

NASA/SP-2010-578



NASA Astronauts on Soyuz: Experience and Lessons for the Future

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National Aeronautics and
Space Administration

Johnson Space Center
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August 2010

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Intended Audience

This document is intended for Johnson Space Center (JSC) employees and contractors and other NASA centers and contractor groups participating in the development, use, study, and human-rating of crewed spaceflight systems.

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Foreword

The chief of the NASA Headquarters Office of Safety and Mission Assurance (OSMA), Bryan O'Connor, requested that the NASA Johnson Space Center (JSC) Safety and Mission Assurance (S&MA) Director, Terrence Wilcutt, convene a team to report on NASA's experience working with the Russians and lessons on astronaut safety assurance of the Soyuz spacecraft. This report on Soyuz history was conceived as a possible analogy relevant to domestic commercial spaceflight vehicles.

On behalf of the JSC S&MA Directorate, David F. Thelen (Manager, Flight Safety Office), and SAIC's [Science Applications International Corporation] Gary W. Johnson were assigned to lead this task. Gary is the former NASA Chairperson of the Shuttle/Mir Joint Safety Assurance Working Group and the International Space Station (ISS) Joint American Russian Safety Working Group. He was also a member of the Apollo-Soyuz Test Project.

Acknowledgements

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Contents

1.0	Executive Summary	1
2.0	Scope	2
3.0	Apollo-Soyuz Test Project	2
3.1	Apollo-Soyuz Test Project organization and management	3
3.2	Apollo-Soyuz Test Project mission objective	3
3.3	Apollo-Soyuz Test Project joint safety assessments	4
3.4	Apollo-Soyuz Test Project unilateral system safety reports.....	5
3.5	Apollo-Soyuz Test Project conclusion	5
4.0	NASA Assessment of the Soyuz Spacecraft for Space Station Freedom Assured Crew Return Vehicle	6
4.1	Soyuz/assured crew return vehicle general lessons learned	8
4.2	Soyuz/assured crew return vehicle conclusion.....	8
5.0	Shuttle/Mir Program.....	8
5.1	Joint safety policy.....	9
5.2	Statement of safety policy	9
5.3	Guidelines.....	9
5.4	Risk assessment of the U.S. astronaut on the Soyuz/Mir	9
5.5	Risk assessment for the joint Shuttle/Mir mission	9
5.6	Shuttle/Mir Safety Integration Assessment Criteria.....	10
5.7	Shuttle/Mir organization.....	10
5.8	Shuttle/Mir conclusion	10
6.0	Phase 1 International Space Station (NASA/Mir).....	10
6.1	Phase 1 Program objectives.....	11
6.2	Phase 1 Program organization	11
6.3	Comparison of NASA and Russian quality, reliability, and safety assurance.....	11
6.4	Russian process for flight readiness	12
6.5	Russian process for hardware acceptance	12
6.6	NASA safety process for Norman E. Thagard's launch on Soyuz.....	13
6.7	Soyuz TM assessments by safety working group.....	13
6.8	Soyuz TM training.....	13
6.9	Soyuz landing rocket failure.....	15
6.10	Phase 1 Program conclusion.....	15
7.0	International Space Station Program.....	15
7.1	International Space Station Program U.S./Russian organization and management	16
7.2	Soyuz safety assurance for the International Space Station Program	17
7.3	Probabilistic risk assessment of Soyuz.....	17
7.4	Soyuz flight experience.....	18
7.5	International Space Station Program Safety Review Panel.....	18
7.6	Soyuz TMA upgrade	19
7.7	NASA astronaut and flight controller training on the Russian segment	19
7.8	Crew health and medical	19
7.9	Certification of flight readiness	20
7.10	Independent assessment organization.....	20

7.11	Additional assurance examples	20
8.0	Lessons Learned.....	20
9.0	Conclusions	22
10.0	References	23
	Appendix A: Uncrewed Development, Tests and Flights.....	26
	Appendix B: Crewed Soyuz Flights.....	27

Acronyms

ACRV	assured crew return vehicle
ASTP	Apollo-Soyuz Test Project
CoFR	certification of flight readiness
CSM	command and service module
DDT&E	design, development, test, and evaluation
DM	descent module
EVA	extravehicular activity
FRR	Flight Readiness Review
GCTC	Gagarin Cosmonaut Training Center
GDR	General Designers Review
IBMP	Institute of Biomedical Problems
IED	interacting equipment document
ISM	instrument service module
ISS	International Space Station
JARSWG	Joint American Russian Safety Working Group
JSAWG	Joint Safety Assurance Working Group
JSC	Johnson Space Center
MCC	Mission Control Center
MMOD	micrometeoroid orbital debris
MOU	memorandum of understanding
MSC	Manned Spacecraft Center
NCR	noncompliance report
NPR	NASA Procedural Requirement
OM	orbital module
OSMA	Office of Safety and Mission Assurance
PRA	probabilistic risk assessment
PRCB	Program Requirements Control Board
RF	radio frequency
RSA	Russian Space Agency
RSC	Rocket Space Corporation
S&MA	safety and mission assurance
SAIC	Science Applications International Corporation
SM	service module
SORR	Stage Operations Readiness Review
SR&QA	safety, reliability, and quality assurance
SRM&QA	safety, reliability, maintainability, and quality assurance
SRP	Safety Review Panel
SSF	Space Station Freedom
SSP	Space Station Program
TIM	technical interchange meeting
TM	transport module
TMA	transportation modified anthropometric
Vdc	volts, direct current
WG	working group

1.0 Executive Summary

The question of how to human-rate new spacecraft has been asked many times throughout the history of human spaceflight. The U. S., Russia, and, now China have each separately and successfully addressed this question. NASA's operational experience with human-rating primarily resides with Mercury, Gemini, Apollo, Space Shuttle, and the International Space Station (ISS). NASA's latest developmental experience includes Constellation, but also encompasses X38, X33, and the Orbital Space Plane.

If domestic commercial crew vehicles are used to transport astronauts to and from space, the Soyuz vehicle would be another relevant example of the methods that could be used to human-rate a spacecraft and how to work with commercial spacecraft providers.

As known from history, the first U.S. astronaut to orbit on a Soyuz spacecraft was Thomas P. Stafford on July 17, 1975, during the Apollo-Soyuz Test Project (ASTP) mission. Norman E. Thagard was the first U.S. astronaut to launch on a Soyuz launch vehicle, Soyuz TM-21, on March 14, 1995, on a flight to the Russian Mir Space Station. This flight was associated with the U.S./Russian - Shuttle/Mir Program. The first Soyuz launched to ISS included astronaut William M. Shepherd, Soyuz TM-31, on October 31, 2000. Prior to this, NASA studied Soyuz as an assured crew return vehicle (ACRV) for Space Station Freedom (SSF) to be launched on the Space Shuttle. Presently, in preparation for Space Shuttle retirement, all U.S. astronauts are being transported to and from ISS in the Russian Soyuz spacecraft, which is launched on the Soyuz launch vehicle.

In the case of Soyuz, NASA's normal assurance practices have had to be adapted. For a variety of external reasons, NASA has taken a "trust but verify" approach to Soyuz and international cargo vehicles. The verify approach was to perform joint safety assurance assessments of the critical spacecraft systems. For Soyuz, NASA's primary assurance was (and continues to be) its long and successful flight history. The other key measure relied on diverse teams of NASA's best technical experts working very closely with their foreign counterparts to understand the essential design, verification, and operational features of Soyuz. Those experts used their personal experiences and NASA's corporate knowledge (in the form of agency, program, center, and other standards) to jointly and independently assess a wide range of topics. These assessments were enabled by open source data (e.g., flight history) and by design/operations documentation obtained through formal contracts or less formal working-level "protocol" exchanges. Further assurance was provided by first-hand practical exposure to Soyuz training (using Russian facilities/instructors/manuals) and crew medical practices. There were also tours of manufacturing, assembly, testing, launches, and landings in progress. From this dialog and study, a picture was composed that focused on the core of the Soyuz spacecraft, but also touched on the launch vehicle and its escape system. While more reliant on the trust side of "trust but verify," this defense in depth still culminates in Soyuz readiness reviews in which NASA internally polls its responsible organizations and experts for their go/no-go recommendations using limited, but best, available data.

Building on NASA's Soyuz experience, this report contends that all past, present, and future vehicles rely on a range of methods and techniques for human-rating assurance. The components of such assurance include requirements, conceptual development, prototype evaluations, configuration management, formal development reviews (safety, design, operations), component/system testing on the ground, integrated flight tests, independent assessments, and a series of launch readiness reviews. For additional information, see NASA Procedural Requirement (NPR) 7120.5, NASA Space Flight Program and Project Management Requirements, and NPR 7123.1, NASA Systems Engineering Processes and Requirements. In addition, the Arc of Acceptability, located in Section 9.0 of this report, illustrates the trade made between proven flight experience vs. the assurance components mentioned above. This approach involves a multidiscipline team effort that is typically spread over an extended period of time. When various constraints (cost,

schedule, international) limit the depth or breadth of one or more preferred assurance means, ways are found to bolster the remaining areas.

The body of this report provides information exemplifying the above safety assurance model for consideration with commercial or foreign-government-designed spacecraft. The covered topics include U.S./Soviet-Russian government/agency agreements and the engineering/safety assessments performed along with other lessons learned in these historic U.S./Russian joint space ventures.

2.0 Scope

The scope of this report, because of history, primarily includes the orbital considerations for safe human spaceflight aboard and/or in rendezvous with the Russian Soyuz spacecraft. It also covers the safety considerations for a NASA astronaut to launch and return on a Soyuz spacecraft. It reflects the related critical engineering and safety assessment elements used to determine an acceptable risk to U.S. astronauts.

The report summarizes the safety assessments performed for the ASTP, the SSF ACRV, the Shuttle/Mir Program, the ISS Phase 1 Program (NASA/Mir), and the present ISS Program. A presentation of inter-government space agency policy is covered that addresses joint safety cooperatives, as well as policy governing responsibilities on the ISS. These highlights reveal instrumental precedent setting and a historic perspective on the continuing development of international human spaceflight safety.

3.0 Apollo-Soyuz Test Project

In July 1969, while on Air Force One flying toward the anticipated splashdown of Apollo 11, NASA Administrator Thomas O. Paine discussed the future of human space exploration with President Richard M. Nixon. Paine argued convincingly for NASA's plans to seek increased multinational space ventures. The President and his advisors agreed that this was a laudable goal and encouraged Paine to pursue his contacts with the Soviets.¹

The first step toward closer cooperation grew out of a formal exchange of letters between Administrator Paine and the President of the Soviet Academy of Sciences, Mstislav Vsevolodovich Keldysh. President Nixon formed an interagency committee to study the ramifications, both positive and negative, that would arise relative to cooperative space ventures with the Soviet Union. The members of this committee favored broader efforts toward cooperation. One suggestion for joint work concerned those areas of human space activity affecting safety and common flight operations procedures (e.g., the development of compatible docking hardware and the standardization of flight control and rendezvous systems to permit the creation of a reciprocal space rescue capability).¹

In support of their government leaders, joint technical meetings between Soviet engineers and NASA engineers at the Manned Spacecraft Center (MSC) in Houston were conducted to reach agreement on the feasibility and means of accomplishing a joint mission. With this technical foundation in place, an overall formal agreement occurred at the U.S./Soviet Summit in May 1972 with President Richard Nixon and General Secretary of the Communist Party of the Soviet Union Leonid Brezhnev signing the Space Cooperation Agreement. The agreement stated: "The US and USSR agree to enhance cooperation in outer space by utilizing the capabilities of both countries for joint projects of mutual benefit. NASA and the Soviet Academy of Sciences will oversee implementation of the agreement. The rendezvous and docking systems of US and Soviet spacecraft will be made compatible so as to provide for joint missions and rescue operations. The US and USSR agree to a joint, manned space flight in 1975 using Apollo-type and

Soyuz-type spacecraft. The two spacecraft will rendezvous and dock in space, and the cosmonauts and astronauts will visit the respective spacecraft.”²

3.1 Apollo-Soyuz Test Project organization and management

To implement the above government-level agreements, the number of U.S./Soviet technical meetings increased and three working groups (WGs) were formed. Later, the ASTP WGs were expanded to six. The WGs (all within NASA’s MSC organization – now the Johnson Space Center [JSC]) were as follows:

1. WG 0 - Technical Project Director (Apollo Spacecraft Program Office)
2. WG 1 - Mission Model (Flight Operations)
3. WG 2 - Guidance and Control Docking Aids (Engineering and Development)
4. WG 3 - Mechanical Design (Engineering and Development)
5. WG 4 - Communications and Tracking (Engineering and Development)
6. WG 5 - Life Support and Crew Transfer (Engineering and Development)

All WGs had a NASA MSC cochair and a Soviet cochair. These WGs jointly signed the meeting minutes and developed formal technical ASTP documents. In addition to the technical documents, safety assessment reports were jointly developed covering the safety hazards for Apollo and Soyuz for the planned mission. Only an overview of these safety assessment reports is covered in this report.

The most difficult problem for the U.S. and Soviets was language and communications, which necessitated the use of experienced professional interpreters and translators. This was a critical factor in the success of the ASTP mission. Another complexity at that time was that the Soviets carefully monitored the activities of their Soviet engineers while they were in the U.S. and the NASA engineers were closely monitored while in the USSR. A related reason was that information exchange was strictly limited to the accomplishment of the ASTP mission. The Soviet engineers had to get approval from their management before providing information to NASA. NASA personnel had to internally justify a need to know specific to the ASTP mission.

To achieve successful technical communication, it was best for NASA to provide the Soviets with information on their systems (Apollo electrical power system) before requesting the same information on Soyuz systems (Soyuz electrical power system). In some cases, the Soviets, knowing that they would need to provide the same detailed information in return (which they did not want to do), would not accept the information from NASA. Technical data exchange and review was limited to the Apollo and Soyuz spacecrafts and did not cover the Soyuz or Apollo launch vehicles.

To further improve working relations, the NASA WGs held informal gatherings at their homes.

3.2 Apollo-Soyuz Test Project mission objective

Apollo-Soyuz was the first international crewed spaceflight. It was designed to test the compatibility of rendezvous and docking systems for U.S. and Soviet spacecraft, and to open the way for international space rescue as well as to future joint crewed spaceflights. Additional requirements to fulfill the ASTP objectives for the Soyuz spacecraft were as follows:

1. Integration of compatible rendezvous and docking systems in the spacecraft (Soyuz passive)
2. Realization of the Apollo-Soyuz joint spaceflight
3. Pressure reduction in the living modules up to 520 ± 30 mmHg
4. Execution of joint experiments
5. Joint filming and TV transmissions

3.3 Apollo-Soyuz Test Project joint safety assessments

To provide safety assurance, NASA and Soviet engineers collaborated to develop Safety Assessment Reports on the Apollo command and service module (CSM) and the Soyuz spacecraft, which consisted of a service module (SM), an orbital module (OM), and a descent module (DM). These reports were jointly approved by the engineers and their program management. In addition to the safety assessment reports, a large number of jointly signed design requirements and systems description, testing, and operations documents were developed. They were called interacting equipment documents (IEDs) with 50000 series numbers. For example: The 50000 series was on the docking systems, the 50400 series addressed stabilization and control, the 50600 series contained communications (IED 50601.5, ASTP Cable Communications Requirements, USA-USSR, August 15, 1974), the 50700 series was on atmosphere and environmental control, etc. For a complete list of identified ASTP documents, see Reference 1, Note. The Soyuz safety assessments covered below are limited to the safety hazards associated with rendezvous, docking, crew transfer while docked, and undocking.

The **Safety Assessment Report for the Soyuz Structural Ring Latches** covered the hazard of inadvertent release of the Soyuz structural ring latches, resulting in loss of pressure integrity. The conclusion stated: “The assessment given makes it possible to conclude that the latches’ design, logic and electrical control diagrams are designed taking into account a sufficient number of structural, circuitry and procedural features that prevent inadvertent release of the Soyuz structural ring latches at design interface loads.”³

The **Safety Assessment Report for Soyuz Propulsion and Control Systems** covered the attitude and translation control system of the Soyuz spacecraft and its associated instruments. The safety of the attitude and translation control system was assured by

1. The redundancy of the attitude and translation control system modes.
2. Arranging the most important instruments of the system in a configuration yielding reliable performance (triple redundancy).
3. The redundancy of command sensors (two complete sets), the thrusters (two complete sets), and the corrective engines (two complete sets). The switching of these instruments and assemblies were implemented either from the cosmonaut control panel or on a radio-link.
4. Monitoring, on the cosmonaut control panel, of the telemetry condition of the main and backup corrective engine system, docking and orientation engine system, and operation of the system’s engines. The propulsion system was also assured by monitoring the performance of commands and software programs.
5. The selection of the sequence of commands and operations to eliminate any spurious inputs of commands.⁴

To address Apollo 1 lessons, the **Safety Assessment Report for Soyuz Fire and Fire Safety** covered the fire safety of Soyuz vehicles and the principles of Soyuz fire safety provisions. To control fire risks, electronic equipment was placed outside the crew compartment and filled with an inert gas (nitrogen). Additionally, the crew quarters used a mixed-gas atmosphere (nitrogen and oxygen) and controls to prevent the oxygen percentage from exceeding 31%. All spacecraft components were checked under the most severe temperature conditions, and maximum nominal current loads in the atmosphere with oxygen content of 40% and total pressure up to 960 mmHg. Electric power was found to be based on a two-wire circuit (power return isolated from vehicle ground or structure) and protected by circuit breakers and fuses. Additional provisions and controls for nonmetallic materials were also covered in the report.⁵

The **Safety Assessment Report for Soyuz Pyrotechnic Devices** covered the pyrotechnic devices, electric circuitry, circuit protection, tests and checkout, and influence of radio frequency (RF) radiation on the

pyrotechnic devices. Results obtained from the analysis and testing, of a full-scale Soyuz mockup with RF power, provided confidence that there was no danger of the Soyuz pyrotechnic device initiating because of electromagnetic irradiation from on-board radio systems and ground stations.⁶

The **Safety Assessment Report for Soyuz Habitable Modules Overpressurization and Depressurization** concluded that, during joint flight, the Soyuz modules would not be overpressurized, there would be no Soyuz failures leading to rapid gas leakage, and the pressurization system would maintain the necessary atmospheric pressure up to equivalent leakage through a 5-mm-diameter hole.⁷

The **Safety Assessment Report for Soyuz Manufacturing, Test and Checkout Flow** provided a list of the new and modified systems to support the ASTP mission (e.g., the androgynous periphery docking system and the automatic control equipment for docking assemblies installed in the OM were on this list along with the reason for the change). A description of the development tests and integrated ground tests for this system were covered at the manufacturer, launch complex, and launch pad. They also performed flight testing, covering all operations except for the actual docking with Apollo.⁸

The **Safety Assessment Report for Soyuz Radio Command Systems** described the radio command system consisting of the Mission Control Center (MCC), ground tracking stations, and command system on-board equipment. Inadvertent commands that could affect crew safety were covered in detail. Information was provided on the following:

1. Protection against accidental commands
2. Measures against command distortion
3. Measures to exclude any accidental commands
4. Measures against operator mistakes
5. Measures against missing a command transmitted to the spacecraft⁹

3.4 Apollo-Soyuz Test Project unilateral system safety reports

To provide detail on Soyuz systems not covered in the Joint Safety Assessment reports, the NASA JSC Safety, Reliability, and Quality Assurance (SR&QA) Office developed unilateral System Safety Reports.

For example, JSC 09265, Unilateral System Safety Report for Soyuz Pyrotechnic Devices for the ASTP, covered and documented the descriptions, locations, and characteristics of Soyuz pyrotechnic devices including the safe no-fire power limits as compared to the similar provisions for Apollo (1.5 milliwatts/50 milliamps for Soyuz vs. 1 watt/1 ampere for Apollo).¹⁰

Another unilateral report covered the Soyuz Electrical Power System (JSC 09267). This report documented the power system descriptions, locations, and power supply system schematic of the Soyuz electrical power system, which was proven to be isolated from structure by means of high resistance.¹¹ The report also concluded that at least two insulation faults are required (one positive and one negative) before a Soyuz short can occur. Power and return are in separate connectors. Two out of three voting in critical circuits provided series and parallel redundancy. Information for this report was obtained from Soviet WG1 Chairman Vladimir Aleksandrovich Timchenko who provided "Lectures on the Soyuz Power Supply System to be used for Joint Training of the Control Center Personnel," **USSR WG1-100**.¹²

3.5 Apollo-Soyuz Test Project conclusion

What made ASTP a success was formal top-level government agreements with a clear mission objective and the knowledge that both countries would benefit from these agreements. Experienced and dedicated personnel from both sides were assigned with clear responsibilities and reporting. Although this was during

the period of the “Cold War,” engineers on both sides worked together as a team to make sure ASTP was a success.

From a technology perspective, NASA engineers initially were under the impression that the Soviet spacecraft was not equivalent to NASA’s spacecraft, but became aware that the redundancy level was as good as that of the U.S. spacecraft; indeed, in some critical control systems, the Soyuz had three strings of redundancy vs. the two strings of redundancy for Apollo. Soyuz design was deemed to be robust with an objective of being simple rather than complex. Its functions were primarily automated with some crew manual backup vs. Apollo’s greater reliance on crew for spacecraft operations. One example of technical innovation was the Soyuz electromechanical damper vs. the hydraulic damper on the Apollo docking system, which required heaters to maintain temperature.

Although Soyuz and Apollo/Saturn launch vehicles were not formally reviewed or evaluated, the Soviets did provide information on a Soyuz 18A, April 5, 1975, launch that had a problem during the first and second stage that resulted in a successful ascent abort.

4.0 NASA Assessment of the Soyuz Spacecraft for Space Station Freedom Assured Crew Return Vehicle

The SSF Program, ACRV Project Office, was directed by Congress to look at the Russian legacy spacecraft as an ACRV for SSF. The result was the initiation of a joint Scientific and Production Association NPO-Energia and NASA analysis in March 1992.¹³

“In October 1991, during a meeting with Boeing representatives (the main station contractor) the head of NPO-Energia Yuri Pavlovich Semenov offered the company’s Soyuz spacecraft to serve as a lifeboat. In February 1992, the chairman of a congressional subcommittee on space Barbara A. Mikulski urged NASA Administrator Richard H. Truly to evaluate the feasibility of employing Soyuz as a lifeboat. In March 1992, Russian and US space officials discussed the possibility of cooperation in manned space program, including ACRV. On June 18, 1992, after three months of negotiations, NASA Administrator Daniel S. Goldin and Director General of the Russian Space Agency Yuri Nikolayevich Koptev, “ratified” a contract between NASA and NPO-Energia to study possible application of the Soyuz spacecraft and Russian docking port in the Freedom project. The agreement would also cover a study of the possible use of the Mir space station for the US life-science research in support of the Space Station Freedom project. The contract worth \$1 million was expected to last a year.”¹⁴

As a result, in May 1992, the NASA Administrator delivered a preliminary feasibility assessment report (JSC 34023) on the possible use of the Soyuz transport module (TM) as the ACRV for the SSF Program to George E. Brown, Jr., Chairman of the House Committee on Science, Space and Technology. This report was followed by a NASA feasibility study contract with NPO-Energia in June 1992. Phase A of the Soyuz TM feasibility and definition study was completed in December 1992.¹⁵

The ACRV Project Office, on January 1993, requested that Langley Research Center conduct a study to accommodate the Soyuz/ACRV. The objective of this study was to evaluate the technical impacts of accommodating two Soyuz vehicles on SSF for assured crew return. The study was completed, and the results were presented on March 4, 1993. The identified general issues included increased keep-alive Soyuz power requirements, conversion of 120 Vdc [volts, direct current] to 28 Vdc power, and communication/telemetry interfaces.¹⁶

NASA initiated a Phase B Soyuz ACRV definition study in March 1993 with NPO-Energia. This study looked at extending the orbital lifetime using a NASA-compatible communication system, improved land targeting, an androgynous docking system, Soyuz compatibility for launch within the Space Shuttle payload bay, mission support architecture (MCC-Houston and MCC-Moscow), and Russian standards and certification processes.¹³

On April 27, 1993, the ACRV Project Office identified the products of the Phase A technical feasibility study of the Soyuz TM as a space station ACRV. This study included a safety, reliability, maintainability and quality assurance (SRM&QA) analysis based on a review of the NPO-Energia specifications, standards, and design requirements obtained during the technical interchange meetings (TIMs).

During the course of the TIMs, the Russians stated that the Soyuz vehicles supporting space stations Salyut and Mir would always be docked for immediate return. Emergency evacuation procedures were practiced and demonstrated as possible within 15 minutes. The Soviets had used emergency procedures on their stations four times. Two were for medical evacuations, one was for contaminated atmosphere, and one was for a damaged space station window.¹⁷

In June 1993, NASA JSC's Space and Life Sciences Directorate evaluated the Soyuz TM spacecraft and Kazbek launch and entry couch for the medical transport role. Due to Soyuz hatch and couch constraints, essentially no medical restraint system was possible, each patient had to "bend in." An ill or injured crew member would need to be secured in the center couch for reach and vision. The report summary concluded that Soyuz appears feasible for a medically critical but stable patient.¹⁸

The ACRV Project Office presentation, given on July 27, 1993, on the preliminary assessment of the Soyuz TM system included a review of NPO-Energia engineering standards and procedures to assess their differences and similarities with those of NASA. It asserted that Soyuz TM is a mature, proven spacecraft designed, built, and certified to NPO-Energia engineering standards and processes that are similar but not identical to NASA's engineering standards and processes. A comparison of these standards was later documented in Space Station Program (SSP) 50094, NASA/Russian Space Agency (RSA) Joint Specifications Standards Document for the ISS Russian segment. If the modified Soyuz ACRV had been implemented, it was to be built and certified by the manufacturer, NPO-Energia, to the Soyuz ACRV Project verification/certification requirements. Where mandatory, to accommodate unique requirements or environments of the ACRV mission, these processes and appropriate standards were to be modified on mutual agreement by NASA and NPO-Energia. NASA's assurance that the Soyuz ACRV Project would meet the intent of the SR&QA requirements was to be based on the following:

1. Successful completion of a system-level analysis designed to assess and demonstrate that the safety and reliability of the Soyuz ACRV had not been compromised by modifications to the vehicle and its mission environment
2. Successful completion of the NASA safety review process for Soyuz ACRV as Shuttle and space station payloads and as an autonomous spacecraft¹³

The ACRV Project Office developed a NASA JSC document, JSC 34056, Soyuz ACRV Policy on Standards, Certification and SR&QA, dated August 17, 1993. This document encapsulated the policy on standards, verification, SR&QA, and rationale. The rationale within this document stated the following:

"Applying the NASA system of verification/certification and standards to an existing flight-proven vehicle design would not only be prohibitively expensive, but would also introduce changes to a successful DDT&E [design, development, test, and evaluation] process. Applying the complete NASA SR&QA program of requirements and controls would invalidate the previous flight history of the vehicle with respect to its [*sic*] Safety and

Reliability. Alternatively, oversight of the DDT&E process would provide insight and a method of assurance that the intent of the SR&QA requirements was being met. Safety of the crew is considered to be an essential part of the Soyuz ACRV program, and since there is not a formal Safety review process for the Soyuz TM, NASA is imposing its Safety review processes and procedures.”¹⁹

4.1 Soyuz/assured crew return vehicle general lessons learned²⁰

1. Meetings with the Russians were highly dependent on the use of interpreters and required more time than NASA expected.
2. Continuing relationships with particular specialists greatly improves communications. A level of trust is established and seems to be very strong. Constantly changing personnel interfacing with the Russians is counter-productive.
3. Word choice is important. Consistent use of agreed-to technical terminology is essential. NASA-only terminology can cause misunderstandings.
4. There is very little empowerment in Russian industry. The transfer of Russian/Soviet information required more management approval than NASA is used to in normal business operations.
5. The work done by NPO-Energia was more compartmentalized than that done by NASA. This made it very important to have the particular expert present when discussing any given topic.
6. Protocols for meetings were very important to the Russians, and a signature on a protocol was significant and treated as a binding commitment.

4.2 Soyuz/assured crew return vehicle conclusion

Work with the Russians was easier in terms of obtaining information on the Soyuz spacecraft compared to that on ASTP. The Russian company NPO-Energia, later changed to Rocket Space Corporation (RSC)-Energia, wanted to market to NASA the use of the Soyuz as an ACRV for the U.S. space station. This effort to use the Soyuz as an SSF ACRV ended when the Russian Federation became a partner on the ISS, in December 1993. During this short period of time, March 1992 until December 1993, the ACRV Project Office evaluated the Soyuz as an SSF ACRV, but no formal safety assessments were performed beyond the establishment of a Policy on Standards, Certification, and SR&QA.

5.0 Shuttle/Mir Program

The Shuttle/Mir Program was formally initiated as a limited joint endeavor involving a single Russian cosmonaut on the Shuttle and a single U.S. astronaut on Mir with one docking between the Shuttle/Mir. On June 17, 1992, the U.S. President, George H. Bush, and the President of the Russian Federation, Boris Nikolayevich Yeltsin, signed a formal agreement between the United States of America and the Russian Federation concerning cooperation in the exploration and use of outer space for peaceful purposes.

Within this agreement, Article 1 stated

“Cooperation may include human and robotic space flight projects, ground-based operations and experiments and other activities in such areas as:

- Monitoring the global environment from space;
- Space Shuttle and Mir Space Station missions involving the participation of U.S. astronauts and Russian cosmonauts;
- Safety of space flight activities;
- Space biology and medicine; and

- Examining the possibilities of working together in other areas, such as the exploration of Mars.”²¹

5.1 Joint safety policy

On March 18, 1993, the SSP Level II Program Requirements Control Board (PRCB) approved the Change Request Number S052830 Safety Policy for the Joint U.S./Russian missions.

5.2 Statement of safety policy

“It is the policy of NASA to maintain a comprehensive and effective system safety program to ensure the safety of personnel and equipment. Risks associated with the joint Shuttle/Mir Mission will be identified. Exposures to these risks will be eliminated or minimized to a level acceptable to both agencies. Accomplishment of these will rely on:

- Safety experience developed in support of Shuttle, payloads and space station efforts.
- Safety experience developed in support of Mir, Soyuz and Progress programs.
- Experience and knowledge acquired by Russia in support of Space endeavors.
- Assessment of docking system hardware, Shuttle/Mir interfaces, and Shuttle/Mir normal and contingency operations to ensure that safeguards and controls are documented and implemented.”

5.3 Guidelines

- Mutual acceptance and trust of each country’s system safety program is the basis for system safety efforts, recognizing the experience each country had with successful manned space programs.
- A mutual understanding of each country’s safety process is expected. Differences between the Shuttle and Mir safety processes will be identified and resolved to the satisfaction of both countries.
- Detailed assessments may be performed for specific issues that were identified.
- Safety assessments of integrated operations will be performed to identify potential hazards and the controls to mitigate these hazards.

5.4 Risk assessment of the U.S. astronaut on the Soyuz/Mir

NASA will review and understand the Russian safety philosophy/process and astronaut training/certification to provide a better understanding of the risk NASA is accepting for this mission.

5.5 Risk assessment for the joint Shuttle/Mir mission

Mating system hardware will meet current Shuttle/Orbiter system safety requirements. Any deviations from NASA requirements and hazards associated with the hardware procured from Russia (the androgynous peripheral docking assembly, including avionics and ground support equipment) will be identified to the Program for resolution.

Payloads and experiments will meet current Shuttle requirements as applicable.

Risk assessments of hazards affected by joint integrated Shuttle/MIR operations will be provided through integrated hazard analyses and safety assessment reports. Integrated hazard assessment criteria will be per the attached appendix.

The System Safety Assessment methodology will be developed to determine the level of detail required to assess the risks associated with these operations.

5.6 Shuttle/Mir Safety Integration Assessment Criteria

The Shuttle/Mir Safety Integration Assessment Criteria, dated February 12, 1993, was baselined by the Shuttle PRCB. These criteria were derived from existing program requirements (Vol. X, NSTS 1700.7B, etc.) and were tailored for minimum operational impact while maintaining the level of safety consistent with manned Shuttle flights.

These criteria were not intended to impose redesign requirements for existing Shuttle/Mir hardware, but were instead used as a basis for evaluating and defining the acceptability of those risks unique to the Shuttle/Mir mission.²²

5.7 Shuttle/Mir organization

As was done during ASTP, it was agreed to organize this program's work into six WGs. These were:

1. WG 0 - Joint Management
2. WG 1 - Public Affairs
3. WG 2 - Safety Assurance
4. WG 3 - Flight Operations and Systems Integration
5. WG 4 - Mission Science
6. WG 5 - Crew Exchange and Training

The WGs consisted of experts from RSC-Energia, NASA, RSA, the Institute for Biomedical Problems, Gagarin Cosmonaut Training Center (GCTC), and other organizations and companies. The WGs prepared the organizational and technical documentation and carried out the flight plans. Each country designated a cochair for each group. The cochairs conducted joint meetings and were empowered to sign protocols that documented agreements made within their discipline.

5.8 Shuttle/Mir conclusion

Before this program was fully enacted, it was greatly expanded in scope to include more Shuttle flights to Mir with more cosmonauts to fly on the Shuttle. The following pages expand on the resulting lessons.

6.0 Phase 1 International Space Station (NASA/Mir)

U.S. Vice President Albert A. Gore, Jr. and Russian Prime Minister Victor Stepanovich Chernomyrdin issued a joint statement on expanded cooperation in space on September 2, 1993. The first phase was planned to use the Russian Mir Space Station and the U.S. Space Shuttle in the multiple missions that would prepare both nations for further joint activities in a unified ISS. This expansion from one to multiple missions to Mir was called NASA/Mir. This joint statement asserted that the inclusion of Russia in ISS would offer significant advantages to all concerned, including current U.S. partners from Canada, Europe and Japan.²³

On December 6, 1993, a formal invitation was extended by the Government of Canada, the European Governments, the Government of Japan, and the Government of the United States to the Government of the Russian Federation to become a partner in the detailed design, development, operation, and utilization of the space station within the framework established by the Space Station Agreements.²⁴

On December 17, 1993, the Government of the Russian Federation gave a positive response to that invitation and agreement. The management portion of this agreement (article 7) stated that NASA, in

accordance with the memorandum of understanding (MOU), was to be responsible for the establishment of overall safety requirements and plans.²⁵

In this context, the Phase 1 Program represented the building blocks used to create the experience and technical expertise for the ISS. This preparatory program brought together the U.S. and Russia in a major cooperative and contractual program to take advantage of both countries' capabilities.

6.1 Phase 1 Program objectives

1. Learn how to work with International Partners.
2. Reduce risks associated with developing and assembling a space station.
3. Gain operational experience for NASA on long-duration missions.
4. Conduct life science, microgravity, and environmental research programs.

The Phase 1 Program management plan was established on October 6, 1994 by the NASA Headquarters Associate Administrator for Spaceflight. This plan established a program manager and program organization.²⁶

6.2 Phase 1 Program organization²⁶

The Phase 1 Program organization used the same Shuttle/Mir WGs and added three additional Shuttle/Mir WGs for a total of nine WGs. These were:

1. WG 0 - Joint Management
2. WG 1 - Public Affairs
3. WG 2 - Safety Assurance
4. WG 3 - Flight Operations and Systems Integration
5. WG 4 - Mission Science
6. WG 5 - Crew Exchange and Training
7. WG 6 - Mir Operations and Integration
8. WG 7 - Extravehicular Activity (EVA)
9. WG 8 - Medical Operations

6.3 Comparison of NASA and Russian quality, reliability, and safety assurance

The RSC-Energia's Reliability Laboratory provided NASA with a briefing on Mir/Shuttle Project quality, reliability, and safety assurance. The Russians mentioned that they did not have a safety program requirement. Instead, they have a Quality and Reliability Program Requirement. In Russian standards, quality encompasses a very broad range of factors that defines the consumer value of a product. Quality includes reliability, safety, and a set of other factors described as fabrication quality, documentation quality, workmanship, etc. While reliability and safety relate to a significant extent to vehicle characteristics, other aspects of quality can describe both the hardware and other elements of the vehicle development process.

Of the two concepts, "reliability" and "safety," the RSA narrowed the definition most for vehicle reliability. In its general meaning, dependability includes the following properties: reliability, longevity, preservability, and maintainability. Reliability is analyzed primarily by performing quantitative analysis on probability parameters.²⁷

Russian experts indicated that they rely on four levels of technical standards. At the top level are RSA and government standards. The second level defines the enterprise Rocket Space Technology. The third level is composed of standards from facilities such as NPO-Energia. The fourth level is product standards.²⁸

Safety means roughly the same thing to RSA and NASA; specifically, it is the capability to prevent damage to the health of the crew and service personnel, along with major losses of material and property. The relationship between reliability and safety can be illustrated by an expression often used at RSA: “safety is assured primarily by reliability.” Those safety assurance facilities and procedures with no relation to reliability are primarily geared toward controlling contingency (hazardous) situations, e.g., situations that arise due to a lack of hardware reliability. Russia makes far less use of quantitative indices for safety than for dependability (e.g., crew hazard probability, specific contingency occurrence probability).

The Russians consider this approach to reliability and safety as being close to the one taken by NASA. One of the main differences is in the methods and forms of reliability and safety analysis. For example, NASA emphasizes measures to prevent hazardous situations from arising in its safety analysis. The RSA essentially examines those measures as part of a reliability analysis, while focusing most of its attention on measures to control off-nominal situations in its safety analysis.

NASA and the RSA have roughly identical principles for safety and reliability assurance to include: development in stages; establishing, implementing, and monitoring compliance with requirements; redundancy principles, etc. They also have similar approaches to problem resolution to include: tasks are similar in terms of goals and content; methods and procedures for task resolution vary; and there are significant differences with respect to formats for analyses and reports generated on their results.

6.4 Russian process for flight readiness²⁸

Although the final decision to launch is made by the assembly company (General Designer), there is a Space Committee (approximately 20 people) headed by a 3-Star General for Air and Space with the following representation:

- RSA
- NPO-Energia
- General Designer
- Central Institute of Machine Building
- Ministry of Defense
- Physicians
- Baikonur

When different countries/companies are involved, (e.g., Ukraine), they will have representation on the Space Committee. At NPO-Energia’s final report before a mission, the Ministry of Defense representative states that everything has been checked. For Soyuz launches, the Ministry of Defense still signs the flight readiness document verifying that an independent check of the crewed requirements are met. All preparations for flight at Baikonur are performed by the military. Independent assessment is performed by the Central Institute of Machine Building for every flight. Overall check for compliance with requirements is process oriented, but assessment is not done on an item-by-item basis.

6.5 Russian process for hardware acceptance

Institutions designing hardware have an organization representing the Ministry of Defense. This organization does inspections and checks on hardware being built to requirements for all phases of production. All design changes have to be agreed to with this organization. Two signatures are required for hardware acceptance (General Designer and Ministry of Defense). The General Designer can overrule the Ministry of Defense representative’s position, but this almost never happens.

Every piece of measuring equipment must have a stamp from the manufacturing facility with an associated stamp from the Central Institute of Machine Building (independent assessment of equipment). This type of equipment undergoes receiving inspection/control. For equipment to be used in space, high-level sample testing is performed to obtain a number certifying the equipment. Electrical components do not carry a “Manned Flight Certificate,” but are part of the military standard process. Any instrument/assembly has to have a report that identifies that it is “Good for Manned Flight.” The certificate is called a “Passport” and has the information regarding the testing and acceptance of that hardware.²⁸

6.6 NASA safety process for Norman E. Thagard’s launch on Soyuz

The Russian Flight Readiness process, described above, was used to certify astronaut Norman E. Thagard for launch on Soyuz TM-21 on March 14, 1995. NASA astronaut Bonnie J. Dunbar, who was the backup to Thagard for the mission, went through the same certification for launch on the Soyuz. The NASA JSC Space and Life Sciences Flight Surgeon Michael R. Barratt’s role was to get Thagard, and later other Phase 1 astronauts, past the Russian Medical Commission so they could be presented by the Institute of Biomedical Problems (IBMP) and GCTC at the Flight Readiness Review (FRR). Michael R. Barratt stated he had sporadic involvement in the overall safety and risk issues for the first mission. This meant that IBMP counterparts would address the safety and risk issues with JSC Space and Life Sciences representatives at dedicated medical meetings. This did improve over the course of the Phase 1 flights, but Thagard’s flight differed greatly from the follow-on missions, as he was being launched on a Soyuz to Mir.

Attendance at the various review meetings was as follows:

The final medical review meeting was attended by Michael R. Barratt, David C. Leestma, the Director of Flight Crew Operations, and William F. Readdy, the Star City Lead astronaut.

At the Star City crew training final review meeting, Leestma and Readdy, along with the Phase 1 Deputy Program Manager, Frank L. Culbertson, Jr., and the Manager of the Moscow Space Station Program Office, Kenny L. Mitchell, were in attendance.

The NASA Phase 1 Program Manager, Tommy W. Holloway, and the Deputy Program Manager, Frank L. Culbertson, Jr., attended the General Designer Review (GDR) held at NPO-Energia. The GDR is what NASA refers to as the FRR.

The NASA Associate Administrator Space Flight Office Dr. Jerrell Wayne Littles, Director Space Station Wilbert C. Trafton, Associate Administrator Life Sciences & Microgravity Harry C. Holloway, Chief Health & Medical Officer Arnauld E. Nicogossian, JSC Center Director Carolyn L. Huntoon, Flight Crew Operations Director David C. Leestma, Phase 1 Program Manager Tommy W. Holloway, Deputy Program Manager Frank L. Culbertson, Jr., astronauts William F. Readdy and Ronald M. Sega, Soyuz TM-21 backup Bonnie J. Dunbar, Moscow Technical Liaison Office Manager Kenny L. Mitchell, and Deputy Manager David G. Herbeck were present at Baikonur for pre-launch meetings and the launch.

6.7 Soyuz TM assessments by safety working group

The safety assessments and hazard reports that were developed were for the Shuttle docking mission to Mir; they did not cover the Soyuz TM. The joint agreement was that the Russians were responsible for the safety of U.S. astronauts being transported to and from Mir.

6.8 Soyuz TM training

U.S. astronauts went through the same level of training as the cosmonauts did on the Soyuz. Classroom training was done on Soyuz systems and required crew operations. Passing an oral test on the material

presented was required for certification as a Soyuz crewmember. Training was also done on Soyuz mock-ups and simulators. Two weeks before launch, after passing all the tests, the crew is flown to Baikonur to participate in a test at the launch site to go through all of the steps associated with a launch. The Soyuz instructor during training becomes what NASA calls a capsule communicator (Cap Comm) for launch through the first couple of orbits before it is turned over to MCC-Moscow. Norman E. Thagard, who was launched on a Soyuz TM, received training for returning on a Soyuz during which, he flew a manual entry in the landing simulator located in the centrifuge; however, he returned on the Space Shuttle (STS-71).²⁹

This training is also conducted for the NASA astronauts on the ISS Program. Such training adds to the knowledge gleaned by the technical WGs. As an ISS example, NASA astronaut Kenneth D. Bowersox, who launched on the Space Shuttle STS-113 on November 23, 2002, and was the first NASA astronaut along with NASA astronaut Donald R. Pettit to return on a Soyuz spacecraft, Soyuz TMA-1, May 3, 2003, provided the following information on the training he had received:

Climbing out of the Soyuz is the prime mode for emergency egress until about T-15 minutes when the abort system is armed. Probably possible to arm up before that, but do not have any data to support the assumption. Did not receive much more detail than that during training. There are three hatches that must be opened to egress; believe all three hatches can be opened by the crew, but do not remember how the fairing hatch works. The orbital module hatch opens inward, as does the hatch between the descent and orbital modules. Believe the fairing hatch opens outward. Once out of the Soyuz would anticipate using the stairs as the most reliable emergency egress option, but do not know for sure. Our Russian partners worry much less about egress than we do here in America.³⁰

On the question of is a safe abort capability retained for all launch trajectory deviations, Bowersox says:

Do not believe guidance is smart enough to ensure all aborts will be safe during ascent, no data to confirm that though. The ascent abort system has six modes, depending on time since liftoff, and various discrettes in the system. Depending on the mode, booster engines may be shut down, and different sequences of solids can be fired to for the abort. The abort tower is jettisoned shortly after the strap-ons separate. After tower jettison, but before fairing jettison, small solids on the sides of the fairing can separate the Soyuz and fairing from the stack. After fairing jettison, the abort system shuts down the booster engine, and Soyuz pretty much falls off the stack for a ballistic entry.³⁰

On the question of how a launch abort is initiated, Bowersox says:

Do not know all of the abort triggers for Soyuz. From my limited training, it is a pretty simple system, mostly cued off of acceleration (a drop in axial acceleration), rates, and a rough attitude error. The crew does not have an abort command capability, but the system has an auto mode, and the ground can send an abort command. If the auto system or ground command an abort, the crew gets a light. Crew has very little data to judge an abort, just a clock, and seat-of-the-pants estimate of vehicle vibration/ acceleration - no altitude or vehicle performance information, just some information on life support systems, propellant tanks, and a rate gyro read out if [crewmembers] want to call it up. The crew could call the ground and request an abort, if the radio link was working. As far as I know, the auto abort coverage goes all the way to the end of powered flight, and only relies on the escape tower for part of the trip. The flight crew has no control of the ascent stack during powered flight, so engine shutdown has to be auto or ground commanded. At least they never taught the Americans about a way to shut down the booster during ascent....³⁰

On the question of what the wind constraints and redundancy of the parachute system are, Bowersox says:

Do not have any info on abort or launch wind constraints. If the wind is blowing very much at landing, the vehicle will end up on its side, and the chute will drag it. The commander controls chute jettison with a switch mounted where he can reach it while strapped in the seat. Depending on the wind, if the main chute is not jettisoned, the Soyuz and crew get [dragged] along until they reach the nearest obstacle, or the wind stops. The parachute hatch has pyrobolts that sound like a machine gun firing when they go off. If the main parachute has a problem, then the reserve comes out - based on descent rate going through a pre-set altitude band.³⁰

6.9 Soyuz landing rocket failure

On one of the Mir return missions, August 14, 1997, the Soyuz TM-25 landing rockets fired prematurely when the system was armed at heat shield jettison, resulting in a harder-than-normal landing. Failure analysis indicated that moisture had gotten into the connectors, causing a short that bypassed the gamma-ray sensor that detects distance from the ground.

The Russian cochair of the Joint Safety Assurance Working Group (JSAWG) provided information to NASA on the failure and corrective action. He also gave a detailed briefing on the design of the Soyuz landing system and the inhibits to prevent the hazard of firing rockets with the heat shield in place.³¹

6.10 Phase 1 Program conclusion

The NASA/Mir Program gave NASA crewmembers and ground teams their first direct, in-depth look at the full scope of Soyuz operations. In all areas of engagement, the program established the joint personal relationships and trust that made the ISS Program possible and successful. The WGs that retained NASA and Russian chairpersons throughout the Phase 1 Program developed a high degree of trust and were the most successful. The Russians maintained the same chairperson, but high turnover of the NASA chairperson in some WGs resulted in those WGs being less effective. During this time, Russian and U.S. practices were found to be more similar than different. The experience and knowledge that each earned over multiple decades proved essential to having mutual assurance in the safety, reliability, and success of their combined endeavors. This expertise, added at this time, became embedded in ISS practices via the team members who subsequently took up active positions in the ISS Program and/or institutionalized their lessons in ISS documentation (requirements, flight rules, etc). For more information on this era of spaceflight, refer to the final joint report, the illustrated official history book, and NASA's collection of oral histories available at

<http://spaceflight.nasa.gov/history/shuttle-mir/welcome/w-jointreport.htm>

<http://spaceflight.nasa.gov/history/shuttle-mir/welcome/w-book.htm>

<http://spaceflight.nasa.gov/history/shuttle-mir/people/oral-histories.htm>

The Phase 1 Program officially ended with the STS-91 OV-103/*Discovery* landing in June 1998.

7.0 International Space Station Program

At a U.S./Russian Joint Commission on Economic and Technological Cooperation, on June 23, 1994, a definitive contract agreement was signed between NASA and the RSA for \$400M of goods and services

to be provided during Shuttle/Mir operations and during the early ISS assembly phase.³² The MOU between NASA and RSA concerning cooperation on the civil ISS, dated April 21, 1997, defined both work and respective responsibilities.³³ For example: Article 6, Respective Responsibilities, 6.1 NASA Responsibilities, item 6 stated: “Conduct, together with RSA and the other partners as necessary: overall Space Station technical reviews, including integrated design, critical design, design certification, safety and mission assurance, operations, readiness and FRRs, in order for NASA to certify that the RSA’s elements are acceptable for on-orbit assembly and orbital operations.” Section 6.2 identified the RSA responsibilities.

7.1 International Space Station Program U.S./Russian organization and management

The ISS Program technical teams were structured the same as they had been with the other space station International Partners. Several of the Mir groups remained intact into the ISS era and, in fact, worked simultaneously on both programs to their benefit. Institutionally oriented experts in mission operations, EVA, and safety exemplified this corporate knowledge approach. For example, the JSAWG in Phase 1 became the Joint American Russian Safety Working Group (JARSWG) for ISS. The name change was due to the change in the Russian cochair for ISS. Now, Soyuz interactions tend to be led by NASA’s launch package manager with augmented aid from the ISS Mission Management Team and the ISS Program Manager during readiness reviews.

On the ISS Program joint work with the Russians was conducted in TIMs. Technical teams were identified in February 1994 and, as work progressed, more teams were added. These teams were as follows:

1. Team 0 - Technical Management
2. Team 0A - Schedules
3. Team 1A - Assembly Configuration
4. Team 1B - Integrated Performance
5. Team 2A - Functional Cargo Block
6. Team 2B - Interfaces
7. Team 3 - Russian Vehicle
8. Team 4A - Service Module
9. Team 5A - Control and Data Handling
10. Team 5B - Communications and Tracking/Electromagnetic Interference
11. Team 5C - Approach Rendezvous and Docking
12. Team 5D - Guidance, Navigation, and Control
13. Team 5E - Power
14. Team 6A - Life Support
15. Team 6B - Crew Health Care System
16. Team 6C - Thermal Control
17. Team 6D - Propulsion
18. Team 7A - EVA
19. Team 7C - Airlock
20. Team 8A.1 - Structures
21. Team 8A.2 - Micrometeoroid Orbital Debris (MMOD)
22. Team 8A.3 - Loads and Dynamics
23. Team 8B - Materials and Processes
24. Team 9 - Test and Verification
25. Team 10 - Safety and Risk
26. Team 11 - Crew Rotation
27. Team 11A - Command and Control Center

28. Team 11B - Crew/Flight Training
29. Team 11C - Tactical Planning
30. Team 11D - Logistic and Maintenance
31. Team 12A - Requirements
32. Team 12B - Interface Control Document

Currently, WG arrangements are described in the NASA/Roscosmos Joint Technical Team Structure as established in SSP 50200-01, Station Program Implementation Plan, Volume 1, Appendix I, NASA/Roscosmos Bilateral Processes, and maintained via SSP 50123, Configuration Management Handbook, Appendix I, NASA/Roscosmos Bilateral CM Processes.³⁴ The team numbers were changed to V, V-0 Team Management to V-15 Cargo Certification (see reference 34 for the complete listing). This ISS technical team structure is presently not well known, as a present member of the JARSWG said he/she was not aware and had not heard of this team structure. It was stated that safety is known as JARSWG, not as Team V-10.

7.2 Soyuz safety assurance for the International Space Station Program

In the ISS era of Soyuz, assurance confidence was jointly captured in multiple documents [e.g., ISS Russian Segment Specification (SSP 41163), NASA/RSA Joint Specifications Standards Document for the ISS Russian Segment (SSP 50094), NASA/RSA Bilateral S&MA [Safety and Mission Assurance] Process Requirements for the ISS (SSP 50146), and the review and approval of Soyuz hazard reports at the ISS Program Safety Review Panel (SRP) per the ISS Program Safety Requirements Document (SSP 50021)]. Although these efforts are applicable to more than just Soyuz, they served as a means of jointly understanding and recording the similarities and differences between NASA and Russian design requirements and meeting ISS safety requirements. It turned out that, because of basic physics and hard-won experience, Russian design principles were not very different from NASA. In some areas such as structure, their designs were very robust because, as with the Shuttle, their vehicles could readily accommodate the needed mass associated with design margins and redundancies (like and unlike) for human spaceflight. Soyuz reliance on automation was greater than that of Apollo and was less on manual control by the crew. Soyuz Control and Command System failure tolerance was two of three voting vs. the Apollo CSM dual redundancy (two systems plus manual backup). By analogy, the ISS visiting vehicle requirements were similarly negotiated and customized for commercial off-the-shelf cargo purposes and their safety aspects were verified by the SRP.

7.3 Probabilistic risk assessment of Soyuz³⁵

Building on the 1993 ACRV efforts, the ISS Program in 1997 assigned a task to assess the adequacy of Soyuz reliability as the ISS ACRV using a quantitative probabilistic risk assessment (PRA). The objective was to obtain confidence in the design and operations that principally contribute to loss of vehicle function.

From this study, details were compiled on Soyuz design history, reliability, and performance. It was confirmed that the Soyuz TM had gone through three major design changes since 1967, but remained the same basic three modules: the instrument service module (ISM), the OM, and the DM. Since the vehicle is largely automated, the crew does very little to interfere in its normal operation. The Soyuz spacecraft contains power and life support for up to 5 days. If required, the DM/ISM could separate from the ISS without the OM and still complete a successful entry and landing. During entry, a failed control system defaults to a zero-lift resulting in a continuous roll ballistic entry. Ballistic loads are 8-g to 10-g vs. the nominal 4-g to 5-g. Parachute deployment is completely automated (main plus a smaller backup chute). The crew cannot manually deploy the chutes. The success criterion for this assessment was the safe return of crewmembers with medical conditions. Ballistic entry was considered a failure because the high-g exacerbates the medical condition.

In terms of overall integrated operations, it was learned that Russian claims the Soyuz's reliability as an ACRV at 0.98 to 0.99 (from a 1992 NPO-Energia report). While investigating this conclusion, researchers found that contingency evacuation procedures have been used at least four times in the history of Salyut/Mir space stations, two of which were medical conditions or 0.062 per year (JSC 26770, Mir Hardware Heritage, October 1994).

At the time of this assessment, April 1997, the history of 186 separate Soyuz spacecraft flights was known with most of the major failure events occurring early in the Soyuz history. Of the 175 undockings, two failures occurred, the last in 1976. Of the 98 module separations, one failure occurred in 1969. Of the 111 crewed and uncrewed spacecraft landings (including entry and parachute deploy), eight failures occurred. Of the eight failures, all but one landing occurred in the first 5 years of flight operations, with the last one in 1980. During the approximately 80 crewed Soyuz missions since 1967, at least three have been ballistic high-g entry and one medium high-g entry, none in the Soyuz TM. Note: As we now know from the ISS Program, we had two Soyuz TMA ballistic entries, both separation (DM/ISM) failures, Soyuz TMA-10, April 7, 2007, and Soyuz TMA-11, October 10, 2007.

When this 1997 assessment was complete, it showed the reliability of Soyuz TM used as an ACRV during any given mission at approximately 0.991 (or a failure frequency of 1/111 ACRV missions). These results were consistent with the NPO-Energia claims for Soyuz TM as an ACRV.

To further augment overall confidence in Soyuz, in 2001 NASA contractually obtained a detailed report on Soyuz spacecraft reliability as a part of the ISS Program (S. P. Korolev, RSC-Energia, ISS Russian Segment Reliability and Maintainability Assessment Report, DID R-10-R02, Version 8, dated February 2001).³⁶ This report covered the Russian Segment elements; i.e., the functional cargo block, SM, science power platform, docking module, Soyuz, and Progress. In terms of loss of crew, Soyuz safety was again confirmed by the dozens of flights since the late 1960s (including successful crewed launch aborts). Using such information, NASA's PRAs of Soyuz have since been updated for Constellation-comparative purposes.

7.4 Soyuz flight experience

While this wealth of Soyuz flight experience cannot be readily afforded by those starting from scratch, it does exemplify the importance of sufficient integrated flight tests as a major element of safety assurance. The proper number of such flights is debatable but, based on Russian experience, is more than zero and more than likely closer to a handful (given that Russia's success is founded on multiple uncrewed precursors to Vostok, Voshkod, and Soyuz as described in Volume 3 of the Boris Chertok history series).

See Appendix A for a list of Uncrewed Development, Tests and Flights and Appendix B for Crewed Soyuz Flights. Appendix B is up to date as of February 5, 2010.

7.5 International Space Station Program Safety Review Panel

All ISS elements are required to present to the ISS Program SRP their safety hazards and associated safety hazard reports. Any noncompliance reports (NCRs) must be approved by the ISS Program Manager. When the NASA governance model was implemented in 2008, it stated that NCRs must now be approved by Headquarter representatives from the Chief Engineering and Chief Safety and Mission Assurance Offices.

RSC-Energia developed hazard reports on the Soyuz spacecraft; these were reviewed and presented to the ISS Program SRP by the Russian chairperson of the JARSWG and the Soyuz spacecraft designer. The scope of the safety assessment was the on-orbit phase of approach, docking, docked, undocking, and

separation from ISS. This was done in accordance with SSP 50021. The Soyuz hazard reports were approved along with three NCRs that were presented with rationale for acceptance. The NCRs were as follows:

1. NCR-RSCE-0029, Noncompliance with the requirement regarding the docking mechanism drive failure
2. NCR-RSTV-02, Rationale of Soyuz TM vehicle design decisions to assure pressurization
3. NCR-ISS-0301, Protecting the Soyuz Transport Vehicle from Meteoroids and Orbital Debris

Beyond the hazard analyses provided by Russian personnel, NASA personnel performed their own internal assessments of Russian vehicle MMOD risks. This dual-verification path is common for understanding/accepting such significant threats.

7.6 Soyuz TMA upgrade³⁷

Based on issues identified during the Mir Program, Soyuz for ISS was modified from the TM configuration to the TMA [transportation modified anthropometric] model to accommodate larger and smaller crewmembers. The work was funded by NASA and enabled the following:

1. Cosmonaut panel reduced in size (“glass cockpit”)
2. Cooler/dehumidifier unit redesigned (smaller)
3. Valves relocated inside DM
4. Various hardware modifications (more powerful entry computer, new three-axis accelerometer, improved soft-landing jets)
5. Landing impact testing in Russia using JSC-provided crash dummies (report delivered contractually)
6. Access to Soyuz manufacturing and assembly facilities in Russia

Russian representatives also presented information on the TMA modifications to the SRP, and none of the changes were found to require new or modified hazard reports beyond showing TMA effectivity.

7.7 NASA astronaut and flight controller training on the Russian segment

Training and flight control systems have been further critical constants during all periods of NASA’s engagement with Soyuz. Intimate familiarity with nominal and off-nominal Soyuz operations (as a full crewmember and not just a passenger) has always been irreplaceable via theoretical training, hands-on training, procedures, simulations, etc. NASA, although not directly in control, has long benefited from having a small team of its flight controllers embedded in MCC-Moscow during joint operations. They provide real-time feedback to NASA’s program management, flight directors, and other experts while encouraging implementation of NASA’s expectations (captured in joint flight rules and procedures) by their Russian team mates.

7.8 Crew health and medical

Crew health care through all phases of Soyuz flight has been a further assurance measure. NASA’s medical doctors shepherd their assigned crewmembers through all mission phases, including training, medical exams, pre-launch suit-up, and post-landing recovery. These doctors are so essential they are always first on scene for landing. If crewmembers were not mentally and physically healthy, their nominal and emergency interactions with the vehicle might be fatally compromised.

7.9 Certification of flight readiness

SSP 50322, ISS Vehicle Office CoFR [certification of flight readiness] Implementation Plan,³⁸ states that International Partners/Participants will certify the flight readiness of their ISS vehicle systems in accordance with SSP 50108, Certification of Flight Readiness Process Document,³⁹ and their associated Joint Management Plans. The ISS Program will conduct the Stage Operations Readiness Review (SORR), chaired by the ISS Program Manager, 1 week prior to the Joint Shuttle/Station FRR. The primary purpose of the SORR is to determine the operational readiness of station elements, personnel, and facilities for launch and on-orbit operations.

The RSA ISS CoFR Process in Appendix G of SSP 50108 documents the requirements that support the ISS CoFR Process as agreed to by NASA and RSA. Details of the Joint Safety Process are contained in SSP 50146, NASA/RSA Bilateral S&MA Process Requirements for the ISS. The Joint Safety and hardware/software certification processes are executed to support the CoFR process.

These processes have been developed to be consistent with the standard Russian certification process for certifying their modules/vehicles or deliverable cargo and to allow the ISS Program (NASA) to have access to the data and insight for integration of all hardware/software supporting the ISS. The Russian process will follow the standard timeline and procedure for certifying their modules/assembly stages or deliverable cargo. The NASA ISS Program Manager (or authorized representative) will report on ISS readiness for a particular launch during the FRR of the Russian module at the GDR. RSA presents its complete certification in support of the NASA SORR.

For launch of Russian elements, the RSA Program Manager, or designee, will serve as a Co-deputy Chair of the ISS SORR Board, and representatives from RSC-Energia and Khrunichev will serve as members of the ISS SORR Board and will participate in the ISS SORR process. If the RSA Program Manager, or designee, wishes to send a representative in his/her place, a letter delegating authority will be required for the RSA representative. Likewise, the NASA ISS Program Manager, or his/her designee, may participate in all Russian vehicle FRRs, or relevant meetings, such as the GDR or the InterState Panel Meeting. This CoFR process is separate from the independent preexisting Russian launch vehicles certification process.

7.10 Independent assessment organization

The NASA Headquarters S&MA organization will sign the CoFR certificate for each flight during the assembly phase and participate in the process through the ISS Independent Assessment Office. The Independent Assessment CoFR procedures are defined in JSC 27771, Independent Assessment CoFR Implementation Process Plan.

7.11 Additional assurance examples

Further examples of the diversity of Soyuz assurances can be found in the records offered by flight readiness data packages, joint management/technical protocols, joint WG documents, contract deliverables, jointly negotiated technical requirements, oral/written lessons learned, and the other data that remains stored at JSC.

8.0 Lessons Learned

NASA experts, using Soyuz as an example in retrospect, effectively satisfied the vast majority of the subsequently defined top-level human-rating requirements found within NPR 8705.2 by sufficiently confirming its satisfaction of failure tolerance, aborts, failure intervention, human factors, autonomy, manual control, flight testing, and appropriate “referenced” technical design standards. Given this

history, it may be possible for other groups with sufficient independent resources, motivation, and knowledge to eventually provide successful low-Earth orbit access. They will need help learning the ultimate expectations and past experience that can be communicated via clear and timely requirements along with constructive insight/oversight during the spacecraft development and operation life cycle. Because various contractors and subcontractors have always done most of the heavy lifting for NASA's human spacecraft, it would not be totally unprecedented for nontraditional contractors/partners to provide similar services. By creatively adapting and rebalancing a wide range of proven assurance methods, private ventures may yet succeed in applying their own resources and assuming more initial risk while leveraging NASA's experience and satisfying NASA's expectations. Early and ongoing communication is important along with attention to the following specific lessons:

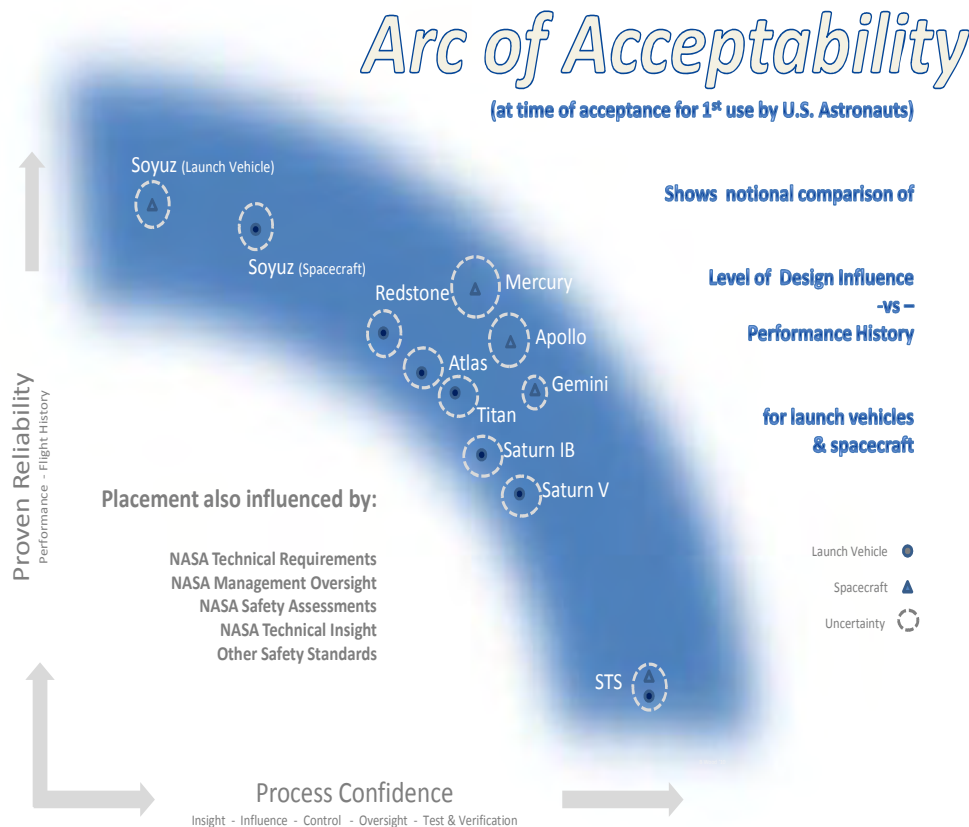
1. Have relationships/partnerships authenticated with formal documents/memoranda of agreement, etc. signed by high-level management or government officials.
2. Understand and be aware of the diversity of NASA's human spaceflight requirements (and their rationale) as evolved from past practical experience. No single source is sufficient alone, so relevant generic requirements and standards should be understood and negotiated from agency, directorate, center, program, and discipline-specific sources. These sources should also be augmented with applicable military, industry, and international standards. Ignoring the breadth, depth, and intent of these lesson sources risks costly and hazardous repetition of past mistakes.
3. Use case/vehicle-specific "situational awareness" to determine an appropriate tailoring strategy for requirements definition, equivalence determination, targeted process insight/oversight, deliverables, decision-making, and milestones.
4. For strong insight, establish appropriate, experienced, and credible technical WGs and forums for information exchange and strategy implementation.
5. Joint technical WGs that retained the same cochair or had low turnover developed a high degree of trust and were the most successful.
6. Develop close relationships with technical and systems experts and document exchanged information in such a way that it is accessible to other technical forums (e.g., the "engineering" community has made use of system schematics and drawings originally acquired by the "operations" community in their "operations/training" forums).
7. Establish clearly understood and agreed-to expectations early. Agreements subject to broad interpretations can become disconnects during implementation.
8. Think "long-term" relationships and partnerships. The knowledge, experience, and attitude of personnel representing all parties are important to success.
9. Strict compliance policing of NASA requirements and processes/practices is less valuable than a mentality of experience and seasoned risk assessment.
10. To minimize spacecraft complexity, weight, cost, and schedule the level of redundancy should be determined based on the following factors: criticality, flight experience, and technology maturity [Technology Readiness Level]. An overall requirement to be two-fault tolerant or "fail-operational/fail-safe" could increase spacecraft complexity and, in some cases, result in the spacecraft being less reliable. For example, the level of redundancy varied on the Apollo spacecraft. The fuel cell was a new technology for aerospace applications while the electrical power buses and power contactors for switching were a proven technology. Therefore, the level of redundancy for the fuel cells was three and for the main buses was two. If the function was Criticality 1 (Crew Safety), the design could have no single-point failures; it had to be fail-safe.⁴⁰

11. For high-risk areas (e.g., launch, staging, MMOD, entry and landing), NASA is wise to conduct independent analyses and tests that confirm or question the conclusions of its hardware providers, unless the hardware (e.g., the Soyuz) has extensive flight experience. Alternate informed opinions are essential to avoid inadvertent errors.
12. As an ultimate safety assurance method, there is no substitute for conducting realistic, high-fidelity, pre-flight testing of components/systems and fully integrated flight tests using production-quality vehicles. Confidence increases as successes accumulate in a no-crew environment. Based on Soyuz flight tests in the 1960s, three to five flight tests with no crew are recommended for nominal launch/orbit/landing conditions along with several tests of launch abort cases.

9.0 Conclusions

While the general perception is that NASA has always tightly managed all aspects of its human space-flight programs, there have been good reasons for that approach as well as prominent and subtle exceptions. The space environment is harsh and unforgiving; therefore, the comparatively low production/flight rates and correspondingly high costs of human spaceflight are not easily achieved. This is why only three wealthy nations and no other organizations (including purely private enterprises) have so far demonstrated the ability to achieve Earth orbit. Only the U.S. has left Earth orbit.

With Soyuz at one end of the spectrum, the following graphic conceptually illustrates and compares the range of safety approaches to human spaceflight. It is intended to show that multiple solutions that fit along a trend arc have been successful. For others to succeed, they should strive to balance their assurances to fit somewhere along this historic path to avoid risks failures that cost time, money, and lives.



This report demonstrates that space vehicles rely on a range of methods and techniques for human-rating assurance. It shows that the components of such assurance include requirements, conceptual development, prototype evaluations, configuration management, formal development reviews (safety, design, operations), component/system testing on the ground, integrated flight tests, independent assessments and a series of launch readiness reviews. This defensive, in-depth approach involves a multidiscipline team effort that is typically spread over an extended period of time. It works well when those involved are highly experienced and able to focus on new challenges without having to slow down to relearn past lessons. When various constraints (cost, schedule, international) limit the depth or breadth of one or more preferred assurance means, ways can be found to bolster the remaining assurances.

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Appendix A: Uncrewed Development, Tests and Flights

Flight #	Date	Soyuz	Variant	Note
1	11/28/1966	Cosmos 133	7K-OK	Attitude control system malfunction resulted in expenditure of fuel. Required multiple attempts to initiate entry. Spacecraft overshot the programmed landing location and likely initiated a self-destruct charge.
2	12/14/1966		7K-OK	The first-stage (strap-on) motors shut down after the failure of an oxygen bypass valve; however, the motors on the core (second stage) continued running but lacked sufficient power to move the vehicle. The launch was aborted and the pad flooded with water. When the gyroscopes of the launch escape system were powered down the decrease in RPM results in the gyros moving enough to activate the launch escape system. A fire was started when the 32 pyrotechnic bolts fired to separate the crew module from the instrument module. The Soyuz capsule pulled away from the rocket. The fire spread to the fueled third stage and produced an explosion that killed several people on the ground and significantly damaged the launch pad.
3	2/7/1967	Cosmos 140	7K-OK	An attitude control problem occurred due to a faulty star sensor. This resulted in excessive fuel consumption and difficulties in keeping the batteries charged with the solar arrays. The crew module depressurized when it separated from the instrument (service) module. The attitude control problem then led to a ballistic entry. A 300-mm hole burned through the heat shield during re-entry. The recovery system functioned properly, and the capsule landed in the frozen Aral Sea, 3 km from shore and 500 km short of the intended landing zone.
4	4/8/1967	Cosmos 154	7K-L1	Trans-lunar injection stage failed to fire. Vehicle burned up when the orbit eventually decayed.
5	10/27/1967	Cosmos 186	7K-OK	Was to dock with Cosmos 188. Achieved capture but could not complete docking due to incorrect attitude relative to each other. Star tracker failed, resulting in ballistic entry.
6	10/30/1967	Cosmos 188	7K-OK	Was to dock with Cosmos 186. Achieved capture but could not complete docking due to incorrect attitude relative to each other. The ion orientation system was used when the star tracker failed. However, it too was faulty and resulted in an off-course entry. As a result of being too far off-course, the self-destruct system destroyed the spacecraft.
7	4/14/1968	Cosmos 212	7K-OK	Successfully docked with Cosmos 213 on first orbit. The entry and landing were also successful.
8	4/15/1968	Cosmos 213	7K-OK	Successfully docked with Cosmos 212 on first orbit. The entry and landing were also successful; however, the capsule was dragged by heavy winds when the parachute lines did not jettison at touchdown.
9	8/28/1968	Cosmos 238	7K-OK	Not Applicable
10	10/25/1968	Soyuz 2	7K-OK	Crewless docking target for Soyuz 3. Soyuz 3 crew failed to dock with Soyuz 2. Entry and landing were nominal.

Appendix B: Crewed Soyuz Flights

Flight #	Date	Soyuz	Variant	Note
1	4/23/1967	Soyuz 1	7K-OK	Cosmonaut Vladimir Komarov perished due to failure of parachute recovery system.
2	10/25/1968	Soyuz 2	7K-OK	Unmanned docking target for Soyuz 3. Soyuz 3 crew failed to dock with Soyuz 2. Entry and landing were nominal.
3	10/26/1968	Soyuz 3	7K-OK	Fails to dock with Soyuz 2 due to crew error.
4	1/14/1969	Soyuz 4	7K-OK	First crew transfer via EVA - launched with 1 cosmonaut, returned with 3.
5	1/15/1969	Soyuz 5	7K-OK	First crew transfer - launched with 3 cosmonauts, returned with 1. Service module failed to separate, resulting in nose first entry. Soft-landing rockets failed to fire resulting in the cosmonaut fracturing several teeth.
6	10/11/1969	Soyuz 6	7K-OK	Three vehicles in orbit. The capsule ended up landing "right beside a children's school."
7	10/12/1969	Soyuz 7	7K-OK	Three vehicles in orbit.
8	10/13/1969	Soyuz 8	7K-OK	Three vehicles in orbit.
9	6/1/1970	Soyuz 9	7K-OK	
10	4/23/1971	Soyuz 10	7K-OKS	The probe-cone docking mechanism failed during docking with Salyut-1, resulting in a captured but undocked module. The undocking command failed to release the Soyuz. The crew jumped back and forth within the capsule to rock the vehicle, which fortunately resulted in it being released. While descending under parachute, the capsule was headed for a lake. A last-minute breeze blew the capsule onland, where it landed 44 meters from the shore of the lake.
11	6/6/1971	Soyuz 11	7K-OKS	Crew (3) dies when crew module depressurizes on entry.
12	9/27/1973	Soyuz 12	7K-T	Crew (2) now wears pressure suits on launch and entry.
13	12/18/1973	Soyuz 13	7K-T	
14	7/3/1974	Soyuz 14	7K-T	
15	8/26/1974	Soyuz 15	7K-T	Soyuz failed to dock with Salyut 3 due to a Soyuz systems failures. The mission was aborted. The crew returned at night and descended through a thunderstorm.
16	12/2/1974	Soyuz 16	7K-T	ASTP rehearsal flight to test mission specific hardware.
17	1/11/1975	Soyuz 17	7K-T	
18	4/5/1975	Soyuz 18a	7K-T	(aka Soyuz 18-1) A failure of staging resulted in need to use the launch escape system. The crew endures high-G's during the launch abort followed by a 20 G landing in mountains near Chinese border. After touch-down, the capsule slid down a slope towards a cliff. Fortunately the parachute snagged on a tree and halted the capsule. One cosmonaut suffered internal injuries that prevented further flights.
19	5/24/1975	Soyuz 18	7K-T	
20	7/15/1975	Soyuz 19	7K-TM	Apollo-Soyuz Test Program
21	7/6/1976	Soyuz 21	7K-T	Emergency return from Salyut station due to acrid odor in space station. The first attempt to release from the space station failed when the release latches signaled they were "open" prior to being completely open. The "open" signal triggered the firing of separation thrusters, which resulted in jamming the partially open latches. Fortunately subsequent commands to open the latches were successful and the Soyuz was freed.
22	9/15/1976	Soyuz 22	7K-TM	

Flight #	Date	Soyuz	Variant	Note
23	10/14/1976	Soyuz 23	7K-T	The crew landed in partially frozen Lake Tengiz approximately 2 km from the shore. An electrical short caused the reserve parachute to deploy. The deployed parachutes resulted in the capsule floating on its side, which prevented hatch opening and blocked the fresh air intake. The radio antennas were inoperable due to submersion. Ice formed on the inner walls of the capsule and the crew struggled to survive while waiting 9 hours for recovery team. The recovery crew assumed the crew was dead and dragged the capsule to shore and waited for a special team to remove the bodies. The cosmonauts had to open the hatch themselves 11 hours after landing.
24	2/7/1977	Soyuz 24	7K-T	Landed during a snowstorm. Search and rescue antenna was jammed closed by impacted snow. Recovery crew could not locate the capsule until one of the cosmonauts freed the antenna.
25	10/9/1977	Soyuz 25	7K-T	
26	12/10/1977	Soyuz 26	7K-T	
27	1/10/1978	Soyuz 27	7K-T	
28	3/2/1978	Soyuz 28	7K-T	
29	6/15/1978	Soyuz 29	7K-T	
30	6/27/1978	Soyuz 30	7K-T	
31	8/26/1978	Soyuz 31	7K-T	
32	2/25/1979	Soyuz 32	7K-T	
33	4/10/1979	Soyuz 33	7K-T	Experienced high-G ballistic entry after unknown propulsion system anomaly.
34	6/6/1979	Soyuz 34	7K-T	
35	4/9/1980	Soyuz 35	7K-T	
36	5/26/1980	Soyuz 36	7K-T	Soft landing rockets failed to fire resulting in a 30-G impact force.
37	6/5/1980	Soyuz T-2	T	
38	7/23/1980	Soyuz 37	7K-T	
39	9/18/1980	Soyuz 38	7K-T	
40	11/27/1980	Soyuz T-3	T	
41	3/12/1981	Soyuz T-4	T	
42	3/22/1981	Soyuz 39	7K-T	
43	5/14/1981	Soyuz 40	7K-T	
44	5/13/1982	Soyuz T-5	T	
45	6/24/1982	Soyuz T-6	T	
46	8/19/1982	Soyuz T-7	T	Crew module rolled down hillside and came to rest on its side. Flight engineer thrown from couch and landed on top of Commander.
47	4/20/1983	Soyuz T-8	T	
48	6/27/1983	Soyuz T-9	T	
49	9/26/1983	Soyuz T-10-1	T	Fire prior to launch results in use of launch escape system to save crew.
50	2/8/1984	Soyuz T-10	T	
51	4/3/1984	Soyuz T-11	T	Experienced medium-high (5-6) G-forces during entry. Likely due to partial failure of atmospheric entry control system.
52	7/17/1984	Soyuz T-12	T	
53	6/6/1985	Soyuz T-13	T	

Flight #	Date	Soyuz	Variant	Note
54	9/17/1985	Soyuz T-14	T	
55	3/13/1986	Soyuz T-15	T	
56	2/5/1987	Soyuz TM-2	TM	
57	7/22/1987	Soyuz TM-3	TM	
58	12/21/1987	Soyuz TM-4	TM	Landing site was in area experiencing heat wave. Temperature was 42 deg C (108 deg F). Extreme heat had dried up the salt marsh the vehicle landed in.
59	6/7/1988	Soyuz TM-5	TM	The crew was nearly lost due to two fail de-orbit burn attempts. The first firing was prevented due to a sensor glitch. The glitch cleared after seven minutes and the firing then started. The crew manually halted the firing after 3 seconds. A second firing was attempted 2 revolutions later, but the firing was cut-off after 60 seconds (possibly 39 seconds) by the autopilot. Had the crew not deactivated the landing sequencer the descent - equipment module pyros would have fired. Since the de-orbit engines are on the equipment module, the descent module would have remained in orbit until atmospheric drag deorbited it, which would have occurred long after all life support resources were depleted.
60	8/29/1988	Soyuz TM- 6	TM	
61	11/26/1988	Soyuz TM- 7	TM	Gusting winds at landing site resulted in a double-impact "hard landing". One cosmonaut incurred a leg injury requiring medical treatment at the recovery site.
62	9/5/1989	Soyuz TM- 8	TM	Tipped over onto its side in a shallow snowfield.
63	2/11/1990	Soyuz TM- 9	TM	
64	8/1/1990	Soyuz TM- 10	TM	
65	12/2/1990	Soyuz TM- 11	TM	
66	5/18/1991	Soyuz TM- 12	TM	Hard impact on landing with the capsule ending up on its side. Television crew reported that the capsule was "very dented".
67	10/2/1991	Soyuz TM-13	TM	
68	3/17/1992	Soyuz TM-14	TM	Hard impact on landing, probably due to high winds. Capsule ended up on its side. Crew module hatch could not be opened by recovery crew. Cosmonauts had to use tools to unstick the hatch.
69	7/27/1992	Soyuz TM-15	TM	Rolled down a hill and stopped 150 meters from the shore of a salt marsh. Capsule came to rest on its side.
70	1/24/1993	Soyuz TM-16	TM	
71	7/1/1993	Soyuz TM-17	TM	Missed landing aim point by 100 km.
72	1/8/1994	Soyuz TM-18	TM	
73	7/1/1994	Soyuz TM-19	TM	Rough landing (bounced) due to strong winds at landing site.
74	10/3/1994	Soyuz TM-20	TM	
75	3/14/1995	Soyuz TM-21	TM	
76	9/3/1995	Soyuz TM-22	TM	
77	2/21/1996	Soyuz TM-23	TM	
78	8/17/1996	Soyuz TM-24	TM	
79	2/10/1997	Soyuz TM-25	TM	Soft landing rockets fired prematurely (at time of heat shield jettison) resulting in hard landing. Reported as one of the roughest landings experienced by a returning Mir crew.
80	8/5/1997	Soyuz TM-26	TM	
81	1/29/1998	Soyuz TM-27	TM	
82	8/13/1998	Soyuz TM-28	TM	

Flight #	Date	Soyuz	Variant	Note
83	2/20/1999	Soyuz TM-29	TM	
84	4/4/2000	Soyuz TM-30	TM	
85	10/31/2000	Soyuz TM-31	TM	
86	4/28/2001	Soyuz TM-32	TM	
87	10/21/2001	Soyuz TM-33	TM	
88	4/25/2002	Soyuz TM-34	TM	
89	10/30/2002	Soyuz TMA -1	TMA	
90	4/26/2003	Soyuz TMA -2	TMA	
91	10/18/2003	Soyuz TMA -3	TMA	
92	4/19/2004	Soyuz TMA -4	TMA	
93	10/14/2004	Soyuz TMA -5	TMA	
94	4/15/2005	Soyuz TMA -6	TMA	
95	10/1/2005	Soyuz TMA-7	TMA	
96	3/30/2006	Soyuz TMA-8	TMA	
97	9/18/2006	Soyuz TMA-9	TMA	
98	4/7/2007	Soyuz TMA-10	TMA	Service module fails to separate resulting in nose forward entry.
99	10/10/2007	Soyuz TMA-11	TMA	Service module fails to separate resulting in nose forward entry. One crewmember injured due to high loads.
100	4/8/2008	Soyuz TMA-12	TMA	
101	10/12/2008	Soyuz TMA-13	TMA	
102	3/26/2009	Soyuz TMA-14	TMA	18S
103	5/27/2009	Soyuz TMA-15	TMA	19S
104	9/30/2009	Soyuz TMA-16	TMA	20S
105	12/20/2009	Soyuz TMA-17	TMA	21S
106	4/2/2010	Soyuz TMA-18	TMA	22S
107	6/16/2010	Soyuz TMA-19	TMA	23S
108	9/31/10	Soyuz TMA-20	TMA	24S

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE August 2010	3. REPORT TYPE AND DATES COVERED Special Publication		
4. TITLE AND SUBTITLE NASA Astronauts on Soyuz: Experience and Lessons for the Future			5. FUNDING NUMBERS	
6. AUTHOR(S) OSMA Assessments Team*				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lyndon B. Johnson Space Center Houston, Texas 77058			8. PERFORMING ORGANIZATION REPORT NUMBERS S-1076	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER SP-2010-578	
11. SUPPLEMENTARY NOTES *NASA Johnson Space Center, Houston				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified/Unlimited Available from the NASA Center for AeroSpace Information (CASI) 7115 Standard Hanover, MD 21076-1320 Category: 18			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The U. S., Russia, and, China have each addressed the question of human-rating spacecraft. NASA's operational experience with human-rating primarily resides with Mercury, Gemini, Apollo, Space Shuttle, and International Space Station. NASA's latest developmental experience includes Constellation, X38, X33, and the Orbital Space Plane. If domestic commercial crew vehicles are used to transport astronauts to and from space, Soyuz is another example of methods that could be used to human-rate a spacecraft and to work with commercial spacecraft providers. For Soyuz, NASA's normal assurance practices were adapted. Building on NASA's Soyuz experience, this report contends all past, present, and future vehicles rely on a range of methods and techniques for human-rating assurance, the components of which include: requirements, conceptual development, prototype evaluations, configuration management, formal development reviews (safety, design, operations), component/system ground-testing, integrated flight tests, independent assessments, and launch readiness reviews. When constraints (cost, schedule, international) limit the depth/breadth of one or more preferred assurance means, ways are found to bolster the remaining areas. This report provides information exemplifying the above safety assurance model for consideration with commercial or foreign-government-designed spacecraft. Topics addressed include: U.S./Soviet-Russian government/agency agreements and engineering/safety assessments performed with lessons learned in historic U.S./Russian joint space ventures.				
14. SUBJECT TERMS human factors engineering; human resources; commercial spacecraft; space commercialization; assurance; redundancy; reliability			15. NUMBER OF PAGES 42	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	
