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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NEIL WILMSHURST
Vice President and
Chief Nuclear Officer

Ref. EPRI Project Number 669

February 6, 2017

Document Control Desk
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Request for Withholding of the following Proprietary Information Included in:

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

To Whom It May Concern:

This is a request under 10 C.F.R. §2.390(a)(4) that the U.S. Nuclear Regulatory Commission ("NRC") withhold from public disclosure the report identified in the enclosed Affidavit consisting of the proprietary information owned by Electric Power Research Institute, Inc. ("EPRI") identified in the attached response. Proprietary and non-proprietary versions of the Response and the Affidavit in support of this request are enclosed.

EPRI desires to disclose the Proprietary Information in confidence as a means of exchanging technical information with the NRC. The Proprietary Information is not to be divulged to anyone outside of the NRC or to any of its contractors, nor shall any copies be made of the Proprietary Information provided herein. EPRI welcomes any discussions and/or questions relating to the information enclosed.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (704) 595-2732. Questions on the content of the Report should be directed to Andy McGehee of EPRI at (704) 502-6440.

Sincerely,

Attachment(s)

c: Sheldon Stuchell, NRC (sheldon.stuchell@nrc.gov)

1300 West W.T. Harris Boulevard, Charlotte, NC 28262-8550 USA • 704.595.2732 • Mobile 704.490.2653 • nwilmshurst@epri.com

ELECTRIC POWER
RESEARCH INSTITUTE

AFFIDAVIT

RE: Request for Withholding of the Following Proprietary Information Included In:

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

I, Neil Wilmshurst, being duly sworn, depose and state as follows:

I am the Vice President and Chief Nuclear Officer at Electric Power Research Institute, Inc. whose principal office is located at 1300 W WT Harris Blvd, Charlotte, NC. ("EPRI") and I have been specifically delegated responsibility for the above-listed response that contains EPRI Proprietary Information that is sought under this Affidavit to be withheld "Proprietary Information". I am authorized to apply to the U.S. Nuclear Regulatory Commission ("NRC") for the withholding of the Proprietary Information on behalf of EPRI.

EPRI Proprietary Information is identified in the above referenced response by a solid underline with highlighted text, and double brackets. An example of such identification is as follows:

[[This sentence is an example.{E}]]

Tables containing EPRI Proprietary Information are identified with double brackets before and after the object. In each case the superscript notation {E} refers to this affidavit and all the bases included below, which provide the reasons for the proprietary determination.

EPRI requests that the Proprietary Information be withheld from the public on the following bases:

Withholding Based Upon Privileged And Confidential Trade Secrets Or Commercial Or Financial Information (see e.g., 10 C.F.R. § 2.390(a)(4):

a. The Proprietary Information is owned by EPRI and has been held in confidence by EPRI. All entities accepting copies of the Proprietary Information do so subject to written agreements imposing an obligation upon the recipient to maintain the confidentiality of the Proprietary Information. The Proprietary Information is disclosed only to parties who agree, in writing, to preserve the confidentiality thereof.

b. EPRI considers the Proprietary Information contained therein to constitute trade secrets of EPRI. As such, EPRI holds the Information in confidence and disclosure thereof is strictly limited to individuals and entities who have agreed, in writing, to maintain the confidentiality of the Information.

c. The information sought to be withheld is considered to be proprietary for the following reasons. EPRI made a substantial economic investment to develop the Proprietary Information and, by prohibiting public disclosure, EPRI derives an economic benefit in the form of licensing royalties and other additional fees from the confidential nature of the Proprietary Information. If the Proprietary Information were publicly available to consultants and/or other businesses providing services in the electric and/or nuclear power industry, they would be able to use the Proprietary Information for their own commercial benefit and profit and without expending the substantial economic resources required of EPRI to develop the Proprietary Information.

d. EPRI's classification of the Proprietary Information as trade secrets is justified by the Uniform Trade Secrets Act which California adopted in 1984 and a version of which has been adopted by over forty states. The California Uniform Trade Secrets Act, California Civil Code §§3426 – 3426.11, defines a "trade secret" as follows:

> "'Trade secret' means information, including a formula, pattern, compilation, program device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy."

e. The Proprietary Information contained therein are not generally known or available to the public. EPRI developed the Information only after making a determination that the Proprietary Information was not available from public sources. EPRI made a substantial investment of both money and employee hours in the development of the Proprietary Information. EPRI was required to devote these resources and effort to derive the Proprietary Information. As a result of such effort and cost, both in terms of dollars spent and dedicated employee time, the Proprietary Information is highly valuable to EPRI.

f. A public disclosure of the Proprietary Information would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Proprietary Information both domestically and internationally. The Proprietary Information can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated herein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of North Carolina.

Executed at 1300 W WT Harris Blvd being the premises and place of business of Electric Power Research Institute, Inc.

Date: 2-6-2017

Neil Wilmshurst

(State of North Carolina)
(County of Mecklenburg)

Subscribed and sworn to (or affirmed) before me on this 6th day of February, 2017, by Neil Wilmshurst, proved to me on the basis of satisfactory evidence to be the person(s) who appeared before me.

Signature Deborah H. Rouse (Seal)

My Commission Expires 2nd day of April, 2021

DEBORAH H. ROUSE
NOTARY PUBLIC
CABARRUS
COUNTY
NORTH CAROLINA

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%.
[[
Issue: In Section 2.2.1.2, the TR discusses the materials used in the jet pump assembly and states Content Deleted – EPRI Proprietary Licensed Material
. 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% ferrite and CASS > 7.5% 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.

BWRVIP Response to RAI-3

Evaluations previously documented in BWRVIP responses to NRC RAIs on BWRVIP-234 provide a comprehensive evaluation of ferrite estimate uncertainties associated with use of Hull's equations (BWRVIP letter 2014-086 [3a]). It is concluded from these evaluations that ferrite estimates made using Hull's equations are reasonably accurate and do not systematically under-predict or over-predict ferrite content. These evaluations further document that the standard error in the Hull's equations predictions is "of the order of 3% delta ferrite, or perhaps as low as 2% delta ferrite".

Separately, NRC concerns related to IGSCC of CASS components were addressed in BWRVIP letter 2015-150 [3b]. This BWRVIP letter addresses several points related to IGSCC. The points most relevant to this RAI response are briefly summarized below as background information:

(1) The staff position for CASS in Generic Letter 88-01 is focused on weld-induced sensitization and its impact on susceptibility to IGSCC. Even when the CASS material was beyond the carbon and ferrite limits it was allowed to be examined at the same frequency as non-susceptible or resistant material. This letter further notes that if sensitization is the limiting concern for IGSCC of CASS components, the impact would be limited to weld HAZ, for which inspection data are available for jet pump components (described below).]] TS

(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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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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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] ϕ_{mean} is the mean of the EOL peak neutron fluence values from the 16 units included in the study.

[3] ϕ_{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 $3x10^{20}$ 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 $5x10^{20}$ 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.

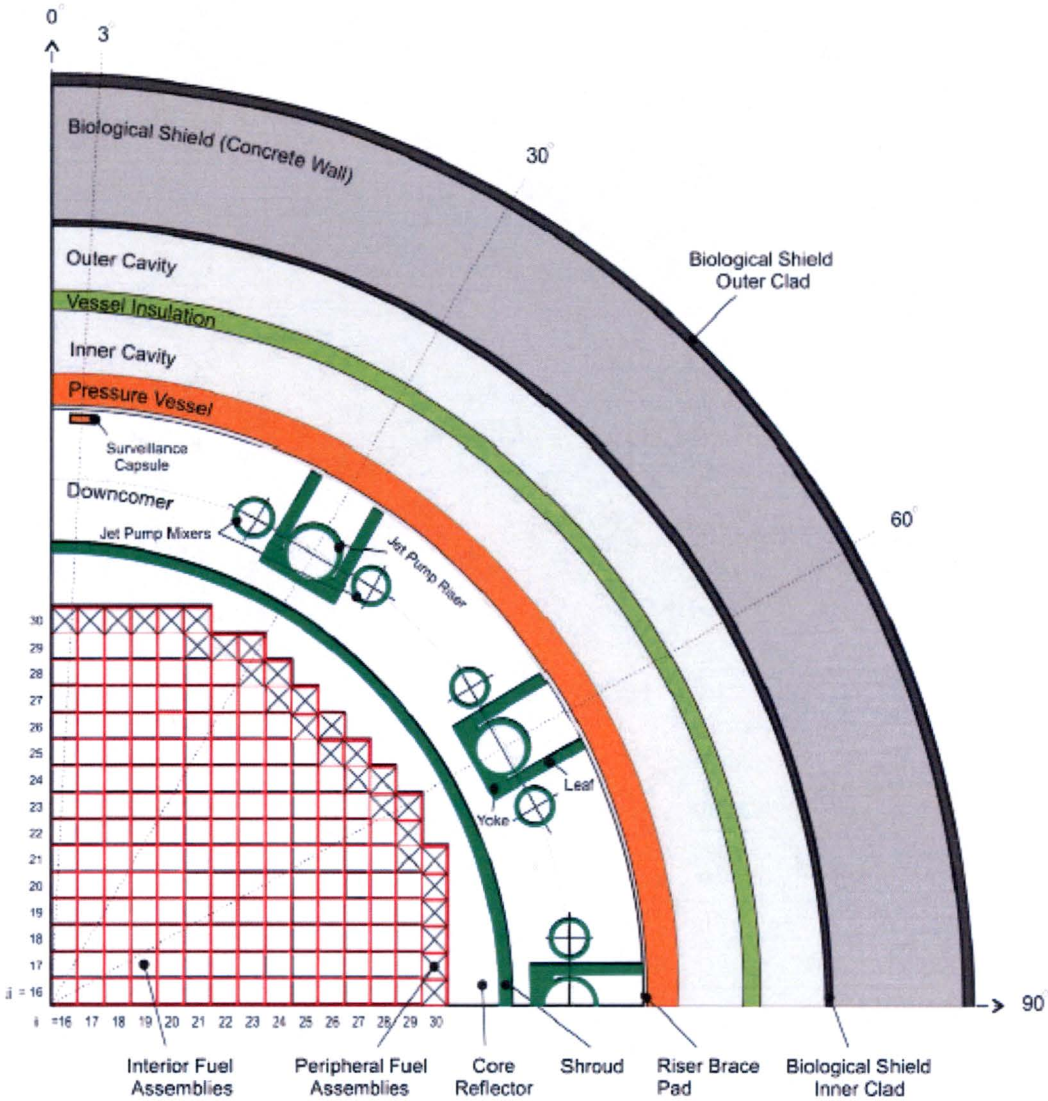

Figure 4A: Plan View of Typical BWR Reactor
(excerpted from BWRVIP-281NP, Figure 3-2)

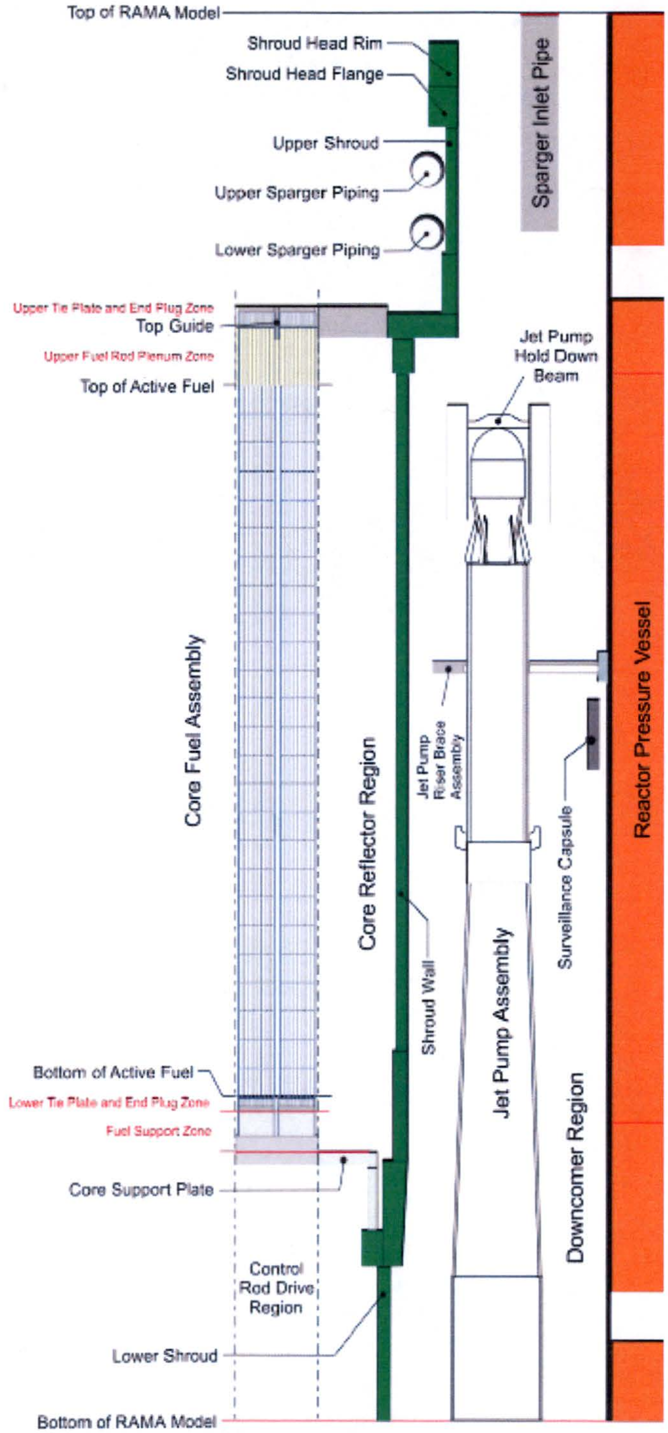

Figure 4B: Elevation View of Typical Jet Pump Assembly
(excerpted from BWRVIP-281NP, Figure 3-3)

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Figure 4C: Jet Pump Assembly Weld Locations

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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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The preceding evaluation specifically addresses riser pipe weld locations common to all jet pump BWRs. However, an understanding of fluence variation occurring along the length of the riser pipe, as well as for the jet pump inlet and mixer welds (located to either side of the riser pipe) is also useful in understanding jet pump EOL fluence. To provide this information, fluence maps visually illustrating EOL fluence across the entire jet pump assembly were developed. Figure 4D provides an example of such a jet pump fluence map.

Fluence profiles similar to that provided in Figure 4D were developed for all 16 plants in the study. The following additional observations can be made from the fluence profile study results:

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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

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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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Figure 4D: Jet Pump Assembly Fluence Profile

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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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Finally, the BWRVIP notes that although a generic threshold fluence of $5x10^{20}$ n/cm^2 has been used throughout the discussion presented above, there is little evidence that accumulation of fluence at or just beyond this threshold, as will be the case with the jet pump locations described above, will result in an adverse trend in cracking. Although some enhanced growth of flaws could be conjectured, existing guidance is adequate to manage flaw growth, regardless of fluence. There are few data to characterize the potential for new flaw initiation in the fluence range occurring for jet pump components that are both uncracked and protected by hydrogen water chemistry technologies. Periodic examination of BWR internals subject to significantly higher fluence (i.e., core shroud and top guide) have not identified clear evidence of a significant adverse trend in new SCC initiation. Were such an effect relevant to jet pumps to exist, it should have already been manifested in core shroud or top guide performance, since the accumulated fluence values for these components at present is already significantly higher than the estimated jet pump peak EOL fluence.

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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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Current BWRVIP guidance regarding SCC CGRs to be used in flaw evaluations of thin-walled components[4] requires that a CGR of $5x10^{-5}$ inches per hour be assumed for all austenitic stainless steel flaw evaluations, including all irradiation levels and all water chemistries.

A CGR of $5x10^{-5}$ inches per hour has been found over time to represent a conservative upper end value for all BWR internals evaluations. It has been routinely applied to irradiated BWR internals for the purpose of core shroud flaw evaluations and found, in all cases, to conservatively encompass uncertainties associated with not only irradiation, but the potential for new flaw initiations as well. Since this value is found appropriate for all irradiation levels, there is no impact with regard to management of existing jet pump flaws.[5]

With regard to fracture toughness, BWRVIP-266 (Section 4.1) notes the following:

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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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A new Section 5.1.2.2 will be added to alert program owners to the need for consideration of irradiation effects in structural evaluations:

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CONCLUSIONS

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The majority of jet pump locations associated with IASCC concerns will continue to be routinely examined under the optimized inspection program. Within the set of higher fluence jet pump locations, the only locations having any history of IGSCC are the Reinspection of these locations provides data that can be used to identify any significant adverse trends potentially associated with IASCC.

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Additionally, as discussed above and generally illustrated in the figures and tables presented in the response to RAI-4, the 5×10^{20} n/cm^2 threshold is exceeded only for upper riser, inlet and mixer welds in a limited number of high fluence units. Even in these cases, the threshold is exceeded only along weld zones nearest the core. For circumferential welds, most of the weld length is subject to much lower fluence. Finally, for welds found to contain IGSCC flaws, BWRVIP guidance is available to address flaw tolerance evaluation. To ensure that plants appropriately consider fluence in jet pump aging management, additions to BWRVIP-41 are proposed.]] TS

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 5×10^{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

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.

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). . For UT systems demonstrated in accordance with BWRVIP-03, there is high confidence that indications having significant circumferential length would be detected.

Confidence in long-term integrity is additionally supported by an assessment of the characteristics of the flaw(s) identified. Many years of study have resulted in development of a sound engineering basis for managing IGSCC.

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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

Therefore, it is concluded that the bases for the scope expansion exemption are sufficiently conservative to address any postulated differences in the effectiveness of various hydrogen water chemistry technologies. The water chemistry regime in use between the outage in which the baseline UT was performed and the current outage is not relevant to the application of the scope expansion exemption.

With regard to the examples provided within the RAI, these examples do not include information regarding the inspection history of the welds to be exempted from scope expansion examinations nor details regarding characterization of the cracking observed. As a result, it is not possible to provide definitive conclusions regarding the applicability of the exemption allowed by Section 3.2.8.1.2 to the examples. However, based on the information provided, it can be concluded that neither of these examples present clear challenges to the fundamental premise underlying the exemption; that the large diameter jet pump diffuser and adapter welds are tolerant of significant amounts of cracking and that relatively short IGSCC flaws do not represent a substantial challenge to jet pump integrity.

Finally, to ensure that the exemption intended by Section 3.2.8.1.2 is clear, the BWRVIP proposes the following enhancement of this section:

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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.

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%.

[[

Issue: In Section 2.2.1.2, the TR discusses the materials used in the jet pump assembly and states Content Deleted – EPRI Proprietary Licensed Material . 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% ferrite and CASS > 7.5% 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.

BWRVIP Response to RAI-3

Evaluations previously documented in BWRVIP responses to NRC RAIs on BWRVIP-234 provide a comprehensive evaluation of ferrite estimate uncertainties associated with use of Hull's equations (BWRVIP letter 2014-086 [3a]). It is concluded from these evaluations that ferrite estimates made using Hull's equations are reasonably accurate and do not systematically under-predict or over-predict ferrite content. These evaluations further document that the standard error in the Hull's equations predictions is "of the order of 3% delta ferrite, or perhaps as low as 2% delta ferrite".

Separately, NRC concerns related to IGSCC of CASS components were addressed in BWRVIP letter 2015-150 [3b]. This BWRVIP letter addresses several points related to IGSCC. The points most relevant to this RAI response are briefly summarized below as background information:

(1) The staff position for CASS in Generic Letter 88-01 is focused on weld-induced sensitization and its impact on susceptibility to IGSCC. Even when the CASS material was beyond the carbon and ferrite limits it was allowed to be examined at the same frequency as non-susceptible or resistant material. This letter further notes that if sensitization is the limiting concern for IGSCC of CASS components, the impact would be limited to weld HAZ, for which inspection data are available for jet pump components (described below).]] TS

(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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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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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] ϕ_{mean} is the mean of the EOL peak neutron fluence values from the 16 units included in the study.

[3] ϕ_{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 3×10^{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 5×10^{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.

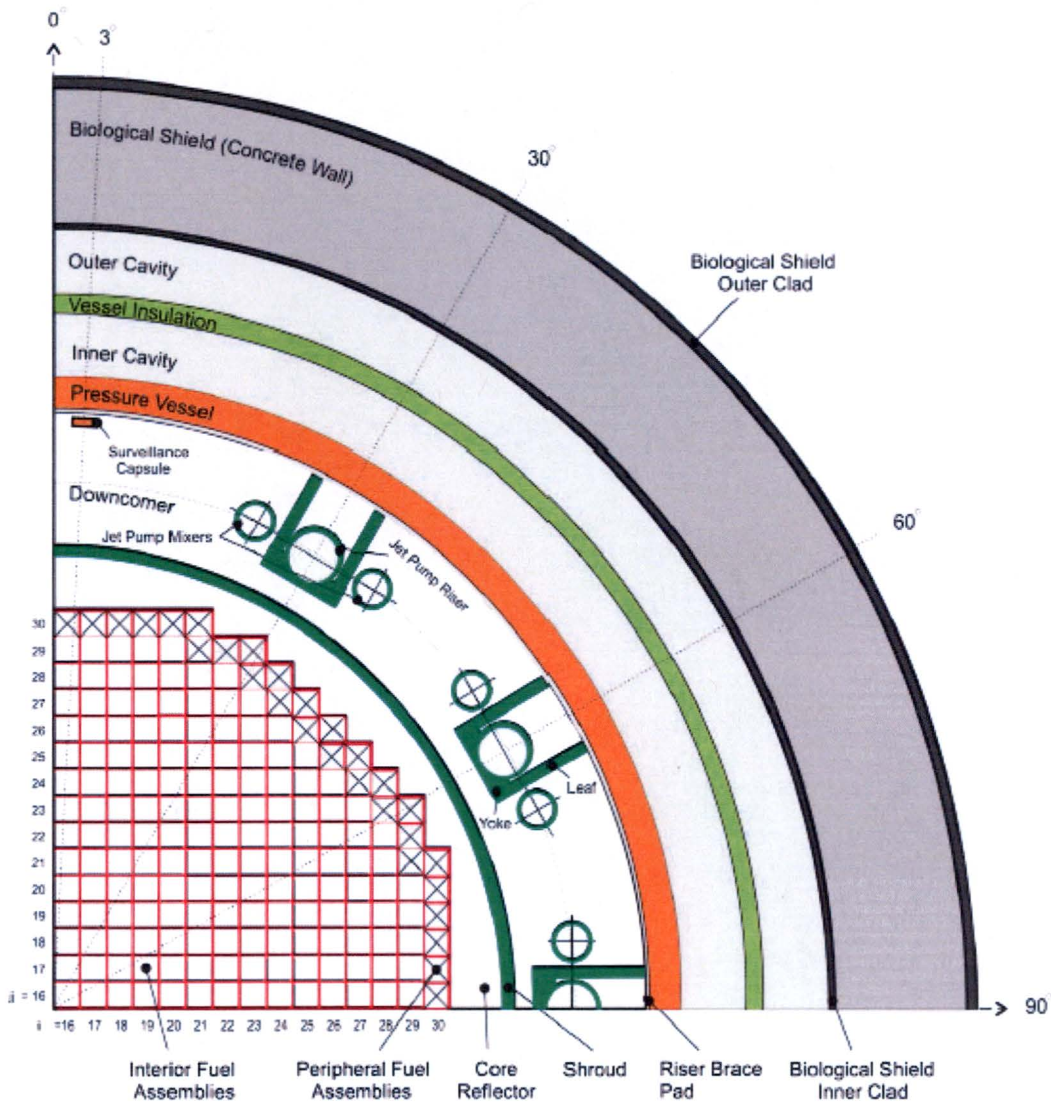

Figure 4A: Plan View of Typical BWR Reactor
(excerpted from BWRVIP-281NP, Figure 3-2)

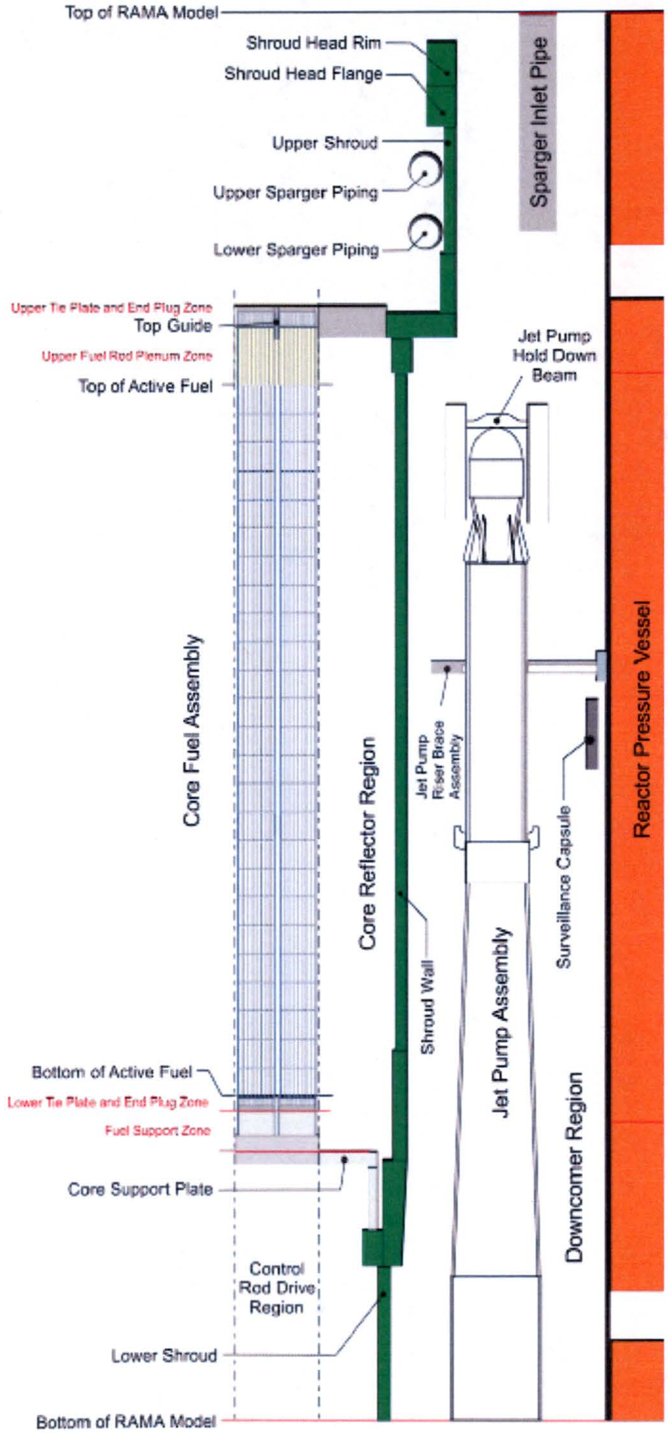

Figure 4B: Elevation View of Typical Jet Pump Assembly
(excerpted from BWRVIP-281NP, Figure 3-3)

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Figure 4C: Jet Pump Assembly Weld Locations

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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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The preceding evaluation specifically addresses riser pipe weld locations common to all jet pump BWRs. However, an understanding of fluence variation occurring along the length of the riser pipe, as well as for the jet pump inlet and mixer welds (located to either side of the riser pipe) is also useful in understanding jet pump EOL fluence. To provide this information, fluence maps visually illustrating EOL fluence across the entire jet pump assembly were developed. Figure 4D provides an example of such a jet pump fluence map.

Fluence profiles similar to that provided in Figure 4D were developed for all 16 plants in the study. The following additional observations can be made from the fluence profile study results:

In summary, the fluence study described above illustrates that, based on conservative assumptions, jet pump locations potentially subject to fluence exceeding the threshold

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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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Figure 4D: Jet Pump Assembly Fluence Profile

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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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Finally, the BWRVIP notes that although a generic threshold fluence of 5×10^{20} n/cm^2 has been used throughout the discussion presented above, there is little evidence that accumulation of fluence at or just beyond this threshold, as will be the case with the jet pump locations described above, will result in an adverse trend in cracking. Although some enhanced growth of flaws could be conjectured, existing guidance is adequate to manage flaw growth, regardless of fluence. There are few data to characterize the potential for new flaw initiation in the fluence range occurring for jet pump components that are both uncracked and protected by hydrogen water chemistry technologies. Periodic examination of BWR internals subject to significantly higher fluence (i.e., core shroud and top guide) have not identified clear evidence of a significant adverse trend in new SCC initiation. Were such an effect relevant to jet pumps to exist, it should have already been manifested in core shroud or top guide performance, since the accumulated fluence values for these components at present is already significantly higher than the estimated jet pump peak EOL fluence.

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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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Current BWRVIP guidance regarding SCC CGRs to be used in flaw evaluations of thin-walled components[4] requires that a CGR of $5x10^{-5}$ inches per hour be assumed for all austenitic stainless steel flaw evaluations, including all irradiation levels and all water chemistries.

A CGR of $5x10^{-5}$ inches per hour has been found over time to represent a conservative upper end value for all BWR internals evaluations. It has been routinely applied to irradiated BWR internals for the purpose of core shroud flaw evaluations and found, in all cases, to conservatively encompass uncertainties associated with not only irradiation, but the potential for new flaw initiations as well. Since this value is found appropriate for all irradiation levels, there is no impact with regard to management of existing jet pump flaws.[5]

With regard to fracture toughness, BWRVIP-266 (Section 4.1) notes the following:

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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

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[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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A new Section 5.1.2.2 will be added to alert program owners to the need for consideration of irradiation effects in structural evaluations:

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CONCLUSIONS

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The majority of jet pump locations associated with IASCC concerns will continue to be routinely examined under the optimized inspection program. Within the set of higher fluence jet pump locations, the only locations having any history of IGSCC are the Reinspection of these locations provides data that can be used to identify any significant adverse trends potentially associated with IASCC.

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Additionally, as discussed above and generally illustrated in the figures and tables presented in the response to RAI-4, the $5x10^{20}$ n/cm^2 threshold is exceeded only for upper riser, inlet and mixer welds in a limited number of high fluence units. Even in these cases, the threshold is exceeded only along weld zones nearest the core. For circumferential welds, most of the weld length is subject to much lower fluence. Finally, for welds found to contain IGSCC flaws, BWRVIP guidance is available to address flaw tolerance evaluation. To ensure that plants appropriately consider fluence in jet pump aging management, additions to BWRVIP-41 are proposed.]] TS

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

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.

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.

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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). . For UT systems demonstrated in accordance with BWRVIP-03, there is high confidence that indications having significant circumferential length would be detected.

Confidence in long-term integrity is additionally supported by an assessment of the characteristics of the flaw(s) identified. Many years of study have resulted in development of a sound engineering basis for managing IGSCC.

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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

Therefore, it is concluded that the bases for the scope expansion exemption are sufficiently conservative to address any postulated differences in the effectiveness of various hydrogen water chemistry technologies. The water chemistry regime in use between the outage in which the baseline UT was performed and the current outage is not relevant to the application of the scope expansion exemption.

With regard to the examples provided within the RAI, these examples do not include information regarding the inspection history of the welds to be exempted from scope expansion examinations nor details regarding characterization of the cracking observed. As a result, it is not possible to provide definitive conclusions regarding the applicability of the exemption allowed by Section 3.2.8.1.2 to the examples. However, based on the information provided, it can be concluded that neither of these examples present clear challenges to the fundamental premise underlying the exemption; that the large diameter jet pump diffuser and adapter welds are tolerant of significant amounts of cracking and that relatively short IGSCC flaws do not represent a substantial challenge to jet pump integrity.

Finally, to ensure that the exemption intended by Section 3.2.8.1.2 is clear, the BWRVIP proposes the following enhancement of this section:

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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.