FENOC

FirstEnergy Nuclear Operating Company

Davis-Besse Nuclear Power Station
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Oak Harbor, Ohio 43449

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January 20, 2010
L-10-027

10 CFR 50.90

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT:
Davis-Besse Nuclear Power Station, Unit No. 1
Docket No. 50-346, License No. NPF-3
Response to Request for Additional Information Related to License Amendment Request to Update the Leak-Before-Break Evaluation for the Reactor Coolant Pump Suction and Discharge Nozzle Dissimilar Metal Welds (TAC No. ME2310)

By letter dated September 28, 2009, (Agencywide Documents Access and Management System [ADAMS] Accession No. ML092790438), FirstEnergy Nuclear Operating Company (FENOC) submitted a license amendment request to update the leak-before-break evaluation for the reactor coolant pump suction and discharge nozzle dissimilar metal welds for the Davis-Besse Nuclear Power Station (DBNPS). By letter dated December 3, 2009, (ADAMS Accession No. ML093450484), FENOC submitted a request to withhold from public disclosure the Structural Integrity Associates, Inc. (SIA) Report Number 0800368.404, Revision 0, July 20, 2009, which was included with the leak-before-break license amendment request.

By letter dated January 5, 2010, (ADAMS Accession No. ML093520549) the Nuclear Regulator Commission (NRC) staff requested additional information to complete its review of the license amendment request to update the leak-before-break evaluation for the reactor coolant pump suction and discharge nozzle dissimilar metal welds at DBNPS. The FENOC response to this request is attached.

Enclosure A is the revised SIA Report Number 0800368.404, Revision 1, dated January 11, 2010. This report has been updated to incorporate clarifications and improve readability. This report is considered proprietary information and should be withheld from public disclosure under 10 CFR 2.390.

Enclosure B provides the nonproprietary version of the SIA Report Number 0800368.404, Revision 1, dated January 11, 2010.

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Enclosure C, "Evaluation of Overlay Coverage Approaching 700 Square Inches Based on EPRI 36-inch Diameter Optimized Weld Overlay Mockup," is also provided to support the responses to the NRC questions.

Finally, Enclosure D provides the SIA and AREVA NP Inc., proprietary information affidavits.

There are no regulatory commitments contained in this submittal. If there are any questions or if additional information is required, please contact Mr. Thomas A. Lentz, Manager – Fleet Licensing, at 330-761-6071.

I declare under penalty of perjury that the foregoing is true and correct. Executed on January 20, 2010.

Sincerely,

Clark A. Price
Director, Site Performance Improvement

Attachment:
Response to Request for Additional Information

Enclosures:
A. Structural Integrity Associates, Inc., Report Number 0800368.404, Revision 1, January 11, 2010. [PROPRIETARY]
B. Structural Integrity Associates, Inc., Report Number 0800368.404, Revision 1, January 11, 2010. [NONPROPRIETARY]
C. "Evaluation of Overlay Coverage Approaching 700 Square Inches Based on EPRI 36-inch Diameter Optimized Weld Overlay Mockup," October, 2009. [NONPROPRIETARY]
D. Affidavits, Structural Integrity Associates, Inc. and AREVA NP, Inc. [NONPROPRIETARY]

cc: NRC Region III Administrator (w/o Enclosure A)
NRC Resident Inspector (w/o Enclosure A)
Nuclear Reactor Regulation Project Manager (w/o Enclosure A)
Utility Radiological Safety Board (w/o Enclosure A)

To complete its review, the Nuclear Regulatory Commission (NRC) staff has requested the following additional information in a letter dated January 5, 2010 (ADAMS Accession No. ML093520549). The NRC staff request is provided below in bold type followed by the FirstEnergy Nuclear Operating Company (FENOC) response for Davis-Besse Nuclear Power Station (DBNPS).

1. Identify which weld overlay, the full structural weld overlay (FSWOL) or optimized weld overlay (OWOL), was used in the stress distributions as shown in Figures 3-3, 3-4, 3-5, and 3-6 (for the reactor coolant pump (RCP) inlet nozzle) and Figures 3-7, 3-8, 3-9, 3-10 (for the RCP outlet nozzle).

Response

For the leak-before-break (LBB) evaluation in the report, stress distributions for both the minimum and maximum FSWOL and OWOL thicknesses were evaluated. The OWOL design with the minimum thickness produces the less conservative residual stress distribution for crack growth, so it is conservative to use for the crack growth analysis. Thus, the OWOL minimum weld overlay thicknesses were used for the stress distributions as shown in Figures 3-3, 3-4, 3-5, and 3-6 (for the RCP inlet nozzle) and Figures 3-7, 3-8, 3-9, 3-10 (for the RCP outlet nozzle).

Section 3.2 of the report has been updated and notes have been added to Figures 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9 and 3-10 for clarification.

2. The last paragraph on Page 3-2 states that an OWOL may still be applied to a dissimilar metal weld (DMW) which contains a flaw that has a depth of greater than 50 percent but less than 75 percent through-wall. The staff does not agree with applying an OWOL on a DMW with a pre-existing flaw that is greater than 50 percent through-wall. Discuss the basis for applying an OWOL on such a degraded DMW.

Response

If a flaw (embedded or inside-surface-connected) is identified during an inspection it will be characterized in accordance with the American Society of Mechanical Engineers (ASME) IWA-3300, "Flaw Characterization" and evaluated in accordance with the acceptance standards of ASME IWB-3500, "Acceptance Standards."

The following considerations will be applied to determine if an optimized weld overlay may be applied or if a full structural weld overlay must be utilized:

- Axial or circumferential flaws located entirely within the inner 50 percent of the original dissimilar metal weld wall thickness may be repaired with an OWOL.

- Axial flaws that do not extend into the outer 25 percent will be evaluated for repair with an OWOL.

- Axial flaws that extend into the outer 25 percent of the original dissimilar metal weld wall thickness must be repaired with an FSWOL.

- Circumferential flaws that extend into the outer 50 percent of the original dissimilar metal wall thickness must be repaired with an FSWOL.

Section 3.1 of the report has been updated accordingly.

3. The third paragraph on Page 3-3 discusses thermal boundary conditions (wet or dry) during weld overlay installation. Water backing effects (cooling during the weld overlay laydown) and weld overlay sequencing may affect the weld residual stress model results. Discuss whether water cooling and weld sequencing effects were analyzed, or if not, what was the justification for not considering the effects of these conditions on the modeled residual stresses? Discuss whether weld overlay installation at the RCP inlet and outlet nozzles will be performed when the inside of pipe will be dry or with water.

Response

For the optimized weld overlay locations (reactor coolant pump discharge nozzles), the same welding procedure is used with either water-backed or dry pipe conditions. For these locations, water-backed or dry pipe conditions are not critical inputs. Residual stress analyses, as discussed below, have determined that the optimized weld overlays can be performed either wet or dry.

Dry, empty pipe conditions provide less heat removal (heat sink) capacity than do wet, water-backed pipe conditions. The residual stress benefit produced by a weld overlay is greater in the inner portion of the component when the welding is performed while water backed. Therefore, the crack growth analysis assumes a dry, empty pipe condition since it results in a reduced (more conservative) and therefore, bounding residual stress benefit. Hence, with respect to this aspect, the actual optimized weld overlay can be performed either wet or dry without invalidating the current residual stress analysis.

Weld sequencing effects have been modeled in the analyses performed, to reflect the direction of welding.

FENOC will decide whether to weld wet or dry per their water management plan depending on the conditions at the plant during the outage when overlay welding is to be applied.

A note has been added to Table 3-1 to clarify the conservative thermal boundary condition (air-backed pipe) used.

4. The third paragraph on Page 3-8 states that "...As an alternative to the above requirements, for cases in which if current examination requirements are satisfied by inspecting the inner 1/3 of the original DMW from the inside diameter (ID) of the nozzle, the utility may continue to perform such examinations, in lieu of the WOL examinations specified above. In such cases, the outside diameter (OD) examination requirement is just the overlay itself, and is required only for the pre-service inspection performed after WOL application..." (a) It appears that if ultrasonic testing (UT) is performed from the ID and OD surfaces, the OD inspection will only inspect the weld overlay and not the base metal. The staff believes that the outer 50 percent of the base metal thickness should also be inspected by UT from the OD surface because the overall integrity of the pipe relies on both the OWOL and the outer 25 percent wall thickness of the base metal. The staff does not believe this requirement is included in the submitted weld overlay relief request. Clarify the above statement.

Response

FENOC presented the ID inspection discussion solely as background related to available inspection techniques. FENOC did not include this requirement in the submitted weld overlay relief requests and does not plan to perform any UT examinations from the ID surface.

The report has been updated by removing the paragraph in question on page 3-8 to reflect this response.

5. The first paragraph on Page 3-10 states that for a DMW containing a pre-existing flaw, the overlaid DMW shall be inspected once in the next 5 years. This is contrary to previously NRC approved relief requests which require that the overlaid DMW be inspected during either the first or second refueling outage after overlay installation. Assuming an operating cycle of 18 months, the overlaid DMW should be examined within 3 calendar years after weld overlay installation. Justify the 5-year inspection interval.

Response

Requests RR-A32 and RR-A33 stated that for pre-existing flaws, an in-service examination volume shall be ultrasonically examined once during the first or second refueling outage following the application of the overlay. For OWOL, examination volumes that show no indication of crack growth or new cracking shall be placed into a population to be examined once in a ten-year inspection interval. Whereas, for FSWOL, examination volumes that show no indication of crack growth or new cracking shall be placed into a population of full structural weld overlays to be examined on a

sample basis. Twenty-five (25) percent of this population shall be added to the ISI Program in accordance with ASME Section XI, IWB-2412(b).

Section 3.4 of the report has been updated accordingly.

6. Figure 3-11 showed the stress intensity factor vs. flaw depth for the RCP inlet after FSWOL installation. Figure 3-12 shows the stress intensity factor vs. flaw depth for the RCP outlet after OWOL installation. It appears that the OWOL installation provides more favorable stress intensity factor results than the FSWOL. Explain why the OWOL in Figure 3-12 shows more favorable stress intensity factor results than the FSWOL in Figure 3-11.

Response

The configurations and geometry of the components are different for the discharge and for the suction DMWs. The discharge nozzle contains a safe end which joins the RCP to the carbon steel elbow, and allows for a longer WOL which produces more favorable weld residual stresses and a more favorable stress intensity distribution. For this configuration, an OWOL was an effective crack growth mitigation measure. For the suction configuration, there is no joining safe end where the RCP is connected directly to the carbon steel elbow, and the length of the overlay was restricted by this geometry. Consequently, a FSWOL was required to be designed, rather than an OWOL. The configuration and geometry differences produce different WOL designs and different stress intensity results.

7. Table 3-1 presented the length of time for a postulated initial flaw size to grow to the design flaw size after weld overlay installation. For the RCP outlet nozzle, under the OWOL application, the postulated initial axial flaw of 50 percent through-wall of the pipe thickness will take more than 60 years to grow to the design flaw size. Based on the Davis-Besse relief request, the initial axial flaw should be 75 percent through-wall because the ultrasonic examination has not been qualified to examine outer 50 percent wall thickness of the base metal. The final flaw size for this case should be 100 percent through-wall.

(a) Clarify why the initial axial flaw size for RCP outlet nozzle under the OWOL design is assumed to be 50 percent through-wall.

Response

a. In the underlying crack growth calculation for the RCP outlet nozzle, under the OWOL application, an initial flaw of 75 percent of the original base material thickness was used and the flaw depth after 30 years was reported, which remained unchanged at 75 percent. Table 3-1 has been updated to include footnote (3) for the axial OWOL on the outlet nozzle.

(b) Confirm that the initial circumferential flaw under the OWOL design is 50 percent through-wall and the final flaw size is 75 percent through-wall.

Response

b. Yes, the initial circumferential flaw under the OWOL design is 50 percent through-wall and the final flaw size is 75 percent through-wall.

(c) Based on footnote No. 3 of Table 3-1, the initial circumferential flaw is assumed to be 75 percent through-wall. However, in the Davis Besse relief request, the initial circumferential flaw is assumed to be 50 percent through-wall. Clarify whether there is a discrepancy in the initial circumferential flaw size between the LBB license amendment and the overlay relief request.

Response

c. The initial circumferential flaw was assumed to be 50 percent through-wall in depth measured from the ID surface for the OWOL, 75 percent through-wall in depth measured from the ID surface for the FSWOL, and both are reported in Table 3-1.

Table 3-1 of the report has been updated.

8. The submittal used an axi-symmetric model to analyze residual stresses in the DMW and has been shown to produce conservative results at the ID, but not necessarily at the OD. The RCP discharge and suction nozzles are connected to an elbow. The elbow is a stress concentration location because of its configuration and the weld overlay will be installed on a portion of the elbow. Figures 3-1 and 3-2 included the elbow in the finite element model.

(a) Discuss the impact of the weld overlay on the residual stresses in the elbow.

Response

a. The location of the maximum stress concentration in an elbow is at the center of curvature of the elbow, midway between the ends. The weld overlay is installed on the end of the elbow, away from the location of the stress concentration. Moreover, the extent of the WOL on the adjacent elbow is only 3.5 inches, which is slightly larger than the nominal thickness of the elbow and less than $\frac{1}{2}\sqrt{Rt}$ of the elbow. Therefore, the WOL is not expected to significantly change the stress concentration at the elbow, nor are the resulting residual stresses expected to be any different than for welding on a nozzle-to-straight pipe configuration.

(b) Discuss any precautions taken in your welding procedures for the weld overlay installation on the elbow to minimize the potential for over-stress of the elbow.

Response

b. Weld overlays are applied uniformly over the outer surface of the component by applying individual weld beads circumferentially to form layers. The overall effect of each layer is to compress the outer surface of the substrate and to cause an oval circumference to become circular (any ovality present will be reduced with each layer deposited). The welding process is designed to produce efficient weld beads that minimize remelting and are controlled by both heat input and power ratio. Interpass temperature is controlled according to a qualified welding procedure. All of these controls have been developed by extensive testing and proven by operating experience. Such controls will minimize the potential for overstressing at elbow locations. As stated in the response to 8a above, the length of the overlay applied to the end of the elbow is limited. In addition, the rounding effect described above will also minimize any geometrical effect of the overlay. Both ends of the WOL are tapered and smoothly blended to the outer surface to facilitate a uniform transfer of loads between the elbow and the overlay. Thus stress concentration effects at the end of the elbow that may be due to overlay will be comparable to that expected at the end of the overlay on the straight pipe.

9. Figure 4-1 showed the crack paths assumed at four locations for the inlet and outlet nozzles.

(a) Discuss why a crack path was not assumed at the middle of the DMW in Figure 4-1.

Response

a. As discussed on page 4-1 of the report, the locations at both sides of the DMW weld are evaluated since the thickness of the DMW and the weld overlay might not be uniform. These two locations in the DMW are adequate to evaluate this range of thickness variation without assuming a separate location in the center of the weld. The weld locations adjacent to the DMW are adequate to evaluate the nozzle, safe end or elbow material at each side of the DMW.

(b) Confirm that for the crack in each path, the material properties of each individual component (i.e., cast austenitic stainless steel RCP nozzles, stainless steel safe end, Alloy 82/182 weld, and ferrite elbow) were used to calculate critical crack size and leak rates for each specific crack path.

Response

b. Using the two-material critical crack size methodology discussed in Appendix A of the report, the material properties of each of the individual materials along each path are considered in calculating critical crack size. As discussed in Section 6.2 of the report, the material properties of the individual materials along each path are used to develop

composite material properties accounting for the actual materials in the leak rate evaluation.

10. Section 4.2 stated that the RCP nozzle loads used in the current LBB evaluation were taken from the AREVA Engineering Information Record, 51-9094884-000, dated October 21, 2008. However, it appears that the RCP nozzle loads in the AREVA report do not include the impact of the weight of weld overlay (i.e., forces and moments generated by the weight of the weld overlay). If the weight of weld overlay is not included in the RCP nozzle loads in the current LBB evaluation, discuss the validity of the critical crack size, leakage crack size, and associated safety margins.

Response

The maximum weight of the weld overlay applied at the reactor coolant pump dissimilar metal weld is conservatively calculated as 0.45 kips. This weight is not significant when compared to the dead weight of 6.1 kips for the adjacent 90 degree elbow filled with water weighing another 1.47 kips. In comparison, the total weight of a typical reactor coolant pump, including motor, casing, pump, and reactor coolant, ranges between approximately 150 kips to 340 kips [1, 2]. Therefore, the added WOL weight is no more than 0.3 percent the weight of the reactor coolant pump. Hence, the effect of the additional weight due to the application of the WOL is negligible as a percentage of the existing weight.

The effect of the increased weight due to WOL material is to slightly increase the dead weight and seismic stresses. The effect of the increased dead weight and seismic stresses would be to slightly decrease the critical flaw size and to increase leakage (for a given flaw size). In light of the large margins demonstrated by the LBB evaluation in Tables 6-3 and 6-4 of the report, these effects would minimally affect the required LBB margins and consequently were not considered in the LBB evaluation.

References:

1. National Report of the Czech Republic under the Nuclear Safety Convention, Appendix 1, Reference No. 10366/2.0/2001.

2. Journal of Korean Nuclear Society, Vol. 1, No. 2, Page 107 (10 pgs.), Year 1969-01.

Section 4.2 of the report has been updated and a note has been added to Table 4-2 for clarification.

11. Section 4.3.3, page 4-3, discussed thermal embrittlement of cast austenitic stainless steel (CASS) material in the RCP nozzles.

(a) Discuss whether the saturated fracture toughness of the CASS was used in the current LBB evaluation.

Response

a. Yes, the saturated fracture toughness of the CASS material of the RCP nozzles was used in the current LBB evaluation in accordance with ASME Section XI Code Case N-481. The saturated fracture toughness is determined from actual material certified material test reports (CMTR). The lower bound fracture toughness of the worst Davis-Besse pump casing considering thermal embrittlement was selected. Using the material properties from the CMTRs, the saturation impact energy (CV_{sat}) used in determining the JR curve (J-Integral resistance curves for stable crack growth) and subsequently the fracture toughness of the CASS material is calculated using the procedure and correlations provided in NUREG/CP-0119. The material properties and CV_{sat} are listed in Table 4-6.

(b) Provide the saturated fracture toughness of the CASS nozzles used in the analysis.

Response

b. The bounding saturated fracture toughness of the CASS material of the RCP nozzles used in the analysis is 1429 in-lb/in^2 as shown in Table 4-6.

Section 4.3.3 of the report and the title of Table 4-6 have been changed to reflect this information.

12. Table 4-2 presented the pipe loads at the DMW. Axial shrinkage of the overlay can cause a tensile axial stress in the rest of the system when the weld overlay is in situ with the pipe system connected to the vessel and steam generator. This shrinkage should result in slightly different thermal stresses at the DMW than the original piping stress analysis. Discuss whether the shrinkage stresses were accounted for in the flaw stability calculation and in the leakage calculation.

Response

Shrinkage stresses were not considered in the evaluation because, typically, the additional loads due to axial shrinkage of a weld overlay are relatively small compared to the thermal expansion loads reported in the original piping stress analysis. Hence, the axial shrinkage stresses are not expected to significantly affect the flaw stability and leakage calculations.

As stated in the "Analyses and Verifications" section of DBNPS Relief Request RR-A32, "Shrinkage shall be measured during the overlay application. Shrinkage stresses arising from the weld overlays at other locations in the piping systems shall be

demonstrated to not have an adverse effect on the systems. Clearances of affected supports and restraints shall be checked after the overlay repair, and shall be reset within the design ranges as required."

Pre-installation weld shrinkage analyses were performed for the DBNPS RCP nozzles to determine the effects of axial shrinkage due to the design weld overlays on the reactor coolant piping system. After implementation of the weld overlays, the as-built shrinkage measurements will be compared to the results of the pre-installation analyses to ascertain whether or not the piping system has been significantly affected by the weld overlay process such that further stress analyses are required. The results of the pre-installation weld shrinkage show that the acceptable axial shrinkages due to the weld overlays are 0.25 inches and 0.14 inches for the suction and discharge lines, respectively.

The axial shrinkage due to the weld overlays on the large diameter RCP nozzle DMW welds are expected to be below the calculated acceptable axial shrinkages reported above. As an example, weld overlay shrinkage measurements were taken on an optimized weld overlay mockup for a 36-inch diameter pipe performed for the Electric Power Research Institute (EPRI) (1). The mockup consisted of a cast stainless steel pipe segment, welded to a 45 degree clad carbon steel elbow, via an Alloy 82/182 DMW. The two pipe segments had 37.4-inch outside diameters, with a 3.37-inch wall thickness. The weld overlay thickness was 0.7-inch with dimensions that approximate those of an OWOL for this size pipe.

The shrinkage measurements taken on the mockup are summarized in the following table which shows that the average axial shrinkage is 0.0025 inch. The average shrinkage is negligible for a pipe of this size and would not produce significant stresses or displacements in a typical PWR large diameter pipe system. Although, the dimensions of the mockup are not exactly the same as those in the current LBB evaluation, they are similar and the results of the mockup provide an illustration of the magnitude of the expected weld overlay axial shrinkage for the 34-inch diameter RCP nozzles.

Axial Shrinkage Measurements on EPRI 36" Diameter Overlay Mockup

Axial Shrinkage (inch)	
Location from Top Dead Center (Degrees)	**8th Layer**
45	-0.014
135	0.036
225	-0.065
315	0.053
Average Shrinkage	0.0025

Although an increase in tensile stresses due to axial weld shrinkage would reduce the critical flaw, it would in turn increase the leakage, resulting in a relatively small impact on the calculated LBB margins.

Reference:

1. Peter C. Riccardella, "Evaluation of Overlay Coverage Approaching 700 Square Inches Based on EPRI 36-inch Diameter Optimized Weld Overlay Mockup," October 2009.

Section 4.2 of the report has been updated and a note has been added to Table 4-2 for clarification.

13. Clarify whether residual stresses calculated in Section 3 of the report were used or were involved in the flaw stability and leakage calculations?

Response

Residual stresses calculated in Section 3 of the report were used to demonstrate that primary water stress corrosion cracking (PWSCC) crack growth would be mitigated in the crack growth analysis. For purposes of flaw stability and leakage calculations, these were not used since these stresses are localized in nature and are self-relieving in the cracked condition assumed for critical flaw and leakage evaluation. This is justified since all welds have residual stresses due to weld shrinkage and these have never been considered in performing LBB evaluations and there is no mention of them in SRP 3.6.3.

Section 4.2 of the report has been updated and a note has been added to Table 4-2 for clarification.

14. Section 4.3.2 discussed the J-T curve for ferritic materials. Section 4.3.3 discussed the lower bound J-T curve for CASS material.

(a) Explain which J-T curve (ferritic or CASS) was used in the flaw stability calculation.

Response

a. As discussed in Section 5.3 of the report, elastic-plastic fracture mechanics, both for the CASS and the ferritic material, was used to verify that Z-factors based on ASME Code Section XI Appendix C could be conservatively used. Evaluations were conducted for each material separately in flaw stability calculations using developed J-T curves.

(b) Discuss why the J-T curve for Alloy 52M overlay material or Alloy 82/182 DMW was not mentioned in Section 4.0 and it appears that they are not used in the flaw stability calculation.

Response

b. The Alloy 52M would be applied using the gas tungsten arc welding (GTAW) process. Hence, no J-T analysis needs to be calculated. For the Alloy 82/182 material, alternate sources of information were used for determination of Z-factors. Using this approach, the J-T curves were not specifically required for determination of critical flaw size. The Z-factors were then used in the model for the two-material cylinders discussed in Appendix A to determine critical flaw sizes for each of the locations.

Section 4.3.2 of the report has been updated for clarification.

15. The first paragraph on Page 5-3 stated that the larger Z-factor for the carbon steel material from the American Society of Mechanical Engineers (ASME) Code will be conservatively used in the critical flaw evaluation. Table 5-1 showed that the Z-factor for the carbon steel elbow is 1.82. Discuss whether 1.82 was used in the critical flaw evaluation for all the materials (i.e., nozzle, safe end, DMW, overlay, and elbow) in crack path 1, 2, 3, and 4 as shown in Table 5-2, because the Z factor of 1.82 is not applicable to nozzle, safe end and DMW, which are not made of carbon steel.

Response

As discussed in Section 5.2, the Z-factors were calculated separately for each material. The Z-factor for carbon steel was used only in the evaluation of the crack path through carbon steel material. For all other paths, the corresponding Z-factors for the materials in the path were used. For all evaluations, the methodology for application of the Z-factors is described in Appendix A of the report.

16. Table 5-2 showed the critical crack size.

(a) Confirm that the through-wall critical crack length in the circumference direction is assumed to be the same in the DMW as in the weld overlay.

Response

a. Based on the methodology for determining critical crack size in Appendix A of the report, the length (crack angle) of the crack in both the DMW and in the weld overlay is assumed to be the same for critical flaw sizing.

(b) Confirm that for the leak rate calculation, the crack size in the base metal and in the overlay is assumed to be the same (page B-7).

Response

b. For the leakage calculation, the methodology described in Section 6.1 and in Appendix B uses composite material properties to account for the base material and the overlay material, so a single crack size is also assumed for the leakage calculation.

(c) Discuss why there is not much difference in the critical crack size for the FSWOL and the OWOL design at RCP discharge nozzle.

Response

c. With regard to the small difference in the critical flaw sizes at the RCP discharge nozzle, there is little difference in thickness between the weld overlay thicknesses evaluated with the minimum and maximum thicknesses of the overlays being 0.84 inch and 1.33 inches, respectively (Table 4-1). Similarly, the base metal thickness is between 2.717 inches and 3.03 inches, being significantly greater than the weld overlay thickness. Since the weld overlay is much thinner than the base metal, the critical flaw size is not changed much by the overlay thickness, and a consistent change is seen from the thinnest to the thickest overlay, where the critical flaw length increases with increasing thickness of the weld overlay.

17. Page 2-2 shows the half critical crack sizes calculated for the base metal and weld metal in the original LBB evaluation. The original LBB evaluation showed that the critical crack sizes for the base metal and weld metal (without the weld overlay) are 20.36 inches (10.18" x 2) and 37.08 inches (18.54" x 2), respectively. The differences between these two critical crack sizes are substantial (20.36" vs. 37.08").

(a) Explain why the critical crack sizes calculated for the weld overlay as shown in Table 5-2 in the current LBB evaluation do not show the same large differences as in the original LBB calculation.

Response

a. In the original LBB evaluation, the large difference between the critical crack sizes of the base metal and the weld metal was due to the differences between the material properties of the base and weld metals. The flow stress of the base metal (RCP) is 43.24 ksi, while the flow stress of the weld metal is 55.04 ksi. In the current evaluation, the flow stress of the WOL material is 54.08 ksi and this WOL material is applied over both the carbon steel or stainless steel base materials and the DMW weld metal. The impact of the difference between the two materials is greatly reduced by the applied WOL material, leading to a smaller difference between critical flaw sizes in the current LBB evaluation.

(b) The increase in critical crack size from the original LBB evaluation (20.36" and 37.08") to the critical crack sizes after weld overlay installation as shown in Table

5-2 is substantial. For example, for the base metal case, the critical crack size increase is about 60 percent (from 20.36" to 50.24"). For the weld metal case, the critical crack size increase is about 35 percent (from 37.08" to 57.89"). It is expected that the critical crack size will be increased after the weld overlay installation. However, it appears that the percentage of critical crack size increase exceeded the percentage of wall thickness increase between the original pipe and the overlaid pipe. Discuss the contributors to the increase in critical crack size after the weld overlay installation.

Response

b. The critical crack size increases due to the application of the WOL. The WOL material has high toughness material and does not require use of a Z-factor, whereas the base/weld metals require use of the Z-factor. The weld overlay material also has a slightly higher flow stress, and is applied at a slightly larger radius than exists for the base materials. Thus, the increment of the critical crack size would not be expected to be linearly proportional to the increment of the thickness. As shown in Appendix A, the equations related to critical crack size calculation contain higher order terms of *t* (thickness) and treats the radius of the base metal and the weld overlay separately. Hence, the percent increase in critical crack size is higher than the percent increase in thickness.

18. Table 6-3 presented leak rates for a leakage flaw size equal to half of the critical flaw size. Explain why the leak rates for cracks in Paths 1 and 4 in Table 6-3 are much higher (as much as 7 times) than the leak rates in Paths 2 and 3, even though the critical crack sizes in Paths 1, 2, 3, and 4 are all about the same.

Response

Crack paths 2 and 3 are through cracks in the 82/182 weld material. For these crack paths, the adverse crack morphology (resulting in significantly less leak rate) associated with PWSCC cracking was assumed as described in Section 6.2 and Appendix B of the report. Therefore, the leak rates are much higher for crack paths 1 and 4 than crack paths 2 and 3.

19. Table 6-5 presented a comparison of the leakage flaw size for the 10 gallons per minute (gpm) leak rate between the original Babcock & Wilcox (B&W) LBB evaluation and the current LBB evaluation. However, the staff cannot find the same leakage flaw size under the current evaluation column in Table 6-5 among the leakage flaw sizes in Table 6-2 (which shows the leakage flaw size for 10 gpm leak rate) of the submittal. Explain where and how the leak rates in Table 6-5 were calculated or taken from.

Response

The purpose of Table 6-5 is to present a comparison between the leakage predictions in the original NRC-approved LBB evaluation and a calculation for the same pipe sizes and moment loadings using the pipe crack evaluation method (PICEP) and the methodology described in Section 6.2. These calculations did not include overlays. Section 6.4 provides the input and assumptions made in performing this comparison. As stated in Section 6.4, this comparison established that the leakage prediction methodology used for the current LBB evaluation was comparable to the LBB evaluation previously approved by the NRC.

Section 6.4 and the title of Table 6-5 have been revised for clarification.

20. The first sentence on Page A-3 stated that, optionally, the effect of internal pressure on the crack surface of both base material and weld overlay can be evaluated. Discuss whether internal pressure was applied to the crack surface of both base material and overlay in calculating the flaw stability.

Response

Although the model described in Appendix A of the report included the terms that could be used for evaluating crack face pressure, consistent with that presented in Appendix A-2, crack face pressure was not used in calculating flaw stability. This is consistent with the net-section collapse equations that are provided in SRP 3.6.3 and in Section XI, Appendix C of the ASME Code.

A note has been added to Table 4-2 for clarification.

21. Section B.3 discusses the effect of crack face pressure on leakage. Clarify whether crack face pressure was considered in the final leak rate results.

Response

Consistent with the critical flaw size calculations, crack face pressure was not applied to the crack face in determining the leakage results.

A note has been added to Table 4-2 for clarification.

22. Item 4.d of Section 6.2 states that: "Crack roughness is taken as 0.000197 inches for fatigue cracking in materials other than the Alloy 82/182 weld. There are no turning losses assumed for fatigue cracking." Section 6.2 did not mention roughness for primary water stress corrosion cracking (PWSCC) in the DMW. For the DMW, Item 5 of Section 6.2 indicates that the crack morphology properties for the PWSCC-susceptible Alloy 82/182 material were taken from Appendix B of the LBB evaluation. Item 5 of Section 6.2 states that "For the weld with Alloy 82/182 material, the adverse effects of PWSCC crack morphology will be considered for

the affected material as described in Appendix B; for other material, the crack morphology for fatigue cracking is used..." NRC staff believes that the fatigue crack morphology properties quoted in Item 4.d of Section 6.2 are significantly lower than the values reported in NUREG/CR-6004 and numerous prior Westinghouse LBB submittals. The lower roughness and number of turns used in the analysis will result in a shorter postulated leakage crack size, hence, the margin between critical crack length and leakage crack length would be overstated with respect to an analysis where one used the NUREG/CR-6004 values.

(a) Justify the use of the crack morphology parameters, e.g. roughness values and number of turns, used in the leak rate calculation.

Response

a. The crack morphology roughness of 0.000197 with no turns was the basis of the leakage calculations in the original NRC-approved LBB evaluation for the B&W plants, where fatigue cracking was assumed. The methodology used in the current evaluation, as presented in Section 6.4, demonstrated that the methodology with PICEP could produce results comparable to those presented in the previous evaluation.

As described in Section 6.2 Item 6, for the Alloy 82/182 materials that would be susceptible to PWSCC, it was conservatively assumed that the morphology associated with PWSCC crack propagation parallel to the long direction of the dendritic grains would be applicable. This data was obtained from the NRC-sponsored research reported in Reference 31 of the report, and is represented by

- Local roughness, inches = .000663778
- Global roughness, inches = .0044842
- Number of 90 degree turns per inch = 150.87
- Global flow path length to thickness ratio = 1.009
- Global plus local flow path length to thickness ratio = 1.243

(b) Discuss how the PWSCC and fatigue properties were combined to yield a single set of composite crack morphology parameters.

Response

b. The method of combining fatigue cracking and PWSCC cracking along the same leakage path is based on the fundamental fluid mechanics principles for evaluating pressure drop along a path, and is described in Appendix B of the report.

(c) Provide the roughness for PWSCC.

Response

c. The roughness for PWSCC is

- Local roughness, inches = .000663778
- Global roughness, inches = .0044842

The resulting roughness is also a function of the crack opening displacement as discussed in Appendix B of the report.

(d) Provide the average number of turns for a typical PWSCC crack.

Response

d. The average numbers of turns (reported as 90 degree turns only) for a typical PWSCC crack is 150.87. However, in the evaluations, the number of turns is modified based on the crack opening displacement as discussed in Appendix B of the report.

(e) Discuss how many 45 and 90-degree turns were modeled in a typical PWSCC crack.

Response

e. PICEP uses an equivalence relationship between 90 and 45 degree turns (as mentioned in Reference B-4 of the report) such that they can be used interchangeably using the relationship:

Number of 45 degree turns = (50/26) x Number of 90 degree turns

Using the methodology from Reference 31 as presented in Appendix B of the report, the actual roughness, number of turns and flow path length varies based on the ratio of the crack opening displacement to the global roughness. The number of 45 degree turns or 90 degree turns were determined to most nearly simulate the total path fluid flow resistance as described in Appendix B, B.3.1 Item 3 of the report.

23. Discuss whether there are laboratory experiments which have been performed to verify the accuracy of the analytical method that the licensee used (i.e., PICEP) to predict the leak rates from through-wall crack in the overlaid DMW. If no experiments were performed, justify the accuracy of the leak rate methodology and results.

Response

The use of PICEP is widely accepted for calculating leakage in through-wall cracked piping, and has been used in numerous LBB evaluations that have been approved by the NRC staff. For example,

- PICEP was used to perform the leakage analysis for a comprehensive evaluation for the Millstone Unit 2 surge line. The analysis was provided to the NRC and was accepted [1]. In the NRC evaluation, the NRC used PICEP with slightly different input [Reference 1, pages 9 and 13] and arrived at the same conclusions regarding LBB acceptance criteria as were provided in the utility submittal that included the SIA analysis.

- PICEP was used to perform leakage analysis for an evaluation of three relatively small diameter lines for Kewaunee. The NRC acknowledged SIA's use of PICEP for the leakage analysis [Reference 2, page 7]. The NRC then reconfirmed the leakage with their independent assumptions using PICEP [2, page 10]. The LBB evaluation, including consideration of other issues regarding restraint for small diameter lines and crack morphology, was approved.

Other similar projects have been conducted by SIA and approved by the NRC. In each case, the NRC tested the conclusions against their own assumptions that may have required different input to PICEP. Finally, the NRC approved the LBB applications in each of the cases.

References:

1. Letter R. B. Eaton (NRC) to R. P. Necci (Northeast Nuclear Energy Co.), "Staff Review of the Submittal by Northeast Nuclear Energy Company to Apply Leak-Before-Break Status to the Pressurizer Surge Line, Millstone Nuclear Power Station, Unit 2 (TAC No. MA4126), May 4, 1999.

2. Letter J. G. Lamb (NRC) to T. Couto (Kewaunee Nuclear Power Plant), "Kewaunee Nuclear Power Plant - Review Of Leak-Before-Break Evaluation For The Residual Heat Removal, Accumulator Injection Line, And Safety Injection System (TAC No. MB1301)," September 5, 2002.

In addition, PICEP was verified during early development by comparison to a large number of tests for leakage through cracks in EPRI Report NP-3395, "Calculation of Leak Rates through Cracks in Pipes and Tubes," December 1983. There have been no tests by industry or by the NRC to verify leakage rates through weld overlaid pipe or through PWSCC cracked piping. It's also recognized there may be uncertainties in the leakage calculations associated with LBB, thus a factor of 10 is applied between the calculated leakage rate and the leakage detection capability in nuclear plants applying LBB. By considering the adverse morphology proposed in Reference 31 of the report, and the methods described in Appendix B, the leakage rates so computed maintain a consistent certainty with the LBB evaluations that have been approved by the NRC in the past.

24. The leaking coolant flows from the inside surface of the pipe through the postulated PWSCC crack in the DMW and the postulated fatigue crack in the weld

overlay to the outside surface of the pipe. It is not clear how the final leak rate was calculated based on the leak rate in the PWSCC crack in the DMW and the leak rate in the fatigue crack in the weld overlay. The leak rate in the crack in the DMW should be slower than the leak rate in the fatigue crack in the base metal.

(a) Discuss how the leak rate in the DMW crack is combined with the leak rate in the weld overlay fatigue crack to derive a final leak rate.

Response

a. By the fundamentals governing conservation of mass, the flow rate in the DMW has to equal the flow rate in the weld overlay. This flow rate is calculated based on the total flow resistance along the leakage path.

(b) Discuss whether the crack opening displacement (COD) in the PWSCC crack is the same as in the fatigue crack. If the COD are not the same, discuss how the final COD is calculated.

Response

b. Since the leakage model must be based on a composite material model, the COD in the base material and the weld overlay is assumed to be the same.

25. Section B.3.1, Item 1 discusses fatigue cracks in a baseline PICEP run.

(a) Discuss whether PWSCC cracks in the DMW are also analyzed in the baseline PICEP run.

Response

a. The discussion in Section B.3.1 of the report shows how PICEP is used to evaluate the effects of crack face pressure (actually not used in the evaluation) and modified crack morphology. In the baseline PICEP run, crack morphology is not important. The purpose of the baseline run is to compute the crack opening displacement. Then, as discussed in Section B.3.1.3, fatigue/SCC morphology is calculated.

(b) Discuss why the baseline run produces 20 leakage calculations for increasing crack size.

Response

b. A series of 20 crack sizes are evaluated so that the relationship between crack size and crack opening displacement will be determined at closely spaced sample points for more accurate interpolation over a range that bounds the crack size of interest. PICEP has a limit of 20 crack sizes maximum between zero and a maximum crack size, so the maximum value is used.

26. Section B.3.1, Item 2 discusses the second set of computer runs which produces modified crack opening displacement as a function of crack size. parameters".

(a) The staff presumes that as crack size increases, crack opening displacement increases which in turn increases leak rate. Is this the correct observation?

Response

a. It is correct to assume that application of crack opening pressure will increase crack opening displacement, which in turn would increase the leakage for a given crack size.

(b) Item 2 states that the leakage flow rate for the original crack parameters for the increased crack opening is generated. Clarify what are "original crack parameters".

Response

b. Item 2 states that a second set of leakage calculations with morphology similar to the baseline run would be created. The original crack parameters would be the roughness and number of turns assumed in the first set of PICEP runs. But, the real purpose of the second set of runs is to obtain the crack opening displacement versus crack length relationship with crack face pressure.

As described in the previous question and response, crack face pressure was not used in this evaluation, so the results of the first and second set of runs would be the same.

The resulting crack opening displacement would be used in the third set of PICEP runs to calculate the modified morphology for each of the 20 crack sizes evaluated in the first two sets of PICEP runs.

27. Under normal operation conditions of the RCP piping, the leakage may occur in a two phase condition (i.e., a mixture of steam and water) at the exit. Clarify whether the two phase flow condition has been considered in the leak rate calculation as such. If a two-phase flow is assumed, discuss how the leak rate of steam is converted to gallons per minute.

Response

The leakage calculation in PICEP considers flashing to two-phase condition in the crack, such that a two-phase mixture will exist at the exit. In PICEP, the mass flow rate (for example lb/sec) is converted to a volumetric flow rate (gpm) and is output at volumetric conditions at 200°F.

The fluid that leaked from the pipe is collected in the sump and its temperature is generally 120°F. Hence, the amount of water collected at the sump has to be multiplied by the ratio of the density of the water at 120°F to the density of water at 200°F. Therefore, to obtain 10 gpm of leakage at the sump a leak rate of 10 x (density of water at 120°F/ density of water at 200°F) = 10 x (8.249/8.037) = 10.264 gpm or 2.64 percent more leakage from the crack in the pipe is required.

The calculated minimum leakage is 289.8 percent more than the required minimum detection rate of 10 gpm, as shown in Table 6-3. Compared to this margin, the difference in the minimum detectable leakage values due to different temperatures (only 2.64 percent) is small and can therefore be ignored.