July 17, 2006

Bill Eaton, BWRVIP Chairman
Entergy Operations, Inc.
Echelon One
1340 Echelon Parkway
Jackson, MS 39213-8202

SUBJECT: SAFETY EVALUATION OF EPRI REPORT, "BWR VESSEL AND INTERNALS PROJECT, EVALUATION OF CRACK GROWTH IN BWR NICKEL BASE AUSTENITIC ALLOYS IN REACTOR PRESSURE VESSEL INTERNALS (BWRVIP-59)"

Dear Mr. Eaton:

The Nuclear Regulatory Commission (NRC)55 staff has completed its review of the Electric Power Research Institute (EPRI) Proprietary Report TR-108710, "BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Nickel Base Austenitic Alloys in Reactor Pressure Vessel Internals (BWRVIP-59)," dated December 1998. This report was submitted for NRC staff review and approval by letter dated December 23, 1998, and supplemented by letters dated December 4, 2000, and February 19, 2001. In addition, the non-proprietary version of the BWRVIP-59 report was submitted to the staff on March 24, 2000.

The staff issued its initial safety evaluation of the BWRVIP-59 report by letter dated July 31, 2001, which included recommendations regarding the proposed crack growth rates (CGRs) for high purity water chemistry, crack growth disposition curves, and the alternate weld sequences. By letter dated December 20, 2004, the BWRVIP provided its responses to the staff's recommendations, and included its revised version of the BWRVIP-59 report, dated December 2004.

The BWRVIP-59 report provides a methodology to disposition flaws in nickel alloy components and weldments in boiling water reactor (BWR) environments. The report includes crack growth curves that are applicable to any nickel alloy component or weldment not subject to high radiation fields. The BWRVIP-59 report also provides the stress intensity factor (K) distributions for a variety of core support structure welds. The specific analyses are for the core support geometry of a BWR Type 6 configuration (BWR-6), but most of the results are also applicable to core support structures for other BWR models.

The NRC staff has reviewed your submittal and the staff's safety evaluation is attached. The staff requests that the BWRVIP submit the -A version of the BWRVIP-59 report within 180 days of receipt of this letter. Please contact Meena Khanna of my staff at (301) 415-2150 if you have any further questions regarding this subject.

Sincerely,

/KA/

Matthew A. Mitchell, Chief
Vessels & Internals Integrity Branch
Division of Component Integrity
Office of Nuclear Reactor Regulation

Enclosure:
Safety Evaluation

cc: BWRVIP Service List

The NRC staff has reviewed your submittal and the staff's safety evaluation is attached. The staff requests that the BWRVIP submit the -A version of the BWRVIP-59 report within 180 days of receipt of this letter. Please contact Meena Khanna of my staff at (301) 415-2150 if you have any further questions regarding this subject.

Sincerely,

/KA/

Matthew A. Mitchell, Chief
Vessels & Internals Integrity Branch
Division of Component Integrity
Office of Nuclear Reactor Regulation

Enclosure:
Safety Evaluation

cc: BWRVIP Service List

DISTRIBUTION:
DCI R/F YDiaz ALee CE Moyer WCullen JWhite, R1 MLesser, R2
DHills, R3 JClark, R4

ADAMS Accession No.: ML062080680

OFFICE	DCI/CVIB	DCI/CVIB	DD/DCI
NAME	MKhanna	MMitchell	BBateman
DATE	07/16/2006	07/17/2006	07/18/2006

OFFICIAL RECORD COPY

cc:

Randy Stark, EPRI BWRVIP
  Integration Manager
Raj Pathania, EPRI BWRVIP
  Mitigation Manager
Ken Wolfe, EPRI BWRVIP
  Repair Manager
Larry Steinert, EPRI BWRVIP
Electric Power Research Institute
P.O. Box 10412
3412 Hillview Ave.
Palo Alto, CA 94303

George Inch, Technical Chairman
  BWRVIP Assessment Committee
Constellation Nuclear
Nine Mile Point Nuclear Station (M/S ESB-1)
348 Lake Road
Lycoming, NY 13093

Jeff Goldstein, Technical Chairman
  BWRVIP Mitigation Committee
Entergy Nuclear NE
440 Hamilton Ave. (M/S K-WPO-11c)
White Plains, NY 10601

Amir Shahkarami, Executive Chairman
  BWRVIP Integration Committee
  Exelon Corp.
Cornerstone II at Cantera
4300 Winfield Rd.
Warrenville, IL 60555-4012

Richard Anderson, Executive Chairman
  BWRVIP Assessment Committee
Vice President, Nuclear
FirstEnergy Service Co.
Perry Nuclear Power Plant (M/S A-PY-290)
10 Center Road
Perry, OH 44081

Rick Libra, BWRVIP Vice Chairman
DTE Energy
Fermi Nuclear Plant (M/S 280 OBA)
6400 N. Dixie Highway
Newport, MI 48166-9726

Robin Dyle, Technical Chairman
  BWRVIP Integration Committee
Southern Nuclear Operating Co.
42 Inverness Center Parkway
(M/S B234)
Birmingham, AL 35242-4809

D. Atwood, Technical Chairman
 BWRVIP Repair Focus Group
Southern Nuclear Operating Co.
Post Office Box 1295
40 Inverness Center Parkway
(M/S B031)
Birmingham, AL 35242-4809
Charles J. Wirtz, Chairman
BWRVIP Inspection Focus Group
FirstEnergy Corp.
Perry Nuclear Power Plant
(M/S A250)
10 Center Road
Perry, OH 44081

Robert Carter, EPRI BWRVIP
  Assessment Manager
Jeff Landrum, EPRI BWRVIP
  Inspection Manager
EPRI NDE Center
P.O. Box 217097
1300 W. T. Harris Blvd.
Charlotte, NC 28221

Scott Oxenford, Executive Chairman
  BWRVIP Mitigation Committee
Vice President, Technical Services
Energy Northwest
P.O. Box 968
Richland, WA 99352-0968

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
SAFETY EVALUATION OF EPRI REPORT TR-108710, "BWR VESSEL AND INTERNALS PROJECT, EVALUATION OF CRACK GROWTH IN BWR NICKEL BASE AUSTENITIC ALLOYS IN REACTOR PRESSURE VESSEL INTERNALS (BWRVIP-59)"

1.0 INTRODUCTION

By letter dated December 23, 1998, as supplemented by letters dated December 4, 2000, and February 19, 2001, the Boiling Water Reactor Vessel and Internals Project (BWRVIP) submitted for staff review and approval the Electric Power Research Institute (EPRI) Proprietary Report TR-108710, "BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Nickel Base Austenitic Alloys in RPV Internals (BWRVIP-59)," dated December 1998.

The staff issued its initial safety evaluation (SE) of the BWRVIP-59 report by letter dated July 31, 2001, which included recommendations regarding the proposed crack growth rates (CGRs) for high purity water chemistry, crack growth disposition curves, and alternate weld sequences. By letter dated December 20, 2004, the BWRVIP provided its responses to the staff's recommendations, and included its revised version of the BWRVIP-59 report, dated December 2004.

The BWRVIP-59 report provides a methodology to disposition flaws in nickel alloy components and weldments in boiling water reactor (BWR) environments. The report includes crack growth curves that are applicable to any nickel alloy component or weldment not subject to high radiation fields. The BWRVIP-59 report also provides the stress intensity factor (K) distributions for a variety of core support structure welds. The specific analyses are for the core support geometry of a BWR Type 6 configuration (BWR-6), but most of the results are also applicable to core support structures for other BWR models.

1.1 Background

In 1993 and 1994, intergranular stress corrosion cracking (IGSCC) of the core shroud was identified as a significant issue for austenitic materials used in BWR internals. In response to these issues, the BWR utilities formed the BWRVIP to address service-related degradation of BWR vessels and internals, including those composed of nickel-based alloys. Key nickel-based components include the core shroud support plate, the core shroud access hole covers, the core shroud support legs and/or gussets, and the vessel attachment brackets. To adequately schedule inspection intervals for these components, the BWRVIP proposed to use a CGR that is based on crack disposition curves for normal water chemistry (NWC), hydrogen water chemistry (HWC), and noble metal chemical addition (NMCA).

ENCLOSURE

1.2 Purpose

The staff reviewed the BWRVIP-59 report, as supplemented by letters dated December 4, 2000, and February 19, 2001, to determine whether its crack growth methodology for BWR nickel-based reactor pressure vessel (RPV) internal components would provide an acceptable level of quality for the inspection and flaw evaluation (I&E) guidelines of the subject safety-related RPV internal components. The review considered the consequences of component failures, potential degradation mechanisms, past service experience, and the ability of the proposed inspections to detect degradation in a timely manner. In addition, the staff evaluated the BWRVIP's responses and its revised version of the BWRVIP-59 report, as provided by letter dated December 20, 2004, to the staff's recommendations that were made in the initial SE dated July 31, 2001.

1.3 Organization of the Report

A brief summary of the contents of the subject report is given in Section 2 of this SE, with the evaluation presented in Section 3. The conclusions are summarized in Section 4. The presentation of the evaluation is structured according to the organization of the BWRVIP-59 report.

2.0 SUMMARY OF THE BWRVIP-59 REPORT

The BWRVIP-59 report provides a methodology to assess crack growth in BWR nickel-based austenitic alloy shroud support structure components and welds. Residual stresses and the corresponding stress intensity factors that control the through-thickness propagation of cracks are computed for a variety of core shroud welds. The geometries of the welds are shown in Figures 1 and 2 of this SE. Welds H8 and H9 are circular welds that attach the shroud support plate to the shroud support cylinder and the RPV. In theory, cracks could grow in length up to 360° through-wall in these welds. The BWRVIP-59 report presents K distributions for finite length flaws with an aspect ratio, a/ℓ [   ], where *a* is the depth of the crack and ℓ is the surface length of the crack. Plant-specific analyses or the use of a bounding CGR would be necessary for cracks longer than those considered in the BWRVIP-59 report. The H10, H11, and H12 welds are support leg welds. The K distributions for these welds conservatively assume a flaw that extends over the entire width of the leg.

The residual stresses are determined by finite element calculations. The specific geometry studied is for a BWR-6 configuration. This choice permits direct comparison with experimental measurements of residual stresses on a spare vessel at River Bend, which is a BWR-6. The results in the BWRVIP-59 report, together with those in other BWRVIP studies, allow for a reasonable estimation of the residual stresses in BWR-3, -4, and -5 designs, as well as BWR-6 designs. However, the BWR-2 design that was used for Nine Mile Point, Unit 1 and Oyster Creek would require an additional evaluation.

The finite element methods for the computation of residual stresses near the welds are similar to those presented in the BWRVIP-14 report, “Evaluation of Crack Growth in BWR Stainless Steel RPV Internals,” where those methods were used to calculate the stresses near the H4 and H5 welds [2]. The plate and “leg” elements that comprise the shroud support structures for the BWR 3-6 models are relatively compliant and the calculations include the effects of this compliance on the residual stresses. In the original calculations, as summarized in Appendix D of the BWRVIP-59 report, the effect of the overall structure on the local weld stresses was determined by the superposition of local solutions with the stresses resulting from the forces and moments needed to maintain continuity of the entire structure.

Such an approach raises questions about the applicability of superpositioning in situations where significant plastic yielding may be occurring. With respect to the new calculations in Appendix E of the BWRVIP-59 report, a much larger overall structure is modeled, thereby eliminating the need to superimpose separate solutions. Such an approach has been made possible by the substantial increases in computing power that have occurred since the original BWRVIP-59 report was prepared. In addition, the calculations in Appendix E of the revised version of the BWRVIP-59 report consider a broader range of weld sequences than those that were considered in the calculations, as documented in Appendix D of the original BWRVIP-59 report. More cross-sections are also considered to help ensure that the subsequent fracture mechanics analyses consider the most severe stress states.

The finite element results were compared with the experimental measurements on the BWR-6 shroud structure. In general, a fairly good agreement was found between the calculated and measured values. That is, the regions of compressive and tensile stresses and the magnitudes of the peak compressive and tensile stresses were found to be in fairly good agreement.

The stress intensity factors for the H8 and H9 welds were computed from the residual stress distributions using the K equation for surface flaws in Appendix A of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI [3]. This solution is based on an isolated flaw in a flat plate. It is applicable to cases where the stress distribution on the plane of the flaw can be represented by a cubic polynomial in x/a, where x is the distance through the wall and a is the crack depth. The ASME Code, Section XI, K equation is valid for all crack depths for which a cubic polynomial provides an accurate representation of the stresses acting on the flaw plane, and it includes corrections for finite flaw length.

The fracture mechanics analyses of the H10, H11, and H12 welds are complex. The K values for the H10, H11, and H12 welds, at the legs, are based on a solution for an edge cracked beam under displacement controlled loading developed by Cheng [4]. Cracks in the leg welds are conservatively assumed to run the full width of the leg. The current analysis of the residual stresses in these welds is much more comprehensive than the analysis in the original report. The results show that the K levels in these welds are so high that the crack growth in these welds is virtually always in a K-independent plateau region.

The residual stresses are not as high in the H8 and H9 welds. In addition, over most of the thickness of these welds, the CGR will be in the K-dependent crack growth region for cracks with an aspect ratio a/ℓ [ ]. The K value will increase with decreasing a/ℓ (longer cracks), however, as noted previously, the BWRVIP-59 report provides the stress intensity factor distributions of the H8 and H9 welds only for cracks with a/ℓ [ ].

Crack growth disposition curves for Alloy 82, 182, and 600 are provided in the report. Two crack disposition curves are proposed. One crack disposition curve is for BWRs that meet the Electric Power Research Institute (EPRI) water chemistry guidelines for NWC. The second crack disposition curve is for BWRs with an “effective” HWC, i.e., low conductivities and electrochemical potentials [ ] mV (SHE). Both the disposition curves consist of a K-dependent portion for K [ ] ksi-in$^{1/2}$ and a constant K-independent portion for [ ] ksi-in$^{1/2}$. The plateau rate for BWRs that meet the EPRI guidelines is [ ] in/h; the plateau rate for plants with HWC is [ ] in/h. The report also observes that much of the data upon which the crack growth disposition curves are based upon were obtained in water chemistries that have higher levels of impurities than those currently found in operating BWRs. It would be expected that the lower impurity levels would be likely to lead to lower CGRs. The current version of the BWRVIP-59 report takes no credit for the lower impurity levels, but it is noted as an unquantified conservatism.

Even in the case of the H8 and H9 welds, K-dependent crack growth is only assumed in determining the through-wall growth of the crack. The growth in length of the crack is assumed to occur at [ ] in/h), i.e., at the plateau rate at both ends of the crack.

The crack growth disposition curves are based on a database which includes in-plant data from nine reactors, General Electric (GE) laboratory data, and data from ABB, Studsvik, Toshiba, and VTT. References to the complete database are not provided. Only the ABB and GE Corporate Research and Development data are readily available in the open literature. The disposition curves bound [ ]% of the data and bound all of the in-plant data and GE laboratory data. The disposition curves also bound greater than [ ]% of the estimated CGRs for observed field cracks that are reported in the BWRVIP-59 report.

[Figure 1 Deleted]

Figure 1 Typical Arrangement of Core Shroud and Support Structure (BWR-6)

[Figure 2 Deleted]

Figure 2 Shroud Support Plate With Legs (CBIN BWR-4, -5, -6 Designs)

3.0 EVALUATION

As stated above, the staff noted that the crack growth disposition curves are based on a database which includes in-plant data from nine reactors, GE laboratory data, and data from ABB, Studsvik, Toshiba, and VTT. The disposition curves are largely based on data for Alloy 182 weld metal. Because virtually all of the data show that stress corrosion cracking (SCC) CGRs in Alloy 600 are less than the SCC CGRs in Alloy 182, this is a conservative assumption.

References to the complete database are not provided except as points in a plot of CGR as a function of the K values. The complete database assembled by the BWRVIP contains over [ ] data points. This data was screened and data with conductivity levels [ ] µS/cm, invalid (high) K levels, and large post-test corrections for crack length were eliminated from the data set. The remaining data set contains [ ] points. Much of the early data was done in very high conductivity solutions and at K levels that were too high for validity. Thus, screening is reasonable and necessary. Again, no detailed information on the data is given, just a plot of CGRs as a function of K. The database was further analyzed to consider only data with conductivity [ ] and [ ] µS/cm. Even the screened databases show approximately 4 orders of magnitude in CGR for a given K level. Part of this may be attributed to the range of electrochemical potentials (ECPs) associated with the data ([ ] mV), but the staff agrees that most of the data is probably in nominal [ ] parts per billion (ppb) dissolved oxygen, corresponding to the higher ECPs.

Andresen discussed the reasoning behind the large scatter of the reported SCC data [5]. The staff believes that this large scatter situation would even be worse in Alloy 182 material. The crack fronts tend to propagate along the dendrites and are often very uneven which makes it difficult to interpret the direct current (DC) potential drop measurements of crack growth or to define a meaningful K value. As Andresen points out, it is more common to generate data that are “too low” than data that are “too high” and thus, in general, “more credibility must be given to the upper [data] but not necessarily the highest data in a highly scattered data set.”

The proposed disposition curve for BWRs with NWC within the EPRI BWR water chemistry guidelines appropriately bounds the applicable data ([ ]% of the lab and in-plant data and greater than [ ]% of the estimated CGRs for observed field cracks). The high-K plateau value of [ ] in/h for the disposition curve for water chemistries that meet the EPRI guidelines has been used and accepted by the staff to disposition cracks in nickel alloys in the past. The BWRVIP has dropped the proposal to use a lower CGR for BWRs with high purity water chemistry, conductivity [ ] µS/cm. Although improving water chemistry will, in general, reduce CGRs, there is insufficient data available to quantify the effects of increasing purity to develop an additional disposition curve.

The proposed disposition curve for HWC is essentially an [ ] lower in CGRs than that proposed for NWC. This is consistent with the data reported in the BWRVIP-59 report and the work of Andresen, Itow et al., and Ljungberg and Stigenberg [6-9]. This degree of reduction is also conservative in comparison to the effects expected for CGRs in sensitized stainless steels for high HWC availability, as shown in Figure 3 of this SE. It is, however, much lower than would be expected in low potential environments in pressurized water reactors (PWRs). At 288 °C, the Materials Reliability Project (MRP) disposition curve for primary water stress corrosion cracking (PWSCC) in PWRs would predict a CGR of about [ ] in/h, which is a factor of [ ] higher than the proposed plateau rate [10]. The staff believes that these nickel alloys would become susceptible to PWSCC at low enough potentials. However, the data seems to demonstrate that at the potentials that are actually achieved in HWC, PWSCC of the type associated with the very low potential characteristic of PWRs does not occur.

The staff noted that the BWRVIP-59 report does not include a discussion of the possible effects of irradiation on the CGRs. Irradiation at sufficiently high fluences is well known to accelerate the CGRs in austenitic stainless steels and there is no reason to expect that sufficiently high fluence levels will not accelerate the CGR in nickel alloys. The fluence levels for these support structures are quite low; however, the staff requests that the BWRVIP address this issue in the -A report and provide an acceptable fluence level for the application of the crack growth methodology provided.

[Figure Deleted]

[Figure Deleted]

(a)

(b)

Figure 3

[Figure Deleted]

(a) Factor of Improvement (FOI) for stainless steels as a function of ECP with a HWC availability of 1; (b) FOI as a function of ECP with a HWC availability of 0.9; (c) FOI as a function of ECP with a HWC availability of 0.8

The results are based on predictions of the BWRVIP-14 model and the GE PLEDGE Code. The PLEDGE Code predictions are regarded as the most realistic.

(c)

The proposed reduction of CGR should be recognized as being dependent upon the amount of time that a plant is actually on HWC. The factor of [ ] proposed in the BWRVIP-59 report is a bounding value for a fully effective HWC plant, and the actual reduction in CGR used for the disposition curve should be dependent on the fraction of time that the HWC is assumed to be effective. The factor of improvement (FOI) for Alloy 182, as proposed in the BWRVIP-62 report (Fig. 4-2, page 4-14) and as reproduced in Figure 4, below, should give conservative estimates of the FOI as a function of the percentage of time that the HWC is effective [11].

[Figure 4 Deleted]

Figure 4 FOI for Alloy 182 at ECP [ ] mV as a function of time on HWC

The assumption that the growth in length of the crack occurs at [ ] times the plateau rate for plants on HWC is conservative if the crack extends only by growth of the pre-existing crack. If, however, the higher stresses ahead of the crack tip promote the initiation of new cracks, there is also the possibility that the crack can also extend by linking with newly initiated cracks ahead of the pre-existing crack. Growth by linking of newly initiated cracks would be a significant concern if the material were highly susceptible to initiation. However, field experience suggests initiation of stress corrosion cracks in these materials in BWR environments is relatively difficult. Thus, the staff finds that the BWRVIP's approach, as addressed in the BWRVIP-59 report, regarding the increase in crack length is acceptable. The staff noted that the growth in length of pre-existing cracks is only an issue for cracks in the H8 and H9 welds. It was also noted that the cracks in the H10, H11, and H12 welds are assumed to extend across the full width of the leg.

The finite element analyses of the residual stresses associated with the core shroud support weldments, as discussed in the revised version of the BWRVIP-59 report, are much more extensive than those discussed in the original BWRVIP-59 report. The revised version of the BWRVIP-59 report now includes the effects of fabrication sequencing (the order that the welds were made) and weld bead sequencing (the ordering of the welding of the double "V" notches). More cut planes (i.e., planes of possible crack growth) through the welds are examined to help ensure that the most severe stress state is determined. In most cases, sequencing, especially weld bead sequencing, seems to have a more significant effect than the choice of the cut plane. However, it is noted that the H12 weld seems to show more variability from the choice of cut plane than the other welds.

The modeling and assumptions for the finite element analyses are similar to those used in the BWRVIP-14 report for other shroud welds such as the H4 weld [2]. The calculations in the BWRVIP-14 report were compared with independent calculations of the residual stresses for the H4 weld that were performed by Battelle Columbus Laboratories [12]. Although the two sets of calculations used different computer codes and made different modeling assumptions, the predicted residual stresses for the two sets of calculations showed acceptable agreement. There was also acceptable agreement with the experimental measurements of the residual stresses by both neutron diffraction and strain relief techniques [2,13]. However, with respect to the calculations in the BWRVIP-14 report, the structural interactions of the different components are less important than those for the support structures considered in the BWRVIP-59 report. It was noted that the integrated treatment of structures used in Appendix E of the BWRVIP-59 report addresses many of the questions that could be raised by the previous attempts to use superposition of solutions for individual components to address structural interactions.

There are no independent calculations of the residual stresses available for the shroud support welds that are considered in the BWRVIP-59 report. However, there is no reason to expect that the adequacy of the modeling procedure and computer codes to predict the local residual stresses for a given weld sequence is any less satisfactory for these welds than those considered in the BWRVIP-14 report. In addition, the comparison of the finite element results with the experimental measurements on the H8, H9, H10, and H12 welds in the BWRVIP-59 report shows acceptable agreement between the calculated and measured values in the sense that the regions of compressive and tensile stresses and the magnitudes of the peak compressive and tensile stresses are in acceptable agreement. There is no experimental comparison available for the H11 weld because the River Bend shroud support structure did not include such a weld.

Although the analyses in Appendix E of the BWRVIP-59 report are quite extensive, the analysis space that represents all possible permutations of weld assembly sequences (legs first vs. last), configurations (H11 or H12 geometry), and reversal of each of the four weld locations, totals 64 cases. Appendix E considers only eight of these cases. For example, the effect of reversing the weld bead sequence was considered only for welds H9 and H12. Reversing the sequence of welds for the H9 weld gave peak stresses for the H8 weld (compare Run E with the other runs in Figure E-50 of the BWRVIP-59 report).

For most of the eight cases that were run, the results tend to cluster fairly closely together (H10, H11, H12, as shown in Figures E-52 through E-54 of the BWRVIP-59 report) or to break into distinct clusters (H8 and H9, as shown in Figures E-50 and E-51 of the BWRVIP-59 report). This suggests that running additional cases will not result in residual stress distributions significantly more severe than those represented by the eight cases already considered in Appendix E of the BWRVIP-59 report. The staff determined that the higher stresses in the H8 weld due to the reversal of welding sequence for the H9 weld would affect only the initial growth of the flaw. The staff found that the residual stresses through most of this thickness for this case are similar to those for other cases.

The staff determined that the use of the Cheng solution for the stress intensity of the H10, H11, and H12 welds is appropriate [4]. In addition, the stress intensity factor solutions resulting from these distributions for these welds are high enough that the corresponding CGRs are in the K-independent regime. Thus, the staff determined that any uncertainties, in either the calculation of the residual stresses in these welds or the associated stress intensity factors, would not have a non-conservative impact on the calculation of crack growth in these weldments.

In addition, the staff determined that the ASME Section XI procedure used to calculate the stress intensity factor, K, for the H8 and H9 welds is conservative for this geometry [3]. Because the support plate is attached to fairly rigid structures and the actual loading is displacement-controlled, rather than load-controlled, as assumed in the ASME Code model, the ASME Code model should give conservative predictions of the stress intensity for cracks in the H8 and H9 welds. The current results are limited to cracks with an aspect ratio a/ℓ [ ].

As noted in the BWRVIP-59 report, the procedure used to calculate the stress intensity factors in the report is not completely consistent with the ASME Code procedure. The ASME Code suggests recomputing the cubic distribution for the stresses acting on the crack plane for each crack depth. The report argues that a single overall cubic distribution provides an adequate fit and that the fit does not need to be refitted for each crack depth. The calculations were performed to determine the sensitivity of the resulting K distributions to the choice of the fitting procedure. The staff finds that the results support the conclusion of the BWRVIP-59 report, that a single fitting polynomial can provide an adequate representation of the stresses on the crack plane.

However, the bounding residual stress profile for the H9 weld, as shown in Figure 3-15 of the BWRVIP-59 report, is stated to correspond to the results of Run E in Section 4 of the BWRVIP-59 report. This is not consistent with the H9 weld stresses, as reported in Appendix E of the BWRVIP-59 report for Section 4 of Run E (Figure E-51). Nor does it seem to conform to any other stress profile reported in Appendix E of the BWRVIP-59 report for the H9 weld. One speculation is that it may correspond to a profile before post-weld heat treatment that is not reported in Appendix E of the BWRVIP-59 report.

The staff determined that this does not appear to have a major impact on the conclusions of the report. Calculations of the stress intensities for the H9 weld, corresponding to stress profiles that do appear to represent the "worst case," such as Section 4 of Run F or the Section 4 of Run E that was actually reported in Appendix E of the BWRVIP-59 report, give results that are similar to those shown in Figure 4-2 of the BWRVIP-59 report. However, the staff noted that this will impact the actual numerical values of K, as shown in Figure 4-2, and the numerical results in Table 6-2 of the BWRVIP-59 report. The staff requests that the BWRVIP resolve this discrepancy in the -A version of the BWRVIP-59 report.

In addition, the staff believes that the cubic polynomial fits to the stress profiles for welds H8 and H9 (Figures 3-14 and 3-15 of the BWRVIP-59 report) should also be represented in the figures, since these fits are actually used to determine the stress intensity factor, not the profiles. The staff requests that the BWRVIP include the cubic polynomial fits to the stress profiles for welds H8 and H9 in Figures 3-14 and 3-15 of the -A version of the BWRVIP-59 report. It was noted that some judgment can be involved in the fitting process (i.e., equal weights at all points, heavier weights on the peak tensile stresses, etc.); but, unfortunately, the staff was not able to exactly reproduce the stress intensity profiles for the H8 and H9 welds. It was noted, however, that the reported profiles in the BWRVIP-59 report are slightly more conservative for most of the values of a/ℓ, when compared to those values that the staff had calculated.

4.0 CONCLUSION

The staff has reviewed the BWRVIP-59 report and the supplemental information that was transmitted by letters dated December 4, 2000, and February 19, 2001. In addition, the staff has reviewed the revised version of the BWRVIP-59 report as submitted by letter dated December 20, 2004. The staff found that the report, as modified and clarified to incorporate the staff's recommendations, provides an acceptable technical justification for a methodology in determining nickel-based austenitic alloy CGRs, based on empirical data that account for parameters that are known to affect crack propagation in BWR plants.

The calculations in Appendix E of the revised version of the BWRVIP-59 report address the issues raised by the staff about the effect of fabrication variability on residual stresses. The current analysis of the residual stresses in these welds is much more comprehensive than those in the original report. Moreover, for the H10, H11, and H12 welds, because the results of these analyses show that the K levels in these welds are so high, the crack growth in these welds is in the K-independent plateau region. Thus, regardless of any remaining uncertainties associated with the residual stresses in these welds, the staff agrees that the CGR is already taken at a bounding level.

The residual stresses are not as high in the H8 and H9 welds, and over most of the thickness of these welds, the CGR will be in the K-dependent region. However, the analyses in Appendix E of the BWRVIP-59 report are sufficiently comprehensive to provide assurance that the residual stress distribution used for the fracture mechanics analysis will be conservative for the range of weld sequences and crack locations of concern. In addition, the use of the ASME Code stress intensity factor is conservative for this application. It should be noted, however, that K will increase as the aspect ratio a/ℓ decreases, i.e., as the crack gets longer. Thus, the results for the H8 and H9 welds in the BWRVIP-59 report are limited to cracks for which a/ℓ [ ]. For longer cracks, either a plant-specific analysis or the use of bounding CGRs will be required. As noted in Section 3.0 of this SE, there is some uncertainty in the appropriateness of the residual stress profiles used for the H9 weld. Therefore, the staff requests that the BWRVIP revise the -A version of the BWRVIP-59 report to address the discrepancy of the calculations of the stress intensities for the H9 weld, as represented in Figure 4-2 and in Table 6-2 of the BWRVIP-59 report. However, it is noted that this uncertainty does not affect the general conclusion that the effects of weld sequencing have been adequately addressed.

In addition, the staff requests that the BWRVIP include the cubic polynomial fits to the stress profiles for welds H8 and H9 in Figures 3-14 and 3-15 of the -A version of the BWRVIP-59 report.

The staff noted that the BWRVIP-59 report does not include a discussion of the possible effects of irradiation on the CGRs. As stated in Section 3.0 of this SER, irradiation at sufficiently high fluences is well known to accelerate the CGRs in austenitic stainless steels and there is no reason to expect that sufficiently high fluence levels will not accelerate the CGR in nickel alloys. The fluence levels for these support structures are quite low; however, the staff requests that the BWRVIP address this issue in the -A report and provide an acceptable fluence level for the application of the crack growth methodology provided.

The assumption that the growth in length of the crack occurs at [ ] times the plateau rate for normal or HWC is acceptable for these materials, since field experience suggests initiation of stress corrosion cracking in these materials in BWR environments is relatively difficult and, hence significant growth by linking of newly initiated cracks is unlikely. The staff finds the BWRVIP-59 report acceptable pending resolution of the staff's comments noted above.

The staff requests that the supplemental information that was provided in response to the staff's RAIs should be incorporated in the -A version of the BWRVIP-59 report. In addition, the modifications addressed above should be incorporated in a revision or the -A version of the BWRVIP-59 report. The BWRVIP-59 report is considered by the staff to be acceptable for licensee usage, as modified by the staff recommendations given below, at any time during either a facility's current operating term or extended license period.

5.0 REFERENCES

1. Evaluation of Crack Growth in BWR Nickel Base Austenitic Alloys in RPV Internals (BWRVIP-59), EPRI TR-108710, EPRI, Palo Alto, CA (1998); Revised Draft December 2004.

2. BWR Vessels and Internals Project, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14), EPRI TR-105873, EPRI, Palo Alto, CA (1996).

3. R. C. Cipolla, “Technical Basis for the Revised Stress Intensity Factor Equation for Surface Flaws in ASME Section XI,” PVP-Vol. 313-1, International Pressure Vessel and Piping Codes and Standards: Volume 1 - Current Applications, American Society of Mechanical Engineers, New York (1995).

4. W. Cheng, “Determination of the Mode I Stress Intensity Factors for an Edge-Cracked Beam with Fixed Ends,” Engineering Fracture Mechanics, 63, pp 193-208 (1999).

5. P. L. Andresen, IGSCC Crack Propagation Rate Measurement in BWR Environments, Executive Summary of a Round Robin Study, Statens Karnkraftinspektion (SKI-Swedish Nuclear Power Inspectorate), SKI Report 98:27, ISSN 1104-1374 (1998).

6. P. L. Andresen, “Observation and Prediction of the Effects of Water Chemistry and Mechanics on Environmentally-Assisted Cracking of Inconels 182 Weld Metal and 600,” Corrosion, 44, No. 6, pp 376-385 (1988).

7. M. Itow, Y. Abe, S. Hida, H. Sakamoto, K. Takamori, S. Suzuki, The Effect of Corrosion Potential on Alloy 182 Crack Growth Rate in High Temperature Water, Proceedings of the Eighth International Symposium on Environmental Degradation of Material in Nuclear Power Systems - Water Reactors, American Nuclear Society, LaGrange, IL, pp. 712-719 (1997).

8. M. Itow, Y. Abe, A. Sudo, and T. Kaneko, Crack Growth Rates of Alloy 182 in High Temperature Water, Proceedings of the Seventh International Symposium on Environmental Degradation of Material in Nuclear Power Systems - Water Reactors, National Association of Corrosion Engineers, Houston, TX, pp. 541-552 (1995).

9. L. Ljungberg and M. Stigenberg, Stress Corrosion Cracking Propagation in Low-Strength Nickel-Base Alloys in Simulated BWR Environments, Proceedings of the Eighth International Symposium on Environmental Degradation of Material in Nuclear Power Systems-Water Reactors, American Nuclear Society, LaGrange, IL, pp. 704-711 (1997).

10. MRP-115, Materials Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds, EPRI TR-1006696, EPRI, Palo Alto, CA Draft C (2004).

11. Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection (BWRVIP-62), EPRI TR-108705, EPRI, Palo Alto, CA (1998).

12. J. Zhang, P. Dong, F. W. Brust, and W. J. Shack, Residual Stresses and Associated Stress Intensity Factors in Core Shroud Weldments, NUREG/CR-5675 (1999).

13. E. A. Payzant, S. Spooner, X. Zhu, C. R. Hubbard, S. T. Rosinski, and J. Dowicki, Experimental Determination of Residual Stress by Neutron Diffraction in a Boiling Water Reactor Core Shroud, Proc. of ASME PVP Conf., Vol. 322, American Society of Mechanical Engineers, New York, pp. 55-61 (1996).