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SUBJECT: Forwards results of analysis based on metallurgical evaluation for failed weld on 2A1 nozzle.

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May 19, 1997

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Subject: Oconee Nuclear Station
Docket Nos. 50-269, -270, -287
Justification for Continued Operation of
Oconee Unit 1 as a Result of Oconee Unit 2
HPI Line Leak
Supplemental Information
NRC TAC No. M98454

In a letter dated May 7, 1997, Duke committed to provide the NRC with the results of a simplified fracture mechanics analysis based on a metallurgical evaluation for the failed weld on the 2A1 nozzle. As agreed upon in an NRC/Duke call on May 16, 1997, it was agreed that submittal of these results could be delayed from May 16 to May 19, 1997. Please find the results of this analysis attached. Please address any questions to D. A. Nix at (864) 885-3634.

Very Truly Yours,

J W Hampton

J. W. Hampton
Site Vice President

A001/1

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Attachment
Results of Simplified Fracture Mechanics Analysis

Question 4e:

Based on the root cause of the cracking, provide an assessment of the time to initiate and propagate a crack through wall of the piping.

Response:

The failure analysis of the 2A1 MU cracked pipe/safe end weld indicates the root cause as being high cycle thermal fatigue, due to thermal mixing of makeup and reactor coolant fluids. The fracture surface revealed the fatigue striations spaced at no more than 1 micron (10^{-6} meter), although the striations were not necessarily evenly spaced, indicating there is probably a spectrum of cyclic events that drove the crack through the wall of the pipe. It is believed that the through-wall propagation of the crack occurred over a long period of time (indicated by a heavily oxidized crack surface).

Based on the ASME Code, Section XI, Appendix C fatigue crack growth curve for austenitic stainless steel, a striation spacing of 1 micron correlates to an alternating crack driving stress intensity of about 40 ksi-in$^{1/2}$. This may be considered to be an upper bound, since the striation spacing is less than 1 micron. In fact, based on the results of the failure analysis, the crack driving stress intensity factor could have contributions as low as 5 ksi-in$^{1/2}$, which is the threshold for fatigue crack growth.

Turbulent penetration of reactor coolant into the MU nozzle could cause fluid temperature variations between 500 °F and 100°F at the unsteady interface between the reactor coolant and makeup fluids. The location of this interface along the MU nozzle would depend on the makeup flow rate. There are currently no measured data or analytical predictions available to provide thermal boundary conditions for a fracture analysis, although computational fluid dynamics (CFD) is underway. However, in order to pursue the theory that turbulent penetration could reach the weld region, a simplified fracture analysis has been performed to correlate thermal mixing with fatigue crack growth, using a worst case temperature change of 400°F. Other sources of significant temperature variation could be: (1) back-flow of reactor coolant into the makeup pipe during partial pump operation and with low normal makeup, and (2) reactor coolant leakage through annular gaps between the thermal sleeve and nozzle.

Examination of the crack surface revealed a circumferential inside surface flaw, extending about 30% into the wall over an arc length of approximately 180°. Over the remainder of the circumference, the flaw depth gradually increased until it became through wall over a 77° arc length. An initial flaw depth of 0.050" was used in the simplified fracture analysis as a starting point for tracking fatigue crack growth through the pipe wall.

The fracture analysis considered a very conservative 400°F change in fluid temperature (from 500°F to 100°F) over a 12 second period as a source of thermal loading for the pipe. As such, this represents the cooling portion of the cyclic event, whereas any associated heating during a recovery portion would be expected to produce compressive stress that would not contribute to crack driving stress intensity factors. One-dimensional transient heat transfer produced a through-wall thermal gradient (with an elastic surface stress of 50 ksi) that results in a stress intensity factor of 20 ksi-in $^{1/2}$ for the 0.050" initial flaw depth. Because of decreasing thermal stress through the pipe wall, the maximum stress intensity factor for this postulated transient is 23 ksi-in $^{1/2}$ at a depth equal to 43% of the wall thickness. These stress intensity factors are within the 5 to 40 ksi-in $^{1/2}$ range indicated by the fatigue striations on the 2A1 cracked surface. It is estimated that it would take about 25,000 cycles to propagate a crack 30% through-wall, and about 100,000 cycles to go 80% through-wall.

Using an austenitic material fatigue curve without any ASME Code safety factors, it is estimated that it would take more than 1,000,000 cycles for a 50 ksi surface stress to initiate a crack. Thus a long incubation period could exist. From a review of plant operating history, the low flow phenomena occurs primarily during heat-up, cool-down and during a full power trip. Additional necessary and sufficient conditions include only one of the two "A" Reactor Coolant Pumps in operation, leakage through RCS/HPI boundary check valve (HP-126 or HP-127), and sufficient temperature in the Reactor Coolant System. Since the original plant startup, Unit 1 has experienced 95 heat-ups and cool-downs and additionally, 61 trips from full power operations. Again, based on plant operating history, it is reasonable to believe that the necessary and sufficient conditions noted above can occur on six occasions during each of the heat-ups, cool-downs and trips. Based on thermocouple data recorded for Unit # 1 at locations adjacent to 1HP-127, it is estimated that the necessary and sufficient conditions could have existed 6 hours per occasion. Given an estimate of three thermal cycling events occurring per minute, the total estimated thermal cycles are as follows:

(95 HU/CD + 61 TRIPS) x
(6 occurrences of necessary conditions / HU/CD and TRIP) x
(6 hrs / occurrence) x (60 min./ hr.) x (3 cycles / min.) = 1,010,880 cycles or approximately 1,000,000 cycles.

This number is an estimate and thus the prediction of a time-to-failure remains speculative until a source and associated frequency of the postulated thermal mixing is identified. Additional analysis is being performed using computational fluid dynamics (CFD) that will evaluate the various mechanisms that contribute to the thermal cycling. This analysis will attempt to identify the frequency of the loading and better qualify time to initiate and propagate a crack through the wall of the piping.