CP&L

Carolina Power & Light Company

MAY 05 1989

SERIAL: NLS-89-131

United States Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, DC 20555

BRUNSWICK STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-324/LICENSE NO. DPR-62
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION
REACTOR RECIRCULATION SYSTEM PIPING JCO

Gentlemen:

On March 27, 1989, the NRC requested additional information concerning the justification for continued operation submitted for the Brunswick Steam Electric Plant, Unit 2, on March 13, 1989. The additional information requested is provided in the enclosure to this letter.

Please refer any questions regarding this submittal to Mr. Stephen D. Floyd at (919) 546-6901.

Yours very truly,

L I Loflin

Leonard I. Loflin
Manager
Nuclear Licensing Section

BAB/bab (\cor\jco)

Enclosure

cc: Mr. S. D. Ebneter
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ENCLOSURE

BRUNSWICK STEAM ELECTRIC PLANT, UNIT 2
NRC DOCKET 50-324
OPERATING LICENSE DPR-62
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION
REACTOR RECIRCULATION SYSTEM PIPING JCO

## NRC QUESTION

Crack growth computations were performed only for a 360° part-throughwall flaw. However, because the crack growth predictions were to be correlated with service experience and because the maximum flaw depth is about 20% larger than the average flaw depth, the computations in Sections 2.4 and 4.2 may not cover the applicable crack growth range for the thermal sleeve attachment.

To ensure appropriate crack geometry and growth range are covered, the computations in Section 4.2 should be repeated to estimate a material crack growth relationship representative of service experience using a semi-elliptical flaw shape with less than a 360° length (e.g., flaw length/depth = 10 or 20). The resulting crack growth relationship should then be used to repeat the calculations in Section 2.4 (Case 2, page 17, Revision 1) and to update Table 2-3, using the shorter assumed part-throughwall flaw length and an initial flaw depth equal to 61% of wall thickness.

## CP&L RESPONSE

### Background

Recirculation inlet safe end cracking at the thermal sleeve attachment weld was found at BSEP-1 and verified by destructive examination [1]. Since BSEP-1 and BSEP-2 have identical N2 safe end designs and have been operating for approximately the same period of time (6.4 and 6.8 EFPYs, respectively), a worst case analysis was performed to justify the continued operation of BSEP-2. This analysis, documented in Reference 1, postulated that the worst case BSEP-1 flaw (average 360° depth of 49% of wall and maximum depth of 61% of wall) also exists in the most highly stressed recirculation inlet safe end in BSEP-2.

The analysis in Reference 1 employed the average 360° crack depth of 49% of wall ($a/t = 0.49$) as the starting point for subsequent predicted SCC growth. The SCC predictions in Reference 1 used several crack growth laws, the most relevant of which was empirically derived from the rate of crack growth experienced in the BSEP-1 and DAEC inconel safe ends at the thermal sleeve-to-safe end weld location.

In response to the NRC request, this letter addresses a postulated starting crack depth of $a/t = 0.61$, and also addresses the effects of cracks shorter than 360° for the experience-based crack growth law. No credit is taken for the potential SCC mitigation afforded by the mechanical stress improvement (MSIP) and hydrogen water chemistry (HWC) implemented at BSEP-2.

## Allowable End-of-Evaluation Period Flaw Sizes

Allowable end-of-evaluation period flaw sizes for the most highly stressed N2 nozzle safe end are documented in Reference 1. These calculations are not affected by the present analysis. Riser C has the most highly stressed safe end with an operating pressure stress of 2.60 ksi, a deadweight stress of 0.67 ksi, and an OBE stress of 1.58 ksi. It can be seen that these primary stresses are quite low, due to the large thickness (1.125 in.) of the safe end at this location and the low applied forces and moments [1]. The thermal expansion stress of 2.33 ksi and the shrinkage stress of 6.24 ksi (resulting from weld overlays on the recirculation piping) are not employed to compute allowable flaw size but are used in SCC growth analyses.

Due to the low primary stresses, the allowable flaw depth is at the maximum of $a/t = 0.75$ permitted by Appendix C of ASME Section XI. Actually, the predicted allowable flaw depth for a 360° circumferential crack is $a/t = 0.86$, using the net section plastic collapse equations of Section XI, Appendix C with a safety factor on stress of 2.77 [1]. Thus, both $a/t = 0.75$ and $a/t = 0.86$ are considered in this evaluation as allowable end-of-evaluation period flaw sizes.

## Stress Intensity Factor (K) Calculations

In order to perform SCC growth calculations, K values must be computed as a function of crack depth for 360° cracks and for circumferential cracks with length-to-depth ($\ell/a$) ratios of 20 and 10, as requested by the NRC. These results are used both for indexing field cracking experience to an appropriate crack growth rate law and for predicting crack growth in other safe ends.

Computation methods for K exist in pc-CRACK, the SI fracture mechanics computer code, for nonlinear stress distributions through the pipe wall for 360° cracks but not for shorter circumferential cracks. There are numerous K solutions for finite length circumferential surface cracks for membrane and linear bending stress distributions, but these are not readily available for the nonlinear stress distribution exhibited by the as-welded residual stresses at the BSEP thermal sleeve-to-safe end weld location [1]. Therefore, the equations for K in Reference 2 were employed for circumferential cracks with $\ell/a = 20$ and $\ell/a = 10$ to calculate K for the applied membrane and bending stresses in the pipe, and the Ks computed by pc-CRACK for the 360° crack and the nonlinear residual stress distribution were conservatively added to the above-applied Ks for each crack depth. In other words, the Ks computed for the as-welded residual stress distribution are for a 360° crack, regardless of actual crack length, whereas the applied stress and shrinkage stress Ks reflect the actual crack length. Reference 2 documents the basis for ASME Section XI flaw acceptance for carbon steel pipe, but the K calculation equations also apply to these inconel safe ends.

Results of the total K versus crack depth (a) calculations, using the above methods, are shown in Figure 1 for 360° $\ell/a = 20$ and $\ell/a = 10$ circumferential cracks. Calculation details for the $\ell/a = 20$ and $\ell/a = 10$ cases are shown in Tables 1 and 2. The K calculation values for the 360° cracks are shown in the pc-CRACK output in Attachment 1. Note in Figure 1 that, within the expected accuracy range for different K solution methods, the K values for $\ell/a = 20$ are approximately equal to those for the 360° solution. This is expected since a crack with $\ell/a = 20$ is about 40% of the safe end circumference for $a/t = 0.80$ (see Table 1, L/circ values). On the other hand, the $\ell/a = 10$ cracks show a significant decrease in K versus crack depth (a) from the 360° case in Figure 1.

SCC Growth Calculations

SCC growth rate calculations were done with pc-CRACK, as shown in Attachments 1 and 2 using the K values computed as described above for the 360° and the $\ell/a = 10$ case. The case for $\ell/a = 20$ was not analyzed since the K values are approximately equivalent to those for the 360° crack as shown in Figure 1. Thus, for a K-based crack growth law, the predicted crack growth for the 360° and $\ell/a = 20$ cases would also be approximately equivalent.

The following SCC growth law was in Reference 1, based on empirical crack growth correlations with service experience for BSEP-1 and DAEC:

$$da/dt = 3.271 \times 10^{-9} K^{2.26}$$

where da/dt is in in./hr. and K is in ksi in. Since this law is based on experience, it also reflects the fact that the large majority of the K contribution in this thermal sleeve-to-safe end weld location is due to displacement-controlled residual stresses of a secondary stress nature. It also reflects the actual material susceptibility to SCC and the actual plant water chemistry conditions. This is in contrast to "faster" laws reported in Reference 1 based on laboratory tests with susceptible materials, extreme environments, and "live loads" or load-controlled tests.

The above law was verified in the present study to still be appropriate for $\ell/a = 10$. Using this law, the time to grow a circumferential crack with $\ell/a = 10$ from a depth of 0.018 in. (corresponding to a threshold K of 15 ksi in. in Reference 1) to $a/t = 0.61$ is 5.5 years versus 5.2 years for a 360° crack. Output from pc-CRACK is shown in Attachments 1 and 2 and is plotted in Figure 2. Both of the above crack growth lives are in substantial agreement with the actual field crack growth life of 5.4 years for the worst BSEP-1 crack, assuming an initiation time of 1 year out of the total life of 6.4 EFPYs [1]. The initiation time is based on laboratory test data [1].

Note in considering the crack growth law verification that for a given crack depth, a shorter crack length results in a lower K and a "faster" law to reach a final growth size in a given time period. However, in the above respect, the choice of crack model is somewhat self-regulating since a shorter crack would index to a slightly faster crack growth law from field experience, but would result in overall slower growth at large crack depths due to lower K values relative to a long crack case. Figure 2 illustrates that the difference in predicted crack growth rate is greatest at large crack depths, consistent with the Figure 1 relative K values. The indexing of the crack growth law to field cracking is done by multiplying the ratio of actual life to predicted life times the coefficient of the growth law. This coefficient is directly proportional to the predicted growth rate or growth life.

In the current case, the growth law in this analysis predicts a growth life to go from a crack depth of 0.018 in. to $a/t = 0.61$ of 5.5 years for a crack with $\ell/a = 10$ and 5.2 years for a 360° crack for a growth life or SCC law coefficient ratio of $5.5/5.2 = 1.06$. On the other hand, as summarized in Table 3, the predicted growth life ratio for $\ell/a = 10$ to 360° cracks is $10.7/8.9 = 1.20$ for an allowable $a/t$ of 0.75 and is $18.0/14.9 = 1.21$ for an allowable $a/t$ of 0.86. Thus, the K effect at large crack sizes more than makes up for the slightly faster crack growth law which would index to shorter cracks at smaller crack depths and results in an overall greater predicted life for shorter cracks when this approach is used. In any event, the effect of crack aspect ratio in the range of $\ell/a = 10$ to 360° does not produce a significant effect (about 6%) on the crack growth law coefficient and is not adjusted for further predictions with these crack shapes.

Finally, the resulting times predicted to grow 360° and $\ell/a = 10$ circumferential cracks from $a/t = 0.61$ to $a/t = 0.75$ and $a/t = 0.86$ are summarized in Table 3. These times range from 8.9 months for a 360° crack to reach $a/t = 0.75$ to 18.0 months for an $\ell/a = 10$ crack to reach $a/t = 0.86$. The $a/t = 0.86$ value is slightly beyond the range for K solutions ($a/t = 0.80$ maximum) and involved extrapolations of predicted SCC growth.

## Conclusions

The following conclusions are reached based on the analyses provided in this letter.

1. The SCC growth law based on field experience was verified as appropriate for circumferential crack shapes of $\ell/a = 10$ as well as for 360° surface cracks.

2. Conservative K solutions for $\ell/a = 20$ and 10 show that the 360° and $\ell/a = 20$ cases produce approximately the same results.

3. Credit was not taken in this analysis for MSIP and HWC mitigation of SCC growth at BSEP-2. The as-welded residual stress distribution and a growth law without HWC were conservatively used for SCC growth predictions.

4. The minimum predicted life for a 360° crack to grow from $a/t = 0.61$ to $a/t = 0.75$ is 8.9 months. This time is in excess of the time for BSEP-2 to reach the scheduled outage (September 1989) for inspection of these welds and continued operation is justified.

## References


1. H. L. Gustin, et al., "Justification for Continued Operation at Carolina Power & Light Brunswick Steam Electric Plant Unit 2," SI Report No. SIR-89-008, Rev. 0, March 8, 1989.

2. "Evaluation of Flaws in Ferritic Piping," EPRI Report No. NP-6045, Novetech, October, 1988.

TABLE 3

Summary of Predicted Allowable Remaining Lives
for the BSEP-2 Recirculation Inlet
Thermal Sleeve-to-Safe End Locations
(Time to Grow from 61% of Wall to Allowable Depth)

| | Time to Grow from a/t = 0.61 to Allowable Depth (mo.) | |
|---|---|---|
| | Allowable Depth, a/t = 0.75 | Allowable Depth, a/t = 0.86 |
| 360° Crack | 8.9 | 14.9 |
| ℓ/a = 20 Crack | 8.9 | 14.9 |
| ℓ/a = 10 Crack | 10.7 | 18.0 |

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