Attachment 1

To

Letter NL-18-021

Fracture Mechanics Assessment of Embedded Flaw Repair Acceptability for Indian Point Unit 2

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Fracture Mechanics Assessment of Embedded Flaw Repair Acceptability for Indian Point Unit 2

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Westinghouse

Background on Embedded Flaw Repair

During the Spring 2018 outage, as part of the bare metal visual inspection (VT-2) associated with the head penetration inspection program for Indian Point Unit 2 (IP2), a white substance, indicative of reactor coolant leakage, was discovered on top of the reactor vessel head at Penetration No. 3. Subsequent liquid penetrant testing (PT) and eddy current testing (ET) examination revealed relevant indications on the inside wetted surface of the J-groove weld. One of the indications in the J-groove weld was determined to be axial with some measurable through-weld distance, and is concluded to be the source of leakage through the annulus region of the penetration. Ultrasonic testing (UT) and ET was also performed from the inside surface of the Alloy 600 penetration tube, which revealed no indications on the inside or outside surfaces of the tube. It should be noted that the VT-2 visual examination of the reactor vessel head did not identify any other relevant indications or base metal wastage.

Therefore, the use of the Westinghouse embedded flaw repair process for Penetration No. 3 at Indian Point Unit 2 is appropriate and is consistent with repairs performed for numerous other plants with similar as-found indications in the J-groove weld. The embedded flaw repair process involves depositing weld material, which is Primary Water Stress Corrosion Cracking (PWSCC) resistant, over the entire surface of the J-groove weld on the penetration nozzle of interest, as well as over the outside surface of the nozzle tube as shown in Figure 1. At least three weld layers of Alloy 52/52M repair weld material are deposited (360° full circumference) covering the wetted surface of the penetration nozzle J-groove weld including 0.5 inch past the J-groove weld buttering and stainless steel cladding interface. At least two weld layers of A52/52M are deposited on the outside surface of the head penetration nozzle below the J-groove weld. Since the Alloy 52/52M repair weld material is PWSCC resistant, the detected indications in the attachment weld of the head penetration nozzle of interest is then isolated from the primary water environment and is no longer susceptible to PWSCC.

Since 2001, Westinghouse has completed approximately 53 embedded flaw repairs (EFR) for indications on the J-groove weld or the outside surface of the penetration nozzle. After each embedded flaw repair was implemented, each repair has been inspected by PT in subsequent outages. To date, no PT examination has shown evidence of PWSCC in the embedded flaw repair deposits. Thus, the lack of any further PWSCC related cracking after the implementation of the EFR demonstrates the overall acceptable inservice performance of this particular repair method.

The embedded flaw repair methodology is based on extensive analytical work completed by the Westinghouse Owners Group (currently the Pressurized Water Reactor Owners Group (PWROG)), and a large collection of test data obtained under the sponsorship of Westinghouse, Babcock & Wilcox (B&W) and the former Combustion Engineering Owners groups (CEOG), as well as the Electric Power Research Institute (EPRI). The technical basis of the embedded flaw repair process is documented in WCAP-15987-P Revision 2-P-A [1] and has been reviewed and accepted by the Nuclear Regulatory Commission (NRC) in the United States. In the NRC Safety Evaluation Report that was incorporated in WCAP-15987-P Revision 2-P-A, the NRC staff concluded that the embedded flaw repair process described in WCAP-15987-P provides an acceptable level of quality and safety. The staff also concluded that WCAP-15987-P is acceptable for referencing in licensing applications.

Embedded Flaw Repair Assessment

With the implementation of the embedded flaw repair process at Indian Point Unit 2, PWSCC is mitigated and no longer a credible crack growth mechanism. Fatigue is the only remaining credible crack growth mechanism. While normal steady state operating stresses are the primary driving forces for crack growth due to PWSCC, the through-wall stresses resulting from plant operating thermal and pressure transients are the driving forces for fatigue crack growth. The pressure and thermal transients in the closure head region are typically very mild as indicated by the low fatigue usage factors in that region. The IP2 fatigue usage at the J-groove weld is approximately 0.3 considering conservative operational basis earthquake (OBE) loads with postulated cycles over 40 years of operation. Since IP2 is only scheduled to operate for an additional two years, the expected usage factor would be decreased to approximately 0.03, with the OBE cycles reduced for a 2 year period. As a result, fatigue crack growth is expected to be negligible, especially for the short time duration of 24 months between inspections.

The previous analyses performed for embedded flaw repairs have demonstrated a design life greater than 10 years considering very conservative postulated flaws. Since the UT technology cannot characterize the flaw shape in the attachment weld, the fracture mechanics evaluations that have been performed assuming a hypothetical flaw that extends radially over the entire attachment weld cross-section. Thus, the historical evaluations have always bounded any actual flaws that may have been present within the attachment weld. The methodology and guidance for the fracture mechanics evaluation used in the embedded flaw repair evaluations are based on the NRC accepted WCAP-15987 Rev 2-P-A, Appendix C.3 [1].

The fatigue crack growth of the postulated J-groove weld flaw considers growth through the weld repair (about 3/16 inch thick) and also through the reactor vessel head. This fatigue crack growth assessment is performed as part of the fracture mechanics evaluation to demonstrate the integrity of the repair layer. Due to the relative thickness of the seal weld compared to the RV head, crack growth analysis results through the repair weld have always been the limiting case; however, the analysis also considers fatigue crack growth through the reactor vessel head as well. Based on the fatigue crack growth results for other four loop plants, with similar vessel head penetration configuration, any assumed postulated flaw in the attachment weld will take a period longer than 10 years to grow through the repair layer. Fatigue crack growth through the reactor vessel head, for postulated flaws in the attachment weld, is much slower and provides more than 40 years of operating life. Fatigue crack growth evaluations of postulated flaws in the Alloy 600 tube (although none are present at Penetration No. 3 at Indian Point Unit 2) have also been performed and have produced insignificant growth of postulated flaws. Any initial postulated axial or circumferential flaws (on the order of 20% of the tube wall thickness) embedded in the Alloy 600 tube after the repair would not reach 75% of the wall thickness (ASME Section XI allowable [2]) in less than 10 years. Thus, these previous fracture mechanics evaluations demonstrate that a postulated flaw size encompassing the attachment weld shape or postulated flaws in the Alloy 600 tube are acceptable for duration of at least 10 years based on ASME Section XI flaw evaluation rules. Since IP2 is only scheduled to operate an additional two years, this results in a significant margin of safety relative to other plants with similar reactor vessel head penetration design.

The above mentioned fracture mechanics evaluations consider through-wall time history transient and welding residual stresses based on the outermost reactor vessel head penetration nozzle, and is based on a detailed three-dimensional elastic-plastic finite element analysis. The outermost penetration nozzle through-wall stresses are the highest, most conservative, and therefore bound the embedded flaw repair analysis of any other inner penetration nozzles. For other plants, the indications are typically found on the outermost penetration nozzle J-groove weld; however, for Indian Point Unit 2 the indication was found on one of the centermost penetrations. In addition, several of the previous reactor vessel head repairs analyzed were four loop Westinghouse plants similar in construction to Indian Point Unit 2, with similar design basis transients. Thus, the fracture mechanics results determined for a typical plant with an indication on the outermost penetration bound the indication found on Penetration No. 3 for Indian Point Unit 2.

Indian Point Unit 2 is requesting operation for one fuel cycle (24 months) with the embedded flaw repair at Penetration No. 3. As mentioned above, plant specific analysis experiences for plants with embedded flaw repairs show that the integrity of the embedded flaw repair and acceptability of the flaws in the repaired penetration nozzles were demonstrated for 10 years or more of plant operation. Examinations performed at these plants in subsequent refueling outages after the repair, have shown no evidence of any crack growth or new cracks in the repaired penetration nozzles of interest. Thus, the 10 year or more service life justified by analysis has remained valid after each inspection, extending the operation duration to another 10 years for the repair.

The flaw detected in Indian Point Unit 2 is typical of those detected in the head penetration nozzle attachment weld that is subjected to PWSCC. Plant specific technical basis evaluations have been performed for a number of plants in the United States that have flaws similar to Indian Point Unit 2, which have been repaired using the embedded flaw repair process. These technical basis evaluations have been submitted, reviewed and accepted by the NRC and have, in each case, confirmed that the embedded flaw repair process meets the acceptable level of quality and safety.

Conclusion of Embedded Flaw Repair Acceptability Assessment

Based on actual plant operating experiences with similar embedded flaw repairs performed for more than 50 penetration nozzles across the US fleet, it is concluded that the Westinghouse Embedded Flaw Repair methodology can be successfully used to repair the as-found flaw detected at Indian Point Unit 2 penetration nozzle attachment weld. The basis for this conclusion has been demonstrated through numerous ASME Section XI analyses reviewed and accepted by the NRC, as well as inspection results since 2001 that have shown no additional flaw growth of any kind after the repairs. The success of the embedded flaw repair is attributed to the PWSCC resistant weld metal used to cover the susceptible region of the head penetrations and the negligible fatigue crack growth rate within the closure head region. Indian Point Unit 2 Penetration #3 is near the center of the reactor vessel head and is bounded by analyzed outer penetration locations previously justified for more than ten years of operation with an embedded flaw repair. Furthermore, the previous fracture mechanics evaluations for the embedded flaw repair performed in accordance with the NRC approved WCAP-15987 Revision 2-P-A [1] report have demonstrated that a postulated flaw size encompassing the attachment weld shape are acceptable for duration of at least 10 years based on ASME Section XI flaw evaluation rules. The embedded flaw repair proposed for Indian Point Unit 2 Penetration No. 3 is considered bounded by previous analyses and therefore the structural integrity of the closure head and the penetration are maintained for at least one fuel cycle of operation (24 months).

References

1. Westinghouse WCAP-15987-P, Revision 2-P-A, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations," December 2003. (Westinghouse Proprietary Class 2)

2. ASME Boiler & Pressure Vessel Code, 2007 Edition with 2008 Addenda, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.

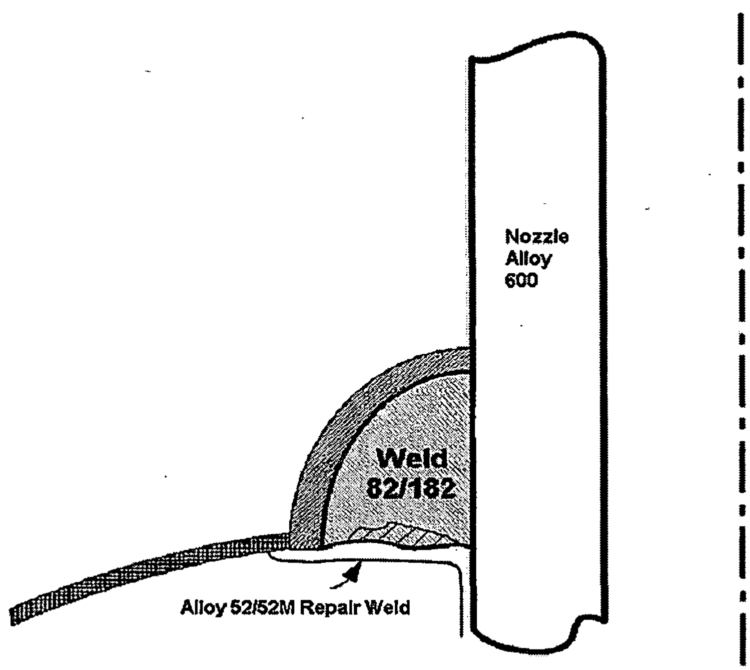

Figure 1 Schematic of Typical Repair Configuration for the Surface Flaw in the J-groove Weld