ELECTRIC POWER RESEARCH INSTITUTE

2012-148 BWR Vessel & Internals Project (BWRVIP)

September 18, 2012

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

Attention: Joseph Holonich

Subject: Project No. 704 – BWRVIP Response to NRC Request for Additional Information on BWRVIP-234

Reference: Letter from John R. Jolicoeur (NRC) to David Czufin (BWRVIP Chairman), "Acceptance for Review and Request for Additional Information, for BWRVIP-234: BWR Vessel and Internals Project: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals (TAC NO. ME5060," dated September 29, 2011.

Enclosed are five (5) copies of the BWRVIP response to the NRC Request for Additional Information (RAI) on the BWRVIP report entitled "BWRVIP-234: BWR Vessel and Internals Project, Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steels for BWR Internals." The RAI was transmitted to the BWRVIP by the NRC letter referenced above.

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 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 10CFR2.390A.

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 questions on this subject please call Randy Schmidt (PSEG Nuclear, BWRVIP Assessment Committee Technical Chairman) at 856.339.3740.

Sincerely,

Dennis Madison
Southern Nuclear
Chairman, BWR Vessel and Internals Project

A004
NRR

Extra copies were sent to the PM

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Attachment 1

NEIL WILMSHURST
Vice President and
Chief Nuclear Officer

Ref. EPRI Project Number 669

September 11, 2012

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 Document:

Request for Additional Information on BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals

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 information identified in the enclosed Affidavit consisting of the proprietary information owned by Electric Power Research Institute, Inc. ("EPRI") identified above (the "Response"). Proprietary and non-proprietary versions of the Correspondence and the Affidavit in support of this request are enclosed.

EPRI desires to disclose the Response in confidence to assist the NRC. The Response 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 Report 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) 704-595-2732. Questions on the content of the Report should be directed to ***Andrew 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 Document:

Request for Additional Information on BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals

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 3420 Hillview Avenue, Palo Alto, California ("EPRI") and I have been specifically delegated responsibility for the above-listed Report that is sought under this Affidavit to be withheld (the "Report"). I am authorized to apply to the U.S. Nuclear Regulatory Commission ("NRC") for the withholding of the Report on behalf of EPRI.

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

Withholding Based Upon Privileged And Confidential Trade Secrets Or Commercial Or Financial Information:

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

b. EPRI considers the Response and the proprietary information contained therein (the "Proprietary Information") to constitute trade secrets of EPRI. As such, EPRI holds the Response in confidence and disclosure thereof is strictly limited to individuals and entities who have agreed, in writing, to maintain the confidentiality of the Response. EPRI made a substantial economic investment to develop the Response, 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 Response. If the Response and 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 Response for their own commercial benefit and profit and without expending the substantial economic resources required of EPRI to develop the Response.

c. EPRI's classification of the Response and 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."

d. The Response and the Proprietary Information contained therein are not generally known or available to the public. EPRI developed the Response 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 Response. EPRI was required to devote these resources and effort to derive the Proprietary Information and the Response. As a result of such effort and cost, both in terms of dollars spent and dedicated employee time, the Response is highly valuable to EPRI.

e. 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 and Response 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 California.

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

Date: 9-11-2012.

[signature]

Neil Wilmshurst

(State of North Carolina)
(County of Mecklenburg)

Subscribed and sworn to (or affirmed) before me on this 11th day of September, 2012 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, 2016

Request for Additional Information on BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals

Non-Proprietary Version

Request for Additional Information on BWRVIP-234: Thermal Aging and Neutron Embrittlement Evaluation of Cast Austenitic Stainless Steel for BWR Internals

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

RAI 1

For Figure 2-1, the absorbed energy saturation values for the CF-8M castings are between 10 and 20 ft-lbs. The saturation is reached in about 10^5 hours at a temperature of 300°C. These values are independent of the delta ferrite content. Is this result consistent with other alloys like CF-8 and CF-3?

BWRVIP Response to RAI 1:

The purpose of Figure 2-1 was to show that CF-8M is very susceptible to thermal embrittlement (TE). In fact it is the least resistant of the CASS materials to TE. This is consistent with results reported in NUREG/CR-4513, Revision 1 (Reference 13 in BWRVIP-234) and Reference 5 of BWRVIP-234.

NUREG/CR-4513, Revision 1, Section 3.2.1, states that the saturation room temperature (RT) impact energy of a specific cast stainless steel is indeed a function of the chemical composition and the ferrite content of the material. Page 3 of NUREG/CR-4513, Revision 1 states the following:

"The decrease in RT Charpy–impact energy during thermal aging at 400°C (752°F) of various heats of cast stainless steel[4–6,15,19,21] is shown in Fig. 1. The results indicate that all the materials reach a "saturation" RT impact energy, i.e., a minimum value that would be achieved by the material after long–term aging. The actual value of saturation RT impact energy for a specific cast stainless steel is independent of aging temperature but depends strongly on the chemical composition of the steel; it is lower for the Mo–bearing CF–8M steels than for the Mo–free CF–3 or CF–8 steels, and decreases with an increase in ferrite content or the concentration of C or N in the steel."

Reference 3 of BWRVIP-234 also provides an excellent review of the available data on the issue. Figure 2 below shows the effect of delta ferrite content, and aging temperature and time, and the impact energy at room temperature. This shows as ferrite content increases, the impact energy at long aging times decreases.

The saturation values of Charpy-impact energy for CF-3 and CF-8 materials used in BWRs are above CF-8M castings. Furthermore, Reference 5 of BWRVIP-234 states that "CF8M shows the greatest susceptibility to thermal aging of any of the other SA-351 grades considered in the screening criteria."

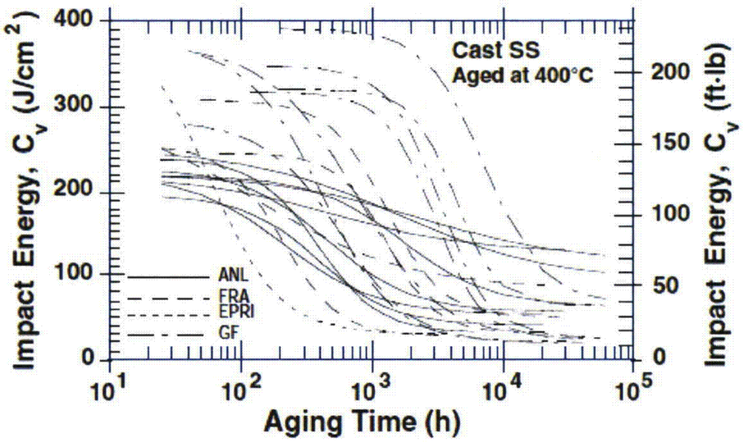

Figure 1. Decrease in Charpy-impact energy for various heats of cast stainless steels aged at 400°C

Reference: NUREG/CR-4513, Revision 1, May 1994.

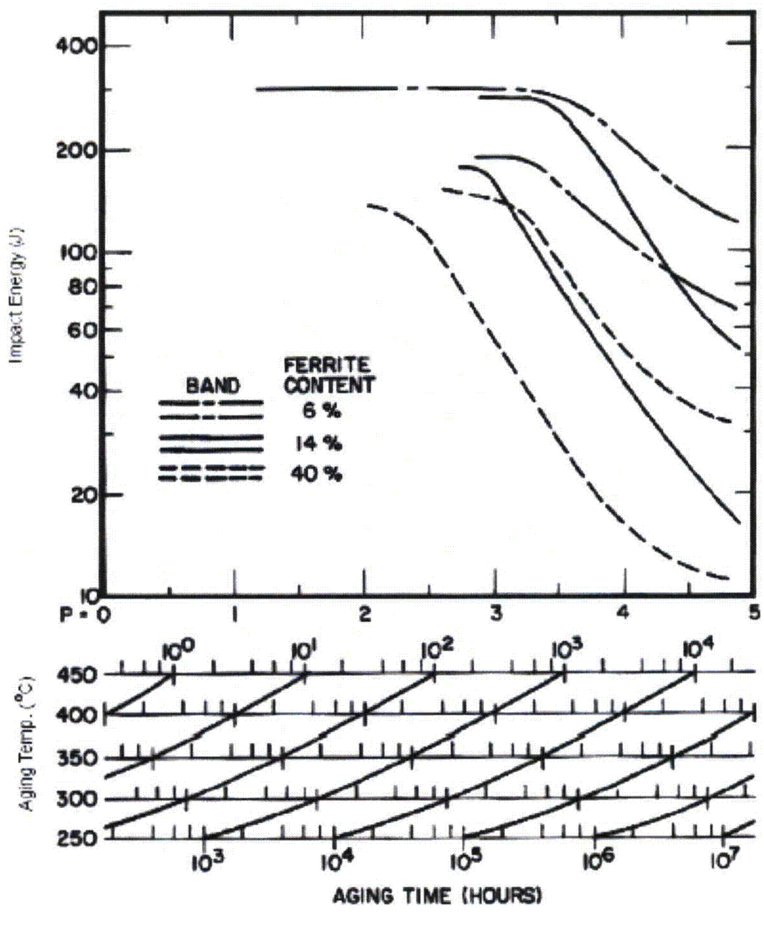

Figure 2. Influence of Ferrite Content on the Embrittlement of Cast Austenitic Stainless Steel as a Function of the Aging Parameter P (Reference 3 of BWRVIP-234)

RAI 2

Please clarify your conclusion in Section 2.1.1 on the differences between the thermal embrittlement (TE) of cast austenitic stainless steel (CASS) components in a pressurized water reactor versus a boiling water reactor (BWR).

BWRVIP Response to RAI 2:

The conclusion in Section 2.1.1 stated the following:

"In other words, the higher the aging temperature, the greater is the deterioration with time. Based on this, one can conclude that the CASS aging embrittlement effects in a BWR are significantly lower than components in a PWR."

The BWRVIP proposes to revise the statement as follows:

"Based on this, the higher the aging temperature, the faster the aging effect reaches saturation. Since PWRs operate at a higher temperature than BWRs, thermal aging embrittlement effects for CASS components in a BWR are expected to occur later in life than for CASS components in a PWR."

RAI 3

Figures 2-4 and 2-5 document the toughness as a function of delta ferrite content. The aging conditions for these test results should be included for our review. If these results represent the saturation of the TE effects, please discuss why these results are different from Figure 2-1 where the TE effects are not a function of delta ferrite content.

For the purposes of this report, are the saturation values for TE of CASS components within the scope of the assessments in this report?

BWRVIP Response to RAI 3:

Figure 2-4 was developed based on the equations contained in Section 3 of NUREG/CR-4513, Revision 1. Excerpts of EPRI report 1016236 (Reference 1 in BWRVIP-234) are contained in Attachment A to provide the staff with background regarding determination of the J-R curves.

The results show that J versus crack extension is a function of the delta ferrite; increasing ferrite content decreases the J-da curve.

For CF-3 and CF-8 materials, the saturation RT impact energy Cvsat is determined using the following equations:

$\log_{10}Cvsat = 1.15 + 1.36\exp(-0.035\Phi)$,

where the material parameter Φ is expressed as

$\Phi = \delta c(Cr + Si)(C + 0.4N)$,

and from

$\log 10 Cvsat = 5.64 - 0.006(\delta c) - 0.185Cr + 0.273Mo - 0.204Si + 0.044Ni - 2.12(C + 0.4N)$.

Equations for Cvsat for CF8M are also provided in NUREG/CR-4513, Revision 1.

The saturation fracture toughness J–R curve for a specific cast stainless steel can be estimated from its RT impact energy at saturation. This is described in Section 3.2.2 of NUREG/CR4513, Revision 1.

There was no intent to apply the RT saturation values of impact energy shown in Figure 2-1 to an evaluation of BWR components. The important parameter used to evaluate component integrity is fracture toughness. For this evaluation, the lower bound value $J = 255\ kJ/mm^2$ has been used as approved by the NRC.

Figure 2-5 is based on the following reference.

O.K. Chopra and M. H. Chung. "Initial Assessment of the Processes and Significance of Thermal Aging in Cast Stainless Steels," presented at the 16th Water Reactor Safety Information Meeting, November 1988.

Examination of the data summarized by Chopra indicates that the only material exhibiting an upper shelf energy level at temperatures below 50 ft. lb. is a very high ferrite level (35%) CASS exposed for 1000 hours at 752°F. At 662°F this level of embrittlement is reached in 10,000 hours. Using the data from Chopra for the worst embrittlement encountered, a plot was constructed of delta ferrite as a function of the observed upper shelf energy from the CVN values measured at elevated temperatures. Thus, the data indicates a clear relationship between upper shelf energy and % ferrite and provides additional justification for selecting 20% ferrite as a threshold for susceptibility.

RAI 4

Discuss why room temperature Charpy absorbed energy is an appropriate way to quantify the extent of TE. The upper shelf energy (USE) that you show in Fig. 2-5 could be a more valuable parameter because USE could be related directly to the service temperature, similar to what is done for ferritic reactor vessel properties.

BWRVIP Response to RAI 4:

Room temperature Charpy absorbed energy is not suggested in BWRVIP-234 as a means to quantify the extent of TE. The intent of any discussions in BWRVIP-234 regarding Charpy energy and upper shelf energy was to show that ferrite plays a strong role in toughness, i.e., as ferrite decreases the fracture toughness increases and vice versa. Regardless, the criteria for fracture toughness is based on Reference 5 of BWRVIP-234.

RAI 5

Please provide clear and consistent definitions for "screening" and "threshold" that can be incorporated in the approved version of BWRVIP-234.

BWRVIP Response to RAI 5:

"Screening" and "threshold" criteria are used to determine the susceptibility of a component to address both TE and neutron embrittlement. In this case, one single criterion is neither sufficient nor appropriate to eliminate the issue from consideration. Therefore, to evaluate the synergistic effects of both TE and neutron embrittlement it was necessary to extend the screening/evaluation criteria to address ferrite content, fluence, available fracture toughness, applied stress and current inspection practice. For example, even if the ferrite level was less than 20% for a low Mo content material, that fact in and of itself, does not mean that the material is not susceptible. The other criteria defined above should also be considered to determine the overall susceptibility of the component. Only in this way, can a meaningful and justifiable conclusion regarding susceptibility of CASS components be determined.

Therefore, the screening methodology discussed in Section 4 of BWRVIP-234 contains several aspects of a TE and neutron embrittlement assessment which when coupled, provide the overall criteria to assess susceptibility. Therefore, it is the opinion of the BWRVIP that the description of the screening criteria discussed in Section 4 of BWRVIP-234 is technically acceptable for determination of augmented inspection requirements.

RAI 6

Welding or weld repairs and how they might affect the properties of a CASS component in the BWR environment were discussed. Welding of CASS components can increase the delta ferrite content in the heat affected zone of the weld (Mimura et al. Welding Journal, 1998, pp 350s-360s). Please discuss the impact that welding and/or weld repairs would have on the component screening.

BWRVIP Response to RAI 6:

In general and depending on the extent of casting defects, weld repairs would be required to correct such defects. However, light welding on CF-3 and CF-8 does not appreciably affect corrosion resistance and therefore minor weld repairs are not expected to impact the susceptibility of the component. It is expected that if significant defects were discovered the casting would be rejected or repaired and then re-solution annealed.

The Mimura paper [1] discusses two test heats of material, both of which are moderately high carbon and Mo. Additionally, one of the heats is very high in ferrite relative to what is usually reported for BWR castings. This material (CF-8M) is known to be much more susceptible to TE. CF3 and CF8 are much less prone to TE in general, and especially at BWR temperatures when the ferrite is 20% or less. Consequently, the BWRVIP believes that the effects of welding on BWR CASS components as reported by Mimura would not affect the screening methodology contained in BWRVIP-234.

Ferrite in castings is beneficial for SCC resistance and any increases in ferrite due to welding of BWR CASS internals to wrought stainless steel is not expected to be significant. Futhermore, there has been no evidence of any SCC in CASS components in BWRs to date. Therefore, welding of CASS components is not expected to impact the screening criteria and assessment of TE.

RAI 7

Typically, the measured delta ferrite values are not reported on the certified material test record. In Section 3.4, "Ferrite Content," the Ni and Cr equivalent equation from Hull are used to calculate the delta ferrite content.

Please discuss how calculated values compare with measured values for CASS components to demonstrate the level of confidence one can place on the calculations. Provide additional discussion in Section 4.1 as to how the uncertainty in the calculations affects the screening process.

BWRVIP Response to RAI 7:

Measured values of ferrite were not available from CMTRs. Consequently, Hull's equivalent factors were used to determine ferrite. Per Reference 5 of BWRVIP-234, this is recommended by the NRC when actual values are not available. Thus, it is not possible to compare calculated and measured values of ferrite content.

As shown in Table A-1 of BWRVIP-234, the Mo content was not measured for all heats collected and thus, there is some uncertainty regarding the calculated ferrite. The variation of ferrite content can be examined as a function of Mo content. Using the data in Table A-1, the Mo content was varied for each heat of material from 0.1 wt.% to 0.5 wt.% in increments of 0.1 wt.%. A limit of 0.5% wt.% was used because this is the upper bound value for CF-3 and CF-8 materials as given in Reference 5 of BWRVIP-234 and SA-351. The results of the analysis are shown in the following table.

Mo (wt.%)	Average % Ferrite	% Ferrite Calculated from Average Chemistry
0.1		
0.2		
0.3		
0.4		
0.5		

TS

Even when assuming all heats are a maximum Mo content of 0.5 wt.%, only three heats are calculated to be slightly greater than the 20% ferrite limit ( ).
TS Therefore, given the relatively small change in percent ferrite shown above from that reported in BWRVIP-234, the uncertainty in Mo in not judged to affect the ferrite screening process for
CF-3 and CF-8 materials.

RAI 8

In Section 4.1, "Screening Based on Ferrite Content," for the discussion about fatigue for CASS jet pump components, BWRVIP-234 suggests that BWRVIP-41 inspections are sufficient to eliminate concern for any augmented inspections for fatigue of CASS jet pump components. BWRVIP-41, Rev. 2, recommends eliminating CASS components from the scope of inspections because castings are considered immune to intergranular stress corrosion cracking.
Please summarize the latest recommendations in BWRVIP-41, Revision 2 and revise this section as-needed to demonstrate how the BWRVIP-41 inspections will impact the screening of CASS components for fatigue in BWRVIP-234.

BWRVIP Response to RAI 8:

BWRVIP-234, page 4-3 states the following relative to fatigue of BWR CASS components.

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BWRVIP-41, Revision 2 continues to state that cast components in jet pumps have not exhibited any cracking to date and thus are considered to have a high resistance to IGSCC in BWR core environments. It also states that it is important to note that TE does not in itself cause cracking to occur. It reduces the structural margin of a material in resisting propagation of cracks due to other initiators like IGSCC or fatigue.

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Due to the field of view **TS** 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. To date, no such cracking has occurred.

Therefore, the BWRVIP believes that the current inspection strategy will provide information on cracking in the HAZ of the casting side of the weld should it manifest itself.

RAI 9

In Section 4.3 "Screening Based on Toughness," the alternative method to estimate the J-R curve parameters from Reference 8 was developed for core shroud welds. The delta ferrite content of core shroud welds is typically lower than the delta ferrite content of the CASS components in the BWR fleet. Given the uncertainty in the calculation of delta ferrite (RAI 7) and the potential for an increase in the % delta ferrite due to welding/weld repairs (RAI 6), discuss the effect that a higher delta ferrite content would have on the methodology to estimate toughness.

BWRVIP Response to RAI 9:

As stated in the responses to RAI 6 and RAI 7, the uncertainty in delta ferrite and potential for a increase in delta ferrite due to welding and weld repairs is not expected to be significant. In RAI 6 it was shown that even when assuming the maximum Mo content of 0.5 wt.% the average increase in ferrite was relatively small. This marginal increase in ferrite would have a slight effect on reducing the toughness of the material (since an increase in ferrite results in a decrease in toughness). However, for the range of exposure conditions that would be experienced for CASS components in a BWR, the toughness values are expected to be well above recommended lower bound toughness of 255 kJ/m^2. Therefore, the BWRVIP believes that use of the lower bound toughness is sufficiently conservative and consequently, would not affect the methodology to estimate the toughness for irradiated conditions.

References:

1. H. Mimura, et al, "Thermal Embrittlement of Simulate Heat-Affected Zone in Cast Austentic Stainless Steels," Welding Journal, 1998, pp 350s-360s

Additional Information Provided by the BWRVIP

During preparation of this RAI response it was discovered that second bullet on page 2-4 of BWRVIP-234 is incorrect.

Currently, the second bullet states the following:

- Statically-cast, low-molybdenum material (CF-8) with relatively high δ ferrite content (> 20%) could be screened out from further evaluation.

The second bullet should read as follows:

- Statically-cast, low-molybdenum material (CF-8) with relatively high δ ferrite content (≤ 20%) could be screened out from further evaluation.

In summary, "(>20%)" should be "(≤ 20%)" to be consistent with Table 4-1. This change will be made in a revision to the report.

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