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

ON THE FLORIDA POWER AND LIGHT COMPANY'S SUBMITTAL DATED 3/2/1995

ST. LUCIE UNIT 2 - FRACTURE MECHANICS EVALUATION

OF PRESSURIZER INSTRUMENT NOZZLES

1.0 INTRODUCTION

On March 2, 1995, Florida Power and Light Company (the licensee) submitted in a report, for NRC approval, its fracture mechanics evaluation of St. Lucie pressurizer instrument nozzles [Reference 1]. In subsequent response to the NRC staff's request for additional information (RAI); the licensee forwarded to the NRC its response to RAI [Reference 2] on July 7, 1995 and Revision 1 [Reference 3] of the report on August 2, 1995. These reports are updates of the submittal [Reference 4] dated March 28, 1994, which was approved by the NRC on April 1, 1994.

IWB-3132 of Section XI of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME) Code states that components with flaw indications shall be acceptable for service without the flaw removal, repair, or replacement if an analytical evaluation, as described in IWB-3600, meets the acceptance criteria of IWB-3600. Using IWB-3600, the licensee's contractor made some very conservative assumptions in its 1994 flaw evaluation to gain approval for one fuel cycle. The current submittal by the licensee was developed by a new contractor, Babcock and Wilcox Nuclear Technologies (BWNT) and is intended to gain approval for 30-year plant life, using more realistic assumptions and employing the finite element method (FEM) in the analytical evaluation of the pressurizer instrument nozzles flaws. A proposed inservice examination plan in accordance with IWB-2420 (b) and (c) is also included in this report.

2.0 BACKGROUND

During the 1994 refueling outage, the licensee found boric acid leakage from the "C" instrument nozzle in the pressurizer upper head of St. Lucie Unit 2. Subsequent nondestructive examination detected indications in two other similar instrument nozzles. To prevent further leakage, the licensee repaired all four nozzles by welding Inconel 690 pads to the nozzles at the outside surface of the pressurizer head. Also, to justify restart without removing and repairing the nozzle flaw at the inside surface of the pressurizer head, the licensee submitted a flaw evaluation in accordance with IWB-3600. This submittal was approved by the NRC on April 1, 1994. Current submittals, 32-1235127-00, -01, and -02, and 32-1235128-00, -01, and -02 for St. Lucie 2 pressurizer instrument nozzles, can be considered as updates of the 1994 report.

3.0 EVALUATION

The current analysis submitted by the licensee used the characterization of the pressurizer instrument nozzles flaw reported in the approved 1994 submittal. The assumed flaw depth of 0.875 inches from the flaw characterization was equal to the weld depth including the butter and is considered reasonable by the staff. Methods and acceptance criteria that are acceptable to the staff for evaluating flaw indications exceeding the allowable flaw size in IWB-3500 are described in IWB-3600 of Section XI of the ASME Code. The six BWNT reports submitted by the licensee on St. Lucie 2 pressurizer instrument nozzles were developed based on the above-mentioned acceptance criteria of the ASME Code. The staff's evaluation includes the following subjects: transient selection, finite element modeling, film coefficients for the thermal analysis, the proper formula for applied K calculations, and the fracture toughness curves (K_{Ic} and K_{Ia}) from Appendix A of Section XI of the ASME Code. In the fatigue analysis, the crack growth rate curves used were from Figure A4300-1 of the same appendix. Water environment curves were used for these surface flaws.

3.1 TRANSIENT SELECTION

The report reviewed the transients likely to produce maximum tensile stress on the inside surface of the pressurizer. They include 100°F/hr heatup, 200°F/hr cooldown, an upset condition transient of 53°F/hr step-down (pressure = 1740 psia), a 53°F/hr step-up (pressure = 2400 psia), and loss of secondary pressure. A total of 15 cases were analyzed with their stresses documented in Report 32-1235127-02. Among them, the 53 °F/hr step-down transient gave the highest stresses and was identified as the bounding transient. In the fatigue analysis, the report assumed 375 cycles of normal heatup/cooldown, 360 cycles of upset condition transients, 150 cycles of leak test, 4 cycles of emergency condition transients, and some secondary normal operating transients. Since all design transients of significance have been considered, the staff agrees with the licensee in its selection of transients and the definition of design transients and their cycles in the fatigue analysis for 30 more years of plant operation.

3.2 FINITE ELEMENT MODELING

To account for the "Hillside Effect" caused by the non-radial penetration of the instrument nozzle to the pressurizer wall, the report used a radius, which is 1.52 times the actual radius of the pressurizer, in its FEM modeling. The staff pointed out in the RAI that this approach would take care of the stresses due to the pressure load, but not the stresses due to the thermal load. In Revision 1 of the reports (the -02 series), the staff's concern is alleviated by the licensee's approach of separating the final nozzle stresses into a pressure part and a thermal part and increasing the thermal part by 20% to account for the "Hillside Effect." An assessment of the effect of model radius on thermal stresses was given in Reference 2.

It should be pointed out that a mistake in the equation for calculating the non-radial nozzle stress concentration factor, K_{nr}, in the previous version of the reports (the -00 and -01 series) has been corrected in Revision 1 of the reports. As a result, the multiplying factor applied to the radius of the FEM modeling was reduced from 2.5 to 1.52 and the overall safety margins for crack growth increased significantly.

3.3 FILM COEFFICIENTS

In the thermal analysis, the report used heat transfer coefficients in the water space instead of the coefficients in the steam space. This resulted in conservative tensile stresses because of the use of lower heat transfer coefficient in heating and higher coefficient in cooling of the pressurizer inside surface. Specifically, the report used a coefficient of 461 BTU/(hr-ft^2-°F) based on a natural convection in the turbulent region over a horizontal plate with an average temperature of 650°F and a delta T of 15°F. In response to the staff's request to reexamine this coefficient, the licensee expanded its consideration in Revision 1 to include the case for the step-down transient, where boiling can occur, and used a heat transfer coefficient of 10,000 BTU/(hr-ft^2-°F) for that case. The staff considers these values reasonable based on the arguments supplied in Reference 2 and Reference 3. Further, when compared to the heat transfer coefficient used in the inside surface of the pressurizer in a typical RELAP analysis, the report's coefficient appears to be adequate.

3.4 MARGINS BETWEEN APPLIED STRESS INTENSITY FACTOR AND MATERIAL TOUGHNESS

In the fracture mechanics analysis, the formula for a nozzle corner crack from an EPRI report [Reference 5] was used to calculate the applied stress intensity factors for various load cases. For the arrest toughness, K_{Ia}, the report used 200 ksi(in)$^{1/2}$, the maximum value of the arrest toughness curve in Appendix A, Section XI of the ASME Code. Using this upper-shelf value was conservative considering the high temperature of the transients in the analysis.

The report employed the bounding upset transient of 375 cycles in the fatigue analysis to bound the transients mentioned in Section 3.1, which consist of 375 cycles of normal heatup/cooldown, 360 cycles of upset condition transients, 150 cycles of leak test, and 8 cycles of pressure tests. The report arrived at an applied stress intensity factor of 46.42 ksi(in)$^{1/2}$ at the final flaw size of 0.966 inches for the normal and upset loading condition. The stresses associated with the bounding upset transient were determined by the FEM analysis. When this stress intensity factor was compared to the K_{Ia} of 200 ksi(in)$^{1/2}$, a safety factor of 4.31 would ensue, which has a comfortable margin over the factor of (10)$^{1/2}$ or 3.16 required by the ASME Code. The transient used in the report for the emergency and faulted loading condition is the loss of secondary pressure transient. The report