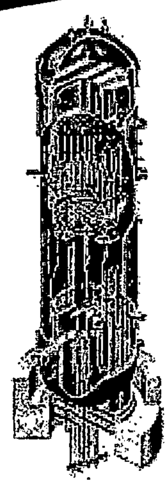
ELECTRIC POWER
RESEARCH INSTITUTE

2018 TECHNICAL REPORT

# BWRVIP-41NP, Revision 4-A: BWR Vessel and Internals Project

## BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines





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PREPARED UNDER THE NUCLEAR QA PROGRAM

# BWRVIP-41NP, Revision 4-A: BWR Vessel and Internals Project

BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines

**3002014254NP**

Final Report, December 2018

EPRI Project Manager
J. Hosler

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|---|
| All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product. |
| YES NO |

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## NOTE

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# ACKNOWLEDGMENTS

The following organization prepared this report:

Electric Power Research Institute
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This report describes research sponsored by EPRI and its BWRVIP participating members.

This report was prepared using a graded approach to quality following guidance of NQA-1-2008, Subpart 4.2, required by QAP 2.2.

This report is based on the following previously published report:

*BWRVIP-41, Revision 4: BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines.* EPRI, Palo Alto, CA: 2014. 3002003093.

This publication is a corporate document that should be cited in the literature in the following manner:

*BWRVIP-41NP, Revision 4-A: BWR Vessel and Internals Project: BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines.* EPRI, Palo Alto, CA: 2018. 3002014254NP.

# ABSTRACT

Based on industry jet pump inspection experience and a safety assessment completed by the BWR Vessel and Internals Project (BWRVIP), entitled *Safety Assessment of BWR Reactor Internals (BWRVIP-06-Revision 1-A)*, EPRI report 1019058, December 2009, it has been determined that inspection and evaluation procedures have a role in assuring the long-term integrity of the jet pump safety functions and maintaining the design basis of the jet pump assembly. The safety functions include ensuring 2/3 core height re-flooding capability and maintaining low-pressure coolant injection (LPCI) operability for those plants that use the recirculation system to perform the LPCI function.

This inspection and evaluation (I&E) guideline provides information on potential failure locations in BWR/3–6 jet pump components. For each location, a discussion of the function, configuration, susceptibility, loading, and consequences of failure is provided. A summary of field experience is also provided. It was determined that many of the jet pump locations are susceptible to cracking due to intergranular stress corrosion cracking (IGSCC), fatigue, or both. Embrittlement was also considered and was not found to be a significant degradation mechanism for the jet pump components. Also, in evaluating the consequences of potential cracking, the conclusion for some locations is that significant cracking can be tolerated without loss of essential jet pump safety functions.

This guideline is intended to present the appropriate inspection recommendations to assure safety function integrity. Economic and normal operational consequences of cracking are not directly factored into the recommendations. The inspection recommendations are dependent on BWR type and, where appropriate, plant-specific configuration differences. It is the intent that, for BWRVIP members, these guidelines can be followed in the place of prior GE SILs (Service Information Letters) related to safety to assure the essential safety functions of the jet pump.

This BWRVIP report provides information on potential failure locations in BWR/3–6 jet pump components and recommends an inspection program designed to ensure that the integrity of all jet pump safety functions is maintained. This revision (Revision 4-A) of BWRVIP-41 is based on the previously published Revision 4 and incorporates the NRC Safety Evaluation and supporting correspondence.

**Keywords**
Boiling water reactor
Flaw evaluation
IGSCC
Jet pump assembly

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# EXECUTIVE SUMMARY

**Deliverable Number: 3002014254NP**

**Product Type: Technical Report**

## Product Title: BWRVIP-41NP, Revision 4-A: BWR Vessel and Internals Project: BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines

**PRIMARY AUDIENCE:** BWR Vessel and Internals Project (BWRVIP) Program Owners

**SECONDARY AUDIENCE:** Utility in-vessel inspection staff

### KEY RESEARCH QUESTION

Based on industry jet pump inspection experience and a safety assessment completed by the BWRVIP, entitled *Safety Assessment of BWR Reactor Internals* (BWRVIP-06-Revision 1-A, EPRI report 1019058), it has been determined that inspection and evaluation (I&E) procedures play a role in ensuring the long-term integrity of the jet pump safety functions and maintaining the design basis of the jet pump assembly. This report, *BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines*, was developed and is maintained to present appropriate inspection recommendations to assure safety-function integrity.

### RESEARCH OVERVIEW

A group of utility and industry experts evaluated available information—including BWR inspection data and information on intergranular stress corrosion cracking (IGSCC), fatigue, and embrittlement—to identify potential failure locations in BWR/3–6 jet pump components. The consequences and likelihood of a failure at each location were evaluated. Factors considered included component function, plant-specific configuration variations, cracking susceptibility, and inspection history. The project team then made both baseline inspection and reinspection recommendations based on BWR type and (where appropriate) plant-specific configuration differences. With baseline inspections now complete, this revision of the guideline presents only recommendations for periodic reinspection. New data (for example, changes to susceptibility trends identified as inspection data accumulates) are incorporated into this guidance over time. Accordingly, periodic revision of this guideline over time is anticipated to occur. This -A version of Revision 4 of the report includes the NRC Safety Evaluation on BWRVIP-41, Revision 4 and supporting correspondence.

### KEY FINDINGS

- These inspection guidelines encompass all welded and bolted locations identified from design drawings of the jet pump assembly and present cracking-susceptibility considerations for the jet pump, as well as the consequences of failure at each location.
- The susceptibility and consequence considerations, coupled with plant operating experience, are used to establish and maintain a comprehensive inspection program.
- The guidelines also discuss cases in which the scope of the inspection may need to be expanded and describe areas of the assembly that are not inspectable.

### WHY THIS MATTERS

The BWRVIP undertook an extensive program to develop and maintain a comprehensive set of guidelines that will provide every member utility with the necessary information to make cost-effective decisions on degradation management for key plant components. This series of I&E guidelines provides BWR owners with NRC-approved tools to answer questions on what needs to be inspected, when it needs to be inspected, and the technical basis for run-repair decisions when degradation is observed.

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## EXECUTIVE SUMMARY

### HOW TO APPLY RESULTS

Utilities should incorporate the inspection and flaw evaluation guidance provided in this guideline into their plant-specific BWR vessel internals inspection program. Utility implementation of these guidelines for safety-critical BWR internals will ensure that components have not approached safety limits, thus confirming their serviceability.

### LEARNING AND ENGAGEMENT OPPORTUNITIES

- *BWRVIP-266: BWR Vessel and Internals Project: Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program*, EPRI report 1025140
- BWR Vessel and Internals Project (BWRVIP)

**EPRI CONTACTS:** John Hosler, Technical Executive, jhosler@epri.com

**PROGRAM:** BWR Vessel and Internals Project (BWRVIP), P41.01.03

**IMPLEMENTATION CATEGORY:** Regulatory

# RECORD OF REVISIONS

| Revision Number | Revisions |
|---|---|
| BWRVIP-41 | Original Report (TR-108728) |
| BWRVIP-41, Rev. 1 | TR-108728 was revised to incorporate changes proposed by the BWRVIP in responses to NRC Requests for Additional Information, recommendations in the NRC Safety Evaluation (SE), and other necessary revisions identified since the last issuance of the report. In addition, the report includes revised guidance for inspecting jet pump wedges and incorporates the new jet pump beam inspection recommendations recently published in BWRVIP-138. All changes except corrections to typographical errors are marked with margin bars. The NRC SE for the original BWRVIP-41 report and the NRC Final Safety Evaluation accepting the original report for referencing in license renewal applications are included as appendices. Non-essential format changes were made to comply with the current EPRI publication guidelines.<br>Appendix B added: NRC Final Safety Evaluation.<br>Appendix C added: NRC Acceptance for Referencing Report for Demonstration of Compliance with License Renewal Rule.<br>Details of the revisions can be found in Appendix D. |
| BWRVIP-41, Rev. 2 | BWRVIP-41, Revision 1 was revised to incorporate changes proposed by the-BWRVIP to include the results of comprehensive fracture mechanics evaluations performed on Group 2 and Group 3 jet pump beam designs documented in BWRVIP-138 Revision 1 (EPRI 1016574) and other necessary revisions identified since the last issuance of this report. All changes since the last issuance of this report except corrections to typographical errors are marked with margin bars. Details of the revisions can be found in Appendix E. |
| BWRVIP-41, Rev. 3 | BWRVIP-41, Revision 2 was revised to incorporate an inspection strategy and leakage evaluation for inaccessible welds. All changes, except corrections to typographical errors, are marked with margin bars. Details of the revision can be found in Appendix F. |
| BWRVIP-41, Rev. 4 | BWRVIP-41, Revision 3 was revised to incorporate changes to the periodic inspection program based on a detailed evaluation of plant operating experience. This evaluation is documented in BWRVIP-266, *BWR Vessel and Internals Project: Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program*. This revision addresses only ongoing periodic inspection recommendations as all baseline inspections have been completed. Details of the revision can be found in Appendix G. |

| Revision Number | Revisions |
|---|---|
| BWRVIP-41, Rev. 4-A | NRC approved version of BWRVIP-41, Revision 4-A (EPRI report 3002014254) published in 2018<br>BWRVIP-41, Revision 4 (EPRI report 3002003093) was revised to incorporate changes proposed by the BWRVIP in responses to NRC Requests for Additional Information (RAIs), recommendations in the NRC Safety Evaluation (SE), and other necessary revisions identified since the last issuance of the report. In accordance with an NRC request, the SE on BWRVIP--41, Revision 4 is included in the report front matter and the report number includes an "-A" indicating the version of the report accepted by the NRC staff. Non-essential format changes were made to comply with the current EPRI publication guidelines.<br>Appendix A modified: Demonstration of compliance of the information provided in BWRVIP-41 with the Technical Information Requirements of the License Renewal Rule (10 CFR 54.21) was deleted consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines.<br>Appendix B Title updated to indicate that the SE refers to original issue of BWRVIP-41.<br>Appendix C modified: -NRC SE on License Renewal Appendix deleted consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines.<br>Appendix H added: NRC RAIs on BWRVIP-41, Revision 4, dated April 25, 2016. (BWRVIP Correspondence Number 2016-042A).<br>Appendix I added: BWRVIP Responses to NRC RAIs on BWRVIP-41, Revision 4, dated February 8, 2017. (BWRVIP Correspondence Number 2017-022).<br>Appendix J added: Record of Revisions for BWRVIP-41, Revision 4-A.<br>Details of the revision can be found in Appendix J. |

# NRC SAFETY EVALUATION OF BWRVIP-41, REVISION 4

In accordance with an NRC request, the Non-Proprietary Version of the NRC Safety Evaluation of BWRVIP-41, Revision 4 immediately follows this page. Other pertinent NRC and BWRVIP correspondence is included in appendices.

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

July 2, 2018

Mr. Tim Hanley
Senior Vice President West Operations, Exelon
Chairman, BWR Vessel and Internals Project
3420 Hillview Avenue
Palo Alto, CA 94304-1395

SUBJECT: FINAL NONPROPRIETARY SAFETY EVALUATION FOR ELECTRIC POWER RESEARCH INSTITUTE TOPICAL REPORT BWRVIP-41, REVISION 4, "BWR JET PUMP ASSEMBLY INSPECTION AND FLAW EVALUATION GUIDELINES" (CAC NO. MF4887; EPID L-2014-TOP-0008)

Dear Mr. Hanley:

By letter dated September 24, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14279A437), the Boiling Water Reactor (BWR) Vessel and Internals Program (BWRVIP) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review the Topical Report (TR) BWRVIP-41, Revision 4, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines." By letter dated April 20, 2018, the NRC staff issued its draft safety evaluation (SE) on BWRVIP-41, Revision 4 (ADAMS Accession No. ML17171A317).

By letter dated May 9, 2018 (ADAMS Accession No. ML18131A164), the BWRVIP provided comments on the NRC draft SE. The comments provided by the BWRVIP were related to the identification of proprietary information in the draft SE, clarifications and accuracy.

The NRC staff has found that BWRVIP-41, Revision 4 is acceptable for referencing in licensing applications for nuclear power plants to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that EPRI publish approved proprietary and non-proprietary versions of TR BWRVIP-41, Revision 4 within six months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The approved versions shall include an "-A" (designating approved) following the TR identification symbol.

As an alternative to including the RAIs and RAI responses behind the title page, if changes to the TRs provided to the NRC staff to support the resolution of RAI responses, and the NRC staff reviewed and approved those changes as described in the RAI responses, there are two ways that the accepted version can capture the RAIs:

1. The RAIs and RAI responses can be included as an Appendix to the accepted version.
2. The RAIs and RAI responses can be captured in the form of a table (inserted after the final SE) which summarizes the changes as shown in the approved version of the TR. The table should reference the specific RAIs and RAI responses which resulted in any changes, as shown in the accepted version of the TR.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, EPRI will be expected to revise the TR appropriately. Licensees referencing this TR would be expected to justify its continued applicability or evaluate their plant using the revised TR.

If you have any questions or require any additional information, please feel free to contact the NRC Project Manager for the review, Joseph Holonich at (301) 415-7297 or joseph.holonich@nrc.gov.

Sincerely,

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Docket No.: 99902016

Enclosure:
Final Safety Evaluation

FINAL SAFETY EVALUATION BY THE U.S. NUCLEAR REGULATORY COMMISSION STAFF

FOR TOPICAL REPORT BWRVIP-41, REVISION 4,

"BWRVIP JET PUMP ASSEMBLY INSPECTION AND FLAW EVALUATION GUIDELINES"

CAC NO. MF4887; EPID L-2014-TOP-0008

## 1.0 INTRODUCTION

### 1.1 Background

By letter dated September 24, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14279A437), the Electric Power Research Institute submitted for U.S. Nuclear Regulatory Commission (NRC) staff review topical report (TR) Boiling Water Reactor (BWR) Vessel Internals Project (BWRVIP)-41, Revision 4, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines." This revision of the NRC staff accepted-for-use BWRVIP-41, includes a reduction in inspection frequency for the jet pump welds. The NRC staff's initial safety evaluation (SE) was issued on June 20, 2000, and the final SE on February 4, 2001 (ADAMS Accession Nos. ML003725033, and ML010460111).

The technical basis for the reduction in inspection frequency proposed in BWRVIP-41, Revision 4, is addressed in BWRVIP-266, "Technical Bases for Revision of the BWRVIP-41 Jet Pump Assembly Inspection and Flaw Evaluation Guidelines" (ADAMS Package Accession No. ML14343A098). The technical bases in the BWRVIP-266 report were developed using the fleet-wide inspection results of the jet pump assembly welds. The BWRVIP-266 report was submitted to the NRC staff for information only, hence, the NRC staff did not issue a SE for BWRVIP-266.

The BWRVIP-41, Revision 4, report will be referred to as the "TR" in this SE. By letter dated February 8, 2017 (ADAMS Accession No. ML17045A013), EPRI responded to the NRC staff requests for additional information (RAIs).

### 1.2 Purpose

The NRC staff reviewed the TR to determine whether the justification provided is valid for the current licensing period and the period of extended operation (PEO). The review considered the: consequences of component failures, potential degradation mechanisms, and past service experience; validity of the structural analyses based on intergranular stress-corrosion cracking (IGSCC); ability of the proposed inspections to detect degradation in a timely manner; and acceptability of the flaw evaluation and inspection criteria.

## 2.0 SUMMARY OF BWRVIP-41, REVISION 4

BWRVIP-41, Revision 4, contains a discussion of the technical basis for a reduction in inspection frequency based on the fleet-wide inspection results for the jet pump assembly welds. The TR also provides descriptions of the jet pump assembly designs and their IGSCC susceptibility factors, inspection program, loading conditions, evaluation methodologies, flaw

Enclosure

evaluation, seismic inertia analysis, and license renewal issues. The aforementioned topics are addressed in various sections of the TR, as summarized below:

Section 1, "Introduction" - provides a brief background review of prior industry inspections of jet pump assemblies and the cracking history.

Section 2, "Jet Pump Assembly Analysis" - addresses jet pump assembly designs that are applicable to BWR/3, 4, 5, and 6 designs. This section also addresses the susceptibility of the jet pump assembly components to IGSCC, fatigue, and embrittlement. TR Section 2 focuses on potential failure locations in the jet pump assembly.

Section 3, "Inspection Strategy" - provides inspection guidelines for jet pump assemblies of applicable BWR designs, proposed inspection frequency, scope expansion, re-inspection guidelines, and flaw acceptance criteria for continued operation.

Section 4, "Loading" - provides details of various loadings and the load combinations that need to be considered to determine the primary and secondary stress levels appropriate for the jet pump assembly welds for various operating conditions.

Section 5, "Structural and Leakage Evaluation Methodologies" - provides structural and leak evaluations to ensure leakage margins are maintained for a cracked jet pump assembly and welds during operation.

Appendix A - provides details related to license renewal requirements for jet pump assemblies.

## 3.0 TECHNICAL EVALUATION

The format of this SE is consistent with the order in which the TR sections were presented, as described in Section 2.0 of the SE. The technical contents in Section 1 of the TR remain unchanged from BWRVIP-41. Therefore, the NRC staff review of Section 1 of the TR is not discussed further in this SE. The NRC staff identified some issues with other TR sections as discussed in the following sections of the SE.

### 3.1 Inspection Criteria for the Cast Austenitic Stainless Steel Components

Cast austenitic stainless steel (CASS) may be susceptible to thermal aging embrittlement or IGSCC, depending on its composition and processing. The susceptibility of CASS to thermal aging embrittlement is determined based on the casting method, molybdenum content, and ferrite content. This criteria is described in an NRC letter dated May 19, 2000 (ADAMS Accession No. ML003717179). Based on the review of the TR, the NRC staff has concluded that the calculated ferrite levels in CASS jet pump components are in compliance with the criteria described in the aforementioned NRC letter. Therefore, the NRC staff concludes that the aging degradation due to thermal embrittlement in CASS jet pump components is acceptably addressed in the TR.

Section 2.2.1.2 of the TR discusses the materials used in the jet pump assembly. The NRC staff noted that TR Section 2.2.1.2 attributes [redacted] TR Table 3-1, "Matrix of Inspection Options," includes weld locations where CASS materials are used on one or both sides of a weld.

The NRC staff recognizes that the high resistance of CASS to IGSCC is related to the two-phase microstructure. Historically, CASS material has been considered resistant to IGSCC provided that it contains an adequate ferrite content (i.e., 7.5 percent). Based on its review, the NRC staff concludes that the proposed inspection strategy in TR Table 3-1 is acceptable for CASS material that contains an adequate ferrite content to be considered resistant to IGSCC.

The NRC staff notes that a population of CASS jet pump locations do not have a ferrite content of greater than 7.5 percent and may not be resistant to IGSCC. BWRVIP-234, "BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals" (ADAMS Accession No. ML102570723) discusses BWR internal components fabricated of CASS and aspects related to their ferrite content. Section 3.2 of BWRVIP-234 states that, by the early 1970s, the ferrite content in the General Electric drawings for BWR jet pump components was specified as a minimum 8 percent, as calculated using the Schaeffler diagram (Section III of American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code)).

Appendix A of BWRVIP-234 provides the certified material test record (CMTR) chemistries for approximately 80 heats of CASS material (i.e., CF-8). The ferrite content of these heats was calculated using the NRC endorsed Hull's equations. The results of these calculations are provided in BWRVIP-234, Table 3-2, "Summary of CMTR Data," which shows the range in ferrite content to be from 3.21 to 18.8 percent. BWRVIP-234, Table 3-2, also shows that the average minus one (-1) standard deviation value is less than 7.5 percent ferrite. Error or uncertainty in the calculated ferrite contents is not considered in these values.

The TR does not address the susceptibility of CASS jet pump components with a ferrite content below 7.5 percent to IGSCC. TR Table 3-1, "Matrix of Inspection Options," provides the inspection requirements for each jet pump location. [redacted]

By letter dated April 25, 2016, the NRC staff issued RAI-3 (ADAMS Accession No. ML16077A129) requesting that the BWRVIP discuss: the uncertainty related to the ferrite content; what effect the uncertainty in ferrite content has on the potential for IGSCC cracking in jet pump welds; and the need to inspect welds with CASS material on one or both sides.

By letter dated February 8, 2017, (ADAMS Accession No. ML17045A013), the BWRVIP replied to RAI-3. [redacted] BWRVIP letter 2014-086 (ADAMS Accession No. ML14174A841) is also referenced in the RAI response to address the uncertainty in the ferrite content using the Hull's equations.

The RAI response addresses the potential for IGSCC cracking in CASS jet pump welds by referencing BWRVIP letter 2015-150 (ADAMS Accession No. ML15155B487) and notes that: Generic Letter (GL) 88-01 (ADAMS Accession No. ML031130463) allows for CASS material beyond the carbon and ferrite limits to be examined at the same frequency as IGSCC resistant material; and operating experience (OE) supports a conclusion that CASS BWR internals are resistant to IGSCC. The RAI response also references BWRVIP letter 2012-148 (ADAMS Accession No. ML12265A078) and states that the CASS side of a weld would be in the "field of view" when performing enhanced visual testing (EVT)-1 examinations on the wrought side of the weld. Therefore, cracking of any significance on the CASS side of the weld would likely be detected and reported when performing EVT-1 examinations on the wrought side of the weld. These EVT-1 examinations have not identified cracking in a CASS components while inspecting the wrought side of a weld.

Additionally, the RAI response provides Table 3A, "Listing of Typical Jet Pump Casting Locations for U.S. BWRs," which identifies welds with CASS material on one or both sides of the weld. The RAI response states that IGSCC has not been detected in any of the welds listed in Table 3A. The lack of IGSCC on the wrought side of the welds in Table 3A suggests that the local stress is not high enough and/or the environment is not aggressive enough to initiate IGSCC. The response also notes that the most likely region for IGSCC to occur are the weld heat-affected-zone (HAZ).

The NRC staff reviewed the BWRVIP's response to RAI-3 and the applicable portions of the cited references. [redacted] However, the NRC staff maintains the position that there is a ferrite threshold below which CASS becomes susceptible to IGSCC; therefore, the NRC staff cannot conclude that ferrite uncertainty is not relevant to susceptibility of CASS jet pump components to IGSCC.

The NRC staff acknowledges that the NRC staff position in GL 88-01 allows for BWR austenitic stainless steel piping beyond the carbon and ferrite limits to be examined at the same frequency as IGSCC resistant material. [redacted] The NRC staff also acknowledges that in some instances the CASS side of a weld may be in the "field of view" when performing EVT-1 examinations on the wrought side of the weld. However, while the CASS HAZ may be in the "field of view" of an adjacent EVT-1 examination, these examinations are not focused on inspecting the CASS material for cracks and cannot be generically given inspection credit. The NRC staff acknowledges that the most likely region for IGSCC to occur are weld HAZs.

The staff concludes that CASS material that does not contain an adequate ferrite content cannot be considered resistant to the aging effect of cracking due to IGSCC. If the material does not contain an adequate ferrite content then it cannot be considered resistant to the aging effect of cracking due to IGSCC. The staff recognizes that IGSCC initiation is not solely dependent on the susceptibility of a material but also requires an aggressive environment and high enough sustained tensile stress. The relatively low number of IGSCC occurrences reported by the BWR fleet in the jet pump assemblies suggests that one of the necessary conditions for IGSCC to occur is not present. BWRVIP-266 (ADAMS Accession No. ML14343A112) provides a review of the inspection data for the jet pumps. [redacted]

The NRC staff has also determined that there is a low likelihood of IGSCC cracks in the HAZ of CASS jet pump components affecting the safe shutdown of a plant. This determination is partially based on the contents of BWRVIP-06-A, "Safety Assessment of BWR Reactor Internals," (ADAMS Accession No. ML021500624) and BWRVIP-09, "Quantitative Safety Assessment of BWR Reactor Internals." The NRC staff recognizes that accident mitigation systems and redundancies provide a level of defense-in-depth if IGSCC were to occur and result in a failure in the HAZ of a CASS weld. Additionally, the technical specifications for BWR plants provide surveillance requirements associated with the jet pump flow. Significant degradation would be detected by these surveillance requirements and the limiting conditions for operation would require the plant to shutdown prior to the safety of the plant being challenged.

The NRC staff notes that as part of the license renewal application (LRA), an applicant is required to implement an aging management program (AMP) for the BWR internal components, which includes the jet pump assembly. Program element 10 of all NRC approved plant-specific AMPs is "Operating Experience." The function of the "Operating Experience" program element is to ensure that the AMP is informed and enhanced when necessary through the systematic and ongoing review of both plant-specific and industry OE to maintain the effectiveness of the AMP. An increased frequency in detection of IGSCC in the jet pump assembly or CASS locations in the internals would be evaluated in accordance with the plant-specific AMP to ensure that the CASS HAZ locations in TR Table 3-1 remain appropriately age managed.

Based on its review, the NRC staff concludes that the proposed inspection strategy in TR Table 3-1 is acceptable for CASS material. The NRC staff has concluded that the calculated ferrite levels in CASS jet pump components are in compliance with NRC Letter dated May 19, 2000 (ADAMS Accession No. ML003717179); therefore, aging degradation due to thermal embrittlement in CASS is acceptably addressed in the TR. The NRC staff has concluded that the proposed strategy in TR Table 3-1 is acceptable for inspecting CASS jet pump components for IGSCC because: the locations have adequate ferrite content to be considered resistant to IGSCC; or there is a low likelihood of IGSCC cracks in the HAZ of CASS jet pump components affecting the safe shutdown of a plant and OE will continue to be considered to ensure effective aging management.

### 3.2 Inspection Criteria of Irradiation Assisted Aging Degradation

Some of the jet pump components are potentially susceptible to irradiation-assisted stress corrosion cracking (IASCC) when they are exposed to a neutron fluence value that exceeds the threshold limits. The NRC staff notes that aging degradation due to IASCC is not addressed in the TR. Therefore, by letter dated April 25, 2016, the NRC staff issued RAI-4 requesting that the BWRVIP discuss the aging degradation in jet pump components due to IASCC for 60 years of operation. In its reply dated February 8, 2017, the BWRVIP addressed the 60 year fluence estimates for jet pump components and the inspection program for the components that are potentially susceptible to IASCC.

In its review of the BWRVIP RAI-4 response, the NRC staff noted that most of the jet pump components are exposed to lower fluence than the core shroud because the jet pump components are farther from the core. The fluence estimates provided in the response also indicate that some weld locations in a relatively small population of U.S. BWR units would be exposed to fluence exceeding $5 \times 10^{20}$ n/cm$^2$ (E > 1 MeV) and susceptible to IASCC during the PEO. These weld locations are included in the periodic inspections specified in TR Table 3-1.

[redacted]

The NRC staff notes that as part of the LRA, an applicant is required to implement an AMP for the BWR internal components, which includes the jet pump assembly. The function of AMP element 10 is to ensure that the AMP is informed and enhanced when necessary through the systematic and ongoing review of both plant specific and industry OE to maintain the effectiveness of the AMP. Factors influencing the effectiveness of the plant-specific AMP to manage IASCC would include the timing of examinations and selections of welds for examination considering the IASCC fluence threshold. Additionally, if a sampling based inspection strategy (i.e., X% every Y years, where X is less than 100) is used for a weld location, high fluence plants should consider fluence effects when establishing its inspection program.

The staff's concerns associated with RAI 4 have been resolved. All weld locations estimated to be exposed to fluence exceeding $5x10^{20}$ n/cm2 are included in TR Table 3-1. [redacted] Subsections have also been added to the TR that address the effects of irradiation, as it relates to SCC and flaw evaluations. Additionally, during the PEO plant-specific AMP element 10 ensures that IASCC remains appropriately age managed and that the plant-specific AMP is enhanced if warranted.

3.3 Scope Expansion Criteria

Scope expansion criteria for the inspections of the jet pump welds are addressed in TR Section 3.2.8.1. TR Section 3.2.8.1.2 includes exemptions from the scope expansion for specific welds. By letter dated April 25, 2016, the NRC staff issued RAI-7 requesting that the BWRVIP discuss the scope expansion for inspections of the welds in jet pump components if one or more flaws are found during the inspection or re-inspection of a same type of weld. In its response to RAI-7, the BWRVIP proposed enhancements for inspections.

Based on its review of the RAI-7 response, the NRC staff determined that the proposed enhancement to the scope expansion exemptions described in TR Section 3.2.8.1.2 provides reasonable assurance that the aging degradation in structurally challenged welds would be identified in a timely manner during the PEO. However, with respect to the selection of welds that would qualify for the exemption from the scope expansion criteria, the NRC staff is concerned that the criteria do not adequately consider the previous ultrasonic testing (UT) inspection coverage.

TR section 3.2.8.1.2 requires that welds that are exempted from scope expansion must have been examined in a previous refueling outage by UT. However, the NRC staff notes that some of the previous UT examinations of jet pump welds had inspection coverages of less than 50 percent weld area. The NRC staff is concerned that cracking in the uninspected area could be undetected and that the extent of aging degradation cannot be effectively assessed in the uninspected area. Therefore, the NRC staff determined that the scope examination exemptions shall be limited to the welds that were previously examined with a UT technique that achieved an inspection coverage of greater than 75 percent area of the weld. This criterion (75 percent area of the weld area) was previously addressed in the staff's SE, dated June 22, 2011, (ADAMS Accession No. ML111600498) for the MRP-227-A, "Pressurized Water Reactor Internals Inspection and Evaluation Guidelines" report (ADAMS Package Accession No. ML090160212).

Based on its review, the NRC staff finds that the following condition is necessary: Exemptions of welds from scope expansion shall be limited to welds that were previously examined with a UT technique that achieved inspection coverage, for the "areas of interest" as defined by BWRVIP-03, for at least 75 percent of the weld circumference. **This is TR Condition 1 in Section 5.0 of this SE.**

3.4 Proposed Inspection Strategy

The inspection strategy for the applicable jet pump locations is provided in TR Table 3-1. The NRC staff noted that the proposed inspection strategy will be effective in identifying active aging degradation in a timely manner, when the BWR units implement an effective hydrogen water chemistry (HWC) or HWC + noble metal chemical addition (NMCA) program. Therefore, the NRC staff determined that the proposed inspection strategy will be adequate provided the owners of BWR units implement the requirements of BWRVIP-62-A, "Technical Basis for Inspection Relief for BWR Internal Components with Hydrogen Injection."

Based on its review, the NRC staff finds that the following condition is necessary: Licensees shall comply with the requirements of a NRC-approved HWC program (e.g., BWRVIP-62-A). **This is TR Condition 2 in Section 5.0 of this SE.**

3.5 Structural and Leakage Evaluation Methodologies

The NRC staff reviewed Section 5 of the TR, which presents the methodologies and calculation procedures for structural and leakage evaluation of cracks detected in both accessible and inaccessible welds in the jet pump assembly. The NRC staff noted that the changes between BWRVIP-41 and the TR were mostly organizational and editorial.

Examples of these changes include revised section heading titles and order of presentation of material. The NRC staff found these organizational and editorial changes to be acceptable. The NRC staff identified the following changes between BWRVIP-41, Section 5 and the TR that were not organizational or editorial, and evaluated each change in the subsections that follow.

- Item 1
  Location: Section 5.1.1.1, "(Nondestructive Examination) NDE Uncertainty," of the TR
  Change: Addition of section on NDE uncertainty

- Item 2
  Location: Last paragraph of Section 5.1.1.2, "Consideration of Welds with Partial Inspection Access," of the TR
  Change: Addition of discussion of welds that are

- Item 3
  Location: Last paragraph of Section 5.1.1.3, "Crack Growth," of the TR
  Change:

- Item 4
  Location: Section 5.1.2.1, "Limit Load Evaluation Methodology," and Section 5.1.2.1.1, "Z factor," of the TR
  Change: Revisions and additions to the limit load equations

- Item 5
  Location: Section 5.1.2.1.2, "Flaw Proximity Considerations," of the TR
  Change: Addition of BWRVIP-158-A, "Flaw Proximity Rules for Assessment of BWR Internals" (ADAMS Accession No. ML12349A336) for addressing combination of multiple indications

- Item 6
  Location: Section 5.1.4.1, "Leak Rate from Crack Detected in Accessible and Partially Accessible Welds," of the TR
  Change: Additional sentence that clarifies the type of loads to be considered in calculating the crack opening area; additional sentence that clarifies the crack sizes to be used in the leak rate evaluation.

- Item 7
  Location: Section 5.1.3, "Leakage Considerations," and Section 5.1.4, "Leak Rate Calculation Methods," of the TR
  Change: Revisions to leak rate methodology

3.5.1 Evaluation of Item 1

For NDE uncertainty, the TR indicates that the measured length and depth of observed flaws may need to be adjusted in accordance with current BWRVIP recommendations. This is acceptable because the staff, in its SE dated December 23, 2011 (ADAMS Accession No. ML113550419), resolved the open item on NDE uncertainty specified in the SE dated August 20, 2001 (ADAMS Accession No. ML012320436) on BWRVIP-63, "Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," and accepted the BWRVIP recommendation on measured flaw length and depth adjustments.

The NRC staff notes that although BWRVIP-63 is specifically for vertical welds on the core shroud, Section 4.0 of the December 23, 2011, SE states that: "...the proposed BWRVIP guidance on NDE uncertainty can be extended to all BWR vessel internals." Therefore, the NDE uncertainty methodology that the NRC staff accepted in the December 23, 2011, SE can be extended to the jet pump assembly.

3.5.2 Evaluation of Item 2

The additional paragraph (last paragraph) in Section 5.1.1.2 of the TR refers to the inspection strategy in [[ ]]. The NRC staff determined that, although the subject of Section 5.1.1, "Flaw Characterization," of the TR is flaw characterization, the intent of the additional paragraph is for information only. It is not for presenting guidelines for flaw characterization in [redacted] Therefore, the NRC staff accepts the addition of the last paragraph of TR Section 5.1.1.2.

3.5.3 Evaluation of Item 3

[redacted] The NRC staff notes that the BWRVIP has developed specific guidance on CGR for BWR vessel internal components, such as Final Report 1016569NP, "BWRVIP-14NP-A: BWR Vessel & Internals Project - Evaluation of Crack Growth in BWR Stainless Steel RPV Internals" (ADAMS Accession No. ML101880724) for stainless steel components and BWRVIP-59NP-A, "BWR Vessel and Internals Project Evaluation of Crack Growth in BWR Nickel Base Austenitic Alloys in RPV Internals" (ADAMS Accession No. ML17277A824) for nickel-based alloy components since the issuance of BWRVIP-41.

3.5.4 Evaluation of Item 4

Regarding the structural evaluation using limit-load analysis, TR Section 5.1.2.1 recommends the limit-load methodology described in Appendix C of Section XI of the ASME Code for the riser pipe, inlet mixer, and diffuser locations of the jet pump assembly. The NRC staff confirmed that the general form of the limit-load equations in the TR is consistent with the limit-load equations in BWRVIP-41 but noted the following changes and additions:

(a) Addition of equations for [redacted]

(b) The Z factor equation now [redacted] Previously, there was a separate Z factor equation for [redacted]

(c) Addition of Z factor equations for [redacted]

Regarding item (a), the NRC staff confirmed that the form of the limit-load equations [redacted] is consistent with the ASME Code. The NRC staff determined that the equations provide useful additional information for flaw evaluation and therefore, determined that the additional equations are acceptable.

Regarding item (b), the NRC staff performed confirmatory calculations and determined that the single Z factor equation generates Z factors for [redacted] that are higher, and thus are more conservative, than those calculated from the previous Z factor equation. Therefore, the NRC staff determined that the single Z factor equation that is applicable for [redacted]

Regarding item (c), the NRC staff confirmed that the Z factor equations for [redacted] have been approved and incorporated into the ASME Code in the 2009 Addenda. This addenda has been incorporated by reference into Title 10 *Code of Federal Regulation* (10 CFR) 50.55a. Therefore, the NRC staff finds the addition into the TR acceptable.

Also, the NRC staff confirmed that the general form of the limit-load equations in the TR is consistent with the latest edition of the ASME Code incorporated by reference in 10 FR 50.55a, but noted the following differences:

(d) [redacted] The ASME Code (starting from the 2001 Edition) defines flow stress as, $\sigma_f = (S_y + S_u)/2$, where $S_y$ and $S_u$ are the ASME Code specified yield and ultimate strength, respectively, of the material. If the measured material properties are known, $\sigma_f = (\sigma_y + \sigma_u)/2$, where $\sigma_y$ and $\sigma_u$ are the measured yield and ultimate strength, respectively, of the material.

(e) The equations relating the applied stresses and the failure bending stress (i.e., Equations 5-5 and 5-6 of the TR) were revised in the ASME Code to reflect different safety factors for membrane and bending stresses.

Items (d) and (e) reflect changes made to the ASME Code, Section XI, starting with the 2001 Edition. The NRC staff identified these same changes in the limit-load equations used for structural evaluation of the core spray piping that has been accepted by the NRC staff, in Section 5.1.2, "Structural Evaluation," of BWRVIP-18, Revision 2-A, "BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines" (ADAMS Accession No. ML16302A123).

Equations 5-1 through 5-4 of BWRVIP-18, Revision 2-A are identical to Equations 5-1 through 5-4 of TR Section 5.1.2.1. In Section 4.2.1 of the SE for BWRVIP-18, Revision 2-A (ADAMS Accession No. ML16011A190), the NRC staff explained that the BWRVIP provided a quantitative analysis assessing the impact of the two ASME Code changes to the limit-load methodology. The results of that quantitative analysis indicated that the non-conservatism associated with the revised definition of flow stress and the conservatism associated with the structural factors cancel each other. This leads to similar evaluation results between the limit-load equations proposed in BWRVIP-18, Revision 2-A and those in the latest edition of the ASME Code incorporated by reference in 10 CFR 50.55a.

The NRC staff further determined that this same quantitative analysis applies to the limit-load equations in TR Section 5.1.2.1 since they are identical to the limit-load equations in BWRVIP-18, Revision 2-A. The NRC staff also noted that $S_m$ values are now in Part D of Section II of the ASME Code. Therefore, the NRC staff accepts for use the limit-load equations proposed in the TR with respect to differences from the current ASME Code identified above in items d and e.

Based on the evaluation of items (a) through (e) above, the NRC staff accepts the limit-load methodology proposed in the TR.

3.5.5 Evaluation of Item 5

If multiple indications are detected during the inspection of the jet pump assembly, the TR proposes to use the proximity rules of BWRVIP-158-A. BWRVIP-158-A has a condition to use the treatment of NDE uncertainty when the BWRVIP-63 open item on the NDE uncertainty issue is resolved. As stated earlier in the discussion of "Item 1," the BWRVIP-63 open item was resolved in the NRC staff SE dated December 23, 2011, in which the NRC staff accepted the BWRVIP's recommendation on measured flaw length and depth adjustments.

Hence, the TR may use the proximity rules in BWRVIP-158-A without any NRC-specified limitations and conditions.

3.5.6 Evaluation of Item 6

[redacted] The NRC staff finds both statements to be accurate. The NRC staff determined that the statements are clarifications on how leak rate is calculated.

3.5.7 Evaluation of Item 7

TR Section 5.1.3 discusses leakage considerations for the jet pump riser pipe, inlet-mixer, and diffuser locations. The NRC staff reviewed the text of TR Section 5.1.3 and compared it with the text of Section 5.1.1.6 of BWRVIP-41. The NRC staff determined that the content of Section 5.1.3 of the TR is essentially unchanged from the content of BWRVIP-41, Section 5.1.1.6.

The differences are limited to editorial revisions (such as rearranged sentences and added/deleted words) and clarification that leakage from accessible and inaccessible welds needs to be considered in the leakage evaluation. The NRC staff accepts the differences between Section 5.1.3 of the TR and BWRVIP-41 Section 5.1.1.6 because the NRC staff has determined that the differences do not affect the NRC-approved content in BWRVIP-41, Section 5.1.1.6.

TR Section 5.1.4 provides leak-rate calculation methods for the jet pump riser pipe, inlet-mixer, and diffuser locations. For these locations, there are accessible (or partially accessible) and inaccessible welds. TR Section 5.1.4 provides a method for calculating leak rates for cracks in accessible and partially accessible welds (TR Section 5.1.4.1) and inaccessible welds (TR Section 5.1.4.2). TR Section 5.1.4.1 contains the same leak-rate calculation methodology as in BWRVIP-41, Section 5.1.1.5, with the clarifications discussed in Section 3.5.6 of this SE. Accordingly, the NRC staff determines that the leak-rate methodology for cracks in accessible and partially accessible welds specified in TR Section 5.1.4.1 is acceptable for use.

TR Section 5.1.4.2 presents a procedure for estimating the leak rate from inaccessible welds. The basic approach is to estimate the leak rate from inaccessible welds using the leak rate from similar accessible welds determined from the equation given in TR Section 5.1.4.1. The definition of "similar accessible welds" is in TR Section 3.2.7.2.

The NRC staff compared the steps for predicting the leak rate from inaccessible welds given in TR Section 5.1.4.2 with those from BWRVIP-18, Revision 2-A, Section 5.1.4 (in the subsection named "Leak Rate from Cracks in Inaccessible Welds") for the core spray piping, which has been accepted for use by the staff. The NRC staff determined that while the numbering of the steps in TR Section 5.1.4.2 is different than those of BWRVIP-18, Revision 2-A, Section 5.1.4, the content and sequence of the steps are the same.

The NRC staff also determined that the procedure for estimating the leak rate from inaccessible welds in BWRVIP-18, Revision 2-A, Section 5.1.4 is not a procedure specific to the core spray piping system. The basic principle behind the procedure, which the NRC staff finds reasonable, is that the amount of leakage in inaccessible welds is expected to be proportionally the same as the amount of leakage in accessible welds exposed to the same degradation mechanism as the inaccessible welds. Thus, the NRC staff determined that the procedure for estimating the leak rate from inaccessible welds in Section 5.1.4.2 of the TR is acceptable because it is the same procedure the NRC staff accepted for use in BWRVIP-18, Revision 2-A, which was based on a generic proportionality principle.

3.5.8 Plant-Specific Leakage Assessment and the Operating Experience Consistency for Adopting the BWRVIP's Proposed Inspection Plan

The NRC staff noted that the leakage discussion in TR Section 5 is not clear on whether the plant-specific leakage is bounded by the allowable leakage limits from the plant-specific loss-of-coolant accident (LOCA) analysis. The plant-specific leakage assessment must demonstrate that the computed leakage rates (both from detected and postulated flaws) in the jet pump systems are bounded by the allowable leakage limits based on the plant-specific LOCA analysis. These allowable leakage limits include those resulting from not exceeding the peak clad temperature (PCT) criterion and from any other plant-specific licensing basis criteria related to the plant-specific LOCA analysis.

Based on its review, the NRC staff finds that the following condition is necessary: All licensees shall compute leakage rates from detected and postulated flaws in the jet pump assemblies as required by the TR and demonstrate that the calculated leak rates are bounded by the leakage rates resulting from the plant-specific LOCA analysis. The leakage rates resulting from plant-specific LOCA analysis include those resulting from not exceeding the PCT criterion and from any other plant-specific licensing basis criteria related to the plant-specific LOCA analysis. **This is TR Condition 3(a) in Section 5.0 of this SE.**

The NRC staff also noted that the structural evaluation discussion in TR Section 5 is not clear on how to treat the stability of new cracking or defects in unflawed welds. Based on its review, the NRC staff finds that the following condition is necessary: Following the discovery of any new service-induced cracking, all licensees shall reinspect these locations for a minimum of two consecutive refueling outages. Following these two consecutive reinspections, the proposed inspection schedule may be resumed provided the CGR has been established and has been determined to be below the proposed bounding CGR. **This is TR Condition 3(b) in Section 5.0 of this SE.**

4.0 <u>REFERENCING OF THE TR FOR LICENSE RENEWAL</u>

Appendix A of the TR contains the BWRVIP's assertion that the TR meets the requirements for use in the license renewal process (10 CFR 54) and the basis for that assertion. In Appendix A, the BWRVIP notes that there have been changes in the technical aspects of the BWRVIP-41 report since the report was approved in 2001. However, the BWRVIP proposes that these changes do not affect the basis for the acceptability of the use of the topical report in the license renewal process.

The NRC staff reviewed the TR including its Appendix A. The NRC staff finds that the changes made to the TR do not change the basis for acceptability of the use of the TR with respect to license renewal as compared to the previously approved BWRVIP-41 report. As a result, the NRC finds that its acceptance of the BWRVIP-41 report in the previous safety evaluation

(June 5, 2001; ADAMS Accession No. ML011570460) remains valid. The NRC staff concludes that, upon completion of the renewal applicant action items described below, referencing the TR in a LRA is acceptable.

(1) The license renewal applicant is to verify that its plant is bounded by the TR. Further, the license renewal applicant is to commit to programs described as necessary in the TR to manage the effects of aging on the functionality of the jet pump components during the PEO. The applicant will be responsible for describing any such commitments and identifying how such commitments will be controlled. Any deviations from the AMP within the TR necessary to manage the effects of aging during the PEO and to maintain the functionality of the components or other information presented in the report (such as materials of construction) will have to be identified by the license renewal applicant and evaluated on a plant-specific basis in accordance with 10 CFR 54.21(a)(3) and (c)(1).

(2) 10 CFR 54.21(d) requires that an Final Safety Analysis Report (FSAR) supplement for the facility contain a summary description of the programs and activities for managing the effects of aging and the evaluation of time-limited aging analyses for the PEO. The license renewal applicant referencing the TR for the jet pump components shall ensure that the programs and activities specified as necessary in the TR are summarily described in the FSAR supplement.

(3) 10 CFR 54.22 requires that each application for license renewal include any technical specification changes (and the justification for the changes) or additions necessary to manage the effects of aging during the PEO as part of the renewal application. In its Appendix A to the TR, the BWRVIP stated that there are no generic changes or additions to technical specifications associated with the jet pump assembly as a result of its AMR and that the applicant will provide the justification for plant-specific changes or additions. The applicant for license renewal referencing the TR for the jet pump assembly shall ensure that the inspection strategy described in the TR does not conflict or result in any changes to their technical specifications. If technical specification changes do result, then the applicant should ensure that those changes are included in its application for license renewal.

## 5.0 CONDITIONS

Condition #1 for the Exemptions to the Welds Categorized Under Scope Expansion Criteria:
Exemptions of welds from scope expansion shall be limited to welds that were previously examined with a UT technique that achieved inspection coverage, for the "areas of interest" as defined by BWRVIP-03, for at least 75 percent of the weld circumference.

Condition #2 for the Proposed Inspections and Criteria:
Licensees shall comply with the requirements of a NRC-approved HWC program (e.g., BWRVIP-62-A).

Condition #3 for Plant-Specific Leakage Assessment and the Operating Experience Consistency for Adopting the BWRVIP's Proposed Inspection Plan:

(a) All licensees shall compute leakage rates from detected and postulated flaws in the jet pump assemblies as required by the TR and demonstrate that the calculated leak rates are bounded by the leakage rates resulting from the plant-specific LOCA analysis. The leakage rates resulting from plant-specific LOCA analysis include those resulting from not exceeding the PCT criterion and from any other plant-specific licensing basis criteria related to the plant-specific LOCA analysis.

(b) Following the discovery of any new service-induced cracking, all licensees shall reinspect these locations for a minimum of two consecutive refueling outages. Following these two consecutive reinspections, the proposed inspection schedule may be resumed provided the CGR has been established and has been determined to be below the proposed bounding CGR.

## 6.0 CONCLUSION

The NRC staff has reviewed the TR and supplemental information that was transmitted to the NRC by letters dated September 24, 2014, and February 8, 2017. Based on its review, the NRC staff concluded that the conditions described in Section 5.0 of this SE shall be incorporated into the -A version of the BWRVIP-41, Revision 4 report.

The NRC staff finds that the TR, as modified and clarified to incorporate the NRC staff conditions, is acceptable for use with respect to the proposed inspections and flaw evaluation guidelines for the BWR jet pump components. The TR, as modified by the conditions stated above, is considered by the NRC staff to be acceptable for use during either a facility current operating term or the PEO. As described in Section 4.0 of this SE, a license renewal applicant should address license renewal action items for aging management in its plant-specific submittal.

Principal Contributors: Christopher Hovanec, Lead Reviewer
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Date: July 2, 2018

## BWRVIP Comment Summary Table

| Comment No. | Draft SE Location | Comment Type | Comment | NRC's Response |
|---|---|---|---|---|
| 1 | Pg. 1 line 19 | Inaccuracy | The NRC did issue an SE for the initial revision of BWRVIP-41, but a "-A" version was never submitted to or accepted by the NRC. The "-A" should be stricken. Note that this change should be made wherever BWRVIP-41-A is referenced herein. | Edit(s) accepted |
| 2 | Pg. 1 line 32 | Inaccuracy | EPRI is not a licensee. Replace "licensee" with "EPRI." | Edit(s) accepted |
| 3 | Pg. 1 line 44 through Pg. 2 line 10 | Clarification | The relevancy of the stated regulatory requirements is not clear. The stated regulatory requirements are for BWR core spray systems not jet pump assemblies. Please clarify the application of the stated regulatory requirements to this SE or delete them since they are not really applicable. | Deleted and renumbered Sections |
| 4 | Pg. 2 line 25 | Inaccuracy | As indicated in BWRVIP-41, Revision 4 in a number of locations, the information therein is applicable only to BWR/3-6s as BWR/2s do not have jet pumps. As such, strike BWR/2 from the list of designs. | Edit(s) accepted |
| 5 | Pg. 3 line 11 | Editorial | "Acceptability" should be "acceptably". | Edit(s) accepted |
| 6 | Pg. 3 lines 14-16 | Proprietary Information Identification | The bracketed and highlighted text is a direct excerpt from Section 2.2.1.2 and was marked as proprietary information when BWRVIP-41, Rev. 4 was submitted to the NRC. | Edit(s) accepted |
| 7 | Pg. 6 lines 28 to 32 | Clarification | It is assumed that "each specified population of welds" refers to welds that require sample-based periodic inspections as grouped in Table 3-1 and that "shall be included in the program" means included in the periodic inspection sample for that population. For clarification, suggest re-writing it to read, "When fluence exceeding $5 \times 10^{20}$ n/cm$^2$ (E > MeV) is present within a specified population of welds that are identified for periodic inspection in Table 3-1 (e.g., riser pipe, inlet, mixer, diffuser, etc.), at least one location exposed to that fluence shall be included in the periodic sample for that population." | Edit(s) accepted with two minor changes.<br><br>"(E > MeV)" was changed to "(E > 1 MeV)"<br><br>"etc." was deleted from "(e.g., riser pipe, inlet, mixer, diffuser, etc.)"<br><br>Using both e.g. and etc. is repetitive. |
| 8 | Pg. 7 line 1 | Inaccuracy | The section number is actually 3.2.8.1.2 not 3.8.2.1.2. | Edit(s) accepted |
| 9 | Pg. 7 lines 16 and 17 | Clarification | "Area of the weld" is not how inspection coverage is described in BWRVIP guidelines. BWRVIP-03 defines "Areas of Interest" for weld inspections (e.g., weld and ¾" on both sides of the weld). For clarification, it is suggested the condition be revised to read, "...that achieved inspection coverage for the "areas of interest" as defined by BWRVIP-03 for at least 75 percent of the weld circumference." | Edits accepted with a minor editorial change. |

## BWRVIP Comment Summary Table (Cont.)

| Comment No. | Draft SE Location | Comment Type | Comment | NRC's Response |
|---|---|---|---|---|
| 10 | Pg. 7 line 31 | Clarification | The BWRVIP understands the NRC's intent with this condition to be that plants are implementing a "NRC approved" HWC program. In order to clarify this intent and not limit the condition to only the use of BWRVIP-62-A, the BWRVIP suggests that the following language, which is similar to that used in BWRVIP-75-A, be used: "Licensees shall comply with the requirements of a NRC-approved HWC program (e.g., BWRVIP-62-A)." | Edit(s) accepted |
| 11 | Pg. 8 lines 8 to 10 | Proprietary Information Identification | The bracketed and highlighted text of the change description provides specifics of Section 5.1.1.3 that were marked as proprietary information when BWRVIP-41, Revision 4 was submitted to the NRC. | Comment/edit(s) accepted |
| 12 | Pg. 9 lines 15 to 19 | Proprietary Information Identification | The bracketed and highlighted discussion involves specifics of Section 5.1.1.3 that were marked as proprietary information when BWRVIP-41, Revision 4 was submitted to the NRC. | Comment/edit(s) accepted |
| 13 | Pg. 10 lines 16 and 17 | Proprietary Information Identification | The bracketed and highlighted definition of flow stress given in the TR was marked as proprietary information when BWRVIP-41, Revision 4 was submitted to the NRC. | Comment/edit(s) accepted |
| 14 | Pg. 10 line 35 | Editorial | Delete the extra space at the beginning of the second sentence and the extra "ML" in the Accession No | Comment/edit(s) accepted |
| 15 | Pg.11 lines 18 to 22 | Proprietary Information Identification | The bracketed and highlighted discussion involves specifics of Section 5.1.4.1 that were marked as proprietary information when BWRVIP-41, Revision 4 was submitted to the NRC. | Comment/edit(s) accepted |
| 16 | Pg. 11 line 36 | Editorial | Delete "TR" as it is repetitive. | Comment/edit(s) accepted |
| 17 | Pg. 12 lines 33 and 34 | Clarification | The TR does not require computing leakage for all postulated flaws, only those postulated for inaccessible welds. This is similar to the leakage evaluation requirements approved by the NRC in BWRVIP-18, Rev. 2-A and BWRVIP-42, Rev. 1-A. The condition is understood to apply to what must be done with the calculated leak rates, not how they are calculated. Thus, to clarify the condition, it is suggested that it be revised to read, "...from detected and postulated flaws in jet pump assemblies as required by the TR and demonstrate ..." | The NRC staff accepts the BWRVIP's suggested revision. |

## BWRVIP Comment Summary Table (Cont.)

| Comment No. | Draft SE Location | Comment Type | Comment | NRC's Response |
|---|---|---|---|---|
| 18 | Pg. 12 line 40 | | Since there was no RAI related to the subject requirements, the BWRVIP requests clarification of the NRC's statement, "Section 5 is not clear on how to treat new cracking or defects in unflawed welds." Section 5 clearly provides the requirements for evaluation of any cracking found during BWRVIP-41 required inspections and establishing the time to reach minimum structural margin (refer to Section 5.1.2.1.5). In practice, this means the end of interval (EOI) before which time the cracking must be reinspected. The BWRVIP acknowledges this is not explicitly stated, and if that is what was meant by the NRC's statement that Section 5 was not clear, can make that change in order to resolve this Condition. | The NRC staff acknowledges that Section 5 is for evaluation of any cracking, but the objective of the subject condition is to ensure that new cracking or defects (see response on #19 regarding "defect") in unflawed welds have "stabilized". This condition is a slight rewording of Condition 1(b) of the SE in BWRVIP-18, Revision 2-A. The word "stabilized" went away in the rewording. The NRC staff proposes to revise the sentence to read "...TR Section 5 is not clear on how to treat the stability of new cracking or defects..." |
| 19 | Pg. 12 line 43 | Clarification | The subject condition concerns crack growth rates and it is unclear what "or defect" is meant to mean in this context. A similar condition was placed on BWRVIP-18, Revision 2-A and it did not say "or defect." Suggest "or defect" be deleted or further explanation of what "or defect" means in the context of this condition needs to be provided. | The subject condition is a slight rewording of Condition 1(b) of the SE in BWRVIP-18, Revision 2-A, which begins: "If any new cracking or a defect..." EPRI provided additional explanation for removing "or defect" and the NRC staff finds the additional explanation acceptable. Therefore, the NRC staff finds it acceptable to remove "or defect." |
| 20 | Pg. 13 line 49 to Pg. 14 lines 4 | Clarification | Same as Comment #7. | Same as Comment #7. |
| 21 | Pg. 14 lines 8 to 10 | Clarification | Same as Comment #9. | Edits accepted with a minor editorial change. |
| 22 | Pg. 14 lines 13 and 14 | Clarification | Same as Comment #10. | Edit(s) accepted |
| 23 | Pg. 14 line 20 | Clarification | Same as Comment #17. | See response to Comment #17 |
| 24 | Pg. 14 line 27 | Clarification | Same as Comment #19. | See response to Comment #19 |
| 25 | Pg. 15 line 2 | General | As a general clarification request, there is no mention of the NRC's acceptance of the BWRVIP's responses to RAIs 1, 2, 5, and 6. Typically the final SE provides resolution for all the RAIs. The BWRVIP requests the some statement to the effect that the BWRVIP's proposed responses for those SE's are acceptable to the staff. | The NRC staff finds the proposed text in the responses to RAIs-1, 2, 5, and 6 acceptable for incorporation into the –A version of the TR. |

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# CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# 1 INTRODUCTION

## 1.1 Background

Prior to issuance of the original version of BWRVIP-41, jet pump failures had been addressed by a number of General Electric Service Information Letters (GE SILs). In February of 1980, a jet pump hold-down beam failure was reported at one site. Subsequent inspections revealed similar cracks in other units. In June 1980, GE issued SIL No. 330, "Jet Pump Beam Cracks" [1] to highlight the problem of jet pump beam cracking. SIL No. 420, "Inspection of Jet Pump Sensing Lines," [2] was issued in March of 1985 and recommended VT-3 inspections of the sensing lines. SIL No. 551, "Jet Pump Riser Brace Cracking," [3] was issued in February of 1993 and provided recommendations for inspections of riser braces. In October of 1993, GE provided additional jet pump inspection recommendations through the issuance of SIL No. 574, "Jet Pump Adjusting Screw Tack Weld Failures." [4]

The BWR internals safety assessment conducted in 1995 and documented in BWRVIP-06, Revision 1-A [5] concluded that inspection and evaluation procedures play a role in assuring the long-term integrity of the jet pump safety functions and maintaining the design basis of the jet pump assembly. As a result, the BWRVIP developed a jet pump inspection and evaluation guideline (BWRVIP-41: *BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines*) that was published in October of 1997 as EPRI Report TR-108728 and was subsequently implemented by member utilities. The final Safety Evaluation (SE) of BWRVIP-41 was issued in February of 2001. Subsequently, in 2001 NRC accepted BWRVIP-41 for referencing in license renewal applications based on the content of Appendix A to BWRVIP-41, "*Demonstration of Compliance with the Technical Information Requirements of the License Renewal Rule (10 CFR 54.21)*."

In September of 2005, the BWRVIP published Revision 1 of BWRVIP-41 as EPRI Report 1012137. This revision incorporated changes made in response to NRC Requests for Additional Information and Safety Evaluations received as part of the NRC review of the original report. This revision also included new guidance on jet pump beam inspections and restrainer bracket and wedge inspections and changed the visual examination technique specified from MVT-1 to EVT-1.

GEH SIL 660, "BWR-5 Riser Piping Cracking," [6] was issued in response to identification of a large FIV-induced fatigue crack in the fall of 2008. Subsequently, BWRVIP letter 2009-202 [7] was issued on June 18, 2009 to provide interim guidance and called for inspection of all riser pipe to riser brace welds and jet pump wedges on an accelerated schedule.

In July of 2009, BWRVIP published Revision 2 of BWRVIP-41 as EPRI Report 1019570. Revision 2 incorporated the results of comprehensive fracture-mechanics evaluations performed on Group 2 and Group 3 jet pump beam designs, previously documented in BWRVIP-138, Revision 1 [8]. Other minor revisions to the report were also made.

BWRVIP-41 Revision 3 was published by the BWRVIP in September 2010 as EPRI Report 1021000. This revision added inspection and flaw evaluation guidelines for inaccessible jet pump assembly welds. The approach utilizes inspection results from similar accessible welds to assess the condition of the inaccessible welds.

Since implementation in 1997, all accessible jet pump assembly welds in the U.S. fleet have been inspected at least once. Baseline examination of high priority locations was completed over a 6-year interval and baseline examination of medium and low priority locations was completed over 12 years. As of 2011, more than half of the high priority inspection locations and a significant portion of the medium and low priority locations have now been re-inspected.

In 2009, the BWRVIP began a comprehensive inspection optimization program to collect and evaluate field inspection data. The results of the evaluation are used to better assess the susceptibility of various component locations to degradation and to support revisions to inspection program criteria. This Revision 4 to BWRVIP-41 represents a substantial revision to the jet pump assembly inspection criteria based on the results of the inspection optimization program evaluation. BWRVIP-266 [9] provides the technical bases for the changes.

## 1.2 Objectives and Scope

This Jet Pump Inspection and Flaw Evaluation (I&E) Guideline contains generic guidelines intended to present inspection recommendations sufficient to assure continued integrity of all jet pump safety functions and to maintain the design basis of the jet pump assembly. Economic and normal operational consequences of cracking are not factored into the recommendations. The specific safety functions of the jet pump assembly are to maintain the ability to reflood the reactor to 2/3 core height in an accident scenario and, for some plants, to provide a path for Low Pressure Coolant Injection (LPCI) into the core. It is the intent that, for BWRVIP members, this Guideline can be followed in the place of prior GE SILs (Services Information Letters) related to safety (see Section 3.2) to assure the essential safety functions of the jet pumps. The Licensee is encouraged, however, to review all SILs to determine any non-safety commercial issues that need to be addressed, for example, operating procedures and performance monitoring.

The Guideline addresses the following issues:

- Evaluation of any potential cracking locations on the jet pump assembly
- Categories of plants for which inspection needs differ
- Extent of inspection for each location
- Flaw evaluation procedures to determine allowable flaw sizes for locations where flaw sizing is relevant

This I&E Guideline provides design information on the jet pump geometries and weld locations for BWR/3-6 plants (BWR/2 plants do not contain jet pumps). Table 1-1 shows the plant configurations that were specifically evaluated in preparing this Guideline. Configuration and material information included in the guideline is based on the best information available. Plants are advised to confirm the accuracy of these configurations to evaluate the applicability of the inspection recommendations. In addition, plants not listed in Table 1-1 should obtain their configuration and material information.

**Table 1-1**
**Plants Configurations Evaluated**

| Plant Type | Plant Names |
|---|---|
| BWR/3 | Pilgrim, Monticello, Quad Cities 1,2, Dresden 2,3, Santa Maria de Garoña |
| BWR/4 | Vermont Yankee, Fermi 2, Hope Creek 1, Limerick 1,2, Susquehanna 1,2, Browns Ferry 1,2,3, Peach Bottom 2,3, Brunswick 1,2, Hatch 1,2, Cooper, Fitzpatrick, Duane Arnold |
| BWR/5 | LaSalle 1,2, Laguna Verde, Nine Mile Point 2, WNP2 |
| BWR/6 | Perry 1, Grand Gulf 1, River Bend, Clinton 1, Cofrentes |

The Guideline's scope addresses all welded and bolted locations identified from design drawings of the jet pump assembly. A typical jet pump assembly configuration is shown schematically in Figure 1-1. This figure and other more detailed figures identify the welded and bolted locations.

Susceptibility considerations for the jet pump are presented, as well as the consequences due to failure at each location. The susceptibility and consequence considerations are factored into the inspection recommendations.

The Guideline presents inspection approaches which vary depending on the type of plant and its associated jet pump configuration. Inspection options are also presented which consider implementation of repairs.

Load combination recommendations which can be followed in performing plant-specific analyses are provided. Flaw evaluation methodologies are provided for those locations where flaw evaluation is appropriate.

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Figure 1-1
Typical Jet Pump Assembly

## 1.3 Implementation Requirements

The inspection and evaluation guidance in Sections 3, 4 and 5 of this report are considered "needed" in accordance with the requirements of Nuclear Energy Institute (NEI) 03-08, Revision 3, *Guideline for Management of Material* Issues [10]. The remaining sections are for information only.

Note: In order to implement the revised inspection strategy defined in Table 3-1, the plant must comply with the requirements of an NRC-approved HWC program (for example, BWRVIP-62-A). However, there is no requirement to perform a full baseline exam while operating on HWC prior to using the revised program. Should a plant be unable to meet the requirements of an NRC-approved HWC program going forward from publication of this revision, the plant shall revert to the inspection recommendations provided in BWRVIP-41, Revision 3.

# 2
# JET PUMP ASSEMBLY ANALYSIS

## 2.1 Jet Pump Assembly Configuration and Function

The jet pumps are located in the annulus region between the core shroud and the vessel wall and provide core flow to control reactor power. Between 6 and 12 pairs of jet pumps are found in BWR/3 through BWR/6 plants, depending on plant rating. BWR/2 plants do not contain jet pumps. During normal operation, each pair of jet pumps is driven by flow from a common riser pipe. The jet pump drive flow is pumped through the recirculation system through the riser and into each jet pump. Additional fluid from the annulus region is entrained into the jet pump flow which is then directed to the lower plenum region.

Figure 1-1 shows a typical jet pump assembly. Each jet pump assembly is composed of two jet pumps and a common riser assembly. The riser assembly is a pipe, internal to the RPV, which connects the recirculation pump discharge line to the jet pump pair. A riser brace attaches the riser pipe to the vessel wall to provide lateral support.

Each jet pump has an inlet-mixer assembly and a diffuser assembly. The inlet-mixer assembly consists of a 180-degree elbow, a nozzle section with suction inlets, and a mixing section. The inlet-mixer assembly is clamped to the riser transition piece by the beam-bolt assembly and fits into a slip joint at the top of the diffuser assembly. A restrainer bracket attached to the riser provides lateral support for each mixer section to increase the stiffness of the assembly and reduce the effects of vibration. The diffuser assembly consists of a gradual conical section terminating in a straight cylindrical section at the lower end which is welded to the shroud support plate. Instrumentation monitors jet pump flow through the diffuser to ascertain individual and collective jet pump flow rates under operating conditions.

For post-accident core re-flooding, the jet pump assembly assures re-flooding to no less than 2/3 core height. Assuming intact jet pump assembly, there is no recirculation line break scenario which can prevent re-flooding of the core to 2/3 core height, the height of the jet pump suction inlets.

An additional safety function of the jet pump assembly at some plants is to provide a flow path for LPCI flow into the core. All BWR/3s and BWR/4s except Hope Creek 1, and Limerick 1 and 2 inject LPCI through the jet pumps.

## 2.2 Susceptibility Factors

Within the jet pump assembly there are a number of factors that affect susceptibility. Materials, water environment, loading (both static and dynamic), and stresses attributed to either manufacture or to plant operation, all contribute to the jet pump's susceptibility. Many different materials and material conditions are present in the jet pump assembly, making this component difficult to analyze without looking at each sub-component separately and in detail.

There are three key degradation mechanisms that must be considered when analyzing the jet pump assembly sub-components: Intergranular Stress Corrosion Cracking (IGSCC), fatigue, and thermal embrittlement. Each will be discussed separately in the following sections, and the applicability of each of these degradation factors to each jet pump sub-component is summarized in Section 2.3. In addition, Irradiation Assisted Stress Corrosion Cracking (IASCC) was considered, but it was determined that the fluence levels are not high enough in the jet pump assembly locations to make IASCC a potential degradation mechanism.

### *2.2.1 Intergranular Stress Corrosion Cracking (IGSCC)*

The occurrence of IGSCC relies on the combined presence of an aggressive environment, a susceptible material, and tensile stress.

#### 2.2.1.1 Environment

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#### 2.2.1.2 Materials

From the material perspective, there are a large number of parameters that determine the component's resistance to IGSCC. These parameters include:

- Material (304, 316, 304L, 316L, Alloy 600, Alloy 182, X-750, and Stellite)
- Material product form (wrought plate, forging, and casting)
- Material condition (annealed and welded)
- Material chemistry (composition, for example, carbon level)
- Component form (seamless pipe, rolled and welded pipe)

- Type of weld/weld design (fillet and groove)
- Welding process (shop and field)
- Weld filler material product form (flux shielded vs. wire)

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#### 2.2.1.3 Tensile Stress

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#### 2.2.1.4 Operating Experience: IGSCC

*Stainless Steel Weld HAZs:*
To date, jet pump assembly weld and weld HAZ-related IGSCC performance is very good [9]. Where observed, degradation is found to be limited to a particular subset of weld locations and jet pump assembly design configurations.

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*High-strength Nickel-base Alloy X-750 Hold-down Beams*:

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#### 2.2.1.5 Effects of Irradiation

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### *2.2.2 Fatigue*

Fatigue is the term given to both crack initiation and subcritical crack growth under the influence of fluctuating or cyclic applied stresses. There are three sources of fatigue significant to the BWR: 1) system cycling fatigue (low-cycle fatigue), 2) high-cycle thermal fatigue, and 3) vibration-induced fatigue. System cycling refers to changes in the reactor system which cause variations in pressure and temperature at the component. Examples of system cycling are start-up, shutdown, SCRAM, and safety relief valve (SRV) blowdown. System cycling is generally accounted for in the initial design analysis. High-cycle thermal fatigue (for example, thermal mixing) is generally not an issue for jet pump components. This leaves high-cycle fatigue due to vibration as the primary fatigue issue for the jet pump components.

#### 2.2.2.1 Fatigue Load Sources

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#### 2.2.2.2 IGSCC Interaction

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#### 2.2.2.3 Operating Experience: Fatigue

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### *2.2.3 Embrittlement*

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## 2.3 Potential Failure Locations

The potential failure locations discussed in this section are based closely on the list of potential failure locations for the jet pump assembly presented in BWRVIP-06, Revision 1-A [5]. However, some of the locations were combined or separated into different parts to facilitate the susceptibility analysis. Therefore, the list of locations presented here does not exactly correspond to those identified in BWRVIP-06, Revision 1-A.

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For each jet pump location a discussion of its function, configurations, loading (pertaining to crack initiation and/or crack growth during normal operation), susceptibility, failure consequences, and inspection recommendation technical basis are given in the following sub-sections. The figures included in this section are intended to show the general design features of each of the locations, and therefore some features shown may not be applicable to all plants. The licensees should verify their plant-specific configurations for applicability with respect to the component description, figures, and materials shown in this guideline. Loading information provided in Section 2.3 is meant to give a generic description of the types of loads applied to each location. A more thorough discussion of applicable loads is found in Section 4.

### 2.3.1 Riser Brace

#### 2.3.1.1 Function

The riser brace attaches the riser pipe to pads which are welded to the vessel wall. Its main function is to limit the vibration and maintain the orientation of the jet pump assembly. The riser brace leaves are designed to be flexible enough to accommodate the differential thermal expansion between the stainless steel riser pipe and carbon steel pressure vessel.

#### 2.3.1.2 Configurations – Locations RB-1 to RB-5

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**Figure 2-1**
**Typical Primary Single-Leaf Riser Brace**

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**Figure 2-2**
**Typical Primary Double-Leaf Riser Brace**

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**Figure 2-3**
**Typical Secondary Double-Leaf Riser Brace**

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**Table 2-1**
**Riser Brace Configurations**

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#### 2.3.1.3 Loading

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### 2.3.1.4 Susceptibility

Jet pump riser braces can suffer from two forms of environmentally assisted cracking, IGSCC of stainless steel heat affected zones (HAZs) and fatigue.

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### 2.3.1.5 Failure Consequences

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### 2.3.1.6 Inspection Recommendations

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### 2.3.2 Jet Pump Holddown Beam and Bolt

Jet pump beam failures have been extensively studied and documented in a recent BWR VIP report, BWRVIP-138, Revision 1 [8]. The discussion and inspection recommendations below are extracted from that report. The reader is referred to BWRVIP-138, Revision 1 for additional information.

#### 2.3.2.1 Function

The jet pump holddown beam and bolt assembly secures the inlet mixer assembly to the riser transition piece. During normal operation the beam is locked into place, and the beam bolt is torqued to a specified preload value.

#### 2.3.2.2 Jet Pump Beam Design and Configurations

The inlet-mixer section of each jet pump, which extends from the entrance of the 180° bend (elbow) to the slip joint with the diffuser, is shown in Figure 1-1. The inlet-mixer is held in place by a nickel-base Alloy X-750 beam stainless steel bolt assembly located in the riser transition piece. The beam ends are positioned in pockets in the transition piece, and the beam installation pre-load is transferred to the inlet-mixer elbow through a bolt located in the center of the beam. As described in the following paragraphs, four different beam designs exist. The BWR/3 design is included for historical interest. Since the BWR/4-6 design is interchangeable with the BWR/3 design, all BWR/3 replacement beams are of the newer designs.

##### *2.3.2.2.1 BWR/3 Beam Design*

The BWR/3 beam design was fabricated from a closed-die forging of Alloy X-750 material. The beams were subsequently equalized at 1625°F (885°C) for 24 hours, followed by aging at 1300°F (704°C) for approximately 20 hours. This heat treatment condition was referred to as 'equalized and aged' (EQA). Since the process used a closed die forging to achieve near net shape, only portions of the beam (the bolt hole region and the transition region) were machined. Most of the beam surface, including the tapered region, was left in the as-forged condition, although subsequent grinding of the surface was required by the fabrication drawing. Prior to final assembly, the beam was liquid penetrant examined. At the time of the publication of BWRVIP-41, Revision 1, no BWR/3 beams remained in service. Figure 2-4 shows the BWR/3 beam assembly.

#### *2.3.2.2.2 BWR/4-6 Beam Design – Group 1*

The Group 1 BWR/4-6 design beams used the same material and heat treatment as the BWR/3 design and were also fabricated from closed die forgings. Similar to the BWR/3 design, the surfaces of the beam were both as-forged and machined. The final beam surfaces were also examined by liquid penetrant prior to final assembly. The major change in the beam design was dimensional – the beam depth increased from 2.02 to 2.30 inches (51.3 to 58.42 mm). In addition, the installation preload was increased from 25 to 30 kips (111 kN to 133 kN). At the time of the publication of BWRVIP-41 Revision 3, no BWR/4-6 Group 1 beams remained in service. Figure 2-5 shows the Group 1 BWR/4-6 beam assembly.

#### *2.3.2.2.3 BWR/4-6 Beam design – Group 2*

As a result of the failures of the equalized and aged beams (BWR/3 and Group 1 designs), the heat treatment of the beam material was changed. The revised heat treatment consisted of solution annealing at 2000°F (1093°C) for 1-2 hours, followed by water quench and then by aging at 1300°F (704°C) for approximately 20 hours. This heat treatment is referred to as 'high temperature anneal and aged' (HTA). The change to the HTA heat treatment was combined with a reduced preload, from 30 kips to 25 kips (133 to 111 kN). The initial beams were manufactured from closed die forgings, with the attendant combination of machined and as-forged surfaces, followed by liquid penetrant examination of the final beam surfaces. Beginning in 1994, some of the Group 2 beams were supplied as open-die forgings and as a result were machined on all surfaces, removing any as-forged surfaces. Liquid penetrant examination of final machined surfaces was also performed. Another change that occurred in 1994 was the addition of a baseline inspection by ultrasonic techniques (UT) of the BB-1 and BB-2 regions prior to installation. Since the Group 1 and Group 2 beams are dimensionally identical, Figure 2-5 also represents the configuration of the Group 2 beam assembly.

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**Figure 2-4**
**BWR/3 Beam-Bolt Assembly**

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**Figure 2-5**
**BWR/4-6 Beam Bolt Assemblies (Groups 1 and 2)**

#### *2.3.2.2.4 BWR/4-6 Beam Design – Group 3*

Group 3 beams were introduced in 2001. The beam is fabricated from an "open die" bar forging. The beam is machined on all surfaces and subsequently liquid penetrant examined. The rectangular bar forging is fabricated from Alloy X-750 with the "HTA" heat treatment. The material is tested in accordance with MIL-DTL-24114F (the 'rising load test'). This beam-bolt assembly also incorporates a "ratchet" lock plate and keeper in place of the tack welded keeper used in the previous beam-bolt assembly designs. The beam has been made thicker in the center and the ends to reduce the mean stress in the beam after installation. Figure 2-6 shows the configuration of the Group 3 beam assembly.

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**Figure 2-6**
**BWR/4-6 Beam Bolt Assembly (Group 3)**

### 2.3.2.3 Inspection Regions

As discussed in Section 2.2.1.4, jet pump beam cracking has occurred in three different locations, warranting non-destructive examination (NDE) of all three regions where cracking has occurred. All three regions are shown schematically in Figure 2-7.

Since the loading results in a bending stress that is tensile on the top surface of the beam and compressive on the bottom surface, IGSCC originating on the bottom surface of Alloy X-750 beam is highly unlikely. In addition, any IGSCC that may form would preferentially orient in the transverse (made at right angles to the long axis of the beam) direction due to the bending stress. It is therefore important that the inspection technique be directed towards cracking with significant transverse orientation. Any transverse oriented beam cracking detected during an examination shall result in the beam's replacement prior to restarting the plant unless the flaw can be demonstrated by an EVT-1 inspection to be wholly located in the "exclusion zone" as shown in Figure 2-7. For this case only, the beam is acceptable for continued service for one additional operating cycle and must be re-inspected at the next refueling outage.

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**Figure 2-7**
**Schematic Diagram of the Inspection Regions for the Jet Pump Beam**

### 2.3.2.4 Loading

The majority of the load on the jet pump beams is the applied preload. The applied stress developed by this preload on the beam is a major contributor to determining the time to IGSCC failure. The various beam designs have different applied stresses, as shown in Table 2-2; all are shown for a 25 kip (111 kN) preload.

**Table 2-2**
**Comparison of Maximum Principal Stress without Thermal Relaxation**

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## 2.3.2.5 Susceptibility

### *2.3.2.5.1 Beam Susceptibility*

The only significant failure mechanism associated with the jet pump beam is intergranular stress corrosion cracking (IGSCC) which is aggravated by high stress, poor material properties (including heat treatment) and an aggressive environment.

Under normal water chemistry (NWC) conditions, the environment in the annulus region is highly oxidizing in all BWRs. Radiolysis model calculations predict that the environment has a significant concentration of $H_2O_2$. Both the initiation and growth of cracks will be promoted by the high electro-chemical potential (ECP) that exists in the annulus region under NWC conditions.

Effective hydrogen water chemistry reduces the amount of oxidizing species in the water, and hence, the ECP. This lowering of ECP is expected to result in an increase in time to initiation of cracking, as well as a reduction in crack growth rate.

All beams are fabricated from Alloy X-750. However, differences in heat treatment and applied stress result in different probabilities of crack initiation. Beams in the EQA condition are expected to fail much earlier than HTA beams. For beams in the HTA condition and under NWC conditions, a statistical evaluation of the Group 2 and Group 3 beams (based on applied stress) has been used to quantify the significant differences in the predicted beam life (that is, the mean time to beam failure due to IGSCC initiation) in the jet pump beams [17]. The beam life for a Group 2 beam is 40 years. Due to the lower applied stress found in the Group 3 beams, the Group 3 life is significantly longer (240 years). Hydrogen water chemistry conditions would significantly increase both of these values. Table 2-3 shows the predicted life of the Group 2 and Group 3 beams in NWC. (Note that EQA beams are not shown; the U.S. BWR fleet has replaced all EQA beams with HTA.)

**Table 2-3**
**Predicted Beam Life (NWC Conditions)**

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Based on this discussion, it can be seen that the various beam designs are predicted to have significantly different lifetimes. Therefore, different inspection intervals are warranted based on design and water chemistry considerations.

#### *2.3.2.5.2 Beam Bolt*

Replacement beam-bolt assemblies (beam, bolt, keeper, plate, two screws, two pins as supplied as a unit) were provided with a Type 316L stainless steel rather than a Type 304 stainless steel bolt. Although no IGSCC has been identified on the Type 304 stainless steel bolt, nor would it be expected on this low stress component, the Type 316L stainless steel bolt was used to provide additional IGSCC margin even though the design stress allowable for Type 316L stainless steel is slightly less than that for Type 304 stainless steel.

### 2.3.2.6 Failure Consequences

Failure of the jet pump holddown beam during operation results in the ejection of the inlet-mixer assembly and loss of jet pump operability. In the absence of the jet pump beam, the only mechanisms tending to resist inlet-mixer ejection are gravity and frictional forces at the interface with the transition piece, at the slip joint with the top of the diffuser, and at the restrainer bracket. The upward loads due to pressure differences and fluid momentum transfer are sufficient to overcome the frictional forces and dead weight, and separate the inlet-mixer from the riser transition piece.

Ejection of an inlet-mixer assembly creates a large leak path between the lower plenum and the annulus region. During a recirculation line LOCA this leak path will affect the ability to maintain 2/3 core coverage as well as LPCI injection. The subsequent safety implications are dependent on the performance of plant ECCS systems.

Inlet-mixer ejection is immediately detectable by numerous jet pump flow, core flow, and power indicators.

### 2.3.2.7 Inspection Recommendations

A comprehensive fracture mechanics evaluation of the Group 2 and Group 3 jet pump beam designs was performed to establish the flaw tolerance of the designs currently installed in the BWR fleet [8]. The flaw tolerances were used to determine the jet pump beam inspection intervals. The inspection intervals are based on both initiation and crack growth analyses.

The initiation data [17] was used to define the time of the initial inspection. The re-inspection intervals are based on the time for an assumed flaw (smaller than the detection limit) to reach a critical size. The time for an assumed flaw to reach the critical size is dependent on the initial flaw depth, the location, and the operating environment.

All holddown beam locations described above (BB-1, BB-2, and BB-3) require inspection as shown in Table 3-1. Inspection requirements depend on beam design, the location inspected, and plant water chemistry. Longer inspection intervals are dependent on credit for mitigation based on requirements given in BWRVIP-62-A [12] as accepted by the NRC. Mitigation credit for jet pump beams is applicable for plants operating on NMCA or OLNC™, but not applicable for plants operating on NWC or HWC. Technical bases for the inspection recommendations in Table 3-1 can be found in BWRVIP- 138, Revision 1-A [8] and in the current edition of BWRVIP-03 [18].

No inspection is recommended for the stainless steel beam bolt.

### 2.3.3 Nozzle Thermal Sleeve

#### 2.3.3.1 Function

The recirculation nozzle inlet thermal sleeve attaches the N2 nozzle safe end to the jet pump riser elbow. The thermal sleeve is designed to provide a pressure retaining flow path for drive flow to the jet pumps. Secondarily, the thermal sleeve reduces temperature variations, and thus thermal loading, on the pressure vessel nozzle.

#### 2.3.3.2 Configurations – Locations TS-1 to TS-4

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**Note**: During N2 nozzle safe end replacement, welds in addition to those shown in Figure 2-8 may have been made on the thermal sleeves. It is also possible that materials other than those listed in Table 2-4 were used in the replacement thermal sleeves. Therefore, it is recommended that each plant verify the materials of construction and configuration of their thermal sleeves to determine the applicability of the inspection recommendations in this document.

#### 2.3.3.3 Loading

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**Figure 2-8**
**Three Configurations for the Thermal Sleeve**

**Table 2-4**
**Thermal Sleeve Configurations**

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#### 2.3.3.4 Susceptibility

The relative IGSCC susceptibility of the thermal sleeve welds is primarily dictated by the thermal sleeve configuration and material.

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#### 2.3.3.5 Failure Consequences

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2.3.3.6 Inspection Recommendations

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### 2.3.4 Riser Pipe

2.3.4.1 Function

The riser pipe connects the inlet nozzle thermal sleeve to the transition piece. The riser directs recirculation flow from the recirculation inlet nozzles to the jet pump inlet-mixers.

2.3.4.2 Configurations – Locations RS-1 to RS-11

Table 2-5 details the different materials and configurations used in the construction of the riser pipe for BWR/3 through BWR/6.

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**Figure 2-9**
**Typical BWR/3 Riser Assembly**

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**Figure 2-10**
**Typical BWR/4-6 Riser Assembly**

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**Figure 2-11**
**Riser Elbow and Thermal Sleeve**

**Table 2-5**
**Riser Materials and Configurations**

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#### 2.3.4.4 Susceptibility

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#### 2.3.4.5 Failure Consequences

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2.3.4.6 Inspection Recommendations

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### 2.3.5 Transition Piece

#### 2.3.5.1 Function

The transition piece is welded to the top of the riser pipe and provides the seating surface for the two inlet-mixer assemblies. The transition piece also provides the load transfer path for the jet pump beams.

#### 2.3.5.2 Configurations – Locations TR-1 to TR-5

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**Figure 2-12**
**Typical Transition Piece**

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**Figure 2-13**
**Welded Transition Piece Detail**

**Table 2-6**
**Transition Piece Configurations**

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#### 2.3.5.4 Susceptibility

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#### 2.3.5.5 Failure Consequences

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#### 2.3.5.6 Inspection Recommendations

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### 2.3.6 Inlet (Elbow and Nozzle)

#### 2.3.6.1 Function

The inlet is part of the inlet-mixer assembly and consists of a 180 degree elbow and a nozzle. The beam-bolt assembly contacts the top of the elbow and holds the inlet-mixer in place on the transition piece seating surface. The nozzle accelerates the drive flow from the recirculation system and directs the fluid into the mixer section of the inlet-mixer. The nozzle is open to the annulus region so that the low static pressure created by the accelerated nozzle flow will entrain fluid from the annulus into the mixer. The ratio of the drive flow to the entrained flow (or suction flow) is referred to as the M ratio.

#### 2.3.6.2 Configurations – Locations IN-1 to IN-5

Table 2-7 details the materials of construction of the inlet subcomponent for the different plant designs.

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**Figure 2-14**
**Inlet with Single-Hole Nozzle**

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**Figure 2-15**
**Inlet with Five-Hole Nozzle**

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**Figure 2-16**
**Inlet-Mixer with Clamp Connection**

**Table 2-7**
**Inlet Configurations**

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#### 2.3.6.4 Susceptibility

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#### 2.3.6.5 Failure Consequences

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### 2.3.6.6 Inspection Recommendation Technical Basis

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### 2.3.7 Mixer (Throat)

#### 2.3.7.1 Function

The function of the mixer, or throat, is to mix the drive flow and the suction flow in the jet pump. The bottom of the mixer section forms a slip joint with the top of the diffuser collar. The purpose of the slip joint is to allow for differential thermal expansion between the jet pump assembly and the reactor vessel.

#### 2.3.7.2 Configurations – Locations MX-1 to MX-7

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**Figure 2-17**
**Typical BWR/3 Mixer without an Adapter**

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**Figure 2-18**
**Typical BWR/3 Mixer with an Adapter**

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**Figure 2-19**
**Typical BWR/4 Mixers**

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**Figure 2-20**
**Typical BWR/5-6 Mixer Section**

**Table 2-8**
**Mixer Configurations**

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### 2.3.7.4 Susceptibility

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#### 2.3.7.5 Failure Consequences

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#### 2.3.7.6 Inspection Recommendations

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### 2.3.8 Restrainer Bracket Assembly

#### 2.3.8.1 Function

The restrainer bracket assembly is composed of the restrainer bracket, the wedge assembly, and the restrainer bracket adjusting screws.

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#### 2.3.8.2 Configurations – Locations RK-1 to RK-5, WD-1 to WD-2, AS-1 to AS-2

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**Figure 2-21**
**BWR/3 Swing Gate Restrainer Bracket Design**

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**Figure 2-22**
**BWR/3,4 Solid Ring Restrainer Bracket Design**

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**Figure 2-23**
**Solid Ring Restrainer Bracket Design Typical of Most BWR 4-6s**

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**Table 2-9**
**Restrainer Bracket Configurations**

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**Figure 2-24**
**BWR/3 Wedge Assembly—Welded to Restrainer Bracket (Swing Gate Design)**

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**Figure 2-25**
**BWR/3 Wedge Assembly—Welded to Mixer**

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**Figure 2-26**
**Typical BWR/4-6 Wedge Assembly**

**Table 2-10**
**Wedge Assembly Configurations**

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Table 2-11 lists the configuration for the set screws or bolts used in the different plants. Figures 2-22 to 2-23 show the restrainer bracket and adjusting screw configurations.

**Table 2-11**
**Adjusting Screw Configurations**

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#### 2.3.8.4 Susceptibility

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### 2.3.8.5 Failure Consequences

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### 2.3.8.6 Inspection Recommendations

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### 2.3.9 Diffuser Collar

#### 2.3.9.1 Function

The diffuser collar is attached to the top of the diffuser and forms the slip joint with the bottom of the inlet-mixer. The slip joint allows vertical displacement to occur between the diffuser and inlet-mixer, but restricts horizontal displacement. Vertical displacement occurs as a result of differential thermal expansion between the jet pump assembly and the reactor vessel.

#### 2.3.9.2 Configurations – Locations DC-1 to DC-4

Table 2-12 lists the materials for the weld locations in the diffuser collar. Figure 2-27 shows the

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**Table 2-12**
**Diffuser Collar Configurations**

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Figure 2-27
Diffuser Assembly Typical of BWR/3 Plants with External Sensing Line Manifolds

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**Figure 2-28**
**Diffuser Assembly Typical of BWR/3 Plants with Partially Internal Sensing Line Manifolds**

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**Figure 2-29**
**Typical BWR/4 Diffuser Assembly**

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**Figure 2-30**
**Typical BWR/5 Diffuser Assembly**

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**Figure 2-31**
**Typical BWR/6 Diffuser Assembly**

#### 2.3.9.4 Susceptibility

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#### 2.3.9.5 Failure Consequences

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#### 2.3.9.6 Inspection Recommendations

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### *2.3.10 Diffuser and Tailpipe*

#### 2.3.10.1 Function

The diffuser and tailpipe provide the flow path for the recirculation flow through the shroud support plate and into the lower plenum. The diffuser shell connects the diffuser collar to the tailpipe, and the tailpipe connects the diffuser shell to the adapter. In plants without adapters, the tailpipe welds to the lower ring.

#### 2.3.10.2 Configuration – Locations DF-1 to DF-4

Table 2-13 lists the different configurations for the diffuser and tailpipe components. Figure 2-27 shows the typical configuration for BWR/3s with entirely external sensing line manifolds. Figure 2-28 shows the typical configuration for BWR/3s with partially internal manifolds. The typical configuration for BWR/4s is shown in Figure 2-29.

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**Table 2-13**
**Diffuser and Tailpipe Configurations**

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#### 2.3.10.4 Susceptibility

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#### 2.3.10.5 Failure Consequences

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**Figure 2-32**
**Straight Adapter Assembly**

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**Figure 2-33**
**Curved Adapter Assembly**

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**Figure 2-34**
**Straight Adapter Assembly with Overlap**

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#### 2.3.10.6 Inspection Recommendations

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### 2.3.11 Adapter/Lower Ring

#### 2.3.11.1 Function

The adapter connects the diffuser tailpipe to the shroud support plate. In plants without adapters, the bottom of the tailpipe or lower ring welds directly to the shroud support plate.

#### 2.3.11.2 Configurations – Locations AD-1 to AD-4

Table 2-14 lists the configurations for the adapter/lower ring which is attached to the shroud support ledge at typically the elevation of the H8 and H9 shroud welds.

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Figure 2-35
Lower Ring Connection to Shroud Support Plate Typical of Most BWR/5s and 6s

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### 2.3.11.3 Loading

The loading of the adapter is similar to that for the tailpipe discussed in Section 2.3.10.

**Table 2-14**
**Jet Pump Adapter Configurations**

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### 2.3.11.4 Susceptibility

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Discussion regarding IGSCC susceptibility and fleet operating experience is provided in Section 2.2.1 above. Detailed review and evaluation of field inspection data and flaw tolerance assessments are documented in Reference 29.

### 2.3.11.5 Failure Consequences

The consequences of failure of the adapter circumferential welds AD-1 and AD-2 are similar to those of the diffuser shell-to-tailpipe weld (DF-2) discussed in Section 2.3.10, except for plants with a curved adapter design.

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### 2.3.11.6 Inspection Recommendations

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### 2.3.12 Jet Pump Sensing Lines

#### 2.3.12.1 Function

The jet pump sensing lines are used to measure the differential pressure inside the diffuser. These measurements are used to determine the flow rate in the pump.

#### 2.3.12.2 Configurations

Table 2-15 lists the configurations for the jet pump sensing lines.

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**Figure 2-36**
**Sensing Line Configuration for BWR/3s With Entirely External Manifold**

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**Figure 2-37**
**Sensing Line Configuration for BWR/3-4s With Partially Internal Manifold**

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**Figure 2-38**
**Typical BWR/5-6s Sensing Line Configuration**

**Table 2-15**
**Sensing Line Configurations**

| |
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### 2.3.12.3 Loading

### 2.3.12.4 Susceptibility

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### 2.3.12.5 Failure Consequences

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### 2.3.12.6 Inspection Recommendations

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## 2.4 Overview of Changes to Inspection Recommendations in Revision 4

The susceptibility evaluation documented in Section 2.2 and the jet pump component evaluations documented in Section 2.3 identify IGSCC and fatigue as the degradation mechanisms for which inspection is warranted. The inspection program described in Section 3 provides inspection requirements for jet pump components determined to have generic susceptibility to IGSCC or fatigue and whose failure would have an adverse impact on plant safety. No inspections are considered for component locations determined not to be generically susceptible to either IGSCC or fatigue or whose failure would not have an adverse impact on plant safety.

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# 3 INSPECTION STRATEGY

## 3.1 Inspection Methods

The following discussions refer to several inspection methods under the general categories of ultrasonic (UT) and visual (VT).

The specific methods are briefly described below. Implementation requirements and definitions are as described in the current edition of BWRVIP-03 [18].

**UT:** UT is an ultrasonic method of volumetric inspection.

**VT-1:** VT-1 is defined using the ASME Section XI criteria from the Edition and Addenda applicable to the Owner's in-service inspection program.

**Enhanced VT-1:** Enhanced VT-1 (EVT-1) is defined in latest revision of BWRVIP-03.

**VT-3:** VT-3 is defined using the ASME Section XI criteria from the Edition and Addenda applicable to the Owner's inservice inspection program.

## 3.2 BWRVIP Inspection Guidelines

These inspection guidelines are intended to provide flexible options for inspection while ensuring that structural integrity and/or function of the jet pump are adequately maintained. The guidelines also are generic in nature, based on the overall understanding of the various designs of the jet pump. There may be plant-specific situations where more rigorous inspections are chosen or where less rigorous inspections are justified. For example, if a location for which inspection is required were shown for a specific plant to be solution annealed, a plant-specific evaluation could specify that no inspection is required.

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A detailed description of the technical basis for the inspection program presented in this section can be found in BWRVIP-266 [9].

SILS: The recommendations in this Jet Pump Inspection and Flaw Evaluation Guideline document provide inspections necessary to ensure jet pump integrity for continued safety and replace the inspection recommendations of GE SILS. For assurance of safety, the Jet Pump Inspection and Flaw Evaluation Guideline document replaces the inspection recommendations of:

- SIL 330 (Jet Pump Beam Cracks)
- SIL 420 (Sensing Line Failures)
- SIL 551 (Jet Pump Riser Brace Cracking)
- SIL 574 (Jet Pump Adjusting Screw Tack Weld Failures)
- RICSIL 086 (Jet Pump Beam Cracks)

However, these SILS do contain other information relative to operational performance and field experience that may assist licensees with investment protection, cost management and optimization of operational performance. Each Licensee should review the current SILS, and stay cognizant of any future changes, for information that may affect reactor operation or performance.

### 3.2.1 Periodic Inspection

The previous revision of this report specified inspection intervals based on operating cycles. The new criteria use a time-based specification of inspection intervals. This approach simplifies the determination of inspection frequencies. Table 3-1 provides periodic inspection requirements for each inspection location. With the exception of jet pump beams, baseline inspection requirements have been removed from the Table.

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### 3.2.2 Inspection Technique

In all cases where a VT-1 or EVT-1 inspection is recommended, either a higher resolution visual technique or a suitable NDE examination technique meeting the requirements of the current edition of BWRVIP-03 [18] may be substituted.

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### 3.2.3 Deviations from BWRVIP Inspection Guidance

### 3.2.4 Consideration of Un-inspectable Areas in Partially Accessible Welds

Periodic inspection recommendations are intended to apply to all areas accessible for inspection. Some welds may have segments that are accessible for inspection and portions that are not. In

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### 3.2.5 Inaccessible Welds

Some welds in the jet pump assembly may be completely inaccessible for inspection.

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### 3.2.6 Inspection Strategy for Accessible and Inaccessible Weld Programs

An overview of the inspection, re-inspection and scope expansion process for the accessible and inaccessible weld inspection programs is shown in Figure 3-1. Note that Section 3.2.7 is invoked when flaws are detected in accessible welds that are similar to inaccessible welds. Scope expansion criteria for accessible and inaccessible welds are contained in Section 3.2.8.

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**Figure 3-1**
**Overview of Accessible and Inaccessible Weld Inspection Programs**

**Table 3-1**
**Matrix of Inspection Options**

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**Table 3-1 (continued)**
**Matrix of Inspection Options**

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**Table 3-1 (continued)**
**Matrix of Inspection Options**

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**Table 3-1 (continued)**
**Matrix of Inspection Options**

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**Table 3-1 (continued)**
**Matrix of Inspection Options**

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**Matrix of Inspection Options**

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**Matrix of Inspection Options**

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**Table 3-1 (continued)
Matrix of Inspection Options**

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**Matrix of Inspection Options**

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**Matrix of Inspection Options**

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**Table 3-1 (continued)**
**Matrix of Inspection Options**

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### 3.2.7 Inspection Program for Inaccessible Welds

As shown in Table 3-1, there are inaccessible welds in the jet pump thermal sleeves (TS-1, TS-2, TS-3, TS-4), in the diffuser (DF-3) and in the lower adapter (AD-1, AD-2). The thermal sleeve welds are inaccessible in most plants; the adapter and diffuser welds are inaccessible only in a few plants.

Two strategies are used to ensure the integrity of inaccessible welds.

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#### 3.2.7.1 Basis for the Allowable Inspection Interval for Inaccessible Welds

Several principles are used to define the inspection strategy for inaccessible welds in the jet pump assembly.

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Section 3.2.7.2 provides the guidelines for identifying similar accessible welds, and Section 3.2.7.3 describes the detailed information and guidelines used to determine the beginning and length of the inspection interval for the inaccessible welds.

### 3.2.7.2 Similar Accessible Welds

#### *3.2.7.2.1 Susceptibility Categories*

Plant-specific accessible welds similar to the inaccessible welds must be identified to use the inspection or leakage evaluation strategy. Section 2.2.1.2 and Section 2.3 identify a number of factors that affect the susceptibility of the various alloys and weld configurations to degradation in the jet pump assembly. For the purpose of evaluating inaccessible welds, the following susceptibility categories are defined:

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#### *3.2.7.2.2 Similar Accessible Welds for Nozzle Thermal Sleeve Welds TS-1, TS-2, TS-3 and TS-4*

As indicated in Table 2-4, there are three nozzle thermal sleeve weld configurations. These

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#### *3.2.7.2.3 Similar Accessible Welds for Diffuser and Tailpipe Welds DF-3*

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#### *3.2.7.2.4 Similar Accessible Welds for Adaptor/Lower Ring Welds AD-1 and AD-2*

The adapter connects the diffuser tailpipe to the shroud support plate. Most adapters are fabricated from two pieces.

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#### 3.2.7.3 Guidelines for Determining the Inspection Interval for Inaccessible Welds

The following procedure can be used to determine the plant-specific inspection interval for Priority H/M/L inaccessible welds. The required leakage evaluation is described in Section 5.1.4.

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#### 3.2.7.4 Example Inspection Interval Determination for Inaccessible Welds

The following is an example of the application of this procedure.

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### 3.2.8 Scope Expansion for Accessible and Inaccessible Weld Inspection Programs

#### 3.2.8.1 Accessible Welds Inspection Program

##### 3.2.8.1.1 General Requirements

The following procedure shall be used to expand the inspection scope for accessible welds that are not included in an inaccessible weld program. Also refer to Figure 3-1 for an illustration of the process.

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##### 3.2.8.1.2 Exemptions

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#### 3.2.8.2 Inaccessible Weld Inspection Program

The following procedure shall be used to expand the inspection scope for similar accessible welds that are included in an inaccessible weld program. Also refer to Figure 3-1 for an illustration of the process.

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### *3.2.9 Scope Expansion for Components Other Than Piping Welds*

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### *3.2.10 Jet Pump Beam Flaw Disposition*

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# 4 LOADING

In the event that plant-specific flaw evaluations are required, loads and load combinations must be defined. This section describes the details of the various loading and the load combinations that need to be considered to determine the primary and secondary stress levels appropriate for various operating conditions. The flaw evaluation methodology is described in Section 5.

## 4.1 Applied Loads

The applied loads on the jet pump assembly consist of the following: deadweight, hydraulic loads, seismic inertia, seismic anchor displacements, safety relief valve opening, annulus pressurization, condensation oscillation, chugging, fluid drag, loads due to flow induced vibration, and thermal anchor displacements. Each of these loads are briefly discussed in the following sections.

### *4.1.1 Deadweight (DW)*

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### *4.1.2 Hydraulic Loads (F1, F2)*

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### *4.1.3 Seismic Inertia*

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#### 4.1.4 Seismic Anchor Displacements

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#### 4.1.5 Safety Relief Valve Opening (SRV)

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### 4.1.6 Annulus Pressurization (AP)

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### 4.1.7 Condensation Oscillation and Chugging (CO, CHG)

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### 4.1.8 Fluid Drag and Acoustic Loads

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### 4.1.9 Flow Induced Vibration (FIV)

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### 4.1.10 Thermal Anchor Displacements

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### 4.1.11 Applicability of Hydrodynamic Loads

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## 4.2 Load Combinations

The load combinations used in the evaluation shall be consistent with the requirements of the plant FSAR, UFSAR or related licensing basis documentation. Typically, Section 3.9 of the FSAR or UFSAR contains the information on this subject, including for some plants, hydrodynamic loads (that is, "new loads") and/or annulus pressurization loads. The following represents a suggested set of load combinations that shall be considered for the normal/upset condition if not specified in the plant licensing basis documentation. The (P) suffix indicates a primary load and the (S) suffix indicates a secondary load.

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## 4.3 Loading for Degraded Jet Pump Assemblies

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### 4.3.1 Recirculation Pump Vane Passing Frequency

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### 4.3.2 Turbulent Fluid Flow within the Jet Pump

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### 4.3.3 Cross Flow over the Jet Pumps in the Annulus

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#### 4.3.4 Leakage Flow Mechanism at the Mixer to Diffuser Slip Joint

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# 5 STRUCTURAL AND LEAKAGE EVALUATION METHODOLOGIES

Structural and leak rate evaluations must be performed to ensure that adequate structural and leakage margins are maintained for cracked jet pump assembly components during operation. This section describes the structural and leak rate evaluation methodologies and computational procedures needed to evaluate cracks in both accessible and inaccessible welds. Crack growth considerations also are provided.

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The structural and leakage evaluation approaches for flaws in welds in the riser pipe, inlet mixer and diffuser are presented in Section 5.1. Different evaluation approaches are used for the jet pump beams, riser brace and set screw gaps and are described separately in Sections 5.2, 5.3 and 5.4, respectively.

## 5.1 Riser Pipe, Inlet-Mixer and Diffuser Locations

This section provides methods for evaluating the acceptability of flaws in the jet pump assembly riser pipe, inlet-mixer and diffuser. Based on observed flaw lengths and assumed crack growth rates, a point in time can be calculated at which the flaws will have grown to such a size that jet pump assembly function may be impaired. Reinspection of the flaws must be scheduled prior to the time at which the flaws have grown to unacceptable sizes. However, in no cases can the results of a flaw evaluation be used to extend the reinspection interval beyond that described in Section 3.

### 5.1.1 Flaw Characterization

#### 5.1.1.1 NDE Uncertainty

In performing some flaw evaluations, the measured length and depth of observed flaws may need to be adjusted to account for NDE uncertainty. These adjustments shall be made in accordance with current BWRVIP recommendations.

#### 5.1.1.2 Consideration of Welds with Partial Inspection Access

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#### 5.1.1.3 Crack Growth

In evaluating whether an observed crack is acceptable with respect to continued plant operation, assumptions must be made regarding crack growth rates.

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### 5.1.2 Structural Evaluation

#### 5.1.2.1 Limit Load Evaluation Methodology

The limit load methodology described in Appendix C of ASME Section XI [24] and in [25] is presented in this section as one of the approaches that may be used to determine the critical and allowable flaw lengths for a pipe. Alternative methods may also be used if justified.

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**Figure 5-1**
**Stress Distribution in a Cracked Pipe at Limit Load**

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#### 5.1.2.1.1 Z Factor

Some alloys and welds used in jet pump assembly may have lower toughness than is necessary to achieve limit load. These materials include austenitic stainless steel submerged arc welds (SAW) and shielded metal arc welds (SMAW), and alloy 600 and associated weld materials alloy 82/182. When flaws are detected in these materials, a factor, Z, is used to account for the reduced load carrying capacity relative to limit load for the cracked section, and the expression for the failure bending stress is:

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#### 5.1.2.1.2 Flaw Proximity Considerations

If multiple indications are detected during the inspection at a location, then the interactions, if any, between these indications must be accounted for in the structural margin evaluation. Flaw proximity assessment rules provided in BWRVIP-158-A [29] may be applied to address combination of indications.

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*5.1.2.1.3 Limit Load Methodology for Multiple Circumferential Indications*

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*5.1.2.1.4 Allowable Flaw Size Determination*

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*5.1.2.1.5 Time to Reach the Minimum Acceptable Structural Margin*

The time to reach the minimum acceptable structural margin, SF, is the time it takes for a crack to grow from the size at which it is first detected to the allowable flaw size determined from the previous paragraph using the NDE uncertainty, where applicable, and the crack growth rate defined in Section 5.1.1. The time to reach the minimum acceptable structural margin can be obtained from the general expression:

Allowable flaw size = Detected flaw size + Additional allowance due to NDE uncertainty (if appropriate) + Crack growth (crack growth rate * time) at both tips.

#### 5.1.2.2 Effects of Irradiation

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### *5.1.3 Leakage Considerations*

Leakage from known flaws as well as from assumed cracks in partially accessible and inaccessible welds must be evaluated as described in Section 5.1.4 to ensure that the leakage is bounded by plant-specific leakage margins.

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### 5.1.4 Leak Rate Calculation Methods

#### 5.1.4.1 Leak Rate from Cracks Detected in Accessible and Partially Accessible Welds

Leakage from the jet pump assembly into the RPV annulus could come from a number of sources such as through the gap at the slip joint between the diffuser and the mixer, or through the presence of any through-wall cracks in the piping. The leakage rate through a crack, can be estimated assuming incompressible Bernoulli flow through an opening:

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### 5.1.4.2 Leak Rate from Cracks in Inaccessible Welds

The leakage discussed in Section 5.1.3 includes leakage from cracks in accessible and inaccessible welds. The previous paragraph provides a methodology for determining the leakage from through-wall cracks where the flaw size is known from the inspection results, as defined in Section 5.1.1. This section presents an approach to compute the leak rate from inaccessible welds where the flaw size is unknown.

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#### 5.1.4.2.1 Example Applications

As an example, consider the following conditions.

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**Table 5-1**
**Calculated Leak Rate Distribution for Eight Similar Accessible Welds with Through-Wall Flaws**

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**Figure 5-2**
**Plot of the Leak Rate Distribution for Similar Accessible Welds and the Estimated Leak Rates for Inaccessible Welds**

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## 5.2 Jet Pump Beam

Cracking of jet pump hold-down beams has occurred at several operating BWRs. Several beam failures due to these cracks have occurred during plant operation, causing jet pump mixer displacement. For more information regarding the jet pump beam failure incidences, refer to References [1], [32] and [8].

Failed beams and several beams with small cracks have been examined to determine the failure mechanism of the beam.

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## 5.3 Riser Brace

Riser brace cracking has been observed in a BWR/3 and in a BWR/4. For the GE BWR/3 where cracking was found in the riser brace leaf, a detailed analysis and vibration test program was completed.

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## 5.4 Set Screw Gap Evaluation

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## 5.5 Ability of Riser Brace to Prevent Jet Pump Disassembly

In some cases, an intact riser brace may be shown by analysis to be able to prevent jet pump disassembly in the presence of a cracked riser pipe.

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# 6
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# A
# LICENSE RENEWAL

The demonstration of compliance with the technical information requirements of the License Renewal Rule [A1] previously contained in this Appendix was developed based on the content of the original version of BWRVIP-41, Revision 1 [A2]. As a result of revisions to BWRVIP-41 made since that time, the content of this appendix is now out of date.

The original intent of the license renewal appendix was to support generic acceptance of BWRVIP guidance as being adequate to manage applicable aging effects during renewal periods. This original need has been effectively eliminated by the availability of generic aging lessons learned (GALL) NUREG reports for license renewals [A3], [A4]. As a result, the BWRVIP concluded that maintenance of LR Appendix content and associated safety evaluations is not an efficient use of industry resources.

Therefore, the content previously included in this appendix has been designated historical. Further, to eliminate any potential for misuse or misinterpretation, the content of this appendix has been removed. The prior content can be found in Appendix A of BWRVIP-41, Revision 1 [A2].

Finally, even though a means of generic acceptance is now available through a demonstration of consistency with AMPs provided in GALL NUREG reports, the BWRVIP reviewed the changes included in this revision of BWRVIP-41 to ensure that the guideline remains adequate to meet the technical information requirements of the License Renewal Rule with regard to demonstrating that the effects of aging will continue to be adequately managed.

[A1] Title 10, U.S. Code of Federal Regulations (CFR), Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants".

[A2] *BWR Vessel and Internal Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41, Revision 1).* EPRI, Palo Alto, CA 2005. 1012137.

[A3] NUREG-1801, Rev. 2, "Generic Aging Lessons Learned (GALL) Report", 2010.

[A4] NUREG-2191, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", Volumes 1 and 2, 2017.

# B
# NRC FINAL SAFETY EVALUATION (BWRVIP-41)

The following Safety Evaluation refers to the original version of BWRVIP-41 (EPRI Report TR-108728).

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

February 4, 2001

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

SUBJECT: FINAL SAFETY EVALUATION OF THE "BWR VESSEL AND INTERNALS PROJECT, BWR JET PUMP ASSEMBLY INSPECTION AND FLAW EVALUATION GUIDELINES (BWRVIP-41)," (TAC NO. M99870)

Dear Mr. Terry:

The NRC staff has completed its review of the Electric Power Research Institute (EPRI) proprietary report TR-108728, "BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41)". This report was submitted by letter dated October 15, 1997, and was supplemented by letter dated August 4, 1999, in response to a staff's request for information dated February 12, 1999, and by letter dated November 17, 2000, which was in response to the open items in the staff's initial safety evaluation (SE), dated June 20, 2000.

The BWRVIP-41 report, as supplemented, provides generic guidelines intended to present the appropriate inspection and flaw evaluation recommendations to assure safety function integrity of the subject safety-related reactor pressure vessel (RPV) internal components. These guidelines considered degradation susceptibility, degradation mechanisms, loads, and inspection strategies for jet pump assemblies.

The NRC staff has reviewed the proposed revisions to the BWRVIP-41 report and finds, in the enclosed SE, that the revised guidance of the BWRVIP-41 report, with the modifications as described in the enclosed SE, is acceptable for inspection of the subject safety-related RPV internal components. This finding is based on information submitted by the above cited letters. The staff has concluded that licensee implementation of the guidelines in the BWRVIP-41 report, as modified, will provide an acceptable level of quality for inspection and flaw evaluation of the safety-related components addressed.

Carl Terry -2-

The staff requests that you incorporate the staff's recommendations, as well as your responses to other issues raised in the staff's initial SE, into a revised, final BWRVIP-41 report. Please inform the staff within 90 days of the date of this letter as to your proposed actions and schedule for such a revision.

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

Sincerely,

Jack Strosnider

Jack R. Strosnider, Director
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: See next page

U.S. NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

SAFETY EVALUATION OF EPRI PROPRIETARY TOPICAL REPORT TR-108728

BWR VESSEL AND INTERNALS PROJECT, BWR JET PUMP ASSEMBLY

INSPECTION AND FLAW EVALUATION GUIDELINES (BWRVIP-41)

## 1.0 INTRODUCTION

### 1.1 Background

By letter dated October 15, 1997, as supplemented by letters dated August 4, 1999, and November 17, 2000, the Boiling Water Reactor Vessel and Internals Project (BWRVIP) submitted both proprietary and non-proprietary versions of the Electric Power Research Institute (EPRI) proprietary report TR-108728, "BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41)".

The staff requested additional information (RAI) in a letter dated February 15, 1999, and the BWRVIP responded to the RAI in a submittal dated August 4, 1999. By letter dated June 20, 2000, the staff provided an initial safety evaluation (SE) with several open items to the BWRVIP. By letter dated November 17, 2000, the BWRVIP provided its response to the open items in the staff's initial SE.

### 1.2 Purpose

The staff reviewed the BWRVIP-41 report, as supplemented, to determine whether its revised guidance addressed the open items in the staff's initial SE, and if it would provide acceptable levels of quality for inspection and flaw evaluation (I&E) of the subject safety-related RPV internal components. The review considered the consequences of component failures, potential degradation mechanisms and past service experience, and the ability of the proposed inspections to detect degradation in a timely manner.

### 1.3 Organization of the Report

Because the BWRVIP-41 report is proprietary, this safety evaluation (SE) was written so as not to repeat information contained in the report. This SE gives a brief summary of the general contents of the report in Section 2.0 and the detailed evaluation in Section 3.0 below. The SE does not discuss in any detail the provisions of the guidelines nor the parts of the guidelines that the staff finds acceptable.

ENCLOSURE

## 2.0 SUMMARY OF BWRVIP-41 REPORT

The BWRVIP-41 report addresses the following topics in the following order:

- Jet Pump Assembly Analysis - The jet pump assemblies are described in detail by a series of illustrations and differences among the various models of BWRs (BWR/3 through BWR/6). The various types of jet pump susceptibility factors and material degradation mechanisms, e.g., intergranular stress corrosion cracking (IGSCC), which has factors that include environment, materials and stress state; fatigue by flow induced vibration and/or thermal cycling; and, thermal embrittlement (aging), that could impact the jet pump assemblies are described in general terms. Potential failure locations are addressed from the standpoint of inspection priority, susceptibility to degradation, and consequences of failures in terms of component functions and plant safety.

- Inspection Strategy - The BWRVIP-41 report recommends the specific locations, NDE methods, and inspection frequencies for examinations of the jet pump assemblies. The report also describes the inspection basis and methods, the recommended baseline inspection scope, the reinspection frequency, scope expansion, and reporting of inspection results.

- Loads and Load Combinations - The various types of loads (e.g., pressure, seismic, etc.) of concern and the load combinations are listed and load combinations are described. Consideration for degraded assemblies are also detailed.

- Structural Evaluation Methodologies - This section presents methods which can be used to determine allowable flaw size determinations for different parts of the assemblies, set screw gap evaluation, and the ability of the riser brace to prevent jet pump disassembly.

The BWRVIP-41 report also contains an Appendix A on Demonstration of Compliance with the Technical Information Requirements of the License Renewal Rule, (10 CFR 54.21). Appendix A to the BWRVIP-41 report is not evaluated in this SE report, but will be evaluated under a separate license renewal review.

## 3.0 STAFF EVALUATION

The staff's June 20, 2000, initial SE provided three open items. The BWRVIP, in its letter of November 17, 2000, addressed these items, which are discussed below.

Issue 1: Un-inspectable Thermal Sleeve Welds

The staff's June 20, 2000, initial SE stated:

> With the exception of the issue described below, as requested in Question 6 of the staff's February 12, 1999, RAI, and stated in BWRVIP's August 4, 1999, response, this review finds that the inspection guidance provided in the subject report to be acceptable:
>
> 1. If analysis cannot be provided to alleviate the weld inspections, what type of recommended inspections are being considered for the thermal sleeve welds? Will the

3

inspections be performed over two inspection cycles with at least 50% of the inspections being performed in the first cycle?

BWRVIP Response:

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BWRVIP's November 17, 2000, response stated:

> The BWRVIP will be re-evaluating the need to inspect the hidden welds in the jet pump, core spray and LPCI systems in 2001. This re-evaluation will review the bases for requiring the welds to be examined and determine if a technical basis exists to exclude them from the scope of inspections. However, the issue of hidden welds in the jet pump thermal sleeve is identical to the issue of LPCI hidden welds which was previously resolved between the NRC and BWRVIP. In response to the NRC question on hidden LPCI welds, the BWRVIP responded:
>
> *The I&E guidelines contain numerous recommendations that require extensive technological development for their implementation such as inspection of the subject LPCI locations. It is possible that, after adequate attempts, the industry may determine that a recommendation (such as the inspection of the hidden LPCI welds), as written, cannot be implemented as set forth in the I&E guideline. Rather than track this inaccessible location issue separately through the Staff's SE, we propose that the BWRVIP provide a report to the NRC which describes our progress on the development of inspection tooling for inaccessible locations. In addition, to address future situations where a BWRVIP recommendation cannot be implemented, the BWRVIP proposes a programmatic control that includes NRC notification. BWRVIP-42 will be revised to include the below paragraph.*
>
> > *"If, during the course of implementing these recommendations, it is determined that implementation cannot be achieved as described in the I&E guideline, or that meaningful results are not obtained, the user shall notify the BWRVIP with sufficient details to support development of alternative actions. These notifications, as well as planned actions by the BWRVIP, will be summarized and reported to the NRC ."*

*It is also proposed that, when the other I&E guidelines are revised for final issuance, the paragraph above be included. These actions allow BWRVIP members to identify recommendations that cannot be implemented and provides for appropriate notification and coordination with the NRC.*

The BWRVIP intends to revise the Jet Pump I&E Guideline (BWRVIP-41) to contain this same language as discussed in the BWRVIP-42 SE response. Consequently, the issue of hidden thermal sleeve welds should not be considered an open issue. Rather, it should be considered closed by the additional commitment of the BWRVIP to report to the NRC any instances where inspections, as written, cannot be performed.

Staff's Evaluation:

The staff finds that these actions adequately addresses this open item.

Issue 2: Thermal Sleeve Inspection Requirements

The staff's June 20, 2000, initial SE stated:

The staff requested a description of the plant-specific analysis that could be done to alleviate or reduce the inspection requirements of the thermal sleeve welds, TS-1 through TS-4, the riser pipe welds, RS-1, RS-2, and RS-4 through RS-7, the diffuser and tailpipe welds, DF-1 through DF-3, and the adaptor/lower ring welds, AD-1 through AD-3a,b. With respect to the safety consequences, BWRVIP stated that a plant-specific analysis could be done to show that the failure location would not compromise the jet pump's ability to maintain the water level at 2/3 core height. A plant-specific analysis could also show that the failure does not allow the jet pump to disassemble. For other locations, the plant-specific analysis could focus on the redundancies of the core cooling system. Since some of these welds are classified as high priority inspection welds, the staff believes that the description of the plant-specific analyses of the safety consequences should be included in the appropriate sections of the BWRVIP-41 report.

BWRVIP's November 17, 2000, response stated:

The BWRVIP agrees that a description of the plant-specific analyses should be included in the Guideline. The BWRVIP proposes to add the following paragraph to Section 3:

3.2.x Plant-specific Analyses to Modify/Eliminate Inspection Requirements

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Staff's Evaluation:

The staff finds that this proposed addition to the BWRVIP-41 report adequately addresses this open item.

Issue 3: Structural Evaluation Methodologies

The staff's June 20, 2000, initial SE stated:

The staff finds the methodology provided for determination of allowable flaw size for the riser, inlet-mixer and diffuser and the set screw evaluation method to be acceptable. Methodology is not provided for the jet pump beam, the riser brace or for an evaluation of the ability of the riser brace to prevent jet pump disassembly. Plant-specific analyses will be needed for evaluation of degradation that is identified for all of the jet pump components.

BWRVIP's November 17, 2000, response stated:

As noted by the staff, the Guideline does not include flaw evaluation methods for all jet pump components. BWRVIP members would expect to submit to the NRC any flaw evaluations which are not in accordance with methods presented in the Guideline. The BWRVIP proposes to clarify this by revising Section 5 of the guideline to include the following paragraph that comes from Section 4.3 of BWRVIP-76 and provides additional clarification. Furthermore, all future revisions to BWRVIP reports will contain these generic reporting requirements.

Analytical Evaluations of Inspection Results

Analytical evaluations performed to the guidance of this report for the acceptance of inspection results do not require a specific NRC review prior to restart of the plant following a refueling outage. However, results of such analyses shall be provided by the licensee to the NRC. Analytical evaluations that deviate from the guidance of this report (e. g., assumptions, methods, acceptance criteria, etc.), or evaluations of components not described in this report, shall be communicated to the NRC prior to plant restart.

Staff's Evaluation:

The staff finds that this response adequately addresses this open item.

It should be noted that, with regards to the potential degradation mechanism of thermal embrittlement caused by high fluence levels, the BWRVIP-41 report does not recommend specific inspections of CASS jet pump assembly components to inspect for embrittlement-related degradation beyond that recommended for IGSCC concerns. The staff notes that irradiation embrittlement of CASS components becomes a concern only if cracks are present in the components, and that significant cracking has not been observed in CASS jet pump assembly components. To verify this, the BWRVIP and the NRC's Office of Nuclear Regulatory Research (RES) is engaged in a joint confirmatory research program to determine the effects of high levels of neutron fluence on BWR internals. The results of this program should be used by the BWRVIP to evaluate the need for additional inspections of the CASS jet pump assemblies in the renewal period, and to modify the inspection scope and/or frequency, as needed.

## 4.0 CONCLUSION

The staff has reviewed the BWRVIP-41 report, as revised, and finds that the guidance of the BWRVIP-41 report is acceptable for inspection of the subject safety-related internal components. The staff has concluded that licensee implementation of the guidelines in the BWRVIP-41 report will provide an acceptable level of quality for examination of the safety-related components addressed in the BWRVIP-41 report.

## 5.0 REFERENCES

1. Terry, C., BWRVIP, to USNRC, "BWR Vessel and Internals Project: BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41)," EPRI TR-108728, October 15, 1997.

2. Carpenter, C.E., USNRC, to C. Terry, BWRVIP, "Proprietary Request for Additional Information - Review of "BWR Vessel and Internals Project, Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41)" (TAC No. M99870)," February 12, 1999.

3. Wagoner, V., BWRVIP, to USNRC, "BWRVIP Response to NRC Request for Additional Information on BWRVIP-41 (Reference Project 704)," August 4, 1999.

# C

# NRC ACCEPTANCE FOR REFERENCING REPORT FOR DEMONSTRATION OF COMPLIANCE WITH LICENSE RENEWAL RULE

The license renewal (LR) safety evaluation previously included in this appendix was developed based on Revision 1 of BWRVIP-41, including the LR evaluation provided in Appendix A to BWRVIP-41, Revision 1. As described on page A-1 of this report, the BWRVIP has concluded that maintenance of LR evaluations and associated LR safety evaluations is not an efficient use of industry resources. To eliminate any potential for confusion, the content of this appendix has been removed. The LR safety evaluation content previously included in this appendix can be found in Appendix C of BWRVIP-41, Revision 1 [C1]. This approach is consistent with the approach taken for LR appendix content described on page A-1.

[C1] *BWRVIP-41, Revision 1: BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines*. EPRI, Palo Alto, CA: 2005. 1012137.

# D
# REVISION 1 RECORD OF REVISIONS

| | |
|---|---|
| BWRVIP-41-R1 | Information from the following documents was used in preparing the changes included in this revision of the report:<br>1. "BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41)," EPRI Report TR-108728, October 1997.<br>2. Letter from C.E. Carpenter (NRC) to Carl Terry (BWRVIP Chairman), "Proprietary Request for Additional Information - Review of BWR Vessel and Internals Project, Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP -41)," dated 2/12/99 (BWRVIP Correspondence File Number 99-056A).<br>3. Letter from Carl Terry (BWRVIP Chairman) to C.E. Carpenter (NRC), "BWRVIP Response to NRC Request for Additional Information on BWRVIP-41 (Reference Project 704)," dated 8/4/99 (BWRVIP Correspondence File Number 99-306).<br>4. Letter from J. R. Strosnider (NRC) to Carl Terry (BWRVIP Chairman), "Initial Safety Evaluation Report, "BWR Vessel and Internals Project, BWR Jet Pump Inspection and Flaw Evaluation Guidelines (BWRVIP-41)," (TAC NO. M99870)," dated 6/20/2000 (BWRVIP Correspondence File Number 2000-184).<br>5. Letter from Carl Terry (BWRVIP Chairman) to C.E. Carpenter (NRC), "BWRVIP Response to NRC Safety Evaluation of BWRVIP-41" dated 11/17/00 (BWRVIP Correspondence File Number 2000-319).<br>6. Letter from Jack Strosnider (NRC) to Carl Terry (BWRVIP Chairman), "Final Safety Evaluation of the "BWR Vessel and Internals Project, BWR Jet Pump Inspection and Flaw Evaluation Guidelines (BWRVIP-41)" (TAC NO. M99870)," dated 2/4/01 (BWRVIP Correspondence File Number 2001-062).<br>7. Letter from Christopher Grimes (NRC) to Carl Terry (BWRVIP Chairman), "Acceptance for Referencing of "BWR Vessel and Internals Project, Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP -41), EPRI Topical Report TR-108728"and Appendix A "Demonstration of Compliance with the Technical Information Requirements of the License Renewal Rule (10CFR54.21)," dated 6/5/2001 (BWRVIP Correspondence File Number 2001-194A).<br>8. "BWRVIP-94: BWR Vessel and Internals Project, Program Implementation Guide," EPRI Report 1006288, August 2001.<br>9. "BWRVIP-138: BWR Vessel and Internals Project, Updated Jet Pump Beam Inspection and Evaluation Guidelines," EPRI Technical Report 1008213, December 2004.<br>Details of the revisions can be found in Table D-1. |

**Table D-1**
**Revision Details BWRVIP-41 Rev. 1**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| MVT-1 to be changed to EVT-1 | Response to RAI (99-307) | MVT-1 changed to EVT-1 throughout. |
| The following paragraph will be included in all revised I&E Guidelines: *"If, during the course of implementing these recommendations, it is determined that implementation cannot be achieved as described in the I&E guideline, or that meaningful results are not obtained, the user shall notify the BWRVIP with sufficient details to support development of alternative actions. These notifications, as well as planned actions by the BWRVIP, will be summarized and reported to the NRC."* | Response to Initial SE (2000-319) | Discussion included in BWRVIP-94. No change to BWRVIP-41. |
| Include a description of plant specific analyses that can be used to modify/eliminate inspections. | Response to Initial SE (2000-319) | New Section 3.2.6 added. Section content derived from SE response with minor changes. |
| Include paragraph from BWRVIP-76 regarding submittal of flaw evaluations to NRC | Response to Initial SE (2000-319) | Discussion included in BWRVIP-94. No change to BWRVIP-41. |
| | General Comment | Section 5.1.2.2 revised to indicate that crack growth rates used in flaw evaluations shall be in accordance with current BWRVIP guidance. |
| All I&E Guidelines to be revised to replace CSVT and MVT by EVT-1, VT-1 or VT-3. "EVT-1 will be specified as the primary technique when fine, tight IGSCC is a primary concern. In other locations, VT-1 or VT-3 will be used as appropriate." | Response to SE on BWRVIP-03, Item 3.3-4 (99-115) | MVT-1 changed to EVT-1 throughout. |

**Table D-1 (continued)**
**Revision Details BWRVIP-41 Rev. 1**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| BWRVIP will propose response to "Use of NDE Uncertainty" at a later date. | Response to SE on BWRVIP-63 (2001-189) | New Section 5.1.1 added: Flaw Characterization |
| | General Comment | Limit load equations in section 5.1 revised for consistency among BWRVIP I&E Guidelines. |
| | General Comment | Sect 3.1: Note regarding cleaning deleted. Cleaning is addressed in BWRVIP-03. Reference to BWRVIP-03 changes to refer to the "current edition of BWRVIP-03." (Also in Section 3.2.4.) |
| | Editorial | Section 3.2.4: Rationale for use of MVT-1 vice EVT-1 deleted. |
| | Editorial | Table 3.3.1 revised: Inspection requirements for MX-2 for BWR/5 and /6 changed to "None Required" for consistency with Section 2.3.7.7. |
| | Editorial | "Enhanced VT-1" changes to "EVT-1" throughout. |
| | Editorial | Section 2.3.3.7 revised. |
| | Editorial | Section 3.2.7 revised. |
| | Editorial | Table 3.3.1 revised ("Note" for locations TS-1, TS-2, TS-3, TS-4, DF-3, AD-1 and AD-2 revised). |
| | Editorial | Section 5.1.2.1 revised for consistency with other I&E Guidelines. |
| | General Comment | Inspection recommendations for jet pump beams revised in Section 2.3.2, Table 3.3.1 and Section 5.1.3 per BWRVIP-138. |
| | Editorial | Section 2.3.4.7: "fillet" deleted. |

**Table D-1 (continued)**
**Revision Details BWRVIP-41 Rev. 1**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| | Editorial | Figure 2-31 revised to show welds DF3-a and DF3-b |
| | Editorial | Section 3.2.3: Note added regarding scope expansion for wedges. |
| | Editorial | Figures 3.2.1-1 and 3.2.2-1 deleted. References to figures deleted from sections 3.2.1 and 3.2.2. |
| | Editorial | Reference 15 deleted; references 16-21 renumbered accordingly. New reference 21 added. |
| | Editorial | Section 5.1.2.4: Use of 2x for uninspected region clarified. |
| | General Comment | Section 2.3.8.7 and Table 3.3-1: Wedge inspections revised based on recent operating experience. |
| | Editorial | Section 5.1.2.3: Equation edited. |
| | General Comment | Sampling approach for selecting inspection locations defined (Sect. 3.2.1, 3.2.2) per BWRVIP Inquiry Resolution 2005-002. |
| **End of Revisions** | | |

# E
# REVISION 2 RECORD OF REVISIONS

| | |
|---|---|
| BWRVIP-41-R2 | Information from the following documents were used in preparing the changes included in this revision of the report:<br>1. "BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41, Rev. 1)," EPRI Report 1012137, 2005.<br>2. "BWRVIP-138, Rev. 1: BWR Vessel and Internals Project, Updated Jet Pump Beam Inspection and Evaluation Guidelines," EPRI Technical Report 1016574, December 2008.<br>Details of the revisions can be found in Table E-1. |

**Table E-1**
**Revision Details BWRVIP-41 Rev. 2**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Non-technical format changes and updates to reference documents | EPRI publication guidelines | Format changes and updates to references were made throughout the document. Revision bars are not indicated for the format changes. |
| | NEI-03-08 | Added Section 1.3 Implementation Requirements |
| | General Comment | Updated figures 2-1, 2-2 & 2-3 for additional clarity on the locations of welds RS-8 through RS-11. |
| Revise BWRVIP-41 Rev. 1 to include updated information contained in BWRVIP-138 Rev. 1 | BWRVIP-138, Rev. 1 | Section 2.3.2.3 and Figure 2-7 revised to add clarity to beam inspection regions. |
| | General Comment | Updated Section 2.3.2.4 and Table 2-2 on beam design loading description. |
| Revise BWRVIP-41 Rev. 1 to include updated information contained in BWRVIP-138 Rev. 1 | BWRVIP-138, Rev. 1 | Revised content in 2.3.2.5.1 Beam Susceptibility. |
| | General Comment | Revised 2.3.2.7 Inspection History to clarify beam operating experience by beam region. |
| Revise BWRVIP-41 Rev. 1 to include updated information contained in BWRVIP-138 Rev. 1 | BWRVIP-138, Rev. 1 | Revised 2.3.2.8 Jet Pump Beam Bolt Inspection Recommendation Technical Basis and Tables 2-4 and 2-5 to reflect the revised inspection frequencies for Group 2 and Group 3 beams. |
| | General Comment | Revised 2.3.4.7 Riser Brace Inspection Recommendation Technical Basis. In light of recent industry OE the BWRVIP is currently not pursuing analyses to reduce or alleviate inspection of the Riser Brace welds. Deleted "In addition, the BWRVIP is pursuing analyses which may reduce or alleviate inspection of the RS-1, RS-2, and RS-4 through RS-7 welds." |
| | General Comment | Deleted BWRVIP-41 Rev. 1 Table 2-4 Probability of Failure |

**Table E-1 (continued)**
**Revision Details BWRVIP-41 Rev. 2**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| | BWRVIP-219 | Updated Tables 2-5 & 3.3-1 (BB-1, BB-2 & BB-3) to clarify applicability of HWC inspection frequencies for jet pump beams |
| | General Comment | Updated 2.3.10.7 to add clarity for inspection of AD-3a and AD-3b welds |
| Update Inspection Definitions | BWRVIP-03 Rev. 11 | Section 3.1 updated definition of Enhanced VT-1 to require need to resolve the ASME Code Section XI VT-1 0.044 inch characters and updated VT-3 for clarity. |
| | BWRVIP Interpretation 2005-001 | Section 3.2.1 page 3-2, added clarification of the start of the first Inspection Cycle. |
| | BWRVIP Interpretation 2008-004 | Section 3.2.2 added clarification of Re-inspection Cycles |
| | General Comment | Table 3.3-1, Section 4, Updated Figure Number references for RS-8, RS-9, RS-10 and RS-11 |
| Revise BWRVIP-41 Rev. 1 to include updated information contained in BWRVIP-138 Rev. 1 | BWRVIP-138, Rev. 1 | Updated Table 3.3-1 to update the inspection options for the B-1, BB-2 and BB-3 regions of the Group 2 and Group 3 beams. Removed inspection strategy for BWR/3 and Group 1 beams as all U.S. BWR's have replaced these designs with Group 2 or Group 3 beam designs. |
| | General Comment | Updated Table 3.3-1 Section 8, WD-1 Baseline and Re-Inspection text to provide additional clarity to the guidance. |
| | BWRVIP-03 Rev. 10 & BWRVIP Interpretation 2007-006 | Updated Table 3.3-1 notes for DF-3, AD-1, AD-2 and AD-3a,b. |
| | General Comment | Section 4.2 updated for consistency with Implementation Requirements, the word 'should' changed to 'shall' |
| | ASME Section XI, Appendix C | Updated the Z-factor information contained in Section 5.1.2.1 "Limit Load Methodology". |
| | Editorial | Updated Section 6 References |

# F
# REVISION 3 RECORD OF REVISIONS

| | |
|---|---|
| BWRVIP-41-R3 | Information from the following documents were used in preparing the changes included in this revision of the report:<br><br>1. *BWRVIP-41, Revision 2: BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines.* EPRI, Palo Alto, CA: 2009. 1019570.<br><br>Details of the revisions can be found in Table F-1. |

**Table F-1**
**Revision Details BWRVIP-41 Rev. 3**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| | General comment | Revised note to Revision 3 to point out that the NRC has not reviewed the content contained in Revisions 1, 2 or 3 of BWRVIP-41. Nevertheless, the technical revisions to this report are more conservative than contained in the original issuance of BWRVIP-41 (EPRI Report TR-108728). It is the BWRVIP's position that implementation should proceed as normal per Section 1.3 and BWRVIP-94, Rev. 1. |
| Revised Table 2.3.3-1 | Utility comment | Table 2.3.3-1 revised to change the material of the thermal sleeve to 316L for the Cooper Nuclear Station |
| Identify welds that are inaccessible for inspection | General comment | Revised Section 2.3.3.7 to address inspection methodology for TS-1, 2, 3 and 4 welds<br>Revised Section 2.3.10.7 to address inspection methodology for DF-3 weld for LaSalle 1 and Fermi 2<br>Revised Section 2.3.11.7 to address inspection methodology for AD-1 and AD-2 for LaSalle 1a and Fermi 2<br>Revised Table 3-1 to include the above statements |
| | Internal comment | Revised Section 2.3.8.4 to state that tack welds are unlikely to produce IGSCC. Also stated that cracking in the stellite surface of wedges has been observed but no but no adverse effects from this cracking have been reported |
| Update definitions of inspection methods | Internal comment | Revised Section 3.1 to update definitions |

**Table F-1 (continued)**
**Revision Details BWRVIP-41 Rev. 3**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Incorporate inspection strategy for inaccessible welds | General comment | Revised Section 3.2.5 to address partially inaccessible welds.<br>Revised Table 3.3-1 for TS-1, 2, 3, 4; AD-1, -2; and DF-3 welds to indicate that until an inspection technique becomes available the inaccessible welds shall be evaluated according to the guidelines in Section 3.2.8<br>Added Section 3.2.8 to incorporate inspection strategy for inaccessible welds |
| Incorporate leakage evaluation for inaccessible welds | General comment | Revised Section 5 to incorporate methodology for determining leakage from inaccessible welds |
| Update Section 5 for clarity | Internal comment | Restructured Section 5 to improve clarity |
| | Editorial | Renumbered References in Section 6 |
| **End of Revisions** | | |

# G
# REVISION 4 RECORD OF REVISIONS

| | |
|---|---|
| BWRVIP-41-R4 | Information from the following documents were used in preparing the changes included in this revision of the report:<br>1. *BWRVIP-266, BWR Vessel and Internals Project, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program.* EPRI, Palo Alto, CA: 2012. 1025140.<br>2. *BWRVIP-234: BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals*. EPRI, Palo Alto, CA: 2009. 1019060.<br>3. *BWRVIP-158-A: BWR Vessel and Internals Project, Flaw Proximity Rules for Assessment of BWR Internals*. Electric Power Research Institute, Palo Alto, CA: 2010, 1020998.<br>4. *BWRVIP-41, Revision 3: BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines.* EPRI, Palo Alto, CA: 2009. 1021000.<br>5. Supplemental Jet Pump Wedge Rod Inspection Guidance (BWRVIP Correspondence 2014-019).<br>Revision 4 to BWRVIP-41 incorporates the results of BWRVIP-266 [9]). Details of the revisions can be found in Table G-1. |

**Table G-1**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| All Sections | Various | Cited references were revised to include the most recent revision, where applicable.<br>Section references were updated as needed as some section reorganization occurred in this Revision. |
| Various Sections | N/A | Reference to Millstone was removed from Table 1-1, various Section 2 Tables, and Table 3-2. Reference to Millstone was also removed from selected Section 2.3 susceptibility and inspection recommendation subsections. Millstone Unit 1 is now decommissioned. |
| **Section 1** | | |
| Revised Section 1.1, Background | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | The background section was expanded to give a more complete history of jet pump inspection guidance; from early inspection guidance documents up through the current BWRVIP-41 revision. |
| Revised Section 1.2, Objectives and Scope | Editorial | Minor editorial changes. |
| Revised Section 1.2, Objectives and Scope | Editorial | Text indicating that the report was developed under an Appendix B QA program removed. Revision 4 was not developed under Appendix B QA. |
| Revised Section 1.3, Implementation Requirements | N/A | This section is revised to note that implementation of new requirements cannot be implemented until approved by the NRC. Additionally, within the list of sections identified as “needed” guidance, “Section 4.2” was revised to “Section 4”. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Revised Section 2.0, Jet Pump Assembly Analysis | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | General changes to this section include:<br>Removing or revising information about material susceptibility as recent data analyses indicate changes to the earlier conclusions concerning susceptibility.<br>Removal of individual inspection history sections as this revision is based on a significant amount of recent inspection data.<br>Addition of operating experience sections for IGSCC and fatigue to summarize new inspection findings. |
| Revised Section 2.1, Jet Pump Configuration and Function | Editorial | Removed "rectangle" symbol in second line of third paragraph and inserted "-degree" to preclude future conversion issues. |
| Revised Section 2.2.1.1, Environment. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Section 2.2.1.1 discusses environment considerations associated with IGSCC. This section was updated to include discussion of hydrogen water chemistry technologies that have been widely adopted by U.S. BWRs (that is, HWC-M, NMCA, and OLNC™). |
| Revised Section 2.2.1.2, Materials. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Section 2.2.1.2 discusses IGSCC susceptibility with regard to material. This section was updated to:<br>1) Address IGSCC resistance of solution annealed components installed without field welding.<br>2) Update material susceptibility information based on the current state of knowledge. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Revised Section 2.2.1.3, Tensile Stress. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Section 2.2.1.3 discusses the effect of tensile stress on IGSCC susceptibility. This section was edited to emphasize the increased propensity for IGSCC associated with field welds and in particular final field assembly welds (for example, RS-1). |
| Inserted new Section 2.2.1.4, Operating Experience: IGSCC | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Operating experience discussion added to summarize the results contained in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. Subsections are provided for stainless steel weld HAZs and Ni-base alloys. |
| Section 2.2.2, Fatigue Susceptibility | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | General discussion updated to reflect the results contained in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |
| Section 2.2.2.1 heading added, "Fatigue Load Sources" and related discussion revised. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Relocated discussion related to fatigue load sources into a separate subsection. Discussion is updated to reflect the results contained in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |
| Section 2.2.2.2 heading added, "IGSCC Interaction". | Editorial | Relocated discussion related to fatigue interaction with IGSCC into a separate subsection. |
| Inserted new Section 2.2.2.3, Operating Experience: Fatigue | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Operating experience discussion added to summarize the results contained in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Revised Section 2.2.3, Embrittlement | BWRVIP-234, BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals. | Updated the embrittlement susceptibility discussion to include the 60-year neutron fluence evaluation results contained in BWRVIP-234. |
| Removed Section 2.2.4, Conclusions | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This section was removed because it was out of date and provided limited value to the report. A new section; Section 2.4, Overview of Changes to Inspection Recommendations in Revision 4" provides an updated set of conclusions based on the results of BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |
| Revised Section 2.3, Potential Failure Locations. | N/A | Language regarding timing for performance of baseline inspections was removed since all baseline exams have been completed for some time now. Additional editorial changes were also made. |
| Revised "Susceptibility" sections 2.3.1.4, 2.3.3.4, 2.3.4.4, 2.3.5.4, 2.3.6.4, 2.3.7.4, 2.3.9.4, 2.3.10.4, and 2.3.11.4. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Susceptibility discussions for the riser brace, thermal sleeve, riser pipe, inlet, mixer, throat, diffuser and tailpipe, and adapter / lower ring welds were updated based on the results of BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. Additionally, susceptibility discussions were streamlined to refer back to the susceptibility discussion provided in Section 2.2 and to remove extraneous information related to priority and inspection locations. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Revised "Inspection Recommendation" sections 2.3.1.6, 2.3.3.6, 2.3.4.6, 2.3.5.6, 2.3.6.6, 2.3.7.6, 2.3.9.6, 2.3.10.6, and 2.3.11.6. Note: These were sections 2.3.1.7, 2.3.3.7, 2.3.4.7, 2.3.5.7, 2.3.6.7, 2.3.7.7, 2.3.9.7, 2.3.10.7, and 2.3.11.7 in the previous revision of BWRVIP-41. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Renamed these sections from "Inspection Recommendation Technical Basis" to "Inspection Recommendations". Detailed technical bases for the inspection recommendations made in these sections are provided in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program.<br><br>Inspection recommendation discussions for the riser brace, thermal sleeve, riser pipe, inlet, mixer, throat, diffuser and tailpipe, and adapter/lower ring welds were updated based on the results of BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. Inspection requirements were clarified as needed through the addition of lists of locations where inspection is required and lists of locations where no inspection is required.<br><br>Discussion in these sections was edited to remove reference to baseline vs. reinspection since baseline inspections are now complete. Discussion in these sections was also edited to remove reference to specific inspection techniques since the revised inspection program now includes UT inspection criteria. This discussion was somewhat redundant since Table 3-2 specifies inspection methods and periodic inspection intervals. Reference to Table 3-2 was added in place of this discussion.<br><br>For Section 2.3.3.6, Thermal Sleeves, reference to the criteria for inaccessible welds was revised from 3.2.8 to 3.2.7, consistent with changes in Section 3 described below. A statement clarifying the inspection program for inaccessible welds and referencing Table 3-2 was also added. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Removed "Inspection History" sections 2.3.1.6, 2.3.2.7, 2.3.3.6, 2.3.4.6, 2.3.5.6, 2.3.6.6, 2.3.7.6, 2.3.8.6, 2.3.9.6, 2.3.10.6, 2.3.11.6, and 2.3.12.6. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | The inspection histories in these sections were based on older data. Therefore, these inspection history sections were removed. A summary of operating history based on up to date data is provided in new Sections 2.2.1.4 and 2.2.2.3 for IGSCC and fatigue, respectively. |
| Revised Table 2-4 | Reviewer comment | Revised to show the Browns Ferry Unit 1 thermal sleeve as a Type A configuration that it does not include any creviced locations. |
| Revised Section 2.3.2.2.2, BWR/4-6 Beam Design – Group 1 | Editorial | Replaced "this report" with BWRVIP-41 Revision 3 and made this reference past tense. |
| Revised Section 2.3.2.3, Inspection Regions | Editorial | The operating experience information referenced is now in Section 2.2.4 instead of Section 3.2.7. |
| Revised Section 2.3.2.5.1, Beam Susceptibility | Editorial | Minor editorial corrections and clarifications. |
| Revised Section 2.3.2.7, Inspection Recommendation Technical Basis | N/A, changes made do not affect the technical results. Rather they improve the section organization and clarity. | Consistent with the approach taken for weld locations, this section was renamed from "Inspection Recommendation Technical Basis" to "Inspection Recommendations". Detailed technical bases for the inspection recommendations made in these sections are provided in BWRVIP-138 Revision 1.<br><br>This section was edited to frame inspection requirements in terms of "NMCA and OLNC" vs. "other chemistries" rather than using "NWC" vs. "HWC" and notation to clarify that only NMCA and OLNC can be credited for HWC inspection intervals. Tables 2-4 and 2-5 were removed. These tables were redundant to Table 3-2. Instead, reference to Table 3-2 is provided.<br><br>The conclusion that no inspection is required for the stainless steel beam bolt is added to this section for clarity. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 2** | | |
| Table 2-4 (previously Table 2-6 in Revision 3), Thermal Sleeve Configurations | Editorial | A clarifying table note was added to highlight that N2 nozzle replacement activities could have affected the information contained in the Table and plants should verify thermal sleeve material and configuration. This is a clarification only. A similar note already existed in Section 2.3.3.2 above but was not directly tied to the table. |
| Revised Section 2.3.4.2, Configuration – Locations RS-1 to RS-11 | Editorial | Clarified that welds RS-8 through RS-11 are "groove welds with reinforcing fillets" and not simply "fillet welds". |
| Revised Section 2.3.4.5, Failure Consequences (Riser Pipe) | Editorial | Reference to Section 5.3 revised to refer to Section 5.5 instead. |
| Revised Section 2.3.6.1, Inlet (Elbow and Nozzle) | Editorial | Removed "rectangle" symbol in second line of third paragraph and inserted "-degree" to preclude future conversion issues. |
| 2.3.8.4, Susceptibility (Restrainer Bracket Assembly) | Editorial | Minor editorial clarification. |
| 2.3.8.4, Inspection Recommendations (Restrainer Bracket Assembly) | N/A | Consistent with the approach taken for weld locations, this section was renamed from "Inspection Recommendation Technical Basis" to "Inspection Recommendations".<br><br>Specific reference to VT-1 examination is removed and replaced with "visual examination". Reference to Table 3-1 is added. |
| Revised Section 2.3.10.2, Configuration – Locations DF-1 to DF-4 | Editorial | Added a clarification that BWR/6s have an additional ring weld between the tailpipe and lower ring, resulting in two welds at DF-3 shown as DF-3a and DF-3b in Figure 2-31. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Revised Section 2.3.11.6 to clarify that for plants with curved adapters (Fermi 2 and LaSalle 1), failure of AD-1 or AD-1 results in loss of LPCI function only for Fermi 2. | Reviewer comment | The existing text implied that failure of AD-1 or AD-2 for plants with curved adapters results in both loss of 2/3 core coverage and loss of LPCI function. LaSalle 1 has a LPCI coupling and therefore loss of LPCI function does not occur as a result of an AD-1 or AD-2 failure. This clarification does not change the consequence result for the AD-1 or AD-2 welds at LaSalle 1, nor the inspection requirements contained in Table 3-1. |
| Added new Section 2.4, Overview of Changes to Inspection Recommendations in Revision 4. | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This new section summarizes the inspection program revision recommendations provided in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |
| **Section 3** | | |
| Revised Section 3.1, Inspection Methods | N/A | The definitions of VT-1 and VT-3 are revised to use the ASME Section XI criteria from the Edition and Addenda applicable to the Owner's inservice inspection program. |
| Revised Section 3.2, BWRVIP Inspection Guidelines | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This section is revised to specify that the revised inspection guidance provided is dependent on implementation of HWC-M, NMCA, or OLNC consistent with BWRVIP-62 Revision 1, BWRVIP-219, and BWRVIP-245. Prior language addressing BWRVIP efforts to reduce inspection requirements based on HWC was removed. |
| Removed Section 3.2.1, Baseline Inspection | N/A | Baseline inspections have now been completed, so the requirements for baseline inspections are removed from the report. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Revised Section 3.2.2, Re-Inspection (Section 3.2.1, Periodic Inspection, in Revision 4) | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This section is now Section 3.2.1, 'Periodic Inspection". As baseline inspections are complete, the term "re-inspection" is changed to "periodic inspection." This section was revised to incorporate new bases for periodic inspection requirements found in BWRVIP-266.<br>Additionally, the section was amended to allow a 6-month extension of the inspection interval to accommodate outage scheduling. |
| Revised Section 3.2.3, Inspection Technique (Section 3.2.2 in Revision 4) | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This section was modified to summarize the approach toward introduction of UT-based inspection intervals. |
| Revised Section 3.2.5, Consideration of Un-inspectable Areas in Partially Accessible Welds (Section 3.2.4 in Revision 4) | Editorial | Minor editorial change to remove the term "baseline" and replace "re-inspection" with "periodic inspection". |
| Revised Sections 3.2.6 and 3.2.7 (Sections 3.2.5 and 3.2.6 in Revision 4) | Editorial | Section references updated. |
| Revised Figure 3-1, Overview of Accessible and Inaccessible Weld Inspection Programs | Editorial | The flowchart was revised to clarify the process for determining inspection requirements for both accessible and inaccessible welds. Note the chart is fundamentally the same, but appropriate section changes were made. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Revised Table 3-2, Matrix of Inspection Options (Table 3-1 in Revision 4) | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | Table 3-2 (Now Table 3-1 due to elimination of Table 3-1 in Revision 3) was revised to include new periodic inspection requirements and options in accordance with BWRVIP-266.<br>Additionally, the inspection requirements for jet pump beam locations (BB locations) were reorganized to present period inspection criteria in terms of NMCA & OLNC vs. other chemistry types. This is not a technical change, but rather a clarification of the existing requirements.<br>Throughout the table, minor editing was performed to improve the consistency and clarity of the inspection requirements. In a number of cases, clarifying notes were added. |
| Revised Section 3.2.8.1 (Section 3.2.7.1 in Revision 4), Accessible Welds Inspection Program (Scope Expansion) | BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. | This section (now 3.2.8.1) was revised to include new exemptions associated with welds having prior UT exams. Exemptions are based on recent inspection data and associated evaluations presented in BWRVIP-266, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program. |
| Wedge rod inspections added Section2.3.8.6 | BWRVIP supplemental inspection guidance (BWRVIP Correspondence (2014-019) | Section 2.3.8.8 and Table 3-1 revised to include wedge rod inspection guidance. |
| Section 3.2.10 (Section 3.2.9 in Revision 4), Scope Expansion for Components Other Than Piping Welds | Editorial | Text modified to remove baseline" and "re-inspection" terms. Reference to baseline inspection is no longer meaningful in the context of weld inspection since all baseline exams are now complete. |

**Table G-1 (continued)**
**Revision Details BWRVIP-41 Rev. 4**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| **Section 5** | | |
| Section 5.1.4.2 | Editorial | Table and Section references updated as needed to reflect changes made in Section 3. |
| Revised Section 5.1.1.2, Consideration of Welds with Partial Inspection Access | Editorial | The section describing inaccessible weld inspection strategy is 3.2.7 in Revision 4. The reference was updated consistent with this change. |
| Revised Section 5.1.2.1.2, Flaw Proximity Considerations | BWRVIP-158-A: BWR Vessel and Internals Project, Flaw Proximity Rules for Assessment of BWR Internals. | Language describing flaw proximity considerations was updated to include reference to BWRVIP-158-A and to clarify the applicability of the guidance contained in BWRVIP-158-A for jet pump weld evaluations. |
| **Appendices** | | |
| Revised Appendix A, License Renewal | N/A | An introduction to Appendix A is added to note the Appendix content as historical and to document the BWRVIP conclusion that although the aging management strategy contained in BWRVIP-41 has been significantly modified from the Version of BWRVIP-41 that the NRC License Renewal SE is based on, none of the program revisions alter the conclusion reached previously; that the guideline is adequate to meet the technical information requirements of the license renewal rule and to ensure the effects of aging are managed in the period of extended operation. |
| Revised Appendix B, NRC Final Safety Evaluation | N/A | An introductory statement was added to note that the SE contained in this Appendix refers to the original version of this report. |
| Revised Appendix C, NRC Acceptance for Referencing Report for Demonstration of Compliance with License Renewal Rule | N/A | An introductory statement was added to note that the License Renewal Acceptance Letter refers to the original version of this report. |
| **End of Revisions** | | |

# H
# NRC REQUEST FOR ADDITIONAL INFORMATION ON BWRVIP-41, REVISION 4

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

April 25, 2016

Tim Hanley
Senior Vice President West Operations, Exelon
Chairman, BWR Vessel and Internals Project
3420 Hillview Avenue
Palo Alto, CA 94304-1395

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION FOR BWRVIP-41, REVISION 4, "BWR JET PUMP ASSEMBLY INSPECTION AND FLAW EVALUATION GUIDELINES" (TAC NO. ME4882)

Dear Mr. Hanley:

By letter dated September 24, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14279A437), the Boiling Water Reactor (BWR) Vessel and Internals Program (BWRVIP) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report BWRVIP-41, Revision 4, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines." Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. The additional RAI questions are provided in the enclosure to this letter.

In an email exchange between Mr. Chuck Wirtz representing EPRI and me, we agreed that the NRC staff will receive your response to the enclosed RAI questions by October 31, 2016. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-7297 or Joseph.Holonich@nrc.gov.

Sincerely,

Joseph J. Holonich, Senior Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 704

Enclosures:
1. RAI questions (non-proprietary)
2. RAI questions (proprietary)

## REQUEST FOR ADDITIONAL INFORMATION
## ON AGING MANAGEMENT PROGRAM FOR THE
## BWR-41, REVISION 4: BWR VESSEL INTERNALS PROJECT,
## BWR JET PUMP ASSEMBLY INSPECTION AND FLAW EVALUATION GUIDELINES
## (TAC NO. MF4887)

In a letter dated September 24, 2014, the Boiling Water Reactor (BWR) Vessel Internals Project (BWRVIP) submitted a Topical Report (TR), BWRVIP-41, Revision 4, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines," which included inspection recommendations and flaw evaluation guidelines for the jet pump assembly welds. This revised version included updated guidance for inspection of high priority locations and a reduction in inspection frequency for the medium and low priority locations. The technical basis for this reduction in the inspection frequency was addressed in BWRVIP-255, "Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program," dated October 2014. The BWRVIP-255 was submitted to the U.S. Nuclear Regulatory Commission (NRC) staff for information only. The NRC staff reviewed the BWRVIP-41, Revision 4 and BWRVIP-255 reports, and developed the following request for additional information (RAI) questions.

### Loading and Flaw Evaluation Methodology:

#### RAI-1

In Section 5.1.2.1.3, the TR proposed an alternative limit load methodology with Reference 30 (a GE report dated 1995) as an alternative. The staff notes that Section 5.1.2 in BWRVIP-18, Revision 2, used BWRVIP-76 as the reference for the same alternative. Please confirm the correct reference, BWRVIP-76 or the 1995 GE report.

#### RAI-2

Section 2.3.10.3 of the TR discusses the loading on the diffuser and tailpipe, which includes strong acoustic waves that could be generated by an instantaneous pipe break. The NRC is aware of some safety communications (SC) from General Electric-Hitachi that would increase the annulus pressurization (AP) loads acting on the reactor vessel internal components due to a pipe break.

The NRC staff requests that the BWRVIP address whether the AP loads and associated calculations included in BWRVIP-41, Revision 4, properly reflect the correct hydrodynamic loads in response to the SC.

### Susceptibility to Intergranular Stress Corrosion Cracking (IGSCC):

#### RAI-3

<u>Background:</u> The staff notes that for license renewal [Ref. 1], a minimum ferrite content of 7.5 percent is specified in pressurized water reactor (PWR) piping systems to ensure resistance to IGSCC. Furthermore, recent information on cast austenitic stainless steel (CASS) reactor vessel internal (RVI) components [Refs. 2 and 3] indicate that RVI components are often fabricated from CASS materials where the calculated ferrite content is less than 7.5 percent.

Enclosure 2

Issue: In Section 2.2.1.2, the TR discusses the materials used in the jet pump assembly and states [[ ]] Table 3-1 lists several weld locations, both high and medium priority locations, where no inspections are recommended because CASS materials are used on one or both sides of a weld. Section 3.2.7.2.1 includes a separate susceptibility category for CASS materials in consideration of the inaccessible weld inspection program, but does not differentiate between CASS with < 7.5 percent ferrite and CASS > 7.5 percent ferrite.

Request: The staff asks the BWRVIP to discuss the uncertainty related to the ferrite content and what effect that has on the potential for IGSCC cracking in jet pump welds and the need to inspect welds with CASS material on one or both sides.

**RAI-4**

Background: The staff notes that MRP-175, Figure B-2, shows that failures in BWRs related to irradiation-assisted stress corrosion cracking (IASCC) start to occur when the fluence reaches about $5 \times 10^{20}$ n/cm$^2$. The staff notes that some jet pump components in a foreign BWR have been exposed to fluence above $5 \times 10^{20}$ n/cm$^2$ [Ref. 4].

Issue: The recommended inspections and guidelines in the TR do not address the susceptibility to IASCC.

Request: The staff asks the BWRVIP to include a discussion of IASCC and how the neutron exposure of the jet pump assembly in the US domestic BWR fleet varies with location within the vessel and over the expected 60 year service life.

**Jet Pump Beam and BWRVIP-138, Rev. 1:**

**RAI-5**

Background: Section 5.2 of the TR states the following:

[[

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**EPRI Proprietary Information**

Issue: The staff notes that this text is carried over from BWRVIP-41, Rev. 1, dated September 2005, and does not reflect the text in BWRVIP-138, Rev. 1 (Reference 8 in the TR, dated 2008).

Request: The staff asks the BWRVIP to revise the text in Section 5.2 to reflect the current NRC-approved version of BWRVIP-138, Rev. 1-A, dated October 2012 [Ref. 5].

**Inspection Requirements:**

**RAI-6**

Background: Section 3.2.3 of the TR covers plant-specific analyses to modify/eliminate inspection requirements. This section was the subject of Item 2 from the staff's initial safety evaluation (SE) to Revision 0 of the TR [Ref. 6]. On November 17, 2000, the BWRVIP responded with a proposed revision to the TR that the staff approved in the final SE of Revision 0 [Ref. 7].

Issue: In the subsequent revisions to the TR, the final sentence of the BWRVIP response to Item 2 was dropped. That sentence stated:

> *Results of these plant-specific analyses should be submitted to the NRC for review and approval.*

Request: The staff asks the BWRVIP to revise Section 3.2.3 of the TR to include the complete text from the November 17, 2000, BWRVIP response or provide a rationale for why it was dropped from the revision.

**RAI-7**

Background: Section 3.2.8.1 of the TR covers scope expansion for accessible and partially accessible weld. Section 3.2.8.1.2 includes an exemption from expanding the scope of inspections for specific weld locations.

Issue: The details related to when expansion of the scope for inspections will occur are not clear to the staff. Should this be applied the same for both ultrasonic (UT) and enhanced visual (EVT-1) inspection techniques? It appears to the staff that there would be significant differences if the re-inspection used UT (as done in the baseline) vs. EVT-1. Specifically, there is no mention of how inspection coverage and history of hydrogen water chemistry mitigation is taken into account when determining if the observed cracking is consistent with fleet operating experience. Two examples are suggested for consideration.

First, consider a case where a flaw 2 inches long is detected with an EVT-1 inspection (20% coverage) at the AD-3a,b location from a BWR/4 with the legs configuration that had previously been inspected with UT (100% coverage). The UT inspection found no indication and was performed while the plant was under noble metal chemistry addition. During the more recent EVT-1 inspection, the plant was operating under online noble chemistry injection (OLNC). The staff could interpret the text in Section 3.2.8.1.2 as allowing no scope expansion.

Second, consider a case where a flaw 2 inches long is detected with an EVT-1 inspection (15% coverage) at a AD-2 location from a BWR/5 with the legs configuration that had previously been inspected with UT (50% coverage). The UT inspection found no indication and was performed while the plant was under modified hydrogen water conditions. During the more recent EVT-1 inspection, the plant was operating under OLNC. Again, the staff could interpret the text in Section 3.2.8.1.2 as allowing no scope expansion.

Request: Provide a discussion of how Section 3.2.8.1.2 would be applied for the examples cited above. If no expansion of inspection is the intended outcome, explain how not expanding the inspection scope will allow determination of whether the degradation observed is consistent with past operating experience. Consider more explicit description of what inspection results would be exempt from scope expansion.

**References**

[1] NUREG-1801, Rev. 2, "The Generic Aging Lessons Learned (GALL) Report," December 2010.

[2] *BWRVIP-234: BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals.* EPRI, Palo Alto, CA: 2009, TR1019060.

[3] PWROG-15032-NP, Revision 0, "PA-MSC-1288 Statistical Assessment of PWR RV Internals CASS Materials," Westinghouse Electric Company LLC, November 2015.

[4] *Materials Reliability Program: A Review of Radiation Embrittlement of Stainless Steels for PWRs (MRP-79) – Revision 1,* EPRI, Palo Alto, CA: 2004. TR1008204.

[5] *BWRVIP-138, Revision 1-A: BWR Vessel and Internals Project, Updated Jet Pump Beam Inspection and Evaluation Guidelines.* EPRI, Palo Alto, CA: 2012, TR1025319.

[6] Initial SE for BWRVIP-41, Revision 0, dated June 20, 2000, ADAMS Accession No. ML003725033.

[7] BWRVIP response, dated November 17, 2000, to Initial SE for BWRVIP-41, Revision 0, ADAMS Accession No. ML003770389.

# I

# BWRVIP RESPONSE TO NRC REQUEST FOR BWRVIP RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION ON BWRVIP-41, REVISION 4

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

2017-022 BWR Vessel & Internals Project (BWRVIP)

February 8, 2017

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

Attention: Joseph Holonich

Subject: Project No. 704 – BWRVIP Response to RAIs on BWRVIP-41, Rev. 4 to NRC

References: 1. BWRVIP Letter 2016-042A: NRC Letter from Joseph Holonich at NRC to BWRVIP Chairman Tim Hanley, "Request for Additional Information for BWRVIP-41, Revision 4, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines" dated April 25, 2016 (TAC NO. ME4882).

Enclosed are five (5) copies of the BWRVIP proprietary response to the NRC Request for Additional Information (RAI) on the BWRVIP report entitled "BWRVIP-41, Revision 4, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines".

Please note that the enclosed response contains proprietary information. A letter requesting that the response be withheld from public disclosure and an affidavit describing the basis for withholding this information are provided as Attachment 1. The response includes yellow shading and brackets to indicate the proprietary information. The proprietary information is also marked with the letters "TS" in the margin indicating the information is considered trade secrets in accordance with 10CFR2.390.

Two (2) copies of a non-proprietary version of the BWRVIP response to the RAI are also enclosed. This non-proprietary response is identical to the enclosed proprietary response except that the proprietary information has been deleted.

If you have any comments or questions please contact Steve Richter at 509-377-4703 or by email at skrichter@energy-northwest.com.

Sincerely,

A. O. McGehee    Tim Hanley

Andrew McGehee, EPRI, BWRVIP Program Manager
Tim Hanley, Exelon, BWRVIP Chairman

c: BWRVIP Technical Chairs
BWRVIP EPRI Task Managers

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**BWRVIP Responses to NRC Requests for Additional Information on BWRVIP-41, Revision 4: Jet Pump Inspection and Flaw Evaluation Guidelines**

(Non-Proprietary Version)

Each item from the NRC Request for Additional Information (RAI) is repeated below verbatim followed by the BWRVIP response.

**RAI-1**

In Section 5.1.2.1.3, the TR proposed an alternative limit load methodology with Reference 30 (a GE report dated 1995) as an alternative. The staff notes that Section 5.1.2 in BWRVIP-18, Revision 2, used BWRVIP-76 as the reference for the same alternative. Please confirm the correct reference, BWRVIP-76 or the 1995 GE report.

**BWRVIP Response to RAI-1**

The BWRVIP agrees that the reference should be changed to be consistent with other, more recently published inspection and flaw evaluation guidance. In the "-A" version of BWRVIP-41 Revision 4, the reference will be changed to cite the most recent version of BWRVIP-76 instead of the 1995 GE Report.

**RAI-2**

Section 2.3.10.3 of the TR discusses the loading on the diffuser and tailpipe, which includes strong acoustic waves that could be generated by an instantaneous pipe break. The NRC is aware of some safety communications (SC) from General Electric-Hitachi that would increase the annulus pressurization (AP) loads acting on the reactor vessel internal components due to a pipe break.

The NRC staff requests that the BWRVIP address whether the AP loads and associated calculations included in BWRVIP-41, Revision 4, properly reflect the correct hydrodynamic loads in response to the SC.

**BWRVIP Response to RAI-2**

Section 4 of BWRVIP-41, Revision 4 defines the loads and load combinations that must be considered for jet pump components. Section 4.1.6 of BWRVIP-41, Revision 4 addresses annulus pressurization (AP) loads. To acknowledge the need to consider the potential for increased AP loads associated with General Electric-Hitachi SC 09-01, the BWRVIP proposes to add the following guidance to Section 4.1.6 of BWRVIP-41, Revision 4:

"*Plants should reexamine their AP load calculations and update those calculations, where necessary, considering the potential for increased AP loads as documented in reference [X].*"

(where reference X will be added to the list of references in Section 6 as *GE-Hitachi Safety Communication SC 09-01, "Annulus Pressurization Loads Evaluation," June 8, 2009.*)

The BWRVIP notes that this proposed resolution is consistent with that previously proposed by the BWRVIP and accepted by the NRC to address AP loads associated with LPCI Coupling components in BWRVIP-42, Revision 1 (ML16124A139).

This change will be made in the "-A" version of BWRVIP-41, Revision 4.

**RAI-3**

Background: The staff notes that for license renewal [Ref. 1], a minimum ferrite content of 7.5% is specified in pressurized water reactor (PWR) piping systems to ensure resistance to IGSCC. Furthermore, recent information on cast austenitic stainless steel (CASS) reactor vessel internal (RVI) components [Refs. 2 and 3] indicate that RVI components are often fabricated from CASS materials where the calculated ferrite content is less than 7.5%.

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**EPRI Proprietary Information**

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(2) Regardless of casting composition, operating experience supports a conclusion that cast BWR internals are resistant to IGSCC. To date, there have been no reported instances of cracking in cast BWR internals.

Finally, the BWRVIP in its response to NRC RAI 8 for BWRVIP-234 (BWRVIP letter 2012-148 [3c]), directly addressed the issue of inspection of CASS jet pump components, noting that "due to the field of view using typical EVT-1 methods, cracking of any significance on the casting side of the weld will likely be detected should it occur and thus, would be reported."

Based on the above, it is reasonable that jet pump casting IGSCC concerns be focused on welded locations and to conclude that if significant cracking were occurring, such cracking would have been detected and reported. Table 3A provides an overview of the weld locations in U.S. BWR jet pumps for which one or both of the base materials joined by the weld is cast. From this table, it is observed that the majority of jet pump welds involving cast materials join a cast component to a wrought or forged component. In these cases, inspections performed by EVT-1 would include the cast component within the field of view. Within the U.S. fleet, the majority of these exams are performed visually. There have been hundreds of EVT-1 examinations performed since initial implementation of BWRVIP-41, with no IGSCC detected for any of the welds listed in Table 3A. Since IGSCC in the BWR environment has been observed to be an early life cracking mechanism, if cast components were susceptible to IGSCC, some number of indications should have been identified by now. As a final point, it is observed that the wrought / forged component HAZs associated with the welds listed in Table 3A have also been found to be free of IGSCC to date. Were material susceptibility a critical factor for IGSCC of these locations, it would be anticipated that several IGSCC occurrences should have been identified in the wrought / forged component HAZs. This has not been the case, suggesting that local stress and water chemistry conditions are such that material content and weld sensitization are not sufficient to induce IGSCC initiation for these locations. As a result, it is reasonable to conclude that the exact ferrite content for any cast component is also not likely to be a significant factor with regard to IGSCC susceptibility.

Therefore, the BWRVIP maintains that ferrite uncertainty is not relevant to jet pump casting IGSCC susceptibility. Although some uncertainty in ferrite content is acknowledged to exist, the uncertainty is relatively small, with a standard error in the range of 2 to 3 percent delta ferrite. From a practical perspective, the most likely region for IGSCC occurrence are weld HAZs. As a result of implementation of BWRVIP-41, hundreds of EVT-1 examinations have been performed where the cast component is in the field of view of the EVT-1 examination. No cracking has been identified to date on either the cast component side or the wrought / forged component side of these welds.

RAI-3 RESPONSE REFERENCES

[3a] BWRVIP letter 2014-086, Project No. 704 – BWRVIP Response to NRC Request for Additional Information on BWRVIP-234, May 23, 2014. (ADAMS Accession No. ML14174A841)

[3b] BWRVIP letter 2015-150, Project No. 704 – BWRVIP Response Regarding Proposed Words in BWRVIP-234 Draft Safety Evaluation, November 19. 2015. (ADAMS Accession No. ML15155B487)

[3c] BWRVIP letter 2012-148, Project No. 704 – BWRVIP Response to NRC Request for Additional Information on BWRVIP-234, September 18, 2012. (ADAMS Accession No. ML12265A078)

**Table 3A: Listing of Typical Jet Pump Casting Locations for U.S. BWRs**

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**EPRI Proprietary Information**

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**Table 3A Notes:**

[1] For weld locations where only one side of the weld joint is a casting, (CASS) denotes the cast component.

[2] In a limited number of cases, the material of construction for components in a specific plant may not be available. As a result, the plant applicability listing is typical and not exact.

**RAI-4**

Background: The staff notes that MRP-175, Figure B-2, shows that failures in BWRs related to irradiation-assisted stress corrosion cracking (IASCC) start to occur when the fluence reaches about 5 x $10^{20}$ n/$cm^2$. The staff notes that some jet pump components in a foreign BWR have been exposed to fluence above 5 x $10^{20}$ n/$cm^2$ [Ref. 4].

Issue: The recommended inspections and guidelines in the TR do not address the susceptibility to IASCC.

Request: The staff asks the BWRVIP to include a discussion of IASCC and how the neutron exposure of the jet pump assembly in the US domestic BWR fleet varies with location within the vessel and over the expected 60 year service life.

**BWRVIP Response to RAI-4**

The BWRVIP response is organized into the following sections:

1) Jet pump fluence evaluation
2) Assessment of IASCC Considerations on Optimized Inspection Program
3) Fluence Considerations Relative to Jet Pump Component Flaw Evaluation
4) Conclusions

JET PUMP FLUENCE EVALUATION

In order to provide a comprehensive response to this RAI, the BWRVIP undertook a significant data collection effort, resulting in a substantial database of jet pump end-of-life (EOL) fluence values. The collected data represent sixteen domestic BWRs that currently have renewed operating licenses (i.e., 60-year operating licenses), are in the process of applying for a renewed operating license, or have announced plans to submit a license renewal application for license renewal in the future. All of the evaluations were performed using the RAMA fluence methodology and the results are reported in terms of EOL values associated with a 60-year operating life (roughly equivalent to 54 EFPY). Data were collected from all four relevant BWR design types operated in the U.S. that employ jet pumps (BWR/3-6s) and for multiple reactor sizes and licensed power conditions. These data are based on cycle-specific evaluations for historical cycles. Projections for future operating cycles assume continued operation without any changes from the last cycle evaluated.

As anticipated, differences in plant design were found to result in significant variations in jet pump EOL fluence. Design factors affecting EOL fluence estimates include, but are not limited to, reactor size, number of fuel bundles / fuel arrangement, power uprate status, and the size of the annulus region. Further, within a single plant, some jet pumps are subject to higher fluence than others as a result of azimuthal location. Since the fuel bundles are rectangular, the distance from the edge of the core to the jet pump varies somewhat, resulting in different EOL fluence estimates. Figure 4A provides a plan view of the reactor core, core shroud, and jet pumps that illustrates this geometry. The fluence values presented below are based on the highest fluence jet pump in each unit evaluated.

Finally, within a single jet pump assembly, the estimated EOL fluence for individual weld locations varies substantially as a function of elevation. The lower end of the jet pump assembly is located well below the core plate, in a region of low fluence. Jet pump locations higher in elevation are exposed to progressively increasing neutron flux, with a substantial increase in fluence occurring for components located within the height of active fuel. Figure 4B provides a typical jet pump assembly elevation view in relation to the core.

Table 4A provides a summary of the results associated with selected set of jet pump riser welds that are common to all jet pump designs. A focus on weld locations is appropriate since any IASCC would likely manifest as new cracking that is largely indistinguishable from IGSCC occurring in weld HAZs. Figure 4C illustrates the general location of the riser welds listed in Table 4A.

**TABLE 4A: JET PUMP RISER END-OF-LIFE NEUTRON FLUENCE ESTIMATES [1]**

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**EPRI Proprietary Information**

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**Table 4A Notes:**

[1] All fluence values reported are based on estimated end-of-life (EOL) neutron fluence associated with a 60-year service life (54 EFPY).

All values are reported as fast neutron fluence ($E \geq 1.0$ MeV)

The neutron fluence inputs used to generate Table 4A are in all cases based on the peak fluence value associated with any given location. For example, fluence inputs for values reported in the RS-3 Weld ID row are associated with the point on the RS-3 circumferential weld that results in the greatest fluence value. This location is always near the point on the weld closest to active fuel.

If there are differences in accumulated neutron fluence among jet pumps in a single unit due to differences in proximity to active fuel, the input value is the peak neutron fluence for the highest fluence jet pump in the unit.

All neutron fluence values are estimates based on each plant's most recent fluence evaluation and based on the plant's power history. Future changes in operating conditions or rated power could have an effect on these values.

[2] $\phi_{mean}$ is the mean of the EOL peak neutron fluence values from the 16 units included in the study.

[3] $\phi_{high}$ is the single highest EOL peak neutron fluence value from the 16 units included in the study.

[4] The number of units (*percentage of units in the evaluation*) having an EOL peak neutron fluence exceeding $3 \times 10^{20}$ n/cm$^2$ ($E \geq 1.0$ MeV) for the Weld ID at EOL.

[5] The number of units (*percentage of units in the evaluation*) having an EOL peak neutron fluence exceeding $5 \times 10^{20}$ n/cm$^2$ ($E \geq 1.0$ MeV) for the weld ID at EOL.

[6] For the RS-8 / RS-9 welds, the EOL peak fluence reported is conservatively taken from a location on the edge of the riser brace, some distance closer to active fuel than the weld itself. As a result, the values reported are slightly higher than those reported for RS-3.

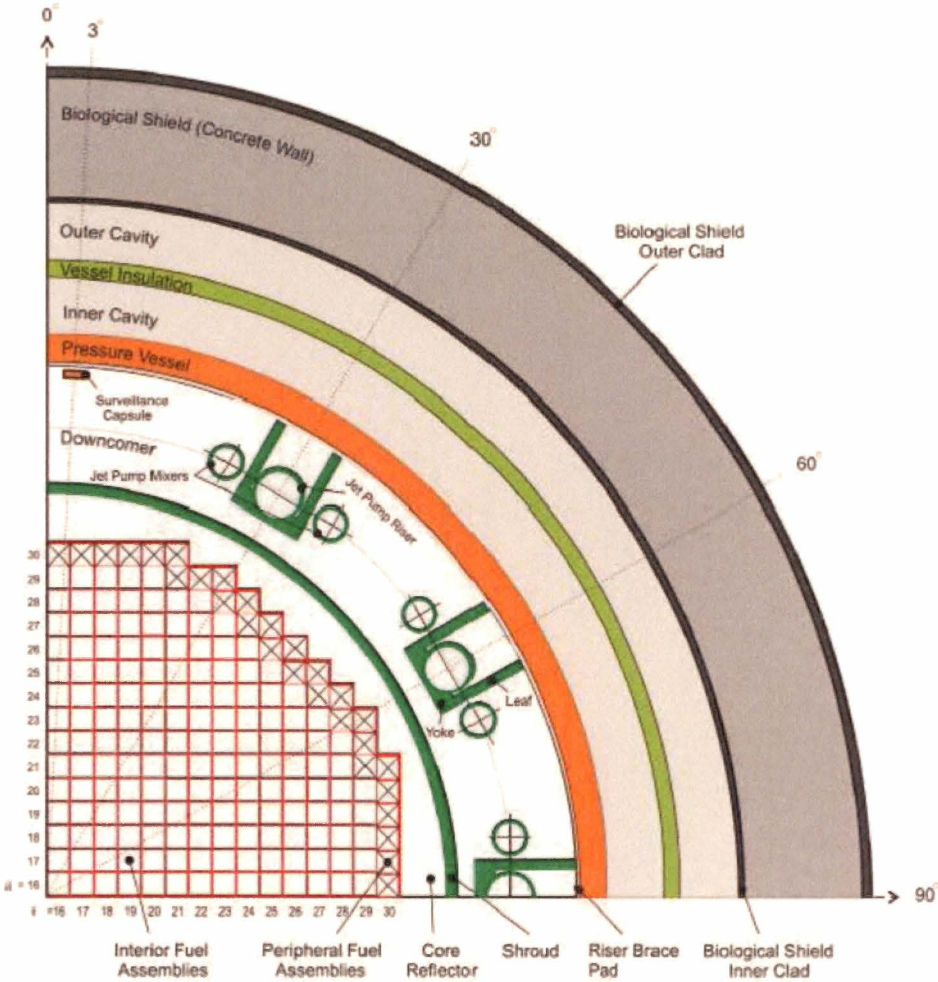


**Figure 4A: Plan View of Typical BWR Reactor**
**(excerpted from BWRVIP-281NP, Figure 3-2)**

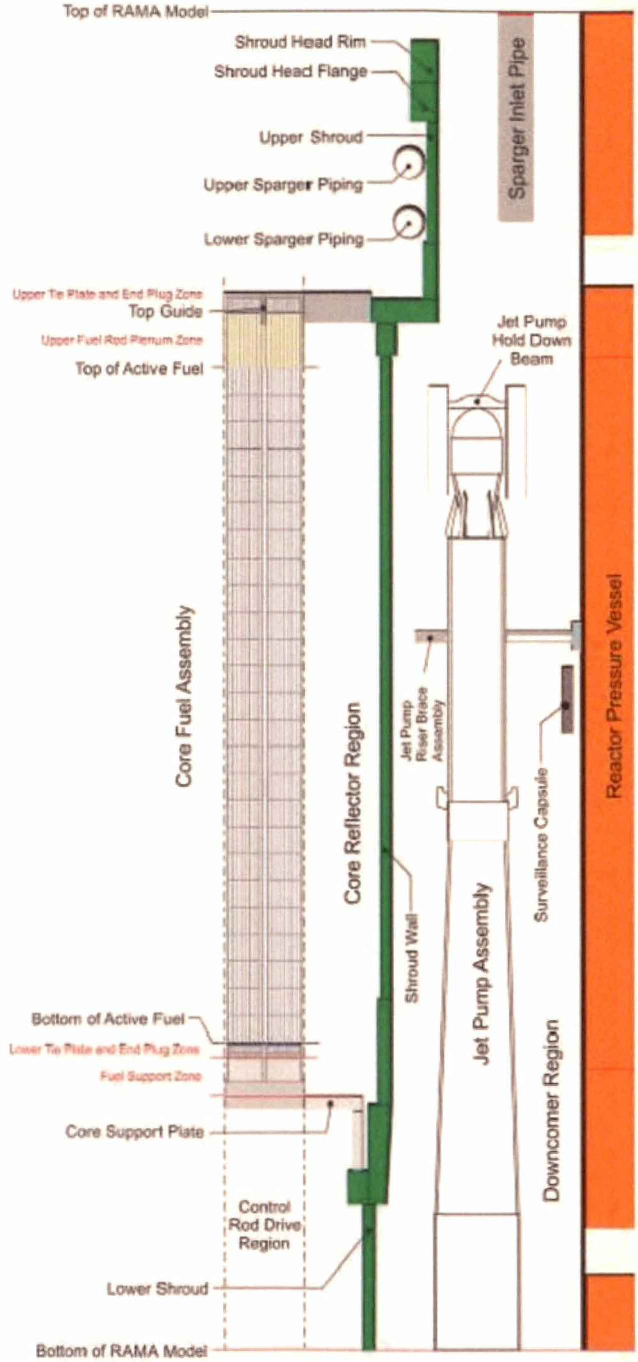


**Figure 4B: Elevation View of Typical Jet Pump Assembly**
**(excerpted from BWRVIP-281NP, Figure 3-3)**

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**Figure 4C: Jet Pump Assembly Weld Locations**

A fluence of $5x10^{20}$ n/cm$^2$ (E> 1.0 MeV) is generally accepted as a lower bound for the onset of IASCC concerns for austenitic stainless steels in BWRs. [4a], [4b]. The results presented in Table 4A illustrate that the 60-year jet pump riser fluence in most BWRs remains less than this threshold for IASCC, although there are a small number of higher fluence plants for which the 60-year EOL fluence will marginally exceed $5x10^{20}$ n/cm$^2$ (E> 1.0 MeV).[[

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In summary, the fluence study described above illustrates that, based on conservative assumptions, jet pump locations potentially subject to fluence exceeding the threshold for IASCC at EOL are limited to welds located in the upper portion of the riser pipe or in the adjacent inlet / mixer locations in a small number of higher fluence plants. In all cases, fluence near the generally accepted threshold for IASCC concerns occurs only for the regions of the welds located nearest to the core shroud. This means that for all jet pump circumferential welds, the majority of the weld circumference is exposed to significantly lower fluence because the location is further from the core and is often shielded by the jet pump itself.

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ASSESSMENT OF IASCC CONSIDERATIONS ON OPTIMIZED INSPECTION PROGRAM

Table 4B, adapted from Table 5-1 in BWRVIP-266 [4c], illustrates the weld locations that were included in the inspection optimization effort and which also have EOL fluence exceeding $5x10^{20}$ n/cm$^2$ or potentially approaching that value at EOL. Results presented in Table 4B present a very conservative perspective of the effects of fluence on jet pump aging management since all riser welds at or above the restrainer bracket and all inlet / mixer welds are assumed to have EOL fluence sufficient to result in IASCC concerns even though the fluence assessment determined that only a small number of plants will have peak EOL fluence exceeding $5x10^{20}$ n/cm$^2$. Within Table 4B, bold & underlined font / red text indicates the weld locations that are conservatively assumed to be subject to fluence sufficient to result in any possibility of IASCC. Other weld locations, shown in normal font /black text, are retained in Table 4B for completeness, but have EOL peak fluence far too low to result in any IASCC concern. Evaluating the results of this exercise in the context of the optimized inspection program presented in BWRVIP-41 Rev. 4 and based on BWRVIP-266, the following observations can be made:

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[1] BWRVIP-266, Section 3.

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**TABLE 4B: ASSESSMENT OF JET PUMP WELD LOCATIONS WITH SIGNIFICANT EOL NEUTRON FLUENCE**

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**Table 4B Notes:** ]]

Table 4B lists only jet pump weld location IDs considered for inspection optimization as described in BWRVIP-266 (i.e., not all jet pump assembly weld locations are shown in this table).

**Bold & underlined font / red text** indicates the weld locations that are conservatively assumed to be subject to fluence sufficient to result in any possibility of IASCC. Other weld locations, shown in normal font /black text, are retained in Table 4B for completeness, but have EOL peak fluence well below the generally accepted IASCC threshold fluence of $5x10^{20}$ n/cm$^2$.

FLUENCE CONSIDERATIONS RELATIVE TO JET PUMP COMPONENT FLAW EVALUATION

If cracking is detected in a weld subject to significant neutron fluence, the effect of fluence on material properties must be considered in the flaw evaluation. The two relevant parameters controlling the flaw evaluation methods applied and allowable re-inspection intervals obtained are crack growth rate (CGR) and fracture toughness. With regard to CGR, BWRVIP-41, Revision 4 states the following in Section 5.1.1.3, Crack Growth:

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Given the results described above, there are now data indicating fluence potentially exceeding the $5x10^{20}$ n/cm$^2$ value. However, this condition does not invalidate the flaw evaluation guidance available to members. In general, the conclusion presented in BWRVIP-266 remains accurate since in most cases, the 60-year fluence only marginally

[4] All jet pump component are considered to be thin-walled and no credit is taken in flaw evaluations for cracking in the depth direction. All indications are, for the purposes of flaw evaluation, conservatively assumed to be through-wall.

[5] It is noted that jet pump flaw evaluations do not take credit for crack growth in the depth direction and thus the K-dependent correlations for cracking in the depth direction provided in BWRVIP-14-A and BWRVIP-99-A are, in practice, not applicable to jet pump aging management.

exceeds $5x10^{20}$ n/cm$^2$. Further, as noted previously, the accumulated EOL fluence drops dramatically in weld regions further from the core, such that for most regions of the weld fluence remains low. As such, continued use of limit-load evaluation remains generally appropriate.

However, in order to ensure that the effects of irradiation are conservatively considered, the BWRVIP proposes the following additions to BWRVIP-41, Revision 4 to address this topic:

A new section 2.2.1.5 will be added to address irradiation effects on IGSCC:

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BWRVIP 2017-022

CONCLUSIONS

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Therefore, the BWRVIP maintains that, with the minor additions to BWRVIP-41 proposed above, the optimized program recommended in BWRVIP-41, Revision 4 remains appropriate, even with consideration of EOL fluence approaching or potentially exceeding $5x10^{20}$ n/cm$^2$ at EOL.

RAI-4 RESPONSE REFERENCES

[4a] *BWRVIP-26-A: BWR Vessel and Internals Project, BWR Top Guide Inspection and Flaw Evaluation Guidelines*, EPRI, Palo Alto, CA: 2004. 1009946.

[4b] P.L. Andresen, F.P. Ford, and J.M. Perks, "State of Knowledge of Radiation Effects on Environmental Cracking in Light Water Reactor Core Materials", *Proceedings of Fourth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors*, NACE, 1990.

[4c] *BWRVIP-266: BWR Vessel and Internals Project, Technical Bases for Revision of the BWRVIP-41 Jet Pump Inspection Program*, EPRI, Palo Alto, CA: 2012. 1025140.

**Jet Pump Beam and BWRVIP-138, Rev. 1:**

**RAI-5**

Background: Section 5.2 of the TR states the following:

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Issue: The staff notes that this text is carried over from BWRVIP-41, Rev. 1, dated September 2005, and does not reflect the text in BWRVIP-138, Rev. 1 (Reference 8 in the TR, dated 2008).

Request: The staff asks the BWRVIP to revise the text in Section 5.2 to reflect the current NRC-approved version of BWRVIP-138, Rev. 1-A, dated October 2012 [Ref. 5].

**BWRVIP Response to RAI-5**

The BWRVIP agrees that Section 5.2 of BWRVIP-41, Revision 4 should have been updated to reference the most recent version of BWRVIP-138 available at the time BWRVIP-41, Revision 4 was developed, BWRVIP-138, Revision 1-A, which provides significant additional detail regarding prediction of crack growth as well as guidance that can be applied in developing technical bases for flaw acceptance. The following revision to Section 5.2 of BWRVIP-41, Revision 4 is proposed by the BWRVIP (changes shown in red, additions in bold text, deletions in strikethrough text):

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This change will be made in the "-A" version of BWRVIP-41, Revision 4.

**RAI-6**

<u>Background:</u> Section 3.2.3 of the TR covers plant-specific analyses to modify/eliminate inspection requirements. This section was the subject of Item 2 from the staff's initial Safety Evaluation (SE) to Revision 0 of the TR [Ref. 6]. On November 17, 2000, the BWRVIP responded with a proposed revision to the TR that the staff approved in the final SE of Revision 0 [Ref. 7].

<u>Issue:</u> In the subsequent revisions to the TR, the final sentence of the BWRVIP response to Item 2 was dropped. That sentence stated:

> *Results of these plant-specific analyses should be submitted to the NRC for review and approval.*

<u>Request:</u> The staff asks the BWRVIP to revise Section 3.2.3 of the TR to include the complete text from the November 17, 2000 BWRVIP response or provide a rationale for why it was dropped from the revision.

**BWRVIP Response to RAI-6**

The BWRVIP acknowledges that the sentence quoted in the RAI response was not added to BWRVIP-41. However, the content of Section 3.2.3 was originally added to provide additional guidance regarding the "plant-specific analysis" option indicated for inspection of many jet pump locations in Table 3.3-1 of BWRVIP-41, Revision 0. Although this column was removed from the inspection program tables contained in subsequent revisions of BWRVIP-41, the accompanying amplifying text currently contained in Section 3.2.3 was retained. While this guidance was appropriate at the point in time when BWRVIP-41, Revision 0 was developed, current practice is that any deviation from BWRVIP guidance is addressed by the deviation disposition process described in Appendix B of BWRVIP-94NP, Revision 2. As a result, the guidance contained in Section 3.2.3 is no longer needed and can be removed.

BWRVIP proposes to delete Section 3.2.3 in its entirety instead of adding the sentence indicated in RAI-6. This change will be made in the "-A" version of BWRVIP-41, Revision 4.

**RAI-7**

Background: Section 3.2.8.1 of the TR covers scope expansion for accessible and partially accessible weld. Section 3.2.8.1.2 includes an exemption from expanding the scope of inspections for specific weld locations.

Issue: The details related to when expansion of the scope for inspections will occur are not clear to the staff. Should this be applied the same for both ultrasonic (UT) and enhanced visual (EVT-1) inspection techniques? It appears to the staff that there would be significant differences if the re-inspection used UT (as done in the baseline) vs. EVT-1. Specifically, there is no mention of how inspection coverage and history of hydrogen water chemistry mitigation is taken into account when determining if the observed cracking is consistent with fleet operating experience. Two examples are suggested for consideration.

First, consider a case where a flaw 2 inches long is detected with an EVT-1 inspection (20% coverage) at the AD-3a,b location from a BWR/4 with the legs configuration that had previously been inspected with UT (100% coverage). The UT inspection found no indication and was performed while the plant was under noble metal chemistry addition. During the more recent EVT-1 inspection, the plant was operating under online noble chemistry injection (OLNC). The staff could interpret the text in Section 3.2.8.1.2 as allowing no scope expansion.

Second, consider a case where a flaw 2 inches long is detected with an EVT-1 inspection (15% coverage) at a AD-2 location from a BWR/5 with the legs configuration that had previously been inspected with UT (50% coverage). The UT inspection found no indication and was performed while the plant was under modified hydrogen water conditions. During the more recent EVT-1 inspection, the plant was operating under OLNC. Again, the staff could interpret the text in Section 3.2.8.1.2 as allowing no scope expansion.

Request: Provide a discussion of how Section 3.2.8.1.2 would be applied for the examples cited above. If no expansion of inspection is the intended outcome, explain how not expanding the inspection scope will allow determination of whether the degradation observed is consistent with past operating experience. Consider more explicit description of what inspection results would be exempt from scope expansion.

**BWRVIP Response to RAI-7**

Within the RAI, the staff questions the relevance of the inspection method detecting the flaw, as well as the relevance of water chemistry regime. The BWRVIP maintains that neither of these specific elements are directly relevant to the scope expansion exemption provided in Section 3.2.8.1.2 of BWRVIP-41, Rev. 4.

With regard to inspection method, the method detecting the flaw(s) is not directly relevant because the exemption is not applied to the weld inspected in the current outage that has been found to contain one or more flaws. Rather, the exemption is applicable to other jet pump welds in the unit having the same weld ID which were not inspected during the current outage, but have been inspected previously by UT. The primary consideration is that the inspection provides high confidence in the integrity of the welds to be exempted from scope expansion, such that continued periodic inspection in accordance with Table 3-1 of BWRVIP-41, Rev. 4 remains appropriate. High confidence in weld integrity is provided by UT examination performed using a demonstrated technique in BWRVIP-03. Where applied, UT of diffuser and adapter welds generally attains high coverage (refer to BWRVIP-266, Table 3-14). [[

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Additionally, the generic parametric evaluation in BWRVIP-266 forming the basis for the scope expansion exemption in Section 3.2.8.1.2 of BWRVIP-41, Rev. 4 includes cases based on an effective crack growth rate (CGR) of $5x10^{-5}$ inches per hour. This CGR has been generally accepted as an upper end rate adequate to address not only continued growth of existing flaws under NWC, but also the potential for new crack initiations as well. Assuming that 10% of the weld circumference is initially cracked, these analyses conclude that even if CGRs based on NWC conditions are applied, the resulting operating times to reach the allowable flaw size are substantial (refer to BWRVIP-266, Table 4-3). If more realistic effective CGRs and initial flaw lengths were considered, operating times to reach the allowable flaw sizes would be [[

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This change will be made in the "-A" version of BWRVIP-41, Revision 4.

**References For RAIs**

[1] NUREG-1801, Rev. 2, "The Generic Aging Lessons Learned (GALL) Report," December 2010.

[2] *BWRVIP-234: BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals.* EPRI, Palo Alto, CA: 2009, TR1019060.

[3] PWROG-15032-NP, Revision 0, "PA-MSC-1288 Statistical Assessment of PWR RV Internals CASS Materials," Westinghouse Electric Company LLC, November 2015.

[4] *Materials Reliability Program: A Review of Radiation Embrittlement of Stainless Steels for PWRs (MRP-79) – Revision 1,* EPRI, Palo Alto, CA: 2004. TR1008204.

[5] *BWRVIP-138, Revision 1-A: BWR Vessel and Internals Project, Updated Jet Pump Beam Inspection and Evaluation Guidelines.* EPRI, Palo Alto, CA: 2012, TR1025319.

[6] Initial SE for BWRVIP-41, Revision 0, dated June 20, 2000, ADAMS Accession No. ML003725033.

[7] BWRVIP response, dated November 17, 2000, to Initial SE for BWRVIP-41, Revision 0, ADAMS Accession No. ML003770389.

# J
# BWRVIP-41, REVISION 4-A RECORD OF REVISIONS

| | |
|---|---|
| BWRVIP-41, Revision 4-A | Information from the following documents was used in preparing the changes included in this revision of the report:<br>1. *BWRVIP-41, Revision 4 "BWR Vessel and Internals Project: BWR Jet Pump Assembly Inspection and Evaluation Guidelines*. EPRI, Palo Alto, CA. 2014, 3002003093.<br>2. Letter, Joseph Holonich (NRC) to Tim Hanley (BWRVIP Chairman), Request for additional information for BWRVIP-41, Revision 4 "BWR Jet_Pump Assembly Inspection and Evaluation Guidelines" (TAC NO. ME4882), dated April 25, 2016. (BWRVIP Correspondence File-042A).<br>3. Letter, Tim Hanley (BWRIP Chairman) and Andrew McGehee (BWRVIP Program Manager) to Document Control Desk, U.S. Nuclear Regulatory Commission, Attention: Joseph Holonich, Project No. 704 – BWRVIP Responses to RAIs on BWRVIP-41, Rev. 4 to NRC, dated February 8, 2017. (BWRVIP Correspondence File Number 2017-022).<br>4. Letter, Dennis C. Morey (NRC) to Tim Hanley, (BWRVIP Chairman), Final Proprietary Safety Evaluation for Electric Power Research Institute Topical Report BWRVIP-41, Revision 4, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines" (CAC NO. MF4887; EPID L-2014-TOP-0008), dated June 26, 2018. (BWRVIP Correspondence File Number 2018-077A). |

**Table J-1**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Add NRC Safety Evaluation (SE) on BWRVIP-41, Revision 4 after Title page | NRC request | Added NRC Safety Evaluation (SE) on BWRVIP-41, Revision 4 after Disclaimer page. |
| Need to revise Section 1.3 "Implementation requirements to recognize that the report is now approved for implementation | Editorial | Section 1.3 - Deleted first paragraph and changed "will be considered" to "are considered". |
| Need to change "should" to "shall" for where appropriate | BWRVIP practice to address NEI-03-08 requirements | Changed "should" to "shall", or "are" to "shall be" or "may" to "shall" where appropriate, Changes were made in Sections 1.3, 2.3.2.3, 2.3.8.6, 3.2, 4.1, 4.2, 4.3, 5.1, and 5.5. In addition, changes were made in Table 3.1. |
| Need to incorporate NRC SE Condition 2:<br>Add requirement that in order to implement the revised inspection guidance in BWRVIP-41, Revision 4, Licensees must comply with the requirements of a NRC-approved HWC program (for example, BWRVIP-62-A) | NRC SE Condition 2 | Added the following sentence to Sections 1.3 "Implementation Requirements" and 3.2 "BWRVIP Inspection Guidelines":<br>Note: In order to implement the revised inspection strategy defined in Table 3-1, the plant must comply with the requirements of an NRC-approved HWC program (for example, BWRVIP-62-A). However, there is no requirement to perform a full baseline exam while operating on HWC prior to using the revised program. Should a plant be unable to meet the requirements of an NRC-approved HWC program going forward from publication of this revision, the plant shall revert to the inspection recommendations provided in BWRVIP-41, Revision 3. |
| Add new Section 2.2.1.5 "Effects of Irradiation" | BWRVIP commitment made in response to NRC RAI-4 | Added new Section 2.2.1.5 "Effects of Irradiation" as follows:<br>Accumulated fluence can potentially be significant for jet pumps in high fluence plants. Within these jet pumps, locations in the upper riser, inlet and mixer could be subject to fluence marginally exceeding the threshold for onset of irradiation-induced SCC (IASCC). However, there is no evidence at present of any increased propensity for cracking associated with increased end-of-life fluence and no impact on the inspection program recommended in Section 3. |

**Table J-1 (continued)**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Need to update Reference in Section 2.3.2.7 | Editorial | Revised Reference from "BWRVIP-138, Rev 1" to BWRVIP-138, Rev 1-A. |
| Need to incorporate NRC SE Condition 3b:<br>"Following discovery of any new service induced cracking identified in jet pump components, all Licensees shall inspect these locations for a minimum of two consecutive refueling outages. Following these two consecutive reinspections, the proposed inspection schedule may be resumed provided the CGR has been established and has been determined to be below the proposed bounding CGR " | NRC Condition 3b | The following text was added to Section 3.2.1 ("Periodic Inspection" and Section 5 "Structural and Leakage Evaluation Methodologies":<br>Note: Regardless of the periodic inspection guidance provided in Table 3-1, the following limitations are imposed on inspection intervals for flawed welds established by plant-specific analyses:<br>1. If new cracking in a weld is identified, the weld shall be reexamined, as a minimum, during the next two consecutive refueling outages. This limitation ensures that newly identified cracks are reexamined at least twice before permitting inspection intervals based on plant specific analysis.<br>2. Further, if reexamination identifies any unexpected crack growth (that is, growth exceeding $5x10^{-5}$ inches per hour), then the weld must continue to be reexamined at each refueling outage until the crack is found to be stable as demonstrated by crack growth less than $5x10^{-5}$ inches per hour for two consecutive operating cycles. This limitation ensures that frequent reinspection is continued for weld locations where high crack growth rates are observed.<br>3. In no case shall the time to the next scheduled reinspection exceed the time to reach the minimum acceptable structural margin as calculated based on the guidance in Section 5. |
| Delete Section 3.2.3 "Plant Specific Analysis to Modify/Eliminate Inspection Requirements" | BWRVIP commitment made in response to NRC RAI-6 | Deleted title and text of Section 3.2.3 and changed Section 3.2.3 to read as follows:<br>3.2.3 Deviations from BWRVIP Inspection Guidance<br>Any deviations from BWRVIP inspection "needed" guidance shall follow the deviation disposition process described in Appendix B of the most recent revision of BWRVIP-94NP. |

**Table J-1 (continued)**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Revise Reference to BWRVIP-18 in Section 3.2.7 | Editorial | Revised Reference in Section 3.2.7 from "BWRVIP-18 Revision 1" to "BWRVIP-18, Revision 2-A". |
| Correct reference to Section 2.3.8.7 to 2.3.8.6 in Section 3.2.9 | Editorial | In Section 3.2.9 changed reference to Section 2.3.8.7 to 2.3.8.6 |
| Add requirement that "Exemptions of welds from the scope expansion shall be limited to welds that were previously examined with a UT technique that achieved inspection coverage, for the "areas of interest" as defined in BWRVIP-03, for at least 75 percent of the weld circumference and clarify the intent of Section 3.2.8.1.2 "Exemptions" | NRC SE Condition 1 and BWRVIP commitment in response to NRC RAI 7. | Revised Section 3.2.8.1.2 "Exemptions" to read:<br>If IGSCC is detected in a large diameter diffuser, adapter, or lower ring weld or HAZ (that is, DF-1, DF-2, DF-3, AD-1, AD-2, or AD-3a, b), other weld locations of the same nomenclature on other jet pumps not examined during the current refueling outage may be exempted from scope expansion requirements of Section 3.2.8.1.1 if the following conditions are met:<br>1. The IGSCC observed is consistent with fleet operating experience and does not represent a significant challenge to structural integrity and<br>2. Each location to be exempted from the scope expansion requirement of Section 3.2.8.1.1 must have been examined in a prior refueling outage by UT performed using a demonstrated technique in BWRVIP-03 and that achieved inspection coverage, for the "areas of interest" as defined by BWRVIP-03, for at least 75 percent of the weld circumference.<br>Scope expansion examinations are required if the inspection performed in the current outage indicates involvement of a relevant degradation mechanism other than IGSCC) which represents a more substantial challenge to structural integrity than IGSCC. Scope expansion examinations are also required if the IGSCC observed is not consistent with past operating experience; for example, indications of unexpectedly high crack growth rates (that is, crack growth rates significantly greater than $5 \times 10^{-5}$ inches per hour) or unexpected numbers of new crack initiations. |

**Table J-1 (continued)**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Add a new Section 3.2.10 "Jet Pump Beam Flaw Disposition" | Clarification of "needed" requirement | Re-stated jet pump flaw disposition requirements from Section 2.3.2.3 to a new Section 3.2.10 to clarify that these are 'needed" requirements. |
| Need to alert Utilities that loads on jet pumps due to annulus pressurization (AP) may be affected by GE-Hitachi Safety Communication SC 09-01 | BWRVIP commitment made in response to NRC RAI-2 | The following sentence was added to Section 4.1.6 "Annulus Pressurization (AP)":<br>Note: Plants shall reexamine their AP load calculations and update those calculations, where necessary, considering the potential for increased AP loads as documented in GE-Hitachi Safety Communication SC 09-01 [34]. |
| Need to update reference for an alternative limit load methodology in Section 5.1.2.1.3. | BWRVIP commitment in response to NRC RAI 1 | Section 5.1.2.1.3 was revised to reference BWRVIP-76, Revision 1-A (BWR Shroud Inspection and Flaw Evaluation Guidelines) for an alternative limit load methodology. |
| Add new Section 5.1.2.2 "Effects of Irradiation" | BWRVIP commitment made in response to NRC RAI-4 | Added new Section 5.1.2.2 "Effects of Irradiation" as follows:<br>IGSCC flaw evaluations for welds shall account for the effects of irradiation if a plant-specific assessment indicates that the end-of-interval (EOI) fluence may exceed $3x10^{20}$ n/cm$^2$ for any portion of the weld being evaluated. One evaluation approach that may be used is to perform a limit load analysis assuming that the length of the weld exceeding $3x10^{20}$ n/cm$^2$ at EOI is removed from the weld. Alternatively, the weld may be evaluated using limit load analysis and either linear-elastic fracture mechanics or elastic-plastic fracture mechanics techniques. These approaches to evaluating high fluence welds are described in additional detail in Appendix D of BWRVIP-76, Revision 2. |

**Table J-1 (continued)**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Add requirement that all licensees shall compute leakage rates from detected and postulated flaws in the jet pump assemblies as shown in the TR and demonstrate that the calculated leak rates are bounded by leakage rates resulting from plant-specific LOCA analysis. The leakage rates resulting from plant-specific analyses include those resulting from not exceeding the PCT criterion and from any other plant-specific licensing basis criteria related to plant-specific LOCA analysis. | NRC SE Condition 3a | Added the following sentence to Section 5.1.3 "Leakage Considerations":<br><br>Specifically, licensees shall compute leakage rates from detected and postulated flaws in the jet pump assemblies as shown in the following sections and demonstrate that the calculated leak rates are bounded by the allowable leakage rates resulting from plant-specific LOCA analyses. The allowable leakage rates resulting from plant-specific analyses include those resulting from not exceeding the PCT criterion as well as any other plant-specific licensing basis leakage criteria related to plant-specific LOCA analyses. |
| Need to update reference for prediction of CGRs | BWRVIP commitment in response to NRC RAI-5 | The second and third paragraphs of Section 5.2 "Jet Pump Beam" were revised as follows:<br><br>Failed beams and several beams with small cracks have been examined to determine the failure mechanism of the beam. Results show that the failure mechanism was IGSCC, although other factors may have influenced crack initiation. Studies were also performed to estimate the crack initiation and propagation rates based on available material property data and the calculated stresses during failure. The most recent findings are presented in BWRVIP-138, Revision 1-A [8] or, if applicable, a more recent version of BWRVIP-138.<br><br>BWRVIP-138, Revision 1-A provides a methodology that could be applied for development of plant-specific jet pump beam flaw evaluations for situations where implementation of the jet pump beam flaw disposition requirements in Section 3.2.10 cannot be fulfilled. |
| Need to update/revise References | Editorial | Updated References 8 and 10 to most recent revisions. Deleted Reference 30 and re-numbered References 31-34 to 30-33. Added new Reference 34. Updated Reference 23 to most recent version of BWRVIP-76. |

**Table J-1 (continued)**
**Revision Details BWRVIP-41, Revision 4-A**

| Required Revision | Source of Requirement for Revision | Description of Revision Implementation |
|---|---|---|
| Modify Appendix A to delete Demonstration of Compliance of the Information provided in BWRVIP-41 with the Technical Information Requirements of the License Renewal Rule (10 CFR 54.21) to be consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines. | BWRVIP Position on LR Appendices implemented in other I&E Guidelines | Appendix A modified: Demonstration of compliance of the information provided in BWRVIP-41 with the Technical Information Requirements of the License Renewal Rule (10 CFR 54.21) was deleted consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines. |
| Revise Appendix B Title | Editorial | Appendix B title revised to indicate that the SE refers to the original version of BWRVIP-41. |
| Modify Appendix C to delete NRC SE on License Renewal Appendix consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines. | BWRVIP Position on LR Appendices implemented in other I&E Guidelines | Appendix C modified: NRC SE on License Renewal Appendix deleted consistent with BWRVIP position on LR Appendices implemented in revisions to other I&E Guidelines. |
| Add new Appendix H added: NRC RAIs on BWRVIP-41, Revision 4, dated April 25, 2016. (BWRVIP Correspondence Number 2016-042A). | NRC request | Appendix H added: NRC RAIs on BWRVIP-41, Revision 4, dated April 25, 2016. (BWRVIP Correspondence Number 2016-042A). |
| Add new Appendix I: BWRVIP Responses to NRC RAIs on BWRVIP-41, Revision 4, dated February 8, 2017. (BWRVIP Correspondence Number 2017- 022) | NRC request | Appendix I added: BWRVIP Responses to NRC RAIs on BWRVIP-41, Revision 4, dated February 8, 2017. (BWRVIP Correspondence Number 2017-022). |
| Add Appendix J: Record of Revisions for BWRVIP-41, Revision 4-A | Editorial | Appendix J added: Record of Revisions for BWRVIP-41 Revision 4-A. |
| **End of Revisions** | | |

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