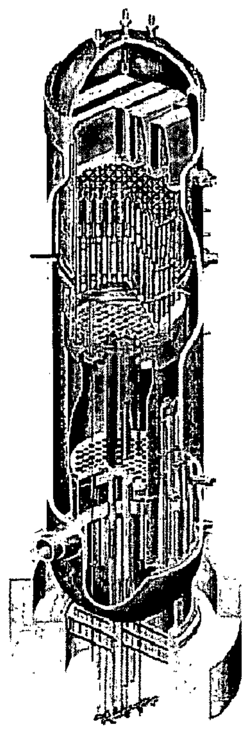
ELECTRIC POWER RESEARCH INSTITUTE

BWRVIP-97NP-A: BWR Vessel and Internals Project

Guidelines for Performing Weld Repairs to Irradiated BWR Internals



BWRVIP-97NP-A: BWR Vessel and Internals Project

Guidelines for Performing Weld Repairs to Irradiated BWR Internals

1019054NP

Final Report, October 2009

EPRI Project Manager
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NRC SAFETY EVALUATION

In accordance with an NRC request, the NRC Safety Evaluation immediately follows this page. Other NRC and BWRVIP correspondence on this subject are included in appendices.

Note: The changes proposed by the NRC in this Safety Evaluation as well those proposed by the BWRVIP in response to NRC Requests for Information have been incorporated into the current version of the report (BWRVIP-97-A).

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 30, 2008

Rick Libra
Exelon
Chairman, BWR Vessel and Internals Project
Electric Power Research Institute
3420 Hillview Avenue
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SUBJECT: SAFETY EVALUATION FOR ELECTRIC POWER RESEARCH INSTITUTE (EPRI) BOILING WATER REACTOR (BWR) VESSEL AND INTERNALS PROJECT (BWRVIP) REPORT 1003020 (BWRVIP-97) "BWR VESSEL AND INTERNALS PROJECT, GUIDELINES FOR PERFORMING WELD REPAIRS TO IRRADIATED BWR INTERNALS" (TAC NO. MC3948)

Dear Mr. Libra:

By letter dated November 27, 2001, as supplemented by letters dated July 25, 2005, and October 5, 2006, the EPRI submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval BWRVIP report 1003020 (BWRVIP-97), "BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals." By letter dated May 23, 2003, EPRI submitted a non-proprietary version of BWRVIP-97. By letters dated January 8, 2003, March 18, 2004, and August 7, 2006, the NRC staff sent the BWRVIP requests for additional information (RAIs) for several BWRVIP reports including BWRVIP-97. In addition, by letter dated October 7, 2004, the NRC staff sent an RAI regarding EPRI report 108198 (BWRVIP-34), "Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Spray Piping," as it was relevant to the review of BWRVIP-97.

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.

The NRC staff has reviewed BWRVIP-97 and finds that this BWRVIP report is acceptable for referencing in licensing documentation for General Electric-designed boiling water reactors to the extent specified and under the limitations delineated in the BWRVIP report and in the enclosed SE. The SE defines the basis for our acceptance of the BWRVIP-97.

Our acceptance applies only to material provided in the subject BWRVIP report. We do not intend to repeat our review of the acceptable material described in the BWRVIP report. When the BWRVIP report appears as a reference in licensing documentation, our review will ensure that the material presented applies to the specific plant involved. Licensees will be expected to implement the provisions of BWRVIP-97, subject to the limitations in the enclosed SE, as part of their BWRVIP program unless deviations from the requirements are justified. Licensees shall identify such deviations to the NRC staff in accordance with BWRVIP program requirements.

In accordance with the guidance provided on the NRC website, we request that the BWRVIP publish accepted proprietary and non-proprietary versions of this BWRVIP report within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC staff RAIs and the responses. The accepted versions shall include an "-A" (designating accepted) following the BWRVIP report identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this BWRVIP report, the BWRVIP and/or licensees referencing it will be expected to revise the BWRVIP report appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

Mark J. Maxin, Acting Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 704

Enclosure: Safety Evaluation

cc w/ encl: See next page

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3/13/08

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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

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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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Date: June 30, 2008

CITATIONS

This report was prepared by

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Palo Alto, CA 94304

This report describes research sponsored by EPRI and its participating BWRVIP members.

The report is a corporate document that should be cited in the literature in the following manner:

BWRVIP-97NP-A: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals, EPRI, Palo Alto, CA: 2009. 1019054NP.

This report is based on the following previously published report:

BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals, EPRI, Palo Alto, CA: 2001. 1003020, authored by Structural Integrity Associates, principle investigators B. Gordon and A. Giannuzzi.

REPORT SUMMARY

The BWR Vessels and Internals Project (BWRVIP), formed in 1994, is an association of utilities focused on boiling water reactor (BWR) vessel and internals issues. Between 1994 and 1998, BWRVIP developed a set of Repair Design Criteria guidelines for BWR internal components. This BWRVIP report supplements those guidelines by providing additional information related to performing welded repairs on irradiated components. A previous version of this report was published as BWRVIP-97 (1013020). This report (BWRVIP-97-A) incorporates changes proposed by the BWRVIP in response to U.S. Nuclear Regulatory Commission (NRC) Requests for Additional Information, recommendations in the NRC Safety Evaluation (SE) and other necessary revisions identified since the previous publication of the report. All changes except typographical errors are marked with margin bars. In accordance with a NRC request, the SE is included in the report front matter and additional NRC correspondence is included as appendices. The report number includes an "A" indicating the version of the report accepted by the NRC staff.

Background

The BWRVIP Repair Design Criteria documents were developed to provide guidance to utilities for designing, fabricating, and installing repairs to BWR internal components. Both mechanical and welded repairs are addressed. However, at the time the reports were developed, information was not available in sufficient detail to appropriately address welded repair of irradiated components. Welding on irradiated material, if not done properly, can result in cracking due to release of helium gas that may be contained in the material.

Objective

To provide guidance to utilities performing welded repairs to irradiated stainless steel components.

Approach

An interim welding guideline was developed in 2000 based on the best information available at that time. The project team began with the interim guideline and supplemented it with recent test results. The most significant new results are based on tests performed on irradiated materials by the Japanese Owners Group. These tests were conducted over several years and were recently made available to BWRVIP. Tests were performed using various welding techniques, a range of welding parameters, and were performed on materials with widely varying irradiation levels. Information from this research significantly enhanced the technical basis for the Guideline.

Results

The Welding Guidelines conclude that, in a typical BWR, there are a number of components that can be repaired by welding with conventional techniques. These locations are not highly irradiated. The number of locations is most numerous during the early years of operation and decreases as the reactor ages and the fluence increases. The report specifies a list of components that can be safely welded even after 40 years of operation. A second category of locations with intermediate fluence levels is defined where welding can be performed if special techniques are used. Methods are presented for determining the helium content of metal at a given location and, based on the helium determination, selecting an appropriate welding technique. Finally, high-fluence regions exist where successful welding has not been demonstrated. However, even in these regions it is possible that successful welds can be made if appropriate controls are applied. The Guideline includes a method for performing an in-situ welding qualification at the location of interest as a means of demonstrating the acceptability of the technique.

EPRI Perspective

Welding is often the preferred method of repairing degraded reactor internal components. As reactors age and repairs become necessary, it will become more important to consider irradiation effects on the weldability of stainless steel components. These guidelines provide a means for determining the weldability of reactor internal components and, therefore, allow designers to assess whether weld repair is an acceptable option.

Keywords

BWR
Repair specifications
Welding
Irradiated materials
Stress corrosion cracking
Vessels
BWR internals

RECORD OF REVISIONS

Revision Number	Revisions
BWRVIP-97	Original Report (1003020)
BWRVIP-97-A	This report (BWRVIP-97-A) is based on a previous report (BWRVIP-97) that was reviewed by the U.S. Nuclear Regulatory Commission (NRC). It incorporates changes proposed by BWRVIP in response to NRC Requests for Additional Information, recommendations in the NRC Safety Evaluation, and other necessary revisions identified since the previous publication of the report. All changes, except corrections to typographical errors, are marked with margin bars. Non-essential format changes were made to comply with current EPRI publication Guidelines. In accordance with NRC guidelines, the NRC Safety Evaluation as well as other NRC correspondence related to this report has been included. NRC Safety Evaluation added to Frontmatter Appendices A-E added: NRC correspondence Details of the revisions are found in Appendix F

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BACKGROUND

1.1 Introduction

BWRs have experienced intergranular stress corrosion cracking (IGSCC) in a number of austenitic stainless steel and nickel alloy reactor pressure vessel (RPV) internal and external (e.g., recirculation piping, etc.) components. Figure 1-1 presents the various components where IGSCC has been identified in the BWR, while Table 1-1 details the history of BWR internals cracking [1-2]. Significant cracking has occurred in jet pump riser pipes and braces, core spray piping and core shrouds.

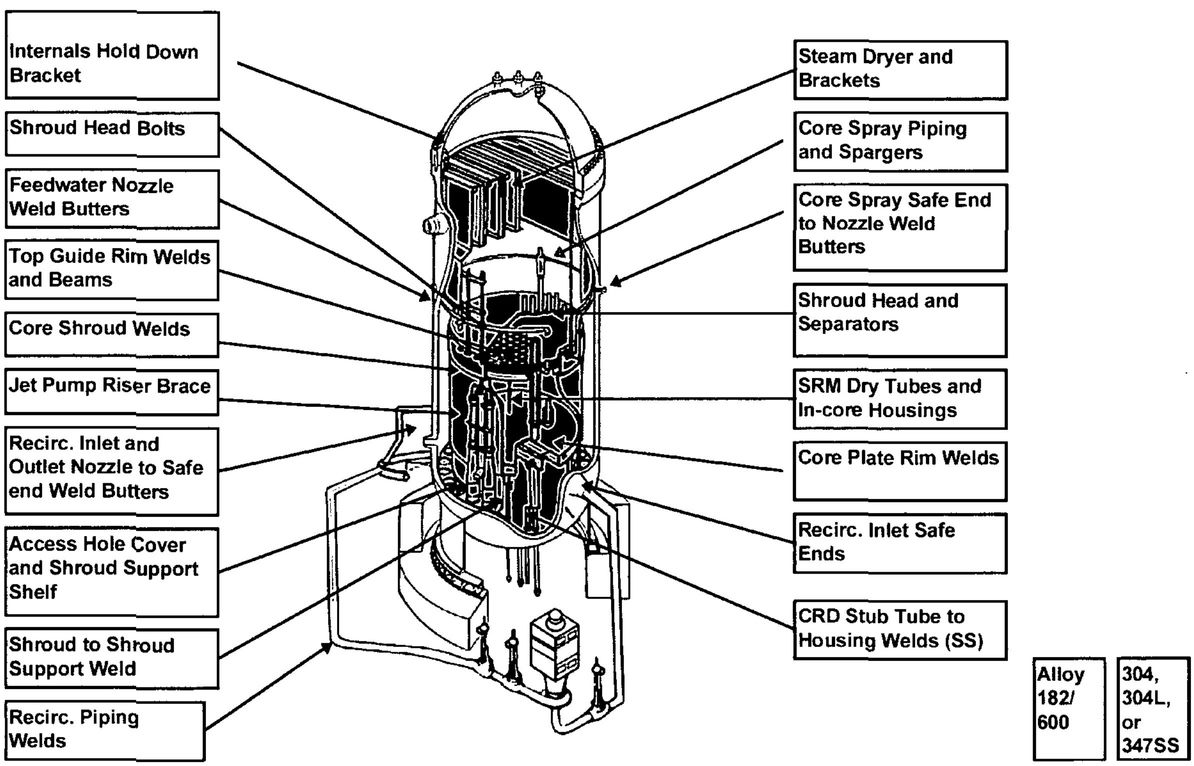

Figure 1-1
Summary Schematic of BWR Components with IGSCC [1]

Table 1-1
History of BWR Internals IGSCC [1-2]

EVENT	*YEAR OF DETECTION*
IGSCC of Alloy X750 Jet Pump Beam	Late 1970s
Accelerating Occurrence of IGSCC of BWR Internals	Late 1970s
Core Spray Spargers	
Shroud Head Bolts (Alloy 600)	
Access Hole Covers (Alloy 182/600)	
Nozzle Butters	
Control Blades	
SRM/IRM Dry Tube Cracking	
Jet Pump Beam Bolts	
Cracking of Low Carbon (304L/316L) and Stabilized Stainless Steels (347/321/348) in Vessel Locations	Late 1980s – present
Core Spray	
Creviced Safe Ends	
Shrouds (304L and 347)	
Top Guide (304, 304L, 347)	
Core Support Plate (347)	
Cracking of Internal Core Spray Piping	1990 - present

In some cases the preferred or only method of repair or replacement for the affected RPV internal component is welding. For components located in regions of low thermal fluence, the welding process is difficult and complicated, but metallurgically straightforward. However, in high thermal fluence regions, weld repair of irradiated BWR internal components is further complicated by the presence of insoluble He in the irradiated base material [3, 4]. Helium is produced by the transmutation of B and Ni. The release of the He when the metal melts during welding produces porosity and cracking. High He concentrations produce porosity along grain boundaries in the fusion zone. Lower concentrations of He can produce cracking in the heat affected zone (HAZ) resulting from bubbles formed by migration of He under the influence of high temperatures and stress. Thus, if a sufficient accumulation of He is present, the gaseous He released when the metal is melted can result in degraded mechanical properties of the welded joint, (e.g., reduced strength, cracking, etc.).

The BWRVIP has undertaken three activities to help improve the understanding of the effects of irradiation on welding:

1. In September 1997, the report "Weldability of Irradiated LWR Structural Components (BWRVIP-45)" was published [3]. This report included:

   a. A literature review to estimate the maximum amount of He for which conventional welding techniques could be used.

   b. Fluence calculations for a typical BWR/4 to predict He concentrations at various locations in the reactor.

c. A "Weldability map" based on the fluence calculations that indicated locations in the typical BWR where conventional welding techniques could (and could not) be used.

2. The BWRVIP has negotiated with the Japanese Owners Group (JOG) for rights to use Japanese data on welding of irradiated materials. This information includes results of experiments conducted to define the maximum He concentration under which conventional welding may be used, as well as results of experiments with welding techniques that allow welding on metal with higher He concentrations, (e.g., low heat input methods).

3. The BWRVIP, in collaboration with the NRC, has conducted a project to obtain samples of irradiated metal from the jet pump riser brace pad location in three operating BWRs. The samples were analyzed to determine the He content, the initial B content, the fluence and other parameters.

The results of these three activities have been key sources of information for this Guideline.

1.2 Welding Guidelines Objective

The objective of this Guideline is to provide utilities with a methodology that can be used to determine if weld repair to an irradiated component can be successfully performed and, if so, by which welding techniques. Note that the Guideline deals only with the aspects of performing a welded repair that are directly affected by the fact that the component has been irradiated. Other guidance for performing welded repairs that may be applicable is found in the BWRVIP Repair Design Criteria [5-13]

This Guideline has the following major elements:

1. Definition of Weldability Boundary - A "weldability boundary" is defined in Section 2. This boundary defines the locations in any BWR where He levels are sufficiently low (with a very high degree of assurance) to allow a repair to be performed using conventional welding techniques. For locations that do not fall within the boundary, additional considerations are required to determine if welding can be successfully performed.

2. Methodology for Helium Determination – For locations outside the weldability boundary, one method for determining weldability requires that the He content of the metal be known. This requires a plant specific evaluation. The methodology for such an evaluation is discussed in Section 3.

3. Survey of Applicable Welding Techniques – While welding on irradiated components may not be successful with conventional welding techniques; it has been successfully performed using low heat input methods. Section 4 presents these welding methods and describes the conditions where each may be used.

4. Welding Guidelines - Based on Items 1, 2 and 3 above, a Guideline for welded repair of irradiated components is presented in Section 5. The Guideline contains the methodology for determining which welding techniques may be used and presents guidance on required qualification tests, inspections, etc.

The flow chart shown in Figure 1-2 presents the overall logic of this Guideline.

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Figure 1-2
Flow Chart for Determining Applicable Welding Techniques

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Figure 1-2
Flow Chart for Determining Applicable Welding Techniques (Continued)

1.3 Implementation Requirements

In accordance with the requirements of Nuclear Energy Institute (NEI) 03-08, Guideline for Management of Material Issues, the requirements of this report are "Needed" when performing weld repairs to irradiated reactor internal components.

1.4 References

1. R. M. Horn, et al., "*Experience and Assessment of Stress Corrosion Cracking in L-Grade Stainless Steel BWR Internals*," Nuclear Engineering and Design, 174 (1997), p. 313.

2. "*BWR Vessel and Internals Project, BWR Water Chemistry Guideline – 2000 Revision (BWRVIP-79),*" EPRI TR-103515-R2, Palo Alto, CA, March 2000.

3. "*BWR Vessel and Internals Project, Weldability of Irradiated LWR Structural Components (BWRVIP-45)*," EPRI TR-108707, Palo Alto, CA, September 1997.

4. A. L. Lund, "*Underwater Welding of Highly Irradiated In-Vessel Components of Boiling Water Reactors – A Literature Review*," NUREG-1616, paper presented at the Welding of Irradiated materials Workshop, September 3-4, 1997, Charlotte, NC.

5. "*BWR Vessel and Internals Project, Internal Core Spray Piping and Sparger Replacement Design Criteria (BWRVIP-16),*" EPRI report TR-106708, March 1997.

6. "*BWR Vessel and Internals Project, Internal Core Spray Piping and Sparger Repair Design Criteria (BWRVIP-19),*" EPRI Report TR-106893, September 1996.

7. "*BWR Vessel and Internals Project, Top Guide/Core Plate Repair Design Criteria (BWRVIP-50),*" EPRI Report TR-108722, May 1998.

8. "*BWR Vessel and Internals Project, Jet Pump Repair Design Criteria (BWRVIP-51),*" EPRI Report TR-108718, May 1998.

9. "*BWR Vessel and Internals Project, Shroud Support and Vessel Bracket Repair Design Criteria (BWRVIP-52),*" EPRI Report TR-108720, June 1998.

10. "*BWR Vessel and Internals Project, Standby Liquid Control Line Repair Design Criteria (BWRVIP-53),*" EPRI Report TR-108716, July 1998.

11. "*BWR Vessel and Internals Project, Lower Plenum Repair Design Criteria (BWRVIP-55),*" EPRI Report TR-108719, September 1998.

12. "*BWR Vessel and Internals Project, LPCI Coupling Repair Design Criteria (BWRVIP-56),*" EPRI Report TR-108717, November 1998.

13. "*BWR Vessel and Internals Project, Instrument Penetrations Repair Design Criteria (BWRVIP-57),*" EPRI Report TR-108721, December 1998.

2 DEFINITION OF WELDABILITY BOUNDARY

In this section, a He threshold for weldability is first established. Below the threshold, welding by conventional techniques may be used. Above the threshold, low heat input methods will be required. Using this threshold and the results of a BWR fluence calculation, a generic weldability boundary is defined that is applicable to any BWR. Conventional welding may not be successful on reactor components outside the weldability boundary. Additional evaluations must be performed if a welded repair is to be considered.

2.1 Helium Induced Cracking Background

Helium is produced by irradiation of metals via an (n, α) reaction where the metallic element nucleus absorbs a neutron and emits an alpha particle (α) that is identical to a He nucleus [1]. The He atom thus produced is very stable and remains in the metal indefinitely. In BWRs, the dominant method of production is by (n, α) reactions due to the interaction of thermal neutrons ($E < 0.5$eV) with boron (B) and nickel (Ni).

Boron is typically present as an impurity in stainless steels and Ni base alloys in concentrations from <5 to >30 ppm. However, B is sometimes deliberately added to improve the hot workability of steel. Boron has two naturally occurring isotopes ^{11}B and ^{10}B where ^{10}B is 19.9% of total B. Only ^{10}B atoms undergo the (n,α) reaction with thermal neutrons.

Helium is often quantified in atomic percent rather than weight percent because it is such a light element. One weight percent of B in Fe is equivalent to 5.18 atomic percent. Since ^{10}B is only 19.9% of B, one weight percent B is equivalent to 1.03 atomic percent ^{10}B. Since every atom of ^{10}B will eventually transmute to ^{4}He, one weight percent natural B can produce one atomic percent He.

Depending on the exact alloy, Ni becomes a larger source of He at high thermal fluences $>10^{21}$ to 10^{22} n/cm^2. The behavior of Nickel is more complex than that of B since two transmutation steps are required. Nickel 58 is 68.1% of natural Ni and undergoes the following reactions with thermal neutrons:

$$^{58}Ni + n \rightarrow {}^{59}Ni + \gamma$$

$$^{59}Ni + n \rightarrow {}^{56}Fe + {}^{4}He$$

Since ^{59}Ni is not naturally occurring, the production rate of He is initially zero, but increases as ^{59}Ni accumulates. Unlike B, Ni is a major alloying element of BWR austenitic stainless steels, i.e., 8 to 14%, and, of course, Ni base alloys. Alloy 600 is 76% Ni. Therefore, the concentration of He can increase to many thousands of atomic ppm (appm) provided there is sufficient thermal fluence. The thermal fluence threshold where He from Ni becomes greater than from B is approximately 7 x 10^{21} for Type 304 stainless steel [1].

The preferred nucleation sites for He cracking are lattice inhomogeneities such as radiation-induced defects, precipitate interfaces, dislocations and, most importantly, grain boundaries [2]. Since boron is an insoluble impurity element, it is expected that helium produced from boron will be located preferentially at the grain boundaries, and since nickel is an alloying element and present throughout the matrix, helium produced from nickel will be found spread throughout the matrix.

Once He is produced above threshold levels, it can produce serious materials degradation during a welding process since He is basically insoluble in metals. He diffuses through the matrix and segregates at various defects and grain boundaries. Helium coalesces into bubbles that degrade cohesion at grain boundaries and will eventually cause failure [1]. During welding, He bubbles are typically trapped in the fusion zone. The high temperatures allow rapid diffusion and rapid He accumulation at grain boundaries. Damage occurs at the HAZ at lower He concentrations. The presence of a tensile stress due to volumetric contraction during solidification and subsequent cooling allows the formation of larger He bubbles. Rapid growth of the He bubbles fed by rapidly diffusing He leads to grain boundary cracking in the HAZ.

2.2 Helium Concentration Cracking Threshold

A previous literature review indicated that the threshold for He induced weldability problems is 1 appm [1] when conventional welding techniques are employed. It is the He concentration in the metal, not the thermal (or fast) fluence, per se, that determines whether He induced cracking is possible. Higher He thresholds have been obtained when compressive stress or low heat input weld overlays have been applied. For example, successful welds in irradiated material containing 80 appm He (He from tritium decay) have been produced through the application of a compressive stress during welding. Although low heat input overlays have also been successfully made in materials containing up to 85 appm He, the welds contained small amounts of underbead cracking [1].

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2.3 Calculation of Helium Content in a Typical BWR

Analyses have been performed to calculate He concentrations throughout a typical BWR/4 (Susquehanna) for 1, 15 and 30 full power years [1]. These analytical results can be used to define a generic weldability boundary. Table 2-1 shows the predicted He concentrations for a material containing 1 ppm B at various locations in the typical reactor. For alloys with different B concentrations, the data are simply multiplied by the concentration of B. For example, if the material contained 5 ppm B, the amount of He generated would be increased by a factor of five.

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Table 2-2 summarizes the He data for a material containing 10% Ni. For alloys with different Ni concentrations, the data are simply multiplied by the Ni ratio. For example, if the material contained 12% Ni, the amount of He generated would be increased by a factor of 1.2.

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2.4 Bounding Helium Evaluation

To establish a generic weldability boundary, a worst-case calculation was performed using conservative values of B and Ni concentrations. A "worse-case" Type 316 stainless steel containing a specification maximum allowable Ni content of 14 % plus a high end B concentration of 20 ppm is assumed. The 1999 average B for Type 316 stainless steel was 16 ppm [2]. Although Type 304 stainless steel has been used more commonly for BWR internals, Type 316 stainless steel was used for this example due to its higher Ni content (10–14% versus 8 – 10.5 %) and typically higher average B content (16 ppm versus 12 ppm for 1999) than Type 304 stainless steel.

Table 2-3 presents the Helium concentrations predicted using the Susquehanna calculations with the conservative values of B and Ni. [[

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2.5 Generic Weldability Boundary

Based on the results of the worst-case evaluation performed above and shown in Table 2-3, a "generic weldability boundary" may be defined. [[

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Using this criterion, a review of Table 2-3 indicates that the following locations will be weldable in any BWR without consideration of helium content:

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These locations define the generic weldability boundary. Other components not specifically mentioned, but lying in close proximity to those listed, are also considered weldable.

This model is consistent with the actual RPV welding experience since the following internal components have been successfully weld repaired in BWRs:

Core spray line

Feedwater sparger pipe

Jet pump adjusting screw tack welds

Steam dryer

Table 2-1
Atomic ppm He from Only 1 ppm B as a Function of Component and Location Based on Susquehanna

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Table 2-2
Atomic ppm He from Only 10% Ni as a Function of Component and Location Based on Susquehanna

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Table 2-3
Total Atomic ppm He from 20 ppm B and 14% Ni as a Function of Component and Location Based on Susquehanna

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2.6 References

1. "*BWR Vessel and Internals Project, Weldability of Irradiated LWR Structural Components (BWRVIP-45),*" EPRI TR-108707, Palo Alto, CA, September 1997.

2. W. T. Wood e-mail to B. M. Gordon, "*Boron Concentrations of Types 304 and 316 Stainless Steel,*" June 1, 2000.

3 DETERMINATION OF HELIUM CONTENT

For locations in the reactor that do not fall within the generic weldability boundary, it will be necessary to estimate the He content of the subject material to determine if welding can be successfully performed. This may be accomplished by calculations or by measurements as described in the following sections.

3.1 Helium Concentration By Calculation

Calculation of the He concentration at a specific location begins with a calculation of the fluence at the location projected to the time at which the weld repair is anticipated. Once the fluence is determined, the amount of helium expected from transmutation of B and Ni is calculated. A sample calculation for the Susquehanna BWR 4 is presented in Appendix B of [1] and may be used as an example. While the *thermal* fluence typically accounts for the majority of the helium produced, in some cases, *fast* fluence can make a significant contribution.

Calculation of helium concentration must be performed with a model that has been suitably benchmarked (e.g., Reference 3). The calculation requires assumptions regarding the B and Ni composition of the material. The Ni composition can be readily obtained from handbooks. The B concentration may be available from material certifications or from an archive sample. In the event that a B concentration for the material cannot be found, a conservative bounding value of 50 ppm may be used.

For most BWR components, the He produced from B will provide a sufficiently accurate estimate of the He concentrations. However, high thermal fluence regions require consideration of He contributions from the transmutation of Ni.

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3.2 Sample Removal

The most accurate method to obtain He concentration is by performing laboratory measurements on a sample removed from the target component. Helium (as well as thermal fluence, boron content, and other parameters) can be determined from small shavings removed from the component. Acceptable methods for removing and analyzing these samples are described in [2]. The required sample size is approximately 50 milligrams and the accuracy of the He determination is approximately one percent.

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In one sense sample removal is superior to calculation as a method for determining helium content in that it eliminates uncertainties and conservatisms that are inherent in the fluence calculation process.

3.3 References

1. "*BWR Vessel and Internals Project, Weldability of Irradiated LWR Structural Components (BWRVIP-45)*," EPRI TR-108707, Palo Alto, CA, September 1997.

2. "*BWRVIP-96-A: BWR Vessel and Internals Project, Sampling and Analysis Guideline for Determining Helium Content of Reactor Internals*," EPRI 1014613, Palo Alto, CA 2006.

3. "BWRVIP-121: BWR Vessel and Internals Project, RAMA Fluence Methodology Procedures Manual," EPRI Technical Report 1008062, October 2003.

4
APPLICABILITY OF WELDING TECHNIQUES

4.1 Introduction

A number of sources were used to establish the weldability of irradiated materials using various welding techniques. These include the BWRVIP literature survey conducted in 1997 [1], the JOG data recently obtained by the BWRVIP [2], as well as over one hundred articles identified from Metal Abstracts (ASM), Energy Science and Technology (DOE), USG/NTIS and Engineering Index and Weldasearch.

Following is a brief summary of the test results that were evaluated. A more complete discussion may be found in [2].

4.2 Applicability of Welding Techniques

4.2.1 Weldability Boundary

Figure 4-1 summarizes the effect of He concentration on cracking as a function of heat input based on JOG, BWRVIP-45 and other studies for Type 304, 304L, 316 and 316L stainless steel and for Alloy 600. The points are annotated to show which conditions resulted in cracking and which did not. For some tests, results indicate that small He "bubbles" were observed. Due to their spherical shape, small diameter (<100 nm) and spacing (1 μm), He bubbles were not considered an engineering concern and were not treated as cracks.

A weldability border between the cracking and no cracking points was constructed on Figure 4-1 for the stainless steel data. The most conservative values were used to anchor the borders with a minimum of a factor of two additional margins based on He content. For example, if no He cracking was identified at 1 appm He and cracking was identified at 2 appm at the same heat input, the borderline was constructed to be at or below the 0.5 appm point. Figure 4-1 indicates that successful welds can be obtained on irradiated material at relatively high He contents if the appropriate technique is selected. [[

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It is important to note that, even if the He content of a component is on the "cracking" side of the weldability boundary, it is not necessarily true that welding cannot be performed by a suitable welding technique. This concept is supported by the fact that there were several successful welds performed at higher He concentrations (open points to the right of the line).

Additionally, the majority of the data shown in Figure 4-1 was obtained from specimens that were shield welded inside a habitat. It is expected that water-backed welded (or underwater welded) components would be characterized by superior results than the results obtained inside a habitat, i.e., water-backed welding should allow welding at higher heat inputs and/or higher He contents due to the quenching effects of the adjacent water.

Due to the paucity of data on Alloy 600, no general boundary between cracking and no cracking could be defined. Utilities may, however, find the data useful in making plant specific decisions regarding the weldability of those materials.

4.2.2 Transmutation Helium versus Tritium Decay Data

A technique for producing He in materials that does not require irradiation is often used in laboratory studies. Since the isotope of hydrogen, tritium, decays to ^{3}He, tritium can be utilized to study the effects of He on welding in irradiated material. This technique known as the "tritium trick" method and consists of diffusing tritium into a metal at elevated temperatures and pressures. The metal is then cooled and aged at cryogenic temperatures until the desired concentration of He is formed. It is then heated in a vacuum to permit the tritium to diffuse out leaving the He. Although the 12.3 year tritium half life means a slow He doping process, the use of sufficient amounts of tritium allows significant He generation to be achieved. The greatest advantage of this technique is that the material is not irradiated and thus not activated. This eliminates the need for hot cells in performing tests. This "helium doping" methodology is often used in testing materials simulating He damage due to irradiation.

However, implanting He by irradiation or tritium can result in different levels of cracking in the material after welding [3]. This difference can be explained by the difference in He locations. Irradiation of the material results in transmutation of B at the grain boundaries and transmutation of Ni homogeneously throughout the material. Tritium decay will only result in a homogeneous distribution of He with no concentration of He at the grain boundaries. These differences are critical in interpreting test results.

Irradiated material is also metallurgically damaged, i.e., high dislocation densities, dislocation loops, vacancies, etc. Such damage to the matrix has a role in subsequent material performance. No such irradiation damage exists in tritium decay treated materials.

Due to these differences, data obtained using the tritium trick method were not considered in establishing the weldability boundary shown on Figure 4-1. The available tritium-trick data are presented separately for information in Figure 4-2.

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Figure 4-1
Effect of He and Heat Input on the Weldability of Stainless Steel and Alloy 600 - He Data

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Figure 4-2
Effect of He and Heat Input on the Weldability of Stainless Steel - Tritium Decay Data

4.2.3 Successful Industry Experience with Welding of Irradiated Material

Numerous tests have been performed to investigate suitable techniques for successfully welding irradiated stainless steel. Samples of those tests are described in the following paragraphs.

Westinghouse Savannah River has developed a low penetration gas metal arc (GMAW) overlay welding technique that minimized cracking in irradiated Type 304 stainless steel that contained 10 appm He from tritium decay [3-4]. Surface cracking that was present in conventional welds made on the same steel at the same and lower He concentrations was eliminated. Underbead cracking was minimal compared to conventional welding methods. This overlay technique provides a potential method for repair or modification of irradiated materials.

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4.3 Summary of Advanced Welding Techniques

Based on the welding data presented in this guideline, as summarized in Figure 4-1, it is clearly possible to weld repair highly irradiated austenitic materials using a number of techniques. These techniques include:

1. Low heat input GTAW, also referred to as TIG.
2. Low penetration GMAW or (GMAW-S)
3. Laser beam welding (LBW)

In general, the threshold curve depicted on Figure 4-1 is expected to be applicable to all conduction-limited welding processes: GTAW, GMAW, FCAW (Flux Core Arc Welding), PTAW (Plasma Transfer Arc Welding), SMAW (Shielded Metal Arc Welding) and Laser (provided that it is not operating in the key-hole mode).

In some instances, successful welding may require the use of autogenous techniques.

Although there is no information currently available in the open literature, other welding techniques may also be applicable provided suitable qualifications are performed.

Note that the welding tests that form the basis for Figure 4-1 were performed in air. Since underwater welding diminishes the time at which materials are subject to temperatures where helium bubble growth occurs, it is expected that the threshold in Figure 4-1 would be conservative for welds performed underwater. However, test data to confirm this qualitative assessment is not available.

4.4 References

1. "*BWR Vessel and Internals Project, Weldability of Irradiated LWR Structural Components (BWRVIP-45)*," EPRI TR-108707, Palo Alto, CA, September 1997.
2. "*BWR Vessel and Internals Project, BWRVIP-98: Technical Basis for Guidelines for Performing Weld Repairs to Irradiated BWR Internals)*," EPRI TR-1006385, Palo Alto, CA, 2001.
3. W. R. Kanne, et al. "*Welding Irradiated Stainless Steels*," Journal of Nuclear Materials, Vol. 225, August 1995, p. 69.
4. W. R. Kanne, et al. "*Weld Repair of Irradiated Materials*," Materials Characterization, Vol. 43, August – September 1999, p. 203.
5. S. Nishimura, et al., "*YAG Laser Welding of Neutron Irradiated Stainless Steels*," Journal of Nuclear Materials, Vol. 258-263 (Part B), October 1998, p. 2002.
6. C. A. Wang, et al., "*Welding of Irradiated Steels*," Journal of Nuclear Materials, Vol. 233-237, October 1996, p. 213.
7. C. A. Wang, et al., "*The Effect of an Applied Stress on the Welding of Irradiated Steels*," Journal of Nuclear Materials, Vol. 239, November 1996, p. 85.

8. W. R. Kanne, Jr. et al, "*Repair Welding of Irradiated 304 Stainless Steel*," paper presented at Maintenance and Repair Welding In Power Plants V, November 30 – December 2, 1994, Orlando, FL, published in Proceedings, American Welding Society, Miami, FL, 1995, p. 129.

9. E. A. Franco-Ferreira and W. R. Kanne, Jr., "*Remote Reactor Repair: Avoidance of Helium-Induced Cracking Using GMAW*," Welding Journal, Vol. 71, No. 2, February 1992, p. 43.

10. K. Tsuchiya, H. Kawamura and R. Oyamada, "*Joining Technology Development of Advanced Materials/SS304 by Friction Welding*," JAERI Technical Report 95-017.

5
WELDING GUIDELINES SUMMARY

Section 5.1 presents a simple guideline for determining the weldability of a component based on the considerations discussed in previous sections. If the component is determined to be weldable, certain qualifications, analyses and inspections are required. These are presented in Sections 5.2 through 5.4.

5.1 Weldability Determination

The process for determining whether a weld repair can be successfully performed is shown schematically in the flow chart presented in Figure 1-2. It consists of the following steps:

1 Determine if the component lies within the generic weldability boundary as defined in Section 2. If so, welding may be performed by conventional means without regard for effects of irradiation.

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3 If the component is outside the boundary and the thermal fluence exceeds $1x10^{18}$ n/cm^2, then two options are available for determining weldability:

a. Weldability Determination by Estimation of He Concentration

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b. Weldability Determination by Test

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5.2 Additional Considerations

Welding on irradiated austenitic materials in nuclear power plants may involve special issues related to the irradiation-induced degradation of the material. The production of He in the alloy as a result of neutron exposure may affect the weldability of the component depending upon the amount of He that has been produced and the welding heat input employed. This section of this report provides guidance related to additional controls that are required to weld on these highly irradiated components. It is the intention of the BWRVIP for these controls to be implemented for both ASME Code and non-Code vessel internals components in the BWR.

5.2.1 Required Qualification Tests

The ASME Code, Section IX, provides the essential and non-essential variables in its weld procedure specifications (WPS) and procedure qualification records (PQR) that give the criteria for welding on materials in power plant applications. These guidelines do not provide for additional requirements in the event that the material has become susceptible to specific environmental effects that would compromise the weldability of the material. The guidance for providing additional welding requirements when performing specialized welding, such as underwater welding, falls to the individual book Section of the Code for which the construction is performed. In the case of nuclear power plants, Section XI is the responsible book section for in-service repairs or replacements, and therefore, it is Section XI that should provide the specific guidance for such repairs. Section XI does not, however, provide specific guidance with respect to welding on irradiated materials.

This report has described three regimes of varying helium concentration where welding may or may not be possible. A generic weldability boundary has been defined within which the effects of irradiation are benign and conventional welding may be used. A second regime is identified in which welding is possible provided the heat input is controlled. And a third regime exists where welding at these He levels has not been completely demonstrated, and a demonstration will be required to show that successful welding on the specific component can be performed.

The following paragraphs describe the required qualifications for welding in each of these three regimes. In some cases, the requirements are in addition to the requirements of the Code. For ASME Code repairs, it is anticipated that the additional welding requirements identified below can be represented as "supplementary essential variables" and be incorporated into the Plant welding program when appropriate.

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5.2.2 Required Inspections

5.2.2.1 Kinetics of He Cracking

It is believed that the detrimental effects of He would be seen immediately, i.e., it is not a time dependent reaction, and that, if a component was welded without any evidence of cracking, cracking would not appear at a later date.

Underbead cracking is a concern and may be difficult to detect. Welding studies have indicated that while overlay welds eliminated weld toe cracking that had been observed in conventional welds, both conventional and overlay welds can suffer underbead cracking [1]. Underbead cracking is typically confined to within one or two grains of the weld interface.

However, since underbead cracking is embedded in the material, remote from the weld toe and not exposed to the environment, underbead cracking is more of a net section concern and must be analyzed to assure structural integrity. Since the weld repair itself is designed to address any net section or embedded flaw concern, this evaluation should be rather straightforward. Any weld toe cracking should be repaired by grinding and repair.

5.2.2.2 ASME Code Requirements

The ASME Code requires that following the detection and repair of a flaw, the inspection to be performed should be the same as the inspection that identified the flaw. In the case of welding on irradiated materials, i.e., those materials for which the level of He in the alloy produces a risk for HAZ cracking, the Code rules are inadequate. Whereas the weld repair may repair or remove the flaw that necessitated the repair, the actual weld may create new defects in the weld HAZs produced on each toe of the weld. In addition, the repair may also produce imbedded cracking beneath the weld repair in the original base metal. As a result of this additional potential cracking, additional NDE testing is required to demonstrate that no cracking detrimental to the future performance of the component remains. [[

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5.2.3 Required Analyses

No additional analyses are required by the rules of the ASME Code for these irradiated and welded components. However, an analysis may be used to demonstrate the acceptability of certain observed flaws. Paragraph IWB-3600 of Section XI of the ASME Code provides for the acceptance of flaws in a component if one can justify that the design safety margin has not been compromised for the ensuing operating interval. (Note that paragraph IWB-3600 specifically addresses flaws found during in-service inspections. For the current purpose, flaws that are found during a post-weld inspection will be addressed by the same paragraph.) This Code provision allows the utility Owner to accept a limited distribution of defects that could occur during the weld repair allowing for continued operation of the component. These include embedded defects, where no additional driving mechanism is available, since the environment cannot get to the flaw, and the stress has been reduced to an acceptable level due to the weld repair. For toe cracks associated with high He level HAZ cracking, removal of these surface cracks and analysis of the slight depression may allow for continued successful operation of the component. Additionally, depending upon the location and severity of the He induced HAZ cracking, the defect may be benign and allow for additional operation with the defect in place. Each of these cases would need to be evaluated individually, and a decision made accordingly.

5.3 References

1. "*BWR Vessel and Internals Project, Weldability of Irradiated LWR Structural Components (BWRVIP-45)*," EPRI TR-108707, Palo Alto, CA, September 1997.

A
NRC REQUEST FOR ADDITIONAL INFORMATION

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 8, 2003

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

SUBJECT: PROPRIETARY REQUEST FOR ADDITIONAL INFORMATION - REVIEW OF BWR VESSEL AND INTERNALS PROJECT REPORTS, BWRVIP-96, -97, -99, AND -100 (TAC NOS. MB3947, MB3948, MB3951, AND MB3946)

Dear Mr. Terry,

By applications dated November 27, November 29, December 10, and December 20, 2001, respectively, you submitted for NRC staff review, four Electric Power Research Institute (EPRI) proprietary reports, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals (BWRVIP-97)," "Sampling and Analysis Guidelines for Determining the Helium Content of Reactor Internals (BWRVIP-96)," "Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds (BWRVIP-100)" and "Crack Growth Rates in Irradiated BWR Stainless Steel Internal Components (BWRVIP-99)." These BWRVIP reports provide a methodology for assessment and repair of irradiated stainless steel BWR internal components.

BWRVIP-96 involves the development of a sampling and analysis methodology to provide utilities with guidance on performing sampling for determination of helium concentrations by direct measurement. Helium content, one factor that affects the weldability of stainless steels in BWR reactors, is produced when thermal neutrons interact with boron and nickel. High levels of helium can produce small bubbles in the melted metal that results from the welding process. If the concentration of helium is above some threshold amount, the bubbles can affect the as-welded strength of the material. Therefore, accurate helium concentration determination is required to determine the acceptability of welds to irradiated materials.

BWRVIP-97 provides a methodology to determine if weld repair to irradiated components can be successfully performed and, if so, by which welding technique. Four major elements to the methodology are evaluated: (1) definition of weldability boundary, (2) methodology for helium determination, (3) survey of applicable welding techniques, and (4) welding guidelines.

BWRVIP-99 addresses the crack growth correlation that can be applied under normal water chemistry or hydrogen water chemistry at fluences greater than $5x10^{20}$ n/cm^2. Higher fluences will be of greater concern as the plants apply for license renewal to operate for 60 years. NRC has previously accepted the EPRI approach for crack growth correlation (BWRVIP-14), but only to fluences less than $5x10^{20}$ n/cm^2.

Carl Terry -2-

BWRVIP-100 addresses the relationship between fracture toughness and neutron fluence for conditions representative of BWR core shrouds. The report evaluates experimental results of fracture toughness data and provides a flaw evaluation methodologies as a function of fluence by limit load and fracture mechanics analyses. This report is relevant to BWRVIP-76 (BWR Core Shroud Inspection and Flaw Evaluation Guidelines).

The NRC staff has completed its preliminary review of the BWRVIP-96, -97, -99, and -100 reports. As indicated in the attached request for additional information (RAI), the NRC staff has determined that additional information is needed to complete the respective reviews. Since the attached concerns reports that the NRC staff has found to be proprietary in nature, the requested information will also be considered proprietary. If you have any questions, please contact me at (301) 415-2150.

Sincerely,

Meena Khanna, Materials Engineer
Materials and Chemical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

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PROPRIETARY

PROPRIETARY REQUEST FOR ADDITIONAL INFORMATION
OF THE BWRVIP VESSEL AND INTERNALS PROJECT REPORTS
BWRVIP-96, -97, -99, AND -100

BWRVIP-96: Sampling and Analysis Guidelines for Determining the Helium Content of Reactor Internals

RAI 96-1

Section A.1.9 of the BWRVIP-96 report states that the reproducibility of the helium content measurements between the replicate analysis averaged 4%. Section A.1.9 also states that reproducibility in the analysis system for these types of samples is 0.5%. The review of Table A-4 on which these statements are based indicates that the spread of the reproducibility is between about 0.5% and 8% for the pre-exposure samples and about 2.4% and 8% for the post-exposure samples. What is the source of this spread of reproducibility? Discuss the reasons for this spread, including if relevant, the possible relationship to the helium homogeneity issue discussed in Section A.1.5 of the report. Explain the wider spread in the reproducibility in the pre-exposure samples compared to the post-exposure samples. The report states that analysis and sampling have been performed for three plants and that detailed results for all three plants were presented in Reference 1, memo from V. Wagoner to all BWRVIP committee members, dated October 4, 2001, "Transmittal of Summary Reports on Jet Pump Riser Brace Pad Sample Analysis." In BWRVIP-96, only the results of the analysis and sampling for one of the plants are presented. What are the spreads in reproducibility observed in samples analyzed from the other two plants as part of the BWRVIP/NRC project and what are the reasons for any observed spreads in reproducibility for these two plants? Also, provide a copy of Reference 1, memo from Vaughn Wagoner to all BWRVIP Committee Members, dated October 4, 2001, "Transmittal of Summary Reports on Jet Pump Riser Brace Pad Sample Analysis."

RAI 96-2

Since every atom in ^{10}B will eventually transmute to ^{4}He and one weight-percent natural B can produce one atomic percent He (see 3rd paragraph on page 2-4, BWRVIP-97), the weldability would vary considerably with the variations in boron content in the riser brace pad regions of the plants. Sections A.1.1 and A.1.9 of the BWRVIP-96 report state that the range of boron concentration values is higher which is explained by measurement uncertainty or boron heterogeneity, suggesting real variations in the boron contents between the four jet pump riser brace (JPRB) samples which all came from the same plant. What is the source of these real variations? What variations in boron contents have been observed in samples from the other two plants and what is the source for these variations?

PROPRIETARY

BWRVIP-97: BWR Vessel and Internals Project Guidelines for Performing Weld Repairs to Irradiated BWR Internals

RAI 97-1

Section 2.2 of the BWRVIP-97 report states that a previous literature review (the reference is BWRVIP-45) indicated that the threshold for He-induced weldability problems is 1 appm when conventional welding techniques are employed. BWRVIP-45 (2nd paragraph, p. 6) states that the study that most accurately fixed the helium threshold at approximately 1 appm was conducted with the tritium-trick method. Using this result for the helium threshold, BWRVIP-97 sets the engineering threshold for helium concentration to an order of magnitude lower at 0.1 appm. The discussion below raises concerns on using tritium-tricked samples for determining the threshold, i.e., 0.1 appm for He-induced weldability of irradiated components.

> Page 6 of the BWRVIP-45 report states "Tritium diffuses rapidly in metals, but is retained at sinks or traps. These are sites such as dislocations or grain boundaries. If the tritium is trapped at grain boundaries, then the helium is born at the grain boundaries. In this case, helium does not have to diffuse over long distances to form bubbles and to permit the bubbles to grow to a critical size for fracture during welding." On the basis of this reasoning, BWRVIP-45 concludes that tritium-trick doping is a worst case for weldability of stainless steel samples as compared to irradiated samples and that actual threshold (for irradiated stainless steels) may be somewhat higher.
>
> However, other published literature contradicts this conclusion. For example, Kanne, et al. (*Welding of Irradiated Stainless Steel, J. Nuclear Materials, 225, 1995, p. 69,* and Ref. 2-18 in BWRVIP-98) presents results on welding of helium-containing stainless steel samples showing that the extent of cracking in the irradiated material was 28 to 31 times greater than in the tritium charged and aged material at the same helium concentration and welded by the same processes. As discussed by Louthan, et al. (*Helium Embrittlement Model and Program Plan for Weldability of ITER Materials (U), WSCR-TR-97-0031, February 1997*), tritium tricked samples are generally thin, unconstrained samples, because tritium charging and aging of this type of sample is quicker and can be done at lower temperatures than is practical for full size components. However, constraint contributes to higher tensile stresses and stress gradients in a full size component during welding, and, therefore, can have a significant impact on the weldability. Higher tensile stresses and stress gradients make the component more susceptible to helium cracking during welding. Therefore, weldability studies on thin, unconstrained, tritium-tricked samples are not necessarily indicative of the behavior of full size components.

Taking into account the two above-mentioned differences between the weldability of tritium-tricked samples and irradiated samples, justify the use of tritium-tricked samples to determine 0.1 appm as a helium concentration-cracking threshold for irradiated stainless steel vessel internals, as recommended in Section 2.2 of BWRVIP-97.

PROPRIETARY

-3-

RAI 97-2

Figure 1-2 of the BWRVIP-97 report presents a quantitative criterion for a helium concentration threshold (i.e., 0.1 appm), followed by Figure 4-1 to determine if the material may be welded at reduced heat input expressed as kJ/cm. Kanne, et al. (*Weld Repair of Irradiated Materials, Materials Characterization, 43, 1999, p. 203*) identified six variables that influence helium embrittlement during the welding of irradiated stainless steel. The three primary variables are helium concentration, temperature, and stress; the three secondary variables are metallurgical condition of the alloy, gradients in the alloy, and time at temperature. Tensile stresses and stress gradients are due to volumetric contraction of weld metal and structural constraints present in the component being repaired. The guidance presented in BWRVIP-97 for welding irradiated stainless steel accounts for only two of these variables. Provide revised guidance in the report to account for the remaining four variables, especially stress and stress gradients in the material.

RAI 97-3

Section 2.1 of the BWRVIP-97 report states that boron is typically present as an impurity in stainless steel and nickel-based alloys in concentrations of <5 to >30 ppm. Explain what the term "concentrations of <5 to >30 ppm" implies. Explain why Section 1.0 of the BWRVIP-96 report identifies different ranges for boron concentration (less than 1 ppm to over 50 ppm). Section 2.1 of the BWRVIP-97 report further states that boron is sometimes deliberately added to improve the hot workability of steels. How common is this practice of adding boron? What is the range of this deliberately added boron? Section 2.4 of the BWRVIP-97 report states that a "worst case" Type 316 stainless steel containing a specification maximum allowable nickel content of 14% and high-end boron concentration of 20 ppm is assumed. Justify why a boron concentration >20 ppm should not be used as a worst case for 316 stainless steel. What are the upper bound values for the other vessel internals materials, e.g., Type 304 stainless steel and Alloy 600?

RAI 97-4

Section 2.3 of the BWRVIP-97 report presents results for calculations of helium content in a typical BWR/4 plant (Susquehanna) for 1, 15 and 30 effective full power years (EFPYs) at an assumed boron and nickel concentration of 1 appm boron (Table 2-1), 10% nickel (Table 2-2), and 20 appm boron and 14% nickel (Table 2-3). How are these tables applicable to the other BWR plants? If they can be used for other BWR plants, discuss in the report, the basis for that application.

RAI 97-5

Section 4.2.2 of the BWRVIP-97 report states that data obtained using the tritium-trick method, shown on Figure 4-1 with the notation "TD" (tritium decay), were not considered in establishing the weldability boundary. Therefore, to place the results in better context, replace Figure 4.1 with two figures, one with only the data on the irradiated materials and one with the tritium-trick data.

PROPRIETARY

Confirm whether the weldability boundary established in Figure 4-1 is applicable only for the following four welding method/material combinations: GTAW/304-308LSS, GTAW/304SS, GTAW/316LSS, and YAG/304LSS.

What are the guidelines for repairing irradiated stainless steels with other welding techniques, such as the low penetration GMAW overlay welding technique? (Note: Ref. 4 listed in Section 4.4 does not contain the data, nor the plot of Figure 4-1.)

RAI 97-6

Section 4.2.1 states that the most conservative values were used to anchor the boundaries for susceptibility to cracking with a minimum of a factor of two additional margins based on helium content. For example, if no helium cracking was identified at 1 appm helium and cracking was identified at 2 appm helium at the same heat input, the boundary was constructed to be at or below the 0.5 appm point. Inspection of the data in Figure 4-1 does not reveal how the boundaries for cracking and no cracking, i.e., the dotted bilinear lines, were established for GTAW 304 (knee), YAG 304L (lower portion), GTAW 316L and GTAW 304-308L (upper portion). Explain how the subject boundaries were established.

Figure 4-1 shows that at high helium concentrations, small changes in heat input can have a large impact on the susceptibility of the weld to crack. Therefore, while it is sensible to define margin in terms of helium concentration for the steep portion of the weldability boundary, for the shallow portion of the boundary, it may be appropriate to define margin in terms of heat input. The staff recommends that the weldability boundary shown in Figure 4-1 should be revised as described above.

RAI 97-7

Section 5.2.2.2 of the BWRVIP-97 report states "In addition, if possible, surface and volumetric examinations of the component should be performed, with special attention paid to the toes of the repair and to the base metal beneath the repair." It appears that if a component is accessible to weld repair, surface and volumetric examinations of that component should be possible. Describe the conditions under which inspections of a repaired component may not be possible.

BWRVIP-99: Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components

RAI 99-1

The proposed disposition curve for irradiated stainless steels (SSs) for use in effective hydrogen water chemistry (HWC) (Figure 8-2) represents a factor of improvement of three relative to the disposition curve for use in normal water chemistry (NWC) (Figure 8-1). Both of these curves are applicable for the fluence range of 5×10^{20} to 3×10^{21} n/cm^2. Provide the fluence levels for the data plotted in Figures 8-1 and 8-2 and sort and bin the data in plots into different ranges of fluence such that the effect of fluence is clearly shown. Also, provide a table summarizing the material, environmental, and loading conditions for the data shown in Figures 8-1 and 8-2 to place the results in better context.

PROPRIETARY

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RAI 99-2

Provide the basis for the selection of the proposed disposition curves in Figures 8-1 and 8-2. Also, BWRVIP-99 states that the NWC disposition curve in Figure 8-1 bounds 92% of the relevant data. Discuss any effects of this correction on the proposed NWC disposition curves.

RAI 99-3

The crack growth rate (CGR) curves proposed in BWRVIP-99 are more than an order of magnitude higher than the curves obtained from the correlations presented in BWRVIP-14 for the same environmental conditions but <5 x 10^{20} n/cm^2 fluence. Discuss the applicability of BWRVIP-14 at fluence levels up to 5 x 10^{20} n/cm^2 in light of the additional data now available on CGRs in irradiated materials. Provide guidance on how to handle the transition from the methodology of BWRVIP-14 to that proposed in BWRVIP-99.

RAI 99-4

Comparisons with the field data for average CGRs determined from the re-inspections are used to demonstrate the overall acceptability of the crack growth methodology developed in BWRVIP- 9, "Quantitative Safety Assessment of BWR Reactor Internals." These comparisons are now presented in terms of CGR as a function of initial depth. This has the effect of shifting the data to the left in Figures 8-3 and 8-4 and gives non-conservative estimates. The CGRs should be evaluated as a function of average crack depth (the "best estimate"), or final crack depth (a conservative estimate), rather than the initial crack depth used in Section 3 and Figures 8-3 and 8-4.

RAI 99-5

Because CGRs will often be highly non-uniform over an inspection interval, comparisons with predicted CGRs can be strongly dependent on whether the measured CGR is assumed to be representative of the initial depth, the average depth, or the final depth. A more meaningful comparison of the methodology may be to compare the predicted increases in crack depth over an interval with the observed changes. Explain how the field data for these plants compare with the predicted values obtained from the results such as those in Figure 9-2, i.e., enter the data from the curve in Figure 9-2 for the measured depth d_1 and determine the corresponding time t_1, determine d_2 at the time t_1 + the inspection interval, and compare the predicted d_2-d_1 with the observed value.

BWRVIP-100: Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds

RAI 100-1

Although the data are scattered, the proposed variation of the J-R curve power law parameter n, as a function of neutron fluence, appears counter to the expectation that irradiated materials will exhibit less ductile behavior both in terms of the value of J as well as the variation of J with crack growth. Discuss this apparent contradiction.

PROPRIETARY

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RAI 100-2

In Table 2-1, no ductile extension was observed for 9 specimens tested for fluence in the range from 3-3.5 x 10^{21} n/cm^2. These results are used to define the transition between elastic-plastic fracture mechanics (EPFM) and linear elastic fracture mechanics (LEFM) at a fluence of 3 x 10^{21} n/cm^2. What data are available for these same materials for fluences less than 3 x 10^{21} n/cm^2? How dependent is the fluence limit on the heat of material, i.e., what confidence exists that all materials with fluences less than 3 x 10^{21} n/cm^2 will show ductile extension?

RAI 100-3

The relationship between fracture toughness and neutron fluence presented in BWRVIP-100 is based on the data obtained on austenitic stainless steel base metals and weld metals that were either taken from operating BWRs or were irradiated in test reactors. However, the power-law relationship for the parameter C as a function of fluence (Figure 2-2, Eq. 2-2) primarily represents the trend observed for the weld metal. For clarity, in Figures 2-2 and 2-3, the staff recommends that separate symbols for base and weld metals be used.

In general, fracture toughness of weld metal at high fluence levels is lower than that of the base metal (Mills, *Intl. Metal Review*, Vol. 42, 1997). *It is possible that there is a synergistic* embrittlement of stainless steel welds by thermal aging and neutron irradiation, e.g., the embrittled δ-ferrite could serve as an effective site for microvoid nucleation. How does the irradiated database include results on materials that would have thermal aging comparable to in-reactor components? How are cracks in heat affected zones to be treated?

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EPRI Proprietary Information

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RAI 100-4

Several correlations are available in the open literature for estimating the increase in tensile strength of austenitic stainless steel as a function of fluence. For example, the correlation proposed by Odette and Lucas (J. Nucl. Mat., pages 179-181, 1991) or the Cooperative IASCC Research (CIR) program for the increase in yield stress as a function of fluence has been referenced in BWRVIP-99 for specimen K/size criteria assessment. Discuss how the estimates based on the BWRVIP-100 correlation (Eq. 2-5) compare with the prediction from these other correlations which are used in other BWRVIP documents.

RAI 100-5

The report recommends that Appendix C of BWRVIP-76 should be updated to use EFPM analysis methods to determine the margins and inspection intervals for fluence levels <3 x 10^{21} n/cm^2, and LEFM analyses with K_{Ic} = 55 MPa $m^{0.5}$ (50 ksi $in^{0.5}$) for fluence

PROPRIETARY

$\geq 3 \times 10^{21}$ n/cm^2. The report also recommends that an EFPM methodology similar to that specified in the ASME Code be used for the EFPM evaluation and incorporated into BWRVIP-76 and the core shroud distributed ligament length computer software. Provide details regarding how and when these recommendations will be implemented.

PROPRIETARY

B

NRC SUPPLEMENTAL REQUEST FOR ADDITIONAL INFORMATION

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 18, 2004

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

SUBJECT: SUPPLEMENTARY REQUEST FOR ADDITIONAL INFORMATION - REVIEW OF BWR VESSEL AND INTERNALS PROJECT REPORT, BWRVIP-97, "GUIDELINES FOR PERFORMING WELD REPAIRS TO IRRADIATED BWR INTERNALS"

Dear Mr. Eaton:

By letter dated November 27, 2001, you submitted for NRC staff review, Electric Power Research Institute (EPRI) proprietary report, BWRVIP-97, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals." BWRVIP-97 provides a methodology to determine if weld repair to irradiated components can be successfully performed, and if so, by which welding technique. The NRC staff sent a request for additional information (RAI) related to BWRVIP-97 by letter dated January 8, 2003.

The purpose of this letter is to forward to you supplementary RAIs that evolved from a review of Chapter 5.0 of BWRVIP-34, "Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping," which contains an evaluation of the effects of irradiation on the weldability of core spray piping. The staff has determined that this additional information is needed to complete the review of BWRVIP-97. Please contact Meena Khanna of my staff at 301-415-2150 if you have any further questions regarding this subject.

Sincerely,

Stephanie M. Coffin, Chief
Vessels & Internals Integrity and Welding Section
Materials and Chemical Engineering Branch
Division of Engineering

Project No. 704
Enclosure: As stated

cc: BWRVIP Service List

cc:

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U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
SAFETY EVALUATION OF THE BWRVIP VESSEL AND
INTERNALS PROJECT "BWR VESSEL AND INTERNALS
PROJECT, GUIDELINES FOR PERFORMING WELD REPAIRS TO IRRADIATED
BWR INTERNALS (BWRVIP-97)" EPRI PROPRIETARY REPORT TR-1003020

SUPPLEMENTARY REQUEST FOR ADDITIONAL INFORMATION

Note: During a conference call on January 15, 2004, it was agreed that all RAIs that relate to weldability of irradiated materials that were developed during the review of BWRVIP-34, be included as supplementary RAIs to BWRVIP-97.

Supplementary RAI 97-8

Section 4.2.1 of the BWRVIP-97 report states, "Figure 4-1 indicates that successful welds can be obtained on irradiated material at relatively high He [helium] contents if the appropriate technique is selected." Therefore, Section 4.2.1 should state that the weldability boundary developed in that section is applicable only when the gas metal arc welding (GTAW) or the yttrium-aluminum-garnet (YAG) laser technique is used for repairing irradiated stainless steel. (Note: although the data associated with the GMAW technique are presented in Figure 4-1, these data, according to Section 4:2.2 of the BWRVIP-97 report, were not considered in establishing the weldability boundary because they are associated with tritium-tricked samples and not irradiated samples. Therefore, the weldability boundary presented in Figure 4-1 is not applicable when the GMAW technique is used.)

Supplementary RAI 97-9

In response to RAI 2(a) (from the BWRVIP-34 review), the BWRVIP provided the following introductory comments: "As a preamble to this response, it should be noted that the cracking caused by entrapped helium during welding of irradiated materials does not occur in such a way as to present a safety hazard. The cracking occurs immediately after the welding is performed, and does not occur on a delayed basis. Should a utility attempt a welded repair on highly irradiated material, any cracking due to entrapped helium would be immediately obvious in post weld inspections and could be addressed appropriately at that time. As such, the issue of attempting a weld repair at a location for which the weldability cannot be accurately determined becomes only an economic concern for the utility. Should the weld crack, an alternate means of repair will be required. However, no safety concerns result."

Welding of irradiated stainless steel could degrade the mechanical properties without causing immediate cracking due to helium embrittlement. For example, in 1998, Robinson reported that when helium-charged samples of 304L stainless steel were subject to transient thermal cycles, simulating those occurring in the heat-affected zone of a gas tungsten arc weld, peak temperatures above 800°C (1472°F) caused severe ductility losses, fracture mode changes (from ductile transgranular rupture to ductile intergranular fracture), and losses in ultimate tensile strength.

ATTACHMENT

The staff requests that the BWRVIP provide a comprehensive assessment of how welding of irradiated stainless steel degrades its mechanical properties. This assessment should consider the welding methods considered in the BWRVIP-34 and -97 reports (SMAW, FCAW, GTAW, GMAW and YAG)[1] and include any effect of underwater welding on mechanical properties.

Supplementary RAI 97-10

The staff's review of the BWRVIP-45 and BWRVIP-97 reports reveals that the helium threshold criterion does not adequately take into account the effect of physical constraints. The staff raised this concern earlier in its review of BWRVIP-97. In addition, the helium threshold criterion addresses only cracking due to helium embrittlement and not any degradation of mechanical properties such as loss of ductility, fracture mode shape and reduction in ultimate tensile strength.

The staff requests that the BWRVIP provide a comprehensive review of the effect of physical constraints on weldability of irradiated materials. This information, along with the information on the effects of helium concentration on cracking and material properties degradation [see Supplementary RAI 97-9], should be considered when developing the helium threshold criterion.

Supplementary RAI 97-11

Section 5 of the BWRVIP-34 report states that the boron content of the stainless steel vessel internals is not well-established and that there is a relatively large uncertainty in the thermal fluence calculations. As a result, a large uncertainty exists in the calculated helium content in the irradiated components. Therefore, some cases may require direct measurement of helium content, if the calculated values equal a certain fraction of the threshold value for welding.

The staff requests that the BWRVIP develop specific guidelines for removing a sample from a vessel internal component that is being considered for weld repair and measuring its helium content. The guidelines should address the uncertainty in determining the boron content and in estimating thermal flux. In addition, the staff requests that the BWRVIP provide the technical basis for the guidelines.

---

[1]SMAW = shielded metal arc welding, FCAW = flux cored arc welding, GTAW = gas metal arc welding, GMAW = gas metal arc welding, YAG = yttrium-aluminum-garnet (laser beam welding)

C
BWRVIP RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION

ELECTRIC POWER RESEARCH INSTITUTE

2005-305 ________________ BWR Vessel & Internals Project (BWRVIP)

July 25, 2005

Document Control Desk
U. S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Attention: Meena Khanna

Subject: Project No. 704 – BWRVIP Response to NRC Requests for Additional Information on BWRVIP-97

References:

1. Letter from Meena Khanna (NRC) to Carl Terry (BWRVIP Chairman) "Proprietary Request for Additional Information – Review of BWR Vessel and Internals Project Reports, BWRVIP-96, -97, -99, and –100 (TAC NOS. MB3947, MB3948, MB3951, and MB3946)," dated January 8, 2003.
2. Letter from Stephanie M. Coffin (NRC) to Bill Eaton (BWRVIP Chairman) "Supplementary Request for Additional Information – Review of BWR Vessel and Internals Project Report, BWRVIP-97, Guidelines for Performing Weld Repairs to Irradiated BWR Internals," dated March 18, 2004.
3. Letter from Stephanie M. Coffin (NRC) to Bill Eaton (BWRVIP Chairman) "Supplementary Request for Additional Information – Review of BWR Vessel and Internals Project Report, BWRVIP-34, "Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping" dated October 7, 2004.
4. Letter from Carl Terry (BWRVIP Chairman) to Document Control Desk (NRC) "Project 704 – BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals," dated November 27, 2001.
5. Letter from Carl Terry (BWRVIP Chairman) to Document Control Desk (NRC) "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)," dated May 22, 1997.

Enclosed are five (5) copies of the BWRVIP response to the NRC Requests for Additional Information (RAIs) on the BWRVIP report entitled "BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals," that were transmitted to the BWRVIP by the Reference 1 and 2 NRC letters identified above.

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BWRVIP 2005-305
July 25, 2005

Also included in the enclosure is the BWRVIP response to questions 34-7-1 and 34-A-4 that were transmitted to the BWRVIP by the Reference 3 NRC letter identified above. These questions are being addressed here due to their relevance to BWRVIP-97. The enclosure repeats each of the requests for information from the NRC verbatim followed by the BWRVIP response to that request.

Please note that the enclosed document contains proprietary information. Therefore, the requests to withhold the BWRVIP-97 and BWRVIP-34 reports from public disclosure which were transmitted to the NRC by the Reference 4 and 5 letters identified above also apply to the enclosed document.

If you have any questions on this subject, please contact Denver Atwood (Southern Nuclear, BWRVIP Repair Focus Group Chairman) by telephone at 205.992.7461.

Sincerely,

William A Eaton

William A. Eaton
Entergy Operations
Chairman, BWR Vessel and Internals Project

EPRI Proprietary Information

BWRVIP Response to NRC Request for Additional Information on BWRVIP-97

Items from the NRC Request for Additional Information on BWRVIP-97 are repeated below verbatim followed by the BWRVIP response to that item.

RAI 97-1

Section 2.2 of the BWRVIP-97 report states that a previous literature review (the reference is BWRVIP-45) indicated that the threshold for He-induced weldability problems is 1 appm when conventional welding techniques are employed. BWRVIP-45 (2nd paragraph, p. 6) states that the study that most accurately fixed the helium threshold at approximately 1 appm was conducted with the tritium-trick method. Using this result for the helium threshold, BWRVIP-97 sets the engineering threshold for helium concentration to an order of magnitude lower at 0.1 appm. The discussion below raises concerns on using tritium-tricked samples for determining the threshold, i.e., 0.1 appm for He-induced weldability of irradiated components.

Page 6 of the BWRVIP-45 report states "Tritium diffuses rapidly in metals, but is retained at sinks or traps. These are sites such as dislocations or grain boundaries. If the tritium is trapped at grain boundaries, then the helium is born at the grain boundaries. In this case, helium does not have to diffuse over long distances to form bubbles and to permit the bubbles to grow to a critical size for fracture during welding." On the basis of this reasoning, BWRVIP-45 concludes that tritium-trick doping is a worst case for weldability of stainless steel samples as compared to irradiated samples and that actual threshold (for irradiated stainless steels) may be somewhat higher.

However, other published literature contradicts this conclusion. For example, Kanne, et al. (Welding of Irradiated Stainless Steel, J. Nuclear Materials, 225, 1995, p. 69, and Ref. 2-18 in BWRVIP-98) presents results on welding of helium-containing stainless steel samples showing that the extent of cracking in the irradiated material was 28 to 31 times greater than in the tritium charged and aged material at the same helium concentration and welded by the same processes. As discussed by Louthan, et al. (Helium Embrittlement Model and Program Plan for Weldability of ITER Materials (U), WSCR-TR-97-0031, February 1997), tritium tricked samples are generally thin, unconstrained samples, because tritium charging and aging of this type of sample is quicker and can be done at lower temperatures than is practical for full size components. However, constraint contributes to higher tensile stresses and stress gradients in a full size component during welding, and, therefore, can have a significant impact on the weldability. Higher tensile stresses and stress gradients make the component more susceptible to helium cracking during welding. Therefore, weldability studies on thin, unconstrained, tritium-tricked samples are not necessarily indicative of the behavior of full size components.

- Taking into account the two above-mentioned differences between the weldability of tritium-tricked samples and irradiated samples, justify the use of tritium-tricked samples to determine 0.1 appm as a helium concentration-cracking threshold for irradiated stainless steel vessel internals, as recommended in Section 2.2 of BWRVIP-97.

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BWRVIP Response to RAI 97-1

As noted at the end of Section 4.2.2 in BWRVIP-97, tritium trick data were not used for establishing the weldability barrier in Figure 4-1. Data obtained using the tritium trick method that are shown on Figures 4-1 with the notation "TD" (tritium decay) were placed on the plot for information only. As discussed in the response to RAI 97-5, the tritium trick data will be plotted separately in a final version of the report.

RAI 97-2

Figure 1-2 of the BWRVIP-97 report presents a quantitative criterion for a helium concentration threshold (i.e., 0.1 appm), followed by Figure 4-1 to determine if the material may be welded at reduced heat input expressed as kJ/cm. Kanne, et al. (Weld Repair of Irradiated Materials, Materials Characterization, 43, 1999, p. 203) identified six variables that influence helium embrittlement during the welding of irradiated stainless steel. The three primary variables are helium concentration, temperature, and stress; the three secondary variables are metallurgical condition of the alloy, gradients in the alloy, and time at temperature. Tensile stresses and stress gradients are due to volumetric contraction of weld metal and structural constraints present in the component being repaired. The guidance presented in BWRVIP-97 for welding irradiated stainless steel accounts for only two of these variables.

- Provide revised guidance in the report to account for the remaining four variables, especially stress and stress gradients in the material.

BWRVIP Response to RAI 97-2

Unfortunately, comprehensive data do not exist that would allow guidance to be developed on all six variables discussed by Kanne, et.al. Helium content and weld heat input are the only two parameters of the six listed that can be measured and controlled in situ, these two parameters were used to provide the basis for the welding guidance. It is partially in recognition of the fact that the other variables may have some effect on weldability that the helium threshold for determining weldability was set conservatively low.

As additional data become available in the literature, the BWRVIP will continue to compare the reported results to the BWRVIP-97 threshold curve and make adjustments as appropriate. To date, no data have been found to violate the BWRVIP-97 curve.

RAI 97-3

Section 2.1 of the BWRVIP-97 report states that boron is typically present as an impurity in stainless steel and nickel-based alloys in concentrations of <5 to >30 ppm.

- Explain what the term concentrations of <5 to >30 ppm implies.
- Explain why Section 1.0 of the BWRVIP-96 report identifies different ranges for boron concentration (less than 1 ppm to over 50 ppm).

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- Section 2.1 of the BWRVIP-97 report further states that boron is sometimes deliberately added to improve the hot workability of steels. How common is this practice of adding boron? What is the range of this deliberately added boron?
- Section 2.4 of the BWRVIP-97 report states that a worst-case Type 316 stainless steel containing a specification maximum allowable nickel content of 14% and high-end boron concentration of 20 ppm is assumed. Justify why a boron concentration >20 ppm should not be used as a worst case for 316 stainless steel.
- What are the upper bound values for the other vessel internals materials, e.g., Type 304 stainless steel and Alloy 600?

<u>BWRVIP Response to RAI 97-3</u>

The NRC is correct in their observation that the BWRVIP has described the observed range of boron concentrations in a number of different ways. While none of these is technically incorrect and they do not alter the fundamental conclusions in the report, it may have led to some confusion.

First, with respect to the deliberate addition of boron to steels, the report is misleading. While it is true that boron is added to some materials to improve workability, it is not clear whether this was common practice for reactor materials (304SS, 316SS and Alloy 600). In any event, the boron contents referenced in BWRVIP-97 are based on available data as described further below.

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RAI 97-4

Section 2.3 of the BWRVIP-97 report presents results for calculations of helium content in a typical BWR/4 plant (Susquehanna) for 1, 15 and 30 effective full power years (EFPYs) at an assumed boron and nickel concentration of 1 appm boron (Table 2-1), 10% nickel (Table 2-2), and 20 appm boron and 14% nickel (Table 2-3).

- How are these tables applicable to the other BWR plants?
- If they can be used for other BWR plants, discuss in the report, the basis for that application.

BWRVIP Response to RAI 97-4

The helium content for Susquehanna was used to establish which internal components could be welded without regard for effects of irradiation. Clearly, the results are not strictly applicable to other plants. For any given plant, differences in geometry, fuel and operation will result in slightly different helium concentrations than were calculated for Susquehanna. However, there [[is a significant amount of conservatism built into the analysis of Section 2.3 and 2.4.

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RAI 97-5

Section 4.2.2 of the BWRVIP-97 report states that data obtained using the tritium-trick method, shown on Figure 4-1 with the notation TD (tritium decay), were not considered in establishing the weldability boundary. Therefore, to place the results in better context, replace Figure 4.1 with two figures, one with only the data on the irradiated materials and one with the tritium-trick data.

BWRVIP Response to RAI 97-5

Agreed. Figures 1 and 2 (attached here) provide separate plots for irradiated data and tritium decay data, respectively. These figures will replace the existing Figure 4-1 in a final version of the report.

RAI 97-6

Section 4.2.1 states that the most conservative values were used to anchor the borders with a minimum of a factor of two additional margins based on He content. For example, if no helium cracking was identified at 1 appm He and cracking was identified at 2 appm He at the same heat input, the borderline was constructed to be at or below the 0.5 appm point. Inspection of the data in Figure 4-1 does not reveal how the anchors are established for the boundary of cracking and no cracking, i.e., the dotted bilinear lines for the GTAW 304 (knee), YAG 304L (lower portion), GTAW 316L and GTAW 304-308L (upper portion). Please explain.

BWRVIP Response to RAI 97-6

The crack-no crack borderline was constructed using the following five data points:

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RAI 97-7

Section 5.2.2.2 of the BWRVIP-97 report states "In addition, if possible, surface and volumetric examinations of the component should be performed, with special attention paid to the toes of the repair and to the base metal beneath the repair." It appears that if a component is accessible to weld repair, surface and volumetric examinations of that component should be possible. Describe the conditions under which inspections of a repaired component may not be possible.

BWRVIP Response to RAI 97-7

The NRC is correct that if a component is accessible for weld repair, it will most likely be accessible for surface and/or volumetric examinations. In cases where surface or UT exams are possible, they would be performed in accordance with the guideline. There may, however, be cases (e.g., a fillet weld) where the configuration of the weld does not allow a meaningful UT exam to be done. If meaningful UT or surface exams cannot be performed, a visual examination would likely have to be substituted.

Supplementary RAI 97-8

Section 4.2.1 of the BWRVIP-97 report states, "Figure 4-1 indicates that successful welds can be obtained on irradiated material at relatively high He [helium] contents if the appropriate technique is selected." Therefore, Section 4.2.1 should state that the weldability boundary developed in that section is applicable only when the gas metal arc welding (GTAW) or the yttrium-aluminum-garnet (YAG) laser technique is used for repairing irradiated stainless steel. (Note: although the data associated with the GMAW technique are presented in Figure 4-1, these data, according to Section 4.2.2 of the BWRVIP-97 report, were not considered in establishing the weldability boundary because they are associated with tritium-tricked samples and not irradiated samples. Therefore, the weldability boundary presented in Figure 4-1 is not applicable when the GMAW technique is used.)

BWRVIP Response to RAI 97-8

(Note: We believe that the reference to "GTAW" in the second sentence of the RAI should read "GMAW" and our response is made on that basis.) Weldability of He containing material is primarily related to the heat input and the stress distribution upon cooling. These variables are predominately controlled by the heat flow during welding and the geometric configuration of the component being repaired. When heat input requirements are developed for one process, there is no technical justification for not applying them to all conduction limited welding processes: GTAW, GMAW, FCAW, PTAW, SMAW, and Laser (provided that it is not operating in the Key-hole mode). This is evidenced by the fact that the laser data and the GTAW data both indicate similar weldability thresholds at helium contents of approximately 8appm (Ref. Figure 1, attached).

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The BWRVIP is currently conducting additional research to attempt to more accurately account for welding process efficiencies and to determine if second order effects exist that depend on the process type. When that research is complete, it will be reported to the staff. In the interim, the BWRVIP suggests that the conservative threshold shown on Figure 1 should be considered applicable to the welding processes listed above.

Supplementary RAI 97-9

In response to RAI 2(a) (from the BWRVIP-34 review), the BWRVIP provided the following introductory comments: "As a preamble to this response, it should be noted that the cracking caused by entrapped helium during welding of irradiated materials does not occur in such a way as to present a safety hazard. The cracking occurs immediately after the welding is performed, and does not occur on a delayed basis. Should a utility attempt a welded repair on highly irradiated material, any cracking due to entrapped helium would be immediately obvious in post weld inspections and could be addressed appropriately at that time. As such, the issue of attempting a weld repair at a location for which the weldability cannot be accurately determined becomes only an economic concern for the utility. Should the weld crack, an alternate means of repair will be required. However, no safety concerns result."

Welding of irradiated stainless steel could degrade the mechanical properties without causing immediate cracking due to helium embrittlement. For example, in 1998, Robinson reported that when helium-charged samples of 304L stainless steel were subject to transient thermal cycles, simulating those occurring in the heat-affected zone of a gas tungsten arc weld, peak temperatures above 800°C (1472°F) caused severe ductility losses, fracture mode changes (from ductile transgranular rupture to ductile intergranular fracture), and losses in ultimate tensile strength.

The staff requests that the BWRVIP provide a comprehensive assessment of how welding of irradiated stainless steel degrades its mechanical properties. This assessment should consider the welding methods considered in the BWRVIP-34 and -97 reports (SMAW, FCAW, GTAW, GMAW and YAG)[1] and include any effect of underwater welding on mechanical properties.

BWRVIP Response to RAI 97-9

(Note: In the footnote to this RAI, we believe that "GTAW = gas metal arc welding" should read "GTAW = gas tungsten arc welding".) The Robinson data is not considered to be directly applicable to weldability considerations addressed in BWRVIP-97. The helium content of the material tested (335 to 526 appm) is exceedingly high compared to the values addressed in BWVIP-97. In addition, the Robinson tests utilized samples in which helium was implanted

[1]SMAW = shielded metal arc welding, FCAW = flux cored arc welding, GTAW = gas metal arc welding, GMAW = gas metal arc welding, YAG = yttrium-aluminum-garnet (laser beam welding)

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using the tritium implantation method. Both the NRC and the BWRVIP have stated that they do not believe this method should be used in evaluating weldability issues.

However, the BWRVIP does recognize that some changes in mechanical properties occur when welding is performed on irradiated materials. While mechanical property data is not available for all test points described in BWRVIP-97, data for some tests does exist. The available mechanical properties data were evaluated and compared against ASME Section III requirements. In all cases where the subject weld (data point) fell below the BWRVIP-97 threshold line (i.e., on the no-crack side), post-weld mechanical properties were found to exceed the Section III requirements. Consequently, while recognizing that a large systematic database of mechanical properties information does not exist, the available information indicates that, if welds are performed in accordance with the BWRVIP guidelines, the resulting mechanical properties will be acceptable.

Data is not currently available for the effect of welding underwater on the mechanical properties of irradiated materials. It is widely accepted in the scientific community that the degradation to the mechanical properties of welded irradiated materials is directly related to the growth of helium bubble. Underwater welding diminishes the time at which materials are subjected to temperatures where helium bubble growth occurs. Consequently, a qualitative assessment would indicate that underwater welding creates a less severe environment for helium bubble growth and would lead to less severe material degradation. The BWRVIP-97 threshold curve would thus be conservative for welds performed underwater.

Supplementary RAI 97-10

The staff's review of the BWRVIP-45 and BWRVIP-97 reports reveals that the helium threshold criterion does not adequately take into account the effect of physical constraints. The staff raised this concern earlier in its review of BWRVIP-97. In addition, the helium threshold criterion addresses only cracking due to helium embrittlement and not any degradation of mechanical properties such as loss of ductility, fracture mode shape and reduction in ultimate tensile strength.

The staff requests that the BWRVIP provide a comprehensive review of the effect of physical constraints on weldability of irradiated materials. This information, along with the information on the effects of helium concentration on cracking and material properties degradation [see Supplementary RAI 97-9], should be considered when developing the helium threshold criterion.

BWRVIP Response to RAI 97-10

Comprehensive data on the effects of physical constraints are not available. However, the data used to develop the threshold curve in BWRVIP-97 is based on samples that include broad ranges of thickness and joint configuration. The threshold curve was drawn to bound all of these configurations and thus inherently accounts for variations in the type of physical constraint.

Subsequent to the issuance of BWRVIP-97, some additional data has been published that reports welds performed on very stiff components (approximately 1-inch in thickness). The new data

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(Reference 1) indicate that successful GTAW welds can be performed at heat-inputs that significantly exceed the BWRVIP threshold. This gives additional confidence that the BWRVIP-97 curve is conservative with respect to the condition of physical restraint.

Supplementary RAI 97-11

Section 5 of the BWRVIP-34 report states that the boron content of the stainless steel vessel internals is not well-established and that there is a relatively large uncertainty in the thermal fluence calculations. As a result, a large uncertainty exists in the calculated helium content in the irradiated components. Therefore, some cases may require direct measurement of helium content, if the calculated values equal a certain fraction of the threshold value for welding.

The staff requests that the BWRVIP develop specific guidelines for removing a sample from a vessel internal component that is being considered for weld repair and measuring its helium content. The guidelines should address the uncertainty in determining the boron content and in estimating thermal flux. In addition, the staff requests that the BWRVIP provide the technical basis for the guidelines.

BWRVIP Response to RAI 97-11

The report "BWRVIP-96: BWR Vessel and Internals Project, Sampling and Analysis Guidelines for Determining the Helium Content of Reactor Internals" contains the requested information. This report is currently under review by the staff.

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NOTE: The following questions (34-7-1 and 34-A-4) were transmitted to the BWRVIP by the NRC as part of the Supplemental RAI on BWRVIP-34. As described in the BWRVIP response to the RAI on BWRVIP-34, they are being addressed here due to their relevance to BWRVIP-97.

RAI 34-7.1

Kane et al. (1993) and Goods and Karfs (1991) report that underbead cracking, but no toe cracking, was present in a Type 304 stainless steel specimen containing entrapped helium and repaired by a gas metal arc overlay. The staff requests that the BWRVIP explain whether the inspection methods considered in Section 7.0 are qualified for detecting and sizing underbead cracking.

BWRVIP Response to Supplementary RAI 34-7.1

The work done to develop the information in Section 7.0 of BWRVIP-34 did not address inspecting for cracks caused by welding of irradiated material. However, since the BWRVIP has committed to require compliance with BWRVIP-97 in BWRVIP-34, the inspection requirements of BWRVIP-97 would be performed if the material is determined to have a helium content that could give rise to cracking during welding.

BWRVIP-97 requires a visual inspection of the weld as well as UT and surface exams if access is available. As discussed in the response to RAI 97-7, it is unlikely that the weld would not be accessible for these inspections.

The ability of UT to detect underbead cracking depends strongly on the size and extent of the cracking as well as on the locations available for placement of the UT transducer. Larger cracks would be detectable given reasonably expected transducer placement. Small cracks would be more difficult, or impossible, to detect under certain conditions. However, it must be remembered that the weldability threshold presented in BWRVIP-97 was designed to preclude the generation of helium-related cracks in the first place. Consequently, if the heat-input threshold curve is observed, no cracking is expected.

RAI 34-A-4

In response to RAI 9, the BWRVIP stated that since the weldability of an irradiated material is affected by a number of parameters (e.g., the stress state of the joint), and since all of these parameters could not be duplicated reliably in a mockup, demonstration on an irradiated mockup does not appear to be a practical approach. The staff agrees with the BWRVIP that a demonstration on an irradiated mockup is not a practical approach. However, a finite element analysis evaluating thermo-mechanical response of an underwater weld overlay repair of the heavily irradiated welds (e.g., P4c, P4d, P8a, P8b as shown in Figure 2-1 of BWRVIP-34) may be practical and may provide sufficient information about stress and temperature distribution in the piping being repaired so that its weldability can be evaluated. Appendix L of BWRVIP-34 should include a statement about requiring a finite element analysis, and a statement about requiring removal of a small piece of material for direct measurement of helium content at the repaired weld.

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BWRVIP Response to Supplementary RAI A-4

In response to the staff's Supplemental Request for Information on the BWRVIP-34 report, the BWRVIP proposed to amend BWRVIP-34 to reference BWRVIP-97 for considerations of welding irradiated material. As such, the BWRVIP suggests that changes due to RAI-34-A-4 should be addressed in BWRVIP-97 rather than Appendix L of BWRVIP-34.

BWRVIP-97 currently recognizes that removal of a material sample is one acceptable method of determining the helium content of reactor material; thus no change is required to address this aspect of the staff's suggestion.

The BWRVIP agrees that finite element analysis may be a valuable tool in determining weldability and is currently conducting research to address this technical approach. When that research is completed, results will be shared with the staff. However, until that research is complete, the BWRVIP is not in a position to make specific recommendations regarding criteria that should be utilized in evaluating the suggested finite element analyses. Therefore, we propose no change to the report until specific recommendations can be made.

References:

1. Asano, et.al., "Thick Plate Welding of Irradiated Stainless Steels," *Effects of Radiation on Materials: 19th International Symposium*, ASTM STP 1366

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Table 1-Helium Content, Boron and Fluences from Plant Samples

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Figure 2]]TS
Effect of He and Heat Input on the Weldability of Stainless Steel – Tritium Decay Data

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Figure 3]]TS
Addition of Crack/No Crack Data Points to Figure 4-1 of BWRVIP-97

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NRC SUPPLEMENTARY REQUEST FOR ADDITIONAL INFORMATION

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 7, 2006

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

SUBJECT: SUPPLEMENTARY REQUEST FOR ADDITIONAL INFORMATION-REVIEW OF BOILING WATER REACTOR VESSEL AND INTERNALS PROJECT REPORT, "GUIDELINES FOR PERFORMING WELD REPAIRS TO IRRADIATED BWR INTERNALS (BWRVIP-97)" (TAC NO. MB3948)

Dear Mr. Eaton,

By letter dated November 27, 2001, and supplemented by letter dated July 25, 2005, you submitted for Nuclear Regulatory Commission staff review, Electric Power Research Institute proprietary report, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals (BWRVIP-97)." The BWRVIP-97 report provides a methodology to determine if weld repairs to irradiated components can be successfully performed and, if so, by which welding technique. Four major elements to the methodology are evaluated: (1) definition of weldability boundary, (2) methodology for helium determination, (3) survey of applicable welding techniques, and (4) welding guidelines.

The staff has determined that additional information is needed to complete the review. The supplemental request for additional information (RAI) regarding the BWRVIP-97 report is enclosed. Please note that these RAI questions were discussed with your staff on August 2, 2006. If you have any questions, please contact me at (301) 415-1467.

Sincerely,

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

Project No. 704

Enclosure:
Request for Additional Information

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SUPPLEMENTAL REQUEST FOR ADDITIONAL INFORMATION REGARDING THE "BWR VESSEL AND INTERNALS PROJECT, GUIDELINES FOR PERFORMING WELD REPAIRS TO IRRADIATED BWR INTERNALS (BWRVIP-97)"

SUPPLEMENTAL RAI 97-1

By letter dated July 25, 2005, the Boiling Water Reactor Vessel and Internals Project (BWRVIP), in response to Supplementary RAI 5-1 (Nuclear Regulatory Commission letter dated October 7, 2004), stated that underwater welding will slightly affect the residual stresses. The BWRVIP also stated that outer diameter (OD) welding with a water-solid condition at the inner diameter (ID) has proven to be beneficial in producing improved ID and through-wall stresses. The staff does not accept this response because the OD welding with a water-solid condition at the ID is different than the underwater welding of the core spray piping where both the inside and outside piping surfaces are exposed to water. The staff agrees with the BWRVIP that residual stresses at the ID are likely to be beneficial (compressive), and, therefore, do not cause any intergranular stress corrosion cracking concerns. However, the presence of compressive stresses on the OD and ID surfaces imply a likely presence of tensile stresses at some point in the thickness. This location may become susceptible to helium embrittlement if exposed to high thermal neutron fluences. The staff requests the BWRVIP address this issue and include its discussion of this issue in the -A version of the BWRVIP-97 report.

SUPPLEMENTAL RAI 97-2

The staff requests that the BWRVIP evaluate any synergistic interactions between radiation embrittlement and thermal aging of the ferrite in the weld overlay material. The staff requests that the BWRVIP address this issue regarding the synergistic interactions and include its discussion of this issue in the -A version of the BWRVIP-97 report.

ENCLOSURE

E
BWRVIP RESPONSE TO NRC SUPPLEMENTARY REQUEST FOR INFORMATION

ELECTRIC POWER RESEARCH INSTITUTE

2006-440 ______________________ BWR Vessel & Internals Project (BWRVIP)

October 5, 2006

Document Control Desk
U. S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Attention: Matthew A. Mitchell

Subject: Project No. 704 – BWRVIP Response to NRC Supplementary Request for Additional Information on BWRVIP-97

References:
1. Letter from Carl Terry (BWRVIP Chairman) to Document Control Desk (NRC) "Project 704 – BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals," dated November 27, 2001.
2. Letter from Matthew A. Mitchell (NRC) to Bill Eaton (BWRVIP Chairman) "Supplementary Request For Additional Information-Review of Boiling Water Reactor Vessel And Internals Project Report, "Guidelines For Performing Weld Repairs to Irradiated BWR Internals (BWRVIP-97)" (TAC NO. MB3948)," dated August 7, 2006.

Enclosed are five (5) copies of the BWRVIP response to the NRC Supplementary Request for Additional Information (RAI) on the BWRVIP report entitled "BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals," that was transmitted to the BWRVIP by the Reference 2 letter identified above.

Please note that the enclosed document contains proprietary information. Therefore, the request to withhold the BWRVIP-97 report from public disclosure which was transmitted to the NRC by the Reference 1 letter identified above also applies to the enclosed document.

If you have any questions on this subject, please contact Denver Atwood (Southern Nuclear, BWRVIP Repair Focus Group Chairman) by telephone at 205.992.7461.

Sincerely,

William A Eaton

William A. Eaton
Entergy Operations
Chairman, BWR Vessel and Internals Project

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BWRVIP Response to NRC Request for Additional Information on BWRVIP-97

The NRC Supplementary RAIs are repeated below followed by the BWRVIP response.

> [Note: These RAIs were initially written with respect to BWRVIP-34 ("Part-Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping"). However, since the questions deal with aspects of welding of irradiated materials, it was agreed that they would be addressed as part of the NRC review of BWRVIP-97.]

SUPPLEMENTAL RAI-1

By letter dated July 25, 2005, the Boiling Water Reactor Vessel and Internals Project (BWRVIP), in response to Supplementary RAI 5-1 (Nuclear Regulatory Commission letter dated October 7, 2004), stated that underwater welding will slightly affect the residual stresses. The BWRVIP also stated that outer diameter (OD) welding with a water-solid condition at the inner diameter (ID) has proven to be beneficial in producing improved ID and through-wall stresses. The staff does not accept this response because OD welding with a water-solid condition at the ID is different than the underwater welding of the core spray piping where both the inside and outside piping surfaces are exposed to water. The staff agrees with the BWRVIP that residual stresses at the ID are likely to be beneficial (compressive), and, therefore, do not cause any intergranular stress corrosion cracking concerns. However, the presence of compressive stresses on the OD and ID surfaces imply a likely presence of tensile stresses at some point in the thickness. This location may become susceptible to helium embrittlement if it is exposed to high thermal neutron fluences. The staff requests the BWRVIP address this issue and include its discussion of this issue in the -A version of the BWRVIP-97 report.

BWRVIP Response to Supplemental RAI-1

The BWRVIP agrees that tensile stresses likely exist at some point between the OD and ID of piping which has been overlayed. If the helium content of the material is sufficiently high (due to high fluence), it is possible that the combination of high temperature from the welding process and the presence of tensile stresses could cause cracking to occur. However, in the response to a separate RAI on BWRVIP-34, the BWRVIP agreed to require that the weld overlays be performed in accordance with the requirements of BWRVIP-97. These requirements limit the weld heat-input to a level that precludes cracking. Consequently, cracking due to helium embrittlement will not occur in the weld overlays. Since adequate guidance for prevention of helium embrittlement cracking already exists in the BWRVIP-97 guideline, the BWRVIP proposes that no additional change is warranted.

EPRI Proprietary Information

SUPPLEMENTAL RAI-2

The staff requests that the BWRVIP evaluate any synergistic interactions between irradiation embrittlement and thermal aging of the ferrite in the weld overlay material. The staff requests that the BWRVIP address this issue regarding the synergistic interactions and include its discussion of this issue in the -A version of the BWRVIP-97 report.

BWRVIP Response to Supplemental RAI-2

In response to a separate RAI related to BWRVIP-34, the BWRVIP agreed to limit the ferrite content of overlay welds to 12FN. This measure should preclude concerns related to thermal aging. Any synergistic aging/irradiation effects related to the overlay should be no different than for other welds in the core spray piping system. Such effects have not been observed to date in spite of the fact that many piping system welds have been in service for 20 to 30 years. Should the suggested synergistic effects prove to be problematic in the future, it would be anticipated that they would manifest themselves first in the older welds which have received a much higher fluence and likely have a similar or higher ferrite content than the new overlay welds. (Note that material requirements in place at the time of original construction of most plants would have allowed a ferrite content as high as 20FN as opposed to the BWRVIP-34 requirement of 12FN.) Since the current requirements for ferrite in BWRVIP-34 (as revised by the BWRVIP response to NRC RAIs) are appropriate and since the suggested synergistic effects do not appear to present a concern for the overlay welds, the BWRVIP suggests that no additional discussion be added to BWRVIP-97.

F
RECORD OF REVISIONS

BWRVIP-97-A	Information from the following documents was used in preparing the changes included in this report: 1. *BWRVIP-97: BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals*, EPRI, Palo Alto, CA: 2001. 1003020. 2. Letter from Meena Khanna (NRC) to Carl Terry (BWRVIP Chairman), "Proprietary Request for Additional Information – Review of BWR Vessel and Internals Project Reports, BWRVIP-96, -97, -99, and -100 (TAC NOS. MB3947, MD3948, MB3951, and MB3946)," dated January 8, 2003 (BWRVIP Correspondence File Number 2003-022) 3. Letter from Stephanie M. Coffin (NRC) to William Eaton (BWRVIP Chairman), "Supplementary Request for Additional information - Review of BWR Vessel and Internals Project Report, BWRVIP-97, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals" dated March 18, 2005 (BWRVIP Correspondence File Number 2004-130). 4. Letter from William A. Eaton (BWRVIP Chairman) to Meena Khanna (NRC), "PROJECT NO. 704 – BWRVIP Response to NRC Request for Additional Information on BWRVIP-97" dated July 25, 2005 (BWRVIP Correspondence File Number 2005-305). 5. Letter from Matthew Mitchell (NRC) to William Eaton (BWRVIP Chairman), "Supplementary Request for Additional Information – Review of Boiling Water Reactor vessel and Internals Project Report, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals (BWRVIP-97)" TAC NO. MB3948, dated August 7, 2006, (BWRVIP Correspondence File Number 2006-403). 6. Letter from William A. Eaton (BWRVIP Chairman) to Matthew Mitchell (NRC) "Project 704 – BWRVIP Response to NRC Supplementary Request for Additional Information on BWRVIP-97" dated October 5, 2006 (BWRVIP Correspondence File Number 2006-440). 7. Letter from Mark Maxin (NRC) to Rick Libra (BWRVIP Chairman) "Safety Evaluation for Electric Power Research Institute (EPRI) Boiling Water Reactor (BWR) Vessel and Internals Project (BWRVIP) Report 1003020 (BWRVIP-97) "BWR Vessel and Internals Project, Guidelines for Performing Weld Repairs to Irradiated BWR Internals" TAC NO. MC3948, dated June 30, 2008 (BWRVIP Correspondence File Number 2008-217). Details of the revisions can be found in Table F-1.

Table F-1
Revision Details

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Add NRC Correspondence	NRC Request	NRC Safety Evaluation added behind report title page. Remainder of correspondence added as Appendices A through E.
Revise Figure 4-1 to clearly delineate tritium-trick samples	Response to RAI 97-5 (2005-305)	Tritium-trick data removed from Figure 4-1 and moved to separate figure (4-2).
Revise reference to ASME Code Case N-516	NRC Safety Evaluation (2008-217)	Section 5 revised to reference Code Case N-516-3 as approved in RG 1.147.
Clarify applicable welding processes	Response to NRC Supplementary RAI 97-8 (2005-305)	Discussion of welding processes for which Table 4-1 is applicable added to Section 4.3.
Clarify applicability of Figure 4-1 to underwater welding	Response to NRC Supplementary RAI 97-9 (2005-305)	Discussion added to Section 4.3.
Clarify inspection requirements	Response to NRC RAI 97-7 (2005-306)	Discussion added to Section 5.2.2.2.
Delete simplified equations in Section 3.1 as an acceptable means of calculating helium content.	BWRVIP comment	The simplified equations in the original version of BWRVIP-97 have been found to result, in some cases, in non-conservative estimates of the helium content. Section 3.1 has been revised to require the use of an appropriately benchmarked methodology for establishing the helium content by calculation.
Add NEI 03-08 Implementation Requirements	BWVIP-94, Revision 1 requirement	Implementation requirements added in Section 1.3
End		

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