July 31, 2001

Carl Terry, BWRVIP Chairman
Niagara Mohawk Power Company
Post Office Box 63
Lycoming, NY 13093

SUBJECT: SAFETY EVALUATION OF BWR VESSEL AND INTERNALS PROJECT BWRVIP-59 REPORT (TAC NO. MA4467)

Dear Mr. Terry:

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 requested additional information in a letter dated November 29, 1999. The BWRVIP provided its response by letter dated December 4, 2000. The February 19, 2001, letter proposed an interim crack growth rate (CGR) of 2.5×10^{-5} in/hr for nickel base austenitic alloys in BWR plants under hydrogen water chemistry/noble metal chemical application conditions (HWC/NMCA).

The BWRVIP-59 report provides a methodology for assessing crack growth in BWR nickel base alloy shroud support structures and in other nickel base alloy components. This methodology, specifically developed for crack growth in the radial (through-thickness) direction, would apply to Alloy 82 and 182 weld materials and Alloy 600 types of nickel base austenitic materials. Residual and applied stresses and stress intensity factors have been developed for crack propagation in the same direction.

The staff has reviewed the BWRVIP-59 report, the BWRVIP response to the staff's request for additional information (RAI), and the proposed interim CGR. The NRC staff, with assistance from Argonne National Laboratory (ANL), finds that the use of the calculated residual stresses and stress intensity factors combined with the crack disposition curves should generally result in conservative estimates of crack growth. However, the staff has several recommendations contained in the enclosed safety evaluation (SE). The staff requests that these recommendations be reviewed and incorporated, as appropriate, in the BWRVIP-59 report as part of the methodology presented in the BWRVIP-59 report. Please inform the staff within 90-days of the date of this letter as to your proposed actions and schedule for any revisions.

The staff also finds that the proposed interim CGR for HWC/NMCA is superceded by the CGR of 5.0×10^{-6} in/hr proposed in the BWRVIP-59 report. Based on the staff's review of the BWRVIP-59 and BWRVIP-62 reports, the CGR of 5.0×10^{-6} in/hr, subject to the same conditions as those in the BWRVIP-59 report, is acceptable for use as a reference value after a plant-specific CGR has been calculated. Therefore, the request for the interim crack growth rate of 2.5×10^{-5} in/hr for HWC/NMCA is not necessary.

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169 if you have any further questions regarding this subject.

Sincerely,

/ra/

William H. Bateman, Chief
Materials and Chemical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: BWRVIP Service List

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169 if you have any further questions regarding this subject.

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William H. Bateman, Chief
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Office of Nuclear Reactor Regulation

Enclosure: As stated

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OFFICE OF NUCLEAR REACTOR REGULATION

DIVISION OF ENGINEERING

SAFETY EVALUATION OF EPRI TOPICAL REPORT TR-108710

"BWR VESSEL AND INTERNALS PROJECT, EVALUATION OF

CRACK GROWTH IN BWR NICKEL BASE AUSTENITIC ALLOYS IN RPV INTERNALS"

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 requested additional information regarding the BWRVIP-59 report in a letter dated November 29, 1999. The BWRVIP provided its response by letter dated December 4, 2000. The February 19, 2001 letter proposed an interim crack growth rate (CGR) of 2.5×10^{-5} in/hr for nickel base austenitic alloys in BWR plants under hydrogen water chemistry and noble metal chemical application conditions (HWC/NMCA).

The BWRVIP-59 report provides a methodology for assessing crack growth in BWR nickel base alloy shroud support structures and in other nickel base alloy components. This methodology, specifically developed for crack growth in the radial (through-thickness) direction, would apply to Alloy 82 and 182 weld materials and Alloy 600 types of nickel base austenitic materials. Residual and applied stresses and stress intensity factors have been developed for crack propagation in the same direction.

The NRC staff, with assistance from Argonne National Laboratory (ANL), has assessed the BWRVIP's submittal, as supplemented, in this safety evaluation (SE).

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 Boiling Water Reactor Vessel and Internals Project to address service-related degradation of BWR vessels and internals, including those composed of nickel-base alloys. Key nickel-base components include the core shroud support plate, the access hole covers, the shroud support legs and/or gussets, and the vessel attachment brackets. To adequately schedule inspection intervals of these components, the BWRVIP is proposing to use a CGR based on crack disposition curves for normal water chemistry (NWC) and HWC/NMCA.

ENCLOSURE

1.2 Purpose

The staff reviewed the BWRVIP-59 report, as supplemented, to determine whether its crack growth methodology for BWR nickel-base reactor pressure vessel (RPV) internal components would provide acceptable levels of quality for inspection and flaw evaluation (I&E) 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.

1.3 Organization of the Report

This SE contains a brief summary of the BWRVIP-59 report followed by the staff's evaluation and conclusions. Because the BWRVIP-59 report is proprietary, the staff wrote this SE to exclude proprietary information presented in the report. This SE gives a brief summary of the general contents of the report in Section 2.0 and the detailed evaluation in Section 3.0. Section 4.0 contains recommendations based on the staff review and the ANL technical evaluation of the BWRVIP-59 report. This SE does not discuss the proprietary portions of the BWRVIP-59 report.

2.0 SUMMARY OF BWRVIP-59 REPORT

The BWRVIP-59 report provides a methodology for assessment of CGR's in nickel base austenitic alloy shroud support materials and welds, including attachments to the RPV made from these alloys (e.g., Alloy 82, 182, and 600). This methodology has been developed specifically for crack growth in the through-thickness direction with stress intensity factors developed for crack propagation in this orientation. The methodology involves development of crack growth disposition curves which account for the variability of IGSCC parameters on the CGR assessment for these alloys.

The development of CGR's in nickel base alloys involved the determination of the through-thickness residual stress and stress intensity distributions for core support structure welds representative of BWR's in service. The BWRVIP-59 report outlines the experimental and analytical techniques used to determine the residual stress distributions. The experimental techniques involved the use of samples from spare BWR-6 RPV's at River Bend Nuclear Station and Grand Gulf Nuclear Station, both fabricated by CBI Nuclear Company (CBIN). The analytical technique included a finite element analysis of the residual stress distribution. The residual stress distributions were used in a fracture mechanics analysis to determine the through-wall stress intensity distributions for welds H8, H9, H10, H11, and H12.

The BWRVIP submitted the analysis of two weld sequences. The first weld sequence was submitted with the December 28, 1998, BWRVIP-59 report, and the second sequence was described in Attachment 2 to the December 4, 2000, BWRVIP response to the NRC RAI dated November 29, 1999. The BWRVIP-59 report maintains that, in general, the results of the experimental measurements and the analytical techniques are comparable.

In addition, Structural Integrity Associates (SIA) used the stress intensity distributions derived from these results to determine crack growth distribution curves for three environments: (1) NWC at or below EPRI Water Chemistry Action Level 1 conditions (BWRVIP-29), (2) high purity normal water chemistry with conductivity at or below 0.15 μS/cm, and (3) HWC/NMCA within EPRI guidelines. The crack growth distribution curves were compared to a database of Alloy 182 and Alloy 600 crack growth rates. This database was developed from a combination of General Electric Nuclear Energy (GENE) data, BWRVIP peer data such as ABB and Studsvik, and BWRVIP data generated from the in-plant crack arrest verification system (CAVS).

The crack growth disposition curves consist of a stress intensity dependent (K-dependent) portion for K < 25 ksi $\sqrt{in}$ and a constant K-independent portion for 25 < K $\leq$ 45 ksi $\sqrt{in}$. The K-dependent CGR's are significantly smaller (10^{-10} to 10^{-8} in/hr) than the K-independent CGR's. Therefore, the BWRVIP used the more conservative CGR's in the evaluation. The BWRVIP report recommends the crack growth rates shown in Table 1.

Environment	CGR (in/hr) (25 < K $\leq$ 45 ksi $\sqrt{in}$)
NWC (EPRI Guidelines)	5×10^{-5}
NWC ($\leq$ 0.15 μS/cm)	2.5×10^{-5}
HWC/NMCA	5×10^{-6}

Table 1: Proposed BWRVIP-59 CGR's associated with specified water environment.

3.0 STAFF EVALUATION

The staff has reviewed the BWRVIP-59 report and ANL's technical evaluation. The staff finds that the recommendations listed in Section 4.0 should be incorporated into a revised BWRVIP-59 report in order for the methodology presented in the subject report to be acceptable. Once the BWRVIP-59 report has been revised, the staff finds that the use of the calculated residual stresses and stress intensity factors combined with the crack disposition curves should generally be acceptable and result in conservative crack growth rate estimates.

4.0 RECOMMENDATIONS

The following recommendations are based on staff review and the evaluation performed by ANL.

4.1 Proposed CGR for High Purity Water Chemistry

The proposed CGR for NWC within the EPRI guidelines (5×10^{-5} in/hr) appears to bound the data that remained after the SIA screening process. However, the proposed CGR for high purity water chemistry (conductivity $\leq$0.15 μS/cm) does not bound the applicable data as rigorously as the CGR for NWC within the EPRI guidelines. To assure that the applicable data is bounded for both NWC conditions (EPRI guidelines and high purity water chemistry), the staff recommends the use of the more conservative crack disposition curve when evaluating crack growth. For example, the BWRVIP-59 proposed CGR of 5×10^{-5} in/hr for NWC conditions would be more appropriate for both NWC conditions since it is more conservative than the high purity water CGR of 2.5×10^{-5} in/hr.

4.2 Crack Growth Disposition Curves

The use of calculated residual stresses and stress intensity factors combined with crack growth disposition curves should generally result in conservative estimates of crack growth. However, the uncertainty in the residual stress/stress intensity calculations and its effect on crack growth has not been determined. To compensate for this deficiency, the staff recommends that the CGR's of 5 x 10^{-5} in/hr for NWC and 5 x 10^{-6} in/hr for HWC/NMCA be used as references after the fracture mechanics methodology presented in the BWRVIP-59 has been adjusted for plant-specific variables and applied. The staff will determine the acceptability of the plant-specific CGR's based on the accuracy of the calculations, their underlying assumptions, and the potential consequences of the predicted crack growth.

4.3 Alternate Weld Sequence

In the December 4, 2000 response to the staff's RAI's, the BWRVIP included an additional analysis of an alternate weld sequence used in the fabrication of the BWR shroud support structure. This alternate weld sequence was analyzed using the same methodology as the weld sequence presented in the original BWRVIP-59 report. The resulting crack growth rates from this alternate weld sequence are bounded by the original BWRVIP-59 sequence. However, the staff recommendations from sections 4.1 and 4.2 of this SE also apply to this alternate sequence. For plants that use the alternate weld sequence or any sequence different than the one presented in the BWRVIP-59 report, the crack disposition curves should be plant-specific and the final CGR's should appropriately bound the applicable data.

5.0 CONCLUSIONS

The staff concludes that, although the use of the calculated residual stresses and stress intensity factors combined with the crack disposition curves should generally be acceptable and result in conservative estimates of crack growth, in order to accept the methodology presented in the BWRVIP-59 report, the above recommendations in the SER should be incorporated. The staff will determine the acceptability of the plant-specific CGR's based on the accuracy of the calculations, their underlying assumptions, and the potential consequences of the predicted crack growth.

The staff also finds that the proposed interim CGR, as requested by letter dated February 19, 2001, and limited in scope to HWC/NMCA, is superceded by the CGR of 5.0 x 10^{-6} in/hr presented in the BWRVIP-59 report. Based on the staff's review of the BWRVIP-59 and BWRVIP-62 reports, the CGR of 5.0 x 10^{-6} in/hr, is acceptable for use as a reference value after a plant-specific CGR has been calculated. Therefore, the request for the interim crack rate of 2.5 x 10^{-5} in/hr is not necessary.