**Report of the PRESIDENTIAL COMMISSION on the Space Shuttle Challenger Accident**

## Volume 2: Appendix H - Flight Readiness Review Treatment of O-ring Problems

[**H1**] *Flight Readiness Review Treatment of O-ring Problems*

This Appendix describes case-to-case field joint and nozzle-to-case joint O-ring anomalies experienced in flight and documents to what extent these anomalies were discussed in subsequent Flight Readiness Reviews. The sequence of Flight Readiness Review briefings on the Solid Rocket Boosters included up to five successive briefings at Marshall: SRM Preboard, SRB Board, Shuttle Projects Office Board, and Center Board. The Flight Readiness Review briefings were culminated with a Level I Headquarters briefing, nominally 10 days prior to launch and typically referred to as "the" Flight Readiness Review.

The second Shuttle flight, STS-2, launched November 12, 1981, experienced erosion of the primary O-ring in the right SRM aft field joint. The eroded area was at the 90° location and was a maximum of 0.053 inches deep. However, this erosion was not discussed in the STS-3 Flight Readiness Reviews, even though other anomalies mentioned in these reviews were identified as "Not a Crit. I/II failure." The field joint seal was, of course, classified Criticality 1R. This erosion was the deepest experienced in flight in a case field joint, until STS 51-L.

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STS-6 (flight 6) was the first use of the lightweight SRM case; it was also the first flight following the case joint seal criticality change from IR to 1. At the STS-6 SRB Preboard on January 4,1983, Marshall Safety, Reliability, and Quality Assurance mentioned the criticality change as "in approval cycle." At the Marshall Center Board briefing on February 25, 1983, responding to an STS-6 Vehicle Configuration Review action item, Thiokol discussed the gap size and O-ring squeeze for the lightweight case segments, also referring to the criticality change: (Chart 1).

Subsequently, Mr. Lawrence Mulloy, the SRB Project Manager, also mentioned the pending criticality change in his Flight Readiness Review briefing to Level I on March 17, 1983. It was identified as not being an open item, even though the waiver for flight as a Criticality I was not approved by Level I until March 28, 1983: (Chart 2).

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STS-6 was launched on April 4, 1983. When the SRMs were dismantled, blowholes through the putty in both nozzle joints were found. The O-rings were affected by heat, but were not eroded. The blowholes were at 318° on the left nozzle and 251° on the right nozzle. These observations were not discussed in any of the STS-7 Flight Readiness Reviews.

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STS 41-B (flight 10), experienced O-ring erosion in both the right hand nozzle joint and the left SRB forward field joint. The field joint O-ring erosion was centered at the 351° location and the area of maximum erosion extended over 3 inches with a maximum depth of 0.040 inches. The nozzle O-ring erosion was at the 14.4° location. The erosion was localized, extending only over a 0.75 inch span to a depth of 0.039 inches. These anomalies were described by Thiokol in the STS 41-C SRB Board briefing on March 2, 1984: (Charts 3, 4).

In the same briefing, O-ring erosion was presented as a technical issue. For the first time in any Flight Readiness Review, the O-ring problems on STS-2 and STS-6 were mentioned. The idea that putty blow holes and O-ring erosion were related was also discussed for the first time: (Charts 5, 6, 7).

On March 8, 1984, at the Shuttle Projects Office Board for STS 41-C (flight 11), the notion of "acceptable" erosion is first mentioned: (Chart 8).

In assessing the erosion, the concern was expressed in terms of the following: erosion of the primary O-ring could lead to erosion of the secondary O-ring and subsequent joint failure. However, the joint had been reclassified as Criticality I, not I R, indicating the primary O-ring should have been considered a single point failure. Also noteworthy in this briefing was the first mention of an analysis showing that the "maximum possible" erosion for joint O-rings was .090 inches and the rationale that this was acceptable since a test showed that O-rings with a simulated erosion of .095 inches could seal at three times motor pressure: (Charts 9, 10, 11, 12, 13).

The concept of "acceptable erosion" was advanced again in the Flight Readiness Review briefing to the Marshall Center Board on March 20, 1984: (Chart 14).

At that same briefing, Thiokol discussed the O-ring erosion in some detail. The briefing was substantially the same as that given at the Shuttle Projects Board.

Similar charts were used by Mr. Mulloy at the Level I Flight Readiness Review on March 27, 1984: (Charts 15, 16, 17, 18, 19).

During the Level I briefing, Mr. Mulloy received an action item to review the case and nozzle joint seals. The action item was identified as "Outside the Flight Readiness Review," which indicated that the action did not have to be completed before the STS 41-C flight: (Chart 20).

Mr. Lawrence Wear, the SRM Element Manager, subsequently directed Thiokol to establish a plan and a test program to investigate the issue. In his tasking, he asked Thiokol to determine if the O-ring erosion was acceptable, and if so, why: (Charts 21 and 21A).

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STS 41-C (flight 11), launched April 6, 1984, experienced erosion of the primary O-ring in the right-hand nozzle joint. The erosion, located at 319°, was 0.034 inches deep and extended over a 1.8 inch span. The primary O-ring in the left-hand aft field joint was affected by heat in areas adjacent to blow holes in the putty, but there was no measurable erosion. A Thiokol presentation to the STS 41-D SRM Preboard Flight Readiness Review on May 30, 1984, described these anomalies: (Charts 22, 23, 24, 25, 26).

The nozzle joint O-ring erosion was also discussed as a technical issue in the same briefing: (Charts 27, 28).

Similar charts were prepared by Thiokol for the Marshall Center Board on June 8, 1984, but they were not presented. The STS 41-C O-ring erosion was not mentioned in the STS 41-D Level I Flight Readiness Review on June 18, 1984.

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STS 41-D (flight 12), launched August 30, 1984, experienced primary O-ring erosion in both the right-hand forward field joint and the left-hand nozzle joint. The field joint erosion was 0.028 inches deep and occurred over a 3 inch span at the 275° location. The nozzle O-ring was eroded to a depth of 0.046 inches over a 4 inch span at the 309.6° location. Further, there was a [**H2**] small amount of soot behind the primary O-ring, indicating short duration blow-by. This was the first occurrence of blow-by in either the case-to-case or nozzle-to-case joints.

At the STS 41-G SRM Preboard on September 12, 1984, Thiokol discussed the 41-D O-ring erosion: (Chart 29).

Mr. Mulloy also discussed the erosion at the 41-G Shuttle Projects Board on September 19, 1984, referring to "allowable" erosion for the first time: (Chart 30).

He used a similar chart at the Marshall Center Board on September 20, 1984: (Chart 31).

The concept of "allowable" erosion was also used at the Level I Flight Readiness Review on September 26, 1984: (Chart 32).

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The next two flights, STS 41-G (flight 13) and STS 51-A (flight 14) experienced no O-ring erosion in either the case-to-case or nozzle-to-case joints. The absence of O-ring damage was noted in the SRM Preboards for STS 51-A and STS 51-C.

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STS 51-C (flight 15), launched January 24, 1985, experienced blow-by in both nozzle joints and erosion and blow-by in two case joints. The calculated O-ring temperature was 53 degrees Fahrenheit, the coldest prior to STS 51-L. The flight hardware evidenced the worst case of "blow-by" experienced by any Shuttle flight. The primary nozzle joint O-rings were not damaged. The primary O-ring in the left-hand forward field joint was eroded 0.010 inches deep over a 4.25 inch span at the 163° location, with a considerable amount of soot between the primary and secondary O-rings. The primary O-ring in the right-hand center field joint was eroded 0.038 inches deep over a 12.5 inch span at the 354° location. There was black grease (sooted) behind the primary O-ring over a 110° arc and the secondary O-ring was affected (but not eroded) by heat over a 29.5 inch span.

At the STS 51-E SRM Preboard on January 31, 1985, Thiokol included a quick-look description of the field joint O-ring damage. The nozzle had not yet been disassembled, so there was no mention of the nozzle joint O-ring blow-by. However, the Thiokol briefing, TWR 14740 Rev B, described the case-to-case field joint O-ring damage in some detail; recounted the pre-flight tang and clevis measurements, putty amounts used, and leak check procedures followed; summarized O-ring damage from previous SRMs; and showed analytical predictions for maximum expected erosion. It concluded with Charts 33 and 34.

The inclusion of the O-ring erosion discussion was apparently the result of the January 31, 1985, "Certified Urgent" message from Mr. Mulloy to Mr. Wear (see Commission Report, Vol. 1, Appendix D).

A much more detailed treatment of the STS 51 -C O-ring anomalies was presented to Mr. Mulloy at the SRB Board on February 8, 1985 (some charts were not reproducible and have been retyped): (Charts 35 through 60).

On February 12, 1985, Mr. Mulloy and Thiokol presented a slightly condensed version of the briefing to the Shuttle Projects Office Board. In the Action Items Summary, the 51-C O-ring related items are shown as "closed": (Chart 61).

The Problem Summary portion of the briefing refers to the field joint O-ring blow-by as an "acceptable risk": (Chart 62).

Thiokol then briefed the O-ring erosion as a Special Topic: (Charts 63 through 78).

It should be noted that in this and the preceding briefing, the secondary O-ring was referred to as "a redundant seal using actual hardware dimensions" even though the field joint seal had been officially classified as Criticality I (not redundant) for two years. Also, both briefings as part of their conclusion on O-ring erosion offered that "low temperature enhanced probability- STS 51-C experienced worst case temperature change in Florida history."

At the February 14, 1985 Marshall Center Board, Mr. Mulloy did not address the 51-C O-ring anomalies in detail: (Chart 79).

At the Level I Flight Readiness Review on February 21, 1985, Mr. Mulloy again did not present a detailed briefing, presenting only two charts: (Charts 80 and 81).

After the Commission Report was published, the Commission received a videotape of Mr. Mulloy presenting the STS 51 -E Level I Flight Readiness Review. The transcript of the portion pertaining to the preceding two charts is included with the charts.

The mission designated STS 51 -E never flew. Payload problems forced a change in the cargo manifesting and STS 51-D (flight 16) was the next launch. The Shuttle hardware scheduled for STS 51-E was actually used on STS 51-B (flight 17) after STS 51-D. The STS 51 -D Flight Readiness Reviews did not readdress STS 51-C performance; only those issues associated with the processing of the STS 51-D elements were discussed.

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STS 51-D (flight 16), launched April 12, 1985, experienced erosion of the primary O-rings in both nozzle joints. The righthand nozzle primary O-ring eroded to a depth of 0.068 inches over a 6 inch span at 116°. The left-hand nozzle primary O-ring eroded to a depth of 0.011 inches over a 2.12 inch span at the 14.4° position. There was no blow-by past either nozzle O-ring.

The Board for STS 51-B (flight 17) was conducted on April 8, 1985, before the STS 51-D launch. Consequently, STS 51-D anomalies were not discussed; however, the nozzle from STS 51 -C (flight 15), had been disassembled by this time and the O-ring blow-by discovered. The findings were presented to Mr. Mulloy: (Charts 82, 83, 84).

There was no mention of either the STS 51-C or STS 51-D nozzle anomalies at the STS 51-B Shuttle Projects Board on April 17, 1985, or the Level I Flight Readiness Review on April 23, 1985.

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STS 51-B (flight 17), launched April 29, 1985, suffered the worst O-ring erosion experienced prior to STS 51-L. The lefthand nozzle primary O-ring eroded to a depth of 0.171 inches over a 1.59 inch span at the 54° location. There was evidence of considerable blow-by. The secondary O-ring was eroded to a depth of 0.032 inches over a 3.1 inch span, also at the 54° location. The right-hand nozzle O-ring eroded to a depth of 0.005 inches over a 3.4 inch span at the 14.4° location. There was no blow-by associated with this erosion.

The SRB Board for STS 51-F (flight 19) and STS 51-G (flight 18) were combined and held on May 8, 1985, before the STS 51-B (flight 17) nozzles had been disassembled. It was noted that there were blow holes through the putty in one field joint from each of the STS 51-B SRMs; however, the O-rings were not damaged. No O-ring related anomalies were discussed at the STS 51-G Shuttle Projects Board on May 29, 1985, the Center Board on May 31, 1985, or the Level I Flight Readiness Review On June 11, 1985.

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STS 51-G (flight 18), launched June 17, 1985, experienced blow-by and erosion in both nozzle joints. The right-hand nozzle primary O-ring was eroded in two different places-0.023 inches over a 0.88 inch span at 342° and 0.009 inches over a 2 inch span at 270°. The left-hand nozzle primary O-ring eroded to a depth of 0.013 inches over a I .12 inch span at 151.2 ° . There was blow-by associated with all three locations, although neither of the secondary O-rings were damaged.

The Flight Readiness Review process for STS 51-F (flight 19) continued with an update SRB Board on June 21, 1985. The Shuttle Projects Board occurred on dune 25, 1985. At this time, the STS 51 -B (flight 17) nozzle joint O-ring damage had still not [**H3**] yet been discovered, nor had the STS 51-G nozzle been disassembled. Before the STS 51-F Marshall Center Board Flight Readiness Review on dune 27, 1985, took place, the STS 51-B nozzle O-ring anomaly was finally discovered. Mr. Mulloy addressed the issue at the Center Board: (Charts 85 through 95).

On July l, 1985, Thiokol presented a more extensive analysis of the STS 51 -B anomaly at a combined Flight Readiness Review for the Marshall SRM Preboard, SRB Board, Shuttle Projects Office Board, and Marshall Center Board: (Charts 96 through 129).

Mr. Mulloy's briefing to the Level I Flight Readiness Review the next day (July 2, 1985) presented the 51-B O-ring erosion problem as "closed," offering a resolution based on the use of a higher (200 psi) leak check stabilization pressure and introducing for the first time a rationale for accepting secondary O-ring erosion: (Charts 130, 131, 132, 133).

The Commission could find no reference to the STS 51 -D (flight 16) and STS 51-G (flight 18) nozzle joint O-ring anomalies in any Flight Readiness Review.

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STS 51-F (flight 19) was launched on duly 29, 1985, and experienced no O-ring erosion; however, there was a blow hole through the putty in the right-hand SRM nozzle and the primary O-ring was affected by heat.

The SRM nozzles were apparently being disassembled much faster than previously; the absence of STS 51-F nozzle O-ring damage was noted at STS 51-I Shuttle Projects Board on August 7, 1985, the Marshall Center Board on August 13, 1985, and the Level I Flight Readiness Review on August 15, 1985.

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On August 19, 1985, Thiokol presented to Level I a detailed discussion and analysis of primary seal erosion in the igniter, field, and nozzle joints. The briefing, prepaid at the request of Level I, was prompted by heightened concern following the STS 51-B (flight 17) nozzle joint anomaly. Although not an element of the Flight Readiness Review process, the briefing is included here because of its inherent importance and because it was the vehicle through which Marshall attempted to close the April 5, 1984, Action Item from the STS 41-C Level I Flight Readiness Review: (Charts 134 through 188).

After the briefing, Mr. Mulloy submitted a request to close the STS 41-C Action Item: (Chart 189).

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STS 51-I (flight 20), launched August 27, 1985, suffered primary O-ring erosion in two locations on the left-hand SRM nozzle joint: 0.064 inches deep over a 13.5 inch span at the 18° location and 0.030 inches deep over a 1.5 inch span at the 0° location. There was no blow-by associated with either occurrence.

Mr. Wear briefed the O-ring damage at the STS 51-J SRB Board Flight Readiness Review on September 9, 1985: (Chart 190).

At the STS 51-J Shuttle Projects Board on September 17, 1985, the Center Board on September 19, 1985, and the Level I Flight Readiness Review on September 26, 1985, the incident was simply itemized as "LH nozzle to case primary O-ring erosion within experience base."

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STS 51 -J (flight 21) flew on October 3, 1985, and experienced no O-ring damage. Anomalies were briefed as "TBD" at the STS 61-A SRB Board Flight Readiness Review on October 7, 1985, possibly indicating that the SRMs had not been inspected. At the Shuttle Projects Board on October 15, 1985, the lack of O-ring erosion was noted: "SRM joint O-ring performance nominal.

STS 61-A (flight 22) launched October 30, 1985, experienced erosion of the right-hand nozzle primary O-ring to a depth of 0.075 inches over a 13 inch span at the 97.2° location. Also experienced on STS 61-A was the first case-to-case field joint O-ring anomaly since mission STS 51-C. There was blow-by past the primary O-rings in the center and aft field joints on the lefthand SRM. The O-rings were not damaged.

The anomalies were not discussed at the STS 61-B SRB Board on November 4, 1985; however, at the Shuttle Projects Board on November 6, 1985, Mr. Mulloy's briefing included the note: "SRM joint O-ring performance within experience base." At the Marshall Center Board on November 12, 1985, and the Level I Flight Readiness Review on November 18, 1985, he briefed that "Post flight inspection of SRM revealed hot gas erosion of primary nozzle/case joint-O-ring on RH SRM-Within previously accepted experience."

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STS 61-B (flight 23), launched November 26, 1985, experienced primary O-ring erosion in both nozzle joints. The righthand nozzle O-ring eroded 0.039 inches over a 7 inch span at the 0° position. The left-hand nozzle O-ring eroded 0.017 inches over a 3 inch span at the 345.6° location. There was blow-by past the primary O-ring in the left-hand nozzle joint.

These observations were briefed at the STS 61-C SRB Board Flight Readiness Review on December 2, 1985: (Chart 191).

At the December 4, 1985 STS 61-C Shuttle Projects Board, Mr. Mulloy noted "SRM joint O-ring performance within experience base." The Commission's copy of the December 9, 1985 Marshall Center Board briefing was incomplete; however, at the December 11, 1985 Level I Flight Readiness Review, it was reported that there were "No 61-B flight anomalies."

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STS 61-C (flight 24), launched on January 12, 1986, experienced nozzle joint O-ring erosion and blow-by and field joint O-ring erosion. The right-hand nozzle joint primary O-ring was eroded 0.011 inches over an 8 inch span at the 162° location. There was blow-by past the primary O-ring in the left-hand nozzle joint between the 255.6° and 334.8° positions. The primary O-ring in the left SRM aft field joint was eroded 0.004 inches over a 3.5 inch span at the 154° location.

The STS 51-L SRB Board Flight Readiness Review On January 3, 1986, Shuttle Projects Board On January 8, 1986, and Marshall Center Board on January 13, 1986, all occurred before the STS 61-C SRBs were available for inspection. However, at the STS 51-L Level I Flight Readiness Review On January 15, 1986, Mr. Mulloy noted that there were "No 61-C Flight Anomalies," and that there were "No Major Problems or Issues."

STS 51-L (flight 25) was launched on January 28, 1986.

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[Please note that some of the titles to the references listed below do not appear in the original text. Titles are included to identify and clarify the linked references- Chris Gamble, html editor]

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- [**H4**] STS-6 Flight Readiness Reviews: Charts 1-2 [Chart 1: Marshall Center Board (February 25, 1983); Chart 2: Level I (March 17, 1983) Marshall Space Flight Center- SRB, STS-6 Flight Readiness Review.].
- [**H5-H14**] STS 41-C Flight Readiness Reviews. Charts: 3-4 [Chart 3: SRB Board (March 2, 1984), STS-11 Postflight Inspection (Cont.); Chart 4: STS-11 Postflight Inspection (continued)], Charts 5-7 [Chart 5: STS-11 O-Ring anomalies; Chart 6: STS-11 O-Ring anomalies- continued; Chart 7: STS-11 O-Ring anomalies- continued], Charts 8-9 [Chart 8: Shuttle Projects Office Board (March 8, 1984) Problem Summary; Chart 9: STS-11 (SRM-10) O-Ring Erosion Assessment], Charts 10-11 [Chart 10: SRM Nozzle-to-case joint; Chart 11: SRM case field joint], Charts 12-13 [Chart 12: STS-11 (SRM-10) O-Ring Erosion Assessment-continued; Chart

13: STS-11 O-Ring anomalies], Charts 14-15 [Chart 14: Marshall Center Board (March 20, 1984) Problem Summary (Continued); Chart 15: Level I (March 27, 1984) MSFC Shuttle Projects- Problem Summary], Charts 16-17 [Chart 16: MSFC Shuttle Projects-Solid Rocket Booster: STS 41-B (SRM-10) O-Ring Erosion Assessment; Chart 17: SRM Case Field Joint], Charts 18-19 [Chart 18: SRM Case Field Joint; Chart 19: STS 41-B (SRM-10) O-Ring Erosion Assessment], Charts 20, 21-21A [Chart 20: STS 41-C Programmatic Action Item (outside the flight readiness review; Chart 21: Letter from L.O. Wear to Joe Kilminster. Date: April 1984. Subject: Review of SRM Case-to-Case and Case-to-Nozzle Joint Sealing Procedures; Chart 21A: Letter from L.O. Wear to Joe Kilminster. Date: April 1984. Subject: Review of SRM Case-to-Case and Case-to-Nozzle Joint Sealing Procedures-continued].

- [**H14-H17**] STS 41-D Flight Readiness Reviews: Charts 22 [Chart 22: SRM Preboard (May 30, 1984) Problem summary (continued), 41-C (STS-13) Postflight hardware assessment (continued)], Charts 23-24 [Chart 23: Problem summary (continued), 41-C (STS-13) Postflight hardware assessment (continued); Chart 24: Problem summary (continued), 41-C (STS-13) Postflight inspection (continued)], Charts 25-27 [Chart 25: Problem summary (continued), 41-C (STS-13) Postflight hardware assessment (continued); Problem summary (continued), 41-C (STS-13) Postflight hardware assessment (continued); Chart 26: Problem summary (continued), 41-C (STS-13) Postflight hardware assessment (continued); Chart 27: Technical issues- STS-13 O-Ring/Vacuum putty analysis], Charts 28 [Chart 28: Technical issues- STS-13 O-Ring/Vacuum putty analysis-continued].
- [**H17-H19**] STS 41-G Flight Readiness Reviews: Charts 29 [Chart 29: SRM Preboard (September 12, 1984), Problem Summary (cont) STS-41D Preliminary SRM postflight hardware damage assessment field joints], Charts 30-32 [Chart 30: Shuttle Projects Office Board (September 19, 1984)- Problem Summary; Chart 31: Marshall Center Board (September 29, 1984)- Problem Summary, STS 41-D Post Flight Retrieval inspection significant observations; Chart 32: Level I (September 26, 1984)-Problem summary, STS 41-D Post Flight Retrieval inspection significant observations].
- [**H19-H42**] STS 51-E Flight Readiness Reviews: Charts 33-34 [Chart 33: SRM Preboard (January 31, 1985), Flight Readiness Assessment for STS-51E; Chart 34: Flight Readiness Assessment for STS-51E: Rationale for acceptance], Charts 35-37 [Chart 35: SRB Board (February 8, 1985) Technical Issues; Chart 36: Technical issues- SRM-HPM Field Joint; Chart 37: Technical Issues (continued)], Charts 38-39 [Chart 38: STS-51C (STS-20) (SRM-15) Technical Issues (cont); Chart 39: SRM-15A FWD Primary Seal], Charts 40-41 [Chart 40: STS-51C (STS-20) (SRM-15) Performance (cont)- Preliminary postflight hardware damage assessment (cont); Chart 41: 5 Photographs- Not Reproducible], Charts 42-43 [Chart 42: STS-51C (STS-20) (SRM-15) Technical Issues (cont)-Preliminary postflight hardware damage assessment (cont); Chart 43: STS-51C (STS-20) (SRM-15) Technical Issues (cont)], Charts 44-45 [Chart 44: SRM-15B CTR Primary Seal; Chart 45: SRM-15B CTR Secondary Seal], Charts 46-47 [Chart 46: STS-51C (STS-20) (SRM-15) Performance (cont)-Preliminary postflight hardware damage assessment (cont); Chart 47: 2 Photographs- Not Reproducible], Charts 48-49 [Chart 48: SRM-13A Nozzle joint O-ring; Chart 49: Technical Issues (continued): Analysis of soot from STS-51C LH forward field], Charts 50-51 [Chart 50: History of SRM O-Ring damage; Chart 51: Comparison of STS-51-C and STS-51-E], Charts 52-53 [Chart 52: Technical Issues (continued)- Scenario; Chart 53: Technical Issues (continued)], Charts 54-55 [Chart 54: STS 51C (SRM 15) STS-20 O-Ring erosion scenario; Chart 55: STS 51C (SRM 15) STS-20 O-Ring erosion scenario-continued], Charts 56-57 [Chart 56: Unreadable; Chart 57: SRM 16B center field joint squeeze analysis with temperature differential], Charts 58-59 [Chart 58: Technical Issues; Chart 59: Flight readiness assessment for STS-51E (cont)], Charts 60-61 [Chart 60: Flight readiness assessment for STS-51E (cont); Chart 61: Shuttle Projects Office Board (February 12, 1985-Summary of Action Items], Charts 62-63 [Chart 62: Problem Summary; Chart 63: STS-51C (SRM-15) Postflight hardware damage assessment], Charts 64-65 [Chart 64: STS-51C (STS-20) (SRM-15) Performance Preliminary Postflight Hardware Damage Assessment; Chart 65: STS-51C (SRM-15) Postflight Hardware Damage Assessment (continued)], Charts 66-67 [Chart 66: STS-51C (STS-20) (SRM-15) Performance Preliminary Postflight Hardware Damage Assessment; Chart 67: O-Ring erosion patterns], Charts 68-69 [Chart 68: Analysis of soot from STS-51C LH forward field joint; Chart 69: History of SRM O-Ring damage], Charts 70-72 [Chart 70: Comparison of STS-51C and STS-51E; Chart 71: O-Ring erosion scenario; Chart 72: STS-51C (SRM-15) STS-20 O-Ring erosion scenario], Charts 73-74 [Chart 73: HPM Predicted Pressure During Ignition; Chart 74: STS-51C (SRM-15) STS-20 O-Ring erosion scenario (cont)], Charts 75-76 [Chart 75: Volumetric and thermal analysis and test results; Chart 76: Why do most o-rings not erode and why don't why we see shoot behind primary o-rings more often?], Charts 77-78 [Chart 77: Rationale for acceptance; Chart 78: Flight readiness

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