ATTACHMENT

GENE-B13-01805-49, EVALUATION OF
THE HATCH UNIT 1
SHROUD VERTICAL WELD INDICATIONS

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Evaluation of the Indications in the Shroud Vertical Welds at Hatch 1

1. Background

Shroud repair was installed at Hatch Unit 1 in the fall of 1994. The design basis of the shroud repair was to structurally replace the horizontal welds from H1 through H7 (Figures 1 and 2). Therefore, no inspection was required for these welds prior to shroud repair. However, since the repair design did not structurally 'replace' the vertical welds, inspection of the vertical welds was required. Most of the vertical weld cracking observed in other plants at that time was confined to the region near the intersection with the horizontal welds in the belt line region and the lengths of such cracks were less than 3 in. (except one crack which was 15 in.). Furthermore the crack driving force was small (due to hoop stress resulting from the core ΔP) and allowable through wall crack sizes were large. In view of the small observed cracks observed in the industry and the large crack tolerance, the recommended inspection for the vertical welds at Hatch 1 was limited to visual inspection of 12 in. of the V-3, V-4, V-5, and V-6 welds near the intersection with the H4 weld. In reality, the actual length of inspection for these welds was 18 inches. No indications were seen during this limited inspection and the unit was returned to service.

During the Spring 1996, Hatch 1 refueling outage, and the vertical welds were examined again visually. The inspections were more extensive, in accordance with the recently issued BWR VIP recommendations on shroud reinspection (Ref. 1). As a result of planned inspection scope and subsequent expansion, all accessible regions of all the vertical welds have been inspected visually by enhanced VT-1 examination according to the BWR VIP inspection guidelines (Ref. 2) from the OD. The welds V-5 and V-6 were examined both from the ID and the OD. Except for two indications on the outside of the V-5 and V-6 welds, no other indications were seen. On the V-5 weld, two separate indications 2 in. and 12 in. long were seen on the OD. On the V-6 weld, a continuous indication 32 in. long reaching up to the H4 weld intersection and four small (~ 1/2 inch) axial indications on the right side of the weld were seen on the OD. Inspections on the ID *showed no indications of cracking* for both the V-5 and V-6 welds. The objective of this report is to evaluate the significance of these indications.

2. Explanation of the observed indications

The axial cracking in itself is not new; axial weld cracks have been seen in several plants, but the observed length at Hatch 1 in the V-6 weld seems to be somewhat larger. Most of the cracks in other plants have been around 3 in. with one case where it was about 15 in. So the 32 in. indication is longer than those seen elsewhere. Of greater interest is that at least a part of the region of the V-6 indication was visually inspected in 1994 and found to be uncracked. Unless indications were missed before, one has to conclude that the observed indication is new.

Hatch 1 has operated with excellent hydrogen water chemistry (HWC) during the last cycle, with calculated ECP levels below the -230 mV SHE threshold in the region of the

H4 weld, the apparent 'new' initiation (if it is) is surprising. Review of the videotape by materials experts at GE was inconclusive on the question of whether the indications represent actual shroud cracks. Some experts suggested that the indications may not be cracks at all and that they could be due to changes in the structure of the oxide film as a result of HWC. Similar indications were seen in the region of the access hole cover in another BWR operating under HWC. Subsequent UT showed no cracking. Others felt that shallow cracking existed during the prior outage, and HWC induced changes in the oxide structure could have made the preexisting cracks visible. HWC also makes the surface topography more clear.

The fact that there were no indications on the ID of the V-5 and V-6 welds is good, and suggests that the OD indication could have been due to other reasons such as cold work. There was general agreement that the indications did not have clear opening, and appeared to be tight suggesting that they are shallow.

Potential vibration causes were evaluated but judged to be not credible. The crack location (near the center of the shroud, near welds but not near the contact area of the springs) suggests that vibration is not a likely mechanism. Even if vibration played a role, it would cause overturning moment stresses that would most likely cause circumferential cracking not the long axial cracks seen at V-6.

The stresses due to shroud repair were reviewed and found to be small. The average stress due to the tie rod loads is less than 0.5 ksi. Even if one assumes the *local* stress near the tie rod attachment were an order of magnitude higher, it would still not be sufficient to cause the axial cracking. Thus steady state stress resulting from shroud repair was ruled out as a potential cause of cracking.

Irradiation Assisted Stress Corrosion Cracking (IASCC) was also determined to be not a significant factor since the indications were on the outside surface of the shroud where the fluence is lower than that at the inside surface. The peak fluence (considering both axial and azimuthal variation) of the ID surface is almost twice as high as that on the OD (estimated to be $\sim 10 \times 10^{20}$ n/cm^2 on the ID and 5×10^{20} n/cm^2 on the OD). The actual fluence in the region of cracking is expected to be lower since this does not necessarily coincide with the axial and azimuthal peak' Furthermore, the extent of branching of the cracks was not consistent with that under IASCC where extensive branching and grain fallout are seen.

The consensus of opinion of the GE experts was that the change in oxide structure due to HWC is the most likely cause of 'seeing' crack-like indications that might have been there during the last outage. While there were some differences in opinion on whether the indications were cracks, still there was general agreement that even if the indications did represent cracking, they are tight and likely to be shallow.

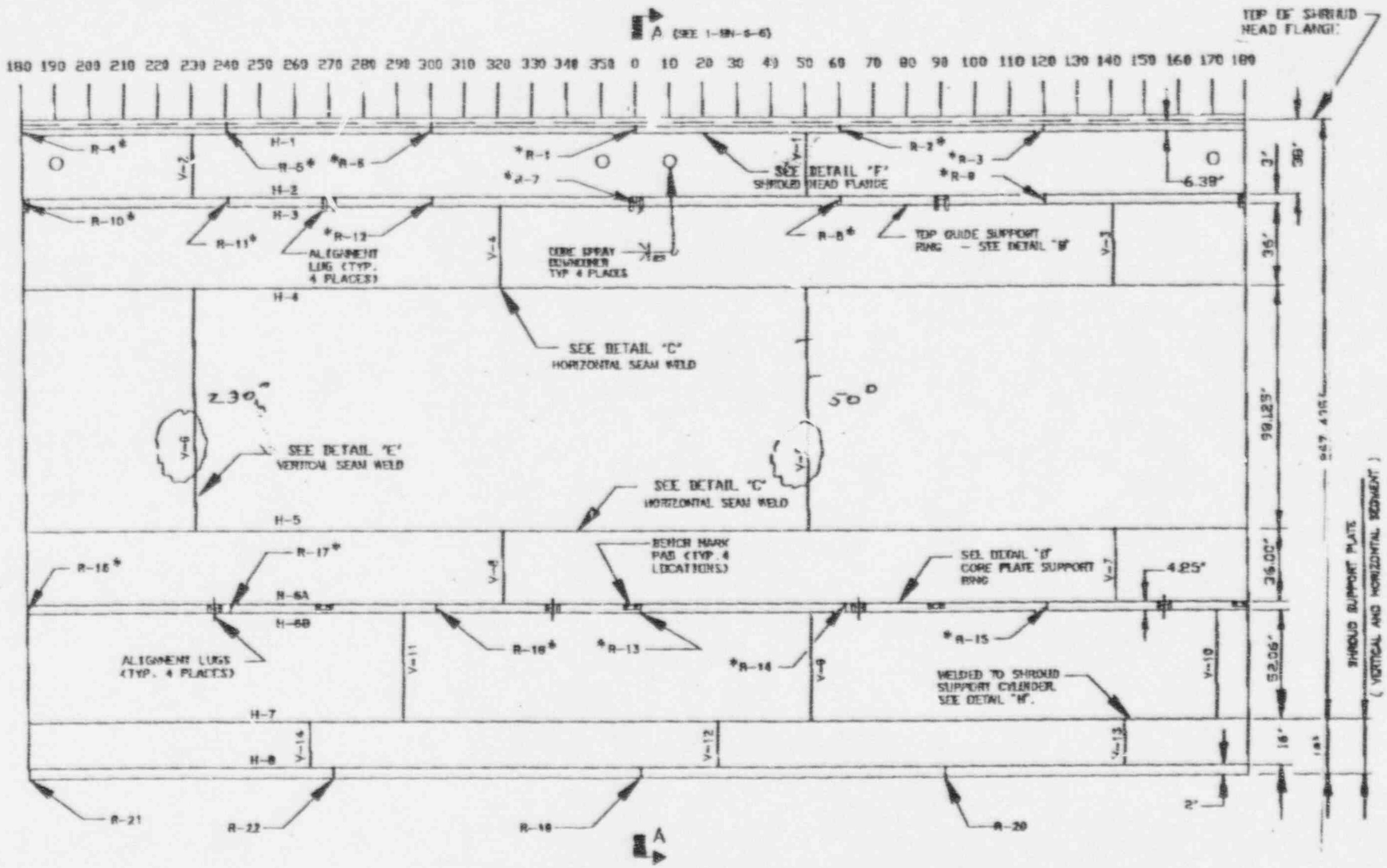

Figure 1 - Core Shroud Weld Identification Layout

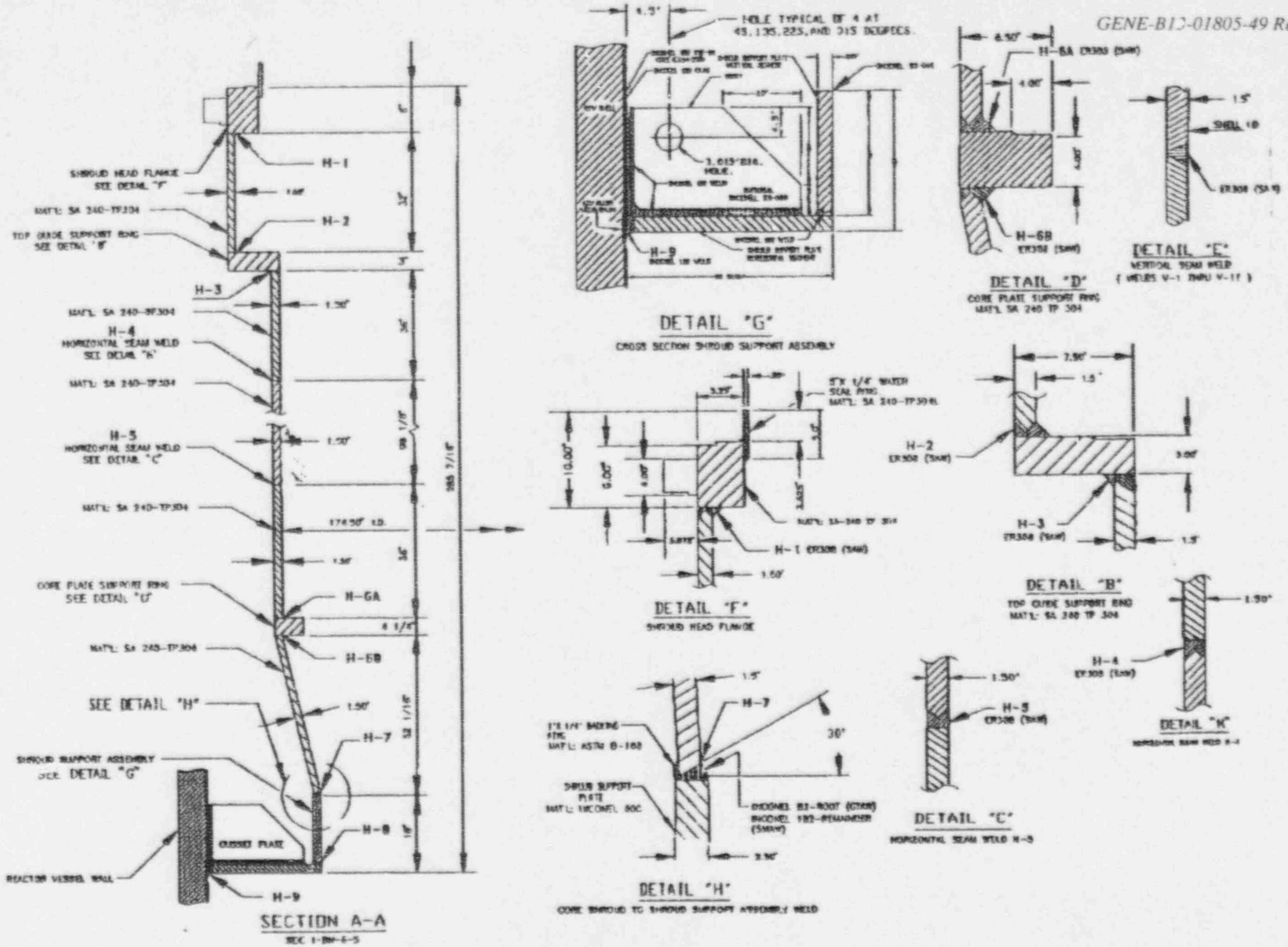

Figure 2 - Core Shroud Section (with Details)

3. Allowable crack lengths

Vertical welds were inspected for indications and observations were compared with analytical requirements. Allowable crack lengths were calculated based on both linear elastic fracture mechanics (LEFM) and limit load analysis. The high fluence region where there is a potential irradiation embrittlement issue is limited to the shroud section between horizontal welds H3 and H6. Therefore, both LEFM and limit load analysis were used for vertical welds in this region. Specifically, LEFM was governing for the welds V-5 and V-6 and limit load was governing for welds V-3, V-4 and V-7, V-8. The vertical welds in all other regions were governed by limit load analysis. Both methods of analysis are described below.

Linear elastic fracture mechanics

The stress intensity factor for a *through thickness axial crack* of length 2a, in an infinite cylinder is given by:

$$K = M\sigma_m\sqrt{\pi a} \ , \qquad [1]$$

where σ_m is the nominal hoop stress, and M is a factor that accounts for curvature effects, and is given by:

$$M = \sqrt{1 + 1.61\frac{(2a)^2}{4Rt}} \ , \qquad [2]$$

where 2a is the crack length, as defined above; R is the mean radius of the shroud; and t is the shroud thickness.

Equation 1 assumes a cylindrical shell of infinite length (Figure 3a). This is a reasonable assumption for the realistic cases where limited cracking (part through cracking) is observed. With this assumption, in most cases the allowable through wall crack length exceeds the length of the weld seam itself, confirming the large crack tolerance for vertical welds. However, the design postulate for the shroud repair assumes that all circumferential welds have 360° through thickness cracking. This essentially means that each shell course between two horizontal welds should be considered as a separate, free standing finite width cylindrical shell (similar to drum open at both sides). In order to account for the finite width of the shroud section being considered, a *finite width correction factor* given by $\sqrt{\sec(\pi a/2b)}$ is applied (Figure 3b). This is based on correction factors for through thickness cracks in plates, and when used in conjunction with the

curvature correction factor for the shell provides a reasonable representation for a through thickness crack in a finite width cylindrical shell.

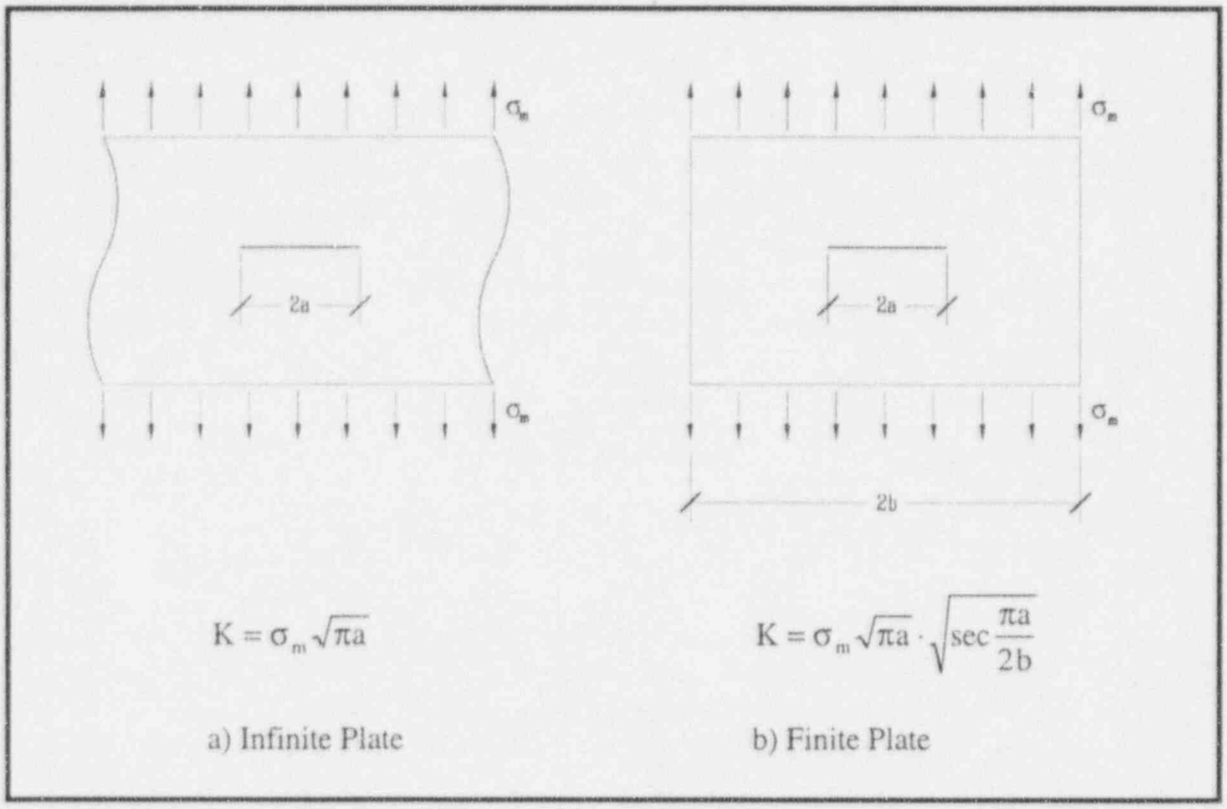

Figure 3 - Infinite and Finite Width Plate With Through Cracking

The final form of K used for this analysis becomes:

$$K = \sigma_m \sqrt{\pi a} \cdot \sqrt{1 + 1.61 \frac{(2a)^2}{4Rt}} \cdot \sqrt{\sec \frac{\pi a}{2b}} \quad , \qquad [3]$$

where 2b is the height of the shroud section being considered.

The calculated stress intensity factor when multiplied by the appropriate safety factor (3 for normal and 1.5 for faulted conditions) can be compared with the available fracture toughness of 150 ksi*in^0.5 and the allowable through wall crack length (with the required safety factor) can be determined. The allowable through wall crack length was determined to be 66.4 inches (or a = 33.2 in.). Specifically, for a = 33.2, the K value is as shown below: [Equation 4]:

$$K = 2.708\text{ksi}\sqrt{\pi \cdot 33.2\text{in}} \cdot \sqrt{1 + 1.61\frac{(2 \cdot 33.2\text{in})^2}{4 \cdot \frac{177.5\text{in}}{2} \cdot 1.50\text{in}}} \cdot \sqrt{\sec\frac{\pi \cdot 33.2\text{in}}{98.75\text{in}}} = 149.8\text{ksi} \cdot \sqrt{\text{in}}\,.$$

This means that an allowable flaw size of 66.4 inches is acceptable when K is limited to 150 ksi*in^0.5. As expected, because of the finite width cylinder assumption, the allowable crack length is less than the width of the shell course for V-5 and V-6, in this case 98.8 inches for Hatch Unit 1. Alternatively, the required uncracked ligament is 98.8 - 66.4 = 32.4 inches. The required ligament is increased when the effects of NDE uncertainty and crack growth are included.

Limit Load Analysis

The limit load analysis applies to all welds and the allowable crack size is the smaller of the limit load and LEFM (where applicable) crack lengths. The limit load calculations were performed using concepts similar to that in the ASME Code. For the limit load analysis the minimum required ligament is calculated as the uncracked section of the weld needed to resist a force due to the pressure differential across the shroud (Figure 4). This force P, acts upon a projected area D*L on the shroud, where D is the diameter of the shell segment, and L is the height of the shell course. Therefore,

$$P \cdot D \cdot L = 2 \cdot \left(\frac{\sigma_f}{SF} \cdot \ell \cdot t\right), \qquad [5]$$

where σ_f is the flow stress (assumed to be equal to $3S_m$ where S_m is the ASME code allowable design stress intensity, equal to 16.9 ksi for the shroud material at 550° F), SF is the safety factor, ℓ is the required uncracked ligament length, and t is the thickness of the shroud. This assumes that the entire weld , except for the ligament has through thickness cracking. It also considers conservatively, cracking on both sides as shown in Figure 4.

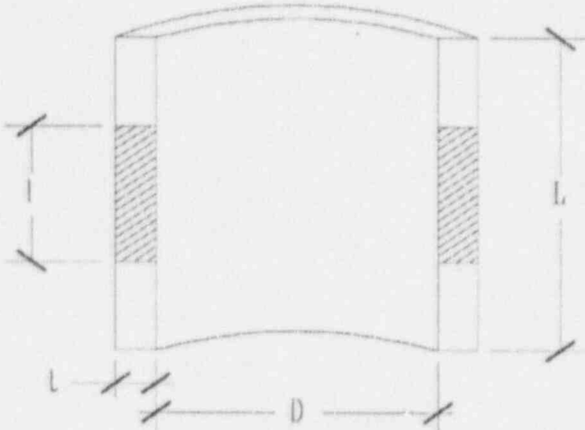

Figure 4 - Partial Shell Section

Rearranging Equation 5 and noting the definition of hoop stress, the following results:

$$SF \cdot \frac{P \cdot D}{2t} \cdot \frac{L}{\sigma_f} = \ell \qquad [6]$$

$$SF \cdot \sigma_m \cdot \frac{L}{\sigma_f} = \ell \qquad [7]$$

where σ_m is once again the nominal hoop stress for this shell segment. In determining the required uncracked ligament, the bounding case of normal conditions (SF = 3.0) and faulted conditions (SF = 1.5) should be considered. As stated earlier, the analysis for the required ligament is conservative since cracking is assumed on both sides.

<u>Required uncracked ligament</u>

Table 1 shows the allowable crack length as well as the required uncracked ligament lengths for all vertical welds. Welds V-3, V-4, V-5, V-6, V-7, and V-8 were evaluated using both LEFM and limit load methods. LEFM was controlling for welds V-5 and V-6 and limit load was governing for all other welds. The recent BWR VIP criteria for reinspection of shrouds recommend that allowances for crack growth (based on an assumed crack growth rate of $5x10^{-5}$ in/hr) and uncertainty in the inspection be added to the required uncracked ligaments. Assuming 8000 hot hours per year and a two year cycle, the adder for growth in the crack length is ($5x10^{-5}$ in/hr x 8000 hr/year x 2 years)x2 =1.6 in. where the factor of two accounts for crack growth at two crack tips. The BWR

VIP criteria also recommends that an inspection uncertainty factor be applied. A conservative factor of 4t = 6 in. where t is the thickness of the shroud was chosen based on Ref. 2. Essentially, this means that the required uncracked ligament length be increased by (6.0 + 1.6) or 7.6 in. to account for the crack growth and inspection uncertainty.

4. Justification for Continued Operation

The vertical welds were examined on the OD by enhanced VT-1 and except for the welds V-5 and V-6, no cracking was observed at all other welds. Two indications (2 in. and 12 in.)were observed in V-5 whereas one indication 32 in. long and four small (~1/2 in.) axial indications were observed in the V-6 weld, both on the OD. Subsequent enhanced VT-1 examination of the ID surfaces showed no indications confirming that both were part through indications. The allowable *through thickness* crack length for the V-5 and V-6 welds is 66.4 inches, including the safety factor. It also considers accident conditions and assumes that both H4 and H5 welds are fully cracked (360 degree through thickness cracking). If inspection uncertainty and crack growth for one cycle is considered, the allowable crack length is (66.4 - 7.6) = 58.8 in. This compares against the as found part through indication of 32 in. Alternatively, the required ligament is 40 in. compared to the available uncracked ligament of 98 - 8 - 32 = 66.4 in. Clearly, there is sufficient margin to justify continued operation beyond one cycle.

Other conservatisms in the analysis are summarized below:

- Even if one assumes that there is a part through crack 32 in. long on the outside, the expected through thickness crack growth in one cycle is 2.5E-05 in/hr x 12000 hr. = 0.30 inch for normal water chemistry. The assumed crack growth rate is based on the recent draft BWR VIP report on crack growth rates. For hydrogen water chemistry the expected through thickness growth is even lower. Thus it is highly unlikely that the crack will become a through thickness crack.

- For the more realistic case of no through thickness crack at H4 and H5, the critical crack length for an axial crack length is expected to be in excess of the length of the weld itself (length exceeding 98.8 inches), confirming the large crack tolerance in the shroud.

- The crack driving force for an axial weld crack is the hoop stress in the shroud. For normal operation, the hoop stress is 0.5 ksi corresponding to a delta P value of 8.5 psi. Even under a steam line break the hoop stress is only 1.8 ksi corresponding to peak pressure of 30.5 psi. In both cases the driving force is small.

5. Conclusions

The lengths of the observed indications in the Hatch 1 shroud vertical welds are well below the allowable crack lengths determined here. The other conservatisms in the analysis (assumptions of through wall cracking, separate cylinders for each shell course) and the fact that the plant is operating under hydrogen water chemistry with excellent water conductivity provide added assurance of margin. Thus, continued operation for at least one cycle is justified. Additional inspections can be performed at the next outage to provide the basis for future inspections at that time.

6. References

1. EPRI TR-105747, Feb. 1996, BWR Vessel and Internals Project - Guidelines for Reinspection of BWR Core Shrouds (BWR VIP - 07)

2. EPRI TR-105696, Oct. 1995, BWR Vessel and Internals Project - Reactor Pressure Vessel and Internals Evaluation Guidelines (BWR VIP - 03)

Table 1 - Allowable Flaw Sizes for the Hatch 1 Shroud Vertical Welds

Weld ID	Weld Length, in	Allowable Through wall crack length, in.	Minimum required ligament, in.	Min. Ligament including crack growth (two years) and NDE Uncertainty, in.
V-1, V-2	32	30	2	9.6
V-3, V-4	36	34	2	9.6
V-5, V-6	98.8	66.4	32.4	40.0
V-7, V-8	36	34	2	9.6
V-9, V-10, V-11	52	45	7	14.6
V-12, V-13, V-14	16	14	2	9.6

1. Based on a conservative flow stress of 48 ksi (3Sm assuming Sm = 16 ksi).

2. Welds V-12, V-13, V-14 are made of Alloy 600 plate and use of Sm = 16 ksi is conservative.

3. Crack growth based on $5x10^{-5}$ in/hour and 8000 hot hours per year.