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Shroud Repair Anomalies
Nine Mile Point Unit 1, RFO14

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Nine Mile Point Unit 1, RFO14

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EXECUTIVE SUMMARY

During the Spring 1997 refueling outage of Nine Mile Point Unit 1, the nuclear core shroud repair assemblies were found to be degraded. The shroud repair assemblies had been installed during the 1995 outage. This report describes the as found condition, the consequences of the degraded condition on previous plant operation, the root cause of the degraded condition, and the repairs implemented to assure continued safe and reliable future plant operation. The degradation consisted of loose tie rods and failed lower spring contact wedge latches. The root cause of the degraded shroud repair condition was unacceptable movement of the shroud repair assemblies during plant operation caused by failure to recognize the impact of clearances between toggle bolts and the holes, and an incorrect design assumption regarding sliding at the vessel to wedge interface. The repairs to be implemented this outage assure that unacceptable consequences of movement of the repair assemblies will not occur in the future.

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1.0 INTRODUCTION

During the Spring 1997 refueling outage at Nine Mile Point Unit 1 (NMP1), anomalies were found with the shroud repair hardware. This report describes those anomalies and discusses the root cause and corrective action. The shroud repair hardware was inservice for approximately two years. The anomalies consisted of loose tie rods and failed lower spring wedge latches.

The anomalies were found during planned visual inspections of the shroud repair hardware and during the planned replacement of a shroud repair assembly at 270 degrees.

2.0 SUMMARY

All four shroud repair assemblies were found to have lost vertical preload and three of the latches that prevent relative motion between the lower spring and the wedge were damaged. One latch had failed inservice, another failed during the removal process, and a third has visual evidence of damage. Similar latches on the mid-supports and on the upper springs were found to be normal. These latches are similar in physical features but have different applied loadings.

The evaluation of the as-found condition shows that both the latch failure and tie rod looseness were related. The design of the lower spring contact implicitly assumed that the lower spring contact would slide along the Reactor Pressure Vessel (RPV) wall. If sliding always occurred at this interface, then no additional stress would be induced in the latches. On the other hand, if the friction on the lower spring contact area prevents sliding, this could cause high stresses and yielding in the latch. This in turn could cause SCC of the material. Given that there is no sliding on the lower spring contact area on the vessel, stresses in the latch could be developed as a result of two conditions:

- If the lower support/toggle bolt assemblies were installed such that these assemblies moved up the shroud support cone, toward the shroud, when the plant reached normal operating conditions, the resulting vertical displacement could cause high stresses in the latch.

- Differential motion could also be caused by the deflection of the C-spring under tie rod load for heat up. This could also cause stresses in the latch, although somewhat less than in the previous case.

The evaluation showed that if sliding does not occur, the stresses from the movement associated with installation and subsequent thermal displacement, could cause sufficiently higher stresses. This explains the observed deformation and the subsequent SCC failure.

Motion of the tie rod assembly relative to the vessel surface can also cause the thermal preload to be overcome and cause tie rod looseness.

The root cause of the latch failure and the tie rod looseness is related to the design assumption of sliding on the vessel surface. While this appeared reasonable initially, the observed deformation on the latch confirms that sliding did not occur, and that the original assumption of sliding was incorrect.

An evaluation was performed to show that operation during the previous fuel cycle, with the degraded shroud repair assemblies, did not result in operation of the plant in an unsafe manner.

The shroud repair assemblies have been repaired by removing the looseness by pushing the lower support toggle bolt assemblies to the shroud side of the holes in the shroud support cone. The latches have been replaced with a new design which is more tolerant of differential motion. These two changes assure that the shroud repair assemblies will function as originally intended during all modes of plant operation.

3.0 EVALUATION

The as found condition, design description, additional inspections, and the loads applied to the shroud repair assemblies are discussed in this section.

3.1 As Found Condition

Figure 1 shows an elevation view of one set of shroud repair hardware. There are four such sets of hardware at azimuths 90, 166, 270, and 350 degrees around the core shroud. Briefly, the tie rod is the main component for reacting axial loads. The lower spring is the linear spring for supporting the shroud at the core plate elevation. The lower wedge is a component that was machined based on actual site measurement to fit between the RPV and the lower spring with a small (0.010 inch) compression of the lower spring at room temperature. The latch is a wishbone shaped piece, that is intended to prevent relative motion between the lower wedge and the lower spring. Similar latches are also used to prevent relative motion at the mid-support and at the upper spring. The lower support is an assembly that connects the shroud repair hardware to the shroud support cone. The tie rod nut is at the top of the tie rod and is used to tighten the assembly. During installation, the tie rod nut was torqued clockwise to preload the assemblies to assure minimal tightness of components. The mid-support is used to limit relative motion between the middle of the shroud and the RPV. The upper spring is a linear spring for supporting the shroud at the top guide elevation.

3.1.1 Tie Rod Nuts

During the planned replacement of the shroud repair assembly at 270 degrees, the tie rod nut was found to be loose. The nut locking device was normal and the nut was not able to be moved without removal of the locking feature. However, there was no preload between the nut and the tie rod. After removal of the locking feature, the nut was turned with less than 25 foot pounds. The rotation of the nut prior to tightening at 25 foot pounds was equivalent to an axial clearance (i. e. vertical movement) of 0.08 inch.

3.1.2 Latches

The lower support wedge latch at 90 degrees was found during the visual inspection to be broken. A piece of the latch was missing and later found on the lower support cone at approximately azimuth 330 degrees. Figure 2 is a photograph of the failure surface. Based on an examination of this photograph and other video tapes, the failure is not consistent with a fatigue mechanism. There is no visible evidence of plastic deformation, which would be necessary for a single overload type of failure. The failure surface appears consistent with a stress corrosion failure under high stress. Based on the visual information, high stress causing stress corrosion is more likely than an overload, but until results of a metallurgical evaluation are available, overload can not be eliminated.

Video tape inspection of the other three lower wedge latches showed them all to be in one piece, but the 350 degree latch appeared to be bent. In addition, the lower spring wedges have evidence of local hard contact, due to vertical loads, with the latches. Since the latches are alloy X-750 and the lower spring wedges are Type 316 low carbon stainless steel, the lower spring wedges will show surface wear before the latches.

One similar latch is used in each mid-support assembly and two similar latches are used in each upper support assembly. The latches on the mid-support and on the upper support have been visually examined and all twelve are normal. Because of design differences, these latches can not be loaded as severely as the lower wedge latches. The contact force between the RPV and the shroud repair is much smaller at these locations as compared to the contact force at the lower wedge. In addition, these latches are not loaded during plant heat-up.

3.1.3 Lower Spring Wedges

The lower wedge at 90 degrees had dropped to the bottom of the post on the lower spring. The lower wedge at 350 degrees appeared to be approximately 1/8 inch below its normal position. The other two wedges were in their normal position.

3.1.4 Marks on RPV Wall

Contact sliding marks have been observed on the RPV wall at 166 degrees above the lower contact point of the upper spring assembly. Sliding marks are not evident at all other contact points relative to this upper spring or at all contact points for the upper springs at 90, 166, and 350 degrees.

3.1.5 Shroud Support Cone

Visual inspection of the shroud support cone did not reveal any differences from the original installation.

3.1.6 Mid-Supports

Visual inspection of all mid-support contacts confirmed that there was contact with the RPV surface in the cold condition. During normal operation, the mid-support compression on the RPV increases due to thermal conditions. Thus the function of providing a load path from the tie rod to the RPV (also intended to increase the natural frequency of the tie rod assemblies) was maintained. Following this inspection, in-veesel work related to verification of the root cause of the latch failure, involved application of forces that led to displacement of two mid-supports. This left a condition with a gap at azimuths 90 and 166 degrees relative to the vessel wall. New mid-supports are being fabricated and will be installed with the original design preload. The mid-support at 350 degrees will be verified for proper preload. The 270 degree mid-support will be verified for proper preload during installation of the new tie rod. Therefore, the required support configuration will still be maintained for future operation.

3.2 Design Description

The shroud repair was designed to structurally replace the circumferential welds in the core shroud. Four assemblies are placed approximately uniformly around the shroud (azimuths 90, 166, 270, and 350). Each assembly functions to vertically hold the shroud to the shroud support cone and to horizontally support the shroud at the top guide and core plate elevations. In addition, there are other horizontal supports that would prevent unacceptable

horizontal movement of any shroud cylindrical segment that could be produced by failure of the horizontal shroud welds.

3.2.1 Vertical Restraint

Vertical restraint is provided by an alternate load path between the top of the shroud and the shroud support cone. This load path consists of the upper support, tie rod, C spring, lower support, and toggle bolt. Differential thermal expansion due to the different materials used for components of this load path, provide a thermal preload at plant operating conditions. The thermal preload is sufficient to hold the shroud in place for all normal operating conditions, such as the vertical upward force applied to the shroud by the coolant flow and pressure. The vertical load path is also designed to have a vertical spring rate that both prevents unacceptable vertical load during plant upset thermal conditions and provides acceptable dynamic response during a plant seismic event.*

3.2.2 Horizontal Restraint

The shroud is supported by linear springs at the top guide and the core plate elevations. At the top guide elevation the linear spring consists of the upper spring, upper wedge, upper contact, and the upper support. At the core plate elevation the spring consist of the lower wedge, lower contact, and lower spring. The horizontal spring rate of these springs were designed to produce acceptable horizontal dynamic response during a plant seismic event. The horizontal displacement of the shroud during all events must be limited by these springs to assure control rod insertion and prevention of unacceptable leakage.

In addition, unacceptable displacement of other cylindrical sections of the shroud between postulated cracks in horizontal shroud welds are prevented by displacement limiters, such as the mid support and top support.

3.2.3 Installation

The necessary attachment features were machined into the shroud head and the shroud support cone to install the shroud repair hardware. The lower support toggle bolts were inserted through the shroud support cone and tightened to   . The tie rod nut

was tightened to . The lower wedge was machined to provide a compression of the lower spring. The mid-support was machined to provide a horizontal displacement of the tie rod. The upper spring jacking bolt was adjusted to provide a compression of the upper spring of . All moveable features were locked in place with mechanical devices such as crimps or spring retainers. The lower spring wedge latches discussed in Section 3.1.2 are one type of spring retainer.

Thus, after installation, the upper and lower springs were compressed between the shroud and the reactor pressure vessel and the tie rod was tight with a small preload. The lower support/toggle bolt assemblies were tight to the shroud support cone, but their position in the hole in the cone had not been properly specified by the engineering documentation. They could be at any position allowed by the size of the hole in the cone and their outside shape. The design maximum diameter of the holes in the cone was 4.09 inches. Six of the eight holes were machined oversized with a maximum as built diameter of 4.11 inches. The oversized holes increased the amount of clearance around the toggle bolts by approximately 10% to 20%. The maximum tie rod vertical looseness that could have been caused by the actual holes is 0.18 inch. Figure 3 shows the toggle bolts and the hole in the shroud support cone.

3.3 Additional Inspections

Based on the as found condition, additional inspections were determined to be required. A detailed procedure was developed for performing the inspections as well as to replace the latches on the lower wedges. That procedure is given in Reference 3.1. The purposes of the procedure are to: remove the latches from the other lower wedges, determine if the other tie rod nuts are also loose as the 270 degree one was, identify the source of the looseness of the tie rod nuts, and install new lower wedge latches and retorque the tie rod nuts to the required value.

The following information was obtained by following the Reference 3.1 procedure.

1. Three lower wedge latches were successfully removed. The 350 degree latch broke during the removal. The fourth latch at 270 degree is still installed in the repair assembly. This repair assembly was completely removed for replacement.

2. The tie rod nut at 90 degrees could not be turned with 25 foot pounds until the lower support was pushed up the shroud support cone. After a jack was installed to push the lower support up the shroud support cone toward the shroud, the tie rod nut could then be turned. The total nut rotation, at the final installation torque of 190 foot pounds, was 272 degrees. This is equivalent to an axial clearance (i.e. vertical movement) of 0.151 inch.

3. Prior to jacking the lower support/toggle bolt assemblies, the tie rod nut at 350 degrees turned 38 degrees with 25 foot pounds applied. After a jack was installed to push the lower support up the shroud support cone, toward the shroud, the tie rod nut could be turned even further. The total nut rotation at the final installation torque of 190 foot pounds was 98 degrees. This is equivalent to an axial clearance of (i.e. vertical movement) 0.054 inch.

4. Prior to jacking the lower support/toggle bolt assemblies, the tie rod nut at 166 degrees could be turned 67 degrees with 25 foot pounds applied. After a jack was installed to push the lower support up the shroud support toward the shroud the tie rod nut could be turned even further. The total nut rotation at the final installation torque of 190 foot pounds was 168 degrees. This is equivalent to an axial clearance (i.e. vertical movement) of 0.093 inch.

In conclusion, all four tie rod nuts were found to be loose. The amount of axial clearance, found from the nut rotation, varied between 0.054 and 0.151 inches. The clearance between the toggle bolts and the upper portion of the hole in the shroud support cone was eliminated. All four tie rods were torqued to the original required installation value. All of the verification activities were performed in accordance with the procedure in Reference 3.1.

3.4 Source of Loads on Shroud Repair Assemblies

During normal plant operation there are only a few sources of loads on the shroud repair. These are installation, differential thermal and pressure expansion, fluid flow and dead weight. The dead weight, fluid flow, and installation stresses are low. The main forces on the

shroud repair are due to differential thermal expansion between the shroud, RPV, and shroud repair, which both are in the vertical and horizontal directions. The following differential motions occur between plant shutdown conditions and normal plant operating conditions. The values are the relative motions between the RPV and the shroud repair hardware. They are based on the assumption that the shroud repair hardware moves freely in the vertical direction, and the fact the lower springs compress in the radial direction.

Location and Description	Direction
Lower spring wedge at RPV	Radial
Lower spring wedge at RPV	Vertical
Tie rod (full length) to shroud	Vertical

The differential motion in the vertical direction between the shroud and tie rod causes a design axial force of 79,600 pounds. The differential radial expansion at the lower support, plus the installation preload, causes a design force of approximately 21,800 pounds. The differential radial expansion, plus the installation preload at the upper spring, causes a design force of 3,600 pounds. The installation preload, plus the differential radial expansion at the mid-support, causes a design force of less than 1000 pounds. The differential vertical motions between the RPV and the lower support, mid-support, and the upper spring were assumed to not cause forces in the repair components. Sliding was expected and assumed. However, if sliding does not occur, then there will be forces. The relatively low contact forces at the mid-support, and at the upper spring, increases the probability of sliding at the RPV for these locations.

The lower wedge/vessel interface surface is in the same plane as the applied vertical loads on the shroud repair assembly. Since the vertical load reaches 79,600 lbs (primarily from the thermal expansion) while the horizontal lateral load is only 21,800 lbs, sliding will occur on this surface when the friction forces are exceeded. The lower wedge surface is a machined stainless steel surface; whereas, the vessel wall is an as-welded clad stainless steel surface which has peaks and valleys on the surface.

The lower wedge/lower spring interface has a 5 degree angle with respect to the vertical load direction. when the vessel is heated, the 5 degree angle is oriented such that it increases the possibility of sliding as compared to an in-plane orientation. Likewise, when the vessel is cooled down, the 5 degree angle acts to resist sliding. The lower wedge contact surface is a machined stainless steel surface, and the lower spring contact surface is a machined X-750 surface. Having dissimilar metals with different hardness at this interface is an optimal condition for sliding to occur.

In comparing the above two surfaces which are subject to sliding, it is expected that the vessel clad surface will have a higher friction factor than the friction factor at the machined surfaces at the lower wedge/lower spring interface. Therefore, sliding at the lower wedge/lower spring interface is more likely to occur. Considering the operation of the NMP1 plant with the original latches, it was concluded that sliding on the vessel wall must have occurred at the locations where the latches did not fail; whereas, the failed latches experienced sliding at the lower wedge/lower spring interface. Therefore, the location where sliding occurs is highly dependent on the friction factors at the contact surfaces. Consequently, when there is a relatively higher friction factor at one of the surfaces in comparison to the other one, sliding will predominately occur at the contact surface with the lower friction factor.

Based on the as found condition, sliding occurred at the upper spring wedge and contact and at the mid-support, which is consistent with the low contact forces at those locations. Sliding did not always occur between the RPV and the lower spring wedges, which is consistent with the higher contact forces at those locations, and explains why some latches failed and some did not fail. At the lower wedges it is likely that sliding at the RPV occurred at the 166 degree location, while no sliding at the RPV occurred at the 90 and 150 degree locations. Sliding at the RPV probably occurred at the 270 degree lower wedge location.

4.0 CONSEQUENCES TO PREVIOUS PLANT OPERATION

The NMP1 plant had been operating for one cycle since the installation of the shroud repair hardware. Upon inspection, as identified earlier, the following was determined:

1. The tie rods were loose, the looseness ranging from 0.054 to 0.151 inches axial in the four tie rods. The differential thermal expansion between the shroud and the tie rod assembly during normal operation is 0.155 inches. Thus, the thermal preload is lost by the amount equivalent to the looseness of the tie rod assembly. The cumulative looseness was (.054+.080+.093+.151) = 0.378 inches. The remaining thermal preload is (0.155 x4 -0.378) x 514 = 124. 4 kips.

2. The retainer latch in one of the lower stabilizer spring had broken, resulting in no contact between the lower spring and the RPV. Therefore, it was rendered ineffective.

This assessment was performed to determine if the failures would have impaired the safe operation of the plant during the past operating cycle. For purpose of this assessment, it is conservatively assumed that:

1. All lower spring or stabilizers are ineffective in providing lateral restraint
2. All horizontal welds have through-wall cracks
3. All horizontal weld cracks are 360°, with no ligament remaining.

The critical hardware loads were recomputed and compared to the hardware design loads, (References 3.2, 3.3). If the new load is smaller than the design load, the hardware remains qualified. If the new load is larger than the design load, the new stresses will be compared to the available stress margins/code allowables. In addition, impact on leakage is addressed.

4.1 Normal Condition

Tie Rod Load

Since there is preload loss, the difference between the upward pressure load and the downward thermal load and the weight, acting in a upward direction could cause separation. The design values of the ΔP in the stress report correspond to a 105% core flow condition. At 100% core flow (the condition during the last cycle) the ΔP values are somewhat lower. The separation values are calculated for the 100% core flow and design condition.

$$\text{Net Tie Rod Primary Load} = \frac{[\Delta P\ \text{load} - (\text{Dead Weight} - \text{Buoyancy}) - \text{Thermal preload}]}{4}$$

For the 105% core flow condition (shroud head ΔP of 5.9 psi and core support ΔP of 15.9 psi), the total pressure load is 339.8 kips. While for the 100% core flow condition (shroud head ΔP=5.5 psi and core support ΔP of 14.5 psi), the total load is 312 kips. The net weight, including buoyancy, is 174.9 kips

Condition	Shroud head ΔP	Core Support ΔP	Pressure load	Net load / tie rod	Separation	Leakage area
105% flow	5.9 psi	15.9 psi	339.8 kips	10.1 kips	0.020 in.	11.8 sq. in.
100% flow	5.5 psi	14.5 psi	312 kips	3.2 kips	0.006 in.	3.5 sq. in.

The leakage rates, associated with the calculated leakage areas, are estimated to be 410 gpm for the 105% core flow, and 120 gpm for the 100% flow condition. Adding this to the estimated leakage, due to postulated through wall cracks in the vertical welds, and the leakage from the shroud repair installation, the total leakage for both conditions is less than 1% of the total core mass flow. This is small compared to the core flow uncertainty itself. The peak clad temperature impact associated with this leakage is not significant. Therefore, the postulated leakage would not have had safety implications with the stated conservative assumptions.

Stresses in the tie rod during normal operation are not limiting. Even if one assumes that the entire net pressure load is taken by one tie rod assembly, for the design condition during normal operation, the tie rod stress would have been as follows:

Single tie rod stress = Net load/tie rod area = (339.8-174.9)/8.76 = 18.8 ksi < Sm = 22.9 ksi.

Therefore, stresses in the tie rod would have been acceptable, even with the as stated conservative assumptions.

4.2 Upset Condition

Upset 1a : Loss of Feedwater Heating

The upset thermal differential expansion between the shroud and the tie rod assembly is 0.367 inches. This is per the original analytical calculations for the shroud repair. Upon closure of the looseness in the tie rod, the remaining thermal expansion will load the tie rod. This value is smaller than the load due to the constraint of the entire differential expansion. Thus, because of the thermal preload loss due to tie rod looseness, the upset condition secondary load will be smaller than the upset secondary load for which the hardware is designed to. Therefore, no further evaluation is required for the upset secondary load. Also, because of the higher thermal differential expansion, there will be higher preload and therefore no crack separation would have occurred during this event.

Upset 1b: Upset Pressure

The BWRVIP criteria does not require prevention of separation during upset events. The expected leakage will be somewhat higher than under normal operation, but as identified previously, the safety impact of the leakage is insignificant. Leakage in excess of 3% of core flow will be detected through reduction in power and corrective action would have been taken.

Upset 2 : Upset Pressure - (DW-Buoyancy) + Seismic Primary Load

Upset pressure load - (DW-Buoyancy) = 442.5 - 179.4 = 263.1 kips

Tie rod load = 65.8 kips

Since separation would exist during normal conditions, seismic load will be based on the "Roller" assumption at the crack. Using the H-7 "Roller" condition, the associated tie rod load is kips. The tie rod load due to the vertical seismic event is 3.2 kips per tie rod. The total tie rod load is:

Tie Rod load =

The stress corresponding to this load is
Therefore, stresses in the tie rod would have been acceptable even with the conservative assumptions previously stated.

Displacement at Core Plate Elevation

The lateral displacement at the core plate elevation, based on the H-6B Roller seismic case, is now considered. From scram capability considerations, it is assumed that the seismic event is sensed approximately two seconds after the initiation of the seismic event. Control rod insertion will typically be complete within approximately three seconds of the event being recognized. Thus, the scram will be complete within approximately five seconds upon initiation of the seismic event. The maximum seismic elastic displacement, within this time period, has been analyzed and evaluated for the case of separation at Weld H-6b. It has found to be within allowable values. Details of this analysis are documented in Reference 3.3. Thus, the actual displacement is within the allowable and therefore there would not have been a safety concern.

4.3 Emergency Condition

Emergency 1: [Normal Pressure - (DW+Buoyancy)] + DBE

Since the DBE is the same for Upset 2 and Emergency conditions, Upset 2 loads apply to this condition as well. The allowables are higher for the Emergency 1 condition. Therefore, all stress limits met for the Upset 2 condition, will be met for the Emergency 1 condition also. Displacement limits are also covered by the Upset 2 event.

Emergency 2: MSLB LOCA pressure - (DW-Buoyancy)

In the original shroud horizontal weld repair design, the MSLB LOCA is axisymmetric. Vertical load is completely resisted by the four tie rods, since crack separation was postulated for this condition. Hence, the loss of preload would not have any impact on this condition, and the original design load remains unaffected. Also, there is no impact on lateral load since the loading is vertical and axisymmetric.

Emergency 3: Recirculation Outlet LOCA (RLB) Load plus Dead Weight Effects:

In the case of RLB LOCA, the negative pressure across the core plate does not contribute to the tie rod load. The pressure differential across the shroud head however contributes to the tie rod load. A crack at weld H-1 (with least dead weight compensation) would then govern.

$$\text{Primary load due to [Delta P - (DW - Buoyancy)]} = \frac{292{,}490 - 68{,}300}{4}$$

$$= 56{,}048 \text{ lbs.}$$

In addition, asymmetrical lateral pressure load exists on the shroud. The lateral load will be resisted by the restoring force offered by upper stabilizer springs, in conjunction with the dead weight of the shroud between H-1 and H-7. Since for this case, separation of the crack at H-1 is postulated, the tie rod is assumed to not take part in resisting the effects of lateral load. Thus no additional tie rod load is applicable due to the RLB asymmetric load condition.

The maximum upper stabilizer load =

Additionally, the limit stops serve to prevent any unlikely possibility of excessive sliding. Thus safety would not have been impaired.

4.4 Faulted Condition

Faulted 1: MSLB LOCA + DW + DBE

This condition has been addressed previously in GENE Report No. B13-01739-25, wherein, the lower stabilizer was assumed ineffective and there was no safety concern. The tie rod preload loss has no impact on this load combination since crack separation is already postulated for this combination.

Faulted 2: RLB Inlet LOCA + DW + DBE

There is no tie rod load contribution from the negative pressure across the core plate. Asymmetric Load is not applicable. Thus, the tie rod load due to RLB Delta P across the shroud head only is applicable, and is the same as in the Emergency 2 case :

Tie rod load =

Consistent with this condition where H-1 is assumed a Roller, the corresponding DBE load from the "H-1 Roller + Other Welds Hinged" case will be considered. This crack condition results in the same loads as the "All Hinge" case. The previous GENE Report No. B13-01739-25 addressed the "All Hinge" case with ineffective lower stabilizer, using new and improved methodology. The seismic loads from this case will therefore be used.

Tie rod load due to DBE =
Total tie rod load for this combination =
Upper Stabilizer Load due to DBE =

These loads are smaller then the design loads for this service condition. Therefore, there was no safety concern.

<u>Faulted 3: RLB Outlet LOCA + DBE +DW</u>

RLB load is same as in Emergency 3 and the DBE load is the same as in Faulted 2.

Total Tie Rod Load =
Total Upper Stabilizer Load =

Additionally, the limit stops serve to prevent any unlikely possibility of excessive sliding. Thus safety would not have been impaired.

4.5 Flow Induced Vibration (FIV)

Natural frequency evaluation no lower spring contact and no preload and no preload of tie rod assemblies showed the frequency was lower (15 Hz) compared to the original design value (28 Hz). This is still well in excess of the vortex shedding frequency (7 Hz) and will not cause vibration or high cycle fatigue. This was supported by stress analysis which shows that the stress amplitude was below the endurance limit. If FIV had occurrred there would have been damage on the RPV cladding at the mid-support location. Inspection of those areas showed no evidence of damage. This confirms that FIV was not an issue in the previous plant cycle of operation.

4.6 Conservatism

The above load calculations are based on the conservative assumptions listed in Section 4.0. It is known based on actual inspection of the shroud that, in the regions where inspection has been performed, no through wall crack had been found in any of the horizontal welds. Thus, considerable conservatism is built into the above calculations/model.

Also, based on the screening criteria, the required ligament sizes are much smaller than what are actually available, which means that by satisfying the minimum required ligament requirement, the shroud is still safely operable even without the repair in place.

4.7 Conclusion

In conclusion, even with the degraded repair hardware and existing shroud weld cracking, there was no safety concern in terms of safe shutdown capability or core cooling functionability, during the past operational cycle of the plant.

5.0 ROOT CAUSE OF FAILURE

Based on the initial observations of the loose tie rod at 270 degrees and the failure of the latch at 90 degrees, different potential causes were postulated. These causes were possible vibration leading to fatigue of the latch, or yielding of the tie rods, or other unexpected displacements.

A review of the stress analyses showed that the tie rods could not have been overloaded to yield. Evaluations solely by IVVI techniques and photo macrographs of the fracture face of the latch, are of course insufficient evidence to establish the actual cause of latch fracture. However, the evidence obtained by macroscopic observation strongly suggests that the latch fracture was due to a stress corrosion mechanism rather than a fatigue or mechanical overload failure.

The logged, irregular failure surface of the broken 90 degree latch again tends to rule out fatigue as a possible failure mechanism. The failure surface does not show evidence typical of a single over loading as there is no visible plastic deformation. The surface does however, have characteristics suggestive of stress corrosion under high stress. The only known source of high stress is due to restraint of differential vertical motion between the RPV and the lower spring wedge. If the lower spring wedge did not slide vertically along the RPV, then the differential displacement must occur between the lower spring and the lower wedge. Such movement will cause high stress in the latch. Sources of such differential displacement are the vertical looseness of the tie rods and the differential displacements tabulated in Section 3.4. At plant operating conditions, the entire value of tie rod looseness would add to the differential displacement at the lower spring wedge resulting in a total differential movement of at least 0.121 inch (.054 inch +.067 inch). Such a displacement would result in stresses in the latch of well over yield. Crack growth rates in alloy X-750, with applied stresses over yield stress, can be quite high. Values well in excess of 0.2 inch per year (thickness of latch) have been reported.

Therefore, the root cause of the latch failure and the tie rod looseness is related to the design assumption of sliding on vessel surface. While this appeared reasonable initially, the observed deformation on some of the latches confirms that sliding did not occur and that the original assumption of sliding was incorrect. Given that friction on the lower spring contact area can

prevent sliding, the shroud support/toggle bolt assemblies should have been installed as close to the shroud as possible, and as allowed by the holes in the shroud support cone. With the incorrect assumption, the importance of the clearance between the toggle bolts and the hole was not recognized and not incorporated into the installation engineering documentation. Therefore, all four shroud repair assemblies had an installed looseness of 0.054 to 0.151 inch. This looseness was removed by the 79,600 pound force applied by differential thermal expansion of 0.155 inch at plant operating conditions. This 0.054 to 0.151 displacement combined with the unexpected no slippage of contact displacement, over-stressed the latch (assuming no slippage between the RPV and the wedge). The high stress is likely to have resulted in stress corrosion and latch separation in two years.

6.0 CORRECTIVE ACTIONS

There are two corrective actions. The first is to remove the looseness between the toggle bolts and the shroud support cone. This has been, or will be, accomplished with the Reference 3.1 procedure. The second is to install new latches which are more tolerant of differential vertical displacement. The design of the new latches maintains the original design function, which is to lock the wedge to the lower spring whenever it is not supported, but modifies the latch mechanism to incorporate another spring mechanism which can tolerate vertical displacements. Therefore, the original functional requirement is accomplished while adding more flexibility in the vertical direction to accommodate the now recognized vertical displacements. The new latch is again made from X-750 material because of its high strength capabilities. Testing of X-750 has shown that it is resistant to stress corrosion cracking for stresses up to 75 ksi. In comparison, the only other high strength material with excellent corrosion resistance properties and with in-vessel experience is XM-19. However, for this material the yield strength is only 38 ksi. Likewise, the ultimate strength of X-750 is significantly higher than XM-19 (142 ksi vs. 88 ksi). Therefore, X-750 continues to be the best choice. The design of the latch will accommodate all potential vertical displacements without exceeding the ASME code limits. Under the most probable operating and sliding conditions the new latch design is expected to perform satisfactorily for the remaining life of the plant. Even for worst case postulated conditions, the latch is capable of operating without failure.

7.0 PERFORMANCE OF REPAIRED DESIGN

The removal of the clearance between the toggle bolts and the shroud support cone will assure that the tie rod vertical forces will be as intended in the original design. With the tie rod in a tight condition at startup, the proper vertical thermal expansion loads can be accomplished during the heat-up of the reactor, and maintain the hold down forces on the shroud.

The new latches which are being supplied can tolerate a differential vertical displacement for the worst case thermal transient event (loss of feedwater heating) without experiencing an overstress condition. Also for normal plant operation, the maximum vertical differential displacement under probable wedge interaction conditions (assuming no slippage between the RPV and the wedge) is 0.10 inches. Under this deflection the stresses in the new latches will be less than the stress limit established to prevent stress corrosion in X-750 material for a 40 year lifetime. In comparison, X-750 is also used for the jet pump beams. Jet pump beams with the same heat treatment as the new latches have been in operation since 1980 without any service failures.

A comparison of the original latch design to the new design has been performed using common finite element modeling methods. The results show that the new latch is 8 to 12 times more capable of tolerating vertical displacements than the original design.

The function of the original latch was to secure the wedge to the lower spring. This is primarily needed when the wedge loses contact with the reactor vessel wall. This is an important function since the wedge will otherwise slide down and create excessive gaps. The new latch design maintains the wedge support capability and can readily support the dead weight and flow forces which could act to push the wedge down.

Based on the above, the new latch design is now fully capably of accommodating the potential postulated vertical displacements and associated loads during operation.

8.0 REFERENCES

3.1 NMP-SHD-003 Revision 1 "Lower Wedge Latch Replacement and Tie Rod Torque Checks" including Special Process Control Sheet SPCS # 01 Revision 1.

3.2 GENE-B13-01739-04, "Nine Mile Point 1 - Shroud Repair Hardware Stress Analysis", including Supplement 2.

3.3 GENE-B13-01739-25, April, 1996, "Core Shroud Repair - 270° Tie Rod Assembly Assessment"

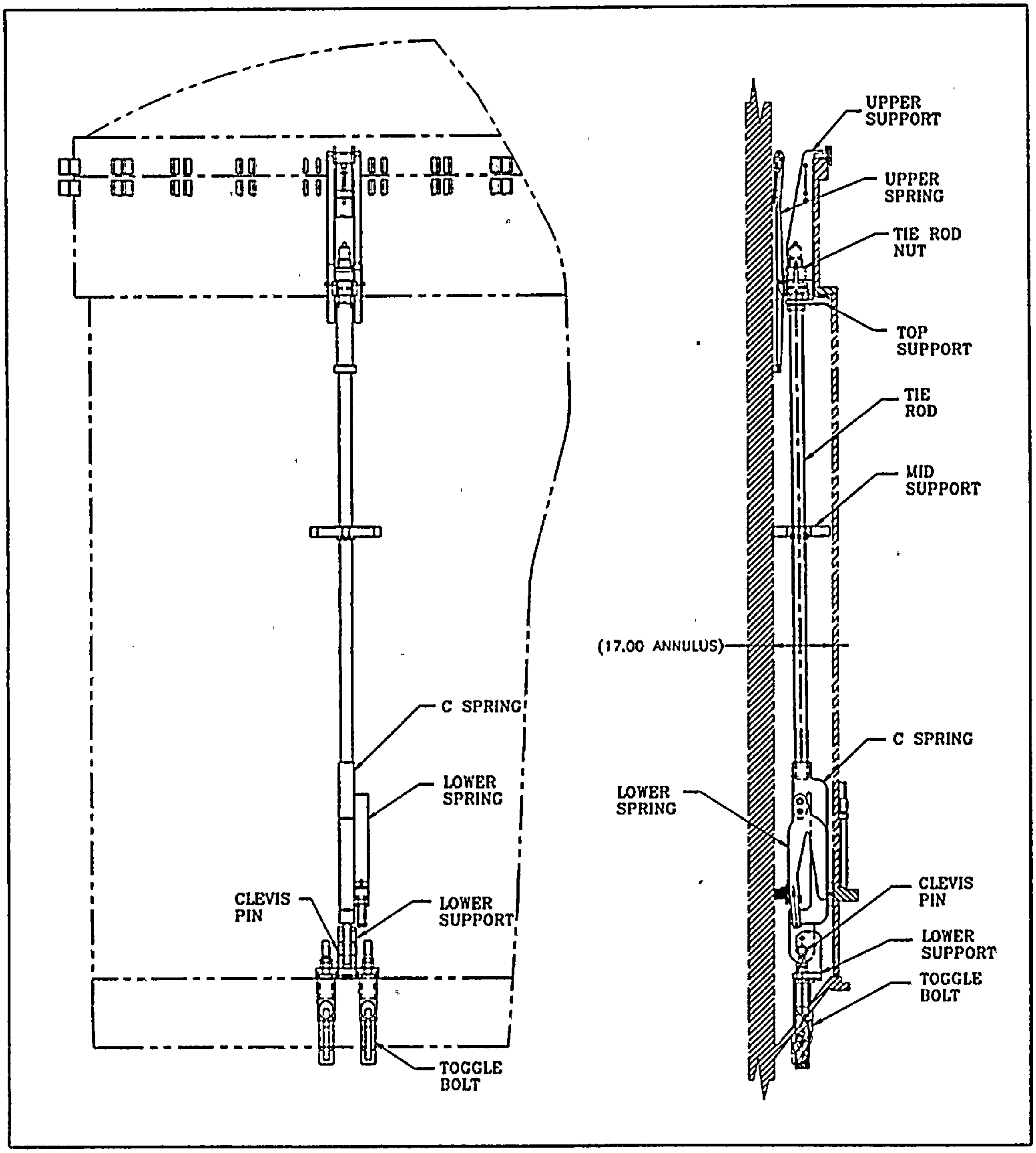

Figure 1
Shroud Repair Assemblies

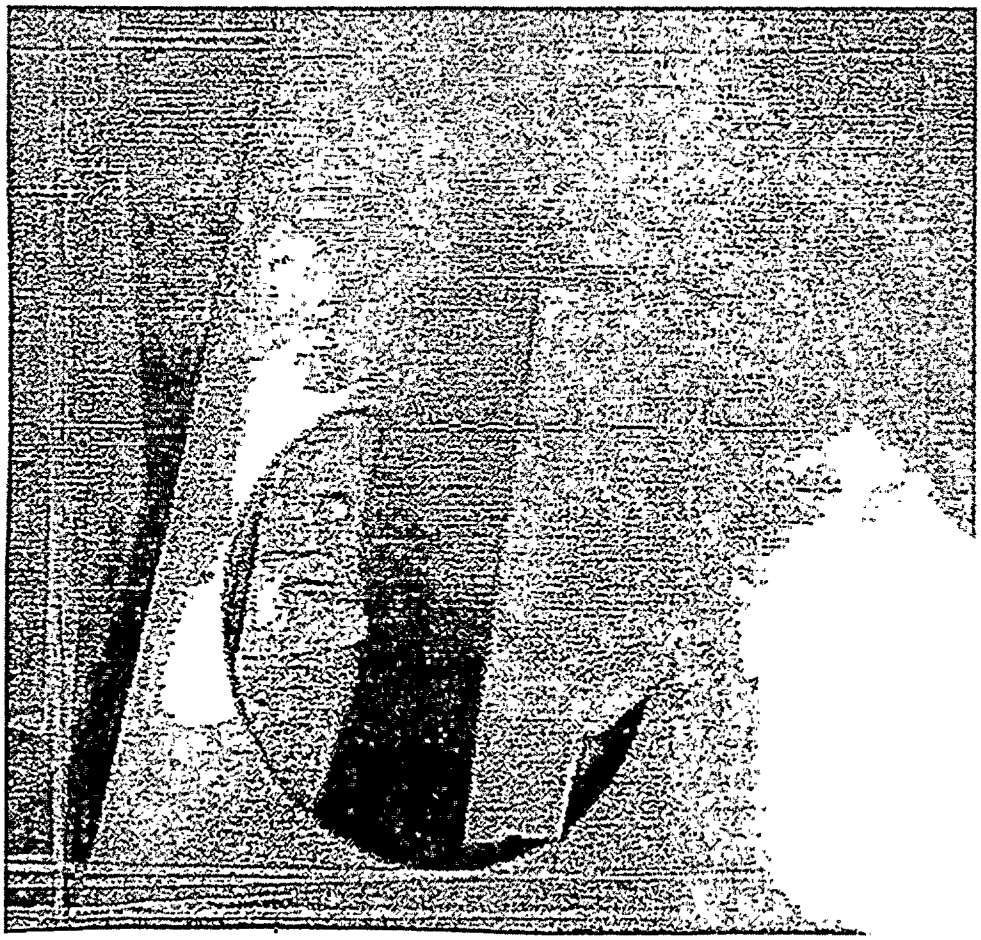

Figure 2

Photograph of Failure Surface

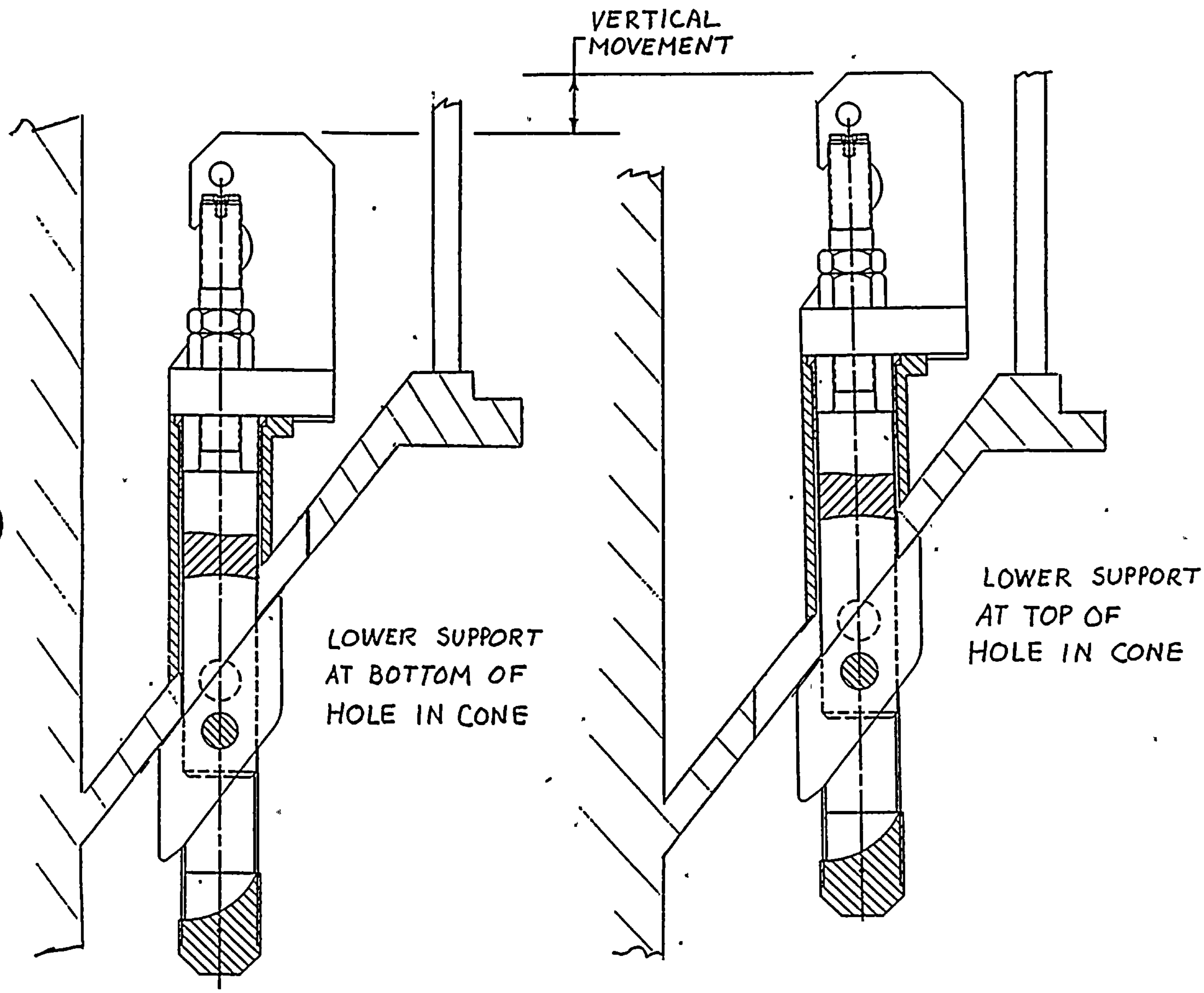

Figure 3

Toggle Bolt Movement in Shroud Support Cone

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