ATTACHMENT 3

General Electric Company Report GENE-523-A69-0594, dated June 1994, Evaluation of the Indications Found at the H5 Weld Location in the Dresden Unit 3 Shroud.

GE Nuclear Energy

TECHNICAL SERVICES BUSINESS
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Evaluation of the Indications Found at the H5 Weld Location in the Dresden Unit 3 Shroud

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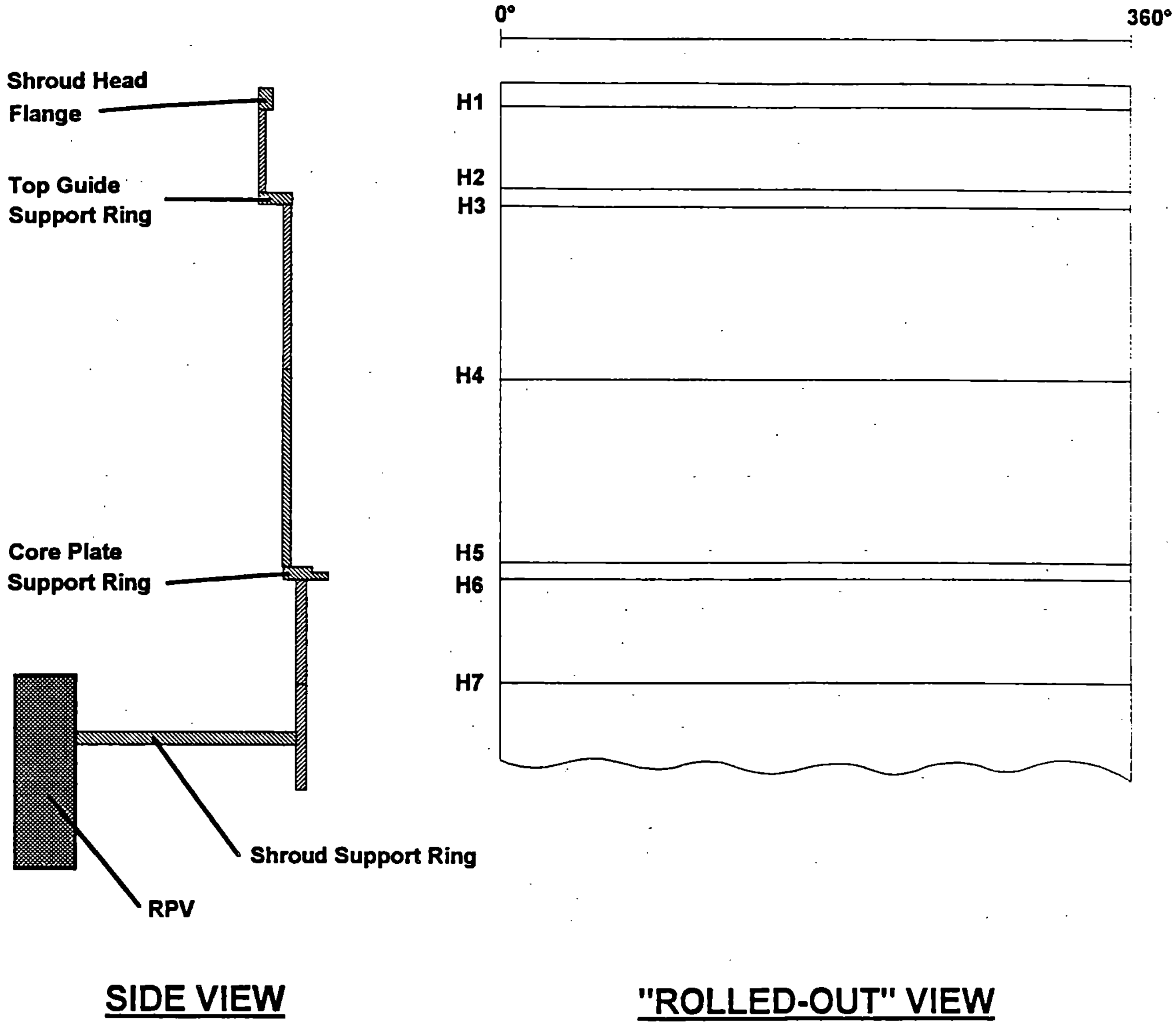
1.0 INTRODUCTION

During the current refueling outage at Dresden Unit 3, core shroud inspections were performed in accordance with recommendations given in GE Services Information Letter No. 572, Rev. 1 (SIL 572) [1]. During the initial portion of these inspections, crack indications were visually detected in the vicinity of the H5 weld (see Figure 1). The cracking was located immediately below the H5 weld in the core plate support ring. The indications were predominantly circumferential, and were visible at all accessible locations (approximately 150° of the circumference). Subsequent examination by automated ultrasonic testing (UT) of the indications in all areas of the H5 weld accessible by the UT system confirmed the visual indications to be cracks. Based on the results of automated and manual UT exams and on the results of boat samples taken from the H5 weld location provided by Commonwealth Edison Company (CECo), the probability of detection of flaws deeper than 1.24" on the core plate support ring side of the H5 weld is very high, and no flaws deeper than 1.24" were detected. For this reason, the bounding maximum flaw depth used for the purpose of this structural margin assessment is 1.24" [2].

The purpose of this report is to evaluate the indications found near the H5 weld from a structural standpoint. Limit load calculations are performed consistent with the previous Screening Criteria generated for the Dresden Unit 3 shroud [3], and structural margins are determined taking into account appropriate crack growth values and ASME Code, Section XI [4] safety factors.



NOTE: NOT TO SCALE

FIGURE 1: DRESDEN UNIT 3 SHROUD HORIZONTAL WELD CONFIGURATION

2.0 TECHNICAL APPROACH

The Reference 3 report documents screening criteria developed for the Dresden Unit 3 shroud based on limit load and linear elastic fracture mechanics (LEFM) techniques. The purpose of that report was to develop criteria that allowed indications discovered during visual inspection to be screened for further evaluation. Since the criteria were based on visual examinations, all flaws were conservatively assumed to be through-wall and allowable flaw lengths were calculated using limit load and LEFM techniques.

This evaluation determines allowable flaw depth, since UT examination has confirmed that the cracking is not through-wall. The cracking was assumed to be 360° around the circumference of the shroud for the purposes of this evaluation, since the indications discovered were seen at all accessible locations. Similar calculations to those included in the Reference 3 report were performed for a fully circumferential, part through-wall crack. Crack growth estimates were combined with the resulting allowable flaw size to determine structural margin. The results are described in detail in the sections that follow.

2.1 Allowable Flaw Size

The Reference 3 analysis conservatively included LEFM effects for welds H4 and H5 due to potential fluence effects. The fluence estimated for the H5 weld is low (3×10^{16} n/cm^2) [5]. Since the irradiation level is low, the fracture toughness is comparable to that of unirradiated material where ductile behavior governs. This is supported by studies performed by EPRI [6] where the impact of fluence in the amount accumulated by the H5 weld is negligible. Therefore, limit load calculations which use ASME Code, Section XI safety factors are the appropriate technique for evaluating structural margins for this location.

The limit load approach used here is depicted in Figure 2, as obtained from a net section collapse formulation [4,7]. The neutral axis shown in Figure 2 is determined by equilibrating the force resulting from the applied membrane stress, P_m, in the uncracked cross section with the force resulting from a stress equal to the flow stress in the remaining ligament (uncracked region) at the crack cross section.

For the case where $\alpha = 180°$ (i.e., 360° flaw), the following equations apply:

$$\beta = \frac{\pi(1 - d/t - P_m/\sigma_f)}{2 - d/t}$$

$$P_b' = \frac{2\sigma_f}{\pi}(2 - d/t)\sin\beta$$

where:
- t = shroud thickness, inches
- d = crack depth, inches
- α = half crack angle
- β = angle that defines location of neutral axis
- P_m = applied membrane stress, psi
- P_b' = failure bending stress, psi
- σ_f = flow stress of the material = $3S_m$

From Reference 3, the faulted load condition was determined to be limiting. The faulted load condition conservatively includes loading from both a design basis earthquake (DBE) and a main steam line break. For this load case, the membrane stress, P_m, was previously determined to be 0.067 ksi and the bending stress, P_b, was determined to be 1.213 ksi. These stresses are the result of deadweight, seismic and pressure loads. Per Section XI of the ASME Code, a safety factor of 1.4 for the faulted condition was applied to these stresses in the allowable flaw size calculations. The value of S_m at 550°F for the 304 stainless steel shroud material is 16,900 psi. Trial and error solution of the equations given above using these values is shown in Table 1.

The results of Table 1 show that a crack depth of 98% (i.e., a/t = 0.98) of the shroud thickness can be tolerated while still maintaining all ASME Code structural margins. The Dresden Unit 3 shroud has a 2 inch wall thickness, and the H5 weld is backed by a 1" fillet weld, as shown in Figure 3. The location of the observed cracking is also shown in Figure 3. The minimum thickness through which the crack must traverse before reaching through-wall is therefore 3 inches. Therefore, the allowable flaw depth in this region, based on limit load analysis, is 2.94" (i.e., 3" x 0.98).

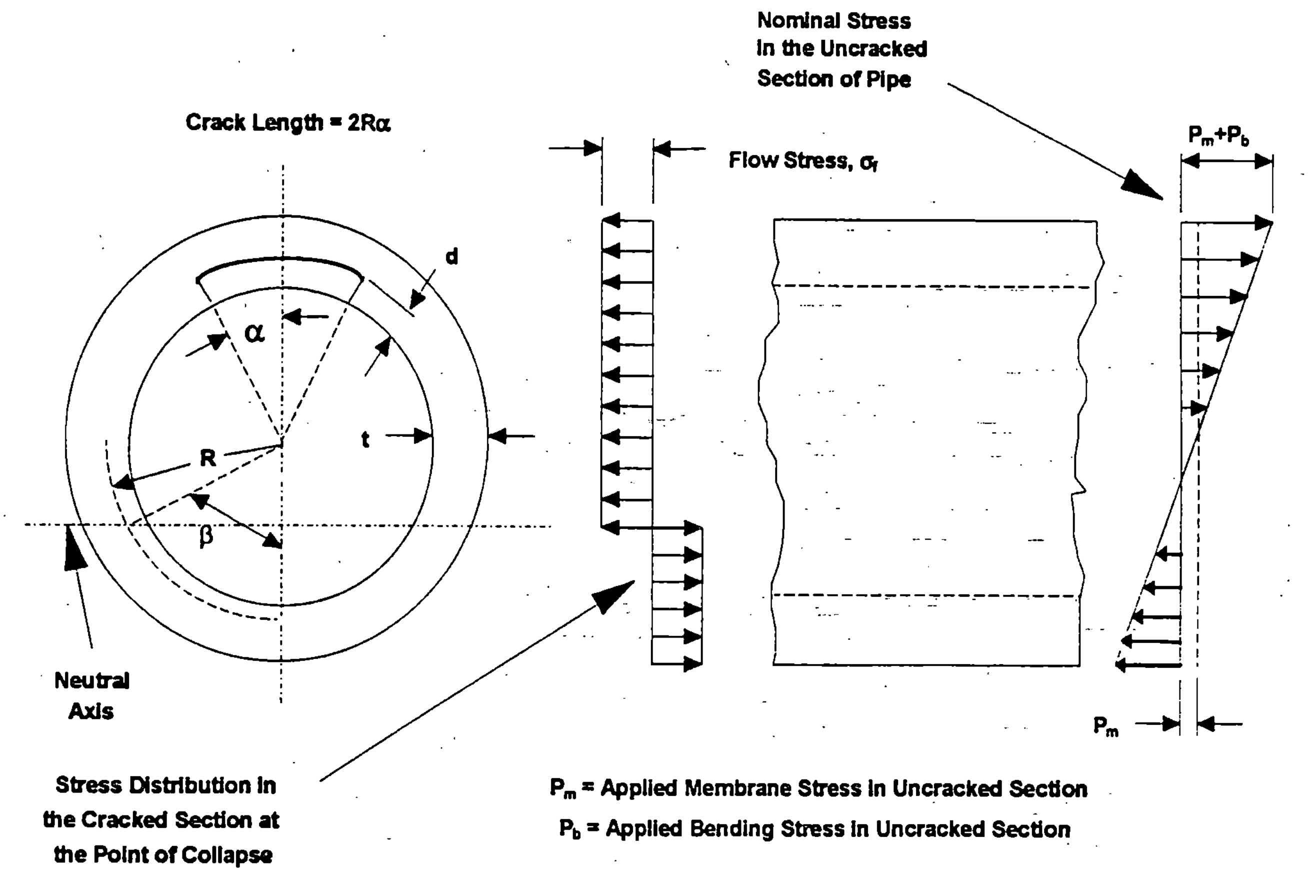


FIGURE 2: LIMIT LOAD METHODOLOGY

TABLE 1: LIMIT LOAD EVALUATION FOR WELD H5

Case #2: The neutral axis is located such that $\alpha + \beta > \pi$ (this is checked below)

$$\beta = \frac{(1 - d/t - P_m{}^*SF/\sigma_f)\pi}{2 - d/t}$$ (from References 4 and 7)

$P_b' = (2^*\sigma_f/\pi) * (2 - d/t) \sin\beta$

Given:	P_m =	67	psi (Reference 3)		
	P_b =	1,213	psi (Reference 3)		
	Safety Factor, SF =	1.4	(for Faulted conditions = limiting per Reference 3)		
	P_m*SF =	94	psi		
	P_b*SF =	1,698	psi		
	S_m =	16,900	psi (at 550°F for 304 SS)		
	$3S_m$ =	50,700	psi = σ_f		
	α =	180	* =	3.1416	radians.
Thus:	β = (	3.1358	-	3.1416	d/t) / (2 - d/t) [Eqn. 1]
	P_b' =	32276.6	* (2 - d/t) sinβ		[Eqn. 2]

Solving by trial and error:

d/t	β from [Eqn. 1] (radians)	P_b' from [Eqn. 2] (psi)	Difference = P_b' - P_b*SF	β (°)	α + β > π ?
0.1000	1.4851	61,100	59,402	85.1	YES
0.2000	1.3930	57,182	55,484	79.8	YES
0.3000	1.2902	52,724	51,026	73.9	YES
0.4000	1.1745	47,639	45,941	67.3	YES
0.5000	1.0433	41,834	40,136	59.8	YES
0.6000	0.8934	35,212	33,513	51.2	YES
0.7000	0.7205	27,684	25,985	41.3	YES
0.8000	0.5188	19,203	17,505	29.7	YES
0.9000	0.2803	9,823	8,124	16.1	YES
0.9100	0.2541	8,843	7,144	14.6	YES
0.9200	0.2273	7,856	6,158	13.0	YES
0.9300	0.2001	6,864	5,166	11.5	YES
0.9400	0.1723	5,867	4,169	9.9	YES
0.9500	0.1441	4,866	3,167	8.3	YES
0.9600	0.1152	3,860	2,162	6.6	YES
0.9700	0.0859	2,851	1,153	4.9	YES
0.9800	0.0559	1,839	141	3.2	YES
0.9810	0.0529	1,738	40	3.0	YES
0.9820	0.0498	1,637	-61	2.9	YES
0.9818	0.0504	1,657	-41	2.9	YES
0.9817	0.0508	1,667	-31	2.9	YES
0.9816	0.0511	1,677	-21	2.9	YES
0.9815	0.0514	1,688	-11	2.9	YES
0.9814	**0.0517**	**1,698**	**-1**	**3.0**	**YES**
0.9813	0.0520	1,708	10	3.0	YES

2.2 Crack Growth Assessment

Prior analyses [3] have conservatively used a crack growth rate of $5x10^{-5}$ inch/hour. This was intended to be a bounding value that covered both intergranular stress corrosion cracking (IGSCC) and irradiation assisted stress corrosion cracking (IASCC). More recent predictions made with the GE PLEDGE predictive model [8] where plant-specific water chemistry and other effects were included suggest a crack growth rate of $1.24x10^{-5}$ inch/hour, as shown in Figure 4. Thus, the $5x10^{-5}$ inch/hour value based on the IGSCC/IASCC combination is definitely conservative for the H5 weld.

A significant point to be made is that the observed cracking thus far is mainly due to prior operation at relatively high conductivities, including aggressive anions such as sulfates and chlorides. With the increased attention to IGSCC, most boiling water reactor (BWR) plants have dramatically reduced their aggressive anion input, thus assuring that future crack growth rates are much lower than those in the past. Dresden Unit 3 currently operates below 0.1 μS/cm conductivity and 5 ppb chloride and sulfate combined. Figure 4 shows the dependence of the predicted growth rate on the conductivity based on the GE predictive model for IGSCC. Figures 5 and 6 show the dependence on sulfate and chloride species [9]. In all cases, the lower sulfate and chloride levels lead to dramatically lower crack growth rates. Thus, any margin assessments based on the two growth rates ($5x10^{-5}$ inch/hour for bounding values and $1.24x10^{-5}$ inch/hour based on the GE PLEDGE predictive model) are conservative.

Pre-operational testing of BWR internals has demonstrated that high cycle fatigue resulting from flow induced vibration is not a concern for the core shroud. Additionally, low cycle fatigue caused by thermal and/or pressure changes in the core region are negligible since all anticipated changes in these parameters result in relatively low stresses in the core shroud. This is further supported by the fact that no fatigue cracking was observed from boat samples removed from the cracked areas of the Dresden 3 shroud, as well as the core shrouds of other BWRs. Therefore, the impact of fatigue on the core shroud is concluded to be negligible, and is not considered to be a further contributor to the crack growth values discussed here.

The use of the automated UT system combined with enhanced manual UT provided crack depths at a number of locations along the circumference. As expected, the crack depths varied along the circumference of the inspected regions. For conservatism, the bounding maximum flaw depth of 1.24" was used in the limit load evaluation described in this report. Since the evaluation for limit load is based on the total structural <u>area</u> available, the more appropriate value to use is the average depth, not the bounding maximum depth. Therefore, the structural margins shown in the next section are likely to reflect even more conservatism.

2.3 Structural Margin Determination

Since crack indications with a bounding maximum depth of 1.24" were estimated based on UT and boat sample evaluation, a maximum crack depth of 1.24" was conservatively used for evaluating structural margin. Crack growth values corresponding to each of the two crack growth values identified above were added to this maximum flaw depth. Structural margin was assessed by comparing the remaining ligament to the required ligament obtained from the limit load evaluation. The results are shown in Table 2.

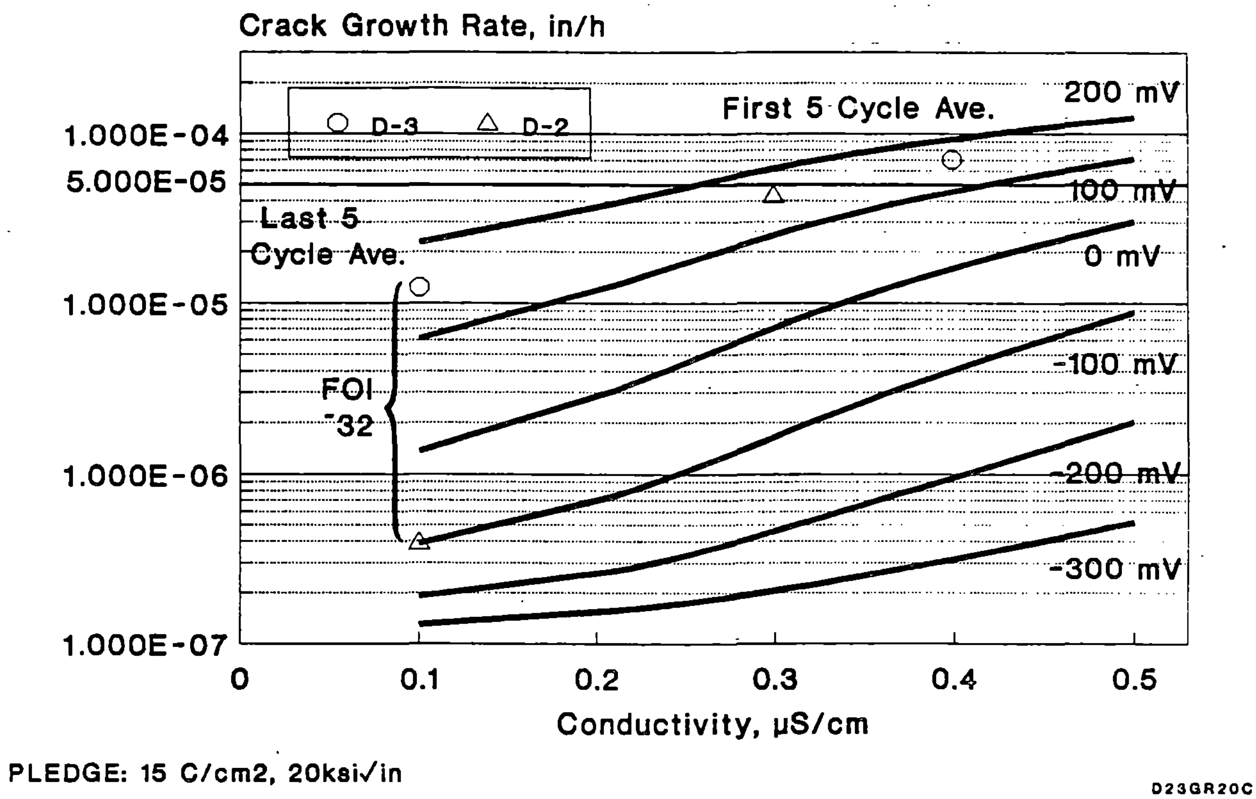


FIGURE 4: PLEDGE MODEL PREDICTION FOR DRESDEN 2/3

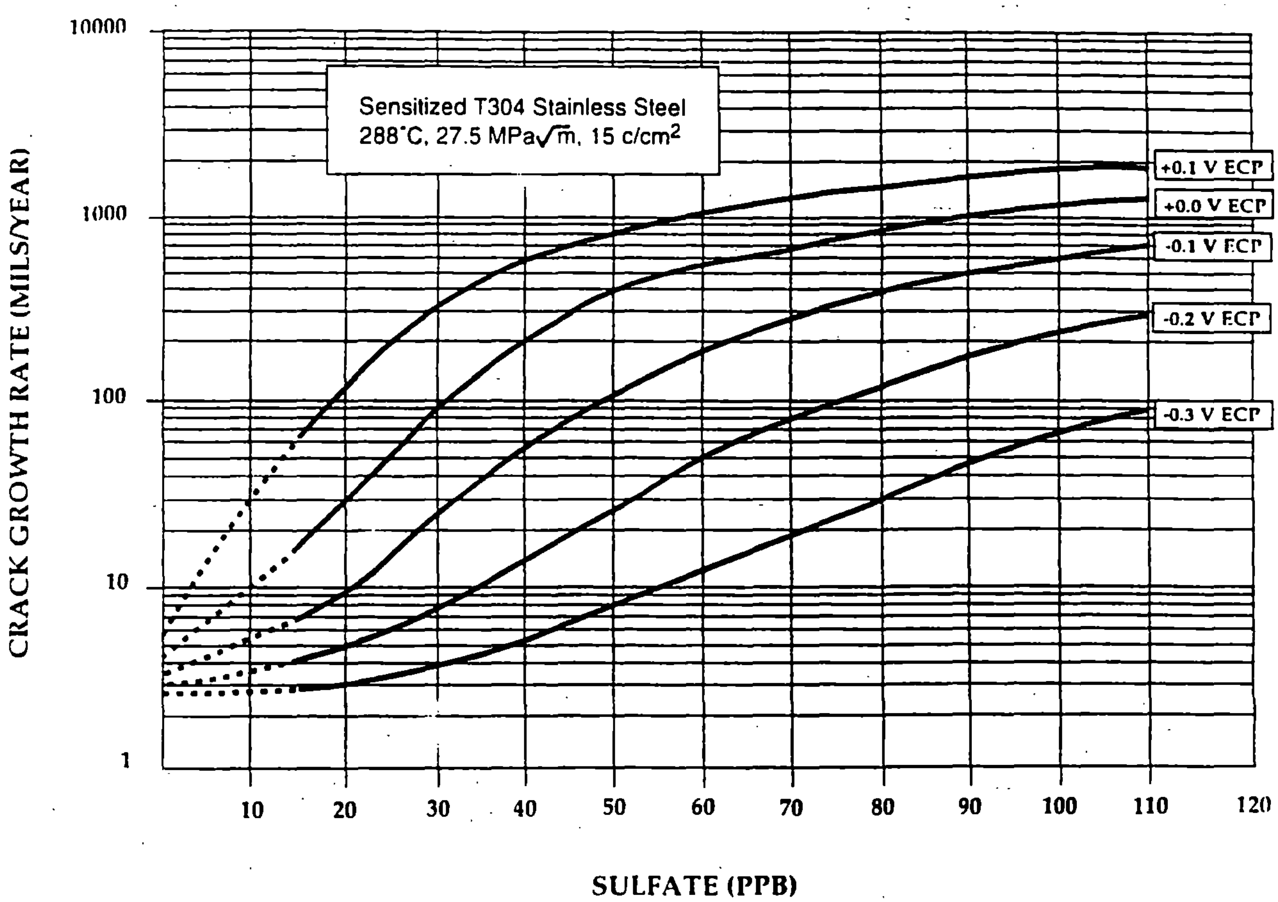


FIGURE 5: CRACK GROWTH RATE AS A FUNCTION OF SULFATE

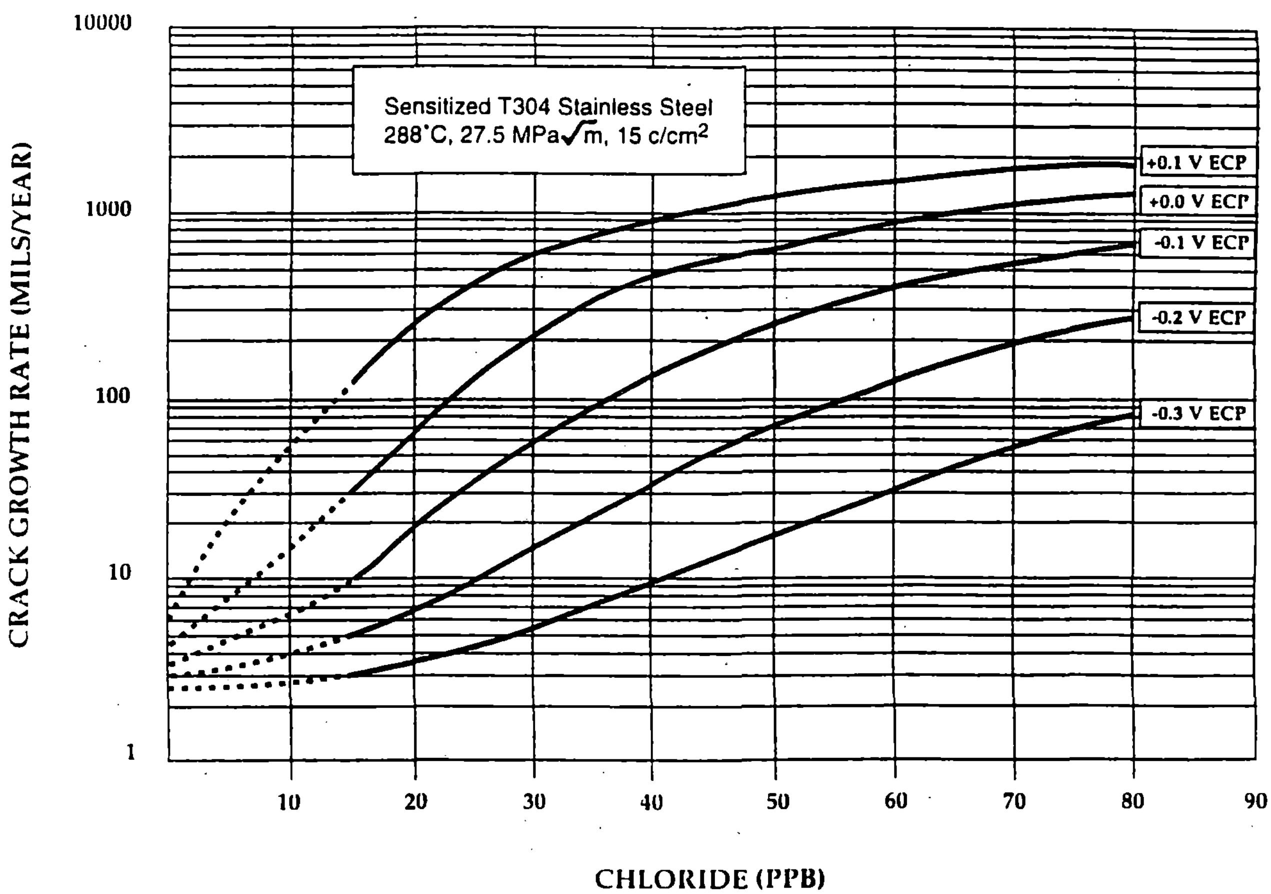


FIGURE 6: CRACK GROWTH RATE AS A FUNCTION OF CHLORIDE

TABLE 2: STRUCTURAL MARGIN RESULTS FOR WELD H5

(Based on a 360°, 1.24" Depth Flaw)

Case	Crack Growth Rate [inch/hour]	Crack Growth Period [months]	Crack Growth[1] [inches]	Final Crack Depth [inches]	Allowable Crack Depth [inches]	Margin Factor[2]	Time Until Allowable Depth is Reached[3] [hours (yrs)]
1	$5x10^{-5}$	6	0.20	1.44	2.94	26.0	34,000 (4.3)
2	$5x10^{-5}$	24	0.80	2.04	2.94	16.0	34,000 (4.3)
3	$1.24x10^{-5}$	6	0.05	1.29	2.94	28.5	137,000 (17.1)
4	$1.24x10^{-5}$	24	0.20	1.44	2.94	26.0	137,000 (17.1)

NOTE: (1) Crack growth is determined for each crack growth period assuming 8,000 hours per year (≈91% availability).

(2) The margin factor is calculated by dividing the remaining ligament by the required ligament, as follows (for case #1, thickness = 3"):

Margin Factor = Remaining Ligament/Required Ligament
= (3.0-1.44)/(3.0-2.94)
= 26.0

(3) The time until the allowable crack depth is reached is determined by dividing the minimum existing ligament by the crack growth rate, as follows (for case #1):

Time = Minimum Existing Ligament/Crack Growth Rate
= (Allow. Depth-Current Maximum Depth)/Crack Growth Rate
= $(2.94-1.24)/5x10^{-5}$
= 34,000 hours
or 34,000/8,000 = 4.3 years

3.0 CONCLUSIONS

This evaluation provides a structural margin assessment of the indications found near the H5 weld in the Dresden Unit 3 shroud. Limit load techniques and ASME Code, Section XI safety factors were used to demonstrate adequate structural margin for the next 24-month fuel cycle of operation assuming a 360°, 1.24-inch deep flaw at the H5 weld location. The structural margin results are summarized in Table 2. A list of all of the conservative assumptions used in the evaluation is provided in Table 3.

The results of Table 2 demonstrate, based on limit load techniques, that a factor of sixteen is available in terms of required area for a 24-month fuel cycle of operation with a bounding maximum flaw depth of 1.24" in the H5 weld of the Dresden Unit 3 shroud.

TABLE 3: CONSERVATIVE ASSUMPTIONS INCLUDED IN LIMIT LOAD EVALUATION

1. A 360° crack was assumed, even though only approximately 150° of the circumference was examined and found to have cracking.

2. Crack depth was based on the maximum bounding crack depth which can be detected with high probability by UT rather than the average crack depth.

3. The bounding crack growth estimated for the next fuel cycle was included in the structural margin assessment.

4. ASME Code pressure boundary safety margins were applied even though the shroud is not a primary pressure boundary.

4.0 REFERENCES

[1] GE Nuclear Energy, "Core Shroud Cracks," GE Services Information Letter No. 572, Revision 1, October 4, 1993.

[2] Letter from M. D. Lyster (CECo) to W. T. Russell (NRC) dated 6/6/94, "Response to NRC Request for Additional Information Concerning Core Shroud Cracking at Dresden Units 2 & 3 and Quad Cities Units 1 & 2."

[3] GENE-523-05-0194, Revision 0, "Evaluation and Screening Criteria for the Dresden 2 and 3 Shrouds," W.F. Weitze, GE Nuclear Energy, San Jose, CA, March 1994.

[4] ASME Boiler & Pressure Vessel Code, Section XI, "Rules for Inservice Inspection for Nuclear Power Plant Components," 1989 Edition, American Society of Mechanical Engineers, New York.

[5] Letter from Sylvia Wang (GE) to Kris Kotak (GE), "Estimated Fast Neutron Fluence at Dresden 3 Shroud Welds," April 29, 1994.

[6] EPRI Report NP-4767, Project 2680-2, "Evaluation of BWR Top-Guide Integrity," Electric Power Research Institute, Component Reliability Program, Nuclear Power Division, Final Report, November 1986.

[7] Sampath Ranganath and Hardayal S. Mehta, "Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping," Elastic-Plastic Fracture: Second Symposium, Volume II -- Fracture Resistance Curves and Engineering Applications, ASTM STP 803, American Society for Testing Materials, 1983.

[8] GE-NE-A00-05652-03, "Preliminary Safety Assessment of Core Shroud Indications for Cycle 14 Operation of Dresden Unit 2," H. Choe, GE Nuclear Energy, May 1994.

[9] EPRI Report TR-103515, Project 2493, "BWR Water Chemistry Guidelines -- 1993 Revision, Normal and Hydrogen Water Chemistry," Electric Power Research Institute, BWR Water Chemistry Guidelines Revision Committee, February 1994.

ATTACHMENT 4

Structural Integrity Report RAM-94-159, Revision 0, dated June 11, 1994, Evaluation of Circumferential Core Shroud Welds at Dresden Unit 3.

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June 11, 1994
RAM-94-159
SIR-94-051
Revision 0

Mr. Jerry Whitman
BWR Engineering Department
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Commonwealth Edison Company
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Morris, IL 60450

Subject: Evaluation of Flaws in Circumferential Core Shroud Welds At Dresden, Unit 3

Dear Jerry:

Structural Integrity Associates (SI) has performed an evaluation of the flaw indications found in circumferential welds H1, H2, H3, H4, H6, and H7 at Dresden, Unit 3, in order to determine the ASME Code structural margin in each of these welds. The evaluation of weld H5 was performed elsewhere and will be submitted under separate cover. The evaluation performed here was designed to evaluate operation without repair of these welds for an additional 24-month operating cycle. The inspection and evaluation were performed following the approach used in the Inspection Criteria [1] and Screening Criteria [2] developed for Dresden, Unit 3, based on limit load and linear elastic fracture mechanics (LEFM) techniques. The purpose of the screening criteria was to develop criteria that allowed indications discovered during visual inspection to be screened for further evaluation. The Inspection Criteria refined the screening criteria, providing for minimum distributed sound material which would allow for operation for the specified additional operating period. Since the criteria were based on visual examinations, all flaws were conservatively assumed to be through-wall, and allowable flaw lengths were calculated using the appropriate limit load or LEFM techniques. The following sections of this letter report describe the methodology used in the initial inspection and the evaluation results.

Initial Inspection and Evaluation Methodology

The inspection and evaluation approach employed at Dresden, Unit 3 provides the necessary information for determination of the allowable flaw lengths, including crack growth for the next operating period for all flaws observed, while assuming that the cracking is through-wall wherever it is observed. An initial sample of four to eight locations, spaced approximately evenly around the circumference of each horizontal weld in the shroud, represented the examination area for the initial in-vessel visual inspection (IVVI) for the core shroud.

The sample was structured such that if sufficient sound metal was found visually to satisfy the screening criterion, the weld was accepted for continued operation for the next operating period. If sufficient sound metal was not observed, the IVVI was to be expanded as additional accessible locations were identified, given the physical constraints associated with the inspection, to other areas around the shroud, and was continued until sufficient sound metal was found, or until all accessible areas were inspected.

This IVVI was performed on the outside surfaces of the core shroud for the H1, H2, H3, H4, H5, H6, and H7 welds, and on the inside surface of welds H3 and H4. Additionally, ultrasonic examination (UT), using sophisticated state-of-the-art equipment, was performed on welds H2, H6 and H7 in order to corroborate the visual qualification.

Acceptance Criteria

The core shroud is a core support structure which provides lateral support for the fuel. The applicable codes, standards and classifications for the core shroud are as follows:

- The core shroud is classified as a safety-related component.
- The core shroud is not an ASME Code component. However, the original design is in accordance with the intent of Section III of the ASME Code.
- The evaluation of the core shroud was performed in accordance with the requirements of Section XI of the ASME Code, 1989 Edition, Paragraph IWB-3142.4. [3]

Flaw Evaluation Results

Following completion of the inspection of the H1, H2, H3, H4, H6, and H7 welds, flaw analyses were performed to demonstrate that the structural margins identified in the screening criteria were maintained for the actual flaw configurations which were identified. The flaw analyses were performed using limit load as the failure criterion for each of the welds. The evaluation performed here takes into account the distribution of uncracked material around the circumference of the shroud, an approach less restrictive than assuming in the limit load analysis that the cracks are continuous. In addition, the H4 weld, which is the core beltline shroud weld, was also evaluated using LEFM fracture methodology to be consistent with the screening criteria [2]. Substantial conservatisms were built into the flaw evaluation to account for the weld area examined, the weld area which was not examined, the limitations in near surface resolution capabilities of UT, through-the-thickness crack growth and circumferential crack growth, and the Section XI flaw proximity criteria as applied to adjacent flaws. The specific conservatisms utilized in this evaluation are as follows:

1. A bounding crack growth rate ($5x10^{-5}$ inches/hour) through-wall and around the circumference was applied to the cracks detected for the next operating cycle (24-months) for the structural margin assessment.

2. All inspected regions which are identified as cracked, whether by IVVI or by UT, are treated as through-wall cracks and assumed to grow by 0.833 inches at each end during the next 24-month operating cycle.

3. For the H2 weld analysis, based upon UT results, areas examined by UT which were found to be unflawed are assumed to contain cracks which are initially 0.5 inches deep and which grow (in-depth and at each end) by 0.833 inches during the next 24-month operating cycle.

4. For the H2 weld analysis, based upon UT results, all uninspected regions are assumed to be cracked through-wall and are grown by the maximum crack growth rate of 0.833 inches on each side during the next 24-month operating cycle.

5. All uninspected regions associated with the IVVI examination are assumed to be cracked through-wall and are grown by the maximum crack growth rate of 0.833 inches on each side during the next 24-month operating cycle.

6. ASME Code pressure boundary safety margins were applied to these evaluations even though the core shroud is not a primary pressure boundary.

7. ASME Code, Section XI proximity rules for adjacent flaws were applied.

The conservative assumptions described above were applied to each of the horizontal welds examined in this report. According to the screening criteria [2], the loading condition which governs the limit load analysis is the faulted condition. The faulted condition also governs the LEFM analysis which was performed on the H4 weld, per the recommendation in the screening criteria [2]. Table 1 presents the membrane and bending stresses for the faulted condition which were used for the limit load analyses for each of the welds identified in the table, and for the LEFM analysis performed for weld H4. One notes from Table 1 that the highest loads are observed at the H6 and H7 welds, and the lowest loads occur at the H1 and H2 weld locations. The limit load analysis was performed for all welds evaluated in this study, the H1, H2, H3, H4, H6, and H7 welds, and LEFM was also performed for the H4 weld.

Table 2 presents the results of the IVVI inspection taken from Reference 4 for each of the horizontal welds evaluated in this report. The Table 2 IVVI results for the H2 weld are reduced by the area found flawed by UT of that weld. Where UT identified flaws in locations previously identified as sound by the IVVI, the sound areas identified in Table 2 reflect the reduction of the UT results from the IVVI results. These combined IVVI and UT results were used for the limit load analysis performed on weld H2. Table 2 also presents the IVVI sound metal locations (no flaws) which were used in the limit load analyses for all of the remaining welds (H1, H3, H4, H6, and H7), as well as for the LEFM analysis of weld H4.

The results of the limit load analysis for each of the horizontal welds is presented in Table 3. One observes from this table that the factors of safety for the faulted condition (Table 1) range from 2.2 for weld H2 to 15.3 for weld H1. This compares to an ASME Code minimum factor of safety of 1.4 specified for pressure boundary components under faulted loading conditions. One should note that the conservatisms utilized in this study are as described previously in this section.

The UT data obtained for the H2 location [5] was evaluated under the Table 1 faulted loading conditions to perform a limit load analysis for this weld. Table 4 reports the results for this analysis using the UT conservatisms described previously in this section.

Finally, an evaluation of the H4 weld was performed using the IVVI data and LEFM methodology to determine the applied stress intensity factor resulting from the conservatively estimated cracking combined with the bounding loading condition (the faulted condition) for this weld location. The conservative LEFM analysis was performed even though limit load governs at this location as well as at all other circumferential weld locations since the fluence at weld H4 at Dresden, Unit 3, is lower than the threshold for toughness degradation. The results of this analysis demonstrate that the 150 ksi-$(in)^{1/2}$ toughness which is presented in the screening criteria [2] as the acceptable fracture toughness for this material under irradiation embrittled conditions is met. Table 5 illustrates that the ASME code minimum factor-of-safety of 1.4 has been met under this loading condition for the flaws present at weld H4.

Summary

Based upon a review of the IVVI data for circumferential welds H1, H2, H3, H4, H6, and H7, as supplemented by the UT results for weld H2, there is substantial ASME Code margin for each of these welds under conservative, bounding conditions to allow for continued operation for a minimum of one additional 24-month operating cycle. The analyses performed included limit load analyses under bounding design basis accident conditions, and LEFM for the postulated highest fluence weld. The evaluations were performed with the assumption that all regions uninspected by IVVI and UT were cracked through wall, that any cracking observed by IVVI and UT was cracked through wall, and that any unflawed regions inspected by UT were cracked to a modest initial depth. Additionally, all areas assumed to be cracked were grown (at each end and in depth) at the bounding crack growth rate of $5x10^{-5}$ in/hr. ASME Code safety margins were used and were exceeded in all cases for the next 24-month operating cycle.

Very truly yours,

[signature] for

R. A. Mattson, P.E.
Associate

/mm
attachments

References

1. GE Nuclear Energy, "Recommended Inspection Criteria for the Dresden 2 and 3 Shrouds", GENE-523-28-0294, Rev. 1, June, 1994.

2. GE Nuclear Energy, "Evaluation and Screening Criteria for the Dresden 2 and 3 Shrouds", GENE-523-05-0194, March, 1994.

3. American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI, 1989 Edition.

4. Commonwealth Edison Company, "Response to NRC Request for Additional Information concerning Core Shroud Cracking At Dresden, Units 2 and 3, and Quad Cities, Units 1 and 2", June 6, 1994.

5. GE Nuclear Energy, "Dresden, Unit 3 UT Inspection Results, Weld H2, Examination Summary Sheet", Report No. R-S02, Data Sheet Nos. D-S04 through D-S08, May 23, 1994.

Table 1

Membrane/Bending Stresses

Weld Location	Shroud Stresses	
	Membrane	Bending
H1	0.205 ksi	0.087 ksi
H2	0.189 ksi	0.182 ksi
H3	0.161 ksi	0.218 ksi
H4	0.120 ksi	0.707 ksi
H6	0.285 ksi	1.331 ksi
H7	0.274 ksi	1.937 ksi

NOTE: 1. All values are for the Faulted Condition. Per the Screening Criteria, the Faulted Condition governs for limit load and LEFM analyses for these welds.

Table 2

"Sound Metal" Locations

Weld Location	IVVI Locations
H1	44°-52°, 53.04°-54°, 136°-144°, 226°-234°, 316°-330°
H2[3]	51°-54°, 227.5°-230.5°, 232°-234.5°, 318.5°-323°
H3	0°-20°, 90°-105°, 180°-190°, 192°-196°
H4	44°-55°, 135°-146°, 146.56°-151°, 226°-227°, 227.56°-230°, 230.56°-234°, 316°-318°, 318.56°-325°
H6	46°-54°, 76°-84°, 143°-151°, 166°-174°, 224°-235°, 256°-264°, 316°-324°, 346°-354°
H7	15°-20°, 20.57°-25°, 105°-115°, 135°-147°, 196°-204°, 286°-292°, 325°-335°

NOTES:

1. Values are from the "Dresden Unit 3 Shroud Visual Inspection Status" [4], except as noted.
2. Values exclude identified indications.
3. Values for weld H2 represent IVVI results reduced by the UT results.

Table 3

Limit Load Factors-of-Safety
Based Upon IVVI Results

Weld Location	Factors-of-Safety
H1	15.3
H2[1]	2.2
H3	11.9
H4	4.0
H6	6.1
H7	2.7

1. Factor-of-safety for H2 given by IVVI results reduced by UT results.

Table 4
Limit Load Factor-of-Safety
Based Upon UT Results

Weld Location	Factor-of-Safety
H2	16.8

Table 5
LEFM Factor-of-Safety
Based Upon IVVI Results

Weld Location	Factor-of-Safety
H4	1.4

ATTACHMENT 5

General Electric Company Letter GLS 94-11, dated June 8, 1994, Response to Commonwealth Edison Technical Audit Questions Regarding the H5 Weld Flaw Evaluations for Dresden Unit 3 and Quad Cities Unit 1.

GE Nuclear Energy

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GLS 94-11
June 8, 1994

cc: S. Ranganath
R. Daniel
DRF 137-0010-7
(GE-NE-523-A69-0594)

TO: **Tom Spry, CECo**
FAX: (815) 942-2920, X-2922

FROM: **Gary L. Stevens -- GE San Jose** Gary

SUBJECT: Response to Commonwealth Edison Technical Audit Questions

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The Reference 1 and 2 reports provide a detailed structural evaluation of the core shroud H5 welds with crack indications for Dresden Unit 3 and Quad Cities Unit 1. The following information is provided to support technical audit questions raised by Commonwealth Edison regarding the core shroud weld H5 analytical evaluation.

<u>Structural Analysis Criteria</u>

The evaluation of flaws in such components as the shroud is not governed by formal criteria or methodology similar to that contained in Section III (Reference 3) or Section XI (Reference 4) of the ASME Code. In fact, the original design basis for the shroud or other reactor internals for the Dresden or Quad Cities plants was not governed by any ASME Code rules. While the shroud is classified as a safety class component, the design rules were not mandated by the ASME Code. In fact, the ASME Code issued Section III, Subsection NG (which would be used for shroud design today) only in 1974, well after the construction of the Dresden and Quad Cities plants. Nevertheless, there were BWR safety standard rules applied to the design of the shroud. This assured that a methodology similar to Section III, Subsection NB (not necessarily identical) was applied for the shroud design. In particular, safety factors similar to that in the ASME Code were built into the design.

Another consideration in the design was the selection of load combinations in the design process. For example, the FSAR for the Dresden or Quad Cities plants did not explicitly include the limiting combination of LOCA (main steam line break) + SSE (or DBE) in the design analysis. This load combination was included later in BWR/6 designs as well as shroud repair designs that have been implemented to-date.

The approach used in References 1 and 2 includes the following considerations:

1. The shroud was evaluated as a safety class component.

2. The evaluation rules considered the appropriate failure modes (e.g., limit load or fracture where applicable), and provided safety factors consistent with the current ASME Code.

3. Bounding crack growth rates appropriate for stress corrosion cracking were included.

4. Methodology similar to that used in Section XI, IWB-3640 were used.

The following discussion addresses specific issues on the structural analysis.

<u>Rationale for the use of IWB-3640/Appendix C limit analysis for the H5 weld configuration</u>:

As stated earlier, IWB-3640/Appendix C was not used; however, the analysis approach used concepts similar to those in Appendix C. The Appendix C rules are strictly intended for piping and consider a combination of limit analysis and linear elastic fracture mechanics (LEFM). For the H5 weld evaluation, the LEFM rules are not applicable since the fluence in the H5 weld region ($3x10^{16}$ n/cm^2) is well below the value where embrittlement effects apply. The limit load approach used in References 1 and 2 is based on the fundamental design philosophy for ductile materials, and is described in Reference 5. This is the basis for the original naval structural design basis (Reference 6) and subsequently Section III (including Subsection NG) of the ASME Code. When IWB-3640 and Appendix C were developed, the same approach was used with modification later for low toughness weld material.

The question of low toughness of the flux weldment was evaluated in conjunction with the measured J-R curve properties from specimens taken from the shroud from an overseas reactor (Reference 7). Although the fluence in the specimen was much higher ($8x10^{20}$ n/cm^2 versus $3x10^{16}$ n/cm^2 for Dresden Unit 3 and Quad Cities Unit 1), the mechanical behavior in the specimen was totally ductile as evidenced by the high J_{max} (equivalent $K_{I,max}$ of approximately 195 ksi-inch$^{1/2}$), stable crack extension (approximately 3 mm) and the morphology of the crack surface (ductile). Furthermore, since the specimen included parts of the weld and the heat affected zone and the crack was located in a region similar to the observed cracking, the measurement reflects the material property accurately. Finally, the applied stress intensity, K, (approximately 15 ksi-inch$^{1/2}$ for a 360° crack with 80% depth) are well below the material toughness (150 ksi-inch$^{1/2}$) after applying any knockdown factors required for the flux weldments.

The 75% limit for the crack depth in IWB-3640 (or 60% depth for flux welds) was based on practical considerations (i.e., it is not reasonable to have near through-wall cracking in pressure boundary components, regardless of the available fracture margins). This is not relevant for the shroud since the shroud is not a pressure boundary component and can tolerate through-wall cracking from a structural standpoint.

Rationale for not using stress intensification factors:

The Appendix C piping rules do include stress indices (stress intensification factors) since they apply for welds to pipe fittings. These rules use the straight pipe stress (i.e., pD/4t or MD/2I) and in turn apply the stress index to determine the maximum stresses in the body of the fitting. Thus, the stress index is used only when the maximum stress is higher at a different location (e.g., the curved surface in an elbow). For a pipe butt weld, the B stress index is in fact 1.0 for moment loading. Therefore, stress indices are not needed where the location of the maximum stress is known and the corresponding stress is used in the analysis. For example, in Section III of the ASME Code, no specific stress indices are needed for non-piping components. Since the Reference 1 and 2 stress analyses already consider the stresses for all shroud locations, no stress indices are necessary.

In particular, analysis has been performed for the H5 weld configuration for Dresden Unit 3, as described below. These results demonstrate that the primary stress calculations (based on strength of materials formulations) are in fact applicable. Thus, no additional stress intensification factors are needed.

Use of R/t ratio relative to the Appendix C assumption:

The shroud was not evaluated as a pipe; therefore, the R/t considerations do not apply.

Use of the 1" fillet weld:

No credit was taken for the 1" fillet weld in the stress calculations performed in References 1 and 2. All of the calculated stresses were based on the shroud thickness (2 inches) alone. The 1" fillet was only considered in terms of the allowable extent of cracking for crack growth evaluation. This is reasonable since the cracking has only been observed in the core plate support ring rather than in the H5 weld itself. Because of the high end grain susceptibility, the cracking is parallel to the plane of the plate and is driven by the combination of the residual and applied stresses. Considering the in-plane growth, it is reasonable to expect that the crack follows the plate orientation as it continues through the weld heat affected zone of the fillet weld before it penetrates the material surface, as shown in Figure 1. Because of higher stress corrosion cracking resistance of the weld metal (due to duplex structure and higher ferrite), the probability of the crack going into the weld metal (instead of the more susceptible plate material) is much lower.

A detailed parametric finite element analysis was performed to evaluate the distribution of stresses in the H5 weld region using the ANSYS finite element computer code (Reference 8). Limit load analyses (References 1 and 2) of the shroud demonstrated that for 360° flaws, crack depths of 96% of wall thickness (i.e., a/t = 0.96) for Quad Cities 1, and 98% of wall thickness (i.e., a/t = 0.98) for Dresden 3 could be tolerated. In the H5 weld region, this corresponds to a depth of 2.88" for Quad Cities 1 and 2.94" for Dresden 3 due to the presence of the 1.0" fillet on the shroud ID. A 0.25" ligament was assumed for the purposes of this parametric finite element analysis based on modeling limitations.

The overall finite element model (FEM) is shown in Figure 2. Figure 3 shows the portion of the FEM for the region of interest. As seen from Figure 3, elements were deleted to simulate the crack. Stresses resulting from deadweight, seismic and pressure previously determined were applied to the end of the model as a membrane stress to simulate shroud loading. Loads resulting from the faulted load condition, which was previously determined to be limiting, were applied to the model including a safety factor of 1.4 consistent with ASME Code, Section XI practice.

The resulting shroud axial stress distribution in the region of interest is shown in Figure 4. A linearized stress profile through the remaining ligament cross section is shown in Figure 5. From Figure 5, the average axial membrane stress is approximately 10,000 psi, which is consistent with hand calculations based on force equilibrium considerations. This average stress is significantly less than the allowable stress of $3S_m$ = 50,700 psi. This confirms that even for very large crack depths, there is a substantial safety margin.

References

[1] GE Report GENE-523-A69-0594, Revision 0, "Evaluation of the Indications Found at the H5 Weld Location in the Dresden Unit 3 Shroud," G. L. Stevens, GE Nuclear Energy, June 1994.

[2] GE Report GENE-523-A79-0594, Revision 0, "Evaluation of the Indications Found at the H5 Weld Location in the Quad Cities Unit 1 Shroud," G. L. Stevens, GE Nuclear Energy, June 1994.

[3] ASME Boiler & Pressure Vessel Code, Section III, "Nuclear Power Plant Components, Class I Components," 1989 Edition, American Society of Mechanical Engineers, New York.

[4] ASME Boiler & Pressure Vessel Code, Section XI, "Rules for Inservice Inspection for Nuclear Power Plant Components," 1989 Edition, American Society of Mechanical Engineers, New York.

[5] Pressure Vessels and Piping: Design and Analysis, Volume 1: Analysis for Design, "Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Sections III, and VIII, Division 2," American Society of Mechanical Engineers, New York, 1972.

[6] "Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Associated Components," United States Department of Commerce, Office of Technical Services, December 1958.

[7] GE Report GENE-523-05-0194, Revision 0, "Evaluation and Screening Criteria for the Dresden 2 and 3 Shrouds," W.F. Weitze, GE Nuclear Energy, March 1994.

[8] G. J. DeSalvo and R. W. Gorman, ANSYS Engineering Analysis System User's Manual, Swanson Analysis Systems, Inc., Houston, PA, Revision 4.4a, May 1, 1989.

Figure 1: Most Likely Path of Crack Propagation

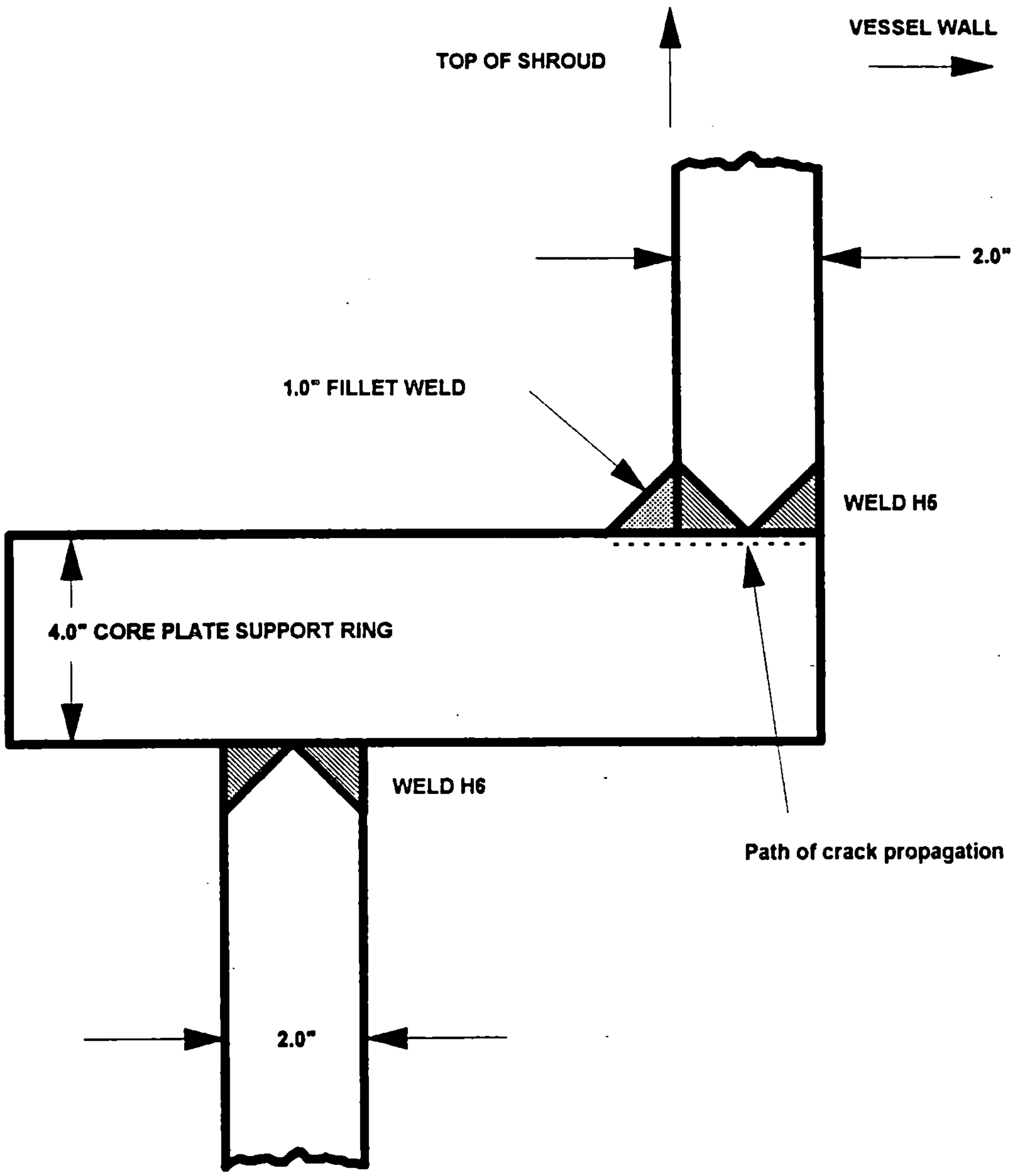

Figure 2: FEM with Simulated Crack for Determining Allowable Flaw Size