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2016-036 BWR Vessel & Internals Project (BWRVIP)

April 4, 2016

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

Attention: Joseph Holonich

Subject: Project No. 704 – BWRVIP Response to BWRVIP-234 Draft Safety Evaluation

Reference: Letter from Kevin Hsueh (NRC) to Tim Hanley (BWRVIP Chairman), "Draft Safety Evaluation of the BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Case Austenitic Stainless Steel for BWR Internals (TAC NO. ME5060)," dated March 8, 2016

The NRC letter referenced above transmitted a draft NRC Safety Evaluation (SE) of the BWRVIP document entitled "BWRVIP-234: BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Case Austenitic Stainless Steel for BWR Internals" to the BWRVIP and requested that the BWRVIP identify any proprietary information in the draft SE. The letter also requested that the BWRVIP provide any comments on factual errors or clarity concerns.

To facilitate the NRC staff's review of the BWRVIP's comments, the NRC requested the BWRVIP provide a marked-up copy of the draft SE showing proposed changes and a summary table of the proposed changes. Attachment 1 provides the marked-up copy with identification of the BWRVIP's comments. Note that the BWRVIP found that the draft SE did not contain any EPRI proprietary information.

If you have any comments or questions please contact Bob Carter at 704.595.2519 or by email at bcarter@epri.com.

Sincerely,

[signatures]

Andrew McGehee, EPRI, BWRVIP Program Manager
Drew Odell, Exelon, BWRVIP Integration Committee Chairman

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DRAFT SAFETY EVALUATION OF THE BWRVIP-234 REPORT

"BWR VESSEL AND INTERNALS PROJECT: THERMAL AGING AND NEUTRON EMBRITTLEMENT EVALUATION OF CAST AUSTENITIC STAINLESS STEEL FOR BWR INTERNALS (BWRVIP-234)"

(TAC NO. ME5060)

1.0 INTRODUCTION

1.1 Background

By letter dated September 10, 2010, the Boiling Water Reactor (BWR) Vessel and Internals Program (BWRVIP) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval the Electric Power Research Institute (EPRI) proprietary version of report TR-1016574 (BWRVIP-234, Ref. 1). This report was supplemented by letters dated September 18, 2012, May 23, 2014, and March 9, 2015 (Refs. 2, 3, and 4) in response to the NRC staff's request for additional information (RAI) questions. Additional background information was provided by a letter dated November 19, 2015 (Ref. 5).

The purpose of the BWRVIP-234 topical report (TR) is to evaluate the material composition, fluence, stresses and the field experience of Cast Austenitic Stainless Steel (CASS) components in BWR applications, and recommend augmented inspections if needed. This TR will also address the technical basis for the evaluation of loss of fracture toughness due to the potential synergistic effects of thermal embrittlement (TE) and neutron irradiation embrittlement[a] (IE) on BWR reactor vessel internal (RVI) components manufactured from CASS materials, as recommended in NUREG-1801, Rev. 1, Section XI.M13 (Generic Aging Lessons Learned (GALL) Report)[b]. The guidelines in the GALL Report are essentially the same as described initially in a letter from the NRC staff to the nuclear industry commonly referred to as the Grimes letter (Ref. 6).

In this TR, the investigators compiled and evaluated information on embrittlement issues with CASS materials for the RVI components in the BWR environment. The investigators applied a systematic screening criteria, based on the significant factors affecting embrittlement, to the components that are typically manufactured from CASS materials in all operating BWRs. The recommendations for any augmented inspections are based on a given component's susceptibility to loss of fracture toughness due to the combined effects of TE and IE.

1.2 Purpose

The NRC staff reviewed the TR and the supplemental information that was submitted to the NRC staff to determine whether the guidance in the document provides acceptable levels of quality for evaluation of the internal BWR component manufactured from CASS materials. The

[a] Sometimes referred to simply as neutron embrittlement.
[b] BWRVIP-234 was submitted before GALL, Revision 2 (December 2011) was approved to replace GALL Revision 1. Revision 2 includes a similar description except that the screening criteria for augmented inspections are found in GALL, Rev. 2, Section XI.M9, BWR Vessel Internals.

review considered the microstructure, irradiated fracture toughness, the neutron fluence, the applied stress on each component, and the ability of current BWRVIP inspections to detect degradation.

1.3 Organization of this report

Because the TR is proprietary, this safety evaluation (SE) was written not to repeat proprietary information contained in the report. The NRC staff does not discuss, in any detail, the provisions of the guidelines nor the parts of the guidelines that it finds acceptable. A brief summary of the contents of the TR is given in Section 2 of this SE, with the evaluation of the submittal along with the significant RAI responses presented in Section 3. The conclusions are summarized in Section 5.

2.0 SUMMARY OF THE BWRVIP-234 REPORT

The TR discusses the following topics:

<u>Section 1:</u> Introduction and Background – provides a brief discussion of the objectives and scope for the report. The GALL Report, Revision 1, Section XI.M13 states that an American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME Code), Section XI, VT-3 examination is required to be performed of RVI components. In addition, the GALL Report specifies that for the license renewal period these inspections shall be augmented by an aging management program to address the synergistic effects of thermal aging and neutron embrittlement in components manufactured from CASS materials. This aging management program consists of (a) identifying susceptible components; and (b) either performing additional inspections of these components, or performing a component-specific evaluation to confirm that the stresses (tensile loading) in the components are sufficiently low such that augmented inspections are not warranted.

This TR is for information only and the implementation requirements of Nuclear Energy Institute 03-08, "Guideline for the Management of Materials Issues," are not applicable.

<u>Section 2:</u> Literature Review – examines the factors that influence the TE mechanism, and how the potential synergism between TE and IE has been addressed in the past.

<u>Section 3:</u> Materials and Environment for BWR Internals – describes the specific factors (chemical composition and neutron fluence) as they relate to the BWR fleet. The key findings in this review were as follows:

- The majority of the components are manufactured according to either ASME SA-351 or ASTM A351 grade CF8 material.
- No molybdenum (Mo) or niobium (Nb) was specified in the grades of castings used for internal BWR components in the USA,
- The minimum ferrite volume fraction was originally specified to be 8 percent, as calculated from the Schaeffler diagram; no maximum ferrite was specified.
- based on review of about 80 available certified material test records (CMTRs), the calculated ferrite content (using Hull's equations for chromium (Cr) and nickel (Ni) equivalent factors) of the CASS components varied between 3 and 19 percent with an average value of 10 percent, and

- the estimated neutron fluence values, based on 60 years of operation, for each of the 10 components potentially fabricated from CASS materials were calculated for a BWR/6, 218-inch plant at extended power uprate (EPU) conditions, which was bounding for 251-inch BWR/5 and BWR/4 plants.

<u>Section 4:</u> Component Screening – described several factors, based on previously approved NRC documents, that could screen out BWR CASS components from augmented inspection requirements. The factors are listed below:

1. Ferrite content,
2. Neutron fluence,
3. Fracture toughness,
4. Stress, and
5. Current BWRVIP inspections.

The BWRVIP noted that operating experience (OE) for components fabricated from CASS materials shows that intergranular stress corrosion cracking (IGSCC) in BWRs is not a problem. Even in type 308 stainless steel welds (which are duplex materials similar to CASS), crack initiation has been extremely rare except in a few cases where the ferrite content was less than 5 percent. CASS components in BWRs are required to contain a minimum of 8 percent ferrite. The report concludes that the ferrite levels by themselves are not adequate to exempt RVI components fabricated with CASS materials from augmented inspections.

For fracture toughness, the Grimes letter considers a J-integral value of 255 kJ/m^2 at a crack extension of 2.5 mm as an adequate basis for a screening criteria to ensure function for a safety-significant component like Class 1 piping. The BWRVIP suggests that the same criteria could be applied as a basis for screening criteria to BWR RVI components fabricated from CASS materials that are potentially susceptible to degradation from TE and IE.

The TR states that little experimental data exists for fracture toughness data of actual CASS components that are known to be susceptible to TE and IE. The BWRVIP has presented two methods to estimate the fracture toughness. The first method is based on the Z-factor correction as defined in the ASME Code, Section XI, Nonmandatory Appendix C (Ref. 7) for austenitic stainless steel pipe welds. The second approach is to use the recommended lower bound properties in BWRVIP-100-A (Ref. 8), based on testing of base metal and core shroud welds, to predict the J-integral vs. crack extension curve, evaluated at 2.5 mm extension. Both the Z-factor correction and the BWRVIP-100-A methods would predict a fracture toughness in excess of the fracture toughness screening level, indicating that no evaluation or inspection is needed to manage the loss of fracture toughness.

The GALL Report allows for the use of a component-specific evaluation to determine the stress on the component during ASME Code Level A, B, C, and D conditions. If the component is loaded in compression or less than 5 kilo pounds per square inch (ksi) in tension, the GALL Report considers that adequate to prevent brittle fracture.

The requirement to address the embrittlement of CASS materials subject to both TE and IE is based on the interpretation that augmented inspections are required unless the screening criteria described above are met. However, the BWRVIP program already requires inspection of many of the CASS components.

Section 5: Stress Evaluation – summarizes the results of stress analysis for the orificed fuel support (OFS), the core spray sparger nozzle (CSSN) elbows, the jet pump (JP) assembly, the JP restrainer bracket, and the low-pressure coolant injection (LPCI) coupling. The analyses presented demonstrate that the tensile stresses in the CSSN elbows are less than 5 ksi and therefore, there is little chance of brittle failure, and no augmented inspections are needed. The other components could have tensile stress greater than 5 ksi,

For the control rod guide tube (CRGT) bases, no analysis was done because the maximum neutron fluence was orders of magnitude below the fluence screening criteria so that no synergistic interaction between TE and IE is anticipated.

Section 6: Combined Assessment of CASS Components– describes an assessment of the need for additional analysis or augmented inspection based on the factors presented in Section 5 of this report. In all cases where there are existing BWRVIP inspections required, the report credits those existing inspections as sufficient to make any additional inspections redundant. The results are summarized in Table 6.1 of the TR.

Section 7: Conclusions - given that all of the CASS components covered by this report are either CF-3 or CF-8 grade castings with an estimated delta ferrite between 3 percent to 19 percent, the recommendations are based on three critical screening criteria: stress, projected neutron fluence for 60 EFPY, and the estimated J-integral value at 2.5 mm of crack extension. Based on the screening criteria and the current BWRVIP inspections, no further augmented inspections of the CASS components are recommended.

Appendix A: The appendix includes the available certified material test records (CMTRs) and the mean, calculated delta ferrite content for each heat that was evaluated.

3.0 EVALUATION

The NRC staff's review focused on the technical basis for the recommendation that no augmented inspections are needed to manage the aging of CASS for the loss of fracture toughness due to the combined effects of TE and IE for the CASS components found in BWR RVI components. During its review of the TR, the NRC staff issued two RAIs that addressed technical issues. The details of the NRC staff's RAIs and the corresponding responses are available in Agencywide Documents Access and Management System (ADAMS). However, the NRC staff did not include all the RAI questions and the BWRVIP's responses in this SE; it included only those salient RAI questions and BWRVIP responses that address specific points of emphasis concerning the potential for augmented inspections.

3.1 NRC Staff Evaluation of Ferrite Content Uncertainty

The NRC staff notes that the ferrite content is an important consideration for CF-3/CF-8 materials. A material with a low ferrite content could be susceptible to IGSCC (similar to a wrought austenitic stainless steel), while a material with a high ferrite content could be susceptible to loss of fracture toughness (similar to an irradiated ferritic steel). The susceptibility to IGSCC is a separate concern that is not covered by the scope of the TR and is not considered further in this SE. This section of the SE will consider how to incorporate the uncertainty associated with the prediction of ferrite level for RVI components fabricated from CF-3/CF-8 materials to retain adequate fracture toughness when subject to both TE and IE.

To estimate the delta ferrite content, the Ni and Cr equivalent equations from Hull are calculated from the heat-specific CMTR. The NRC staff was concerned that the discussion of ferrite in the TR does not accurately reflect the uncertainty associated with the prediction. Specifically, the last sentence in Section 3.4 of the TR states that "there is a 99.8 percent confidence that the ferrite level will be below the 20 percent ferrite limit." Therefore in RAI 7, the NRC staff asked the BWRVIP to discuss how the estimated values compare with measured values for CASS components to demonstrate the level of confidence one can place on the calculations, and to provide additional discussion as to how the uncertainty in the calculations affects the screening process for the combined effects of TE + IE.

In the September 18, 2012, response to RAI 7, the BWRVIP stated that the measured delta ferrite content was not included on the CMTRs so that a comparison of measured to predicted delta ferrite for the RVI components in BWRs is not possible. From the CMTRs, there is no Mo content reported because Mo is not an intended alloying addition to the CF-3 and CF-8 grades used for BWR RVI components; thus, there is some uncertainty regarding the calculated ferrite. A residual level of Mo present in the heat of material would affect the delta ferrite content estimated with Hull's equations. Therefore, the BWRVIP examined how the estimated ferrite content could change given a residual Mo content of 0.5 percent by weight, which is the upper bound value for residual Mo in the CF-3 and CF-8 materials as given in SA-351. The results of the analysis demonstrated that the addition of 0.5 percent Mo would result in only a small increase in percent ferrite above that reported in the TR; therefore, the uncertainty in Mo was judged to not affect the ferrite screening process for loss of fracture toughness due to TE in CF-3 and CF-8 materials.

The NRC staff has reviewed the RAI 7 response and noted that in the May 19, 2000, Grimes letter, the calculated ferrite content from Hull's equations represents the mean value with a significant uncertainty (± 6 percent) when compared to the measured values for CASS materials. For example, heat 68 from Chen, et al., (Ref. 9), has a measured delta ferrite content of 23 percent but a predicted value of 15 percent based on Hull's equations. In RAI 7a, the NRC staff requested the BWRVIP to justify why 6 percent should not be added to the calculated ferrite values based on chemistry to represent a conservative upper-bound to the ferrite content and to provide additional discussion as to how the uncertainty in the prediction of ferrite affects the screening process for TE + IE.

In its May 23, 2014, response to RAI 7a, industry, BWRVIP and the Materials Reliability Program (MRP) provided the following conclusions relative to the prediction of ferrite and screening assessment:

1. It is not reasonable to add 6 percent to the delta ferrite values predicted by Hull's equations, since the available data clearly show that Hull's equations do not systematically underpredict measured values.

2. The standard error in the predictions from Hull's equations is of the order of 3 percent delta ferrite, that level of standard error provides a reasonable estimate of the uncertainty in the delta ferrite prediction.

3. The measured values can vary by 1 or 2 percent delta ferrite, depending on the method used.

4. Since the standard error in prediction of delta ferrite with Hull's equations is roughly of the same order as the accuracy of non-destructive measurements of delta ferrite, and

since some degree of uncertainty was included during the process of establishing the delta ferrite screening limits in the Grimes letter for TE alone, there is no need to alter the screening methodology in order to explicitly include any additional measure of uncertainty related to delta ferrite content in the screening for the combined effects of TE + IE.

The NRC staff has reviewed the response to RAI 7a and agrees with the industry that some degree of uncertainty in ferrite content was incorporated into the delta ferrite screening limits for TE alone, but it was not explicitly stated. In this case, considering the combined effects of TE plus IE, a similar level of uncertainty in the predicted ferrite content should be incorporated into the methodology used to predict fracture toughness as a function of neutron exposure, which in turn, will be compared to the acceptance criteria to determine if further evaluation is needed. As detailed in Section 3.3 of this SE, the NRC staff performed an independent confirmatory assessment of the fracture toughness of the RVI CASS components covered by the TR, using its own alternate screening criteria for IE+TE. The NRC staff's IE+TE screening criteria accounts for the uncertainty in ferrite prediction. The concern of RAI 7 and 7a are therefore resolved.

3.2 Staff Evaluation of Component Neutron Fluence Determination

The NRC staff noted that the material screening depends upon the neutron fluence, which was estimated for each of the ten CASS components in Table 3-3 of the TR. The fluence is an integral part of the fracture toughness evaluation so discussion of these assumed maximum values is incorporated into Section 3.3 of this SE.

3.3 Staff Evaluation of Fracture Toughness Basis for Material Screening

In the Grimes letter, the screening was based on measured properties from NUREG/CR-4513, Rev. 1 for samples aged to the saturation condition to account to TE alone. With the measured database, a lower-bound toughness (J integral value at 2.5 mm crack extension, referred to as J @ 2.5) for a CF-8 material with a calculated ferrite content of 15 to 25 percent was predicted to be 343 kJ/m^2. The ferrite screening criteria was chosen to ensure an end-of-life toughness level of 255 kJ/m^2, which was based on a flaw tolerance analysis of a highly stressed pressure boundary component (Ref. 10) determined to be conservative for pressure boundary components. Since the predicted lower bound saturated toughness of CF-8 material with up to 25 percent ferrite is 343 kJ/m^2, but a toughness level of 255 kJ/m^2 was determined to be sufficient, this would provide inherent margin for material with ferrite up to 25 percent. However, the ferrite screening criteria was set at 20 percent, which provides margin for uncertainty in the predicted ferrite content of 5 percent (which is similar to the stated uncertainty of Hull's equations of +/- 6 percent ferrite). Therefore, margin for uncertainty in the ferrite prediction is built into the Grimes letter ferrite screening criteria for low-molybdenum CASS material.

In the case of RVI components manufactured from CASS materials that receive significant neutron fluence, the screening must consider the combined effect of TE and IE, but the NRC staff and BWRVIP agree that there is little test data available to evaluate the combined effects. The BWRVIP has proposed two different screening methodologies to estimate the lower-bound toughness (the Z-factor correction and BWRVIP-100-A), which are reviewed by the NRC staff in the following subsections.

3.3.1 Fracture Toughness Estimates

The NRC staff considered the details of the two methodologies and had concerns regarding the applicability of the approaches. The NRC staff concerns, expressed in in RAI 9, were related to the basis used to estimate the fracture toughness, which could then be compared to the screening criteria for loss of toughness in CASS in the TR. The issues are summarized below along with the staff position on each.

3.3.1.1 *Z-Factor Correction*

Regarding the use of the Z-factor, it is approved in the ASME Code Section XI, Appendix C practice for flux welds in piping systems to account for an observed reduction in toughness of flux welds compared to non-flux welds. In the limit load evaluation described in Appendix C to the ASME Code, Section XI, the applied load is multiplied by the Z-factor to account for the lower toughness of flux welds. In the TR, the Z-factor approach is applied to CASS by dividing the measured values of J@2.5 for wrought stainless steel at the bounding fluence by Z squared to estimate the equivalent toughness of CF-8 with the same irradiation in the TR methodology (since the applied J is proportional to load squared). The wrought stainless steel J values were taken from the BWRVIP-100-A database. The NRC staff did not find the Z-factor approach to be appropriate to account for loss of fracture toughness due to the combined effects of TE + IE of CASS materials; it was meant to account for a reduction in toughness associated with fluxed welds.

3.3.1.2 *Use of BWRVIP-100-A Fracture Toughness Model*

The other method used in the TR to validate the toughness basis for the screening criteria is the BWRVIP-100-A lower bound curve. To determine whether the use of the BWRVIP-100-A model was appropriate for CASS, the NRC staff compared the prediction methodology for fracture toughness from BWRVIP-100-A to that of NUREG/CR-4513, Rev. 1 (Ref. 11) and NUREG/CR-6960 (Ref. 12). The comparison for J @ 2.5 is shown in Figure 1 along with the range of predicted J values for unirradiated CF-8 with no thermal embrittlement (TE) and maximum TE (no irradiation) for CF-8 with > 15 percent delta ferrite (Section 3.1.1 of Ref. 11) along with the Ref. 12 predicted toughness trend as a function of fluence. The lower-bound from Ref. 12 is lower, and therefore more conservative than the BWRVIP-100-A predicted toughness. The predicted toughness from Ref. 12 at 0 dpa (no irradiation) is also consistent with the minimum predicted toughness for CF-8 material due to TE alone, represented by the bottom of the vertical line at dpa = 0 on Figure 1. If extrapolated beyond where it was intended to be used, BWRVIP-100-A would predict a much higher toughness at 0 dpa. Based on this comparison, the NRC staff determined that the BWRVIP-100-A methodology maybe be an effective way to account for IE in welded, wrought structures like the core shroud, but the predicted toughness does not consider the effect of TE and therefore would not be a suitable methodology to use in the TR to account for the combined effects of TE + IE on CF-3 and CF-8 materials, especially those with greater than 15 percent but less than 20 percent ferrite (these would pass the screening for TE alone in the Grimes letter).

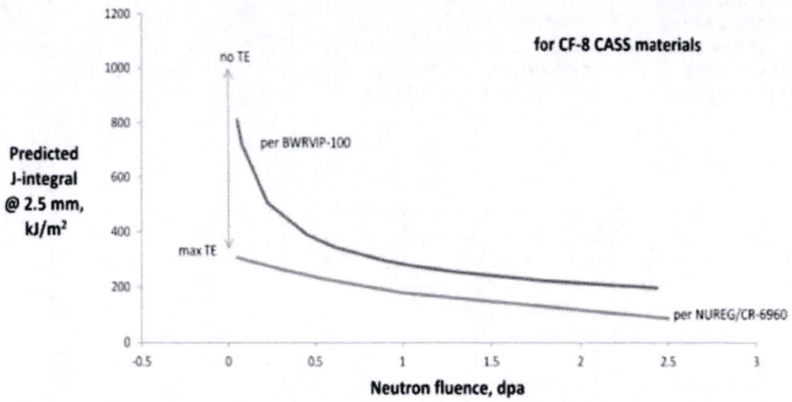

Figure 1. Plot of predicted toughness (J-integral value at 2.5 mm crack extension) from BWRVIP-100-A and NUREG/CR-6960 as a function of neutron fluence. The predicted lower-bound toughness of CF-8 due to TE alone is shown at the bottom of the vertical line at dpa = 0 for reference.

3.3.1.3 <u>Summary</u>

Because of the concerns expressed above with the methods used to validate the toughness screening criteria in the TR and the response to RAI 9, the NRC staff requested in RAI 9a that the BWRVIP review all available data on fracture toughness of irradiated CASS materials, and the associated uncertainties, and to either revise its methodology to predict the lower-bound toughness of CF-3 and CF-8 materials as a function of neutron fluence, or provide further justification that the methodology in the TR is sufficiently conservative.

3.3.2 *Response to RAI 9a*

In its May 23, 2014, response to RAI 9a, the industry provided a discussion of the available data in along with additional justification for why the methodology in the TR is sufficiently conservative; the response also highlighted the problems associated with the sub-size samples needed for evaluation of irradiation effects. The last section included supplemental information related to an industry proposal for screening of RVI components fabricated from CASS. The proposed process for assessment of potential TE and IE of CASS was developed based on a mechanistic model for the effect of which phase is controlling the embrittlement behavior of the CASS material. The proposal uses 1 dpa as a fluence screening limit for IE and is applied to those materials that do not screen in for TE; the format is patterned after that used in the Grimes letter.

The justification for using the TR methodology for CF-3 and CF-8 materials is discussed in the appendix to the RAI 9a response. The response compares the measured toughness for heat affected zone (HAZ) specimens irradiated to 2.15 dpa to the measured toughness of base metal irradiated to 1 dpa. Because the toughness for the base metal specimens at 1 dpa is almost a factor of 3 above the toughness of the HAZ specimens at 2.15 dpa, the industry asserts this is

an adequate demonstration of the adequacy of the methodology in the TR, which is based on dividing actual fracture toughness values from wrought materials in the BWRVIP-100-A database by the Z-factor squared (~ a factor of 2). The NRC staff has reviewed the information in the appendix and notes that the wrought materials and the HAZ samples do not contain any delta ferrite so it is not clear how this methodology could account to the aging effects of TE plus IE on CF-3/CF-8 materials with < 20 percent ferrite.

3.3.3 *Industry's Proposed Joint Revised Screening Criteria*

The May 23, 2014, letter contained supplemental information providing the basis for a proposed revised screening approach for TE and IE of CASS developed by a joint CASS working group comprised of both BWRVIP and MRP representatives. The revised criteria were intended to be applicable to both BWR and pressurized water reactor (PWR) internals. The revised criteria are different than the criteria used in the TR screening process, most notably in that a fluence threshold of 1 dpa is used for susceptibility to IE rather than 0.45 dpa used in the TR.

Regarding the proposed screening criteria for CASS to be used for RVIs, the industry examined the databases that were used in BWRVIP-100 and NUREG/CR-7027 (Ref. 13) in detail. For the range of fluences investigated, the data indicate very little difference between weld metal, base metal, and HAZ. The industry pointed out that this similarity would indicate that the criteria for IE screening for CASS materials should not be markedly different than that for wrought stainless steels. This is in agreement with the industry approach for screening, which proposed setting the fluence screening value for CASS materials to be 2/3 of that for the wrought stainless steels.

The industry approach to screening is supported by test results from Kim, et al. (Ref. 14) and the preliminary data of Chen, et al. (Ref. 15). The discussion highlights the relatively high fracture toughness of CF-8 and CF-3 and the fact that there are no data that demonstrates any exacerbation effect due to the combined thermal and irradiation effects. The industry noted that while the preliminary data of Chen et al. may display some greater loss of toughness on thermal plus irradiation exposures compared to irradiation or thermal exposure alone, these data do not necessarily reflect a significant combined effect. The industry also noted that the compositions of the materials tested by Chen et al., which did display good toughness, would have screened in for TE under the proposed industry screening hierarchy.

3.3.4 *Summary of Initial NRC Staff Review of Industry Response to RAI 9a*

Based on its review of BWRVIP's response, and the proposed joint industry screening criteria, the NRC staff identified several unresolved issues related to the basis for the TR CASS evaluation methodology, and therefore the NRC staff was unable to resolve RAI 9a. These issues are summarized in the following subsections.

3.3.4.1 <u>Use of Room Temperature Data</u>

All of the CF-3 and CF-8 data from Kim, et al. are from tests at room temperature, which is not conservative for the development of a lower bound estimate of fracture toughness at higher temperatures. This is graphically illustrated in Figure 7 of the May 23, 2014, response to RAI 10 where the test results a room temperature are all higher than that measured at higher temperature. It is the NRC staff's opinion that the room temperature results are qualitative evidence of ductile behavior, but not a quantitative assessment of fracture toughness at operating temperature as required for comparison to the acceptance criteria in the Grimes letter.

3.3.4.2 *Significance of Low-Fluence Aged and Irradiated Data*

The testing from Chen, et al. was done at typical operating temperature, but the irradiation conditions were only a fraction of the proposed fluence screening level. The data from Chen et al. suggests that there is a small combined effect of IE + TE at 0.08 dpa, but this does not provide any information about the properties at fluences near 1 dpa, which could support the industry's proposed fluence screening for CF-3 and CF-8 at 1 dpa. Given the points discussed above, the NRC staff still questioned whether the proposed methodology in the TR is sufficiently conservative for determining the lower-bound toughness of CF-3 and CF-8 materials as a function of neutron fluence.

3.3.5 *Development of NRC Proposed Screening Criteria*

With respect to the overall screening process and mechanistic model proposed by industry, the NRC staff developed a draft screening criteria for aged and irradiated CASS (Ref. 16). The NRC staff's criteria are based on a continuous reduction in fracture toughness of the austenite phase in CASS as a function of fluence, without a transition from ferrite controlled to austenite controlled fracture, consistent with the lack of any transition in the fracture appearance of test specimens. The NRC staff agreed with industry that the screening for IE + TE should retain as much consistency as possible with the Grimes letter screening for TE, but the limit on neutron fluence for screening should be reconsidered. Information from NUREG/CR-7027, an update on the data originally included in NUREG/CR-6960, was suggested by the NRC staff as a lower bound curve for the fracture toughness at 2.5 mm crack extension as a function of fluence. The NRC staff also suggested that the differences between the industry and the NRC staff in screening approaches could be resolved by component-specific toughness criteria, something less than 255 kJ/m^2 at 2.5 mm, which takes into account the lower crack driving forces in a RVI component.

3.3.6 *July 15, 2014, Public Meeting*

The NRC staff and industry held a public meeting on July 15, 2014, to discuss the two different proposed screening criteria for CASS. Industry used data from testing at room temperature along with the preliminary data from Chen, et al. for CASS thermally aged and irradiated to 0.08 dpa that showed minimal reduction in toughness, to support its technical basis for the conservatism of its screening methodology. The NRC staff disagreed with the hierarchy or sequence of screening first for TE, then for IE. The NRC staff also did not find that industry had provided a sufficient technical basis for increasing the fluence threshold for IE screening to 1 dpa.

Given the NRC staff's concerns with the industry's May 23, 2014, response to RAI 9a, and the discussions at the July 15, 2014, public meeting, the BWRVIP agreed to expand the response to RAI 9a to demonstrate the adequacy of the proposed screening for RVI components manufactured from CF-3/CF-8 materials, as documented in the meeting summary (Ref. 17).

3.3.7 *BWRVIP 2015-025*

The BWRVIP followed up with the NRC on the issues raised in the July 15, 2014, meeting on CASS with its March 9, 2015, letter. The main points of the supplement are summarized below:

- The industry recognizes that the NRC is intending to revise its original IE position in the Grimes letter from 0.00015 dpa to a position in the region of 0.5 to 1.5 dpa. The industry agrees that a change is appropriate and has proposed a value of 1 dpa.
- The NRC staff's proposal for screening will penalize CF-3 and CF-8 materials because of the lower properties associated with the Mo-containing CF-8M materials that are included in the NUREG/CR-7027 database.
- There is no data that demonstrates a synergistic effect for CF-3 and CF-8. As such the industry has proposed criteria that do not combine TE and IE. Each mechanism is considered distinct and separate.
- The introduction of a new criteria set for materials with ferrite content between 15 and 20 percent (having a lower proposed screening value for IE of 0.45 dpa) is unnecessary and technically unfounded. The introduction of this category of ferrite content is significantly burdensome to licensees since it will require more complex and potentially more error-prone assessments of components fabricated from CASS materials by virtue of having more categories. The industry maintains that the categories of materials and associated ferrite levels contained in the Grimes letter are appropriate.
- The criteria proposed by the industry (20 percent ferrite and 1 dpa) have been shown to project significant margin on toughness reduction and therefore safety when compared to measured embrittlement behavior for CF-3 and CF-8 materials.

The NRC staff has reviewed the March 9, 2015, letter and finds that the lack of high-temperature data above 0.08 dpa for CF-3 and CF-8 materials makes a robust technical basis for any position tenuous. Much of the supporting text in the March 9, 2015, letter is dealing with TE alone, yet the plot in Figure 1 of Attachment B to the March 9, 2015, letter does not include TE alone and depends on tests in air at room temperature to develop an estimate of J @ 2.5 as a function of neutron fluence for CF-3 and CF-8 materials under operating conditions; the proposed lower-bound curve starts at about 550 kJ/m^2 for 0.02 dpa. By comparison, the lower bound toughness for TE alone (0 dpa) in CF-8 with > 15 percent ferrite is < 400 kJ/m^2 which is lower than the BWRVIP's proposed value at 0.02 dpa. Because the trend curve in Figure 1 of Attachment B does not include the lower-bound estimate of toughness due to TE alone, the industry proposed technical basis effectively removes the significant margin that was approved in the Grimes letter, as discussed in the beginning of Section 3.3 of this SE.

The NRC staff agrees with the industry that there does not appear to be any "synergistic" effects, and that terminology should be eliminated. The mechanisms are clearly distinct and separate in the fact that TE mainly affects the ferrite and IE affects both ferrite and austenite. However, the NRC staff feels that any screening criteria should incorporate the bounding toughness for TE alone, and then include the effects of IE by reducing the estimated, lower-bound toughness for TE alone by a factor proportional to the neutron exposure.

3.3.8 *Staff's Revised Screening Criteria*

Based on the discussions with industry, the NRC staff intends to revise its screening criteria for RVIs fabricated from CASS materials based on a new methodology to predict J @ 2.5 as a function of neutron fluence, which takes into account chemical composition, ferrite content, and casting method; the format is similar to what was used in the Grimes letter for TE alone. There are two key differences in the revised screening criteria:

1. the application of a lower acceptance criteria, J @ 2.5 value of 200 kJ/m^2, based on the recognition that RVI components do not need the same level of toughness as pressure boundary components, and
2. the trend curve starts at a dpa = 0 that bounds the estimated J @ 2.5 from NUREG/CR-4513, Rev. 1.

The revised toughness basis supports screening for loss of fracture toughness for CF-3/CF-8 materials with < 20 percent ferrite and a fluence limit of 1 dpa. Therefore, the NRC staff's revised screening criteria are similar to those proposed by the industry in BWRVIP 2015-025, but by bounding the lower-bound estimate of toughness at a dpa = 0, the method maintains the consideration of ferrite uncertainty built into the approved screening from the Grimes letter.

The NRC staff's revised acceptance criteria is supported by the results of some generic flaw tolerance evaluations of representative RVI components found in Appendix D to the BWRVIP 2015-025 letter. It is likely these criteria will be published in the future in an NRC guidance document such as a license renewal interim NRC staff guidance document.

A summary of the technical bases for the NRC staff's screening criteria, is contained in Appendix A.

3.3.9 *Staff Independent Confirmatory Analysis*

The NRC staff applied its screening criteria described in Appendix A using the generic CASS component information in the TR (material grade, ferrite content, and neutron fluence) and determined that all the generic CASS components can be screened out with respect to significant loss of fracture toughness due to TE and IE. No augmented inspections would be required due to toughness considerations for up to 60 years of service (40 year original license plus 20 year renewal).

3.3.10 *Summary – Fracture Toughness Basis for Material Screening*

Based on its independent analysis using its revised screening criteria, the NRC staff determined that the aging management recommendations for the six generic CASS components (i.e., the six CASS components identified in Table 6-1) are acceptable, e.g., no additional inspections are necessary to manage aging due to loss of fracture toughness. However, the NRC staff does not accept the screening methodology as described in the TR, for generic use for screening for loss of fracture toughness in CASS RVI components. The NRC staff has developed an alternative screening process, described in Appendix A, which could be used to replace the screening described in Chapters 4 and 6 of the TR. Furthermore, with the NRC staff's revised methodology to predict the toughness outlined in Appendix A, the uncertainty in ferrite content incorporated into the delta ferrite screening limits for TE alone is also incorporated into the screening limits for TE plus IE. With this alternate screening process, the NRC staff's concern expressed in RAI 9a is resolved.

Commented [C-WC1]: Recommend inserting the parenthetical "(i.e., the six CASS components identified in Table 6-1) to clarify that when the SE refers to "six generic CASS components it means those referenced in Table 6-1 of the TR. Alternatively, wherever "six generic CASS components" is stated in the SE, replace it with "the six CASS components identified in Table 6-1.

3.4 <u>Staff Evaluation of Stress Effects and Material Screening</u>

The NRC staff has reviewed the component-specific stress analyses for the RVI components manufactured from CASS materials in Section 5 of the TR. For CSSN elbows, the analyses demonstrated that the tensile stresses are less than 5 ksi and the NRC staff considers there is little chance of brittle failure when the tensile stresses are below 5 ksi. For the other

components that could be fabricated from CASS material, the stresses are above 5 ksi and therefore, could not be screened out on the basis of stress and would be subject to further evaluation for aging management. The NRC staff finds the screening for stress is satisfactory.

3.5 <u>Staff Evaluation of Material Screening and Existing Inspections</u>

The NDE methods of the existing examinations, discussed in Section 6, "Assessment of CASS Components," were justified because they were capable of detecting degradation other than loss of fracture toughness due to the combined effects of thermal and neutron embrittlement. Given that, based on the NRC staff's initial assessment, the lower-bound toughness for a CASS component subject to both thermal and neutron embrittlement could be less than the toughness screening criteria, the NRC staff asked the BWRVIP in RAI 11 to justify the adequacy of the existing BWRVIP inspections to detect subcritical flaws as discussed in the GALL Report, XI.M9 paragraph 4 -- *Detection of Aging Effects*.

By letter dated May 23, 2014, the industry concluded that while some BWR internal components might exhibit fracture toughness that approaches the lower bound value, this fact does not affect the effectiveness of the existing examinations with respect to detection of cracking before it reaches a critical flaw size that could affect the function of any safety-significant system. The inspections utilized by the BWRVIP for detection of flaws have been reviewed and approved by the NRC.

The BWRVIP also noted that the wrought material is more likely to crack than CASS and inspecting the wrought materials serves as a leading indicator. Furthermore, inspection of wrought to CASS weld joints would also reveal any flaw in the CASS portion of the weld joint. The applicable and NRC-approved BWRVIP guidelines recommend more stringent inspections, such as EVT-1 examinations or ultrasonic methods of volumetric inspection, for certain selected components and locations.

The BWRVIP further noted that even when comparing applied crack-driving forces to lower bound fracture toughness, there are no BWR internals that are discussed in Section 6 of the TR that will fail due to an undetectable flaw and thus challenge the integrity of the component, and that cracks would have to be visible before they are large enough to challenge integrity. Consequently, the aging effects due to TE and IE are considered by the BWRVIP to be adequately managed.

To summarize the BWRVIP's position expressed in the response to RAI 11, the NRC has accepted the aging management approach for BWR internals and no new experience has been observed to date that challenges that position. Based on the above discussions, the BWRVIP believes that the NRC accepts the inspection methodologies for BWR components as capable of performing their intended function of detecting flaws in the reactor vessel internals and detecting cracks of concern associated with non-pressure boundary RPV internals.

Based on the NRC staff's review of the industry response to RAI 11 and several of the existing BWRVIP reports (Refs. 18-20), the NRC staff notes that consideration of the uncertainty in the ferrite content, as discussed in Section 3.1 of this SE, was not included in any of the existing reports; the omission of any consideration of the uncertainty in the ferrite content in the existing BWRVIP reports is not within the scope of the NRC staff's review of the TR, but should be addressed in future updates to the existing BWRVIP reports. What is relevant here is the fact that, with this SE, the NRC staff has reached a satisfactory resolution for RAI 9a in Section 3.3 of this SE for BWRVIP-234; the components will have adequate fracture toughness so that the

structural integrity related to the loss of fracture toughness of the RVIs is not a concern for the license renewal period. Therefore, the issue that raised the NRC staff's concern expressed in RAI 11 is resolved by the fact that there is no need for any augmented inspections related to the loss of fracture toughness due to the combined effects of TE and IE.

3.6 Applicability of the Topical Report

The NRC staff's evaluation was performed using the sample of CMTRs, and conservative fluence analyses based on a BWR/6, 218-inch plant at EPU conditions that translates to a maximum neutron fluence for 60 years of operation. Therefore, application of the TR to the current licensing basis for any BWR to manage loss of fracture toughness of the six generic CASS components covered by the TR is dependent on the following condition. The licensee's plant-specific fluence assessment of the six generic CASS ~~RVI~~ components must demonstrate that the projected neutron fluence is bounded by the maximum fluence stated in Table 3-3 of the TR.

Commented [C-WC2]: Recommend replacing "RVI" with "CASS" to be consistent with the other references to the six CASS components of Table 6-1.

When publishing the approved version of MRP-234, Section 3.5 shall be revised to require a plant-specific fluence assessment of the six generic CASS components ~~for all plant-specific CASS RVI components~~. **This is a Topical Report Condition.**

Commented [C-WC3]: Recommend replacing "for all plant-specific CASS RVI components" with "of the six generic CASS components" to be consistent with the first paragraph of Section 3.6.

4.0 LIMITATIONS AND CONDITIONS

Any deviations from the aging management programs determined to be necessary to manage the effects of aging during the period of extended operation and to maintain the functionality of the components or other information presented in the report, i.e. accumulated neutron fluence, will have to be identified by the licensee/renewal applicant and evaluated on a plant-specific basis in accordance with 10 CFR 54.21(a)(3) and (c)(1).

5.0 SUMMARY AND CONCLUSIONS

The NRC staff has reviewed the BWRVIP-234 report and the supplemental information that was transmitted in the BWRVIP letters on September 18, 2012, May 23, 2014, March 9, 2015, and November 19, 2015. Based on its independent analysis using its revised screening criteria, the NRC staff determined that the aging management recommendations for the six generic CASS components listed in Table 6-1 of the TR are acceptable, e.g., no additional inspections are necessary to manage aging due to loss of fracture toughness. The NRC staff has found that this report, as modified by the **topical report condition** discussed in Section 3.6 of this SE, provides an acceptable basis for plant-specific AMPs for managing the aging effect of loss of fracture toughness in CASS in BWR RVI components.

As modified by this SE and approved by the NRC, any applicant may reference BWRVIP-234 in a License Renewal Application or other licensing action to satisfy the requirements of GALL, Rev. 2, Section XI.M9 for demonstrating that the effect of aging on the RVI components manufactured from CASS materials, within the scope of BWRVIP-234, will be adequately managed for loss of fracture toughness due to TE and IE and any possible combined effects of the two.

6.0 REFERENCES

1. EPRI Report TR-1016574, "Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals (BWRVIP-234)," December 2009 (ADAMS Package Accession No. ML102570749).

2. Letter, BWRVIP 2012-148, from Dennis Madison (BWRVIP Chairman) to Joseph Holonich (NRC), "Request for Additional Information on BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals," September 18, 2012 (ADAMS Accession No. ML12265A078).

3. Letter, BWRVIP 2014-086, from Andrew McGehee, (BWRVIP Program Manager) and Dennis Madison (BWRVIP Chairman) to Joseph Holonich (NRC), "BWRVIP Response to NRC Request for Additional Information on BWRVIP-234," May 23, 2014 (ADAMS Accession No. ML14174A841).

4. Letter, BWRVIP 2015-025, from Andrew McGehee, (BWRVIP Program Manager) and Tim Hanley (BWRVIP Chairman) to Joseph Holonich (NRC), "Summary of Industry Position on Screening Criteria for Thermal and Irradiation Embrittlement for PWR and BWR Reactor Internals Fabricated of Cast Austenitic Stainless Steel," March 9, 2015 (ADAMS Accession No. ML15155B487).

5. Letter, BWRVIP 2015-150, from Andrew McGehee, (BWRVIP Program Manager) and Drew Odell (BWRVIP Chairman) to Joseph Holonich (NRC), "BWRVIP Response Regarding Proposed Words in BWRVIP-234 Draft Safety Evaluation," November 19, 2015 (ADAMS Accession No. ML15155B487).

6. Letter from Christopher I. Grimes, U.S. Nuclear Regulatory Commission, License Renewal and Standardization Branch, to Douglas J. Walters, Nuclear Energy Institute, "License Renewal Issue No. 98-0030, 'Thermal Aging Embrittlement of Cast Stainless Steel Components,'" May 19, 2000 (ADAMS Accession No. ML003717179).

7 ASME Boiler and Pressure Vessel Code, Section XI, "Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components," Appendix C, American Society of Mechanical Engineers, 2004 Edition, No Addenda.

8 EPRI Report TR-1013396, "Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds" (BWRVIP-100-A), August 2006 (ADAMS Accession No. ML062570229), (Not publically available).

9 Y. Chen, B. Alexandreanu, and K. Natesan, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steels," NUREG/CR-7184 (ANL-12/56) Argonne National Laboratory, Argonne, Illinois, November 2012.

10 EPRI Report TR-106092, "Evaluation of Thermal Aging Embrittlement for Cast Austenitic Stainless Steel Components in LWR Reactor Coolant Systems," September 1997 (ADAMS Accession No. ML003727111).

11 O. K. Chopra, "Estimation of Fracture Toughness of Cast Stainless Steels During Thermal Aging in LWR Systems," NUREG/CR-4513 (ANL-93/22), Revision 1, Argonne National Laboratory, Argonne, Illinois, August 1994.

12 O. K. Chopra and W. J. Shack, "Assessment of Thermal Embrittlement of Cast Stainless Steels," NUREG/CR-6960 (ANL-06/2), Argonne National Laboratory, Argonne, Illinois, December 2006.

13 O. K. Chopra, "Degradation of LWR Core Internal Materials Due to Neutron Irradiation," NUREG/CR-7027 (ANL-10/51), Argonne National Laboratory, Argonne, Illinois, December 2011.

14 C. Kim, R. Lott, S. Byrne, M. Burke, and G. Gerzen, "Embrittlement of Cast Austenitic Stainless Steel Reactor Internals Components," in Proceedings of 6th International Symposium on Contribution of Materials Investigations to Improve the Safety of Light Water Reactors – Fontevraud 6, SFEN (French Nuclear Energy Society), 2006.

15. Y. Chen, B. Alexandreanu, and K. Natesan, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steels," Report ANL-12/56, Argonne National Laboratory, Argonne, Illinois, November 2012.

16. NRC Staff Position on CASS Screening, June 11, 2014 (ADAMS Accession No. ML14163A112).

17 Meeting summary from July 15, 2014 (ADAMS Accession No. ML14217A077).

18 EPRI Report TR-1011469, BWR Vessel and Internals Project, "BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines (BWRVIP-18-A)," Electric Power Research Institute, Palo Alto, California, February 2006 (ADAMS Accession No. ML050910315). (Not publically available).

19 EPRI Report TR-1011470, "LPCI Coupling Inspection and Flaw Evaluation Guidelines (BWRVIP-42-A)," Electric Power Research Institute, Palo Alto, California, February 2005 (ADAMS Package Accession No. ML050910286). (Not publically available).

20. EPRI Report TR-108728, BWR Vessel and Internals Project, "BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines (BWRVIP-41, Rev. 0)," Electric Power Research Institute, Palo Alto, California, October 1997.

Attachment: Appendix A

Principal Contributor: Patrick Purtscher

Date: March 8, 2016

Appendix A Screening of CF- 3/CF-8 for Loss of Fracture Toughness Due to TE + IE

The screening is based on the estimated, lower bound value of the J integral at 2.5 mm crack extension (J @ 2.5). Figure A1 plots the predicted values for J @ 2.5 from BWRVIP-100 as a function of neutron fluence along with a new, NRC staff-proposed curve for CF-3 and CF-8 materials where the J @ 2.5 for 0 dpa is set equal to the lower-bound J @ 2.5 value for CF-8 with 15 to 25 percent ferrite from NUREG/CR-4513, Rev. 1. CF-8 material with a calculated ferrite content ≤ 20 percent would not be considered susceptible to TE alone using the Grimes letter. The remainder of the proposed curve is obtained by shifting the BWRVIP-100 curve for J @ 2.5 to the left until it intersects the vertical axis. In this way, the proposed curve takes full account for the saturated lower bound toughness for TE used in the development of the Grimes letter and incorporates an additional margin to account for the further reduction in fracture toughness due to IE. Given that there is no evidence of a synergistic effect, this combined effect is acceptable to the NRC staff. With this method, the lower-bound estimate of J @ 2.5 for static-cast CF-8 with ~~between~~ ≤ 20 percent ferrite equals the acceptance level at about 0.7 dpa.

Commented [C-WC4]: Recommend deleting the word "between" as the sentence does not read correctly.

Furthermore, the NRC staff notes that the discussion in BWRVIP-234 is applicable to an acceptance criteria where the J @ 2.5 is 255 kJ/m^2 (appropriate for pressure-boundary components like the reactor coolant system) yet the discussion in BWRVIP 2015-025, Attachment C, "Reactor Vessel CASS flaw tolerance," demonstrates that the loading for typical RVI components results in an applied J-integral far below the J @ 2.5 of 255 kJ/m^2 level. Furthermore, the NRC staff notes that EPRI report TR-112718[c] calculates applied J values for three different generic models that were designed to simulate RVI components. Both Attachment C and EPRI TR-112718 come to the similar conclusion that the crack driving forces in RVI components are much lower than the current acceptance criteria of J @ 2.5 is 255 kJ/m^2. These results suggest that there is a significant margin between the maximum applied J for RVIs (in Attachment C that would be 83 kJ/m^2) and either acceptance criteria (255 or 200 kJ/m^2). With an acceptance criteria of 200 kJ/m^2, the lower-bound estimate of J @ 2.5 for static-cast CF-8 with between ≤ 20 percent ferrite would exceed the acceptance level up to about 1.7 dpa.

Based on the proposed methodology to estimate fracture toughness of CASS that considers both TE and IE as well as the revised acceptance criteria, the NRC staff has developed a revised screening for low-Mo CASS materials, shown below as Table A1, which is similar to that found in Table 1 from Attachment D of BWRVIP 2015-025. There are two differences between Table A1 here and Table 1 of Attachment D. First, the acceptance criteria in Table A1 is 200 kJ/m^2; in Table 1 of Attachment D, the acceptance criteria is 255 kJ/m^2. The second difference can be found in the fluence limits. Table A1 is valid between 0.00015 and 1 dpa where Table 1 of the industry proposal goes from 0 to 1 dpa. In either case, CASS materials are potentially susceptible to significant loss of fracture toughness above 1 dpa of neutron exposure.

[c] EPRI TR-112718, "Evaluation of Neutron Irradiation Embrittlement for PWR Stainless Steel Internal Component Supports," R. Nickell, M. Rinckel, and W. Pavinich, Electric Power Research Institute, Palo Alto, California, September, 1999.

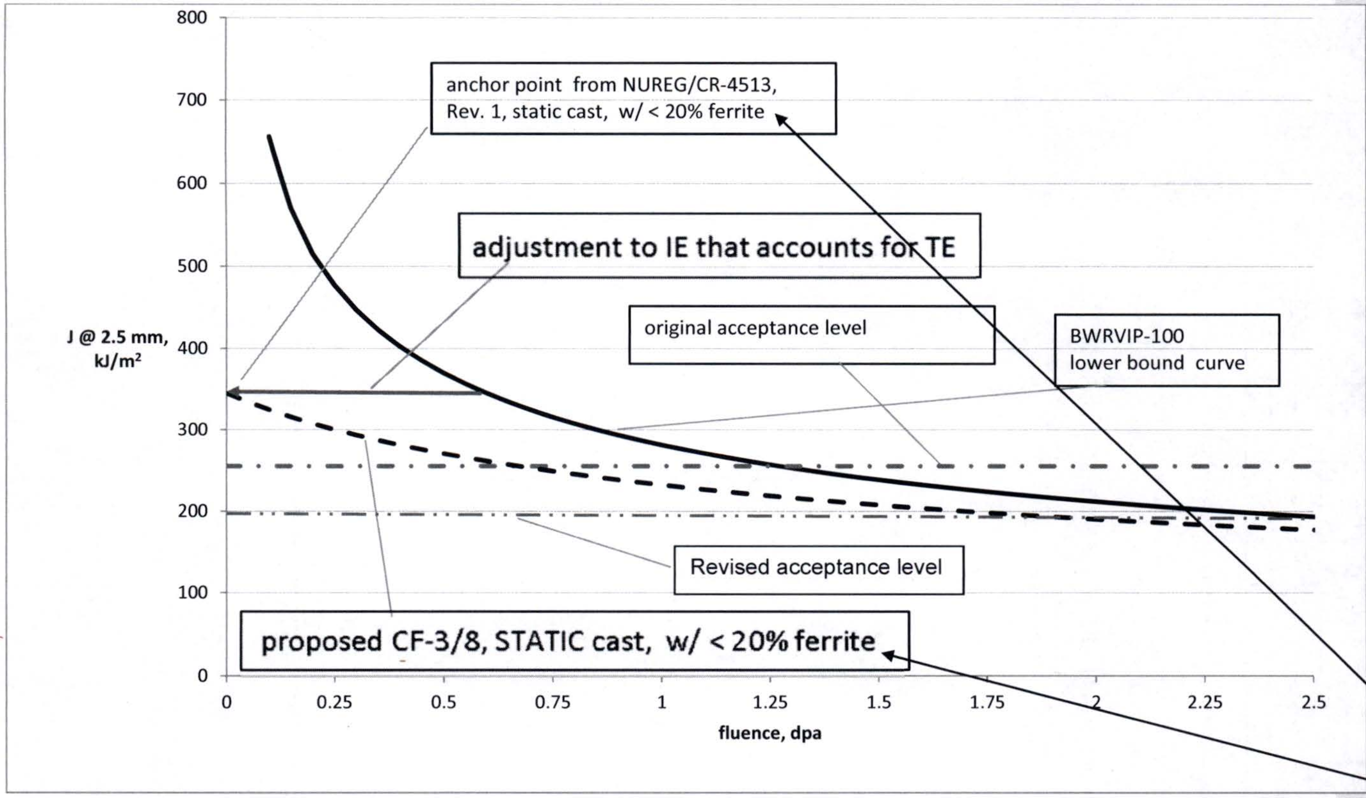

Figure A1. Plot of predicted lower-bound J @ 2.5 mm (BWRVIP-100 and NRC staff proposed) vs. neutron fluence. Arrow reflects shift of BWRVIP-100 curve to the left, represents assumed contribution to lower-bound J @ 2.5 mm due to IE.

Commented [C-WC5]: The "< 20 % ferrite" values in Figure A1 need to be changed to "≤ 20% ferrite" to be consistent with Table A1.

Table A1. Screening for CF-3 AND CF-8 RVI Components with neutron exposure between 0.00015 and 1 dpa.[◊]

Casting Method	Further Evaluation	Delta ferrite %[+]
static	Yes	> 20%
	No	≤ 20%
centrifugal	Yes	>25%
	No	≤ 25%[++]

[◊] All CASS materials need further evaluation above 1 dpa neutron fluence.

[+] Estimate delta ferrite content from chemical composition with Hull's equivalent factors (discussed in Ref. 1). If chemical composition is unknown, further evaluation is required.

[++] Upper limit for validity of ferrite screening of CASS from NUREG/CR-4513, Rev. 1.

BWRVIP Comment Summary Table

Comment No.	Draft SE Location	Comment Type	Comment	NRC's Response
1	Pg. 12, Section 3.3.10, lines 34 and 35	Clarification	Recommend inserting the parenthetical "(i.e., the six CASS components identified in Table 6-1) to clarify that when the SE refers to "six generic CASS components it means those referenced in Table 6-1 of the TR. Alternatively, wherever "six generic CASS components" is stated in the SE, replace it with "the six CASS components identified in Table 6-1.	
2	Pg. 14, Section 3.6, line 13	Clarification	Recommend replacing "RVI" with "CASS" to be consistent with the other references to the six CASS components of Table 6-1.	
3	Pg. 14, Section 3.6, line 18	Clarification & Accuracy	Recommend replacing "for all plant-specific CASS RVI components" with "of the six generic CASS components" to be consistent with the first paragraph of Section 3.6.	
4	Pg. 17, first page of Appendix A, line 14	Editorial	Recommend deleting the word "between" as the sentence does not read correctly.	
5	Second page of Appendix A, Figure A1	Accuracy	The "< 20 % ferrite" values in Figure A1 need to be changed to "≤ 20% ferrite" to be consistent with Table A1.	
6	Headers throughout	Clarification	As the SE does not contain any EPRI proprietary information, "Proprietary Information" can be removed from the headers.	