

ENCLOSURE 2

BRUNSWICK STEAM ELECTRIC PLANT, UNIT 2
NRC DOCKET NO. 50-324
OPERATING LICENSE NO. DPR-62
NUREG-0619 FEEDWATER NOZZLE AND SPARGER EXAMINATION RESULTS

FEEDWATER SPARGER
CIRCUMFERENTIAL CRACKING EVALUATION
FOR BRUNSWICK UNITS 1 AND 2
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FEEDWATER SPARGER
CIRCUMFERENTIAL CRACKING
EVALUATION FOR
BRUNSWICK UNITS 1 AND 2

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CONTENTS OF THIS REPORT

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1.0 EXECUTIVE SUMMARY

Carolina Power & Light (CP&L) requested that analysis be done to address circumferential cracking along welds at the feedwater sparger arm-to-tee connections, to identify allowable conditions for operation one additional cycle. The analysis involved determination of the maximum allowable flaw size, consideration of loose parts issues and estimation of maximum nozzle cracking for a hypothetical sparger crack leak directly onto the nozzle.

A preliminary analysis was performed prior to sparger inspection [1]. The sparger inspections for Unit 2 were subsequently performed [2]. The results of the evaluation and inspections are summarized below:

- The critical flaw size for the circumferential tee weld cracking is 14.1 inches on the outside surface.
- The crack growth in one cycle could be as large as 3.16 inches, due to IGSCC, so the allowable flaw size for the inspection is 10.9 inches.
- Complete separation of the sparger arm at the tee weld would not overstress the vessel bracket connection, and such a separation would be detected by the operator, so there is no loose parts concern for this particular cracking in the spargers.
- Analysis of the hypothetical case of sparger leakage on the nozzle blend radius indicates that a crack would grow no deeper than 0.85 inches due to the leakage thermal cycling. Including system fatigue crack growth for one cycle of 0.05 inches, a crack no deeper than 0.9 inches could be developed in one cycle of operation.
- The Unit 2 inspection showed the longest circumferential crack to be about 2 inches long. Comparison of inspection results from this outage and the previous outage for one of the cracks indicates that no significant crack growth occurred during the last cycle.

2.0 BACKGROUND

The feedwater (FW) spargers in Units 1 and 2 at the Brunswick plants have the originally designed flow holes in the side of the sparger arm pipes, which have demonstrated rapid thermal cycle cracking after a few cycles of operation. As a result, and in compliance with NUREG-0619, CP&L has regularly performed penetrant test (PT) inspections of the flow holes, and has found and monitored flow hole cracking. In the process of performing PT inspections during the last outage, indications were also found along the circumferential welds which connect the sparger arms to the tee. While these indications were not measured for length, some pictures show circumferential indications at least 2 inches long on the visible side of the sparger (see Figure 2-1). Therefore, CP&L requested an evaluation of the structural integrity of the spargers for the next cycle of operation. The evaluation specifically addresses the circumferential cracking along the welds between the sparger arms and tee, and applies to both Units.

The evaluation consists of several aspects, as described below:

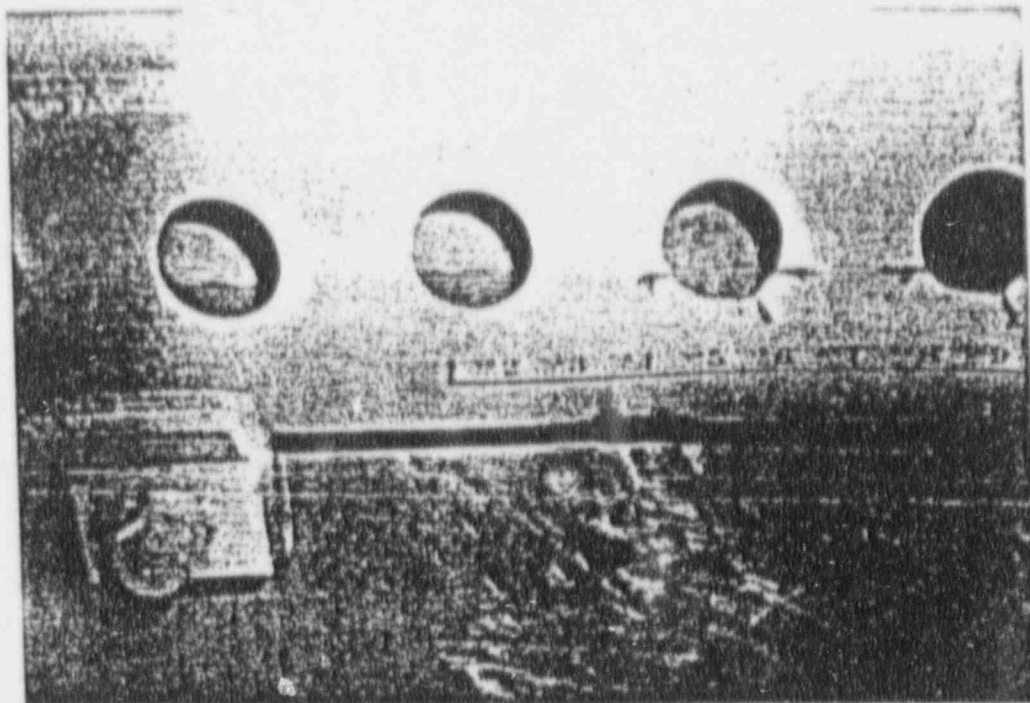
- The critical flaw size for failure of the sparger is determined.
- Maximum expected crack growth is predicted, based on consideration of intergranular stress corrosion cracking (IGSCC) and fatigue.
- The likelihood of complete failure of a sparger tee weld resulting in loose parts is addressed.
- For the worst case scenario where feedwater leaks through the circumferential crack directly onto the blend radius of the feedwater nozzle, the maximum possible nozzle crack depth is predicted.

Inspection results for Unit 2 are presented and conclusions concerning continued operation are made.



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BRUNSWICK STEAM ELECTRIC PLANT
EIGHTH REFUELING OUTAGE, OCTOBER 1989
INVESSEL LIQUID PENETRANT PHOTOGRAPHS



135° HOLE # 17, & 18

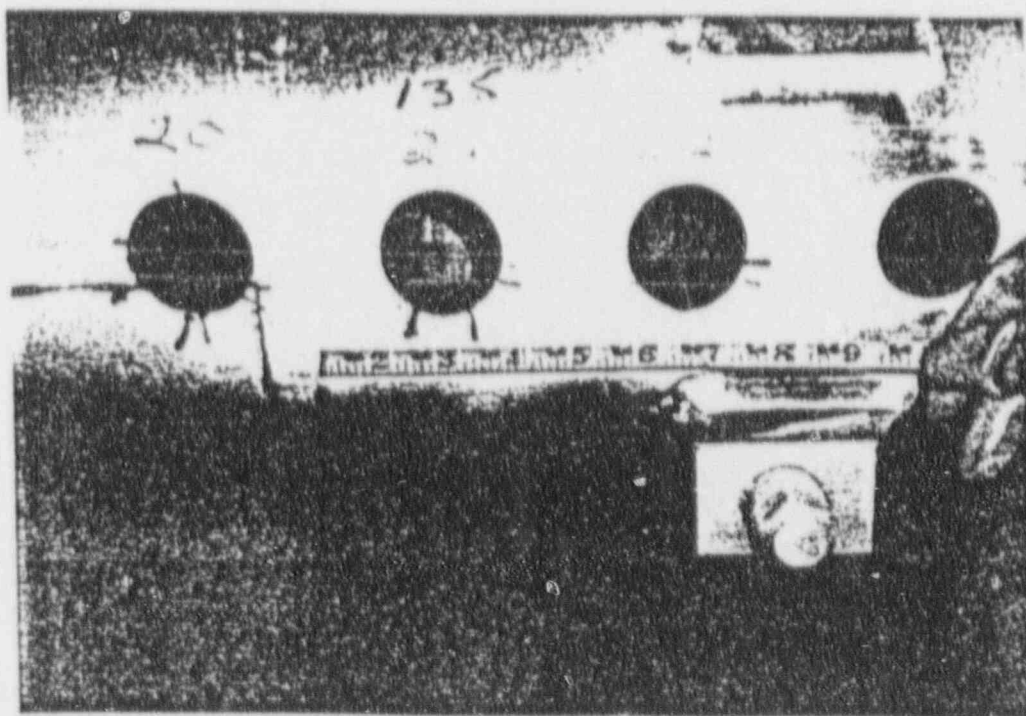


Figure 2-1. Results of 1989 Sparger PT Inspection

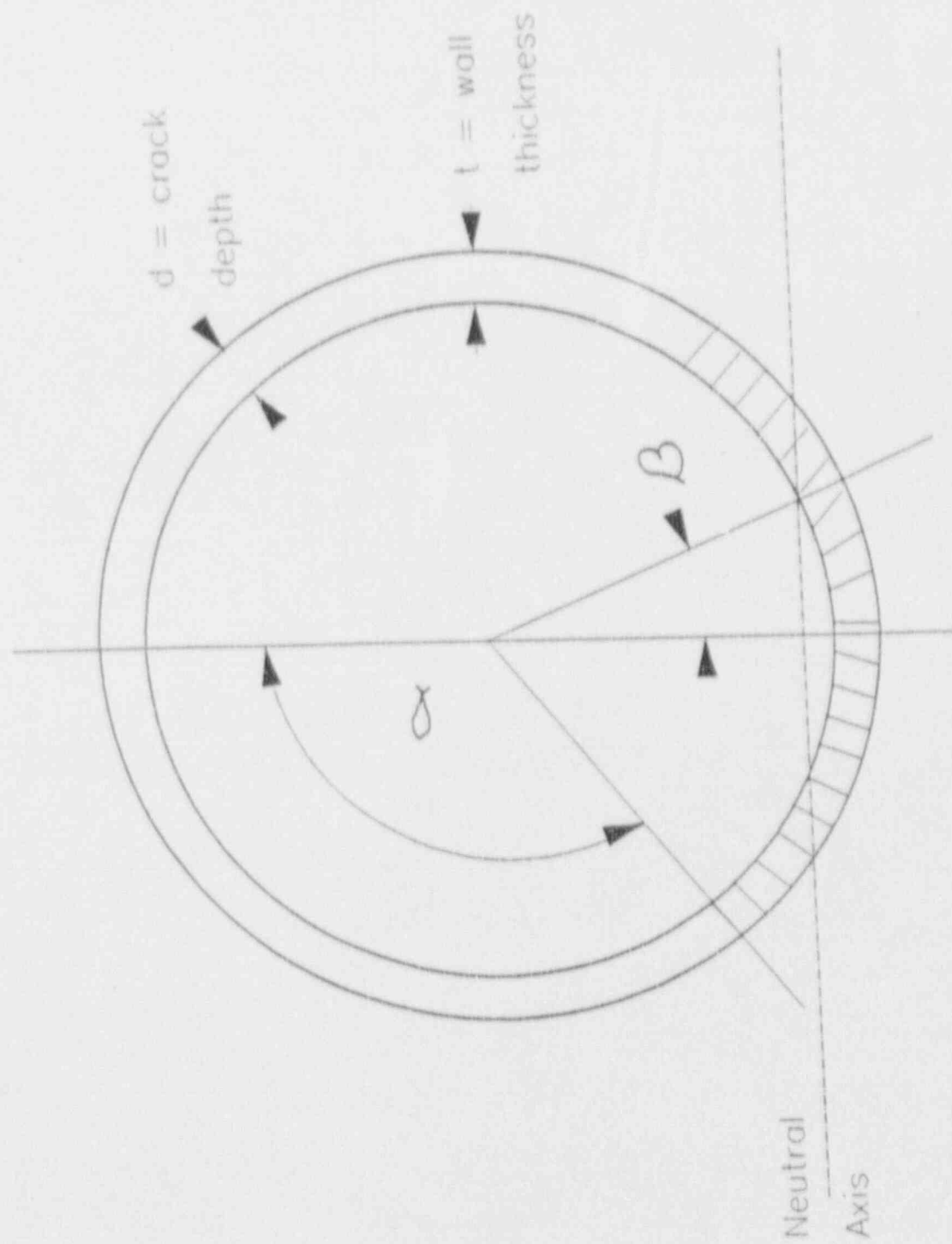


Figure 3-1. Geometric Model for Net Section Collapse Method

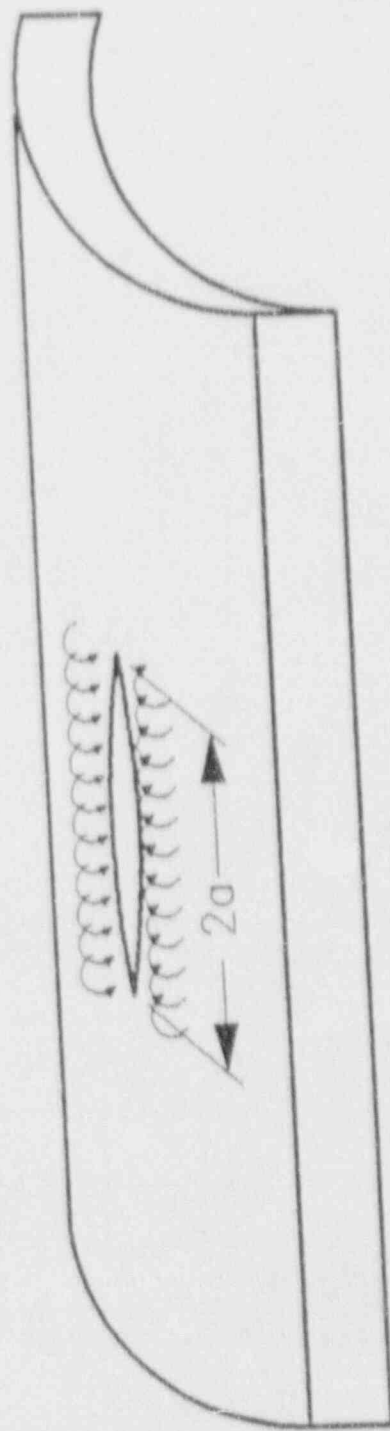


Figure 3-2. K Model for Secondary Bending in a Cracked Pipe

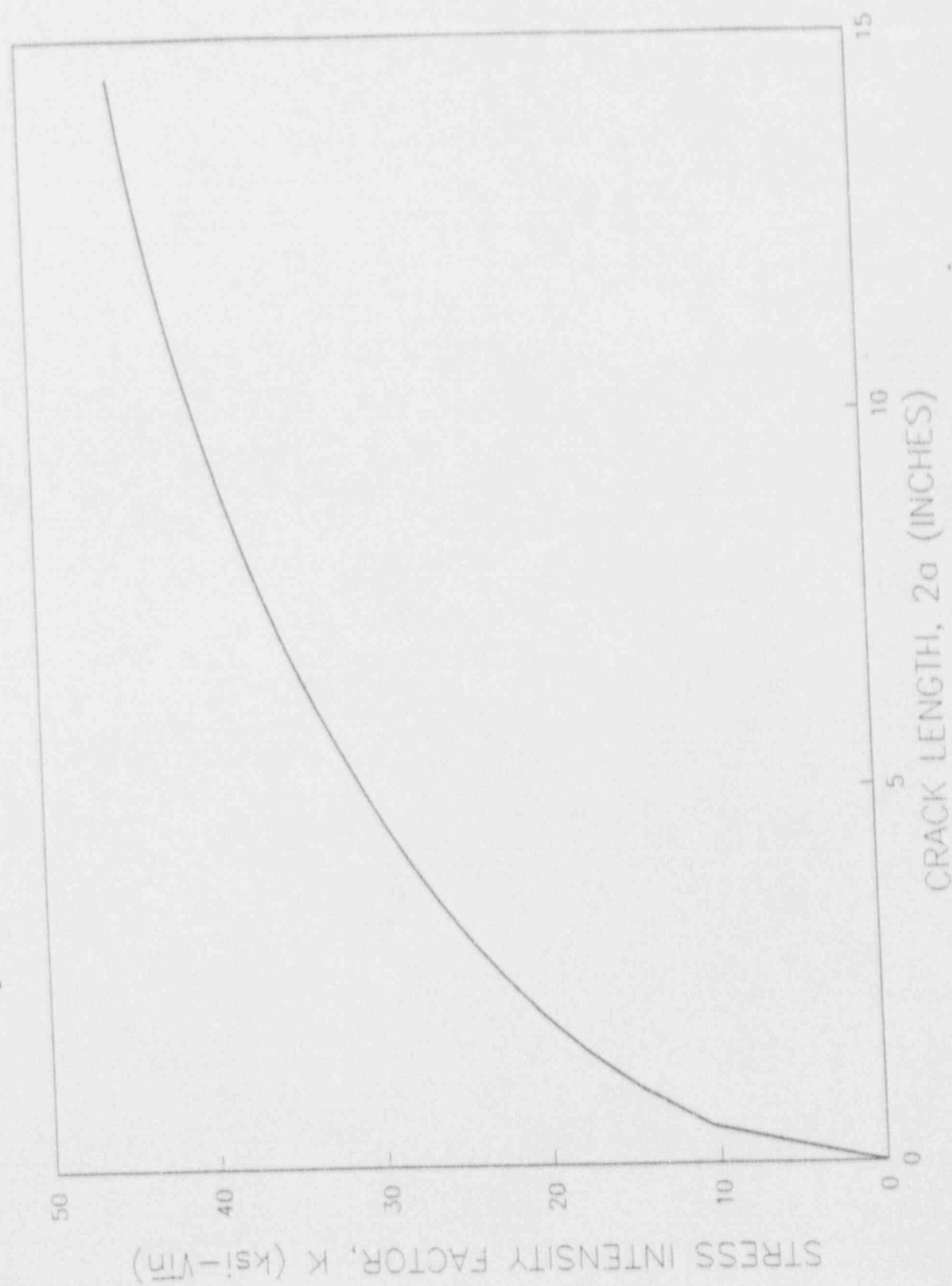


Figure 3-3. K vs. $2a$ for Cracks in Circumferential Sparger Weld

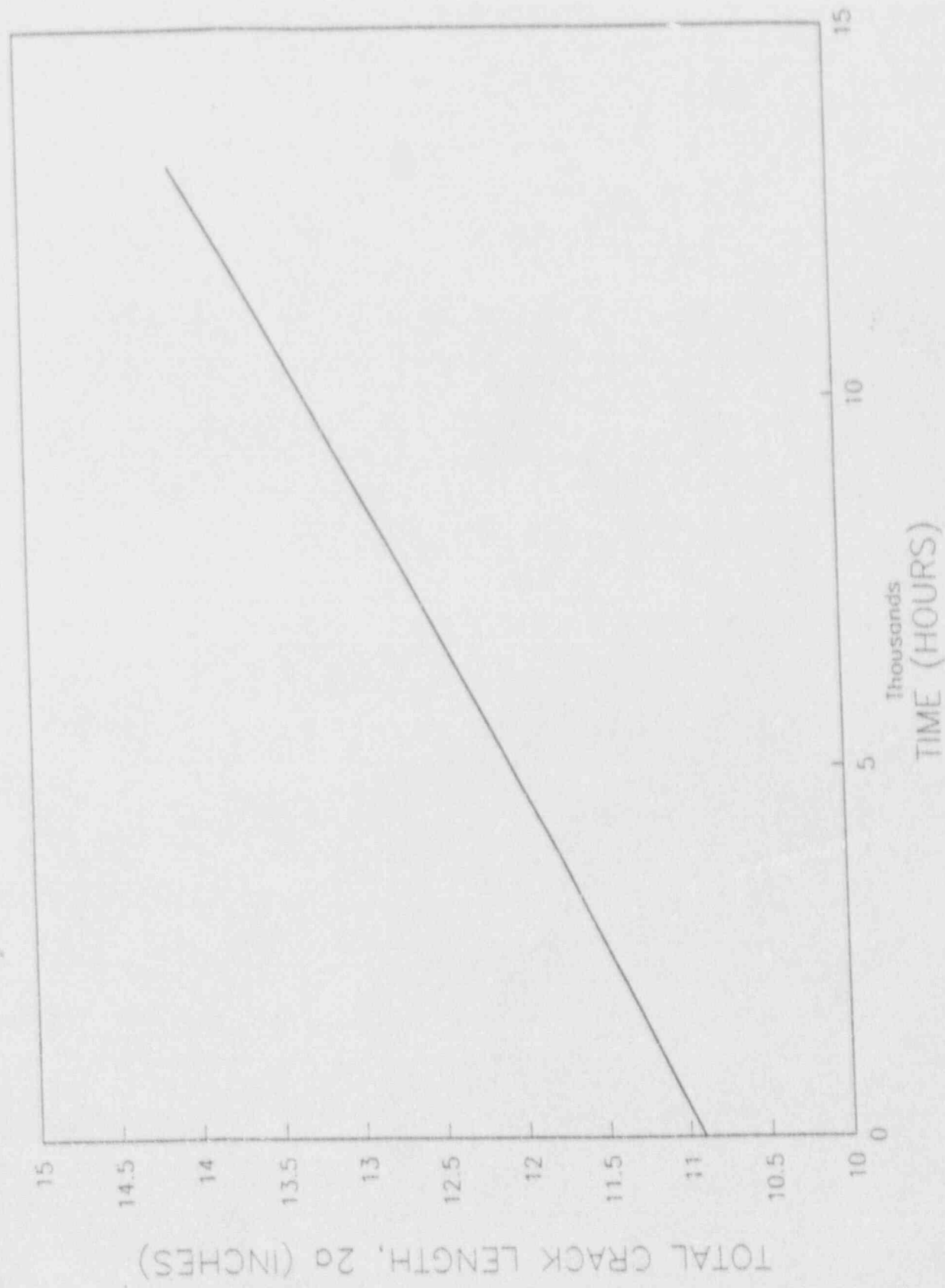


Figure 3-4. IGSCC Growth Predicted for 18 Month Cycle

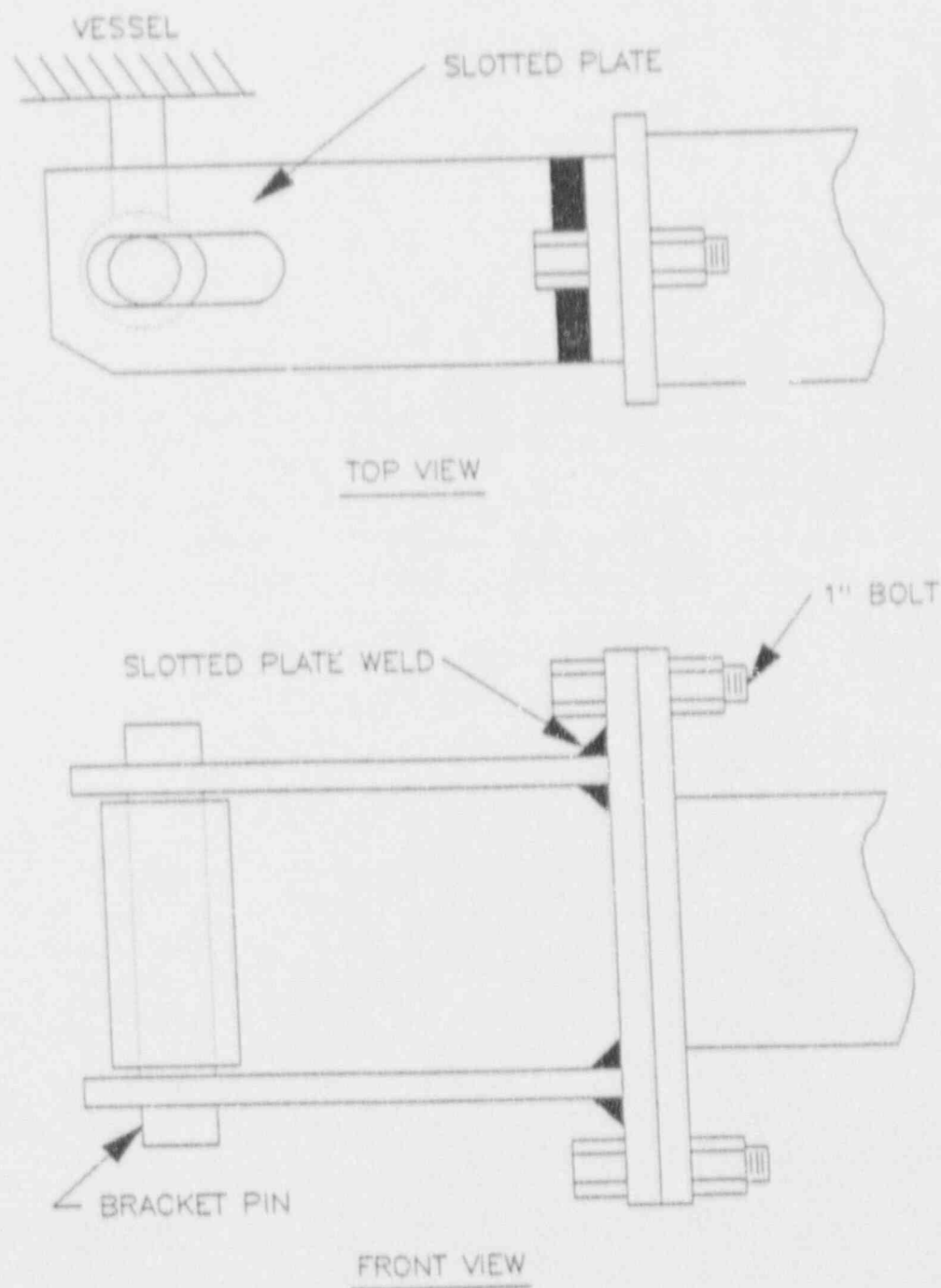


Figure 3-5. Schematic of Sparger Arm Bracket Connection

4.0 FEEDWATER NOZZLE CRACKING IMPACT

In the unlikely event that the sparger weld cracks opened so that feedwater was flowing directly onto the blend radius of a FW nozzle, rapid cycling could cause crack initiation and crack growth. The nature of the damage to the nozzle is similar to two documented cracking phenomena: FW thermal sleeve leakage rapid cycling and flow hole rapid cycling.

Extensive testing and analysis of the thermal sleeve leakage rapid cycling was conducted in the process of designing the triple thermal sleeve. Among the analyses done was an evaluation of the expected crack growth in the blend radius due to rapid cycling [4]. The results showed that ΔK values associated with the rapid thermal cycling drop as a crack proceeds into the nozzle until the crack arrest ΔK threshold of 3 ksi- $\sqrt{\text{in}}$ (for high R-ratios) is reached. The depth of the arrested crack is a function of the frequency of the cycling, as shown in Figure 4-1.

Similar analysis was done for the flow hole cycling phenomenon [5]. Again, the ΔK values drop as a function of distance from the flow hole, until the crack arrest ΔK threshold is reached. In this case, with low R-ratio, the threshold is 5 ksi- $\sqrt{\text{in}}$.

The frequencies and magnitudes of thermal cycles for the case of sparger leakage onto the nozzle are unknown, so any fatigue crack growth calculation would be based on arbitrary assumptions. Instead, the maximum expected crack depth is determined based on the same ΔK attenuation and ΔK threshold approach used for the thermal sleeve leakage and flow hole cases.

4.1 METHODS

The method used to estimate the crack arrest depth follows the methods used for the blend radius in [4], benchmarked by the actual cracking seen in the sparger flow holes. The flow hole cracks have been found to be as large as 0.5 inches, so the benchmark of the ΔK vs. depth calculation is that the curve should pass through 5 ksi- $\sqrt{\text{in}}$ at 0.5 inch depth.

The feedwater nozzle blend radius was modeled, as shown in Figure 4-2, for finite element analysis by ANSYS. The model was subjected to cycles of 130°F step changes between 550°F and 420°F at varying frequencies, and thermal and stress computations were performed. The ANSYS results were used with the ΔK relationship from [4]:

$$K_I = 1.12 \sqrt{\pi a} [A_0 + A_1 * 2a/\pi + A_2 * a^2/2 + A_3 * 4a^3/3\pi] \quad (4-1)$$

where A_0 through A_3 are coefficients to the cubic polynomial curve fit of stress versus depth in the nozzle blend radius, obtained from ANSYS.

4.2 ASSUMPTIONS

The following assumptions were made for the purposes of conservatively simplifying the problem of leakage flow from the sparger onto the blend radius:

- Leakage flow from the cracked sparger would have similar thermal cycling characteristics to those of the sparger flow through the flow holes.
- Radial thermal cycling cracks currently shown at the flow holes with a length of 0.5 inches represent the maximum cracking due to steady state flow fluctuations. Further growth of these cracks is due to transient events such as feedwater flow initiation. This is conservative, as these cracks have already seen over ten years of transient events.
- Magnitudes of temperature fluctuations at the flow holes are greater than fluctuations expected from leakage onto the blend radius.

4.3 RESULTS

Stress range and ΔK profiles were developed for frequencies of 1/8, 1/4 and 1/3 Hz. The 1/4 Hz case was found to come closest to meeting the benchmark condition of 5 ksi- $\sqrt{\text{in}}$ at 0.5 inches. The stress range profile is shown in Figure 4-3. The stress range profile was fit with a cubic polynomial, and then the coefficients were adjusted slightly until the benchmark conditions were met. The resulting ΔK vs. depth plot is shown in Figure 4-4. The curve extends to the high mean stress threshold of 3 ksi- $\sqrt{\text{in}}$ at a depth of 0.85 inches. Therefore, rapid cycling behavior which causes a crack of 0.5 inches at the flow holes is predicted to cause a crack of 0.85 inches in the blend radius.

In addition to the possible crack growth due to rapid cycling, system cycling crack growth could occur. In the most recent NUREG-0619 analysis for Unit 2 [6], which has the greater crack growth rate, the system cycling crack growth for 18 months of operation with a crack 0.85 inches deep is 0.05 inches. Therefore, the maximum expected crack depth for sparger leakage onto the nozzle is 0.9 inches. While this is significant, it is less than the flaw depth allowed in NUREG-0619 of 1.0 inch.

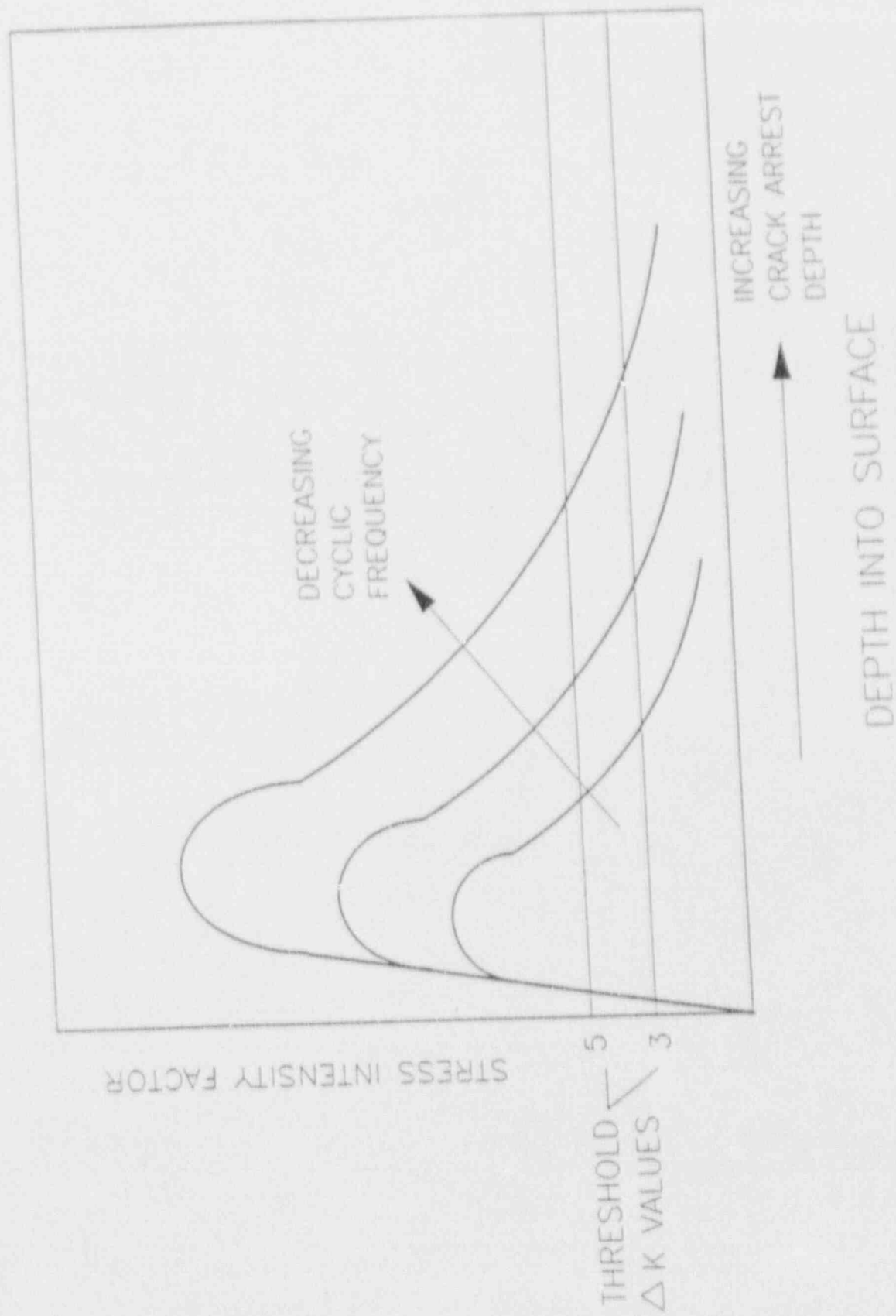


Figure 4-1. Schematic of Frequency Dependency on Crack Arrest Depth

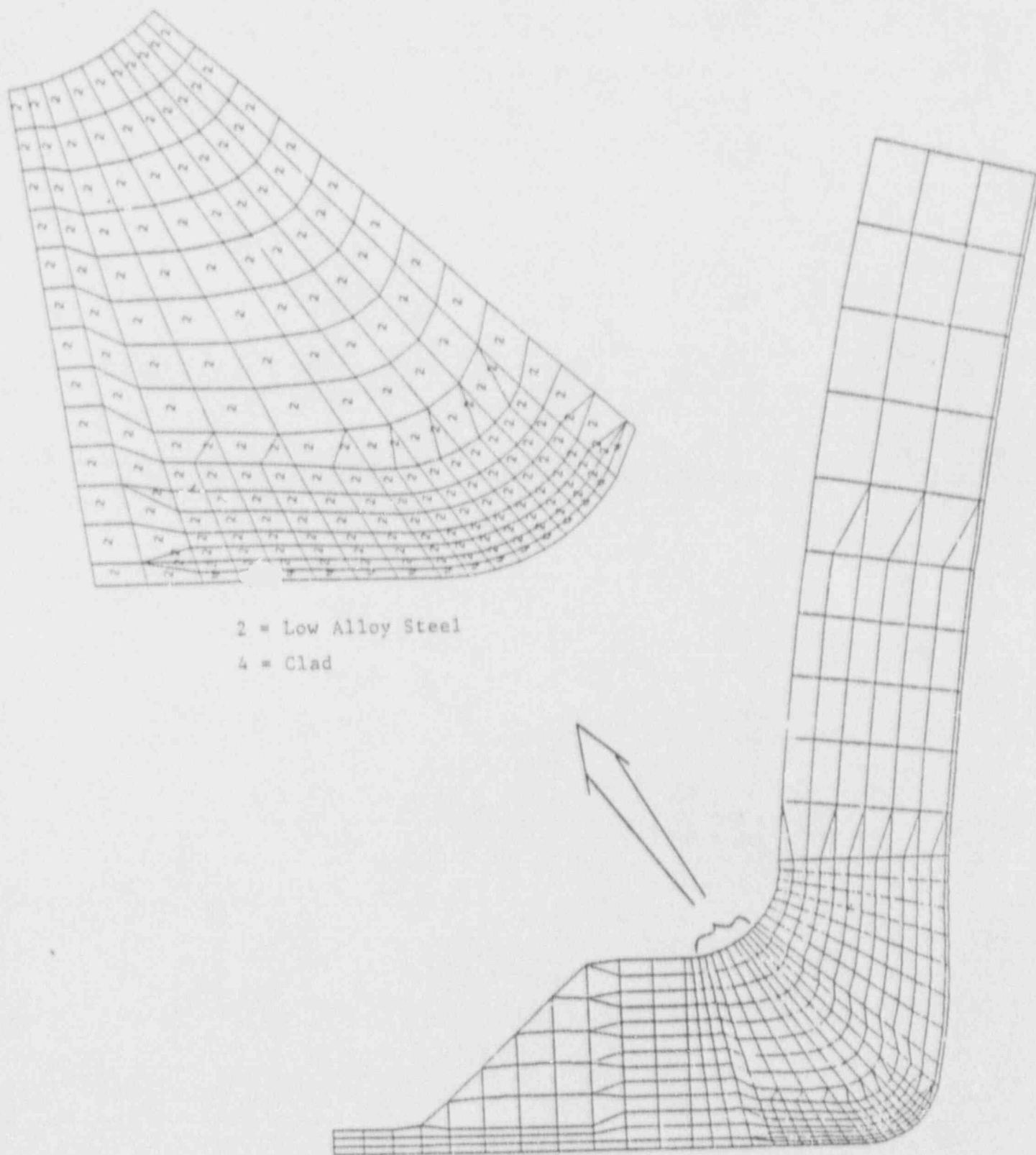


Figure 4-2. ANSYS Model of Feedwater Nozzle Blend Radius

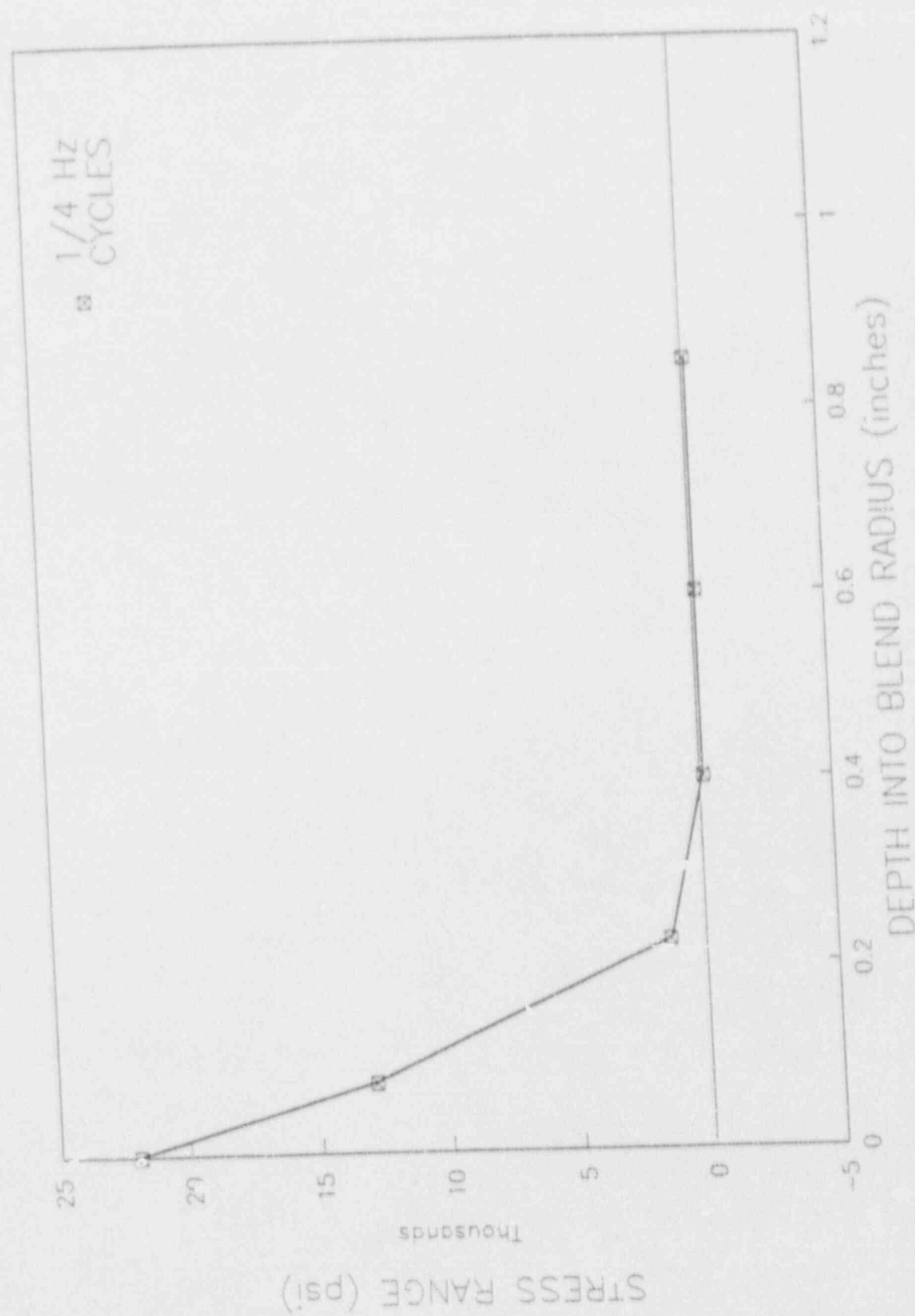


Figure 4-3. Stress Range Profile for Cyclic Leakage on Nozzle

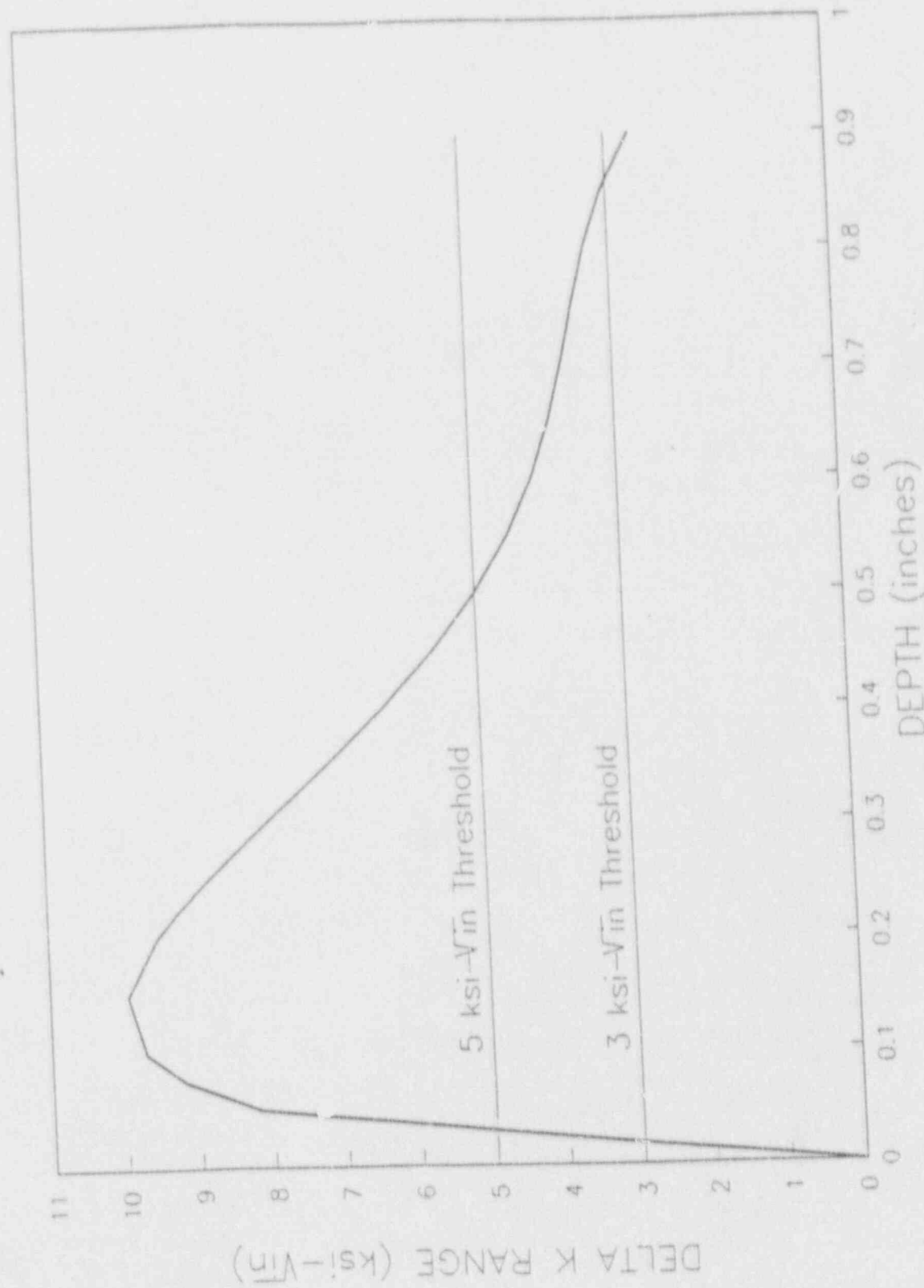


Figure 4-4. Attenuation of ΔK with Depth into Nozzle

5.0 CONCLUSIONS

The results of this report are intended to provide justification for operation for one additional cycle given circumferential cracks less than the maximums allowed in this report. The inspections were done for Unit 2 in October, as discussed below. Conclusions can be drawn for Unit 2, based on those inspection results. If the inspection results for Unit 1 are similar to those for Unit 2, the same conclusions apply.

5.1 UNIT 2 INSPECTION RESULTS

The Unit 2 feedwater nozzles and spargers were inspected according to the requirements of NUREG-0619. The documented results are included in Appendix A. The blend radius of each feedwater nozzle was liquid penetrant (LP) tested, showing no indications.

The circumferential welds were LP tested and ultrasonically tested (UT). The LP tests show the longest crack to be 2 inches. The UT results show that the crack lengths inside the spargers are no more than the LP indications on the outside surfaces. Comparison of a crack length measured during the last outage and during this outage shows that no significant crack growth has occurred.

5.2 OPERATION JUSTIFIED

The analysis in Section 3 provides an allowable through-wall crack length of 10.9 inches, based on 3.16 inches of IGSCC growth in one cycle. The inspection results for Unit 2 show much shorter cracks, about 2 inches, and little if any IGSCC growth. Therefore, operation for the next cycle is justified.

Once crack lengths and IGSCC growth rates are shown to be acceptable by inspection of the Unit 1 spargers, operation for one additional cycle will be justified.

6.0 REFERENCES

- [1] Letter No. ADK-91-079, dated October 4, 1991, AD Ketcham of GE to EA Bishop of CP&L, "Feedwater Sparger Circumferential Cracking Evaluation."
- [2] Letter, dated October 20, 1991, JE Gates of CP&L to AD Ketcham of GE, "Unit 2 Feedwater Nozzle Blend Radius and Sparger Inspection."
- [3] Cartwright, D.J. and Rooke, D.P., Compendium of Stress Intensity Factors, Her Majesty's Stationery Office, publisher, London, 1976, pages 320-322.
- [4] Fife et al, "Boiling Water Reactor Feedwater Nozzle/Sparger Interim Program Report," GE Report NEDO-21480, July 1977.
- [5] Riccardella, P.C. and Sharma, S.R., "Feedwater Sparger Hole Thermal Stress Analysis," GE Report RSA-76-04, March 1976.
- [6] Stevens, G.L., "Brunswick Unit 2 Feedwater Nozzle Fracture Mechanics Analysis," GE Report NEDC-30633, Revision 1, May 1991 (proprietary).

APPENDIX A

FEEDWATER NOZZLE BLEND RADIUS
AND SPARGER INSPECTION

CP&L

Carolina Power & Light Company

October 20, 1991

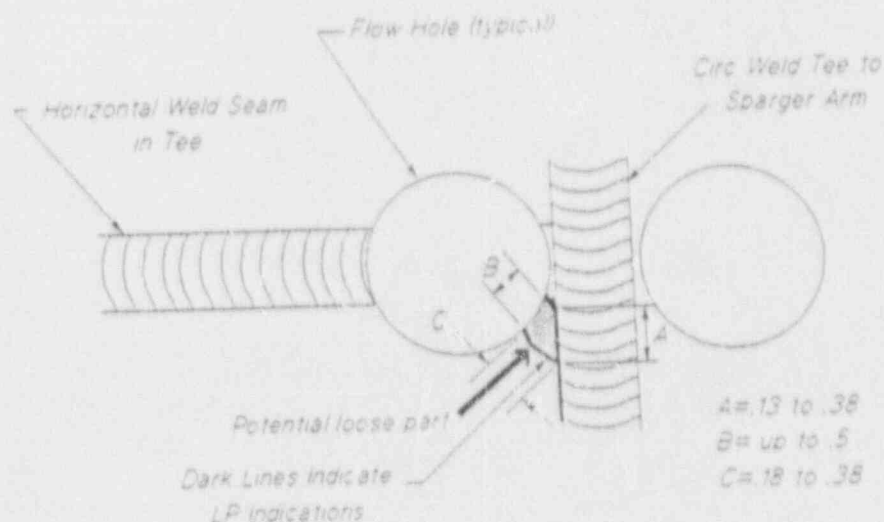
TO: A. D. Ke. n
GE Site Services Manager

FROM: J. E. Gates
NED Responsible Engineer

SUBJECT: Unit 2 Feedwater Nozzle Blend Radius and Sparger Inspection

On October 12, 1991 CP&L inspected the Unit 2 feedwater nozzle inner blend radius in accordance with Nureg 0619 and also performed an LP examination of the feedwater spargers to document the flow hole cracking and circumferential weld cracking. The results of the inspection are as follows:

1. No relevant indications were found on the nozzle inner blend radius.
2. Crack growth continues on the flow holes but no pieces have separated. Note: The pieces did not separate during the hydrolase cleaning operation using a 20,000 psi plus hydrolaser unit prior to the examination. In addition to the horizontal piece between the flow holes which has been previously addressed by GE, the size of other potential loose pieces is as shown. The largest of which has also been previously addressed by GE.

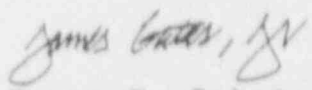


POTENTIAL FEEDWATER SPARGER LOOSE PART

3. The eight circumferential welds connecting the sparger tee to the arms and the four welds connecting the thermal sleeve to the tee were LP examined. No relevant indications were found on the thermal sleeve attachment welds. Indications were found on the tee to arm circumferential welds. Some of these ran into the welds and some were circumferentially oriented following the heat affected zone. The longest circumferentially oriented indication found by LP examination was 2 inches long. Following the LP examination, five of the eight welds were UT examined for the full circumference to determine the ID length of the OD indications. No indications were found to extend beyond the OD indications. By the direction of the cracks they all seem to have originated from the flow hole cracks and are now following the heat affected zone of the weld. They are all growing downward towards the lower half of the sparger arm. No evidence of any other cracking was found in the joint. The longest crack on the right side of the 135° tee did not show significant growth from the last LP examination.

Please prepare the final report for the feedwater spargers incorporating this information into the report. A copy of the inspection documentation is attached (except for the photographs of the LP indications). If you need additional information please contact me at extension 3609.

Sincerely,


James E. Gates, Jr
NED Engineering

JEG/jeg

cc:
S. L. Bertz
E. A. Bishop
J. W. Crider
P. S. Gore

BRUNSWICK STEAM ELECTRIC PLANT UNIT 2
NINETH REFUELING OUTAGE - OCTOBER, 1991
INVESSEL VISUAL INSPECTION (IVVI)
INSPECTION REPORT AND VIDEO REVIEW

NUREG. 0619 INSPECTION

THIS REPORT SUMMARIZES THE INVESSEL VISUAL INSPECTION AND THE VIDEO TAPE REVIEW THAT WAS PERFORMED DURING THE NINETH REFUELING OUTAGE AT BRUNSWICK UNIT 2. THE INSPECTIONS WERE PERFORMED BY GENERAL ELECTRIC COMPANY PERSONNEL.

THE FOLLOWING IDENTIFIES THE WORKSCOPE THAT WAS PERFORMED AND THE VIDEO TAPE REVIEW:

1. FEEDWATER SPARGER
FLOW HOLES

THE FEEDWATER SPARGERS WERE VISUALLY INSPECTED (VT-3) PRIOR TO THE LIQUID PENETRANT EXAMINATION FOR GROSS CRACKING. THE VISUAL EXAM RESULTED IN NO ADDITIONAL HOLES TO LP EXAMINE. A TOTAL OF 55 OF 144 HOLES WERE INSPECTED BY THE LIQUID PENETRANT METHOD. THE FLOW HOLES HAVE LINEAR INDICATIONS WITH GROWTH CONTINUOUS. SEE PHOTOS FOLLOWING THIS REPORT.

2. FEEDWATER NOZZLE
INNER RADIUS

AN LP EXAMINATION WAS ALSO PERFORMED ON THE NOZZLE INNER RADIUS'S @ 45, 135, 225, AND 315 DEGREES RESULTING IN NO RECORDABLE INDICATIONS.

3. FEEDWATER SPARGER
TEE BOX WELDS

THE 12 FEEDWATER TEE BOX CIRCUMFERENTIAL WELDS WERE FIRST LP EXAMINED TO DETERMINE CRACKING EXTENDING FROM THE FLOW HOLES AND TO DETERMINE THE OD LENGTHS. AFTER A REVIEW OF THE VIDEO, FIVE OF THE EIGHT TEE TO SPARGER ARM CIRC WELDS WERE DETERMINED TO HAVE LINEAR CRACKING. THOSE FIVE CIRC WELDS WERE THEN ULTRASONICALLY INSPECTED TO DETERMINE ID LENGTHS. DUE TO THE CONFIGURATION OF THE FLOW HOLES IN RELATION TO THE CRACKING, ONLY TWO OF THE CIRC WELD CRACKS COULD BE ULTRASONICALLY "SIZED" ON THE ID. SEE THE FOLLOWING UT DATA.