SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BOILING WATER REACTOR VESSEL AND INTERNALS PROJECT (BWRVIP)

REPORT 1003020 (BWRVIP-97): "BWR VESSEL AND INTERNALS PROJECT, GUIDELINES

FOR PERFORMING WELD REPAIRS TO IRRADIATED BWR INTERNALS"

BOILING WATER REACTOR VESSEL AND INTERNALS PROJECT

PROJECT NO. 704

1.0 INTRODUCTION

1.1 Background

By letter dated November 27, 2001 (Agencywide Documents and Access Management System (ADAMS) Accession No. ML013340587) as supplemented by letters dated July 25, 2005 (ADAMS Accession No. ML052080227) and October 5, 2006 (ADAMS Package No. ML062850106), the Electric Power Research Institute (EPRI) submitted for NRC staff review and approval BWRVIP report 1003020, "BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals" (BWRVIP-97). By letter dated May 23, 2003, EPRI submitted a non-proprietary version of BWRVIP-97 (ADAMS Accession No. ML031480070). BWRVIP-97 was submitted as a means of exchanging information with the NRC staff for the purpose of supporting generic regulatory improvements related to the repair of irradiated BWR reactor vessel internal (RVI) components. BWRVIP-97 provides a methodology to determine if the irradiated materials can be successfully repaired by using a suitable welding technique. BWRVIP-97 provides guidance on the selection and use of a suitable welding technique for the repair/replacement of irradiated RVI components.

1.2 Purpose

The NRC staff reviewed BWRVIP-97 to determine whether it will provide an acceptable technical justification for the selection and use of a proper welding technique for repair/replacement of irradiated RVI components. The report also addresses general guidelines for determining the weldability of irradiated materials considering, in particular, concerns regarding susceptibility to cracking due to the presence helium in the material. Helium is produced due to interaction of thermal neutrons ($E < 0.5$ eV) with elements (i.e., boron and nickel) that are present in irradiated stainless steel RVI components. Helium concentrations depend on the initial concentration of boron and nickel in the base metal and the amount of helium present increases when concentrations of boron and nickel increase in the component.

ENCLOSURE

BWRVIP-97 provides extensive guidelines for determining the weldability of the irradiated materials based on helium content and the weld heat input associated with any given welding technique.

1.3 Organization of this Report

A summary of the subject report is given in Section 2.0 of this safety evaluation (SE), an evaluation is presented in Section 3.0, and the conclusions are summarized in Section 4.0. The presentation of the evaluation is structured according to the organization of BWRVIP-97.

2.0 SUMMARY OF BWRVIP-97 REPORT

BWRVIP-97 addresses the following topics in the following order:

- Background – Section 1 of BWRVIP-97 provides objective for developing guidelines, including the establishment of a "weldability boundary" and welding techniques for the irradiated materials in RVI components.

- Definition of Weldability Boundary – Section 2 of BWRVIP-97 discusses the definition of a generic weldability boundary (assuming conservative values of boron and nickel concentrations) which is based on the helium concentration in atomic parts per million (appm) and the base metal exposure to thermal neutrons, which can be related to number of effective full power years (EFPY) of plant operation. BWRVIP-97 states that the RVI components that are within the generic weldability boundary can be welded using conventional welding techniques without any verification of their helium content.

- Determination of Helium Content – Section 3 of BWRVIP-97 provides guidelines for determining the helium content in irradiated materials. This section addresses methodologies that can be used to determine helium content in irradiated material that is to be welded. These methods may be used to qualify a component which falls outside the generic weldability boundary for repair by welding. One of the methods is designed to calculate helium concentration based on the thermal neutron fluence values. The other method deals with laboratory measurements on an irradiated sample from the component that requires weld repair. Assessment of helium content in irradiated materials is crucial in the development of successful weld repairs.

- Applicability of Welding Techniques – Section 4 of BWRVIP-97 discusses guidelines for establishing the "weldability border" for irradiated materials. A weldability border is established based on research results in which a clear demarcation is present between cracking and no cracking zones. The weldability border is based on application of weld heat input (in kj/cm) associated with any given welding technique and the helium content in irradiated materials. Section 4 provides bounding values for the welding heat input and for the helium content in RVI components falling outside of the generic weldability boundary. Compliance with these values is essential in successfully welding irradiated materials.

- Welding Guidelines Summary – Section 5 of BWRVIP-97 provides extensive guidelines regarding the qualifications of weld procedures and welders, inspection requirements for the welds, and the acceptance criteria for the inspection.

3.0 EVALUATION

BWRVIP-97 provides guidance for utilities and a methodology that can be used to establish a suitable welding technique to perform weld repairs on irradiated components. Historically, stainless steel materials in RVI components experience intergranular stress corrosion cracking (IGSCC) in the sensitized heat affected zone (HAZ) near the weld region and in stainless steel weld metals with lower delta ferrite content. Therefore, some of these RVI components need to be repaired in order to maintain adequate structural integrity under normal service conditions. When a weld repair is to be performed on a RVI component that is located in a region of high thermal neutron fluence, implementation of an acceptable repair may become difficult. In regions with a high thermal neutron fluence, weldability may be significantly affected by the presence of insoluble helium in irradiated base metals. Helium is produced due to the interaction of thermal neutrons with elements (i.e., boron and nickel) that are present in irradiated stainless steel RVI components. In addition to providing a generic list of components which may be repaired by conventional welding techniques (i.e., those components within the generic weldability boundary), BWRVIP-97 provides guidelines for establishing the helium content in irradiated stainless steel materials, describes various welding techniques that can be successfully used for welding irradiated stainless steel materials, and summarizes welding guidelines for irradiated stainless steel materials.

The NRC staff previously reviewed EPRI report 108198, “BWR Vessel and Internals Project, Technical Basis For Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping” (BWRVIP-34) submitted on May 22, 1997, to the NRC. The NRC staff reviewed and approved BWRVIP-34 in its SE dated June 27, 2007 (ADAMS Accession No. ML071790313). For discussions related to weldability of irradiated materials, Section 5.0 of BWRVIP-34 references BWRVIP-97. In the SE for BWRVIP-34, the NRC staff reiterated that the BWRVIP will provide guidance and discussions regarding weldability of irradiated materials in BWRVIP-97. While reviewing BWRVIP-34, the NRC staff initiated several questions as part of a request for additional information (RAI) dated October 7, 2004 (ADAMS Accession No. ML042880139) that are related to weldability issues associated with irradiated core spray materials. Since those RAI questions are relevant to the evaluation of BWRVIP-97, the NRC staff will discuss all the weldability issues that are related to the irradiated RVI components, including the responses to those RAI questions which were sent by letter dated November 1, 2004 (ADAMS Accession No. ML043090015).

3.1 Background

Section 1 of BWRVIP-97 addresses the need for performing weld repairs on irradiated stainless steel components which experience IGSCC and provides examples of various RVI components that may potentially require weld repairs. As stated above, helium in stainless steel base metal can play a major role in affecting the quality of a weld repair. In Section 1 a brief discussion is also provided regarding the determination of helium content in irradiated stainless steel components. The objective for developing guidelines includes establishment of a weldability boundary and identification of effective welding techniques for the irradiated RVI components.

3.2 Definition of Weldability Boundary

Section 2 of BWRVIP-97 establishes a threshold value of helium for use in assessing the weldability of any given irradiated stainless steel material. This value was selected conservatively to ensure crack-free stainless steel welds when the helium content of the base materials is below a threshold limit. Based on previous data, it was concluded that irradiated stainless steel materials with a helium content below the value indicated in Section 2.2 of BWRVIP-97 can be repair welded without any cracks using conventional welding techniques. The BWRVIP selected a conservative threshold limit with additional margin as the basis for establishing the generic weldability boundary discussed below. The NRC staff agrees with the selection of a conservative threshold limit for helium. This threshold ensures that proper implementation of conventional welding techniques on irradiated stainless steel RVI components with a helium content below this threshold limit will not result in cracking. However, special welding techniques need to be considered when the helium content exceeds this threshold. These techniques include low heat input welding processes.

In Section 2 of BWRVIP-97, the BWRVIP defines a generic weldability boundary (assuming conservative values for the boron and nickel concentrations) which is based on two factors: the helium concentration and the base metal exposure to thermal neutrons, which can be related to the number of EFPYs of plant operation. Tables 2-1, 2-2, and 2-3 of BWRVIP-97 list the helium concentrations found in different RVI components at the Susquehanna Steam Electric Station (SSES) based on EFPY values. BWRVIP-97 categorizes the following RVI components at SSES (shown in Table 2-3 of BWRVIP-97) as within the generic weldability boundary because the projected helium content in these components is below the threshold limit. The helium content of the RVI components listed in Table 2-3 of BWRVIP-97 was predicted using conservative maximum values of boron (20 parts per million (ppm)) and nickel (14 percent). Typically, austenitic stainless steels have concentrations of boron and nickel that are considerably below these values. The BWRVIP proposes that the RVI components listed in Table 2-3 of BWRVIP-97 in any BWR unit can be welded using conventional welding techniques without any verification of their helium contents.

By letter dated January 8, 2003 (ADAMS Accession No. ML030130330), the NRC staff issued an RAI regarding several BWRVIP reports including BWRVIP-97. By letter dated July 25, 2005, the BWRVIP responded to the RAI questions. One of the RAI questions, RAI 97-4, addressed the threshold limit for helium content for RVI components that are within the generic weldability boundary. The NRC staff requested that the BWRVIP provide an explanation of how the information shown in Table 2-3 of BWRVIP-97 is applicable to other BWR plants. The BWRVIP responded to RAI 97-4 by stating that the helium content of RVI components in other BWR plants will be different from the examples provided in Table 2-3. However, establishing a conservative threshold limit for the helium concentration ensures crack-free welds of sound quality for the RVI components within the generic weldability boundary when conventional welding techniques are used. Therefore, the data presented by Table 2-3 in BWRVIP-97 can be used as a guide for implementing a conventional welding technique for RVI components classified as within the generic weldability boundary at other BWR plants. The NRC staff finds this response acceptable because the selection of a helium threshold limit that is conservative by two orders of magnitude bounds the expected plant-to-plant variability in helium concentration for components that are within the generic weldability boundary. Therefore, the NRC staff considers that its concern expressed in RAI 97-4 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

Another RAI question, RAI 97-3, sent by letter dated January 8, 2003, requested that the BWRVIP provide an explanation regarding how maximum allowable values for boron were selected in establishing the generic weldability boundary based on the SSES model, since the presence of boron in irradiated materials affects their weldability. (Helium is produced due to the interaction of thermal neutrons with boron and nickel in irradiated stainless steel RVI components). By letter dated July 25, 2005, the BWRVIP responded to RAI 97-3 by providing three sets of data containing various boron concentrations that are typically present in type

304/316 stainless steel materials. The most conservative value from these sets was used in calculating the helium concentration for various SSES components. The NRC staff reviewed the BWRVIP's response to RAI 97-3 and finds it acceptable because the generic weldability boundary was established by taking into account the most conservative expected boron concentration (20 ppm) in austenitic stainless steel. Therefore, the NRC staff considers its concern related to RAI 97-3 to be resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

Section 2 of BWRVIP-97 also provides details on how helium causes cracking at the grain boundaries when the helium concentration threshold is exceeded and explains the need for using a welding technique with a low heat input in order to avoid cracking in the HAZ. Helium generally accumulates at the grain boundaries and can degrade the cohesion between adjacent grains, especially in the HAZ.

The NRC staff accepts the BWRVIP's selection of the generic weldability boundary for the aforementioned RVI components because: (1) the helium content is projected using the maximum allowable values for boron and nickel that are typically present in a commercial austenitic stainless steel material and these values are conservative for the RVI components in any BWR unit and (2) implementation of a conservative method for projecting the helium content, in conjunction with the selection of a conservative threshold limit for helium, will provide added assurance that the RVI components can be successfully welded using conventional welding techniques without any verification of their helium contents.

3.3 Determination of Helium Content

As stated in Section 3.2 of this SE, verification of the helium content is not necessary for RVI components that are classified as lying within the generic weldability boundary. In any BWR unit, components within the generic weldability boundary can be welded using conventional welding techniques. However, the helium content should be determined to ensure adequate weldability of any irradiated material in RVI components that is outside of the generic weldability boundary. In Section 3 of BWRVIP-97, the BWRVIP provides guidelines for determining the helium content of the subject material, which can be accomplished either by calculation or measurement. In Section 3, BWRVIP-97 also provides formulae for calculating the helium concentration based on the boron concentration, nickel concentration and the thermal neutron fluence value. The helium concentration can also be measured by removing small shavings from the irradiated material to be welded and analyzing them for helium content. Boron concentration values obtained from sample measurements are less prone to uncertainties and tend to be more accurate than calculated values.

By letter dated March 18, 2004 (ADAMS Accession No. ML040850345), the NRC staff issued an RAI with questions including RAI 97-11, which requested that the BWRVIP provide specific guidelines for measuring helium content in irradiated RVI components. The BWRVIP responded to RAI 97-11 in a letter dated July 25, 2005. The BWRVIP stated that it had developed guidelines for measuring helium as part of the development of EPRI report 1003019, "BWR Vessel and Internals Project, Sampling and Analysis Guidelines for Determining Helium Content of Reactor Internals," (BWRVIP-96) which was sent by letter dated November 29, 2001 (ADAMS Accession No. ML013390174). The NRC staff reviewed and approved BWRVIP-96 in an SE dated February 25, 2005 (ADAMS Accession No. ML050660350). Section 3 of BWRVIP-97 references BWRVIP-96 for the methodology for measuring helium in irradiated components. Therefore, NRC staff considers that its concern related to RAI 97-11 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

3.4 Applicability of Welding Techniques

Section 4 of BWRVIP-97 discusses weldability studies on irradiated stainless steel base metals using various welding techniques. Figure 4-1 in Section 4 delineates the effect of helium on cracking as a function of welding heat input. This data was obtained from experimental results in which cracking tendencies due to the presence of helium were observed in irradiated samples. A weldability border Figure 4-1 shows a clear demarcation between cracking and no-cracking zones. This weldability border was developed using data from the following welding techniques: (1) gas tungsten arc welding (GTAW), (2) yttrium-aluminum-garnet (YAG) laser welding and, (3) gas metal arc welding (GMAW). Figure 4-1 may be used for RVI components that are outside the generic weldability boundary as discussed in Section 3.2 of this SE.

The weldability border should be used by implementing the following methods: (1) the helium content of the RVI component should be determined by one of the methods described in Section 3 of BWRVIP-97 and, (2) the optimum weld heat input should be selected based on the helium content to ensure crack-free welds. The weldability border was conservatively established (as described in Section 4.2.1 of BWRVIP-97) based on the helium content that produces crack-free welds. The NRC staff reviewed this data and finds it acceptable because the weldability border is selected with extra margin to ensure crack-free welds provided that an optimum weld heat input is used.

Experimentally, it is possible to introduce helium in a welded test sample without exposing it to any radiation using a method called the “tritium trick” method. Tritium is introduced into the sample by heating it to an elevated temperature under pressure. Helium is produced in the test sample due to the radioactive decay of tritium. When the sample is cooled, residual tritium diffuses out leaving behind the helium.

By letter dated January 8, 2003, the NRC staff sent RAI question RAI 97-1 to the BWRVIP. RAI 97-1 identified the NRC staff concern that for any given welding process, the welded samples of helium-containing irradiated stainless steel showed more extensive cracking than non-irradiated welded samples of stainless steel with the same helium concentration developed utilizing the tritium trick method. The results show that the extent of cracking in the former was 28 to 31 times greater than that found in the latter. The NRC staff further noted that the threshold limits for helium that were determined by using tritium trick samples were less conservative than those determined by using the irradiated stainless steel samples. Therefore, the NRC staff requested that the BWRVIP justify the use of tritium trick samples to determine the helium threshold limit for irradiated RVI components. The BWRVIP responded to RAI 97-1 in a letter dated July 25, 2005, by stating that the tritium trick samples were not used for establishing the weldability border as described in Figure 4-1 of BWRVIP-97. The NRC staff accepts this response because the weldability border was established by using the more conservative test data from irradiated weld samples. Therefore, the NRC staff considers that its concern related to RAI 97-1 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

The welded samples developed using the tritium trick method were not used for developing the weldability border as they do not represent the true characteristics of the degraded microstructure that is typically present in an irradiated stainless steel material. The NRC staff sent RAI question 97-5 by letter January 8, 2003. The BWRVIP responded to RAI 97-5 by letter dated July 25, 2005, and agreed to replace Figure 4-1 with two figures (attached to the response letter dated July 25, 2005) in BWRVIP-97-A. These figures address the weldability border. One of them addresses data from irradiated materials and the other figure (which is not used for establishing the weldability border) addresses data from samples developed using the tritium trick method. The NRC staff accepts this response and considers that its concern related to RAI 97-5 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

The NRC staff sent RAI question 97-6 by letter dated January 8, 2003, requesting that the BWRVIP provide justification for drawing the crack/no-crack boundary as shown in Figure 4-1 for the irradiated materials. By letter dated July 25, 2005, the BWRVIP responded to RAI 97-6 and listed five data points which were used for developing the crack/no-crack boundary. As described previously, this boundary was established using a helium threshold limit which includes a factor of two conservatism for a given weld heat input. The NRC staff accepts this response because the selection of a conservative helium threshold limit provides adequate margin in producing crack-free welds. The NRC staff, therefore, considers that its concern related to RAI 97-6 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

The weldability border is function of weld heat input and helium concentration. In this context, the NRC staff, in RAI 97-8 sent by letter dated January 8, 2003, requested that the BWRVIP provide an explanation how the weldability border can be used when irradiated materials are welded with welding techniques other than GTAW or YAG laser welding. By letter dated July 25, 2005, the BWRVIP responded to RAI 97-8 by stating that once a certain heat input is found to be suitable for one welding technique, this heat input can also be used for any other welding technique. Sound welds can be produced with various welding techniques as long as the heat input is selected to avoid any cracking in the presence of helium. This explanation is supported by the data shown in the attached Figure 1 of the July 25, 2005, submittal. The NRC staff reviewed the data and concludes that for any given helium concentration in irradiated materials, an optimum weld heat input should be used to produce crack-free welds. Therefore, different welding techniques can be used with controlled heat input for RVI components outside the generic weldability boundary (as discussed in Section 3.2 of this SE) provided that the threshold limit for helium is not exceeded. The NRC staff, therefore, accepts this response and considers that its concern related to RAI 97-8 is resolved when the BWRVIP includes its response to this RAI in its issuance of BWRVIP-97-A.

By letter dated March 18, 2004, the NRC staff issued an RAI with questions including RAI 97-10, which requested that the BWRVIP discuss the effect of physical restraint on the weldability of irradiated materials. Physical restraints on a weld joint can create additional stresses which enhances the tendency for cracking when the base material thickness increases. By letter dated July 25, 2005, the BWRVIP responded RAI 97-10, by stating that the weldabilty border was developed to bound all types of weld joint configurations and included additional emerging data which indicated that successful welds have been made on a thick material (approximately 1 inch thick) with a GTAW process. The welding heat input used for welding the thick material exceeded the bounding value specified in the weldabilty border shown in Figure 4-1 of BWRVIP-97. Based on the data obtained thus far, the BWRVIP concludes that the weldability border is conservative with respect to the condition of physical restraint. The NRC staff accepts this response because typical production joints of the RVI components with certain physical restraints can be welded provided that the heat input does not exceed the bounding value established by the weldabilty border. In addition, the NRC staff believes that the weldability border in Figure 4-1 provides adequate guidelines for selecting the welding technique with an optimum heat input to ensure crack-free welds. Since the weld heat input shown in Figure 4-1 is bounding, the NRC staff concludes that RVI components with a typical weld joint design can be successfully repair-welded using an optimum weld heat input per

Figure 4-1. The NRC staff, therefore, accepts this response and considers that its concern related to RAI 97-10 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

By letter dated August 7, 2006 (ADAMS Accession No. ML062300251), the NRC staff sent supplemental RAI questions to the BWRVIP regarding BWRVIP-97, including Supplemental RAI 97-1 (initially written with respect to BWRVIP-34). By letter dated October 5, 2006, the BWRVIP responded to Supplemental RAI 97-1 by stating that BWRVIP-97 adequately addresses the effect of the presence of helium on welding repairs in irradiated materials and provides guidance to prevent cracking. Since Section 5.0 of BWRVIP-34 references BWRVIP-97 for welding irradiated materials, the BWRVIP concluded that it is not necessary to revise BWRVIP-34 and BWRVIP-97. The NRC staff agrees with this response and concludes that irradiated base materials can be successfully welded when suitable welding techniques are implemented (with the controlled heat input specified in BWRVIP-97). Therefore, the NRC staff considers that its concern related to Supplementary RAI 97-1 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

Another RAI question sent by letter dated August 7, 2006, was Supplemental RAI 97-2. Generally, stainless steel welds contain ferrite which can cause thermal embrittlement at ferrite numbers (FN) exceeding 20. The NRC staff in Supplemental RAI 97-2 (initially written with regard to BWRVIP-34) requested that the BWRVIP discuss the synergistic interactions between thermal embrittlement and irradiation embrittlement in stainless steel weld overlays. By letter dated October 5, 2006, the BWRVIP responded to Supplemental RAI 97-2 by stating that the ferrite content in future stainless steel weld overlays will be limited to a conservative value, thereby reducing the potential for degradation due to thermal embrittlement. The BWRVIP further reiterated that original construction welds that have been in service for 20-25 years could contain ferrite contents much higher than those being proposed by the BWRVIP. Since these welds did not show any cracking thus far, it can be concluded that they are not susceptible to thermal embrittlement. The NRC staff agrees with the BWRVIP and concludes that weld repairs (including the weld overlays) which limit the ferrite content to a conservative value will not be prone to thermal embrittlement because operating experience in the BWR fleet thus far revealed no cracking in similar welds with much higher ferrite contents with 20-25 years of service time, which suggests that these welds are not prone to aging degradation due to thermal embrittlement. Therefore, the NRC staff concludes that synergistic interactions between thermal embrittlement and irradiation embrittlement in stainless steel welds (including repair welds) may be considered negligible. The NRC staff, however, reiterates that compliance with the welding guidelines in BWRVIP-97 is mandatory for ensuring that irradiation embrittlement in stainless steel weld repairs, including weld overlays, is minimized. Therefore, the NRC staff considers that its concern related to Supplemental RAI 97-2 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

By letter dated November 1, 2004, the BWRVIP responded to NRC staff Supplementary RAI 6-3, part (a) (initially written with regard to BWRVIP-34 in a letter dated October 7, 2004) by stating that BWRVIP-34 references BWRVIP-97 for issues related to the weldability of irradiated materials. The NRC staff accepts this response because implementation of BWRVIP-34 will require use of the guidelines in BWRVIP-97, which will minimize cracking in welds. Since BWRVIP-97 addresses the weldability of irradiated RVI components, the NRC staff considers that its concern related to Supplementary RAI 6-3, part (a), is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

By letter dated July 25, 2005, the BWRVIP responded to the three issues raised in RAI 34-A-4 (initially written with respect to BWRVIP-34). With respect to the first issue, the BWRVIP agreed with the NRC staff and committed to including a statement that welding of irradiated materials will be per BWRVIP-97. Regarding the second issue, the BWRVIP stated that in Section 3 of BWRVIP-97 the issue of removal of irradiated samples to estimate their helium content for use in assessing the weldability of RVI components is already addressed. Since BWRVIP-97 addresses these issues, the NRC staff considers that these two issues stated in RAI 34-A-4 are adequately resolved and, as such, finds them acceptable when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

With respect to its response to the third issue in RAI 34-A-4, which is related to the application of finite element analysis to the weldability assessment of irradiated materials, the BWRVIP stated that the industry is currently conducting research regarding this issue. The BWRVIP will submit the emerging data to the NRC staff when it is available. The NRC staff reviewed this response and requests the BWRVIP to revise BWRVIP-97 to include the emerging information related to this research as it becomes available.

Another RAI question addressed by the BWRVIP letter dated July 25, 2005, is RAI 97-2. In response to RAI 97-2, the BWRVIP addressed the effect of six variables on helium embrittlement during the welding of irradiated stainless steel materials. The three primary variables are helium content, temperature and stress, and the secondary variables are metallurgical condition, compositional gradient in the alloy, and time at temperature. So far, the weldability of irradiated stainless steel materials has been assessed based on the helium content and weld heat input. Conservative selection of optimum welding heat input based on the helium content ensures sound welds despite the fact that the remaining four other variables (stress, metallurgical condition, compositional gradient in alloy, and time at temperature) were not considered in the weldability assessment. The BWRVIP, however, stated that it will submit emerging data to the NRC staff on the effect of the aforementioned four variables on weldability as it becomes available. The NRC staff reviewed this response and requests the BWRVIP to revise BWRVIP-97 to include the emerging information related to this research as it becomes available.

Another RAI question addressed by the BWRIVP letter dated July 25, 2005, is Supplementary RAI 97-9. This RAI question addressed the effect of dry or underwater welding on the mechanical properties of irradiated stainless steel materials. In response to Supplementary RAI 97-9, the BWRVIP stated that data addressing this specific issue have not been available to date. However, the BWRVIP stated that general results obtained thus far suggest that the as-welded mechanical properties of irradiated stainless steel materials meet the criteria contained in ASME Code, Section III, “Rules for Construction of Nuclear Facility Components.” The NRC staff accepts this response because when the as-welded mechanical properties of irradiated stainless steel materials conform to the criteria found in ASME Code, Section III, it ensures that these welds can sustain service loads under normal operation. For underwater welds, enhanced cooling in the welds will prevent growth of helium bubbles which cause cracking and, therefore, make them less prone to cracking than the welds made in dry conditions. The NRC staff reviewed this response and requests the BWRVIP to revise BWRVIP-97 to include emerging information regarding this issue as it becomes available.

3.5 Welding Guidelines Summary

Section 5 of BWRVIP-97 summarizes the methodology for determining the weldability, qualification tests, inspections and analysis of the welds performed on irradiated materials. These attributes shall be satisfied in order to obtain sound welds in irradiated materials.

BWRVIP-97 recommends the following methodology in determining weldability for the irradiated RVI components:

(1) A convenional welding technique can be used for welding on any component within the generic weldability boundary, which is defined in Section 3.2 of this SE.

(2) For RVI components outside the generic weldability boundary, but with exposure to thermal neutron fluence values described in Section 5 of BWRVIP-97, conventional welding techniques may still be used.

(3) For RVI components outside the generic weldability boundary, and with exposure to thermal neutron fluence values described in Section 5 of BWRVIP-97, the following two options may be used: (a) weldability can be determined by estimating helium concentration or, (b) weldability can be determined by testing the helium concentration at the location of interest prior to welding (details of the testing are found in Section 5.1 of BWRVIP-97).

The NRC staff reviewed this methodology and found it acceptable because: (1) the conservative selection of a welding process based on helium concentration ensures crack-free welds and (2) successful testing of the helium concentration prior to welding ensures the production of good quality welds in irradiated stainless steel RVI components found outside the generic weldability boundary and which are exposed to thermal neutron fluence values described in Section 5 of BWRVIP-97.

To ensure sound welds, adequate mechanical tests of the weld joints in irradiated materials need to be conducted. Section 5 of BWRVIP-97 provides guidelines for the mechanical testing of the welds. The guidelines in Section 5 mandate the use of ASME Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," for welding procedures and weld operator qualifications. In addition, Section 5 of BWRVIP-97 mandates the use of ASME Code Case N-516-3, "Underwater Welding, Section XI, Division 1," for underwater welding of the irradiated materials. The NRC has recently approved the use of Code Case N-516-3, with certain limitations, as documented in Regulatory Guide 1.147, Revision 15, "Inservice Inspection Code Case Applicability, ASME Section XI, Division 1" (ADAMS Accession No. ML072070419). Therefore, the BWRVIP should reference Code Case N-516-3, subject to the limitations identified in Regulatory Guide 1.147, Revision 15, in the approved version ("-A") of BWRVIP-97.

In addition to the ASME Code qualifications, additional required qualification tests are addressed in Section 5.2 of BWRVIP-97. These additional tests provide a sound basis for assessing the weldability of RVI components. The NRC staff reviewed these guidelines and concludes that licensees which reference BWRVIP-97 shall comply with the recommendations contained in Section 5.2 of BWRVIP-97, in some cases prior to welding, to ensure that sound welding techniques are used in producing crack-free welds.

Since the potential for cracking exists in RVI repair welds, BWRVIP-97 recommends that, in addition to the required ASME Code inspections, inspections of the new HAZ areas should be inspected using one of three inspection methods: a high magnification visual examination technique (also known as enhanced visual testing (EVT-1)), a surface examination, or a volumetric examination (i.e., ultrasonic testing (UT)). By letter dated January 8, 2003, the NRC staff sent RAI question RAI 97-7 to the BWRVIP. RAI 97-7 asked questions regarding the inspection methods for repair welds contained in BWRVIP-97. By letter dated July 25, 2005, the BWRVIP responded to RAI 97-7 by stating that it will recommend surface examination or UT examination for repair welds where possible. However, for some welds where the configuration makes UT examination infeasible (e.g. fillet welds), the BWRVIP recommends EVT-1 visual examination. The NRC staff accepts this response and considers that its concern related to RAI 97-7 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

Cracking due to the presence of helium is typically observed in the HAZ immediately after the fabrication of the weld. BWRVIP-97 recommends that after the weld repair is installed, additional inservice inspection should be performed during the next re-fueling outage to ensure that no cracking or crack extension has occurred during the most recent operating interval. BWRVIP-97 further recommends that flaws that are identified in the welds should be analyzed using the criteria from ASME Code, Section XI. The NRC staff accepts these recommendations because they provide adequate assurance that flaws in these welds can be identified in a timely manner so that corrective actions can be taken by the licensee to restore the functionality of the RVI component.

Since embedded (or underbead) cracking can occur in these welds, the NRC staff, by letter dated October 7, 2004 (initially written with regard to BWRVIP-34), sent RAI question Supplementary RAI 7-1 which requested that the BWRVIP provide an explanation of how the inspection methods will identify the embedded cracks by using ASME Code, Section XI. By letter dated July 25, 2005 (the original response to this RAI question sent by letter date November 1, 2004, deferred resolution of the issue to the review of BWRVIP-97) the BWRVIP responded to Supplementary RAI 7-1 (identified as RAI-34-7.1 in the letter dated July 25, 2005) by stating that, in addition to the inspection requirements addressed in ASME Code, Section XI, BWRVIP-97 requires visual (EVT-1), surface, or UT examination for the repair welds. Therefore, the BWRVIP concluded that any of these examinations will adequately identify the potential weld flaws in the repaired component. The BWRVIP further stated that for a given irradiated component that lies outside the generic weldability boundary, cracks are less likely to occur in the weld region if the weld heat input is maintained within the bounding values specified by the weldability border shown in Figure 4-1 of BWRVIP-97. The NRC staff reviewed the BWRVIP's response to Supplementary RAI 7-1 and concludes that since the weld repairs are restricted to irradiated materials that follow the guidance identified in Figure 4-1 and Section 4 of BWRVIP-97, cracking is unlikely to occur in the welds and their HAZ areas. Additionally, since the cracking is generally observed immediately after the fabrication of the weld, they can be detected through visual examination after welding. Therefore, the NRC staff considers that its concern related to Supplementary RAI 7-1 is resolved when the BWRVIP includes its response to this RAI question in its issuance of BWRVIP-97-A.

4.0 CONCLUSION

The NRC staff has reviewed BWRVIP-97 and the supplemental information that was transmitted to the NRC staff by letters dated November 27, 2001, November 1, 2004, July 25, 2005, and October 5, 2006, and found that BWRVIP-97, as modified and clarified to incorporate the NRC staff's comments above, is acceptable for providing guidance for determining the weldability of irradiated RVI components. Therefore, the NRC staff has concluded that implementation of the guidelines in BWRVIP-97, as modified to incorporate the resolution of the RAI questions as discussed in this SE, will provide an acceptable technical basis for the design of weld repairs based on the helium content of irradiated RVI components. In addition, these guidelines provide extensive information with respect to the selection of a suitable welding technique so that sound repair welds can be made in irradiated RVI components.

As a condition of NRC staff acceptance of BWRVIP-97, the BWRVIP should revise BWRVIP-97 to include following items:

(1) Emerging information (when available) regarding the application of finite element analysis for the weldability assessment of irradiated materials.

(2) Emerging information (when available) regarding the effect of stress, metallurgical condition, compositional gradient in the alloy, and time at temperature on weld repairs in irradiated materials.

(3) Emerging information (when available) regarding the effect of dry or underwater welding on the mechanical properties of the irradiated stainless steel materials.

(4) Reference to ASME Code Case N-516-3, with associated limitations as described in Regulatory Guide 1.147, Revision 15, in lieu of ASME Code Case N-516-1, in the "-A" version.

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