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Shroud Repair Anomalies
Nine Mile Point Unit 1, RFO14

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REVISION STATUS SHEET

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IMPORTANT NOTICE REGARDING

CONTENTS OF THIS REPORT

Please read carefully

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 and upper contact points of the upper spring assembly. Sliding marks are not evident at all other contact points for the upper springs located at the 90, 270, and 350 degree locations.

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-vessel 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.

3.3 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.

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.

4.5 Flow Induced Vibration (FIV)

Natural frequency evaluation with 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 occurred 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

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

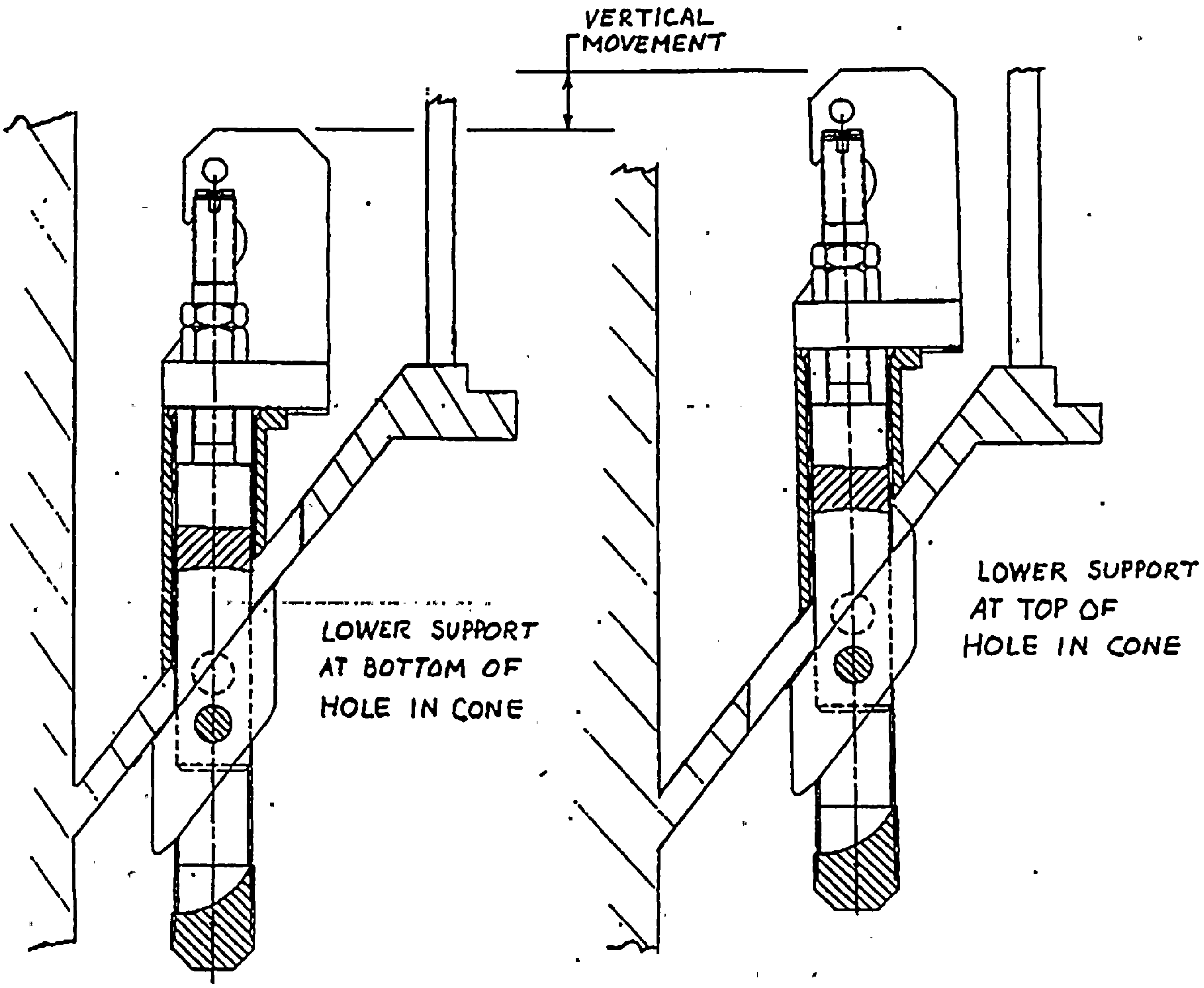

Figure 3

Toggle Bolt Movement in Shroud Support Cone