TVA TENNESSEE VALLEY AUTHORITY

1101 Market Street, Chattanooga, Tennessee 37402

CNL-22-075

September 12, 2022

10 CFR 50.55a

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Browns Ferry Nuclear Plant, Unit 2
Renewed Facility Operating License No. DPR-52
NRC Docket No. 50-260

Subject: **Response to Request for Additional Information Regarding Browns Ferry Nuclear Plant, Unit 2, Request for Alternative, BFN-21-ISI-02, Alternative to American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section XI, Paragraph IWB-2420(b) and the Use of Case N-526 (EPID L-2022-LLR-0008)**

References:

1. TVA Letter to NRC, CNL-21-081, "Browns Ferry Nuclear Plant, Unit 2, Request for Alternative, BFN-21-ISI-02, Alternative to American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section XI, Paragraph IWB-2420(b) and the Use of Case N-526," dated January 14, 2022 (ML22014A344)

2. NRC Email to TVA, "Request for Additional Information Related to TVA Relief Request BFN-21-ISI-02 (CNL-21-081) (EPID L-2022-LLR-0008)," dated July 15, 2022 (ML22208A217)

In Reference 1, Tennessee Valley Authority (TVA) submitted a request for alternative (RFA) for the Browns Ferry Nuclear Plant (BFN), Unit 2, from the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, Code Case N-526. Specifically, the RFA proposed an alternative to successive examination requirements of paragraph IWB-2420(b) of the ASME Code.

In Reference 2, the Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI) and requested that TVA respond by September 13, 2022. Enclosure 1 to this letter provides the response to the RAI.

Additionally, TVA identified an administrative error in Attachment 1 of the enclosure to Reference 1 regarding location of the BFN V-3-A weld flaw after submittal to the NRC. Enclosure 2 to this letter provides a revised weld flaw assessment by Structural Integrity Associates (SI) with the corrected location, and this assessment replaces and supersedes Attachment 1 of Reference 1.

Enclosures 3 and 4 provide the underlying analyses for the responses to RAI-4 and RAI-5, respectively.

There are no new regulatory commitments contained in this letter. Please address any questions regarding this submittal to slrymer@tva.gov.

Respectfully,

Digitally signed by Rymer, Stuart Loveridge
Date: 2022.09.12 22:44:04 -04'00'

Stuart L. Rymer
Director (Acting), Nuclear Regulatory Affairs

Enclosures:

1. Response to NRC Request for Additional Information
2. SI 2100312.401, Revision 2, “BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526”
3. SI 2200769.401, Revision 0, “BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526 under Service Level C/D loadings”
4. SI 2200769.301, Revision 0, “Resolution of RAI-5 (P-T Limits Inquiry)”

cc (with Enclosures):

NRC Regional Administrator - Region II
NRC Senior Resident Inspector - Browns Ferry Nuclear Plant
NRC Project Manager - Browns Ferry Nuclear Plant

Response to NRC Request for Additional Information

Introduction:

By letter dated January 14, 2022, (Agencywide Documents and Access Management System (ADAMS) Accession No. ML22014A344), Tennessee Valley Authority (TVA) submitted request for alternative BFN-21-ISI-02 for the fifth 10-year inservice inspection (ISI) interval at Browns Ferry Nuclear Plant (Browns Ferry or BFN), Unit 2. Pursuant to Title 10 of the Code of Federal Regulations (10 CFR), Part 50, Paragraph 50.55a(z)(1), TVA proposed an alternative to the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code), Section XI, paragraph IWB-2420(b), for deferring the applicable successive examinations of the flaw identified in Weld V-3-A at Browns Ferry, Unit 2, until the normally scheduled inspection during the sixth 10-year ISI interval. The U.S. Nuclear Regulatory Commission (NRC) staff needs additional information to complete its review of the proposed alternative.

Regulatory Basis:

The regulations in 10 CFR 50.55a(g) require that the ISI of ASME Code Class 1, 2, and 3 components be performed in accordance with Section XI of the ASME Code and applicable addenda. Paragraph 10 CFR 50.55a(g)(4) states, in part, that ASME Code Class 1, 2, and 3 components will meet the requirements, except the design and access provisions and the preservice examination requirements, set forth in the ASME Code, Section XI.

ASME Code, Section XI, paragraph IWB-2420(b) requires areas containing flaws or relevant conditions to be reexamined during the next three inspection periods listed in the schedule of the inspection program of IWB-2400 if a component is accepted for continued service in accordance with IWB-3132.3 or IWB-3142.4.

Paragraph 10 CFR 50.55a(z) states that alternatives to the requirements of paragraphs (b) through (h) of 10 CFR 50.55a or portions thereof may be used when authorized by the Director, Office of Nuclear Reactor Regulation. A proposed alternative must be submitted and authorized prior to implementation. The applicant or licensee must demonstrate that: (1) the proposed alternative would provide an acceptable level of quality and safety; or (2) compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for Additional Information:

RAI-1

Background

Section 5 of the proposed alternative states, in part,

> *TVA proposes to apply the alternative requirements of ASME Code Case N-526 to the identified flaw, except that the IWA-3320 surface proximity rules will be used in lieu of the ASME Code Case N-526 proximity rules. The other conditional requirements of ASME Code Case N-526 will be met.*

<u>Issue</u>

The staff lacks clarity regarding what is meant by "other conditional requirements."

<u>Request</u>

Clarify what is meant by "The other conditional requirements of ASME Code Case N-526 will be met."

<u>TVA Response to RAI-1</u>

The reference to "The other conditional requirements of ASME Code Case N-526 will be met," was intended to address the following requirements of ASME Code Case N-526, which states that "re-examinations in accordance with IWB-2420(b) or IWC-2420(b) of vessels examination volumes containing subsurface flaws are not required, provided the following are met:

(a) The flaw is characterized as subsurface in accordance with Figure 1.

(b) The nondestructive examination technique and evaluation that detected and characterized the flaw, with respect to both sizing and location, shall be documented in the flaw evaluation report.

(c) The vessel containing the flaw is acceptable for continued service in accordance with IWB-3600, and the flaw is demonstrated acceptable for the intended service life of the vessel."

The proposed alternative request seeks to utilize ASME Code Case N-526 to eliminate the periodic re-examinations of the subject weld using an alternative to the proximity rules of Figure 1. Therefore, condition (a) of Code Case N-526 will not be met, instead using the subsurface characterization of IWA-3320 as noted in the proposed alternative. The statement in question is an attestation that the conditions (b) and (c) of Code Case N-526 have been met.

RAI-2

<u>Background</u>

Section 6.0 of the proposed alternative states:

> *The proposed alternative is requested for BFN, Unit 2 for the next two subsequent inspection periods, following identification of the flaw during the Unit 2, Cycle 21 refueling outage in spring 2021. After such time, the successive examinations of the subject weld will resume in the sixth inservice examination interval, in accordance with the schedule of ASME Code, Section XI, Table IWB-2500-1.*

It is the NRC staff's understanding that TVA proposes to defer the required successive examinations of weld V-3-A during the next two inspection periods instead of three successive periods, as required by IWB-2420(b), because a third successive examination would resume in the sixth ISI interval.

Issue

Subsection IWB-2420(b) of Section XI (2007 Edition with 2008 Addenda), states

> *If a component is accepted for continued service in accordance with IWB-3132.3 or IWB-3142.4, the areas containing flaws or relevant conditions shall be reexamined during the next three inspection periods listed in the schedule of the Inspection Program of IWB-2400. Alternatively, acoustic emission may be used to monitor growth of existing flaws in accordance with IWA-2234.*

The NRC staff interprets the requirements of IWB-2420(b), regarding the required reexaminations, as performing three consecutive inspections (one inspection per period) irrespective of the ISI interval. Therefore, the third successive inspection of weld V-3-A would be required to be performed in the first period of the sixth ISI interval because it seems that the weld was examined during the first period of the fifth ISI interval.

Request

1. *Confirm whether the flaw in weld V-3-A was identified during the first period of the fifth ISI interval.*

2. *Clarify whether the intent of the proposed alternative is to not perform the first two successive examinations but perform the third required successive examination during the first period of sixth ISI interval. If not, provide the timeframe of when the inspection of weld V-3-A is planned to be performed and justify why this inspection plan is compliant with the ASME Code, Section XI.*

TVA Response to RAI-2

1. The flaw in weld V-3-A was identified during the second period of the fifth ISI interval. Inspection was not required during the first period of the fifth ISI interval.

2. This request for alternative proposes to omit the first two successive examinations, which would have been required in the third period of the fifth interval and in the first period of the sixth interval. Weld V-3-A will then be subsequently examined in the second period of the sixth interval. This schedule meets the requirement of the third successive examination per IWB-2420(b) and is also the next scheduled periodic examination requirement per ASME Code Section XI, Table IWB-2500-1 examination category B1.12. This request does not propose any alternatives to the normal periodic examination requirements of Table IWB-2500-1.

RAI-3

Background

TVA states that the flaw in weld V-3-A at BFN, Unit 2, was identified in the fifth ISI interval during the Cycle 21 refueling outage. Furthermore, the weld was ultrasonically examined in accordance with Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," of Section XI of the ASME Code as incorporated by referenced in 10 CFR 50.55a. Specifically, TVA performed automated scanning from the reactor vessel inside surface using

45-degree shear wave and 60-degree refracted longitudinal (RL) search units. TVA states that a portion of the automated examination was restricted due to the proximity of the feedwater spargers and core spray piping. Consequently, a manual ultrasonic examination was performed using a qualified 60-degree RL search units in the area restricted for automated examination.

Issue

TVA did not provide details regarding previous inspections of weld V-3-A. The NRC staff notes that weld V-3-A is classified as ASME examination category B-A, "Pressure Retaining Welds in Reactor Vessel," which are required to be examined once per ASME Code ISI interval (i.e., 10 years). The NRC staff lacks clarity whether the indication in weld V-3-A had been previously identified.

Request

1. *Provide details regarding the examination and results of weld V-3-A during the previous four 10-year ISI intervals. In your response, include details on the ultrasonic capabilities for each examination that was performed.*

2. *Provide details on whether an evaluation (e.g., root cause) was performed to identify why the flaw was not identified in previous examinations but was identified during the Cycle 21 refueling outage.*

TVA Response to RAI-3

1. The V-3-A weld in the area of the indication has undergone ultrasonic examination three times previously during the BFN Unit 2 spring 2001 (U2R11), spring 2011 (U2R16), and spring 2021 (U2R21) refueling outages in the third, fourth, and fifth 10-year inspection intervals, respectively. The examination performed in U2R11 was conducted using conventional ultrasonic techniques with 100% coverage with no recordable indications. The examination performed in U2R16 was conducted using phased array ultrasonic techniques with 100% coverage with no recordable indications. The examination performed in U2R21 was conducted by a different vendor using conventional ultrasonic techniques with 100% coverage.

   The examination conducted during the second 10-year inspection interval was prior to development of inspection tooling to conduct ultrasonic examinations from the inside surface in boiling water reactors; therefore, an examination was not possible in the area of the V-3-A indication.

2. The following explanation addresses why the flaw was not identified in previous examinations but was identified during the Cycle 21 refueling outage.

   The three ultrasonic examinations performed on the V-3-A weld were conducted by two vendors using three different examination methodologies, which were qualified to ASME Section XI, Appendix VIII criteria in accordance with the performance demonstration initiative (PDI) process. The recording and evaluation criteria specified in accordance with the qualified PDI procedures varied in all three examination efforts.

   The results, even when different techniques are deployed, will be fairly consistent and repeatable. However, it is not uncommon for variations to occur even when deploying the same techniques with the same vendors. A causal evaluation was not performed, and the definitive reasons for why the unacceptable indication in the V-3-A weld was not found during previous examination cannot be ascertained. However, it could be surmised that contributing factors to the failure to identify the weld flaw in previous examination could be coupling, recording criteria, examination methodologies, and differing resolution capabilities.

RAI-4

Background

In Attachment 1 of the proposed alternative, the plant-specific assessment states, "The Service Level A/B RPV transient in Table 4 of Reference [12] with the highest ΔT was chosen as the bounding transient which is the Start-up Transient."

Issue

The NRC staff notes that the Browns Ferry Final Safety Analysis Report (FSAR), Appendix C, "Structural Qualification of Subsystems and Components," describes the basic structural loading criteria and qualification methods used in the original design of BFN, Unit 2, components and piping subsystems. These conditions include normal, upset, emergency, and faulted loading conditions. Furthermore, the staff notes that these loading conditions are the equivalent to the ASME Code, Section III, Level A, B, C, and D service limits. Based on the above statement in Attachment 1 of the proposed alternative, the staff is not clear if loading conditions applicable to service levels C and D were considered in the licensee's analysis provided in the submittal.

Request

Discuss the applicability of all service loadings (i.e., normal, upset, emergency, and faulted) and any combination of them that were taken into consideration in the licensee's analysis in the submittal. Discuss whether loading conditions applicable to service levels C and D were considered in the licensee's analysis. If not considered, provide a justification for not considering the loading conditions applicable to service level C and D in the analysis in the submittal.

TVA Response to RAI-4

As noted in the staff's question, the ASME Code, Section III, service limits A, B, C, and D are equivalent to the loading conditions described in the BFN Updated FSAR. For simplicity, this response will use the ASME service limits. According to the technical basis document of ASME Code Case N-526, only primary membrane and bending stresses are required to be included to develop the plant-specific proximity rule, and secondary stresses due to thermal transients and weld residual stresses are not required. Therefore, the licensee's original analysis considered service level A/B loading conditions to develop the plant-specific proximity curves. Because the as-found flaw is an axial flaw type, bending and axial stresses from service level C/D loadings such as safe shutdown earthquake and loss of coolant accident do not contribute to the crack driving force. Only membrane hoop stress (due to pressure) contributes to the crack-driving force. An additional plant-specific analysis was performed in Enclosure 3 for service level C/D loadings using the same methodology as the technical basis of ASME Code Case N-526 with the plant-specific material properties, operating stress (only internal pressure for service level C/D loadings), and as-found flaw aspect ratio to develop a site-specific proximity curve.

The results of the analysis in Enclosure 3 demonstrate that the plant-specific surface proximity curves for service level C/D loading is slightly higher than that for service level A/B loading (due to higher internal pressure for C/D loadings). However, each of these curves falls below both the IWA-3320 proximity rule and the Code Case N-526 surface proximity rule. Because the as-found flaw must meet the requirements of IWA-3320 to be considered as subsurface, the IWA-3320 rule ($S > 0.4a$) would be the plant-specific proximity rule for the as-found flaw under both service level A/B and C/D loadings.

Because the plant-specific proximity curve remains applicable for both service level A/B and C/D loadings and the as-found flaw is bounded by the plant-specific proximity rule (i.e., above the IWA-3320 curve), it meets the intent of the requirements of ASME Code Case N-526 to exempt the successive re-examinations required by IWB-2420(b), ensuring an acceptable level of performance and safety.

Reference:
N. G. Cofie, P. C. Riccardella, J. H. Merkle, and H. Do, "Technical Basis for Alternate Successive Inspection Requirements for Vessels and Piping Welds as Prescribed in Code Cases N-526 and N-735," Paper No. PVP2008-61412, Proceedings of PVP2008, 2008 ASME Pressure Vessels and Piping Division Conference, July 27-31, 2008, Chicago, Illinois, USA

RAI-5

Background

The pressure-temperature (P-T) limit curves for the operation of the reactor vessel during heat up and cooldown evolution as shown in the plant technical specifications are constructed based on a postulated flaw that has a depth of ¼ of the wall thickness of the reactor vessel shell. The flaw is postulated to initiate from the inside surface and outside surface of the reactor vessel shell.

Issue

TVA has not indicated if the flaw in weld V-3-A affects the P-T limit curves.

Request

Discuss whether the flaw in weld V-3-A affects the existing P-T limit curves in the plant technical specifications. If yes, indicate when TVA plans to revise the P-T limit curves to reflect the impact of the flaw on the P-T limit curves in the technical specifications via a separate license amendment request.

<u>TVA Response to RAI-5</u>

Enclosure 4 provides an evaluation that was performed to address the following: (i) fluence at weld V-3-A compared to that for the Appendix G quarter-T flaw; (ii) the stress intensity factor for the V-3-A indication compared to that for the Appendix G quarter-T flaw; and (iii) comparison of the P-T limit curves for the pressure test (Curve A) and heatup/cooldown (Curves B and C) for the V-3-A indication and for the Appendix G quarter-T flaw. The evaluation confirmed the following.

- The highest fluence at the weld V-3-A is lower than the influence at the quarter-T flaw evaluated in developing the P-T curves per Appendix G.
- The stress intensity factor for the V-3-A indication is lower than that for the Appendix G quarter-T flaw.
- The P-T curve for postulated Appendix G quarter-T flaw bounds that for the weld V-3-A indication.

Based on the analysis, the fracture consequences of the postulated quarter-T flaw bound that of the weld V-3-A indication. Therefore, no revision of the P-T limit curves in the BFN Unit 2 Technical Specifications is required.

Enclosure 2

SI 2100312.401, Revision 2, “BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526”

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July 7, 2022
REPORT NO. 2100312.401
REVISION: 2
PROJECT NO. 2100312.00

Quality Program: ☒ Nuclear ☐ Commercial

Adam Keyser
Tennessee Valley Authority
Browns Ferry Nuclear Plant, Unit 2
PO Box 2000
Decatur, AL 35609

Subject: BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526

Revision 1:
Removed Proprietary Information Notice and proprietary information markers from information previously identified as proprietary. Removed "P" from Report No. Updated Reference 1 to Revision 2.

Revision 2:
Revised Section 4.0, 1: Incorporated the correct elevation of the axial flaw per CAR 22-041.

Dear Adam,

1.0 INTRODUCTION

During the spring 2021 outage at Browns Ferry Nuclear Plant, Unit 2 (BFN), an indication was identified in a vertical weld (Weld No. V-3-A) of the reactor pressure vessel (RPV). This flaw was evaluated by Structural Integrity Associates, Inc. (SI) in SI Calculation 2100264.301P [1] and determined to be acceptable for continued service per the rules of Section XI, IWB-3600 [2]. This evaluation concluded that the flaw met the criteria set forth in ASME Code Case N-526 for exemption of the three successive inspections required by IWB-2420, when considering the proximity of the flaw to the inside (ID) surface (which is the most critical since it is in contact with the reactor coolant). However, when the evaluation was performed using the distance from the outside (OD) surface, the flaw does not meet the criteria set forth in ASME Code Case N-526 [3] for exemption from three successive IWB-2420 examinations.

Since ASME Code Case N-526 does not specify which surface is supposed to be used for proximity evaluation, it was conservatively assumed that the calculation should apply the lesser of these two distances. However, upon review of the ASME Code Case N-526 technical basis [4], it is evident that the calculational basis was developed based on the flaw's proximity to the ID surface. Additionally, conservative assumptions were identified in the technical basis of Code Case N-526 regarding stresses and flaw aspect ratio. In accordance with Reference [5], SI was contracted to determine if the BFN RPV weld flaw will meet the intent of Code Case N-526 if plant-specific materials, stresses, and aspect ratio are utilized, using the technical basis of Code Case N-526 [3] as guidance.

2.0 BACKGROUND

In Reference [1], it was demonstrated that successive examinations in accordance with IWB-2420 (b) and (c) of the indication identified in Weld V-3-A are not required per the technical basis document [4] for Code Case N-526 [3] using the ID surface to apply the proximity rule. However, since Code Case N-526 does not specify to use the ID surface to apply the proximity rule, the successive examinations are required when the most conservative interpretation of the Code Case using the OD surface to apply the proximity rule is used. However, upon review of the ASME Code Case N-526 technical basis [4], it was noted that some conservative assumptions were made regarding stresses and flaw aspect ratio in developing the Code Case N-526. This report provides a plant-specific Code Case N-526 assessment of the Browns Ferry V-3-A weld flaw, conservatively utilizing the flaw's OD surface proximity, plant-specific operating stresses, and as-found flaw aspect ratio, following the same procedure used in the technical basis of Code Case N-526 to determine if the intent of Code Case N-526 is met.

3.0 METHODOLOGY

The methodology used for this plant-specific assessment develops the proximity rule from the OD surface for subsequent augmented re-examinations for the BFN RPV weld flaw by following the same procedure used in the technical basis document [4] for ASME Code Case N-526 but using the operating stresses and as-found flaw aspect ratio. A summary of the procedure used in the technical basis document [4] is described below followed by the procedure used for the plant-specific assessment.

3.1 Methodology Used in Code Case N-526 Technical Basis

The intent of the technical basis for Code Case N-526 [4] is to provide alternate proximity criteria for distinguishing subsurface from surface defects in Class 1 and 2 vessels to eliminate the need for the successive inspection requirements in these components. This is based on the argument that if a flaw is very close to inside surface, then there is a possibility of yielding of the remaining ligament between the flaw and the inside surface, thus exposing the flaw to the reactor coolant, and potentially to accelerated crack growth. As noted in the technical basis that the concern is only regarding the flaws near the ID surface due to reactor coolant exposure for potential accelerated crack growth. However, since Code Case N-526 does not specify to use

ID surface to apply the proximity rule, a conservative assumption is made to apply the proximity rule in Code Case N-526 to both the ID and OD surfaces.

In developing the proximity rule, the basic premise for the criterion is that the average stress in the remaining ligament should not exceed the material flow strength, which would potentially create a risk for rupture of the remaining ligament. It should be noted that in the technical basis [4], the terminology yield strength (σ_y) was used synonymous with the flow stress (σ_f). The approach is illustrated in Figure 1. Yielding of the average net-section area (considering flaw) defined as A_n in Figure 1 will occur when the nominal membrane and bending stresses (as given by Equation 1 below) exceeds the flow strength of the material.

$$\sigma_n = \frac{\sigma_m + \sigma_b \left\{ 1 - \frac{\left[\frac{w_2}{t} - \frac{4}{3}\left(\frac{c+a}{t} \right) \right]}{\left(\frac{w_2}{c+a} - 1 \right)} \right\}}{\left(1 - \frac{\pi ab}{A_g} \right)} \le \sigma_f \qquad \text{---------- Eq. 1}$$

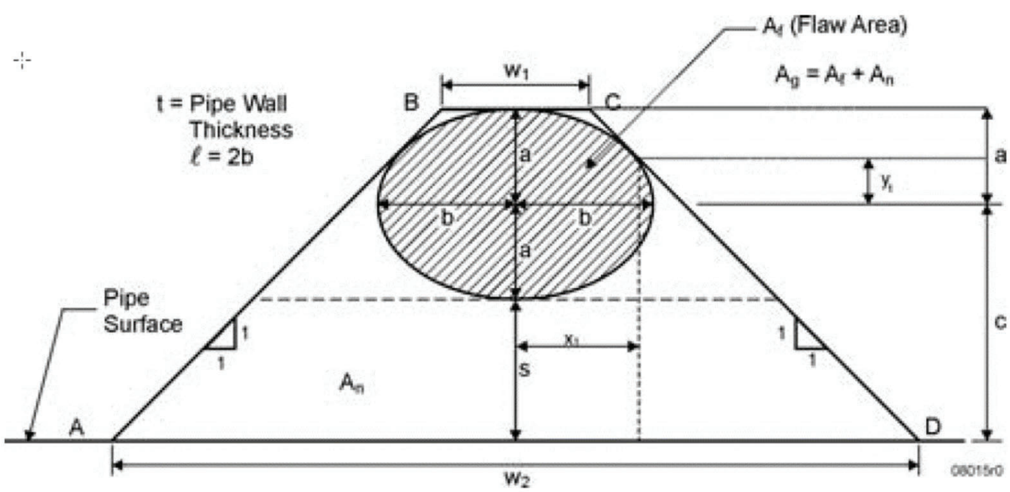

Figure 1. Model for ligament tearing [4]

In the technical basis document [4], the flaw proximity criterion (using Equation 1) for vessels was determined using the primary membrane stress (P_m) to be equal to the ASME Section III allowable stress intensity, S_m = 30 ksi and the primary membrane plus bending stress ($P_m + P_b$) was assumed to be equal to $1.5S_m$ = 45 ksi. A flow strength value of σ_f = 65 ksi for vessel materials was used for the evaluation which is a mid-range value for various vessel materials at 70ºF. Figure 2 presents the locus of flaw parameters (a/l and S) which would produce net section yielding. The ASME Code, Section XI surface proximity rule [2], as described in IWA-3320 is also shown in Figure 2 (S=0.4a). There are three curves shown in Figure 2 for different flaw aspect ratios, a/l of 0, 0.1 and 0.2. Flaws which lie above these curves for their respective aspect ratio would not cause yielding in the remaining ligament between the flaws and the vessel surface, even for vessel stress all the way to ASME Code, Section III primary membrane and bending stress allowables. As the trend shows, curves for higher aspect ratios would lie below these. The successive examination surface proximity rule per Code Case N-526 is also shown in Figure 2 (S>a line) which closely corresponds to yielding curve for a/l of 0.2. According to Code Case N-526, the successive examination is not required if the flaw can be characterized as subsurface flaw in accordance with Code Case N-526 rule (heavy line in Figure 2).

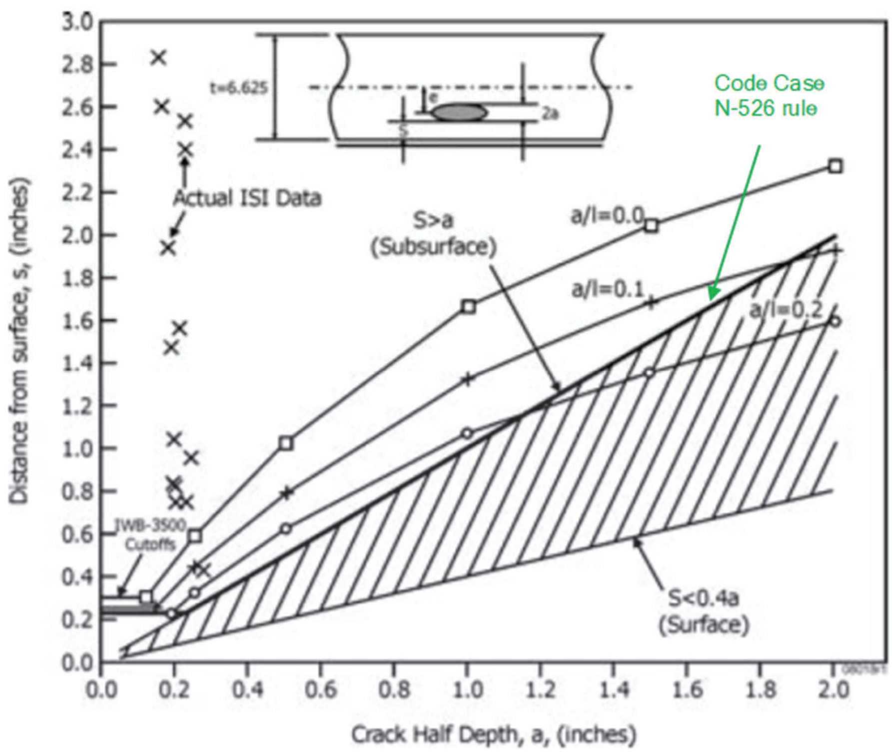

Figure 2. Development of Proximity Rules for Code Case N-526 [4]

3.2 Methodology Used for BFN Plant-Specific Assessment

As described in the previous section, the successive examination surface proximity rule per Code Case N-526 is based on preventing a flaw from causing yield in the remaining ligament of the ID surface by ensuring that the applied stress in the component (vessel) remains below the flow strength of the materials. In that regard, a plant-specific surface proximity rule can be developed based on the same technical requirements. To develop the plant-specific proximity rule from the OD surface for subsequent augmented re-examinations for the BFN RPV weld flaw, the plant-specific applied stresses, flaw dimension (i.e., aspect ratio) and flow strength of the RPV materials are required input.

Using Eq. 1 above and the plant-specific input, the plant-specific proximity rule will be developed based on preventing a flaw from causing yield in the remaining ligament of the OD surface. The flaw proximity curve for the plant-specific flaw aspect ratio (similar to curves shown in Figure 2) with plant-specific input will be developed. Any flaw that falls above this plant-specific proximity curve would be considered as subsurface flaw for successive examination.

4.0 DESIGN INPUTS

As reported in the Reference [1] flaw evaluation, the following design inputs are used:

1. The indication is reported as being subsurface, separated from the vessel base metal/clad interface by 2.2 inches [6]. The cross-flaw depth dimension in the vessel radial direction ($2a$) is 3.2 inches [6]. The flaw is in the vertical weld V-3-A at 107° azimuth, or 42.95 to 46.7 inches above the circumferential weld C-2-3 [6,7]. Details of the geometric parameters of the subsurface flaw are summarized in Figure 3.
2. The plate material of the RPV is SA-302 Grade B [8].
3. From Reference [9, Table Y-1], the yield strength, S_y for SA-302 Grade B, is 50 ksi and 42.1 ksi at 70°F and 600°F respectively. 600°F bounds the plant operating temperature.
4. From Reference [9, Table U], the ultimate strength, S_u for SA-302 Grade B, is 80 ksi for the temperature range of 70°F-600°F. 600°F bounds the plant operating temperature.
5. The vessel has an inside radius (centerline to base metal) of 125.6875 inches [8]. At the flaw location, the vessel wall thickness is 6.4 inches [6].

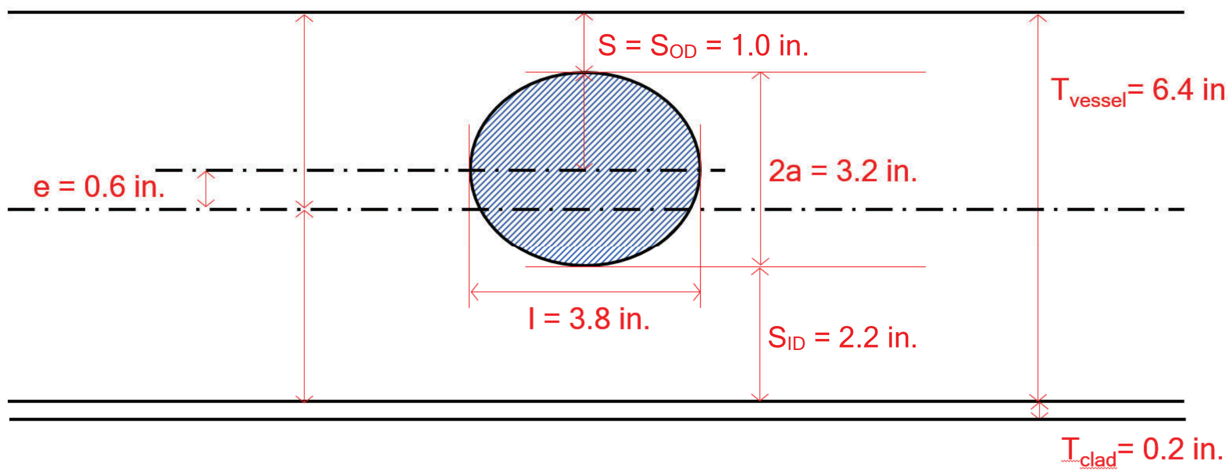

Figure 3. Flaw geometry [6]

5.0 CALCULATIONS

5.1 Flaw Characterization and Flaw Evaluation

The as-found flaw in the vertical weld of the BFN RPV was evaluated as per the requirements of IWB-3600 as reported in Reference [1]. The flaw was characterized as subsurface flaw as per IWA-3320 with a half-depth, a of 1.6-inch and length, l of 3.8-inch (see Figure 3). *Therefore, the aspect ratio of the as-found flaw is (a/l =) 0.421.* During the evaluation of the flaw, it was reported that the observed flaw is acceptable for continued operation per the requirements of ASME Code, Section XI, IWB-3640 and it would take 70 years for the as-found flaw to propagate to the allowable depth.

5.2 Stress Calculation

In the following sections, membrane and bending stresses due to pressure and thermal are calculated.

5.2.1 Stress Due to Pressure Load

The observed flaw is in the RPV shell in a vertical weld. It is therefore subjected to the membrane (hoop) stress due to the internal pressure in this cylindrical location. The membrane stress is calculated as:

Membrane stress due to pressure, $\sigma_{m-p} = PR_m/t$ = 21,024 psi = 21 ksi

where:

P = Maximum pressure = 1044 psig [10]
t = thickness = 6.4 inches [6]
R_m = Mean radius = 128.8875 inches ($D_i/2 + t/2$), D_i = 251.375 inches [8]

5.2.2 Membrane and Bending Stresses Due to Thermal Transient

To determine the thermal stress in the RPV wall, a thermal transient analysis was performed using the ANSYS finite element software [11]. The details of the thermal analysis are given in Reference [1]. The Service Level A/B RPV transient in Table 4 of Reference [12] with the highest ΔT was chosen as the bounding transient which is the Start-up Transient. Hoop stresses are extracted at OD surface and both crack tips, i.e., 2.2-inch and 5.4-inch depth (from ID) during the transient as shown in Figure 4. As seen in Figure 4, hoop stresses at both OD and crack-tip near OD (5.4-inch depth) reached maximum at around the same time (~19,872 seconds). A hoop stress distribution along the RPV thickness is shown in Figure 5 for the time step corresponding to maximum hoop stress (at OD). The total stress is then converted to linear stress distribution which is tangent to the point corresponds to crack-tip near OD as shown in Figure 5 (red line). The linear stress distribution due to thermal transient is given by σ_b = 0.6392x+1.5691 from which membrane and bending stresses are deconstructed as follows.

Membrane stress due to thermal, $\sigma_{m-t} = 0.6392 \times 3.2 + 1.5691 = 3.61$ ksi
Max. bending stress due to thermal, $\sigma_{b-t} = 0.6392 \times 6.4 + 1.5691 - 3.61 = 2.05$ ksi

Note that maximum stresses at OD surface is used to calculate the bounding maximum bending stress.

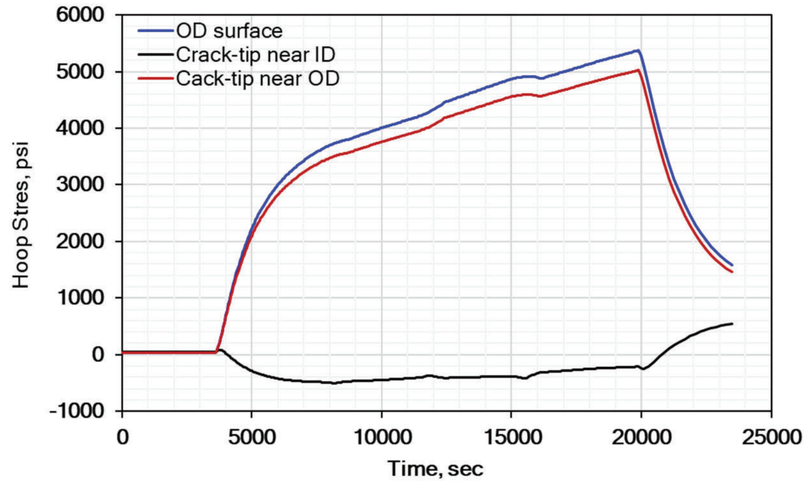

Figure 4. Hoop Stress During Start-up Transient at OD surface, crack-tip near ID and OD

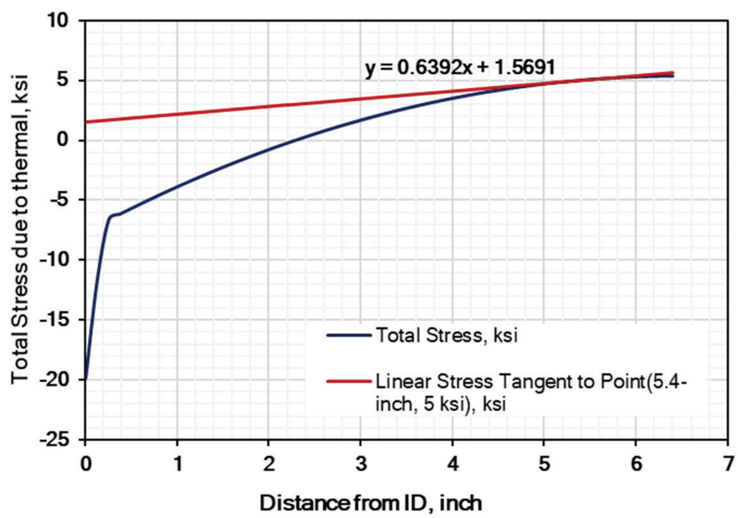

Figure 5. Start-up, Maximum Stress Distribution at Time = 19872 seconds

5.2.3 Total Stresses

Below shows the total membrane and bending stresses due to pressure and thermal transient.

Total membrane stress, σ_m = 21 + 3.61 = 24.61 ksi
Total bending stress, σ_b = 2.05 ksi

5.3 Material Properties

Below shows the bounding flow strength of RPV material at operating temperature of 600ºF which were determined by averaging the yield and ultimate strengths of the material as given in Section 4.0 “Design Input”.

σ_f (at 600F) = (42.1+80)/2 = 61.1 ksi

5.4 The Plant-Specific Surface Proximity Rule

Following the methodology described in Section 3.0, the plant-specific surface proximity curve is determined using the as-found flaw aspect ratio (of 0.421), applied plant-specific stresses and flow strength of RPV material as shown in Figure 6. As per technical basis document of Code Case N-526, the proximity rule was developed using flow strength at room temperature only. However, the bounding flow strength at operating temperature (600ºF) is used in the current analysis for additional conservatism. IWA-3320 proximity and Code Case N-526 surface proximity rules are also added in Figure 6 for reference. As can be seen in the figure, the plant-specific surface proximity curve falls below both IWA-3320 proximity and Code Case N-526 surface proximity rules indicating that the Code Case N-526 surface proximity rule is overly conservative for the as-found flaw in the vertical weld of the BFN RPV. Use of room temperature flow strength in the analysis would provide even more favorable results. However, the as-found flaw must meet the requirements of IWA-3320 to be considered as subsurface and therefore, the S>0.4 line (dotted black line) would be the plant-specific proximity rule for the as-found flaw in the vertical weld of the BFN RPV for the exemption of successive examination.

For reference, the chart also includes the Code Case N-526 proximity analysis result, considering only the distance of the flaw from the ID surface. This data point, in red, shows that the as-found flaw is acceptable per the existing conservative requirements of Code Case N-526, when the Code Case technical basis is applied, which would consider the flaw's proximity to only the ID surface.

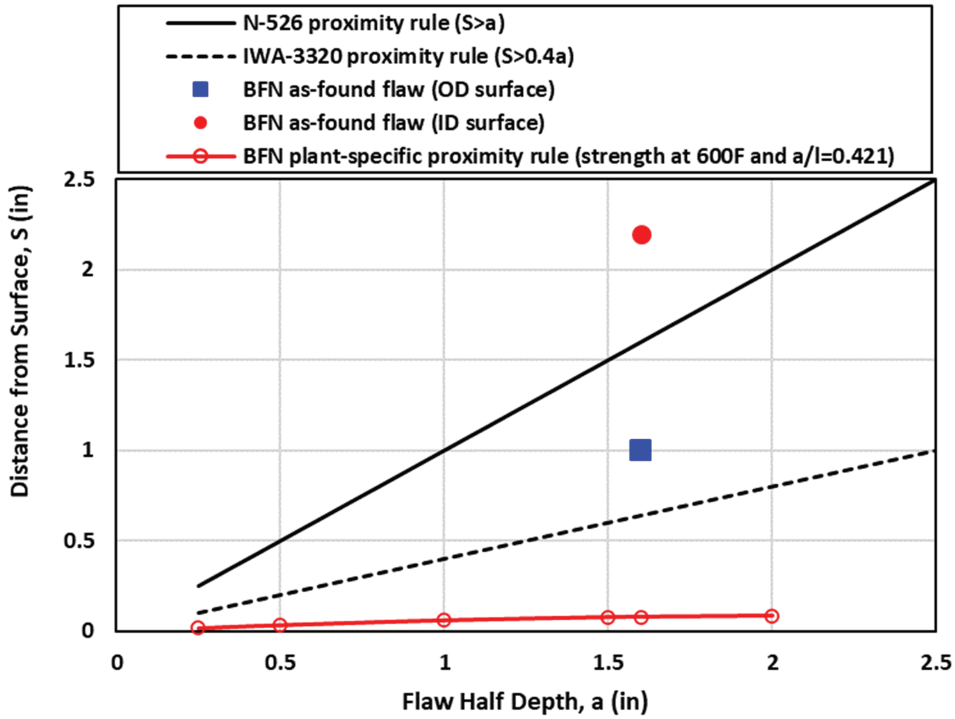

Figure 6. Development of BFN Plant-Specific Proximity Rule

6.0 RESULTS

The as-developed plant-specific surface proximity rule has been applied on the observed flaw in the vertical weld of the BFN RPV. Using the plant-specific proximity curve, developed using the same technical evaluation methods as the Code Case N-526 curve, this graph demonstrates that the as-found flaw is still bounded by the Code Case N-526 technical basis, even when considering the flaw's proximity to the OD surface. As shown in Figure 6 (blue square marker), the minimum distance to the OD surface for the as-found flaw is 1 inch, and the half-flaw depth is a = 1.6 inch. The observed flaw (from OD surface) is above the as-developed plant-specific surface proximity curve in Figure 6 as discussed in Section 5.4 and therefore, it can be classified as a subsurface flaw for the purpose of applying Code Case N-526 successive examination exemption requirements. For completeness, the assessment of the observed flaw from the ID surface is also added in Figure 6 (red circle marker) where the minimum distance to the ID surface for the as-found flaw is 2.2 inch, and the half-flaw depth is a = 1.6 inch. This data point shows that the as-found flaw is acceptable per the existing conservative requirements of Code Case N-526, when the Code Case technical basis is applied, which would consider the flaw's proximity to only the ID surface. As seen in the figure, the observed flaw (from ID surface) meets the requirements of both the Code Case N-526 and as-developed plant-specific proximity rules to be classified as subsurface flaw.

Using either the as-developed plant-specific surface proximity rule, or the ID surface proximity as intended by the Code Case N-526 technical basis, the following requirements specified in Code Case N-526 to exempt the re-examinations in accordance with IWB-2420(b) of vessel volumes containing subsurface flaws are met. Code Case N-526 is accepted without condition in Regulatory Guide 1.147 Revision 19 [13].

(a) The flaw is characterized as subsurface according to the as-developed plant-specific surface proximity rule (shown in Figure 6).

(b) The NDE technique and evaluation that detected and characterized the flaw, with respect to both sizing and location, shall be documented in the flaw evaluation report.

(c) The vessel containing the flaw is acceptable for continued service in accordance with IWB-3600, and the flaw is demonstrated acceptable for the intended service life of the vessel.

7.0 CONCLUSION

A plant-specific assessment surface proximity rule was developed for an as-found flaw in a vertical weld of the BFN RPV using the plant-specific stresses, actual flaw's aspect ratio and bounding flow strength of RPV material.

Using the as-developed plant-specific surface proximity rule, it is demonstrated in Section 6.0 that the observed flaw is classified as a subsurface flaw and meets the intent of the requirements of Code Case N-526 to exempt the re-examinations in accordance with IWB-2420(b) of vessel volumes containing subsurface flaws. Therefore, successive examinations in accordance with IWB-2420 (b) and (c) of the observed flaw in Weld V-3-A BFN Unit 2 RPV are not required.

8.0 REFERENCES

1. SI Calculation No. 2100264.301, Revision 2, “Browns Ferry Unit 2 Reactor Pressure Vessel Vertical Weld Flaw Evaluation”.
2. ASME Boiler and Pressure Vessel Code, 2007 Edition with 2008 Addenda, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components”.
3. ASME Boiler and Pressure Vessel Code, Code Case N-526, “Alternative Requirements for Successive Inspections of Class 1 and 2 Vessels, Section XI, Division 1,” Approved by ASME Code Committee August 9, 1996. Approved in Regulatory Guide 1.147, Revision 19.
4. N. Cofie, P. Riccardella, J. Merkle and H. Do, “Technical Basis for Alternate Successive Inspection Requirements for Vessels and Piping Welds as Prescribed in Code Cases N-526 And N-735”, Proceedings of ASME Pressure Vessel and Piping Conference, Chicago, IL, July 2008.
5. Tennessee Valley Authority (TVA) Purchase Order Number 6831497, Revision 1.
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7. TVA Drawing No. 2-CHM-2046-C-01, Revision 3, “Browns Ferry Nuclear Plant Unit1, Reactor Pressure Vessel, Shell Course Weld/Nozzle Locations (Outside View)” SI File No. 2100264.201.
8. TVA Document No. Form N-1, Unit #2, “Manufacturer’s Data Report for Nuclear Vessels”, SI File Number 2100264.201.
9. ASME Boiler and Pressure Vessel Code, 2007 Edition with 2008 Addenda, Section II, “Materials-Part D (Customary)”.
10. General Electric Hitachi Energy Document No. 24A5890, Revision 7, “Reactor Pressure Vessel – Extended Power Uprate” **PROPRIETARY**, SI File No. 2100264.201P.
11. ANSYS Mechanical APDL (UP20170403) and Workbench (March 31, 2017), Release 18.1, SAS IP, Inc.
12. Structural Integrity Associates, Inc. Calculation Package 1201256.301, Revision 0, “Loading for Browns Ferry Feedwater Piping Limiting Fatigue Location”, 06/03/2013.
13. Regulatory Guide 1.147, “Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1,” Revision 19, Nuclear Regulatory Commission, October 2019.

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Garivalde Dominguez Senior Associate	07/07/2022 Date	Mohammed Uddin Senior Consultant	07/07/2022 Date

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Enclosure 3

SI 2200769.401, Revision 0, "BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526 under Service Level C/D loadings"

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September 8, 2022
REPORT NO. 2200769.401
REVISION: 0
PROJECT NO. 2200769.00

Quality Program: ☒ Nuclear ☐ Commercial

Adam Keyser
Tennessee Valley Authority
Browns Ferry Nuclear Plant, Unit 2
PO Box 2000
Decatur, AL 35609

Subject: BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526 under Service Level C/D loadings

Dear Adam,

1.0 INTRODUCTION

During the spring 2021 outage at Browns Ferry Nuclear Plant, Unit 2 (BFN), an indication was identified in a vertical weld (Weld No. V-3-A) of the reactor pressure vessel (RPV). This flaw was evaluated by Structural Integrity Associates, Inc. (SI) in SI Calculation 2100264.301P [1] and determined to be acceptable for continued service per the rules of Section XI, IWB-3600 [2]. In order to support exemption of the three successive inspections required by IWB-2420 as per ASME Code Case N-526 [3], an additional evaluation was also performed in Reference [5] using the technical basis documents [4] of Code Case N-526 to show that the BFN RPV weld flaw met the intent of Code Case N-526 under Service Level A and B loadings when plant-specific materials, stresses, and aspect ratio are utilized. In the current evaluation, a calculation will be performed to determine if the BFN RPV weld flaw will meet the intent of Code Case N-526 under Service Level C and D loadings.

2.0 METHODOLOGY

The methodology used in Reference [5] for the plant-specific assessment developed the proximity rule from the OD surface for subsequent augmented re-examinations for the BFN RPV weld flaw by following the same procedure used in the technical basis document [4] for ASME Code Case N-526 but using the operating stresses for Service A/B loadings and as-found flaw aspect ratio. A brief description of the procedure used in the technical basis document [4] is also provided in Reference [5].

In developing the proximity rule, the basic premise for the criterion is that the average stress in the remaining ligament should not exceed the material flow strength, which would potentially create a risk for rupture of the remaining ligament. The approach is illustrated in Figure 1. Yielding of the average net-section area (considering flaw) defined as A_n in Figure 1 will occur when the primary membrane (σ_m) and primary bending stresses (σ_b) exceeds the flow strength of the material as given by Equation 1 below.

$$\sigma_n = \frac{\sigma_m + \sigma_b\left\{1 - \frac{\left[\frac{w_2}{t} - \frac{4}{3}\left(\frac{c+a}{t}\right)\right]}{\left(\frac{w_2}{c+a} - 1\right)}\right\}}{\left(1 - \frac{\pi ab}{A_g}\right)} \le \sigma_f \qquad \text{---------- Eq. 1}$$

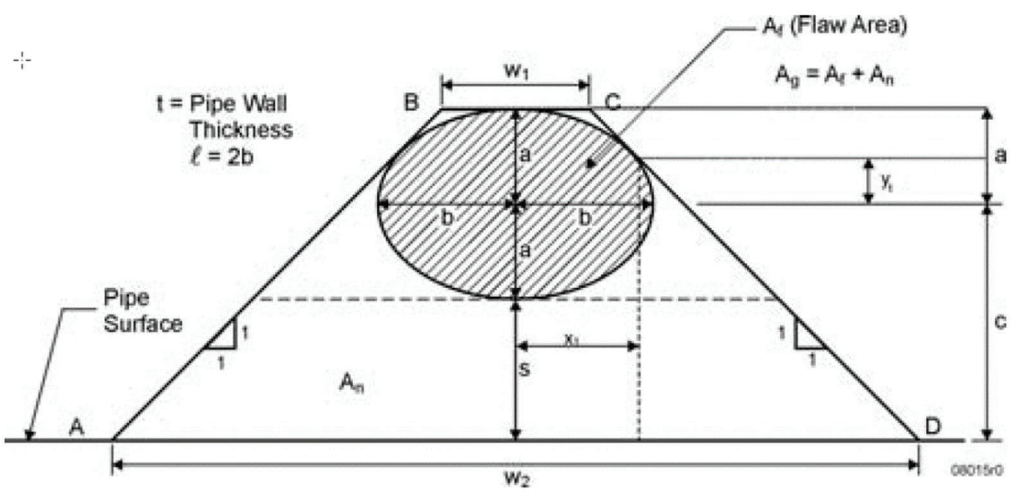

Figure 1. Model for Ligament Tearing [4]

2.1 Methodology Used for BFN Plant-Specific Assessment

The successive examination surface proximity rule per Code Case N-526 is based on preventing a flaw from causing yield in the remaining ligament of the ID surface by ensuring that the applied stress in the component (vessel) remains below the flow strength of the materials. In that regard, a plant-specific surface proximity rule can be developed based on the same technical requirements. To develop the plant-specific proximity rule from the OD surface for subsequent augmented re-examinations for the BFN RPV weld flaw, the plant-specific applied stresses for Service Level C and D, flaw dimension (i.e., aspect ratio), and flow strength of the RPV materials are required input.

Using Eq. 1 above and the plant-specific input, the plant-specific proximity rule will be developed based on preventing a flaw from causing yield in the remaining ligament of the OD surface. The flaw proximity curve for the plant-specific flaw aspect ratio with plant-specific input will be developed. Any flaw that falls above this plant-specific proximity curve would be considered as a subsurface flaw for successive examination.

3.0 DESIGN INPUTS

As reported in the Reference [1] flaw evaluation, the following design inputs are used:

1. The indication is reported as being subsurface, separated from the vessel base metal/clad interface by 2.2 inches [6]. The cross-flaw depth dimension in the vessel radial direction ($2a$) is 3.2 inches [6]. The flaw is in the vertical weld V-3-A at 107° azimuth, or 42.95 to 46.7 inches above the circumferential weld C-2-3 [6,7]. Details of the geometric parameters of the subsurface flaw are summarized in Figure 2.
2. The plate material of the RPV is SA-302 Grade B [8].
3. From Reference [9, Table Y-1], the yield strength, S_y for SA-302 Grade B, is 50 ksi and 42.1 ksi at 70°F and 600°F respectively. 600°F bounds the plant operating temperature.
4. From Reference [9, Table U], the ultimate strength, S_u for SA-302 Grade B, is 80 ksi for the temperature range of 70°F-600°F. 600°F bounds the plant operating temperature.
5. The vessel has an inside radius (centerline to base metal) of 125.6875 inches [8]. At the flaw location, the vessel wall thickness is 6.4 inches [6].

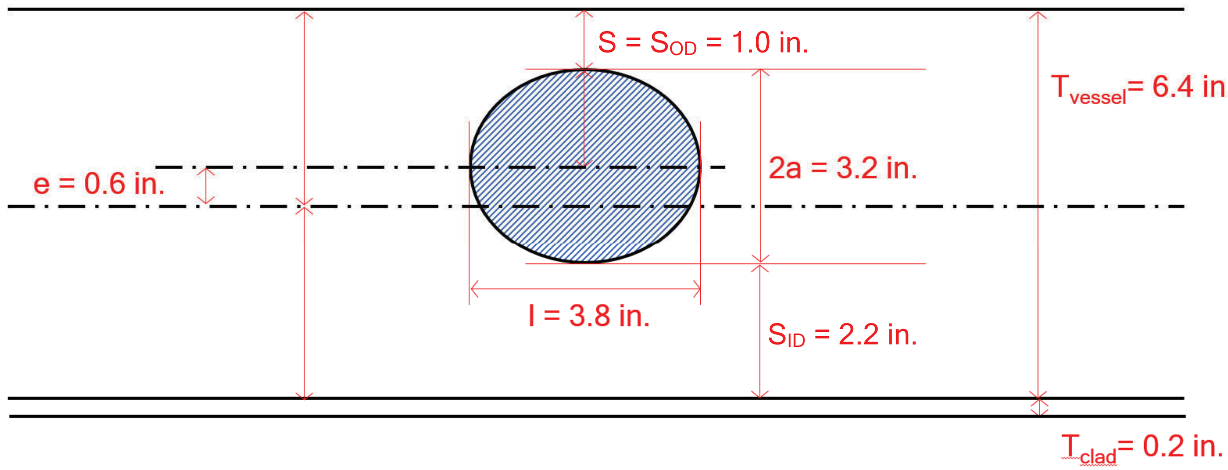

Figure 2. Flaw Geometry [6]

4.0 CALCULATIONS

4.1 Flaw Characterization and Flaw Evaluation

The as-found axial flaw in the vertical weld of the BFN RPV was evaluated as per the requirements of IWB-3600 as reported in Reference [1]. The flaw was characterized as subsurface flaw as per IWA-3320 with a half-depth, a of 1.6-inch and length, l of 3.8-inch (see Figure 2). *Therefore, the aspect ratio of the as-found flaw is (a/l =) 0.42.* During the evaluation of the flaw, it was reported that the observed flaw is acceptable for continued operation per the requirements of ASME Code, Section XI, IWB-3640 and it would take 70 years for the as-found flaw to propagate to the allowable depth.

4.2 Stress Calculation

As noted in Section 3.0 and the technical basis document [4], only primary membrane and primary bending stresses are included in the evaluation to develop the proximity rule. As such, secondary stresses due to thermal transients and weld residual stresses are not included in the current evaluation. Note that secondary stress due to thermal transient was conservatively used in Reference [5] evaluation for service level A/B loadings. Also, since the flaw is an axial flaw, only hoop stresses due to primary loading contribute to the driving force. In that regard, stresses due to deadweight, safe shutdown Earthquake (SSE), Loss of Coolant Accident (LOCA) are not included and only stresses due to pressure is used in the current evaluation. The pressure for Service Level C/D is 1375 psi from the Reactor Overpressure Event as documented in Reference [10, Table 4-1]

4.2.1 Stress Due to Pressure Load

The membrane (hoop) stress due to the internal pressure of 1375 psi is calculated as:

Membrane stress due to pressure, $\sigma_{m-p} = PR_m/t$ = 27,691 psi = 27.7 ksi

where:

P = Maximum pressure (Service Level C/D) = 1375 psig [10]
t = thickness = 6.4 inches [6]
R_m = Mean radius = 128.8875 inches ($D_i/2 + t/2$), D_i = 251.375 inches [8]

4.3 Material Properties

Below shows the bounding flow strength of RPV material at operating temperature of 600ºF which were determined by averaging the yield and ultimate strengths of the material as given in Section 4.0 "Design Input".

σ_f (at 600F) = (42.1+80)/2 = 61.1 ksi

4.4 The Plant-Specific Surface Proximity Rule

Following the methodology described in Section 3.0, the plant-specific surface proximity curve is determined using the as-found flaw aspect ratio (of 0.42), applied plant-specific stresses for Service Level C/D and flow strength of RPV material as shown in Figure 3. IWA-3320 proximity rule and Code Case N-526 surface proximity rule are also added in Figure 3 for reference. As can be seen in the figure, the plant-specific surface proximity curve for Service Level C/D loading is slightly higher than that for service level A/B loading; however, both curves fall below both IWA-3320 proximity and Code Case N-526 surface proximity rules indicating that the Code Case N-526 surface proximity rule is overly conservative for the as-found flaw in the vertical weld of the BFN RPV. Since the as-found flaw must meet the requirements of IWA-3320 to be considered as subsurface, the S>0.4 line (dotted black line) would be the plant-specific proximity rule for the as-found flaw in the vertical weld of the BFN RPV for the exemption of successive examination.

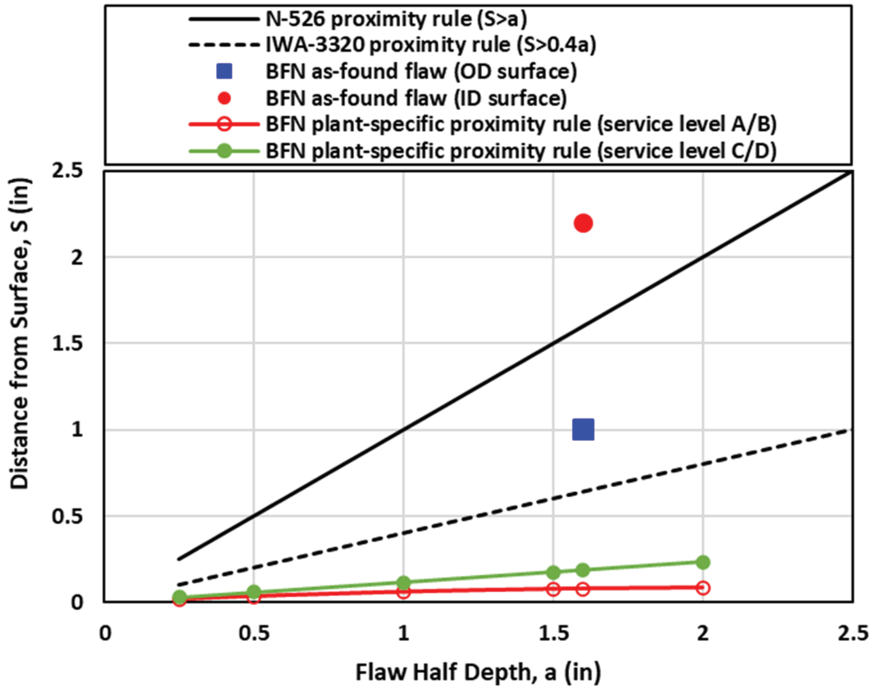

Figure 3. Development of BFN Plant-Specific Proximity Rule

5.0 RESULTS

The as-developed plant-specific surface proximity rule for Service Level C/D has been applied on the observed flaw in the vertical weld of the BFN RPV. Using the plant-specific proximity curve, developed using the same technical evaluation methods as the Code Case N-526 curve, demonstrates that the as-found flaw is still bounded by the Code Case N-526 technical basis, even when considering the flaw's proximity to the OD surface. As shown in Figure 3 (blue square marker), the minimum distance to the OD surface for the as-found flaw is 1 inch, and the half-flaw depth is a = 1.6 inch. The observed flaw (from OD surface) is above the as-developed plant-specific surface proximity curve in Figure 3 and therefore, it can be classified as a subsurface flaw for the purpose of applying Code Case N-526 successive examination exemption requirements. For completeness, the assessment of the observed flaw from the ID surface is also added in Figure 3 (red circle marker) where the minimum distance to the ID surface for the as-found flaw is 2.2 inch, and the half-flaw depth is a = 1.6 inch. This data point shows that the as-found flaw is acceptable per the existing conservative requirements of Code Case N-526, when the Code Case technical basis is applied, which would consider the flaw's proximity to only the ID surface. The observed flaw (from ID surface) meets the requirements of both the Code Case N-526 and as-developed plant-specific proximity rules to be classified as subsurface flaw.

Using either the as-developed plant-specific surface proximity rule, or the ID surface proximity as intended by the Code Case N-526 technical basis, the following requirements specified in Code Case N-526 to exempt the re-examinations in accordance with IWB-2420(b) of vessel volumes containing subsurface flaws are met. Code Case N-526 is accepted without condition in Regulatory Guide 1.147 Revision 19 [13].

(a) The flaw is characterized as subsurface according to the as-developed plant-specific surface proximity rule (shown in Figure 3).
(b) The NDE technique and evaluation that detected and characterized the flaw, with respect to both sizing and location, shall be documented in the flaw evaluation report.
(c) The vessel containing the flaw is acceptable for continued service in accordance with IWB-3600, and the flaw is demonstrated acceptable for the intended service life of the vessel.

6.0 CONCLUSION

A plant-specific assessment surface proximity rule was developed for an as-found flaw in a vertical weld of the BFN RPV using the plant-specific stresses for Service Level C/D loadings, actual flaw's aspect ratio and bounding flow strength of RPV material.

Using the as-developed plant-specific surface proximity rule, it is demonstrated in Section 6.0 that the observed flaw is classified as a subsurface flaw and meets the intent of the requirements of Code Case N-526 to exempt the re-examinations in accordance with IWB-2420(b) of vessel volumes containing subsurface flaws. Therefore, successive examinations in accordance with IWB-2420 (b) and (c) of the observed flaw in Weld V-3-A BFN Unit 2 RPV are not required.

7.0 REFERENCES

1. SI Calculation No. 2100264.301, Revision 3, "Browns Ferry Unit 2 Reactor Pressure Vessel Vertical Weld Flaw Evaluation", July 8, 2022.
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4. N. Cofie, P. Riccardella, J. Merkle and H. Do, "Technical Basis for Alternate Successive Inspection Requirements for Vessels and Piping Welds as Prescribed in Code Cases N-526 And N-735", Proceedings of ASME Pressure Vessel and Piping Conference, Chicago, IL, July 2008.

5. SI Calculation No. 2100312.401, Revision 2, “BFN V-3-A Weld Flaw Plant-Specific Assessment per the Technical Basis for ASME Code Case N-526”.
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12. Structural Integrity Associates, Inc. Calculation Package 1201256.301, Revision 0, “Loading for Browns Ferry Feedwater Piping Limiting Fatigue Location”, 06/03/2013.
13. Regulatory Guide 1.147, “Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1,” Revision 19, Nuclear Regulatory Commission, October 2019.

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Approved by:

Daniel B. Denis, PE Manager - Vessels & Internals	09/08/2022 Date

Enclosure 4

SI 2200769.301, Revision 0, “Resolution of RAI-5 (P-T Limits Inquiry)”

Structural Integrity Associates, Inc.

File No.: 2200769.301

Project No.: 2200769

Quality Program Type: ☒ Nuclear ☐ Commercial

CALCULATION PACKAGE

PROJECT NAME:
Browns Ferry Unit 2

CONTRACT NO.:
PO 7298347 Rev.0 Contract 16692

CLIENT:
TVA

PLANT:
Browns Ferry Unit 2

CALCULATION TITLE:
Resolution of RAI-5 (P-T Limits Inquiry)

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	All	Initial Issue	Approved By: [signature] Daniel B Denis, PE 09/08/2022	Prepared By: [signature] Sam Ranganath 09/08/2022 Checked By: [signature] Daniel B. Denis, PE 09/08/2022

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1.0 INTRODUCTION

During ultrasonic examination of the Browns Ferry Nuclear (BFN) Unit 2 reactor pressure vessel (RPV), an indication in a vertical weld was identified that exceeds the acceptance standards of ASME Code, Section XI, IWB-3500 [1]. Figure 1 shows a schematic of the indication in the Axial weld V-3-A. Therefore, a flaw evaluation per the requirements of IWB-3600 was performed. The fracture mechanics analysis of the V-3-A indication [2] confirmed that the requirements of IWB-3600 are satisfied.

As required by ASME Code, Section XI, IWB-3132.3 [1], indications that exceed the acceptance standards of Table IWB-3410-1 (for vessel welds Table IWB-3510-1) but found acceptable for continued operation by the flaw evaluation methods of IWB-3600 must be subsequently re-examined in accordance with IWB-2420(b) and (d). IWB-2420(b) requires that the area containing the flaw shall be inspected during the next three inspection periods listed in the schedule of the inspection program of IWB-2400. ASME Section XI Code Case N-526 [3] provides alternate requirements for re-examination of subsurface flaws found by volumetric examinations in lieu of the requirements in IWB-2420(b). This Code Case is accepted without condition in Regulatory Guide 1.147 Revision 17 (and Revision 18, 19, and proposed 20) and has also been incorporated in recent Editions of ASME Code, Section XI. Code Case N-526 states that the re-examinations in accordance with IWB-2420(b) of vessel volumes containing subsurface flaws are not required, provided the following are met:

a. The flaw is characterized as subsurface in accordance with the figure provided in the Code Case.
b. The NDE technique and evaluation that detected and characterized the flaw, with respect to both sizing and location, shall be documented in the flaw evaluation report.
c. The vessel containing the flaw is acceptable for continued service in accordance with IWB-3600, and the flaw is demonstrated acceptable for the intended service life of the vessel.

The evaluation in [2] confirmed that above requirements are met and that subsequent augmented re-examinations in accordance with IWB-2420 (b) and (d) of the indication in weld V-3-A are not required. Tennessee Valley Authority (TVA) submitted a request to the NRC for approval of alternative BFN-21-ISI-02 for the fifth 10-year in-service inspection (ISI) interval at Browns Ferry Nuclear (Browns Ferry or BFN), Unit 2. TVA proposed an alternative to the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code), Section XI, paragraph IWB-2420(b), for deferring the applicable successive examinations of the flaw identified in Weld V-3-A at Browns Ferry, Unit 2, until the normally scheduled inspection during the sixth 10-year ISI interval.

The U.S. Nuclear Regulatory Commission (NRC) staff requested additional information (RAI) to complete its review of the proposed alternative. This report provides the technical basis for the response to RAI-5 which is described in detail below:

RAI-5

<u>Background</u>

The pressure-temperature (P-T) limit curves for the operation of the reactor vessel during heat up and cooldown evolution as shown in the plant technical specifications are constructed based on a postulated flaw that has a depth of ¼ of the wall thickness of the reactor vessel shell. The flaw is postulated to initiate from the inside surface and outside surface of the reactor vessel shell.

Issue

TVA has not indicated if the flaw in weld V-3-A affects the P-T limit curves.

Request

Discuss whether the flaw in weld V-3-A affects the existing P-T limit curves in the plant technical specifications. If yes, indicate when TVA plans to revise the P-T limit curves to reflect the impact of the flaw on the P-T limit curves in the technical specifications via a separate license amendment request.

This report provides the technical basis for the response to RAI-5.

2.0 METHODOLOGY

The P-T curves used in the technical specification are based on the requirements of ASME Code, Section XI, Appendix G [4] and 10CFR50 Appendix G (which makes some modifications of the ASME Code, but essentially preserves the Code criteria) [5]. Both the ASME Code and 10CFR50 Appendix G are based on postulating a quarter-thickness semi-elliptic surface flaw with length equal to 6 times the depth (a/L=1/6) and requiring specific fracture margins for the different operating conditions. For the pressure test (also referred to as the leak test) Section XI, Appendix G requires a structural factor of 1.5 on the pressure stress. For other conditions such as heatup and cooldown, the required factors are 2 on pressure stress and 1 on thermal stress. Since BWRs follow the saturation curve for Levels A-D, the temperature is sufficiently high that normal operation (including heatup/cooldown) the P-T curves (referred to as Curves B and C) for these conditions are not governing. The saturation temperature is well in excess of the Appendix G requirements for these cases. The focus is on the pressure test (Curve A) which is governing.

The concern in RAI-5 relates to the question of whether the fracture effect of the Weld V-3-A indication is higher than that due to the postulated quarter-T flaw. Specifically, RAI-5 asks whether the existing P-T limit curves in the plant technical specifications are affected by the presence of the weld V-3-A indication.

3.0 ASSUMPTIONS

One way of answering the question of whether the postulated quarter-T flaw still bounds the weld V-3-A indication, (i.e., the P-T curves based on the Appendix G flaw still cover the V-3-A indication), is to show that the following criteria are met:

- The highest fluence at the weld V-3-A is lower than the fluence at the quarter-T flaw evaluated in developing the P-T curves per Appendix G.
- The stress intensity factor for the V-3-A indication is lower than that for the Appendix G quarter-T flaw.
- A final way to determine whether the postulated Appendix G quarter-T flaw still bounds the weld V-3-A indication is to compare the pressure test P-T curve for the Weld V-3-A with that based on the Appendix G quarter-T flaw. The P-T curve for the weld V-3-A indication is developed by replacing the quarter-T surface flaw with the weld V-3-A subsurface flaw. All other parameters including the structural factor of 1.5 and the 10CFR50 modifications remain unchanged.
- As stated earlier, Curve A is governing, but for completeness, Curve B and C are also plotted.

If the above criteria are met, it can be concluded that that the fracture consequences of the postulated quarter-T flaw bound that of the weld V-3-A indication. Therefore, no revision of the P-T limit curves in the plant technical specifications are required.

4.0 DESIGN INPUTS

- The weld V-3-A indications are as shown in Figure 1.
- The fluences for the limiting plate material and weld V-3-A are based on the TransWare report for the BF Unit 2 Pressure Vessel Fluence Evaluation for Subsequent License Renewal [6], as this is a limiting fluence value relative to the 60 year of operation values assumed in the calculation [2].
- The governing condition for the P-T Limit curve is the pressure test condition, however, Curve B and C are also shown for completeness.

5.0 CALCULATIONS

5.1 Fluence Comparison

Table 1 shows the ID surface fluence for the Subsequent License Renewal period of operation [6]. It is seen that the maximum fluence at weld V-3-A on the ID surface is 4.72x10^{16} n/cm^2 (E > 1 MeV). This is well below the limit of 1 x10^{17} n/cm^2 (E > 1 MeV) for consideration of irradiation effects on the material toughness [7]. The highest fluence is in the plate material with the Shell Course 2 surface fluence of 1.69x10^{18} n/cm^2. This is conservative for the purpose of addressing the RAI, since it corresponds to 64 EFPY. The corresponding fluence at the tip of the flaw for the Appendix G quarter-T flaw and the weld V-3-A indication can be calculated using the following relationship in [7].

$$f = f_{surf} \cdot e^{-0.24x}$$

Where: f = fast neutron fluence (10^{19} n/cm^2, E > 1 MeV)
f_{surf} = fast neutron fluence at the RPV inside surface

Table 2 shows the fluence values at the tip of the indication for the Appendix G flaw (x=0.5*6.4=1.6 in) and the weld V-3-A indication (x=2.2 in.). It is seen that the Appendix G quarter-T flaw has far higher fluence when compared to that for weld V-3-A indicating that from the fluence and toughness viewpoint, the Appendix G flaw is bounding.

The calculation uses conservatively the 64 EFPY fluence and confirms that the fluence at the indication location is less than 1x10^{17} n/cm^2 [2]. Since the fluence is less than the 1x10^{17} n/cm^2 threshold, the unirradiated RT_{NDT} is used in the fracture mechanics analysis for the vessel weld V-3-A (Section 5.3).

5.2 Applied Stress Intensity Factor for the Pressure Test

The stress intensity factors (K_I) for the Appendix G flaw and the weld V-3-A indication for the pressure test are compared in this section. Since the pressure test is the governing case (the P-T curves for other conditions are easily met since the saturation temperature is well in excess of the required temperature from the Appendix G analysis and the comparison of limiting location for Curves B and C follows the same comparison method as for Curve A), the K_I comparisons are performed for the hoop stress under internal pressure.

<u>K_I Value for the Appendix G Quarter T Surface flaw</u>

Appendix G provides the membrane stress K solution for hoop pressure stress (corresponding to the pressure test condition). The K_I value is given by:

$K_{Im} = M_m \frac{Pr_i}{t}$ where $\frac{Pr_i}{t}$ is the hoop stress and $M_m = 0.926\sqrt{t}$. The K value is not directly related to the flaw size since a is equal to 0.25t.

K_I Value for the weld V-3-A subsurface flaw

Appendix A of Section XI, ASME Code provides the stress intensity factor for a subsurface flaw [8]. The K_I is determined by fitting a polynomial to the stress distribution over the thickness of the vessel wall. The polynomial stress distribution is:

$$\sigma = B_0 + B_1(x/t) + B_2(x/t)^2 + B_3(x/t)^3 + B_4(x/t)^4$$

where x is the distance from the surface of the crack and t is the thickness of the section and B_0, B_1, B_2, B_3 *and* B_4 are the polynomial fit coefficients. The stress intensity factor is given by:

$$K_I = (B_0G_0 + B_1G_1 + B_2G_2 + B_3G_3 + B_4G_4)\sqrt{\pi a/Q}$$

G_0, G_1, G_2, G_3 *and* G_4 are coefficients given in Tables A-3312 (Tables A-3610-X) [8], a is the subsurface flaw size (Figure 2) and Q is the flaw shape parameter given by:

$$Q = \varphi - q_y$$

$$\varphi = 1 + 4.593(a/L)^{1.65}$$

$$q_y = ((B_0G_0 + B_1G_1 + B_2G_2 + B_3G_3 + B_4G_4)/S_y)^2/6$$

The coefficients G_0 through G_4 are functions of a/L and d/t and are specified for Points 1, 2, and 3 (Figure 3). S_y is the yield strength assumed to be 50 ksi.

For the pressure test condition, the coefficient $B_0 = \frac{Pr_i}{t}$ and all other coefficients are zero. The ratio a/L for the sub surface flaw = 1.6/3.8 = 0.421 [2].

From the G_0 coefficients in Tables A-3312 [8] for points 1, 2 and 3, it is seen that they are all very close (around 1.0). The value for Point 2 which is bounding is used in calculating the K_I value for the subsurface flaw.

Comparison of the Stress Intensity Factors for the Appendix G Quarter-T Surface flaw and the Weld V-3-A Subsurface Flaw

Figure 4 shows the comparison of the Stress Intensity Factors for the two flaw types as a function of pressure. It is seen that the K_I solution for the Appendix G flaw bounds that for the weld V-3-A indication.

5.3 P-T curve Comparison for the Appendix G flaw and the weld V-3-A flaw

As stated earlier, the final way to determine whether the postulated Appendix G quarter-T flaw still bounds the weld V-3-A indication is to compare the pressure test P-T curve for the Weld V-3-A with that based on the Appendix G quarter-T flaw. The P-T curve for the weld V-3-A indication is developed by replacing the Quarter-T surface flaw with the weld V-3-A subsurface flaw. All other parameters including the structural factor of 1.5 and the 10CFR50 modifications remain unchanged.

The 10CFR50 Appendix G requirements are summarized in Table 3. It represents a combination of the ASME Code Appendix G requirements in addition to other specific criteria. It specifies three curves: Curve A (Hydrostatic pressure and Leak Tests), Curve B (Normal Operation including transients such as Heatup and Cooldown with the Core not critical) and Curve C (Normal Operation including transients with the core being critical). For BWRs where the pressure and temperature follow the steam saturation curve, Curve A requirements are bounding.

The P-T curves for the 80-year SLR period are being developed and not yet available at this time. Therefore, the existing P-T curve for the 48-EFPY period [9] is used for the comparison. Figure 5 from [9] shows Curve A at 48 EFPY. It is seen that the part of the P-T curve is dependent on Items 1a and 1b in Table 3 where the required temperature is governed by the combination of the ASME Appendix G requirement and the additional requirements in 10CFR50 Appendix G related to the flange RT_{NDT}. At pressures below 20% of the system hydrostatic test pressure (1562.5 psi) the required minimum is the Flange RT_{NDT} (Line AB in Figure 5). Above the 20% limit (or 313 psi), the required temperature is the higher of the ASME Appendix G limit and RT_{NDT}+90°F (Line BCD in Figure 5). In the segment ABCD in Figure 5, the flange RT_{NDT} related requirements in 10CFR50 Appendix G are governing, but beyond Point D, the ASME Appendix G limit governs.

Figure 6 shows the comparison of Curve A based on the Weld V-3-A flaw and the Appendix G flaw. Other than the postulated V-3-A subsurface flaw in place of the Appendix G, the P-T curves are developed using the same methodology used in the 48-EFPY P-T curve shown in Figure 5. It is seen that the flange RT_{NDT} related requirements in 10CFR50 Appendix G are always governing for the Weld V-3-A flaw when compared to that from the ASME Appendix G limit. This confirms that that the fracture consequences of the postulated quarter-T flaw bound that of the weld V-3-A indication.

Figure 7 shows Curves B and C [9] for the Appendix G flaw. The figure is the composite of the curves for the belt line region, the bottom head, and the upper vessel. Figure 8 shows the Curves B and C for the. It also includes the saturation temperature curve. As stated earlier, the saturation temperature is much higher than the required minimum temperatures for the V-3-A subsurface flaw and Curve A is governing.

Based on the comparison presented here, the P-T curves for the Appendix G flaw bound the curves for the Weld V-3-A subsurface flaw. Therefore, no revision of the P-T limit curves in the plant technical specifications are required.

6.0 CONCLUSIONS

The fluence comparison shows that the highest fluence at the weld V-3-A is lower than the fluence at the quarter-T flaw evaluated in developing the P-T curves per Appendix G. Furthermore, the stress intensity factor for the V-3-A indication is lower than that for the Appendix G quarter-T flaw. Finally, the comparison of the P-T curves for the pressure test shows that the P-T curve based on the Appendix G Quarter-T flaw bound that for the Weld V-3-A. Therefore, it can be concluded that that the fracture consequences of the postulated quarter-T flaw bound that of the weld V-3-A indication. Therefore, no revisions of the P-T limit curves in the plant technical specifications are required.

7.0 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section XI, Rules for In-Service Inspection of Nuclear Power Plant Components, 2007 Edition with 2008 Addenda.
2. Structural Integrity Associates Calculation, 2100264.301, Revision 3, “Browns Ferry Unit 2 Reactor Pressure Vessel Vertical Weld Flaw Evaluation”, July 7, 2022.

3. ASME Boiler and Pressure Vessel Code, Code Case N-526, “Alternative Requirements for Successive Inspections of Class 1 and 2 Vessels, Section XI, Division 1,” Approved by ASME Code Committee August 9, 1996. Approved in Regulatory Guide 1.147, Revision 17.
4. ASME Boiler and Pressure Vessel Code, Section XI, Rules for In-Service Inspection of Nuclear Power Plant Components, Nonmandatory Appendix G, “Fracture Toughness Criteria for Protection Against Failure”, 2007 Edition with 2008 Addenda.
5. Title 10, Code of Federal Regulations, Part 50, Appendix G, “Fracture Toughness Requirements,” November 29, 2019.
6. TransWare Report BFN-FLU-001-R-003, Revision 0, “Browns Ferry Nuclear Plant Unit 2 Reactor Pressure Vessel Fluence Evaluation – Subsequent License Renewal”, August 2022, SI File Number 2200769.210.
7. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.99, Rev. 2.
8. ASME Boiler and Pressure Vessel Code, Section XI, Rules for In-Service Inspection of Nuclear Power Plant Components, Nonmandatory Appendix A, “Analytical Evaluation of Flaws”, 2007 Edition with 2008 Addenda.
9. GEH Non-Proprietary Report, NEDO-33854, Revision 0, “Pressure and Temperature Limits Report (PTLR) up to 38 and 48 Effective Full Power Years”, April 2014, SI File No. 2100679.211.

Table 1: ID Surface Fluence for the SLR Period [6]

Component	Maximum Fast Neutron Fluence (n/cm^2)	
	EOC 21 (31.9 EFPY)	64 EFPY
RPV Beltline Welds		
C-1-2	6.78E+17	1.34E+18
C-2-3	1.92E+16	5.07E+16
V-1-A	6.17E+17	1.26E+18
V-1-B	4.81E+17	9.60E+17
V-1-C	3.65E+17	7.65E+17
V-2-A	6.26E+17	1.21E+18
V-2-B	6.91E+17	**1.39E+18**
V-2-C	**6.93E+17**	1.36E+18
V-3-A	1.77E+16	4.72E+16
V-3-B	1.67E+16	4.39E+16
V-3-C	1.61E+16	4.43E+16
Nozzle Forging-to-Base-Metal Welds		
Nozzle Weld N2	9.28E+15	1.85E+16
Nozzle Weld N16	**1.52E+17**	**3.47E+17**
Shell Plates		
Shell Course 1	6.78E+17	1.34E+18
Shell Course 2	**8.72E+17**	**1.69E+18**

Table 2: Fluence at the tip of the Appendix G and Weld V-3-A Flaw (64 EFPY)

Flaw description	Surface Fluence n/cm^2	Fluence at the Crack Tip n/cm^2
Appendix G Flaw	1.69×10^{18}	1.15×10^{18}
Weld V-3-A Flaw	4.72×10^{16}	2.78×10^{16}

Table 3: 10CFR50 Appendix G Pressure-Temperature Requirements

Operating condition	**Vessel pressure**[1]	**Requirements for pressure-temperature limits**	**Minimum temperature requirements**
1. Hydrostatic pressure and leak tests (core is not critical):			
1.a Fuel in the vessel	≤20%	ASME Appendix G Limits	([2])
1.b Fuel in the vessel	>20%	ASME Appendix G Limits	([2]) +90 ° F([6])
1.c No fuel in the vessel (Preservice Hydrotest Only)	ALL	(Not Applicable)	([3]) +60 ° F
2. Normal operation (incl. heat-up and cool-down), including anticipated operational occurrences:			
2.a Core not critical	≤20%	ASME Appendix G Limits	([2])
2.b Core not critical	>20%	ASME Appendix G Limits	([2]) + 120 ° F.
2.c Core critical	≤20%	ASME Appendix G Limits + 40 ° F.	Larger of [([4])] or [([2]) + 40° F.]
2.d Core critical	>20%	ASME Appendix G Limits + 40 ° F.	Larger of [([4])] or [([2])+160°F]
2.e Core critical for BWR ([5])	≤20%	ASME Appendix G Limits + 40 ° F.	([2])+60°F

[1] Percent of the preservice system hydrostatic test pressure.
[2] The highest reference temperature of the material in the closure flange region that is highly stressed by the bolt preload.
[3] The highest reference temperature of the vessel.
[4] The minimum permissible temperature for the inservice system hydrostatic pressure test.
[5] For boiling water reactors (BWR) with water level within the normal range for power operation.
[6] Lower temperatures are permissible if they can be justified by showing that the margins of safety of the controlling region are equivalent to those required for the beltline when it is controlling.

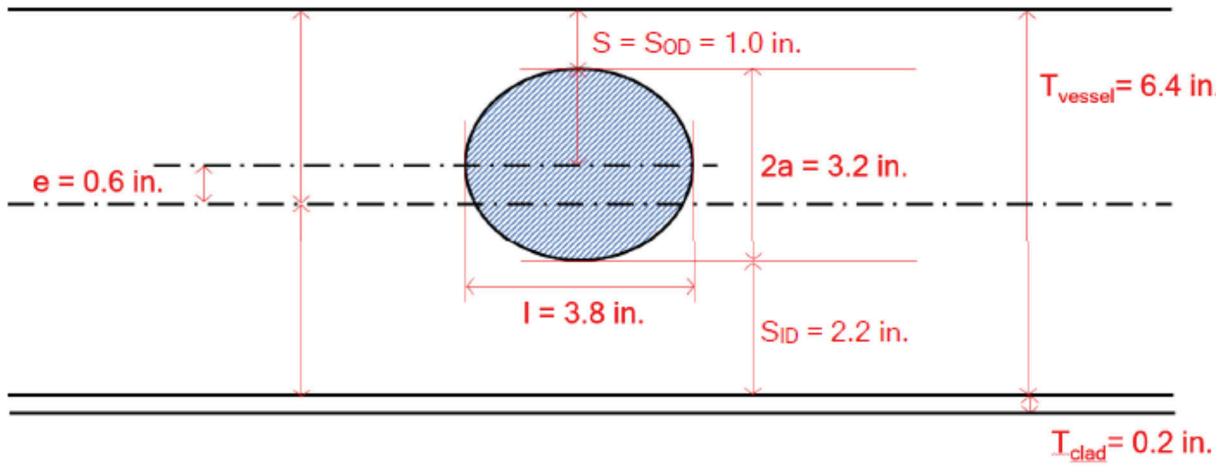


Figure 1: Flaw Geometry for the V-3-A Weld Indication

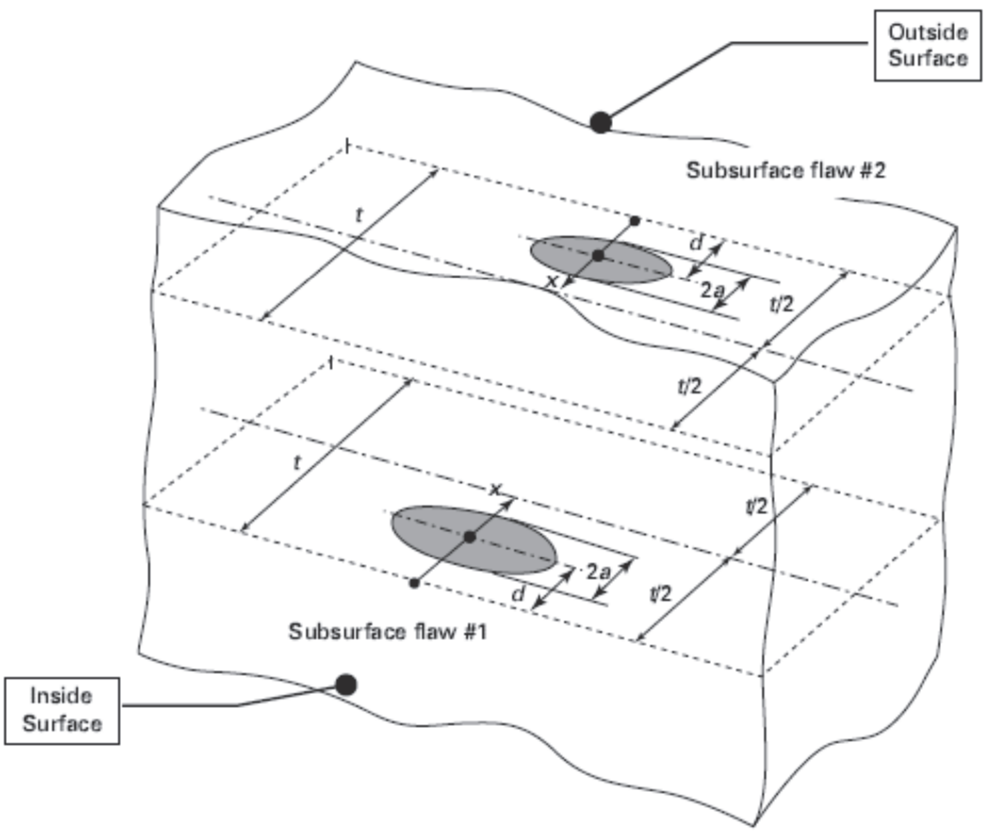
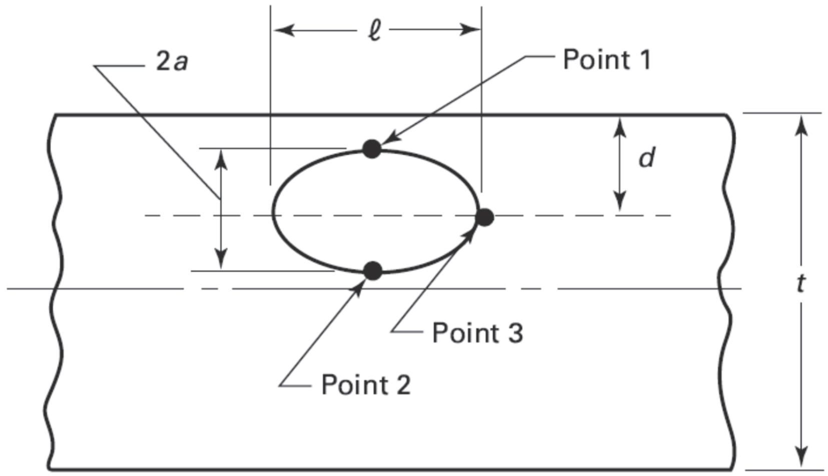


Figure 2: Subsurface Flaw Indication in the Vessel [8]

Figure A-3100-1
Elliptical Flaw Models



(a) Subsurface Flaw

Figure 3: Subsurface Flaw Parameters [8]

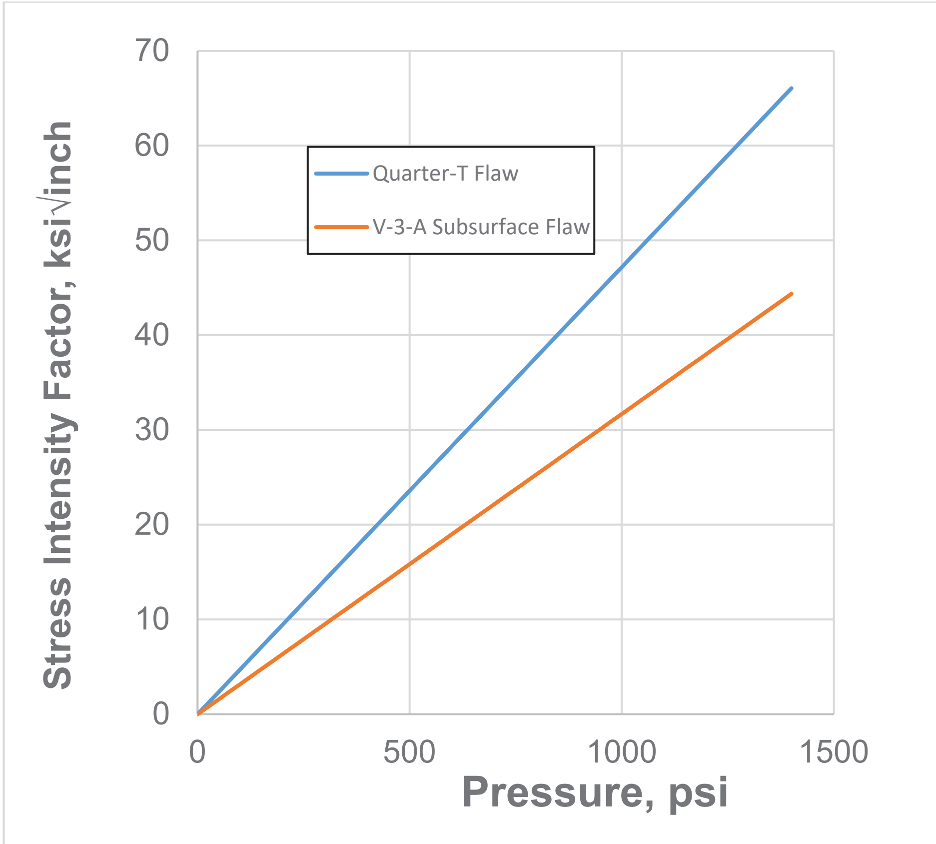


Figure 4: Stress Intensity Factor Comparison - Quarter-T Flaw Versus Weld V-3-A Flaw

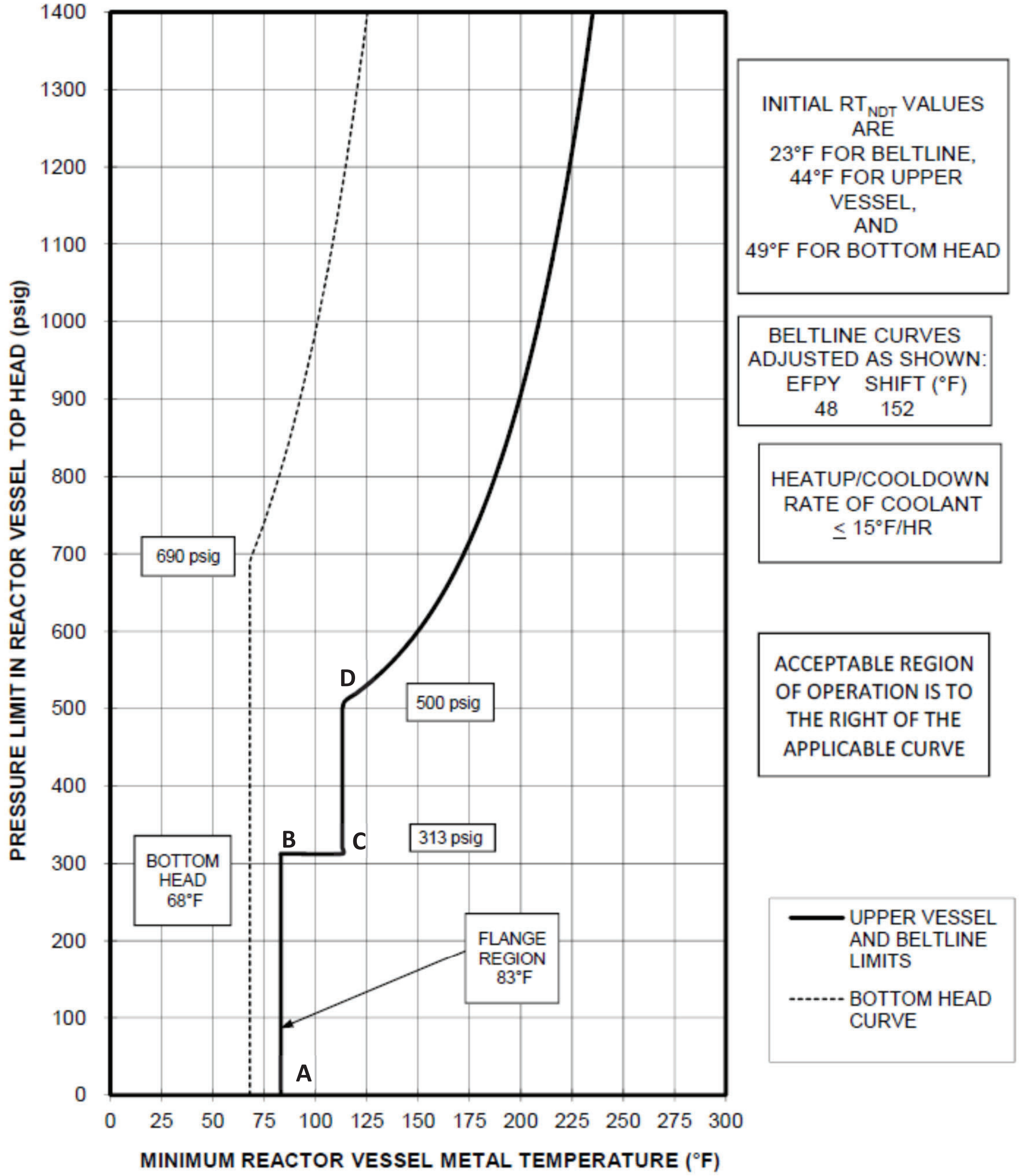


Figure 5: Browns Ferry Unit 2 P-T Curve A 48EFPY [9]

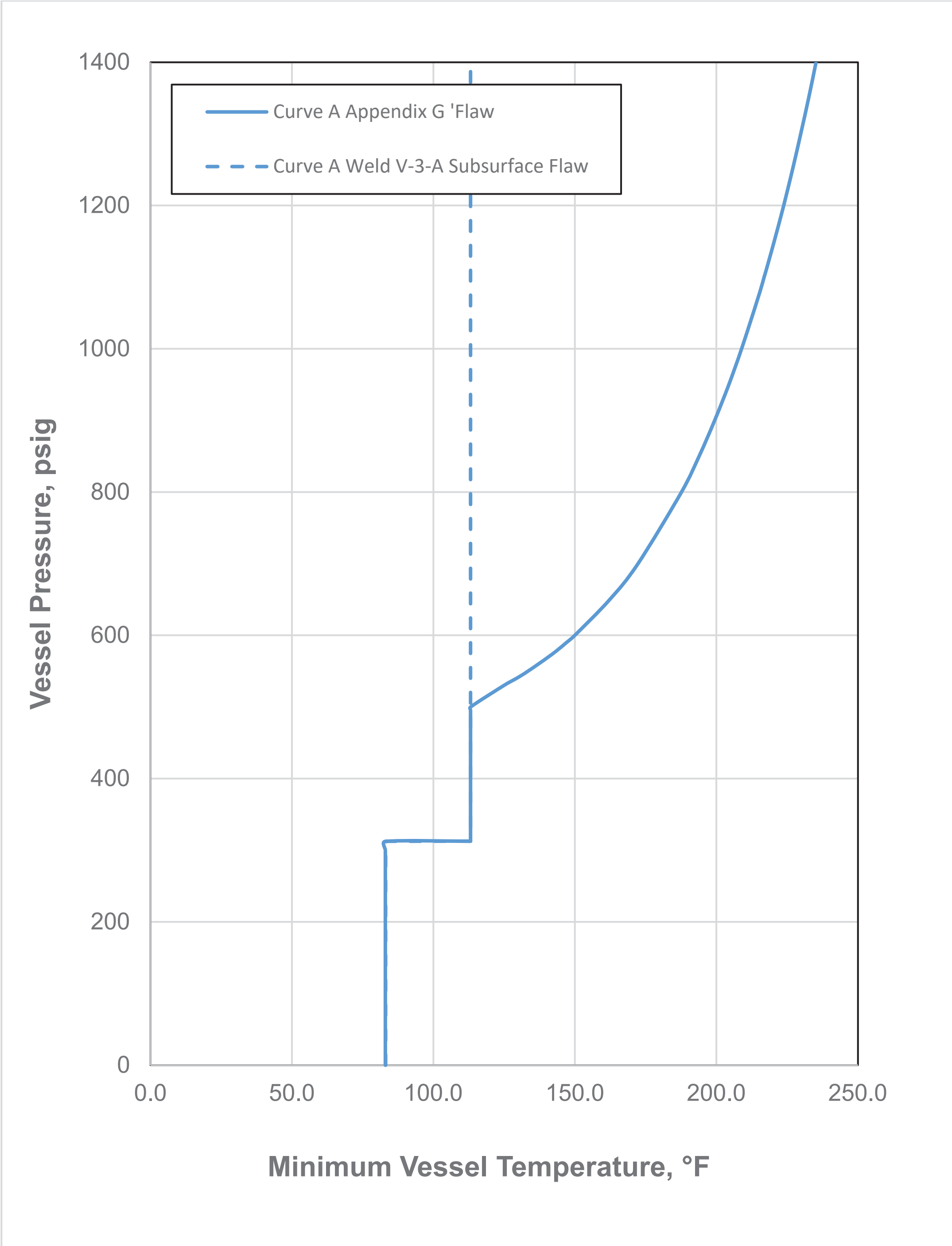


Figure 6: Comparison of the P-T curves for the Appendix G Flaw and the Weld V-3-A flaw

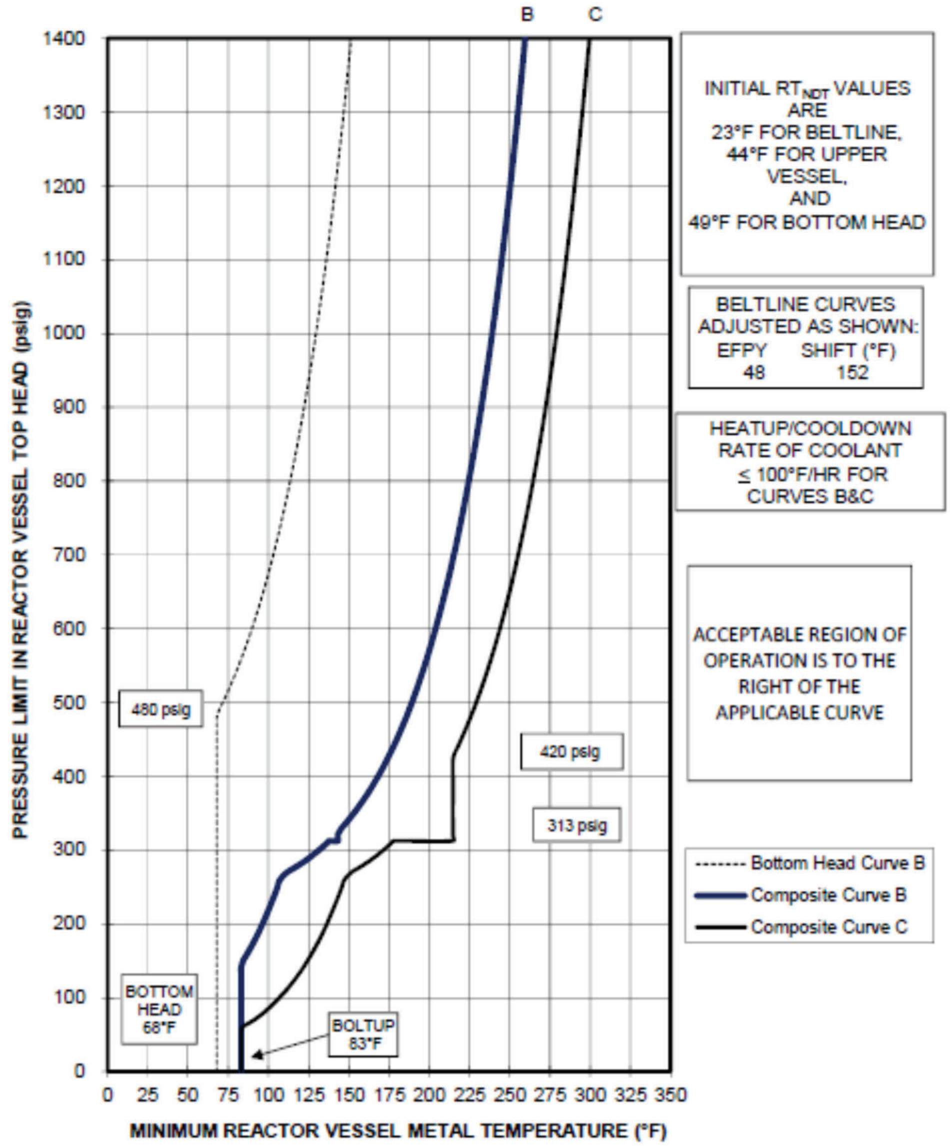


Figure 7: Composite Curves B and C for the Appendix G Flaw 48 EFPY [9]

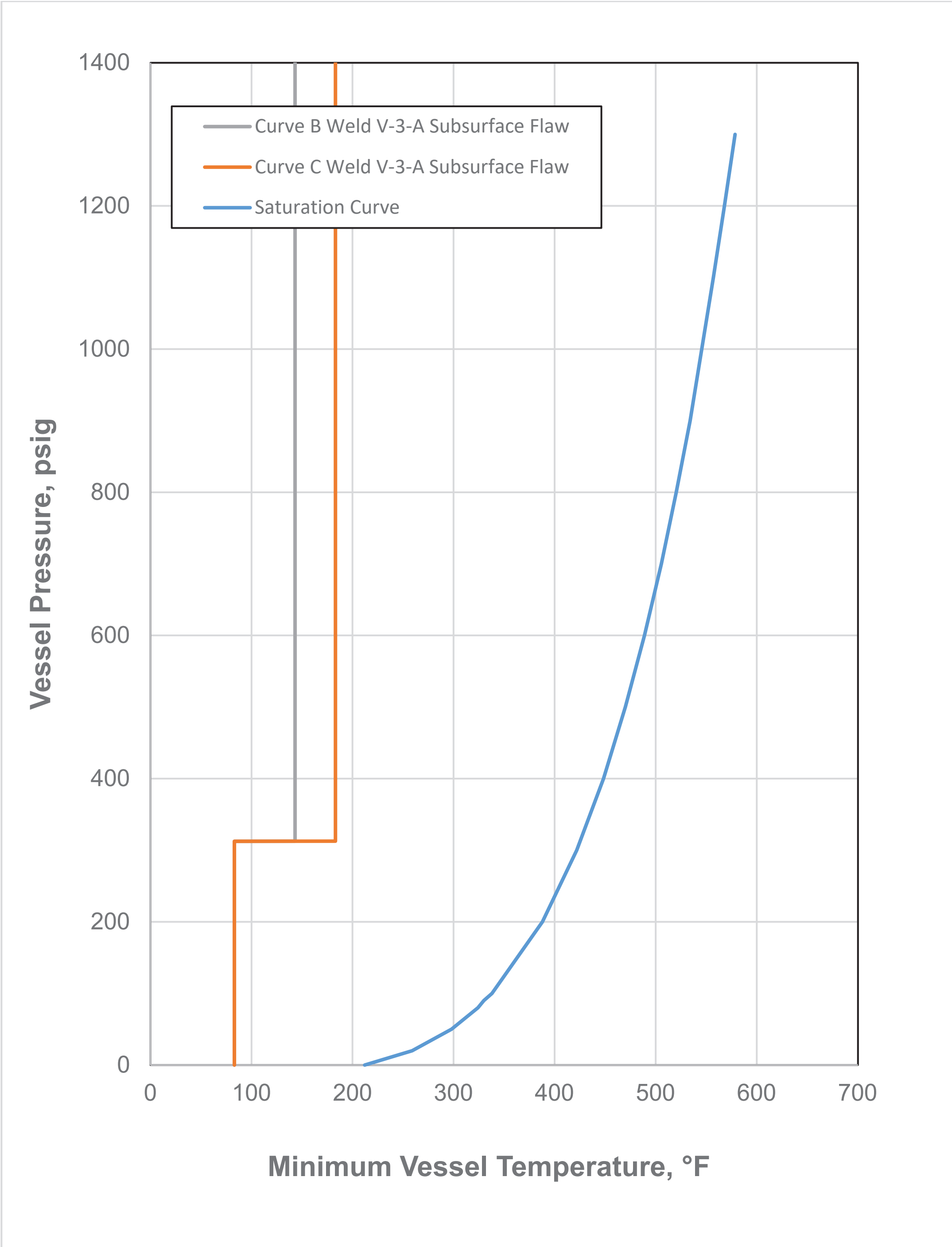


Figure 8: Composite Curves B and C for the Weld V-3-A Flaw