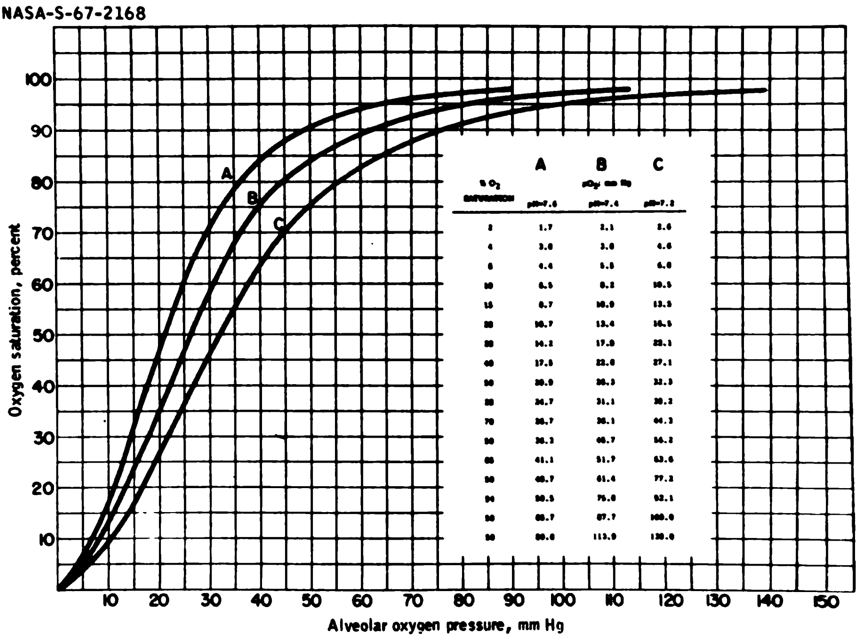


FIGURE 172

After moistening in the trachea, the gas contains a partial pressure of oxygen of 149 millimeters of mercury ($0.21 \times 713 = 149$). When this gas reaches the alveolar spaces and gas exchange takes place across the pulmonary membranes which separate the respiratory gases from the blood perfusing the lungs, oxygen is absorbed by the hemoglobin contained within the red blood cells according to the curve (B) in figure 172. As oxygen is absorbed, carbon dioxide is released from the blood and diffuses into the alveolar spaces. If the volume of carbon dioxide entering the alveolar spaces per unit of time is equal to the volume of oxygen leaving the alveolar spaces in that time, the respiratory exchange ratio R is said to be 1. Thus,

$$R = \frac{\text{Volume } CO_2 \text{ produced}}{\text{Volume } O_2 \text{ consumed}}$$

Because of factors relating to complex metabolic processes and the fact that when a mixed diet consisting of fats, proteins, and carbohydrates is consumed and metabolized in a variety of organs, each with its own pattern of metabolism, the net effect is that the gas exchange in the lungs does not produce a respiratory exchange ratio of 1, but more nearly 0.84. When air, or a similar gas mixture is breathed, the effect of R being less than unity has a minor, but significant influence on the composition of alveolar gas. Taking this into consideration, the composition of a alveolar gas with respect to oxygen is calculated as follows:

$$P_{A_{O_2}} = F_{I_{O_2}} \left[P_B - P_{A_{H_2O}} \right] - P_{A_{CO_2}} \left[F_{I_{O_2}} + \frac{1 - F_{I_{O_2}}}{R} \right]$$

Where: $P_{A_{O_2}}$ = partial pressure, alveolar oxygen

$F_{I_{O_2}}$ = mole fraction, inspired oxygen

P_B = barometric pressure, millimeters of mercury

$P_{A_{H_2O}}$ = partial pressure water at 37° C

$P_{A_{CO_2}}$ = partial pressure, alveolar carbon dioxide (normally regulated by action of the nervous system by adjusting rate and depth of breathing to produce an alveolar partial pressure of carbon dioxide of about 40 mm Hg)

R = respiratory exchange ratio

INFLUENCE OF OXYGEN SATURATION OF THE BLOOD ON PERFORMANCE

It can be shown by the above formula that when air is breathed at sea level, the oxygen partial pressure in the alveolar gas is about 102 to 104 millimeters of mercury. Because some blood traverses the lungs without exchanging gases, the arterial blood reaching the left ventricle for ejection into the body systems never quite reaches 100 percent saturation, but rather may be saturated to the extent of about 97.5 percent. This discrepancy has no influence in the effectiveness of the blood to carry oxygen to the tissues. However, when the oxygen pressure of the alveolar gas is decreased for any of several reasons (reduction in total atmospheric pressure, intentional or accidental alteration of composition of the inspired gas, tracheobronchial obstruction, disease), the amount of oxygen carried by the blood is reduced and the saturation of hemoglobin with oxygen falls accordingly. The unique properties of the hemoglobin molecule along with other properties of the respiratory system provide the human being with a considerable factor of safety. Therefore, symptoms of lack of oxygen (hypoxia) are not likely to be evident until the oxygen saturation of the blood has fallen to a level which affects the most sensitive organs, particularly the brain. Symptoms become more severe the lower the oxygen saturation and the longer the time of exposure to the low oxygen tension.

Attention is drawn to figure 173. It is evident from these curves that there is an "equivalent altitude" breathing oxygen in which the arterial oxygen saturation is the same as would be found breathing air at a correspondingly lower altitude. For example, a saturation of about 87 percent is attained breathing air at 10,000 feet, while the same saturation is attained breathing undiluted oxygen at an altitude of 40,000 feet. Aircraft oxygen systems are designed to meter oxygen with ambient air so that as the altitude increases, the amount of oxygen increases to maintain saturation of the hemoglobin within tolerable levels. This pair of curves illustrates that the saturation of hemoglobin cannot be maintained even while breathing 100 percent oxygen if the altitude exceeds about 35,000 feet. But there is little impairment in performance at an altitude of 5,000 feet breathing air except possibly some decrement in visual performance; it is not entirely out of the question to breathe air at 8,000 or 10,000 feet, but performance is curtailed

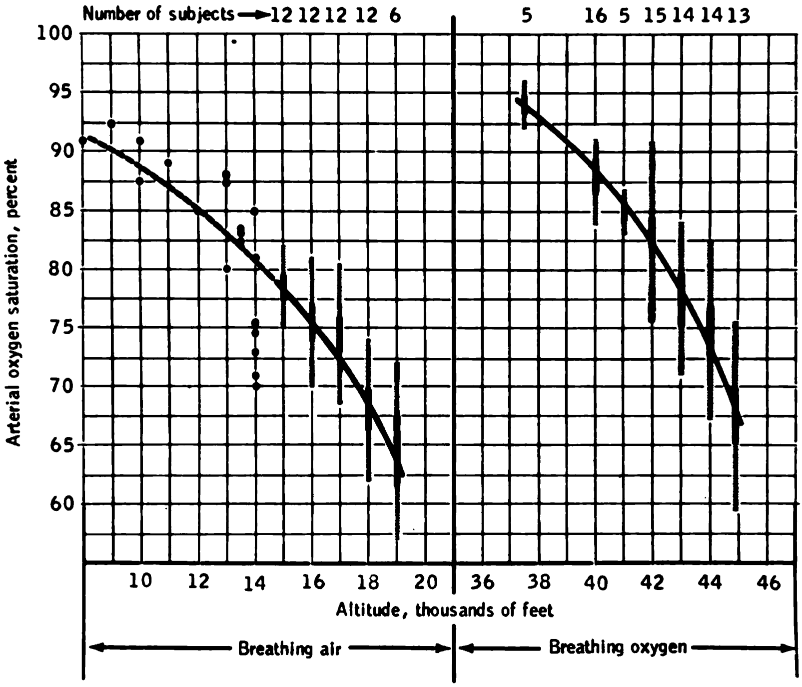


FIGURE 173

to a noticeable degree and especially in an individual called upon to do increased muscular or even mental activity. But there is very little threat to life itself, except that the natural built-in safety factor has been lost, and further hypoxic stress would very likely precipitate complete failure and unconsciousness.

ALVEOLAR OXYGEN TENSIONS THAT PRODUCE OPTIMUM SATURATION OF THE BLOOD

Figure 174 is constructed using the alveolar gas equation and shows the relative proportions of oxygen and diluent (nitrogen) that produce an alveolar oxygen pressure of 104 millimeters of mercury at any selected total ambient pressure between sea level and approximately 3.7 pounds per square inch absolute.

OXYGEN SYSTEM CHANGES

Changes in the command module (CM) oxygen system to increase crew safety include component modifications, overall system-plumbing changes, improvements on the control panels, added operational capability for repressurizing the cabin, and shielding exposed tubes to preclude damage.

CHANGE DESCRIPTION

Oxygen tubing material changes.—The present CM oxygen system consists of 900-, 100-, and 20-pound per square inch aluminum oxygen lines containing 9

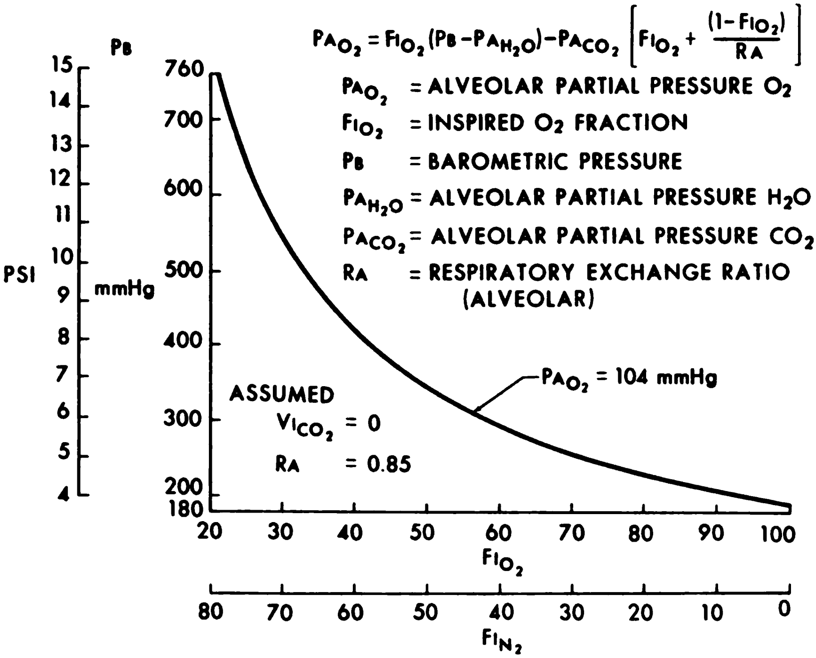


FIGURE 174

solder joints and 38 aluminum tubes. To provide additional protection to the oxygen supply system, all aluminum lines which could cause high oxygen flow, if ruptured, are being changed to stainless steel. The stainless steel lines will be joined by brazing or welding or through the use of high quality steel mechanical fittings. One exception is under consideration for two small local areas where other protection may be more desirable. Specifically, the two small oxygen-line penetration stubs through the aluminum cabin wall could be protected by shielding with insulation rather than permitting a steel-to-aluminum interface at those points.

The planned change is consistent with the Third Interim Report of the AS 204 Review Board.

Control accessibility.—As indicated in the Third Interim Report of the AS-204 Review Board, emergency procedures were to be re-evaluated. Therefore, the flight crews have re-evaluated routine and emergency procedures and have identified several areas of control improvements.

The use of a tool is necessary to actuate several critical ECS controls, and one control could be inaccessible during critical mission phases. It is therefore planned to provide permanent handles on the identified values and the inaccessible components, as required, to improve crew safety (see figs. 175, 176, and 177.) Mockup and flight simulators will be modified and used for training so that background and experience will be provided, prior to use with live systems.

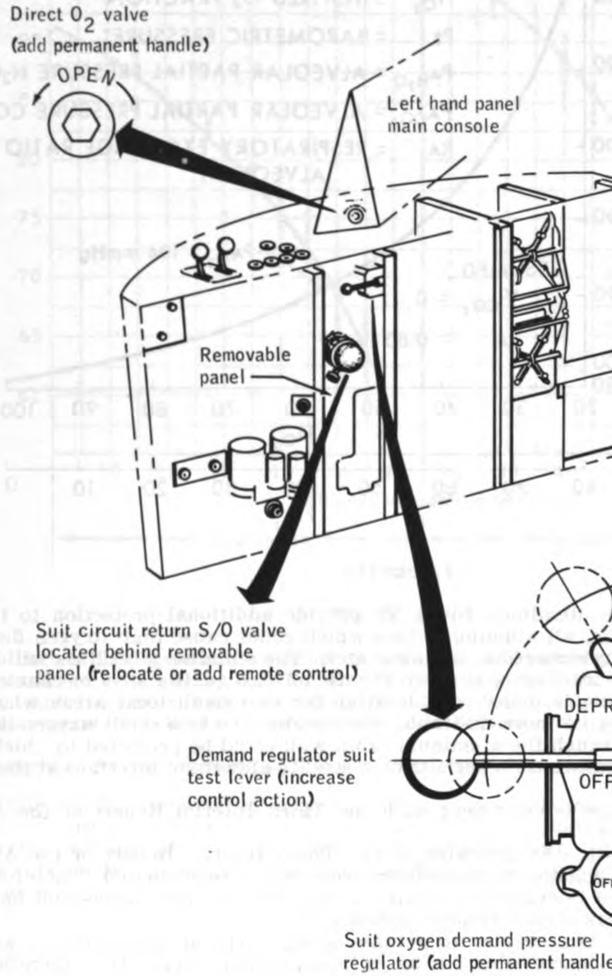
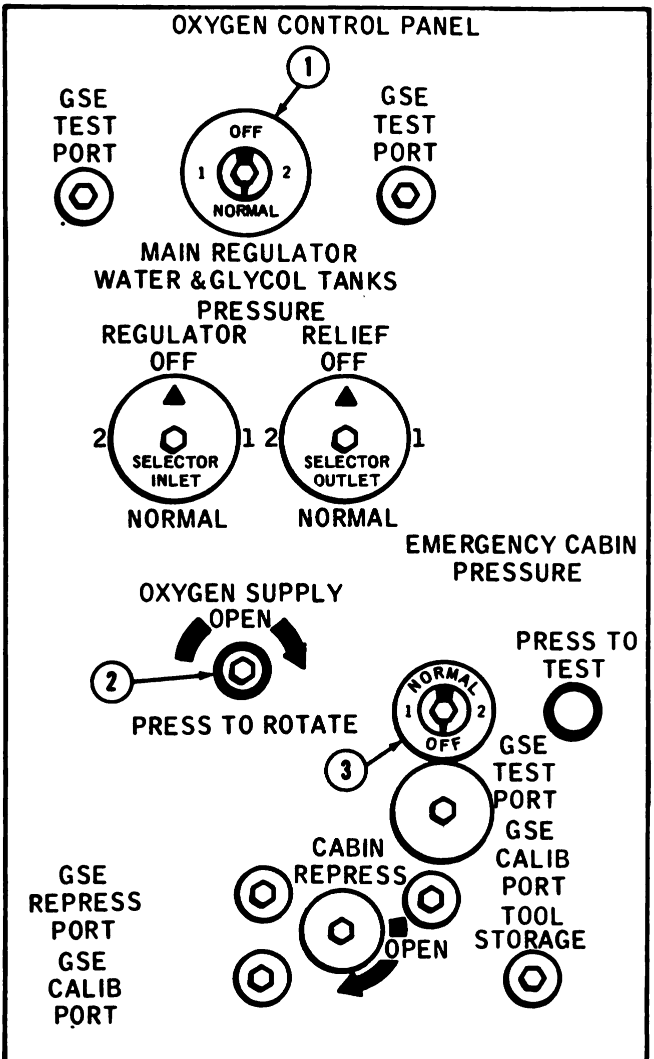

Direct O_2 valve
(add permanent handle)
OPEN
Left hand panel
main console
Removable
panel
Suit circuit return S/O valve
located behind removable
panel (relocate or add remote control)
DEPR
Demand regulator suit
test lever (increase
control action)
OFF
Suit oxygen demand pressure
regulator (add permanent handle

FIGURE 175



(1) Main (oxygen) regulator selector
(2) Oxygen supply shut-off valve
(3) Emergency cabin pressure valve

FIGURE 176

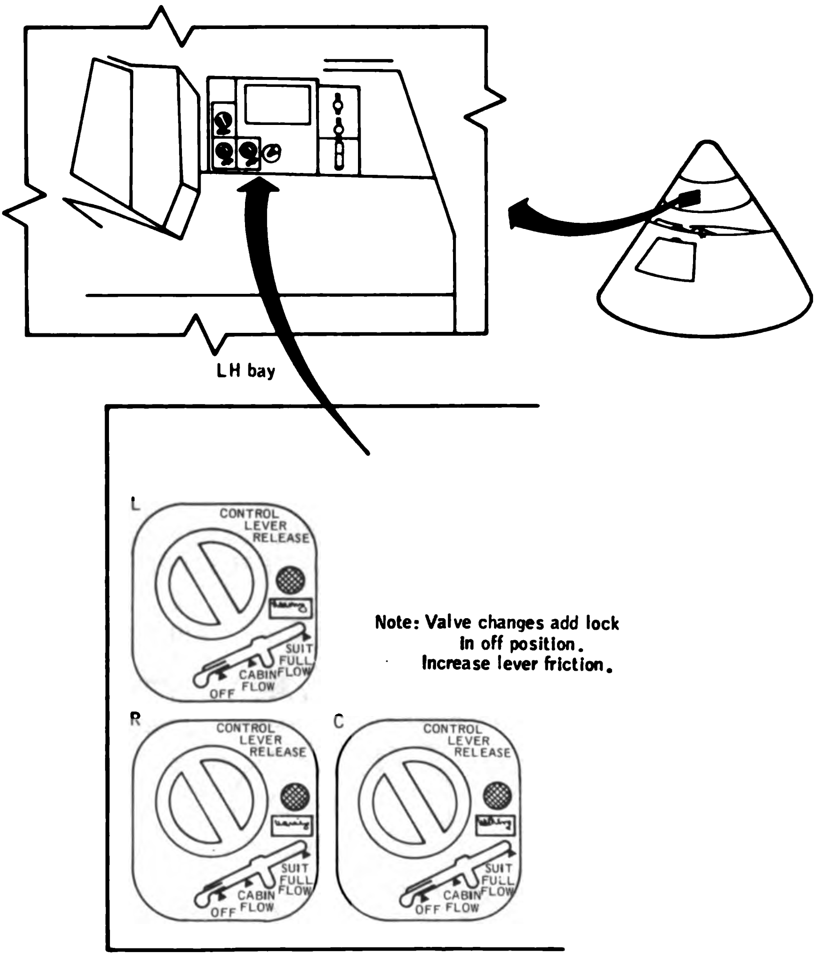


FIGURE 177

Component relocation or redesign is as follows:

1. The suit-circuit return (manual) valve will be placed in the closed position when the crew becomes fully suited. This prevents cabin gas from entering the suit circuit. The valve is inaccessible from the couch and requires removal of a protective panel for accessibility. Since an inflight contingency could require crew suitup, either a lever will be provided with a teleflex cable which can be operated from the left-hand couch, or the valve will be relocated to improve accessibility. Neither approach would interfere with the couch or other systems.

2. The suit demand regulator controls the suit-circuit pressure with either of two redundant valves. A tool is necessary to select either of the redundant valves, to select both valves, or to turn off the control. The selector-valve position indicator is not readily visible to the crewman in the left hand couch; a permanent handle will be added to the selector valve, and the position indicator extended for adequate visibility by the crewman, when in the normal couch position. Positive detents for all four selector valve positions will be added for improved "feel" when manipulating the selector valve. It was also determined that a crewman can inadvertently depressurize the suit circuit during a suit-circuit leakage test. Although not a safety hazard, it is an undesirable situation, requiring a recheck and probably causing a lowering of confidence in the ECS. The suit test lever will be revised so that positive action is required to select either the pressurization or depressurization position. These changes can be incorporated without interference with the couch or other spacecraft systems.

3. The direct oxygen-metering valve permits manual control of oxygen flow into the suit circuit for purging and contingency breathing requirements. The direct oxygen-metering valve has no position indicator on the valve to aid in flow adjustment. Because of its high rate capability the flow adjustment may be difficult in an emergency, and it requires the use of a tool for operation. The following changes are planned for incorporation in the direct oxygen metering valve: to provide a position indicator on the valve, to modify the flow versus position characteristics for improved flow regulation, and to provide a permanent handle on the valve. These changes do not interfere with the couch or other systems.

4. The oxygen valve panel includes the main regulator-selector valve, the oxygen supply-shutoff valve, and the emergency cabin-pressure valve. All require the use of a tool for actuation, and there are cases when a valve position may require changing in an emergency. Permanent handles are planned for the oxygen control panel components to enable quicker, more positive operation. The handles do not interfere with other systems or the couch.

5. The suit flow control valve has no positive lock in the off position and there is insufficient friction in the control lever. A lock in the off position provides assurance against inadvertent operation which might prove hazardous in a contingency operation, such as changing from or back to the ECS in an unpressurized cabin. The lack of friction could make valve positioning difficult and cause a possible inadvertent movement, particularly in a pressurized suit. It is planned to provide a positive lock and to increase the control valve operating forces.

Rapid command module repressurization capability.—The present TCS provides the capability of pressurizing the command module from zero pounds per square inch absolute to 3.0 pounds per square inch absolute in approximately 20 minutes. Due to a recent program requirement to provide EVA capability, crew safety could be affected because of the relatively slow repressurization capability. In order to increase crew safety, particularly for a contingency following EVA, it is planned to provide the capability of repressurizing the command module from zero pounds per square inch absolute to 3.0 pounds per square inch absolute in 1 minute by adding another gaseous 900 pounds per square inch absolute oxygen storage (surge) tank (fig. 178) in the service module, and appropriate valves in the command module which are accessible to the crewman on the left side. The repressurization is to be accomplished by a single action which releases the contents of both tanks directly to the command module.

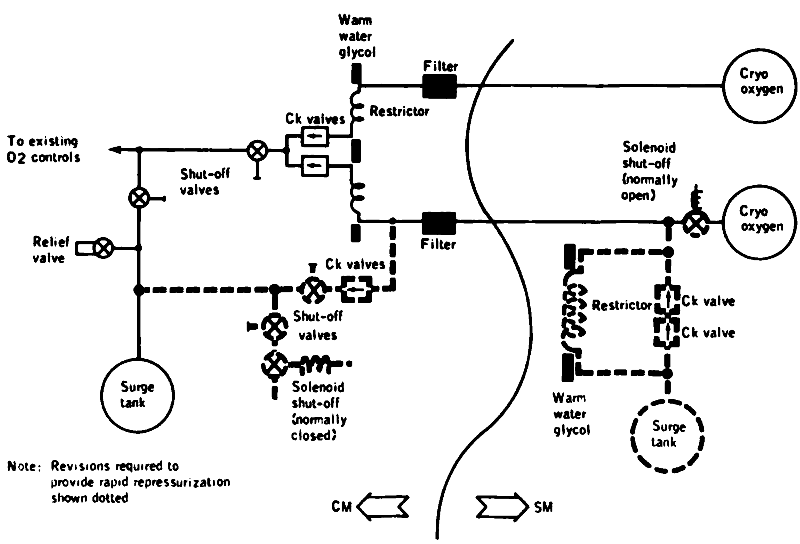


FIGURE 178

The requirement for fast repressurization capability emerged from EVA operational considerations. Of importance is the fact that it is consistent with the use of air in the cabin at launch which requires a depressurization in early orbits. Such a situation makes it operationally desirable to regain a normal or near-normal cabin pressure in a short time (consistent with physiological limits and any system constraints) in order to proceed with other required operations unencumbered by an inflated suit, and fully protected by both a "livable" cabin and a "livable" suit environment. Specific study in this area was not limited as a result of the AS-204 incident, but the capability was considered in various procedural reevaluations. Implementation of the change could enhance safety in contingency cases. Qualifications of components and compatibility verification with other subsystems, as well as interfacing portions of the ECS, will be required. Final proof including operational verification will require vacuum-chamber testing with an active cryogenic supply subsystem.

Tubing protection provisions.—Leaks have developed in the command module ECS plumbing after manufacturing and leakage tests verified that the lines were tight. Mechanical agitation of the lines can result in loads which could cause metallurgical (soldered, brazed, or welded) and mechanical joints to leak. Several of the lines are exposed, permitting the loads to be applied accidentally. Structural covers or shields are planned for the command module oxygen, water-glycol, and water and waste-management system plumbing lines which will protect from kicks, bends, or similar damage from the time of installation throughout checkout, flight, and recovery. Figure 179 shows exposed lines most subject to damage. This provides not only an increase in safety and reliability, but also decreases in rework time and effort caused by leaks. The change is generally consistent with the Third Interim Report of the AS-204 Review Board, and with the tests and analysis reported in the section on ECS tubing and joints. Only the structural capability of the shields requires demonstration in test to insure proper strength and supports.

ECS Tubing, Connections, and Joints

DESCRIPTION

The ECS utilizes three types of metallurgical and two types of mechanical tubing joints. The selection of the type of metallurgical joint (welded, brazed, or soldered) used in particular locations was determined in part by manu-

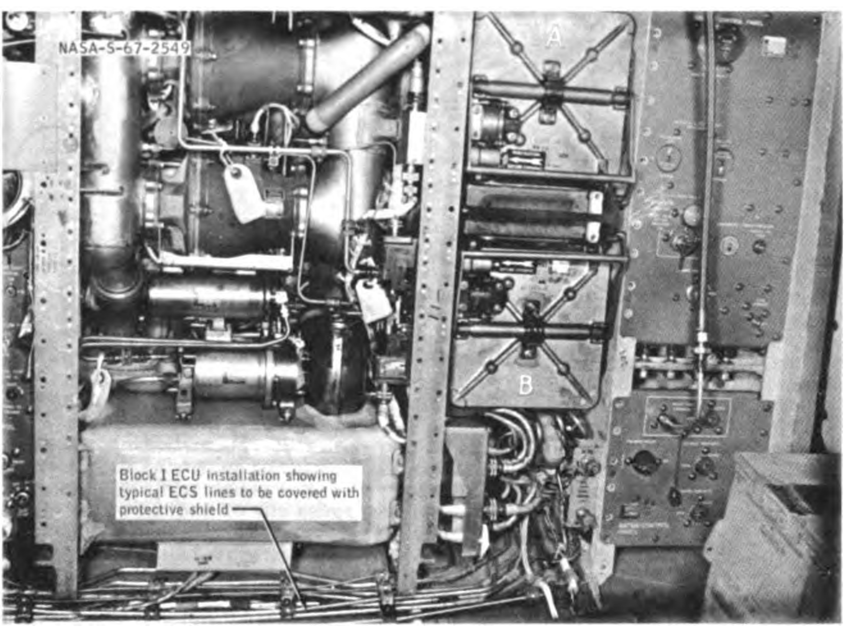


Figure 179

facturing considerations, that is, whether the joining operation had to be performed inside or outside the spacecraft. In general, soldered joints were used when the joint had to be completed inside the spacecraft. The test and inspection sequence is described in appendix II.

The mechanical joints used, B-nuts and quick disconnects, were in general used to connect tubing to system components which might have to be removed during ground operations for test or maintenance. A summary of the total plumbing joint and tube inventory of the water-glycol system for the command module and history of water-glycol leakage for Spacecrafts 012 and 101 are shown in table 10.

HISTORY

North American Aviation failure histories of the joint type indicated that the primary sources of leaks in the ECS were associated with B-nut mechanical connectors and soldered joints (tables 10 and 11). Welded and brazed metallurgical joints, in general, gave little trouble after final system leak checks were completed. Quick disconnects caused few or no leakage problems.

Following considerable history and experience obtained in the use of B-nuts in the Gemini program, it was determined that leakage problems associated with this type of mechanical connector can be essentially eliminated by the introduction of Voi Shan soft metal inserts, which provides a positive, deformable seal surface, and by torquing the B-nuts to a higher-than-minimum acceptable torque during installation and replacement operations. Voi Shan inserts were not used consistently in Spacecraft 012 nor were the fittings torqued above minimum values unless leakage occurred. In the Block II spacecraft, Voi Shan inserts are always used with the B-nut fitting. North American Aviation recently implemented a higher minimum-torque value for assembly of B-nut fittings on Block II spacecraft. In addition to the improved assembly procedures associated with B-nuts, quick disconnects are used on systems components which are frequently removed. This should noticeably reduce the opportunity for inadvertent introduction of residual stresses in fixed-tubing installations during component removal and reinstallation operations, and due to the presence of check valves should reduce or avoid spillage during installation or changing of components.

DISCUSSION

The leakage problem associated with soldered joints will be eliminated in the ECS oxygen tubing in the cabin by replacement of all soldered joints with either welded or brazed joints, or B-nut mechanical fittings.

It is not feasible to remove all soldered joints from the ECS water-glycol system in spacecraft that are already essentially complete; hence, ways of increasing joint capability without replacement were investigated. The results of preliminary tests conducted on standard ⅝-inch North American Aviation soldered joints were compared with a variety of MSC design reinforcements. From the designs, one was selected for preliminary optimization and definitive testing.

The standard North American Aviation soldered joint is shown in figure 180. The joint consists of a Teflon spacer and an aluminum ferrule. The ferrule and tubing are prepared for soldering by application of a nickel plate on the mating surfaces, followed by tinning with a 60–40 lead-tin solder. The grooves shown in the ferrule act as reservoirs for the solder and are not filled after the final heating operation. Table 12 presents data on the temperature capability of this

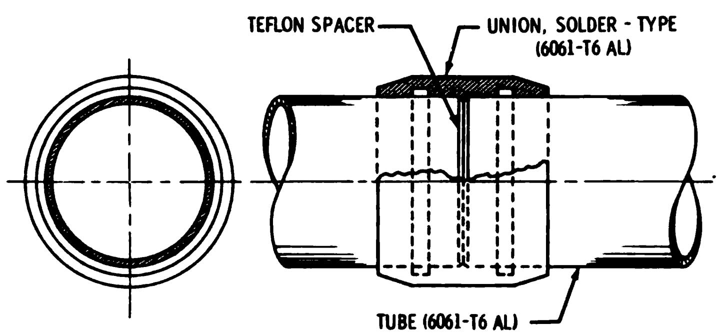


FIGURE 180

type of joint under a pressure load equivalent to 60 pounds per squ
mum operating pressure).

Figures 181, 182, and 183 show designs of adhesively attached
evaluated in the preliminary test program. Table 13 lists the res
testing to an integrated level of 36g conducted on these joints.

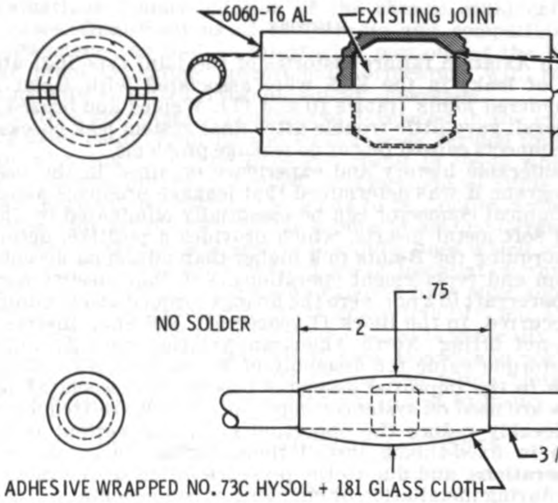


FIGURE 181

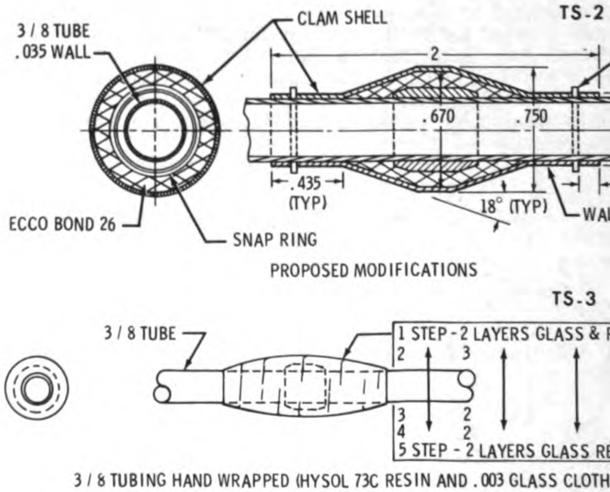


FIGURE 182

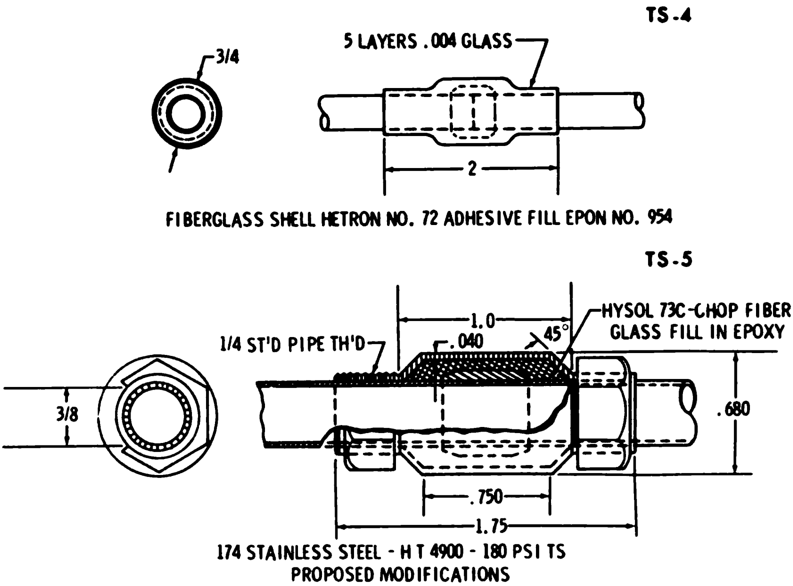


FIGURE 183

purposes, reinforcements were placed over joints which had not been soldered, although the joints had both the Teflon spacer and the ferrule in place. The data shown in table 13 show that the North American Aviation soldered joint is more than adequate for the vibration environment imposed. It also shows that some configurations of armored joints are more than adequate, even though the solder was deliberately omitted. The 36g vibration level previously noted is some four times that expected in flight, and the tests lasted about ten times longer than mission-level testing requirements.

In addition to vibration testing, specimens of the various designs were hydrostatically tested to failure. Data obtained in these tests (table 14) again illustrate the ability of both the North American Aviation soldered joint and the designed reinforcements to carry short-time loads far above those expected from the flight operations environment.

Following completion of the initial screening tests described, the SMD, TS-2, TS-5, and NAA designs were selected for torsional testing. Test results are presented in table 15. The data again illustrates the ability of both the North American Aviation joint and the reinforced joints to carry short-term torques in excess of those expected in service.

Figure 184 presents data developed for torsional creep on standard North American Aviation joints. While the torque loads shown are still high, the mechanism of torsional creep failure illustrated is consistent with the failure descriptions associated with a soldered joint close to a mechanical connection which require torquing for mating and sealing. While torque-free in principle the actual practice can introduce torque, if the mating torques used are not carefully balanced and net rotation of the tubing is permitted. The Block I Spacecraft 012 ECS aluminum-tube installation contained one solder joint/B-nut combination where a torsional stress could be applied to the solder joint by torquing the B-nut. The Block II line routing has been improved to eliminate this problem and additional support has been provided to further reduce the possibility of preloading. Line strengths have been increased to eliminate short-coupled combinations, and bends have been added for additional flexibility. Postinstallation X-ray inspec-

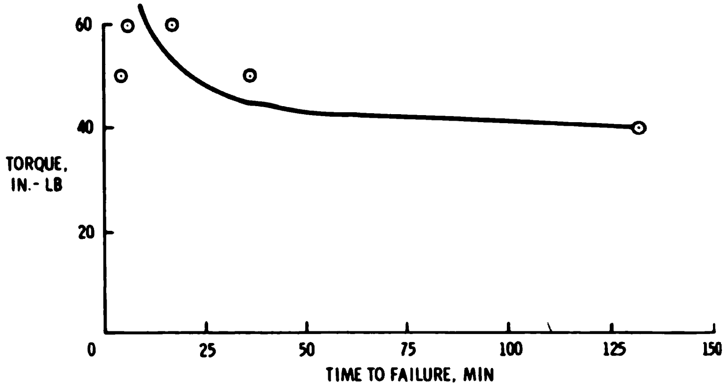


FIGURE 184

tion, while desirable, provides substantially less than 100-percent assurance that an adequate structural joint exists. Similarily leak testing with helium or other pressurizing techniques only establishes that leaks do not exist at the time of test. Absence of assurance of structural integrity by these two techniques leaves the possibility of existence of joints which are initially leak tight but which could fail by torsional creep or under abuse. An inspection technique must be devised which will indicate the presence of significant residual stress in soldered joints after installation if these joints are to be retained without armor in the ECS.

Following completion of the preliminary testing, SMD and TS-5 designs were combined in an effort to provide a semioptimized joint configuration for further test. Vibration, temperature, torsional creep, and "abuse" testing of the selected design is underway and is expected to show that significant protection of the basic North American Aviation soldered joint can be obtained for room temperature and elevated temperature applications.

In addition to the mission stresses already noted on joints and fittings, undefined stress can be placed on exposed soldered joints by inadvertent abuse during manufacturing, maintenance, and activity by servicing personnel or the crew. Structural members must be provided to preclude abuse to the lines during the period from initial installation through flight.

CONCLUSIONS

In summary, the following tentative conclusions can be drawn.

1. The standard North American Aviation solder joint is more than adequate for mission level loads, provided residual stresses leading to creep can be avoided.
2. Creep performance can possibly be improved at moderate temperatures by introducing adhesively bonded doublers (armoring joint).
3. An inspection technique is needed to insure essentially zero, installation induced, residual stress in soldered joints associated with the mating of B-nuts.
4. Structural protection is needed to preclude inadvertent abuse of exposed joints and lines during manufacturing and flight operations.

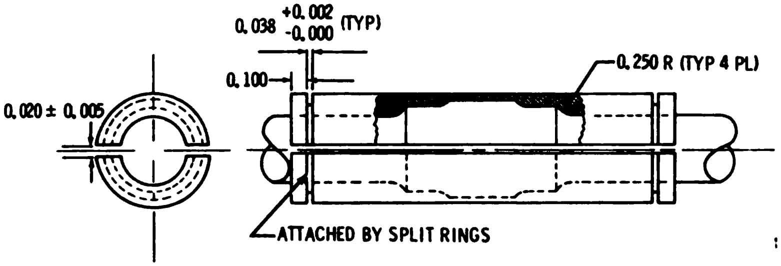


FIGURE 185

In addition to the joint design and test work which was accomplished, considerable thought was given to the problems associated with reinforcing soldered joints in place in hard-to-reach locations. For the selected armor joint (see fig. 185) simple one-hand operations application tools were devised. The tools permit application by touch alone and should simplify installation. In addition, a structurally optimized metallurgical joint is in process and will be tested following completion of design optimization.

TABLE 10.—*Summary of water-glycol joints and leakage history*

Type of joint	Spacecraft 012			Spacecraft 101		
	Total number of joints	Leaking joints		Total number of joints	Leaking joints, Downey	Proposed change
		Downey	KSC			
nuts	16	[1] 25	5	37	13	[2] 37
ldered	66	6	4	166	2	[3] 153
elded	64	2	0	8	0	0
razed	85	2	0	51	1	0

[1] Some recurring leaks.
[2] Voi Shan inserts used on all joints.
[3] 13 joints and 13 tubes eliminated. 16 other joints armored.

ABLE 11.—*Command module environmental control system—Oxygen supply system joint leakage*

Type joint	Spacecraft 012		Spacecraft 101, Downey
	Downey	KSC	
ut	19	9	3
dered	11	0	0
lded	1	0	1
zed	0	1	0

TABLE 12.—*North American Aviation solder joint temperature test* [1]

	Internal temperature, ° F.	External temperature, ° F.[2]
Specimen No.:		
1	365	410
2	370	410
3	360	395
4	365	405
Average	365	405

[1] 4 NAA, ¼-inch-diameter solder joints were loaded in tension to a stress equivalent to that developed by a 60-p.s.i. internal pressure. The specimens were then slowly heated until the joint failed.
[2] At failure.

TABLE 13.—*Vibration test results*

Configurations, ⅜-inch-diameter tube	Time to failure,[1] minutes			Configurations, ⅝-inch-diameter tube	Time to failure, minutes		
	Test 1	Test 2	Test 3		Test 1	Test 2	Test 3
NAA, solder	[2] 12.2	[2] 35.0	[3] 56.5	NAA, solder	30.0	30.0	
SMD, solder	30.0	30.0	30.0	SMD, solder			
SMD, no solder	[2] 44.5	[2] 14.0	[2] 25.0	SMD, no solder	30.0	30.0	
TS-1, solder				TS-1, solder	30.0		
TS-1, no solder	[3] 58.5	60.0	[2] 57.3	TS-1, no solder	[3] 3.5	[3] 16.9	[3] 16.5
TS-2, solder	30.0			TS-2, solder			
TS-2, no solder	[3] 15.0	[3] 7.0	[3] 37.8	TS-2, no solder			
TS-3, solder				TS-3, solder			
TS-3, no solder	30.0			TS-3, no solder			
TS-4, solder				TS-4, solder			
TS-4, no solder	[3] 5.7			TS-4, no solder			
TS-5, solder				TS-5, solder			
TS-5, no solder	30.0	30.0	30.0	TS-5, no solder			

[1] See figures 180 through 183 for configuration.
[2] Failure at tubing end.
[3] Failure in coupling.

TABLE 14.—*Hydrostatic test results*

Configuration	Failing pressure, p.s.i.		
	1	2	3
⅜-inch-diameter tube:			
NAA, solder [1]	[2] 5,950	5,950	[3] 5,700
SMD, solder [4]	6,000	6,000	6,000
SMD, no solder [4]	[2] 5,950	[2] 4,290	[3] 4,350
TS-1, solder [4]			
TS-1, no solder [4]	[2] 2,800		
TS-2, solder [5]	6,000	6,000	
TS-2, no solder [5]	[2] 4,200		
TS-3, solder [5]			
TS-3, no solder [5]	[2] 4,380	[2] 4,600	
TS-4, solder [6]			
TS-4, no solder [6]	[2] 4,400	[2] 2,700	
TS-5, solder [6]			
TS-5, no solder [6]	[2] 3,950	[2] 5,000	
⅝-inch-diameter tube:			
NAA, solder [1]	[2] 2,600	[3] 5,200	[3] 5,280
SMD, solder [4]	[3] 5,200	[3] 5,200	[3] 5,200
SMD, no solder [4]	[2] 2,400	[2] 3,000	[2] 3,200
TS-1, solder [4]			
TS-1, no solder [4]	[2] 2,300	[2] 1,350	
⅜-inch-diameter tube post vibration:			
SMD, solder [4]	6,200	6,100	6,150
TS-1, no solder [4]	[2] 5,500		
TS-2, solder [5]	6,200		
TS-3, no solder [5]	[2] 5,800		
TS-5, no solder [6]	[2] 2,400	[2] 1,800	[2] 2,500

[1] Refer to fig. 180.
[2] Coupling failure.
[3] Tubing failure.
[4] Refer to fig. 181.
[5] Refer to fig. 182.
[6] Refer to fig. 183.

TABLE 15.—*Torsion test results*

Configuration	Solder and bonded cover			Bonded cover only		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
	Torque at failure, inch-pounds					
NAA [1]	210	[2] 204	204			
SMD [3]	228	[4] 192	216	144	120	75
TS-2 [5]	276	[6] 216	204	126	132	45
TS-5 [7]	228	196	192	252	138	240
	Estimated angle at failure, degrees					
NAA [1]	990	675	950			
SMD [3]	990	270	1,170	45	45	75
TS-2 [5]	1,080	840	720	90	120	144
TS-5 [7]	1,080	840	740	630	135	510

[1] Refer to fig. 180.
[2] Tube failed.
[3] Refer to fig. 181.
[4] No failure, B nut slipped.
[5] Refer to fig. 182.
[6] Tube failed under epoxy.
[7] Refer to fig. 183.

FLAMMABILITY OF WATER GLYCOL MIXTURES

INTRODUCTION

Pure ethylene glycol constitutes a slight fire hazard when exposed to heat or flame in air but will not spontaneously ignite. The pure liquid, like most hydrocarbons, can react with oxidizing materials.

Pure ethylene glycol is not used in the Apollo programs; mixtures of ethylene glycol and water with corrosion inhibitors are used. The nominal compositions used in the CM ECS are as follows:

	Percent
Ethylene glycol	62.5
Water	35.8
Triethanol amine phosphate (TEAP)	1.6
Sodium mercaptobenzothiazole (NACAP)	.1

The atmosphere in the CM is nominally 5 pounds per square inch absolute oxygen. It is therefore necessary to define the fire hazards associated with the use of water-glycol mixtures when exposed to oxygen environments.

Early in the Apollo program (1963) MSC had conducted tests of these mixtures in 5 and 14.7 pounds per square inch absolute pure oxygen environments. The results were as follows:

1. The spark-ignition temperature was found to lie in the range of 211° to 293° F. The variability was attributed to water boiloff and possible cooling of the test thermocouple due to splattering of liquid droplets.
2. Ingition of the ECS water-glycol mixture does not occur when the mixture is sprayed on a hot plate heated to 500° F.

Since the AS-204 accident, additional tests have, and are being conducted. The tests can be categorized into three groups; bulk liquid tests, liquid tests, and liquid-soaked material tests.

RESULTS OF TESTS

Bulk liquid tests

Electrical spark and autogenous ignition tests were conducted using thermogravimetric analysis and differential calorimetric techniques. The thermogravimetric analysis technique indicates combustion by the rate of weight loss. Differential calorimetric analysis indicates combustion by noting the energy to maintain a constant rate of temperature increase. Both of these techniques involve controlled heating of the bulk specimen in the environment in question, and both give comparable results. The results obtained using the thermogravimetric anaylzer are:

1. Electrical spark ignition of pure ethylene glycol at 14.7 pounds per square inch absolute oxygen pressure was 190±30° F. The result is about 50° F. lower than the handbook value given for this compound in air. The difference could be

due to the oxygen environment. No autogenous ignition was noted up to the boiling point of the liquid, 388° F.

2. Electrical spark ignition of the CSM water-glycol mixture was found to be 278°±40° F. at 14.7 pounds per square inch absolute oxygen pressure. Again, no autogenous ignition was noted. The rather large variability noted in the results is believed to be due to vaporization of water from the liquid mixture until a glycol-rich liquid is obtained. The composition of this liquid at ignition is not known. Tests are underway to define the ignitable composition.

The results obtained using the differential calorimeter are quite similar to the results obtained using the thermogravimetric analyzer. Again, no autogenous ignition was noted. The electrical spark ignition data for tests in 14.7 pounds per square inch absolute oxygen atmosphere are shown in tables 16 and 17, and figure 186. An attempt was made to obtain data at 5 pounds per square inch absolute oxygen, but the results obtained are not well understood. An apparent lowering of the spark-ignition temperature with increased water content was observed. This is believed to be associated with the lowering of the bulk-fluid temperature by evaporation of water at low pressure. Since the spark-ignition temperature determined in these tests depends upon the concentration of ethylene glycol in the vapor phase over the liquid, it is possible that with time an ignitable mixture develops at apparent bulk temperatures lower than that measured for the pure ethylene glycol. Study of this phenomenon continues.

In addition to the measurements described, some rather crude bulk-fluid experiments were performed. Beakers of the pure ethylene gylcol, a 40–60 water-glycol mixture, and a 60–40 water-glycol mixture were placed in a vacuum desiccator. The desiccator was rapidly evacuated, then back-filled with oxygen to 14.7 pounds per square inch absolute. The desiccator lid was removed and a lighted glass-blower torch (oxygen-natural gas) was applied downward upon the surface of each liquid. Under these conditions neither of the water-glycol mixtures ignited, but the pure glycol ignited and burned vigorously. In fact, both of the water-glycol mixtures extinguished the torch as it entered the fluid.

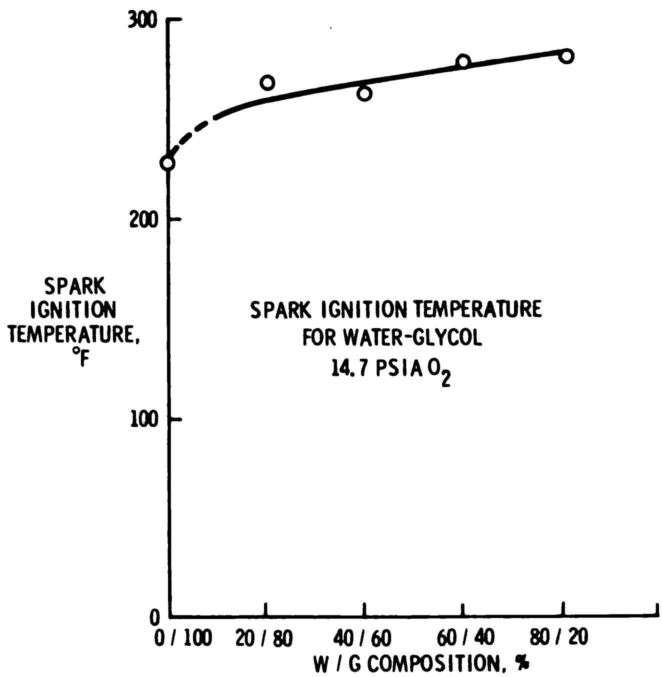


FIGURE 186

Liquid spray tests

To simulate the possible ignition conditions which could be present in the event of rupture of a pressurized water-glycol line, the following test series was performed:

1. The water-glycol mixture was sprayed as an aerosol into a pure oxygen environment at room temperature at 14.7 pounds per square inch absolute. No ignition occurred.

2. The mixture was sprayed on a stainless-steel hot plate in 14.7 pounds per square inch absolute oxygen, at plate temperatures above 800° F. No ignition occurred.

3. The water-glycol mixture was sprayed as an aerosol in a low-velocity oxygen stream (table 18 and fig. 187). This stream then flowed through a pyrex tube containing a heated aluminum plate. No ignition of the stream occurred; however, when excess fluid (probably depleted in water content) collected in the cooler portions of the pyrex tube, the fluid ignited and burned vigorously.

The water-glycol oxygen mixture exited the pyrex tube directly into a bunsen-burner flame. No visual evidence of combustion in the flame was noted.

4. Three mixtures of water-glycol (60 percent glycol, 40 percent water; 50 percent glycol, 50 percent water; and 40 percent glycol, 60 percent water) were sprayed into a flowing oxygen stream in a manner similar to that used with the flame experiment (table 19 and fig. 188). In this experiment, an electrical spark (50 millijoules) was used as an ignition source.

A schematic of the test equipment is shown in figure 189. None of the mixtures tested produced a flash or flame at mixture temperatures of 78° and 257° F.

5. The foregoing experiments constitute a preliminary attempt to refine the ignition characteristics of ethylene glycol and water-glycol mixtures. A more comprehensive study is under way. The study will use equipment similar to that shown in figures 187 and 188 and will be capable of defining ignition conditions over a range of oxygen pressures. The experiments will parametrically examine ignition conditions for a variety of water-glycol mixtures under oxygen pressures ranging from 5 pounds per square inch absolute to above atmospheric pressure. Gas temperatures will also be varied.

The preliminary results obtained indicate that the water-glycol mixtures used in the CSM are quite difficult to ignite. Ignition has been observed only when either high temperatures or low pressures have served to reduce the water content of the mixture to some as yet unknown percentage.

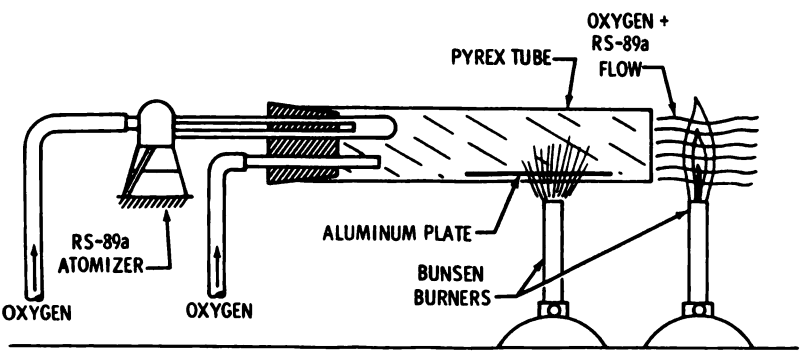


FIGURE 187

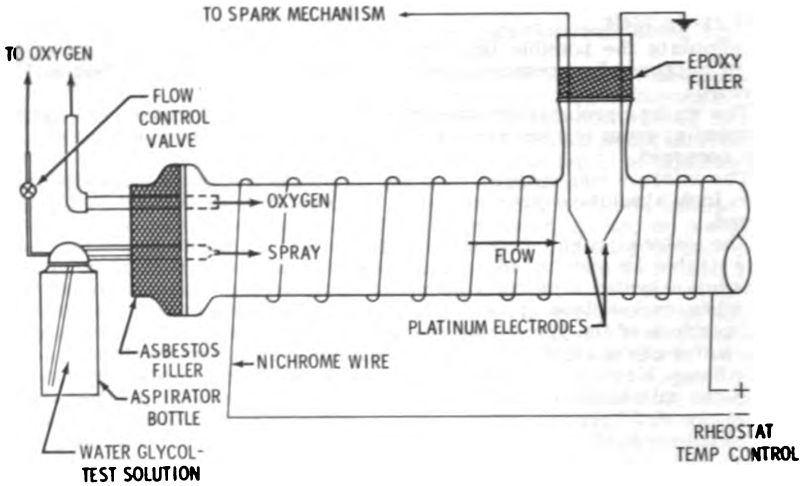


FIGURE 188

WATER-GLYCOL SOAKED MATERIALS

In addition to conducting experiments designed to define ignition conditions of water-glycol per se, a number of tests were conducted to determine the effect of spillage on the subsequent ignition of soaked materials. The following tests were performed.

1. Specimens of Trilock, Raschel knit, and Uralane 577–1 spacecraft materials were soaked in the water-glycol mixture. The specimens were then dried in air, without cleaning. Next, they were heated in a 16.5 pounds per square inch absolute oxygen environment to a temperature above 400° F. to observe autogenous ignition. No ignitions were noted; however, as with the unsoaked specimens, some charring and smoking was observed.

2. Insulated electrical-wire specimens with deliberately induced flaws were exposed to the water-glycol mixture used in the CSM. Three sets of tests are being conducted.

(*a*) Water-glycol was dripped on deliberately damaged wires carrying 28 volts and 3 amperes of current. The tests were conducted in a 16.5 pounds per square inch absolute oxygen environment. Ignition occurred after 8 hour exposure when concentrated inhibitor apparently built a salt bridge between the current-carrying conductors. The ignition time could have been controlled to occur at any time after approximately one-half hour by controlling the drip rate which influences the cooling and washing effects. Incipient failure was noted by a temperature rise at approximately one-half hour, but the failure was intentionally delayed by increasing the drip rate.

(*b*) Three tests similar to that discussed above were conducted using a 60 percent ethylene glycol, 40 percent water mixture without inhibitors. The first test was terminated due to a test chamber malfunction after 19 hours without ignition. The second test terminated with ignition after 24 hours, while the third test is still underway after 150 hours of exposure with no ignition.

(*c*) The third type of test involved soaking damaged wires in the CSM water-glycol mixture and then vacuum drying the wires. These wires were then exposed to a 100-percent humidity, 16.5 pounds per square inch absolute oxygen environment. The test showed no failure after 142 hours of exposure.

(*d*) A fourth type of test also involved soaking damaged wires, followed by an attempt to clean the wire with appropriate wire cleaning fluids. The wires were then exposed to a 100-percent humidity, 16.5 pounds per square inch absolute oxygen environment. After 144 hours of exposure, no ignition was observed.

3. A test series similar to the series conducted with deliberately damaged wire was also performed using spacecraft gas-chromatograph cables. The cables were not deliberately damaged. After 288 hours of exposure, no ignition was noted; however, some deterioration of insulation properties was observed.

The results of soaked-wire tests conducted to date indicate that the corrosion inhibitors used in the water-glycol mixtures play an important role in ignition under the test conditions examined. As a result, a review of data was undertaken as to the selection of the inhibitors used. The inhibitors that were studied are listed in tables 20 and 21. The pertinent observations generated by this review are as follows:

1. Distilled deionized water will corrode the aluminum alloys contained in the Apollo ECS system. There always exists in water (from the electrolytic dissociation of the molecule) 10^{-7} mols/liter of hydrogen ion and 10^{-7} mols/liter of hydroxyl ion. Aluminum is a very reactive metal, with an electrochemical potential such that it should react vigorously with water to liberate hydrogen gas. However, at the near-neutral point (pH around 7) aluminum attains an insoluble coating (aluminum oxide) which slows the reaction to a very low rate. Migration of aluminum ions occasionally occurs through the oxide coating, and when these aluminum ions meet the hydroxyl ions from the dissociation of water, they react to form a very slightly dissociated molecule, AlO(OH), which reinforces the protective oxide layer. The chemical reactions described are represented by the following equations:

$$Al^{+++} + 3OH \rightarrow AlO(OH) + HOH$$
$$Al^{+++} + 2HOH \rightarrow AlO(OH) + 3H^{+}$$

To maintain electrical balance in the solution, a corresponding cathodic reaction must take place nearby, that is, at the surface of the oxide layer. Hydroxyl ions are released, and the pH of the solution remains neutral. The cathodic reaction is given by the equation:

$$3/2HOH + 3e^{-} \rightarrow {}^{3/2H}2 + 3OH^{-}$$

The net result is a slow corrosion rate, with automatic repair of the oxide film at weak points. If conditions prevent the hydrogen and hydroxyl ions from reaching each other, pH variations will result and cause active corrosion.

The presence of any oxygen dissolved in the water-glycol system (even in very small concentrations) produces oxidation of the ethylene glycol to glycolic acid, and this being ionizable increases the hydrogen ion concentration, which tremendously increases the speed of the corrosion-reaction mechanisms described. Similarly, the presence of a heavy metal (such as copper, lead, or silver) forms a preferential cathode resulting in an accumulation of hydroxyl ions at such a site, instead of their existence near anodic sites. Dirt or small crevices, which may hinder diffusion mixing, results in accumulation of hydroxyl ions and a local increase in pH. These hydroxyl ions react with the oxide layer to form soluble aluminate ions resulting in destruction of the protective oxide film; corrosion will then proceed rapidly.

2. Mechanisms for inhibiting corrosion. The aluminum alloys in the ECS systems contain copper as well as other metals. The copper ion induces severe corrosion of aluminum, since the copper will plate out of solution at the expense of the aluminum and cause pitting. One part per million copper ion is sufficient to increase the pitting rate noticeably.

The purpose of the TEAP is to pull the copper atoms on the alloy's surface into solution, where the chelating agent (NACAP) can react with the copper ions to form an undissociated copper chelate (organometallic complex). A second purpose of the TEAP is to supply phosphate ions to form a uniform coating of aluminum phosphate over the metal surfaces, thereby protecting the natural oxide coating. A third action is to serve as a phosphate salt to buffer the pH of the solution close to a pH of 7, and prevent wide local excursions of the hydrogen ion concentration.

Other inhibitor methods are available. One promising method is the use of a selective oxidation agent, that is, potassium perborate, which when used in conjunction with potassium monoacid phosphate and NACAP produces a thin tenacious coating of aluminum oxide-borate on the metal surfaces to prevent corrosion. Another system is to use organic oils to coat the metal surfaces, but these generally increase the heat transfer resistance of the surface and degrade the purpose of the coolant loop; also, organic materials may tend to foam and froth.

3. Inhibitor investigation and evaluation for Apollo coolant loops. A NASA Contract (NAS9-5157) with Illinois Institute of Technology Research Institute (IITRI), completed in August 1966. The contract covered the development of a corrosion-inhibited heat-transfer fluid for the ECS system. The objective of the study was to evaluate various commercial and otherwise known corrosion inhibitors for use in water-glycol fluids from the standpoint of controlling corrosion in the Apollo ECS systems. A variety of materials was screened by using two types of smallscale tests; one consisted of measuring weight loss from metal coupons exposed to various solutions, and the other determined the corrosion-induction period by measuring the time required to produce a given quantity of hydrogen gas from a weighted amount of aluminum powder in a closed system. Finally, a dual corrosion-loop apparatus simulating the Apollo ECS system and its environment was constructed. Water-glycol containing a TEAP/NACAP inhibitor (RS 89-a) in one side of the loop was circulated for 90 days and an ethylene glycol-water mixture containing a perborate inhibitor in the other side of the loop was circulated for 90 days. This test yielded a comparison between the two inhibitor systems under spacecraft fluid-loop conditions. It also provided long-term inhibitor-depletion data, relative effects of crevice induced corrosion, and general corrosive attack information at various strategic locations throughout the system.

4. The conclusions of the study are:

(*a*) A corrosion inhibitor in the glycol-water coolant of the Apollo ECS systems is necessary.

(*b*) An effective corrosion inhibitor must provide a high buffering capacity against pH increase. Phosphates are the best buffers tested.

(*c*) A 90-day test in simulated ECS coolant loops showed that TEAP/NACAP and a phosphate-perborate mixture provided corrosion protection for all metal surfaces; either inhibitor system would perform satisfactory in the ECS system in protecting the system against corrosive attack. Phosphate-borate mixture was recommended on the basis of better physical properties than RS 89-a fluid, and on the basis of possible better heat transfer for the cold plates. The RS 89-a was not changed in favor of the phosphate-perborate mixture because the RS 89-a is as good a corrosion preventer as any known inhibited water-glycol solution, and the only disadvantage the RS 89-a possesses is a slightly less heat-transfer coefficient for the system.

(*d*) Coolant fluids should be filtered before use.

(*e*) Continuous circulation of coolant during nonoperational periods of the Apollo spacecraft is unnecessary. Long-term (20 to 28 weeks) static tests showed very little loss of any inhibitor components for either the TEAP/NACAP (RS 89-a) or phosphate-perborate mixture. It is recommended however that the coolant fluid be circulated for 1 week after filling the ECS system; short periods of circulation every 6 to 8 weeks are recommended to guard against localized inhibitor depletion.

CONCLUSIONS

The test results obtained to date support the following preliminary conclusions.

1. Water-glycol mixtures of the type used in the Apollo ECS are very difficult, if not impossible, to ignite provided that no substantial evaporation of water has occurred.

2. Inhibited glycol-water spillage can lead to deterioration of electrical components, and to subsequent ignition by the development of short circuits.

3. Some reduction in inhibitor conductivity might be obtained by a change of inhibitor. However, since acceptable substitute inhibitors examined to date are ionic in nature and since ignition of damaged wires has been observed using uninhibited water-glycol mixtures, improvement in the spillage-initiated short-circuit problem is not likely to be marked.

RECOMMENDATIONS

It is recommended that water-glycol be retained as the coolant fluid for Apollo. This recommendation is made because of the high probability of success in the effort to prevent leaks in the system, including the positive strengthening and protection of plumbing. In addition, no fluid with reduced flammability characteristics has been found which could be substituted and meet the Apollo system requirements. Any substitute would require significant development effort to overcome the similar problems which were attendant to the water-glycol.

TABLE 16.—*Water-glycol bulk fluid tests*

Thermogravimetric analysis:
- Test Conditions:
  - Specimens continuously weighed during tests.
  - Programed rates of temperature rise imposed, 6° C. per minute.
  - 14.7 pounds per square inch absolute, 100-percent oxygen environment.
  - Spare ignition energy>50 millijoules.
- Mixtures tested: RS–89–a, reagent grade ethylene glycol, various water-glycol mixtures.
- Test results:
  - No autogenous ignition noted.
  - Average spark ignition temperature RS–89–a, 278°±40° F.
  - Average spark ignition temperature of pure ethylene glycol, 190°±30° F.

TABLE 17.—*Water-glycol differential calorimetry tests*

Test conditions:
- Programmed rates of temperature rise at 6° C. per minute.
- 14.7 and 5 pounds per square inch absolute oxygen environment.
- Spark ignition energy>50 millijoules.

Mixtures tested:
- RS–89–a, reagent grade ethylene glycol, various water-glycol mixtures.

Test results:
- No autogenous ignition noted.
- Anomalous behavior at low pressure.

TABLE 18.—*Water-glycol liquid spray tests*

Oxygen ignition:
- Water-glycol mixtures were sprayed into a 14.7 pounds per square inch absolute oxygen environment. No ignition occurred.

Flame ignition:
- RS–89–a fluid was atomized into a low velocity oxygen stream; both flowed over a heated aluminum plate in a pyrex tube. No ignition occurred in tube.
- The flow of oxygen + RS–89–a out of the tube was passed into a burner flame at the tube exit. No ignition of the stream occurred. However, when excess RS–89–a liquid collected in tube, this liquid ignited about 60 seconds after flow was initiated.

TABLE 19.—*Water-glycol liquid spray tests*

Hot plate ignition: RS–89–a fluid was sprayed onto a stainless steel plate which was at red heat (temperature definitely above 800° F.) under 14.7 pounds per square inch absolute oxygen. A similar test was performed with plate at 600° F. No ignition occurred.

Spark ignition: Mixtures of water-glycol were sprayed into an oxygen atmosphere (P=15 pounds per square inch absolute) through which a high energy spark (>50 millijoules) was discharged. None of the mixtures tested produced a flash or flame at temperatures from 25° to 125° C.

TABLE 20.—*Inhibitors found suitable for use in Apollo systems*

Corr-shield K–7, Betz Laboratories, Inc.
Sodium nitrite-borax synergistic organic mixture
Dearborn 524, Dearborn Chemical Company
Dearborn 527, Dearborn Chemical Company
DWT 110, Drew Chemical Corporation
Nalco 39, mixture of boron, nitrogen, and organics
0-percent solution sodium 2-mercaptobenzothiazole
Triethanol amine phosphate plus sodium mercaptobenzothiazole (TEAP plus NACP) [1]

[1] Inhibitor used in Apollo ECS.

TABLE 20.—*Inhibitors found suitable for use in Apollo systems*—Continued

Potassium monoacid phosphate and potassium tetraborate
Inhibited ethylene glycol, Dupont's Telar
Inhibited ethylene glycol, Jeffcool E–100
Potassium monoacid phosphate plus potassium tetraborate plus NACAP
Inhibited ethylene glycol hydraulic fluid, Houghto-Safe 620, E. F. Houghton and Company

TABLE 21.—*Inhibitors found unsuitable for use in Apollo systems*

Sorbitan fatty acid ester
Bis (2-hydroxyethyl) cocoamine
Bis (2-hydroxyethyl) tallowamine
Magnesium petroleum sulfonate
Barium petroleum sulfonate
Calcium petroleum sulfonate
Ameroyal organic
Imidazoline
Nonylphenoxyacetic acid
Oleoyl sarcosine
Nalco 41
Barium dinonylnapthalene sulfonate
Basic barium dinonylnapthalene sulfonate
Petronate CR
Petromix 9
Fatty alkonalamide No. 1
Fatty alkonalamide No. 2
Fatty alkonalamide No. 3
Kontol 141
Petrolite WF–2
Petrolite R–74

WATER-GLYCOL SYSTEM CHANGES

Several changes have been identified which would provide some increased safety in the water-glycol system. Those areas where changes have been initiated are noted, and those areas which are currently under investigation are identified.

SYSTEM CHANGES

Alternate fluid use for ground operations

Suggestions have been made, and considerations given to utilizing an alternate fluid, such as isopropyl alcohol, for ground-checkout operations and reservicing the system with water-glycol prior to flight. This alternate fluid has a high vapor pressure and will evaporate rapidly without leaving a residue. An alternate fluid could be utilized for the initial fill of the system, and for leak-test purposes only. However, it is not recommended that an alternate fluid be utilized for functional test and checkout of the ECS water-glycol system. The system should be tested with water-glycol to obtain actual performance data on the system utilizing the flight-coolant fluid, and to gain operational confidence with the system and components for a period of time prior to flight. The glycol pumps and glycol-temperature control system would be of most concern. The use of an alternate fluid could invalidate the checkout results, and incipient subperformance of components could appear only when the flight fluid is utilized for the component performance tests. The effort expended to incorporate such a change is better directed toward providing a tighter system. Planned changes are underway to shield exposed water-glycol joints and fittings to prevent water-glycol leaks as a result of accidental or intentional application of forces to the plumbing and to armor specific joints which are subjected to stress. The elimination of potential leakage areas through the shielding and armoring techniques render the use of an alternate fluid unnecessary, except possibly for initial system leakage tests prior to water-glycol servicing. This represents a minimal change, readily implemented, and can be adopted without additional tests since cleaning procedures already utilize isopropyl alcohol and there are no material compatibility problems.

LEAKAGE DETECTION IMPROVEMENT

Leakage within the water-glycol system has proved troublesome throughout the program. Improvements have resulted as additional spacecraft have been assembled; however, two additional techniques are under investigation to provide additional assurance of system-pressure integrity. These are the addition of an odor additive and prolonged leak check with a liquid.

Gross leakage is detected by instrumentation which provides data on the quantity of water-glycol contained in the accumulator. The quantity varies with volumetric expansions and contractions due to temperature variations in the system. Small leakage is nondetectable by the instrumentation because of the routine thermal variations. Improved means of detecting small leaks early are desirable to prevent unnecessary contamination.

One technique would add an agent to the glycol, which would have a detectable odor. This would serve to alert, the crew (or workmen as the case may be) that a leak has occurred. This would permit easier locating and correcting on the ground and possibly inflight of the leak; or at least aid in diagnosing corrective actions (such as the use of secondary-coolant loop, purging the cabin with oxygen, or return to the isolated suit circuit).

In order to detect a leak in the ECS coolant system by odor, the type of odor required is of importance. The odor would have to be sharp, distinct, and not have a lingering effect. The spacecraft background odor should not have a masking effect. The odor should also produce an immediate reaction so as to signal the presence of the leak.

The following physical and chemical characteristics must be considered in selection of the odor-providing substance.

Physical characteristics.—1. Solubility in the water-glycol mixture.

2. Odor strength per percent weight or volume of the substance placed in the water-glycol mixture (should not exceed 100 ppm in the water-glycol mixture).

Chemical characteristics.—1. Chemically compatible with ethylene glycol, water, aluminum, and the inhibitors.

2. Should not retard the anticorrosive activity of the inhibitors.

3. Should not be corrosive in itself.

4. The odor strength of the substance should not be diminished by the inhibitors.

5. Should not alter the physical characteristics of the water-glycol mixture.

Sources for selection of an odoriferous substance.—1. Primary agent or ingredients to perfumes and cosmetics—Givardan index.

2. Flavoring agents for foods.

3. Petrochemical industry.

Classes of compounds under consideration.—1. High molecular weight esters—C_7 and greater.

2. High molecular weight ketanes—C_7 and greater.

3. High molecular weight aldehydes—C_7 and greater.

4. Mercaptans.

5. Sulfonated hydrocarbons.

Selected compounds under consideration.—1. Ethyl benzoate—pungent fruity odor; a fruity odor at a strength of 0.01 percent by volume in the coolant fluid.

(*a*) Flash point 190° F.
(*b*) Boiling point 416° F.
(*c*) Vapor pressure 1 mm at 112° F.
(*d*) Animal experiments show low toxicity.

2. Citronella (3,7-dimethyl-6-octen-1-al); lemon-rose odor at 0.01 percent by volume in the coolant fluid: (*a*) Flash point 178° F.

3. 2,6-dimethyl-4-heptanane.

Preliminary work indicates ethyl benzoate is one of the most likely candidates.

A second leakage check, which serves to give a higher degree of confidence but has the shortcoming of not giving a continuous check, is that of running extended leakage checks with a volatile fluid (which must be compatible with system materials) such as isopropyl alcohol prior to water-glycol servicing (also previously referenced). This would provide a visible indication of leaks, but would evaporate and leave no harmful residue. A disadvantage which must be considered is the added hazard of alcohol from a toxicity and fire-safety standpoint. These approaches are still under investigation.

Elimination of glycol from cabin-dual loop

Early reports from the AS–204 accident indicated that the water-glycol used in the heat-transfer system could have been a factor in the fire. NASA studies were initiated to determine what alternatives exist on the premise that glycol would have to be removed. One of these choices is to retain the water-glycol in the radiator system, since it is optimized for the fluid properties of water-glycol. If safety should dictate that glycol must be removed from the cabin area, the best replacement would be water from the standpoint of safety, heat transfer capability, and overall close compatibility with existing hardware.

Equipment designed for use with water-glycol should perform better with water as long as the restrictive temperature limits of water can be accepted. The cabin space has temperatures which are compatible with water; however, an interchange heat exchanger must be provided to transfer heat to the radiators for heat rejection. The interchange heat exchanger would be located in the unpressurized area of the Command Module. The controls for regulation of heat load would be relocated to the Service Module and new control setpoints established and verified. One of the considerations is that the water being circulated in contact with the glycol must be protected from freezing, even considering an equipment malfunction. Figure 189 schematically illustrates the coolant system required for a dual-loop approach. Additional pumps would be required to circulate the water-glycol within the Service Module portion.

Even though the redesign approach minimizes changes as much as possible, there are still penalties involved. The penalties would be an increase in weight of 43 pounds (considering liquid weight increase, dry weight increase, and the weight increase in fuel-cell reactants to provide additional pumping power). Several major areas would require verification prior to full commitment, such as materials compatibility with a different fluid, and verification that the pump and mixing valve can withstand Service Module environments.

The contractor has been requested to investigate further the implications of incorporating such a design. Significant plumbing relocations are involved. The effort will be continued to a reasonable conclusion. The present effort is confined to identification of detail changes required, test plan changes, and scheduling. Basically, this produces a preliminary design but involves no hardware commitments at this time.

SUBSTITUTION OF ALTERNATE FLUIDS

On the same premise as stated previously in the "dual-loop" discussion, the potentiality of substituting an alternate fluid for water-glycol was studied by NASA. Schematic representation is shown in figure 190, which is the same

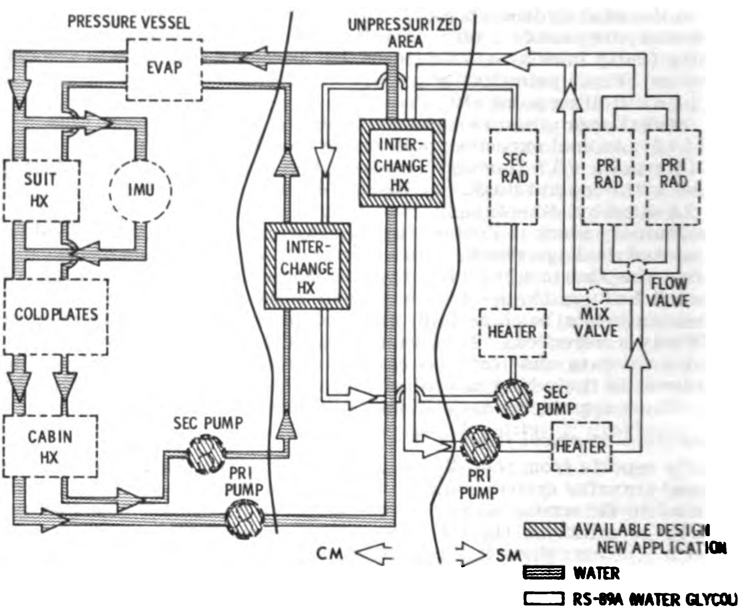


FIGURE 189

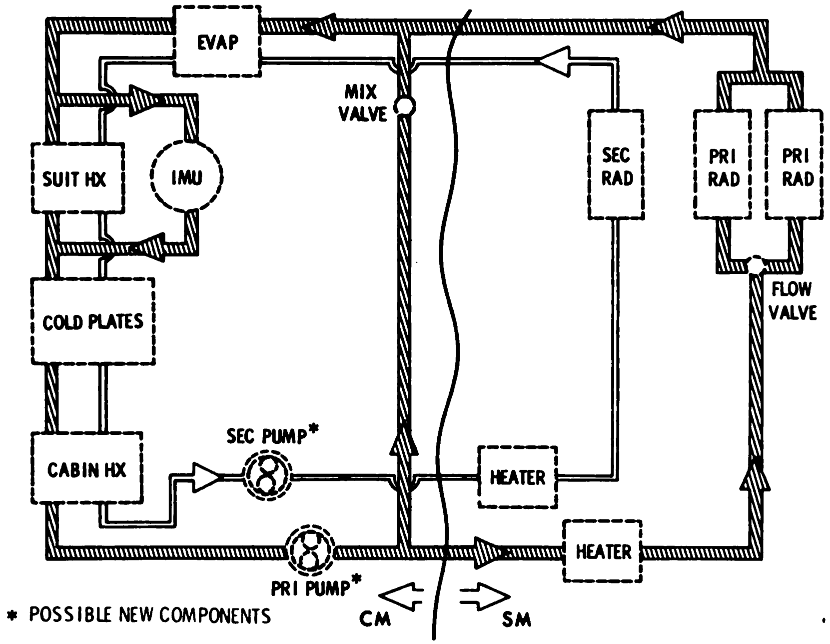


FIGURE 190

as the present coolant loop. The main change required would be a new pump. Radiator performance would be very sensitive to specific mission heat loads and thereby remove system flexibility. Thermal performance was degraded with the fluid selected for detailed study (43 were considered as potential candidates). Fluid E–3 (a member of the freon family) appeared to best meet the criteria and to offer the best match for Apollo requirements. The detailed study with E–3 provided typical data on a substitute fluid as a class. All of the fluids typically possess relatively poor heat-transfer characteristics compared with water-glycol.

A weight increase of 46 pounds would be required, and a detailed review will be required to affirm that performance is acceptable although degraded. The major areas of concern are that heat-exchanger performance and materials compatibility are undemonstrated with this new fluid. Ground support equipment changes will be required.

The contractor was requested to investigate further the implications of incorporating this change. This will provide definitive data on which to base a decision if glycol removal from the spacecraft is finally recommended by the fire investigation board.

CHANGE OF WATER-GLYCOL ADDITIVES

Some aspects of the present inhibitors in the water-glycol have been identified as undesirable. As noted above corrosion inhibitors are required for adequate material protection. The present inhibitors are triethanolamine phosphate and sodium mercaptobenzothiazole. The contractor and NASA are trying to find an inhibitor which would exhibit improved characteristics; namely, low corrosiveness and toxicity, optimal vapor pressure, low electrical conductivity, nonhygroscopic, and noncombustible.

SUMMARY OF GLYCOL EVALUATIONS

Ethylene glycol is an alcohol and will burn; however, in a water-glycol mixture, the heat of vaporization of water impedes its combustion almost to the point of being nonflammable. Water will not "burn"; therefore, the water-glycol mixture burns only after the water is vaporized and dispersed, and the glycol is heated to its ignition temperatures in the presence of sufficient oxygen to support combustion. Thus, it is almost inconceivable that the water-glycol now utilized could trigger a spacecraft fire; but in the course of a spacecraft fire, a line rupture would spray water-glycol, which could act as either an extinguisher or fuel depending on the intensity of the existing fire, and the quantity of water-glycol.

It would be desirable from a fire standpoint to eliminate all spacecraft combustibles. However, with a fluid as noncombustible as water-glycol, other considerations must be weighted carefully prior to the decision to make a spacecraft change.

The design problems associated with the current water-glycol selection concerned the detailed radiator design, and corrosion prevention.

1. A radiator design using water-glycol to accommodate the wide range of heat loads and environmental extremes in the Lunar Landing Mission was thought to be impossible. The only other solution (that of going to a cascade-coolant system with its innately lower reliability, and higher weight and power requirements, and adding a second coolant fluid with its attendant materials-compatibility problems) was considered such a significant program impact that an extensive development effort was initiated which eventually resulted in the currently qualified selective stagnation ECS radiator.

Selective stagnation is a term used in reference to the Block II Apollo radiator design. The concept uses a set of tubes carefully arranged so that selected portions will "freeze" and thereby remove themselves (passively) from the radiator area. This allows passive area control of the radiator in accordance with the heat load.

2. The severe corrosion problems within coolant systems and electronic-cold-plate circuits with water-glycol fluid resulted in the careful selection of coolant-loop materials and the development of corrosion inhibitors.

A fluid substitution to obtain a less flammable fluid now faces these same problems. The only direct-substitution fluid with significantly better flammability properties is water. However, the low operational temperature limit makes heat rejection over the CSM load range not feasible because of freezing the water; thus, the cascade system would be required. This concept requires that both systems function simultaneously for thermal control, at the expense of (1) additional pumps and controls, (2) lower thermal efficiency, (3) higher power, (4) higher weight, and (5) new materials-compatibility problems. The current single-thermal control circuit could be retained with a fluid substitution if certain hardware redesigns are effected to maintain an equivalent thermal situation (e.g., pump, radiator, etc.). However, a new set of materials-compatibility problems would be encountered.

Taking all factors into consideration, it is adjudged desirable that the ECS fluid not be replaced.

RECOMMENDATION

It is recommended that thermal control hardware *not be* redesigned to accommodate a new coolant fluid or the incorporation of a dual loop. Work should continue to improve the inhibitor and provide an additive that has odor for leak detection.

TABLE 22.—*Summary of water-glycol joints and leakage history*

Type of joint	Spacecraft 012			Spacecraft 101		
	Total number of joints	Leaking joints		Total number of joints	Leaking joints Downey	Proposed change
		Downey	KSC			
B-nuts	16	[1] 25	5	37	13	[2] 37
Soldered	66	6	4	166	2	[3] 153
Welded	64	2	0	8	0	8
Brazed	85	2	0	51	1	51

[1] Some recurring leaks.
[2] Voi Shan inserts used on all joints.
[3] 13 joints and 13 tubes eliminated. 16 other joints armored.

Breathing Mask System

DISCUSSION

The desirability of an independent oxygen system is based on the need for a breathing device for unsuited astronauts should a fire occur during the mission after launch. The new materials being planned have improved fire resistance characteristics and will result in small fires and smoky atmospheres. The mask system will allow crewmen sufficient time to extinguish the fire, don the space suits, and connect to the environmental control system suit circuit.

The ground rules chosen for the development of a breathing mask system are as follows:

1. A mask system is considered which provides breathing capability and protection against eye irritation.
2. In the event of a fire, the fire will be small and result in smoky residue.
3. During an emergency, the pressure integrity of the spacecraft cabin is maintained.
4. The breathing mask system is required for transition between contaminated cabin and closed-suit circuit.
5. The mask is stowed during liftoff and connected to the oxygen supply prior to "shirtsleeve" operation.
6. The spacecraft cabin is at 6.2 pounds per square inch absolute and 3 crewmen are in the "shirtsleeve" mode.
7. The mask system shall be fire resistant.

Three types of mask systems are considered feasible: open- and closed-loop with oxygen supplied from the command module surge tanks and service module cryogenic storage to the PLSS fill valve (figs. 191 and 192), and a suit-loop mask (fig. 193) which would connect to the suit hoses. The basic operating principles of the open- and closed-loop mask systems have been demonstrated in aircraft; therefore, the development time for either of systems would be less than that required for the suit-loop mask. Spacecraft-qualified components can be utilized to a large extent in the oxygen supply portion of the open- and closed-loop mask systems which should reduce the amount of component qualification required. Therefore, overall qualification time is comparable to the suit-loop

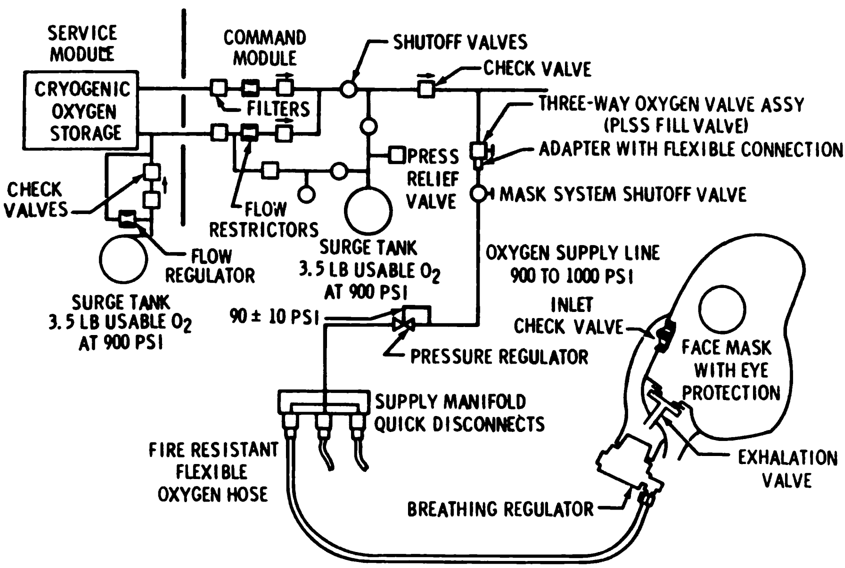


Figure 191

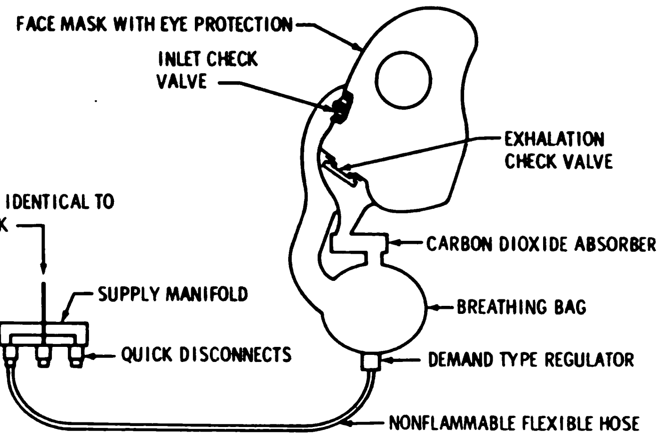


FIGURE 192

mask which requires less component qualification but more systems tests as it affects the suit-circuit operation.

The open-loop mask system will deplete the available oxygen at a higher rate than can be resupplied from the spacecraft cryogenic storage (fig. 194). As illustrated in figure 195, the crewmen would have approximately 25 minutes available breathing time at a work rate of 3,000 B.t.u./hr. However, this work rate could not be sustained for more than approximately 15 minutes before exhaustion. Thus, the time would be increased somewhat by lower metabolic levels. It is felt, however, that this system is limited to less than 1 hour because of the anxiety and work required during an emergency.

The closed-loop and suit-loop mask each require makeup of metabolic oxygen which can only be supplied by the spacecraft (fig. 194). The closed-loop mask is limited by the amount of carbon dioxide absorbent (fig. 195). Spare absorbers could be carried on board and the used absorber replaced periodically.

The suit-loop mask allows direct connection to the suit circuit for breathing and is not time limited.

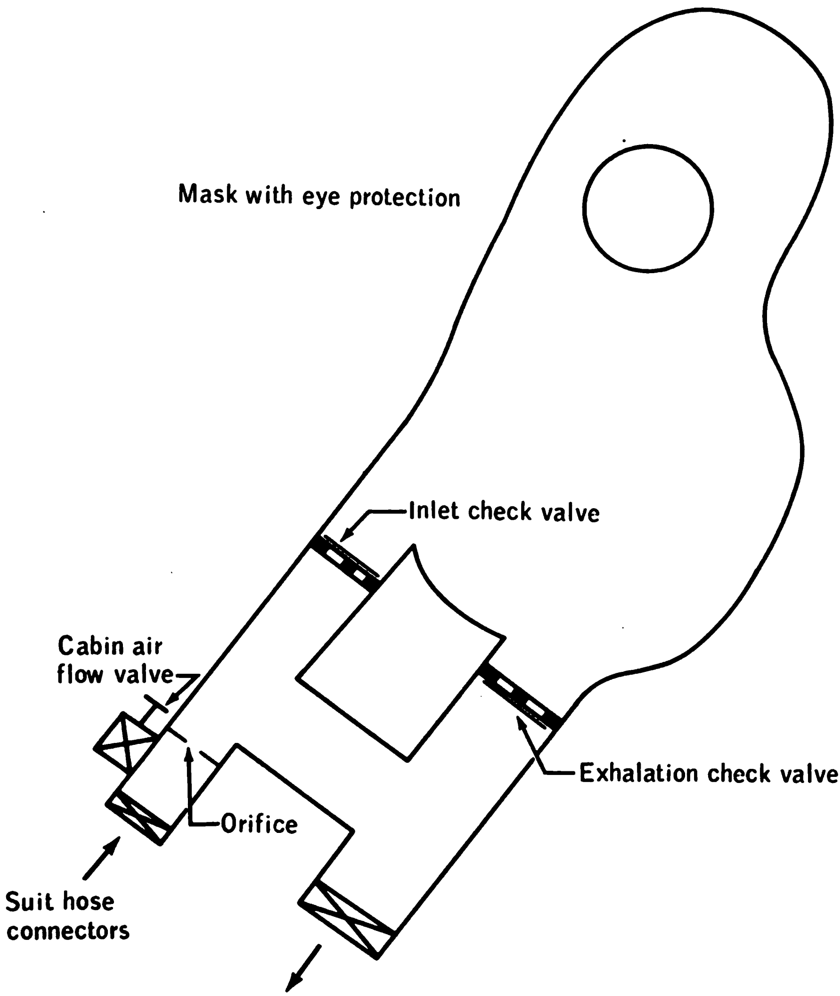
In the event a mask system is placed in the spacecraft, the following tests are required.

1. Determine suit-donning time with crewmen using masks.
2. Correlate cabin temperature and humidity to crewmen comfort when breathing from a mask system.

RECOMMENDATION

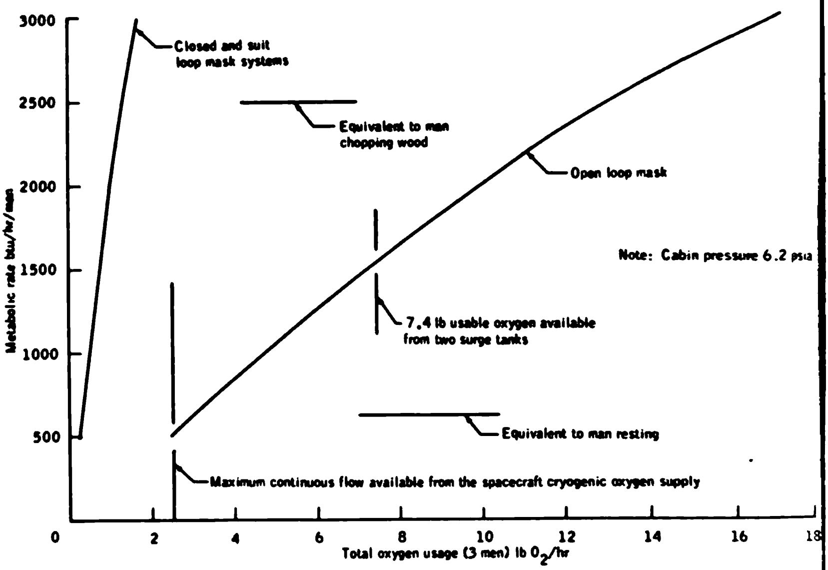
Based on the comparison in table 23, the suit-loop breathing mask system appears most advantageous and should be developed. However, tests are required to verify the design concept and interface with the environmental control system.

NASA-S-67-2492



Suit loop.

FIGURE 193



Fl nts.

FIGURE 194

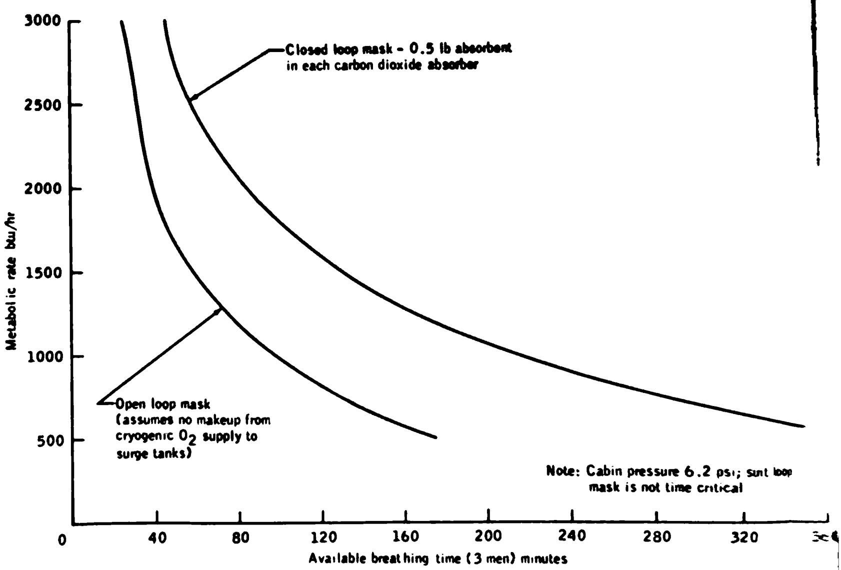
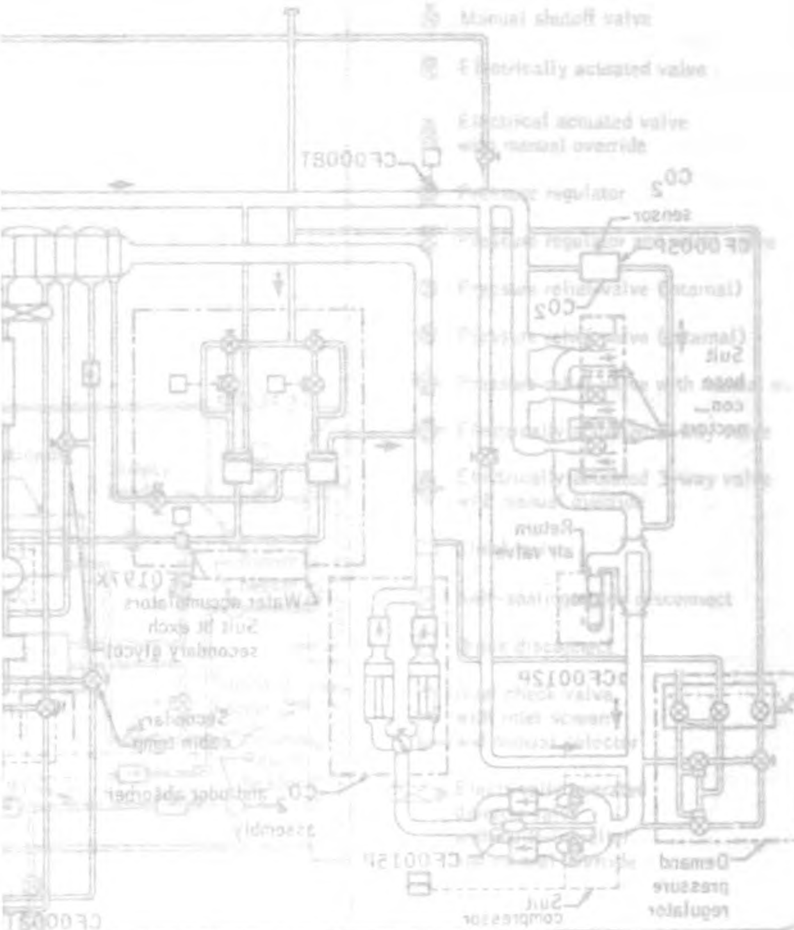


FIGURE 195



Manual shutoff valve
Electrically actuated valve
Electrical actuated valve
with manual override
Pressure regulator
CO_2
sensor
Suit
hose
con_
nectors
Return
air valve
Demand
pressure
regulator

TABLE 23.—*Breathing mask system comparison*

Factors	Open-loop mask	Closed-loop mask	Suit-loop mask
1. Operational limitations.	Less than 1 hour	Limited by carbon dioxide scrubber; scrubber could be replaced periodically to increase time.	Not time critical.
2. Spacecraft installation.	(1)	(1)	None.
3. Cooling provided	None	None	Limited face area.
4. Possible hazard	Dumps oxygen to cabin.	Subject to damage	None.
5. Development time	Short; limited tests; proven design concept.	Short, limited tests; proven design concept.	Long; operational and suit loop interface testing required; new design concept.
6. Crew mobility in cabin.	Good	Somewhat hindered by breathing bag and scrubber.	Hindered by hoses from mask (2 required).
7. Ease of transfer to suit.	Least difficult	Fairly difficult	Most difficult.
8. Estimated stowage volume.	0.35 cu. ft./system	0.45 cu. ft./system	0.30 cu. ft./system.
9. Operation required for use (per man).	Operate 3 valves remotely located from mask.	Operate 2 valves remotely located from mask.	Close 1 valve located near mask.
10. Spacecraft modifications.	(2)	(2)	(2).

[1] Requires installation of oxygen supply from the PLSS fill valve and mounting provision for regulator, manifold, and masks.
[2] Support bracketry and stowage provisions.

CONCLUSIONS

The following conclusions are presented:

1. The Environmental Control System is being modified to permit the use of air or oxygen in the cabin and 100 percent oxygen in the suit circuit. The detailed operational precedures require thorough testing. The decision on the launch pad cabin environment is being reserved until final evaluation of the effectiveness of the nonmetallic materials substitution program, and an appraisal of the operational impact of using air on the pad.

2. The repressurization performance of the cabin is being improved. The repressurization should provide 3.0 pounds per square inch absolute pressure in 1 minute and 3.5 pounds per square inch absolute in 2 minutes.

3. The aluminum lines in the oxygen system where high flow rates can occur are being replaced with stainless steel.

4. All ECS plumbing, that is, oxygen tubes, water-glycol tubes, and water tubes are being protected by structural members to preclude abuse which encourages leaks and other failures. These protective coverings should be in place immediately after installation.

5. The soldered-tube joints used in the water-glycol and water system are suitable for the purpose, provided they are not subjected to high-stress loadings. This type load can be applied by physical abuse if the line is not protected, or by torquing B-nuts in line with the soldered joint. The Block II plumbing has been redesigned to preclude the latter. A technique of armoring soldered joints has been developed and should be applied. Protective covers should be used.

6. The water-glycol coolant fluid should be retained. A substitute inhibitor should be sought and an additive that has a detectable odor should be provided to aid in rapid and early recognition of small water-glycol leaks not detectable on the spacecraft instrumentation.

7. An emergency oxygen mask breathing system should be provided for use should a fire be encountered in flight. This system should provide sufficient time and capability to permit the crew to extinguish the fire and don their space suits.

APPENDIX I—APOLLO BLOCK II CSM ENVIRONMENTAL CONTROL SYSTEM

DESCRIPTION

The present baseline CSM environmental control system (ECS) is designed to provide a conditioned environment within the command module (CM) for the flight crew and electronic equipment. The ECS is aided in the accomplishment of these tasks through an interface with the electrical power system which supplies oxygen for pressurization and potable water for crew use. The ECS also interfaces with the electronic equipment of the several Apollo CSM systems, for which the ECS provides thermal control; and with the lunar module (LM) for initially pressurizing the LM. The ECS also interfaces with the waste-management system to the extent that excess ECS water is dumped overboard through the urine-dump line.

The ECS is operated continuously throughout all Apollo mission phases and provides the following operating capabilities.

1. Controls the pressure, temperature, and composition of the command module cabin atmosphere to a shirtsleeve environment.
2. Provides pressure control and gas ventilation of the pressure-garment assembly through the circulation of conditioned suit-circuit gases during critical mission phases, and in case of a cabin decompression.
3. Provides thermal control of electrical, electronic, and mechanical equipment.
4. Provides management of potable and waste-water supplies.
5. Provides collection of solid waste matter and capability of dumping urine and excess water to space.
6. Provides postlanding ventilation and collection of sea water for conversion to fresh water for postlanding drinking purposes.
7. Provides initial LM cabin pressurization.
8. Provides for oxygen and water recharge of the Portable Life Support System (PLSS).

In order to provide the listed operating capabilities, the ECS is subdivided into the following subsystems, which comprise the total ECS (see figs. 196 and 197).

1. Oxygen supply and pressure control system.
2. Suit circuit system.
3. Thermal control system.
4. Water management system.
5. Waste management system.
6. Postlanding ventilation system.

The main package of the ECS is the Environmental Control Unit (ECU). For reference, this unit is shown in figures 198 and 199.

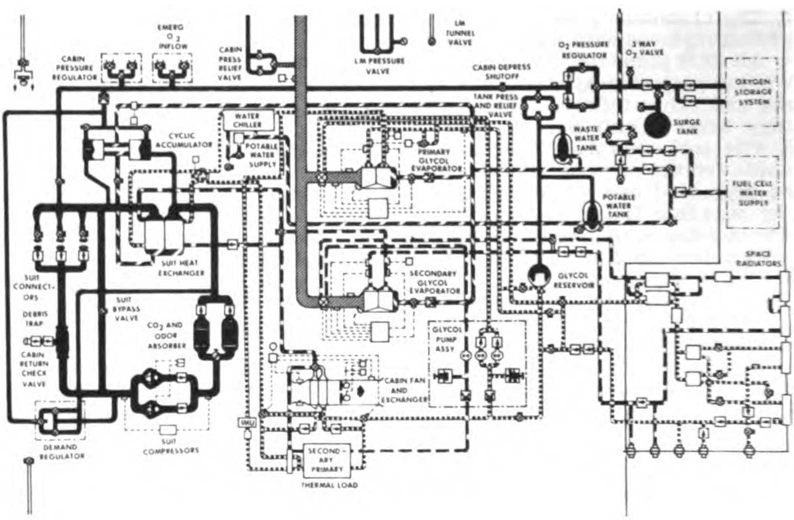


FIGURE 197

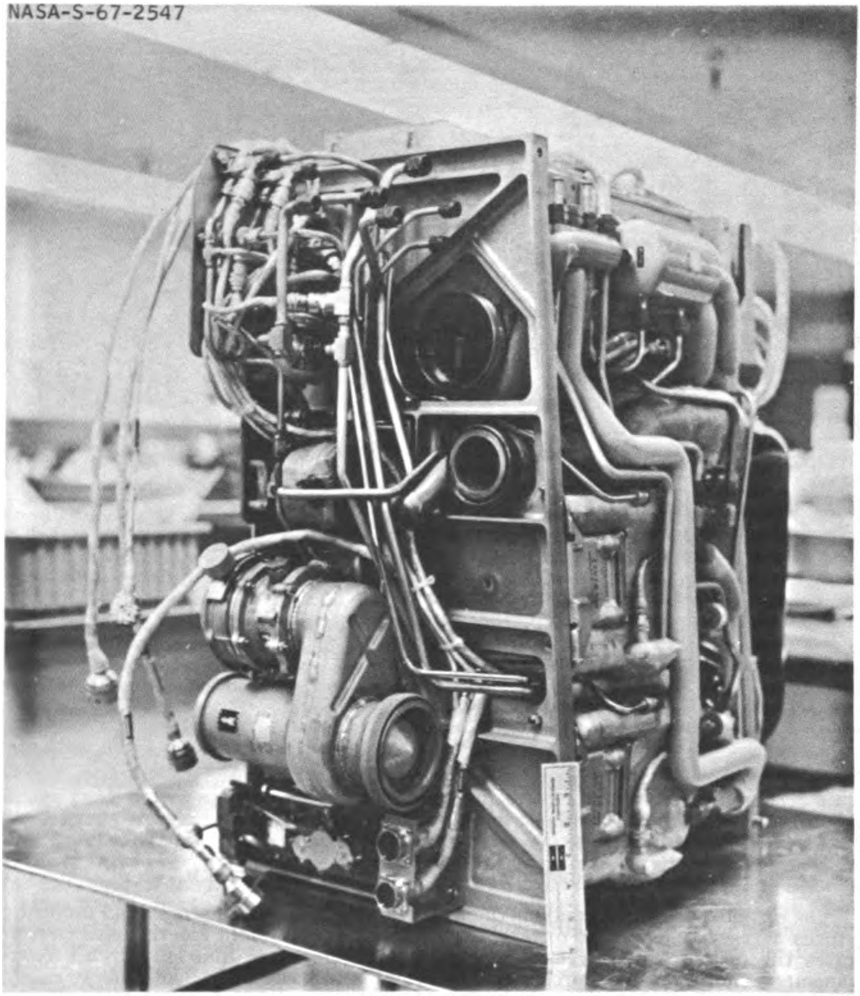


FIGURE 198

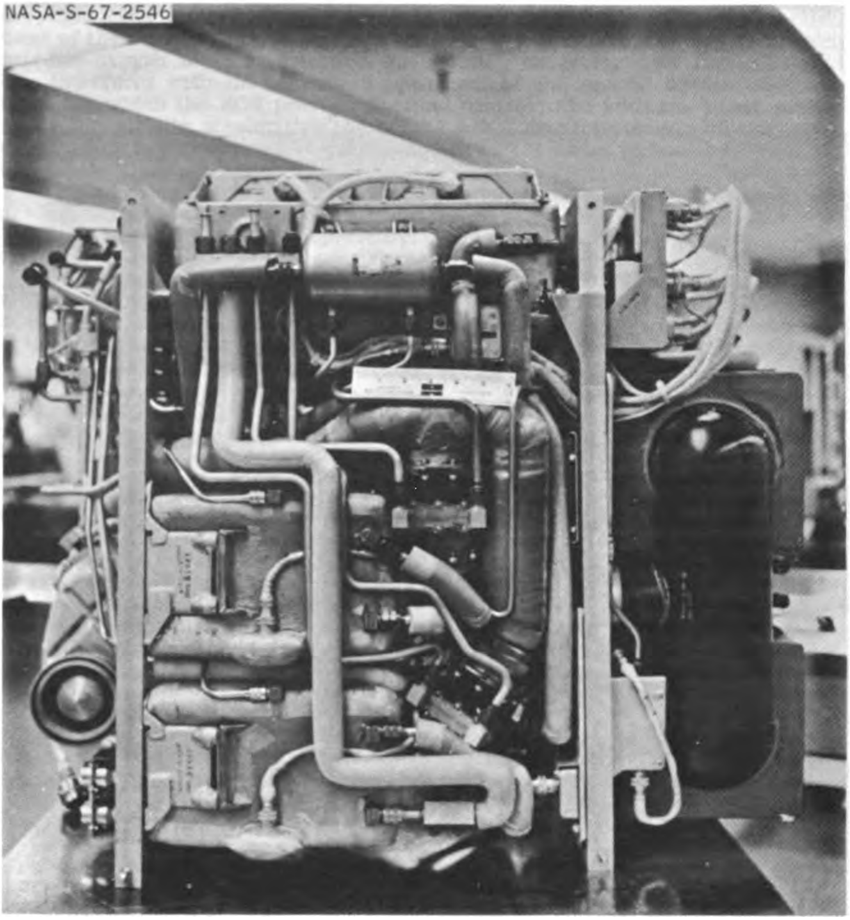


FIGURE 199

OXYGEN SUPPLY AND PRESSURE CONTROL SYSTEM

The oxygen subsystem controls the flow of oxygen within the command module: stores a reserve supply of oxygen for use during entry and emergencies; regulates the pressure of oxygen supplied to the subsystem and suit-circuit components; controls cabin pressure in normal and emergency (high-flow rate) modes; and controls pressure in the water tanks and water-glycol reservoir. The oxygen supply system is composed of the following major components.

1. Demand pressure regulator for suit-circuit pressure control and pressure relief. The suit-circuit pressure is controlled at 3.75 ±0.25 pounds per square inch absolute when the cabin is in the decompressed condition or if the cabin pressure is below 3.75 pounds per square inch absolute. The circuit pressure relief allows a maximum of 9.0 inches of water positive pressure and 3.0 ±0.5 inches of water negative pressure with respect to cabin pressure.
2. Oxygen pressure regulator to reduce service module supplied oxygen at 900 pounds per square inch absolute nominal pressure to a regulate nominal pressure of 100 pounds per square inch gage for ECS use.
3. Portable Life Support System (PLSS) supply valve for servicing the PLSS.
4. Pressure regulator and relief valve for water tank and water-glycol reservoir pressure control (20 ±2 pounds per square inch gage nominal control pressure).

5. Cabin pressure regulator for cabin-pressure control at 5.0 ±0.2 pounds per square inch absolute nominal pressure.

6. Cabin pressure-relief valve for positive and negative pressure relief of the cabin. The positive pressure relief ranges from 5.6 pounds per square inch to 6.2 pounds per square inch. The negative pressure relief is established as a maximum of 25 inches of water.

7. Lunar module pressurization valve for command and lunar modules pressurization.

8. Tunnel pressure-equalization valve to eliminate a pressure differential across the hatch between command module cabin and tunnel prior to opening.

9. Tunnel pressure-gage to indicate cabin-to-command module tunnel differential pressure.

10. Manual oxygen-metering valve to supply direct oxygen to the suit circuit when required.

11. Surge-tank pressure-relief valve to relieve surge-tank pressure between 1,020 and 1,070 pounds per square inch gage.

12. Cabin depressurization-shutoff valve to prevent oxygen flow to the cabin and suit-pressure controls.

13. Emergency oxygen inflow-control valve to provide high oxygen flow to the cabin in case of an unintentional cabin depressurization.

The cabin depressurization shutoff valve, and lunar module equalization valve, pressurization gage, and tunnel-pressure gage, are Block II components that were not included in the Block I ECS.

The oxygen subsystem shares the oxygen supply with the electrical-power system. Approximately 640 pounds of oxygen is stored in two cryogenic tanks located in the service module. Heaters within the tanks change the oxygen from a liquid to a gaseous state (at 900 pounds per square inch gage) for distribution to the ECS and fuel cells.

Oxygen is delivered to the command module through two separate supply lines, each of which terminates at an oxygen-inlet restrictor assembly. Each assembly contains a filter, a capillary line, and a check valve. The filters provide final filtration of gas entering the command module. The capillaries, which are wound around the hot glycol line, serve two purposes; they restrict the total oxygen flow rate to 9.0 pounds per hour maximum to maintain oxygen pressure to the fuel cells, and they heat the oxygen to prevent it from entering the ECS in a liquid state. The check valves serve to isolate the two supply lines.

Downstream of the inlet-check valves, the two lines tee together and a single line is routed to the oxygen service module supply valve, used in flight as a shutoff valve to back up the inlet-check valves during entry. It is closed prior to separation of the command service modules.

The outlet of the service module supply valve is connected in parallel to the oxygen-surge tank valve, and to a check valve on the oxygen control panel. The surge tank stores approximately 3.7 pounds of oxygen for use during entry, and for augmenting the service module supply when the operational demand exceeds the flow capacity of the inlet restrictors. The surge-tank pressure-relief and shutoff valve prevents overpressurization of the surge tank, and provides a means for shutting off the flow in case of relief-valve failure.

The PLSS supply valve is used for filling the oxygen tank in the backpack; for connecting the PLSS tank into the system as an auxiliary supply (approximately 0.9 pound of oxygen) for entry and emergencies; and for isolating the PLSS supply line when the backpack is disconnected.

The main high pressure regulator reduces the supply pressure to 100 ±10 pounds per square inch gage for use by the subsystem components. The regulator assembly is a dual unit which is normally operated with both units in parallel. A selector valve at the inlet to the assembly provides a means of isolating either of the units in case of failure, or for shutting both off. Integral relief valves limit the downstream pressure to 140 pounds per square inch gage maximum. The oxygen output of the main regulator passes through a flowmeter, then is delivered directly to the water tank and water-glycol-tank pressure regulator; through the oxygen supply valve to the cabin-pressure regulator, emergency cabin-pressure regular, the oxygen-demand regulator, the direct oxygen valve, and the water-cyclic accumulator valves.

The water tank and glycol tank pressure-regular assembly is a dual unit, normally operating in parallel, which reduces the oxygen at 100 pounds per square inch, to 20 ±2 pounds per square inch gage (relative to cabin) for pressurizing the positive expulsion bladders in the waste and potable water tanks, and in the water-glycol reservoir. Dual integral relief valves limit the downstream pressure to 25 ±2 pounds per square inch above cabin pressure.

The cabin depressurization-shutoff valve controls the supply of oxygen to the cabin and suit-pressure controls, and the water-accumulator valves. It is a motor-driven valve with a manual override; and can be driven to the closed position electrically by means of a switch located on the command module structure between the inner and outer main hatches. The valve must be opened manually. The valve was added for Block II to provide emergency ingress without depleting the oxygen supply, if the crewman inside is incapacitated.

The cabin-pressure regulator controls the flow of oxygen into the cabin to make up for depletion of the gas due to metabolic consumption when the system is operated in the shirtsleeve mode, normal cabin leakage, or repressurization. The assembly consists of two absolute pressure regulators operating in parallel, and a manually operated cabin-repressurization valve. The regulator is designed to maintain cabin pressure at 5 ±0.2 pounds per square inch absolute with losses up to 1.3 pounds per hour. Losses in excess of this value will result in a continual decrease in cabin pressure. When cabin pressure falls to a 3.5 pounds per square inch absolute minimum, the regulator will automatically shut off to prevent wasting the oxygen supply. Following depressurization, the cabin can be repressurized by manually opening the cabin-repressurization valve.

The emergency cabin-pressure regulator provides emergency protection for the crew in the event of a sudden severe leak in the cabin. The regulator valve starts to open when cabin pressure decreases to 4.6 pounds per square inch absolute; and at 4.4 pounds per square inch absolute, the valve is full open for flooding the cabin with oxygen. The regulator supplies oxygen to the cabin at flow rates up to 0.66 pound per minute, to prevent rapid decompression in case of cabin puncture. The valve is capable of providing flow rates which will maintain cabin pressure above 3.5 pounds per square inch absolute for a period of 5 minutes, with a leakage rate equivalent to a ½-inch diameter cabin puncture. The valve is normally used during shirtsleeve operations, and is intended to provide time for donning pressure suits before cabin pressure drops below 3.5 pounds per square inch absolute.

The oxygen demand regulator supplies oxygen to the suit circuit when the suit circuit is isolated from the cabin (return air shutoff valve closed), and during depressurized operations. It also relieves excess gas to prevent overpressurizing the suits. The assembly contains redundant regulators; a single relief valve for venting excess suit pressure, an inlet selector valve for selecting either or both regulators, and a suit-test valve for performing suit-integrity tests.

The direct oxygen-metering valve is a manual metering valve with a flow capability of zero to 0.67 pound per minute. The primary purpose of this valve is for purging the suit circuit.

During the ascent, the cabin remains at sea-level pressure until the ambient pressure decreases 6 pounds per square inch to 8.7 pounds per square inch. At that point, the cabin pressure-relief valve vents the excess gas overboard, maintaining cabin pressure at 6 pounds per square inch above ambient. As the cabin pressure decreases, a relief valve in the oxygen-demand regulator vents suit gases into the cabin to maintain the suit pressure slightly above cabin pressure.

Sometime after attaining orbit, leakage will cause the cabin pressure to decrease from 6 pounds per square inch (as established by the cabin pressure relief valve) to 5 pounds per square inch. At this point, the cabin-pressure regulator will begin supplying oxygen to make up for the leakage, and will maintain the cabin pressure at 5 pounds per square inch absolute. During normal space operations, the cabin-pressure regulator not only maintains cabin pressure, but also supplies the makeup oxygen for the suit circuit through the return shutoff valve. If additional oxygen flow is required (e.g., for purging the suits), the direct oxygen valve can be used.

SUIT-CIRCUIT SYSTEM

The suit circuit provides the crew with a continuously conditioned atmosphere. It automatically controls suit-gas circulation, pressure, and temperature; and removes debris, excess moisture, and carbon dioxide from the suit and the cabin gases.

The suit-circuit system is composed of the following major components.

1. Suit-circuit compressor for continuous circulation of suit-circuit gases.

2. Carbon dioxide and odor-absorber canister for removal of carbon dioxide and odors from suit-circuit and cabin gases.

3. Suit heat-exchanger package for removal of suit-circuit sensible heat, latent heat, and water vapor from the suit gases.

4. Suit-flow limiter to limit gas flow to the individual pressure suits in case of a loss of suit integrity in a decompressed cabin.

5. Debris trap to filter particles of solid matter that may enter the suit-circuit.

6. Suit-bypass valve to permit each crew member to vary individual gas flow to a suit without affecting the gas flow to the other suits.

7. Suit-circuit-return valve to allow cabin gases to enter the suit-circuit for carbon dioxide, water vapor, and odor removal.

8. Carbon dioxide partial-pressure sensor to measure partial pressure of carbon dioxide in the suit-circuit.

The suit-circuit is a circulating gas loop which provides the crew with a continuously conditioned atmosphere throughout the mission. The gas is circulated by two centrifugal compressors, which are controlled by individual switches. Normally only one of the compressors is operated at a time; however. the individual switches provide a means for connecting either or both of the compressors to either ac bus.

The gas leaving the compressor flows through the carbon dioxide and odor-absorber assembly. The assembly is a dual unit containing two filter elements in separate compartments with inlet and outlet manifolds common to both. A diverter valve in the inlet manifold provides a means of isolating one compartment or the other (without interrupting the gas flow) for the purpose of replacing a spent element. An interlock mechanism between the diverter-valve handle and the cover handles is intended to prevent opening both compartments at the same time. The filter elements contain lithium hydroxide, and activated charcoal for removing carbon dioxide and odors from the suit gases. Dacron pads on the inlet and outlet sides trap small particles and prevent filter-element materials from entering the gas stream.

From the filter, the gas flows through the suit heat exchanger where the gases are cooled and the excess moisture is removed. The heat-exchanger assembly is made up of two sets of broad, flat tubes through which the coolant flow/bypass is controlled by two 3-way valves. The suit heat exchanger secondary-glycol valve must be positioned manually. The space between the tubes forms passages through which the suit gases flow. The coolant flowing through the tubes absorbs some of the heat from the suit gases. As the gases are cooled, the excess moisture condenses and is removed from the heat exchanger by a pair of water accumulators.

The water accumulators are piston-type pumps, which are actuated by oxygen pressure (100 pounds per square inch) on the discharge stroke, and by a return spring for the suction stroke. The oxygen flow is controlled by two water-accumulator selector-valve assemblies, that are programed to automatically actuate every ten minutes.

The cool gas (50° F. nominal) flows from the heat exchanger through the suit-flow limiters and the flow-control valves, into the suits.

A suit-flow limiter is installed in each suit supply duct to restrict the gas-flow rate through any one suit. The flow limiter is a tube with a Venturi section, sized to limit flow to 0.7 pound per minute. The limiter offers maximum resistance to gas flow through a badly leaking suit, when cabin pressure is near zero pounds per square inch absolute. The oxygen-demand regulator will supply oxygen at flow rates up to 0.66 pound per minute (for at least 5 minutes) to maintain pressure in the circuit.

The flow-control valves are part of the suit-hose connector assembly. The valves provide a means for adjusting the gas flow through each suit individually.

A suit bypass-relief valve is installed between the suit heat exchanger outlet and the compressor inlet, and is intended to maintain a relatively constant pressure at the inlets to the three suits by relieving transient-pressure surges.

The gas leaving the suits flows through the debris trap assembly, into the suit compressor. The debris trap is a mechanical filter for screening out solid matter that might otherwise clog or damage the system. The trap consists of a stainless-steel screen designed to block particles larger than 0.040 inch, and a bypass valve which will open at a differential pressure of 0.5-inch water in the event the screen becomes clogged.

The suit-circuit return valve is installed on the debris trap upstream of the screen. The return air valve permits cabin gases to enter the suit circuit for carbon dioxide, odor, temperature control, and water vapor removal. The valve consists of two flapper-type check valves, and a manual shutoff valve, in series. The valve provides a means for manually isolating the suit circuit from the cabin. The valve will automatically close and maintain suit pressure in case of a cabin decompression.

The carbon-dioxide sensor is connected between the suit inlet and return manifold. A carbon-dioxide high-partial pressure-warning light is activated when the carbon dioxide partial pressure within the suit circuit reaches 7.6 millimeters of mercury.

THERMAL CONTROL SYSTEM

The thermal control system provides cooling for the suit circuit, the potable water chiller, spacecraft equipment, and heating or cooling for the cabin atmosphere.

The thermal control system, or water-glycol system, is composed of a primary and secondary cooling loop. The principal components in the thermal control system are as follows.

1. Glycol pump assembly for continuous water-glycol circulation at a pressure rise of 36 pounds per square inch gage and 200 pounds per hour flowrate.
2. Back-pressure control valve to control the steam pressure in the glycol evaporator.
3. Space radiator panels to reject heat loads to deep space.
4. Suit heat exchanger for suit-circuit heat rejection.
5. Cabin heat exchanger for cabin-gas cooling or heating.
6. Electronic-coldplate network to provide electronic-equipment temperature control.
7. Glycol evaporator to remove heat from the water-glycol circulating fluid, and reject the heat load to space through water evaporation.

The primary loop is operated continuously throughout the mission, unless damage to the equipment necessitates shutdown. The secondary loop is operated at the discretion of the crew, and provides a backup for the primary loop. Both loops provide cooling for the suit and cabin atmospheres, and the electronic equipment. The secondary water-glycol coolant loop was designed to provide adequate, immediate emergency return from the lunar orbit utilizing minimum ECS components and automatic controls. Consequently, the secondary coolant loop is not identical to the primary coolant-loop design, but does contain the capability of an emergency return to earth with loss of the primary coolant loop. The primary loop also serves as a source of heat for the cabin atmosphere, when required. During prelaunch operations, ground servicing equipment cools the water-glycol and pumps it through the primary loop, providing cooling for the electrical and electronic equipment, and the suit and cabin heat exchangers. The cold water-glycol is also circulated through the glycol reservoir to make a larger quantity of coolant available for use as a heat sink during ascent.

During flight, the coolant is circulated through the loops by a pumping unit consisting of two redundant pumps, a full flow filter, and an accumulator for the primary loop; and a single pump, filter, and accumulator for the secondary loop. The purpose of the accumulators is to maintain a positive pressure at the pump inlets by accepting volumetric changes due to changes in coolant temperature.

The output of the primary pump flows through a passage in the evaporator steam-pressure-control valve to prevent ice formation at the valve throat. The coolant next flows through the oxygen-restrictor assembly, through the service module radiators, and returns to the command module. The coolant returning to the command module flows to the glycol-reservoir valves where it can either bypass or flow through the reservoir. After orbit insertion, the reservoir is isolated from the primary loop to provide a reserve supply of coolant for refilling the loop in the event a leak occurs.

The coolant flow from the evaporator divides into two branches. One branch carries a flow of 33 pounds per hour to the inertial measurement unit, and into the coldplate network. The other branch carries a flow of 167 pounds per hour to the water chiller, then through the suit heat exchanger to the primary cabin temperature-control valve.

The primary cabin temperature-control valve routes the coolant to either the cabin heat exchanger or to the coldplate network. The valve is positioned automatically by the cabin temperature control, or manually by means of an override control on the face of the valve. The valve is so constructed that in the cabin full-cooling mode, the flow of coolant from the suit heat exchanger (167 pounds per hour) is routed first through the cabin heat exchanger and then through the thermal coldplate where it joins with the flow (33 pounds per hour) from the inertial-measurement unit. In the cabin full-heating mode, the total flow (200 pounds per hour) is routed through the thermal coldplates first, where the water-glycol absorbs heat; from there it flows through the cabin heat exchanger. In the intermediate valve positions, the quantity of cool water-glycol flowing through the heat exchanger is reduced in proportion to the demand for cooling or heating. Although the amount of water-glycol flowing through the cabin heat exchanger will vary, the total flow through the thermal coldplates will always be total system flow. The total flow leaving the primary cabin temperature valve enters the primary pump and is recirculated.

The output of the secondary pump flows through a passage in the secondary-evaporator steam-pressure control valve for deicing the valve throat. The coolant next flows through the service module radiators, and returns to the command module.

After returning to the command module, the coolant flows through the secondary evaporator and the suit heat exchanger to the secondary cabin temperature-control valve. The secondary cabin temperature-control valve, a manually operated valve, regulates the quantity of coolant flowing through the cabin heat exchanger in the cooling mode (there is no heating capability in the secondary loop). The coolant from the secondary cabin temperature-control valve and/or the cabin heat exchanger then flows through redundant passages in the cold-plates for the flight-critical equipment, and returns to the secondary pump inlet.

The heat absorbed by the coolant in the primary loop is transported to the radiators where a portion is rejected to space. If the quantity of heat rejected by the radiators is excessive, the temperature of the coolant returning to the command module will be lower than desired (45° F. nominal). If the temperature of the coolant entering the evaporator drops below a nominal 43° F., the mixing mode of temperature control is initiated. The automatic control opens the glycol temperature-control valve, which allows a sufficient quantity of hot coolant from the pump to mix with the coolant returning from the radiators to produce a mixed temperature at the inlet to the evaporator of 45° F. nominal. There is no mixing mode in the secondary loop.

If the radiators fail to radiate a sufficient quantity of heat, the coolant returning to the command module will be above the desired temperature. When the temperature of the coolant entering the evaporator rises to 48° to 50.5° F., the evaporator mode of cooling is initiated. The glycol temperature control opens the backpressure-control valve allowing the water in the evaporator wicks to evaporate. A temperature sensor at the outlet of the evaporator controls the position of the backpressure-control valve to establish a rate of evaporation that will result in a coolant outlet temperature between 40° to 43° F. The evaporator wicks are maintained in a wet condition by the wetness control, which uses the wick temperature as an indication of water content. As the wicks become drier, the wick temperature increases and the water-control valve is opened. As the wicks become wetter, the wick temperatures decrease and the water valve closes. The evaporative mode of cooling is the same for both loops, except that only the primary loop has backup control.

Each coolant loop includes a radiator circuit. The primary radiator circuit consists basically of two radiator panels in parallel with a flow-proportioning control for dividing the flow between them, and a heater control for adding heat to the loop. The secondary circuit consists of a series loop utilizing some of the area of both panels, and a heater control for adding heat to the loop.

The radiator panels are an integral part of the service module skin and are located on opposite sides of the service module. With the radiators diametrically opposite, it is possible that one primary panel may "see" deep space while the other "sees" the sun, earth, or moon. These extremes in environments provide for large differences in panel efficiencies and outlet temperatures. The panel seeing deep space can reject more heat than the panel receiving external radiation; therefore, the overall efficiency of the subsystem can be improved by increasing the flow to the cold panel. The higher flow rate reduces the transit time of the coolant through the radiator, which decreases the quantity of heat radiated.

The flow through the radiators is controlled by the flow-proportioning valve. When the differential temperature between the outlets of the two panels exceeds 10° F., the flow-proportioning valve is positioned to increase the flow to the colder panel.

If the radiator outlet temperature falls below the desired minimum, the effective radiator surface temperature will be controlled passively by the selective-stagnation method. The two primary circuits are identical, each consisting of five tubes in parallel, and one downstream series tube. The two panels, as explained in the flow-proportioning control system, are in parallel with respect to each other. The five parallel tubes of each panel have manifolds sized precisely to provide specific flow rate ratios in the tubes, numbered 1 through 5. Tube 5 has a lower flow rate than tube 4, and so on through tube 1, which has the higher flow. It follows that for equal fin areas the tube with the lower flow rate will have a lower coolant temperature. Therefore, during minimum command module heat loads, stagnation begins to occur in tube 5 as its temperature decreases; for as its temperature decreases, the fluid resistance increases, and the flow rate decreases. As the fin area around tube 5 gets colder, it draws heat from tube 4 and the same process occurs with tube 4. In a fully stagnated condition, there is essentially no flow in tubes 3, 4, and 5, and some flow in tubes 1 and 2, with most of the flow in tube 1.

When the command module heat load increases and the radiator inlet temperature starts to increase, the temperature in tube 1 increases and more heat is transferred through the fin toward tube 2. At the same time, the glycol-temperature control valve starts to close and force more coolant to the radiators, thus helping to thaw the stagnant portion of the panels. As tube 2 starts to get warmer and receives more flow, it in turn starts to thaw tube 3, and so on. This combination of higher inlet temperatures and higher flow rates quickly thaws out the panel. The panels automatically provide a high effectiveness (completely thawed panels operating at a high-average fin temperature) at high-heat loads, and a low effectiveness (stagnated panels operating at a low-average fin temperature) at low-heat loads.

The secondary radiator consists of four tubes which are an integral part of the ECS radiator-panel structure. Each tube is purposely placed close to the hottest primary radiator tubes (i.e., the number 1 and the downstream series tube on each panel) to keep the water-glycol in the secondary tubes from freezing while the secondary circuit is inoperative. The selective-stagnation principle is not utilized in the secondary radiator because of the narrower heat-load range requirements. This is also the reason the secondary radiator is a series loop. Because of the lack of this passive control mechanism, the secondary ECS circuit is dependent on the heater-control system at low-heat loads and the evaporator at high-heat loads for control of the water-glycol temperature.

The Block II radiators differ in design, size, and operation from the Block I radiators. The Block II radiators contain approximately 100 square feet of surface area while the Block I panels contained 60 square feet. I addition, the Block II radiator-control system is more complex than the Block I system, to provide lunar mission capability.

WATER MANAGEMENT SYSTEM

Water management consists of collecting and storing the potable water produced in the fuel cells, and delivering chilled and heated water to the crew for metabolic consumption and hygienic purposes; and the collection and storage of waste water (extracted in the process of controlling humidity), and delivering it to the glycol evaporators for supplemental cooling.

The water-management system is composed of the following major components:

1. Waste water tank to store water for use in the glycol evaporator (56-pound water capacity).
2. Potable water tank to store potable water from the fuel cells (36-pound water capacity).
3. Potable water-supply assembly to deliver hot or cold water to the crew.
4. Primary and secondary glycol evaporator water-inflow-control valves to control the water flow to the glycol evaporator.
5. Potable water tank pressure-relief valve to permit flow of potable water into the waste water tank when the potable tank is full.
6. Overboard water pressure-relief valve to permit flow of water overboard when both the potable and the waste tanks are full.

The water subsystem consists of two individual fluid-management networks which control the collection, storage, and distribution of potable and waste water. The potable water is used primarily for metabolic and hygienic purposes. The waste water is used solely as the evaporant in the primary and secondary glycol evaporators. Although the two networks operate and are controlled independently, they are interconnected in a manner which allows potable water to flow into the waste system under certain conditions.

Potable water produced in the fuel cells is pumped into the command module at a nominal flow rate of 1.5 pounds per hour. The water flows through a check valve on the water-control panel, to the inlet ports of the potable tank inlet and waste tank inlet valves. The check valve at the inlet prevents loss of potable water after separation of the command-service modules.

The potable tank inlet valve is a manual shutoff valve used for preventing the flow of fuel-cell water into the potable system in the event the fuel-cell water becomes contaminated.

The waste tank inlet valve is an in-line relief valve, with an integral shutoff valve. The relief valve allows potable water to flow into the waste water tank whenever the potable water pressure is 6 pounds per square inch above waste water pressure. This pressure differential will occur when the fuel cells are pumping water, and either the potable water tank is full, or the potable tank inlet valve is closed; or when the waste water tank is completely empty and the water-glycol evaporators are demanding water for cooling. In the latter case, the water flow is only that quantity which is demanded. The shutoff valve provides a means of blocking flow in case the relief valve fails. If such a failure occurs, potable water can flow through the valve (provided the potable water pressure is higher than the waste), until the two pressures are equal. Reverse flow is prevented by a check valve downstream of the waste-tank inlet valve.

In the event that both water tanks are full, the fuel-cell excess potable water will be dumped overboard through the overboard pressure-relief valve.

Potable water flows from the control panel to the potable water tank, the food preparation water unit, and the water chiller. Chilled water is delivered to the food preparation water unit through the drinking water supply valve and to the drinking water dispenser.

The water chiller cools and stores 0.5 pound of potable water for crew consumption. The water chiller is designed to supply 6 ounces of 50° F. water every 4 minutes.

The food preparation water unit heats potable water for use by the crew, and allows manual selection of hot or cold potable water; the cold potable water is supplied by the water chiller. The unit consists of an electrically heated water reservoir and two manually operated valves. The insulated reservoir has a capacity of 2.5 pounds of water. Thermostatically controlled heating elements in the reservoir, heat the water and maintain it at 154° F. nominal. Two metering valves dispense either hot or cold water in 1-ounce increments, through a common nozzle.

The drinking water supply valve provides a means for shutting off the flow of water to the drinking water dispenser in case of a leak in the flex hose.

The waste water and potable water is stored in positive expulsion tanks, which with the exception of capacity, are identical in function, operation, and design.

Waste water extracted from the suit heat exchanger is pumped into the waste water tank, and is delivered to the primary and secondary water-glycol evaporator water inflow control valves. When the tank is full, excess waste water is dumped overboard through the overboard water pressure relief valve. The evaporator water control valves consist of a manually operated inlet-shutoff valve and a solenoid valve.

WASTE MANAGEMENT SYSTEM

The function of the waste management system is to control and/or dispose of waste solids, liquids, and gases. The major portion of the system is located in the right-hand equipment bay.

The basic requirements of the system are ease of operation, accessible supplies, containment and stowage of feces, removal of odor, overboard dump of urine, removal of urine from the pressure-garment assembly, urination while in the couches, and collection of loose debris.

The waste management system contains urine, fecal, and vacuum-cleaner subsystems with their associated supplies and equipment.

The urine, oxygen, and the fecal odors of the waste management system, as well as emergency relief of fluids from the command module batteries, and excess water from the water system are routed overboard through the ECS water-urine dump line. Incorporated at the outlet of the dump line is a 0.55-inch orifice urine dump nozzle that restricts gas flow to a maximum of 1 cubic foot per minute and liquid flow to 1.25 pounds per minute. The restriction of liquid flow, in conjunction with redundant 5.7 watt sump-nozzle heaters, prevents the formation of ice at the nozzle, which could block all flow. The urine subsystem contains a urine receptacle, flexible hose (capable of reaching the crewman in a couch) with a ⅜-inch pressure-garment assembly urine valve quick-disconnect, and controls.

The urine receptacle and fecal canister hose connect to fittings on the aft bulkhead which lead to the waste management system unit in the right-hand equipment bay, and then overboard. The waste management system panel contains an overboard drain valve and a battery vent valve. Placing the overboard drain valve to the dump position subjects the waste-management system to a differential pressure of 5 pounds per square inch.

The fecal subsystem not part of the ECS, contains a fecal canister assembly, fecal canister pad, sanitation supply assemblies, and tissue dispensers.

The vacuum subsystem consists of a vacuum cleaner with a 10-foot flex hose adapter nozzle, and refuse bag assemblies. The vacuum cleaner is connected to the overboard urine dump nozzle, which provides the pressure differential required for vacuum cleaner operation.

POSTLANDING VENTILATION SYSTEM

The postlanding ventilation system provides circulation of outside ambient air through the cabin during the postlanding mission phase. The system also provides the capability of collecting sea water for conversion to suitable drinking water for crew use. The postlanding ventilation system is composed of the following major components:

1. Postlanding ventilation blower to provide circulation of ambient air through the cabin at flow rates of either 150 cubic feet per minute or 100 cubic feet.
2. Two postlanding ventilation valves to permit entry and exit of ambient air.
3. Postlanding ventilation inlet duct assembly to direct the flow of ambient air into the command module.
4. Postlanding ventilation water pump assembly to draw water from the sea for conversion to drinking water.

Outside air is drawn into the cabin through an inlet duct containing a shutoff valve and blower. After circulating within the cabin, the air is expelled overboard through the outlet shutoff valve. The blower is capable of two-speed operation, providing either 100 cubic feet per minute of 150 cubic feet per minute air flow, as required. An attitude-sensing switch closes both postlanding ventilation valves if the command module yaws to an angle greater than 60° from the vertical axis or assumes the stable 2 position.

APPENDIX II.—TUBING, JOINTS AND FITTINGS

NAA TEST AND INSPECTION PROCEDURES

The following presents the installation and inspection sequence for a typical solder joint.

1. All lines are installed and solder joints made prior to the installation of components. Each progressive joint is X-rayed for structural verification and pressurized with helium for leak detection. A vacuum boot is used to encapsulate the joint for more accurate determination of leakage (5×10^{-6} scc/sec).
2. A gross system leak check using helium is performed following installation of the ECS components (60 pounds per square inch). If leakage is excessive, individual joint checks are rerun.
3. Another system leak check is performed at proof pressure also using helium (90 pounds per square inch).
4. Prior to servicing with water-glycol, the system is again leak checked with nitrogen (60 pounds per square inch).
5. As a part of the servicing procedure, the system is evacuated to less than 500 microns and a pressure-decay check performed. The system is then serviced with water-glycol. A visual leak check is made.

6. The system is monitored for leakage throughout the individual, combined, and integrated testing at Downey.

7. Prior to system operation, a visual leak test is performed (60 pounds per square inch).

8. The service module is both pressure- and vacuum-leak checked similar to the Building 290 test on the command module in paragraphs 4 and 5.

9. The service module is serviced with water-glycol and a visual leak check is performed.

10. The command and service modules are mated and a visual leak check is performed.

The activity of paragraphs 1 through 6 is accomplished at Downey. The activity of items 7 through 10 is accomplished at KSC. The block diagram (fig. 200) shows the test sequence.

Tests conducted on soldered joints and inspection of soldered joints

1. Sequence of operations (same for repair and replacement):
   - (a) Solder per MA0107–018.
   - (b) X-ray 100 percent per MQ0501–007.
   - (c) Leak check 100 percent per MA0115–027 in subassembly.
   - (d) Test cells system leak checks.
     - CM—Proof pressure decrease to operating pressure. Helium leak check where accessible with mass spectrometer leak.
     - SM—Low pressure leak test. Use soap solution. Leak test accessible joints with mass spectrometer.
2. X-ray:
   - (a) Sensitivity 2 percent or less.
   - (b) Two views at 90°, straight into joint; adequate to pickup voids.
   - (c) Use collimator (1¾ in. by 7 to 22 in. length) to get into tight areas.
   - (d) Use certified readers; formal training periodic checks.
   - (e) Estimate void areas if obviously over 20 percent; measure void areas if questionable.
   - (f) Void areas very visible because of solder alloy containing lead.
   - (g) Doubtful X-rays; take 3 shots at 60°.
3. Leak check:
   - (a) Certified operators.
   - (b) Use covers over joints, either Tygon tubing or rubber booties (Bldg. 290).
   - (c) Leak rate 5.6×10^{-6} std cc He/sec.
   - (d) Test cells.
     - SM—Use mass spectrometer plus leak solution.
     - CM—Mass spectrometer. May test in tight areas without bagging joints.

REFERENCES

1. Lambertsen, C. J.: Physiological Interactions and Gaseous Environment in Manned Exploration of Space. Federation Proceedings (Symposia and Reports), vol. 22 (No. 4), 1963.

2. Roth, E. M.: Space-Cabin Atmospheres. Parts I, II, III and IV. Fire and Blast Hazards. NASA–SP–48, National Aeronautics and Space Administration, Washington, D.C., 1964.

3. Hearing before the Committee on Aeronautical and Space Sciences, United States Senate, Ninetieth Congress. Relating to the Apollo Accident of January 27, 1967. Part I, February 7, 1967, Washington, D.C.

4. Hearing before the Committee on Aeronautical and Space Sciences, United States, Ninetieth Congress. Relating to the Apollo Accident of January 27, 1967. Part II, February 27, 1967, Washington, D.C.

5. Michel, E. L.: Smith, G. B., Jr.; and Johnston, R. S.: Gaseous Environment Considerations and Evaluation Programs Leading to Spacecraft Atmosphere Selection. NASA TN D–2506, Washington, D.C., January 1965.

6. Excerpts from 1964 NASA Authorization. Hearings before the Subcommittee on Manned Space Flight of the Committee on Space and Astronautics, U.S. House of Representatives, June 6, 1963.

7. Soviet Space Programs, 1962–65; Goals and Purposes, Achievements, Plans and International Implications. A Staff Report by the Committee on Aeronautical and Space Sciences, United States Senate, December 30, 1966.

8. Sax: The Handbook of Hazardous Industrial Materials, p. 804.

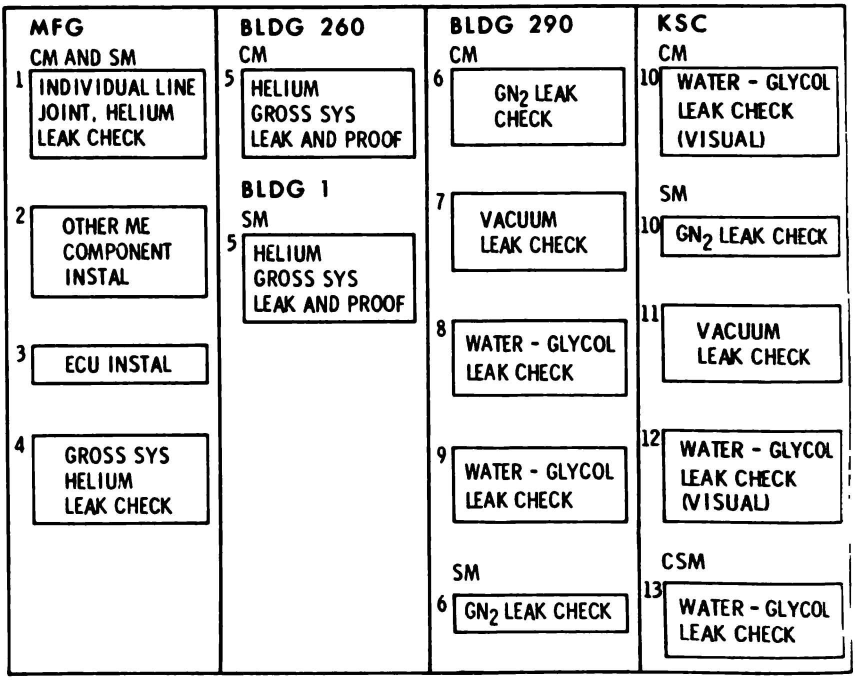

MFG
CM AND SM
1 INDIVIDUAL LINE JOINT, HELIUM LEAK CHECK
2 OTHER ME COMPONENT INSTAL
3 ECU INSTAL
4 GROSS SYS HELIUM LEAK CHECK
BLDG 260
CM
5 HELIUM GROSS SYS LEAK AND PROOF
BLDG 1
SM
5 HELIUM GROSS SYS LEAK AND PROOF
BLDG 290
CM
6 GN_2 LEAK CHECK
7 VACUUM LEAK CHECK
8 WATER - GLYCOL LEAK CHECK
9 WATER - GLYCOL LEAK CHECK
SM
6 GN_2 LEAK CHECK
KSC
CM
10 WATER - GLYCOL LEAK CHECK (VISUAL)
SM
10 GN_2 LEAK CHECK
11 VACUUM LEAK CHECK
12 WATER - GLYCOL LEAK CHECK (VISUAL)
CSM
13 WATER - GLYCOL LEAK CHECK

FIGURE 200

Section VI

ELECTRICAL SYSTEM

Since the AS–204 accident, a thorough review of the spacecraft electrical system has been completed. The review was conducted from two points of view. First, the Block I and Block II spacecraft were examined to determine if any of the components or subsystems represented possible ignition sources. Secondly, a group of specialists from industry and government reviewed the adequacy of the design of the Block II spacecraft electrical system and the adequacy of manufacturing, installation and testing practices. In these reviews a strong emphasis was placed on the elimination of potential ignition sources and on conformance to accepted practices and standards for wiring.

In general, it was found that the Block II spacecraft electrical system design is satisfactory and that the plan of implementation conforms to acceptable practices. Changes that will be made can be categorized into two areas: first, design changes and second, changes in implementation.

DESIGN

The design of the electrical system includes the use of fuses and circuit breakers to protect wiring and equipment from electrical overloads in case of short circuits or other failures. The circuit protection philosophy is that in case of an overload, the circuit breaker will operate and remove power before a wire can overheat and be a potential ignition source. As changes are made in circuits it is necessary to go back and make sure that the proper sized breaker has been used. A review of circuit breaker sizes and corresponding wire sizes for the Block II spacecraft has been completed. Necessary changes are being made to ensure compatibility with the design requirements.

A thorough study has been made to determine whether or not, during normal operation, a powered circuit must be connected or disconnected in the cabin. This review of hundreds of circuits in the Block II spacecraft has concluded that this is already a feature of the Block II spacecraft design and that no changes are required.

IMPLEMENTATION

The NASA/industry team of specialists paid particular attention to the methods used to fabricate, install and test electrical cables in the Block II spacecraft. They also examined the documentation required to control the process. In general, the specifications and practices were found to be acceptable but improvements are planned as discussed below.

Testing procedures have been reviewed to insure that wire received from manufacturing meets the specifications before it is built up into a wire bundle. In the receiving inspection procedures, the number of sampling tests has been increased and additional electrical tests of dielectric strength and insulation resistance are being made.

For the Block II spacecraft, three-dimensional jigs are used to fabricate the cables so that the finished bundles can be fitted into the spacecraft without stress or strain.

The Block II spacecraft design incorporates a number of significant improvements over the Block I spacecraft design in wire bundle routing and protection. For example, the umbilical which connects the Command Module to the Service Module was relocated and this decreased the number of wire bundles routed across the spacecraft floor. The construction of the lower equipment bay was also revised and this provides improved wire routing and easier access for equipment and connector installation. A protective cover protects the bundles on the floor of the Block II spacecraft.

The NASA/industry team suggested additional measures to protect wiring from abuse. More extensive support will be provided for the bundles and covers will be installed to protect wiring from damage during manufacture and test as well as in flight.

Finally, the number of inspections has been increased to insure that spacecraft wiring conforms to all criteria and that the workmanship is adequate. A Mandatory Inspection Point Plan for both the contractor and NASA is now in use. This plan requires a mandatory inspection of wiring at specified points in the manufacturing process before workmen can go on to the next step in spacecraft construction and test.

Inspections have also been accomplished of spacecraft already built and in the final stages of assembly so that any deficiencies in wiring can be corrected. These inspection procedures are now an integral part of our program.

SUMMARY

In summary, an ignition sources review and an overall review of the Block II spacecraft electrical system has been completed. No confirmed ignition sources have been found. However, evaluation is being made of the need for further testing of a few components which are not completely sealed from the cabin environment. All circuit breakers will conform to a sizing criteria to properly protect the wiring.

The improvements incorporated into the Block II spacecraft resulted in improved wire bundle fabrication techniques such as the use of three-dimensional jigs, improved wire bundle routing, and improved wire bundle protection. Additional changes have been made in the procedures and in wiring bundle protection to reduce the possibility of wire damage during installation or testing. Finally, mandatory inspections have been added to the work plan to ensure that all wiring meets rigid standards. These steps will provide increased assurance against the possibility of ignition of a fire from the spacecraft electrical system.

ADDITIONAL DATA

The following Technical Report discusses in detail the Apollo Spacecraft Electrical System and the reviews that have been made.

Electrical Systems (T)

NASA APOLLO PROGRAM WORKING PAPER NO. 1287

Manned Spacecraft Center, Houston, Tex.

April 7, 1967

REEVALUATION OF THE BLOCK II APOLLO SPACECRAFT ELECTRICAL SYSTEM

Summary

This report contains a summarization of the significant work of two reviews started as a result of the AS–204 incident.

The command module crew compartment ignition sources and contiguous nonmetallic materials study was to (1) ascertain whether any of the subsystems contained ignition sources that might have contributed to the AS–204 incident, and (2) to identify similar anomalies that might exist in the Block II spacecraft and document them for input to the overall spacecraft design review activity.

A design review of Apollo spacecraft, Block II, electrical power system and wiring, was conducted. The primary areas considered were the adequacy of the design to accomplish the specific objective of the Apollo program and the adequacy of practices and procedures utilized in manufacturing. Emphasis was placed on the elimination of potential fire ignition sources and conformance to accepted practices and standards.

The criteria utilized in the design of the Apollo spacecraft electrical system are generally in conformance with accepted practices and standards. Those areas of discrete deviations are being corrected.

Introduction

As a direct result of the AS–204 incident, two review groups were organized to investigate several discrete areas.

The first group, the Ignition Sources Review Group, was organized to investigate all subsystem components to determine the existence of potential ignition sources and their association with nonmetallic materials. The second group, a MSC-organized Government/Industry Review Group, was given the task of evaluating the electrical power system design, and the practices and procedures for the fabrication, installation, and protection of electrical wiring harnesses. A summary of both of these efforts is contained in this report.

Nomenclature

CM ---------------------- Command module of the Apollo spacecraft.
CSM ---------------------- Command and service modules of the Apollo spacecraft.
DAIP ---------------------- Diallyl phthalate.
DSKY ---------------------- Manual data insertion keyboard.
ECS ---------------------- Environmental control system.
ECU ---------------------- Environmental control unit.
EPS ---------------------- Electrical power system.
G&N ---------------------- Guidance and navigation.
H–film ---------------------- Fluorinated ethylene propylene coated polyimide tape.
IMU ---------------------- Inertial measurement unit.

74–521 O—67—pt. 7——11

NOMENCLATURE—Continued

LEB	Lower equipment bay of the command module, located at the crew's feet.
LHEB	Left-hand equipment bay of the command module, located to the left of the crew.
LHFEB	Left-hand forward equipment bay, located to the left and above the crew.
MDC	Main display and control.
RF	Radio frequency.
RHEB	Right-hand equipment bay of the command module, located to the right of the crew.
RTV	Room temperature vulcanizing.
SM	Service module of the Apollo spacecraft.
TFE	Polytetrafluoroethylene.
TV	Television.

IGNITION SOURCES REVIEW

All subsystems for Block I and Block II spacecraft were reviewed to determine the existence of potential ignition sources and their association with nonmetallic materials. The review was conducted by engineering personnel at MSC and at the North American plant at Downey, California.

The following categories of ignition sources were considered:

1. Corona discharge.
2. Electrical arcs or sparks from motor brushes, exposed relay contracts, switches, etc.
3. Overheating caused by circuit failures.
4. Overheating because of loss of cooling.
5. Overheating because of inadequate or improper lubrication.
6. Chemical sources.

In order for the components to be classified as possible ignition sources, an ignition source was defined as any component that can produce on arc or cause overheating of sufficient magnitude for ignition or flame to propagate outside the confines of the component. Specific examples are switches or circuit breakers, since they create arcs across their contacts during normal operation but, if adequately sealed, were not classified as ignition sources, since these arcs are confined and cannot propagate outside the enclosure.

Since the propagation of ignition or flame is directly related to the type of seal incorporated on a given enclosure, the following definitions were utilized:

1. *Hermetically sealed.*—An equipment or component is considered hermetically sealed if it is sealed, either by using a bonded-metal cover, or a gasketed cover (a molded-in-place elastomer gasket) which is designed to be capable of remaining pressurized or evacuated for the specific life of the equipment or component.

2. *Environmentally sealed.*—An equipment or component is considered environmentally sealed if it is not hermetically sealed but is potted, foamed, and/or conformally coated such that it will withstand the Apollo qualification environments, particularly with regard to the humidity and salt fog environments. This type of packaging generally breathes and is normally enclosed in a metal package.

Tabulated below are the specific equipment or components in the subsystems that were determined to be probable ignition sources. In no cases were ignition sources found to occur during the normal mode of operation, that is, a malfunction must occur to create a potential ignition source.

BLOCK I

Electrical power subsystem.—The following components of the electrical power subsystem are considered possible sources of ignition under a failure condition: (1) general usage connectors, (2) special purpose connectors, (3) modular terminal boards, and (4) electrical wiring.

These possible sources are generally generated by procedural and human error problems such as broken wires, damaged insulation, bent connector pins, and damaged or lack of conformal coating on terminal boards. Evaluation of the detailed data in the study revealed that there were several cases on Spacecraft 012 where apparent incompatibilities existed between circuit breaker and wire sise. The basic ignition-source study covered an analysis of each of these cases and evaluation of these analyses reveals that they conformed to good engineering practice.

The cable assemblies were considered since breakage or abrasion could provide a source of ignition in that some harnesses are in direct contact with nonmetallic materials.

Displays and controls subsystem.—The following components of the displays and controls subsystem are considered possible sources of ignition under a failure condition: (1) MDC panels (wiring and terminal strips), and (2) lower equipment bay panels (wiring and terminal strips).

Excessive handling and human error problems associated with these components can lead to damage of wiring and conformally coated terminal strips. This damage could, in turn, lead to an arcing or shorting failure mode.

The waste management system blower is considered suspect because failures of a shorting or arcing nature within the blower motor have been experienced during the program.

Guidance and navigation subsystems.—The following components of this subsystem are considered possible ignition sources under a failure condition: (1) DSKY electroluminescent panels, (2) G&N harness, (3) IMU control panel switches, and (4) Eyepiece heaters.

A failure of the sealing for the electroluminescent lights on the DSKY panel could allow moisture to provide a shorting path for 250 volts used to excite the luminescent material. These seals did experience failure in qualification testing during low-temperature storage.

The IMU control panel pushbutton lighted switches which contain bulbs do not constitute a hermetically or environmentally sealed device. Cracked bulbs or poor contact due to corrosion are possible ignition sources.

The eyepieces contain resistance heaters which operate at 28 volts and 0.1 amp. These eyepieces are subject to much handling before, and during, flight, and are, therefore, subject to a greater probability of damage than fixed electrical components. Such damage could result in arcing or shorting.

Caution and warning subsystem.—The elapsed time indicator in this subsystem is considered a possible ignition source under a failure condition.

This device is removed prior to flight and is, therefore, a potential ignition source only during ground operations. The Block I program has experienced one problem with this indicator on Spacecraft 014 during checkout at Downey that could have caused it to be an ignition source. Smoke was observed in this particular case when a spike suppression capacitor overheated.

Environmental control subsystem.—The following components of this subsystem are considered possible ignition sources under a failure condition; glycol evaporator back pressure controller, and waste management system blower.

The glycol evaporator back pressure controller was considered as a potential source only in that there is some probability that overheating of the controller under an internal failure condition could ignite the encapsulating material. It is not known whether such a condition could result in ignition of the insulation, so it must be classified as suspect.

There is also a general concern with regards to potential ignition sources because if failure of the cooling system should be lost, electrical components could overheat. Whether or not ignition temperatures of adjacent nonmetallics could be attained is not known.

Stabilization control subsystem.—The following components of this subsystem are considered possible ignition sources under a failure condition: (1) Rotational control, and (2) Velocity change indicator (delta V).

These two components of the stabilization control subsystem contain nonhermetically sealed switches. If a failure occurs in the arc-suppression diodes, a short-to-ground could cause arcing of the contacts.

Spacecraft communications subsystem.—The following components of this subsystem are considered possible ignition sources under a failure condition: (1) RF connectors, (2) Overheating of equipment due to loss of cooling, (3) Elapsed time indicators (see caution and warning subsystem), and (4) High-density connectors.

Arcing of RF connectors and pin-to-pin shorting of the high-density connectors are potential ignition sources under a failure condition.

Television subsystem.—The following components of the television subsystem are considered possible ignition sources under a failure (procedural) condition: television bulkhead connectors and cable assemblies.

If the TV power switch is left in the "on" position during connection or disconnection of the TV power cable, arcing could occur, thereby providing an ignition source.

Subsystems containing no probable ignition sources.—Based on this evaluation utilizing the established ground rules, the following subsystems are considered nonsuspect from a probable ignition source standpoint: (1) Sequential events controller, (2) Mission control programer, (3) Crew communications, (4) Instrumentation, (5) Experiments and scientific equipment defined for Block I, and (6) Crew equipment.

BLOCK II

Fourteen Block II components are considered to be possible ignition sources under failure conditions. This is seven fewer components than were listed in the Block I subsystems. The reduction in number is due in all cases to either one of two conditions:

1. The Block I component is not used in Block II.
2. The Block II components have been redesigned to eliminate the problem that existed in the Block I component. In many cases nonhermetically sealed components in Block I had been previously redesigned to incorporate hermetic seals due to concern over moisture penetration.

The following list by subsystem of the Block II components are considered possible ignition sources under failure conditions. The reasons for their being suspect can be found under the previous Block I sybsystem discussion of the component in question, since the reasons apply identically to these Block I and Block II components.

Electrical power subsystems.—(1) General usage connectors, (2) Special purpose connectors, (3) Modular terminal boards, and (4) Electrical wiring.

Displays and controls subsystem.—MDC and LEB panels (wiring and terminal strips).

Environmental control subsystem.—(1) Glycol evaporator back pressure controller, (2) Cable assemblies, and (3) Overheating of equipment due to loss of cooling.

Guidance and navigation subsystem.—(1) G&N interconnecting harness, and (2) Eyepiece heaters.

Stabilization control subsystem.—Rotational control.

Spacecraft communication subsystem.—RF connectors.

Television subsystem.—Television bulkhead connectors and cable assemblies.

Subsystems containing no probable ignition sources.—Based on this evaluation utilizing the established ground rules, the following subsystems are considered nonsuspect from a probable ignition source standpoint: (1) Sequential events controller, (2) Mission control programer, (3) Crew communications, (4) Instrumentation, (5) Experiments and scientific equipment defined for Block II, and (6) Crew equipment.

Block II command module subsystem review.—In this review it was found that such conventional nonmetallic materials as silicone rubber, nylon, epoxy, RTV, etc., which will burn in an oxygen atmosphere were being used in areas contiguous to possible ignition sources of the following subsystems: (1) Electrical power; (2) displays and controls; (3) environmental control; (4) guidance and navigation; (5) stabilization and control; and (6) communications.

The use of any nonmetallic materials in the command module is undergoing intense review, and measures are being taken to essentially eliminate to the maximum extent possible, all such materials which may be flammable in the spacecraft environment. Substitute materials must be able to meet the requirements of upgraded Nonmetallic Materials Selection Criteria (refer to NASA Apollo Program Working Paper No. 1232, Spacecraft Materials) which provide for stringent control on the flammability characteristics and application of all such materials. Requirements for nonmetallic materials in proximity to possible ignition sources of the above listed subsystems will be met with suitable substitutes of nonflammable materials.

STATIC ELECTRICITY

After completion of the basic ignition sources review, it was realized that a potential problem might exist in the form of static electrical discharges.

The static electrical charge can occur when two materials are rubbed together. The amount of static charge attained is dependent on the type of material, the length of time the materials are rubbed together, the capability of the material to hold a static charge, and the relative humidity.

The problem does not affect the subsystem hardware since protection against this static discharge is adequately provided by electrically bonding all equipments, including the crew couches, to the spacecraft structure. There is, however, a possibility of this static charge buildup occurring in the multilayer construction of the space suit. This condition is currently being investigated to determine the probability of this occurrence, the magnitude, and the methods of eliminating the static charge, if required.

CONNECTION AND DISCONNECTION OF ELECTRICAL CONNECTORS

Another potential ignition source could exist due to the necessity to connect and disconnect electrical connectors from various equipment during the mission. It is possible to create an arc if a connector is disconnected while supplying power to the equipment. The outlets for power to TV camera, scientific equipment, and crew personal equipment are all provided with on-off switches, but do not preclude the possibility of inadvertent disconnect while power is still on. A definite set of procedures must be implemented, and the importance of switching power off prior to disconnection of equipment must be emphasized.

CHEMICAL SOURCES

The potential problem of a spill of water-glycol solution and its relation to electrical wiring and connectors as a potential ignition source is being evaluated and is being treated in another report.

Another potential chemical ignition source is the electrolyte contained in the five batteries located in the spacecraft crew compartment. The electrolyte is highly corrosive but is required in the chemical reaction that takes place to generate electricity. The electrolyte is sealed in individual cells and these cells are sealed in a fiber glass battery case. Each individual cell is vented by a pressure relief valve to prevent the buildup of a pressure that could result in cell damage. It is considered that adequate protection has been provided to eliminate the battery electrolyte as a potential ignition.

EXPLOSION-PROOF TESTING

Explosion-proof testing is not normally required of devices that are hermetically sealed since no hazardous gases can be ingested into the enclosure.

However, MSC is presently engaged in an investigation to examine the necessity of explosion-proof testing of power-switching devices within the command module crew compartment.

CONCLUSIONS AND RECOMMENDATIONS

The Ignition Source Review Group has examined all components contained within the interior of the Block I and Block II command modules. Careful evaluation was made of those components having any possible source of ignition. Except for those items discussed in the preceding summary of ignition sources, all others were eliminated from consideration because (1) they contained no potential ignition source, or (2) the nature of the component packaging technique permitted their exclusion due to self-containment of any ignition sources within the component.

All areas considered by the Review Group to be potential problems contained a source of electrical or RF energy. It follows that the conclusions and recommendations relate to such components.

1. Conclusions from this study indicate that the circuits in Block II vehicles require further analysis relative to adequacy of circuit protection.

Follow-up action.—A complete review is in progress of all Block II command module wiring and protective devices and will provide an analysis of the compatibility of wire size to protective device. If necessary, where data are not available, tests are being performed to verify the adequacy of circuit protection. Further, the change procedures are being reviewed to assure their adequacy with regard to circuit protection when spacecraft wiring is affected by a change.

2. Since the interior of the command module contains wire harnesses, terminal boards, etc., that are susceptible to damage incident to installation, maintenance, and general traffic, it is necessary to provide adequate physical protection to such items.

Follow-up action.—A complete review and an evaluation of the Block II command module interior are being undertaken with regard to physical protection of electrical wires and harnesses, adequacy of conformal coating and potting, and provision of further protection where required.

3. Historically there have been problems associated with the handling of electrical and RF connectors. It is logical to assume that some problems will persist for Block II vehicles.

Follow-up action.—All installation, checkout, and handling procedures will be reviewed to assure the continued high integrity of these devices. Inspection procedures have been reviewed to assure that mandatory inspections are required, especially for connectors located in difficult-to-install positions.

4. The stabilization and control system rotational controller qualification testing was done at less than the operating load. Components of the controller were tested at full operating load.

Follow-up action.—The certification test requirements for Block II equipment will be reviewed to assure that all items will be tested under the electrical loads representative of actual spacecraft operation.

5. The stabilization control subsystem rotational controller utilizes hermetically sealed switches in its design implementation. During the qualification test program, a degradation of the hermetic seal on these controllers has been noticed.

Follow-up action.—MSC is presently investigating the need for retaining the hermetic-seal feature in this switch as opposed to hermetically sealing the entire controller.

6. A certain amount of engineering judgment was used in not classifying certain components as ignition sources. It is desirable that some testing be performed to validate these decisions. A review of failures, of a shorting or arcing nature, shows that in all cases where packaged components are involved, the anomaly did not propagate outside of the package.

Follow-up action.—Tests on representative components that are hermetically sealed, environmentally sealed or structurally isolated should be conducted. These tests should be conducted with an intentionally introduced partial short in the component, exposed to the proper spacecraft environment, and a combustible material adjacent to the container. Such tests would simulate conditions postulated in the criteria established for this review.

Design Review of Apollo Spacecraft, Block II, Electrical Power System and Wiring

Subsequent to the incident on Spacecraft 012, MSC organized a Government/Industry Review Group to critique the Block II spacecraft electrical power system and wiring. The primary areas considered were the adequacy of the design to accomplish the specific objective of the Apollo program, and the adequacy of practices and procedures utilized in manufacturing. Emphasis was placed on the elimination of potential fire ignition sources and conformance to accepted practices and standards. The review participants included representatives from five aerospace companies and two government agencies: the FAA and NASA (Marshall Space Flight Center and the Manned Spacecraft Center).

As most of the review participants were not associated with the Apollo program, a series of technical briefings and facility inspection tours were executed as an expedient to aid in familiarization with: (1) System requirements; (2) system design philosophy; (3) system operational modes and characteristics; (4) components selection criteria; (5) component characteristics; (6) specific practices and procedures; and (7) repetitive problem areas.

Subsequent to the familiarization briefings and tours, the review effort was subdivided into two groups: Design, and Practices and Procedures. To implement these tasks, all pertinent North American Aviation and NASA documentation was made available.

The significant findings of this review group are reflected in this report.

Circuit Protection

The command and service modules use several types of circuit protectors. The protectors fall into the following categories: (1) Circuit breakers, (2) Fuses, and (3) Reverse current and over-current sensing device.

The philosophy for circuit protection is primarily to prevent wires from over-heating and creating a fire. With proper sizing of the circuit protectors, the type of circuit protection used will perform this function. For any faults in equipment, the danger of a resulting fire by over-heated power wires is minimized. It should be noted that any type of circuit protection will allow arcing, as there is a finite interval of time required for the circuit protector to respond to the overload and open the circuit. During this period of time, depending on the resistance of the fault and line, considerable energy can be dissipated in the form of heat. In an oxygen atmosphere, any type of insulation or metal raised to a high enough temperature becomes a fuel. When the circuit protector opens, and the source of heat is removed, the fire should be extinguished, since Teflon wire insulation, copper, nickel, etc., will not support combustion. This philosophy assumes that there are no materials in contact with the harness which will support combustion.

To arrive at a suitable circuit protector to prevent wire damage requires knowledge of the wire's performance under various electrical loads, including those sufficient to fail the insulation. The wire data used in the Apollo program were provided mainly by another program (B–70) on a similar wire. Although these data were generated at higher ambient temperatures, the data are considered applicable by similarity. The ambient temperature for most of the testing was at 150° F. and the time for failure versus load data was obtained at ambient conditions of 530° F. and 0.1 pound per square inch absolute air. Figure 201 is a chart utilized to select circuit breakers and wire-size combinations for a given load current. The figure is a compilation of data that takes into consideration circuit breaker response time to overloads and the wire capability to withstand overloads without insulation degradation. Circuit protection sized to these data should adequately protect the wire. From a total of 228 circuit breakers, 153 breakers were checked with respect to wire size.

From this study, 20 breakers were identified as being incorrectly sized according to the criteria established. These breakers are shown in table 24. North American Aviation has been directed to make an analysis of all circuit breakers/wire in the spacecraft. Their analysis must be made using data on the specific wire utilized in Block II. The results of this analysis will determine what additional changes to circuit breakers or wires will be necessary.

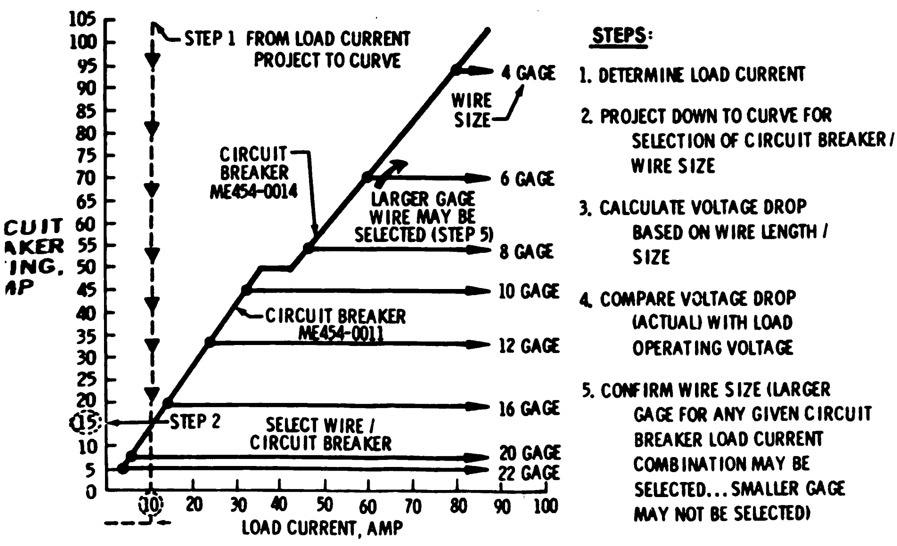


FIGURE 201

TABLE 24.—*Circuit breaker—wire compatibility*

Panel reference designation	Description	Circuit breaker rating present	Wire gage	Wire time to failure at 200 percent C/B load, sec.[1]
C14A7-CB7	Flight and postlanding battery bus A	25	20	9.0
C14A7-CB8	Flight and postlanding battery bus B	25	20	9.0
C14A7-CB13	Flight and postlanding battery C	25	20	9.0
C14A7-CB9	Main A battery bus A	80	12	11.0
C14A7-CB10	Main B battery bus B	80	12	11.0
C14A7-CB11	Main A battery C	80	12	11.0
C14A16-CB22	Battery C power entry (postlanding)	100	8	
C14A16-CB20	Battery A power entry (postlanding)	100	8	
C14A16-CB21	Battery B power (postlanding)	100	8	
C14A16-CB19	Battery B to pyro bus tie	20	20	11.0
C14A16-CB18	Battery A to pyro bus tie	20	20	11.0
C15-2A205-CB66	LM power main B	15	20	3.4
C15-2A205-CB12	Battery relay bus A	20	20	11.0
C15-2A205-CB13	Battery relay bus B	20	20	11.0
C15-2A208-CB4	Logic B battery B	15	22	3.4
C15-2A208-CB3	Logic B battery A	15	22	3.4
C15-4A403-CB7	Fuel cell 1 bus cont	10	22	38.0
C15-4A403-CB9	Fuel cell 3 bus cont	10	20	
C15-4A403-CB8	Fuel cell 2 bus cont	10	20	
C15-2A205-CB23	Spacecraft 1 equipment non-essential 1	20	22	5.5
C15-2A205-CB53	C/W main B	10	22	38.0
C15-2A205-CB52	C/W main A	10	22	38.0

[1] Data based on 530° F. and 0.104 pounds per square inch absolute air conditions.

CIRCUIT BREAKERS AND FUSES

Circuit breakers used in the command module for both Blocks I and II utilize thermal elements; their trip characteristics are dependent on the ambient temperature. The circuit breakers are environmentally sealed and have been qualified for the Apollo environments. Fuses are used in the Apollo Spacecraft primarily in instrumentation circuits to protect equipment from electrical overload. There are also fuse resistors used to protect ordnance circuits from faults developing after initiator firing. Both of these devices were flown and operated satisfactorily on Spacecraft 009 and Spacecraft 011.

OVER-CURRENT—POWER SWITCH

These switches are used to place individual fuel cells on the dc power-distribution busses. The switches contain circuitry to sense overload or reverse current conditions which will automatically disconnect the fuel cells from the bus. The units are located in the service module, and can be turned on or off with toggle switches in the command module.

SELECTION OF WIRE

The wiring for manned spacecraft has progressed through several evolutionary phases. The basic requirement of soundness, both electrically and mechanically, has consistently been imposed. Due to the ever-present desire for volume and weight reductions, a continuous search has been made to find a better wire with less penalties.

The Mercury Spacecraft used a polyolefin insulated conductor as its basic wiring. This same wire construction was proposed for use on the Gemini Spacecraft. Tests conducted at MSC, in 1963, showed that this type of insulation supports combustion in an oxygen atmosphere. The use of this wiring was discontinued in the pressurized area of the Gemini Spacecraft. In its place, the Gemini Spacecraft used a wire whose insulation, TFE Teflon, will not support combustion.

The TFE Teflon-insulated wire is used on the Block I command and service modules of the Apollo Spacecraft. To achieve a volume and an appreciable weight savings, approximately 400 pounds on each spacecraft, the Block II command and service modules use a thin-wall TFE Teflon, polyimide-coated insulated wire. Figures 202, 203, and 204 give a comparison between the Block I and Block II wire characteristics and construction.

CHARACTERISTIC	BLOCK I WIRE	BLOCK II WIRE
1. CONDUCTOR	NICKEL-PLATED COPPER	NICKEL-PLATED COPPER
2. INSULATION	9 MIL NOMINAL EXTRUDED TFE TEFLON	6 MIL NOMINAL - 4 MIL MINIMUM; EXTRUDED TFE TEFLON, 1/4 MIL MINIMUM; POLYIMIDE ABRASION PROTECTION COATING
3. DIELECTRIC	5400 V - NOMINAL	4850 V - NOMINAL 3650 V - MINIMUM
4. TFE IGNITION TEMPERATURE	1250° F (WILL NOT SUPPORT COMBUSTION)	1250° F (WILL NOT SUPPORT COMBUSTION)
5. CUT THROUGH	APPROXIMATELY SAME	APPROXIMATELY SAME
6. WEIGHT	1650 LB	1200 LB

FIGURE 202

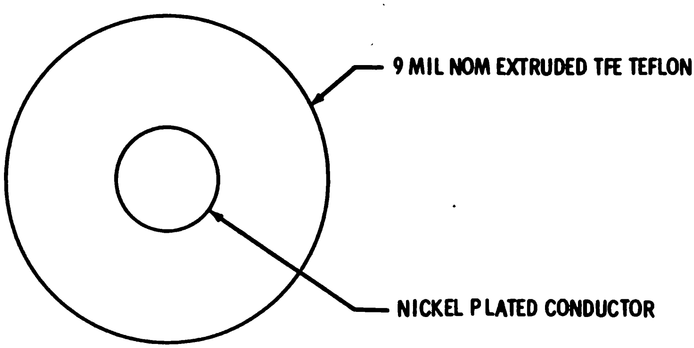


FIGURE 203

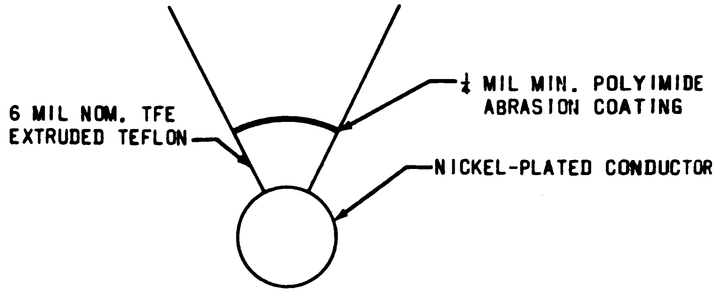


FIGURE 204

In order to aid in the selection of the Block II wire insulation, the results of a number of tests were considered. An overall study was initiated which investigated the characteristics of 16 different wire insulation constructions. Some additional flammability tests were also conducted on several of the available lightweight insulations. The results of these tests indicate the decision to use thin-wall TFE Teflon, polyimide-coated insulated wire is technically valid. This wire possesses all of the mechanical and electrical properties necessary to satisfy the spacecraft requirements. It should be noted that no single wire construction is best under all operating conditions. Rather, an engineering compromise must be made on the basis of anticipated operating conditions and known performance characteristics of various thin-wall wire constructions.

HARNESS FABRICATION

There is considerable improvement over the Block I fabrication techniques being used on Block II. The fabrication techniques eliminate many connections and much wirework inside the spacecraft. Wiring is handled as a bundle and results in much less chance of having potential ignition sources due to broken wires or bad connections.

Figure 205 illustrates a typical flow of wire from the time of receipt until the finished harnesses are installed in the spacecraft.

The fabrication of the main crew compartment harness for a Block II spacecraft is started on a two-dimensional tooling board. The assembly is then installed in a mockup spacecraft, shaped, and the wire is cut to length. The harness is then removed from the mockup spacecraft and installed on a three-dimensional tooling board (figs. 206 and 207). All other work prior to installation in the spacecraft, such as the attachment of connectors and terminal boards, and a continuity and insulation integrity test, is accomplished on this three-dimensional tooling board. After installation in the spacecraft, the main crew compartment harness is again similarly checked to determine if any damage was incurred during installation.

Harnesses, other than the main crew compartment harness, are fabricated on a two-dimensional tooling board (fig. 208). A continuity and insulation integrity test is performed after fabrication and again after installation in the spacecraft.

ROUTING AND PHYSICAL PROTECTION

A number of significant improvements were incorporated into the Block II spacecraft. The relocation of the command module-service module electrical um-

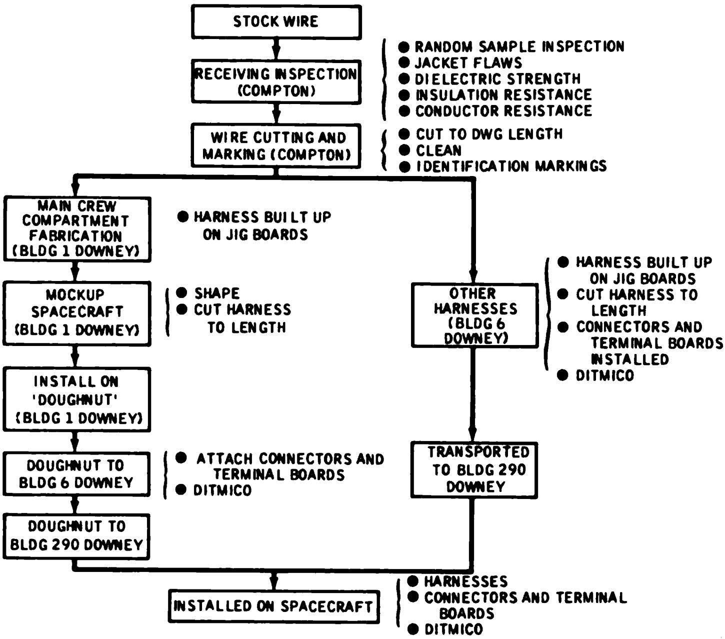


FIGURE 205

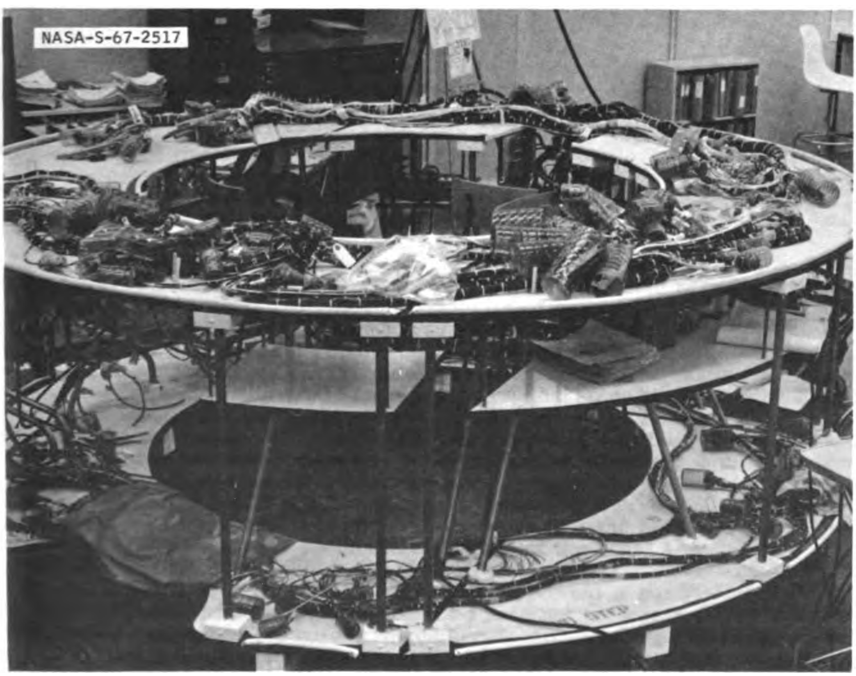


FIGURE 206

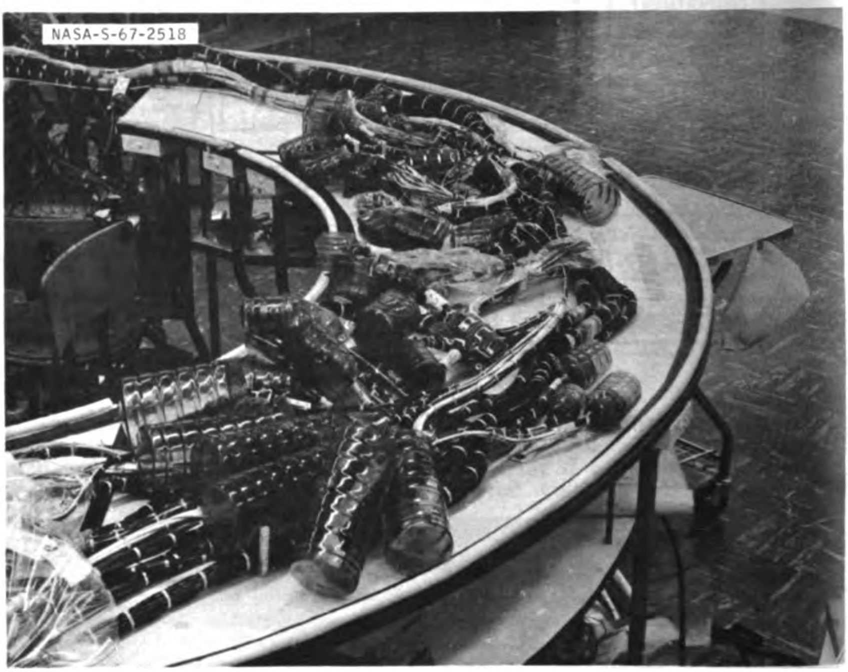


FIGURE 207

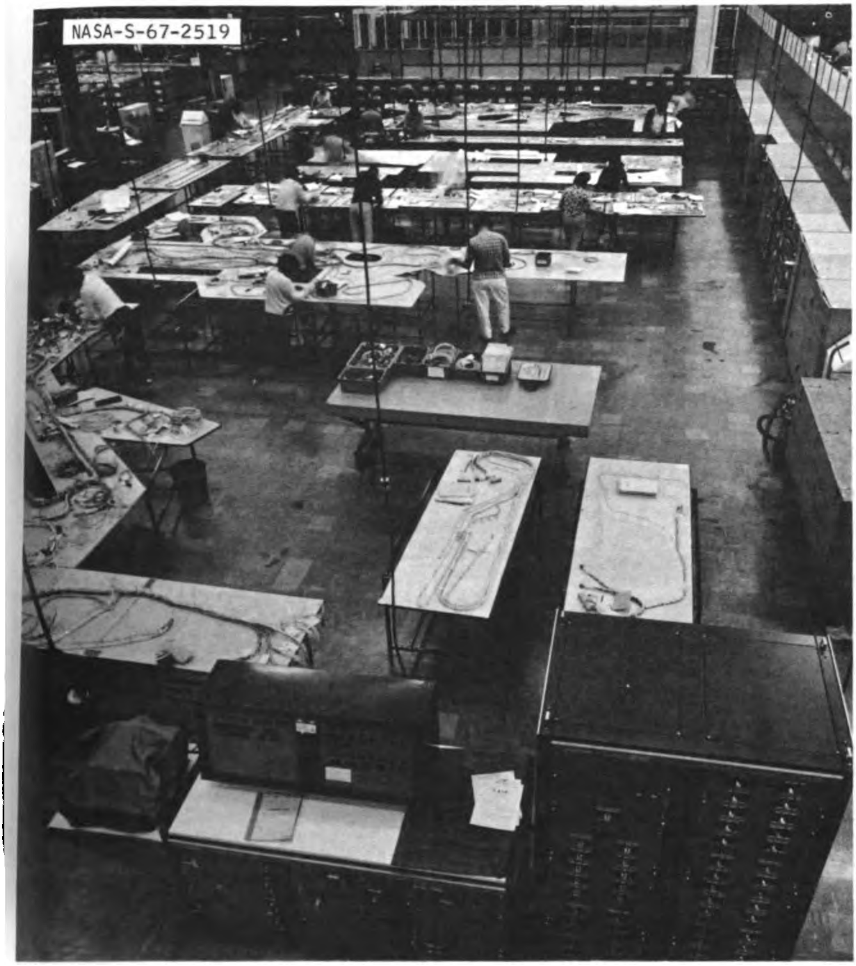


FIGURE 208

bilical allowed a reduction in the number of harnesses routed across the spacecraft floor. This greatly reduced the possibility of wire damage during normal installation and checkout of spacecraft equipment. The construction of the lower equipment bay was revised which eliminated routing of wires through narrow channels and many 90° bends. Another improvement has been the incorporation of connectors on the inverters in place of the terminal studs as used on the Block I units. Relocation of the battery circuit-breaker panel has improved wire routing and also allows for pyro-battery replacement without disturbing wire harnesses. Figure 209 shows a typical Block II spacecraft lower equipment bay wiring.

Although the Block II wire routing is an improvement over Block I, other improvements being made include a means to prevent the harnesses from contacting the floor because of the abrasive texture of the floor. Also, metallic protective covers are being installed over the harnesses.

Some of the floor clamps will be enlarged to prevent a possible gradual deformation of the insulation due to localized external pressures. In other areas in the spacecraft where the wire is routed across corners, chafe guards have been added to preclude localized damage. Materials used as spacers and cushions in some harness clamps are silicone rubber, which is a combustible material. The replacement of these materials with noncombustible types is under investigation.

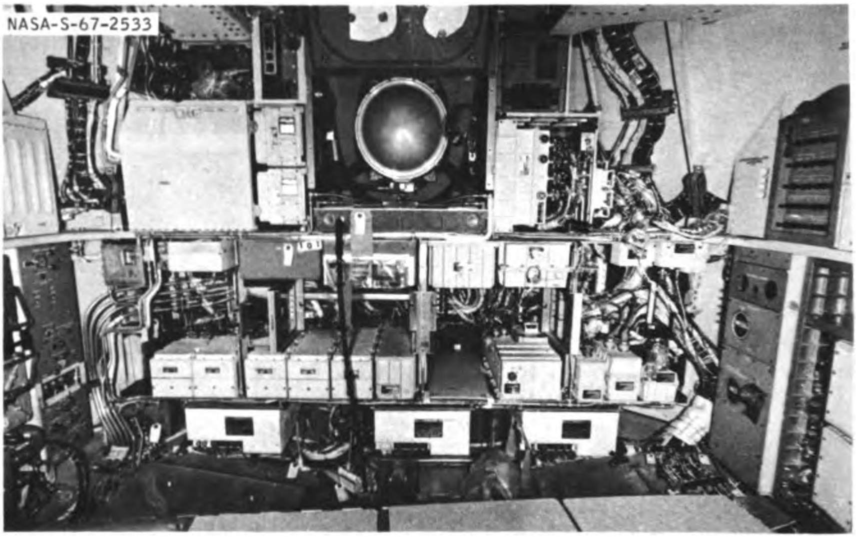


Figure 209

Section VII

Fire Extinguishment

NASA APOLLO PROGRAM WORKING PAPER NO. 1257

Manned Spacecraft Center, Houston, Tex.

April 5, 1967

Summary

A test program has been established to evaluate various fire extinguishing agents and extinguisher concepts for combating fires in the pure oxygen atmosphere of a spacecraft. Of the extinguishing agents tested, water or a water-base gel or foam appears to be the most feasible agents for use in a spacecraft. Testing will continue on these agents.

The testing of fire extinguishing concepts has been narrowed to manually operated portable extinguishers. Tests have indicated that a portable system can put out fires in a spacecraft with good reliability and, therefore, an extinguishing system will be incorporated on all manned flights. Current testing results indicate the system will be hose/nozzle connection into the spacecraft water supply, but development will continue with aerosol containers and aqueous gel blankets.

Introduction

To minimize the hazard of fires in the Apollo spacecraft, a program was approved on August 19, 1966, to develop a fire extinguisher for combating fires in the pure oxygen atmosphere. The program was accelerated after the Spacecraft 012 accident. A major step in preventing fires has been the judicious replacement of flammable materials. But, for the combustible items that are necessarily still present in the new materials selection, a fire extinguishing capability is required.

Over 90 boilerplate fire tests have been conducted to date in conjunction with this test program. This report will not attempt to discuss each test but rather will discuss the significant results of the test program to date.

Description of Test Apparatus

An Apollo boilerplate was selected as a combustion chamber for full-scale testing to evaluate various fire extinguishers and extinguishing agents for use in manned spacecraft. The test fuel selected for evaluating agents was a square foot of foamed polyurethane, two inches thick. This open cell material was ignited at one corner by a piece of electrically-heated Nichrome wire. Although this fuel is not considered typical of spacecraft material, it was felt to afford a "worst case" condition such that any agent that could deal with a polyurethane fire should be adequate for use on less flammable materials. Three 2-inch cubes of the same polyurethane were placed at a gap of 2 inches from the large piece of foam. This fuel configuration would demonstrate any "fire spread" caused by the extinguishing agent.

The Apollo boilerplate test chamber has an interior volume of approximately 90 cubic feet. A four-inch flange was installed on the boilerplate to allow connection to a 50-cubic-foot-per-minute vacuum pump. Connections for adding gaseous oxygen, sampling of the atmosphere, and venting to equalize pressure was also provided. Instrumentation in the boilerplate includes (1) thermocouples placed at selected locations, (2) internal pressure sensor, and (3) two motion picture cameras containing 16-mm color film. Still photography was also obtained by taking shots through a port located on the boilerplate hatch.

Figure 210 shows the exterior equipment and the boilerplate as used for most of the extinguishment tests.

Test Procedures

To evaluate all candidate fire extinguishing agents, a test criterion of "extinguishing effectiveness only" was established. After effective agents were found, they were later evaluated for weight, toxicity, ease of application, causing loss of visibility, etc. To first evaluate the candidates, a standardized procedure was established. The only variable in each test was the extinguishing agent's composition and weight; the following items were constant for each test:

1. Fuel composition and dimension.
2. Ignition source and location.
3. Time from ignition to agent application.
4. Initial atmospheric pressure, temperature, and content.
5. Test chamber volume.
6. Extinguisher nozzle location.

A typical test includes a pump-down to 0.1 or 0.2 pounds per square inch, followed by backfilling with bottled aviation breathing grade oxygen to 5 pounds per square inch absolute; a gas sample is then taken. Recorders, lights, and cameras are then turned on. After ten seconds. the ignition switch is closed and the fuel ignited. The fire is allowed to burn undisturbed for 10 seconds and then the extinguishing system is actuated. No additional oxygen is pumped in during the test. Several still photographs are made through the view port as the test progresses. When the fire is out, whether by fuel exhaustion or effective extinguishment, cameras are stopped and another gas sample is taken. The system is vented to atmospheric pressure and the hatch is opened. After the cabin atmosphere clears, additional photographic coverage is made. Documentation is supplemented by measuring certain events by stopwatch and weighing extinguishers before and after test.

The extinguishing agents that have been tested include gases, solids, and liquids. The gaseous extinguishing agents were tested in one of the following ways:

1. Using commercially available portable fire extinguishers.
2. Using storage bottles with two nozzles.
3. Using three tubular, large-diameter rings that had a total of 2,300 openings to give a uniformly diffused flow.

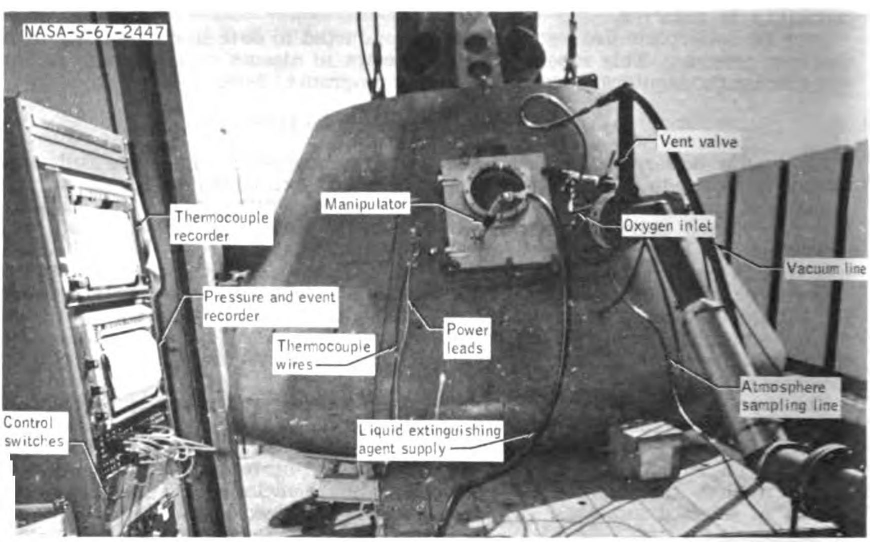


FIGURE 210

The two solids that were tested were sodium bicarbonate (dry chemical) and potassium bicarbonate (purple K). They were applied from commercial extinguishers which contained a nominal agent weight of 2½ pounds. Pressurized carbon dioxide provided the driving force. Figure 211 shows the Apollo boilerplate interior before a test with a pair of the manually operated, portable extinguishers.

The liquid agents were tested with single and dual nozzles involving various flow rates and spray patterns. In later tests of evaluating different hose/nozzle systems, the atmosphere was varied in starting pressure. Pure oxygen at 1.7, 3.5, 5.0, 7.0, 10.0, and 14.7 pounds per square inch absolute was used. Dilution of the oxygen with helium and with nitrogen was included to note effects on burning rates and extinguishment. Procedures varied slightly according to the situation, but, in general, the only changes in these tests were to eliminate the preburn time in some cases and to use a manual manipulator in others. The agent (water) was applied in various ways. Rigidly mounted nozzles, varying in number from one to six, were used; a tubular ring system was used which consisted of a lower 5-foot diameter ring, an 8-foot center ring, and a 3-foot upper ring to give a uniform spray throughout the chamber. A single nozzle was also used with a manipulator system. Several nozzle designs were used to achieve different flow rates. The manipulator controlled the nozzle location from the outside of the boilerplate. It consisted of a rigid control rod passing in a vacuum feed-through socket, as shown in figure 212. A later manipulator was made from tubing and allowed a more flexible internal fluid discharge (see fig. 213).

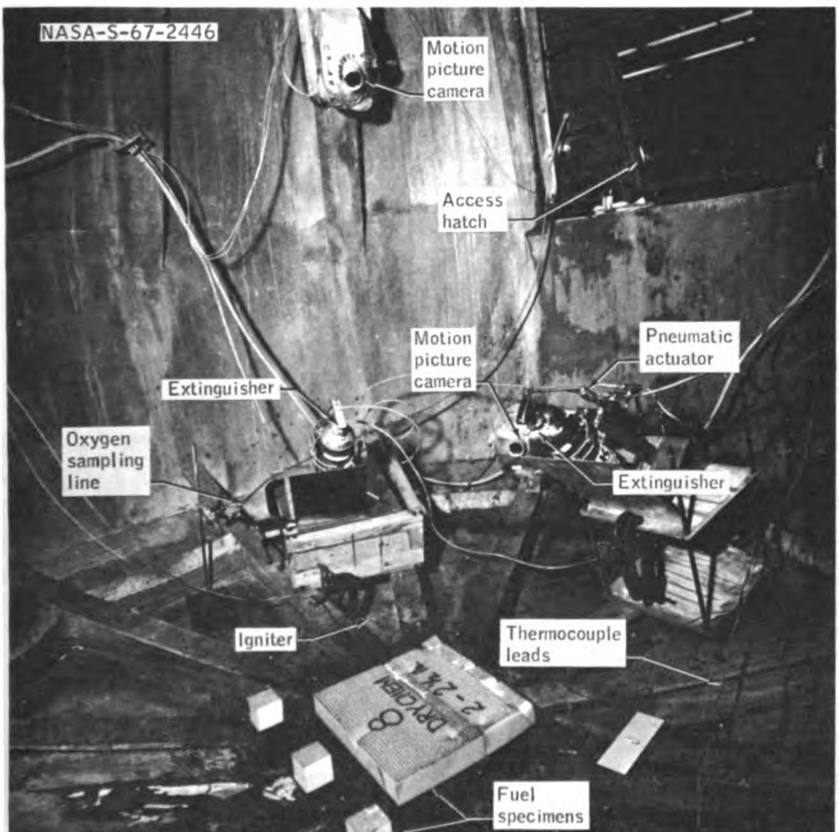


FIGURE 211

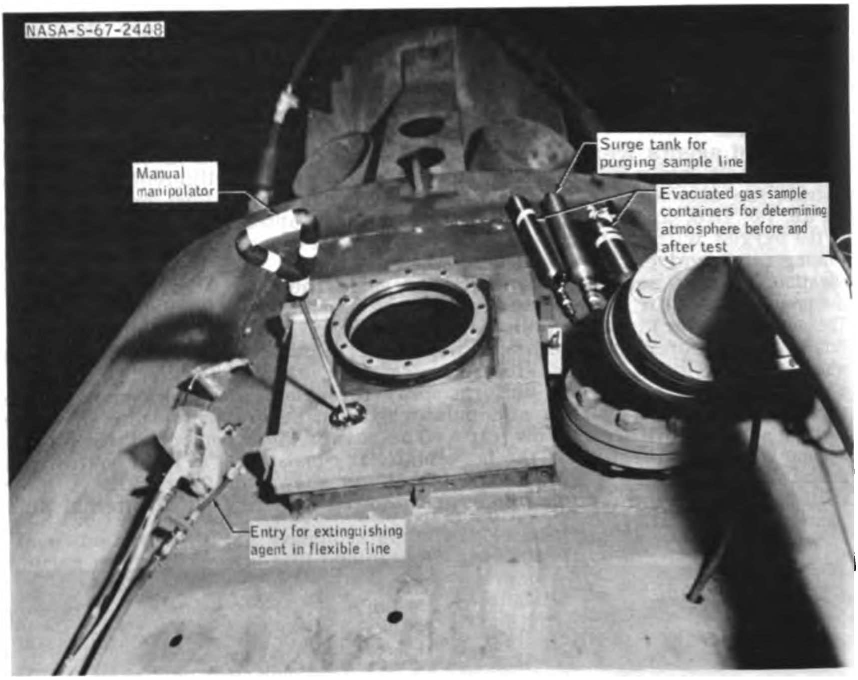


FIGURE 212

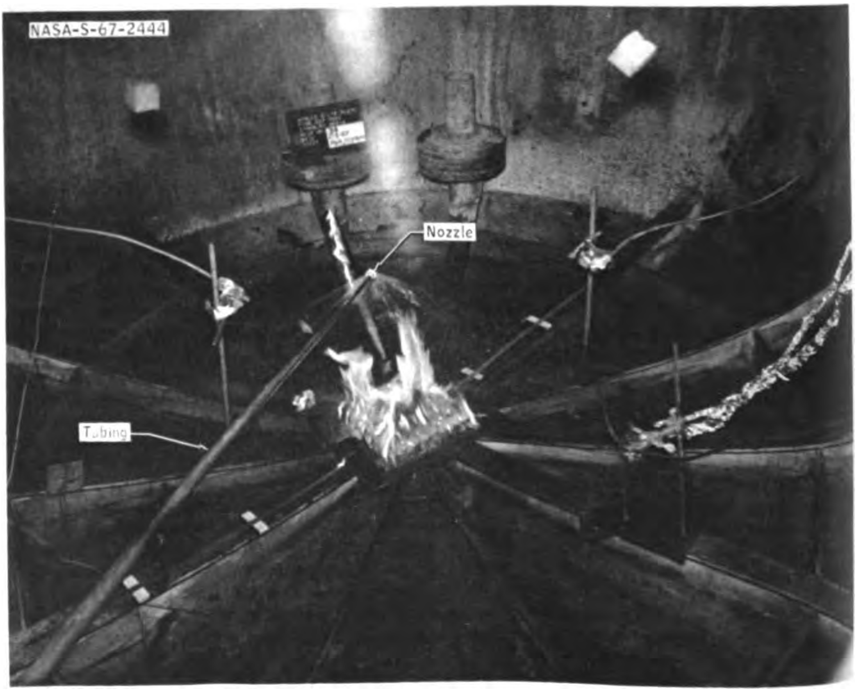


FIGURE 213

RESULTS AND DISCUSSION

PRELIMINARY SCREENING TESTS

The major emphasis on the first part of the test program was the evaluation of extinguishing agents. Most of the feasible, commercially available extinguishing agents have been tested, and the basic results of some of these are shown in table 25. The tested agents include gases, solids, and liquids. None of the gas agents tested extinguished the test fires, but rather they caused enough turbulence to increase the burning rate in pure oxygen or to spread the fire. The solids (powders) that were tested showed no significant effects on the test fires.

TABLE 25.—*Candidate fire extinguishing agents tested*

Agent	Form	Conclusions		Remarks
		Effective	Not effective	
Water	Liquid	X		
Aqueous gel [1]	do	X		On open flame, considered more effective only at high cabin pressures.
Water with surfactant [2]	do	X		Not superior to water.
Fluorocarbon fluid	do		X	Supported combustion.
Bromotrifluoromethane	Gas		X	Increased burning rate.
Helium	do		X	Do.
Nitrogen	do		X	Do.
Argon	do		X	Do.
Carbon dioxide	do		X	Do.
Sodium bicarbonate	Solid		X	No significant effect on fire.
Potassium bicarbonate	do		X	Do.

[1] 0.25 percent solution of water soluble polymer (gelling agent) with measured viscosity of 300 to 350 centistokes.
[2] Reduces surface tension.

Some of the liquids that have been tested actually supported combustion when used in a pure oxygen environment. Of the effective extinguishing liquids tested, water and aqueous gel agents appeared to extinguish the test fires equally well at cabin pressures of 5 or 6 pounds per square inch absolute, although the aqueous gel proved the more efficient on the hotter test fires at cabin pressures over 10 pounds per square inch absolute. The significant test results achieved with water or water-based agents are as follows:

1. Quenched major flames in 2 to 3 seconds.
2. Sharply reduced burning rates.
3. Limited temperature and pressure rises.
4. Cabin could be entered with little or no irritation.

Further development work and evaluation will be conducted on foams and different types of aqueous gel.

EXTINGUISHER CONCEPTS TESTED

After effective candidate agents were demonstrated on test fires, a test series for evaluating different extinguisher concepts in conjunction with these agents was initiated. The basic extinguisher concepts considered were lightweight portable extinguisher nozzles and built-in nozzles for total cabin coverage. The portable nozzles proved to be very efficient, since their mobility allowed the extinguishing agent to be applied directly to the area which was burning, therefore requiring only small quantities of agents to extinguish fires. The built-in nozzle concepts demonstrated the capability of extinguishing large-scale fires, but large quantities of the extinguishing agent were required to put out a local fire. In a spacecraft, this large quantity of sprayed fluid could prove injurious to systems not affected by the fire and, therefore, could greatly reduce the reliability of the systems. The quantities of agent required could also result in significant weight and stowage problems. The total built-in system would probably require a complex installation in the spacecraft.

Since nonmetallic materials in the cabin are being replaced where possible with materials that do not burn, the possibility of a large scale fire has been greatly decreased, if not eliminated. Mockup fire tests of the new materials have indicated slow burning rates which were compatible with a portable extinguisher concept. Also, the results of boilerplate extinguisher tests indicate that small quantities of extinguishing agents can extinguish fires which are supported by combustible items that are necessarily still present in the new materials selections. For these reasons, and because of the questionable effects of large quantities of agent exposed to the spacecraft systems from the built-in extinguishers, a portable extinguisher is considered the best concept for spacecraft use. The portable extinguisher concepts which are considered practical and which are being evaluated are as follows:

1. Water hose with spray nozzle connected into the existing spacecraft water system.
2. Aerosol container using gelled water or foam.
3. Aqueous gel blanket.

The concept of the water hose connected into the spacecraft water supply appears to be a readily adaptable system. For example, one of the feasible connection points for the hose to the command module water supply presently being studied is at the waste tank servicing valve on the water control panel (see fig. 214). This valve is used for ground support operations and is normally closed and capped for flight. From this valve, water can be obtained from both the waste water tank and the drinking water tank, both of which receive water generated by the fuel cells. These tanks always have a positive pressure of 20 pounds per square inch above cabin pressure and have a combined maximum capacity of 92 pounds of water.

Boilerplate feasibility tests are presently being conducted to evaluate the capability of using part of the command module onboard water supply as an extinguishing agent. Results from two of the latest tests are presented here.

The fuel in both tests totaled approximately 5 pounds and consisted of the following items (see fig. 215).

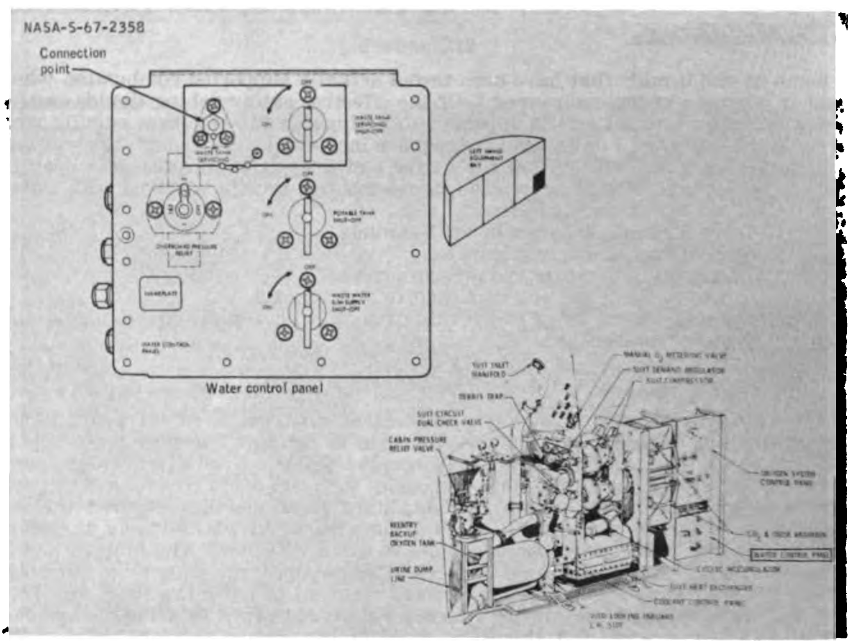


FIGURE 214

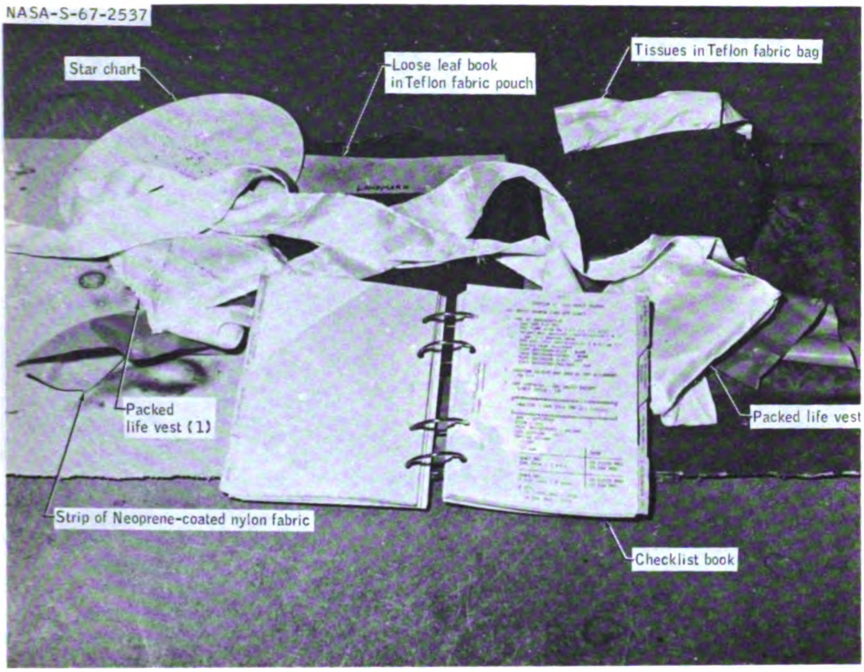


FIGURE 215

1. One 8- by 10-inch loose leaf book in Teflon fabric pouch.
2. One 6- by 8-inch check list book opened to middle page.
3. Pack of tissues in Teflon fabric bag.
4. Two packed life vests.
5. One star chart.
6. Strip of Neoprene-coated nylon fabric (used as starter).

These tests were run at a cabin pressure of 5 pounds per square inch absolute with approximately 97 percent oxygen. During the first test, the fire (see figs. 216 and 217) was allowed to "free burn" for 1 minute 50 seconds, with a resulting increase in cabin pressure of less than 0.8 pound per square inch (see fig. 218). The fire was extinguished 6 seconds after the extinguisher was turned on, using 2.6 pounds of water (0.43 pound per second flow rate). The nozzle pressure was 18 pounds per square inch above cabin pressure. The extinguished fuel is shown in figure 219.

The fire in the second test was allowed to "free burn" for 1 minute 30 seconds. The fire was extinguished in 15 seconds with 3.5 pounds of water (0.23 pound per second). The nozzle pressure was 12.5 pounds per square inch above cabin pressure.

Testing with the second portable concept, an aerosol container, has just started and the preliminary results look promising. This type of extinguisher could be used to apply its agent directly to an exposed fire or, in cases of hidden flames, foamed into panel compartments through special nozzle fittings.

The third type of extinguisher, and aqueous gel blanket, has yet to be evaluated. The system is made of flexible pads consisting of an impermeable backing and an aqueous agent. The pad would be physically applied directly to localized fires.

FIGURE 216

FIGURE 217

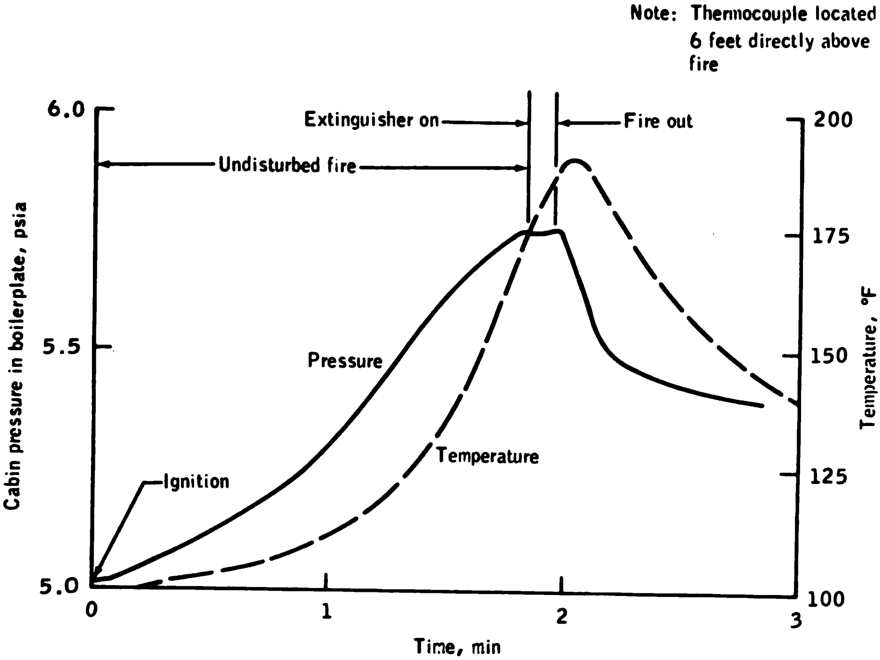


FIGURE 218

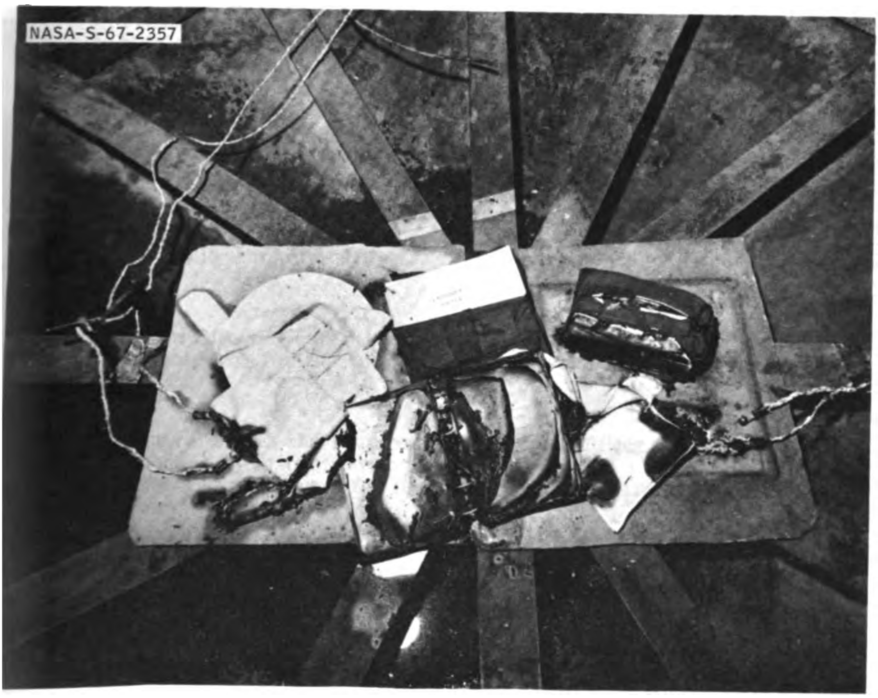


FIGURE 219

Conclusion

Although judicious spacecraft materials selections have greatly decreased the possibility of a large-scale fire, small quantities of combustible items will necessarily still be used in the spacecraft. For this reason, an extinguishing system will be incorporated on all manned flights. Current testing results indicate that the system will be a hose/nozzle connection into the spacecraft water supply, but development will continue with the aerosol containers and aqueous gel blankets.

Section VIII

MANAGEMENT

The Apollo Program management structure and process have been discussed at length in previous testimony. Dr. George E. Mueller's testimony before the United States Senate on March 10, 1965, contained an extensive treatment of the subject. His subsequent testimony before the Senate on April 13, 1967 provided additional detail and amplification of the organization and management practices in effect at the time of the accident. These previous discussions are not repeated in this paper.

The fundamental soundness of the Program's management structure and process has been demonstrated over the years by the successes of the Mercury and Gemini Programs and in the Apollo Program's 13 successful missions to date.

In carrying out its investigation, the Board found instances where the documentation of responsibilities between organizational elements differed from the operating practices in force, instances where that documentation was either out of date or not sufficiently specific, and instances where documentation was not readily available to all parties involved. The management review carried out by the Apollo Program Office since the accident has noted no areas requiring major organizational change but has identified the need for greater centralization and clarification in documenting and updating the specific responsibilities of the organizations within the Apollo Program.

Therefore, several program directives have been prepared to replace and consolidate previous individual directives and inter-Center agreements. These directives are designed to remove possible ambiguities in the assignment of program responsibilities and to reinforce control of waivers and deviations. These directives are attached and cover the following:

1. Preparation of test and checkout plans and procedures at KSC.
2. MSF test procedure preparation and deviation reporting.
3. Center responsibilities in the Apollo Program.
4. Functions and authority—Apollo Program.
5. MSF Quality Control Audit and Reporting.

APOLLO PROGRAM DIRECTIVE No. 26 (MA 009-026-1B)

From Apollo Program Director.

o : Distribution.
ubject: Preparation of test and checkout plans and procedures at KSC.
eference: Apollo Program Directive, Center responsibilities in the Apollo Program.

Purpose

This Program Directive covers the preparation and control of test and checkout ans and procedures for the preparation and launch of Apollo-Saturn space hicles at KSC.

Scope

This Directive defines the requirements, responsibilities and inter-center coination necessary to the development, revision and execution of test and ckout plans and procedures for the preparation and launch of Apollo-Saturn ce vehicles at KSC.

Responsibility

The Directors of KSC, MSC, and MSFC are responsible for taking action as essary to implement this Directive. Responsibilities assigned in this Directive y be delegated except in instances where the delegation of responsibility shall o lower than the level specified herein.

IV. Time compliance

This Directive is effective for all subsequent Apollo-Saturn missions except that the use of standardized names for KSC Test and Checkout Plans and Test and Checkout Procedures shall be effective for AS-205 and AS-503 and subsequent missions.

V. Implementation

A. The Manned Space Flight Centers shall prepare directives to implement the responsibilities assigned herein and submit copies to Apollo Program Director by May 15, 1967.

B. Any inter-center problem arising in the implementation of this Directive which cannot be resolved shall be brought to the immediate attention of the Apollo Program Director.

VI. General

A. Development organizations (MSFC and MSC) are responsible for defining specific test and checkout requirements that must be performed on flight vehicles at the factory prior to acceptance and at the launch site prior to flight. Test and checkout requirements to demonstrate the performance of ground support equipment provided by the development organization which is associated with factory acceptance and launch site preparation shall be included. The test and checkout requirements shall clearly define what is to be tested. Test methods, hardware configuration, test sequence and other constraints shall be identified to the extent necessary to assure attainment of test objectives, protect hardware from damage and provide for the safety of personnel.

B. The combined factory and launch site test and checkout requirements shall provide an integrated flow of testing. The objective of the integrated test flow shall be to permit verification of the functional performance of essential systems and their integration into the space vehicle without unnecessary repetition of factory level testing. To the extent practicable, the overall test flow shall permit correlation of data between factory and launch site testing for critical flight hardware components.

C. Development organizations are responsible for providing test specifications and criteria or limits including redline values and associated configuraton constraints by which to judge acceptable performance of flight hardware and ground support equipment furnished by the development organization.

D. The development organizations use different titles and formats for Test and Checkout Requirements and Test Specification and Criteria documents. At the earliest time convenient without republishing existing documents these shall be renamed as the Test and Checkout Requirements Document and the Test and Checkout Specifications and Criteria Document. If desired, the later document may be included as a part of the Test and Checkout Requirements Document.

E. MSC and MSFC shall prepare and approve Test and Checkout Requirements and Test and Checkout Specifications and Criteria Documents for the flight vehicles and GSE which they develop. Approved documents shall be provided to the launch organization (KSC) no later than four months prior to delivery of flight vehicles to the Cape.

F. MSC is responsible for preparing flight crew procedures for use on launch day and during flight. These procedures and changes thereto shall be made available to KSC for use in preparing test and checkout procedures involving flight crew participation.

G. The above documentation provides the framework within which the launch organization prepares test and checkout plans for integrating all test activities at the launch site and develops detailed test and checkout procedures for each test.

VII. Test and checkout plan

A. A test and checkout plan shall be prepared by KSC. It shall provide an outline for accomplishing development center test and checkout requirements at the launch site and shall include any additional test requirements necessary to verify launch facility, Manned Space Flight Network and launch crew readiness or satisfy range and safety requirements.

B. The following information shall be included:

1. A flow plan designating the sequence of tests to be performed.
2. Identification of the facilities involved in the overall test flow.
3. Specific outlines for each test including the following:

a. Test title and procedure number.
b. Test objectives.
c. Test location and facility.
d. Test description in sufficient detail to define the procedure in outline form.
e. Flight hardware and GSE configuration requirements.
f. Software requirements.
g. Significant support requirements.
h. Identification of any hazardous operations.
i. Safety requirements including any special equipment, personnel, procedures or training required for test.
j. Identify organizations outside of KSC that will be involved.
k. A cross reference to the development center test requirements where applicable.

4. A detailed list of deviations from development center test requirements.

VIII. Test and checkout procedures

A. Test and Checkout Procedures shall be prepared by KSC. A Test and Checkout Procedure shall define the detailed step-by-step sequence of events in a specific test and shall be generated for each test during preparation and launch of flight vehicle.

B. KSC and contractor responsibilities and interfaces in the preparation revision and execution of Test and Checkout Procedures shall be clearly defined by a KSC Management Instruction or other suitable document approved by the KSC Director. This document shall designate the official, at an appropriately high level in the KSC organization, who is responsible for determining which tests are hazardous.

C. MSC and MSFC will review KSC developed Test and Checkout Procedures to assure that they are adequate to meet their requirements. Any recommended changes shall be provided to KSC no later than 15 days prior to the start of the test.

D. MSC and MSFC shall establish a mechanism to process launch site recommended changes in factory testing.

E. The following guidelines shall be used in the preparation, revision and execution of KSC test and checkout procedures.

1. Factory or test site test and checkout procedures which have been approved by the development organization shall be used as a baseline in the development of Launch Site Test and Checkout Procedures. Whenever possible, Test and Checkout Procedures written for use in the factory will be modified for use at the launch site to fit unique facility requirements, safety considerations, integrated space vehicle test requirements and to meet objectives in the test and checkout plan.

2. MSC is required to deliver approved flight crew procedures to KSC at least 40 days prior to a test or checkout operation involving the flight crew (See paragraph IX, B-2). Flight Crew Procedures as approved and published by MSC shall be used by KSC when applicable in preparing those test and checkout procedures involving the flight crew. In any cases where incompatibility between test and checkout procedures and flight crew procedures exist, KSC will obtain MSC approval of the Test and Checkout Procedure.

3. All Test and Checkout Procedures involving hazardous operations shall contain or provide specific reference to written instructions for identifying emergency situations, safing of hardware and implementing emergency actions required to evacuate or safeguard personnel and combat or limit the extent of the damage should an emergency arise.

4. Test and Checkout Procedures shall be standardized in regard to the following items:

a. Major policy and procedure matters regarding preparation, review, approval and change cycle.
b. Control, approval level and documentation of trouble shooting during the conduct of Test and Checkout Procedures.
c. Extent of quality control participation and sign off during execution of Test and Checkout Procedures.
d. Extent of safety and medical organization participation. (See NMI 8900.1)

e. Recording and approval level for deviations encountered during implementation of Test and Checkout Procedures.

f. Policy concerning multiple effectivity of Test and Checkout Procedures.

g. Inclusion or exclusion of preparation steps in Test and Checkout Procedures.

h. Recording of OIS channels during execution of Test and Checkout Procedures.

i. Appropriate use of warning and caution notes.

5. Prior to publication of a test and checkout procedure it shall be approved by the KSC Safety Office for assurance that operations are compatible with applicable safety criteria and use appropriate safety personnel, techniques and equipment.

6. Test and checkout procedures involving human test subjects shall be coordinated with medical personnel for assurance that potential risks to the health of test subjects are minimized. (See NMI 8900.1)

7. Test and Checkout Procedures shall be provided to the KSC Launch Vehicle or Spacecraft Quality Surveillance Division for review and use in preparing for participation in test and checkout operations.

8. Test and Checkout Procedures and changes thereto for tests involving flight crew participation shall have signature approval of MSC.

9. Approved Test and Checkout Procedures shall be distributed one month prior to the date of the test.

10. A Test and Checkout Procedure control system shall be established which places positive control over changes subsequent to the distribution of approved copies to the test team. Only those changes in spacecraft, launch vehicle or space vehicle test and checkout procedures which will improve safety or are mandatory because of late changes in hardware configuration shall be approved in the last seven calendar days before scheduled start of a test unless approved by the following organizational level for the tests indicated.

a. Launch Operations Manager:

(1) Flight Readiness.

(2) Countdown Demonstration.

(3) Countdown.

b. Test Supervisor.

(1) CSM or LM altitude chamber tests in MSOB.

(2) CSM or LM final integrated systems test in MSOB.

(3) CSM or LM integrated test in VAB or on pad prior to mating with space vehicle.

(4) L/V overall tests 1 and 2 in VAB or on pad.

(5) S/V overall tests 1 and 2 in VAB or on pad.

(6) S/C or L/V propellant loading on pad.

(7) S/V simulated flight in VAB or on pad.

(8) Pyrotechnic installation in VAB or on pad.

11. Revisions to Test and Checkout Procedures shall be provided to test team members at least 48 hours in advance of the start of the test. Waivers to this requirement shall be approved at the organizational level established by the KSC Director except that this approval cannot be delegated lower than specified in VIII E–10 above for the tests indicated.

12. Prior to initiation of a test, briefings shall be conducted for all key members of the test team to review the sequence of test activities, the Test and Checkout Procedures and any hazardous operations or emergency procedures.

13. Prior to initiating a test, a review shall be made of all open work recorded against the hardware to be tested. A determination shall be made that the hardware (including GFE) is properly configured and that the Test and Checkout Procedure, Flight Crew Procedure and hardware are compatible. This determination shall be recorded and approved by KSC and contractor organizations involved in the test. The procedure for recording and the level of approval shall be as specified by the KSC Director. For spacecraft hardware tests involving flight crew participation, this determination shall have signature approval of MSC.

14. Approval to initiate non-hazardous tests shall be at the organizational level established by the KSC Director.

15. Approval to initiate any test involving a hazardous operation shall be at the organizational level established by the KSC Director in accordance with VIII E–10 above.

16. The Director, MSC, and the Director, MSFC, shall delegate the authority either to KSC or to the appropriate official of their own organizations to approve real time deviations to Test and Checkout Procedures involving compromise in test and checkout requirements.

17. Changes in flight hardware configuration, test and checkout requirements, or test and checkout specifications and criteria shall be approved by MSC and MSFC for the spacecraft and launch vehicle respectively.

18. The flight crew shall use Test and Checkout Procedures when participating in flight hardware tests at the launch site. Flight crews shall come under KSC control during the time they are actively participating in tests of flight vehicles except that the flight crew may take any action necessary for its safety.

19. Deficiencies encountered by the flight crew while participating in KSC tests shall be recorded and dispositioned using the same documentation system as that used by the test team.

20. KSC shall make an analysis of Test and Checkout Procedures deviations subsequent to completion of major tests for the purpose of reducing deviations in subsequent Test and Checkout Procedures.

21. Tests involving hazardous operations shall not be conducted unless communciations are adequate to support emergency operations.

IX. Center responsibilities

A. MSFC and MSC are responsible for—

1. Preparing an appropriate document which assigns responsibility for functions and actions contained herein.

2. Establishing and maintaining test and checkout requirements, test and checkout specifications and criteria, and launch mission rules inputs which are necessary to assure test and checkout and flight readiness.

3. Providing signature approval on KSC test and checkout plans.

4. Approving deviations or waivers to test and checkout requirements, test and checkout specifications and criteria, and launch mission rules specified in IX A-2 above.

5. Participation in preparation, revision and execution of KSC Test and Checkout Procedures in accordance with Section VIII.

6. Assuring that adequate testing is being accomplished without unnecessary overlap and duplication.

7. Providing signature approval on KSC criteria for determining hazardous operations.

B. MSC is responsible for—

1. Advising KSC in writing of tests requiring flight crew and/or flight control personnel participation.

2. Providing approved flight crew procedures to KSC at least 40 days prior to a test or checkout operation involving the flight crew.

3. Providing signature approval on KSC Test and Checkout Procedures involving flight crew participation.

4. Providing signature approval on pre-test reviews of spacecraft hardware (including GFE) and Test and Checkout Procedure compatibility for those tests involving flight crew participation.

C. KSC is responsible for—

1. Preparing an appropriate document which assigns responsibility for functions and actions contained herein.

2. Developing test and checkout plans as defined in Section VII at least one month prior to delivery of flight hardware for each mission.

3. Securing MSC and MSFC signature approval on test and checkout plans and changes thereto before these documents are approved or implemented.

4. Preparing, revising and executing Test and Checkout Procedures in accordance with Section VIII.

5. Providing Test and Checkout Procedures to MSC and MSFC one month prior to the start of a test and assuring expeditious distribution of changes thereto.

6. Securing MSC signature approval on Test and Checkout Procedures and changes thereto and the pre-test reviews of spacecraft hardware and test and checkout procedure compatibility for those tests in which the flight crew has a requirement to participate.

7. Assuring that MSC flight crew and flight control personnel are integrated into the KSC test team for those tests in which they have a requirement to participate.

8. Developing criteria for determining hazardous operations and securing signature approval of MSC and MSFC.

9. Making final determination that Test and Checkout Procedures are adequate, safe and in accordance with development organizations test and checkout requirements, test and checkout specifications and criteria, flight crew procedures and launch mission rules.

10. Obtaining deviations and waivers from development organizations test and checkout requirements, test and checkout specifications and criteria and launch mission rules which will not be fulfilled.

Management Instruction

Subject: MSF test procedure preparation reporting.
From: George E. Mueller, Associate Administrator for Manned Space Flight.

1. *Purpose.*—This Instruction establishes the requirement for a reporting system pertaining to the preparation of Test and Checkout Procedures.

2. *Applicability.*—This Instruction is applicable to the Office of Manned Space Flight and Manned Space Flight field installations.

3. *References.*—(*a*) Apollo and Apollo Applications Program Development Plans. (*b*) NHB 2330.1, "Program Scheduling and Revision Handbook."

4. *Definitions.*—(*a*) *Test and checkout procedure.*—A Test and Checkout Procedure is defined as the detailed step-by-step procedure used at a factory, test site or launch site for checkout and verification of equipment performance during acceptance, static firing, prelaunch or launch preparation.

5. *Test and checkout procedure reporting.*—This Instruction establishes a requirement to present a monthly status report on the preparation of test and checkout procedures for management review. The report shall be submitted in accordance with NHB 2330.1 and shall provide status information on the preparation of test and checkout procedures for major tests during factory or test site acceptance and prelaunch preparation at KSC.

The report will be limited to test and checkout procedures for major tests selected by the Apollo and Apollo Applications Program Directors. Test and checkout procedures included as sub-tasks in the control test and checkout procedure need not be reported. For each selected test the report shall indicate the date the approved procedure is released to the test team and the number of revisions made between the initial release of the approved procedure and the start of the test. Center Program Managers shall report on test and checkout procedure preparation status during regularly scheduled presentations to the MSF Management Council.

6. *Implementation.*—The Apollo and Apollo Applications Program Directors shall prepare appropriate Program Directives to implement this Instruction. These Directives shall contain standardized procedures and formats for the monthly reports and identify the tests to which this Instruction shall apply. These Directives shall be coordinated with the Manned Space Flight Field Centers prior to issuance.

APOLLO PROGRAM DIRECTIVE

To: Distribution.
From: Apollo Program Director.
Subject: Center Responsibilities in the Apollo Program.

I. Purpose

The purpose of this Directive is to assign responsibility and functions and define inter Center relationships for the conduct of the Apollo Program.

II. Scope

This Directive assigns responsibilities and functions to MSF Centers for accomplishment of the Apollo Program in amplification of and in consonance with NMI 1142.1 Functions and Authority—Manned Spacecraft Center, NMI 1142.3 Functions and Authority George C. Marshall Space Flight Center, and NMI 1142.2 Functions and Authority—John F. Kennedy Space Center.

III. Responsibility

A. The Director of the Manned Spacecraft Center is responsible for design, development, fabrication, qualification, acceptance test and delivery of Apollo spacecraft, associated ground support equipment and assigned experiments; for the planning of all Apollo Missions; for the control of the flight phase of Apollo Missions including the development of ground equipment necessary for mission control and not provided by other centers in the execution of their missions; for the selection, training and assignment of flight crews; for the development of software as needed for spacecraft guidance, checkout, and mission control; for establishing prelaunch requirements for test, checkout and inspection of Apollo spacecraft with definitive criteria; and for the planning and implementation of a lunar science program to support the Apollo Program.

B. The Director of the George C. Marshall Space Flight Center is responsible for the design, development, fabrication, qualification, acceptance test and delivery of the Saturn launch vehicles including engines, associated ground support equipment and assigned experiments; providing mission planning data from the standpoint of overall vehicle performance; providing launch vehicle data and software for launch vehicle guidance and checkout; for establishing pre-launch requirements for test, checkout and inspection of Saturn launch vehicles with definitive criteria; and supporting launch and flight operations as requested by KSC and MSC.

C. The Director of the John F. Kennedy Space Center is responsible for development and operation of launch and industrial facilities and associated ground support equipment and assembly, test, inspection, checkout and launch of Apollo-Saturn space vehicles at KSC.

IV. Functions

A. *Manned Spacecraft Center.*—The Manned Spacecraft Center is assigned the following functions for the Apollo Program.

1. *Hardware.*—*a.* Providing for the detailed specifications, design, manufacture, checkout, test, reliability and quality qualification, and acceptance of MSC developed hardware.

b. Developing and delivering to KSC spacecraft which has been qualified for flight along with associated hardware, software, data and support equipment.

c. Providing for the detailed specifications, design, development, fabrication, qualification, acceptance test and delivery of experiments flight hardware and associated specialized ground equipment for those experiments approved by the Manned Space Flight Experiments Board and assigned by the Apollo Program Director.

d. Providing logistic support planning and implementation at factory, test and launch sites for MSC developed hardware.

e. Controlling receipt and stowage of flight crew personal equipment which is scheduled for flight and providing to KSC a list of equipment which is considered flight crew personal equipment.

2. *Configuration control.*—*a.* Establishing and controlling configuration of spacecraft hardware, associated software and support equipment (designed or provided by MSC) at each stage of preparation or test in the factory, test or launch site, including approval of changes at KSC.

b. Providing and maintaining a list of acceptable items and materials that may enter the spacecraft for checkout and for flight.

3. *Test and checkout.*—*a.* Establishing and maintaining test and checkout requirements and test and checkout specifications and criteria for factory or test site acceptance and launch site preparation of MSC developed hardware (including Ground Support Equipment and software).

b. Providing Center-approved test and checkout requirements, plans and procedures for factory or test sites to KSC for use as a baseline in the development of similar plans and procedures required at the launch site.

c. Reviewing launch site test and checkout plans and procedures developed by KSC to assure that they meet their test and checkout requirements.

d. Providing written approval on KSC test and checkout plans in consonance with paragraphs IV.A.3a and IV.A.3b.

e. Providing requirements and criteria to KSC for assuring flight readiness of experiments flight hardware, unless KSC and MSC on the basis of written agreement for a specific experiment make other arrangements for flight readiness determination.

f. Determining functional performance and flight readiness of flight hardware closed out at the factory or test site and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

g. Providing such technical assistance or data as may be requested by KSC in preparation of hardware for flight.

h. Assuring that MSC personnel participating in KSC tests are responsive to KSC direction during conduct of the tests and attend pre-test briefings and participate in training exercises as required by KSC in accordance with responsibilities outlined herein.

i. Providing an assessment of flight readiness of the spacecraft and associated software at the Flight Readiness Review in accordance with Apollo Program Directives.

4. *Reliability and quality assurance*.—*a*. Providing quality control requirements and inspection criteria for MSC developed hardware for use at the factory, test site and launch site.

b. Conducting audits to evaluate and optimize contractor factory and test site performance in accordance with MSC quality control requirements and inspection criteria for MSC developed hardware, and participating at the option of MSC in audits conducted by KSC at the launch site.

c. Determining corrective action and disposition of MSC developed hardware which fails, malfunctions or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC. This responsibility does not include routine trouble-shooting or maintenance of MSC developed ground support equipment operated by KSC.

5. *Systems engineering*.—Providing MSC technical representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

6. *Operations*.—*a*. Developing flight techniques and necessary equipment, hardware and software for mission control except that provided by other centers in the Manned Space Flight Network and launch area.

b. Developing mission objectives, plans and rules to support Apollo mission assignments.

c. Conducting flight operations.

d. Obtaining from KSC the operational requirements pertaining to checkout and launch which need to be incorporated into MSC designed hardware.

e. Planning jointly with the Department of Defense the provision of recovery support.

f. Providing input to and comment on KSC launch rules.

g. Identifying MSC operational support requirements according to approved procedures and evaluating support implementation of said requirements.

7. *Flight crew*.—*a*. Providing trained flight crews and personal equipment for manned missions.

b. Directing all astronaut activities except during the time they are participating in KSC flight hardware tests. The flight crew may take any action necessary for their safety.

c. Developing and operating flight crew simulators and training equipment.

8. *Medical* (see NMI 8900.1).—*a*. Provide for the medical surveillance and support of the astronauts during all phases of the Apollo Program at any location including test and checkout operations.

b. Provide for the evaluation of medical data obtained during manned tests, to insure that the interpretation of such data regarding the acceptability of equipment performance is properly reflected in test results.

c. Provide for the development and implementation of medical disaster plans associated with the test of Apollo hardware at MSC.

9. *Safety*.—*a*. Providing written approval of KSC criteria for determining hazardous operations at the launch site affecting MSC furnished hardware; and reviewing to the extent MSC finds appropriate any other KSC procedures for hazardous operations involving MSC furnished hardware.

b. Reviewing, to the extent that MSC finds appropriate, any other KSC test and checkout procedure involving other MSC furnished hardware.

c. Reviewing and approving any KSC test and checkout procedure in which the flight crew participates.

10. *Management*.—*a*. Providing contract authority for KSC control of spacecraft contractor's test and checkout activities at KSC through a supplemental contract under KSC administration.

b. Developing and operating Center facilities required for the Apollo Program, including adequate provisions for security.

c. Establishing detailed schedules (Levels 2, 3, and 4) for MSC hardware, software and associated equipment and operations activities consistent with the basic schedules (Level 1) approved by the Director, Apollo Program, and the Director, Mission Operations.

11. *Science.—a.* Planning and implementation of a lunar science program to support Apollo, including site selection, lunar science operations, the Lunar Receiving Laboratory operation and lunar sample analysis.

B. *George C. Marshall Space Flight Center.*—The George C. Marshall Space Flight Center is assigned the following functions for the Apollo Program.

1. *Hardware.—a.* Providing for the detailed specifications, design, manufacture, checkout, test, reliability and quality, qualification and acceptance of MSFC developed hardware.

b. Developing and delivering to KSC launch vehicles including engines which have been qualified for flight along with associated software, data and support equipment to KSC.

c. Providing for the detailed specifications, design, development, fabrication, qualification, acceptance test and delivery of experiments flight hardware and associated specialized ground equipment for those experiments approved by the Manned Space Flight Experiments Board and assigned by the Apollo Program Director.

d. Providing logistics support planning and implementation at factory, test and launch sites for MSFC controlled hardware.

2. *Configuration control.*—Establishing and controlling configuration of launch vehicle hardware, associated software and support equipment (designed or provided by MSFC) at each state of preparation or test in the factory, test or launch site, including approval of changes at KSC.

3. *Test and checkout.—a.* Establishing and maintaining test and checkout requirements and test and checkout specifications and criteria for factory or test site acceptance and launch site preparation of MSFC developed hardware (including ground support equipment and software).

b. Providing Center-approved test and checkout requirements, plans and procedures for factory or test sites to KSC for use as a baseline in the development of similar plans and procedures required at the launch site.

c. Reviewing launch site test and checkout plans and procedures developed by KSC to assure that they meet their test and checkout requirements.

d. Providing written approval of KSC test and checkout plans in consonance with paragraphs IV.B.3a and IV.B.3b.

e. Providing requirements and criteria to KSC for assuring flight readiness of experiments flight hardware, unless KSC and MSFC on the basis of written agreement for a specific experiment make other arrangements for flight readiness determination.

f. Determining functional performance and flight readiness of flight hardware closed out at the factory or test site and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

g. Providing such technical assistance or data as may be required by KSC in preparation of hardware for flight.

h. Assuring that MSFC personnel participating in KSC tests are responsive to KSC direction during conduct of the tests and attend pre-test briefings and participate in training exercises as required by KSC in accordance with responsibilities outlined herein.

i. Providing an assessment of flight readiness of the launch vehicle and associated software at the Flight Readiness Review in accordance with Apollo Program Directives.

4. *Reliability and quality assurance.—a.* Providing quality control requirements and inspection criteria for MSFC developed hardware for use at the factory, test site and launch site.

b. Conducting audits to evaluate and optimize contractor factory and test site performance in accordance with MSFC quality control requirements and inspection criteria for MSFC developed hardware, and participating at the option of MSFC in audits conducted by KSC at the launch site.

c. Determining corrective action and disposition of MSFC developed hardware which fails, malfunctions, or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC. This responsibility does not include routine troubleshooting or maintenance of MSFC-developed ground support equipment operated by KSC.

5. *Systems engineering.*—*a.* Providing MSFC technical representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

b. Provide the overall integrated space vehicle systems analysis and criteria for operational requirements and limitations for handling checkout, launch and flight as required by MSFC, MSC and KSC.

c. Operating the Manned Space Flight Interface Documentation Repository.

6. *Operations.*—*a.* Providing assistance to MSC in developing mission plans in support Apollo mission assignments.

b. Providing real time mission support as requested by MSC and KSC both on site and at Huntsville.

c. Providing input to and comment on KSC launch and MSC flight mission rules.

d. Obtaining from KSC the operational requirements pertaining to checkout and launch which need to be incorporated into MSFC designed hardware.

e. Identifying MSFC operational support requirements according to approved procedures and evaluating support implementation of said requirements.

7. *Flight crew.*—Provide instructions and material for training and familiarization of flight crews with the Saturn vehicle.

8. *Medical* (See NMI 8900.1).—Provide for the development and implementation of medical disaster plans associated with the test of Saturn hardware at MSFC.

9. *Safety.*—*a.* Providing written approval on KSC criteria for determining hazardous operations at the launch site affecting MSFC furnished hardware, and reviewing to the extent MSFC finds appropriate any other KSC procedures for hazardous operations involving MSFC furnished hardware.

b. Reviewing to the extent MSFC finds appropriate, KSC test and checkout procedures involving MSFC furnished hardware.

10. *Management.*—*a.* Providing contract authority for KSC control of launch vehicle contractor's test and checkout activities at KSC through a supplemental contract under KSC administration.

b. Developing and operating Center facilities required for the Apollo Program, including adequate provisions for security.

c. Establishing detailed schedules (Levels 2, 3, and 4) for MSFC hardware, software, and associated equipment consistent with the basic schedules (Level 1) approved by the Apollo Program Director.

d. Providing liquid hydrogen management for MSFC and KSC.

11. *Science.*—None.

C. John F. Kennedy Space Center.—The John F. Kennedy Space Center is assigned the following functions for the Apollo Program.

1. *Hardware.*—*a.* Providing for detailed specifications, design, manufacture, checkout, test, reliability and quality qualification and acceptance of KSC developed hardware.

b. Developing and delivering qualified ground support equipment, associated with launch facilities and not provided by MSC or MSFC.

c. Developing and operating ground communications, computation, and instrumentation systems and equipment for the conduct of launch operations.

d. Take measures to protect flight hardware and associated ground support equipment from contamination, corrosion or damage which may result from environment, housekeeping, procedure or human error, reporting all suspected incidents to MSC and MSFC as appropriate.

e. Providing logistics support planning and implementation at the factory test or at KSC for KSC developed hardware.

2. *Configuration control.*—*a.* Establishing and controlling configuration of KSC developed launch facilities and ground support equipment at each stage of preparation or test at the factory, test site or at KSC.

b. Maintaining configuration control of MSC and MSFC developed hardware and software after delivery to KSC in accordance with the configuration requirements established by MSC and MSFC. Assuring that prior approval is secured from MSC or MSFC before any changes in configuration are made in spacecraft, launch vehicle, or associated GSE furnished by MSC or MSFC.

c. Controlling everything that enters the spacecraft during checkout at KSC in accordance with the MSC list of acceptable items and materials that may be taken into the spacecraft for checkout and for flight.

3. *Test and checkout.*—*a.* Conducting the assembly, checkout, and launch of flight hardware for Apollo missions and assembly, checkout and operation of required ground support equipment.

b. Providing requirements, specifications and criteria, and procedures for test and checkout of KSC developed support equipment whose performance must be verified for each launch.

c. Providing test and checkout plans in accordance with MSC and MSFC test and checkout requirements plus any additional KSC test requirements necessary to verify launch facility, Manned Space Flight Network and launch crew readiness or to satisfy range and safety requirements.

d. Securing MSC and MSFC written approval on test and checkout plans before the plans are approved or implemented.

e. Developing and providing to MSC or MSFC test and checkout procedures, adapted to the KSC environment using as a baseline the development center approved factory test and checkout procedures, and initiating, for MSC or MSFC approval, changes in their test requirements necessary to verify launch facility, Manned Space Flight Network, and launch crew readiness or to satisfy range and safety requirements.

f. Making final determination that test and checkout procedures are adequate, safe and in accordance with MSC and MSFC test and checkout requirements and test and checkout specifications and criteria.

g. Obtaining approval on deviations and waivers from MSC and MSFC concerning test and checkout requirements, test and checkout specifications and criteria and inspection criteria when unable to meet requirements.

h. Determining functional performance and flight readiness of flight hardware and software in accordance with tests and checkout specifications and test criteria provided by MSC and MSFC except for that which is closed out at the factory and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

i. Determining flight readiness of equipment associated with inflight experiments in accordance with MSC or MSFC (as appropriate) specifications and criteria or in accordance with other mutually agreed upon criteria.

j. Controlling receipt and storage, and assuring flight readiness of all Government Furnished Equipment, other than flight crew personal equipment, which is scheduled for flight and which is not processed to KSC through a contractor responsible to KSC.

k. Provide routine trouble shooting and maintenance for MSC and MSFC developed equipment in accordance with MSC and MSFC requirements, specifications and criteria.

l. Providing an assessment of the flight readiness of the launch complex and associated software at the Flight Readiness Review in accordance with Apollo Program Directives.

4. *Reliability and quality assurance.*—*a.* Providing quality control requirements and inspection criteria for KSC developed hardware for use at the factory, test site and KSC.

b. Conducting audits to evaluate and optimize contractor factory and test site performance in accordance with KSC quality control requirements and inspection criteria for KSC developed hardware.

c. Determining corrective action and disposition of KSC developed hardware which fails, malfunctions, or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC.

d. Generating quality control plans in accordance with MSC and MSFC quality control requirements plus any additional KSC requirements necessary to verify launch facility and space vehicle readiness or satisfy range and safety requirements.

e. Securing MSC and MSFC written approval of quality control plans insofar as development center responsibilities are concerned before the plans are approved or implemented.

f. Conducting quality control inspections and audits of contractor activities at KSC and inviting MSC and MSFC participation as applicable.

g. Obtaining approval from the appropriate development center (MSC or MSFC) to disassemble or open any flight hardware closed out at a factory or test site.

h. Advising MSC or MSFC of any problem arising during prelaunch preparation concerning flight worthiness of flight hardware.

i. Conducting failure analysis as required by MSC and MSFC.

j. Providing adequate participation in MSC and MSFC flight hardware acceptance reviews and advising in writing the MSC or MSFC management on their concurrence in acceptance of hardware for shipment to KSC.

5. *Systems engineering.*—Providing KSC representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

6. *Operations.*—*a.* Identifying KSC operational support requirements according to approved procedures and evaluating support implementation of said requirements.

b. Providing data to MSC and MSFC in accordance with approved Operations Support Requirements Documents and requirements of Launch and Flight Support Teams.

c. Conducting launch operations.

d. Developing launch plans and rules.

7. *Flight crew.*—Coordinating and directing astronaut activities during the time they are actively participating in KSC tests of flight hardware except that the flight crew may take any action necessary for their safety.

8. *Medical.*—(see NMI 8900.1.) Provide for the development and implementation of medical disaster plans associated with the assembly, checkout and prelaunch operations of Apollo flight hardware at KSC.

9. *Safety.*—*a.* Performing as the NASA single point of responsibility for safety in the Merritt Island and Cape Kennedy area and for NASA range safety inputs to the Eastern Test Range.

b. Developing criteria for determining hazardous operations at the launch site and securing written approval of MSC and MSFC for any such criteria which affect their hardware, or in the case of MSC, the safety of astronaut crews.

10. *Management.*—*a.* Providing control of all activities of Apollo contractors at KSC other than those directly associated with astronaut training.

b. Developing and operating Center facilities required for the Apollo Program including adequate provisions for security.

c. Establish detailed schedules (Levels 2, 3, and 4) for KSC hardware, software and associated equipment consistent with the basic schedules (Level 1) approved by the Director, Apollo Program and the Director, Mission Operations.

11. *Science.*—None.

V. Precedence

The Directive takes precedence over any inter-Center agreements on Apollo Program responsibilities.

MANAGEMENT INSTRUCTION

Subject: Functions and authority—Apollo Program, OMSF.
From: George E. Mueller, Associate Administrator for Manned Space Flight.

1. Purpose

This Instruction defines the general responsibilities and detailed functions which have been assigned to the Director, Apollo Program (OMSF). It also enumerates the general and specific authorities delegated to him to carry out overall direction and supervision of the Apollo Program within NASA Headquarters and Centers involved in the conduct of the program.

2. Organizational location

The Director, Apollo Program, reports to the Associate Administrator for Manned Space Flight (AA/MSF).

3. General responsibilities

The Director, Apollo Program, is responsible for directing, supervising, monitoring, integrating, coordinating and evaluating the developmental aspects of the Apollo Program through all phases of the developmental, test, checkout and operations cycles of the program. These responsibilities include programmatic and administrative direction and integration of all aspects of the Apollo Program to insure the success of each flight mission and of the program as a whole.

4. Functions

In further definition of the general responsibilities outlined above and in consonance with the authorities assigned to the Administrator, the Deputy Administrator and the AA/MSF, the Director, Apollo Program, will carry out these functions:

a. Organization and management.—(1) Issuance of a Program Development Plan and Mission Assignments, and changes thereto, after approval by the AA/MSF.

(2) Direction of overall Apollo Program planning, policy development and procedural implementation.

(3) Definition and assignment of programmatic and support responsibilities vested in various MSF organizations both, Headquarters and Field.

(4) Definition of relationships and working arrangements between and among participating organizations involved in the program.

(5) Direction and supervision of overall industrial monitoring and control covering all aspects of contractor effort and audit of progress.

(6) Establishment of an overall Apollo management information and visibility system encompassing both internal and external effort related to the conduct of the program.

(7) Review and approval of major management information systems proposed by each major organizational element of the Apollo Program.

(8) Establishment of an effective management communication system to link all participating elements in the program.

(9) Establishment of decision-making patterns covering all aspects of direct and support effort to identify clearly implementation of responsibilities and to permit assessment of status and progress in the program.

b. Technical management.—(1) Provide overall technical direction for scientific and engineering effort involved in the Apollo Program.

(2) Establish basic plans and specifications for design, development, fabrication, assembly, test and checkout activities in the Apollo Program. This includes the provision of overall systems engineering and the systems safety analysis of hardware design.

(3) Establish and manage a configuration management system applicable to all effort within the Apollo Program.

(4) Monitor technical support effort related to the conduct of the Apollo Program to insure its responsiveness to program needs, and redirect as necessary.

(5) Insure adequate mission planning.

(6) Review and approve all significant mission planning in terms of objectives, rules, design and other constraints, alternative technical approaches, mission options, and related decisions affecting basic technical and operational goals. The AA/MSF provides policy guidelines on mission objectives and mission rules.

(7) Validates the requirements for all phases of operations planning developed by the Director, Mission Operations.

(8) Monitor all Center effort related to the design, development, fabrication, assembly, test and checkout of all Apollo hardware and associated equipment to insure optimum performance and realization of program objectives, and redirect as necessary.

(9) Review and approve basic schedules (Level 1), consistent with the master schedule approved by the AA/MSF and the Deputy Administrator, for Apollo Program hardware, software, and associated equipment including control over any proposed changes in key program milestones.

(10) Provide for and monitor a comprehensive reliability and quality control program covering all aspects of Apollo hardware and associated facilities and equipment.

(11) Direct and monitor a required supporting development program for Apollo through internal and contractual effort.

(12) Develop a comprehensive test philosophy and concept for the Apollo Program and monitor the implementation and execution of this program for developmental tests, through qualification, reliability, acceptance, prelaunch, flight and postflight verification.

(13) Review and approve all significant elements of the medical, engineering, technological and scientific experiments to be performed on Apollo flights in terms of hardware compatibility, mission tradeoffs, safety, and overall performance.

(14) Direct and monitor the design, development, test and checkout and operation of all experiment instrumentation to be carried on Apollo flights.

(15) Direct the overall conduct of Apollo missions.

(16) Establish overall postflight data requirements and provide for the evaluation and reporting of mission results.

c. Support activities.—(1) Approve or concur in appropriate major Apollo procurements, and monitor the overall procurement support to all elements of the program, including activities from prenegotiation planning through contract administration.

(2) Within the limitations establish by Program/Project Approval Documents and other general management limitations, allocate and reprogram R&D funds between program elements as necessary and recommend to the Associate Administrator for Manned Space Flight those necessary adjustments which exceed current resource allocations in the Apollo area. Concur in the allocation and reprogramming of resources other than R&D funds when scope or requirements of the program are affected.

(3) Establish and monitor a data management system for the administration and control of relevant documents in the Apollo Program in both Headquarters and the Field.

(4) Prepare an Apollo safety plan for the approval of the Director, Manned Space Flight Safety, and insure effective administration of all aspects of the program.

(5) Establish and monitor a comprehensive Apollo logistics program encompassing all phases of hardware assembly, checkout, test, operations, refurbishment, transportation and related activities within the program.

(6) Insure that adequate security arrangements and procedures exist throughout the Apollo Program.

5. Authorities

In order to carry out the functions and general responsibilities enumerated above, the Director, Apollo Program (OMSF) has been delegated sufficient authority to direct, supervise and control all Apollo program activity within NASA, and through contractual arrangements with industrial and/or university organizations. This authority carries with it the following explicit or implicit discretion:

a. To establish patterns of program review covering all aspects of assigned activities.

b. To issue program directives to Center Program Managers through the Center Director and to direct full and responsive actions on the basis of these directives.

c. To redelegate to officials within the Apollo Program Office (Washington) and to officials in the Field (through line channels) such authorities as are necessary to insure effective program management and execution of assigned responsibilities.

6. Obligations

In providing overall direction and coordination for the activities assigned to him, the Director, Apollo Program is required to fulfill certain obligations imposed upon him. These include the obligations to recognize, support and to act on the basis of:

a. Functions and authorities assigned to other Headquarters officials whether for functional, institutional or programmatic leadership.

b. Institutional and other programmatic responsibilities assigned to Center Directors.

c. The need for assessment of program performance and status by higher authorities based upon objective information and visibility systems available to all principals involved with Apollo activity.

d. Constraints placed upon his scope of authority by applicable laws or regulations.

7. Approval of organizations

The basic organization of the Apollo Program is outlined on the organization chart (fig. 220). Modifications or changes in the basic organization structure are subject to the approval of the Associate Administrator for Manned Space Flight.

8. *Cancellation*

OMSF Memorandum, August 11, 1964, First Level Functional Statement for OMSF.

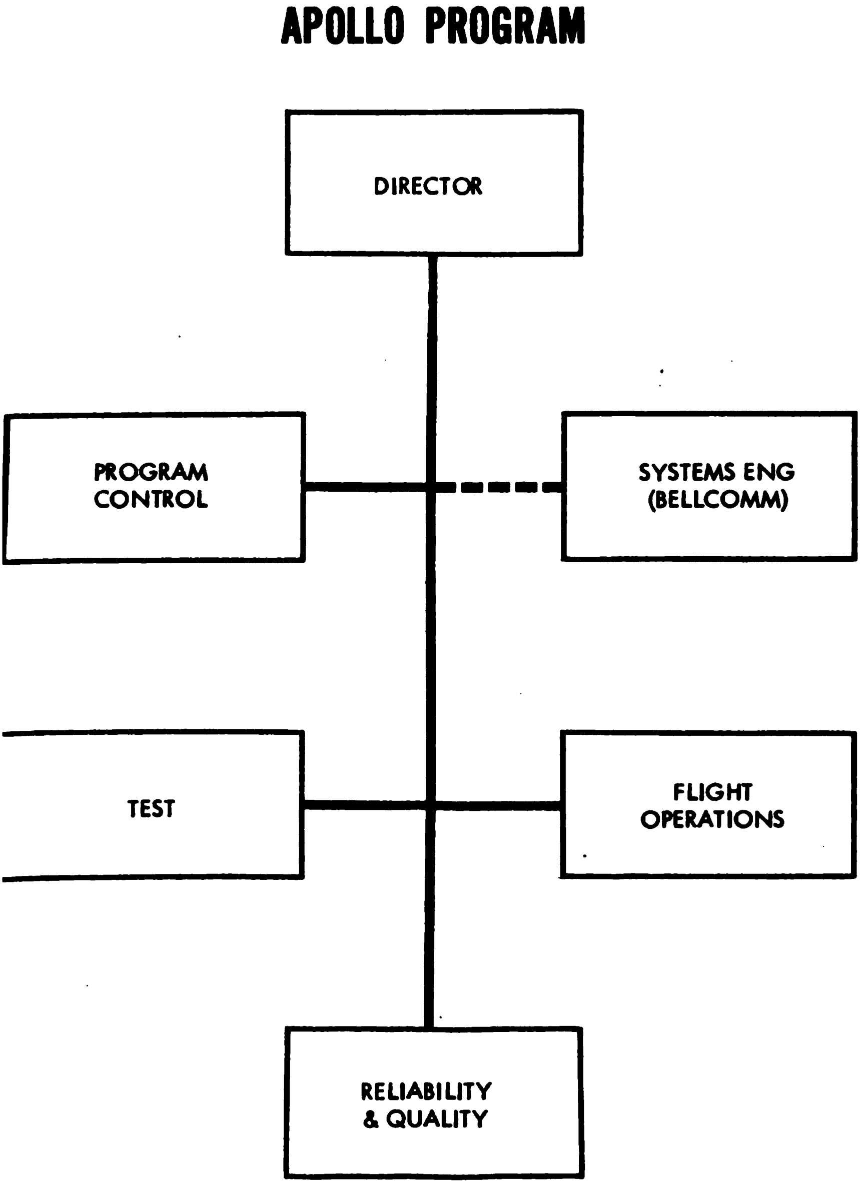


FIGURE 220

MANAGEMENT INSTRUCTION

Subject: MSF quality assurance audit and discrepancy reporting.
From: George E. Mueller, Associate Administrator for Manned Space Flight.

1. Purpose

This instruction establishes the requirement for quality assurance audit programs and discrepancy reporting.

2. Applicability

This instruction is applicable to OMSF and all MSF field installations.

3. References

1. Applicable Project Approval Documents for MSF programs.
2. Apollo and AAP Program Development Plans.
3. NPC 250-1, "Reliability Program Provisions for Space System Contractors."
4. NPC 200-1A, "Quality Assurance Provisions for Inspection Agencies."
5. NPC 200-2, "Quality Program Provisions for Space System Contractors."
6. NPC 200-3, "Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services."
7. NHB 5300.1A, "Apollo Reliability and Quality Assurance Program Plan."
8. NHB 2330.1, "Program Scheduling and Review Handbook."
9. NHB 5330.7, "Management of Government Quality Assurance Functions for Supplier Operations."

4. Definitions

For the purposes of this Instruction, the following definitions apply:

a. Discrepancy.—A discrepancy is any nonconformance of the article with specified engineering requirements. As used herein, "discrepancy" is synonymous with "defect."

b. Resolved discrepancy.—A discrepancy is resolved when final action has been implemented; i.e., engineering order released, specification change approved and published, procedure change approved and published, etc.

c. Engineering Requirements.—"Engineering Requirements" include drawings, specifications, engineering orders, test requirements, computer tapes, and any other documents released by the authorized engineering organization to define fabrication, assembly and test of major flight assemblies including their stages, modules, subsystems and components, and their ground support equipment (GSE).

d. Major Flight Assembly.—The launch vehicle stages and spacecraft modules are major flight assemblies. The S-IB, S-IC, S-II, S-IVB, IU, LM, CM, and SM are examples of major flight assemblies.

5. Procedures

a. An integral part of an effective quality assurance program is the conduct of quality assurance audits. Audits of each NASA and contractor quality assurance organization and their interfaces with other organizations shall be conducted by the next higher level at least annually to assure that proper quality assurance organization, policies and procedures have been developed and are being implemented. Manned Space Flight Program Directors are responsible for establishing audit teams and schedules to review Center quality assurance programs relative to their programs. Center Directors are responsible for establishing audit teams and schedules covering contractor quality assurance activities. Representatives from program control, engineering, test, reliability, quality and other appropriate areas shall be included as a part of the audit teams. Reports of quality assurance audits are to be submitted to Center Program Manager and Center Director for appropriate action necessary to resolve reported deficiencies. Reviews of the results of all quality assurance audits will be given to the MSF Program Management Council at least once each quarter. Audits will be conducted in accordance with NHB 5300.1A.

b. Discrepancy reporting.—Monthly discrepancy reports will be submitted by the MSF Center Program Managers to summarize the number of discrepancies recorded for the major flight assemblies during factory or test site acceptance and preparation for launch. This reporting will be in accordance with NHB 2330.1. It will classify the discrepancies in meaningful categories and indicate the number that have been resolved, and the number which have been outstanding longer than one calendar month. A single quality assurance chart for each major flight assembly will be shown by the appropriate Center Program Office at its regularly scheduled presentation to the MSF Program Management Council. The format shown as Attachment 1 (fig. 221) will be utilized in reporting discrepancies.

c. Implementation.—The Apollo and Apollo Applications Program Directors shall prepare appropriate Program Directives to implement this Instruction. These Directives shall contain standardized procedures for the conduct of quality audits and shall be coordinated with the Manned Space Flight Field Centers prior to issuance.

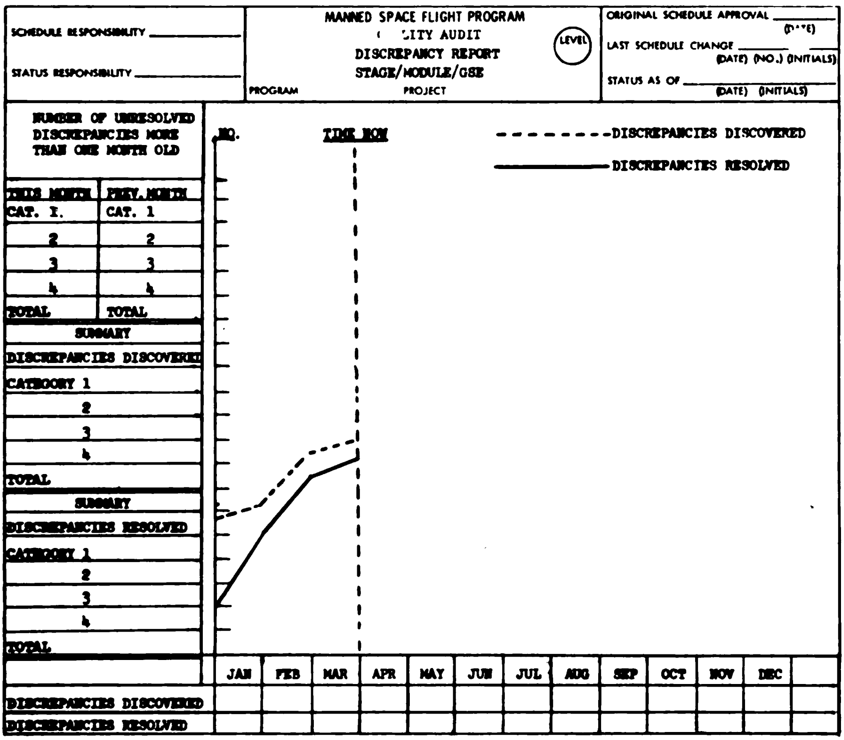


FIGURE 221

Section IX

SUMMARY OF CHANGES

SPACECRAFT MATERIALS

CABIN MATERIALS

An improved materials selection and substitution program has been established. Revised selection criteria and accompanying detailed guidelines for implementation have been completed. Review and approval procedures have been instituted.

The major bulk combustibles in the cabin have been removed and substitutes are under test. A revised stowage mockup which provides fire resistant containers for those combustibles which must remain has been approved.

Final confirmation of materials will be through testing in the full scale command module boilerplate facility. Changes will be effective on all manned spacecraft.

SPACE SUIT MATERIALS

Newly available non-flammable fabrics are being incorporated into an integral fire resistant cover layer for the space suit. Beta fabrics, H Film and Teflon fabric have already been combined into prototype cover layers which, under flame impingement test, have shown ten times the fire resistance of the previous intravehicular space suit cover layer. This change is being incorporated in flight and training suits.

The space suit cotton underwear is being replaced with non-flammable Beta fabric. Prototypes are available and an initial procurement has been made.

EMERGENCY EGRESS

A single, outward-opening, quick-release side hatch will be provided for the command module.

The essential features of this hatch are:

1. Unified hatch replaces separate pressure and heat shield hatch.
2. Can be manually released even with large internal pressures.
3. Can be operated by the flight crew from the inside or by the ground crew from the outside.
4. Manual operation protects against inadvertent opening.

Preparations are being made for structural, flotation, and egress tests with the new hatch. The hatch concept will be verified on AS–501 and AS–502. The new hatch will be installed on the first Block II vehicle.

The Launch Umbilical Tower and Access Arm are being modified to improve emergency egress in the following ways:

1. The access arm adapter hood will be made larger to accommodate the new spacecraft hatch.
2. The access arm mechanism will be modified and the park position changed to shorten reposition time.
3. Steps and protuberances in the egress path will be eliminated and bidirectional swinging doors will be provided.
4. Positive ventilation and improved lighting with redundant power will be provided in the white room.
5. Fire resistant materials will be used in the white room.

COMMUNICATIONS

GROUND COMMUNICATIONS

The operation of the ground communications system will be improved by reducing the number of stations on critical loops. Access to the system will be limited to those stations which are mandatory for the conduct of an operation.

Reliable operation of the present system will be assured by:

1. Making minor design changes (such as deleting the locking feature on push-to-talk microphones).
2. Improving operational procedures including circuit testing, circuit level monitoring, and maintenance.
3. Improving control of circuit configuration particularly with respect to adding stations.

Intercommunications equipment will be added to provide four wire full duplex links on critical circuits. This will permit full duplex operation on critical circuits off-the-pad at KSC and to other locations such as the Mission Control Center at Houston.

These changes will be made before the next manned spacecraft flight.

Spacecraft Communications

The problems associated with Apollo 204 have already been corrected in the present Block II design, and therefore, no spacecraft changes are required.

Only two significant spacecraft communications problem areas were noted in the Apollo 204 review:

1. For certain switch positions, the command pilot's audio center allowed a "hot mike" problem to propagate to other audio centers. Diode isolation of the keying circuits are a part of Block II.
2. The crew umbilicals were cumbersome to use. In Block II the emergency connector and the sleep adapter have been replaced with switched networks, and the noise eliminator circuit has been moved into the helmets.

ENVIRONMENTAL CONTROL SYSTEM

Cabin Atmosphere Control System

1. *Atmosphere for Space (including reentry)*.—Five psi 100% oxygen will be used in space. This requires no changes in the hardware.
2. *Pad/Launch Atmosphere*.—For manned test operations on the ground, the previously used atmosphere of 16.5 psi pure oxygen will continue to be used unless the boilerplate fire safety tests to be conducted with the new materials indicate that an unacceptable fire hazard would exist under these conditions. The option will be provided to use either air of 100% oxygen in ground tests, prelaunch and launch by making the following changes:

a. Bleed oxygen into the suit loop (bleed line, valve, orifice) to keep it above cabin pressure.

b. Provide sensors to ensure that the suit loop system has adequate oxygen.

c. Provide for rapid cabin depressurization and repressurization.

3. *Oxygen plumbing*.—*a*. Aluminum oxygen lines with solder joints will be changed to stainless steel in the cabin.

b. Protective covers will be added to exposed oxygen lines.

Thermal Control System

Materials in the ECS which constitute a fire hazard will be replaced. For example, dacron filters in lithium hydroxide canisters in the suit loop and polyurethane foam insulation in the Environmental Control Unit are being replaced.

The water glycol coolant will be retained. It is essential that an inhibitor be used in the coolant to prevent corrosion. The present inhibitor was selected after an intensive search as the best possible for the system. There is no problem with this inhibitor unless it is spilled or allowed to leak in the cabin. The principal effort, therefore, is to provide a leak-proof coolant system and prevent spills.

Leakage and spillage will be substantially reduced or eliminated:

1. Soft metal washers and improved torquing procedures have been incorporated to effectively prevent leakage of mechanical fittings.
2. Quick disconnects with fluid check valves are being added to prevent water glycol spillage during normal maintenance.
3. It has been determined that solder joints are acceptable if properly made and not abused:

a. Solder joints will be eliminated where possible by combining line segments.

b. Armor will be added to those joints in the water glycol system exposed to structural abuse.

4. Protective covers will be added over all exposed plumbing.

Adequate procedures and materials have been developed to clean up, without leaving a residue, any spills that cannot be prevented. Improved test procedures to ensure proper clean up have been developed.

FIRE PROTECTION

An emergency breathing mask system will be provided to permit crew operations in the event fire breaks out in the shirtsleeve mode of operation.

An additional pressure relief valve will be provided so that the cabin can be depressurized rapidly and a second oxygen surge tank and associated plumbing will be added so that the cabin can be repressurized rapidly.

ELECTRICAL SYSTEM

The improvements previously incorporated in the Block II spacecraft, such as improved wire bundle fabrication (using 3-dimensional jigs) improved cable routing, and improved circuits switching have corrected most of the problems revealed in the 204 investigation. A full review of the Block II spacecraft wiring design and implementation has been conducted. Deficiencies found were minor and are being corrected.

Circuit protection devices (circuit breakers) have been reviewed and changes are being made to ensure compliance with the proper criteria. Protective covers over exposed wiring are being added to prevent damage during installation and test.

The wiring on spacecraft already built has been inspected. Additional mandatory inspections are now required during the manufacturing and test operations of new spacecraft.

FIRE EXTINGUISHMENT

A portable, crew-operated fire extinguisher will be provided in the Command Module. The extinguisher now being designed involves a special hose and nozzle which connects into the spacecraft water supply.

LAUNCH COMPLEX EMERGENCY EQUIPMENT

Adequate provisions for emergencies will be made by:

1. Installing a ground override capability on the elevator.
2. Increasing the permanent explosion-proof lighting in the pad area.
3. Installing additional warning lights and horns.
4. Providing additional gas masks, protective clothing and emergency tools.
5. Providing additional exhaust fans.
6. Providing additional fire hoses on the working levels of the Launch Umbilical Tower.

ADDITIONAL SPACECRAFT CHANGES

The following additional changes which are not a result of the Apollo 204 Board activity have been identified.

1. Purge hydrogen from the water tank quantity gauge to eliminate a possible ignition source.
2. Relocate certain environmental control system controls to facilitate emergency operation.
3. Use the onboard TV camera for crew monitoring during prelaunch test and checkout operations.
4. Provide water chlorination to avoid bacterial growth.
5. Provide a manual lockout for the postlanding vent valve to preclude accidental decompression.
6. Provide for automatic battery bus tie at abort initiation to reduce crew load at this time.
7. Improve pushbutton and toggle switch guards to prevent accidental switch operation.
8. Relocate the couch J–box to prevent wiring damage.
9. Modify the reaction control system dump timers to provide better pad abort conditions.
10. Provide a single mode recovery light to enhance location of the spacecraft on the sea.

11. Replace the hand controller 1.7 sec timer with a 3 sec timer for subsequent operations with the LM.

12. Make minor crew couch changes to provide improved couch operation.

13. Prevent inverter motor lockout which can occur due to inadvertant switching.

14. Add SM RCS check valve filters to prevent contamination.

15. Modify the phase modulation processor circuit breaker to provide redundant power to the S-band system.

16. Add the following instrumentation:

a. 10 sequential events discrete outputs.

b. 1 glycol temperature control cabin monitor.

c. 3 fuel cell radiator inlet temperatures.

d. 3 linear accelerometers to measure inertial loads.

e. 11 environmental control system flight qualification measurements.

17. Add SM RCS thruster filters to prevent contamination.

18. Provide for entry battery C backup to either battery bus for increased redundancy.

19. Change the data storage equipment tape motion flag indicators to avoid loss of recording capability.

These changes as well as those related to the Apollo 204 Board review will be made on the first manned spacecraft.

APPENDIX 2

Summary of Actions Taken of the Findings and Determinations of the AS-204 Accident Review Board Panels

GLOSSARY

AFETR	Air Force Eastern Test Range (Formerly Atlantic Missile Range—AMR).
APOP	Apollo Preflight Operations Procedure.
AS-501	First Saturn V Mission. Uumanned S/C development mission.
ASPO	Apollo Spacecraft Program Office, MSC.
BLOCK	Designation of a class of Apollo spacecraft. The AS-204 spacecraft was designated Block I. Block II is an updated version, capable of supporting Extra Vehicular Activity and designed for the Apollo lunar mission. All future manned Apollo flights will utilize Block II spacecraft.
BOILERPLATE	A test spacecraft reflecting Apollo flight spacecraft weight and structure.
CARR	Customer Acceptance Readiness Review.
CCA	Contract Change Authorization.
CDDT	Countdown Demonstration Test.
CM (C/M)	Command Module.
C/M 008	A flight configured Block I spacecraft used for training purposes at MSC.
CO	Carbon Monoxide.
CO_2	Carbon Dioxide.
CSM	Command and Service Modules (Apollo spacecraft).
DD-250	Receiving and Inspection Report.
ECS	Environmental Control System.
EO	Engineering Order.
FRR	Flight Readiness Review.
GAEC	Grumman Aircraft Engineering Corp., Lunar Module prime contractor.
GFE	Government Furnished Equipment.
GORP	Ground Operations Requirements Plan.
GOX	Gaseous Oxygen.
GSE	Ground Support Equipment.
HEEWG	Hazardous Egress and Evacuation Working Group.
KSC	Kennedy Space Center, Cape Kennedy, Florida.
LC	Launch Complex.
MIP	Mandatory Inspection Points.
MSC	Manned Spacecraft Center, Houston, Texas.
NAA	North American Aviation-Apollo Command and Service Module prime contractor.
NAC	National Agency Check.
O_2	Oxygen.
OCP	Operational Checkout Procedure.
OMSF	Office of Manned Space Flight, NASA Headquarters.
PIRR	Parts Installation and Removal Record.

GLOSSARY—Continued

PSIA	Pounds per square inch, absolute. Sea level standard atmospheric pressure is 14.7 psia.
REFEREE FLUID	A fluid which is substituted during ground testing only. The referee fluid would not be used in flight.
SC(S/C)	Spacecraft.
S/C 012	AS-204 Spacecraft.
S/C 017	Unmanned, Block I spacecraft planned for first Saturn V mission.
S/C 020	Unmanned, Block I spacecraft planned for second Saturn V mission.
SC 101	First Block II, spacecraft, probably to be manned.
T	Time of Launch.
TIR	Temporary Installation Record.
2TV-1	Test Vehicle.
TWX	Telegraphic message. (A TWX is an official document.)

Apollo Program Actions Resulting From the Apollo 204 Review Board Panel Findings and Determinations

INTRODUCTION

The purpose of this report is to outline the specific corrective actions we are taking or will be taking resulting from the findings and recommendations of the appropriate Panels that were established by the Apollo 204 Review Board.

In order to be sure we have taken every action necessary to meet the spirit as well as the specifics of the Apollo 204 Review Board Panels' determinations, each panel finding and recommendation has been reviewed with the appropriate subsystem and system managers with the intent to correct present deficiencies and preclude to the best of our ability any future shortcomings. The resulting actions and planned actions have been evaluated and reviewed by the cognizant Apollo 204 Review Board Panel Chairman to insure that the findings and determinations of the Panel have been properly interpreted.

Specific NASA management reviews of these actions with respect to the findings and recommendations of the Panels were conducted at the Centers and Headquarters to be sure that we have a consistent and adequate approach to the problems and that the corrective actions are feasible and consistent with program progress. A completion date or planned effectivity has been assigned to each action and all actions will be completed prior to the next manned flight.

Panel 1

S/C & GSE CONFIGURATION

Finding No. 1

Finding.—One hundred and sixty-four (164) Engineering Orders (EO's) were not accomplished at the time Spacecraft 012 was received at KSC. Six hundred and twenty-three (623) EO's were released subsequent to receipt at KSC. Of these, twenty-two (22) were recent releases which were not recorded in configuration records at KSC at the time of the accident.

Determination.—Continuing engineering changes indicate progressive development of the Spacecraft configuration through the time of the Space Vehicle Plugs Out Integrated Test. At the time of the test, the configuration could not have been complete with respect to the launch configuration.

Action.—Spacecraft acceptance and DD-250 administration procedures will be strictly enforced to assure that shipping documents accurately reflect hardware status. Further action will be directed toward rigid discipline of configuration management procedures to assure that no work is open unnecessarily at time of shipment.

Identification of mandatory change actions subsequent to shipment of particular spacecraft will continue to be a practical aspect of the program. Configuration management procedures will be amended to include explicit criteria for control of spacecraft post-delivery change actions. This criteria will reflect consideration of the impact of change incorporation on spacecraft checkout status.

Action completion date or effectivity.—July 1, 1967.

Finding No. 2

Finding.—The required Space Vehicle Plugs Out Integrated Test configuration was not explicitly defined by design engineering or test documentation. Definition of required test configuration was limited to test set-up and controls configuration specified in OCP FO-K-0021-1.

Determination.—The absence of explicit definition of spacecraft test configuration requirements relegated such definition to the test organization. Further, it is the opinion of this Panel that the lack of timely and explicit design definition of the required test configuration precluded complete assessment of adverse configuration aspects as constraints to the test.

Action.—NASA and NAA had recognized the problems with the CSM Checkout Process Specifications and measures intended to correct the situation were initiated in February 1967.

Apollo Program Directive No. 26, MA 009-026-1A has been issued and specifies that Test and Checkout requirements clearly define hardware configuration, test methods and other constraints to assure attainment of test objectives. Accordingly, End Item Specification, Part II, are being prepared for all Block II flight vehicles in accordance with the Apollo Configuration Management Manual, NPC 500-1. These specifications will define the acceptance test and checkout requirements, test methods, detail hardware configuration, test prerequisites and constraints necessary to assure attainment of test objectives.

Planned action completion date or effectivity.—The End Item Specification, Part II, will be effective on the first block II flight vehicle.

Finding No. 3

Finding.—Eighty (80) EO's effective on S/C 012 were not accomplished at the time of the accident. Of these, twenty (20) were specified to be accomplished subsequent to the Space Vehicle Plugs Out Integrated Test. Four (4) of the open EO's were of a nature not affecting configuration. Three hundred and eighty-four (384) Parts Installation and Removal Records (PIRR's) and Temporary Installation Records (TIR's) were open, of which one hundred and twenty-five (125) were in compliance with requirements of the test documentation.

Determination.—It is concluded that test requirements had no defined relationship to the open status of fifty-six (56) EO's and two hundred and fifty-nine (259) PIRR's/TIR's. It is the opinion of this Panel that all work items and EO's were not closed because of late receipt of changes or further work scheduled to be accomplished prior to launch.

Action.—The subject of open item review meeting and constraints list is presently in process of re-evaluation by KSC Spacecraft Operations. KSC is in the process of preparing a revision to Apollo Preflight Operations Procedures (APOP) OCP No. O-202 that will re-define the following:

1. A specific definition of the requirement for a pre-test open item review. The review will be co-chaired by the NASA Chief Spacecraft Test Conductor and the Spacecraft Contractor Test Project Engineer.
2. A system of documenting the constraint items with proper approvals for the test in question or waivers as required.
3. A procedure for indicating items that are closed out between the conclusion of the open item review and the scheduled start of the test.
4. A post-test critique at which anomaly items discovered during the performance of the test are evaluated as possible constraints to closeout of the subject test. All such constraints will be monitored during work-off by Quality Control.
5. A preliminary constraints list for the next scheduled major test will also be defined at the post-test critique.
6. A time bar-chart indicating the latest allowable date for a pre-test operation review with reference to the next scheduled test date.
7. Specific responsibilities and applicable authorities will be included.

Action completion date or effectivity.—Estimated completion date May 31, 1967.

Finding No. 4

Finding.—Items were placed onboard the spacecraft during preparation for the Space Vehicle Plugs Out Integrated Test which were not documented by quality inspection records.

Determination.—Procedures for controlling entry of items into the spacecraft were not strictly enforced.

Action.—The existing applicable Apollo Preflight Operations Procedures will be revised to thoroughly define nonflight items which are approved by MSC for temporary use in the spacecraft. Quality inspection will then enforce the procedures.

Action completion date.—June 25, 1967.

PANEL 2

TEST ENVIRONMENTS

Finding No. 1

Finding.—All crew compartment equipment was not tested to be explosion proof.

Determination.—There was insufficient testing of possible ignition sources.

Action.—Review adequacy of certification testing specification for explosion proof testing of cabin equipment.

Develop requirements for and means of accomplishing any additional explosion testing necessary for potential ignition sources in the cabin.

Planned action completion date or effectivity.—Preliminary direction is being sent to the spacecraft contractors. Response required by June 1, 1967.

Finding No. 2

Finding.—Crew compartment equipment of Spacecraft 012 were exposed to water/glycol contamination. Untested cleaning techniques were employed for that equipment discovered to be wet.

Determination.—None.

Action.—1. The ECS plumbing will be modified to reduce the possibility of glycol spillage.

2. A substitute fluid (which would have little or no deleterious spillage effects) is being studied for use in the spacecraft for testing and operation up until the time of final servicing for launch.

3. Specific cleaning procedures to be utilized in the event of glycol spillage shall be prepared and instituted. These specific instructions will include techniques dictated by tests conducted to determine optimum means for removal of glycol from electrical harnesses.

Action date.—These actions will be taken prior to the next flight.

Finding No. 3

Finding.—Some of the C/M cabin equipment exhibited arcing or shorting during either certification or SC 012 testing. There is no positive way to determine from the records reviewed whether SC anomalies (possibly caused by a short or an arc) are reviewed by systems engineers and the test conductor prior to a test.

Determination.—Review of possible ignition sources prior to manned testing was inadequate.

Action.—The Customer Acceptance Readiness Review (CARR) will be revised to emphasize the detailed review and evaluation of all open, unresolved failures pertinent to the spacecraft. After the CARR, the list of open failures will be kept current so that, at a suitable time prior to each manned test, the open failures can be identified and necessary action taken.

Action date.—The above action will be accomplished by a letter of direction to the contractor by May 23, 1967.

Finding No. 4

Finding.—Not all equipment installed in C/M 012 at the time of the accident was intended to be flown. Some components were installed for test purposes only.

Determination.—The suitability of this equipment in the C/M for test was not established.

Action.—The Customer Acceptance Readiness Review (CARR) will be revised to emphasize the detailed review and evaluation of a list of non-flight equipment aboard the spacecraft for test purposes only. After the CARR, the list will be kept current so that, at a suitable time prior to each manned test, the non-flight equipment can be identified and necessary action taken.

Action date.—The above action will be accomplished by a letter of direction to the contractor by May 23, 1967.

Finding No. 5

Finding.—Noncertified equipment was installed in the C/M at the time of the accident. The "cobra cable" P/N V16-601263 and "T" adapter P/N V16-601396 are examples.

Determination.—The suitability of this equipment in the C/M for this test was not established.

Action.—The Customer Acceptance Readiness Review (CARR) will be revised to emphasize the detailed review and evaluation of the certification status of flight hardware. After the CARR, the status will be kept current so that, at a suitable time prior to each manned test, the remaining noncertified flight equipment, if any, can be identified and necessary action taken.

Action date.—The above action will be accomplished by a letter of direction to the contractor by May 23, 1967.

Finding No. 6

Finding.—The mating and demating of "hot" electrical connectors was permitted in the crew compartment during tests with 100% oxygen environments. The "Crew Electrical Umbilical" (cobra cable) and the "S" Bank equipment exemplify this practice.

Determination.—The practice of breaking "hot" electrical circuits by means of electrical connectors can produce sparks of ample magnitude to ignite combustible mixtures.

Action.—Changes have been made in the Block II spacecraft to avoid the necessity of connecting or disconnecting hot electrical circuits in the cabin during normal operations. A review of appropriate specifications and procedures has been done and necessary changes are being implemented.

Planned action completion date or effectivity.—These actions will be taken prior to manned tests.

Panel 3

SEQUENCE OF EVENTS

No action required.

Panel 4

DISASSEMBLY ACTIVITIES

No action required.

Panel 5

ORIGIN & PROPAGATION OF FIRE

No action required for findings 1, 2, 5, 6, 7, 8, and 10.

Finding No. 3

Finding.—Severe damage to wiring was found at the bottom of the Lower Equipment Bay along the aft bulkhead. Evidence of arcing was found on the cover in front of C-15-1A-52 and adjacent wires. Damage was less severe in the +Y (right hand) direction in this bay.

Determination.—Electrical arcing in the extreme lower left hand corner of this bay could have provided a primary ignition source.

Action.—Electrical wire installation in Block II is being completely reviewed to determine and eliminate potential ignition sources.

Protective covers will be placed over exposed wire bundles.

Combustible material will be removed from the vicinity of power conducting wires.

Action effectivity.—Requisite changes will be incorporated in all spacecraft used in manned ground and flight tests.

Finding No. 4

Finding.—Right hand portions of the Left Hand Equipment Bay received severe damage. Wiring, tubing, and components in the carbon dioxide absorber compartment and oxygen/water panel compartment were burned and melted. Penetrations in the aft bulkhead and pressure vessel wall were observed. The carbon dioxide absorber compartment showed heavy fire damage and failure was due to pressure overload and melting caused by the fire in this area.

Determination.—Electrical arcing in the right hand portion of this bay could have provided a primary ignition source.

Action.—Electrical wire installation in Block II is being completely reviewed to determine and eliminate potential ignition sources.

Protective covers will be placed over exposed wire bundles.

Combustible material will be removed from the vicinity of power conducting wires.

Action effectivity.—Requisite changes will be incorporated in all spacecraft used in manned ground and flight tests.

Finding No. 9

Finding.—Evidence of electrical arcs from conductor to conductor and conductor to structure was found.

Determination.—No arc could be positively identified as the unique ignition source. Three were found that had all of the elements needed to cause the disaster. Two of these showed evidence of the poor engineering and installation.

Action.—Electrical wire installation in Block II is being completely reviewed to determine and eliminate potential ignition sources.

Protective covers will be placed over exposed wire bundles.

Combustible material will be removed from the vicinity of power conducting wires.

Action effectivity.—Requisite changes will be incorporated in all spacecraft used in manned ground and flight tests.

PANEL 6

HISTORICAL DATA

Finding No. 1

Finding.—The Ingress-Egress Log discloses several instances where tools and equipment were carried into the spacecraft, but the log does not show these tools as removed.

Determination.—The maintenance of the Ingress-Egress Log is inadequate.

Action.—A revised Apollo Preflight Operations Procedure (APOP) is being coordinated between the contractor and NASA. This procedure will require a new format for the log and provide more definition, rigor, and accounting for personnel, materials and tools used in the spacecraft. The responsibility for the maintenance of the log will be defined. NAA-NASA Quality personnel will assure this procedure will be enforced.

Planned action completion date or effectivity.—May 25, 1967.

Finding No. 2

Finding.—*a.* Shakedown inspection periods are not shown on the Master Flow Plan.

b. There are no definitive inspection criteria to perform shakedown inspections for the Apollo Program.

Determination.—*a.* Hardware condition prior to major tests and milestones is difficult to establish.

b. Inspection personnel are not able to assess the condition of the spacecraft for compliance with definitive criteria, but rather assess it in accordance with their knowledge of standard practices.

Action.—*a.* Present operating procedures at KSC will be revised to call out the requirement that major shakedown inspection periods be shown on the Master Flow Plan. This will be effective with spacecraft 017 now at KSC.

b. Inspection criteria have been released for use on spacecraft 017 and 020. Inspection criteria will be released by April 30, 1967. Concurrently a review of the Block II process specifications will be completed by June 15, 1967 and revised specifications released by July 15, 1967. (Upgraded inspection criteria resulting therefrom will be released August 1, 1967.) These inspection criteria will be used by NASA/NAA-KSC personnel.

Planned action completion date or effectivity.—Revised KSC Operating Procedures, May 25, 1967. Block I Inspection Criteria, released. Block II Inspection Criteria, April 30, 1967. Block II Specification Update, July 15, 1967. Revised Block II Inspection Criteria, August 1, 1967.

Finding No. 3

Finding.—Inspection personnel do not perform a pre-scheduled inspection with a checklist prior to hatch closing.

Determination.—Inspection personnel could not verify these functions during this period.

Action.—Action will be taken to provide a checklist defining specific inspection activities during and after flight crew ingress. This checklist will be included into the applicable operation checkout procedures. NAA and NASA quality personnel will verify that the checklist is performed.

Planned action completion date or effectivity.—May 25, 1967.

Finding No. 4

Finding.—Formal approval by NASA or NAA Quality Control of the con-constraints list is not required.

Determination.—NASA/NAA Quality Control cannot discharge their responsibilities without approving the constraints list.

Action.—The applicable Apollo Preflight Operation Procedure will be revised to reflect formal concurrence of the constraints list by Government and Contractor Quality Control, Engineering, and Operations. If disagreement of the constraints list exist, the Director, Spacecraft Operations, will resolve the disagreement. Reference Panel 1, Finding No. 3.

Planned action completion date or effectivity.—May 25, 1967.

Finding No. 5

Finding.—The requirements for Mandatory Inspection Points are not clearly defined in the Apollo Preflight Operations Procedures.

Determination.—Proper inspection coverage is not assured without clearly defined mandatory inspection points.

Action.—Action is underway to further define government and contractor Mandatory Inspection Points (MIP). These definitions will be made part of the Apollo Preflight Operational Procedures and implemented through the applicable operations checkout.

Planned action completion date or effectivity.—May 25, 1967.

Finding No. 6

Finding.—At the time of shipment of the spacecraft to KSC, the contractor ubmitted an incomplete list of open items. A revision of the said list significantly nd substantially enlarged the list of open items.

Determination.—The true status of the spacecraft was not identified by the ontractor.

Action.—Effective with spacecraft 101, modification periods for change incor-oration are scheduled at specific times making the configuration update easier. lso, no major modifications will be scheduled after completion of integrated sts. Any open work subsequent to this period will be transferred to KSC and own on the DD–250. In addition, as part of the shakedown inspection prior shipment, effective with spacecraft 020, an audit of the configuration listing rsus the spacecraft hardware will be made by NASA/NAA Quality Control.

Planned action completion date or effectivity.—Effective with spacecraft 101.

nding No. 7

Finding.—There is no efficient system which readily identifies that results omplished by rework are verified by retest.

Determination.—The present system of verification of rework by retest is nbersome.

ction.—Each NASA/NAA–KSC systems engineer is charged with the responility of assuring that retest is accomplished. Previously, paperwork describing ork was closed out when rework was complete. KSC APOP procedures are ng revised to require the paperwork to remain open until retest is completed documented.

lanned action completion date or effectivity.—KSC APOP Procedure Revision, 25, 1967. Spacecraft Effectivity: Partial spacecraft 017, Complete spacet 020 and subsequent.

Finding No. 8

Finding.—There is no requirement to maintain records by subsystem classification, nor does the system present status in this fashion.

Determination.—The recovery of pertinent historical information is extremely difficult.

Action.—Records in the Quality Data Center at the factory and at KSC will be established by subsystem.

Planned action completion date or effectivity.—May 1, 1967.

PANEL 7

TEST PROCEDURES REVIEW

No action required on findings 7–10.

Finding No. 1

Finding.—The panel documented the plugs-out test procedure (FO–K–0021–1) as it had been performed.

Determination.—The test procedure did not contribute to the accident. There was a defect in the procedure in that power was applied to the uncapped gas chromatograph power cable after the gas chromatograph had been removed from the spacecraft.

Action.—This is a problem of human error, therefore more stringent controls are being implemented, applicable to late deviations, to minimize potential human error. Additional technical review and higher management approval will help to insure timely and correct pretest deviations in those cases where such deviations are mandatory.

Planned action completion date.—May 31, 1967.

Finding No. 2

Finding.—Two hundred and nine pages of the 275 page OCP were revised and released on the day before the test. Less than 25 per cent of the line items, however, were changed. Approximately one per cent of the change was due to errors in technical content in the original issue of the procedure. In addition, 106 deviations were written during the test.

Determination.—Neither the revision nor the deviations are known to have contributed specifically to the incident. The late timing of the change release, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

Action.—Apollo Program Directive No. 26, MA–009–026–1A has been issued which will ensure that the necessary control and lead time is provided for test procedure preparation and approval.

KSC-Spacecraft Operations is presently preparing a Test Preparation and Revision Plan that will be used to implement the intent of the Apollo Program Directive. The plan will include required input deadlines, review dates and approval dates, as well as direction for revisions. This plan will be controlled by the OCP Control Board which consists of NASA KSC and the S/C Contractor Organization. The plan will be placed into effect through a revision to the Apollo Prelaunch Operations Plan (APOP) OCP Procedure No. 0–202.

Planned action completion date or effectivity.—Estimated completion date May 23, 1967.

Finding No. 3

Finding.—During the Altitude Chamber Tests the cabin was pressurized at pressures greater than sea level with an oxygen environment 2½ times as long as the cabin was pressurized with oxygen prior to the accident during Plugs Out Test.

Determination.—The spacecraft had successfully operated at the same cabin conditions in the Chamber for a greater period of time than on the pad up to the time of the accident.

Action.—The command module is being modified to permit the use of air during sea level operations if our analysis shows that it is desirable. Simulations in the altitude chamber will be planned to duplicate the conditions on the pad and during launch and orbit. If air is used in the cabin during sea level operations, the altitude chamber tests will become especially important in verifying that the depressurization and purge required to provide a 100% oxygen environment for orbital operations will be successful.

Planned action date or effectivity.—Request for Engineering Change Proposal has been issued to NAA for necessary changes in the Environmental Control System. Changes will be effective on 2TV-1 and CSM-101.

Finding No. 4

Finding.—The Plugs Out OCP was not classified as hazardous.

Determination.—The hazard level was not recognized and consequently the procedure was processed through the review cycle as a non-hazardous procedure.

Action.—In the future, all tests in a closed, oxygen rich environment, will be considered hazardous. The contractor safety engineer will continue to review all procedures and make recommendations to KSC safety on hazardous content. KSC Safety Office will review and approve all procedures.

Action completion date or effectivity.—In effect at the present time.

Finding No. 5

Finding.—Only local control is provided for certain systems which may require remote control for safety reasons such as service structure water and hypergolic supply sources.

Determination.—The full potential of the safety systems is not utilized due to the lack of remote control capability.

Action.—1. KSC-Spacecraft Operations is investigating possible changes to hypergolic system design criteria to provide both local and remote override control on major supply sources. These recommendations will be presented to MSC for implementation into existing GSE.

2. A study is in progress by KSC Launch Operations to review the operational requirement for additional control sites for the water deluge system on the service structure.

Action completion date or effectivity.—1. Completion of hypergolic system design criteria May 31, 1967.

2. Estimated completion of water deluge system study July 1, 1967.

Finding No. 6

Finding.—The open item constraint test was not formalized as required by APOP No. 0-202.

Determination.—Pretest constraints were evaluated informally on a system-by-system basis by the test team (enclosure 7-2).

Action.—The subject of open item review meeting and constraints list is presently in process of re-evaluation by KSC Spacecraft Operation. KSC is in process of preparing a revision of Apollo Preflight Operations Procedure (APOP) OCP Procedure #0-202 that will re-define the following:

1. A specific definition of the requirement for a pretest open item review. The review will be co-chaired by the NASA Chief, Spacecraft Test Conductor and the Spacecraft Contractor Test Project Engineer.

2. A system of documenting the constraint items with proper approvals for the test in question or waivers as required.

3. A procedure for indicating items that are closed out between the conclusion of the open item review and the scheduled start of the test.

4. A post-test critique at which anomaly items discovered during the performance of the test are evaluated as possible constraints to closeout of the subject test. All such constraints will be monitored during work-off by Quality Control.

5. A preliminary constraints list for the next scheduled major test will also be defined at the post-test critique.

6. A time bar-chart indicating the latest allowable date for a pretest operation review with reference to the next scheduled test date.

7. Specific responsibilities and applicable authorities will be included.

Planned action completion date or effectivity.—Estimated completion date May 1, 1967.

Finding No. 7

Finding.—Troubleshooting of the communication problem was not controlled by any one person, and was at times independently run from the spacecraft, Launch Complex 34 blockhouse, and the Manned Spacecraft Operations Building. Communications switching, some of which was not called out in the OCP, was performed without the control of the Test Conductor.

Determination.—The uncontrolled troubleshooting and switching contributed to the difficulty experienced in attempting to assess the communication problem.

Action.—The troubleshooting procedure in Apollo Prelaunch Operations Procedure (APOP) #T-502 is to be expanded and clarified. Specific instructions will be included to delineate the requirements for coordination with Technical Support Operations activities (such as the blockhouse communications personnel) through documented, established channels.

Action completion date or effectivity.—June 1, 1967.

Finding No. 8

Finding.—KSC was not able to insure that the spacecraft launch operations plans and procedures adequately satisfied, on a timely basis, the intent of MSC. Changes to S/C testing by KSC could not be kept in phase with the latest requirements of MSC. Prelaunch checkout requirements (GORP) were not formally transmitted to KSC from MSC.

Determination.—Prelaunch test requirements control for the Apollo Spacecraft Program is constrained by slow response to changes, lack of detailed KSC-MSC inter-Center agreements, and by the lack of official NASA approved Test Specifications applicable to prelaunch checkout.

Action.—Apollo Program Directive 26, MA-900-026-1A has been issued and specifically defines the inter-Center responsibilities and relations in the development and implementations of spacecraft testing. In addition, it defines the specific documentation required to fully control test requirements and test implementation planning on a timely basis.

Action completion date or effectivity.—The requirements of Apollo Program Directive 26 are to be implemented in total for all future flights.

Finding No. 9

Finding.—The Test Specifications for Spacecraft 012 were not written in a convenient to use format, did not contain field tolerances, were not NASA approved, were not maintained up-to-date, and were not transmitted to NASA/KSC.

Determination.—The lack of usefulness of the Test Specifications has been recognized by NAA, Downey and measures intended to correct the situation have been initiated.

Action.—A test specification which includes the criteria and limits to which the spacecraft and GSE will be judged acceptable will be provided by MSC. The specification will be maintained in an up-to-date status with any deviations being approved by MSC. For these deviations which require immediate response, authority is delegated to the MSC ASPO Resident Manager at KSC.

Planned action completion date or effectivity.—The test specification will be available by July 1, 1967.

PANEL 8

MATERIALS REVIEW

No action required on findings 3b, 3c, and 4c.

Finding No. 1a

Finding.—Complete documentation which identified potentially combustible nonmetallic materials used in S/C 012 is not available in a single readily usable format. A total of 2,528 different potentially combustible nonmetallic materials which were probably used on S/C 012 were found by a review of available documentation.

Determination.—The program for identification and documentation of nonmetallic materials used in the S/C, including their weights and surface areas, was not adequate. There is no system in effect through which nonmetallic materials configuration changes are tracked, reported, evaluated, and controlled in an integrated manner.

Action.—The requirement for identification of all nonmetallic materials, their location, weight, and surface area, has been imposed on all organizations furnishing equipment for use in the crew bay. Prepare means for integrated control over nonmetallic materials.

Planned action completion date or effectivity.—*Identification*: Action was taken for GFE materials by letter AR51-3-11, March 16, 1967; action was taken for CM materials by CCA 1295, March 23, 1967.

Control: For CM—Included in CCA 1361, April 17, 1967; for GFE—To be accomplished by May 31, 1967.

Materials displays for use in integrated control: For CM, action by April 30, 1967; MSC display room started by May 1, 1967; and direction to KSC before May 10, 1967.

Finding No. 1b

Finding.—Test data providing individual combustion properties in environments of 5 psia to 21 psia oxygen were available for 550 of the potentially combustible non-metallic materials identified as possibly being used. Data on higher pressure testing were available only on suit materials, Velcro and flight paper.

Determination.—Flammability test requirements were not standardized at the time the referenced tests were accomplished.

Large numbers of potentially combustible non-metallic materials were used in the fabrication of SC–012 without specific correlated combustibility test data. Test data were available at high O_2 pressures (to 21 psia) to define the combustion characteristics of some of the major materials which contributed heavily to the fires.

Action.—Prepare new nonmetallic material selection criteria that limit the overall selection and placement of materials in the crew bay such that if an ignition should occur, the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of flight and nonflight equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion data or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. 2

Finding.—Raschel Knit, Velcro, TriLock and Polyurethane foams burn about twice as fast (in the downward direction) in 16.5 psia as in 5 psia O_2.

Determination.—The primary fuels for the fire burned over twice as fast in the early stages of the fire in accident conditions (16.5 psia) than in space flight atmosphere for which they were evaluated (5 psia).

Action.—Prepare new non-metallic material selection criteria that limit the overall selection and placement of materials in the crew bay such that if an ignition should occur, the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of flight and non-flight equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion date or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. 3a

Finding.—Laboratory analysis indicate that solvent retention by test specimens was significant. The analyses also indicate that the evaporation characteristics of the solvent is such that vapor concentration fell below the lean flammability limit after 1½ hours.

Determination.—The presence of significant volumes of concentrated vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignitability.

Action.—The Program Office is in the process of preparing new Quality Assurance Requirements to be imposed on the spacecraft contractor which will include provisions for prohibiting the use of dangerous solvents and for limiting to a safe amount and to a proper time those solvents which are *required* for use to accomplish a process within the crew bay.

Action date.—It is expected that the new Quality Assurance Requirements will be completed by May 10 and imposed on the contractor by May 30 effective on Block II spacecraft.

Finding No. 3b

Finding.—Odors similar to that of sour milk and methyl-ethyl-ketone were reported before the fire during suit cabin purge operations.

Thresholds of methyl-ethyl-ketone and isopropyl alcohol detection by smell are approximately .01 percent to .03 percent by volume and concentrations described as strong, irritating or sickening range from 1 percent to 4 percent by volume.

Determination.—There is no evidence that significant concentrations of organic vapors were present in S/C 012 at the time of the fire.

Action.—Technical direction to program contractors covering solvent use and control is being included in the new Quality Assurance Requirements being generated by ASPO. Materials odor criteria per MSC–A–D–66–3 will remain in effect for materials selected for use in the crew bay.

Action date.—It is anticipated that the new Quality Assurance Requirements will be completed by May 10, 1967, and issued to the contractor by May 30, 1967. Effectivity to be for all Block II Spacecraft.

Finding No. 3d

Finding.—Connecting and disconnecting of spacecraft qualified Cobra connectors at normal loads did not create sufficient energy to ignite concentrations up to saturation (approximately 12 percent) of methyl-ethyl-ketone in 16.4 pounds per square inch absolute oxygen. An increase in loading to 2.5 times operating amperage in 4.0 percent of MEK yielded no ignition.

Determination.—Ignition of flammable concentrations of solvent vapors by connecting and disconnecting Cobra connectors is an unlikely ignition source for the SC 012 fire.

Action.—The Block II Command Module design provides the capability of removing electrical power from circuits like the cobra cables, which have to be disconnected in regular operations. Procedures will be applied where switches and circuit breakers are available to dead-face other applications (such as cameras).

Planned action completion date or effectivity.—These design changes will be effective in all Block II spacecraft. Procedures to require dead-facing by utilizing available switches and circuit breakers in other applications are to be required by letter of direction to contractor before May 25, 1967.

Finding No. 3e

Finding.—Preliminary high energy impact tests on Velcro and Raschel Knit 16.5 pounds per square inch absolute oxygen produced ignition and burning.

A survey of similar spacecraft and mockup failed to disclose the possibility of any high impact conditions.

Determination.—None.

Action.—There is no currently available standard test for the S/C conditions available. Contacts are being made with Government and industry organizations to identify such a test procedure for determining the sensitivity of materials in GOX.

Planned action completion date or effectivity.—The information, report and procedure for conducting such tests under representative S/C conditions is expected in May. A report closing this activity is anticipated May 31, 1967.

Finding No. 3g

Finding.—Conditions required for wet-wire fire ignition through electrolytic action are damaged wire insulation, presence of an electrolyte and electric potential between damaged wires and a flammable substance in the proximity. A test has shown that ECS coolant applied to a purposely damaged wire of a type used in the C/M caused a fire.

Determination.—The required conditions could have been present in S/C 012.

Action.—Testing of this nature is continuing. Changes are being made in the ECS to reduce or eliminate coolant leakage.

Planned action completion date or effectivity.—The final report will be issued by May 26.

Finding No. 3h

Finding.—An unpotted connector with some unused pin channels subjected to water/glycol and placed under DC stress developed a short circuit.

Determination.—Water/glycol electro-corrosion products and residue are conductive and capable of acting as an electrolyte.

Action.—Tests were run on representative spacecraft harnesses with joined connectors as used in the spacecraft to determine effects of immersion in water/glycol.

These tests were completed in the laboratory at KSC before April 1, 1967, on five such assemblies without failure. Recommend close out of this item.

Action date.—April 1, 1967.

Finding No. 4a

Finding.—There have been 35 instances of water/glycol leakage on Block I spacecraft involving approximately 320 ounces.

Determination.—The water/glycol distribution system requires corrective action to eliminate leakage.

Finding.—Prior to the accident there had been no electrical system failures attributable to the water/glycol leaks.

Determination.—The electrical system has some tolerance to water/glycol spillage.

Finding.—There is no standard cleaning procedure in effect to remove water/glycol spills or residue.

Determination.—There is a probability that water/glycol residue is present in areas of all Block I spacecraft.

Finding.—Six instances of water/glycol leakage were recorded for S/C 012. Of these, one soaked several SCS connectors and wire bundles. Some corrective action was taken to clean all known spills in S/C 012.

Determination.—Water/glycol residues may have been present in areas of S/C 012, including on wire bundles and connectors.

Action.—In order to prevent future leakage or spillage of water/glycol, protection from abuse is being provided for the coolant joints and lines, and self-checking quick disconnects are being added to the ECU. The Block II design already incorporates improved mechanical fittings. In addition, procedures are being developed to provide a standard method for cleaning water/glycol spills if they should occur.

Planned action completion date or effectivity.—The above actions will be effective for the first Block II spacecraft.

Finding No. 4b

Finding.—Tests in a 14.7 psia oxygen atmosphere on horizontal surface show films of C/M coolant will not propagate a flame before or after air drying for up to 48 hours. Films of coolant will propagate a flame after exposure to reduced pressure for periods of 60 to 80 hours. Pure ethylene glycol will propagate a flame in a similar atmosphere.

Determination.—Residues from previous standard coolant fluid spills in S/C 012 might have provided a path for flame propagation on materials that were wetted. Spills or leaks in the early stages of the fire would burn when heated.

Action.—The Block II design already incorporates improved mechanical fittings. The following changes will be made to the Block II design:

1. Provide structural cover plate protection to all exposed coolant lines in the cabin from manufacturing through flight to prevent inadvertent abuse.
2. Armor those joints in the cabin that cannot be protected adequately by cover plates.
3. Study use of a referee fluid instead of water/glycol for early testing.

Planned action completion date or effectivity.—The above actions will be effective for the first Block II spacecraft.

Finding No. 4d

Finding.—The condition and appearance of individual materials after the 16.5 psia oxygen boilerplate test approximated materials conditions observed in S/C 012. The pressure rise measured in the boilerplate test approximated that in the S/C 012.

Determination.—A reasonable simulation of the S/C 012 accident was achieved by the boilerplate tests.

Finding.—The rate of flame propagation, the rate of pressure increase and the maximum pressures achieved and the extent of conflagration in 5 psia oxygen boilerplate tests was much less severe than observed in the 16.5 psia oxygen boilerplate tests. Burning or charring was limited to approximately 29 percent of the nonmetallic materials by oxygen depletion.

Determination.—The conflagration which occurred in S/C 012 at 16.5 psia would be far less severe and slower in a spacecraft operating with an environment of 5 psia oxygen if additional large quantities of oxygen are not fed into the fire.

Finding.—The early stages of fire propagation in the boilerplate tests were observed to be dependent upon the combustion rate and location of the materials. The observed rates appeared to have been much greater than the factor of two increase measured downward in the laboratory tests when the oxygen pressure is increased from 5 psia to 16.5 psia. The additional increase in rate in the boilerplate tests most likely occurs because of the combined effect of burning upward and along the continuous paths provided by flammable materials. This is substantiated by preliminary results referenced in 8–106.

Finding No. 4d

Determination.—The spread of fire at 16.5 psia operating pressures is too rapid for effective remedial action in spacecraft with combustible materials arranged as in C/M 012. The spread of fire at 5 psia operating pressures is probably too rapid for effective remedial action by an unsuited crewman.

Action.—A nonmetallic materials selection criteria and a preliminary set of implementation guidelines that limit the selection and placement of materials in the crew bay areas have been completed and implemented. After final material selections have been made, tests will be made on a full-scale mockup with the proper atmosphere to assess the fire risk.

Planned action completion date or effectivity.—These tests are scheduled to be completed before any future manned testing (ground or flight) of the modified Block II spacecraft.

Finding No. 4e

Finding.—The energy available from about four ounces of Raschel Knit or Velcro could raise the pressure in a closed C/M from 16.5 psia to 36 psia in less than 14 seconds after ignition. (Calculations assume complete combustion and adiabatic conditions.)

Determination.—There was considerable excess combustible material available with which to raise the C/M pressure to the estimated burst pressure.

Finding.—Teflon materials did not burn appreciably in S/C 012. Calculations based on laboratory data indicate the Teflon could not have contributed appreciably to the rate of pressure rise. The total energy available from the Raschel Knit, Velcro, foam, Trilock, and polyurethane materials was much greater than necessary to raise the cabin pressure from 16.5 psia to 36 psia.

Determination.—Teflon provides an insignificant fire risk.

Action.—A nonmetallic materials selection criteria and a preliminary set of implementation guidelines that limit the selection and placement of materials in the crew bay areas have been completed and implemented. After material selections have been made, tests will be made on a full-scale mockup with the proper atmosphere to assess the fire risk.

Planned action completion date or effectivity.—These tests are scheduled to be completed before any future manned testing (ground or flight) of the modified Block II spacecraft.

Finding No. 5a

Finding.—The NAA material selection specification MAO 155–008 requires only that a material pass a 400° F spark ignition test in 14.7 psia oxygen.

Determination.—The NAA criteria for materials flammability control were inadequate.

Finding.—A system for control of nonmetallic materials usage existed at NAA during the design, fabrication and assembly of C/M 012. The NAA materials control system is design oriented.

Determination.—The system is permissive to the extent that controls over the installation or use of flammable materials are not adequate.

Finding.—There were nonflight items containing combustible materials in C/M 012 during this test.

Finding.—No flammability criteria or control existed covering nonflight items installed in C/M 012 for test.

Determination.—Lack of control of nonflight material could have contributed to the fire.

Action.—Prepare new nonmetallic materials selection criteria that limit the selection and placement of materials in the crew bay such that if a fire should start that the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion date or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. 5b

Finding.—The NASA material selection criteria MSC–A–D–63 and MSC–A–D–66–4 requires that a material pass a 400° F spark ignition test and a 0.5 in/sec combustion rate (measure downward in 5 psia O_2). Raschel Knit and Velcro (hook) pass this test.

Determination.—The NASA criteria for materials flammability control are not sufficiently stringent.

Finding.—The system for control of nonmetallic material usage at MSC during the design and development of government furnished equipment used in C/M 012 depended on identification of noncompliance with criteria by the development engineers.

Determination.—The NASA materials control system is permissive to the extent that installation or use of flammable materials were not adequately reviewed by a second party.

Finding.—The NASA criteria were intended to limit the use of Velcro and Uralane foam to distances greater than 12 inches from wire bundles.

Finding.—Nonmetallic material selection criteria utilized by NAA and NASA are not consistent. The NASA criteria, although more stringent, were not contractually imposed on the S/C contractor.

Determination.—Materials were evaluated and selected for usage in C/M 012 using different criteria. Application of the NASA criteria to the C/M would have reduced the amount of the more flammable materials (Velcro and Uralane foam).

Finding.—Visual "walk-through" inspections had resulted in removal of combustibles in proximity of wire bundles on S/C 012 before delivery and on C/M 008 before manned testing. Such inspection had not been made before OCP FO–K–0021–1.

Determination.—Visual inspections have resulted in removal of combustible material from potential ignition sources (wire bundles).

Action.—Prepare new nonmetallic material selection criteria that limit the overall selection and placement of materials in the crew bay such that if an ignition should occur, the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of flight and nonflight equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion date or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. 5c

Finding.—Alternate materials which are nonflammable or significantly less flammable than those used on C/M 012 are available for many applications.

Determination.—The amount of combustible material used in Command Modules can be limited.

Action.—Prepare new nonmetallic material selection criteria that limit the overall selection and placement of materials in the crew bay such that if an ignition should occur, the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of flight and nonflight equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion date or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. 6

Finding.—Current information and displays of the potentially flammable materials configuration of S/C 012 was not available prior to the fire.

Finding.—A centralized source for materials data was established for the Board Panel 8 (Materials Review).

Determination.—Maintenance of data and displays at central locations and test ... for management visibility and control of flammable materials is feasible ... useful.

Action.—Action has been taken to establish materials information desks, including materials usage displays, at MSC, KSC, NAA and GAEC.

Training films and motivation aids are being prepared for orientation briefings of contractor and Government personnel. The CARR and FRR hardware milestone will continue to have materials reviews and walk through inspections as a portion of the proceedings. The criteria used will be the ASPO–RQTD–D67–5 criteria. The date on which the information desks will have been implemented is May 15.

Action date.—An interim report is anticipated May 31. CARR and FRR reports will be issued prior to the vehicle milestones.

Panel 9

DESIGN REVIEWS

No action required on findings a3, b1, b2, and d1.

Finding No. a(1)

Finding.—Flammable, non-metallic materials are used throughout the spacecraft. In the Block I and Block II spacecraft design combustible materials exist contiguous to potential ignition sources.

Determination.—In the Block I and Block II spacecraft design, combustible materials are exposed in sufficient quantities to constitute a fire hazard.

Action.—Prepare new non-metallic material selection criteria that limit the overall selection and placement of materials in the crew bay such that if an ignition should occur, the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of flight and non-flight equipment intended for use in the crew bay and prepare detailed guidelines to assist in material selection and placement to meet the requirements of the overall criteria.

Planned action completion date or effectivity.—Overall criteria completed and implemented. Preliminary detailed guidelines prepared and under review.

Finding No. a(2)

Finding.—Malfunctions and failures can produce ignition sources in the Command Module.

Determination.—An ignition source in the presence of combustibles in the cabin atmosphere constitutes a fire hazard.

Action.—An iguition source review of all Block II spacecraft circuits has been conducted. Several actions have been taken to reduce the possibility of the Command Module wire harnesses representing a potential ignition source.

1. Circuit protection of all Block II electrical circuits has been reviewed. Changes are being made to ensure that circuit protection meets our criteria to prevent exessive electrical currents and overheated wires in case of failures.

2. A system that provides for the incorporation of changes at selected times in the manufacturing and checkout operations has been adopted. These times are optimized to insure maximum validation and verification of the spacecraft configuration.

3. A mandatory inspection plan has been initiated to assure 100 percent coverage of pertinent items at appropriate times.

4. Protective covers will be utilized during all phases of harness installation, subsequent manufacturing and checkout, and flight.

Planned action completion date or effectivity.—April 13, 1967.

Finding No. a(4)

Finding.—This space suit contains power wiring to electronic circuits; also the astronauts could be electrically insulated.

Determination.—Both the power wiring and potential for static discharge constitute possible ignition sources in the presence of combustible materials. The wiring in the suit could fail from working or bending.

Action.—Suit circuits are adequately protected by circuit breakers. Suit material will be selected to assure that its static charge potential is sufficiently low to prevent buildup of enough surface energy to create a static discharge problem.

Planned action completion date or effectivity.—Effective on first suits used for manned flight.

Finding No. a(5)

Finding.—Eighteen electrical circuits in Spacecraft 012 did not adhere completely to wire size/load/circuit protection design criteria.

Determination.—The condition was examined from the standpoint of overheating, and no problem was found to exist.

Action.—North American Aviation, Inc. has reviewed the Block II wire/circuit breaker compatibility and is making all necessary changes to meet the requirements.

Planned action completion date or effectivity.—May 15, 1967.

Finding No. a(6)

Finding.—Residues of RS89 (inhibited ethylene glycol/water solution) after drying are both corrosive and combustible. RS89 is corrosive to wire bundles because of its inhibitor.

Determination.—Because of the corrosive and combustible properties of the residues, RS89 coolant could in itself provide all of the elements of a fire hazard if leakage occurs onto electrical equipment.

Action.—Action is being taken to prevent future spillage and leakage of water/glycol in Block II Spacecraft by protecting joints and plumbing, the use of quick disconnects with check valves, and improved mechanical fittings and torquing procedures. In addition, procedures have been developed to provide an improved method for cleaning water/glycol spills if they should occur.

Planned action completion date or effectivity.—Effective first Block II spacecraft.

Finding No. a(7)

Finding.—Water/glycol is combustible, although not easily ignited.

Determination.—Leakage of water/glycol in the cabin increases the risk of fire.

Action.—The following changes will be made to the Block II design:

1. Provide structural cover plate protection to all exposed coolant lines from manufacturing through flight to prevent inadvertent abuse.
2. Armor those joint that cannot be protected adequately by cover plates.
3. Study of use of a referee fluid instead of water/glycol for early testing.

Planned action completion date or effectivity.—Effective first Block II spacecraft.

Finding No. a(8)

Finding.—Deficiencies in design, manufacturing, and quality control were found in the post-fire inspection of the wire installation.

Determination.—There was an undesirable risk exposure which should have been prevented by both the contractor and the Government.

Action.—1. The improvements previously incorporated in the Block II spacecraft, such as improved wire bundle fabrication (using 3-dimensional jigs) and improved cable routing, have corrected most of the problems revealed in the 204 investigation.

2. We are adding protective covers over exposed wiring.

3. We have carried out a full review of the Block II spacecraft wiring. Deficiencies found were minor and are being corrected.

Planned action completion date or effectivity.—Effective first Block II spacecraft.

Finding No. a(9)

Finding.—The Environmental Control System is plumbed with aluminum tubing in both the water/glycol and oxygen circuits. Joints in the plumbing are made by nickel plating the aluminum and joining the nickel-plated surfaces with a tin-lead solder. Leakage of the ECS coolant from these joints has been experienced in the Apollo spacecraft.

Determination.—The design of the soldered joints is inadequate to cope with all the conditions experienced in the spacecraft.

Action.—The following changes will be made to the Block II design: 1. Change oxygen tubing in the cabin which has solder joints to stainless steel with brazed joints.

2. Provide structural cover plate protection to all exposed coolant and oxygen lines from manufacturing through flight to prevent inadvertant abuse.

3. Eliminate joints where possible by combining line segments.
4. Armor those coolant joints that cannot be protected adequately by cover plates.

Planned action completion date or effectivity.—Effective on first Block II spacecraft.

Finding No. b(3)

Finding.—Flammability characteristics of non-metallic materials are varied by only a factor of 3 or 4 by diluents in atmospheres containing oxygen at 3 to 5 pounds per square inch partial pressure.

Determination.—Previous analysis leading to the decision to use 5 pounds per square inch absolute pure oxygen cabin environment in space are still valid.

Action.—The use of 5 pounds per square inch absolute pure oxygen cabin environment in space will be continued.

Planned action completion date or effectivity.—April 10, 1967.

Finding No. c(1)

Finding.—Sixty seconds are required for unaided crew egress from the Command Module. The hatch cannot be opened with positive cabin pressure above approximately 0.25 pounds per square inch. The vent capacity was insufficient to accommodate the pressure buildup in the Apollo 204 Spacecraft.

Determination.—Even under optimum conditions emergency crew egress from Apollo 204 Spacecraft could not have been accomplished in sufficient time.

Action.—The spacecraft contractor has been directed to provide an outward opening side hatch capable of quick opening from the inside or outside even with large internal pressures. An additional depressurization valve is being incorporated.

Kennedy Space Center is modifying the Apollo Access Arm to be compatible with the redesigned hatch and quick crew egress requirements.

Planned action completion date or effectivity.—The Command Module hatch modifications are planned to be on the first Block II spacecraft. The modified access arm will be installed for the first flight spacecraft.

Finding No. c(2)

Finding.—Review of the Egress Process: The access arms to the Command Module in Launch Complexes 34 and 39 contain flammable materials, are removed thirty minutes prior to launch, and their doors open the wrong way for easy egress.

Determination.—The access arm could constitute a fire hazard and imposes delays to emergency crew egress.

Action.—1. The arm retraction sequence is to be changed to rotate the arm to a park position near the latch position at T minus 30 minutes to permit quick return to the Command Module. A few seconds before launch it will be swung to the stowed position.

2. The following actions to replace flammable materials and provide a better egress route are underway.

a. Provide fire resistant materials inside Apollo Access Arm cab.

b. Provide less cumbersome path from CM into Apollo Access Arm cab.

c. Provide 2-way swinging doors in two places on Apollo Access Arm and on Apollo Access Arm cab.

d. Eliminate the step which presently exists on each end of Apollo Access Arm.

Planned action completion date or effectivity.—November 1, 1967.

Finding No. d(2)

Finding.—During the Apollo 204 test, difficulty was experienced in communicating from ground to spacecraft and among ground stations.

Determination.—The ground system design was not compatible with operational requirements.

Action.—The Ground Communication System has been reviewed. Changes will be made to (a) reduce the number of stations on those critical loops which are now being overloaded during peak periods, (b) introduce some design changes to assure reliable operation of the present circuits and equipment, (c) add four-wire intercommunications equipment to provide full duplex links among the flight crew, the Blockhouse, the Spacecraft Checkout station, and the Houston Mission Control Center.

Planned action completion date or effectivity.—Prior to launch pad manned tests of the space vehicle for the first manned mission.

PANEL 10

ANALYSIS OF FRACTURE AREAS

No action required on findings 1 through 9.

Finding No. 10

Finding.—Several aluminum tubes were parted at soldered joints at couplings.

Determination..—The soldered aluminum joints at unions will fail if the solder is raised to its melting point of approximately 360° F. The soldered aluminum joints at couplings were not adequate for the temperatures attained during the fire.

Action.—Aluminum oxygen lines with solder joints in the cabin will be replaced by stainless steel lines with brazed joints. The coolant system plumbing has been reviewed to eliminate solder joints where possible. The remaining solder joints which are exposed will be protected by armor plating. Protective covers will be provided for all exposed plumbing.

Planned action completion date or effectivity.—Changes effective on the first Block II spacecraft.

PANEL 11

MEDICAL ANAYLSIS

No action required on findings 1 through 6, 8 through 12, and 16 through 20.

Finding No. 7

Finding.—Hatches were opened at approximately 6:36 pm EST (23:36 GMT) and no signs of life were detected. Three physicians viewed the suited bodies at approximately 6:45 pm EST (23:45 GMT) and decided that resuscitation efforts would be to no avail.

Determination.—Time of death cannot be determined from this finding.

Action.—Occupants normally assigned to duty in the White Room or other high risk areas will be properly trained in rescue and resuscitation procedures and will be supported by professional medical personnel stationed in the rear vicinity. Training and practice will be scheduled on a regular basis and all emergency procedures will be reviewed prior to the conduct of any test determined to be hazardous.

Planned action completion date or effectivity.—Plan to be implemented immediately.

Finding No. 13

Finding.—The Environmental Control System contains activated charcoal which, if heated, will produce CO.

Determination.—It is the opinion of Panel 5 that heating of the CO_2 canister occurred late in the progress of the fire after significant levels of CO were already present in the cabin atmosphere, and after at least one suit had failed.

Action.—Carbon monoxide (CO) produced by over heating the activated charcoal in the carbon dioxide (CO_2) canister can constitute a hazard only after an intense fire has progressed for a sufficient period in the Environment Control System. This effect is therefore considered to be a secondary effect of a fire which can be obviated by eliminating the possibility of fire. Organic materials in the Environmental Control System will be inventoried and controlled by new specifications.

Planned action completion date or effectivity.—May 31, 1967.

Finding No. 14

Finding.—The distribution of CO in various organs indicates that circulation stopped rather abruptly when high levels of carboxyhemoglobin reached the heart.

Determination.—Loss of consciousness was due to cerebral hypoxia due to cardiac arrest, due to myocardial hypoxia. Factors of temperature, pressure and environmental concentrations of carbon monoxide, carbon dioxide, oxygen and pulmonary irritants were changing at extremely rapid rates. It is impossible to integrate these variables, on the basis of available information with the dynamic physiological and metabolic conditions they produced in order to arive at a precise statement of time when consciousness was lost and when death supervened. The combined effect of these environmental factors dramatically increased the lethal effect of any factor by itself. It is estimated that consciousness was lost between 15 and 30 seconds after the first suit failed. Chances of resuscitation decreased rapidly thereafter and were irrevocably lost within four minutes.

Action.—The reduction of combustible materials in the spacecraft will materially reduce the concentration of toxicants but will not eliminate the hazard completely. Operational procedures and suit ECS integrity are being reexamined to minimize the hazard to the crewman. Occupants normally assigned to duty in the White Room or other high risk areas will be properly trained in rescue and resuscitation procedures and will be supported by professional medical personnel stationed in the near vicinity. Training and practice will be scheduled on a regular basis and all emergency procedures will be reviewed prior to the conduct of any test determined to be hazardous.

Planned action completion date or effectivity.—Prior to resumption of testing.

Finding No. 15

Finding.—All three suits were breeched by fire to some degree.

Determination.—The suits were not capable of providing crew protection in a fire of this intensity.

Action.—The pressure suits are being redesigned to provide for a fireproof or effective fire retardant outer layer. The Apollo space suit over garment originally designed to provide additional thermal and micrometeorite protection while operating on the lunar surface will be made an integral part of the suit. The constant wear garment used by the crews during flight will be fabricated from Beta-cloth, a fiber glass material having superior fire resistant characteristics.

Planned action completion date or effectivity.—Changes will be completed by 1 July 1967 and implemented for LM tests as well as 2TV-1 and subsequent manned flights.

Finding No. 21

Finding.—It was not possible from biomedical and environmental data to accurately construct a time line of environmental conditions or crew activities during this emergency.

Determination.—Available environmental and biomedical instrumentation cannot be considered optimum for a potentially hazardous test or for flight.

Action.—Studies are being conducted to determine the feasibility of expanding the Apollo Bioinstrumentation System to include additional measurements.

Planned action completion date or effectivity.—Feasibility studies will be completed by June 30, 1967.

Finding No. 22

Finding.—Medical examinations of the rescue personnel were made by the Pan American World Airways Dispensary. Breath analysis from the most severe victims of smoke inhalation were negative for gases other than low concentrations of carbon monoxide. Urinalyses for beryllium and chest X-rays were also negative in these men.

Determination.—Medical records indicate that there were no permanent injuries to rescue personnel.

Action.—This item relates to Finding 11–24 which disclosed that the gas masks available were not of proper design for fire fighting. Emergency procedures during all phases of test and flight operations are under review. Proper emergency equipment will be available for any contingency including fire.

Planned action completion date or effectivity.—Action will be completed prior to resumption of testing.

Finding No. 23

Finding.—The purge with 100-percent O_2 at above sea-level pressure contributed to the propagation of fire in the Apollo 204 Spacecraft.

Determination.—This was the planned cabin environment for testing and launch, since prelaunch denitrogenation is necessary to forestall the possibility of bends at the mission ambient pressure of 5 pounds per square inch absolute.

A comprehensive review of the operational and physiological trade-offs of the various methods of denitrogenation is in progress.

Action.—Additional studies are required to weigh the relative merits of a pure oxygen versus other gaseous combinations during launch operations. These studies will include physiological evaluation to assess the bends hazard, mock up fire tests to study fire propagation in the capsule, and time-line studies of flight operational procedures in various suited configurations. While this action will require time, the engineering design is proceeding with a system that will operate on either the 100% O_2 or other gas mode during prelaunch.

Planned action completion date or effectivity.—Approved design changes will be incorporated in 2TV-1.

Finding No. 24

Finding.—Rescue personnel were equipped with gas masks designed for protection against hypergolic vapors. They had no heat-protective garments.

Determination.—Rescue personnel were inadequately equipped for a fire-type rescue.

Action.—Emergency rescue personnel will be equipped with heat protective garments and self contained air breathing apparatus and will be on station in accordance with our revised and more stringent criteria for definition of hazardous procedures. In addition, self-contained breathing apparatus will be stored in emergency equipment lockers at selected levels of the Service Structure and Launch Umbilical Tower.

Planned action completion date for effectivity.—May 31, 1967.

Panel 12

WITNESS STATEMENTS

No action required.

Panel 13

GROUND EMERGENCY PROVISIONS REVIEW

No action required on finding 4.

Finding No. 1

Findings.—The applicable test documents and flight crew procedures for the AS-204 Space Vehicle Plugs Out Integrated Test did not include safety considerations, emergency procedures or emergency equipment requirements relative to the possibility of an internal spacecraft fire during the operations.

Determination.—The absence of any significant emergency preplanning indicates that the test configuration (pressurized 100 per cent oxygen cabin atmosphere) was not classified as a potentially hazardous operation.

Action.—A hazards criteria review instruction is being prepared by the KSC Safety Office. KSC Safety Office will review and approve all OCP's. All spacecraft test procedures will include safety requirements applicable for the specific test. Test sequence within the test procedures that contain hazardous activities or conditions will be specifically and clearly indicated as hazardous. Safety and emergency procedures will be included in the procedures immediately prior to each group of hazardous test sequences.

Planned action completion date or effectivity.—May 15, 1967.

Finding No. 2

Finding.—There are no documented safety instructions or emergency procedures in existence which are applicable to the possibility of a serious internal spacecraft fire.

Determination.—The occurrence of an internal spacecraft fire of the magnitude and intensity experienced in this accident was not considered to be a significant possibility under any operational circumstances.

Action.—A hazards criteria review instruction is being prepared by the KSC Safety Office. The purpose of this instruction is to insure a methodical means of evaluating the hazard level of all procedures by taking into account factors such as materials, test environment, vehicle configuration and personnel placement. The procedures that have been evaluated as hazardous are then compared against a set of checklists to insure compliance with safety practices.

Planned action completion date or effectivity.—The hazards criteria review instruction and checklist will be released on May 15, 1967.

Finding No. 3

Finding.—The propagation rate of the fire involved in the AS-204 accident was extremely rapid (Reference report by Panel 5). Removal of the three spacecraft hatches to effect emergency egress from either the inside or outside involved a minimum of 40 and 70 seconds respectively under ideal conditions.

Determinations.—Considering the rapidity of propagation of the fire and the time constraints imposed by the existing spacecraft hatch configuration, it is doubtful that any amount of emergency preparation would have precluded injury to the crew prior to crew egress.

Action.—We are providing a single, outward-opening, quick-release side hatch for the command module. The essential features of this hatch are:

a. Unified hatch replaces separate pressure and heat shield hatch.

b. Can be manually released even with large internal pressures.

c. Can be operated by the flight crew from the inside or by the ground crew from the outside.

d. Manual operation protects against inadvertent opening.

We are preparing for structural, flotation, and egress tests with the new hatch.

Planned action completion date or effectivity.—A mockup of the design has been reviewed. The new hatch will be installed on the first manned spacecraft.

Finding No. 5

Finding.—The Apollo Flight Crew Hazardous Egress Procedures Manual contains procedures relative to unaided, aided, and incapacitated flight crew egress. By scope and definition, this document is concerned only with evacuation of the flight crew from the spacecraft and the pad under hazardous conditions occurring primarily external to the spacecraft during a launch operation.

Determination.—The Apollo Flight Crew Hazardous Egress Procedures Manual does not contain adequate emergency provisions for significant emergency conditions internal to the spacecraft any time the crew is onboard.

Action.—A Hazardous Egress and Evacuation Working Group (HEEWG) has been established to prepare hazardous egress procedures covering the time period subsequent to completion of space vehicle fueling during CDDT and launch operations at any Apollo/Saturn pad as well as during any simulated launch operations wherein the spacecraft is closed with personnel onboard. The HEEWG will provide guidelines, make recommendations, and develop appropriate plans and procedures as necessary to coordinate and integrate all elements of spacecraft crew egress and operations personnel evacuation.

Procedures are being generated to include actions in the event of internal spacecraft or launch complex associated emergencies and will cover *all* personnel on the launch complex who in any way could affect the emergency operation.

Planned action completion date or effectivity.—Prior to countdown demonstration test on AS-501.

Finding No. 6

Finding.—The spacecraft pad work team on duty at the time of the accident had not been given emergency training drills for combating fires in or around the spacecraft or for emergency crew egress. They were trained and equipped only for a normal hatch removal operation.

Determination.—The spacecraft pad work team was not properly trained or equipped to effect an efficient rescue operation under the conditions resulting from the fire.

Action.—Plans have been formulated to locate emergency equipment, including self contained breathing apparatus, at the launch complexes and to train spacecraft pad work team members in the correct use of this equipment for immediate reaction to emergencies.

Planned action completion date or effectivity.—May 31, 1967.

Finding No. 7

Finding.—There was no equipment onboard the spacecraft designed to detect or extinguish a cabin fire.

Determination.—The flight crew had to rely upon physiological cues to detect the presence of a fire. When all face masks were closed, the cues were limited to sight and touch. Once detected, there were no means by which the fire could have been contained or extinguished.

Action.—We are continuing to test possible fire detection systems and have placed increased emphasis on this area since the Apollo 204 accident. At this time we have not found a system which provides significant advantages over the crew's ability to detect fires and which can meet the other requirements for manned spacecraft systems.

We plan to provide a portable fire extinguisher for the spacecraft. The design now under review consists of a hose and nozzle connected to the spacecraft water supply.

We will provide emergency breathing oxygen masks for crew protection from smoke and toxic fumes.

Planned action completion date or effectivity.—Fire extinguisher and oxygen masks effectivity on 2TV-1 and first manned spacecraft.

Finding No. 8

Finding.—Frequent interruptions and failures had been experienced in the overall communications system during the operations preceding the accident. At the time the accident occurred, the status of the system was still under assessment.

Determination.—The status of the overall communications system was marginal for the support of a normal operation. It cannot be assessed as adequate in the presence of an emergency condition.

Action.—The Ground Communication System has been reviewed. Changes will be made to (a) reduce the number of stations on those critical loops which are now being overloaded during peak periods, (b) introduce some design changes to assure reliable operation of the present circuits and equipment, (c) add four-wire intercommunications equipment to provide full duplex links among the flight crew, the Blockhouse, the Spacecraft Checkout station, and the Houston Mission Control Center.

Planned action completion date or effectivity.—Prior to first manned launch.

Finding No. 9

Finding.—Emergency equipment provided at the spacecraft work levels consisted of portable CO_2 fire extinguishers, Rocket Propellant Fuel Handler's gas masks and 1¼'' fire hoses.

Determination.—The existing emergency equipment was not adequate to cope with the condition of the fire. Suitable breathing apparatus, additional portable CO_2 fire extinguishers, direct personnel evacuation routes and smoke removal ventilation are significant items which would have improved the reaction capability of the personnel involved.

Action.—Safety equipment lockers equipped with emergency equipment i.e., air breathing apparatus, additional fire fighting equipment, medical equipment will be installed at selected levels of the Service Structure and Umbilical Tower. Steps are being eliminated and doorways reconfigured to incorporate 2-way swinging doors in order to aid rapid crew egress through the Apollo Access Arm. A slide wire escape system is being provided from the Apollo Access Arm level of the umbilical tower to a point on the ground 600 feet away from the base of the tower. Smoke removal ventilation is being provided in the Environmental Chamber of the Apollo Access Arm. The total launch crew will be trained for emergency conditions using this equipment.

Planned action completion date or effectivity.—Safety lockers with emergency equipment will be installed by May 31, 1967. Slide wire escape system and Apollo Access Arm modifications will be installed by November 1, 1967.

Finding No. 10

Finding.—There are steps and doorways on the Launch Complex 34 Apollo Access Arm and in the environmental enclosure (White Room) which constitute safety hazards, particularly under emergency conditions.

Determination.—The present configuration of the Access Arm and White Room is not compatible with emergency personnel evacuation requirements or with fast, safe flight crew egress.

Action.—The doorways are being reconfigured to incorporate 2-way swinging doors.

The Environmental Chamber is being lowered to eliminate the step from the chamber to the Apollo Access Arm. The umbilical tower platform is being modified to eliminate the step at the end of the arm next to the umbilical tower.

Planned action completion date or effectivity.—November 1, 1967.

Finding No. 11

Findings.—During the preparation of spacecraft test procedures at KSC, safety considerations for hazardous operations and documentation of applicable emergency procedures are limited in most cases to routine safety reference notations and emergency power-down instructions.

Determination.—Insufficient emphasis is applied by the test procedure originator upon documenting emergency procedures and identifying specific hazards and applicable safety requirements.

Action.—Spacecraft test procedures at KSC will now include safety requirements applicable for the specific test. Test sequences within the test procedure that contains hazardous activities or conditions will be specifically and clearly indicated as hazardous. Safety considerations and emergency procedures will be included in the test procedures immediately prior to each group of hazardous test sequences. Emergency procedures manuals will be referred to in the spacecraft test procedures where applicable as the source of definition of required follow-up action in an emergency situation. A Launch Operations directive is being developed to provide guidelines for the inclusion of the above items into the test procedures.

Planned action completion date or effectivity.—1 July 1967.

Finding No. 12

Finding.—Under the existing method of test procedure, processing at KSC, the cognizant Safety Offices review only those procedures which are noted in the OCP outline as involving hazards. Official approval by KSC and AFETR Safety is accomplished after the procedure is published and released.

Determination.—The scope of contractor and KSC Safety Office participation in test procedure development is loosely defined and poorly documented. Post-procedure-release approval by the KSC Safety Office does not insure positive and timely coordination of all safety considerations.

Action.—In the future, all tests in a closed, oxygen rich environment will be considered hazardous. The contractor safety engineer will continue to review all procedures and make recommendations to KSC Safety on hazardous content. KSC Safety Office will receive and approve *all* procedures before publication.

Planned action completion date or effectivity.—The above system is in effect at the present time.

Finding No. 13

Finding.—Criteria for defining hazardous test operations are not complete.

Determination.—A positive method does not exist for insuring identification and documentation of all possible hazards involved in test operations.

Action.—A hazards criteria review instruction is being prepared by the KSC Safety Office. The purpose of this instruction is to insure a methodical means of evaluating the hazard level of all procedures by taking into account factors such as materials, test environment, vehicle configuration and personnel placement. The procedures that have been evaluated as hazardous are then compared against a set of checklists to insure compliance with safety practices.

Planned action completion date or effectivity.—The hazards criteria review instruction and checklist will be released on May 15, 1967.

Finding No. 14

Finding.—Requirements for the review and concurrence of KSC S/C Test Procedures by MSC are not well defined.

Determination.—The present review system does not insure that MSC concurs with released KSC test procedures.

Action.—The OMSF Apollo Program Director has issued an Apollo Program Directive which will ensure that the necessary control and lead time is provided for test procedure preparation and approval. This directive requires formal signature approval by MSC on all test procedures involving flight crew participation.

Planned action completion date or effectivity.—Action is in effect now.

PANEL 14

SECURITY OPERATIONS

No action required on findings 1, 2, and 3.

Finding No. 4

Finding.—Apollo Preflight Operations Procedures (APOP) 0-201, dated October 17, 1966, and January 24, 1967, concerning access control of test and work areas, required that: (1) access controls to spacecraft work areas be exercised by the contractor; (2) the contractor maintain a log of all personnel permitted access during "off-shift"/non-work periods; (3) the contractor control Command Module ingress-egress, and maintain a log concerning same.

Determination.—The procedures established in the APOP were not followed in that: (1) The contractor failed to exercise adequate access control on the fifth, sixth, and seventh spacecraft levels; (2) the contractor failed to maintain an "off-shift" log; (3) the command module ingress-egress log was inadequately maintained.

Action.—KSC Spacecraft Operations will ensure that the contractor performs as required by the APOP.

Planned action completion date or effectivity.—Action in effect now.

Finding No. 5

Finding.—The investigative program which was used as the basis for authorizing access to LC 34, consisted of a determination that a National Agency Check (NAC) investigation had been conducted on each Government or contractor employee. In the absence of a NAC, an escort was required. (Similar provisions existed at the Mission Control Center, Houston.)

Determination.—This practice provides inadequate support for the objective of NASA management that great care be taken to assign reliable and trustworthy persons to perform critical work during mission periods.

Action.—Reviews of the security programs for control of personnel performing critical work during mission periods have resulted in a pilot program of increased clearance procedures. It consisted of a check of pertinent files of appropriate Federal agencies not checked during the course of a National Agency Check. This pilot program has just been completed. Preliminary analysis indicates that such a program presents real advantages. The pilot program of additional clearance procedures is being expanded immediately to apply to all applicable personnel.

Planned action completion date or effectivity.—Action is in effect now.

Finding No. 6

Findings.—*a.* Access to the Astronaut Quarters and the Suiting Room was limited by an access list attached to the Security Post Orders, to those few people having an official reason to be there, i.e., astronauts, biomedical people, suit technicians, etc. Compliance with this procedure was enforced by KSC uniformed security patrolmen. The Van used to transport the astronauts from their Quarters to Launch Complex was inspected, driven, and remained under the control of KSC Security personnel when astronaut activity was involved. Uniformed security personnel escorted the Van when astronauts were being transported.

b. The purchase, handling, and delivery of the astronauts' food (non-flight) served in their Quarters is processed through the contractor's routine channels.

c. Only the results of an NAC are available to NASA management in their evaluation of the reliability and trustworthiness of support personnel in the Astronaut Quarters.

Determination.—*a.* The personnel access controls for the Astronaut Quarters, the Suiting Room, and the Van were adequate.

b. Inadequate safeguards are provided concerning the purchase, handling, and delivery of astronauts' food (non-flight), notwithstanding the fact that it is known by persons coming in contact with it that it is to be consumed by the astronauts.

c. NASA management has insufficient knowledge to fully evaluate the reliability and trustworthiness of support personnel in the Astronaut Quarters.

Action.—*b.* The KSC Security Officer and the MSC Chief, Mission Support Office at Cape Kennedy, have already begun discussions aimed toward assuring adequate protective measures involving purchase, handling, and delivery of astronaut food (nonflight). They will consult with other appropriate personnel including medical personnel to help define potential problems and to help define critical time periods.

c. In a meeting at NASA Headquarters on February 9, 1967, concerning Apollo Security matters, General Phillips directed the KSC Security Officer to establish procedures providing for a full field investigation on support personnel in the Astronaut Quarters.

Planned action completion date or effectivity.—*b.* The protective measures will be implemented prior to the arrival of the crew assigned to the next manned mission.

c. The KSC Security Officer will cause full field investigations to be accomplished as directed by General Phillips prior to the arrival of the crew assigned to the next manned mission.

PANEL 15

BOARD ADMINISTRATIVE PROCEDURES

No action required.

PANEL 16

SPECIAL TESTS

No action required.

PANEL 17

FINAL BOARD REPORT

Not applicable to panel finding action.

PANEL 18

INTEGRATION ANALYSIS

No action required.

PANEL 19

SAFETY OF INVESTIGATIONS

No action required.

PANEL 20

IN-FLIGHT FIRE EMERGENCY PROVISIONS REVIEW

No action required on finding 2.

Finding No. 1

Finding.—An in-flight fire procedure was published and available to the crew for the Apollo 204 Mission. The procedure was analyzed with reference to the Apollo 204 Command Module 012 configuration.

Determination.—Based on this review, it is the judgment that the existing in-flight fire procedures are deficient in the following areas:

a. The cabin fans should be turned off as the first item of the procedural checklist. This may help prevent the spread of a fire by minimizing cabin air currents.

b. The procedure should have specified the length of time to keep the cabin depressurized to insure the fire had been extinguished and that all materials had cooled to below their ignition temperature.

Action.—In-flight fire procedures available to the crewmen utilized the existing hardware to reduce cabin pressure to ambient conditions. Based on the AS-204 experience, procedural steps will be rearranged to expedite extinguishing a fire.

We are providing a portable fire extinguisher for use by the crew in the cabin. The design now under review consists of a hose and nozzle connected to the spacecraft water supply.

We are providing emergency breathing oxygen masks for crew protection from smoke and toxic fumes.

Planned action completion date or effectivity.—It is planned that action will be completed and effective on 2TV-1 and the first manned spacecraft.

Finding No. 3

Finding.—Coordination with Panel 8, Materials Review, and Panel 5, Origin and Propagation of Fire, indicates many materials combustible in 100% 5 psi oxygen were on board Apollo 204 Command Module 012.

Determination.—It is the judgment of the Panel that these materials would yield a dangerous propagation rate in case of fire in the Command Module during the boost, orbital and entry phases of flight.

Action.—Prepare new non-metallic materials selection criteria that limit the selection and placement of materials in the crew bay such that if a fire should start that the resulting fire in the crew bay area cannot propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft. Impose such a criteria on all suppliers of equipment intended for use in the crew bay.

Action completion dates.—Preliminary criteria completed—ASPO-RQTD-67D-5, dated April 10, 1967. Imposed on NAA by CCA 1361, April 17, 1967. To be imposed on GAEC by CCA—Expected April 28, 1967. To be imposed on GFE Manager by Memo—Expected April 28, 1967.

Finding No. 4

Finding.—Lengthy suit donning times were incompatible with fire propagation times.

Determination.—The published in-flight fire procedure was impractical in view of the rapid fire propagation rate expected for an Apollo 204 in-flight fire.

Action.—Materials changes are being made to prevent rapid propagation of fire in the cabin. When the final materials selections are made, full-scale Command Module mockup tests with the appropriate atmospheres will be conducted to demonstrate the reduced fire hazard.

We are also providing a portable fire extinguisher for use by the crew in the cabin. The design now under review consists of a hose and nozzle connected to the spacecraft water supply.

We will provide emergency breathing oxygen masks for crew protection from smoke and toxic fumes while out of their suits.

Planned action completion date or effectivity.—Effectivity on 2TV-1 and first manned spacecraft.

Finding No. 5

Finding.—The Command Module depressurization times from 5 pounds per square inch to 0.5 pounds per square inch can vary from 1 minute and 45 seconds to 3 minutes and 20 seconds based on the flight phase ambient pressure.

Determination.—The depressurization time is too slow to effectively combat a cabin fire.

Action.—We are providing an outward-opening hatch that can be quickly released even with large internal pressures. The new hatch also contains a vent valve system to decrease depressurization time.

Planned action completion date or effectivity.—The hatch redesign is to be completed for the first manned spacecraft.

Finding No. 6

Finding.—The emergency cabin repressurization time from a vacuum to 3.5 pounds per square inch is 35 minutes.

Determination.—The time required to repressurize the cabin to a minimum acceptable pressure is excessive in view of the possible fire damage to the closed loop pressure suit circuit.

Action.—CCA 1315 has been submitted to provide an additional gaseous oxygen surge tank in the command module. The new surge tank will permit repressurization from zero to three pounds per square inch in one minute. The design concept has been reviewed and accepted with the hardware change in progress.

Planned action completion date or effectivity.—The change is effective on Spacecraft 2TV-1 and subsequent.

Finding No. 7

Finding.—Actuation of the suit circuit return valve, the cabin repressurization valve, and emergency cabin repressurization valve are critical in producing an adequate cabin decompression and subsequent repressurization.

Determination.—The placement of ECS controls and displays complicates the execution of the existing in-flight fire procedure.

Action.—CCA 1311 has been submitted to provide improved accessability to the environmental system controls for normal and emergency operations. The location and design of the controls has been submitted by NAA and accepted by the Crew System Division.

Planned action completion date or effectivity.—The change is effective on Spacecraft 2TV-1 and subsequent.

Panel 21

S/M DISPOSITION

Not applicable.

Summary

NASA has taken or is taking specific corrective actions in response to each of the findings of the Panels that were established by the Apollo 204 Review Board. These actions include system validation reassessments, more stringent materials criteria, system and structural design changes, procedural changes for quality control, additional and revised safety and hazardous tests procedures and provisions, and retesting to insure that both redesign performance and the operational procedures are adequate. Certain findings related to communications, structures, and wiring had been recognized in the development of Block I spacecraft and were already being changed in the Block II spacecraft. However, not only the Block II changes but additional design changes and the retest required as a result of the panels' findings have been identified and corrective actions are being or will taken as described in the details of this report. Modifications to the launch complex to enhance safety of personnel are also underway as well as improvements in the ground communication system.

The Apollo mission represents exploration in a hostile environment where inherent risks must be faced. These risks are recognized by NASA and the astronauts and must in turn be recognized and accepted by the Nation. However, we are confident that the changes we are making in our hardware and procedures will enable us to carry out our planned tests and flight operations with maximum astronaut safety and mission success.

APPENDIX 3

Manned Space Flight Report—Block II Spacecraft

Preface

The purpose of this paper is to describe the principal new features of the Block II Command and Service Module as compared to the Block I and the testing planned to validate these changes.

Block II Command and Service Module

INTRODUCTION

The Block II design of the Command and Service Module was initiated in early 1964. The original Command and Service Module design (Block I) had been based on the earth orbit rendezvous mode where no Lunar Module was employed. The basic change between Block I and Block II is the addition of the provision for docking and crew transfer with the Lunar Module. The Block II redesign point was also utilized as a convenient time for the incorporation of design improvement and weight savings changes. At the same time, inflight maintenance as a design philosophy was eliminated.

DIFFERENCES FROM BLOCK I

One of the ground rules used in selecting the changes to be incorporated was that no change would be large enough to require unmanned flight requalification.

Certain subsystems and units were carried over from Block I with no significant change. These are tabulated on Figure 222.

Figure 223 shows new systems that were introduced in the Block II design. To accomplish docking and intravehicular crew transfer, a docking tunnel and a system for mating with the Lunar Module was added. Provisions were added, so that after transposition and docking, the Block II Command and Service Module could be electrically connected to the Lunar Module by umbilicals. This was primarily to enable Lunar Module extraction from the launch vehicle. Provisions were added to allow pressurization by the Command and Service Module to raise the Lunar Module to operating pressure. The functions of docking and separating the Lunar Module from the launch vehicle required the addition of Command Module sequencers. Flush omnidirectional and high gain antennas were also added to the Block II configuration for use with the unified S-Band system.

Figures 224 through 229 show the systems that were changed from Block I to Block II and indicate the type of change incorporated.

CREW SAFETY SYSTEMS

The first manned Apollo flight will be a low earth orbital mission. In such a mission, operation of the Reaction Control System is adequate to bring the spacecraft out of orbit. Therefore, although the main spacecraft propulsion system is available, it is not required to provide mission termination and its operation is not required for a safe flight.

Using safe mission termination as the criteria, the spacecraft subsystems can be classified into two groups: (1) those which are required for crew safety, and (2) those which are required for mission success but not for crew safety.

The crew safety systems are listed in Figure 230. This list represents the systems that must be operative to provide safe recovery of the crew during a mission.

The first three on this list, the Launch Escape, the Emergency Detection Systems and the Sequential Events Control System are unchanged from Block I and, therefore, have been qualified by Little Joe II tests at White Sands Missile

Range, and by the AS-201 and 202 uprated Saturn I flights. The remaining systems have had varying degrees of change and their qualification has been established by the ground test program. In these systems, the major elements have remained unchanged.

In the Earth Landing System, the same parachutes are used but the system is repackaged and the Command Module attachment is changed.

In the Environmental Control System, the basic atmosphere supply system is the same but redundancy has been added.

The Command Module Reaction Control System is the same even though there has been a relocation of some of the elements of the system due to other Block II changes. The Service Module Reaction Control System uses the same engine clusters but the tank capacity has been increased.

The Electrical Power System uses the same fuel cell power plants and batteries but a distribution bus has been added and changes have been incorporated in the radiator configuration.

The Command Module heat shield uses the same basic technology as Block I but thicknesses have been revised and the configuration has been altered. The structure also retains the same basic technology but has been revised to accommodate the Block II changes.

MISSION SUCCESS SYSTEMS

The major systems required for mission success but not for safety of flight are listed in Fgure 231. The first two systems on this list are unchanged from Block I. These are the spacecraft Adapter used to house the Lunar Module and attach the spacecraft to the launch vehicle and the waste management system. The remaining systems have had varying degrees of change but have completed their ground qualification tests.

BACKUP SYSTEMS AND REDUNDANCY

All of the spacecraft subsystems have some component redundancy. This has been required since it is not planned to rely on inflight maintenance to assure continued system operation. In addition to component redundancy, certain systems are internally redundant; that is, they contain two or more paths for accomplishing the system operation. In addition, there is redundancy between systems. Some subsystems act as backup systems to accomplish required operations.

The systems with internal redundancy are listed in Figure 232. The Command Module Reaction Control System contains two independent systems and the Service Module Reaction Control System is configured to allow continued operation even if individual thrusters fail. The Communication System contains multiple links which can be used independently, and this system is not required for safe entry since the required deorbit information is stored on board and periodically updated. The Electrical Power System has redundant batteries, fuel cells and distribution buses. The fuel cells in this system are not required to assure a safe landing since the batteries are adequate for this purpose. The Environmental Control System has separate cabin and suit environments. The Sequential Events Control System contains two completely independent systems. The Emergency Detection System contains internal redundancy and the Earth Landing System has redundant main chutes, drogue chutes and uprighting systems.

Figure 233 lists the backup capabilities for the various systems. The Service Propulsion System (SPS) deorbit function is backed up by the Reaction Control System's capability to accomplish deorbit. The Reaction Control System used in providing attitude control and lift vector control during entry could be backed up by the capability to enter ballistically in an emergency. In this case, the Service Module RCS would be used to provide the necessary spin up. The Guidance and Control System functions on an earth orbital mission are completely backed up by the capabilities of the Stabilization and Control System. This system is, in turn, backed up by the crews' capabilities to manually control the spacecraft.

The systems that have essentially no backup or independent internal redundancy are the Launch Escape System, the Command Module heat shield and certain basic structural elements. It should be noted that the Launch Escape System is a backup system itself and would be used only in the case of launch aborts.

FLIGHT SAFETY SYSTEMS CHANGED IN BLOCK II

There are no significant changes in the Launch Escape System and the Emergency Detection System and therefore, it can be considered that their certification for manned flight has previously been accomplished. The systems involved in flight safety that have been changed in the Block II configuration are given in Figure 234.

The first of these, the Earth Landing System, uses steel risers in Block II and has been repackaged. Figure 235 illustrates this change. These changes have been evaluated by aircraft drop tests.

The change in the Service Module Reaction Control System is that the propellant capacity has been increased by 40% by adding two additional tanks on each of four independent tankage systems. Figure 236 illustrates this change. Existing tanks have been used and the system has been certified by ground test.

The Electrical Power System changes involve wiring and harnessing improvements and changed radiator area to be compatible with Block II power loads. These changes will be throroughly checked by planned ground test evaluations. Figure 237 illustrates the changed radiator configuration.

The Environmental Control System has had changes in Block II both prior to the accident and after the accident. Figure 238 lists the changes prior to the accident and Figure 239 lists the changes we are evaluating since the accident. Of these changes, only the first three on Figure 238 are considered of major importance although all of the changes must be qualified by test. The radiators (Figure 237) were enlarged by 60% and relocated around the base of the Service Module. The secondary cooling loop has been added for critical components as backup cooling. The repackaging of the unit involves both relocation of components and redesign of a heat exchanger. Ground qualification testing and the thermal vacuum chamber tests of the complete installed system will provide the final evaluation prior to flight.

The Command Module structure and heat shield have been changed in several ways. The major change has been that associated with docking capability. Figure 240 is a schematic of the forward Command Module compartment in both Block I and Block II. The Block II configuration has a blunt apex to allow for the docking interface. A second change in structure is caused by the relocation of the Command Module-Service Module umbilical connection. This change has been made to adjust the aerodynamic configuration of the Command Module. Figure 241 shows this basic change. These two changes have required that the inner Command Module structure be altered at the docking tunnel, the forward bulkhead, the parachute attachment and the umbilical locations. The outer structure and heat shield have been altered due to these changes and to allow for the relocation of the other items changed in Block II, such as the RCS thrusters. Another change in the structure system is the change from the inner and outer hatch to the unified hatch design. Figure 242 illustrates this change. These changes will be validated by the ground static and dynamic tests.

The Block II Service Module contains redesigned forward and aft bulkheads, panels and beams which have been tested under static load and in acoustic vibration tests.

The Service Propulsion System has been redesigned in Block II in several areas. A changed oxidizer-fuel ratio has required larger fuel lines and a modification in the tank utilization. The tanks are 11.8 inches shorter and changed in thickness. The gimbal actuator design has been revised to give increased lifetime. The engine injector has a modified pattern and baffles. The ablative thrust chamber design and fabrication technique have undergone minor changes.

These changes have been validated by the engine qualification tests and by ground firings of the complete propulsion system. The flights of AS-201 and 202 have confirmed the ability of these tests to adequately certify changes of this nature.

TEST PROGRAM DESCRIPTION

INTRODUCTION

The development of the spacecraft systems is accomplished by ground test wherever this is possible. Inability to adequately simulate reentry and zero gravity environments makes unmanned flight test development necessary for some spacecraft systems. These systems include the Command Module Heat Shield and the spacecraft propulsion systems. However, the unmanned flights of AS-201 and AS-202 have confirmed the analytical techniques used in system design and the ability of the ground propulsion system testing to validate system changes. Final verification of spacecraft systems, prior to the lunar landing mission, is planned to be accomplished through the flight test program.

The structural system is one that can be more completely evaluated by ground testing than by flight. This is because multiple and controlled conditions of loads can be applied to determine the limits of the structural capability. The flight tests do not normally reach the design loads.

The Environmental Control System can be better evaluated by manned rather than unmanned testing, whether this be on the ground or in flight. This is because its operation is affected by the activities of the crew. A completely satisfactory means of simulating manned loading on the system has not been developed. The development of the Launch Escape System, the Emergency Detection System and the Earth Landing Systems has been accomplished by Little Joe II testing at White Sands Missile Range, by airplane drops and by simulated pad and launch abort tests. The variety of conditions needed for these tests can best be attained by controlled-parameter testing which is not part of a normal flight mission.

MAJOR TEST PROGRAMS

Figure 243 lists the major Block I ground tests by type and Figure 244 lists the White Sands Missile Range flight tests that have been conducted. Figures 245 and 246 list the major Block II ground tests by type. Those listed on Figure 246 have been added as a result of the AS-204 accident. Over 744 major Block I tests and over 200 Block II tests have been conducted. Of the Block I tests, over 500 are directly applicable to Block II. The tests shown on Figures 245 and 246 are of interest here because they represent the additional testing performed on the changes that have occurred on Block II. The first item on Figure 245 represents the test programs for the parachute system. This provides qualification of the system by use of aircraft drop tests. This test provides in effect the invironment that would be experienced on an actual mission. The second item covers tests on the Service Module propulsion system. These have been conducted to evaluate the changes resulting from the changed fuel/oxidizer ratio. The next three items cover the test programs that allow the Service Module structure and the Command Module structure to be tested under environments closely simulating those expected in flight. The Command Module water impact tests allow accurate determination of the design limits. A good simulation of the launch and boost environment can be made now that the flight data from AS-202 and 202 are available. The last test program listed covers the Block II and crew interactions in a thermal vacuum environment which closely simulates that expected in space.

REVISED TEST PROGRAM

Figure 246 lists the revisions and additions that have been made to the test programs as a result of the AS-204 accident. The first test program listed on Figure 246 is an extension of the thermal vacuum testing described on the previous figure. This testing will use the basic Block II configuration with the fire related and safety changes added. Such items as the new hatch seal and armored oxygen lines will be included to determined their performance in an environment closely simulating space conditions.

The second item on Figure 246 provides the functional qualification of the unified hatch design. The postlanding systems operation will expose the Block II to the environments expected at the termination of a flight and verify proper operation of the system.

The acoustic vibration test of the Block II CSM has been added as a result of the board recommendation in this area. The testing should allow detail confirmation of the expected levels of vibration at the subsystem locations and expose the interconnecting systems to the vibration environment. The Block II Service Module structural vibration tests, in conjunction with Block I testing, have already provided the ground qualification of the Block II spacecraft for the vibration environment. The added Block II CSM vibration test recommended by the board should increase our confidence in the overall spacecraft.

The next item on Figure 246 is the materials testing which will continue to evaluate the flammability of materials.

The Command Module fire testing using boilerplate spacecraft represents a new technique in materials testing. The boilerplate is outfitted with various configuration of nonmetallic materials and fires are initiated to obtain information of the mode, rate, and scope of fire propagation. The configurations tested to date have included the Spacecraft 012 materials and the new, less flammable materials in atmospheres of oxygen at several pressures and in air at 14.7 pounds per square inch absolute. This testing will be continued to validate the new approach being used for Block II.

The last two items cover the additional testing to be performed on the extravehicular mobility unit and the environmental control unit to requalify these units with the changed materials and fabrication techniques.

Subsystems and units unchanged for Block II CSM

Launch escape system
Command module reaction control system
Service module reaction control system engine cluster
Fuel cell power plants and entry batteries
Cryogenic oxygen and hydrogen storage system
Sequential events control system
Emergency detection system
Spacecraft LM adapter
Atmosphere supply system
Primary equipment cooling loop
Waste management system
Crew couches
C-band radar transponder
Ordnance devices
Parachutes and recovery aids

FIGURE 222

New subsystems and units in Block II CSM

Docking system	Docking tunnel and probe.
	Umbilical and pressurization.
	Rendezvous radar transponder.
Sequence controllers	LM docking and separation events.
S-Band antennas	Flush omnidirectional.
	High gain.

FIGURE 223

Subsystems and units changed in Block II CSM

Structure:	
Command module	Docking provisions, mechanism and hatch.
	Extravehicular capability.
	CM/SM mechanical connection.
	Scientific airlock available.
Service module	Propellant tanks.
	Empty bay.
	Internal rearrangement.
	Structural redesign.
	Radiator areas.
	RCS mounting panels.

FIGURE 224

Propulsion:	
Service module propulsion system	Mixture ratio.
	Thrust chamber.
	Gimbal actuator.
Service module reaction control	Propellant capacity.
	MMH fuel.

FIGURE 225

Crew support:	
Environmental control system	Redundant cooling loop. Radiator design and area.
Space suit	Apollo suit. Extravehicular capability.
Displays and controls	Panel structure. Electro luminescent lighting. Entry monitor system.

FIGURE 226

Power and communication:	
Electrical power system	Radiator area. Distribution bus added. Cable harnessing. Pyrotechnic initiator. Wire deadfacing at separation.
Unified S-band	Primary mode for all communications. Repackaged. Simultaneous data and tape dump or TV. Electrical redundancy.
Voice VHF	Redundant and duplex.

FIGURE 227

Guidance and control:	
Guidance and navigation	Digital autopilot. Computer repackaged. Electronics repackaged. Navigation base support.
Stabilization and control system	Revised interface. Electronics repackaged. Redundant attitude display.

FIGURE 228

Atmospheric entry and touchdown:	
Heat shield	Redistributed ablative thickness. Truncated apex. Umbilical location. Flush antennas.
Earth landing system	Steel parachute risers. Parachute attach points. Repackaged.

FIGURE 229

Crew safety systems

1. Launch escape system
2. Emergency detection system
3. Sequential events control system
4. Earth landing system
5. Environmental control system
6. Reaction control system
7. Electrical power system
8. Command module heat shield
9. Structure system

FIGURE 230

Mission success systems

1. Spacecraft adapter
2. Waste management system
3. Guidance and control system
4. Stabilization and control system
5. Communications system
6. Displays and controls
7. Service propulsion system

FIGURE 231

Subsystems with internal redundancy

Subsystem	*Major function*
1. CM reaction control system	Attitude control. Lift vector control.
2. SM reaction control system	Attitude control. S-IVB/CSM separation. CM/SM separation.
3. Communications system	Navigation data. Voice, telemetry, and tracking. Recovery.
4. Electrical power system	Electrical power.
5. Environmental control system	Equipment cooling. Cabin environmental control.
6. Sequential events control system	Separation signals. Earth landing functions.
7. Emergency detection system	Launch vehicle malfunction.
8. Earth landing system	Atmospheric descent. Uprighting at impact.

FIGURE 232

Backup system capabilities for earth orbital flight

Subsystem	Major function	Backup
Service propulsion system	Deorbit	SM-RCS; CM-RCS.
Command module reaction control system.	Attitude control	SM-RCS spin up prior to separation for ballistic reentry.
Guidance and control system	Attitude, translation, and lift vector control. Control of SPS burns	Stabilization and control system.
Stabilization and control system	Backup attitude, translation, and SPS control.	Manual.

FIGURE 233

Flight safety systems changed in Block II

1. Earth landing system
2. Service module reaction control system
3. Electrical power system
4. Environmental control system
5. Command module heat shield
6. Structural system
7. Service propulsion system

FIGURE 234

EARTH LANDING SYSTEM

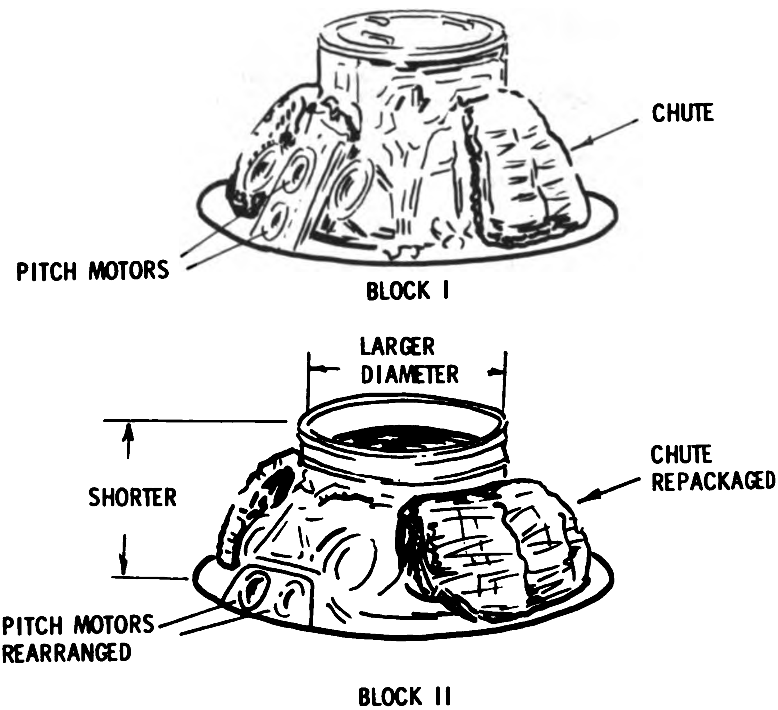


FIGURE 235

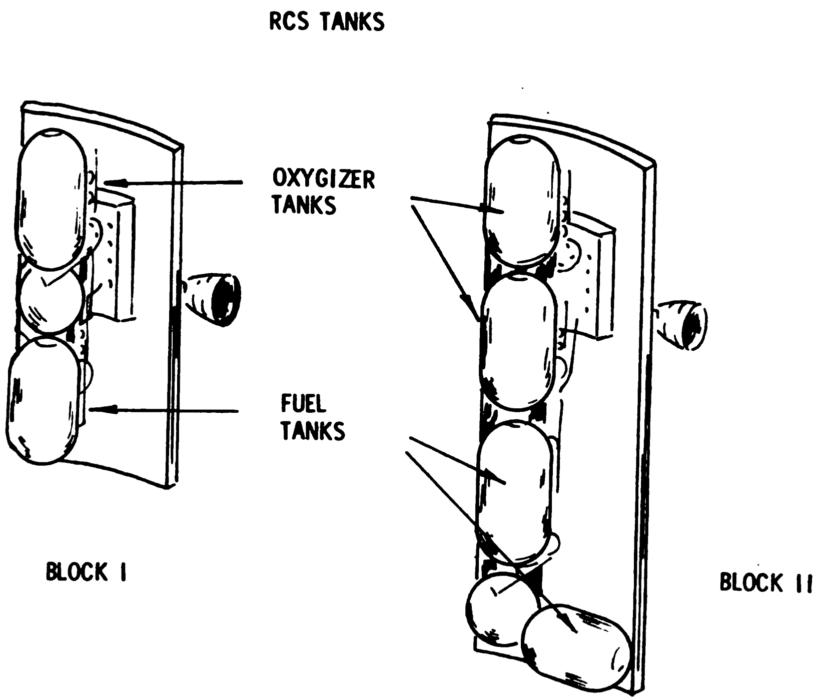


FIGURE 236

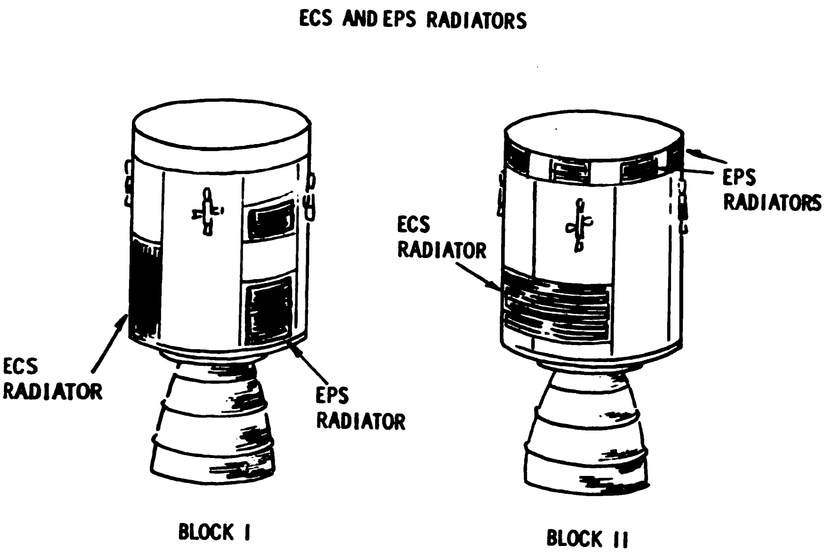


FIGURE 237

ECS changes for Block II prior to AS-204 accident

1. New radiator design:
   Increased size.
   Selective stagnation control.
   Secondary loop tubes.
2. Secondary coolant loop:
   Additional pump.
   Redundant cold plate passages.
3. Repackage environmental control unit (ECU):
   Coolant pumps relocated external to ECU, repackaged and capacity increased.
   Coolant reservoir located external to ECU.
   Redesigned suit heat exchanger.
4. LM pressurization capability.
5. Relocate postlanding ventilation valves.
6. Redesigned steam duct.
7. Added rendezvous radar cold plates in SM.

FIGURE 238

Proposed ECS changes for Block II after the AS-204 accident

Add armor plating to exposed solder joints.
Change soldered aluminum O_2 lines to stainless steel.
Rapid cabin repressurization.
Improve accessibility of selected ECS controls.
Shields for plumbing lines.
Optional use of air in cabin during launch.
Emergency breathing masks.
Quick disconnects added to environmental control unit.
Replace selected materials.

FIGURE 239

FORWARD COMPARTMENT CONFIGURATION

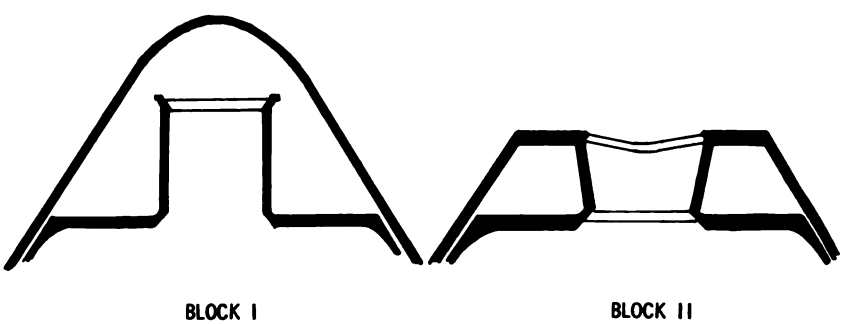


FIGURE 240

CSM UMBILICAL ENTRY CONFIGURATION

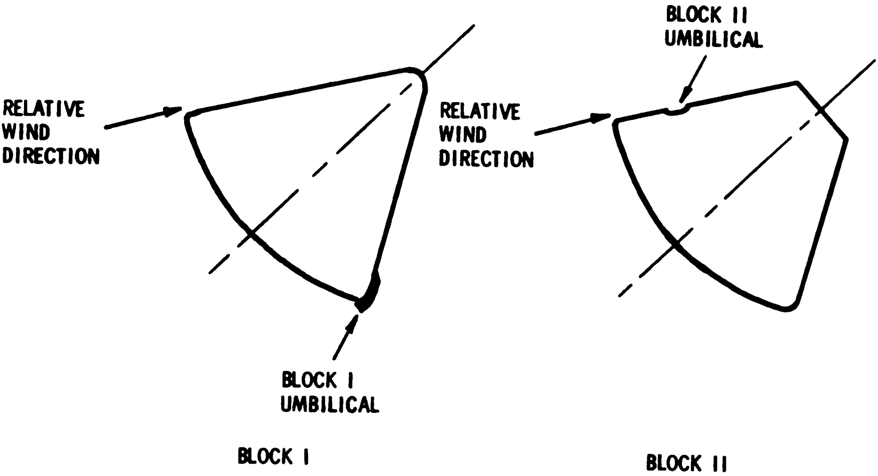


FIGURE 241

CREW HATCH

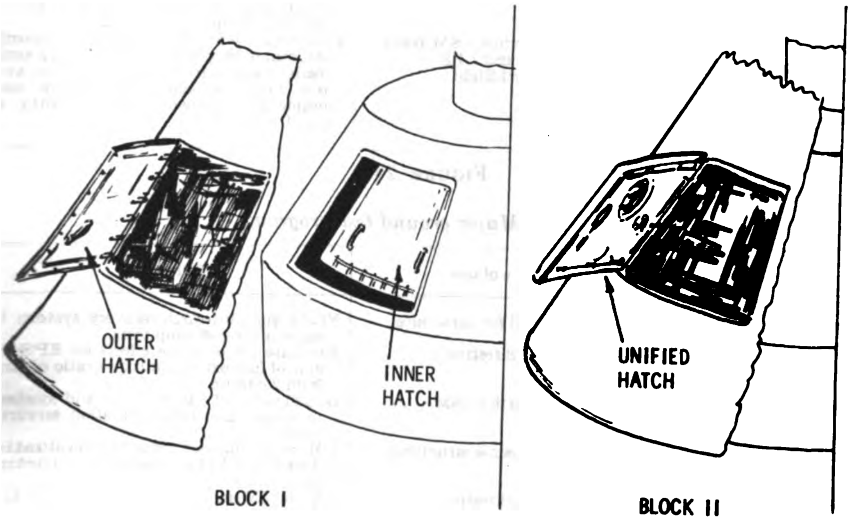


FIGURE 242

Block I—Major ground test programs

Test article	Type of test	Purpose
CM BP-6A	Boilerplate CM for parachute drop testing.	Flight qualified earth recovery system by series of aircraft drop test.
SM-001	SPS propulsion ground test	Demonstrated SPS performance (O/F=2) 2d SPS/structure compatibility.
SLA	SLA static structural test	SLA static structural load capability (ULT).
CSM-004	Static and thermal structural ground test.	CM static structural load test (ULT). CSM static structural load test (ULT). CM thermal structural load test (reentry design).
CSM-007	Spacecraft used for varied testing	CM and SM acoustic vibration environment. CM water landing impact drop tests. Postlanding systems operational/crew compatibility tests (uprighting, postlanding ECS, postlanding communications).
CSM-008	Complete systems spacecraft for thermal vacuum testing.	Demonstrate structural, integrated subsystems and crew compatibility under thermal vacuum environment.

FIGURE 243

White Sands missile range flight tests

Test article	Type of test	Purpose
BP-6	Boilerplate—LES pad abort flight test.	Demonstrated launch escape system pad abort performance.
BP-12	Boilerplate—LES transonic abort flight test.	Demonstrated launch escape system transonic abort performance.
BP-23	Boilerplate—LES high dynamic pressure abort flight test.	Demonstrated launch escape system maximum dynamic pressure region abort performance.
BP-23A	Boilerplate—LES pad abort flight test.	Demonstrated launch escape system pad abort performance with Canard, BPC, and major sequencing changes.
CSM-002	Spacecraft structure—SM boost environment and LES tumbling abort flight.	Determined actual spacecraft SM dynamic structural response to boost dynamic loads. Demonstrated launch escape system tumbling abort performance and plume impingement load capability of CSM.

FIGURE 244

Block II—Major ground test programs

Test article	Type of test	Purpose
BP-6B	Boilerplate CM for parachute drop testing.	Flight qualified earth recovery system by series of aircraft drop tests.
F-2A	Fixture for SPS testing	Evaluate performance effects on SPS engine of fuel/oxidizer mixture ratio change from 2.0 to 1.6.
180° SM segment	Acoustic test article (SM)	Qualification of SM structure and systems to launch and boost vibration environment.
CM-2S-1	Static and dynamic structural testing.	CM water impact structural evaluation. docket CM/LM interface static structural tests.
CMS-2S-2	Static structural testing	CM and SM static structural testing (ULT)
CMS-2TV-1	Complete systems spacecraft thermal vacuum testing.	Demonstrate structural, integrated subsystems, crew compatibility, and life support under thermal vacuum environment.

FIGURE 245

Block II—Revisions and additions to major ground test programs

Test article	Type of test	Purpose
2TV-1	Complete spacecraft thermal vacuum.	Qualify fire related changes.
004A, 007A	Unified hatch qualification	Functionally qualify acoustic testing post-landing testing.
CSM	Acoustic vibration	Demonstrate functional and structural integrity of stacked CSM-SLA.
Material	Materials evaluation	Continue evaluation of non- or low-flammable material.
Boilerplate	Command module fire test	Evaluate fire propagation in flight configuration C/M interior.
EMU articles	Extravehicular mobility unit qualification.	Qualification of block II unit with materials change.
ECU articles	Environmental control unit qualification.	Qualification of block II unit with all required modifications.

FIGURE 246

O

APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

SECOND SESSION

TWO-VOLUME REPORT ENTITLED "STATUS OF ACTIONS TAKEN ON THE APOLLO 204 REVIEW BOARD REPORT"

JANUARY 1968

PART 8

WASHINGTON, D.C.

Printed for the use of the Committee on Aeronautical and Space Sciences

U.S. GOVERNMENT PRINTING OFFICE

89-181 WASHINGTON : 1968

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 25 cents

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES

CLINTON P. ANDERSON, New Mexico, *Chairman*

RICHARD B. RUSSELL, Georgia
WARREN G. MAGNUSON, Washington
STUART SYMINGTON, Missouri
JOHN STENNIS, Mississippi
STEPHEN M. YOUNG, Ohio
THOMAS J. DODD, Connecticut
HOWARD W. CANNON, Nevada
SPESSARD L. HOLLAND, Florida
WALTER F. MONDALE, Minnesota

MARGARET CHASE SMITH, Maine
BOURKE B. HICKENLOOPER, Iowa
CARL T. CURTIS, Nebraska
LEN B. JORDAN, Idaho
EDWARD W. BROOKE, Massachusetts
CHARLES H. PERCY, Illinois

JAMES J. GEHRIG, *Staff Director*
EVERARD H. SMITH, Jr., *Professional Staff Member*
Dr. GLEN P. WILSON, *Professional Staff Member*
CRAIG VOORHEES, *Professional Staff Member*
WILLIAM PARKER, *Professional Staff Member*
SAM BOUCHARD, *Assistant Chief Clerk*
DONALD H. BRENNAN, *Research Assistant*

CONTENTS

INTRODUCTION

By letter dated January 8, 1968, Dr. George E. Mueller, Associate .dministrator for Manned Space Flight, National Aeronautics and pace Administration, transmitted to the chairman of the committee two-volume report entitled "Status of Actions Taken on the Apollo 04 Review Board Report." This report describes the actions taken by ASA through December 28, 1967, to implement the findings, deterinations, and recommendations of the Apollo 204 Review Board and s 21 panels. On January 26, 1968, the committee ordered the report nd the letter from Dr. Mueller to be printed as part 8 of the comittee hearings on the Apollo 204 accident. The letter and report llow:

LETTER OF TRANSMITTAL

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION,
Washington, D.C., January 8, 1968.

[on. CLINTON P. ANDERSON,
hairman, Committee on Aeronautical and Space Sciences, U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: At the request of the Administrator, I am nding you the enclosed report of the actions taken in response to the commendations made by the Apollo 204 Review Board. This report ıs been prepared by the Apollo program office in conjunction with .e cognizant NASA centers and headquarters offices. The report consts of two volumes. The first volume describes the actions taken to ıplement the recommendations made by the Review Board itself. he second volume describes the actions taken to correct the conditions entified by each Review Board panel.

Through your committee and its staff's continuous review of the pollo and all our programs I am sure you are aware that some actions suing from the AS–204 accident cannot be completed until a series ground qualification and flight tests have been run and their results aluated. For example, the new unified hatch will require extensive sting during 1968.

It is important to recognize that in addition to the actions on the ecific recommendations of the Apollo 204 Review Board, other acıns have been taken in the areas of management and safety. For ample, the Manned Space Flight Safety Office has been formed and fety personnel assigned to AAP and Apollo; systems safety discinnes have been established in the manned space flight programs to ntify hazards and control them; and the manner space flight field ıter safety directors will be responsible for the total center safety :ivity.

Generally, the recovery of the program has been encouraging from standpoint that the Apollo Government-industry team showed ength and resilience as evidenced by the successful Apollo 4 mission.

Sincerely yours,

GEORGE E. MUELLER,
Associate Administrator
for Manned Space Flight.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STATUS OF ACTIONS TAKEN ON THE APOLLO 204 REVIEW BOARD REPORT

89-181—68——2

INTRODUCTION

A detailed review of action items that evolved from the Apollo 204 accident has been completed by the Apollo Program Office. These action items were derived from the recommendations of the Apollo 204 Review Board which was established on January 27, 1967, and the Review Board's 21 Task Panels. The recommendations of the Apollo 204 Review Board have been or are being implemented by the Apollo program. This report presents the status of actions taken on the 204 Review Board Report. Two volumes are provided:

Volume I. Status of actions taken on the Apollo 204 Board findings and recommendations.

Volume II. Status of actions taken on the Apollo 204 Panel findings and determinations.

Volume I describes the actions taken by the Apollo Program Office to implement the recommendations made to NASA by the Apollo 204 Review Board. In some cases, volume I actions refer to volume II Panel findings for additional detail. Volume II describes the status of actions by the Apollo Program Office to implement the determinations of the individual Panels of the Apollo 204 Review Board.

This report is based on efforts on the part of NASA and its contractors to correct the hazardous conditions identified in the investigation of the Apollo 204 accident.

Some design changes and additional tests were accomplished prior to the release of the Apollo 204 Review Board final report of April 5, 1967. Other changes to hardware, test programs, and procedures were made as a result of the Review Board report and in some areas are still being assessed. These will not be completed until a series of ground, qualification and flight tests are conducted and the results are evaluated. For those actions that require additional testing and analysis, planning data is provided in both volumes which describes the steps that will be taken to demonstrate the acceptability of design solutions to specific problems.

VOLUME I

STATUS OF ACTIONS TAKEN ON THE APOLLO 204 REVIEW BOARD FINDINGS AND RECOMMENDATIONS

REFERENCE INFORMATION

The actions reported in this volume are based on the findings, determinations, and recommendations found in part VI of the Report of the Apollo 204 Review Board to the Administrator, National Aeronautics and Space Administrtaion, dated April 5, 1967.

AS–204 Review Board findings 1 and 3 contained findings and determinations only.

The Review Board findings, determinations, and recommendations are reproduced at the heading of each page as they appear in the report referenced above. The "Action" section describes the actions taken by the Apollo Program Office to implement each recommendation of the Review Board.

BOARD FINDINGS

Board Finding No. 2

Finding.—(*a*) The command module contained many types and classes of combustible material in areas contiguous to possible ignition sources. (*b*) The test was conducted with a 16.7 pounds per square inch absolute, 100-percent oxygen atmosphere.

Determination.—The test conditions were extremely hazardous.

Recommendation.—The amount and location of combustible materials in the command module must be severely restricted and controlled.

Action.—The amount of combustible materials in the command module has been greatly reduced. There were 1,412 nonmetallic materials identified in the CSM. Seventy-nine percent or 1,113 have been deleted, replaced, redesigned, or determined to be acceptable. The remaining nonmetallic materials are currently being evaluated and work on this effort is scheduled for completion early in 1968. This effort includes flammability tests to be conducted early next year at MSC on a full-scale command module boilerplate (BP-1224). These tests are fully described under Board Finding No. 8, which deals specifically with full-scale mockup flammability testing. Descriptions of the extensive nonmetallic material changes that have been made to the CSM crew equipment stowage, ECS suit loop, space suit, and other CSM equipment are provided in volume II, Panel finding 8–1a (p. 33).

The requirement for identification of all nonmetallic materials, their location, weight, and surface area has been imposed on all organizations furnishing equipment for use in the CSM crew compartment. Standardized reporting formats have been adopted and a central source to provide materials data has been established.

The basic discipline being applied throughout the spacecraft program is to limit the selection and placement of materials in the crew bay so that if a fire should start, it could not propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft.

Control over nonmetallic mtaerials is exercised by both the contractor and MSC. The contractor bears the primary design responsibility for the selection of materials. NASA bears the responsibility for the review of the selection of certain classes of materials. Where NASA organizational elements are supplying GFE they will submit change requests to the MSC Nonmetallic Materials Selection Review Board. The contractors have within their own organizations, and have established at their subcontractors' installations, one or more cognizant materials engineers who will be responsible for reviewing materials problems, formulating deviation requests, and submitting them to the MSC Materials Selection Review Board. The NASA-MSC Materials Selection Review Board has the final responsibility for approval of changes. This Board is located at MSC and is chaired by the Chief of the R&QA Division. Representation is from all cognizant technical areas including flight safety, space medicine, materials reliability and control, and materials engineering. A second board is located at the spacecraft contractor's facility. This board has as its chairman the contractor's counterpart to the NASA-MSC board chairman and has the same type of membership as the NASA-MSC board. The contractor's board is basically responsible for approving or disapproving changes and submits all actions to the MSC board for final approval.

Materials selection guidelines and test procedures have been prepared and implemented through the following basic documents:

ASPO-RQTD-D67-5, Nonmetallic Materials, Selection Guidelines, dated April 10, 1967, Revision A, isued May 5, 1967. (This document establishes acceptance guidelines and test requirements for nonmetallic materials in the spacecraft. It includes general fire control criteria and eight categories of materials classified according to functional application and distribution in the spacecraft. Toxicity, flammability, design, and test requirements are also defined.)

MSC-A-D-66-3, Revision A, Procedures and Requirements for the Evaluation of Spacecraft Nonmetallic Materials, dated June 5, 1967. (This document contains detailed test procedures and requirements for combustion rate, flammability, odor, offgassing and ignition tests that conform to the more rigid selection requirements of the Nonmetalic Materials Selection Guideline described above.)

Board Finding No. 4

Finding.—Due to internal pressure, the command module inner hatch could not be opened prior to rupture of the command module.

Determination.—The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture.

Recommendation.—The time required for egress of the crew be re-
ıced and the operations necesary for egress be simplified.
Action.—A new hatch has been designed to replace the two-cover
ıtch system on Block II command modules. The single door is called
"unified hatch" and is made of aluminum with added fiber glass and
›lative material. The hatch has flexible thermal seals, a latch and
nkage mechanism, hinges, window, and a boost-protective hatch
›ver that swings open on separate hinges. There is a single cabin vent
ılve for ground testing or cabin purging. The door development
echanism contains a counterbalancing device to offset gravity, and a
ıkage that locks the hatch in full open position. The door-unlatching
echanism can be operated either by the flightcrew in less than 3 sec-
ıds or by the ground crew for emergency or normal operations in
ss than 10 seconds.
Ground and flight tests are in progress to qualify the new hatch to
sure the following items: (*a*) Effective operation, (*b*) integrity in
e vibration environment encountered during launch and reentry, (*c*)
›mpatability with crew requirements including EVA, (*d*) integrity
ıring reentry heating, and (*e*) emergency operations. These tests are
ing conducted on ground test articles, on the thermal vacuum model,
ıd on unmanned Saturn V flights.
This hatch will be incorporated in all manned spacecraft.

BOARD FINDING NO. 5a

Finding.—Those organizations responsible for the planning, con-
ıct, and safety of this test failed to identify it as being hazardous.
ontingency preparations to permit escape or rescue of the crew from
ı internal command module fire were not made. No procedures for this
pe of emergency had been established either for the crew or for the
›acecraft pad work team.
Determination.—Adequate safety precautions were neither estab-
hed nor observed for this test.
Recommendation.—Management continually monitor the safety of
l test operations and assure the adequacy of emergency procedures.
Action.—All spacecraft test procedures are required to contain
›plicable emergency procedures. These procedures are reviewed dur-
g the test checkout procedure safety review activity defined in APOP
›. G–102, safety considerations for TCP's, released July 17, 1967.
The KSC Safety Office and NAR Safety are presently reviewing and
›proving by signature all spacecraft test procedures. The KSC Safety
fice makes the final determination as to the hazardous classification of
l tests, based on the stringent criteria for definition of hazardous pro-
dures provided in APOP No. G–102. The procedures that have been
aluated as hazardous are then compared against a set of checklists to
sure compliance with safety practices.
Emergency equipment to be added to all launch complexes to im-
ove escape and rescue operations is described in Board finding 5b.
rsonnel training and practice for emergency procedures are des-
ibed in Board finding 5c. Changes made to the service structure and
ıbilical tower to improve emergency egress are described in Board
ding 5d.

Management will continually monitor the safety of all test operations and insure the adequacy of emergency procedures through the review and approval cycle described.

BOARD FINDING No. 5b

Finding.—Those organizations responsible for the planning, conduct, and safety of this test failed to identify it as being hazardous. Contingency preparations to permit escape or rescue of the crew from an internal command module fire were not made. The emergency equipment located in the white room and on the spacecraft work levels was not designed for the smoke condition resulting from a fire of this nature.

Determination.—Adequate safety precautions were neither established nor observed for this test.

Recommendation.—All emergency equipment (breathing apparatus, protective clothing, deluge systems, access arm, etc.) be reviewed for adequacy.

Action.—All emergency equipment has been reviewed for adequacy and improvements are being made by the addition of equipment at the launch complexes.

Emergency safety lockers, containing air packs, fire blankets, gas masks, axes, tools, special fire extinguishers and other emergency items are being installed at selected levels of the service structure, umbilical tower and other key locations on the launch complexes. A detailed discription of all items to be included in the safety lockers is provided in volume II, Panel finding 13–9 (p. 56). Lockers and equipment will be installed to support manned flight requirements on both LC–34 and LC–39.

Emergency rescue personnel are equipped with heat protective garments and self-contained breathing apparatus.

A slide wire emergency escape system for the flight crew and ground closeout crew is being provided on LC–34 from the Apollo access arm level of the umbilical tower to a point on the ground 1,200 feet away from the base of the tower. The operational ready date will be in early 1968. This system is also being evaluated for possible use on LC–39.

The water deluge system on the service structure has been evaluated in detail and has been found to be adequate both as to the number and location of control stations. The hypergolic servicing systems at the launch complexes have also been completely reviewed from the standpoint of remote control capability and the present systems were found to be adequate.

Emergency procedure improvements are described in Board finding 5a. Personnel training and practice for emergency procedures are described under Board finding 5c. Changes made to the service structure and umbilical tower to improve emergency egress are described in Board finding 5d.

BOARD FINDING No. 5c

Finding.—Those organizations responsible for the planning, conduct, and safety of this test failed to identify it as being hazardous. Contingency preparations to permit escape or rescue of the crew from an internal command module fire were not made. Emergency fire, rescue, and medical teams were not in attendance.

Determination.—Adequate safety precautions were neither estab-ished nor observed for this test.

Recommendation.—Personnel training and practice for emergency rocedures be given on a regular basis and reviewed prior to the con-uct of a hazardous operation.

Action.—Personnel emergency procedure training and practice have een and will continue to be given on a regular basis. Training profi-iency will be reviewed before conducting all hazardous operations.

Evacuation routes have been posted and evacuation drills are run n a scheduled basis.

A training program has been initiated by NASA KSC Training, afety, and Fire Departments in cooperation with the spacecraft con-ractors that includes the use of firefighting equipment, first aid, and ıe handling of personnel requiring aid in the event of an emergency.

An access arm and command module mockup (in the block II CSM nfiguration with the new quick-opening unified hatch) are being set p at KSC for development of emergency crew egress procedures and aining. This training facility will be operational early in 1968.

Changes made to the service structure and umbilical tower to im-rove emergency egress are described in Board finding 5d. Emergency uipment to be added to all launch complexes to improve escape and scue operations is described in Board finding 5b. Emergency pro-dure improvements are described in Board finding 5a.

Board Finding No. 5d

Finding.—Those organizations responsible for the planning, con-ıct, and safety of this test failed to identify it as being hazardous. ntingency preparations to permit escape or rescue of the crew from ı internal command module fire were not made. Both the spacecraft ork levels and the umbilical tower access arm contain features such steps, sliding doors, and sharp turns in the egress paths which nder emergency operations.

Determination.—Adequate safety precautions were neither estab-hed nor observed for this test.

Recommendation.—Service structures and umbilical towers be modi-d to facilitate emergency operations.

Action.—Service structures and umbilical towers are being modified improve emergency personnel and crew evacuation capability. ıanges were authorized to be made on LC–34 on April 21, 1967, and lude:

(1) Reconfiguring the environmental chamber (EC) adapter hood to provide a flatter egress path from the spacecraft to the EC;

(2) Eliminating the step at each end of the Apollo access arm;

(3) Incorporating two-way swinging doors on the Apollo access arm and on the access arm cab;

(4) Providing smoke removal ventilation in the Apollo access arm cab;

(5) Changing the arm retraction sequence to rotate the arm to a park position near the latch position at T–30 minutes to permit quick return to the command module. At T–4 minutes the arm will be swung to the stowed position;

(6) Incorporating fire-resistant materials inside the Apollo access arm.

89–181—68——3

Effectivity for LC–34 is for the first manned spacecraft. The operational ready date is early in 1968. Effectivity for LC–39 is for the first manned Apollo-Saturn V flight. The operational ready date is in the second quarter of 1968.

Emergency procedure improvements are described in Board finding 5a. Emergency equipment to be added to all launch complexes to improve escape and rescue operations is described in Board finding 5b. Personnel training and practice for emergency procedures are described in Board finding 5c.

BOARD FINDING NO. 6

Finding.—Frequent interruptions and failures had been experienced in the overall communication system during the operations preceding the accident.

Determination.—The overall communication system was unsatisfactory.

Recommendations.—(*a*) The ground communication system be improved to assure reliable communications between all test elements as soon as possible and before the next manned flight. (*b*) A detailed design review be conducted on the entire spacecraft communication system.

Action.—The ground communications system has been reviewed in detail and improvements are being made to insure reliable communications between all test elements. Specific equipment modifications include:

(1) For Launch Complex 34:

(*a*) Undesirable coupling in the astronaut communications panels has been eliminated and duplex communications to the spacecraft umbilical cable have been provided with minimum use of VOX devices;

(*b*) Headset frequency response has been improved and its efficiency raised;

(*c*) Central testing facilities are being added to permit contonuous monitoring of circuit quality;

(*d*) Continuous recordings of critical voice communication loops will be provided.

Effectivity is for the first manned spacecraft and the operational ready date is the second quarter of 1968.

(2) For Launch Complex 39:

(*a*) Evaluations are currently being made of Launch Complex 39 communications based on the changes being incorporated in Launch Complex 34.

(*b*) Effectivity for all changes to the LC–39 ground communications system will be for the first manned Apollo/Saturn V flight.

(3) Procedural changes to be made for all launch complexes:

(*a*) Reduction in the number of stations on critical communication loops;

(*b*) Inspection and verification by test of system configuration and operational readiness before each major space vehicle test;

(*c*) Provision for knowledgeable communications system engineers to be on duty during all major space vehicle tests.

These procedures will be used to support all manned flights from both LC–34 and LC–39.

The ground communications system is designed to meet all operational requirements to support manned flights from all launch complexes.

The spacecraft communications system has been reviewed in detail and has been designed to eliminate the type of anomalies that were detected prior to the AS204 accident. Additional detail in this area is provided in volume II, under Panel finding 9–d(1) (p. 48).

Board Finding No. 7

Finding.—Revisions to the operational checkout procedure for the test were issued at 5:30 p.m. e.s.t. January 26, 1967 (209 pp.), and 10 a.m. e.s.t., January 27, 1967 (4 pp.).

Determination.—Neither the revision nor the differences contributed to the accident. The late issuance of the revision, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

Recommendation.—Test procedures and pilot's checklists that represent the actual command module configuration be published in final form and reviewed early enough to permit adequate preparation and participation of all test organizations, and that timely distribution of test procedures and major changes be made a constraint to the beginning of any test.

Action.—Change release timing is being expedited by the implementation of APOP No. 0–202 (Preparation and Release of Test and Checkout Procedures, released) July 12, 1967 (effective date of August 1, 1967). This procedure provides instructions and assigns responsibilities including the following:

(1) A timeline is established that specifies deadlines for preparation, review, approval, and release of TCP's;

(2) The TCP control board, which consists of NASA/KSC and NAR personnel has the responsibility for establishing policy governing NAR launch operations TCP's and insuring that timely and technically adequate TCP's are published.

In accordance with this procedure, TCP's will include safety considerations, applicable safety requirements, and emergency procedures when personnel are sealed in the command module in an environment that deviates from normal atmosphere. Flight crew safety emergency procedures will be included in the TCP. TCP's which involve flight crew participation will have MSC coordination and signature approval. The TCP's will be released 30 days prior to the test to support manned spacecraft test and checkout at KSC.

In addition, APOP No. 0-222, TCP Open Item Reviews, Constraints Listings, Pretest Briefings, and Posttest Debriefings, was released August 2, 1967. This procedure provides instructions and assigns responsibilities including the following:

(1) A specific definition of the requirement for a pretest open item review. The review will be cochaired by the NASA spacecraft test conductor or his designee and the NAR test project engineer;

(2) A system of documenting the constraint items with proper approvals or waivers as required for each specific test;

(3) A procedure for indicating items that are closed out between the review establishing the items as open and the scheduled start of the test;

(4) A posttest critique at which anomaly items discovered during the performance of the test are evaluated as possible constraints to closeout of the subject test. All such constraints will be monitored during workoff by quality control;

(5) A preliminary constraints list for the next scheduled major test will also be defined at the posttest critique.

BOARD FINDING No. 8

Finding.—The fire in command module 012 was subsequently simulated closely by a test fire in a full-scale mockup.

Determination.—Full-scale mockup fire tests can be used to give a realistic appraisal of fire risks in flight-configured spacecraft.

Recommendation.—Full-scale mockups in flight configuration be tested to determine the risk of fire.

Action.—A full-scale mockup, in flight configuration will be tested early next year at MSC to determine the risk of fire.

The overall objective of this test program is to insure that no flammability hazards exist in manned spacecraft. If hazards are discovered as a result of this command module mockup test program, materials may be relocated, removed, or replaced. The following are specific objectives:

(1) Define the degree of propagation and magnitude of each fire resulting from the ignition source;

(2) Measure the rate and magnitude of pressure and temperature increases resulting from combustion;

(3) Determine length of time a reasonable degree of crew visibility would be retained;

(4) Identify toxic products occurring as a result of the ignition.

These tests will be performed at 6.2 pounds per square inch absolute and then at 16.5 pounds per square inch absolute with a 100-percent oxygen environment. Ignition will first be attempted by means of a deliberate electrical circuit overload. In the event ignition does not occur, a nichrome wire will be used as an ignition source.

The test article consists of boilerplate 1224 with the interior built up simulating a flight command module, including—

(1) All storage compartments and boxes;

(2) The complete internal electrical wire harness including all wire protective wraps, spot ties, clamps, spacers, and conformal coatings;

(3) Rotational and translational controllers on the couches;

(4) Two suits and oxygen supply hoses with cobra cables;

(5) A pump accumulator and reservoir providing water-glycol flow rates and pressures representative of manned spacecraft;

(6) Cabin fans and cabin pressure relief valve;

(7) All contractor and Government-furnished equipment having nonmetallics such as tools, food, procedures manuals, medical supplies, sanitary supplies, clothing, etc.

Details of the test environment, ignition technique, and safety requirements are found in volume II, panel finding 8–1a (p. 33).

This full scale test is being preceded by a large number of component and subsystem tests made in boilerplate No. 1250. These tests have been run on such items as wiring and wire bundles, specific sections of the crew compartment, and circuit breaker panels.

A Flammability Test Review Board has been established to determine whether the full-scale test configuration is a proper one and whether the test results verify that the spacecraft is fire safe. Dr. Gilruth, Director of MSC, is Chairman and among the senior representatives are key personnel from NAR, OMSF, medical research and operations, flight safety, and flight crew operations.

BOARD FINDING NO. 9

Finding.—The command module environmental control system design provides a pure oxygen atmosphere.

Determination.—This atmosphere presents severe fire hazards if the amount and location of combustibles in the command module are not restricted and controlled.

Recommendations.—(*a*) The fire safety of the reconfigured command module be established by full-scale mockup tests. (*b*) Studies of the use of a diluent gas be continued with particular reference to assessing the problems of gas detection and control and the risk of additional operations that would be required in the use of a two-gas atmosphere.

Action.—The fire safety of the reconfigured command module will be established by full-scale mockup tests in a pure oxygen environment as described in board finding No. 8.

It has been reconfirmed by a detailed review of operational requirements that the inflight cabin atmosphere should continue to be 100-percent oxygen at 5 pounds per square inch absolute to combine the greatest opportunity for mission success with safety for manned operations in space.

The command module systems have however, been modified to be capable of using air, as well as oxygen, as a pressurant on the launch pad in accordance with Apollo Program Directive No. 29: "Post-Accident Changes to Apollo CSM and Related Ground Facilities," dated July 6, 1967. This capability will be implemented if the full-scale flammability tests indicate a need to change to an air atmosphere for ground operations. Changes will be effective for all manned spacecraft as authorized by MSC–CCA–1319, revision A, dated May 25, 1967, and include—

(1) A sensor to measure suit-to-cabin differential pressure; and

(2) Mounting provisions for a cabin gas analyzer to detect air leakage into the suit loop (if air is used as a pressurant).

The risks due to the additional operational requirements of using air on the pad are being controlled by conducting ground tests and developing appropriate crew procedures. Training of the crew in these procedures will be accomplished prior to the first manned flight test.

Board Finding No. 10a

Finding.—Components of the environmental control system installed in command module 012 had a history of many removals and of technical difficulties including regulator failures, line failures and environmental control unit failures. The design and installation features of the environmental control unit makes removal or repair difficult.

Determination.—These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operations.

Recommendation.—An in-depth review of all elements, components and assemblies of the environmental control system be conducted to assure its functional and structural integrity and to minimize its contribution to fire risk.

Action.—The block II ECS to be used in all manned spacecraft is an improvement over the block I ECS used in spacecraft 012. The block II ECS has been reviewed in depth and this system's functional and structural integrity is being evaluated through an extensive series of component, subsystem and system tests. The possible ECS contribution to fire risk has been reduced by changing the block II design to eliminate to the greatest extent possible the leakage and spillage.

Insulation and filter material changes to reduce possible ECS contribution to a fire are described in volume II, panel finding 8–4a (p. 38) ECS plumbing changes to reduce spillage are described in board finding 10b.

Board Finding No. 10b

Finding.—Coolant leakage at solder joints has been a chronic problem.

Determination.—These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operations.

Recommendation.—Present design of soldered joints in plumbing be modified to increase integrity or the joints be replaced with a more structurally reliable configuration.

Action.—Test and analyses show that armored solder joints are superior to nonarmored joints in fire resistance, creep, resistance to damage, and reduction of leakage. In recognition of these advantages, the maximum number of solder joints in each spacecraft will be armored.

Water/glycol ECS joints are being armored as follows:

(1) Early manned spacecraft will have 103 of 179 solder joints in the cabin armored. All joints in the service module will be armored:

(2) Later manned spacecraft will have all solder joints in CM and SM armored;

(3) Voishan washers will be installed on all mechanical joints in all manned spacecraft that do not already contain them, when the connectors are uncoupled. The retorquing of all B-nuts will be incorporated on all manned spacecraft;

(4) The aluminum oxygen lines in the cabin have been replaced with stainless steel lines on all manned spacecraft. Aluminum oxygen lines in the oxygen valve panel and the ECU are welded rather than soldered and will not be replaced.

BOARD FINDING No. 10c

Finding,—The coolant is both corrosive and combustible.

Determination.—These deficiencies created an unnecessarily haz-rdous condition and their continuation would imperil any future pollo operations.

Recommendation.—Deleterious effects of coolant leakage and spill-ge be eliminated.

Action.—The deleterious effects of coolant leakage and spillage are eing eliminated by making plumbing changes to minimize water/gly-ol leakage. This is discussed in Board finding No. 10b.

The use of self-sealing quick-disconnect fittings for those joints that nust be occasionally parted for normal maintenance will minimize or liminate the incidence of leaks and spills.

An MSC procedure has been developed to define the method for leaning water/glycol spillage. This "Procedure for Removal of Ethyl-ne Glycol Solution Spillage," MSC–Proc–C–105, dated July 12, 1967, stablishes the methods for removing solutions that have spilled on lectrical equipment, structural components and plumbing in the space-raft.

BOARD FINDING No. 10d

Finding.—Deficiencies in design, manufacture, installation, rework nd quality control existed in the electrical wiring.

Determination.—These deficiencies created an unnecessarily hazard-ous condition and their continuation would imperil any future Apollo perations.

Recommendation.—Review of specifications be conducted, 3-dimen-sional jigs be used in manufacture of wire bundles and rigid inspection at all stages of wiring design, manufacture and installation be en-forced.

Action.—

(1) The electrical wiring design, fabrication, and installation practices and procedures have been reviewed to determine their adequacy.

(2) On spacecraft where wiring was installed and complete, a reinspection was conducted using more stringent acceptance criteria.

(3) On early manned spacecraft, a special wiring design task team was formed to review the wiring modification made as a result of the design changes and insure the proper fabrication and installation of the wiring modifications in the spacecraft. This task team, made up of representatives from contractor engineering, manufacturing, quality control and NASA engineering and quality control, reviewed the entire installation area by area and recommended modifications.

(4) The actual rework of the harness installation in early manned sapcecraft was accomplished with an "overlay harness." After installation of this "overlay harness," the spacecraft was physically inspected and tested to assure that there were no shorts from wire to wire or from wire to ground, and that the wire insulation was not damaged. These tests have been successfully completed and the wiring system accepted by MSC.

(5) An MSC review board determined that the wiring in early spacecraft was acceptable.

(6) On all block II spacecraft the following has been accomplished:

(*a*) Three-dimensional wiring jigs are being used;

(*b*) Hard metallic covers have been placed on all wire harnesses on the spacecraft floor as physical protection;

(*c*) In areas where hard covers are not practical and additional physical protection is needed, single wire wraps and/or harness wraps have been used;

(*d*) Where possible, sharp edges and corners are being removed. If removal is not practical, the edge or corner is provided with a grommet or the harness is provided with additional wraps;

(*e*) Where possible and practical, combustible material touching the wiring or close to it is being replaced with an acceptable material. In all cases, the criteria specified in ASPO-RQTD-D67-5A are being imposed and any deviations must be reviewed and approved by NASA on an individual basis. Board finding No. 2 provides additional information on materials selection and control.

Board Finding No. 10e

Finding.—No vibration test was made of a complete flight-configured spacecraft.

Determination.—These deficiencies created an unnecessarily hazardous condition and their continuation would imperial any future Apollo operations.

Recommendation.—Vibration tests be conducted of a flight-configured spacecraft.

Action.—CS M105 has been designated for use as an acoustic-vibration ground test vehicle and NAR is incorporating the necessary changes to this spacecraft including the capability to verify the structural integrity of the new hatch.

Specifically, the testing will simulate both low-vibration levels and those maximum conditions expected during flight. These tests will demonstrate the functional and structural integrity of the subsystem integration and CSM interconnections (such as tubing, wiring, and brackets). Also, the spacecraft will be subjected to a vibration environment in excess of qualification levels to validate any modifications accomplished as a result of the above testing and to provide confidence in the CSM's ability to withstand off-nominal conditions such as abnormal flight conditions or design and manufacturing tolerance variations. Verification of test results will be completed before the first manned flight.

Board Finding No. 10f

Finding.—Spacecraft design and operating procedures currently require the disconnecting of electrical connections while powered.

Determination.—These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operations.

Recommendation.—The necessity for electrical connections or disconnections with power on within the crew compartment be eliminated.

Action.—All equipment requiring electrical connection or disconnection were reviewed for flight and ground tests. The following are being provided for all manned spacecraft:

(1) Utility outlets and scientific equipment outlets have switches and/or circuit breakers that can turn power off before the need for disconnection;

(2) The cobra cable power can be switched off before the need for disconnection;

(3) The TV camera can be switched off before the need for disconnection;

(4) Checkout procedures now specify that power will be taken off any connections or any circuits that must be disconnected during checkout or flight.

Board Finding No. 11

Finding.—An examination of operating practices showed the following examples of problem areas:

(*a*) The number of the open items at the time of shipment of the command module 012 was not known. There were 113 significant engineering orders not accomplished at the time command module 012 was delivered to NASA; 623 engineering orders were released subsequent to delivery. Of these, 22 were recent releases which were not recorded in configuration records at the time of the accident.

(*b*) Established requirements were not followed with regard to the pretest constraints list. The list was not completed and signed by designated contractor and NASA personnel prior to the test, even though oral agreement to proceed was reached.

(*c*) Formulation of and changes to prelaunch test requirements for the Apollo spacecraft program were unresponsive to changing conditions.

(*d*) Noncertified equipment items were installed in the command module at time of test.

(*e*) Discrepancies existed between NAA and NASA MSC specifications regarding inclusion and position of flammable materials.

(*f*) The test specification was released in August 1966 and was not updated to include accumulated changes from release date to date of the test.

Determination.—Problems of program management and relationships between centers and with the contractor have led in some cases insufficient response to changing program requirements.

Recommendation.—Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

Action.—A number of steps has been taken to improve understanding between all organizations to improve implementation of practices and procedures.

APOP 0–202, Preparation and Release of Test and Checkout Procedures, was released July 12, 1967, and describes the MSC–KSC system requirements for reviewing and approving all spacecraft test procedures. All spacecraft test procedures are forwarded from KSC to MSC for review and comment. The MSC flight crew checklist information is required to be furnished to KSC 40 days before the scheduled test date with all MSC procedures comments due no later than 15 days before the scheduled test date. MSC will also approve by signature, all spacecraft test procedures that include participation of the flight crew. All revisions to actual test plans must be in the hands of the test team 2 days before the test. No last-minute revisions to operational test procedures are acceptable and this limitation can only be waived by the KSC Director, or his designated alternate. Other key documents defining and clarifying KSC-contractor relationships include APOP No. 0–222, TCP Open Item Reviews, Constraint Listings, Pre-Test Briefings, and Post-Test Debriefing released August 2, 1967. This APOP requires pretest open item reviews, documentation of constraint items with proper approvals, open item closeout verification, and post-test anomaly critiques. This APOP includes a methodical means of evaluating the hazard level of all spacecraft procedures and assuring that safety practices are followed.

The following safety reviews were recently conducted by NASA and contractor personnel:

(1) Launch vehicles for missions AS–501 and AS–204 had detailed electrical and corrosion inspections at KSC to determine any potentially hazardous conditions. All discrepancies noted have been formally closed out.

(2) All KSC operating procedures for launch vehicle AS–501 which was launched on November 9, 1967, were subjected to an operational system safety evaluation; 1,354 procedures were reviewed in detail and all problems noted were closed out by formal reports prior to the launch.

(3) A KSC ad hoc safety review of documentation involving Launch Complex 39 hardware and safety conditions was conducted prior to the AS–501 launch. All potential problem areas are being corrected.

(4) A preoperational safety review of spacecraft 017 was conducted by KSC and MSC personnel. All potential problems identified were acted upon prior to the AS–501 flight readiness test.

VOLUME II
STATUS OF ACTIONS TAKEN ON THE APOLLO 204 PANEL FINDINGS AND DETERMINATIONS

REFERENCE INFORMATION

The actions reported in this volume are based on the panel findings and determinations found in appendix D of the report of the Apollo 204 Review Board to the Administrator, National Aeronautics and Space Administration, dated April 5, 1967.

The panel findings and determinations are reproduced at the beginning of each finding exactly as they appear in the report referenced above. The "Action" section describes the actions taken by the Apollo program to correct the conditions described in the panel findings and determinations. The "Responsible organization" heading refers to the NASA Center which was required to take action on the specific panel finding and determination.

The following AS204 panel findings contain determinations that do not require action on the part of the Apollo program:

Panel No.—	*Finding No.*—
3	1.
4	Not applicable.
5	1, 2, 5, 6, 7, 8, 10.
7	10.
8	1c, 3c, 3f, 4c.
9	a3, b1, b2.
10	1 to 9.
11	1 to 12, 16 to 20, 22.
12	Not applicable.
13	4.
14	1, 2, 3.
15 to 19	Not applicable.
20	2.
21	1 to 6.

PANEL FINDINGS

Panel No. 1. S/C and GSE Configuration

FINDING NO. 1

Finding.—One hundred and sixty-four (164) engineering orders (EO's) were not accomplished at the time Spacecraft 012 was received at KSC. Six hundred and twenty-three (623) EO's were released subsequent to receipt at KSC. Of these, twenty-two (22) were recent releases which were not recorded in configuration records at KSC at the time of the accident.

Determination.—Continuing engineering changes indicate progressive development of the spacecraft configuration through the time of the space vehicle plugs out integrated test. At the time of the test, the configuration could not have been complete with respect to the launch configurations.

Responsibile Organization.—MSC.

Action.—Spacecraft acceptance and DD-250 administration procedures will be strictly enforced to insure that shipping documents accurately reflect hardware status. Further action has been directed toward rigidly observing configuration management procedures to insure that no work is open unnecessarily at the time of shipment. Specifically, the revised CARR plan requires an updated configuration index and listing of open work for each spacecraft before acceptance. It also provides for a KSC representative to review and accept in writing all open work outstanding on each spacecraft. After delivery of the spacecraft to KSC, all changes will be reviewed and approved by NASA. CARR report requirements have been implemented for all spacecraft.

NAR has revised its policies and procedures (P. & P.'s) on configuration, management to insure more complete and timely configuration identification, from manufacturing, through each major test to launch. These P. & P.'s are:

(1) F-403, Change Verification Record System, April 13, 1967.
(2) C-432, Engineering Change System, June 24, 1967.
(3) C-432.1, Engineering Change Approval Processing, June 22, 1967.
(4) C-432.3, Engineering Change Product Plans, June 22, 1967.
(5) C-432.4, Engineering Change Control for Subcontracted Equipment, July 7, 1967.
(6) C-432.6, Engineering Change Control for Interdivisional Work Authorizations, August 18, 1967.

FINDING NO. 2

Finding.—The required space vehicle plugs out integrated test configuration was not explicitly defined by design engineering or test documentation. Definition of required test configuration was limited to test setup and controls configurations specified in OCP FO-K-0021-1.

Determination.—The absence of explicit definition of spacecraft test configuration requirements relegated such definition to the test organization. Further, it is the opinion of this Panel that the lack of timely and explicit design definition of the required test configuration precluded complete assessment of adverse configuration aspects as constraints to the test.

Responsible organization.—MSC.

Action.—The test and checkout procedures (TCP's) define the spacecraft and GSE configuration required for each test. MSC will review all of the spacecraft TCP's written by KSC and will exercise signature approval of the document for those TCP's involving crew participation. An open items/constraints list review meeting (see Panel No. 1, finding No. 3 for additional details) with the responsible systems engineers of KSC and the contractor will be held prior to initiating any TCP's. This review will include evaluations of—

(1) Unqualified hardware list;
(2) Suspect failed hardware list;
(3) Temporary installation records (TIR's).

All nonflight hardware items will be recorded as temporary installations.

The customer acceptance readiness review (CARR) has been modified to require that the spacecraft contractor determine any test constraints associated with each item of unqualified hardware. The CARR is the final review conducted between NAR and NASA to formally evaluate the spacecraft for NASA acceptance prior to shipment to KSC. The CARR is based primarily on the results of acceptance checkout, but also includes evaluation of existing open work, waivers and deviations, and quality control and reliability verifications. The timely and explicit definition of each required test configuration has been accomplished by requiring the spacecraft contractor to maintain and update the unqualified hardware constraints list and the suspect failed hardware list in support of the open item/constraint list review meeting. This CARR plan is effective for all manned spacecraft.

FINDING NO. 3

Finding.—Eighty EO's effective on S/C 012 were not accomplished at the time of the accident. Of these, 20 were specified to be accomplished subsequent to the space vehicle plugs out integrated test. Four of the open EO's were of a nature not affecting configuration. Three hundred and eighty-four parts installation and removal records (PIRR's) and temporary installation records (TIR's) were open, of which 125 were in compliance with requirements of the test documentation.

Determination.—It is concluded that test requirements had no defined relationship to the open status of 56 EO's and 259 PIRR's/TIR's. It is the opinion of this Panel that all work items and EO's were not closed because of late receipt of changes or further work scheduled to be accomplished prior to launch.

Responsible organization.—KSC.

Action.—Test requirements for all spacecraft testing will be related to all open work items. Closure of open work items will be expedited by implementing the instructions of APOP No. 0–222 TCP Open Item Reviews, Constraints Listings, Pretest Briefings, and Post-Test Debriefings, released August 2, 1967. This procedure includes and assigns responsibilities for:

(1) A specific definition of the requirement for a pretest open item review. The review will be cochaired by the NASA spacecraft test conductor or his designee and the spacecraft contractor test project engineer.

(2) A system of documenting the contraint items with proper approvals for the test in question or waivers as required.

(3) A procedure for indicating items that are closed out between the conclusion of the open item review and the scheduled start of the test.

(4) A posttest critique at which anomaly items discovered during the performance of the test are evaluated as possible constraints to closeout of the subject test. All such constraints will be monitored during workoff by quality control.

(5) A preliminary constraints list for the next scheduled major test will also be defined at the posttest critique.

This procedure is now in effect.

FINDING NO. 4

Finding.—Items were placed on board the spacecraft during preparation for the space vehicle plugs out integrated test which were not documentated by quality inspection records.

Determination.—Procedures for controlling entry of items into the spacecraft were not strictly enforced.

Responsible organization.—KSC.

Action.—Apollo Preflight Operations Procedure No. 0–203, titled "Access to the Command and Service Modules" (CSM) was released on May 22, 1967. This procedure provides instructions and outlines responsibilities for controlling ingress/egress of personnel and/or materials to the CSM, and it establishes the requirements for a NAR Q & RA crew compartment and service module monitor.

This procedure clearly defines the requirements for the maintenance of the ingress/egress log to include all personnel and each item by name, quantity, part number, and work authorization. It further defines the type of equipment and materials which must be accepted in accordance with MSC specification MC 999–0058, titled "Approved Materials for use in the Apollo Spacecraft."

NASA KSC quality control personnel will verify and enforce contractor performance relative to controlling ingress/egress as part of their periodic inspections of the CSM.

This procedure is now in effect.

PANEL NO. 2. TEST ENVIRONMENTS

FINDING NO. 1

Finding.—All crew compartment equipment was not tested to be explosion proof.

Determination.—There was insufficient testing of possible ignition sources.

Responsible organization.—MSC.

Action.—Numerous ignition tests have been conducted in support of the accident investigation and as part of the ongoing Apollo program engineering, test, and evaluation efforts. The results of the latest 11 ignition tests which were conducted as part of the AS204 Review Board activity, but released subsequent to the Board's report, are described under Panel finding 9–a(2) p. 43).

All anomalies during the spacecraft manufacturing, certification, and test operations which could represent possible explosion sources will be completely reviewed prior to acceptance of the spacecraft by NASA and corrective actions taken immediately. This is discussed under Panel finding 2–3.

All equipment requiring electrical connection or disconnection that could be a potential fire-initiation or explosion hazard is capable of being turned off before the need for disconnection. This is discussed under Panel finding 2–6.

Extensive reviews of electrical wiring design, fabrication, and installation were conducted to determine that the wiring is not an ignition source. This is discussed under Panel finding 9–a(8) (p. —).

Tests were conducted to determine the effect of water glycol on connectors. These tests, discussed under Panel finding 8–3g (p. 38) lisclosed no evidence of electrical breakdown or degradation due to mmersion in water/glycol.

Tests and evaluations were conducted on all spacecraft circuitbreakers and other electrical equipment such as power inverters to insure they can comply with new stringent size/load/circuit protection design criteria. These are discussed under Panel finding 9a(5) (p. 44).

Certification testing of equipment continues as part of the continuing program actions to insure that all equipment anomalies that can potentially cause a fire hazard or explosion are identified and corrected.

FINDING NO. 2

Finding.—Crew compartment equipment of C/M 012 was exposed to water/ethylene glycol contamination. Untested cleaning techniques were employed for that equipment discovered to be wet.

Responsible organization.—MSC.

Action.—The ECS plumbing has been modified to minimize the possibility of water/glycol spillage as described under Panel finding 8–4a (p. 38).

A new, more effective MSC procedure has been developed to define the method for cleaning water/glycol spillage. Procedure for Removal of Ethylene Glycol Solution Spillage, MSC–Proc–C–105, dated July 12, 1967, establishes the methods for removing solutions that have spilled on electrical equipment, structural components, and plumbing in the spacecraft.

FINDING NO. 3

Finding.—Some of the C/M cabin equipment exhibited arcing or shorting during either certification or S/C 012 testing. There is no positive way to determine from the records reviewed whether S/C anomalies (possibly caused by a short or an arc) are reviewed by systems engineers and the test conductor prior to a test.

Determination.—Review of possible ignition sources prior to manned testing was inadequate.

Responsible organization.—MSC.

Action.—CARR requirements now include a record of all spacecraft anomalies experienced during hardware certification and spacecraft acceptance checkout that can possibly create an ignition hazard. The CARR report also provides a history of previous flight anomalies in addition to the subject spacecraft on the spacecraft checkout anomaly summary form. Subsequent to delivery, anomalies are documented by discrepancy reports against the operational test procedures or TPS authorizing the work, as required by Apollo program directive No. 26, Preparation of Test and Checkout Plans and Procedures at KSC, dated April 18, 1967. The CARR is described in Panel finding 1–2 (p.—).

The test checkout requirements document (TCRD) written by MSC and concurred in by KSC provides for an open item/constraints list review meeting before the initiation of any test and checkout procedures (TCP's). Items to be included in this review are all open discrepancy reports on potential fire hazards. The assessment of these items against a particular test will be determined by the systems engineers who are intimately familiar with the subsystems and the TCP's.

FINDING NO. 4

Finding.—Not all equipment installed in C/M 012 at the time of the accident was intended to be flown. Some components were installed for test purposes only.

Determination.—The suitability of this equipment in the C/M for this test was not established.

Responsible organization.—MSC.

Action.—An open item/constraints list review meeting between the responsible systems engineers of KSC and NAR will be held before the initiation of any TCP's. Included in this open-item review is the list of all of the nonflight hardware to be on board or connected to the command module for the particular test under review. The suitability of all nonflight hardware and equipment will be evaluated to determine that they present no safety or fire hazard. MSC will review all the TCP's and will exercise signature approval for those TCP's involving crew participation. This review meeting requirement is now in effect and is discussed under Panel finding 1–3 (p. 21).

FINDING NO. 5

Finding.—Noncertified equipment was installed in the C/M at the time of the accident. The "cobra cable" P/N V16–601263 and "T" adapter P/N V16–601396 are examples.

Determination.—The suitability of this equipment in the C/M for this test was not established.

Responsible organization.—MSC.

Action.—The CARR will determine the specific test constraint at KSC for each of the remaining unqualified hardware items. Identification of these items will be maintained on an up-to-date list and be presented at the open item/constraint list review meetings (see Panel finding 1–3, p. 21) held at KSC prior to initiation of testing. The suitability of these items will be evaluated to determine that they present no safety or fire hazard.

FINDING NO. 6

Finding.—The design required the mating and demating of "hot" electrical connectors as normal crew procedure. Changing to a spare "cobra cable" is an example.

Determination.—The practice of breaking "hot" electrical circuits introduces fire initiation hazards.

Responsible organization.—MSC.

Action.—All equipment requiring electrical connection or disconnection was reviewed and action was taken to correct the practice of breaking "hot" circuits.

All equipment requiring electrical connection or disconnection in flight or simulated flight is controlled by the following provisions:

(1) The two spacecraft utility outlets and the scientific equipment outlet have switches and/or circuit breakers that can turn power off before the need for disconnection.

(2) The cobra cable power can be turned off before the need for disconnection.

(3) The TV camera can be turned off before the need for disconnection.

Checkout and flight procedures have been revised to specify that power will be taken off any connections on any circuits that must be disconnected during checkout or flight.

Panel No. 5. Origin and Propagation of Fire

FINDING NO. 3

Finding.—Severe damage to wiring was found at the bottom of the lower equipment bay along the aft bulkhead. Evidence of arcing was found on the cover in front of C–15–1A–52 and adjacent wires. Damage was less severe in the +Y (right-hand) direction in this bay.

Determination.—Electrical arcing in the extreme lower lower left-hand corner of this bay could have provided a primary ignition source

Responsible organization.—MSC.

Action.—A series of detailed reviews, inspections, and tests have been conducted to insure that the electrical wiring throughout the spacecraft is not a source of electrical arcing or other potential ignition hazard. The results of the latest ignition tests involving wiring, which were conducted as part of the AS 204 Review Board activity, but released subsequent to the Board's report, are described under Panel finding 9–a(2) (p. 43).

Extensive reviews of electrical wiring design, fabrication, and installation were conducted to determine that the wiring is not an ignition source. Changes have been made to effectively protect all exposed wiring. This is discussed under Panel finding 9–a(8) (p. 45).

FINDING NO. 4

Finding.—Right-hand portions of the left-hand equipment bay received severe damage. Wiring, tubing, and components in the carbon dioxide absorber compartment and oxygen-water panel compartment were burned and melted. Penetrations in the aft bulkhead and pressure vessell wall were observed. The carbon dioxide absorber compartment showed heavy fire damage and failure was due to pressure overload and melting caused by the fire in this area.

Determination.—Electrical arcing in the right-hand portion of this bay could have provided a primary ignition source.

Responsible organization.—MSC.

Action.—The actions described under Panel finding 5–3 cover the steps that were taken to insure that the electrical wiring in the right-hand portions of the left-hand equipment bay, as well as the rest of the spacecraft, is not a source of electrical arcing or other potential ignition hazard.

FINDING NO. 9

Finding.—Evidence of electrical arcs from conductor to conductor and conductor to structure was found.

Determination.—No arc could be positively identified as the unique ignition source. Three were found that had all of the elements needed to cause the disaster. Two of these showed evidence of poor engineering and installation.

Responsible organization.—MSC.

Action.—The actions described under Panel finding 5–3 cover the steps that were taken to insure that the electrical wiring in the spacecraft is not a source of electrical arcing from conductor to conductor or from conductor to structure. Panel finding 9–a(8) (p. 45) describes the reviews and evaluations that were conducted to correct engineering and installation deficiencies.

PANEL NO. 6. HISTORICAL DATA

FINDING NO. 1

Finding.—The ingress-egress log discloses several instances where tools and equipment were carried into the S/C, but the log does not show these tools as removed.

Determination.—The maintenance of the ingress-egress log is inadequate.

Responsible organization.—KSC.

Action.—Apollo Preflight Operations Procedure No. 0–203, titled "Access to the Command and Service Modules" (CSM) was released on May 22, 1967. This procedure which is now in effect provides instructions and outlines responsibilities for controlling ingress-egress of materials to the CSM, and establishes the requirements for an NAR Q. & R.A. crew compartment and service module monitor. Additional details are furnished under Panel finding 1–4 (p. 22).

FINDING NO. 2

Finding.—(*a*) Shakedown inspection periods are not shown in the master flow plan. (*b*) There are no definitive inspection criteria to perform shakedown inspections for the Apollo program.

Determination.—(*a*) Hardware condition prior to major tests and milestones is difficult to establish. (*b*) Inspection personnel are not able to assess the condition of the S/C for compliance with definite criteria, but rather assess it in accordance with their knowledge of standard practices.

Responsible organization.—MSC.

Action.—Hardware condition before major tests and milestones is established through a series of reviews and inspections starting from the time the spacecraft is at the NAR facility in Downey, Calif., to the time it is prepared for tests at KSC.

The basic identification of hardware condition is based on a set of spacecraft inspection criteria, prepared by NAR for each spacecraft as it is being built. These inspection criteria are in turn based on a specification which defines the specific design, test, and acceptance requirements of each spacecraft. The first manned spacecraft specifications and inspection criteria are all being updated to incorporate the changes which evolved from the AS–204 accident. A major area of change is the provision for the new Nonmetallic Materials Selection Guidelines, ASPO–RQTD–D67–5A, dated May 3, 1967. The extent of changes due to these requirements is descrbied in Panel finding 8–1a (p. 33).

Before acceptance of the spacecraft by NASA, a detailed review of the spacecraft open work, quality control and reliability verifications, and hardware constraints is conducted. This review, the CARR, is described under Panel finding 1–2 (p. 20). The result of this review include an identification of all hardware status and condition at the time of acceptance by NASA.

NAR maintains an up-to-date listing of the spacecraft hardware status, and reviews this status at an open-item review with KSC while the spacecraft is being processed at KSC for launch operations. This is described under Panel finding 1–3 (p. 21).

During processing and prelaunch operations at KSC, the spacecraft is inspected according to a set of detailed shakedown inspection requirements called inspection and test instructions (ITI's). The performance of these ITI's is identified on the master flow plan and provide an up-to-date identification of specific hardware status as the spacecraft processing proceeds at KSC. The shakedown inspections cover a wide range of areas and provide for complete inspection of all spacecraft hardware before major testing. Seven ITI's for activities before, during, and after hatch closure are listed under Panel findings 6–3. Over 40 ITI's have been updated to conform to new, more stringent requirements covering inspections at NAR Downey and at KSC.

With the records of the reviews and inspections described above, the hardware condition before major tests and milestones can be established on an up-to-date basis. Inspection personnel have definitive criteria upon which to assess the condition of the spacecraft through use of the updated ITI's.

FINDING NO. 3

Finding.—Inspection personnel do not perform a prescheduled inspection with a checklist prior to hatch closing.

Determination.—Inspection personnel could not verify these functions during this period.

Responsible organization.—KSC.

Action.—Specific inspection instructions and checklists for activities before, during, and after hatch closure have been defined in inspection test instructions (ITI's) No. 816–1 through 816–7, prepared by NAR R & QA. These ITI's will be revised and updated for each spacecraft to include any special areas, including ingress, inherent to the specific spacecraft or mission. The authorization to implement the ITI's is included as a sequence in the applicable test procedures (see Panel finding 7–2, p. 29). Before and after crew ingress, NAR and NASA R & QA personnel will verify accomplishment of the checklists.

These ITI's have been revised on May 3, 1967, and are in effect:

(1) ITI 816–1, detail requirements for shakedown inspection of complete CSM.

(2) ITI 816–2, detail requirements for shakedown inspection of service module.

(3) ITI 816–3, detail requirements for shakedown inspection of SLA.

(4) ITI 816–4, detail requirements for shakedown inspection of CM exterior.

(5) ITI 816–5, detail requirements for shakedown inspection of CM top deck.

(6) ITI 816–6, detail requirements for shakedown inspection of LES.

(7) ITI 816–7, detail requirements for shakedown inspection of CM interior.

FINDING NO. 4

Finding.—Formal approval by NASA or NAA Quality Control of the constraints list is not required.

Determination.—NASA/NAA Quality Control cannot discharge their responsibilities without approving the constraints list.

Responsible organization.—KSC.

Action.—The formal concurrence on the constraints list by NASA and contractor quality control, engineering, and operations organizations is required by the procedure APOP No. 0–222, TCP Open Item Reviews, Constraints Listings, Pre-test Briefings and Post-test Debriefings, released August 2, 1967. In addition to assigning the responsibilities noted above, this procedure requires that any disagreement on the constraints list must be resolved by the Director, KSC-Spacecraft Operations. Additional information on constraint requirements is provided under Panel finding 1–3 (p. 21).

FINDING NO. 5

Finding.—The requirements for mandatory inspection points (MIP's) are not clearly defined in the Apollo preflight operations procedures.

Determination.—Proper inspection coverage is not assured without clearly defined MIP's.

Responsible organization.—KSC.

Action.—Proper inspection coverage will be assured through implementation of APOP No. 0–309, Mandatory and Designated Inspection Points, released November 6, 1967. This procedure clearly defines the Government and contractor quality control mandatory inspection points (MIP's). This procedure is effective for all manned spacecraft.

FINDING NO. 6

Finding.—At the time of shipment of the S/C to KSC, the contractor submitted an incomplete list of open items. A revision of the said list significantly and substantially enlarged the list of open items.

Determination.—The true status of the S/C was not identified by the contractor.

Responsible organization.—MSC.

Action.—The actions taken to identify the actual status of the spacecraft are described under Panel finding 6–2.

Open items are more stringently controlled by NAR and reviewed once the spacecraft is at KSC for prelaunch processing. This is described under Panel findings 1–1 and 1–3 (pp. 19–21).

FINDING NO. 7

Finding.—There is no efficient system which readily identifies that results accomplished by rework are verified by retest.

Determination.—The present system of verification of rework by retest is cumbersone.

Responsible organization.—KSC.

Action.—An efficient system of verification of rework by retest has been developed in procedure APOP No. T–502, Discrepancy Recording System, released August 16, 1967. This procedure now in effect defines and implements the requirement that retests (after rework has been accomplished) must be completed prior to the closeout of the discrepancy report (DR). A DR is listed as "open" until retesting is accomplished.

FINDING NO. 8

Finding.—There is no requirement to maintain records by subsystem classification, nor does the system present status in this fashion.

Determination.—The recovery of pertinent historical information is extremely difficult.

Responsible organization.—MSC.

Action.—The recovery of historical information will be assisted by implementation of the following NAR internal procedures, which are now in effect:

(1) Processing and filing of completed spacecraft TAIR records, release June 1967;

(2) Fabrication, assembly, and inspection record (FAIR) system, released February 1967;

(3) Change verification record system, released April 1967.

The above documents established and maintain traceability and provide permanent records of completion, inspection and acceptance.

Panel No. 7. Test Procedures Review

FINDING NO. 1

Finding.—The Panel documented the plugs out test procedure (FO-K-0021-1) as it had been performed.

Determination.—The test procedure did not contribute to the accident. There was a defect in the procedure in that power was applied to the uncapped gas chromatograph power cable after the gas chromatograph had been removed from the spacecraft.

Responsible organization.—KSC.

Action.—The procedural requirements in this area are being more carefully controlled by additional technical review, management control, and approval of test procedure deviations, as defined in APOP No. 0-221, Execution and Acceptance of Test and Checkout Procedures released July, 20, 1967. This procedure is in effect.

FINDING NO. 2

Finding.—209 pages of the 275 page OCP were revised and released on the day before the test. Less than 25 percent of the line items, however, were changed. Approximately 1 percent of the change was due to errors in technical content in the original issue of the procedure. In addition, 106 deviations were written during the test.

Determination.—Neither the revision nor the deviations are known to have contributed specifically to the incident. The late timing of the change release, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

Responsible organization.—KSC.

Action.—Change release timing is being expedited by the implementation of APOP No. 0-202, Preparation and Release of Test and Checkout Procedures, released July 12, 1967 (effective date August 1, 1967). This procedure provides instructions and assigns responsibilities including the following:

(1) A time line is established which specifies deadlines for preparation, review, approval, and release of TCP's.

(2) The TCP Control Board, which consists of NASA/KSC and the S/C contractor organization, has the responsibility for establishing policy governing NAR launch operations TCP's and assuring that timely and technically adequate TCP's are published. All revisions for actual test plans must be in the hands of the test team 2 days before the test. No last minute revisions for operational test procedures are acceptable, and this' limitation can only be waived by the KSC director, or his designated alternate.

FINDING NO. 3

Finding.—During the altitude chamber tests the cabin was pressurized at pressures greater than sea level with an oxygen environment 2½ times as long as the cabin was pressurized with oxygen prior to the accident during plugs out test.

Determination.—The spacecraft had successfully operated at the same cabin conditions in the chamber for a greater period of time than on the pad up to the time of the accident.

Responsible organization.—MSC.

Action.—The possibility of using air on the pad during sea level operation is discussed under Panel finding 9–b(3) (p. 46).

FINDING NO. 4

Finding.—The plugs out OCP was not classified as hazardous.

Determination.—The hazard level was not recognized and consequently the procedure was processed through the review cycle as a nonhazardous procedure.

Responsible organization.—KSC.

Action.—The KSC safety office and NAR safety are presently reviewing and approving (by signature) all spacecraft test procedures. A KSC management instruction (KMI) is in preparation that establishes and defines the requirement for this review. The KSC safety office makes the final determination as to the hazardous classification of the test. The total TCP safety review plan is defined in APOP No. G–102, Safety Considerations for Checkout Procedures, released July 17, 1967. This procedure is in effect.

Panel finding 13–1 (p. 52) provides additional discussion on the safe aspects of recognizing hazard levels and the safety review cycle.

FINDING NO. 5

Finding.—Only local control is provided for certain systems which may require remote control for safety reasons, such as service structure water and hypergolic supply sources.

Determination.—The full potential of the safety systems is not utilized due to the lack of remote control capability.

Responsible organization.—KSC.

Action.—Detailed studies have been completed that reviewed the advantages and disadvantages of remote control capability to systems such as the service structure water deluge and hypergolic supply sources. As a result of these studies, it was concluded that in both of these systems, a remote control capability or additional control stations would not improve the safety aspects of systems control. The studies were conducted by KSC spacecraft operations, launch operations, and design engineering personnel. Based on these studies, it is concluded that the full potential of the safety systems in question is currently being used.

FINDING NO. 6

Finding.—The open item constraint list was not formalized as required by APOP No. 0–202.

Determination.—Pretest constraints were evaluated informally on a system-by-system basis by the test team.

Responsible organization.—KSC.

Action.—Pretest constraints will be formally evaluated and documented by the implementation of APOP No. 0–222, TCP Open Item Reviews, Constraints Listing, Pretest Briefings, and Post-test Debriefings, released August 2, 1967. This procedure, now in effect, provides instructions and assigns responsibilities including the following:

(1) A specific definition of the requirement for a pretest open item review. The review will be cochaired by the NASA spacecraft test conductor or his designee and the spacecraft contractor test project engineer.

(2) A system of documenting the constraint items with proper approvals for the test in question or waivers as required.

(3) A procedure for indicating items that are closed out between the conclusion of the open item review and the scheduled start of the test.

FINDING NO. 7

Finding.—Troubleshooting of the communication problem was not controlled by any one person. At times, it was run independently from the spacecraft, Launch Complex 34 Blockhouse, and the Manned Spacecraft Operations Building. Communications switching, some of which was not called out in the OCP, was performed without the control of the test conductor.

Determination.—The uncontrolled troubleshooting and switching contributed to the difficulty experienced in attempting to assess the communication problem.

Responsible organization.—KSC.

Action.—KSC Launch Operations Directive No. 8, Control of Operational Intercommunications (OIS) Troubleshooting During Apollo/Saturn Major Test, was released October 30, 1967. This directive, now in effect, defines and implements the following requirements:

(1) No OIS troubleshooting will take place during major testing (space vehicle overall test, flight readiness test, countdown demonstration test, and countdown) without prior approval of the NASA test supervisor.

(2) The NASA spacecraft test conductor will maintain overall direction and control of the troubleshooting effort on all circuits that interface with the spacecraft.

APOP No. 0-221, Execution and Acceptance of Test and Checkout Procedures, now in effect, specifically defines the requirement that all S/C OIS troubleshooting activities will be under the control of the NASA spacecraft test conductor.

FINDING NO. 8

Finding.—KSC was not able to insure that the spacecraft launch operations plans and procedures adequately satisfied, on a timely basis, the intent of MSC. Changes to S/C testing by KSC could not be kept in phase with the latest requirements of MSC. Pre-launch checkout requirements (GORP) were not formally transmitted to KSC from MSC.

Determination.—Prelaunch test requirements control for the Apollo spacecraft program is constrained by slow response to changes, lack of detailed KSC–MSC intercenter agreements, and by the lack of official NASA approved test specifications applicable to prelaunch checkout.

Responsible organization.—MSC.

Action.—Prelaunch test requirements control for the Apollo spacecraft program are defined in Apollo Program Directive No. 26, Preparation of Test and Checkout Procedures at KSC, released April 18, 1967. Response to changes has been expedited by conducting a series of reviews and by requiring configuration data to be maintained on a current basis as described in Panel finding 1–2 and 1–3.

Detailed KSC–MSC intercenter agreements have also been developed based on the Apollo program directive mentioned above. MSC is currently required to furnish an MSC-approved test and checkout requirements document to KSC 4 months before delivery, and the test specification and criteria document 2 months before delivery of the first manned spacecraft. For subsequent spacecraft, the requirement is 4 months before delivery for both documents. NAR will submit the proposed documents to MSC at least 1 month before the required MSC approval dates. Additional test specification information is furnished under Panel finding 7–9.

FINDING NO. 9

Finding.—The test specifications for spacecraft 012 were not written in a convenient-to-use format, did not contain field tolerances, were not NASA approved, were not maintained up to date, and were not transmitted to NASA/KSC.

Determination.—The lack of usefulness of the test specifications has been recognized by NAA, Downey and measures intended to correct the situation have been initiated.

Responsible organization.—MSC.

Action.—NAR is preparing a test and checkout requirements document and a test specification and criteria document to cover the checkout activities at KSC. These documents will replace the ground operations requirements plan (GORP) for Block II spacecraft and will include required tests and prerequisites to each testing phase as well as the field tolerances required to be met for acceptance of tests. These documents will have NASA MSC approval and will be forwarded to KSC for implementation to support the first manned spacecraft. The action was assigned by Apollo Program Directive No. 26.

PANEL NO. 8. MATERIALS REVIEW

FINDING NO. 1a

Finding.—Complete documentation which identified potentially combustible nonmetallic materials used in S/C 012 is not available in a single readily usable format. A total of 2,528 different potentially combustible nonmetallic materials which were probably used on S/C 012 were found by a review of available documentation.

Determination.—The program for identification and documentation of nonmetallic materials used in the S/C, including their weights and surface areas, was not adequate.

There is no system in effect through which nonmetallic materials configuration changes are tracked, reported, evaluated, and controlled in an integrated manner.

Responsible organization.—MSC.

Action.—The amount of combustible materials in the command module has been greatly reduced. There were 1,412 nonmetallic materials identified in the CSM. Seventy-nine percent of 1,113 have been deleted, replaced, redesigned, or determined to be acceptable. The remaining nonmetallic materials are currently being evaluated and work on this effort is scheduled for completion early in 1968. This effort includes flammability tests to be conducted early next year at MSC on a full-scale command module boilerplate (BP–1224).

The overall objective of the full-scale flammability test program is to insure that no fire hazards exist in maned spacecraft. If hazards are discovered as a result of this command module mockup test program, materials may be relocated, removed, or replaced. The following are specific objectives:

(1) Define the degree of propagation and magnitude of each fire resulting from the ignition source;

(2) Measure the rate and magnitude of pressure and temperature increases resulting from combustion;

(3) Determine length of time a reasonable degree of crew visibility would be retained;

(4) Identify toxic products occurring as a result of the ignition.

These tests will be performed at 6.2 psia and then at 16.5 psia with a 100-percent oxygen environment. Ignition will first be attempted by means of a deliberate electrical circuit overload. In the event ignition does not occur, a nichrome wire will be used as an ignition source.

The test article consists of boilerplate 1224 with the interior built up simulating a flight command module, including:

(1) All storage compartments and boxes;

(2) The complete internal electrical wire harness including all wire protective wraps, spot ties, clamps, spacers, and conformal coatings;

(3) Rotational and translational controllers on the couches;

(4) Two suits and oxygen supply hoses with cobra cables;

(5) A pump accumulator and reservoir providing water/glycol flow rates and pressures representative of manned spacecraft;

(6) Cabin fans and cabin pressure relief valve;

(7) All contractor and Government-furnished equipment having nonmetallics such as tools, food, procedures manuals, medical supplies, sanitary supplies, clothing, etc.

Ignition will be imposed by overloading electrical conductors in wire bundles, at circuit breaker terminal posts, and through potted connections. No systems or circuits will be live other than the ignition source. Oxygen handling procedures are being defined in detail to be in accordance with MSC safety regulations.

This full-scale test is being preceded by many component and subsystem tests made in boilerplate 1250. These tests have been run on such items as wiring and wire bundles, specific sections of the crew compartment, and circuit breaker panels.

A senior flammability test review board has been established to determine whether the full-scale test configuration is a proper one and whether the test results verify that the spacecraft is fire safe. Dr. Gilruth is chairman and among the senior representatives are key personnel from NAR, OMSF, medical research and operation, flight safety, and flight crew operations.

The requirement for identification of all nonmetallic materials, their location, weight, and surface area has been imposed on all organizations furnishing equipment for use in the CSM crew compartment as follows. CCA 1361 was issued April 17, 1967, for the CSM. CCA 428 was issued April 19, 1967, for the guidance and navigation system. Letter PR2/M67–119 was issued May 8, 1967, for Government-furnished equipment. Standardized reporting formats have been adopted by implementation of the COMAT Instruction Manual, dated July 7, 1967. Extensive nonmetallic materials revisions have been made to the CSM crew equipment stowage, ECS suit loop, spacesuit, and other CSM equipment as follows:

(1) *CSM crew equipment stowage.*—The following stowage bags and boxes have been deleted and redesigned to use a metal box:

(*a*) Forward sanitation supplies stowage box;

(*b*) Aft sanitation supplies stowage box;

(*c*) PLSS cable stowage container;

(*d*) LH upper equipment bay stowage bag;

(*e*) RH upper equipment bay stowage bag;

(*f*) Thermal meteoroid garment stowage bag;

(*g*) Inflatable tool set stowage pouch;

(*h*) The sanitation supplies bag was redesigned to use a Teflon bag;

(2) *CSM ECS suit loop materials.*—The following nonmetallic materials used in the ECS suit loop were replaced:

(*a*) Dacron filters in LiOH canister;

(*b*) Polyurethane foam insulation on the ECU;

(*c*) Silicon foam insulation;

(*d*) In addition, NAR was directed by CCA 1323 and CCA 1324 to investigate replacement of the polyurethane seats located in the relief valve and regulator.

The dacron filter was replaced with an Armalon filter that meets the requirements of MSC Specification 66–3A. Environmental Control Unit Specification ME901–0218 was revised June 22, 1967, to effect this change. The polyurethane foam insulation will be replaced by TG 15000 (postcured fiberglass) wrapped with Beta glass (Pyrolace STFE 40B).

(3) *Space suit materials.*—Space suit material changes have been made. The materials used in the block II EMU (space suit) are described in detail in document CSD–A–523, Materials Report for EMU Garments and Accessories.

(4) *CSM nylon fastener replacements.*—Nylon fasteners were replaced by mechanical fasteners in 28 locations. The nylon Velcro was removed from 18 locations in the CSM.

Control over nonmetallic materials is exercised by both the contractor and MSC. The contractor bears the primary design responsibility for the selection of materials. NASA bears the responsibility for the review of the selection of certain classes of materials. Where NASA organizational elements are acting as major contractors; i.e., for GFE, they will submit deviation requests to the MSC nonmetallic materials selection review board. The contractors have within their own organization, and have established at their subcontractors installation, one or more cognizant materials engineers who will be responsible for reviewing materials problems, formulating deviation requests and submitting them to the MSC materials selection review board.

The NASA-MSC materials selection review board has the final responsibility for approval of deviations. This board is located at MSC and is chaired by the chief of the RQ&T Division. Representation is from all cognizant technical areas including flight safety, space medicine, materials reliability and control, and materials engineering. A second board is located at the spacecraft contractor's facility. This board has as its chairman the contractor's counterpart to the NASA-MSC board chairman and has the same type of membership as the NASA-MSC board. The contractor's board is basically responsible for approving or disapproving deviations and submits all actions to the MSC board for final approval.

The basic discipline being applied throughout the spacecraft program is to limit the selection and placement of materials in the crew bay so that if a fire should start, it could not propagate or burn sufficiently to incapacitate the crew or result in critical structural or functional damage to the spacecraft.

Materials selection guidelines and test procedures have been prepared and implemented through the following basic documents:

ASPO–RQTD–D67–5, Nonmetallic Materials Selection Guidelines dated April 10, 1967, Revision A, issued May 5, 1967. (This document establishes acceptance guidelines and test requirements for nonmetallic materials in the spacecraft. It includes general fire control criteria and eight categories of materials classified according to functional application and distribution in the spacecraft. Toxicity, flammability, design, and test requirements are also defined.)

MSC–A–D–66–3, Revision A. Procedure and Requirements for the Evaluation of Spacecraft Nonmetallic Materials, dated June 5, 1967. (This document contains detailed test procedures and requirements for combustion rate, flammability, odor, offgassing, and ignition tests that conform to the more rigid selection requirements of the Nonmetallic Materials Selection Guidelines described above.)

FINDING NO. 1b

Finding.—Test data providing individual combustion properties in environments of 5 p.s.i.a. to 21 p.s.i.a. oxygen were available for 550 of the potentially combustible nonmetallic materials identified as possibly being used. Data on higher pressure testing were available only on suit materials, Velcro, and K–10 flight paper.

Determination.—Flammability test requirements were not standardized at the time the reference tests were accomplished.

Large numbers of potentially combustible nonmetallic materials were used in the fabrication of S/C 012 without specific correlated combusitbility test data. Test data were available at high O_2 pressures (to 21 p.s.i.a.) to define the combustion characteristics of some of the major materials which contributed heavily to the fire.

Responsible organization.—MSC.

Action.—Flammability test requirements have been standardized as part of the overall fire control program being accomplished on all manned spacecraft.

Combustibility test data will be obtained on all nonmetallic materials used in the spacecraft at 16.5 p.s.i.a with a 100 percent oxygen environment. These tests and requirements for selection and test verification of nonmetallic materials are discussed in Panel finding 8–1a.

FINDING NO. 2

Finding.—Raschel Knit, Velcro, Trilock, and polyurethane foams burn about twice as fast (in the downward direction) in 16.5 p.s.i.a. as in 5 p.s.i.a. O_2.

Determination.—The primary fuels for the fire burned over twice as fast in the early stages of the fire in accident conditions (16.5 p.s.i.a.) than in space flight atmosphere for which they were evaluated (5 p.s.i.a).

Responsible organization.—MSC.

Action.—All nonmetalic materials will be extensively tested in a 16.5 p.s.i.a., 100 percent oxygen atmosphere. Full-scale mockup tests to determine overall flammability characteristics are described in Panel finding 8–1a.

FINDING NO. 3a

Finding.—Laboratory analyses indicated that solvent retention by test specimens was significant. The analyses also indicate that the evaporation characteristics of the solvent are such that vapor concentration fell below the lean flammability limit after 1½ hours.

Determination.—The presence of significant volumes of concentrated vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignitability.

Responsible organization.—MSC.

Action.—Quality assurance requirement MSC–A-D67–5 includes provision for prohibiting the use of dangerous solvents and for limiting those solvents that are required for use to accomplish a process within the crew compartment. Contractual action has been completed.

FINDING NO. 3b

Finding.—Odors similar to that of sour milk and methyl-ethyl-ketone were reported before the fire during suit and cabin purge operations.

Thresholds of methyl-ethyl-ketone and isopropyl alcohol detection by smell are approximately 0.01 percent to 0.03 percent by volume and concentrations described as strong, irritating, or sickening range from 1 percent to 4 percent by volume.

Determination.—There is no evidence that significant concentrations of organic vapors were present in S/C 012 at the time of the fire.

Responsible organization.—MSC.

Action.—Solvent use and control has been included in the new quality assurance requirements developed by MSC as described in Panel finding 2-2 (p. 23).

Criteria for conducting tests on odors emanating from nonmetallic materials at elevated temperatures are now in effect based on MCS-A-D-66-3 (defined under panel finding 8-1a). Each test is witnessed by the assigned quality assurance inspector and each step is verified and stamped as required by the procedure. Other tests have been conducted according to these criteria to determine the organic offgassing products and CO generation of nonmetallic materials. These tests will be culminated in the full-scale testing described in Panel finding 8-1a.

FINDING NO. 3d

Finding.—Connecting and disconnecting of spacecraft-qualified cobra connectors at normal loads did not create sufficient energy to ignite concentrations up to saturation (approximately 12 percent) of methyl-ethyl-ketone in 16.4 p.s.i.a. oxygen. An increase in loading to 2.5 times operating amperage in 4 percent of MEK yielded no ignition.

Determination.—Ignition of flammable concentrations of solvent vapors by connecting and disconnecting cobra connectors is an unlikely ignition source for the S/C 012 fire.

Responsible organization.—MSC.

Action.—The cobra cable power can be turned off prior to the need for disconnection by suit power switch and the audio panel module switch.

Checkout procedures are being revised to specify that power will be taken off any connections on any circuits that must be disconnected during checkout or flight.

FINDING NO. 3e

Finding.—Preliminary high-energy impact tests on Velco and Rashel Knit in 16.5 psia oxygen produced ignition and burning.

Determination.—A survey of similar spacecraft and mockup failed to disclose the possibility of any high impact conditions.

Responsible organization.—MSC.

Action.—A test procedure has been developed and tests have been conducted as part of MSC-A-D-66-3, Revision A, dated June 5, 1967 (see Panel finding 8-1a for description of this procedure). This specific procedure provides a method for determining the sensitivity and compatabilty of nonmetallic materials with pure oxygen. This test is applicable to materials selected for use in the high-pressure oxygen system. Acceptability criteria include disapproving the material if there is discoloration, evidence of ignition, or detonation.

FINDING NO. 3g

Finding.—Conditions required for wet-wire fire ignition through electrolytic action are damaged wire insulation, presence of an electrolyte and electric potential between damaged wires and a flammable substance in the proximity. A test has shown that ESC coolant applied to a purposely damaged wire of a type used in the C/M caused a fire.

Determination.—The required conditions could have been present in S/C 012.

Responsible organization.—MSC.

Action.—Tests were conducted to determine the effect of water/glycol on connectors. A typical test consisted of briefly immersing mated connectors in water/glycol, cleaning by normal procedure, and then applying normal spacecraft electrical power through them while in a 100 percent oxygen atmosphere. No evidence of electrical breakdown or degradation was noted in the cable/connector assemblies from any of the tests.

Reducing the possibility of fire from this source has been accomplished by:

(1) Minimizing water/glycol leakage (see Panel finding 8-4a);

(2) Correcting wiring deficiencies (see Panel finding 9–a(8), p. 45);

(3) Providing for more effective water/glycol cleaning procedures (see Panel finding 2–2; p. 23).

FINDING NO. 3h

Finding.—An unpotted connector with some unused pin channels subjected to water/glycol and placed under DC stress developed a short circuit.

Determination.—Water/glycol electrocorrosion products and residue are conductive and capable of acting as an electrolyte.

Responsible organization.—MSC.

Action.—Actions taken to reduce the possibility of fire from water/glycol electrocorrosion products and residue include:

(1) Minimizing water/glycol leakage (see Panel finding 8-4a);

(2) Providing for more effective water/glycol cleaning procedures (see Panel finding 2–2, p. 23);

(3) Conducting a study on possible improvement of inhibitor characteristics. Nineteen inhibitors were evaluated and none was found superior to that currently being used for ethylene glycol/water fluids.

FINDING NO. 4a

Finding.—There have been 35 instances of water/glycol leakage on Block I Spacecraft involving aproximately 320 ounces.

Determination.—The water/glycol distribution system requires corrective action to eliminate leakage.

Finding.—Prior to the accident there had been no electrical system failures attributable to the water/glycol leaks.

Determination.—The electrical system has some tolerance to water/glycol spillage.

Finding.—There is no standard cleaning procedure in effect to remove water/glycol spills or residue.

Determination.—There is a probability that water/glycol residue is present in areas of all Block I spacecraft.

Finding.—Six instances of water/glycol leakage were recorded for S/C 012. Of these, one soaked several SCS connectors and wire bundles. Some corrective action was taken to clean all known spills in S/C 012.

Determination.—Water/glycol residues may have been present in areas of S/C 012 including on wire bundles and connectors.

Responsible organization.—MSC.

Action.—There were occasions when water/glycol was spilled in the cabins of Block I command modules, either when ECU connections to the spacecraft distribution system leaked on removal of the ECU, or when joints leaked. For the most part, wiping operations were employed to soak up the spillage and in some cases water and isopropyl alcohol rinses followed by dry nitrogen drying were used, particularly when spilalge was known to have wetted connectors in S/C 012. No failures of the electrical systems were reported in the programs as attributable to the water/glycol spillage; thus, it can be assumed that the wiping and cleaning operations, while not standardized, were sufficiently good in combination with sufficiently sealed equipment to prevent trouble in the areas of known spillage.

Action is being taken to minimize leakage of the water/glycol distribution system and adequately cleaning any residues. These include armoring the water/glycol ECS joints as follows:

(1) Early manned spacecraft will have 103 to 179 solder joints in the cabin armored. All joints in the service module will be armored;

(2) Later manned spacecraft will have all solder joints in CM and SM armored;

(3) Voishan washers will be installed on all mechanical joints in all manned spacecraft that do not already contain them, when the connectors are uncoupled. The retorquing of all B-nuts will be incorporated on all manned spacecraft;

(4) The aluminum oxygen lines in the cabin have been replaced with stainless steel lines on all manned spacecraft. Aluminum oxygen lines in the oxygen valve panel and the ECU are welded rather than soldered and will not be replaced.

Providing for more effective water/glycol cleaning procedures is described in Panel finding 2–2 (p. 23).

FINDING NO. 4b

Finding.—Tests in a 14.7 p.s.i.a. oxygen atmosphere on horizontal surface show films of C/M coolant will not propagate a flame before or after air drying for up to 48 hours. Films of coolant will propagate a flame after exposure to reduced pressure for periods of 60 to 80 hours. Pure ethylene glycol will propagate a flame in a similar atmosphere.

Determination.—Residues from previous standard coolant fluid spills in S/C 012 might have provided a path for flame propagation on materials that were wetted. Spills or leaks in the early stages of the fire would burn when heated.

Responsible organization.—MSC.

Action.—Provisions for more effective cleanup of coolant fluid spill residues are described in Panel finding 2–2 (p. 23).

FINDING NO. 4d

Finding.—The condition and appearance of individual materials after the 16.5 p.s.i.a. oxygen boilerplate test approximated materials conditions observed in S/C 012. The pressure rise measured in the boilerplate test approximated that in the S/C 012.

Determination.—A reasonable simulation of the S/C 012 accident was achieved by the boilerplate tests.

Finding.—The rate of flame propagation, the rate of pressure increase and the maximum pressures achieved, and the extent of conflagration in 5 p.s.i.a. oxygen boilerplate tests was much less severe than observed in the 16.5 psia oxygen boilerplate tests. Burning or charring was limited to approximately 29 percent of the nonmetallic materials by oxygen depletion.

Determination.—The conflagration which occurred in S/C 012 at 16.5 p.s.i.a. would be far less severe and slower in a spacecraft operating with an environment of 5 p.s.i.a. if additional large quantities of oxygen are not fed into the fire.

Determination.—A fire in a spacecraft configured as S/C 012 operating with a 5 p.s.i.a. oxygen environment could be fatal.

Finding.—The early stages of fire propagation in the boilerplate tests were observed to be dependent upon the combustion rate and location of the materials. The observed rates appeared to have been much greater than the factor of two increase measured downward in the laboratory tests when the oxygen pressure is increased from 5 p.s.i.a. to 16.5 p.s.i.a. The additional increase in rate in the boilerplate tests most likely occurs because of the combined effect of burning upward and along the continuous paths provided by flammable materials.

Determination.—The spread of fire at 16.5 p.s.i.a operating pressures is too rapid for effective remedial action in spacecraft with combustible materials arranged as in C/M 012. The spread of fire at 5 p.s.i.a. operating pressures is probably too rapid for effective remedial action by an unsuited crewman.

Responsible organization.—MSC.

Action.—Full-scale boilerplate tests will be conducted on a flight-type command module. Increased testing of nonmetallic materials has been accomplished at 16.5 p.s.i.a. and materials replaced or removed if they could not pass the new stringent flammability criteria. These tests are discussed under Panel finding 8–1a.

FINDING NO. 4e

Finding.—The energy available from about 4 ounces of Raschel Knit or Velcro could raise the pressure in a closed C/M from 16.5 p.s.i.a. to 36 psia in less than 14 seconds after ignition. (Calculations assume complete combustion and adiabatic conditions).

Finding.—Teflon materials did not burn appreciably in S/C 012. Calculations based on laboratory data indicates that Teflon could not have contributed appreciably to the rate of pressure rise. The total energy available from the Raschel Knit, Velcro, foam, Trilock and polyurethane materials was much greater than necessary to raise the cabin pressure from 16.5 p.s.i.a. to 36 p.s.i.a.

Determination.—Teflon provides an insignificant fire risk.

Determination.—There was considerable excess combustible material available with which to raise the C/M pressure to the estimated burst pressure.

Responsible organization.—MSC.

Action.—The selection and control of combustible materials is being accomplished through an extensive series of subscale, component, and full-scale flammability tests as described in Panel finding 8–1a.

FINDING NO. 5a

Finding.—The NAA materials selection specification MAO 155–008 requires only that a material pass a 400°F. spark ignition test in 14.7 p.s.i.a. oxygen.

Determination.—The NAA criteria for materials flammability control were inadequate.

Finding.—A system for control of nonmetallic materials usage existed at NAA during the design, fabrication, and assembly of C/M 012. The NAA materials control system is design oriented.

Determination.—The system is permissive to the extent that controls over the installation or use of flammable materials are not adequate.

Finding.—There were nonflight items containing combustible materials in C/M 012 during this test.

Finding.—No flammability criteria or control existed covering nonflight items installed in C/M 012 for test.

Determination.—Lack of control of nonflight material could have contributed to the fire.

Responsible organization.—MSC.

Action.—The NAR criteria for materials flammability control have been revised and are now used for all nonmetallic materials testing Installation of flammable materials is being rigidly controlled through the use of contractor and MSC material review boards. The above areas are described in detail in Panel finding 8–1a.

Nonflight material is carefully screened as to their potential fire hazard as described in Panel finding 2–4 (p. 24).

FINDING NO. 5b

Finding.—The NASA materials selection criteria MSC–A–D–63 and MSC–A–D–66–4 requires that a material pass a 400° F. spark ignition test and a 0.5 in/sec combustion rate (measure downward in 5 psia 02). Raschel Knit and Velcro (hook) pass this test.

Determination.—The NASA criteria for materials flammability control are not sfficiently stringent.

Finding.—The system for control of nonmetallic materials usage at MSC during the design and development of Government furnished equipment used in C/M 012 depended on identification of noncompliance with criteria by the development engineers.

Determination.—The NASA materials control system is permissive to the extent that installation or use of flammable materials were not adequately reviewed by a second party.

Finding.—Nonmetallic materials selection criteria utilized by NAA and NASA are not consistent. The NASA criteria, although more stringent, were not contractually imposed on the S/C contractor.

Determination.—Materials were evaluated and selected for usage in C/M 012 using different criteria. Application of the NASA criteria to the C/M would have reduced the amount of the more flammable materials (velcro and uralane foam).

Finding.—Visual "walk-through" inspections had resulted in removal of combustibles in the proximity of wire bundles on C/M 012 before delivery and on C/M 008 before manned testing. Such inspection had not been made before OCP FO–k–0021–1.

Determination.—Visual inspections have resulted in removal of combustible materials from potential ignition sources (wire bundles).

Responsible organization.—MSC.

Action.—The NASA criteria for materials flammability control have been revised to make them cover all possible nonmetallic flammability test conditions. The NASA materials control system has been extensively revised to provide for reviews of flammable material use by a second party. Materials will be evaluated and selected for use on a standardized set of criteria. These areas are fully described under Panel finding 8–1a.

Shakedown inspections have been carefully reviewed and augmented as described in Panel finding 6–2 (p. —). Wiring installations are being inspected to new stringent criteria as described under Panel finding 9–a(8) (p. 45).

FINDING NO. 5C

Finding.—Alternate materials which are nonflammable or significantly less flammable than those used on C/M 012 are available for many applications.

Determination.—The amount of combustible material used in command modules can be limited.

Responsible organization.—MSC.

Action.—The amount of combustible material in the command module has been greatly limited as described in Panel finding 8–1a.

FINDING NO. 6

Finding.—Current information and displays of the potentially flammable materials configuration of S/C 012 was not available prior to the fire.

Finding.—A centralized source for materials data was established for the Board Panel 8 (materials review).

Determination.—Maintenance of data and displays at central locations and test sites for management visibility and control of flammable materials is feasible and useful.

Responsible organization.—MSC.

Action.—Materials displays and information desk requirements have been implemented at MSC, NAR, and KSC. A materials display area has been activated in room 534, building 2 at MSC. Implementation for materials use displays and information desks has been established by CCA 1361, to NAR, dated April 17, 1967, and letter PR2-67-BG52-427, dated June 13, 1967.

Panel No. 9. Design Rules

FINDING NO. a(1)

Finding.—Flammable, nonmetallic materials are used throughout the spacecraft. In the block I and block II spacecraft design, combustible materials exist contigous to potential ignition sources.

Determination.—In the block I and block II spacecraft design, combustible materials are exposed in sufficient quantities to constitute a fire hazard.

Responsible organization.—MSC.

Action.—The quantities of combustible materials are being greatly reduced to minimize the fire hazard in the spacecraft. This is discussed in detail under Panel finding 8–1a (p. 33).

FINDING NO. a(2)

Finding.—Malfunctions and failures can produce ignition sources in the command module.

Determination.—An ignition source in the presence of a combustible in the cabin atmosphere constitutes a fire hazard.

Responsible organization.—MSC.

Action.—The Apollo 204 Review Board released subsequent to its final report of April 5, 1967, an additional volume of data. This document (app. G, pt. 2) reported on the items that were incomplete at the time of the total Review Board report. Extensive tests were conducted on equipment that were suspected as the possible cause of ignition. These tests included: (The results in brief are described in the parentheses.)

(1) Open circuit breaker analyses (no new wiring area anomalies were identified).

(2) Open fuse analyses (no new wiring area anomalies were identified).

(3) Electrical system continuity checks (all suspect wiring was installed as required).

(4) Command pilot boots examination (no arcing phenomena was observed on any of the velcro pad screws on the boots).

(5) Cabin air fan wiring examination (it was concluded that shorting was a result rather than the cause of the fire).

(6) Octopus cable examination (it was concluded that shorting was a result rather than the cause of the fire).

(7) Lithium hydroxide access door examination (no evidence of arcing on the door was revealed).

(8) Gas chromatograph data interpretation (telemetry indications were most probably caused by movement near cable or application of heat to cable).

(9) Water/glycol effects on connectors (no evidence of electrical breakdown or degradation).

(10) DC instrumentation harness examination (no wires were shorted or damaged).

(11) ECS cable assemblies examination (one electrical cable assembly, P/N 836602-1-1, is still considered a suspect source of ignition).

All equipment requiring electrical connection or disconnection that could be a potential fire initiation hazard is capable of being turned off prior to the need for disconnection. This is discussed under Panel finding 2-6 (p. 24).

Extensive reviews of electrical wiring design, fabrication and installation were conducted to determine that the wiring is not an ignition source. This is discussed under Panel finding 9-a(8).

Tests were conducted to determine the effect of water/glycol on connectors. These tests, discussed under Panel finding 8-3g (p. 38), disclosed no evidence of electrical breakdown or degradation due to immersion in water/glycol.

Tests and evaluations were conducted on all spacecraft circuit breakers and other electrical equipment such as power inverters to assure they can comply with new stringent size/load/circuit protection design criteria. These are discussed under Panel finding 9-a(5).

All anomalies during the spacecraft manufacturing, certification, and test operations which could represent possible ignition sources will be completely reviewed prior to acceptance of the spacecraft by NASA and corrective actions taken immediately. This is discussed under Panel finding 2-3 (p. 23).

FINDING NO. a(4)

Finding.—The space suit contains power wiring to electronic circuits; also, the astronauts could be electrically insulated.

Determination.—Both the power wiring and potential for static discharge constitute possible ignition sources in the presence of combustible materials. The wiring in the suit could fail from working or bending.

Responsible organization.—MSC.

Action.—Tests have been run which show that in environments where the humidity is greater than 50 percent, such as inside the suit, the static charge potentials that can accumulate are not sufficient to cause ignition. Because the cabin relative humidity will also be high (greater than 50 percent), it is considered highly unlikely that a sufficient electrostatic buildup will take place during operations inside the command module. Extensive design verification and qualification tests will be conducted in addition to those tests discussed above, during which any potential static problems could be exposed.

Tests have been performed at MSC under varying conditions which demonstrate that insufficient current exists in the suit due to wire breakage or shorting, to ignite dry or soiled cotton. A factor of safety of 10 existed for every test condition.

Suit materials have been carefully selected, as described in Panel finding 8-1a (p. 33).

FINDING NO. a(5)

Finding.—Eighteen electrical circuits in Spacecraft 012 did not adhere completely to wire size/load/circuit protection design criteria.

Determination.—The condition was examined from the standpoint of overheating, and no problem was found to exist.

Responsible organization.—MSC.

Action.—There were 204 circuit breakers in Spacecraft 012. A wire/circuit breaker compatibility study was made to determine the adequacy of protection. A set of stringent ground rules (such as stating that the wire must be capable of carrying continually a current of two times the circuit breaker rating, at an ambient temperature of 150° F. and stabilize at less than 500° F.) was established. These were purposely stringent rules to eliminate all well-protected circuits. More realistic ground rules were used such as actual circuit breaker trip characteristics, wire time/heat rise characteristics, to evaluate those circuits not meeting these original ground rules. Of the 204 circuits, only 18 failed to satisfy the original ground rules. These 18 circuits were further evaluated using the actual circuit breaker and wire characteristics. As a result, these 18 circuits were also judged to be adequately protected.

A complete review of Block II circuits was accomplished and all wiring and circuit breakers changed where necessary to comply with size/load/circuit protection design criteria, as discussed under Panel finding 9–a8.

FINDING NO. a(6)

Finding.—Residues of RS89 (inhibited ethylene glycol/water solution) after drying are both corrosive and combustible. RS89 is corrosive to wire bundles because of its inhibitor.

Determination.—Because of the corrosive and combustible properties of the residues, RS89 coolant could in itself provide all of the elements of a fire hazard if leakage occurs onto electrical equipment.

Responsible organization.—MSC.

Action.—Action has been taken to prevent spillage of water/glycol in Block II spacecraft. This is described under Panel finding 8–4a (p. 38). In addition, procedures are being developed to provide a standard method for cleaning water/glycol spills if they should occur. This is described under Panel finding 2–2 (p. 23).

FINDING NO. a(7)

Finding.—Water/glycol is combustible, although not easily ignited.

Determination.—Leakage of water/glycol in the cabin increases the risk of fire.

Responsible organization.—MSC.

Action.—Action has been taken to prevent leakage of water/glycol in the cabin as described in Panel finding 8–4a (p. 38).

FINDING NO. a(8)

Finding.—Deficiencies in design, manufacture, and quality control were found in the postfire inspection of the wire installation.

Determination.—There was an undesirable risk exposure which should have been prevented by both the contractor and the Government.

Responsible organization.—MSC.

Action.—A review of electrical wiring design, fabrication, and installation practices and procedures has been conducted to determine their adequacy. Corrective action was taken where necessary. On spacecraft where wiring was installed and complete, a reinspection was conducted using more stringent acceptance criteria. Corrective action was taken on the deficiencies identified.

On early manned spacecraft, a special wiring design task team was formed to review the wiring modification made as a result of the design changes and insure the proper fabrication and installation of the wiring modifications in the spacecraft. This task team, made up of representatives from contractor engineering, manufacturing, quality control, and NASA engineering and quality control, reviewed the entire installation area by area and recommended modification where necessary.

The actual rework of the harness installation in early manned spacecraft was accomplished with an "overlay harness." After installation of this "overlay harness," the spacecraft was physically inspected and tested to insure that there were no shorts from wire to wire or from wire to ground, and that the wire insulation was not damaged. These tests have been successfully completed and the wiring system accepted by MSC.

An MSC review board chaired by Dr. Gilruth determined the acceptability of the wiring in early spacecraft.

On all Block II spacecraft the following has been accomplished:

(1) Hard metallic covers have been placed on all wire harnesses on the spacecraft floor as physical protection;

(2) In areas where hard covers are not practical and additional physical protection is needed, single wire wraps and/or harness wraps have been used;

(3) Where possible, sharp edges and corners are being removed. If removal is not practical, the edge or corner is provided with a grommet or the harness is provided with additional wraps;

(4) Where possible and practical, combustible material touching the wiring or close to it is being replaced with an acceptable material. In all cases, the criteria specified in ASPO–RQTD–D67–5A are being imposed and any deviations must be reviewed and approved by NASA on an individual basis. Panel finding 8–1a (p. 33), provides additional information on materials selection and control.

FINDING NO. a(9)

Finding.—The environmental control system is plumbed with aluminum tubing in both the water/glycol and oxygen circuits. Joints in the plumbing are made by nickel plating the aluminum and joining the nickel-plated surfaces with a tin-lead solder. Leakage of ECS coolant from these joints has been experienced in the Apollo spacecraft.

Determination.—The design of the soldered joints is inadequate to cope with all the conditions experienced in the spacecraft.

Responsible organization.—MSC.

Action.—The design of soldered joints has been revised to include armoring as described in Panel finding 8–4a (p. 38).

FINDING NO. b(3)

Finding.—Flammability characteristics of nonmetallic materials are varied by only a factor of 3 or 4 by diluents in atmospheres containing oxygen at 3 to 5 p.s.i. partial pressure.

Determination.—Previous analyses leading to the decision to use 5 p.s.i.a. pure oxygen cabin environment in space are still valid.

Responsible organization.—MSC.

Action.—The fire safety of the reconfigured command module will be established by full-scale mockup tests in a pure oxygen environment as described in Panel finding 8–1a (p. 33).

It has been reconfirmed by a detailed review of operational requirements that the inflight cabin atmosphere should continue to be oxygen at 5 p.s.i.a. A 5 p.s.i.a. 100 percent oxygen atmosphere in the spacecraft cabin combines the greatest opportunity for mission success with safety for manned operations in space.

However, the command module systems have been modified to be capable of using air, as well as oxygen, as a pressurant on the launch pad in accordance with Apollo program directive No. 29, Post-Accident Changes to Apollo CSM and Related Ground Facilities, dated July 6, 1967. This capability will be implemented if the full-scale flammability tests indicate a need to change to an air atmosphere for ground operations. Changes will be effective for all manned spacecraft as authorized by MSC CCA 1319, revision A, dated May 25, 1967, and include:

(1) A sensor to measure suit-to-cabin differential pressure.

(2) Mounting provisions for a cabin gas analyzer to detect air leakage into the suit loop (if air is used as a pressurant).

The risks due to the additional operational requirements of using air on the pad are being controlled by conducting ground tests and developing appropriate crew procedures. Training of the crew in these procedures will be accomplished before the first manned flight test.

FINDING NO. C(1)

Finding.—Sixty seconds are required for unaided crew egress from the command module. The hatch cannot be opened with positive cabin pressure above approximately 0.25 p.s.i. The vent capacity was insufficient to accommodate the pressure buildup in the Apollo 204 spacecraft.

Determination.—Even under optimum conditions emergency crew egress from Apollo 204 spacecraft could not have been accomplished in sufficient time.

Responsible organization.—MSC.

Action.—A new hatch has been designed to replace the two-cover hatch system on Block II command modules. The single door is called a unified hatch and is made of aluminum with added fiber glass and ablative material. The hatch has flexible thermal seals, a latch and linkage mechanism, hinges, window, and a boost-protective hatch cover that swings open on separate hinges. There is a single cabin vent value for ground testing or cabin purging. The door deployment mechanism contains a counterbalancing device to offset gravity, and a linkage that locks the hatch in full-open position. The door unlatching mechanism can be operated either by the flightcrew in less than 3 seconds or by the ground crew for emergency or normal operations in less than 10 seconds.

Ground and flight tests are in progress to qualify the new hatch to assure the following items: (1) effective operation; (2) integrity in the vibration environment encountered during launch and reentry;

(3) compatibility with crew requirements including EVA: and (4) integrity during reentry heating. These tests are being conducted on ground test articles, on the thermal vacuum model, and unmanned Saturn V flights.

This hatch will be incorporated in all manned spacecraft.

FINDING NO. C(2)

Finding.—The access arms to the command module in launch complexes 34 and 39 contain flammable materials, are removed 30 minutes prior to launch, and their doors open the wrong way for easy egress.

Determination.—The access arm could constitute a fire hazard and imposes delays to emergency crew egress.

Responsible organization.—KSC.

Action.—Service structures and umbilical towers are being modified to improve emergency personnel and crew evacuation capability. Changes were authorized to be made on LC–34 on April 21, 1967, and include:

(1) Reconfiguring the environmental chamber (EC) adapter hood to provide a flatter egress path from the spacecraft to the EC;

(2) Eliminating the step at each end of the Apollo access arm;

(3) Incorporating two-way swinging doors on the Apollo access arm and on the access arm cab;

(4) Providing smoke removal ventilation in the Apollo access arm cab;

(5) Changing the arm retraction sequence to rotate the arm to a park position near the latch position at T–30 minutes to permit quick return to the command module. At T–4 minutes the arm will be swung to the stowed position;

(6) Incorporating fire-resistant materials inside the Apollo access arm.

Effectively for LC–34 is for the first manned spacecraft. The operational ready date is early in 1968. Effectivity for LC–39 is for the first manned Apollo-Saturn V flight. The operational ready date is in the second quarter of 1968.

FINDING NO. d(1)

Finding.—The control circuit from the command pilot developed a condition of continuous keying during the test.

Determination.—An anomaly existed in the spacecraft communication system.

Responsible organization.—MSC.

Action.—The continuous keying that occurred was thoroughly reviewed by continuity measurements on wiring and associated control circuits. No specific malfunction could be identified. The block II design is such that if this same anomaly occurred, it would not affect the other crewmembers.

FINDING NO. d(2)

Finding.—During the Apollo 204 test, difficulty was experienced in communicating from ground to spacecraft and among ground stations.

Determination.—The ground system design was not compatible with operational requirements.

Responsible organization.—KSC.

Action.—The ground communications system has been reviewed in etail and improvements are being made to insure reliable communications between all test elements. Specific equipment modifications nclude:

(1) For launch complex 34:

(*a*) Undesirable coupling in the astronaut communications panels has been eleminated and duplex communications to the spacecraft umbilical cable have been provided with minimum use of VOX devices;

(*b*) Headset frequency response has been improved and its efficiency raised;

(*c*) Central testing facilities are being added to permit continuous monitoring of circuit quality;

(*d*) Continuous recordings of critical voice communication loops will be provided.

Effectivity is for the first manned spacecraft and the operational ready date is the second quarter of 1968.

(2) For launch complex 39:

(*a*) Evaluations are currently being made of launch complex 39 communications based on the changes being incorporated in launch complex 34;

(*b*) Effectivity for all changes to the LC–39 ground communications system will be for the first manned Apollo-Saturn V flight.

(3) Procedural changes to be made for all launch complexes:

(*a*) Reduction in the number of stations on critical communication loops;

(*b*) Inspection and verification by test of system configuration and operational readiness before each major space vehicle test;

(*c*) Provision for knowledgeable communications system engineers to be on duty during all major space vehicle tests.

These procedures will be used to support all manned flights from both LC–34 and LC–39.

The ground communications system will be capable of meeting all operational requirements to support manned flights from all launch complexes.

Panel No. 10. Analysis of Fracture Areas

FINDING NO. 10

Finding.—Several aluminum tubes were parted at soldered joints at unions.

Determination.—The soldered aluminum joints at unions will fail if the solder is raised to its melting point of approximately 360° F. The soldered aluminum joints at unions were not adequate for the temperatures attained during the fire.

Responsible organization.—MSC.

Action.—The soldered aluminum joints are being armor plated to eliminate leakage, as described in Panel finding 8–4(a) (p. 38).

Panel No. 11. Medical Analysis

FINDING NO. 13

Finding.—The environmental control system contains activated charcoal, which, if heated, will produce CO.

Determination.—It is the opinion of Panel 5 that heating of the CO_2 canister occurred late in the progress of the fire after significant levels of CO were already present in the cabin atmosphere, and after at least one suit had failed.

Responsible organization.—MSC.

Action.—CO from this source can only constitute a hazard after an intense fire has progressed for a sufficient period to overheat the activated charcoal in the environment control system.

The quantity of charcoal contained in each canister is very small and is used to absorb a variety of noxious and toxic gaseous compounds. Charcoal can be beneficial in absorbing combustion byproducts when ambient temperatures are not excessively high.

The primary means of reducing this type of secondary fire effect will be through the limitation of basic nonmetallic materials and thus reducing the probability of a high-temperature fire. This is described in Panel finding 8–1a (p. 33).

FINDING NO. 14

Finding.—The distribution of CO in various organs indicates that circulations stopped rather abruptly when high levels of carboxyhemogoblin reached the heart.

Determination.—Loss of consciousness was due to cerebral hypoxia due to cardiac arrest, due to myocardial hypoxia. Factors of temperature, pressure, and environmental concentrations of carbon monoxide, carbon dioxide, oxygen, and pulmonary irritants were changing at extremely rapid rates. It is impossible to integrate these variables, on the basis of available information with the dynamic physiological and metabolic conditions they produced in order to arrive at a precise statement of time when consciousness was lost and when death supervened. The combined effect of these environmental factors dramatically increased the lethal effect of any factor by itself. It is estimated that consciousness was lost between 15 and 30 seconds after the first suit failed. Chances of resuscitation decreased rapidly thereafter and were irrevocably lost within 4 minutes.

Responsible organization.—MSC.

Action.—The reduction of combustible materials in the spacecraft will materially reduce the concentration of toxicants, but will not eliminate the hazard completely. Emergency breathing oxygen has been provided to prevent inhalation of toxic fumes during a fire. Operational procedures and suit ECS integrity are being reexamined to minimize the hazard to the crewman. Occupants normally assigned to duty in the white room or other high-risk areas will be properly trained in rescue and resusitation procedures and will be supported by professional medical personnel stationed nearby. Training and practice will be regularly scheduled and all emergency procedures will be reviewed before the conduct of any test determined to be hazardous.

CCA 1361 dated April 17, 1967, to Contract NASA–150 implements guidelines for reduction of flammable materials. Additional description can be found in Panel finding 8–1a (p. 33). All changes will be effective before manned testing.

FINDING NO. 15

Finding.—All three suits were breeched by fire to some degree.

Determination.—The suits were not capable of providing crew protection in a fire of this intensity.

Action.—Block II suits are different in detail design than the suits used during Block I (Spacecraft 204). However, these also would not (as originally configured) provide crew protection from a fire of the intensity of the 204 accident. Thus, the "Finding and determination" statements are applicable to Block II suits.

Redesign of the outer layers of Block II suits has been accomplished to use less flammable materials. The Nomex outer layer of thermal meteoroid garment (TMG) has been changed to Beta fabric. Internal alternating layers of the superinsulation (thermal layers) have been changed from aluminized mylar film to aluminized H-film (Kapton). The TMG configuration (multilayer cross section) is designed to provide thermal protection, micrometeoroid protection, and limited flame impingement protection (45 seconds at 1800° F. without degradation of the innermost bladder layer of the pressure garment).

RECP 7E152 defining the TMG configuration and identifying it as an integral part of the suit assembly was approved by the spacecraft program manager. Implementation was by Change Order No. 79 to International Latex Corp., Contract NAS9–6100, issued on July 13, 1967.

All nonmetallic materials in the suit will again be reviewed by a materials selection review board in accordance with the instructions of MSC–A–D–66–3 Revision A, and by the program manager as required by Apollo Program Directive No. 29, paragraph 3. Additional details on this review board are found in Panel findings 8–1a (p. 33).

Effectivity of the TMG with the redesigned cover layers will be for all future flight and training suits.

FINDING NO. 21

Finding.—It was not possible from biomedical and environmental data to accurately construct a time line of environmental conditions or crew activities during this emergency.

Determination.—Available environmental and biomedical instrumentation cannot be considered optimum for a potentially hazardous test or for flight.

Responsible organization.—MSC.

Action.—TV coverage will be provided for all hazardous testing in the command module and lunar module. Simultaneous continuous biomedical telemetry will be provided, selective from each astronaut, from all three crew members in the command module. Direction to provide simultaneous continuous telemetry from all crew members in the spacecraft was given to NAR in CCA 1482 dated June 19, 1967. TV coverage will be provided for all manned hazardous testing in the command module.

FINDING NO. 23

Finding.—The purge with 100 percent O_2 at above sea level pressure contributed to the propagation of fire in the Apollo 204 spacecraft.

Determination.—This was the planned cabin environment for testing and launch, since prelaunch denitrogenation is necessary to forestall the possibility of bends at the mission ambient pressure of 5 pounds per square inch absolute. A comprehensive review of the operational and physiological trade-offs of the various methods of denitrogenation is in progress.

Responsible organization.—MSC.

Action.—Studies have been made assessing the bends hazard. The operational requirements of using air on the pad and the effects on overall mission and hardware performance have been evaluated. The full-scale command module flammability tests described in Panel finding 8–1a must be completed before a program decision can be made on the type of atmosphere to be provided for spacecraft ground testing. However, engineering design is providing for hardware that will operate on either 100 percent oxygen or air on the pad. Additional details on this subject are found in panel finding 9–b(3) (p. 46).

FINDING NO. 24

Finding.—Rescue personnel were equipped with gas masks designed for protection against hypergolic vapors. They had no heat-protective garments.

Determination.—Rescue personnel were inadequately equipped for a fire-type rescue.

Responsible organization.—KSC.

Action.—Emergency rescue personnel are equipped with heat-protective garments and self-contained breathing apparatus, and will be on station in accordance with the revised and more stringent criteria for definition of hazardous procedures per APOP No. G–102, "Safety Considerations for TCP's," released July 17, 1967. Self-contained breathing apparatus will be stored in emergency equipment lockers at selected levels of the service structure and umbilical tower.

Emergency equipment to be available for any contingency, including fire, will be available in safety lockers placed at various locations throughout KSC. This equipment is described under Panel finding 13–9 (p. —). These actions were in effect for spacecraft 017 and will be for all subsequent space craft.

PANEL NO. 13. GROUND EMERGENCY PROVISIONS REVIEW

FINDING NO. 1

Finding.—The applicable test documents and flight crew procedures for the AS–204 space vehicle plugs out integrated test did not include safety considerations, emergency procedures, or emergency equipment requirements relative to the possibility of an internal spacecraft fire during the operation.

Determination.—The absence of any significant emergency preplanning indicates that the test configuration (pressurized 100-percent-oxygen cabin atmosphere) was not classified as a potentially hazardous operation.

Responsible organization.—KSC.

Action.—A procedure has been released that identifies more stringent hazard criteria for any environment that deviates from normal atmosphere (chemical composition, pressure, or temperature). This procedure, APOP No. G–102, "Safety Considerations for Checkout Procedure," was released July 17, 1967.

An access arm and CM mockup are being set up at KSC for development of emergency crew egress procedures and subsequent training. The CM mockup will be a Block II configuration with the new quick-opening unified hatch. This training facility will be operational early in January 1968 to support the first manned spacecraft requirements.

APOP No. 0–202, "Preparation and Release of Test and Checkout Procedures," was released July 12, 1967. In accordance with this procedure, TCP's will include safety considerations, applicable safety requirements, and emergency procedures when personnel are sealed in the command module in an environment that deviates from normal atmosphere. Flight crew safety emergency procedures will be included in the TCP. TCP's which involve flight crew participation will have MSC coordination and signature approval. The TCP's will be released 30 days prior to the test to support first manned spacecraft test and checkout at KSC.

Effectivity is for the first manned and all subsequent spacecraft.

FINDING NO. 2

Finding.—There are no documented safety instructions or emergency procedures in existence which are applicable to the possibility of a serious internal spacecraft fire.

Determination.—The occurence of an internal spacecraft fire of the magnitude and intensity experienced in this accident was not considered to be a significant possibility under any operational circumstances.

Responsible organization.—KSC.

Action.—Test and checkout procedures will contain adequate emergency procedures with respect to the possibility of internal spacecraft fires. The TCP will be released 30 days prior to any test in which personnel are sealed in the command module.

Two procedures require that provisions for safety instructions and emergency operations be defined in applicable spacecraft test procedures. These are APOP No. G–102 "Safety Considerations for Checkout Procedures," released July 17, 1967, and APOP No. 0–202, "Preparation and Release of Test and Checkout Procedures," released July 12, 1967. Additional details on these procedures are provided in Panel findings 13–1 and 13–13.

FINDING NO. 3

Finding.—The propagation rate of the fire involved in the AS–204 accident was extremely rapid. Removal of the three spacecraft hatches to effect emergency egress from either the inside or outside involved a minimum of 40 and 70 seconds, respectively, under ideal conditions.

Determination.—Considering the rapidity of propagation of the fire and the time constraints imposed by the existing spacecraft hatch configuration, it is doubtful that any amount of emergency preparation would have precluded injury to the crew prior to crew egress.

Responible organization.—MSC.

Action.—The amount of combustible materials in the command module is being reduced to a minimum and a unified, quick-opening side hatch is being provided. The hatch is outward opening and may be operated from either the interior or exterior. Details on the hatch operation are described in Panel finding 9–c(1) (p. —). CCA 1326 to contract NAS9–150 directed the contractor to incorporate the hatch revisions into ground and flight test spacecraft as well as all manned spacecraft. Hatch qualification will be completed before manned use.

Details on the reduction of nonmetallic materials are provided in Panel finding 8–1a (p. 33).

FINDING NO. 5

Finding.—The Apollo Flight Crew Hazardous Egress Procedures Manual contains procedures relative to unaided, aided and incapacitated flight crew egress. By scope and definition, this document is concerned only with evacuation of the flight crew from the spacecraft and the pad under hazardous conditions occurring primarily external to the spacecraft during a launch operation.

Determination.—The Apollo Fight Crew Hazardous Egress Procedures Manual does not contain adequate emergency provisions for significant emergency conditions internal to the spacecraft any time the crew is on board.

Responsible organization.—KSC.

Action.—The Hazardous Evacuation Procedures, Apollo/Saturn V, LC–39, (600–40–0006), dated September 25, 1967, includes actions to be taken in the event of an emergency that occurs after space vehicle tanking is completed during countdown demonstration tests (CDDT's) and launch operations. This procedure is in effect.

An access arm and command module mockup are being set up at KSC for development of emergency crew egress procedures and training. This training will include simulation of emergency conditions internal to the spacecraft. This training facility will be operational early in 1968.

The flight crew hazardous egress procedure will be published 30 days before the test in accordance with APOP No. 0–2–2, Preparation and Release of Test and Checkout Procedures, released July 12, 1967.

Development of crew procedures for spacecraft emergencies during test and in flight is underway. These procedures must take into account specific mission requirements and will be provided for use in all manned test operations.

FINDING NO. 6

Finding.—The spacecraft pad work team on duty at the time of the accident had not been given emergency training drills for combating fires in or around the spacecraft or for emergency crew egress. They were trained and equipped only for a normal hatch removal operation.

Determination.—The spacecraft pad work team was not properly trained or equipped to effect an efficient rescue operation under the conditions resulting from the fire.

Responsible organization.—KSC.

Action.—The spacecraft pad work team personnel have received pecial training in the use of fire-fighting equipment located in their espective work areas by the KSC Fire Department. This will be coninued on a regularly scheduled basis.

Additional details on the training program and emergency equipnent to be available at all launch complexes are found in Panel finding 13–9.

The training program and new emergency equipment available will rovide team personnel with the capability to conduct an efficient resue operation under any emergency situation.

FINDING NO. 7

Finding.—There was no equipment on board the spacecraft deigned to detect or extinguish a cabin fire.

Determination.—The flight crew had to rely upon physiological ues to detect the presence of a fire. When all face masks were closed, he cues were limited to sight and touch. Once detected, there were no neans by which the fire could have been contained or extinguished.

Responsible organization.—MSC.

Action.—A jelled water foam portable fire extinguisher has been leveloped and will be stowed in the CM during all manned missions and closed hatch tests. Two of these extinguishers will be carried in the command module and can be used on open fires or on fires behind panels by inserting them into special ports provided for this purpose.

Three special oxygen masks to protect the shirtsleeve crew in the command module from toxic fumes will be provided. The command module oxygen system is being modified to provide the capability for this emergency oxygen mask breathing system. All plumbing associated with this system will be protected to preclude damage.

A detailed study of fire detection requirements was conducted. The present crew detection and spacecraft instruments were deemed adequate.

FINDING NO. 8

Finding.—Frequent interruptions and failures had been experienced in the overall communications system during the operations preceding the accident. At the time the accident occurred, the status of the system was still under assessment.

Determination.—The status of the overall communication systems was marginal for the support of normal operation. It cannot be assessed as adequate in the presence of an emergency condition.

Responsible organization.—KSC.

Action.—The overall ground communication system has been reviewed and modifications have been, and will continue to be, made to improve system adequacy and operational capability. KSC CCBD No. PPR–4–0531, dated July 5, 1967, approves GE ECP No. CM–1779P, including the following changes:

(1) Reduction in number of stations on those critical loops now being overloaded during peak periods;

(2) Introduction of design changes to insure reliable operation of the present circuits and equipment;

(3) Addition of four-wire intercommunications equipment to provide full duplex links among the flightcrew, the blockhouse,

the spacecraft checkout station, and the Houston Mission Control Center.

The changes will be completed in time to support the first manned launch on LC 34. Additional information is provided in Panel finding 9–d2 (p. 48).

FINDING NO. 9

Finding.—Emergency equipment provided at the spacecraft work levels consisted of portable CO_2 fire extinguishers, rockets propellant fuel handler's gas masks, and 1¼-inch-diameter firehoses.

Determination.—The existing emergency equipment was not adequate to cope with the conditions of the fire. Suitable breathing apparatus, additional portable CO_2 fire extinguishers, direct personnel evacuation routes, and smoke removal ventilation are significant items which would have improved the reaction capability of the personnel involved.

Responsible organization.—KSC.

Action.—The capability of pad personnel to adequately react to emergencies has been improved by the addition of emergency equipment and smoke removal ventilation, and making personnel evacuation routes more direct. These improvements are:

(1) *Additional emergency safety equipment.*—Emergency safety equipment lockers will be installed at selected levels of the service structure (SS) and umbilical tower (UT).

For S/C 017 test and launch operations, the following equipment was available at the spacecraft levels:

(*a*) Twenty emergency explosion-proof lights;
(*b*) Fifteen air packs;
(*c*) Eight fire blankets;
(*d*) Two pry axes—fire;
(*e*) Two first aid kits;
(*f*) Twenty 15-pound CO_2 fire extinguishers.

Fifty safety lockers will be placed at various locations throughout the launch complexes and will contain:

(*a*) Two air packs;
(*b*) Five gas masks with 5-minute air bottle;
(*c*) One pry ax;
(*d*) One handtool kit;
(*e*) Two fire blankets;
(*f*) Three explosion-proof emergency lights;
(*g*) Two 50-foot ⅜-inch steel cables;
(*h*) Two CO_2 fire extinguishers;
(*i*) Two AEC dry powder fire extinguishers;
(*j*) Two pair electricians gloves with shells;
(*k*) Two fire suits;
(*l*) Two safety belts;
(*m*) Two 6-foot lifeline lanyards;
(*n*) Two 50-foot braided ropes;
(*o*) One hydraulic jack kit;
(*p*) Two fireman's gloves;
(*q*) One fireman's insulated cutter.

This equipment has been procured and will be installed on the launch complexes before the end of this year.

(2) *Crew egress path.*—The crew egress path from the command module has been thoroughly reviewed. Modifications that have been made include:

(*a*) Eliminating the step that existed on each end of the Apollo access arm;

(*b*) Provision of two-way swinging doors on the Apollo access arm and on the Apollo access arm cab;

(*c*) Provision of smoke removal ventilation in the Apollo access arm cab;

(*d*) Additional provisions are described in Panel finding 9–c(2) (p. 48).

The access arm and umbilical tower modifications to reduce the fire hazard and delays to emergency crew egress have been authorized by the following KSC documents:

(*a*) LC–34 modifications: KSC CCBD No. PPR–4–0469, effective for the first manned spacecraft (Chrysler will implement);

(*b*) LC–39 modifications: KSC CCBD No. PPR–5–1135, effective for the first Apollo-Saturn V manned flight (Boeing will implement).

(3) *Slide wire escape system.*—A slide wire escape system is being provided on LC–34 from the Apollo access arm level of the umbilical tower to a point on the ground 1,200 feet away from the base of the tower as authorized in KSC CCBD No. PPR–4–0469 (effective for S/C 101). The need for a slide wire system on LC–39 is being evaluated and a decision will be made prior to the effective need date of the first manned Apollo-Saturn V flight.

(4) *Evacuation training.*—Evacuation routes have been posted and evacuation drills are run on a regularly scheduled basis.

A training program has been initiated by NASA–KSC training, safety, and fire departments in cooperation with the spacecraft contractor. This training and practice, to be conducted on a regularly schedule basis, includes:

(*a*) Use of firefighting equipment;

(*b*) First aid;

(*c*) Handling of personnel requiring aid in the event of an emergency.

(5) *Emergency rescue personnel.*—Emergency rescue personnel are equipped with heat-protective garments and self-contained breathing apparatus, and will be on station in accordance with revised and more stringent KSC criteria for definition of hazardous procedures in APOP No. G–102, "Safety Considerations for Checkout Procedures," dated July 17, 1967.

FINDING NO. 10

Finding.—There are steps and doorways on the launch complex 34 Apollo access arm and in the environmental enclosure (white room) which constitute safety hazards, particularly under emergency conditions.

Determination.—The present configuration of the access arm and white room is not compatible with emergency personnel evacuation requirements or with fast, safe flightcrew egress.

Responsible organization.—KSC.

Action.—The configurations of the access arm and white room have been changed to improve compatibility with emergency personnel evacuation requirements and to provide for fast, safe flightcrew egress. Included in the changes are:

(1) The environmental chamber (EC) adapter hood has been reconfigured to provide a flatter egress path from the spacecraft to the EC;

(2) The EC is being lowered to eliminate the step from the EC to the Apollo access arm (AAA);

(3) The umbilical tower (UT) platform is being modified to eliminate the step at the end of the AAA next to the UT;

(4) The doorways are being reconfigured to incorporate two-way swinging doors.

Additional discussion on this area and relationship to LC–34 and LC–39 is found in Panel finding 13–9.

An access arm and command module mockup (block II configuration with new, quick-opening hatch) are being set up at KSC for development of emergency crew egress procedures and subsequent training. This training facility will be operational early in 1968.

This action will be effective for the first manned and all subsequent spacecraft.

FINDING NO. 11

Finding.—During the preparation of S/C test procedures at KSC, safety considerations for hazardous operations and documentation of applicable emergency procedures are limited in most cases to routine safety reference notations and emergency power-down instructions.

Determination.—Insufficient emphasis is applied by the test procedure originator upon documenting emergency procedures and identifying specific hazards and applicable safety requirements.

Responsible organization.—KSC.

Action.—Procedures defining and implementing applicable safety requirements, emergency procedures, hazard identification, and assigning responsibilities for preparation, review, and approval have been released. APOP No. G–102, Safety Considerations for TCP's, released July 17, 1967, and APOP No. 0–202, Preparation and Release of Test and Checkout Procedures, released July 26, 1967, are described in detail in Panel findings 13–1 and 13–13.

FINDING NO. 12

Finding.—Under the existing method of test procedure processing at KSC, the cognizant safety offices review only those procedures which are noted in the OCP outline as involving hazards. Official approval by KSC and AFETR Safety is accomplished after the procedure is published and released.

Determination.—The scope of contractor and KSC Safety Office participation in test procedure development is loosely defined and poorly documented. Post-procedure-release approval by the KSC Safety Office does not insure positive and timely coordination of all safety consideration.

Responsible organization.—KSC.

Action.—The KSC Safety Office and NAR Safety are presently reviewing and approving, by signature, all spacecraft test procedures before they are released. The KSC Safety Office makes the final determination concerning the hazardous classification of the test. The scope of contractor and KSC Safety Office test development participation is defined in APOP No. G–102, Safety Considerations for TCP's, dated July 17, 1967.

FINDING NO. 13

Finding.—Criteria for defining hazardous test operations are not complete.

Determination.—A positive method does not exist for insuring identification and documentation of all possible hazards involved in test operations.

Responsible organization.—KSC.

Action.—A positive method for insuring identification and documentation of all possible hazards involved in test operations has been developed and published as APOP No. G–102, Safety Considerations for Checkout Procedures, released July 17, 1967. This procedure defines and implements a methodical means of evaluating the hazard level of all spacecraft procedures. The procedures that have been evaluated as hazardous are then compared with a set of checklists to insure compliance with safety practices. Additional details are provided in Panel finding 13–1.

FINDING NO. 14

Finding.—Requirements for the review and concurrence of KSC S/C test procedures by MSC are not well defined.

Determination.—The present review system does not insure that MSC concurs with released KSC test procedures.

Responsible organization.—KSC.

Action.—A revised review system that insures that MSC concurs with released KSC test procedures is defined in APOP No. 0–202 Preparation and Release of Test and Checkout Procedures, dated July 26, 1967.

Presently, all spacecraft test procedures review copies are forwarded to MSC for review and comment. The MSC flight crew checklist information is required to be furnished to KSC–SCO 40 days before the scheduled test date with all MSC procedures comments due no later than 15 days before the scheduled test date. MSC is also to approve, by signature, all spacecraft test procedures that include the participation of the flight crew.

Panel No. 14. Security of Operations

FINDING NO. 4

Finding.—Apollo Preflight Operations Procedure (APOP) 0–201, dated October 17, 1966, and January 24, 1967, concerning access control of test and work areas, required that: (1) access controls to spacecraft work areas be exercised by the contractor; (2) the contractor maintain a log of all personnel permitted access during "offshift"/nonwork periods; (3) the contractor control command module ingress-egress, and maintain a log concerning same.

Determination.—The procedures established in the APOP were not followed in that: (1) the contractor failed to exercise adequate access controls on the fifth, sixth, and seventh spacecraft levels; (2) the contractor failed to maintain an "offshift" log; (3) the command module ingress-egress log was inadequately maintained.

Responsible organization.—KSC.

Action.—NASA KSC quality control personnel will enforce a new set of controls as defined in APOP No. 0–203 Access to the Command and Service Modules (CSM), released May 22, 1967. This procedure is described in Panel finding 1–4 (p. 22), and provides for improved personnel and material access control and ingress-egress log maintenance.

FINDING NO. 5

Finding.—The investigative program, which was used as the basis for authorizing access to LC 34, consisted of a determination that a national agency check (NAC) investigation had been conducted on each Government or contractor employee. In the absence of an NAC, an escort was required. (Similar provisions existed at the Mission Control Center, Houston.)

Determination.—This practice provides inadequate support for the objective of NASA management that great care be taken to assign reliable and trustworthy persons to perform critical work during mission periods.

Responsible organization.—KSC.

Action.—Mission-critical positions have been identified and incumbents are being submitted for required investigation. The investigation program will be completed before the first manned mission and will insure that only reliable and trustworthy persons perform critical work during mission periods.

FINDING NO. 6

Finding.—(*a*) Access to the astronaut quarters and the suiting room was limited by an access list attached to the security post orders, to those few people having an official reason to be there, i.e., astronauts, biomedical people, suit technicians, etc. Compliance with this procedure was enforced by KSC uniformed security patrolmen. The van used to transport the astronauts from their quarters to the launch complex was inspected, driven, and remained under the control of KSC security personnel when astronaut activity was involved. Uniformed security personnel escorted the van when astronauts were being transported. (*b*) The purchase, handling, and delivery of the astronauts' food (nonflight) served in their quarters is processed through the contractor's routine channels. (*c*) Only the results of an NAC are available to NASA management in their evaluation of the reliability and trustworthiness of support personnel in the astronaut quarters.

Determination.—The personnel access controls for the astronaut quarters, the suiting room, and the van were adequate.

Inadequate safeguards are provided concerning the purchase, handling, and delivery of astronauts' food (nonflight), notwithstanding the fact that it is known by persons coming in contact with it that it is to be consumed by the astronauts.

NASA management has insufficient knowledge to fully evaluate the reliability and trustworthiness of support personnel in the astronaut quarters.

Responsible organization.—KSC.

Action.—The KSC Procurement Office in conjunction with the KSC Security Office and the MSC Mission Support Office at KSC has negotiated a contract with Automatic Retailers of America to provide food support to the astronaut quarters (contract NAS–10–5385). Astronaut quarters primary and backup contractor personnel in this and the cleaning services area have been identified and their security papers will be forwarded for investigation as obtained. Astronaut food will be personally purchased, delivered, and handled only by the above-referenced persons for whom security personnel investigations have been conducted, rather than through routine food procurement channels. Security and Mission Support Office personnel will monitor the contractor's performance for adherence to the intent of the contract. Personnel investigations and evaluations will be complete before the permanent billeting of the crews for the first manned mission. Purchase, delivery, and handling procedures will also be implemented before the permanent billeting of the crew for the first manned mission.

Panel No. 20. In-Flight Fire Emergency Provisions Review

FINDING NO 1

Finding.—An in-flight fire procedure was published and available to the crew for the Apollo 204 mission. The procedure was analyzed with reference to the Apollo 204 Command Module 012 configuration.

Determination.—Based on this review, it is the judgment that the existing in-flight fire procedures are deficient in the following areas: (*a*) The cabin fans should be turned off as the first item of the procedural checklist. This may help prevent the spread of a fire by minimizing cabin air currents. (*b*) The procedure should have specified the length of time to keep the cabin depressurized to insure the fire had been extinguished and that all materials had cooled to below their ignition temperature.

Responsible organization.—MSC.

Action.—In-flight fire procedures have been modified to incorporate the results of hardware improvements made by CCA 1326 (hatch vent), CCA 1315 RB (cabin repressurization), CCA 1311 (repressurization controls), CCA 1397 (emergency oxygen system-masks), and RECP 7C348 (portable fire extinguisher). The modified procedures will be incorporated in revisions to the Apollo abort summary document, 67–IN–2, for all manned missions and appropriate Apollo operations handbooks.

Hardware changes are effective with the first manned spacecraft. This area is discussed further under Panel finding 1–3.

FINDING NO. 3

Finding.—Coordination with Panel 8, Materials Review, and Panel 5, Origin and Propagation of Fire, indicates many materials combustible in 100 percent 5 psi oxygen were on board Apollo 204 Command Module 012.

Determination.—It is the judgment of the Panel that these materials would yield a dangerous propagation rate in case of fire in the command module during the boost, orbital, and entry phases of flight.

Responsible organization.—MSC.

Action.—Nonmetallic material selection criteria and control of material location in the command module are described under Panel finding 8–1a (p. 33).

FINDING NO. 4

Finding.—Lengthy suit donning times were incompatible with fire propagation times.

Determination.—The published in-flight fire procedure was impractical in view of the rapid fire propagation rate expected for an Apollo 204 in-flight fire.

Responsible organization.—MSC.

Action.—Practice with spacesuit operations will be conducted based on new procedures prior to any manned flights in the near actual environment of the command module simulator and first manned spacecraft. An auxiliary breathing oxygen system and portable fire extinguishers will be installed to provide a means for combating spacecraft fires until time permits donning pressure suits.

FINDING NO. 5

Finding.—The command module depressurization time from 5 to 0.5 p.s.i. can vary from 1 minute and 45 seconds to 3 minutes and 20 seconds, based on the flight phase ambient pressure.

Determination.—The depressurization time is too slow to effectively combat a cabin fire.

Responsible organization.—MSC.

Action.—With the capability of the new outward opening unified hatch, the spacecraft does not require depressurization prior to crew egress for emergencies on the pad. In addition, portable flight crew-operated fire extinguishers are being provided as described in Panel finding 13–7 (p. 55).

FINDING NO. 6

Finding.—The emergency cabin repressurization time from a vacuum to 3.5 psi is 35 minutes.

Determination.—The time required to repressurize the cabin to a minimum acceptable pressure is excessive in view of the possible fire damage to the closed loop pressure suit circuit.

Responsible organization.—MSC.

Action.—The cabin repressurization time as a postfire action will be decreased to a reasonable value compatible with the potential fire damage to the ECS suit loop and spacecraft interior.

CCA 1315 RB to NAR provides for additional gaseous oxygen tanks in the command module. The new tanks supplement the present system and permit repressurization of the cabin from 0 to 3 pounds per square inch in 1 minute. The change is effective for all manned spacecraft.

FINDING NO. 7

Finding.—Actuation of the suit circuit return valve, the cabin repressurization valve, and emergency cabin repressurization valve are critical in producing an adequate cabin decompression and subsequent repressurization.

Determination.—The placement of ECS controls and displays complicates the execution of the existing in-flight fire procedure.

Responsible organization.—MSC.

Action.—CCA 1311 to NAR provides for remote operation of the suit circuit return valve and a permanent handle for the emergency cabin repressurization valve. CCA 1315 provides for rapid cabin repressurization with the cabin repressurization valve located to be accessible to the crew. The changes are effective on all manned spacecraft.

GLOSSARY

A

AAA	Apollo access arm.
ACED	AC Electronics Division.
AEC	Atomic Energy Commission.
AFETR	Air Force Eastern Test Range.
APD	Apollo program directive.
APOP	Apollo preflight operations procedure.
AS	Designation for Apollo-Saturn mission.
ASPO	Apollo spacecraft program office.
AS–501	1st Saturn V mission. Unmanned S/C development mission. Flight on Nov. 9, 1967.

B

Block II	Block II is an updated class of Apollo spacecraft. All future manned Apollo flights will utilize Block II spacecraft.
BP	Boilerplate.

C

CARR	Customer acceptance readiness review.
CCA	Contract change authorization.
CCB	Configuration control board.
CCBD	Configuration control board directive.
CDDT	Countdown demonstration test.
CM (C/M)	Command module.
CO	Carbon monoxide.
CO_2	Carbon dioxide.
COMAT	Characteristics of materials.
CSM	Command and service modules.

D

DR	Discrepancy report.

E

EB	Equipment bay.
EC	Environmental chamber.
ECS	Environmental control system.
ECU	Environmental control unit.
EMU	Extravehicular mobility unit.
EO	Engineering order.
EST	Eastern standard time.
EVA	Extravehicular activity.

F

°F	Degrees Farenheit.

G

GE	General Electric Corp.
GFE	Government-furnished equipment.
GMT	Greenwich mean time.
GN_2	Gaseous nitrogen.
G. & N	Guidance and navigation.
GORP	Ground operations requirements plan.
GOX	Gaseous oxygen.
GSE	Ground support equipment.

H

H_2	Hydrogen gas.

I

ITI	Inspection test instruction.

K

KMI	KSC management instruction.
KSC	Kennedy Space Center, Fla.

L

LC	Launch complex.
LES	Launch escape system.
LH	Left hand.
LIOH	Lithium hydroxide.

M

MEK	Methyl ethyl ketone.
MIP	Mandatory inspection point.
MSC	Manned Spacecraft Center, Houston, Tex.

N

NAC	National agency check.
NAR	North American Rockwell.

O

OCP	Operations checkout procedure.
OIS	Operational intercommunication system.
O_2	Oxygen gas.

P

PIRR's	Parts installation and removal records.
PLSS	Personnel life support system.
P/N	Part number.
PSIA	Pounds per square inch absolute.

Q

Q. & R.A	Quality and reliability assurance.

R

RECP	Request for engineering change proposal.
RH	Right hand.
R.Q. & T	Reliability, quality, and test.

S

S/C	Spacecraft.
SCO	Spacecraft operations.
SLA	Spacecraft/lunar module adapter.
SM	Service module.
SS	Service structure.

T

T	Launch time.
TCP	Test and checkout procedure.
TCRD	Test checkout requirements document.
TIR	Temporary installation records.
TMA	Thermal meteroid garment.
TPS	Test preparation sheet.

U

USB	Unified S-band.
UT	Umblical tower.

V

VOX	Voice operated.

○