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AUTH.NAME	AUTHOR AFFILIATION
HAMPTON,J.W.	Duke Power Co.
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SUBJECT: Forwards summary on HPI sys analyses associated w/question 4 in NRC 970505 staff request for addl info.

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Duke Power Company
Oconee Nuclear Site
P.O. Box 1439
Seneca, SC 29679

J. W. HAMPTON
Vice President
(864)885-3499 Office
(864)885-3564 Fax

DUKE POWER

May 9, 1997

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

Subject: Oconee Nuclear Station
Docket Nos. 50-269, -270, -287
Response to Request for Additional Information
on the High Pressure Injection (HPI) System
NRC TAC No. M98454

In a letter dated May 5, 1997, the staff requested additional information to support its evaluation of the recent HPI System weld crack on Oconee Unit 2. Responses to the NRC questions were provided in Duke letters dated May 7, 1997 and May 8, 1997. In the May 7, 1997 letter, Duke Power indicated that certain analyses associated with Question 4 in the May 5, 1997, staff request for additional information would be completed by May 9, 1997.

Attached is a summary of the subject analyses. Please address any questions to J. E. Burchfield, Jr. at (864) 885-3292.

Very Truly Yours,

J. W. Hampton

J. W. Hampton
Site Vice President

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xc: L. A. Reyes, Region II
Regional Administrator

D. E. LaBarge, NRR
Project Manager

M. A. Scott, Region II
Senior Resident Inspector

Attachment 1
Supplemental Information Regarding Question 4 in May 5, 1997 NRC Request for Additional Information

Question 4a:

Provide a fracture analysis to determine the critical flaw size required to fracture the piping under normal loads during HPI injection or makeup conditions.

Response:

Analysis has been performed to determine the critical flaw size required to fracture the piping under loads during HPI injection and during normal makeup for the HPI/MU nozzle, using net section plastic collapse (limit load) methodology similar to that from the ASME Section XI, Appendix C source equations. The analysis evaluates the effect of varying part wall flaw depth and through wall flaw depth to determine the combination of flaw sizes that will prevent rupture of the piping.

The weld between the nozzle and the safe-end was made using the tungsten-inert gas (TIG) process. Because of this, the weld is very ductile such that a limit load fracture mechanics analysis is applicable. Per Section XI, Appendix C, the limit load solution does not have to consider thermal expansion stresses due to the extreme ductility of the stainless steel weld and base material.

Based on the bounding stresses at the safe-end to piping welds for the 1A1 and 1A2 nozzles during normal operation, which include those which occur during HPI and makeup injection, the resulting size of critical flaws is shown in Figure 4-1. This figure shows the combination of through wall partial circumference flaws combined with a 100 percent circumferential flaw that would reach the limit load as defined in Section XI, Appendix C during normal operation with a safety factor of 1.0.

Question 4b:

In determining the margins-to-failure, identify all assumptions and inputs into the analysis, including stresses and material characteristics.

Response:

The applicable loadings at the nozzles for Unit 1 are shown in Table 4-1. Although there is not a specific case identified for HPI injection, the piping loads would be identical to those used in the analysis for normal operating conditions. During normal operation, the temperature of the water entering the safe-end is not expected to exceed 120°F. Data collected in 1990 showed that the metal temperature was less than 160°F due to conduction down the nozzle. The material for the pipe and safe-end is 316 stainless steel (A336 F8M for the safe-end and SA 376 TP316 for the pipe). The weld was made with 308SS using the TIG process with a consumable insert for the root pass. The Section III design stress intensity (S_m) for these materials is 20 ksi at room temperature and 16.95 ksi at reactor operating temperature.

Thermal expansion analysis based upon the stratification observed by sensor data taken in 1990 is currently being evaluated as part of a larger program for requalification of all reactor coolant system attached piping at Oconee Units 1, 2, and 3. From the standpoint of determining critical flaw sizes, the absence of this data is not important since thermal expansion stresses do not contribute to the net section failure of this very ductile stainless steel piping. The effect of thermal stratification on the thermal expansion stresses was considered in an analysis for the Unit 2 nozzle, and resulted in a small decrease in the thermal expansion moments at the nozzle. Thus, thermal stratification is not considered to be significant from the standpoint of limit load pipe failure.

Figure 4-2 shows the allowable flaw size that meets the stress criteria of ASME Section XI, Appendix C, including the factor of safety of 2.77. This figure shows that for a 30 percent part-wall circumferencial through-wall crack, combined with a 42 percent of circumference through wall crack would meet Code stress criteria (without the OBE). With the OBE, the allowable through wall crack could be 35 percent of the circumference. The observed cracking in Unit 2 can be approximated as a 33 percent of circumference through-wall crack with a circumferential crack in the remainder of the pipe that is less than 30 percent of thickness. Thus, Section XI stress criteria is satisfied.

Question 4c:

Determine the sensitivity of the critical flaw size and margin-to-failure on the existence of the complex flaw geometry, i.e., 360° internal part through wall crack and through wall cracking.

Response:

A fracture mechanics evaluation based on the geometry of the failed weld on the Unit 2 nozzle (2A1) has been conducted to evaluate the effects of the complex geometry of the flaw on the critical flaw size evaluation. The geometry of the flaw is not exactly like the 360° internal part through wall crack and part circumference through wall crack evaluated in the answers to questions 4a and 4b. This analysis was conducted with a model that determined the limit load on the actual flawed section(using the same criteria as in ASME Section XI, Appendix C) for a pipe with wall thickness distribution as actually determined from the Unit 2 weld failure analysis.

The metallurgical examination results available at this time indicate that the crack in the pipe to safe end weld has a 360 degree ID crack which is about 25% - 30% through wall except that the crack has propagated through the wall for an arc that spans approximately 77 degrees on the OD and 180 degrees on the ID. The results of this analysis show that factor of safety against limit load failure for the combined case of normal operation and the OBE is 3.08. This exceeds the 2.77 required safety factor of ASME Section XI.

Question 4d:

Determine the sensitivity of the critical flaw size and the margin-to-safety on the uncertainty in the mechanical and thermo-hydraulic loads at the pipe/safe-end weld.

Response:

There is little uncertainty in the loadings at the safe end to nozzle weld that would contribute to limit load failure. As discussed above, thermal expansion loadings need not be included because of the ductility of the material and because thermal expansion loadings are self limiting in nature. Other conservatisms include the following:

- The analysis was conservatively conducted using the maximum temperature of the reactor coolant system for determining the material design stress intensity (S_m) of 16.95 ksi. The makeup flow is much colder. At 120F, S_m increases to 20 ksi. A comparable increase in the limit load would be expected.
- The analysis of ASME Section XI is based on thin shell theory. In reality, internal cracking removes material that is closer to the neutral axis of the section. Since the small diameter makeup piping has a relatively small R/t ratio, an actual plastic analysis for the cracked section would show even greater load carrying capacity since the remaining material would be at a further distance from the neutral axis.
- The thermal-hydraulic loadings for the nozzle that contribute to primary loadings (that would lead to pipe rupture) are negligible. Primary fluid loadings due to water hammer, sudden valve closure, etc, that could produce primary loadings, are not expected.
- The actual material properties are expected to be greater than those specified in the ASME Code. Use of actual material properties in the analysis would be expected to show that additional margin exists.

Question 4f:

Provide a revised leak-before-break analysis based on the complex flaw geometry as found in the cracked and leaking pipe/safe end weld.

Response:

Leak-before-break analysis for the pipe/safe end has been performed using the PICEP Code developed by EPRI for finite-length, through-wall circumferential flaws using normal operating loads. Crack models are not available to perform leak-before-break analysis for the complex flaw geometry identified for the Oconee-2 leaking nozzle. As an alternative, PICEP-based leak-before-break analysis has been repeated for varying pipe wall thickness to approximate the geometry of the Oconee-2 flaw. In addition, the sensitivity of the leak-before-break results to pipe loads has been investigated by repeating the analysis with half the normal operating loads. The results of these various leak-before-break analyses are presented below.

Applied Loads at HPI Nozzle *

Temperature = 100 F
Pressure = 2300 psi
Outside Diameter = 2.875 in
Thickness = 0.375 in
Material = 316 Stainless Steel

Loading Condition	**Ma (ft-lbs)**	**Mb (ft-lbs)**	**Mc (ft-lbs)**	**Mr (ft-lbs)**
Weight	191	53	1016	
Thermal	72	-1349	2824	
Normal Operating (Min. Moment)	263	-1296	3840	4061

* Loads are HPI/MU nozzle design loads.

Material Properties

Material : A-376 TP316
Yield Stress : 30 ksi
Ultimate Stress : 75 ksi
Flow Stress : 52.5 ksi ((Yield + Ultimate)/2)
Young's Modulus : 28.3E6 psi
Ramberg-Osgood Parameters
alpha : 3.46
n : 5.68

The following leakage size cracks and critical flaw sizes may be seen with decreasing thicknesses assuming the normal operating external loads.

Thickness (in)	**Leakage Size Crack (in) @ 10 gpm**	**Critical Crack Length (in)**	**Margin Ratio**
0.375	1.24	2.56	2.1
0.25	0.65	1.90	2.9
0.2	0.43	1.34	3.1

The following leakage size cracks and critical flaw sizes may be seen assuming decreasing thicknesses and half the normal operating external loads.

Thickness (in)	**Leakage Size Crack (in) @ 10 gpm**	**Critical Crack Length (in)**	**Margin Ratio**
0.375	2.32	3.56	1.5
0.25	1.81	3.08	1.7
0.2	1.48	2.74	1.9

To investigate the sensitivity of critical crack length results for the weld metal, TIG weld properties were used with one case from above (half normal operating loads and 0.375 in. thickness). The critical crack length found for that case is 4.13 in. compared to 3.56 in. calculated for the base metal with the same loads. The material properties used for the TIG weld are shown in table below.

Material Properties

Material : TIG Weld
Yield Stress : 68.9 ksi
Ultimate Stress : 79.7 ksi
Young's Modulus : 28.3E6 psi
Ramberg-Osgood Parameters
alpha : 6.25
n : 6.8

Table 4-1
Loadings at Nozzle/SE Weld for Nozzle 1A1 and 1A2

		Nozzle 1A1						
	Forces, Lb.			Moments, ft-lb				
	Fx(Axial)	Fy(Vert.)	Fz	Mx	My	Mz	Msrss	Stress,ksi
D. Weight	3	-171	9	145	61	-269	311.6199	2.256753
Thermal	-24	-140	-34	288	225	-1035	1097.631	7.949048
OBE	67	55	85	182	216	151	320.2827	2.319488
DBE	134	110	170	364	432	302	640.5654	4.638977
DBE SAM	122	28	62	156	88	215	279.8303	2.026532
DW+OBE				327	277	420	600.0483	4.345552
		Nozzle 1A2						
	Forces			Moments, ft-lb				
	Fx(Axial)	Fy(Vert.)	Fz	Mx	My	Mz	Mrsss	Stress,ksi
D. Weight	3	-62	-4	-133	30	11	136.7845	0.990594
Thermal	-285	-140	99	18	-630	-1557	1679.724	12.16457
OBE	89	71	81	213	191	240	373.43	2.704382
DBE	178	141	162	426	383	481	748.0147	5.417125
DBE SAM	37	6	24	34	26	36	55.92853	0.405035
DW+OBE				346	221	251	481.2047	3.484886
2300 psig	8157.089							2.76981

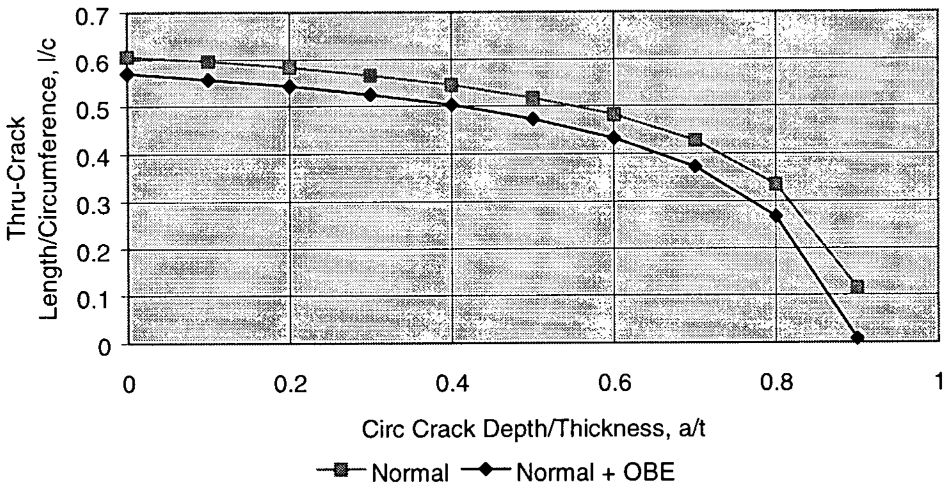

FIGURE 4.1 - CRITICAL FLAW SIZE DISTRIBUTION FOR HPI/MU NOZZLES

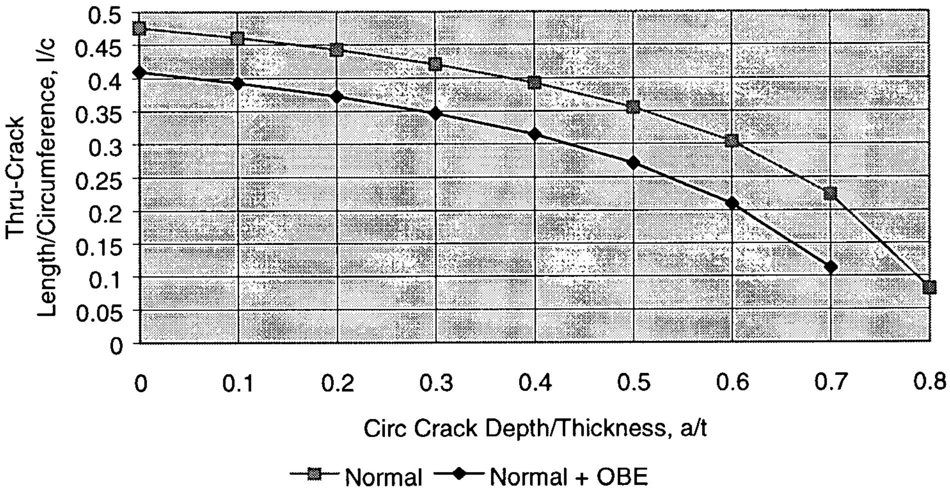

FIGURE 4.2 - ALLOWABLE FLAW SIZE DISTRIBUTION FOR HPI/MU NOZZLES