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EVALUATION OF THE INDICATIONS IN THE PLANT HATCH UNIT-2 CORE SHROUD WELDS H1, H2, H3 and H4

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1. INTRODUCTION

The structural integrity analysis of the indications found in the H1, H2, H3 and H4 core shroud welds at Plant Hatch Unit-2 is presented in this report. Ultrasonic (UT) inspection of these welds was recently performed (March-April 1994). A screening criteria was developed to evaluate the detected indications for acceptance for continued operation over the next two cycles of operation. The methodology used in this evaluation is consistent with that in the BWR Owners' Group Core Shroud Evaluation (Reference 1-1). The results of the evaluation demonstrate that the structural integrity of the core shroud with the indications is assured for at least 2 operating cycles.

Although UT was performed, which demonstrated significant remaining ligament, a flaw evaluation based on the assumption that all UT detected indications were through-wall was used. This is obviously conservative since no credit is taken for any of the remaining ligament as verified by the UT inspections.

The guiding parameter used in the flaw evaluation is the allowable through-wall flaw size, which already includes the ASME Code, Section XI safety factors. If all of the UT detected indications are assumed to be through-wall, then the longest flaws, or combination of flaws, would have the limiting margin against the allowable through-wall flaw size. In reality, the indications are not through-wall, and therefore, the criteria and methods presented in this report are conservative.

The result of this evaluation is the determination of the effective flaw lengths which are used to compare against the allowable flaw lengths. The determination of effective flaw length is based on ASME Code, Section XI, Subarticle IWA-3300 (1989 Edition) proximity criteria. These criteria provide the basis for the combination of neighboring indications depending on various geometric dimensions. Crack growth over the next two operating cycles is factored into the criteria.

Flaws are considered in the same plane if the perpendicular distance between the planes is 3" (2 times the shroud cylinder thickness) or less.

The selection of indications for further evaluation can be performed by evaluating the resulting effective flaw lengths. **Indications with effective flaw lengths greater than the allowable flaw sizes would require more detailed analysis.** The procedure described here is conservative since all of the indications are assumed through-wall and are being compared against the allowable through-wall flaw size.

A list of conservatisms used in this evaluation is summarized in Table 1-1.

Table 1-1 Conservatisms Included In Screening Evaluation

1. All indications were assumed to be through-wall for analysis.
2. All indications were assumed to be grouped together for the limit load calculation and no credit was taken for the spacing between indications.
3. ASME Code primary pressure boundary safety margins were applied even though the shroud is not a primary pressure boundary.
4. ASME Code, Section XI proximity rules were applied.
5. An additional proximity rule which accounts for fracture mechanics interaction between adjacent flaws was used.
6. Both LEFM and limit load analysis were applied (for weld H4). LEFM underestimates allowable flaw size for austenitic materials and is not required per ASME Code, Section XI procedures.
7. Fracture toughness measured for similar materials having a higher fluence was used.
8. The bounding crack growth estimated for the next two fuel cycles was included in flaw lengths used for evaluation.

1.1 References

1-1 BWR Owners' Group Core Shroud Evaluation, GENE 523-148-1193, April 1994.

2. ULTRASONIC INSPECTION RESULTS

Ultrasonic inspection of the H1, H2, H3 and H4 welds and neighboring shroud cylinder material was recently performed. The results of UT inspections are provided in the examination summary sheets which are located in Appendix A. Tables 2-1 through 2-4 summarize the inspection results. These were used in the structural integrity evaluation of the shroud.

In addition there were locations which could not be inspected due to access limitations. The uninspected zones were considered in the evaluation as described in Section 4.0. The uninspected zones are summarized in the examination summary sheets and taken into account in the flaw evaluation presented in Section 4.0.

The four upper most shroud circumferential welds (H1, H2, H3, and H4) were inspected by ultrasonic volumetric examination from the outer diameter (O.D.). The inspection was performed using the General Electric O.D. Tracker UT scanner, the GE SMART 2000 Data Acquisition/Analysis system, and a PC based motion controller (GE Motion Controller).

The search unit used by the O.D. Tracker scanner typically consists of four transducers: two 45° Shear, 2.25 MHz, one looking up and the other looking down, and two 60° RL, 4 MHz, again one looking up and the second looking down. The system was calibrated on a calibration block representative of the Plant Hatch Unit-2 shroud just prior to and immediately following the examination of each weld.

The O.D. Tracker was installed into the vessel and placed on top of the shroud discharge plenum. Two cam rollers were used to straddle the shroud head ring with one roller riding on the I.D. of the steam dam and the other riding on the O.D. of the ring itself. Two drive rollers riding on top of the steam dam enable the tool to be moved remotely about the circumference of the shroud to position the tool at an appropriate inspection location. A

positioning cylinder is used to locate the O.D. Tracker relative to a particular shroud head lug. This, combined with the read out of the encoders associated with the tooling motors, enables the location of the search package to be known within ± 1.0 inch (this tolerance applies for when the search unit is extended several feet away from the tooling body as in the case of H4; much tighter tolerances apply for those packages that inspect welds proximate to the tooling body as in the case of H1 through H3). The O.D. Tracker scanner supports four different configurations: the first is an arm that extends onto the shroud upper barrel and is used to inspect welds H1 and H2, a second actuating arm is used to inspect H3, and extended arms are used to inspect H4. For H1 through H3, spring force only is used to ensure proper transducer contact. The configuration for H4 uses the additional force of a reaction water jet to apply the transducers to the shroud with adequate force. Once the tool is located off a particular lug, air cylinders are actuated to securely fix the tool in that location for the duration of the scan. Approximately 15° can be inspected in one scan before the air cylinders are retracted and the tool moves to the next desired shroud head lug using the drive rollers. The air cylinders are actuated to secure the tool and the process is repeated until the exam is complete.

Because of the multiple interferences present in the annulus between the shroud O.D. and the Reactor Pressure Vessel I.D., the O.D. Tracker was periodically taken off the shroud, manually moved around the obstacle(s) and reinstalled to resume scanning. These interferences included the shroud lifting lugs and core spray spargers.

The entire RF waveform of the data was collected and stored on optical disk for future review. The data was then reduced by GE Level III UT operators using the GE SMART 2000 system, and a complete report given to the plant owners.

In addition to the UT inspection discussed above, five shroud welds (H5, H6A, H6B, H7, and H8) were partially examined by visual techniques from the outside diameter surface. The welds were visually inspected according to the recommendations provided in GE SIL 572, Rev. 1. The IVVI was performed using the IST-1250 black and white underwater

video camera system. The video was recorded on video tape for review and later comparison viewing.

The areas of visual inspection were the accessible weld locations above the access hole covers at 0 and 180 degree azimuths. No indications were found. The inspection was performed by a Level II VT and reviewed by a Level III VT.

Table 2-1 - Weld H1 Indications - 1°=1.65"

Indication	Distance from 0 (inch)	Total Length (inch)	Maximum Depth (inch)	Side of Weld
1	378.2	1.1	0.5	Lower
2	482.9	0.4	0.32	Lower
3	524.5	8.6	0.47	Lower
4	545.5	4.1	0.28	Lower
5	559.2	0.2	0.16	Lower

Table 2-2 - Weld H2 Indications - 1°=1.65"

Indication	Distance from 0 (inch)	Total Length (inch)	Maximum Depth (inch)	Side of Weld
1	43.6	9.5	0.53	Upper
2	64.4	17.1	0.52	Upper
3	86.5	161.7	0.6	Upper
4	381.8	1.0	0.27	Upper
5	395.2	15.8	0.28	Upper
6	428.3	2.4	0.22	Upper
7	477.2	11.0	0.33	Upper
8	505.1	2.4	0.34	Upper
9	528.8	15.9	0.36	Upper

Table 2-3 - Weld H3 Indications - 1°=1.55"

Indication	Distance from 0 (inch)	Total Length (inch)	Maximum Depth (inch)	Side of Weld
1	33.8	3.4	0.23	In Weld
2	48.1	1.8	0.19	In Weld
3	98.7	16.8	0.68	In Weld
4	118.7	0.3	0.59	In Weld
5	125.4	0.2	0.54	In Weld
6	130.1	0.7	0.66	In Weld
7	136.1	9.0	0.60	In Weld
8	500.2	1.2	0.37	In Weld

Table 2-4 - Weld H4 Indications -1°=1.55"

Indication	Distance from 0 (inch)	Total Length (inch)	Maximum Depth (inch)	Side of Weld
1	194.2	1.5	0.35	In Weld
2	321.5	2.8	0.22	In Weld
3	331.2	3.9	0.17	In Weld
4	332.0	3.7	0.32	Upper
5	339.5	5.0	0.16	In Weld
6	374.6	1.0	0.16	Upper
7	377.7	3.5	0.35	In Weld
8	384.1	4.2	0.41	In Weld
9	396.8	3.6	0.24	In Weld
10	406.7	1.7	0.28	In Weld
11	415.1	1.4	0.51	In Weld
12	468.9	1.8	0.43	In Weld
13	516.0	1.6	0.34	In Weld
14	518.9	1.3	0.39	In Weld
15	522.2	10.9	0.49	In Weld

3. FLAW EVALUATION

In this section the flaw evaluation and methodology for the H1 through H4 weld indications are presented. This involves determining the appropriate effective flaw lengths and allowable flaw sizes.

3.1 Structural Analysis

This section describes the details of the structural analysis performed to determine the allowable flaw lengths. The structural analysis consists of two steps: the determination of stress magnitudes in the shroud, and the calculation of the allowable flaw lengths. Both the fracture mechanics (LEFM) and limit load methods were used in the calculation of allowable flaw length for weld H4 since it is near the core. Only limit load was used for welds H1, H2, and H3 since they are located at a sufficient distance from the core such that fluence effects on material fracture toughness are not significant.

3.1.1 Applied Loads and Calculated Stresses

The applied loads on the shroud consist of internal differential pressure, weight and seismic. The seismic loads consist of a horizontal shear force at the top of the shroud and an overturning bending moment. The shear force produces a shear stress of insignificant magnitude, and is not considered. The bending moment stress at a shroud cross-section varies as a function of its vertical distance from the top of the shroud. Because of the inherent ductility of the material, residual stresses and other secondary stresses do not affect structural margin. Thus, they need not be considered in the analysis.

The magnitudes of the applied loads were obtained from the seismic stress analysis, FSAR and system information reports. The nominal shroud radius and thickness (1.5 in) were used to calculate the stresses from the applied loads. The stresses are essentially based on

the strength of materials formulas. The specific loads at each weld location were used in this evaluation. Figure 3-1 shows the weld designation and relative locations in the shroud.

Table 3-1 shows the calculated seismic stress for the four welds of interest. The pressure difference used for the evaluation of the indications was 29 psi and 12.02 psi corresponding to the shroud head ΔP for increased core flow conditions for the faulted and upset conditions, respectively (Reference 3-1).

Table 3-1 Seismic Axial Stresses at Shroud Welds (SSE=2xOBE)

Weld Designation	SSE Moment (in-lbs)	OBE Moment (in-lbs)	Stress (ksi)	
			SSE	OBE
H1	$84.6\text{x}10^6$	$42.4\text{x}10^6$	2.04	1.02
H2	$114.6\text{x}10^6$	$57.4\text{x}10^6$	2.76	1.38
H3	$117.6\text{x}10^6$	$58.8\text{x}10^6$	3.23	1.62
H4	$183.2\text{x}10^6$	$91.6\text{x}10^6$	5.02	2.51

The structural analysis for the indications at weld H4 uses two methods; linear elastic fracture mechanics (LEFM) and limit load analysis. For welds H1, H2, and H3, only limit load was used due to the distance from the core region. Since the limit load is concerned with the gross failure of the section, the allowable flaw length based on this approach may be used for comparison with the sum of the lengths of all the flaws at a cross-section. On the other hand, the LEFM approach considers the flaw tip fracture toughness and thus, the allowable flaw length based on this approach may be used for comparison with the largest effective flaw length at a cross-section. The technical approach for the two methods is described below.

3.1.2 Fracture Mechanics Analysis

The shroud material (austenitic stainless steel) is inherently ductile and it can be shown that the structural integrity analysis can be performed entirely on the basis of limit load. In fact, J-R curve measurements (Figure 3-2) made on a core shroud sample taken from an overseas plant having higher fluence ($8x10^{20}$ n/cm^2) showed stable crack extension and ductile failure. The ASME Code recognizes this fact in using only limit load techniques in Section XI, Subsubarticle IWB-3640 analysis. Nevertheless, a conservative fracture mechanics evaluation was performed using an equivalent K_{jc} corresponding to the material J_{Ic}. The K_{jc} for the overseas plant shroud was approximately 150 ksi$\sqrt{in}$. Use of this equivalence is conservative since:

i) The calculated fluence for Plant Hatch Unit-2 (peak of $\approx 6x10^{20}$ n/cm^2) is lower than that for the overseas plant from which J-R curves were obtained.

ii) The J-R curves show J_{max} values well above the J_{Ic}, confirming that there is load capability well beyond crack initiation (See Figure 3-2).

The J-R curves shown in Figure 3-2 can be used to make the following conclusions regarding behavior of the shroud material:

- Shroud material with fluence up to at least $8x10^{20}$ n/cm^2 contains significant ductility.
- LEFM is conservative for fluence up to at least $8x10^{20}$ n/cm^2.
- There is significant margin between J_{max} and J_{Ic}, demonstrating that there is substantial load carrying capability beyond J_{Ic}.
- The J-R curves were determined from samples considering through-wall crack growth in the weld heat affected zone and thus contain some effects of the weld. Further consideration for weld metal effects would likely have a small impact on allowable flaw size.

Using the safety factor of 2.8 for normal and upset conditions, the allowable K_{Ic} is 53.6 ksi$\sqrt{in}$. For faulted conditions the allowable K_{Ic} is 107 ksi$\sqrt{in}$ using a safety factor of 1.4. For the analysis presented here, the LEFM analysis is confined to the H4 weld. The fluence corresponding to welds H1, H2, and H3 is an order of magnitude lower and the associated fracture toughness is comparable to that of the unirradiated material. For those locations, limit load analysis is used.

An additional consideration that applies only to the fracture mechanics analysis is the question, "When is a flaw independent of an adjacent flaw?". The ASME Code proximity rules consider how flaws can link up and become a single flaw as a result of proximity. However, even when two flaws are separated by a ligament that exceeds the criterion, they may not be considered totally independent of each other. That is, the flaw tip stress intensity factor may be affected by the presence of the adjacent flaw. This can be accounted for by using the finite width correction factor for a flaw in a finite plate. For a through-wall flaw in an "infinite" plate, the stress intensity factor is:

$$K = \sigma\sqrt{(\pi a)}$$

For a finite plate, the K value is higher as determined by the finite width correction factor, F. In this evaluation it is assumed that the plate is "infinite" if the correction factor F is less than 1.1. As seen in Figure 3-3, if the width of the plate exceeds 2.5L (or a/b less than 0.4), then there would be no interaction due to plate end edge effects. If this same condition is applied to two neighboring flaws, then there will be no interaction between the two indications if the tips are at least 0.75(L1'+L2') apart. If the distance between indications is greater than 0.75(L1'+L2'), then they are considered as two separate flaws. However, if they are closer, for the purpose of fracture analysis, the equivalent flaw length is the sum of the two individual flaws.

3.1.3 Limit Load Analysis

A through-wall circumferential flaw was assumed in this calculation. A limit load approach was used in these calculations. The flow stress was taken as $3S_m$. The S_m value for the shroud material (Type 304L stainless steel) is 14.4 ksi at the normal operating temperature of 550°F.

Safety factors similar to those used in the ASME Code (2.8 for normal and upset and 1.4 for emergency and faulted) were used in the analysis. The seismic stress at each weld location is shown in Table 3-1.

It should be noted that this method assumes that all indications are joined and positioned in the limiting location to obtain a conservative allowable flaw size. Alternatively, the safety factor for limit load can be determined for the actual indication pattern. Typically, this method shows that significantly higher safety margins exist.

3.2 Allowable Through-Wall Flaws

Allowable through-wall flaw sizes were determined using both fracture mechanics and limit load techniques for circumferential flaws. It should be emphasized that the allowable through-wall flaws are based on many conservative assumptions and are intended for use only in this conservative flaw evaluation. More detailed analysis can be performed to justify larger flaws (both through-wall or part through-wall).

3.2.1 Allowable Through-Wall Circumferential Flaw Size

Both the LEFM and limit load methods were used to evaluate the allowable through-wall flaws.

3.2.2 Fracture Mechanics Analysis

LEFM was used to evaluate the H4 weld. The total axial pressure and seismic stress corresponding to the faulted condition (limiting condition) is 5.88 for weld H4.

To determine the allowable flaw size based on LEFM methods, the conservatively estimated irradiated material fracture toughness K_{Ic} value of 150 ksi$\sqrt{\text{in}}$ was used. Applying a safety factor of 1.4 for the faulted condition, the allowable K_I of 107 ksi$\sqrt{\text{in}}$ was obtained. The allowable flaw size was calculated using the following equation:

$$K_I = G_m * \sigma * \sqrt{(\pi a)}$$

where G_m is a curvature correction factor as defined in Figure 3-4 (Reference 3-2), σ is the axial stress, and 'a' is the half flaw length. The allowable through-wall circumferential flaw length (2a) was determined to be 73 inches for weld H4.

3.2.3 Limit Load Analysis

A through-wall circumferential flaw was assumed in this calculation. The limit load approach was used in these calculations. The flow stress was taken as $3S_m$. The S_m value for the shroud material is 14.4 ksi at the normal operating temperature of 550°F.

For the faulted condition, the axial force stress was 0.92 ksi for H1 and H2 and 0.86 ksi for H3 and H4. The bending moment stress was 2.04 ksi for H1, 2.76 ksi for H2, 3.23 ksi for H3 and 5.02 ksi for H4. Based on these stresses, the allowable flaw length was determined to be approximately 377 in. for H1, 362 in. for H2, 333 in. for H3, and 305 in. for H4 including the ASME Code, Section XI safety factors.

3.3 Summary of Allowable Through-Wall Flaws

The determination of the allowable through-wall flaws has been described in Section 3.2. The objective was to use the allowable flaw size as the basis for acceptance of the indications. If the allowable flaw size criteria are exceeded, the option of doing further detailed evaluation remains. The effective flaw lengths ($L1_{eff}$, $L2_{eff}$, etc.) determined by combining indications using the proximity and interaction rules, are used in the comparison with the allowable flaw sizes. The determination of effective flaw sizes are discussed in detail in Appendix B. The allowable through-wall flaws are shown in Table 3-2.

Table 3-2 - Allowable Through-Wall Circumferential Flaw Sizes

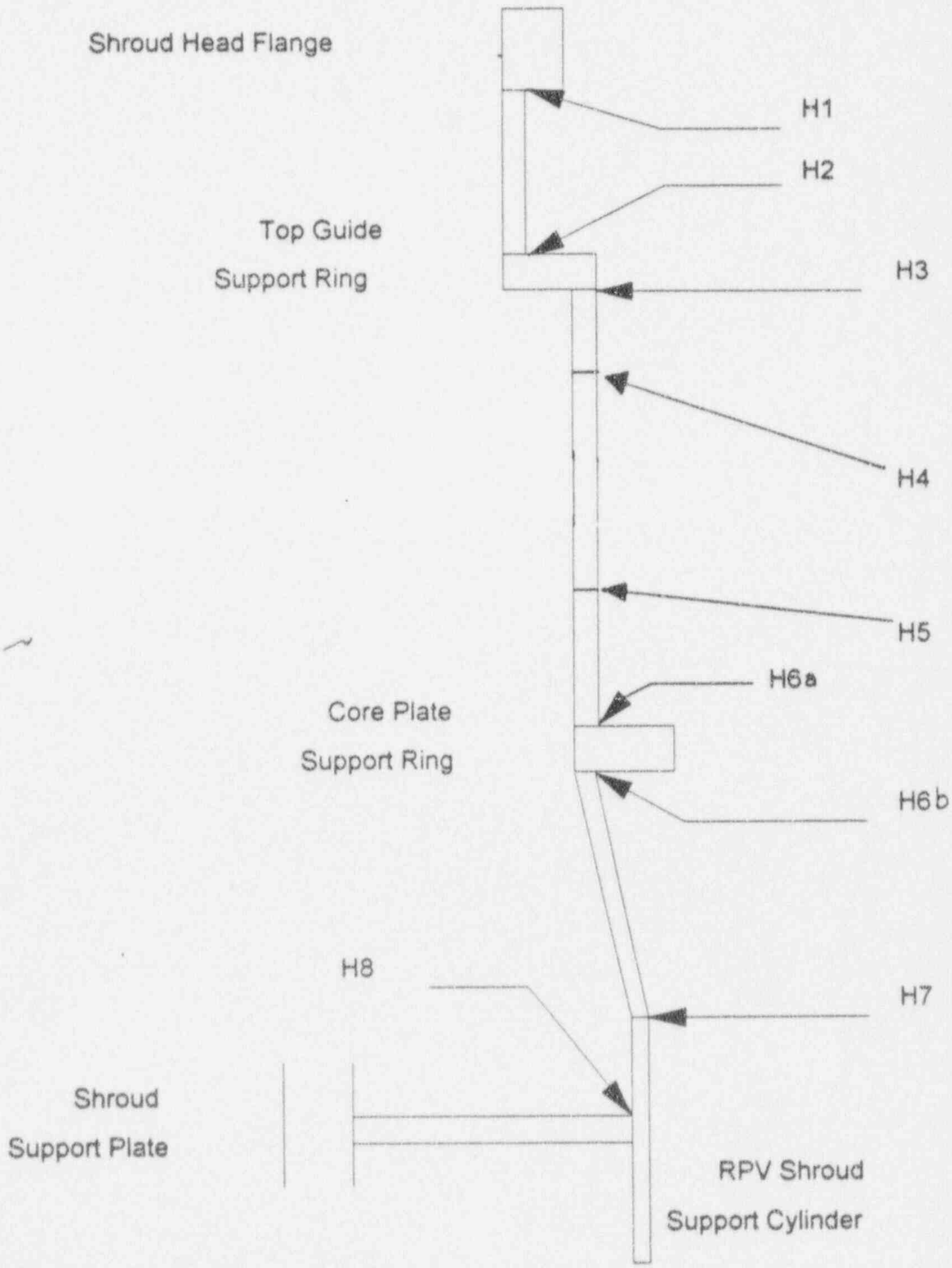
Weld	Cumulative Allowable Flaw Length (in.) (Limit Load)	LEFM Allowable(in.)
H1	377	--
H2	362	--
H3	333	--
H4	305	73

It should be noted that when considering LEFM based evaluations, the crack interaction criteria described in Appendix B, must be applied in comparing against the allowable lengths. For example, the adjacent flaws where the spacing S is less than 0.75 (L1' + L2'), the length L=L1' + L2' is used for comparison with the LEFM based allowable flaw length.

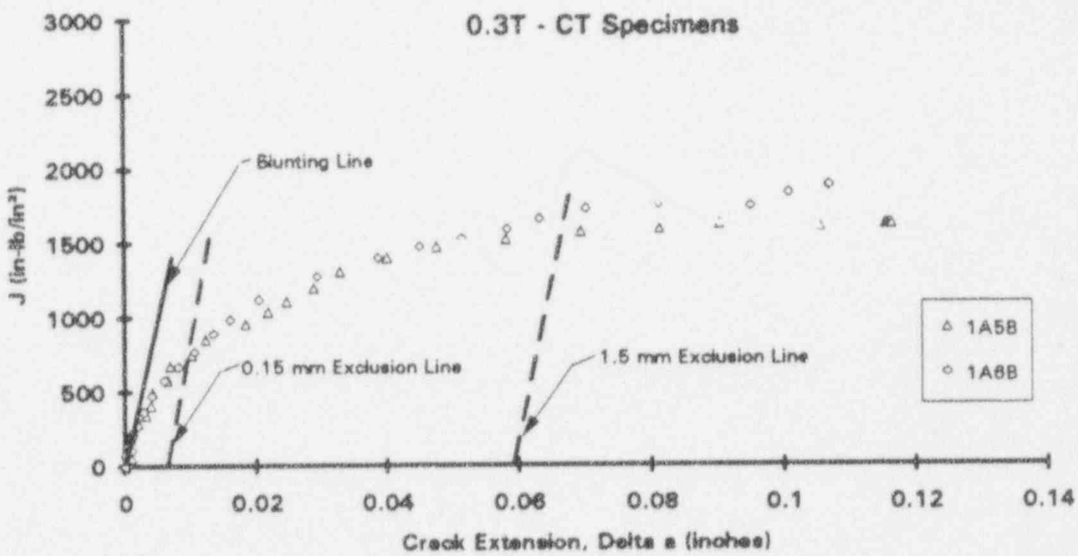
3.4 References

3-1 GE Letter, J. Charnley to J.F. Henning, Subject: Hatch 2 Increased Core Flow Analysis, October 2, 1980.

3-2. Rooke, D.P. and Cartwright, D.J., "Compendium of Stress Intensity Factors," The Hillingdon Press (1976).

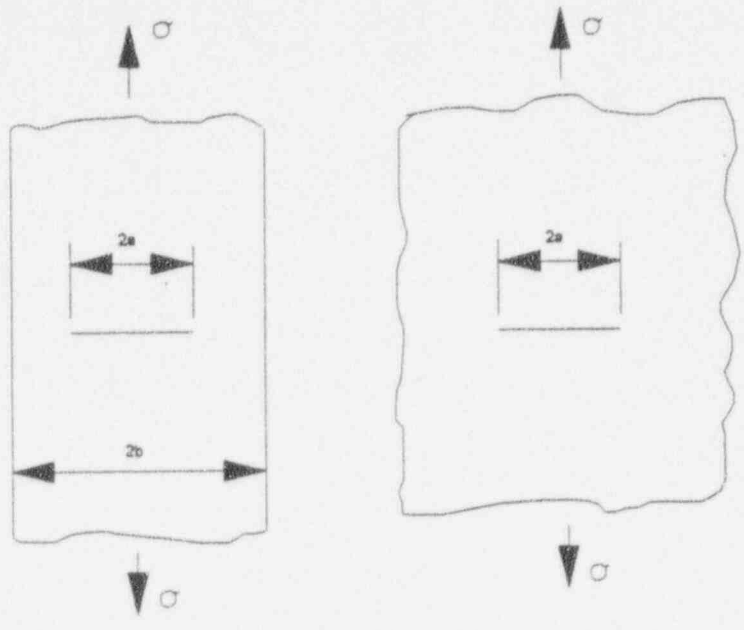


3-1: Sketch Showing Typical Welds in the Core Shroud



Per ASTM Standard E813

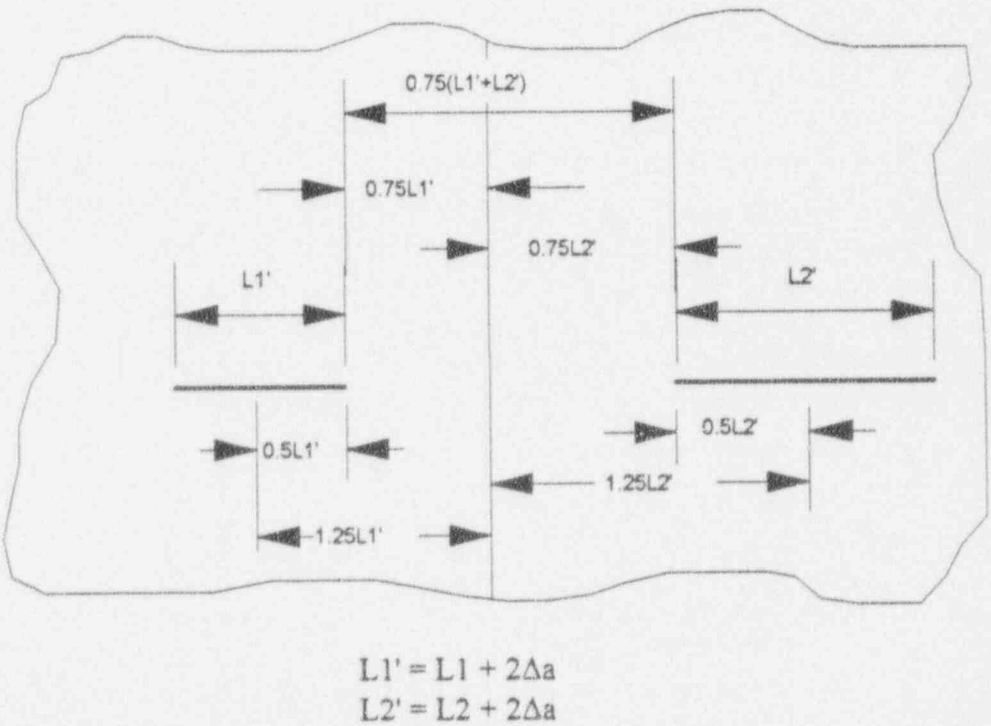
Figure 3-2: Comparison of J-R Curves Developed for Two Irradiated Stainless Steel Specimens



$K = \sigma\sqrt{\pi\, a} * F$

$K = \sigma\sqrt{\pi\, a}$

a/b	F
0.0	1.0
0.1	1.006
0.2	1.0246
0.3	1.0577
0.4	1.1094
0.5	1.1867



$L1' = L1 + 2\Delta a$
$L2' = L2 + 2\Delta a$

Note that L1 and L2 are the lengths of the as-found indications.

Figure 3-3: Schematic Illustrating Flaw Interaction

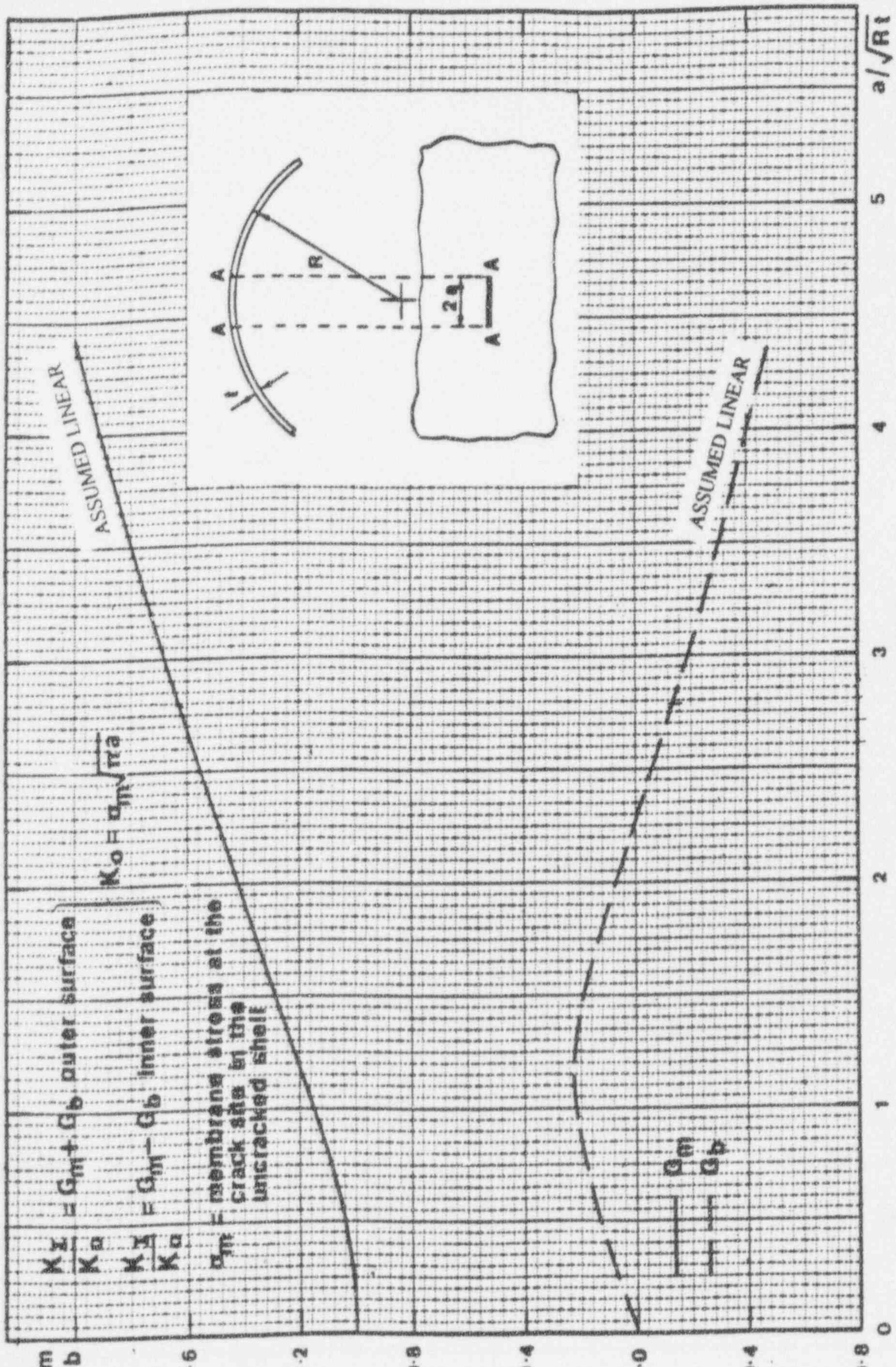


Figure 3-4 - K_I For Point A of a Circumferential Crack in a Cylindrical Shell Subjected to a Uniform Membrane Stress

4. EVALUATION OF INDICATIONS

The application of the screening criteria to the indications at H1 through H4 is presented in this section. The first step in this evaluation is the determination of the effective flaw lengths. The determination of the effective flaw lengths is based on the observed indications and their relative locations, and also includes consideration for locations which could not be inspected. The examination summary sheets are presented in Appendix A.

4.1 Weld H1 Evaluation

The indications observed at weld H1 are summarized in Table 2-1. Table 4-1 summarizes the inspected weld areas at H1.

Table 4-1 Weld H1 Inspected Zones

#	Angle Location (°)	Length (inch)	#	Angle Location(°)	Length (inch)	#	Angle Location(°)	Length (inch)
1	26.9-32.24	8.81	11	127.0-132.2	8.7	21	266.9-272.3	8.86
2	36.89-42.23	8.81	12	136.9-142.2	8.78	22	276.9-282.3	8.81
3	46.89-52.24	8.83	13	146.9-152.3	8.86	23	286.9-292.2	8.66
4	56.91-62.23	8.78	14	156.9-162.2	8.79	24	296.9-302.2	8.84
5	66.9-72.26	8.84	15	206.9-212.2	8.83	25	306.9-312.2	8.78
6	76.92-82.26	8.81	16	216.9-222.2	8.84	26	316.9-322.3	8.83
7	86.92-92.27	8.83	17	226.9-232.3	8.83	27	326.9-332.2	8.73
8	96.9-102.26	8.81	18	236.9-242.2	8.81	28	336.9-342.3	8.91
9	106.0-112.2	8.76	19	246.9-252.2	8.78			
10	116.9-122.3	8.94	20	256.9-262.2	8.78			

Indication 1 falls within inspected zone 17, indication 2 within zone 23, indication 3 within zone 26, indication 4 within zone 27 and indication 5 within zone 28. For purposes of this evaluation, indications 1, 2, 4, and 5 were assumed to equal the length of the zone in which they were found. It is also reasonable to assume that since the lengths of indications 1, 2, 4, and 5 were well within their respective zones (so that the ends of the indications are well defined within the zone), and that the neighboring uninspected zone lengths are relatively short (≈ 8.8 inches), that the neighboring uninspected zones are free of indications. In addition, since indication 3 was nearly the length of zone 26, it will be

assumed that the length of indication 3 equals that of the zone it was found in, plus the length of the neighboring uninspected zones. Since all other zones were relatively close, it is reasonable to assume that the neighboring uninspected zones are also free of indications except as noted above.

The resulting modified lengths are summarized in Table 4-2.

Table 4-2 Modified Indication Lengths

Indication	Modified Length (inch)	Measured Indication (inch)
1	8.83	1.1
2	8.66	0.4
3	24.23	8.6
4	8.73	4.1
5	8.91	0.2

In addition to the uninspected zones between the inspected zones shown in Table 4-1, there were two larger areas which could not be inspected due to the proximity of the shroud head locking lugs and core spray downcomers. These occurred between 342.27° to 26.9° and the second between 162.24° to 206.86°. The equivalent lengths are 73.6 inches for each of these uninspected zones. To address potential indications in the uninspected zones, it is reasonable to assume that the percentage of these zones with indications is the same as that for the inspected zones.

Based on the inspection results, 6% of the inspected areas contain indications. Assuming this same percentage in the uninspected zones results in an additional 8.8 inches of indication. Adding this length to the previously calculated effective length for the inspected zones results in a cumulative effective length of 68.2 inches.

Thus, the total length of the assumed indications used for evaluation purposes is approximately 68.2 inches. This is significantly higher than the actual indication length detected by UT of 14.4 inches. Adding crack growth at each end of the indications (total of five indications for two cycles) results in a cumulative effective length of 80.2 inches

This compares against the allowable flaw length of 377 inches using limit load. Thus, the structural integrity of the H1 weld is assured. It should be added that significant margin would exist even if the entire uninspected zones (342.27° to 26.9° and 162.24° to 206.86°) were assumed to contain throughwall indications (≈147).

4.2 Weld H2 Evaluation

The indications observed at weld H2 are summarized in Table 2-2. Inspection was not performed in two zones due to their proximity to the core spray downcomers. These zones were located between 167° to 209° and 347° to 17°.

Based on the examination summary sheet for weld H2 (in Appendix A), the depth of the deepest indication is 0.6 inch. If it is assumed that all of the indications are 0.6 inch in depth, the indication would be determined to be through-wall based on a crack growth rate of 5×10^{-5} in/hr after two operating cycles. Thus, these indications were assumed to be through-wall in this evaluation. The remainder of the weld region is assumed to be free of indications. It should be noted that based on UT inspection results of a shroud at a European plant, a crack growth rate of 2×10^{-5} in/hr has been observed. If this value were used for weld H2, crack growth through the shroud wall in two cycles would not be expected.

The total length of the indications detected by UT is approximately 236.8 inches. The approximate length of the zones which were not inspected is 118.8 inches. As stated in Appendix B, neighboring indications are combined if the indication crack tips are within 5.4" of each other. Based on the information in Table 2-2, Indications 2 and 3 must be combined. The modified indications are summarized in Table 4-3 (crack growth not included).

Table 4-3 - Weld H2 Combined Indications

Modified Indication #	Modified Length (in)	Comprised of Indications (from Table 2-2)
1	9.5	1
2	183.75	2 and 3
3	1.0	4
4	15.8	5
5	2.4	6
6	11.0	7
7	2.4	8
8	15.9	9

The total length of the modified indications is 241.75 inches. Crack growth over the next two cycles must also be factored into this calculation. Since there are 8 (modified) indications, crack growth from each of these must be considered. Using a crack growth rate of $5x10^{-5}$ in/hr, the crack growth from 16 crack tips is ;

$$\text{Total crack growth} = 2(5x10^{-5})(12000)(16) = 19.2 \text{ inches.}$$

Adding this crack growth to the total modified crack length, results in an effective length of 260.95 inches.

Finally, the uninspected zones must be considered. Due to the proximity to the core spray downcomers, inspection between the azimuths of 167° to 209° and 347° to 17° could not be performed. This is equivalent to an uninspected region of 118.8 inches. To address potential indications in the uninspected zones, it is reasonable to assume that the percentage of these zones with indications is the same as that for the inspected zones.

Based on the inspection results, 50% of the inspected areas contain indications. Assuming this same percentage in the uninspected zones results in an additional 59.4 inches of

indication. Adding this length to the previously calculated effective length for the inspected zones results in a cumulative effective length of 320.4 inches.

The allowable flaw length is 362 inches using limit load. Therefore, the structural integrity of weld H2 is assured.

Alternatively, it can be demonstrated that the structural integrity of weld H2 is assured if the entire uninspected zones are assumed to contain through-wall indications. This can be demonstrated by using the limit load method and accounting for the actual locations of indication-free ligaments. This calculation involves determination of the neutral axis such that the limiting safety factor is obtained.

Results of this calculation for weld H2 show a safety factor well in excess of the ASME Code Section XI safety factors (safety factor ≈ 6). This alternate method also demonstrates that the structural integrity of weld H2 is assured even when assuming that the uninspected regions are assumed to contain through-wall indications.

4.3 Weld H3 Evaluation

The indications at weld H3 are summarized in Table 2-3. Inspection was not performed in two zones due to their proximity to the core spray downcomers. These zones were located between 173° to 197° and 354° to 19°.

The total length of the indications detected by UT is approximately 33.4 inches. The approximate length of the zones which were not inspected is 76 inches. To address potential indications in the uninspected zones, it is reasonable to assume that the percentage of these zones with indications is the same as that for the inspected zones.

Based on the inspection results, 7% of the inspected areas contain indications. Assuming this same percentage in the uninspected zones results in an additional 5.3 inches of indication.

Based on the locations of the indications, it was determined that indications 3 and 4 require combination and indications 5 and 6 require combination per the previously discussed proximity criteria (S<5.4"). The modified indications are summarized in Table 4-4 (crack growth not included).

Table 4-4 - Weld H3 Combined Indications

Modified Indication #	Modified Length (in)	Comprised of Indications (from Table 2-3)
1	3.4	1
2	1.8	2
3	20.3	3 and 4
4	5.4	5 and 6
5	9.0	7
6	1.2	8

The total length of the modified indications is 41.1 in. Crack growth from the 6 modified indications is:

$$\text{Total crack growth} = 2(5\text{x}10^{-5})(12000)(12) = 14.4 \text{ in.}$$

Adding this to the modified lengths results in an effective length of 55.6 in. Adding the length of the uninspected zones gives a cumulative indication length of 60.9 in.

Since this length is well below the allowable flaw length of 333 inches, structural integrity of weld H3 is assured from a limit load viewpoint. It should be added that significant

safety margin exists even if the entire length of the uninspected zones were assumed to contain through-wall indications.

4.4 Weld H4 Evaluation

The indications found in weld H4 are summarized in Table 2-4. Inspection was not performed in two zones between 174° to 202° and 354° to 19°. Application of the proximity criteria requires the combination of some of the indications (S<5.4").

The total equivalent length for the uninspected zones is 81.8 inches. To address potential indications in the uninspected zones, it is reasonable to assume that the percentage of these zones with indications is the same as that for the inspected zones.

Based on the inspection results, 10% of the inspected areas contain indications. Assuming this same percentage in the uninspected zones results in an additional 8.2 inches of indication.

Table 4-5 shows the results of the proximity criteria application including crack growth consideration over two additional cycles.

Table 4-5 Weld H4 Combined Indications

Combined Indication	Length	Comprised of Indications:
1	3.9	1
2	5.2	2
3	15.7	3, 4 and 5
4	16.2	6, 7, and 8
5	6.0	9
6	4.1	10
7	3.8	11
8	4.2	12
9	19.6	13, 14, and 15
10	3.8	Uninspected Zone 1
11	4.3	Uninspected Zone 2

The total length of the combined indications is approximately 87 inches. Since this length is well below the allowable flaw length of 305 inches, structural integrity of weld H4 is assured from a limit load viewpoint. It should be added that significant margin exists even if the entire uninspected zones were assumed to contain through-wall indications.

The proximity check for LEFM combination ($S<0.75(L1'+L2')$) results in a maximum length of 17 in. (12.2 in. plus crack growth from indications 14 and 15 in Table 2-4). This is well below the LEFM allowable flaw size of 73 inches.

5. SUMMARY AND CONCLUSIONS

A conservative evaluation of the Plant Hatch Unit-2 core shroud has been performed to demonstrate that the structural integrity with the indications at welds H1 through H4 is assured for the next two operating cycles. Application of the screening criteria to the UT detected indications demonstrates that the structural integrity of welds H1 through H4 is assured for the next two operating cycles.

The flaw evaluation was presented in this report. The flaw evaluation assumed through-wall indications. By meeting the allowable flaw size criteria, the ASME Code Section XI safety margins are satisfied.

The flaw evaluation considered both linear elastic fracture mechanics (LEFM) and limit load concepts to determine acceptable through-wall indication lengths.

The screening criteria also uses the ASME Code Section XI criteria for combining flaws based on the proximity of indications. In addition, a second method for including the interaction between neighboring indication tips was considered for the LEFM allowable flaw size calculation. The resulting effective flaw lengths were compared against the allowable flaw size to determine if the structural integrity of the shroud was maintained.

APPENDIX A

Examination Summary Sheets

GE Nuclear Energy

EXAMINATION SUMMARY SHEET

REPORT NO.: R-S04

PROJECT: HATCH UNIT 2 1EBT3

PROCEDURE: UT-HAT-503V0 REV: 0 FRR: N/A N/A N/A

N/A REV: N/A FRR: N/A N/A N/A

N/A REV: N/A FRR: N/A N/A N/A

SYSTEM: SHROUD VESSEL

WELD NO.: H-1 (GIRTH WELD)

CONFIGURATION: CIRCUMFERENTIAL WELD SEAM

EXAMINER: P. ANDERSON LEVEL: II

EXAMINER: T. ROCKWOOD LEVEL: II

EXAMINER: A. CONTI LEVEL: II

☐ MT ☐ PT ☒ UT ☐ VT

WELD TYPE: ☒ CIRCUMFERENTIAL ☐ LONGITUDINAL ☒ OTHER SHROUD

DATA SHEET NO.(S): DS-009, DS-010, DS-011, DS-012, DS-013, DS-014, & DS-019

CAL SHEET NO.(S): CS-007, CS-008, CS-009 & CS-010

During the examination of the above referenced weld, five (5) indications associated with IGSCC/IASCC were recorded by the Smart 2000 system utilizing 45° shear wave and 60° refracted longitudinal wave search units.

The 45° shear wave search unit also recorded non-relevant indications, welding discontinuities, along with four (4) of the previously referenced indications from both sides of the weld, as well as inside surface geometry from the fillet weld crown on the upper side of the weld and inside surface geometry and outside surface weld crown geometry from the lower side of the weld.

The 60° RL also recorded non-relevant indications, welding discontinuities, along with the five (5) previously referenced indications from both sides of the weld, as well as fillet weld crown geometry from the upper side of the weld.

The indications referenced in the first paragraph have the following parameters:

Indication Number	Distance From Lo	Total Length	Remaining Ligament	Thruwall Dimension	Side of Weld	Type Reflector	Search Unit
1	378.2"	1.1"	1.00"	.50"	Lower	IGSCC/IASCC	45°/60°
2	482.9"	.4"	1.18"	.32"	Lower	IGSCC/IASCC	60°
3	524.5"	8.6"	1.03"	.47"	Lower	IGSCC/IASCC	45°/60°
4	545.5"	4.1"	1.22"	.28"	Lower	IGSCC/IASCC	45°/60°
5	559.2"	.2"	1.34"	.16"	Lower	IGSCC/IASCC	45°/60°

This examination was also limited to 'L' dimensions of 26.90° to 32.24°, 36.89° to 42.23°, 46.89° to 52.24°, 56.91° to 62.23°, 66.90° to 72.26°, 76.92° to 82.26°, 86.92° to 92.27°, 96.92° to 102.26°, 106.92° to 112.23°, 116.89° to 122.31°, 126.96° to 132.23°, 136.89° to 142.21°, 146.88° to 152.25°, 156.91° to 162.24°, 206.86° to 212.21°, 216.88° to 222.24°, 226.90° to 232.25°, 236.90° to 242.24°, 246.90° to 252.22°, 256.90° to 262.22°, 266.88° to 272.25°, 276.92° to 282.26°, 286.94° to 292.19°, 296.87° to 302.23°, 306.91° to 312.23°, 316.90° to 322.25°, 326.91° to 332.20°, and 336.87° to 342.27° from vessel '0' due to the proximity of the shroud head locking lugs and corespray downcomers. Circumferential 'L' dimensions for all examination scans were recorded in angular units in lieu of linear units. The conversion factor for circumferential measurements is 1.65" per degree.

☐ EXAM COMPLETE ☒ PARTIALLY EXAMINED (EXPLAIN IN COMMENTS) ☐ EXAM COMPLETE IN COMBINATION WITH DATA SHEETS BELOW

RWP NO.: 294-1110

ADDITIONAL DATA SHEETS: N/A

COMPARED TO: ☐ PSI ☐ ISI REPORT NO.(S): N/A ☐ NO CHANGE

NO. OF RECORDABLE INDICATIONS: 5

TOTAL DOSE .008 MAN REM

EXAMINATION RESULTS: ☐ ACCEPTABLE ☐ UNACCEPTABLE

NO. OF REPORTABLE INDICATIONS: 5

Paul Johnson	II	4-12-94	[signature]	4/21/94
SUMMARY BY	LEVEL	DATE	UTILITY REVIEW	DATE
Wes Money	III	4-19-94	N/A	N/A
GE REVIEWED BY	LEVEL	DATE	ANII REVIEW	DATE

PAGE: 1 OF: 38

FORM UT-09 REV. 5

GE Nuclear Energy

EXAMINATION SUMMARY SHEET

REPORT NO.: R-S02

PROJECT: HATCH UNIT 2 1EBT3

PROCEDURE: UT-HAT-503V0 **REV:** 0 **FRR:** N/A N/A N/A

N/A **REV:** N/A **FRR:** N/A N/A N/A

N/A **REV:** N/A **FRR:** N/A N/A N/A

SYSTEM: SHROUD VESSEL

WELD NO.: H-2 (GIRTH WELD)

CONFIGURATION: CIRCUMFERENTIAL WELD SEAM

EXAMINER: T. ROCKWOOD **LEVEL:** II

EXAMINER: P. ANDERSON **LEVEL:** II

EXAMINER: A. CONTI **LEVEL:** II

☐ MT ☐ PT ■ UT ☐ VT

WELD TYPE: ■ CIRCUMFERENTIAL ☐ LONGITUDINAL ■ OTHER SHROUD

DATA SHEET NO.(S): DS-015, DS-016, DS-017, DS-018, DS-020, & DS-021

CAL SHEET NO.(S): CS-011, CS-012, CS-013, & CS-014

During the examination of the above referenced weld, six (6) indications associated with IGSCC/IASCC along with three (3) ID connected planar flaws were recorded by the Smart 2000 system utilizing 45° shear wave and 60° refracted longitudinal wave search units.

The 45° shear wave search unit also recorded non-relevant indications from both sides of the weld, along with inside surface geometry from the fillet weld crown from the lower side of the weld, as well as outside surface geometry from the weld crown, inside surface geometry, welding discontinuities, and the nine (9) previously referenced ID connected indications from the upper side of the weld.

The 60° RL also recorded non-relevant indications and the nine (9) previously referenced ID connected indications from both sides of the weld, along with inside surface geometry from the fillet weld crown from the lower side of the weld, as well as welding discontinuities from the upper side of the weld.

The indications referenced in the first paragraph have the following parameters:

Indication Number	Distance From Lo	Total Length	Remaining Ligament	Thruwall Dimension	Side of Weld	Type Reflector	Search Unit
1	43.6"	9.5"	.97"	.53"	Upper	PLANAR	45°/60°
2	64.4"	17.1"	.98"	.52"	Upper	PLANAR	45°/60°
3	86.5"	161.7"	.90"	.60"	Upper	PLANAR	45°/60°
4	381.8"	1.0"	1.23"	.27"	Upper	IGSCC/IASCC	45°/60°
5	395.2"	15.8"	1.22"	.28"	Upper	IGSCC/IASCC	45°/60°
6	428.3"	2.4"	1.28"	.22"	Upper	IGSCC/IASCC	45°/60°
7	477.2"	11.0"	1.17"	.33"	Upper	IGSCC/IASCC	45°/60°
8	505.1"	2.4"	1.16"	.34"	Upper	IGSCC/IASCC	45°/60°
9	528.8"	15.9"	1.14"	.36"	Upper	IGSCC/IASCC	45°/60°

This examination was also limited to 'L' dimensions of 17° to 167° and 209° to 347° from vessel '0' due to the proximity of the corespray downcomers. Circumferential 'L' dimensions for all examination scans were recorded in angular units in lieu of linear units. The conversion factor for circumferential measurements is 1.65" per degree.

☐ EXAM COMPLETE ■ PARTIALLY EXAMINED (EXPLAIN IN COMMENTS) ☐ EXAM COMPLETE IN COMBINATION WITH DATA SHEETS BELOW

RWP NO 294-1110

ADDITIONAL DATA SHEETS N/A

COMPARED TO ☐ PSI ☐ ISI REPORT NO.(S): N/A ☐ NO CHANGE

NO. OF RECORDABLE INDICATIONS: 9

TOTAL DOSE .215 MAN REM

EXAMINATION RESULTS: ☐ ACCEPTABLE ☐ UNACCEPTABLE

NO. OF REPORTABLE INDICATIONS: 9

Wes D Money	III	4-17-94	[signature]	4/25/94
SUMMARY BY	LEVEL	DATE	UTILITY REVIEW	DATE
[signature]	III	4/19/94	N/A	N/A
GE REVIEWED BY	LEVEL	DATE	ANII REVIEW	DATE

PAGE: 1 OF 47

GE Nuclear Energy

EXAMINATION SUMMARY SHEET

REPORT NO.: R-S01

PROJECT: HATCH UNIT 2
1EBT3

PROCEDURE: UT-HAT-503V0 REV: 0 FRR: N/A, N/A, N/A

N/A REV: N/A FRR: N/A, N/A, N/A

N/A REV: N/A FRR: N/A, N/A, N/A

SYSTEM: SHROUD VESSEL

WELD NO.: H-3 (GIRTH WELD)

CONFIGURATION: CIRCUMFERENTIAL WELD SEAM

EXAMINER: J. LOYD LEVEL: II

EXAMINER: P. ANDERSON LEVEL: II

EXAMINER: N/A LEVEL: N/A

☐ MT ☐ PT ☒ UT ☐ VT

WELD TYPE: ☒ CIRCUMFERENTIAL ☐ LONGITUDINAL ☒ OTHER SHROUD

DATA SHEET NO.(S): DS-001, DS-002, DS-003, & DS-004

CAL SHEET NO.(S): CS-001 & CS-002

During the examination of the above referenced weld, eight (8) ID connected planar flaws within the weld material were recorded by the Smart 2000 system utilizing 45° shear wave and 60° refracted longitudinal wave search units.

The 45° shear wave search unit also recorded non-relevant indications, welding discontinuities, inside surface and weld crown geometry, along with the eight (8) previously referenced indications above from the lower side of the weld.

The 60° RL also recorded non-relevant indications, shear component, welding discontinuities, inside surface and weld crown geometry, along with the eight (8) previously referenced indications from the lower side of the weld.

The indications referenced in the first paragraph have the following parameters:

Indication Number	Distance From Lo	Total Length	Remaining Ligament	Thruwall Dimension	Side of Weld	Type Reflector	Search Unit
1	33.8"	3.4"	1.27"	.23"	In Weld	Planar Flaw	45°/60°
2	48.1"	1.8"	1.31"	.19"	In Weld	Planar Flaw	45°/60°
3	98.7"	16.8"	.82"	.68"	In Weld	Planar Flaw	45°/60°
4	118.7"	.3"	.91"	.59"	In Weld	Planar Flaw	45°/60°
5	125.4"	.2"	.96"	.54"	In Weld	Planar Flaw	45°/60°
6	130.1"	.7"	.84"	.66"	In Weld	Planar Flaw	45°/60°
7	136.1"	9.0"	.90"	.60"	In Weld	Planar Flaw	45°/60°
8	500.2"	1.2"	1.13"	.37"	In Weld	Planar Flaw	45°/60°

No examination was performed from the upper side of the weld due to the component configuration, and the examination from the lower side of the weld was limited due to the proximity of the outside diameter fillet weld. This examination was also limited to 'L' dimensions of 19° to 173° and 197° to 354° from vessel '0' due to the proximity of the corespray downcomers. Circumferential 'L' dimensions for all examination scans were recorded in angular units in lieu of linear units. The conversion factor for circumferential measurements is 1.55" per degree.

☐ EXAM COMPLETE ☒ PARTIALLY EXAMINED (EXPLAIN IN COMMENTS) ☐ EXAM COMPLETE IN COMBINATION WITH DATA SHEETS BELOW

ADDITIONAL DATA SHEETS: N/A

COMPARED TO: ☐ PSI ☐ ISI REPORT NO.(S): N/A ☐ NO CHANGE

EXAMINATION RESULTS: ☐ ACCEPTABLE ☐ UNACCEPTABLE

NO. OF RECORDABLE INDICATIONS: 8

NO. OF REPORTABLE INDICATIONS: 8

RWP NO.: 294-1110

TOTAL DOSE .010 MAN REM

[signature] III 4-14-94
SUMMARY BY LEVEL DATE

[signature] 4/21/94
UTILITY REVIEW DATE

[signature] III 4/14/94
GE REVIEWED BY LEVEL DATE

N/A N/A
ANII REVIEW DATE

PAGE: 1 OF: 27

FORM UT-09 REV. 3

GE Nuclear Energy

EXAMINATION SUMMARY SHEET

REPORT NO.: R-S03

PROJECT: HATCH UNIT 2
1EBT3

SYSTEM: SHROUD VESSEL

WELD NO.: H-4 (GIRTH WELD)

CONFIGURATION: CIRCUMFERENTIAL WELD SEAM

EXAMINER: P. ANDERSON LEVEL: II

EXAMINER: A. CONTI LEVEL: II

EXAMINER: N/A LEVEL: N/A

PROCEDURE: UT-HAT-503V0 REV: 0 FRR: N/A, N/A, N/A

N/A REV: N/A FRR: N/A, N/A, N/A

N/A REV: N/A FRR: N/A, N/A, N/A

☐ MT ☐ PT ■ UT ☐ VT

WELD TYPE: ■ CIRCUMFERENTIAL ☐ LONGITUDINAL ■ OTHER SHROUD

DATA SHEET NO.(S): DS-005, DS-006, DS-007, & DS-008

CAL SHEET NO.(S): CS-003, CS-004, CS-005, & CS-006

During the examination of the above referenced weld, two (2) indications associated with IGSCC/IASCC along with thirteen (13) ID connected planar flaws within the weld material were recorded by the Smart 2000 system utilizing 45° shear wave and 60° refracted longitudinal wave search units.

The 45° shear wave search unit also recorded non-relevant indications, inside surface geometry, weld discontinuities, and inside and outside surface geometry from the weld crown on both sides of the weld, along with the fifteen (15) previously referenced ID connected indications.

The 60° RL also recorded non-relevant indications, welding discontinuities, shear component and inside surface geometry from the weld crown, along with the fifteen (15) previously referenced ID connected indications from both sides of the weld.

The indications referenced in the first paragraph have the following parameters:

Indication Number	Distance From Lo	Total Length	Remaining Ligament	Thruwall Dimension	Side of Weld	Type Reflector	Search Unit
1	194.2"	1.5"	1.15"	.35"	In Weld	PLANAR	45°/60°
2	321.5"	2.8"	1.28"	.22"	In Weld	PLANAR	45°/60°
3	331.2"	3.9"	1.33"	.17"	In Weld	PLANAR	45°/60°
4	332.0"	3.7"	1.18"	.32"	Upper	IGSCC/IASCC	45°/60°
5	339.5"	5.0"	1.34"	.16"	In Weld	PLANAR	45°/60°
6	374.6"	1.0"	1.34"	.16"	Upper	IGSCC/IASCC	45°/60°
7	377.7"	3.5"	1.15"	.35"	In Weld	PLANAR	45°/60°
8	384.1"	4.2"	1.09"	.41"	In Weld	PLANAR	45°/60°
9	396.8"	3.6"	1.26"	.24"	In Weld	PLANAR	45°/60°
10	406.7"	1.7"	1.22"	.28"	In Weld	PLANAR	45°/60°
11	415.1"	1.4"	.99"	.51"	In Weld	PLANAR	45°/60°
12	468.9"	1.8"	1.07"	.43"	In Weld	PLANAR	45°/60°
13	516.0"	1.6"	1.16"	.34"	In Weld	PLANAR	45°/60°
14	518.9"	1.3"	1.11"	.39"	In Weld	PLANAR	45°/60°
15	522.2"	10.9"	1.01"	.49"	In Weld	PLANAR	45°/60°

☐ EXAM COMPLETE ■ PARTIALLY EXAMINED (EXPLAIN IN COMMENTS) ☐ EXAM COMPLETE IN COMBINATION WITH DATA SHEETS BELOW

RWP NO.: 294-1110

ADDITIONAL DATA SHEETS: N/A

COMPARED TO: ☐ PSI ☐ ISI REPORT NO.(S): N/A ☐ NO CHANGE

NO. OF RECORDABLE INDICATIONS: 15

TOTAL DOSE .012 MAN REM

EXAMINATION RESULTS: ☐ ACCEPTABLE ☐ UNACCEPTABLE

NO. OF REPORTABLE INDICATIONS: 15

Wes Money	III	4-16-94	RW Healy	4/21/94
SUMMARY BY	LEVEL	DATE	UTILITY REVIEW	DATE
[signature]	III	4/16/94	N/A	N/A
GE REVIEWED BY	LEVEL	DATE	ANII REVIEW	DATE

PAGE: 1 OF: 49

FORM UT-08 REV 1

GE Nuclear Energy	EXAMINATION SUMMARY CONTINUATION SHEET	REPORT NO.: R-S03

PROJECT: HATCH UNIT 2 1EBT3	SYSTEM: SHROUD VESSEL WELD NO.: H-4 (GIRTH WELD) CONFIGURATION: CIRCUMFERENTIAL WELD SEAM

This examination was limited to 'L' dimensions of 19° to 174° and 202° to 354° from vessel '0' due to the proximity of the corespray downcomers. Circumferential 'L' dimensions for all examination scans were recorded in angular units in lieu of linear units. The conversion factor for circumferential measurements is 1.55" per degree.

Wes Money	III	4-16-94	[signature]	4/21/94	
SUMMARY BY	LEVEL	DATE	UTILITY REVIEW	DATE	
[signature]	III	[illegible]	N/A	N/A	PAGE: 2 OF: 49
GE REVIEWED BY	LEVEL	DATE	ANII REVIEW	DATE	FORM UT-10 REV. 4

APPENDIX B
DETERMINATION OF THE EFFECTIVE FLAW LENGTH

The effective flaw lengths are based on ASME Code, Section XI proximity criteria as presented in Subarticle IWA-3300. The procedure addresses circumferential flaws. Indications are considered to be in the same plane if the perpendicular distance between the planes is less than 3" (2 times the maximum shroud cylinder thickness). All flaws are considered to be through-wall. Therefore, indications on the inside and outside surface should be treated as if they are on the same surface. When two indications are close to each other, rules are established to combine them based on proximity. These rules are described here.

B.1 Proximity Rules

The flaw combination methodology used here is similar to the ASME Code, Section XI proximity rules concerning neighboring indications. Under the rules, if two surface indications are in the same plane (perpendicular distance between flaw planes <3") and are within two times the depth of the deepest indication, then the two indications must be considered as one indication.

In Figure B-1, two adjacent flaws L1 and L2 are separated by a ligament S. Crack growth would cause the tips to be closer. Assuming a conservative crack growth rate of 5×10^{-5} in/hr, crack extension at each tip is 1.2 in. for 2 fuel cycles (each of 12,000 hours duration, see Appendix C for crack growth rate discussion). Therefore, combining the crack growth and proximity criteria, the flaws are assumed to be close enough to be considered as one continuous flaw if the ligament is less than (2 x 1.2 + 2 x shroud thickness). For a shroud thickness of 1.5 in., this bounding ligament is 5.4 in. Thus, if the ligament is less than 5.4 inches, the effective length is (L1+L2+S+2.4"). Note that the addition of 2.4 in. is to include crack growth at the other (non-adjacent) end of each flaw (See Figure B-2).

If the ligament is greater than 5.4 in., then the effective flaw length is determined by adding the projected tip growth to each end of the flaw. For this example, $L1_{eff} = L1 + 2.4"$, and $L2_{eff} = L2 + 2.4"$.

After the flaws have been combined per the above criteria, a map of the effective flaws in the shroud can be made, and the effective flaw length can be used for subsequent analysis. In order to demonstrate the proximity criteria, an example is described below.

Consider two circumferential indications as shown in Figure B-2a. If the distance between the two flaw tips is less than 5.4", the indications must be combined such that the effective length is (See Figure B-2b):

$$L_{eff} = L1 + S + L2 + 2.4"$$

where: L1 = length of first circumferential indication
L2 = length of second circumferential indication
S = distance between two indications

If the distance between the two tips is greater than 5.4", the effective flaw lengths are (See Figure B-2c):

$$L1_{eff} = L1 + 2.4"$$
$$L2_{eff} = L2 + 2.4"$$

B.2 Application of Effective Flaw Length Criteria

The application of the effective length criteria is applied to two adjacent indications at a time. Figure B-3 is a schematic which illustrates the process. For example, using the 0° azimuth as the starting location for a circumferential weld or plane, the general procedure would be as follows:

- Moving in the positive azimuthal direction, the first indication encountered is indication 1.

- The next indication is indication 2.

- Apply proximity rules to the pair of indications (indications 1 and 2). Combine the flaws if necessary ($L1+L2+S+2\Delta a$). If indications are combined, combined indication becomes new indication 2.

- Continue along positive azimuthal direction until the next indication is encountered. This becomes indication 3.

- Apply proximity rules to indications 2 and 3. If indication 2 is a combined flaw, do not add and additional Δa, since it is included in the effective flaw length previously determined.

- Continue proximity rule evaluation until all indications along the subject weld or plane have been considered.

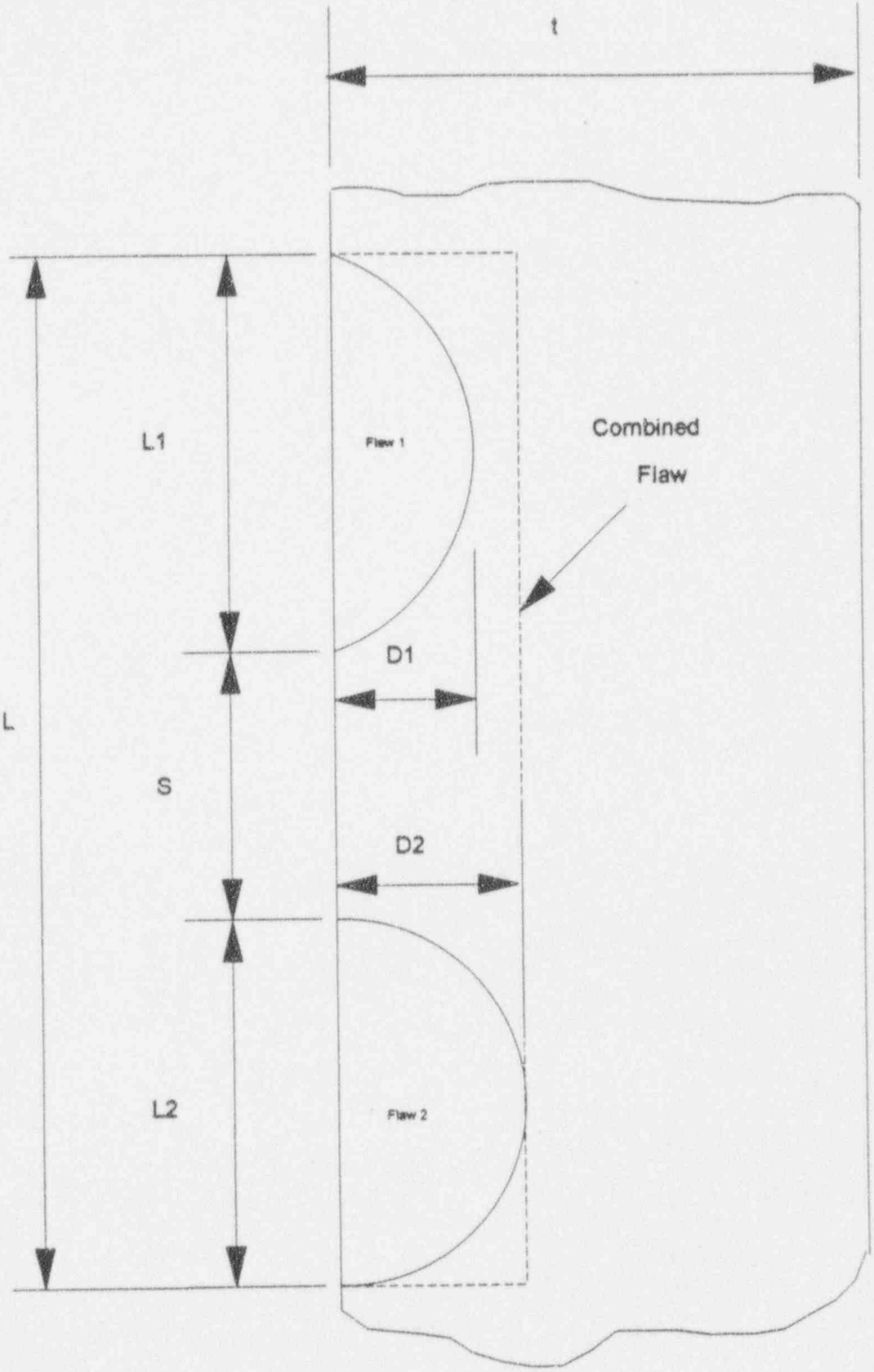


Figure B-1: ASME Code Proximity Criteria

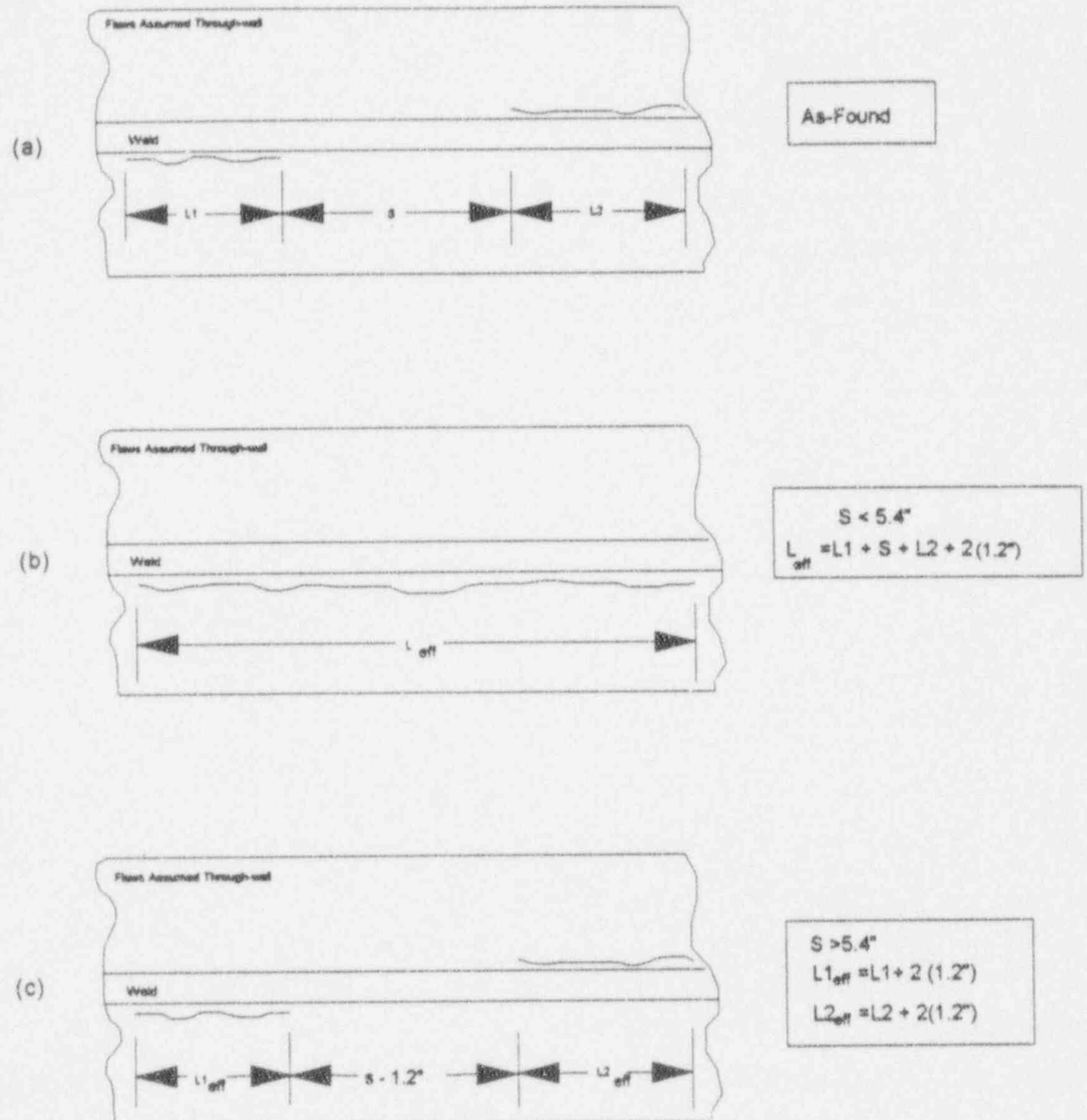


Figure B-2: Application of Proximity Procedure to Neighboring Circumferential Flaws

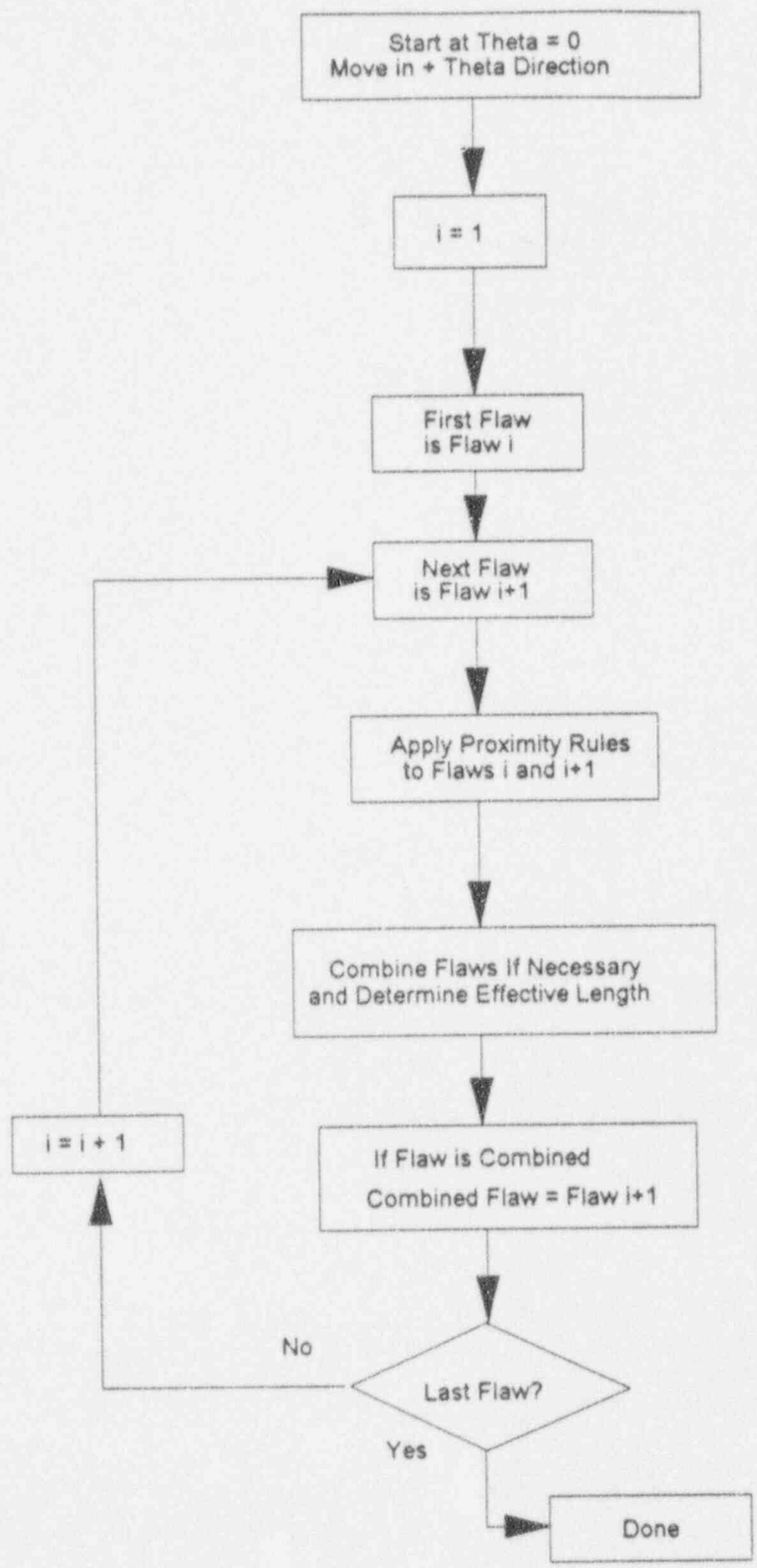


Figure B-3: Process for Determining Effective Circumferential Flaw Length

APPENDIX C

BASIS FOR THE CRACK GROWTH RATE

The basis for the crack growth rate used in the screening criteria is provided in this section. The Plant Hatch Unit-2 shroud cylinder was fabricated from Type 304L stainless steel plate. For purposes of the crack growth rate calculations, the material is assumed to be Type 304. Crack growth rates for Type 304L material are bounded by those for Type 304 material. The shroud is subjected to neutron fluence during the reactor operation which further increases the effective degree of sensitization. The other side-effect of neutron fluence induced irradiation is the relaxation of weld residual stresses. The slip-dissolution model developed by GE quantitatively considers the degree of sensitization, the stress state and the water environment parameters, in predicting a stress corrosion cracking (SCC) growth rate. The crack growth rate predictions of this model have shown good correlation with laboratory and field measured values. This model was used to predict a Plant Hatch Unit-2 specific crack growth rate and a conservative value was then selected.

C.1 Slip-Dissolution Model

Figure C-1 schematically shows the GE slip-dissolution film-rupture model (Reference C-1) for crack propagation. The crack propagation rate V_t is defined as a function of two constants (A and n) and the crack tip strain rate, ε'_{ct}.

$$V_t = A(\varepsilon'_{ct})^n \qquad \text{(C-1)}$$

where $\varepsilon'_{ct} = CK^4$ (for constant load)

$A = 7.8\times10^{-3} n^{3.5}$ (from Reference C-2)

n is defined in Reference C-2

The constants are dependent on material and environmental conditions. The crack tip strain rate is formulated in terms of stress, loading frequency, etc. When a radiation field, such as the case for the shroud, is present, there is additional interaction between the

gamma field and the fundamental parameters which affect intergranular stress corrosion cracking (IGSCC) of Type 304 stainless steel (see Figures C-2 and C-3).

The increase in sensitization (i.e., Electrochemical Potentiokinematic Reactivation, EPR) as a function of neutron fluence (>1MeV) is given as the following:

$$EPR = EPR_0 + 3.36 \times 10^{-24} (\text{fluence})^{1.17} \qquad \text{(C-2)}$$

where, EPR is in units of C/cm^2, fluence is in units of n/cm^2 and the calculated value of EPR has an upper limit of 30.

The constant C is defined as the following:

for fluence $\leq$ 1.4×10^{19} n/cm^2: $C = 4.1 \times 10^{-14}$ (C-3a)

for fluence > 1.4×10^{19} n/cm^2 but $\leq 3 \times 10^{21}$ n/cm^2:, (C-3b)
$C = 1.14 \times 10^{-13} \ln(\text{fluence}) - 4.98 \times 10^{-12}$

for fluence > 3.0×10^{21} n/cm^2: $C = 6.59 \times 10^{-13}$ (C-3c)

C.2 Calculation of Parameters

The parameters needed for the crack growth calculation by the GE model are: stress state and stress intensity factor, effective EPR, water conductivity, and electro-chemical corrosion potential (ECP).

The stress state relevant to IGSCC growth rate is the steady state stress which consists of weld residual stress and the steady applied stress. Figure C-4 shows observed through-wall weld residual stress distribution for large diameter pipes. This distribution is expected to be representative for the shroud welds also. The maximum stress at the surface was nominally assumed as 35 ksi. The steady applied stress on the shroud is due

to core differential pressure and its magnitude is small compared to the weld residual stress magnitude. Figure C-5 shows the assumed total stress profile used in the evaluation. Figure C-6 shows the calculated values of stress intensity factor (K) assuming a 360° circumferential crack. It is seen that the calculated value of K reaches a maximum of approximately 25 ksi$\sqrt{in}$. The average value of K was estimated as 20 ksi$\sqrt{in}$ and was used in the crack growth rate calculations.

The weld residual stress magnitude is expected to decrease as a result of relaxation produced by irradiation-induced creep. Figure C-7 shows the stress relaxation behavior of Type 304 stainless steel due to irradiation at 550° F. Since most of the steady stress in the shroud comes from the weld residual stress, it was assumed that the K values shown in Figure C-6 decrease in the same proportion as indicated by the stress relaxation behavior of Figure C-7.

The second parameter needed in the evaluation is the EPR. In the model, the initial EPR value is assumed as 15 for the weld sensitized condition. Using Equation (C-2), the predicted increase in EPR value as a function of fluence is shown in Figure C-8.

The third parameter used in the GE predictive model is the water conductivity. The reactor water conductivity at Plant Hatch Unit-2 has recently been good (approximately 0.1 $\mu S/cm^2$). This has a significant impact on the predicted crack growth rate (See Figure C-9). To demonstrate that the GE model conservatively reflects the effect of conductivity, Figure C-10 shows a comparison of the GE model predictions with the measured crack growth rates in the crack advance verification system (CAVS) units installed at several BWRs. The comparison with CAVS data in Figure C-10 also demonstrates the conservative nature of crack growth predictions by the GE model.

The last parameter needed in the GE prediction model is the ECP. For the determination of a conservative crack growth rate, the ECP used in this calculation will correspond to that for no hydrogen injection. Figure C-11 shows the measured values of ECP at two

locations in the core. The ECP values at zero H_2 injection are relevant in Figure C-11 for no hydrogen injection. It is seen that the ECP values at zero H_2 injection rate range from 150 mV to 225 mV. Therefore, a value of 200 mV was used in the calculation.

C.3 Crack Growth Prediction

Based on the discussion in the preceding section, the crack growth rate calculations were conducted as a function of fluence assuming the following values of parameters:

Initial K	= 20 ksi$\sqrt{in}$
EPR_0	= 15 C/cm^2
Cond.	= 0.1 μS/cm^2
ECP	= 200 mV

Figure C-12 shows the predicted crack growth rate as a function of fluence. It is seen that the predicted crack growth rate initially increases with the fluence value but decreases later as a result of significant reduction in the K value due to irradiation induced stress relaxation. The crack growth rate peaks at 4.5×10^{-5} in/hr at a fluence of 1×10^{20} n/cm^2. Thus, a bounding value of 5×10^{-5} in/hr can be conservatively used in the structural integrity evaluation for the shroud.

This bounding crack growth rate is quite conservative as can be shown in Figure C-13 from NUREG-0313, Rev. 2. It is seen that the crack growth rate of 5×10^{-5} in/hr at 20 ksi$\sqrt{in}$ is considerably higher than what would be predicted by using the NRC curve. This further demonstrates the conservatism inherent in the assumed bounding value of crack growth rate.

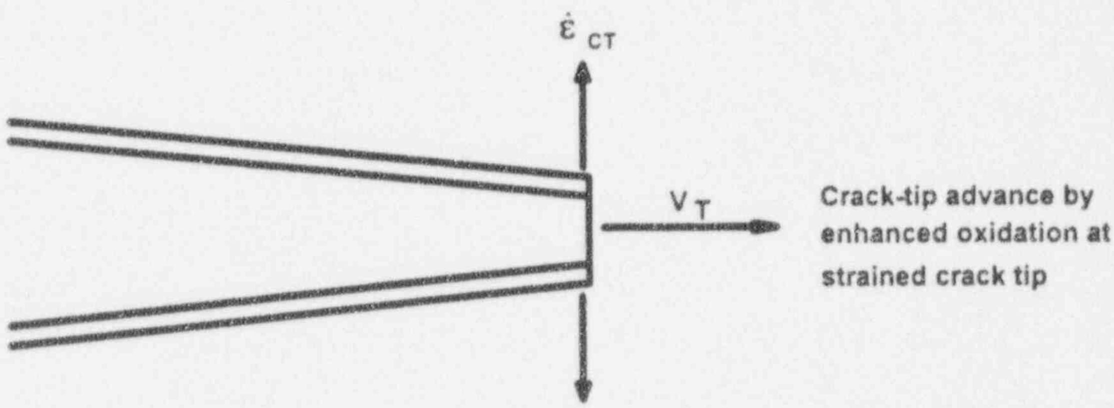
C.4 Conclusion

A crack growth rate calculation using the GE predictive model was conducted considering the steady state stress, EPR, conductivity and ECP values for the Plant Hatch Unit-2 shroud. The evaluation accounted for the effects of irradiation induced stress relaxation and the increase in effective EPR. The evaluation showed that a bounding crack growth rate of 5×10^{-5} in/hr may be used in the structural integrity evaluation of shroud.

C.5 Reference

C-1 F.P. Ford et al, "Prediction and Control of Stress Corrosion Cracking in the Sensitized Stainless Steel/Water System," paper 352 presented at Corrosion 85, Boston, MA, NACE, March 1985

C-2 F.P. Ford, D.F. Taylor, P.L. Andresen & R.G. Ballinger, "Environmentally Controlled Cracking of Stainless Steel and Low Alloy Steels in LWR Environments," 1987, (EPRI Report NP50064M, Contract RP2006-6).



$$V_T = A\,\dot{\varepsilon}_{CT}^{\,n}$$

Where:

V_T = crack propagation rate
A, n = constants, dependent on material and environmental conditions
$\dot{\varepsilon}_{CT}$ = crack-tip strain rate, formulated in terms of stress, loading frequency, etc.

Figure C-1: The GE PLEDGE Slip-Dissolution - Film Rupture Model of Crack Propagation

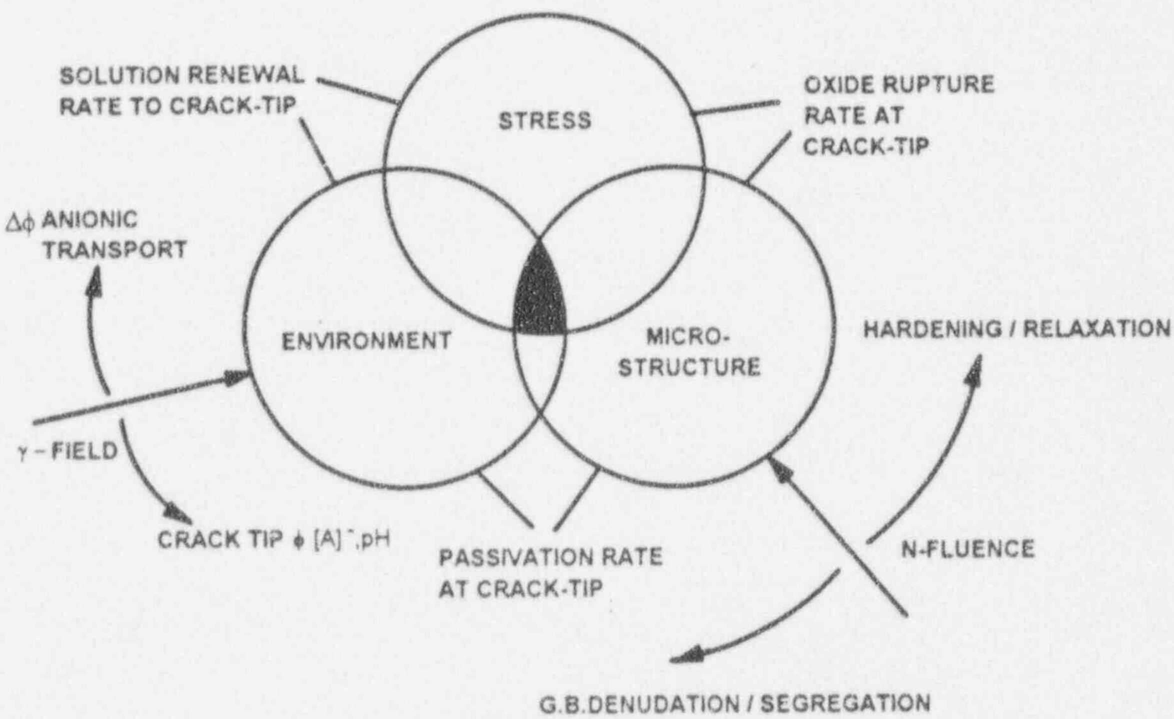
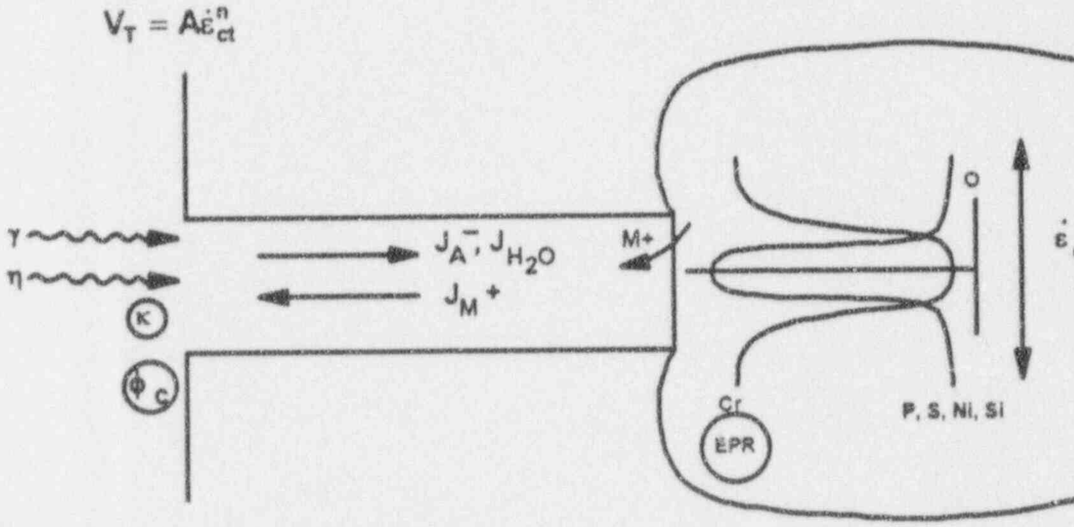


Figure C-2: Effects of Fast Fluence, Flux & Gamma Field on Parameters Affecting IGSCC of Type 304 Stainless Steel



$$V_T = A\dot{\varepsilon}_{ct}^n$$

$$n = \{ e^{f(\kappa)} / (e^{f(\kappa)} + e^{f(\varphi)c}) \}^{f(EPR)}$$

Figure C-3: Parameters of Fundamental Importance to Slip-Dissolution Mechanism of IGSCC in Sensitized Austenitic Stainless Steel

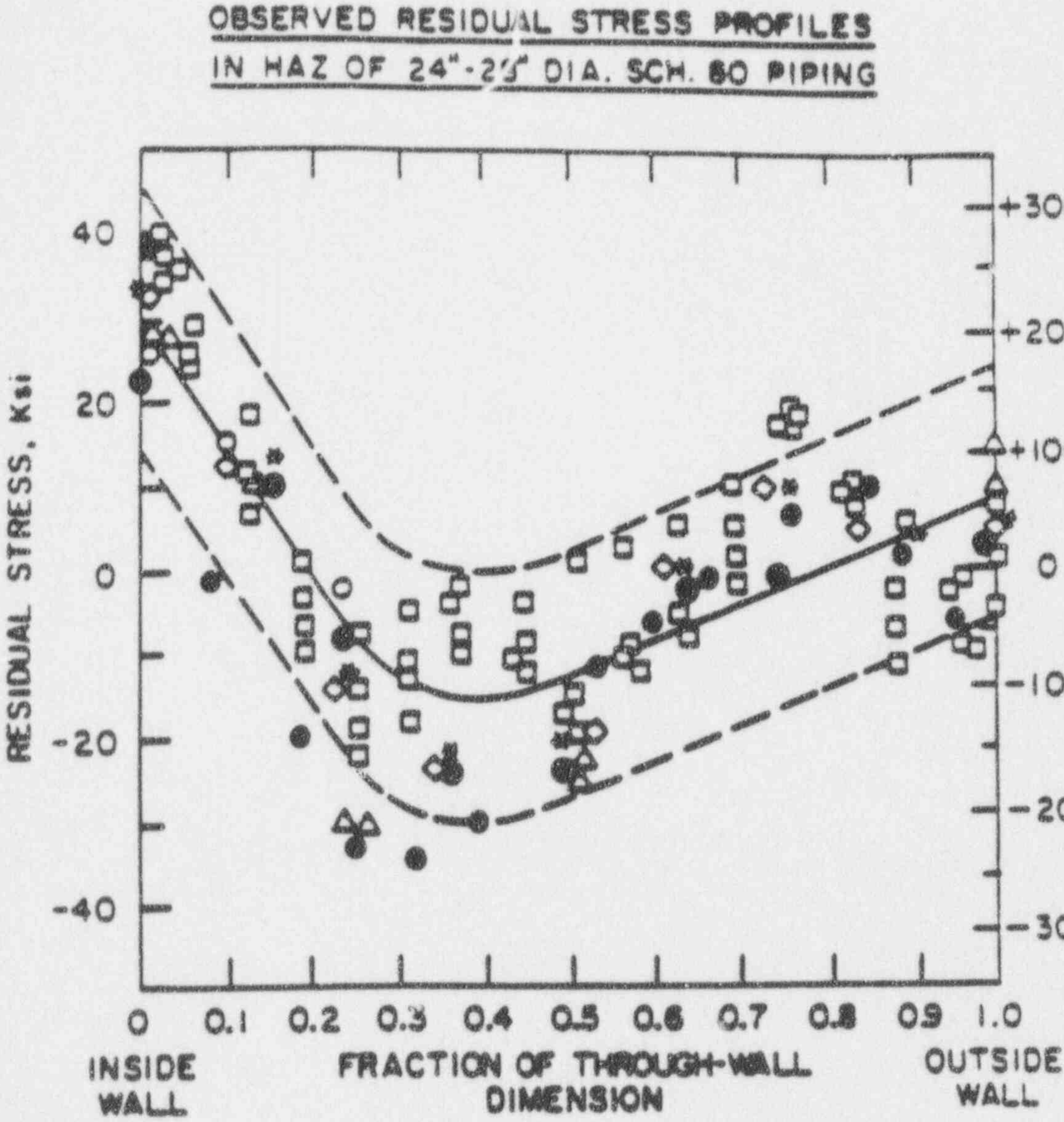


Figure C-4: Through-wall Longitudinal Residual Stress Data Adjacent to Welds in 12 to 28 inch Diameter Stainless Steel Piping

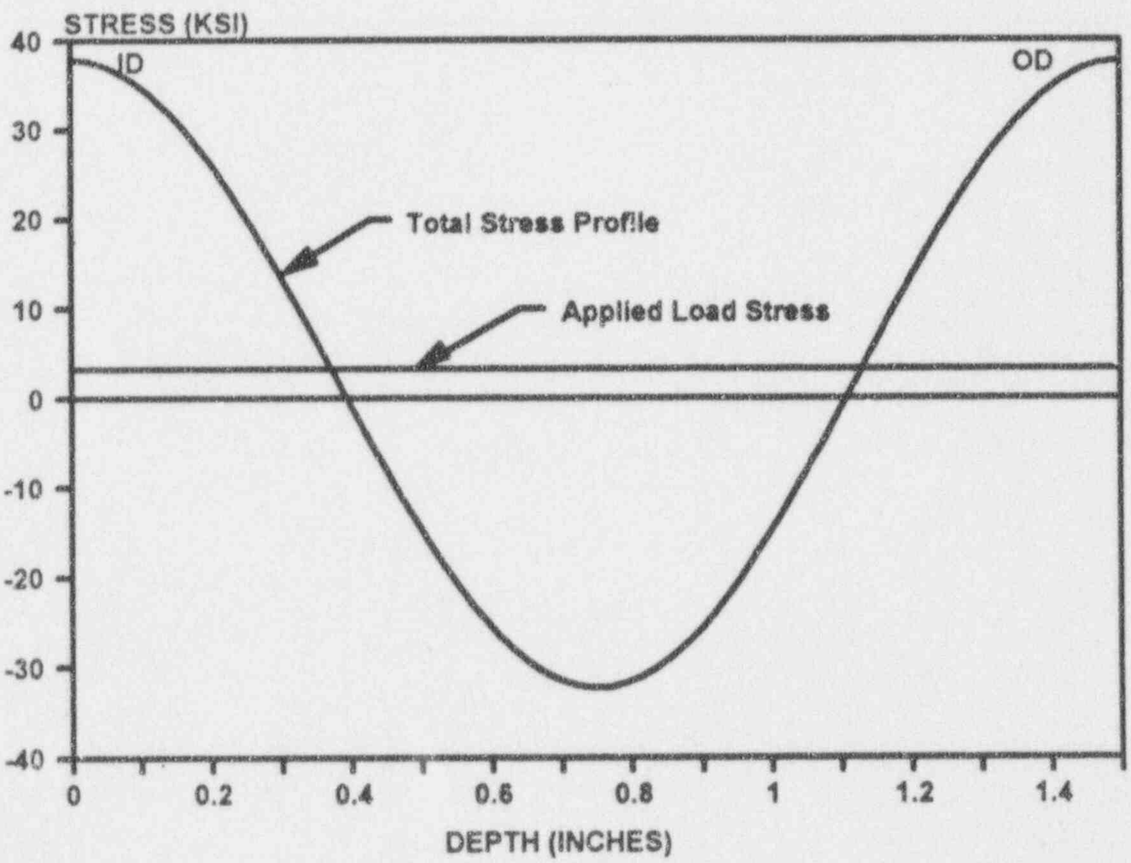


Figure C-5: Conservative Representation of the Shroud Total Through-wall Stress Profile

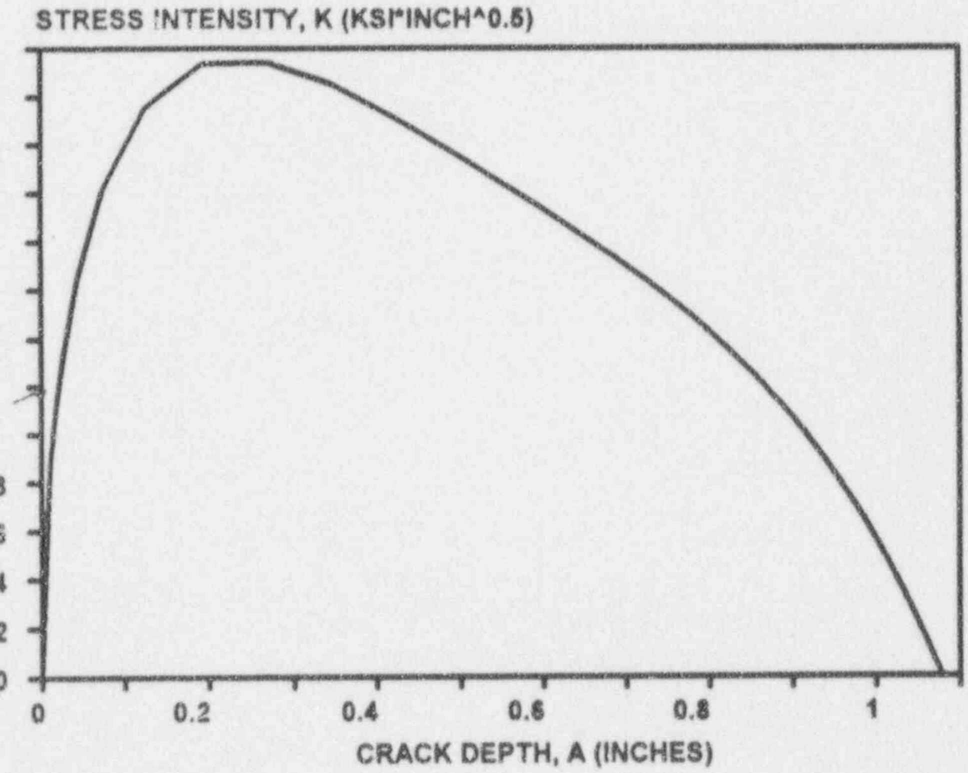


Figure C-6: Shroud Through-wall Stress Intensity Factor

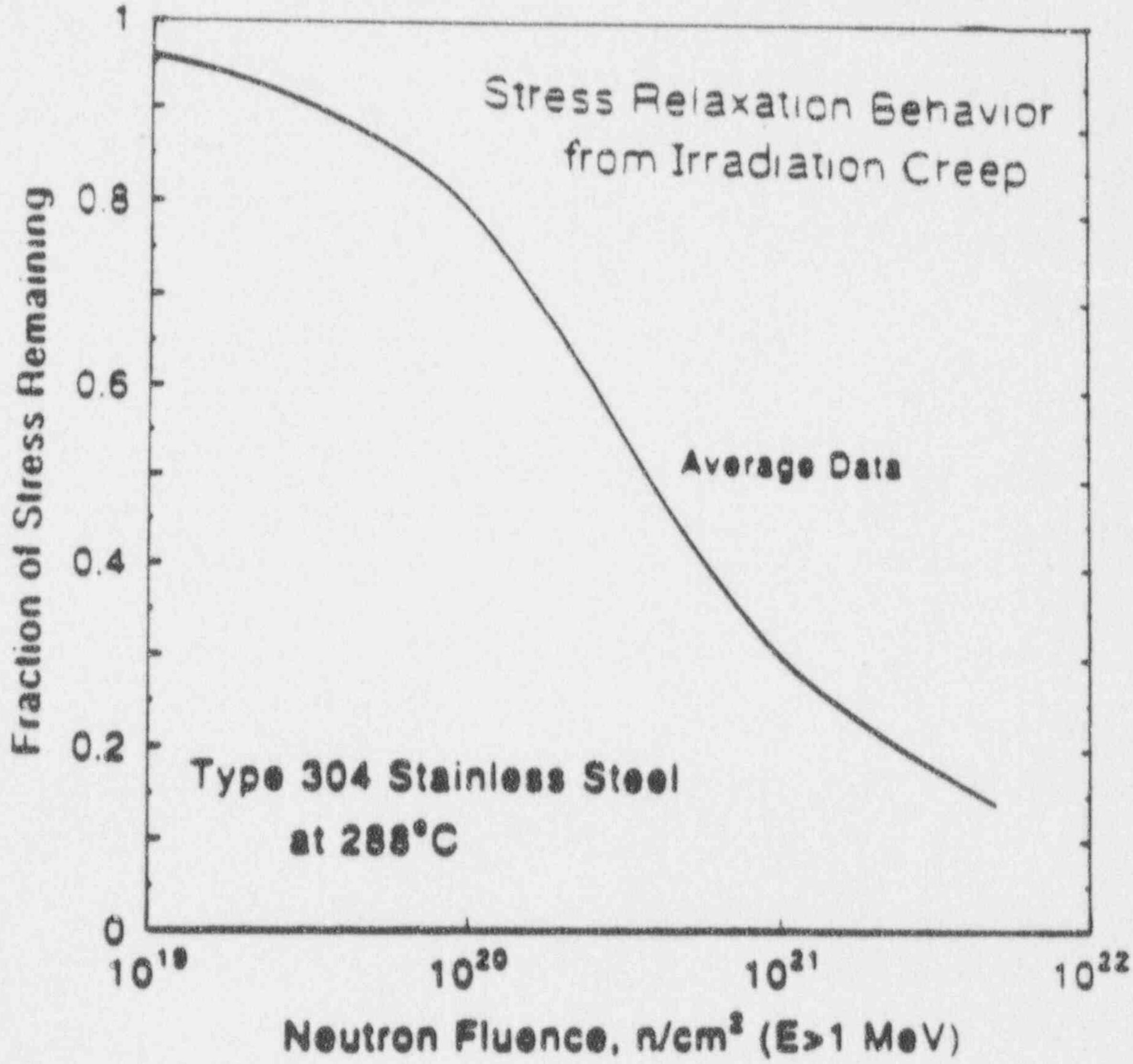


Figure C-7: Stress Relaxation Behavior of Type 304 Stainless Steel Due to Irradiation at 288°C

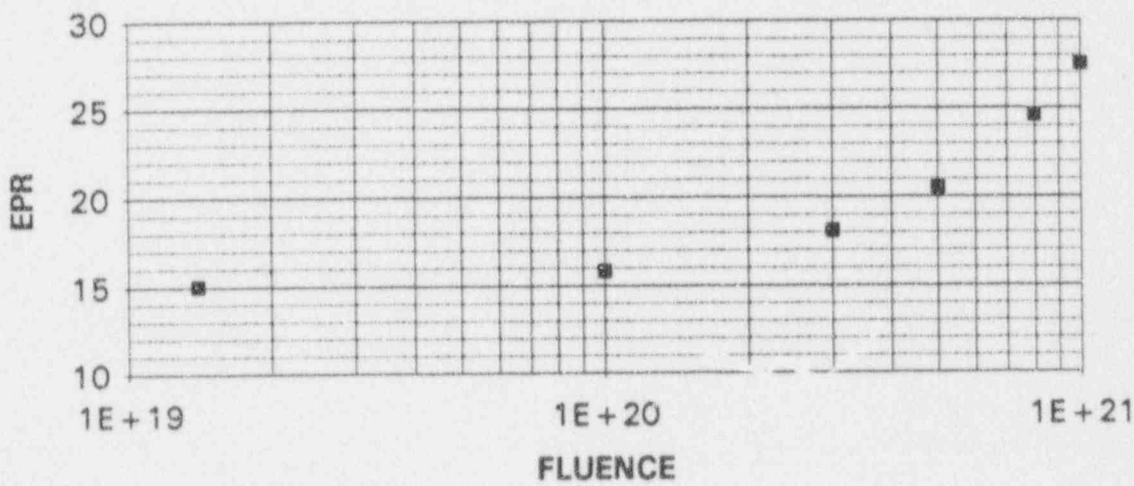
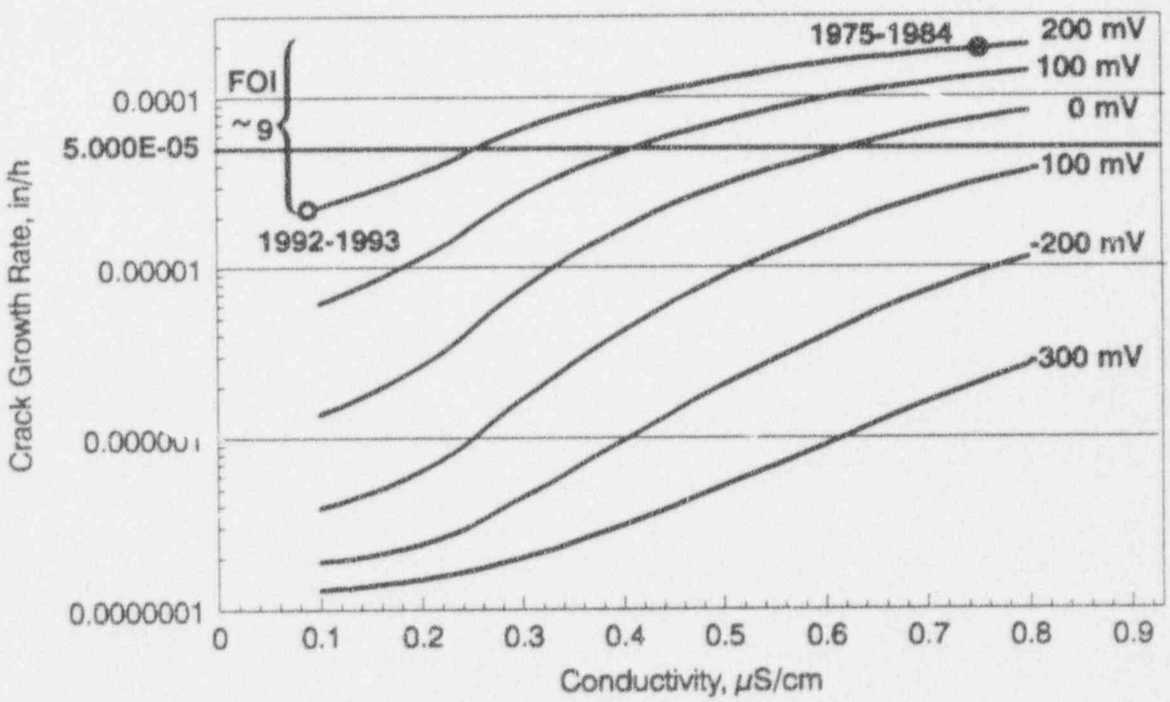
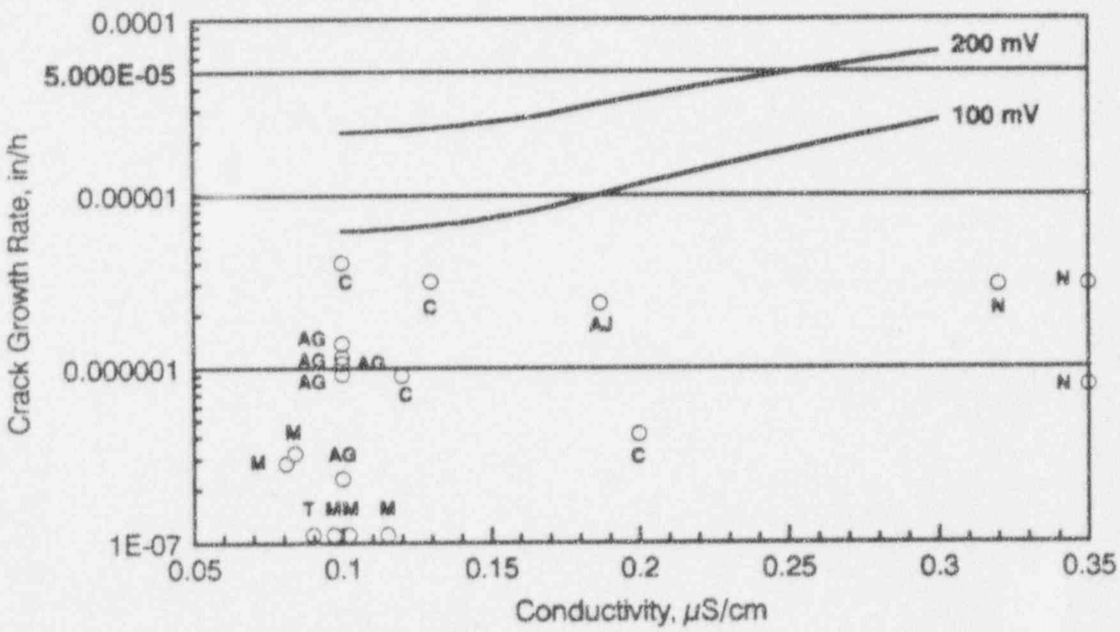


Figure C-8: EPR Versus Neutron Fluence



PLEDGE: 20 ksi$\sqrt{in}$, 15 C/cm^2

Figure C-9: GENE PLEDGE Model Prediction for a BWR-4 (Sensitized Type 304 Crack Growth Rate)



PLEDGE: 20 ksi$\sqrt{in}$, 15 C/cm^2

CAV: 20-25 ksi$\sqrt{in}$, 13 C/cm^2, 100-160 mV

Figure C-10: Effect of Conductivity on Sensitized Type 304 Crack Growth Rate

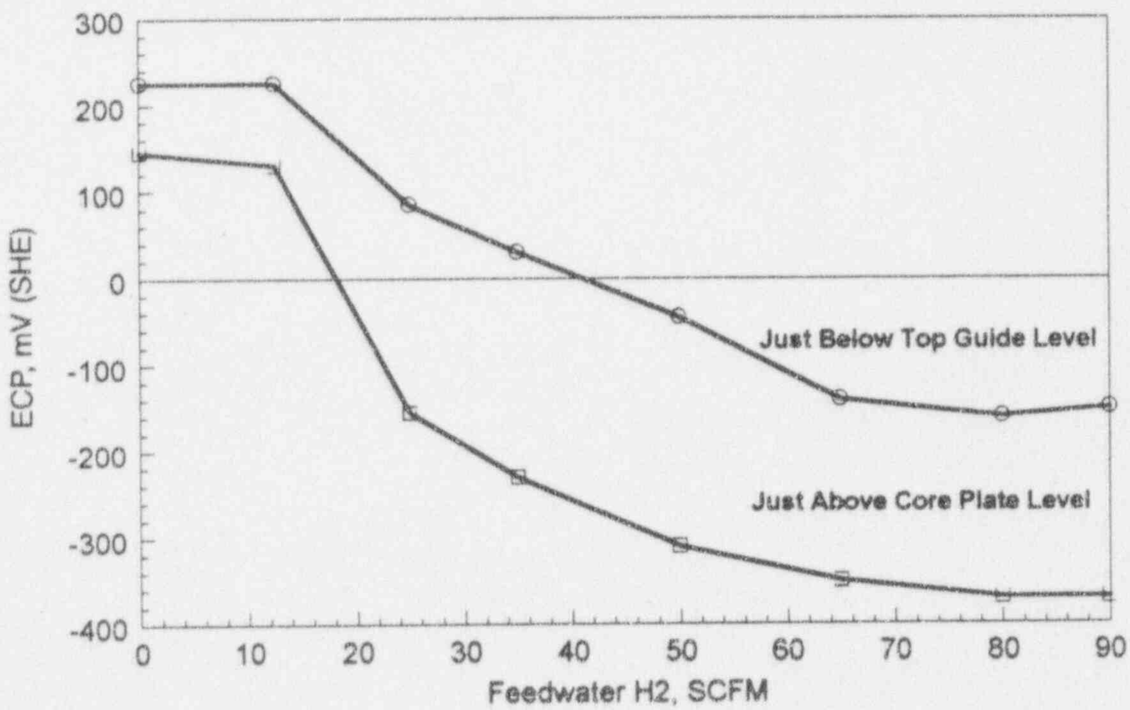
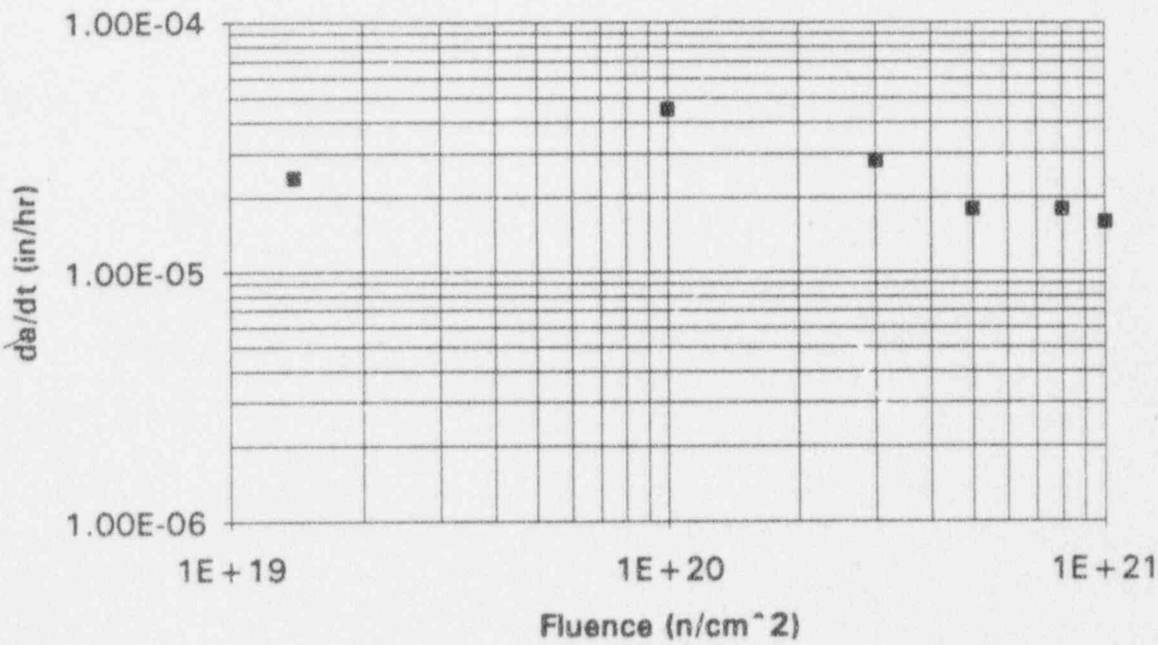


Figure C-11: In-Core Bypass ECP versus Feedwater Hydrogen for BWR-4



Stress Intensity = 20 ksi$\sqrt{in}$, Initial EPR = 15 C/cm^2

Figure C-12: Growth Rate versus Fluence

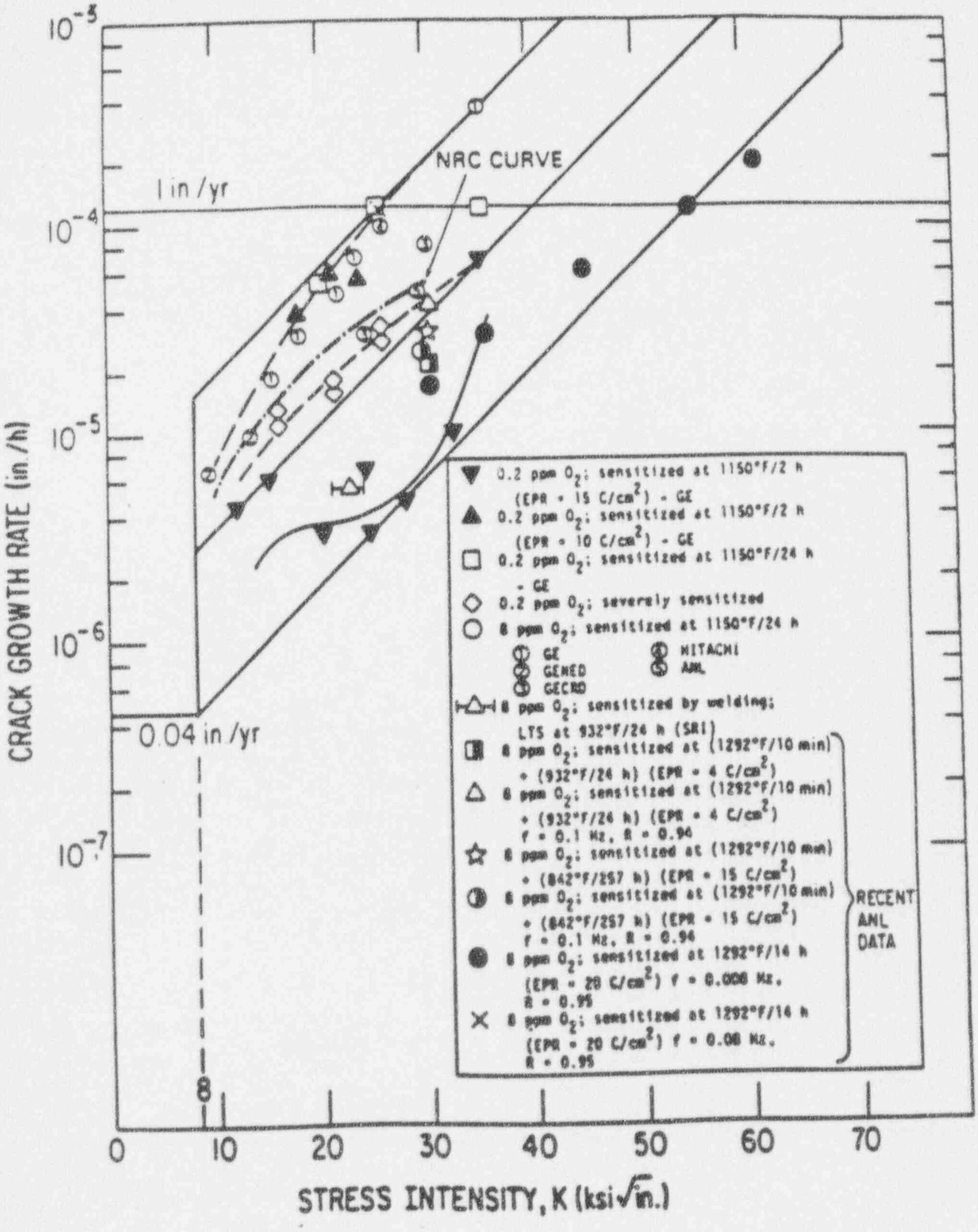
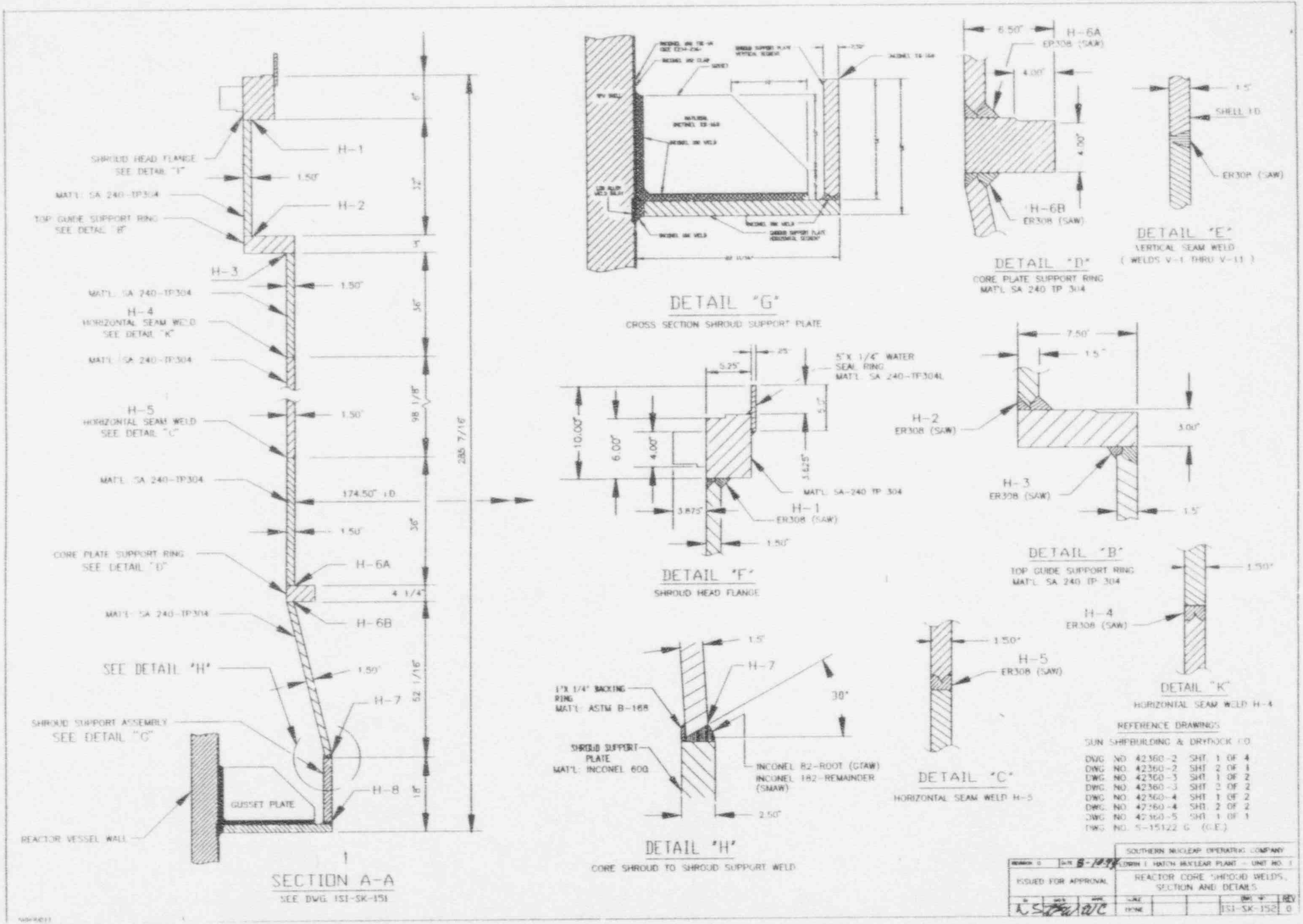


Figure C-13: NUREG-0313 Crack Growth Rate Data

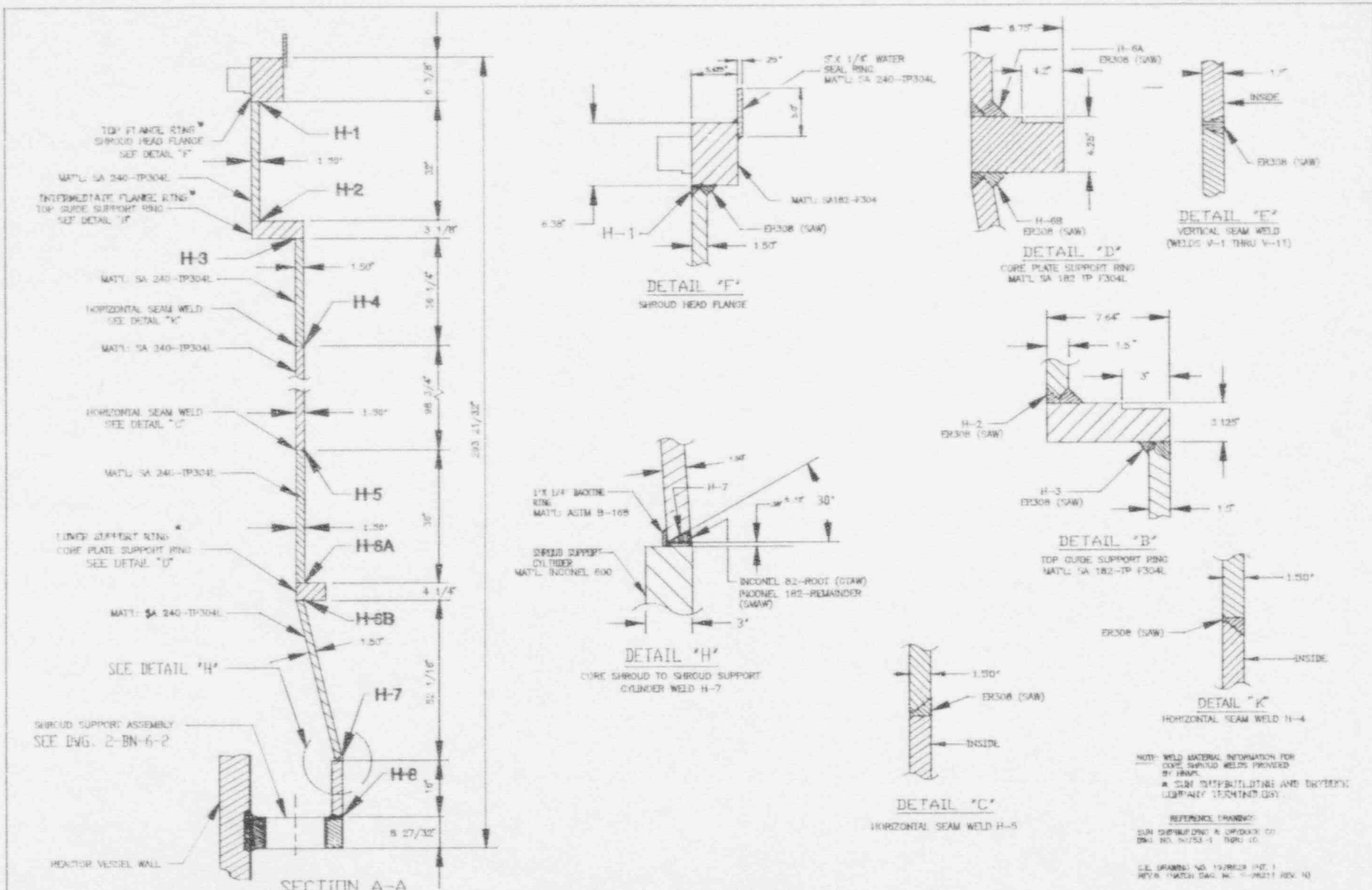
Attachment 3

Edwin I. Hatch Nuclear Plant
Reactor Core Shroud Welds Section And Details

Attachment 3 (Sheet 1 of 2)



Attachment 3 (Sheet 2 of 2)



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PROJECT
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CORE SHROUD WELD SECTION AND DETAILS

ITS REVIEW	ITS APPL	DRAWN BY	SKETCH NUMBER
KFW	WC	WS	2-BN-6-6