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VISSING,G.S.

SUBJECT: Submits response to NRC 980518 RAI re submittal for Leak-Before-Break approval for portions of RHR sys.

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ROBERT C. MECREDY
Vice President
Nuclear Operations

August 6, 1998

U. S. Nuclear Regulatory Commission
Document Control Desk
Attn: Guy S. Vissing
Project Directorate 1-1
Washington, D.C. 20555

Subject: Response to Request for Additional Information (RAI) Related to Leak-Before-Break (TAC No. MA0389)
R. E. Ginna Nuclear Power Plant
Docket No. 50-244

Ref. (1): Letter from Guy S. Vissing (NRC) to Robert C. Mecredy (RG&E), SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RELATED TO "LEAK-BEFORE-BREAK EVALUATION OF PORTIONS OF THE RHR SYSTEM TO THE R. E. GINNA NUCLEAR POWER STATION" (TAC NO. MA0389), dated May 18, 1998

Dear Mr. Vissing:

By Reference 1, the NRC staff requested additional information regarding the submittal for Leak-Before-Break approval for portions of the residual heat removal (RHR) system for the R. E. Ginna Nuclear Power Plant. The attachment to this letter provides the requested information.

Very truly yours,

Robert C. Mecredy

Attachment

xc: Mr. Guy S. Vissing (Mail Stop 14B2)
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Office of Nuclear Reactor Regulation
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U.S. NRC Ginna Senior Resident Inspector

Responses to U.S. NRC Request for Additional Information Regarding Request Leak-Before-Break Approval Portions of the R.E. Ginna Nuclear Power Plant Residual Heat Removal System Piping (TAC MA0389)

Question #1 – Material Properties

The information in Section 4.2 of the SI report indicated that ASME Code values were used for the Young's Modulus, yield strength, and ultimate strength. However, as noted in Section 5.2 of NUREG-1061, Vol. 3, when performing LBB analyses, an emphasis is placed on obtaining and using materials data from specimens manufactured from the actual piping and weld materials used in the facility.

Confirm that no materials test data exists for the Ginna RHR piping or weld materials from the time of facility fabrication. If no data exists, demonstrate when calculating the margin between the leakage flaw size and the critical flaw size that the use of ASME Code minimum values provides a bounding analysis when compared to the use of typical values for the yield and ultimate strengths for Type 316 stainless steel.

Response to Question #1

In performing the analyses, the possibility of using actual material properties for the Ginna RHR piping was explored but the properties were found to be unavailable. Hence, it was decided to use ASME Code minimum properties to describe the stress-strain curve because it is believed that they are reasonably conservative for this type of analysis. It should be noted that for the J-R resistance curve, lower bound generic properties provided in the EPRI Ductile Fracture Handbook (Reference 1) (Reference 9 of SIR-97-077, Rev. 0) for shielded metal arc welds (SMAW) were conservatively used. The material properties (from Table 4-1 in SIR-97-077) are shown in Table 1-1.

Alternate material properties for typical piping materials and associated welds are provided in the EPRI Ductile Fracture Handbook. These are attached in Appendix A of this document. The generic stress-strain properties of Type 316 stainless steel provided in the EPRI Ductile Fracture Handbook and shown in Table 1-2 were used to recalculate the critical flaw sizes. The J-R curve parameters for Type 316 stainless steel base metal is not provided in the EPRI handbook. Hence

for this purpose, the J-R curve provided in Reference 2 was used. This J-R curve is shown in Figure 1. As can be seen from this figure, the maximum crack extension associated with this J-R curve is 0.2 inches with a corresponding J of 12 in-k/in^2. In addition, the welds of the Ginna RHR piping were fabricated using SMAW welding (Reference 6). Hence the properties of SMAW weldments provided in EPRI Ductile Fracture Handbook and shown in Table 1-3 were also used to calculate the critical flaw size. The results of the analyses are provided in Table 1-4. It can be seen that the use of the alternate material properties for the Type 316 stainless steel resulted in very comparable results to those obtained in SIR-97-077 with the two alternate set of properties resulting in slightly larger critical flaw sizes. The leakage through half the critical flaw size was recalculated for the most limiting critical flaw size (Node 680 on the hot leg) using the generic Type 316 stainless steel and SMAW properties and was found to be at least 5.0 gpm compared to 4.71 gpm obtained using the Code minimum properties in SIR-97-077, Rev. 0. In all cases, the leakage is within the detectable limits at Ginna as explained in Response to Question No. 6.

Table 1-1

Material Properties Used in SIR-97-077 for Type 316 Stainless Steel

Property	Value
E (ksi)	25,240
σ_o (= σ_y) (ksi)	18.8
σ_u (ksi)	71.8
σ_{flow} (ksi)	45.282
α	0.776
n	3.81
J_{Ic} (in-kip/in^2)	0.99
J_{max}(in-kip/in^2)	5.0
C	6.033
N	0.391

Table 1-2

Alternate Material Properties for Type 316 Stainless Steel [1,2]

Property	Value
E (ksi)	25,500
σ (ksi) ($=\sigma_y$)	29.6
σ_u (ksi)	58.1
σ_{flow} (ksi)	43.85
α	12.0
n	4.80
J_{Ic} (in-kip/in^2)	10.7
J_{max} (in-kip/in^2)	12.0
C	36.3
N	0.594

Table 1-3

Material Properties for SMAW Stainless Steel Welds [1]

Property	Value
E (ksi)	25,000
σ (ksi) ($=\sigma_y$)	49.4
σ_u (ksi)	61.4
σ_{flow} (ksi)	55.4
α	9.00
n	9.80
J_{Ic} (in-kip/in^2)	0.99
J_{max} (in-kip/in^2)	5.0
C	6.033
N	0.391

Table 1-4

Critical Flaw Sizes and Leakage Using Alternate Material Properties

Node No.	Critical Flaw Size (in)		
	From SIR-97-077, Rev. 0	Using Generic Type 316 Stainless Steel Properties	Using Generic SMAW Weldment Properties
Hot Leg			
680	10.967	11.498	11.976
50	11.499	12.005	12.469
60	11.432	11.934	12.452
70	12.552	12.975	13.425
Cold Leg			
8400	12.065	12.524	12.983
910	10.390	10.956	11.456
920	11.498	11.996	12.469
930	12.436	12.868	13.320
950	13.456	13.815	14.246
960	14.358	15.502	15.832

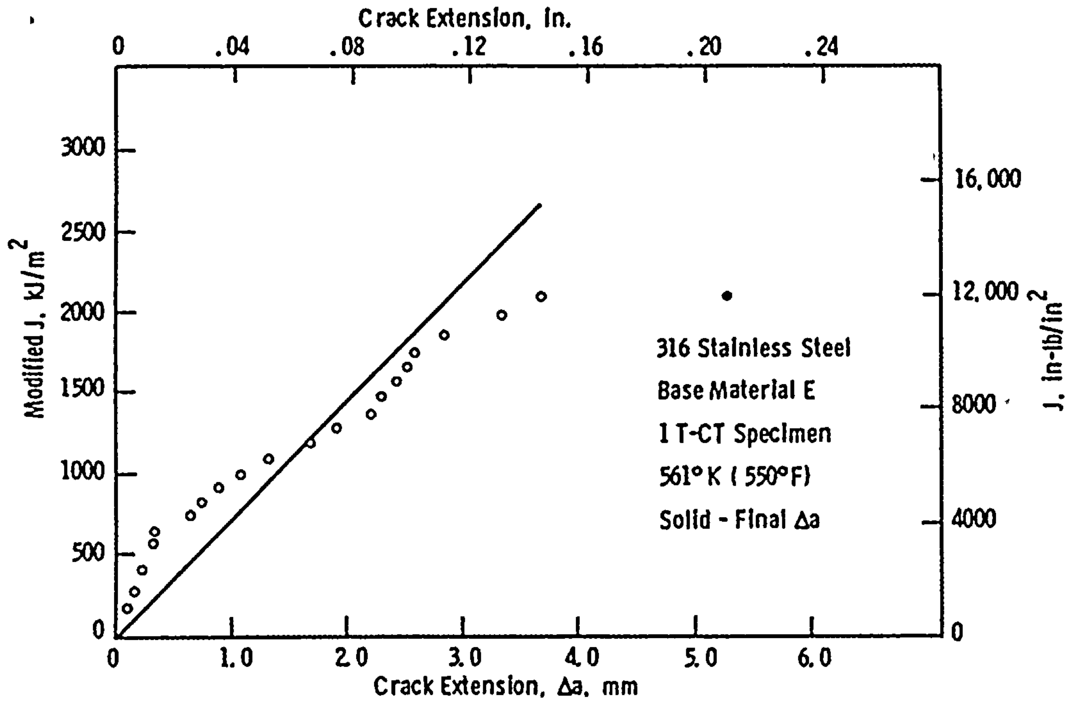

Figure 1. J-R Resistance Curve for Type 316 Stainless Steel [2]

Question #2 – Material Properties

Submit the information from Reference 9 to SIR-97-077 which supports the use of the C and n parameters in Table 4-1 for establishing the J-resistance curve used in this analysis. Define what data was used to develop these fit parameters and the limits of the database used to develop the parameters, i.e. beyond what value of crack extension is the correlation no longer valid.

Response to Question #2

The C and n parameters from Reference 9 of SIR97-077, Rev. 0 (EPRI Ductile Fracture Handbook) are shown in Appendix A of this document. The parameters are those associated with SMAW weldments. It was indicated in the EPRI Ductile Fracture Handbook that these parameters were obtained from Reference 3, which provides the technical basis for flaw evaluation of austenitic steel piping in ASME Code Section XI. J versus crack extension data for the SMAW material was not provided in Reference 3 but the material J-T curve was provided which indicated that the maximum J obtained from the data is approximately 3 in-kip/in^2.

The maximum value of applied J computed in the evaluation was 4 to 4.5 in-kip/in^2. The J-R resistance curve beyond 3 in-kip/in^2 was determined by applying the power law function describing the J-R curve (using the J-R curve parameters shown in Table 4-1 of SIR-97-070). This approach is different from the extrapolation technique recommended in NUREG-1061, Vol. 3, page A-20. Application of NUREG-1061 extrapolation technique does not change the critical flaw by any significant amount (less than 2% at the most critical location).

Question #3 – Material Properties

Explain whether or not the data used to develop the material J-resistance curve addresses the issue of thermal aging of stainless steel pipe welds.

For reference, the staff has examined the information from NUREG/CR-6428, "Effects of Thermal Aging on Fracture Toughness and Charpy-Impact Strength of Stainless Steel Pipe Welds," May 1996. This information appears to indicate that for welds manufactured by the same processes (submerged arc welding or shielded metal arc welding) as those used to fabricate the Ginna RHR line welds, moderate decreases in fracture resistance are to be expected and that a lower bound J-resistance curve to the available data should be more conservative than that defined by the C and n values of Table 4-1.

Response to Question #3

As explained in the response to Question #2, the J-resistance curve used in the analysis is consistent with that used for the flaw acceptance criteria in ASME code Section XI. The issue of thermal aging was not specifically addressed for this curve in Reference 3. As indicated in NUREG-6428, however, the fracture resistance of the fluxed welds is only minimally affected by aging since the fracture toughness is dependent on the inclusions in the welds rather than the kinetics associated with embrittlement during long-term thermal aging.

Based on the small differences in the critical flaw size between the different alternate material properties considered in the response to Question No. 1, it can be expected that the very small change in the J-R curve due to thermal aging of the weld will not affect the conclusions of the evaluation.

Question #4 – Material Properties

Confirm that none of the piping for which LBB approval is sought was manufactured with cast stainless steel (e.g., elbows). If there are cast sections, evaluate their material properties and address concerns regarding the aging of cast stainless steels in your evaluation.

Response to Question #4

Review of the specifications used in the purchase and installation of original RHR piping and fittings (Reference 4) revealed that no cast stainless steel components were provided for the RHR system. Seamless or forged piping and fittings were used.

Question #5 – Piping Geometry

It appears that ASME Code nominal values were used for Schedule 160 piping diameters and wall thickness (8.50 inch ID, 1.125 inch wall thickness, 10.75 inch OD). Explain why the use of these values provides a bounding analysis for the Ginna RHR piping if as-built or as-fabricated dimensions are not available. As noted in question #1 above, the staff considers the use of as-built dimensions, when possible, to be the most appropriate values to use in LBB analyses and requires that conservative values be used if insufficient as-built data is available. If the values used in the SI analysis do not provide a bounding assessment of the margin between the leakage and critical flaw sizes, provide a reanalysis of the Ginna RHR piping or a sensitivity study to demonstrate the effect of non-nominal wall thickness or piping diameters on the conclusions.

Response to Question #5

Since the as-built dimensions of the Ginna RHR piping are unavailable, a sensitivity analysis was performed to determine the effect of non-nominal pipe geometry on the LBB evaluation. The minimum pipe thickness acceptable per ASME Code Section III is 0.875 $t_{nominal}$. This thickness was used to recalculate the stresses for the LBB evaluation. The reduction in the pipe thickness resulted in higher stresses. Another evaluation was also performed with pipe thickness of 1.125 $t_{nominal}$ to investigate the effect of an increased pipe thickness. The results of the critical flaw size determination and leakage through half of the critical flaw sizes for these two cases are presented in Table 5-1. The evaluation was performed using the material properties shown in Table 4-1 of SIR-97-077. Leakage was calculated through half the critical flaw size at Node 680 for the two pipe thicknesses (0.875 $t_{nominal}$ and 1.125 $t_{nominal}$) and were found to be 5.1 gpm and 4.3 gpm compared to the nominal value of 4.71 gpm. The difference in leakage between the various pipe thicknesses is relatively small considering the leakage detection capability at Ginna as explained in the response to Question #6.

Table 5-1

Critical Flaw Sizes and Leakage for Various Pipe Thicknesses

Node No.	Critical Flaw Size (in)		
	From SIR-97-077, Rev. 0 (t_{nom})	$t = 0.875\ t_{nominal}$	$t = 1.125\ t_{nominal}$
Hot Leg			
680	10.967	10.335	11.430
50	11.499	10.811	11.988
60	11.432	10.765	11.903
70	12.552	11.977	12.960
Cold Leg			
8400	12.065	11.471	12.491
910	10.390	10.078	11.239
920	11.498	11.160	11.679
930	12.436	12.085	12.627
950	13.456	13.128	13.629
960	14.358	13.753	15.546

Question #6 – Leakage Margin

As noted in the submittal, the staff has published guidance in NUREG-1061, Vol. 3 regarding issues to be considered in the application of Leak-Before-Break (LBB) calculations. In Section 5.7 of the NUREG, regarding the size of the postulated through-wall leakage flaw to be used in the evaluation, the staff noted, "The margin on the magnitude of the leakage applicable to high energy fluid system piping...should be no less than a factor of 10 or greater than the capability of the leakage detection systems used and adequate sensitivity and reliability of the leakage detection system should be demonstrated." It is the staff's position that this factor of safety must be included without modification in LBB analyses.

The submittal states on page 5-8 that, "...the leakage detection system at Ginna...is capable of measuring 1 gpm leakage...." Therefore, the appropriate leakage flaw size for the LBB analysis would be that flaw which is shown to leak at a rate of 10 gpm. The critical flaw size calculated from examining SSE loading condition should then be a factor of 2 greater than the leakage flaw.

Based upon the results submitted in Table 5-2 (page 5-10), it appears that your calculations have demonstrated that for RHR hot leg nodes 680, 50, 60, and 70 that a flaw one-half of the critical flaw size leaks at rates between 4.71 and 5.74 gpm. Therefore, while your analysis "fixes" the factor of 2 between the critical and leakage flaw sizes, it does not appear that a factor of 10 on the leakage is maintained. Vice versa, based on the plot provided in Figure 5-2, it appears that your calculations predict that it would require a flaw between 7 and 7.5 inches in length to cause 10 gpm of leakage. Since the critical flaw size that you calculated for the subject piping nodes was between 10.97 and 12.55 inches, a factor of 2 between the leakage and critical flaw sizes is not achieved.

Determine what size flaw provides for 10 gpm of leakage at each analyzed location in both the hot and cold legs and demonstrate the critical flaw size exceeds the 10 gpm leakage flaw size by a factor of 2.

Demonstrate that the leakage flaw determined in (a.) "...will not experience unstable crack growth even if larger loads (at least the $\sqrt{2}$ times the normal plus SSE loads)..." [see NUREG 1061, Vol. 3, pg. 5-3, item (1)] are applied.

<u>Response to Question #6</u>

The first part of the question will be answered based on results shown in Table 5-2 of the submittal (SIR-97-077, Rev. 0) and the margin requirements in Section 5.7 of NUREG-1061, Vol. 3. RHR hot legs nodes 680, 50, 60, and 70 have one half of the critical flaw size length leakage between 4.71 and 5.74 gpm. Taking the minimum leakage rate of 4.71 gpm for conservatism, and applying the margin factor of 10, the minimum leakage detection requirement becomes 0.471 gpm.

Reference 5 gives details of the capabilities of Ginna leak detection systems. Of particular importance are the systems outlined below.

1. Containment Air Particulate Monitor, R-11

This is the most sensitive instrument available for detection of Reactor Coolant System (RCS) leakage in containment. It is capable of detecting low levels of radioactivity in containment air. Assuming complete dispersion of leaking radioactive solids consistent with very little or no fuel cladding leakage, R-11 is capable of detecting leaks as small as approximately 0.013 gpm (50 cm^3/min) within 20 minutes. Even if only 10% of the particulate activity is actually dispersed, leakage rate of the order of 0.13 gpm are well within detectable range of R-11, which is much lower than the minimum leakage detection requirement of 0.471 gpm.

2. Liquid Inventory in Process System

Leakage can also be detected by unscheduled increase in the amount of reactor coolant makeup water required to maintain the normal level in the pressurizer. Based on frequency of inventory

balance and volume control tank level instrumentation, the charging system inventory method of leak detection can detect a 0.25 gpm leak which is about half that of the minimum leakage detection requirement of 0.471 gpm.

3. Condensate Measuring System

This system employs the Containment Recirculation Fan Coolers (CRFCs) cooling coils to collect condensate from the containment air that comes off the RCS, and deposited into a drain pan equipped with a standpipe and instrumentation that measures accurately the water level condensate flow from 1 gpm to 30 gpm. Flows less than 1 gpm can be measured by periodic observation of level change in the standpipe. This is a useful backup to the two leak detection systems that can support the minimum leakage requirement of 0.471 gpm.

4. Other Systems

Other leak detection systems that can detect higher leakage capacities include:

a. Radiation Monitor, R-12 which can detect 2 gpm to 4 gpm in less than 1 hour.

b. Humidity Detectors – This system can detect vapor originating from all sources, i.e., not only from RCS, but from main steam and feedwater systems. Capable of detecting 2 gpm to 10 gpm.

In response to the second part of the question, it was noted in SIR-97-077, that the criterion based on a safety factor of 2 on flaw size is bounding compared to the criterion based on a safety factor of $\sqrt{2}$ on stresses. To demonstrate this, the critical flaw sizes were recalculated with the material properties issued in Table 4-1 of SIR-97-077. The critical flaw sizes for this case are shown in Table 6-1. It is shown that at all the node locations, the critical flaw size based on a safety factor of $\sqrt{2}$ on stress is greater than half the critical flaw size based on a safety factor of

one on the stresses. This indicates that the latter is bounding in all cases since it will result in the minimum leakage.

Table 6-1

Comparison of Critical Flaw Sizes with a Safety Factor of Unity and $\sqrt{2}$ on Stresses

Node No.	Half Critical Flaw Size With Safety Factor of Unity on Stress (in.)	Critical Flaw Size With Safety Factor of $\sqrt{2}$ on Stress (in.)
Hot Leg		
680	5.483	7.950
50	5.750	8.524
60	5.716	8.453
70	6.276	9.683
Cold Leg		
8400	6.032	9.156
910	5.195	7.322
920	5.749	8.524
930	6.218	9.555
950	6.728	10.692
960	7.179	11.601

Question #7 – Critical Crack Size Determination

Provide additional explanation regarding the criteria used to determine the critical flaw size for each location in the analysis. In particular, explain what is meant by the statement beginning on page 5-2, "Crack extensions during stable ductile tearing in the EPFM analyses are conservatively not included in the critical flaw length computations." Does this imply that stable crack growth beyond J_{IC} is not included in the determination of the critical flaw size?

Response to Question #7

The J-Integral/Tearing modulus evaluation methodology which considers stable ductile tearing beyond J_{IC} was used to determine the critical flaw sizes. The J-R material resistance curve presented in Table 4-1 of SIR-97-077 was converted to a J-T material curve where the Tearing Modulus (T) is defined as:

$$T = \frac{dJ}{da} \bullet \frac{E}{\sigma_o^{\,2}}$$

where *dJ/da* is the slope of the J-R curve, E is the modulus of elasticity and [$_o$ is the reference stress (assumed to be the flow stress). The applied *J* versus *a* curve is also converted into a *J-T* curve. The intersection of these two curves represents the point of instability and the crack size at this instability point is the critical flaw size. An example of the critical flaw size determination is shown in Figure 7-1.

The statement "Crack extensions during stable ductile tearing in the EPFM analyses are conservatively not included in the critical flaw length computations" on page 5-2 in the report is misleading and is subsequently clarified above.

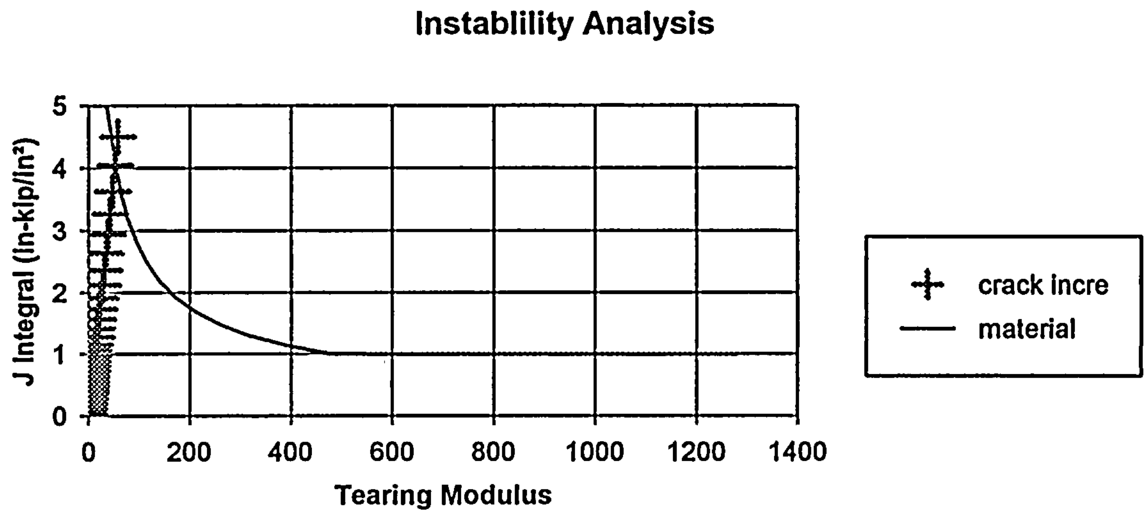

Figure 7-1. Determination of Critical Flaw Size Nuclear Remote Tension for Node 680

Question #8 – Critical Crack Size Determination

Submit the formula used to determine the critical flaw size under bending loads alone and any necessary parameters to be used in the calculation. This formula is alluded to on page 5-2 and is integral to your evaluation given the manner in which you propose to arrive at the critical flaw size under combined tension and bending loads (see question #9 below).

Response to Question #8

The expression for the J-integral for a through-wall crack under bending from Reference 11 of SIR-97-077, Rev. 0 is given by

$$J = f_1\left(a_e, \frac{R}{t}\right)\frac{M^2}{E} + \alpha\sigma_o\varepsilon_o c\left(\frac{a}{b}\right)h_1\left(\frac{a}{b}, n, \frac{R}{t}\right)\left[\frac{M}{M_o}\right]^{n+1}$$

The parameters in the above equations are the same as the tension loading case except

M	=	applied moment = σ_∞ I/R
σ_∞	=	remote bending stress in the uncracked section
I	=	Second moment of inertia of the uncracked cylinder about the neutral axis
M_o	=	limit moment for a cracked pipe under pure bending corresponding to $n = \infty$ (elastic-perfectly plastic case)
	=	$M'_o\left[\mathrm{Cos}\left(\frac{\gamma}{2}\right) - \frac{1}{2}\mathrm{Sin}(\gamma)\right]$
M'_o	=	limit moment of the uncracked cylinder = $4\sigma_o R^2 t$

Question #9 – Critical Crack Size Determination

Given that you have calculated a critical flaw under simple tension loading and under simple bending loading scenarios, justify the technique (shown in the top equation on page 5-3 of the SI report) used to determine the final critical flaw size by linear interpolation of your tension loading and bending loading solution. Demonstrate that this method provides either an exact solution for the critical flaw size under combined loading or that conservatively estimates the critical flaw length or submit a reference in which this is demonstrated.

Response to Question #9

Alternate models for circumferential through-wall flaws under remote tension, remote bending and combination of tension and bending are provided in the EPRI Ductile Fracture Handbook (Reference 1). Solutions are provided in this handbook for pipe radius to thickness (R/t) ratios of 5, 10 and 20 for the remote tension and remote bending cases. However, for combined tension and bending cases, solutions are provided only for R/t = 10 which is different for the piping geometry at Ginna. It is for this reason that the simple linear interpolation scheme in SIR-97-077 was used. To determine the reasonableness of this approach, the models in the EPRI handbook for R/t = 10 were used to determine the critical flaw sizes for remote tension, remote bending and various combination of the tension and bending stresses. The parameters used for the evaluation are:

$$E = 25{,}240 \text{ ksi}$$

$$\sigma_o = 18.764 \text{ ksi}$$

$$\alpha = 0.766$$

$$n = 2 \text{ and } 5$$

$$C = 6.033 \text{ in-kip/in}^2$$

$$N = 0.391$$

$$J_{IC} = 0.99 \text{ in-kip/in}^2$$

The results are presented in Figures 9-1 and 9-2 for combined stresses of 10,15 and 20 ksi. In these figures "T + B" refers to the combined tension and bending solution from the EPRI handbook and "Interpolation" refers to the linear interpolation scheme used in SIR-97-077, Rev. 0. It can be seen that in all cases the critical flaw sizes obtained using the linear interpolation scheme in SIR-97-077, Rev. 0 is bounded by that obtained using the combined tension and bending model or very closely matches it. For the cases where the stresses were assumed to be either all remote tension or bending, the critical flaw sizes obtained with the pc-CRACK program matched those obtained using the alternate model from the EPRI Ductile Fracture Handbook.

To further illustrate the reasonable of the linear interpolation scheme, limit load solution provided in ASME Section XI technical basis document (Reference 3) was used to determine the allowable through-wall crack length under various combination of tension and bending stresses. In this evaluation, a pipe with outside diameter of 10.75 inches and flow stress of 51 ksi was used. Z factor consistent with that in Reference 3 for SMAW material was used. The results of the analysis are shown in Figure 9-3. It can be seen that in this case also, linear interpolation of the pure tension and bending cases gives conservative results compared to the actual combined tension and bending solution shown in Figure 9-3.

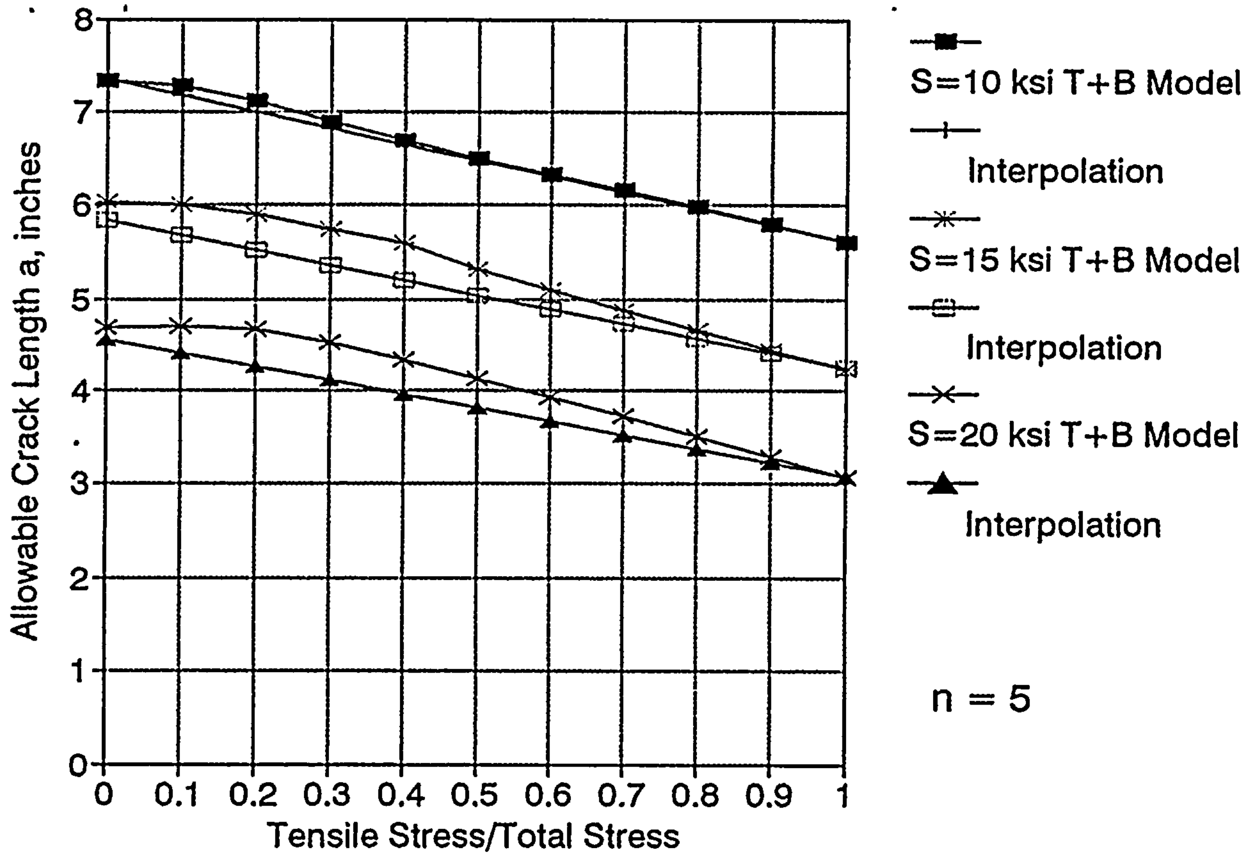

Figure 9-1. Comparison of Solution for Critical Flaw Size Using Exact Solution for Combined Tension and Bending With Linearly Interpolated Values (n = 5)

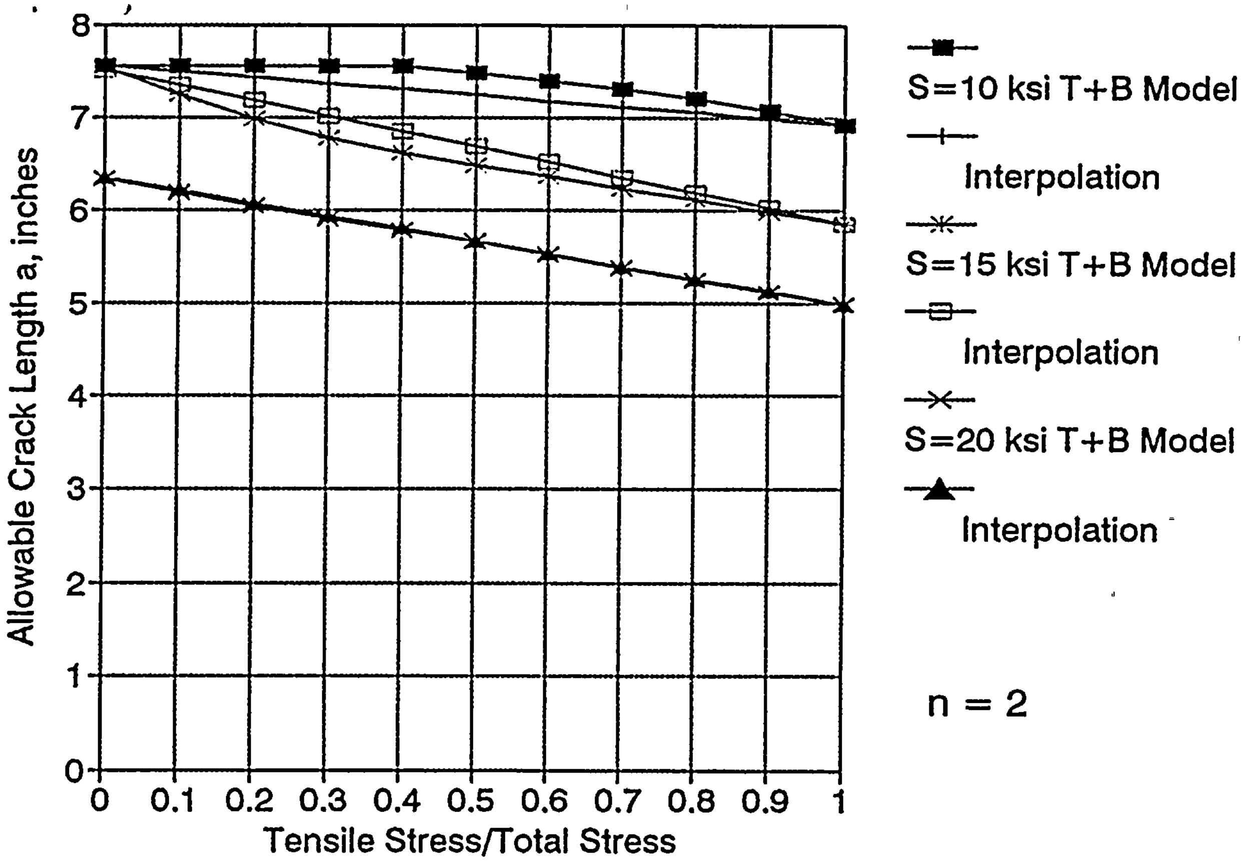

Figure 9-2. Comparison of Solution for Critical Flaw Size Using Exact Solution for Combined Tension and Bending With Linearly Interpolated Values (n = 2)

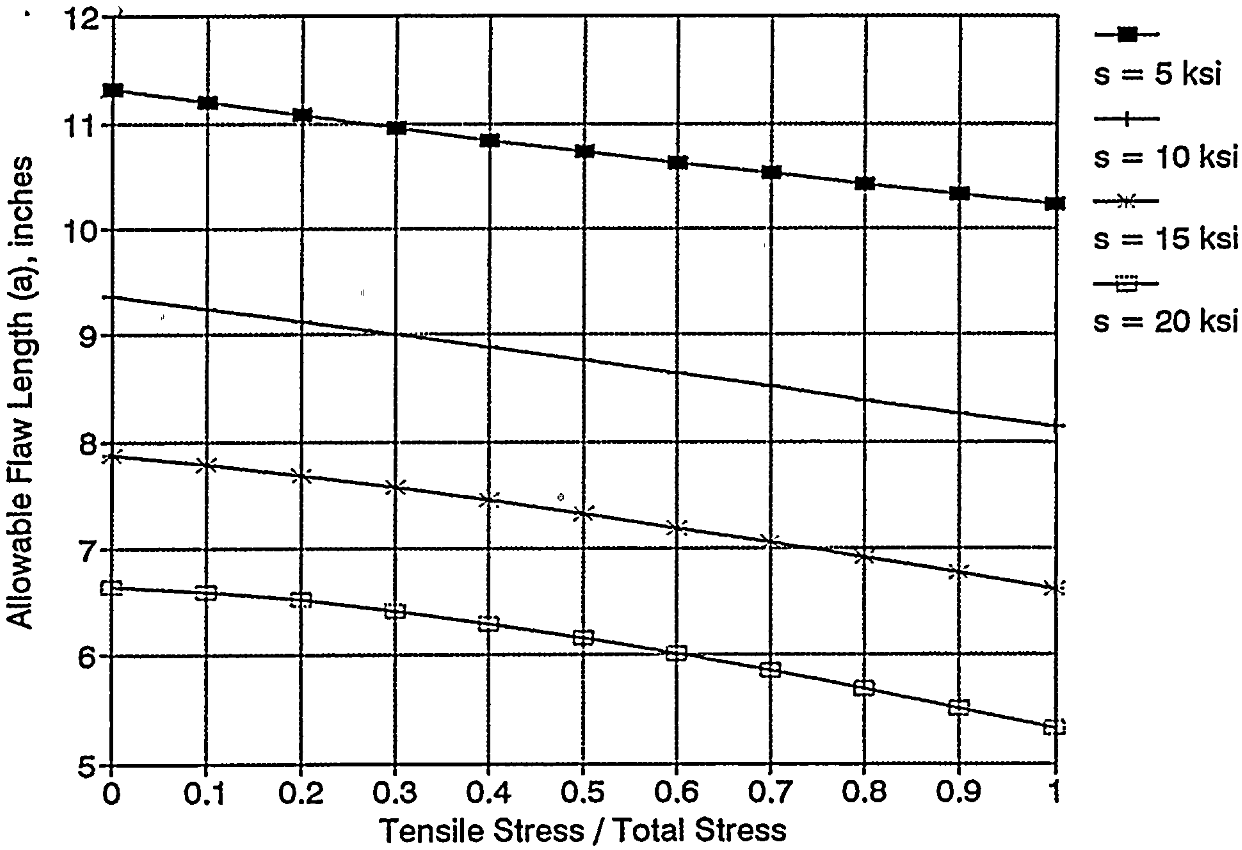

Figure 9-3. Critical Flaw Size Calculated using Limit Load for Combined Tension and Bending Stresses

REFERENCES

1. EPRI Report NP-6301-D, "Ductile Fracture Handbook," June 1989.

2. EPRI Report No. NP-4768, "Toughness of Austenitic Stainless Steel Pipe Welds," October 1986.

3. "Evaluation of Flaws in Austenitic Steel Piping," Prepared by the Section XI Task Group for Piping Flaw Evaluation, ASME Boiler and Pressure Vessel Code Committee, EPRI Report NP 4690-SR, April 1986; see also ASME J. Pressure Vessel Technology, Vol. 108, 1986, pp. 352 – 367.

4. RG&E Technical Specifications (Westinghouse Electric Corp., Contractor), SP-5291, 12/23/67, Line Specification No. 2501.

5. Ginna UFSAR, Rev. 14, Section 5.2.5, "Detection of Leakage Through Reactor Coolant Pressure Boundary".

6. Bechtel Corporation, Welding Standard, Procedure Specifications P8-AT-g ("Y" Type Insert Ring), Rev. 0, March 22, 1967; P8-AT-g, Rev. 3, Feb. 23, 1967.

Appendix A

Material Properties from EPRI Ductile Fracture Handbook

EPRI NP-6301-D, Vol. 3

DUCTILE FRACTURE HANDBOOK
(in three volumes)

VOLUME 3

Research Project 1757-69

January 1991

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Table 13-1

Ramberg-Osgood Stress-Strain Parameters

Material	Temp. °F	α	n	σ_o ksi	σ_u ksi	E 10^6 psi	Ref.
A106 GR B	120	3.80	4.00	37.00	71.70	27.0	2
A106 GR C	550	2.51	4.20	27.10	60.00	26.0	3
A516 GR 70	550	2.51	4.20	27.10	60.00	26.0	3
Generic CS	550	2.51	4.20	27.10	60.00	26.0	4, 8
TP304 SS	75	4.70	3.80	34.50	79.70	28.3	3
TP304 SS	70	9.16	3.20	45.30	---	30.0	16
TP304 SS	70	3.82	5.04	34.70	—	28.3	10
TP304 SS	68	3.46	5.68	39.30	—	28.3	10
TP304 SS	572	2.04	3.87	24.50	—	25.6	10
TP304 SS	550	11.00	6.90	33.70	50.50	25.5	3
TP304 SS	550	7.30	8.90	23.70	63.10	25.5	3, 20
TP316SS	550	12.00	4.80	29.60	58.10	25.5	3
Generic SS/ SMAW	550	9.00	9.80	49.40	61.40	25.0	3, 7
TP304 SS/ SAW & SMAW	550	3.39	6.89	44.80	67.20	25.5	3
Generic SS/ SAW	550	11.00	6.90	33.700	50.50	25.0	3, 7
A508 Cl 3	600	---	---	78.310	102.98	28.0	18

Table 13-2

J - Resistance Curve Data[1]

Material	Temp. °F	Thick. inch	J_i in-lb/in^2	C_0 in-lb/in^2	C_1 in-lb/in^2	n	Ref.
Generic CS-1	550	1.0	350	0.0	1,808	0.277	4, 21
Generic CS-2	550	1.0	600	0.0	2,563	0.274	4, 21
Generic CS-3	550	1.0	1,050	0.0	5,400	0.344	4, 21
TP304 SS	75	1.0	6,500	0.0	32,758	0.519	3
Generic SS/ SMAW	550	1.0	990	0.0	6,033	0.391	3, 7
Generic SS/ SAW	550	1.0	650	0.0	4,448	0.431	3, 7
A508 Cl3	550	1.378	446	0.0	3,443	0.329	19, 18
A106 GR B[2]	120	-	2,900	0.0	13,008	0.334	2
TP304 SS[3]	75	-	8,000	0.0	33,642	0.435	3

Notes:

1. $J = C_0 + C_1 \cdot (\Delta a)^n$

   where J and Δa have in-lb/in^2 and inch units, respectively.
2. 8 inch pipe, 0.54 inch wall thickness
3. 4 inch pipe, 0.34 inch wall thickness