UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO THE CRACK INDICATIONS IN THE CORE SHROUD

CAROLINA POWER & LIGHT COMPANY

BRUNSWICK STEAM ELECTRIC PLANT, UNIT 1

DOCKET NO. 50-325

1.0 INTRODUCTION AND BACKGROUND

In July 1993, the Carolina Power & Light Company (CP&L or the licensee) informed the NRC of numerous cracks contained in the core shroud of Brunswick Steam Electric Plant (BSEP), Unit 1. The cracks were discovered by the licensee during visual examinations (VT) of the core shroud during the current refueling outage. The VTs were performed by the licensee in accordance with the recommendations contained in General Electric Company (GE) Rapid Information Communication Service Information Letter (RICSIL) 054, "Core Support Shroud Crack Indications," that was issued as a result of cracking previously discovered in the core shroud of a foreign-owned GE boiling water reactor (BWR).

The licensee's initial VTs of the BSEP Unit 1 core shroud revealed a circumferential crack at horizontal weld H-3, which joins the top guide support ring (3 inches high x 7 inches deep) to the lower shroud and several short axial cracks in horizontal weld H-4 in the lower shroud. The licensee extended the VT of the H-3 weld to a 100% inside diameter (I.D.) and 100% outside diameter (O.D.) examination of the weld's circumference, and determined that the crack extended nearly 360° around the top guide support ring. Initial depth characterization by ultrasonic testing indicated that the crack at the H-3 weld was at least 0.4 inches deep. However, more detailed testing revealed the actual depth to be up to 1.7 inches.

2.0 CHARACTERIZATION AND ROOT CAUSE ANALYSIS

The occurrence of a crack found at horizontal weld H-3 is potentially significant. This crack is located in the heat affected zone of the weld (2.25 inches thick) and is predominantly circumferential in nature with some short axial branches. The axial components of the crack are insignificant in comparison to the length of the crack's circumferential component. Subsequent evaluations of the H-3 crack by ultrasonic testing (UT) methods and by boat sample analyses indicated that the crack at the H-3 weld is significantly deeper than was originally determined (up to 1.7 inches deep in some radial locations). Numerous other axial and circumferential cracks were also discovered by the licensee at welds H-1, H-2, H-4 and H-5 of the core shroud upon more extensive examinations of the shroud. The cracks associated with the H-1 and H-2 welds were also of significant length. Evaluation of these cracks will be addressed in Section 3.0 of this Safety Evaluation (SE). The cracks associated with the H-4, H-5 and H-6 welds were determined by the licensee to be below the structural integrity screening criteria proposed by GE. These screening criteria are discussed further in Section 3.0 of this SE.

Analysis of the boat samples taken from the H-3 and H-4 welds indicated that the cracking was primarily intergranular stress corrosion cracking (IGSCC). In addition, the cracking found at the H-5 weld location (near midplane of the core beltline) is considered to have been irradiation assisted cracking (IASCC) due to the higher neutron fluence in this region. The top guide support ring in the BSEP Unit 1 core shroud was fabricated from rolled and cut American Society of Mechanical Engineers (ASME) SA 240 Type 304 stainless steel plate segments that were welded together. The plates were initially solution heat treated and air quenched prior to the welding process. The carbon contents of the shroud plates range between 0.04% and 0.08%. Metallurgical analysis of boat samples taken from the H-3 weld have revealed that the cracking occurred radially in the short transverse direction of the plate. This is related to the way the ring was fabricated from plate material. The licensee has determined that the following factors have aggravated the IGSCC of the H-3 weld (1) high early life electro-chemical potential (poor water chemistry), (2) cold work from the machining processes during fabrication of the ring segments, (3) weld residual stresses, (4) thermal sensitization, and (5) exposure of the short transverse plate orientation.

3.0 ASSESSMENT OF EER 93-0536, REV. 1, FLAW EVALUATION

The licensee has performed two safety assessments, incorporated in Engineering Evaluation Report (EER) 93-0536, Rev. 1, and Plant Modification (PM) 93-0382. The scope of these documents cover the evaluation and repair, respectively, of the cracks in the BSEP Unit 1 core shroud. The staff's evaluation of EER 93-0536, Rev. 1, is provided in this section, and the staff's evaluation of PM 93-0382 is provided in Section 5.0 of this SE.

The licensee has evaluated the cracks in the core shroud in accordance with the screening criteria contained in GE Report No. GENE-523-123-0993, Rev. 1, "Evaluation and Screening Criteria for the Brunswick Shroud Indications." GENE-523-123-0993, Rev. 1, contains information regarding (1) use of ASME Boiler and Pressure Vessel Code (Code) proximity rules for the determination of the effective flaw lengths in the shroud; (2) a structural analysis which uses linear elastic fracture mechanics (LEFM) and limit load approaches for the determination of allowable flaw sizes; and (3) screening criteria based on through-wall flaws. Although not required by the ASME Code for austenitic materials such as the stainless steel shroud, the LEFM analysis provided justification for an allowable through-wall flaw length of approximately 110 inches. The LEFM analysis is conservative in comparison to limit load analysis which yielded an allowable through-wall flaw size of approximately 300 inches. Both analyses considered loading contributions from internal differential pressure, weight and seismic for both normal and faulted conditions. The resulting stresses in the shroud were very low (less than 6 ksi). A bounding crack growth rate of 5×10^{-5} inches/hour was used to estimate the amount of crack growth during the upcoming operating cycle. This crack growth was added to the effective flaw lengths determined from the ASME Code proximity rules before comparison with the allowable flaw lengths determined from the analysis.

The report used the 300 inch allowable through-wall flaw length from the limit load analysis as the basis for setting a screening criterion for each 90° quadrant of the shroud. The GE criterion states that the cumulative flaw length cannot be more than 75 inches (i.e., 300 inches/4) in any 90° sector of the shroud. The screening criterion is considered on a "rolling" quadrant basis with the worst cracking defining the radial orientation of a quadrant. It is noted that the screening criterion is conservative with respect to the LEFM analysis. The staff concluded that these criteria constituted an acceptable approach for demonstrating structural integrity of the core shroud.

The cracks in the H-2 and H-3 welds exceeded the limits associated with the above criteria. The licensee decided to implement a repair encompassing the H-2 and H-3 welds to justify continued operation of the shroud. The repair consisted of a series of 12 "clamps" around the shroud circumference, encompassing the H-2 and H-3 welds. In their evaluation, the licensee also concluded that, based on additional fracture mechanics analyses, the H-3 weld would have been acceptable for continued operation without repair. However, the NRC staff has concluded that, considering the uncertainties in nondestructive testing, crack growth analyses and structural evaluations; it would not be prudent to operate with a core shroud having a 360 degree crack of any significant depth. The cracking in the H-1 weld also exceeded the GE screening criteria. The licensee concluded that this cracking did not require repair based on the fracture mechanics evaluation of the H-3 weld cracking which bounded the conditions of the H-1 weld. The staff found this evaluation acceptable because of the lesser severity of the cracking in the H-1 weld. The largest crack discovered at weld locations in the mid-shroud shell plates was a 42 inch long circumferential crack at weld H-5. The length of this crack was within the limits set by the GE screening criterion.

In summary, it is important to emphasize that the NRC staff considers that enough uncertainty exists in the crack sizing, crack growth and structural analyses to have precluded a determination that adequate structural integrity exists with a 360° crack of any significant depth in the shroud. The staff concluded that the safety assessment in EER 93-0536, Rev. 1., is not acceptable based on structural integrity evaluations alone and that the licensee acted prudently in performing a modification (repair) of the shroud as the basis for continued operation of the unit. The staff's evaluation of the licensee's modification to the shroud, as proposed in CP&L PM 93-038, is given in Section 4.0 of this SE.

4.0 EVALUATION OF CP&L PM 93-038 OF THE BSEP UNIT 1 CORE SHROUD

CP&L PM 93-038 contains the licensee's proposed method for modifying the core shroud around the H-2 and H-3 welds, and the licensee's safety assessment of the modification. The NRC staff requested that the licensee submit their safety assessment for staff review. The proposed modification called for installing 12 mechanical clamps symmetrically around the shroud. The clamps are large enough to encompass both the H-2 and H-3 welds. Four holes will be machined through the shroud at each of the 12 clamp locations (two above the H-2 weld and two below the H-3 weld) to allow for positioning and attachment of the clamps. Bolts and keeper nuts will be used to lock the clamps in place following their installation. The keeper nuts will be tack welded to the bolts to fuse the nuts in place and ensure that the bolts remain in position. The licensee has chosen to fabricate the parts used in the modification from IGSCC resistant materials:

- Bolts and keeper nuts - American Society of Testing and Material (ASTM) A479 Type XM-19 steel. The grade chosen is an austenitic, precipitation hardened stainless steel with a maximum carbon content of 0.04%, annealed at 2000°F, followed by rapid cooling at a rate not less than 200°F/minute.

- Repair clamps - ASTM A182 Type 304L stainless steel. The grade chosen is an austenitic grade, annealed at 1900 - 2100°F followed by quenching in circulating water to a temperature below 400°F.

- Washers and retainers - either ASTM A240 or ASTM A276 Type 304, 304L, 316, or 316L stainless steels.

- Weld filler metal - ASME ER308L or ER308 weld material.

The annealing heat treatment selected for the parts fabricated from Type XM-19 steel will keep the yield strength of the parts below 90 ksi. XM-19 stainless steels with yield strengths above 90 ksi have been shown to be susceptible to IGSCC. The licensee has stated that these materials will be tested for sensitization prior to installation of the clamps. The staff has reviewed the materials and fabrication methods selected and has determined that they are acceptable for use in the proposed modification to the shroud.

The design and performance requirements for the shroud repair clamps are documented in "Design Specification, GE 24A5111, Revision 2, Shroud Repair Clamp." The licensee submitted a report which summarized a stress analysis performed by GE to demonstrate that the modification ensures that the shroud satisfies the BSEP licensing basis criteria for stress allowables and deflections as defined in the design specification, and will, therefore, ensure the structural integrity of the shroud in the region of the H-2 and H-3 welds.

The GE stress analysis was documented in GE-NE-523-143-1093, Rev. 1, "Brunswick Unit 1 Shroud Repair Hardware Stress Analysis," dated December 1993. GE analyzed the shroud and repair clamps for normal, upset, emergency and faulted conditions, in accordance with the repair clamp design specification and the requirements of the 1992 Edition of the ASME Code, Section III, Subsection NG, "Core Support Structures." The licensee thus concluded that the modification would ensure that the shroud will meet its safety function of maintaining the core geometry and providing a floodable volume.

The staff held several conference calls with the licensee and GE to obtain clarification of the analytical methodology and discuss some specific aspects of the analysis. In one discussion, the staff requested that the licensee provide information to support its position that a fatigue evaluation was not required. The licensee provided information to demonstrate that the service loadings on the shroud and repair clamps satisfy the requirements of ASME Code, Section III, Subsection NG, Paragraph NG-3222.4(d), "Components Not Requiring Analysis for Cyclic Operation," and, therefore, a fatigue evaluation was not required. In another discussion, the staff questioned the licensee's classification of the bending stress in the repair clamp bolts as secondary, and requested that the licensee revise its analysis with the bolt bending classified as a primary stress. The licensee submitted additional information on January 10, 1994, that provided the revised stress calculations. These revised calculations demonstrated that the bolt stresses were within the allowables defined by the licensee's design specification and within the allowables defined by the ASME Code, and are acceptable to the staff.

The staff also questioned the licensee's use of a coefficient of static friction of 0.5 for determining whether the joint would slip under normal and upset load conditions. This coefficient is inherently difficult to determine and could be lower than 0.5. In response to the staff's concern, the licensee provided limited test data to support the use of a coefficient of friction of 0.5. In addition, the licensee indicated that it had analyzed the repair for normal and upset loads assuming that slip occurred, and that the resulting stresses in the shroud, repair clamps and bolts satisfied the requirements in the design specification and the ASME Code. Further, the licensee stated that any potential joint slippage would not present a safety concern because any such slippage would be limited by the fabrication clearances between the bolts and the bolt holes in the shroud and the clamp and, therefore, would not affect the ability of the top guide to maintain core geometry, or the core spray piping and spargers to provide coolant during emergency conditions. Because the licensee has indicated that potential joint slippage would not present a safety concern, the staff considers this issue to be resolved.

Based on the staff's evaluation above, the staff concludes that the proposed modification of the BSEP Unit 1 core shroud by the licensee provides an acceptable method for ensuring the structural integrity of the core shroud around the H-2 and H-3 welds. The proposed modification is designed to provide adequate shroud structural integrity in the location of the H-2 and H-3 welds for the remaining life of the unit.

5.0 CONCLUSION

The licensee has performed a detailed examination of the entire BSEP Unit 1 core shroud during the current refueling outage and has identified a significant amount of cracking in the shroud. The licensee has evaluated the structural integrity of the core shroud in the shroud's current degraded condition. The licensee has determined that the crack at the H-3 weld represents the bounding case. The licensee has proposed to mitigate the potential for failure of the H-3 weld by modifying the shroud to include a series of mechanical clamps which encompass the H-2 and H-3 welds. Based on the licensee's stress analysis of the repair clamps performed by GE, the staff finds that the licensee's proposed modification to the shroud is acceptable.

Based on the structural integrity analyses, the staff concluded that the flaws associated with the H-1, H-4, H-5, and H-6 welds will not adversely impact the shroud's structural integrity during the next operating cycle. The staff's position is that 360° shroud cracks are unacceptable for continued operation, based on structural integrity analyses alone. In this case (i.e., for 360° cracks), it is important to emphasize the importance of performing an appropriate, acceptable method of repair to assure the structural integrity of the shroud during subsequent operating cycles.

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