UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATED TO FRACTURE TOUGHNESS EVALUATION OF THE SHELL MATERIAL ON THE SECONDARY SIDE OF THE LOW PRESSURE COOLANT INJECTION HEAT EXCHANGERS

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1. INTRODUCTION

In a letter dated May 1, 1989, the staff concluded that all components reviewed as part of SEP Topic III-1, except for the shell material on the secondary side of the low pressure coolant injection heat exchangers (LPCI-HX) have adequate fracture toughness. To demonstrate that this material has adequate fracture toughness, the licensee has performed a fracture toughness analysis. The fracture toughness analysis included an evaluation of stresses during normal operation, a determination of the critical crack size, and a calculation of the amount of fatigue crack propagation during normal operation. These analyses are documented in a letter dated February 4, 1991.

The shell materials on the secondary side of the LPCI-HX were designed as Class C Quality Group and were constructed of carbon steel A-212, Grade B material. The heat exchangers were built to requirements in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) Section III, 1965 Edition. These requirements did not include impact testing to determine fracture toughness.

2.0 LICENSEE EVALUATION

The licensee performed a fracture toughness analysis to demonstrate that the shell material on the secondary side of the LPCI-HX has adequate fracture toughness. The analysis indicates that approximately 1.5×10^6 cycles of heat-up and cooldown would be required to propagate an initial crack of 0.010 inch (the maximum crack size that could go undetected by inspection) to a critical crack size of 5.25 inches. The analysis indicates that approximately 1.4×10^6 cycles would be required to propagate the initial crack through the wall. Since the system startup and shutdown cycle occurs at an average of once per month, the fracture toughness analysis indicates that the number of cycles to cause leakage or failure is far beyond the anticipated service life of the LPCI-HX.

In determining the critical crack size, the licensee calculated the fracture toughness at the minimum heat exchanger service temperature of 51 °F for the A-212, Grade B shell material as 76 ksi $(in)^{1/2}$. This fracture toughness value was determined from extrapolation of two data points. The staff is concerned that extrapolation of two data points might not produce meaningful results. Hence, the staff has performed a confirmatory evaluation, which is documented in the Staff Evaluation section of this report.

The licensee's stress analysis indicates that the maximum principle stress due to steady-state operation is 16,711 psi. The licensee determined this value using hand calculations and computer assisted 2-D and 3-D finite element analyses.

The rate of fatigue crack growth was determined from crack growth studies on material similar to the A-212, Grade B shell material. The fatigue crack growth did not consider accelerated growth that occurs when the applied stress intensity factor reaches a critical value, which is below its fracture toughness. However, since the number of cycles to initiate leakage is a few orders of magnitude greater than the anticipated number of cycles of heatup and cooldown during the life of the plant, accelerated fatigue growth is not considered a significant factor in determining whether the LPCI-HX have adequate fracture toughness.

3.0 STAFF EVALUATION

The licensee's analysis is acceptable except for the determination of the critical crack size which is dependent upon the fracture toughness of the material. The staff is concerned that the extrapolation of two data points could lead to nonconservative results.

To evaluate the licensee's calculated critical crack size the staff used: (a) fracture toughness data reported in NUREG-0577, (b) crack arrest data from Oak Ridge National Laboratory on HFIR plate material and (c) pressurized cylinder burst test data reported by Keifner, et al., in a paper entitled, "Failure Stress Levels of Flaws in Pressurized Cylinder," which was printed in Special Technical Publication 536, Copyright American Society for Testing and Material. According to the material test data in NUREG-0577, A-212 Grade B material should have a mean value for the nil ductility transition temperature of 40 °F and a 90 percent confidence value of 77 °F. Figure 1 compares crack arrest data for A-212 steel (HFIR plate material) and the ASME Code lower bound K_{IR} curve. The data lie above the K_{IR} curve but only slightly above the mean data curve. Hence, we believe the ASME Code mean value K_{IC} curve would be applicable for determining the fracture toughness of A-212, Grade B material.

Using the burst test data in the paper by Kiefner, et al., and the ASME Code mean value K_{IC} curve, the calculated burst crack length is 6.33 inches for material with a nil ductility transition temperatures of 77 °F. The burst test data was used to determine an empirical relationship between plain stress fracture toughness, pipe geometry, flow stress, hoop stress at failure and through-wall flaw size. The burst test geometries are similar to the shell side geometry of the Dresden, Unit 2, LPCI-HX. Hence, the empirical relationship is applicable to Dresden, Unit 2. Since the burst crack length is greater than the critical crack length calculated in the licensee's analysis, the licensee's analysis should provide a conservative estimate of the critical crack size.

4.0 CONCLUSION

Based on the licensee fracture toughness analysis and the staff's confirmatory analysis, the staff concludes that the shell material on the secondary side of the LPCI-HX has adequate fracture toughness.

Attachment: Figure 1

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FIGURE 1

PUBLISHED CRACK-ARREST DATA FOR A-212 STEEL CONFIRM THE APPLICABILITY OF THE ASME K_{IR} CURVE TO HFIR-PLATE MATERIAL