INSPECTION RESULTS OF SONGS - 3 MSIV - 8205

AUGUST 24, 1988

San Onofre Nuclear Generation Station

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INSPECTION RESULTS OF SONGS-3 MSIV 8205 (Revised)

August 24, 1988

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INTRODUCTION

As stated in the companion report, "Root Cause Analysis of the Lev-R-Lock and Guide Rail Interaction Problem for SONGS MSIVs," SCE has concluded that it is unlikely that SONGS MSIVs would experience the failure mechanism that can shear two gate skirt assembly guide rails (the guide rails interacting with the lev-r-lock arm during closing) that occurred in one of the Waterford-3 MSIVs. This conclusion is based on, among other supporting evidence, a dynamic impact analysis and fiber optic inspection results on Unit 3 MSIVs 3HV-8204 and 3HV-8205. The dynamic impact analysis reveals that one of the key parameters determining the magnitude of the shearing energy is the stroke time of the valve in the close direction. Since SONGS MSIVs stroke approximately two and one-half times slower, it is very unlikely that they are subject to the failure mechanism experienced by Waterford-3 MSIVs.

On June 20, 1988, SCE was requested by the NRC to disassemble and inspect Unit 3 3HV-8205 to see if it has experienced the Waterford-3 failure mechanism. The inspection results are documented here as an addendum to the root cause analysis.

Since the inspection confirms the main conclusion of the root cause analysis, the root cause analysis together with the safety evaluation included in the root cause analysis (which constitute the bases for JCO, Justification for Continued Operation) remains valid.

The inspections also revealed that three capscrews at the bottom of one of the two segment skirt assembly guide rails were broken. This guide rail is hereafter referred to as the north segment, or north opening guide rail, and the other is the south segment guide rail. This failure mechanism is believed to be different from the mechanism that has resulted in shearing of the two gate guide rails of the Waterford-3 MSIV. This failure mechanism is analyzed to be much less damaging than the "Waterford-3 failure mechanism" and it is self-limiting. The root cause analysis for this failure mechanism is also documented in this addendum.

INSPECTION RESULTS

Unit 3 MSIV-8205 was disassembled for visual inspection in July, 1988. The inspection results are documented below:

(1) The two gate guide rails were inspected. The 45° chamfers, where the lev-r-lock arm and the guide rails interact during valve closing, do not show signs of galling. However, wear marks, a result of the lev-r-lock arm/guide rail chamfer contact during the close cycle, are evident. Figures 1 and 2 show close-up views of these chamfers.

(2) The 18 capscrews on the two gate guide rails were inspected. All of them appeared to be tight and all of the stakes on the capscrew heads were intact. The guide rails are tightly held against the valve skirt plate. Figures 3 and 4 are close-up views from various angles of the guide rail capscrews.

(3) The two segment guide rails were inspected. The bottom 45° chamfers show signs of galling. The galling occurs on the one chamfer corner which consists of the transition from the bottom end of the rail to the chamfer face. The length of the area which has displaced metal is only approximately 1/4" long. Figures 5 and 6 are close-up views of galling marks for the north and south chamfers.

(4) The capscrews on the opening guide rails were inspected. Three of the 18 capscrews were broken. All the broken capscrews are located at the bottom of the north opening guide rail. There is approximately a 0.050" gap between the north segment guide rail and the skirt plate at the edge of the rail where the three capscrews are missing. Figure 7 shows a close-up view of the empty capscrew holes.

(5) The three empty capscrew holes were inspected for corrosion and misalignment. No galvanic corrosion pits were found. The misalignment between the guide rail holes and the valve skirt sockets ranges between 5 to 10 mils. This is considered insignificant.

(6) All three broken capscrew heads were found at the bottom of the valve cavity. (Approximately 30 capscrews were broken at Waterford 3. All of these except one of capscrew heads were found in the MSIV valve cavities or the turbine stop valve strainer. One capscrew head was never located.) The broken capscrew heads were visually inspected by SCE and WKM engineers at the time they were retrieved from the bottom of the valve cavity. No corrosion pits were found.

(7) The studs of the broken capscrews were removed from the capscrew sockets. They were able to be removed from the skirt plate by hand and visually inspected. No corrosion pits were found.

(8) The fracture faces of the broken capscrews were visually inspected using a 32X light microscope. General deformation around the fracture face is evident for all three broken capscrews, indicating the failure mode is ductile overload.

(9) The fracture paths of all three broken capscrews are at the bottom of the capscrews hexagonal hole. Figure 8 shows a close-up view of the fracture face. Significant magnetite build-up was found on the fracture faces of all three screws. This indicates that the failure did not recently occur. Figure 9 shows this build-up with a 1400 x magnification.

(10) The total depth of the capscrew hexagonal hole, (or keyway for the Allen head wrench) was measured. The depth is approximately 3/8".

(11) The fourth capscrew from the bottom on the guide rail with broken capscrews was found loose; that is, it can be moved by hand. The stake marks on the head of this capscrew appear to be slightly shallower than those for intact capscrews. It was removed to see if it contained any incipient cracks. No flaws were found using a 32X microscope inspection.

(12) The shoes of both lev-r-lock arms were examined. Galling marks were found on the tops of both shoes (The shoe tops may contact the segment guide rails during the valve opening cycle). The shoe bottoms were smooth (The shoe bottoms may contact the gate guide rails during the valve closing cycle). Figures 10 and 11 are close-up views of the galling. Figure 12 is a distant view of the galling.

(13) The dimensions of the gate, segment, guide rails, lev-r-lock arms, and distance between valve seats were measured. All dimensions were within the vendor's specifications.

(14) The length of the north and south arms were measured. It appears that the north arm is about 1/16" shorter at the point of contact with the guide rail. However, due to the measurement difficulty, there is some uncertainty associated with this data.

(15) The lev-r-lock arm ear and the segment slot were inspected and showed no signs of excessive wear.

(16) The valve seats were inspected visually. There are several areas on the gate and opening side valve body seats that show signs of wear marks. The maximum depth was measured to be less than 5 mils.

(17) The gate and segment back angles were inspected visually. Several wear marks were observed.

DISCUSSION OF INSPECTION RESULTS

Based on the visual inspection results, it is reasonable to conclude the following:

1) The fracture of the three broken capscrews seems to be a result of interference with the lower edge of the chamfer and the top of the north arm shoe. Figure A-1 illustrates this interference during valve opening. There are galling marks in the area of interference on both the shoe and the chamfer of the guide rail.

2) The galvanic corrosion, if any, is insignificant. This is supported by the absence of any pitting on the broken capscrew threaded areas inspected by fractography.

3) The depth of the capscrew socket is 0.375". The minimum depth is specified by the ANSI 18.3 standard to be 0.220". Even though there is no maximum depth limit, this 0.375" depth seems to be excessive. To evaluate whether or not these capscrews had experienced overtorquing induced cracks, a torque test was performed. The results are presented later in this report.

Note that the Interim Root Cause Analysis stated the following (refer to page 16 in the Interim Root Cause Analysis):

"INSPECTION RESULTS"

"The key findings of the boroscope inspection on the Unit 3 MSIV are summarized below.

"(1) One broken capscrew was found in the cavity of SONGS-3 MSIV 3HV-8205. The two guide rails (one of the two segment skirt rails and one of the two gate skirt rails) were in place. The rails were found firmly attached to the skirt plates. They did not exhibit any separation that was observed on the LP&L MSIVs. Only four capscrews could be inspected inplace. They were found to exhibit no signs of elongation, deformation, or looseness.

"(2) No broken capscrews were found in the body cavity of SONGS-3 MSIV 3HV-8204. The two guide rails that could be inspected (again, one of two segment skirt rails and one of two gate skirt rails) were also in place.

"(3) The chamfers of both upstream and downstream guide rails for both SONGS-3 MSIVs were inspected for impact marks. Only the chamfer on the downstream, or gate guide rails, in MSIV 3HV-8205 has galling marks. The top edge of the chamfers have been rounded by impact and some metal has been rolled over. This metal roll-over and a relatively high contact stress during impact could be responsible for the observed galling marks.

"(4) The shoes of the lev-r-lock arms for both valves were inspected for impact or galling marks. No visible galling marks were observed for the surfaces that were observed."

Some of the statements in the Interim Root Cause Analysis Report are refuted as a result of the disassembly and inspection of MSIV 3HV-8205. The are identified and explained as follows:

(1) Disassembly of the valve revealed that the gate guide rail chamfers were not galled as concluded after the boroscopic examination. The marks on the chamfer face gave the appearance of galling as viewed using the boroscope even though the chamfers were found to be smooth with no furrowed metal. The corners of the chamfers were no longer sharp but were not galled. The wear of the chamfer corners was concluded after the boroscopic examination. The as found condition of the chamfer was in better condition than had been determined as result of the remote inspection.

Future boroscopic inspections will be improved based upon the knowledge acquired as a result of these inspections. The improved inspection techniques are detailed later in this report. A more careful remote inspection, including profile as well as head on views of the chamfer face, will provide information required to make adequate determination of the material condition of the guide rail in the vicinity of the chamfer.

(2) The galling on top of the lev-r-lock arm shoes, the segment guide rail galling, and the slight separation of the north segment guide rail was not

concluded/observed after the boroscopic examination. The damaged areas were obscured from view when inspected in place with the MSIV in the closed position. When the valve is lev-r-locked closed, the top of the shoes are swung forward (upstream) and are tucked under the ends of the segment skirt assembly guide rails. The galled areas of the shoes were obscured by the rails. It is possible that galled areas of the rails may not be seen even if the shoes are not in their closed position due to the relative position of the galled surface (downward) and the boroscope probe (also downward).

Future inspections will be made with the MSIV in the not fully closed position. This is detailed later in this report.

Item (3) of the Intermin Root Cause Analysis INSPECTION RESULTS above infers that all of the guide rails can be inspected using the boroscope. The item should have stated that one segment and one gate guide rail of each of the two SONGS-3 MSIVs were inspected. This would make item (3) consistent with INSPECTION RESULTS items (1) and (2) in the Interim Root Cause Analysis. Not all of the guide rails can be inspected because the penetration that is used for probe insertion is located on the surface of the bonnet, directly between the segment and gate skirt plates on one side of the valve. This penetration location for SONGS MSIV 3HV-8205 is shown in figure 13. Only the north segment and gate guide rails of this valve can be examined using the boroscope.

POSSIBLE FAILURE SCENARIOS

Several possible scenarios that result in overload fracture of the three capscrews on an opening guide rail are hypothesized. Based on the inspection results, only one of the hypothesized scenarios is considered likely. This can not be refuted by any evidence or observation collected so far. This scenario is stated below.

"At the beginning of valve opening, the friction on the back angles of the segment and gate prevents the assembly from unwedging, or being "unlev-r-locked." As a result, as the assembly moves upward, the top of the lev-r-lock arm shoe comes in contact with the bottom edge of the guide rail chamfer. In the first few opening strokes, the resultant tensile force is preferentially imparted to the north guide rail, either because the north arm is shorter or because the valve skirt is not squarely installed. In addition, the contact area is limited to the lower sharp chamfer edge. This results in sufficiently large stresses such that galling between the guide rail and shoe occur. The galling results in adhesion and generation of large resultant forces. Consequently, the first few bottom capscrews on the north guide rail fail by tensile overload. After metal is removed from the bottom edge of the north guide rail chamfer as a result of a few valve opening cycles, the interference force begins to be shared by both north and south guide rails. The galling process then occurs and removes the sharp corner on the south guide rail. Once the corners of the chamfers are removed, the contact area between the guide rails and the lev-r-lock arm shoes are significantly increased resulting in lower stresses (even though the surfaces have been galled) and discontinuation of the galling and adhesion processes.

It should be noted that the skirt assemblies will tend to be "self-aligning." Each skirt assembly is made up of two guide rails bolted to a plate. The plate is fabricated with a hole with a diameter slightly larger than the valve seat diameter. The skirt assemblies are placed into the valve body and laid around each seat. The gate and segment assembly is placed into the valve, between the seats and skirt plates, and between the guide rails. The skirt assemblies are free to rotate around the seats within the clearances in the valve body as well as the clearances between the rails and the gate and segment assembly. If one lev-r-lock arm is longer than the other, the shoe connected to the shorter arm will contact the guide rail first. This will tend to place a torque on the segment skirt assembly which will rotate within these clearances in an effort to distribute the load equally between both lev-r-lock arms. Although the clearances in relationship to the difference in lev-r-lock arm length could not be correlated, a visual inspection of the alignments and clearances were meticulously performed by SCE and W-K-M engineers. The as-left installation was found to be acceptable.

Because the tensile load is now shared by two guide rails and the friction coefficient decreases as the surface gets recontoured after a few instances of interaction, the damaging mechanism stops and no more capscrews fail."

This hypothesis is supported by the fact that a passivated iron coating was found on the fracture surface of all three failed capscrews which indicated that the failures had not recently occurred.

METALLURGICAL EXAMINATION

The three broken capscrew heads and studs were metallurgically examined. One set consisting of a broken capscrew head and stud was sent to WKM for metallurgical analysis. Two broken studs were sent to Truesdail Laboratory for metallurgical examination. Two broken capscrew heads were examined by SCE for material composition. The results of this examination are documented here.

1) The material of two broken capscrew heads was determined by SCE to be within the specifications of ASTM A193 Gr. B7.

2) The material of two broken studs was determined by Truesdail to be within the specifications of ASTM A193 Gr. B7.

3) The material of one broken capscrew head and one stud was determined by WKM to be within the specifications of ASTM A193 Gr. B7.

4) The hardness of the material for the capscrew kept by WKM was determined to be 302 Brinell. This hardness translates into a tensile strength of 146 ksi. This is greater than the minimum tensile stress of 125 ksi for ASTM A193 B7 bolt.

5) The hardness of the material for a capscrew sent to Truesdail Laboratory was determined to be 362 Brinell. This hardness translates into a tensile strength of 177 ksi, according to ASTM Specification A370.

6) The fracture faces for all three broken capscrews have significant magnetite build-up, indicating that the fracture did not recently occur.

7) The general deformation around the fracture face suggests that the failure mode is ductile overload. However, due to the magnetite build-up on the fracture faces, detailed microscopic examination for dimple marks and fracture face characterization is not possible.

OVERTORQUING TEST PERFORMED BY SCE

The deep capscrew socket, even though its dimension does not violate any capscrew specification as documented in ANSI Standard 18.3, may have contributed to the failure of the three capscrews. One scenario is that these deep socket capscrews were broken during initial assembly by overtorquing. To evaluate whether or not this scenario is valid, a capscrew was removed from the north segment guide rail and was bench tested. A test bench was constructed with identical dimensions of the counter-sink in the guide rail. The capscrew was torqued with an appropriate lubricant at various torques to see if it developed any incipient cracks or permanent deformation. The results are summarized below.

1) Torqued to 150 ft-lbf -- no incipient cracks; no plastic deformation

2) Torqued to 180 ft-lbf -- the Allen wrench starts to deform, no incipient cracks; no plastic deformation

3) Torqued to 250 ft-lbf -- the Allen wrench completely deformed; no incipient cracks; no plastic deformation

4) Torqued greater than 250 ft-lbf -- test discontinued because of tool deformation.

Note that the capscrew was originally installed by WKM with a torque of 150 ft-lbf. According to the test results stated above, this installation torque will not cause incipient cracks. As a result, it is reasonable to dismiss the failure scenario that these three capscrews (even if the capscrew socket is 0.375" deep) were failed due to overtorquing.

STRESS ANALYSIS

Based on a stress analysis documented in Appendix A of this report, the maximum tensile force generated by the interaction between the lev-r-lock arm and the guide rail is estimated to be approximately 95,300 lb*f*. The interaction is assumed to occur with a galling process between two interacting parts. The tensile force needed to fracture a capscrew is estimated to be 32,800 lb*f*, also considering the co-existence of the shear force. Since 32,800 lb*f* is less than 95,568 lb*f*, it is reasonable to conclude that the bottom two to three capscrews of the only interacting guide rail (north guide rail) will fracture.

Once the interfering metal was removed from the chamfer of the north segment guide rail after the first few times of interaction, the friction coefficient of interaction decreased and the total load started to be shared by both the north and south guide rails. As a result, the maximum tensile force is reduced to a level of approximately 16,730 lb*f*. Note that this maximum tensile load is no longer capable of fracturing capscrews.

REPAIR OF MSIV 3HV-8205

The galling marks on the lev-r-lock arm shoes and guide rails were removed by grinding. The chamfer angles were decreased slightly by virtue of the grinding operations. The chamfer angles and shoes were polished to a better than 63 RMS surface finish to minimize the coefficient of friction. The decreased angles were identified by the dynamic impact analysis to result in decreased interaction forces between the shoes and guide rail chamfers. The sharp chamfer corners of all four guide rails were rounded off. Removing the chamfer corners will reduce the contact stress concentrations by providing a larger contact area between the shoes and guide rails. The reduced stress between the chamfers and the shoes in conjunction with the polished surfaces and the reduced chamfer angles should minimize if not eliminate the galling process initiation.

The back angles of the gate and segment as well as the seating surfaces of the gate and segment and the valve body were treated with a polishing stone. This treatment ensures that the surfaces are free of burrs and high spots. This also should reduce the coefficients of friction between the seats and the back angles. Minimizing the friction between these surfaces results in a greater likelihood of gate and segment collapsing during the open and closing cycle instead of the shoes contacting the guide rails further reducing the likelihood of these surfaces galling.

MSIV's which are disassembled and inspected in the future will be modified as discussed above unless further repairs are required.

JUSTIFICATION FOR CONTINUED OPERATION AND RECOMMENDED INSPECTION PLAN

Based on the inspection results and the discussion above, it seems reasonable to conclude the following:

1) SCE's MSIVs are unlikely to experience the Waterford-3 MSIV failure mechanism because their stroke time is significantly longer than Waterford-3 MSIVs.

2) The fracture of the bottom three capscrews on one of the two segment guide rails in Unit 3 MSIV 3HV-8205 discovered during inspection is likely to be a result of excessive interference between the lev-r-lock arm shoe and the guide rail.

3) Based on the failure pattern and the deeper galling mark on the north arm shoe, it seems reasonable to conclude that the preferential loading of the north guide rail is a reasonable explanation for the fact that all three broken capscrews are located on the north guide rail. The preferential loading can be caused either by a shorter lev-r-lock arm or by the out-of-squareness of the guide rail skirt plate installation.

4) Based on the fact that (1) only three capscrews were fractured after more than one-hundred valve openings, (2) the fracture did not recently occur, and (3) the fourth capscrew from the bottom of the north segment guide rail does not show any signs of cracking or deformation, it is reasonable to conclude that this failure mechanism is self-limiting. In other words, the failure stops once the interfering metal is removed from the chamfer and the galled surface is smoothed out.

5) Since the failure mechanism is self-limiting, it is unlikely to fracture more than a few capscrews. As such, it is unlikely to dislodge the whole segment guide rail by this failure mechanism.

6) To ensure that this failure mechanism can be corrected before it results in significant damage, Unit 2 MSIV's 2HV-8204 and MSIV 2HV-8205 will be inspected by boroscope in the next Mode 5 outage with sufficient duration (greater than 7 days). If broken capscrews are found in the valve cavity and/or galling is observed, an evaluation will be made whether to repair the valve immediately or if the valve may be repaired in the next refueling outage. If no broken capscrews are found in the valve cavity and no evidence of galling is found, no action will be taken.

7) All four MSIVs for SONGS 2 and 3 will be inspected by boroscope during the next two refueling outages or the subsequent two refueling outages after any repair. If no broken capscrews and no severe galling marks on both the gate and segment guide rails are found in any of the MSIVs, the inspections will be discontinued.

BOROSCOPIC INSPECTION IMPROVEMENTS

The Interim Root Cause Report stated that only one sheared capscrew head was found on the bottom of MSIV 3HV-8205 valve cavity during the boroscope inspection. However, three sheared capscrews were found when the valve was disassembled. The two additional capscrew heads were also found on the bottom of the valve cavity and all three were located within a few inches of each other. The video tape records of the boroscope inspection was reviewed but it clearly identifies only a single capscrew head. The most probable cause of this inspection deficiency is the lack of a systematic and sweeping movement of the boroscope over the entire bottom of the valve.

In an effort to more accurately assess the condition of the MSIV internals, the boroscopic examination technique will be improved as follows:

1) A thin wire will be attached to the end of the video probe. This will provide increased video probe manipulative capability.

2) The inspection of the valve cavity bottom surface will be done in a systematic sweeping methodology (refer to Figure 13 for the probe penetration points). For example, the inspection will be made starting at the extreme left side of the cavity and inspecting front to back to front. The probe will then be moved about an inch to the right and the front to

back to front sweep is repeated. This sequence is repeated until the entire lower cavity surface is extensively inspected.

3) The inspection of the skirt guide rails and lev-r-lock arm shoes will be enhanced by the use of the wire affixed to the end of the video probe. The increase in probe mobility will improve the quality of the images.

4) The inspection will be performed with the MSIV in the mid-position so that the top surface of the lev-r-rock arm shoe can be inspected and not be obscured by the segment guide rail.

These improvements in the boroscopic examination procedure will enable us to make more accurate assessments of the MSIV internals.

The proposed inspections discussed above are in addition to the Recommended Actions discussed on page 44 of the Interim Root Cause Report. The evaluations and studies that are proposed are summarized in Table 1.

STROKE TIME REDUCTION

One item noted in the Interim Root Cause Analysis is that the MSIV strokes closed faster when both hydraulic fluid dump valves are deenergized than with only one dump valve. A flow orifice will be installed in the common discharge piping for each MSIV in Units 2 and 3 so that the closing stroke time will be virtually unchanged whether one or two dumps are deenergized and to ensure that the stroke time is well above three seconds. The impact energies that the lev-r-lock arm shoe and gate guide rail chamfers undergo were determined to be at acceptable levels for stroke times greater than three seconds as identified by W-K-M engineers and the dynamic impact analysis performed by SCE engineers. This modification will be implemented no later than the cycle 5 refueling outages on both units.

The only way an MSIV could stroke with both dump valves deenergized is if it received a Train A and Train B simultaneous Engineered Safety Feature Actuation Signal concurrent with the valve open. The probability of this occurring and the valve stroking in less than three seconds is remote.

APPENDIX A

Stress Analysis

The purpose of this simplified analysis is to determine whether or not the hypothesized scenario is feasible. Three parameters are calculated by a best-estimate method in this Appendix. They are described as follows:

1) The initial tensile force experienced by one guide rail.
2) The tensile force needed to tensile fracture one capscrew.
3) The tensile force experienced by two guide rails when galling marks were smoothed out.

The Initial Tensile Force

The maximum opening force, Of, can be determined by balancing the hydraulic pressure and the N_2 pressure:

$$Of = (400\ \text{psi}) \times ((12")^2 - 2^2)\,\pi = 176{,}000\ \text{lb}f \qquad (A\text{-}1)$$

The normal force experienced by the guide rail, Fn, is calculated from Of as follows:

$$Fn = Of \cos\theta = 176{,}000 \times \text{Cos}\ 40°$$

$$= 135{,}000\ \text{lb}f \qquad (A\text{-}2)$$

where 40° is the angle between Of and Fn

The tensile force, Ft, is related to Fn by the following formula:

$$Ft = Fn \cdot \mu \times \text{Cos}\ 45°$$

$$= 95{,}300\ \text{lb}f \qquad (A\text{-}3)$$

where $\mu = 1.0$ for a galled surface (Reference A)

Reference A

"Wear Coefficients - Metals", by E. Rabinowicz, Published in Wear Control Handbook, ASME 1980

Fracture Tensile Force

During the interaction, the bottom capscrews will experience both a tensile force and a shear force. The magnitude of the shear force for one capscrew (assuming the loads are equally shared) is:

$$F_s = F_n \sin 45^\circ / 9 = 10{,}600 \text{ lbf}$$

Based on the energy distortion theory (Reference B), the capscrew will fail if the following criterion is met.

$$\left((\sigma_S - \sigma_T)^2 + \sigma_T^2 + \sigma_S^2 \right) = 2\sigma_{US}^2 \qquad \text{(A-4)}$$

where σ_{US} is the ultimate strength.

Equation (A-4) becomes the following formula if each term is multiplied by the square of the bolt area.

$$\left((F_S - F_T)^2 + F_T^2 + F_S^2 \right) = 2F_{US}^2 \qquad \text{(A-5)}$$

$$F_{US} = 125 \text{ ksi} \times 0.5'' \times \pi \times 0.15'' = 29{,}500 \text{ lbf}$$

Based on Equation (A-5), F_T is determined to be 32,800 lbf.

Reference B

J. A. Collins, "Failure of Materials in Mechanical Design -- Analysis, Prevention, and Prediction," John Wiley & Sons, Inc. (1981)

Tensile Force After metal was Removed from the North Guide Rail Chamfer

After enough metal is removed from the north guide rail chamfer, the tensile load will be shared by both guide rails. Also, the friction coefficient decreases as the galled surface is recontoured (see page 7, POSSIBLE FAILURE SCENARIOS). For this case, the tensile load for the bottom capscrews for both opening guide rails is:

$$F_T = \frac{F_n \mu \cdot \cos\theta}{2} \qquad \mu = 0.35 \text{ (smoothed galled surface, Reference C)}$$

$$= 16{,}730 \text{ lbf} \qquad (A \cdot 6)$$

Since 16,730 lbf is less than 32,800 lbf, no capscrews should fail.

Reference C

Personal Conservation between C. Chiu and Professor Ernest Rabinowicz (M.I.T.), May 28, 1988

Table 1

Schedule of MSIV Studies and Inspections

*	Install flow orifice in common discharge line	No later than Cycle 5 Refueling[1]
*	W-K-M to Reevaluate D-2 Valve Design	01/01/89
*	Evaluate MSIV Skirt Assembly and Lev-r-lock Arm Design Enhancements	02/01/89
*	Perform MSIV Borescopic Internal Inspections as follows:	
	2HV-8204	Cycle 5 Refueling[2] Cycle 6 Refueling
	2HV-8205	Cycle 5 Refueling[2] Cycle 6 Refueling
	3HV-8204	Cycle 5 Refueling Cycle 6 Refueling[3]
	3HV-8205	Cycle 5 Refueling Cycle 6 Refueling[3]

NOTES:

1. Orifices will be installed no later than Cycle 5 refueling. The orifices will be installed if an outage of sufficient length occurs after engineering and parts are procured.
2. Inspection will be made at the next Mode 5 outage of duration, but no later than the upcoming Cycle 5 refueling.
3. Inspections may be terminated after the Unit 3 cycle 6 refueling outage based upon the results of the previous outage. This is discussed more in detail in the body of this report.

Figure 1

A Close-up View of the Chamfer for the North Gate Guide Rail

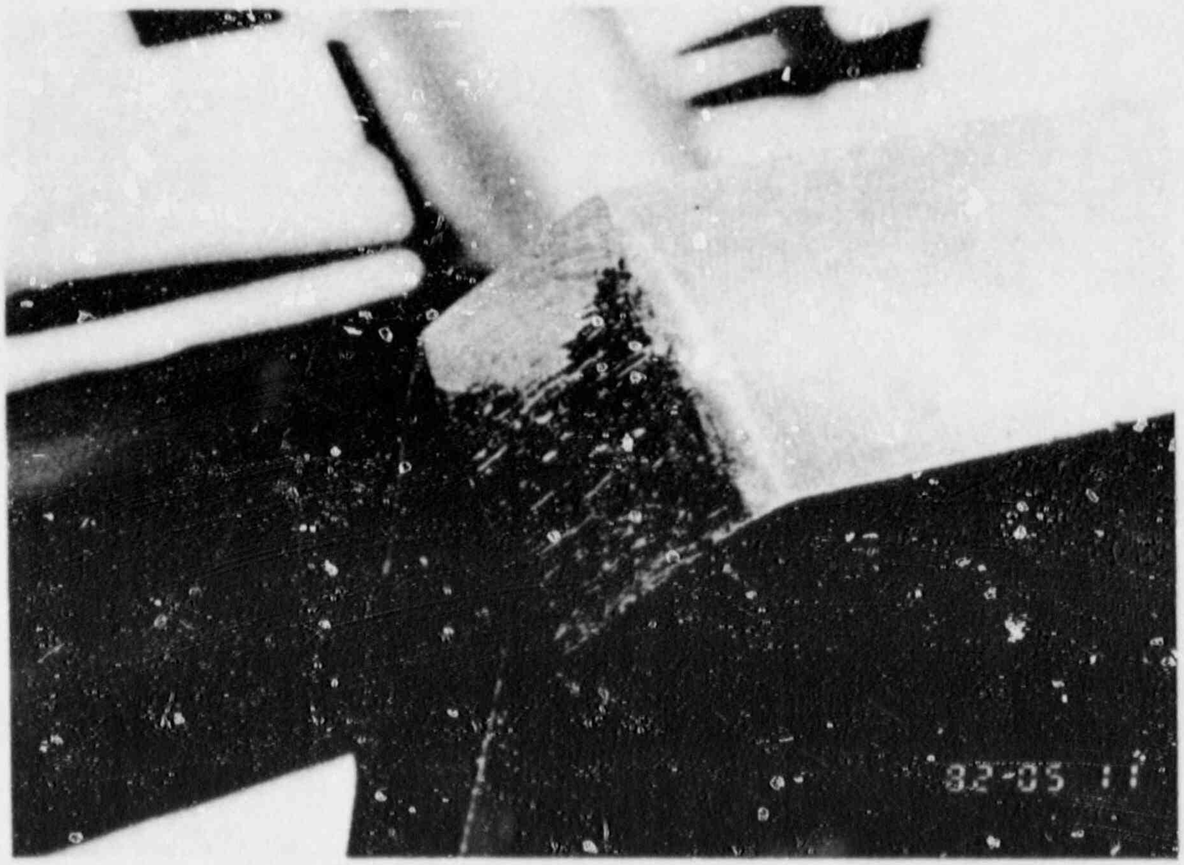

Figure 2

A Close-up View of the Chamfer for the South Gate Guide Rail

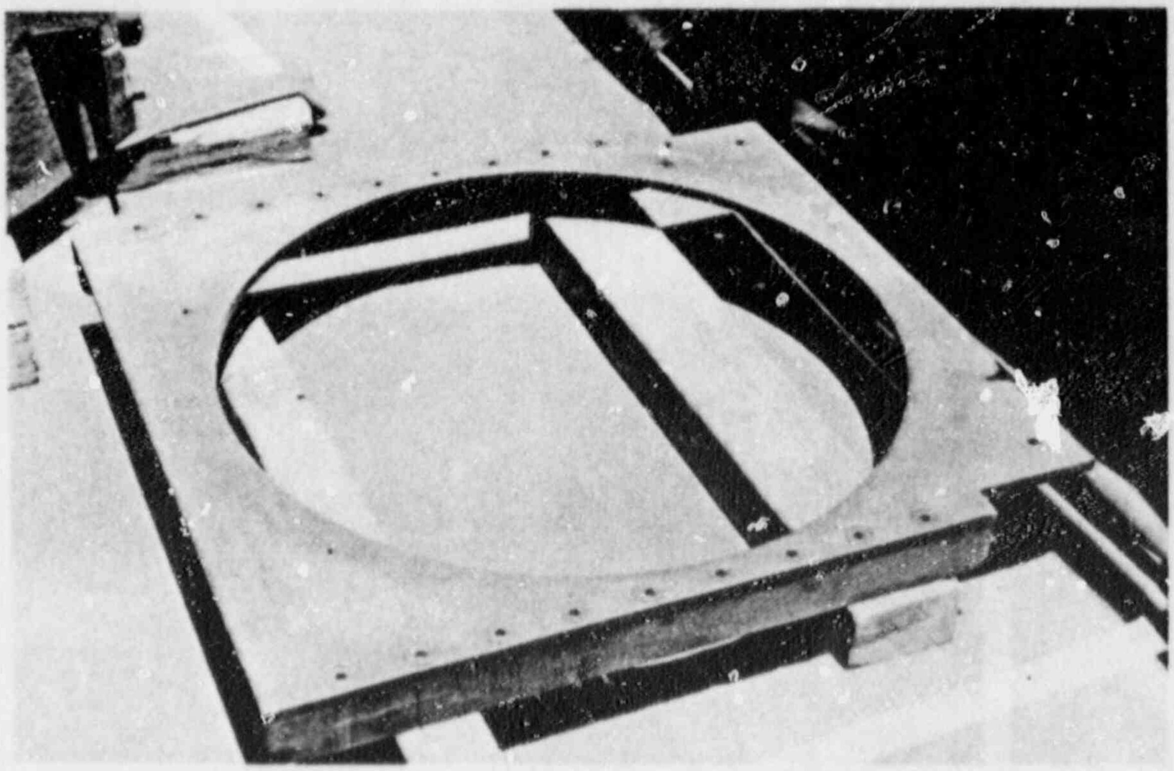

Figure 3

Various Views of Gate Guide Rails and Valve Skirt

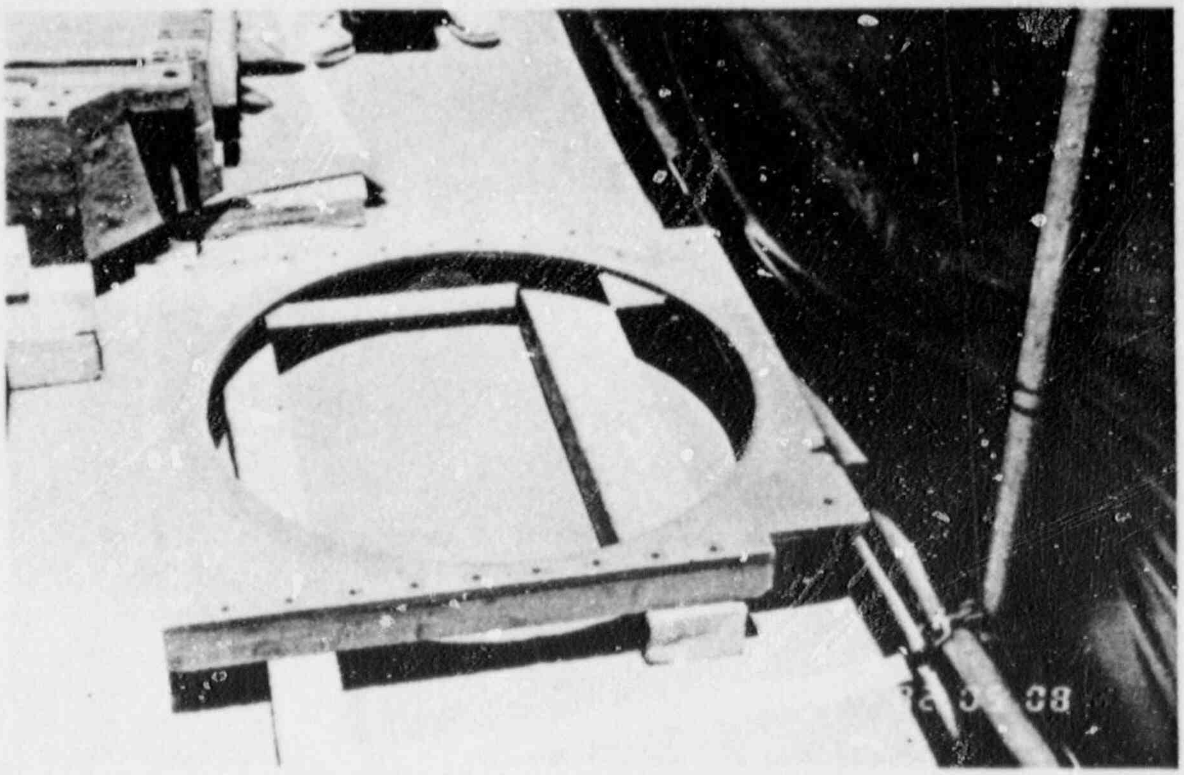

Figure 4

Various Views of Gate Guide Rails and Valve Skirt

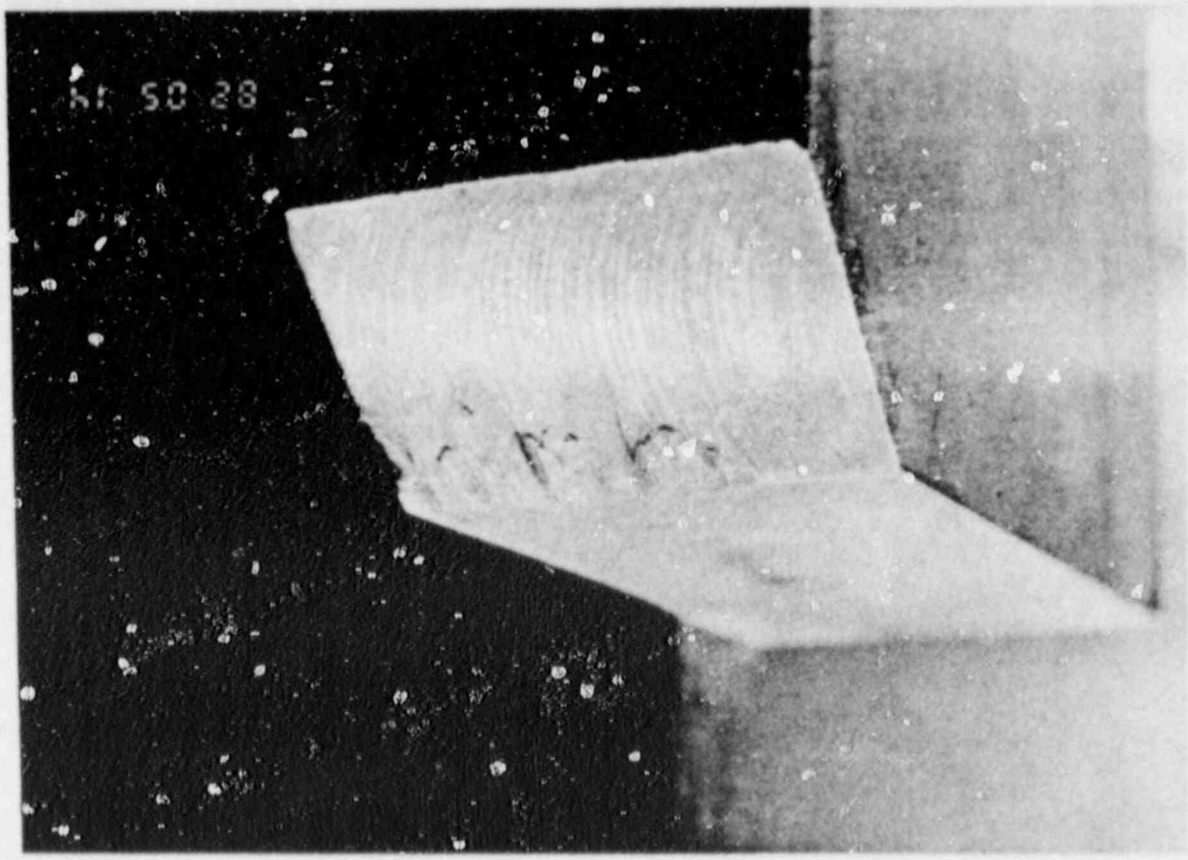

Figure 6

A Close-up View of the Chamfer for the South Segment Guide Rail

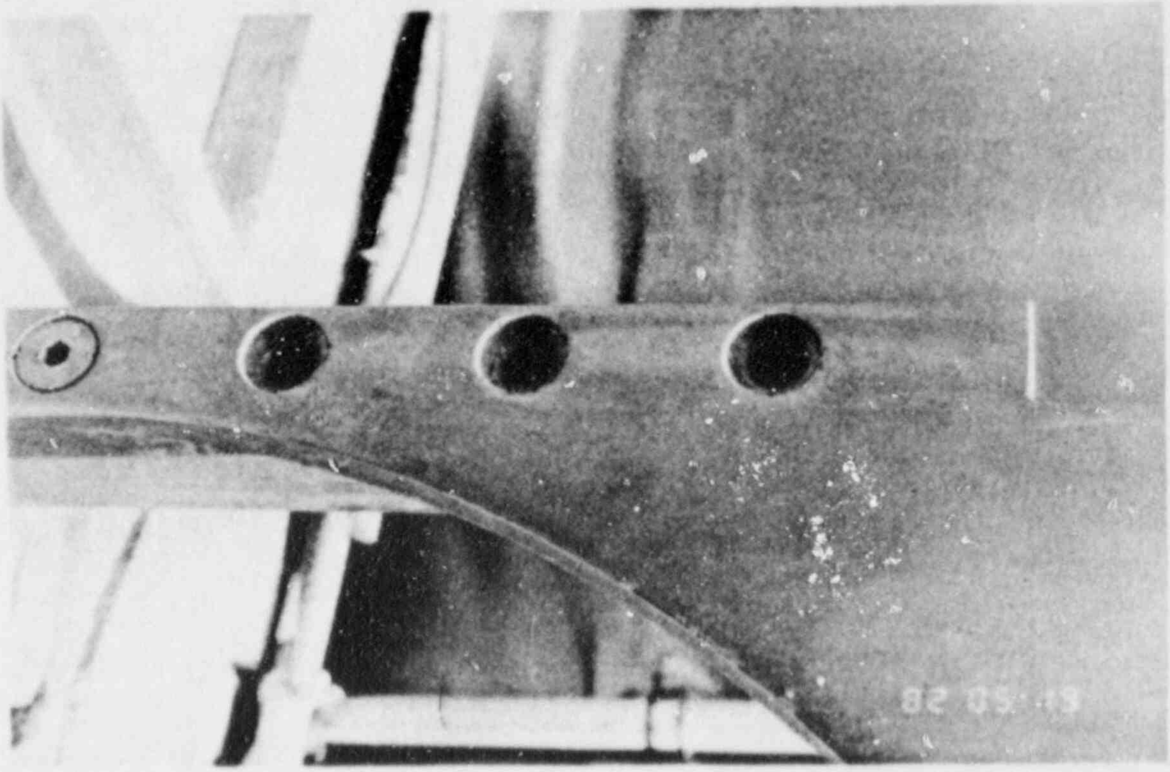

Figure 7

The Location of Three Broken Capscrews

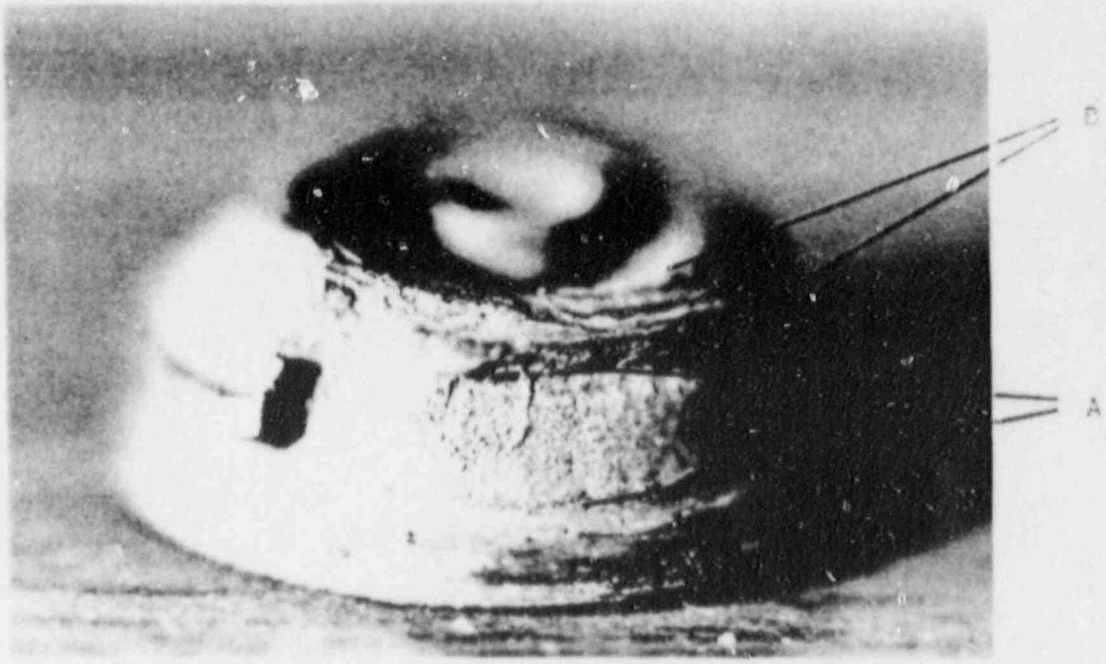

Figure 8

Fracture Face of the Broken Capscrew Stud

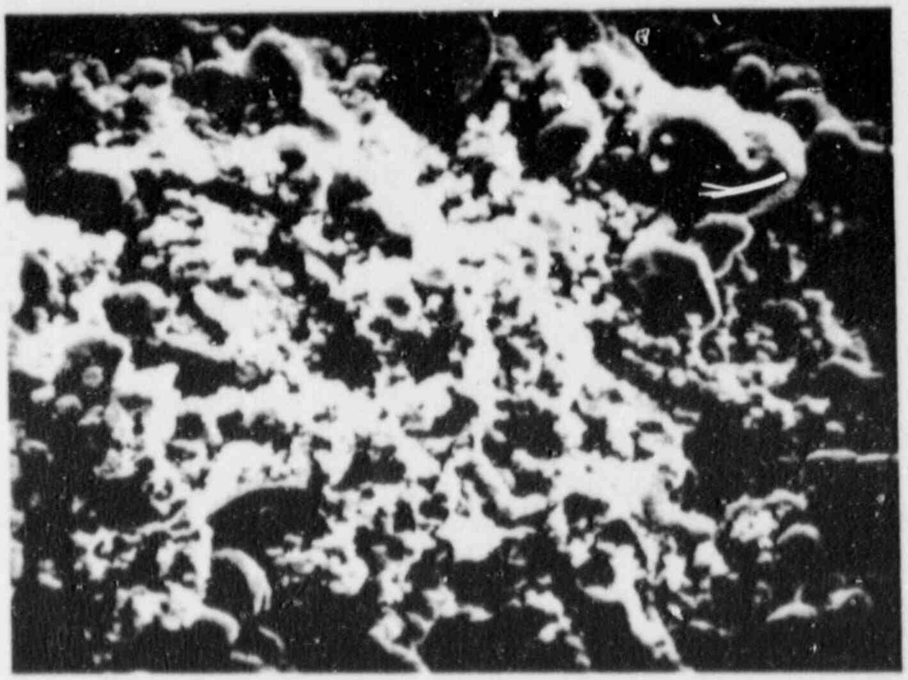

Figure 9

Magnetite Build-up on the Fracture Face (1400 X Magnification)

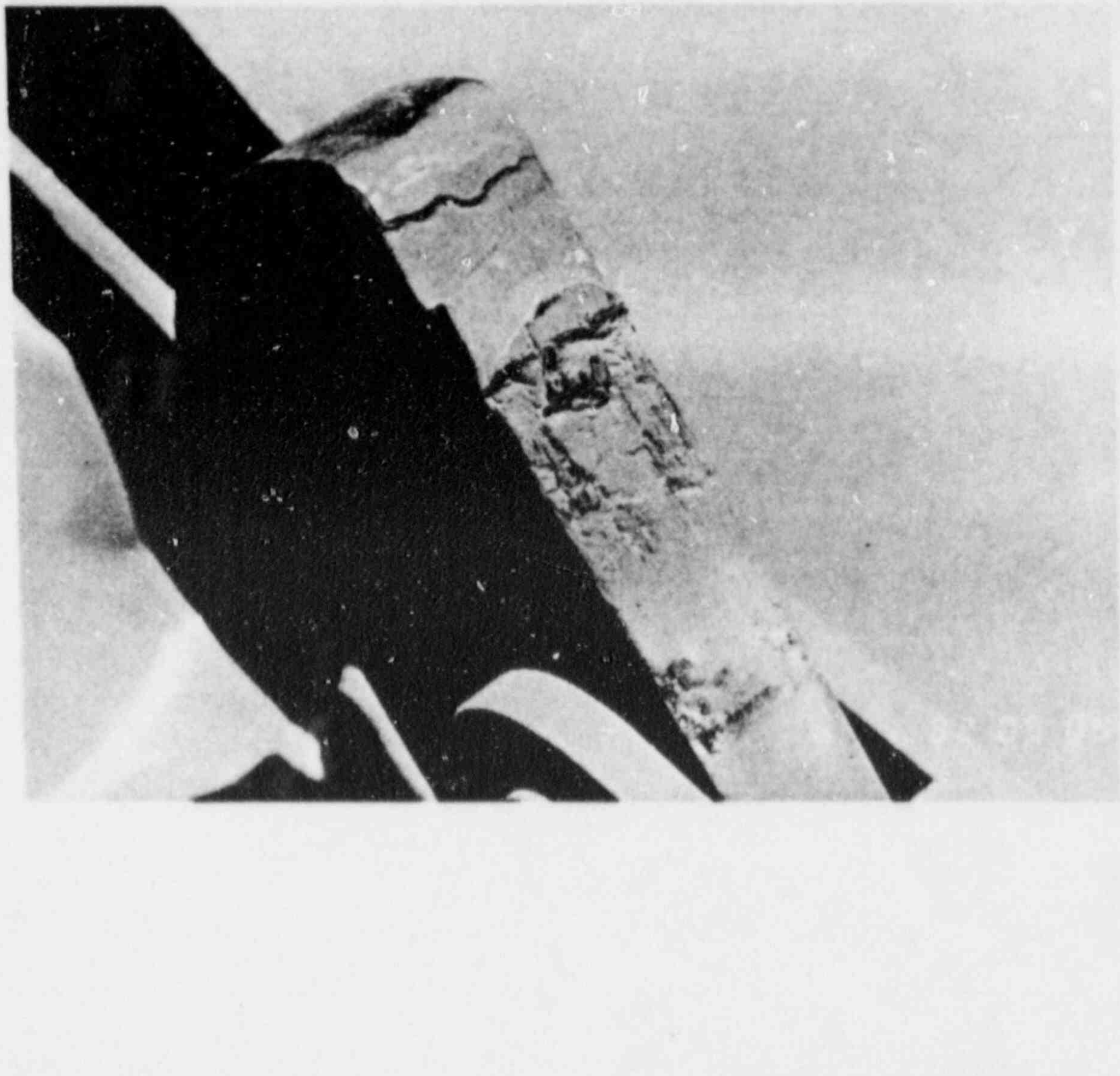

Figure 10

A Close-up View of the Galling Marks on the North Arm Shoe

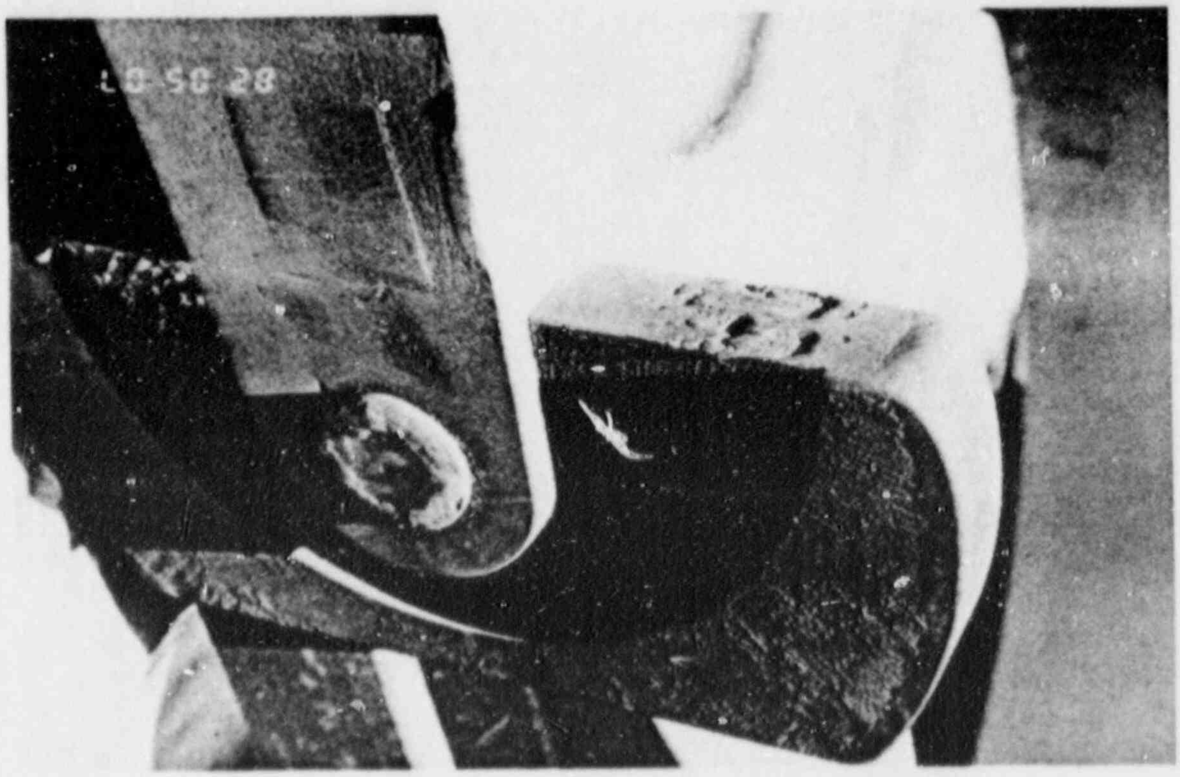

Figure 11

A Close-up View of the Galling Marks on the South Arm Shoe

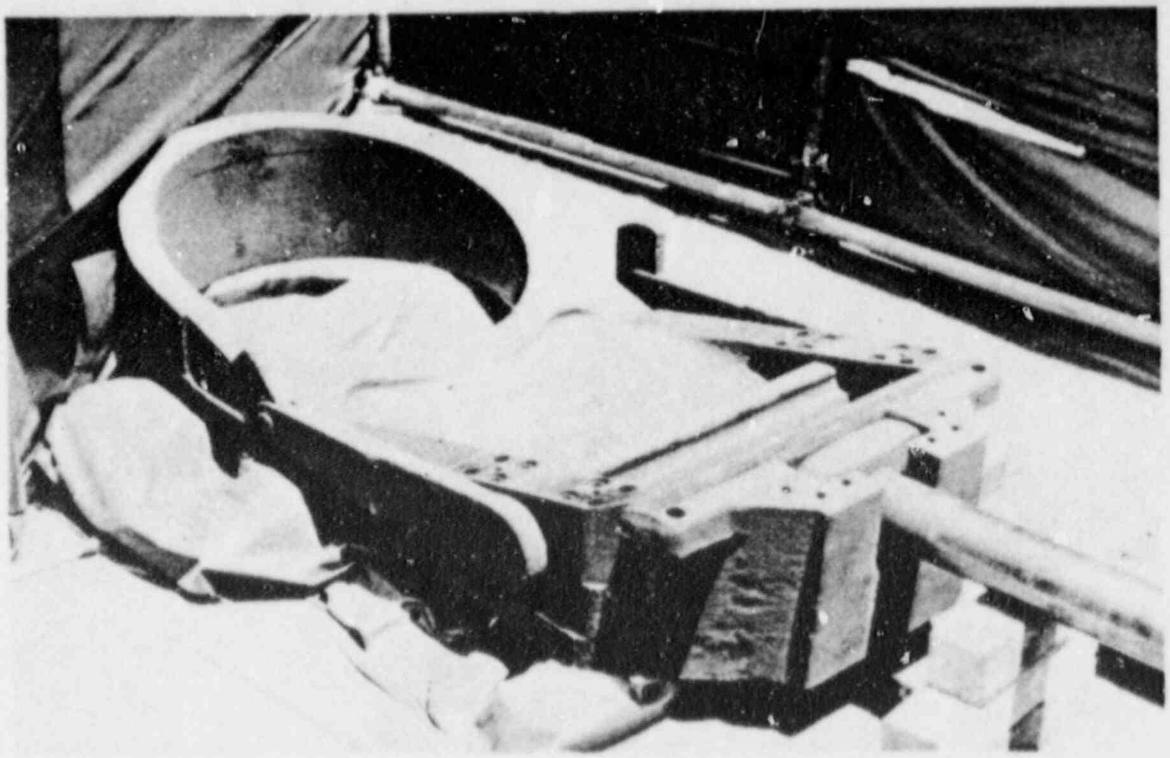

Figure 12

A Distant View of the Galling Marks on the Arm Shoes

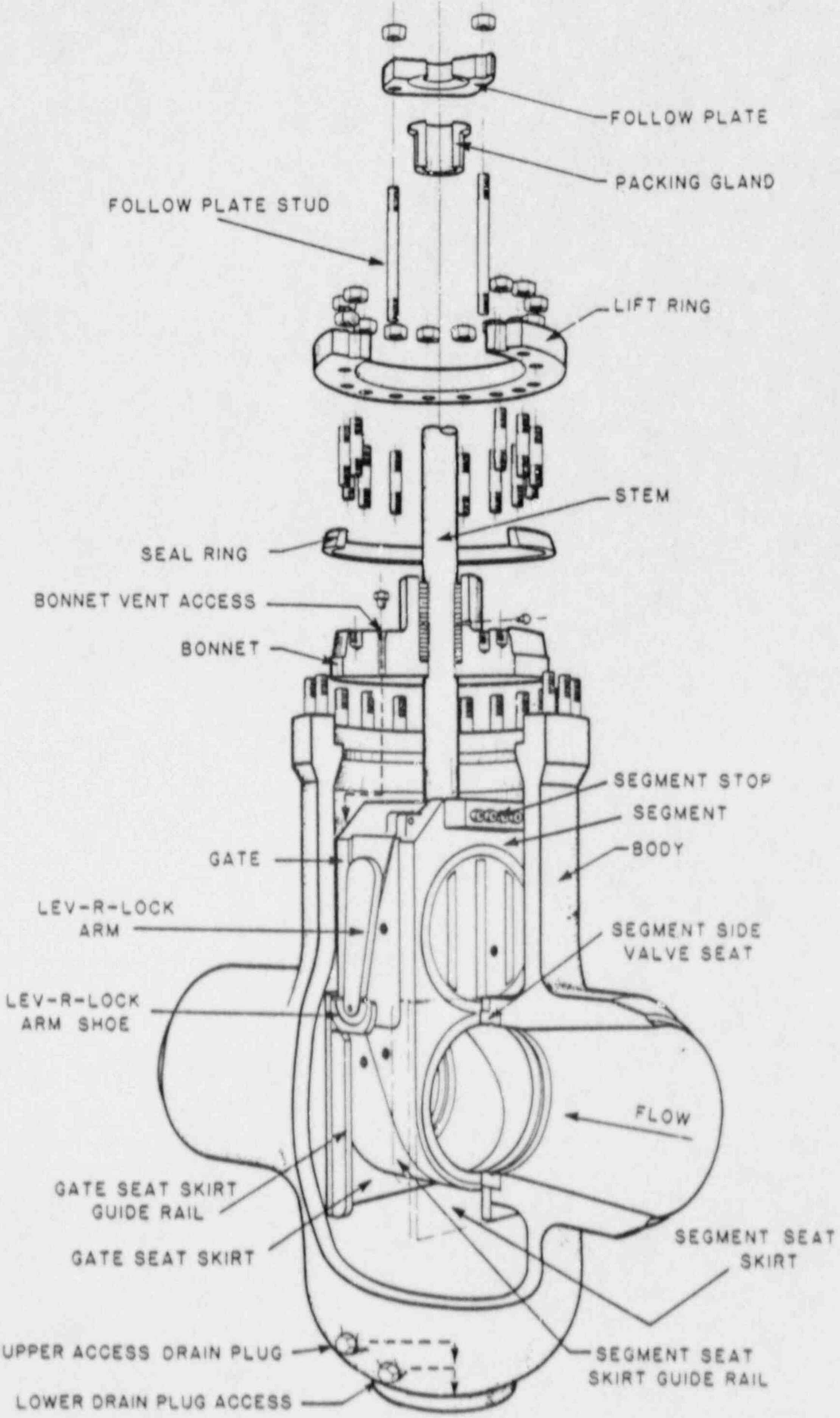

FIGURE 13

Borescope Probe Penetration Points

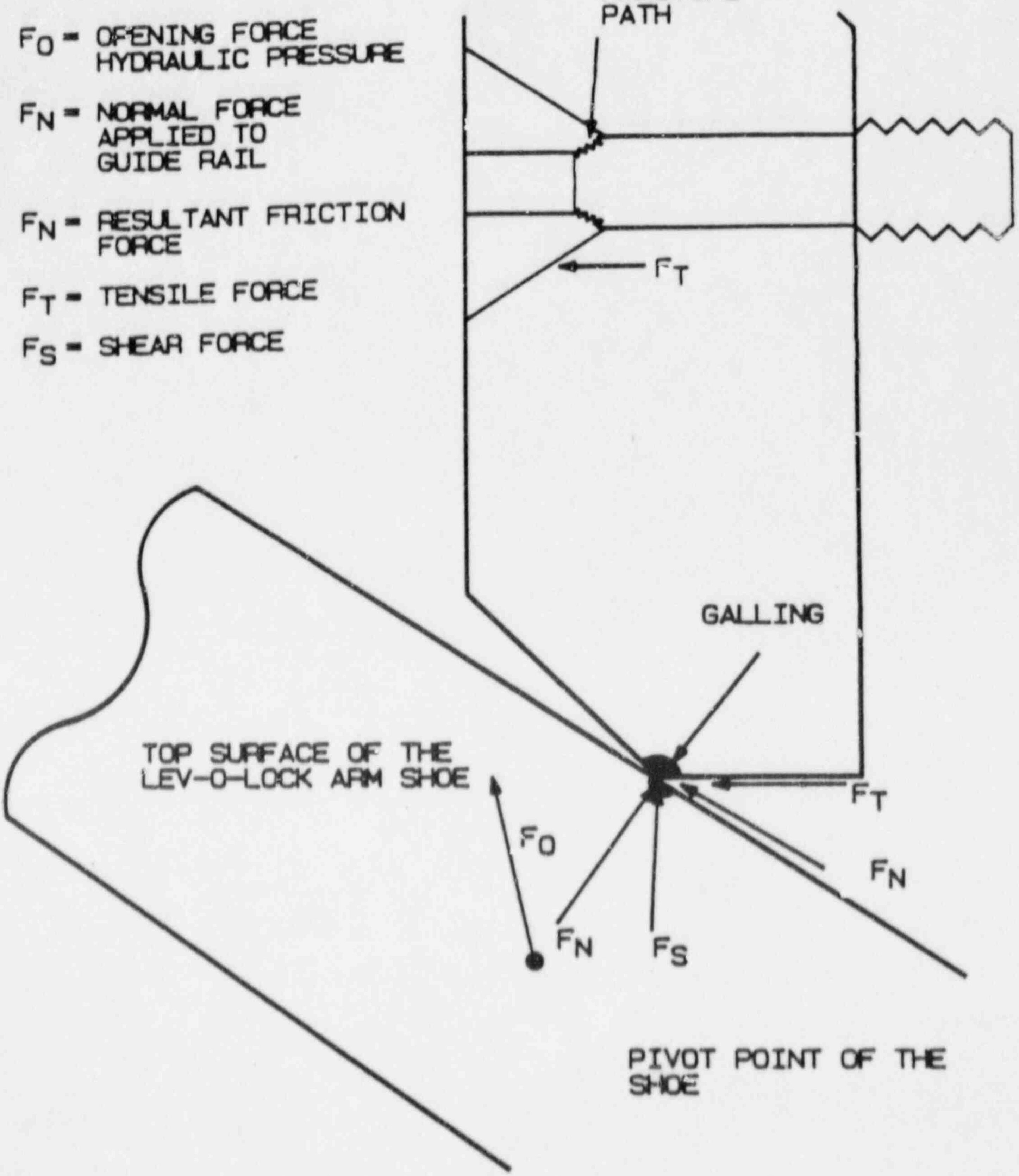

Figure A-1

Forces Resulting from Interference