August 19, 2005

Bill Eaton, BWRVIP Chairman
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SUBJECT: SAFETY EVALUATION OF THE "BWRVIP VESSEL AND INTERNALS PROJECT, UNDERWATER WELD REPAIR OF NICKEL ALLOY REACTOR VESSEL INTERNALS" (BWRVIP-44)," EPRI REPORT 108708

Dear Mr. Eaton:

The NRC staff has completed its review of the Electric Power Research Institute (EPRI) proprietary report, "BWR Vessel and Internals Project, Underwater Weld Repair of Nickel Alloy Reactor Vessel Internals (BWRVIP-44)," EPRI Report 108708. This report was submitted by letter dated October 27, 1997, for NRC staff review and approval. This report provides guidance for underwater weld repair technology for BWR reactor vessel internals components.

The staff noted that the BWRVIP-44 report addresses underwater weld repair of stainless steel reactor vessel internals in addition to the nickel alloy reactor vessel internals; therefore, the staff recommends that the BWRVIP revise the title of the BWRVIP-44 report to include stainless steel reactor vessel internals.

The NRC staff has reviewed your submittal and the staff's safety evaluation is attached. Please contact Meena Khanna of my staff at 301-415-2150 if you have any further questions regarding this subject.

Sincerely,

/(RA by T. Chan)/

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

Enclosure: As stated

cc: BWRVIP Service List

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U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
SAFETY EVALUATION OF THE "BWRVIP VESSEL AND INTERNALS PROJECT,UNDERWATER WELD REPAIR OF NICKEL ALLOY REACTOR VESSEL INTERNALS" (BWRVIP-44)," EPRI REPORT 108708

1.0 INTRODUCTION

1.1 Background

By letter dated October 27, 1997, as supplemented by letter dated July 30, 2004, the Boiling Water Reactor Vessel and Internals Project (BWRVIP) submitted for staff review and approval the Electric Power Research Institute (EPRI) proprietary report 108708, "BWR Vessel and Internals Project, Underwater Weld Repair of Nickel Alloy Reactor Vessel Internals (BWRVIP-44)." The BWRVIP-44 report was submitted as a means of exchanging information with the staff for the purpose of supporting the underwater weld repair program for reactor vessel internal (RVI) components that have been experiencing intergranular stress corrosion cracking (IGSCC). The BWRVIP-44 report provides guidance for the development of underwater welding parameters and the qualification of underwater welding procedure specifications (WPSs) and welders. The BWRVIP-44 also provides guidance for qualification of WPSs and welders in accordance with the requirements of the American Society of Mechanical Engineers (ASME) Section XI Code Case N-516, "Underwater Welding, Section XI, Division 1," and the ASME Section IX Code. In addition, this report delineates feasibility studies related to the underwater weld repairs and the non-destructive examination (NDE) of the repair welds in reactor vessel internals (RVI) components.

1.2 Purpose

The staff reviewed the BWRVIP-44 report to determine whether it will provide an acceptable technical justification for the application of underwater weld repair technology to the RVI components. As stated above, the report addresses general guidelines for the qualification of WPSs and welders in accordance with the requirements of Section XI Code Case N-516 and Section IX of the ASME Code. The report assesses the feasibility of performing underwater weld repairs and NDE on RVI components that have existing cracks. The report also provides extensive guidelines in developing essential welding parameters for repair welds on stainless steel and nickel-alloy RVI components. The underwater weld repair technology that is addressed in this report provides a viable repair option for areas in RVI components that are not suitable for mechanical repairs or not accessible for manual weld repairs.

1.3 Organization of this Report

Because the BWRVIP-44 report is proprietary, this safety evaluation (SE) was written to not repeat proprietary information contained in the report. The staff does not discuss, in any detail, the provisions of the guidelines or the parts of the guidelines it finds acceptable.

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-44 report.

2.0 SUMMARY OF BWRVIP-44 REPORT

The BWRVIP-44 report addresses the following topics in the following order:

- Introduction- discusses the purpose of this document and project objectives with respect to the development and qualification of mechanized underwater flux cored arc welding (FCAW) process for stainless steel and nickel-alloy RVI components.

- Welding Process/Equipment Development- discusses the initial underwater weld repairs using the mechanized FCAW process and associated limitations. It also discusses the development of advanced welding power supplies for the mechanized FCAW process which enhanced the underwater welding performance on stainless steel and nickel-alloy base materials. In addition, the report addresses various methods for the development of weld filler materials for the mechanized FCAW process.

- Qualification of Weldments and Testing Welding at a Depth of 50 Feet - provides guidelines for developing welding qualifications for the mechanized underwater FCAW process in accordance with the ASME Section XI Code Case N-516 and Section IX of the ASME Code.

- Demonstration of Underwater Weld Repair Application - discusses underwater repair applications for stainless steel and nickel-alloy base materials at a depth of 50 feet. Addresses the development of the test matrix based on essential welding parameters that have a significant impact on the mechanical properties of the weld joint. The report also discusses feasibility studies related to the underwater weld repairs of cracked base metals and NDE of the repair welds.

- Conclusions - discusses major accomplishments related to the objectives defined in Sections 2, 3, and 4 of the BWRVIP-44 report.

3.0 STAFF EVALUATION

The BWRVIP-44 report proposes guidance for the development and qualification of an underwater mechanized FCAW process for repairing stainless steel and nickel-alloy RVI components. This guidance is intended to be used by individual licensees for the development and qualification of underwater repair welds in RVI components. Each licensee is responsible for qualification of a WPS and welders in accordance with the requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code. The staff notes that the licensees shall use ASME Section XI Code Case N-516-2 which was approved by the staff in Regulatory Guide 1.147, “Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1", Revision 13, with a limitation requiring the staff’s prior approval of its use for underwater weld

repair/replacements of irradiated materials. The limitation includes an issue related to the effect of neutron fluence (E > 1 MeV) on the weldability of stainless steel and nickel-alloy materials. The BWRVIP, in its research work, has established that underwater welding of irradiated materials can be performed without any occurrence of cracking provided the neutron fluence (E > 1 MeV) values do not exceed maximum threshold limits. The maximum threshold limits for the neutron fluence values are discussed in the BWRVIP-98 report, "BWR Vessel and Internals Project, Technical Basis for Guidelines for Performing Weld Repairs to Irradiated BWR Internals," which is currently being reviewed by the staff. The staff will use the threshold limits for the neutron fluence values, and other limitations on the weldability issues that are specified in the staff's final SE of the BWRVIP-98 report, as criteria for approving the application of the BWRVIP-44 report for underwater welding of the irradiated materials. The staff concludes that the BWRVIP-44 report can be used to support weld repair/replacement of irradiated materials provided the licensee obtains prior approval from the staff.

The following paragraphs address the staff's evaluation on each section of the BWRVIP-44 report.

3.1 Introduction

This section addresses the scope and applicability of this document for the underwater weld repair of the RVI components. Historically, some RVI components have experienced cracking due to IGSCC in a BWR environment, and the BWRVIP developed underwater mechanical and weld repair methods for repairing the cracked RVI components. After extensive developmental work, the BWRVIP decided to use a mechanized underwater weld repair technique which offers benefits over the mechanical or manual weld repair technique. The mechanized underwater weld repair provides a viable option for the repair of RVI components that are not accessible for manual weld repair methods nor suitable for mechanical repair. In addition, this repair method can provide a permanent corrosion resistant repair with crevice-free conditions for the RVI components. The BWRVIP, after conducting extensive developmental work determined that the underwater (at a water depth of 50 feet) mechanized FCAW process offers the best repair methods for the RVI components because it reduces the radiation exposure to personnel and reduces repair time due to high weld deposition rates. The development work was conducted on stainless steel and nickel-alloy base materials using stainless steel and nickel-alloy weld materials, respectively. The FCAW weld filler materials were developed using halogen-free ingredients to reduce the susceptibility of the welds to SCC due to the presence of halogens.

This section also discusses the plan for the underwater weld repair work which was divided into three phases. In Phase I, essential welding parameters were developed for various welding positions which yielded weldments with sound mechanical properties. In Phase II, the weldments were fabricated in groove joint configurations and tested in compliance with requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code. In Phase III, the BWRVIP demonstrated the application of the underwater weld repair technique which represents a typical repair of RVI component.

The staff finds that this section adequately addresses scope and applicability of the mechanized underwater weld repair technique for the RVI components. The staff finds that this section is acceptable as written.

3.2 Welding Process/Equipment Development

In this section of the BWRVIP-44 report, the BWRVIP discusses improvements in welding technology which have allowed the production of higher quality welds. In the past, the welding power sources that were used did not provide stability to the underwater welding arc. The BWRVIP provides information related to newly improved welding power sources which enhanced the welding arc stability, produced ASME Code quality welds, and improved the capability of making underwater welds in all welding positions. The BWRVIP also discusses the attributes and features (including a modified gas nozzle) of a newly designed gas diffuser which improves the water displacement features resulting in a dry hyperbaric chamber at the weld area, an essential requirement for producing sound quality welds with minimum porosity. Finally, the BWRVIP discusses the development of halogen-free flux cored weld filler materials such as 308L (stainless steel) and Alloy 625 (nickel-alloy). These new flux cored weld filler materials include the formulation of flux which enhances weld arc stability, provides adequate shielding gas coverage, and reduces weld defects.

In this section the BWRVIP addresses, in detail, various essential welding parameters which are crucial in creating ASME Code quality welds and by using these parameters the licensees can develop their own underwater WPS for stainless steel and nickel-alloy base materials.

The staff finds that this section adequately provides valuable information with respect to the development of essential welding parameters, an improved gas diffuser, a modified shielding gas nozzle design, and improved welding power sources which are all essential in producing acceptable ASME Code quality underwater welds in all welding positions.

The staff, based on the review, finds that this section adequately addresses the methodology of developing ASME Code quality welds by using an improved weld equipment and welding parameters as stated above. The staff finds that this section is acceptable as written.

3.3 Qualification of Weldments and Testing Welding at a Depth of 50 Feet

This section provides information regarding the qualification tests for underwater welds of 304 stainless steel and nickel-alloy (Alloy 600) base materials using Alloy 625 weld filler material. The qualification tests were performed to comply with requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code. The weld coupons were made with a FCAW process in the flat, horizontal, vertical and overhead welding positions in a hyperbaric chamber at a depth of 50 feet and the test results were recorded. The welding parameters, the improved welding equipment, and the modified flux cored welding filler material, as discussed in Section 3.2, were used in fabricating the welding test coupons. The weld joint geometry included a standard “V” groove configuration on ½ inch thick stainless steel and nickel-alloy base materials. The weld test geometry represented a typical geometry that can be encountered when performing in-situ weld repair on RVI components. The weld tests included three reduced section tensile tests of weldments that were fabricated in the flat, horizontal and vertical welding positions, and two reduced tensile tests in the overhead welding position. The side bend tests of weldments include seven side bend tests in the flat welding position, eight side bend tests in the horizontal welding position, and four side bend tests in the overhead and vertical welding

positions. The tensile and the side bend tests complied with the requirements of the ASME Section XI Code Case N-516 and Section IX of the ASME Code.

The BWRVIP adequately demonstrated that it can successfully qualify underwater welding procedures for stainless steel and nickel-alloy materials using a FCAW process at depths up to 50 feet. The staff finds that this section adequately addresses the methodology of ASME Code qualifications for the underwater WPSs using a FCAW process. The BWRVIP successfully qualified a WPS by using welding parameters, improved welding equipment, and the modified flux cored welding filler material discussed in Section 3.2. Successful qualification of a WPS in accordance with the ASME Code requirements provides adequate assurance that ASME Code quality repair welds can be made in situ on RVI components. The staff finds that this section as written is acceptable because it adequately addresses the methodology for qualifying a WPS in accordance with requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code.

3.4 Demonstration of Underwater Weld Repair Application

This section of the BWRVIP-44 report addresses the methodology for performing underwater weld repairs at depths up to 50 feet using the FCAW process with stainless steel and nickel-alloy weld filler materials on various weld joint configurations such as a fillet weld, “V” groove weld, and overlay weld. The application of specified welding parameters as described in Section 3.2 of this SE produced ASME Code quality welds on the aforementioned weld joint configurations. The BWRVIP also provides detailed information related to the welding technique that was used in making successful fillet weld repairs using stainless steel weld filler material in the horizontal position. Similarly, ASME Code quality repair welds were made with nickel-alloy weld filler material in a “V” groove weld joint. This section also addresses various limitations that are associated with producing ASME Code quality repair welds at depths greater than 50 feet. The BWRVIP made ASME Code quality welds (i.e., bead on plate) in the flat position at a depth of 80 feet, however, as the depth increased beyond 80 feet, the weld quality deteriorated. By letter dated November 18, 2003, the staff requested that the BWRVIP provide information with respect to the application of underwater weld repairs at depths greater than 50 feet. The BWRVIP in its response dated July 30, 2004, stated that the underwater weld repairs that comply with the ASME Code requirements will be limited to a maximum depth of 50 feet for stainless steel and nickel-alloy welds. The staff believes that by successfully qualifying a WPS in accordance with the requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code, the licensees can perform underwater weld repairs on RVI components that are located at depths up to 50 feet.

This section of the BWRVIP-44 report addresses the development of the underwater weld overlay repair techniques on cracked stainless steel using the FCAW process in the flat welding position. The weld overlay repair technique was simulated in a test mock up which represented a typical crack configuration and this technique produced ASME Code quality welds when the crack width was maintained below a maximum threshold value during welding. ASME Code quality welds were produced when the width of the crack was maintained at a maximum value of 0.012 inches and the welding progression was parallel to the orientation of the crack. The maximum threshold value for the crack width was 0.144 inches when the welding direction of the repair welds was perpendicular to the crack orientation. The staff concludes that for

stainless steel and nickel alloy materials, a licensee can implement the guidelines (when necessary) developed in the BWRVIP-44 report, and should establish robust weld parameters and qualified WPSs, including the threshold limits for crack width that yields ASME Code quality welds.

Several tests were also performed to assess the effect of interpass cleaning (cleaning the weld bead prior to the deposition of the next weld bead) on the quality of the repair welds and the results indicated that the quality remained unchanged with and without cleaning when the repair welds were made in the flat position. However, for the welds that were made in horizontal position, the weld quality deteriorated due to lack of interpass cleaning. The staff concludes that in order to maintain ASME Code quality welds, interpass cleaning should be implemented for welds that are to be repaired in all welding positions other than flat.

In this section, the BWRVIP provided a detailed discussion as to how improper shielding gas nozzle orientation deteriorated the quality of the horizontal welds in stainless steel and nickel-alloy base materials and recommended corrective actions to prevent its recurrence. The staff believes that by complying with the BWRVIP's recommendations with respect to the shielding gas nozzle orientation the licensees can produce ASME Code quality welds.

The BWRVIP evaluated the inspectability of underwater repair welds by using ultrasonic testing (UT) and concluded that this technique can detect defects. Further, it recommended usage of an automated UT method to identify defects in repair welds. The staff finds the BWRVIP's assessment acceptable because the automated UT technique will enable the licensee inspect the welds with a minimum amount of radiation exposure to the workers and will enhance detection capabilities of defects.

The staff concludes that by implementation of the weld repair guidelines, including the limitations that are provided in this section, the licensees can develop weld repairs on the RVI components. The staff agrees that licensees can use the essential weld parameters, with limits that are specified in the repair guidelines of the BWRVIP-44 report, in the development and qualification of an appropriate WPS for repairing cracks in the RVI components. The staff finds that this section adequately addresses the underwater repair techniques for the RVI components, and as such, this section is acceptable as written.

3.5 Conclusion

In this section, the BWRVIP provides a brief synopsis of its accomplishment of the project objectives related to the development and ASME Code qualification of underwater weld repairs on stainless steel and nickel-alloy RVI materials using the FCAW process. In addition, it discusses the development of stainless steel and nickel-alloy weld filler materials and their application in successfully qualifying a WPS (using a groove weld joint) at a depth of 50 feet in accordance with the requirements of ASME XI Code Case N-516 and Section IX of the ASME Code. The BWRVIP also discusses its newly developed underwater weld repair techniques for cracked stainless steel base material and its application for potential in situ weld repairs in the RVI components. The staff finds that this section is acceptable as written because it adequately summarizes the development and qualifications of the underwater weld repair/replacement methods for the BWR RVI components.

4.0 CONCLUSIONS

The NRC staff has reviewed the BWRVIP-44 report and finds that the report provides acceptable guidelines for the development and qualification of underwater FCAW processes which comply with the requirements of ASME Section XI Code Case N-516 and Section IX of the ASME Code. The staff concludes that licensees can implement these guidelines for the development and qualification of underwater WPSs for stainless steel and nickel-alloy RVI materials at depths up to 50 feet. Each licensee shall be responsible for qualifying a suitable underwater WPS and welders in accordance with the requirements of ASME XI Code Case N-516 and Section IX of the ASME Code prior to performing any uderwater repair/replacement of the RVI components. As stated in Section 3.0 of this SE, the staff approved the use of the ASME Section XI Code Case N-516-2 for the underwater welding of irradiated materials provided the licensee obtains the staff's prior approval. Therefore, the staff concludes that the BWRVIP-44 report can be used for weld repair/replacement of irradiated materials provided the licensee obtains prior approval from the staff. The staff finds that the BWRVIP-44 report provides adequate guidelines for developing underwater weld overlay repair techniques for cracked stainless steel and nickel-alloy base materials. The staff concludes that each licensee can implement the guidelines (when necessary) developed in the BWRVIP-44 report, and should establish robust weld parameters and qualified WPSs, including the threshold limits for crack width that yields ASME Code quality welds. The BWRVIP-44 report is considered by the staff to be acceptable for use by a licensee at any time during either a facility's current operating term or during the extended license period.