**Response to**

**Request for Additional Information No. 265, Supplement 1**

**9/16/2009**

**U. S. EPR Standard Design Certification**
**AREVA NP Inc.**
**Docket No. 52-020**
**SRP Section: 03.06.03 - Leak-Before-Break Evaluation Procedures**
**Application Section: 03.06.03**

**QUESTIONS for Component Integrity, Performance, and Testing Branch 1 (AP1000/EPR Projects) (CIB1)**

**Question 03.06.03-20:**

Follow-up to RAI Question 03.06.03-3

During the 6/09/2009, audit, the staff reviewed information related to Dynamic Strain Aging (DSA) and recommendations regarding metallurgical and heat treatment specifications as well as improvements to production welding procedures for ferritic base metals that would minimize the concern for dynamic strain aging. AREVA is requested to formally submit this material so the staff can review the recommendations and AREVA's approach.

**Response to Question 03.06.03-20:**

The AREVA NP presentation material from the NRC audit related to impact of DSA on leak-before-break (LBB) analysis was formally submitted to the NRC on July 1, 2009 (reference Accession Number ML091900197). Additional information as requested by the NRC regarding DSA is provided in this response.

Based on Reference 1, DSA can be minimized in carbon steel by minimizing the amount of nitrogen and carbon dissolved in the ferrite, which depends on the steel grade, the deoxidation practice, and the heat treatment.

The steel grade controls the chemical composition of the material, which affects the final properties. One method of minimizing the amount of nitrogen and carbon in solution is to limit the amount in the heat of material. Carbon cannot be reduced without decreasing the strength of the material because it is the main hardening agent. However, SA-106 typically contains a small amount of strong carbide formers (i.e., chromium, vanadium and molybdenum), which remove some of the free carbon from solution, decreasing its role in strain aging. Nitrogen does not provide a significant benefit to the mechanical properties, so it should be held as low as reasonably achievable through modern steel making practices to minimize its role in strain aging (Reference 2).

Carbon steel is killed by adding deoxidizing agents such as silicon and aluminum, which form nitrides and remove nitrogen from the ferrite lattice. This deoxidation practice decreases nitrogen’s contribution to strain aging. Steels that are deoxidized with both aluminum and silicon are most resistant to dynamic strain aging (Reference 2). ASME SA-106 requires that the steel be killed with silicon. Based on Reference 2, the SA-106 Grade C piping will be killed with 0.15-0.25 wt percent silicon and 0.03-0.08 wt percent aluminum. This will reduce the susceptibility to strain aging while not significantly affecting the mechanical properties.

The strain aging response of carbon steel is also a function of heat treatment. For the SA-106 Grade C carbon steel to meet the minimum mechanical property requirements of the MSL piping, it must be quenched and tempered. The rapid cooling during the quenching process traps carbon and nitrogen interstitials in sites too small for the size of these atoms, straining the crystal lattice. At operating temperatures, these interstitial atoms may segregate to dislocations and impede their movement, which contributes to DSA. Tempering causes carbon atoms to form carbide precipitates, which, unlike carbon interstitials, do not increase DSA susceptibility. Tempering temperature has a larger role in carbide precipitation compared to time. The same is true for the stress relief heat treatment because the stress relief temperature is the same as the tempering temperature. As stated in Reference 1, the lowest susceptibility will be associated with treatments that provide precipitation of nitrides and carbides, namely, extended treatment near 600°C (1110°F) followed by slow cooling.

The impact of the welding process on the DSA susceptibility of the base metal was also considered. DSA susceptibility could potentially be increased if a sharp notch near the weld was formed due to a fabrication defect. This is not a concern because such a defect would be found and removed during required post weld inspection. The adverse impact of the welding process on the DSA susceptibility of the base metal is the creation of residual stress in the weld heat affect zone. These stresses will be removed during the post fabrication stress relief heat treatment or the post weld heat treatment. The welding process will not adversely impact base metal DSA susceptibility.

Additionally, the following actions will further minimize the potential for DSA:

- The composition of SA-106 Grade C that will be used for the U.S. EPR MSL piping to reduce the susceptibility to dynamic strain aging is:

  Si: 0.15-0.25 percent.
  Al: 0.03-0.08 percent.
  N: As low as reasonably achievable.

  This composition will decrease the total amount of nitrogen in the material and minimize the amount of free nitrogen by encouraging the formation of nitrides.

- The SA-106 Grade C heat treatment that will be used for the U.S. EPR (MSL) piping is:

  | | |
  |---|---|
  | Heat Treatment: | 1600-1650°F held for two to three hours and water quenched. |
  | Temper: | 1100-1150°F held for four hours and air cooled. |
  | Stress Relief: | 1100-1150°F held for 30 hours and furnace cool to 600°F. |

  This heat treatment is consistent with the recommendations for minimizing susceptibility to DSA in Reference 1 and is also consistent with heat treatment of SA-106 Grade C pipe in service at operating nuclear facilities.

**References for Question 03.06.03-20:**

1. Marschall, C. W., et al., “Effect of Dynamic Strain Aging on Fracture Resistance of Carbon Steels Operating at Light-Water Reactor Temperatures,” Fracture Mechanics: Twenty-First Symposium, ASTM STP 1074, J. P. Gudas, J. A. Joyce, and E. M. Hackett, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 339-360.
2. Leslie, W. C., et al., “Influence of Aluminum and Silicon Deoxidation on the Strain Aging of Low-Carbon Steels,” Transactions AIME, Journal of Metals, Aug. 1953, pp. 1021-1031.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 03.06.03-21:**

Follow-up to RAI Question 03.06.03-6

RAI Question 03.06.03-6 requested AREVA to provide details for the J-R curves used for ALL the calculations as none were provided in the original FSAR. AREVA provided the requested information during an audit conducted on June 26, 2008. The information presented to the staff during the audit indicated that for SST pipe and welds the toughness was reduced by 30% to account for thermal aging. In the formal response to RAI Question 03.06.03-6, dated 9/18/2008, AREVA indicated that the reduction in toughness was to account for heat to heat variations. The staff requests AREVA to provide the justification and the basis for the 30% reduction.

**Response to Question 03.06.03-21:**

As noted in the Response to RAI 48, Question 03.06.03-6, the material constants for the main coolant loop (MCL) stainless steel base metal were reduced by 30 percent to account [ ]. There is no reduction to account for thermal aging of the stainless steel base metal.

The basis for the 30 percent reduction of the stainless steel weld material as a result of thermal aging concerns is provided in this response.

AREVA NP has reviewed the parameters that primarily affect thermal aging of austenitic stainless steels and identified the applicable data for aging of austenitic stainless steel welds. One set of data found in Reference 1 shows lower bound properties in comparison to the parameters used in the U.S. EPR welds. The material, welding process, aging time, and temperature for this set of data are similar or more conservative than the parameters used for the U.S. EPR. The welding process for the data in Reference 1 is unknown, but it is assumed to be the gas tungsten arc weld (GTAW) based on the retention of toughness after extensive aging. Welds made by the GTAW process demonstrate higher toughness than gas metal arc welding (GMAW), submerged arc welding (SAW), and shielded metal arc welding (SMAW) aged welds because the ferrite phase can withstand sizeable deformation prior to fracture, increasing the toughness value in comparison to SMAW or SAW. The material for the data set in Reference 1 is 16-8-2, which is a similar weld material to 316 stainless steel weld material. The data for this set was aged for 100,000 hours at 900°F, which is an order of magnitude greater than the typical aging times from Reference 1. [ ]. Because of its greater aging time and temperature, the data set from Reference 1 is a lower bound toughness data set for 316 GTAW/TIG welds. Four sets of public data (Reference 1 through Reference 4) fall below the data in Reference 1 (16-8-2 material aged for 100,000 hours at 900°F) as shown in Figure 03.06.03-21-1.

Table 03.06.03-21-1 categorizes the four sets of data from Reference 1 through Reference 4. These four sets of data include at least one of the five groupings (size of test specimen, welding process type, amount of delta ferrite present in the welding material, aging temperature, length of aging) that is different from the desired properties [ ]. The four J-R curves from

Reference 1 through Reference 4, shown in Table 03.06.03-21-1, are bounded by Huang's 16-8-2 data set, as shown in Figure 03.06.03-21-1.

The use of J evaluated at a crack extension length of 0.008 in (0.2 mm) is not the most effective way to predict the effect of thermal aging on fracture toughness values for stainless steel welds. Using dJ/da alone can not realistically determine the average percent reduction for aged materials. Combining both $J_{0.2}$ (or $J_{IC}$) and dJ/da to construct a J-R curve beyond the 0.008 in (0.2 mm) crack extension by assuming a two-straight line model provides a more reasonable average percent reduction. From this model, a J value can be obtained at a given crack extension and the percent reduction of fracture toughness at a certain crack extension can be obtained by ratioing aged J versus unaged J. Huang's data was not used in this evaluation because of its unknown welding type. The data from Reference 2 through Reference 5 and the

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This value has been rounded to 30 percent to be conservative and provides the basis for the reduction due to thermal aging for stainless steel welding materials used for the U.S. EPR.

**References for Question 03.06.03-21:**

1. F. H. Huang, DOE Document No. WHC-SD-FF-TRP-019, Rev. 0, "Effect of Long Term Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals," September 27, 1995.
2. W. J. Mills, "Fracture Toughness of Aged Stainless Steel Primary Piping and Reactor Vessel Materials," Transactions of the ASME, Volume 198, November 1987.
3. G. E. Hale and S. J. Garwood, "Effect of Aging on Fracture Behavior of Cast Stainless Steel and Weldments," Materials Science and Technology, Volume 6, 1990.
4. P. Ould, P. Balladon, Y. Meyzaud, "Fracture Toughness Properties of Austenitic Stainless Steel Welds," International Seminar on Stainless Steels, Task Group for the Study of Steels, Technical Faculty of MONS, April 27-28, 1988.
5. F. Faure, P. Ould, and P. Balladon, "Effect of Long Term Aging on the Mechanical Properties of Stainless Steel Welds in PWR," Trends in Welding Research, Gatlinburg, TN, 1992.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

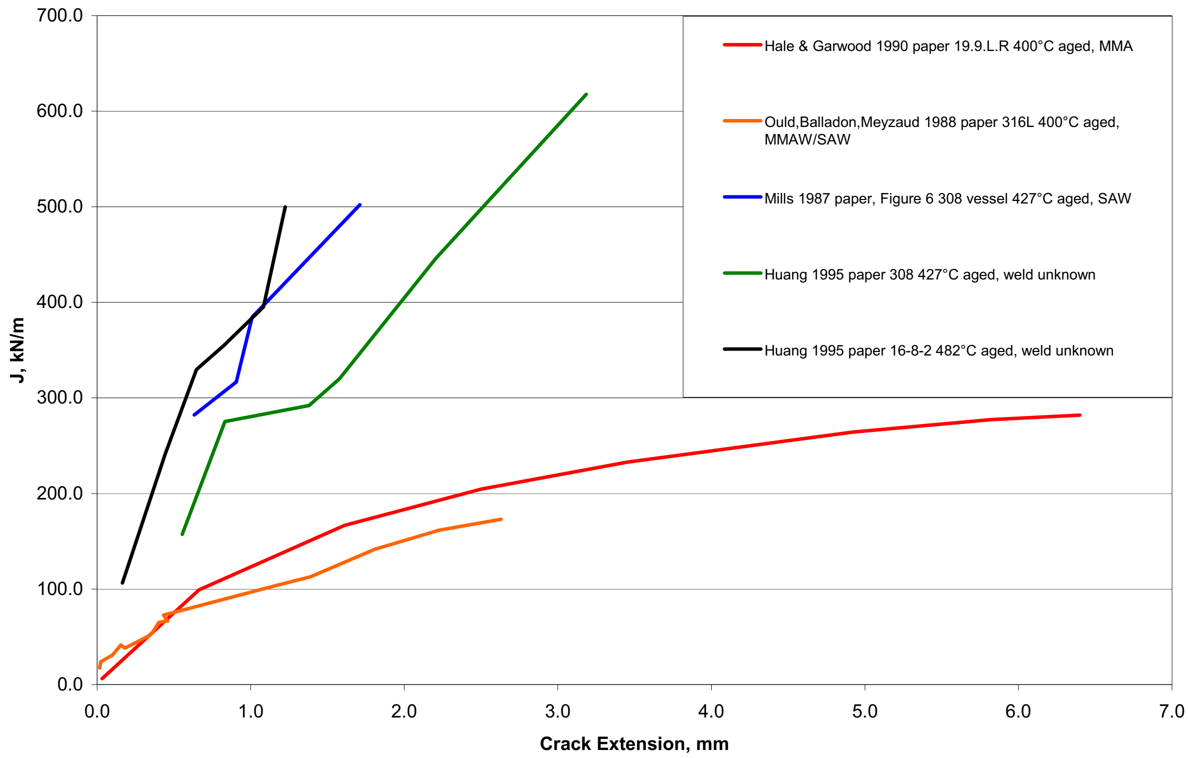
### Table 03.06.03-21-1—Categorization of J-R Data

| Source | Weld | δ Ferrite % | Metal | Aging Conditions | $J_{0.2}$ (kN/m) @ 300°C (572°F) | % Reduction in $J_{0.2}$ | Specimen Size |
|---|---|---|---|---|---|---|---|
| Reference 2 | SAW | 10 | 308 | 10000 hours at 800°F | 269 | 0 | 0.3T (0.3 in) |
| Reference 1 | unknown | unknown | 308 | 100000 hours at 800°F | 103 | 34 | 1T (1 in) |
| Reference 3 | MMA | 5-9 | 19.9.L.R | 10000 hours at 752°F | 28 | 56 | 0.8T (0.79 in) |
| Reference 4 | MMAW/SAW | 7.5 | 316L | 10000 hours at 752°F | 44.45 | unknown | unknown |

### Table 03.06.03-21-2—Average Percent Reduction of Toughness Calculation

| Source | Percent Reduction at $J_{0.2}$ | Percent Reduction at $J_{0.5}$ | Percent Reduction at $J_1$ | Percent Reduction at $J_{1.5}$ | Percent Reduction at $J_2$ | Percent Reduction at $J_{2.5}$ | Percent Reduction at $J_3$ | Average percent Reduction |
|---|---|---|---|---|---|---|---|---|
| OL3 GTAW data | | | | | | | | |
| Reference 2 | | | | | | | | |
| Reference 3 | | | | | | | | |
| Reference 4 | | | | | | | | |
| Reference 5 | | | | | | | | |
| | | | | | | | | |
| Total average | | | | | | | | |

**Figure 03.06.03-21-1—J-R for Aged Stainless Steel Welds**



**Question 03.06.03-22:**

Follow-up to RAI Question 03.06.03-10

In RAI 03.06.03-10 AREVA was requested to justify the use of the crack morphology parameters used in the leakage calculations. During the 06/09/2009 audit, AREVA provided a comparison of the data between KRACKFLO (AREVA) and SQUIRT (NRC) sorfware.

1. AREVA stated in order to get similar results with SQUIRT, they use a penalty factor of 26 in KRACKFLO (and an improved crack morphology option with SQUIRT). Please provide the basis for using these criteria.

2. Additionally, the following factors need to be accounted for by AREVA that could affect the ALL diagram:

   a. Compare crack length for the leakage limits between KRACKFLO and SQUIRT with and without the improved COD-dependant crack morphology.

   b. Examine and validate the effect of tensile stress-strain curve on crack-driving force J-applied to assess, leak versus moment curves as well as J applied for flaw stability analysis.

   c. Effect of J-R material property data being too low. While using a low J-R curve is conservative, the values to fit the J-R curve seemed to result in an unusually low curve and may need to be confirmed.

   d. As was discussed in the audit of June 9, 2009, air fatigue morphology is the least conservative assumption for leak-rate calculations. If an SCC or corrosion morphology is assumed in the calculations (as a lower bound conservative case) each of the ALL diagrams will change. AREVA is requested to provide justification for using air fatigue or provide an analysis using a corrosion fatigue and SCC for comparison. AREVA may want to include in their discussion that SCC can be eliminated for the leak-rate analysis if AREVA's recommended welding procedures (when implemented) **will** produce compressive residual stresses on the ID surface.

**Response to Question 03.06.03-22:**

1. See the Response to Question 03.06.03-25.

2a. The moment versus leakage crack lengths for SQUIRT with improved COD dependant crack morphology and KRAKFLO at five gpm are provided in Attachment 1, Figure 1. The leakage results of the two codes are in agreement with each other. The SQUIRT Code was subsequently rerun to determine the moment versus leakage crack lengths without the improved COD-dependant crack morphology as shown in Attachment 1, Figure 2. The difference in crack length between these two options is that the leakage crack sizes for the SQUIRT Code without COD-dependant crack morphology is as much as an inch bigger in crack size.

2b. As discussed in the Response to Question 03.06.03-26, AREVA NP performed a finite element analysis (FEA) (see Attachment 2). The results of this FEA produced equivalent stress-strain material properties that represent the dissimilar metal weld behavior at the critical fusion line of the DMW. The equivalent material properties are used to develop the leakage crack length versus moment curves and the crack driving force J-applied for the flaw stability analysis (Attachment 3).

2c. The FEA analysis in Attachment 2 addresses the seven C-T specimens used to determine the fusion line toughness through J-R testing. The results from one of these specimens yielded the lower bound fusion line toughness curve that is used in the flaw stability analysis provided in Attachment 3.

2d. The Response to RAI 48, Supplement 1, Question 03.06.03-10 justifies the use of air fatigue in the U.S EPR leak-before-break (LBB) methodology. Because of the NRC's concern that this is the least conservative assumption for leak-rate calculations, additional actions discussed in the Response to Question 03.06.03-23 are being taken to demonstrate that the piping where LBB is being applied is not susceptible to primary water stress corrosion cracking (PWSCC). Based on the Response to RAI 48, Supplement 1, Question 03.06.03-10 and the Response to Question 03.06.03-23, stress corrosion cracking (SCC) is eliminated from consideration in leak-rate analysis of dissimilar metal welds in the U.S. EPR main coolant loop piping and surge line piping.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 03.06.03-23:**

Follow-up to RAI Question 03.06.03-13

In response to RAI 03.06.03-13, AREVA referenced EPRI Report 1009801, "Materials Reliability Program (MRP), Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 152, 52 in Pressurized Water Reactors (MRP-111), Electric Power Research Institute, March 2004, which contained controls for welding dilution effects and chromium content. Please provide the data contained in the EPRI Report for review and clarification of dilution effects and chromium content in nickel based welds.

**Response to Question 03.06.03-23:**

AREVA NP's Response to RAI 48, Supplement 1, Question 03.06.03-13 referred to EPRI Report 1009801 to support the statement that "Alloy 52 has been demonstrated to be more resistant to PWSCC initiation than Alloy 600/82/182 through both laboratory testing and operating experience." There was no reference to EPRI Report 1009801 regarding controls for welding dilution effects and chromium content. AREVA NP recognizes that the referenced EPRI report contains a section titled "Gaps in the Test Data," which states that there is some apparent information gaps in the study of the corrosion behavior of Alloy 690 and its weld metals for pressurized water reactor (PWR) service. This response discusses which weld practices will be used to demonstrate that primary water stress corrosion cracking (PWSCC) is not a concern due to chromium content, dilution effects, cleaning methods, weld qualifications, and environmental effects on crack growth in Alloy 690. Similar information was determined acceptable by the NRC regarding pipe material grades and weld alloys being resistant to PWSCC as stated in Reference 1.

Limiting the amount of carbon and welding heat input reduces susceptibility of stainless steel weld material in PWR coolant to PWSCC. The stainless steel materials, including the welds, have not shown susceptibility to PWSCC in a PWR primary water environment. The only material in existing PWR plants that is susceptible to PWSCC is Alloy 600 and its compatible weld filler metals, Alloy 82/182.

These materials are not found in the dissimilar metal welds joining the ferritic nozzles to the stainless steel piping or safe-ends for the U.S. EPR. For Alloy 182, the Cr content can be as low as 14 percent. This is below the accepted threshold for high resistance to PWSCC (24 percent Cr). Alloy filler metals 52, 52M, and 152 contain nominally 30 percent Cr, which is above the accepted threshold that has been qualified by testing as being highly resistant to PWSCC. This qualification is documented in MRP-139 (Reference 2), where PWSCC resistant materials are identified as including high nickel materials and resistant welding materials, including Alloy 52/52M for gas tungsten arc welding (GTAW) and Alloy 152 for shielded metal arc welding (SMAW), having nominally 30 percent chromium.

To verify that PWSCC will not be a concern for the dissimilar metal welds, the following weld practices will be used:

- The weld material will be procured to an ASME specification, which requires that the material meet the requirements for ERNiCrFe-7 (Alloy 52), ERNiCrFe-7A (Alloy 52M) or ENiCrFe-7 (Alloy 152) or equivalents. The composition of each lot of weld filler metal will be certified by the manufacturer to meet the ASME chemical requirements for those weld filler materials.

- Dissimilar metal welds joining austenitic stainless steel pipe to ferritic steel nozzles will be qualified to establish that the filler materials and welding procedure will produce a chromium level in the initial layers adjacent to the dissimilar metals to a level equal to or greater than 24 percent Cr. This requirement will be validated by a representative mockup, welding procedure qualification test, or both. For machine GTAW, an effective power ratio range (as defined by ASME Section IX) will be established to control weld dilution and provide quality weld deposits. SMAW may be controlled by heat input limits only.
- As required by ASME Code Section IX, weld qualification tests and procedure qualifications will be performed, as required, to verify that the procedure is capable of producing welds that meet the required mechanical and chemical properties for the material specifications. The field welds will be designed to meet these requirements.

To further demonstrate that PWSCC is not a concern for leak-before-break (LBB) candidate piping, the inservice inspection (ISI) program will consider the operating experience of the materials used in the U.S. EPR piping systems qualified for LBB. The U.S. EPR inspection program will be consistent with the inspection program adopted for operating PWRs that use Alloy 690, 52, and 152 in approved LBB applications. U.S. EPR FSAR Tier 2, Table 1.8-2 and U.S. EPR FSAR Tier 2, Section 3.6.3 will be revised to add a new COL information item for a COL applicant that references the U.S. EPR design certification to evaluate and implement ASME Code cases that are developed and approved for augmented inspections of Alloy 690/152/52 material to address PWSCC concerns. As noted in Reference 3, Section 3.6.4, a new requirement was added for licensees to augment their ISI program to use ASME Code Case N-722 for ISI of Alloy 600/182/82 materials to address PWSCC concerns. However, the U.S. EPR design does not utilize Alloy 600/182/82 material. The NRC also noted that the final rule to amend 10 CFR 50.55a (73 FR 52730) issued on September 10, 2008, did not impose any additional requirements for augmented ISI of Alloy 690/152/52 materials. As noted in Reference 3, the NRC determined that the COL information item is consistent with current industry practice and NRC regulations as amended in 10 CFR 50.55a and is acceptable.

Corrosion tests were also performed on the area of dissimilar metal welds in contact with primary water (i.e., the contact between Alloy 52 weld metal and austenitic stainless steels of the nozzle cladding and of the forging, in a representative configuration of dilution). These tests did not show any specific sensitive behavior (i.e., no cracking was observed) of the Alloy 52 weld metal diluted on stainless steel or of the fusion line between Alloy 52 weld metal and stainless steel.

The effect of dilution on the chromium content of the Alloy 52/152 weld metal was investigated by AREVA NP with specific dissimilar metal weld specimens (i.e., composite specimens), including a crack starter in Alloy 182, welded on Alloy 690. With this type of specimen, PWSCC cracks could be initiated in low chromium area of the specimen in Alloy 182. These cracks propagate towards the area where Alloy 182 is enriched in chromium by dilution on Alloy 690 base metal and were shown to arrest in this area, before reaching the fusion line. Measurements by microprobe at arrested crack tips showed that crack arrest took place for a chromium level lower or equal to 23 percent. This type of experiment was the basis for the definition of a criterion on chromium content, to prevent crack propagation, set at 24 percent minimum in the weld metal.

Chemical measurements performed on different representative mockups of narrow gap dissimilar metal welds representative of the U.S. EPR dissimilar metal welds, show that this minimum level of chromium is exceeded (typically achieved values higher than or equal to 26 percent).

**References;**

1. US-APWR DC RAI 485 CIB1 3825, SRP Section: 03.06.03 - Leak-Before-Break Evaluation Procedures, Question 03.06.03-18 (Accession Number ML093140772).
2. MRP-139, Revision 1, Material Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guideline, Electric Power Research Institute, December 2008.
3. BLN SER Chapter 3, "3.0 Design of Structures, Components, Equipment and Systems." (Accession Number ML083440181).

**FSAR Impact:**

U.S. EPR FSAR Tier 2, Table 1.8-2 and Section 3.6.3 will be revised as described in the response and indicated on the enclosed markup.

**Question 03.06.03-25:**

During the NRC/AREVA audit on 06/09/2009, there was much discussion between AREVA and the NRC staff concerning the comparison data between KRACKFLO(AREVA) and SQUIRT(NRC). AREVA stated that in order to get similar results with SQUIRT, it uses a "penalty factor" of 26 for KRACKFLO and an improved crack morphology option for SQUIRT. AREVA is requested to provide the basis for their penalty factor of 26 in KRACKFLO to compare their results to SQUIRT results using the improved crack morphology option. Please identify what variable/variables are modified by the penalty factor in their leak rate analysis.

**Response to Question 03.06.03-25:**

During the NRC audit on June 9, 2009, AREVA NP presented results of the applied moment versus leakage crack length curves at three locations in the surge line, considering air-fatigue morphology (applying number of turns/inch as reported in Reference 1) using three different leakage codes (i.e., KRAKFLO, PICEP and SQUIRT). As a clarification, AREVA NP did not state that in order to get similar results with SQUIRT, AREVA NP used a “penalty factor” of 26 for KRAKFLO. Rather, as a result of this study, AREVA NP observed that the three leak rate codes are in good agreement with one another. Based on this study, SQUIRT agrees with PICEP and KRAKFLO [ ] as was done in this study.

The computer code KRAKFLO has been benchmarked to various types of crack morphology, including intergranular stress corrosion cracking (IGSCC) data that is empirically based. The penalty factor used in the KRAKFLO code has been embedded into the computer code since the code was developed. A penalty factor of 26 is applied as an additional [ ] to the number of [ ] the user specifies for a given crack morphology (typically KRAKFLO recommends number of turns/inch only for tortuous cracks such as primary water stress corrosion cracking (PWSCC) and IGSCC type of cracks). During KRAKFLO’s benchmarking of Collier’s IGSCC Phase II data reported in Reference 2, the KRAKFLO leakage predictions agrees with Collier’s IGSCC data only when an additional [ ] to the KRAKFLO user recommended value of [ ] when considering PWSCC/IGSCC crack morphology. In KRAKFLO, the flow path length [ ] is defined as:

[ ]

Where:

[ ]

**References;**

1. NUREG/CR-6300, “Refinement and Evaluation of Crack-Opening-Area Analyses for Circumferential Through-Wall Cracks in Pipes,” U.S. Nuclear Regulatory Commission, April 1995.
2. EPRI NP-3395, “Calculation of Leak Rates in Pipes and Tubes, “Electric Power Research Institute, 1983.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

**Question 03.06.03-26:**

During the audit on 06/09/2009 between the NRC and AREVA, AREVA stated that the material properties of ASME SA-106 was being used to obtain the moment vs. crack length curves for the surge line in the EPR design. However, the material that is to be used for construction is identified as ASME SA-508. In the staff's confirmatory analysis, the stress-strain curves for ASME SA-508 were higher, which would result in a greater amount of constraint of the plasticity. This was confirmed by the staff's Finite Element analysis. AREVA is requested to:

a. Verify that ASME SA-508 is the material to be used in construction for the nozzles and specify which grade or class of SA-508.

b. Provide a confirmatory analysis on ASME SA-508 and justify that ASME SA-106 is more conservative.

c. Perform a Finite Element analysis between the two materials much like what the staff has performed and discussed during the 06/09/2009 audit.

**Response to Question 03.06.03-26:**

a As noted in U.S EPR FSAR Tier 2, Table 5.2-2, ASME SA-508 Grade 3, Class 2 is the material used for the pressurizer surge nozzle. Prior to the June 9, 2009 audit between the NRC and AREVA NP, AREVA NP was utilizing material properties of ASME SA-106, Grade C for leak-before-break (LBB) analysis of the low alloy pressurizer surge nozzle of the U.S. EPR, even though the actual material for this component is SA-508 Grade 3, Class 2. This is because the stress-strain and J-R data for SA-508 Grade 3, Class 2 is not available. Instead, the material properties for SA -106, Grade C were used because it was representative and conservative compared to the use of actual low alloy steel material properties.

b. Since the June 9, 2009 audit, AREVA NP has obtained the material data for low alloy steel material. SA-508 Grade 3, Class 3 (which is currently classified by ASME Code as SA 508 Grade 3 Class 1) is considered more comparable to the actual SA-508 Grade 3, Class 2 material. As a result, the LBB analysis of the surge line was performed using these sets of material properties. The results of this reevaluation are discussed in the Response to Question 03.06.03-22. Because of this reanalysis, the justification for SA-106 is no longer needed.

c. A finite element analysis (FEA) has been performed and is provided in Attachment 2. As discussed in Item b, a separate FEA using SA-106, Grade C material properties is not required.

**FSAR Impact:**

The U.S. EPR FSAR will not be changed as a result of this question.

# Attachments for RAI 265, Supplement 1

## Attachment 1
## Leak-Before-Break (LBB) Leakage Flaw Size Calculation for U.S. EPR Surge Line (SL)

This report calculates the 5-gpm leakage flaw size for the U.S. EPR SL at the dissimilar metal weld (DMW) fusion line location. This is the second phase of the LBB analysis, which consists of three phases:

1. Equivalent material property determination using elastic-plastic fracture mechanics (EPFM) finite element analysis (FEA) (see Attachment 2).
2. Leakage flaw size calculation.
3. Flaw stability analysis (See Attachment 3).

The calculated leakage flaw size will be used to perform the flaw stability analysis in Attachment 3. The analysis has been performed using the input parameters for geometry, material, and crack morphology. The nominal pressure and temperature for the pressurizer (PZR) are 2235 psig (2250 psia) and 653°F, respectively. The leakage flaw size calculation was performed using both KRAKFLO and SQUIRT.

### I. Leakage Flaw Size Calculation Parameters

<u>Geometry Inputs</u>

Attachment 2, Figure 4 provides a schematic of the PZR nozzle (SA-508 Grade 3 Class 2 material) and the location where the dimensions in the analysis are taken. The dimensions at the DMW fusion line used in this analysis are listed in Table 1. For conservatism in the leakage crack size predictions, the leak rate analysis considers the wall thickness value of [ ] inches, which includes the clad thickness.

<u>Equivalent Material Properties at DMW Fusion Line</u>

The equivalent material properties at DMW fusion line regarding the evaluation of the DM joint are discussed in Attachment 2. The equivalent Ramberg-Osgood material properties are listed in Table 2.

<u>Crack Morphology Parameters</u>

Although the leak rate is primarily determined by the crack opening area (COA), it is also influenced by the crack morphology parameters. The primary crack morphology parameters are surface roughness, number of turns in the leakage path, and entrance loss coefficients. The air-fatigue crack morphology parameters for carbon steel are obtained from NUREG/CR-6004 (Reference 1) and listed in Table 3. The roughness is obtained from Hitachi tests of fatigue in air for ferritic steels. The path deviation corrections, which are needed by SQUIRT, are obtained from an average of six samples for corrosion fatigue in feedwater lines because the path deviation corrections are not available for fatigue in air.

<u>Input Parameters for KRAKFLO and SQUIRT</u>

Table 4 lists the input parameters for KRAKFLO and SQUIRT.

## II. Results and Discussions

The 5-gpm leakage flaw sizes are calculated using KRAKFLO and SQUIRT for various bending moments. KRAKFLO incorporates the number of turns differently than SQUIRT. KRAKFLO does not consider the effect of local roughness and path deviation factor. The SQUIRT run uses the improved COD-dependent model for crack morphology parameters, which predicts more realistic leak rates than the SQUIRT run without using the improved COD-dependent model for crack morphology parameters (see Reference 1). Figure 1 shows the 5-gpm leakage flaw sizes calculated by KRAKFLO and SQUIRT. As shown in Figure 1, the leakage flaw sizes predicted by the two leak rate codes are similar.

SQUIRT with and without COD-Dependant Model

For comparison, Figure 2 shows a separate SQUIRT run without activating the option for the improved COD-dependent model for crack morphology parameters. Figure 2 shows that the leakage flaw size is larger when the improved COD-dependent model is not activated for crack morphology parameters. The improved COD-dependent model decreases the effect of turns when the COD is large and decreases the effect of global roughness by using a combination of the global and local roughness when the COD is small, which results in higher leak rate and shorter leakage flaw sizes.

## III. References

1. NUREG/CR-6004, “Probabilistic Pipe Fracture Evaluations for Leak-Rate-Detection Applications.” U.S. Nuclear Regulatory Commission, April 1995.

**Table 1—Geometry Parameters**

| Parameter | Value |
|---|---|
| | |

**Table 2—Equivalent Material Properties**

| Material Property | Value |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |
| | |

**Table 3—Crack Morphology Parameters for Carbon Steel Fatigue**

| Parameter | Value | Reference |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**Table 4—Input Parameters for Leakage Flaw Size Determination**

| Parameter | KRAKFLO | SQUIRT |
|---|---|---|

[ ]

Notes:

1) This assumes that one 90-degree turn is equivalent to two 45-degree turns. Total number of 45-degree turns implies the number of turns through the entire wall thickness [ ] This includes a penalty factor of 26 (i.e., 208 is approximately 51*2* [ ]

**Figure 1—5-gpm Leakage Flaw Sizes by KRAKFLO and SQUIRT**

**Figure 2—5-gpm Leakage Flaw Sizes by SQUIRT**

[ ]

## Attachment 2

## Leak-Before-Break (LBB) Finite Element Analysis (FEA) for the U.S. EPR Surge Line (SL)

This report estimates equivalent DMW joint material properties to be used in the LBB analysis for the U.S. EPR SL. The analysis has been performed using the following steps:

- Build a finite element model with a crack near the interface between the SA-508 Grade 3 Class 2 low alloy steel PZR surge nozzle and the 52M DMW, which joins the PZR surge nozzle to the SA-182 304L stainless steel safe end.
- Consider the as-designed thickness of the surge nozzle/DMW/safe end joint rather than the reduced wall thickness of the SL piping considered in the previous analyses.
- Conduct an FEA to establish J-applied versus Moment (J-M) curve for a typical crack size.
- Determine the equivalent material properties to be used in the EPRI-GE model.

### I. Material Properties

Material properties, including true stress-strain curve, Young's modulus, and yield stress are presented in Table 1. The material properties for the SA-508 Grade 3 Class 2 are approximated by the material properties for the SA-508 Class 3 (which is currently classified by ASME Code as SA-508 Grade 3 Class1) material obtained from Reference 1. The yield and ultimate stress for the SA-508 Grade 3 Class 2 are obtained from ASME B&PV Code Section II, part D, 2004 to be 53.9 and 90 ksi at 650°F, respectively. [

] The A508 Class 3 stress-strain curve is a reasonable approximation for the SA-508 Grade 3 Class 2 stress-strain behavior. [

]. The material properties for the Alloy 52M were provided by the NRC (Reference 2).

<u>Fusion Line Toughness (J-R Testing)</u>

Ductile resistance tests were conducted for seven C-T specimens. Six of the seven C-T specimens were performed with the fatigue pre-cracks located nearly on or close to the fusion line. [

]

For the seventh specimen, the pre-crack was located in the heat affected zone (HAZ), and the crack propagated along the HAZ.

### II. Finite Element (FE) Model

[

]

[ ]

**III. Equivalent Material Properties**

[ ]

Figure 4 shows the weld locations of the SL piping.

**IV. Validation of the Modified EPRI-GE Method**

To evaluate the applicability of the modified EPRI-GE method to estimate the crack driving force, a FEA of a through cracked pipe made from a single material was analyzed to calculate the J-M curve. [

] A comparison of the J-M curve from the validation FEA and the modified EPRI-GE method are shown in Figure 5. Also shown in Figure 5 the J-M curve as estimated by NRCPIPE using the LBB.ENG2 module.

## V. References

1. NUREG/CR-6837, Volume 2, “The Battelle Integrity of Nuclear Piping (BINP) Program Final Report Summary and Implications of Results,” Appendices, U.S. Nuclear Regulatory Commission, June 2005.
2. E-mail from G. Tesfaye (NRC) to R. Pederson (AREVA), “Follow-up actions from audit on leak-before-break (LBB) analyses on FSAR Section 3.9.6 on 6/9/09,” dated July 27, 2009.

**Table 1—Material properties**

| SA-508 Class 3 used for SA-508 Grade 3 Cl2 (650°F)[1] | |
|---|---|
| Total True strain | True Stress (psi) |
| 0.001321 | 37520.82 |
| 0.001574 | 40125.9 |
| 0.001732 | 42705.7 |
| 0.002008 | 46046.82 |
| 0.002269 | 48206.16 |
| 0.003088 | 51098.11 |
| 0.004108 | 52943.44 |
| 0.005088 | 54261.92 |
| 0.007055 | 56313.38 |
| 0.009132 | 58079.59 |
| 0.020106 | 65093.94 |
| 0.030197 | 69869.66 |
| 0.040275 | 73535.87 |
| 0.050341 | 76336.04 |
| 0.060382 | 78491.03 |
| 0.070416 | 80195.09 |
| 0.090546 | 82574.85 |
| 0.100582 | 83264.39 |
| 0.110656 | 83356.82 |
| | |
| | |
| E= $2.84 \times 10^7$ psi | |

Notes:

1. Refer to detailed explanation in Section I, "Material Properties."

**Table 2—Finite Element Model Dimensions**

[ ]

**Table 3—Ramberg-Osgood Parameters for the Equivalent Material**

[ ]

**Figure 1—Finite Element Model**

**Figure 2—J-M Curve from both FE and EPRI-GE with Equivalent Material Properties**

[ ]

**Figure 3—Stress-Strain Data used for the FE Analysis Including the Equivalent Material Data**

**Figure 4—Schematic of the PZR Surge Nozzle Showing the DMW Location**

**Figure 5—Validation of The Modified EPRI-GE Method**

[ ]

## Attachment 3
## Leak-Before-Break (LBB) Flaw Stability Analysis for U.S. EPR Surge Line (SL)

This report evaluates the flaw stability of the 5-gpm leakage flaw size for the U.S. EPR SL at the dissimilar metal weld (DMW) fusion line location.

Using the 5-gpm leakage flaw sizes calculated from Attachment 1, the crack stability analysis has been performed for the pressurizer (PZR) surge nozzle at the DMW fusion line location (see Attachment 2, Figure 4). The J-integral/tearing modulus (J/T) approach and the limit load (net section collapse) analysis were used to analyze and perform the LBB flaw stability analysis.

This analysis uses the EPRI/GE method modified by Zahoor (Reference 1) and subsequently by Wilkowski (Reference 2) to calculate the J-integral based on elastic-plastic fracture mechanics (EPFM). Specifically, the J-integral is calculated using EPRI/GE J-estimation scheme with plastic zone correction as well as alpha-correction based on Reference 2.

To account for the potential failure mode due to limit moment, a limit load analysis based on ASME Section XI, Appendix C (which is similar to the limit load formulation of Reference 3) was also performed. The overall maximum allowable moment is the lesser value from EPFM and limit load analysis results. If the applied moment at a given LBB critical location is less than the maximum allowable moment, then LBB is justified.

### I. Input Parameters for Flaw Stability Evaluation

<u>Geometry Inputs</u>

Attachment 2, Figure 4 shows a schematic of the PZR nozzle and the DMW location where the dimensions in the analysis are taken. The dimensions at the DMW fusion line are listed in Attachment 1, Table 1. As noted in Attachment 1, the thickness, including cladding, was used for leakage flaw size calculation. For consistency, the thickness, including cladding, was used for the flaw stability evaluation.

<u>5-gpm Leakage Flaw Size</u>

Table 1 lists the 5-gpm leakage flaw sizes for the U.S. EPR SL at the DMW fusion line location using both SQUIRT and KRAKFLO. A safety factor of two is used because the full leakage flaw size listed in Table 1 was used as half the crack length for flaw stability analysis.

<u>Lower Bound Fracture Toughness</u>

Ductile resistance tests for six of the seven C-T specimens were performed with the fatigue pre-crack located nearly on or close to the fusion line. At mid-thickness, the fatigue pre-cracks were located [ ] from the fusion line. For these specimens, the cracks propagated along the fusion line. The J-T tearing criteria have been used, postulating the through-wall crack at the fusion line, and using the fusion line fracture toughness data that are listed in Table 2.

## II. Equivalent Material Properties at DMW Fusion Line

The equivalent material properties at the DMW fusion line are shown in Attachment 2, Table 4. For the flaw stability analysis, the alpha value of the R-O parameter needs to be corrected per Reference 2. Table 3 repeats the equivalent material properties with the alpha corrected value.

## III. Results and Discussions

Using the 5-gpm leakage flaw sizes from the leak rate calculation codes KRAKFLO and SQUIRT, the crack stability analyses have been performed for the PZR surge nozzle fusion line location. The J-Tearing criteria were used with the fusion line fracture toughness. The J-integral is calculated using the modified EPRI/GE J-estimation scheme with plastic zone correction and alpha-correction.

To account for the potential failure mode due to limit moment, a limit load analysis was performed. The overall maximum moment is the lesser value between the EPFM J-T criteria results and the limit load analysis results.

The allowable load limit (ALL) diagrams are shown in Figure 1 and Figure 2. In Figure 1, the leakage flaw size was calculated using KRAKFLO, and in Figure 2 it was calculated using SQUIRT. Both leakage codes yield comparable results. The KRAKFLO leads to slightly more limiting results than SQUIRT.

Figure 1 and Figure 2 also show (see the dashed lines) the maximum moment calculated using NRCPIPE with modified EPRI/GE method (NRCPIPE Option 2) for the leakage flaw sizes calculated by KRAKFLO and SQUIRT, respectively.

## IV. Conclusions

The flaw stability has been evaluated for the 5-gpm leakage flaw sizes determined by KRAKFLO and SQUIRT. The results based on SQUIRT are comparable to KRAKFLO. Using either leak rate codes, the applied moment is lower than the maximum allowable moment with a safety margin of two on the flaw sizes. The LBB is justified for U.S. EPR SL DMW fusion line locations based on the criteria of Reference 3.

## V. References

1. Zahoor, A., and Gamble, R. M., “Evaluation of Flawed-Pipe Experiments,” EPRI Report NP-4883M, November, 1986.
2. Wilkowski, G., et al., “Analysis of Experiments on Stainless Steel Flux Welds,” NUREG/CR-4878, BMI-2151, 1987.
3. NUREG-1061, “Evaluation of Potential for Pipe Breaks, Report of the U.S. Nuclear Regulatory Commission Piping Review Committee,” Volume 3, U.S. Nuclear Regulatory Commission, November 1984.

**Table 1—Flaw Size for 5-gpm Leakage**

| Moment, in-kips | 5-gpm Leakage Flaw Size, inch | |
|---|---|---|
| | SQUIRT | KRAKFLO |
| | | |

**Table 2—J-R Power Law Parameters**

| Parameter | PZR Surge Nozzle Fusion Line |
|---|---|
| | |
| | |

**Table 3—Equivalent Material Properties with Alpha Corrected Value**

| Material Property | Value |
|---|---|
| | |
| | |
| | |
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| | |

**Figure 1—ALL Diagrams with Leakage Flaw Sizes Calculated by KRAKFLO**

**Figure 2—ALL Diagrams with Leakage Flaw Sizes Calculated by SQUIRT**

# U.S. EPR Final Safety Analysis Report Markups

**Table 1.8-2—U.S. EPR Combined License Information Items**
**Sheet 14 of 47**

03.06.03-23

| Item No. | Description | Section | Action Required by COL Applicant | Action Required by COL Holder |
|---|---|---|---|---|
| 3.6-4 | A COL applicant that references the U.S. design certification will provide diagrams showing the final as-designed configurations, locations, and orientations of the pipe whip restraints in relation to break locations in each piping system. | 3.6.2.5.1 | | Y |
| 3.6-5 | A COL applicant that references the U.S. EPR design certification will implement the ISI program as augmented with NRC approved ASME Code cases that are developed and approved for augmented inspections of Alloy 690/152/52 material to address PWSCC concerns. | 3.6.3.3.4.1 | | Y |
| 3.7-1 | A COL applicant that references the U.S. EPR design certification will confirm that the site-specific seismic response is within the parameters of section 3.7 of the U.S. EPR standard design. | 3.7.2 | Y | |
| 3.7-2 | A COL applicant that references the US EPR design certification will provide the site-specific separation distances for the access building and turbine building. | 3.7.2.8 | Y | |
| 3.7-3 | A COL applicant that references the U.S. EPR design certification will provide a description of methods used for seismic analysis of site-specific Category I concrete dams, if applicable. | 3.7.3.13 | Y | |
| 3.7-4 | A COL applicant that references the U.S. EPR design certification will determine whether essentially the same seismic response from a given earthquake is expected at each of the units in a multi-unit site or instrument each unit. In the event that only one unit is instrumented, annunciation shall be provided to each control room. | 3.7.4.2 | Y | |

"sensitization" and renders materials susceptible to SCC. To reduce the susceptibility to SCC, the MCL and SL piping conform to ASME Boiler and Pressure Vessel Code, Section III (Reference 7) requirements supplemented by the guidelines of RG 1.44 and ASME NQA-1-1994 (Reference 8). The stainless steel piping and welds are "L" grade, which reduces the potential for sensitization. The welds between the stainless steel safe ends and the low alloy steel nozzles are Alloy 52, which has a higher resistance to SCC than Alloy 600/82/182.

### Corrosive Environment

Reactor coolant chemistry controls prevent the occurrence of SCC. Dissolved oxygen, halides, and other impurities are monitored by plant surveillance testing. Controlling oxygen is a key to avoiding a corrosive environment. Dissolved oxygen concentrations are maintained at very low levels during normal plant operation by applying hydrogen injection to the coolant system. The design of non-metallic insulation for the RCS conforms to the guidelines in RG 1.36, which restricts the use of chlorides and fluorides in the thermal insulation to prevent SCC.

### Tensile Stress

As the imposed tensile stress increases, the likelihood of initiation and propagation of SCC increases. Stresses close to the material yield strength are required in a light water reactor environment to initiate SCC. The MCL and SL piping conform to ASME Code, Section III requirements, which provide the code-specified margin to yield stress during normal operation. Weld residual stresses can exceed yield; however, because of the U.S. operational experience for controlling material susceptibility and the environment described above, the potential for SCC is minimized.

As noted in SRP 3.6.3, "Primary water stress corrosion cracking (PWSCC) is considered to be an active degradation mechanism in Alloy 600/82/182 materials in pressurized water reactor plants. Alloy 690/52/152 material is not currently considered susceptible to PWSCC for the purposes of LBB application." As noted above, Alloy 52 weld material is used for the U.S. EPR~~; therefore, PWSCC is not a concern~~. To further demonstrate that PWSCC is not a concern for LBB candidate piping, the U.S EPR inservice inspection (ISI) program will consider the operating experience of the materials used in the U.S. EPR piping systems qualified for LBB. The U.S. EPR inspection program will be consistent with the inspection program adopted for operating PWRs that use Alloy 690, 52, and 152 in approved LBB applications. A COL applicant that references the U.S. EPR design certification will implement the ISI program as augmented with NRC approved ASME Code cases that are developed and approved for augmented inspections of Alloy 690/152/52 material to address PWSCC concerns.

03.06.03-23