ENCLOSURE B
L-19-031

LTR-SDA-18-054-NP, Revision 0
Technical Justification to Support the Extended Volumetric Examination Interval
for Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle to Safe End Dissimilar Metal Welds

[22 Pages Follow]

LTR-SDA-18-054-NP Revision 0

Technical Justification to Support the Extended Volumetric Examination Interval for Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle to Safe End Dissimilar Metal Welds

January 2019

Authors:	Tyler F. Gaydosik *, Structural Design Analysis III Alexandria M. Carolan *, Structural Design Analysis III
Verifier:	Anees Udyawar *, Structural Design Analysis III
Manager:	Lynn A. Patterson *, Structural Design Analysis III

Electronically approved records are authenticated in the electronic document management system.

Westinghouse

FOREWORD

This document contains Westinghouse Electric Company LLC proprietary information and data which has been identified by brackets. Coding $^{(a,c,e)}$ associated with the brackets sets forth the basis on which the information is considered proprietary.

The proprietary information and data contained in this report were obtained at considerable Westinghouse expense and its release could seriously affect our competitive position. This information is to be withheld from public disclosure in accordance with the Rules of Practice 10CFR2.390 and the information presented herein is to be safeguarded in accordance with 10CFR2.390. Withholding of this information does not adversely affect the public interest.

This information has been provided for your internal use only and should not be released to persons or organizations outside the Directorate of Regulation and the ACRS without the express written approval of Westinghouse Electric Company LLC. Should it become necessary to release this information to such persons as part of the review procedure, please contact Westinghouse Electric Company LLC, which will make the necessary arrangements required to protect the Company's proprietary interests.

The proprietary information in the brackets has been deleted in this report. The deleted information is provided in the proprietary version of this report (LTR-SDA-18-054-P Revision 0).

1.0 Introduction

The potential for Primary Water Stress Corrosion Cracking (PWSCC) of the reactor vessel (RV) nozzle dissimilar metal (DM) welds requires an appropriate assessment of the examination frequency as well as the overall examination strategy for nickel-base alloy components and weldments. ASME Code Case N-770-2 (Reference 1) provides the visual and volumetric inspection guidelines for the primary system piping DM butt welds to augment the current inspection requirements.

In accordance with ASME Code Case N-770-2 guidelines, volumetric examinations are required for the unmitigated DM butt welds at the RV inlet nozzles every second inspection period not exceeding 7 years. A volumetric examination was previously performed for the Beaver Valley Unit 2 RV inlet nozzle to safe end DM butt welds during the Spring 2014 Refueling Outage (RFO). In accordance with N-770-2, the next volumetric examination for the RV inlet nozzle DM welds is required in the Spring 2020 RFO.

The fracture mechanics evaluation in this report will determine the impact of performing the volumetric examination on Beaver Valley Unit 2 during the Spring 2023 RFO. The time interval between the Spring 2014 RFO and the Spring 2023 RFO is 9 years, rather than the 7 years allowed by Code Case N-770-2. Therefore, Beaver Valley Unit 2 is seeking relaxation from the ASME Code Case N-770-2 examination requirement to be able to defer the volumetric examination from the Spring 2020 RFO to the Spring 2023 RFO.

The technical justification to support this request is developed in this report based on a flaw tolerance analysis. The objective of the flaw tolerance analysis is to determine the largest initial axial and circumferential flaw sizes that could be left behind in service and remain acceptable until the next planned inspection. This maximum allowable initial flaw size can then be compared to a flaw size which would have been detected during the Spring 2014 RFO inlet nozzle DM weld examination based on the inspection detection capability.

The following sections provide a discussion of the methodology, geometry, loading and the flaw tolerance analyses performed to develop the technical justification for deviating from the volumetric examination requirements of ASME Code Case N-770-2.

2.0 Methodology

In order to support the technical justification for deferring the volumetric examination from the Spring 2020 RFO to the Spring 2023 RFO for Beaver Valley Unit 2, it is necessary to demonstrate the structural integrity of the RV inlet nozzle DM welds subjected to the PWSCC growth mechanism. To demonstrate the structural integrity of the DM welds, it is essential to determine the maximum allowable initial flaw size that would not propagate to an unacceptable size in the time period between examinations. This maximum allowable initial flaw size would be the largest flaw size that would remain acceptable until the Spring 2023 RFO. The maximum allowable initial flaw size for a given plant operation duration can be determined by subtracting the PWSCC growth for that plant operation duration from the maximum allowable end-of-evaluation period flaw size, which is determined in accordance with ASME Code Section XI (Reference 2). After the maximum allowable initial flaw size is calculated, it is compared with previous inspection results to verify that no flaws greater than or equal to the maximum allowable initial flaw size were present during the previous examination. Also, the capabilities of the examination equipment is verified to ensure that the equipment was capable of determining flaws as small as the maximum allowable initial flaw size.

To determine the maximum allowable end-of-evaluation period flaw sizes and the crack tip stress intensity factors used for the PWSCC analysis, it is necessary to establish the stresses, crack geometry, and the material properties at the locations of interest. The applicable loadings which must be considered consist of piping reaction loads acting at the DM weld regions and the welding residual stresses which exist in the region of interest.

The piping loads at the RV inlet nozzle DM weld locations are used to determine PWSCC growth. In addition to the piping loads, the effects of welding residual stresses are also considered. For PWSCC, the crack growth model for the DM weld material is based on information given in MRP-115 for Alloy 182 weld material (Reference 3); this PWSCC growth model is also documented in ASME Section XI (Reference 2). Note that per ASME Code Section XI (Reference 2) and MRP-115 (Reference 3), the Alloy 182 PWSCC crack growth rate bounds that of the Alloy 82 material. The nozzle geometry and piping loads used in the fracture mechanics analysis are shown in Section 3.0. A discussion of the welding residual stress distributions used for the DM welds is provided in Section 4.0. The determination of the maximum allowable end-of-evaluation period flaw sizes is discussed in Section 5.0.

The maximum allowable initial flaw size will be determined based on the crack growth due to the PWSCC growth mechanism at the RV inlet nozzle DM weld. The PWSCC growth is calculated based on the normal operating temperature and the crack tip stress intensity factors resulting from the normal operating steady state piping loads and welding residual stresses as discussed in Section 6.0. Section 7.0 provides the crack growth curves used in developing the technical justification to deviate from the ASME Code Case N-770-2 (Reference 1) guidelines by deferring the volumetric inspection of the RV inlet nozzle DM welds from the Spring 2020 to the Spring 2023 RFO.

3.0 Nozzle Geometry and Loads

The DM weld geometry for the Beaver Valley Unit 2 RV inlet nozzles is based on the nozzle detail drawings (Reference 4). The normal operating temperature of the reactor vessel inlet nozzles is taken from Table 5.1-1 of the BVPS-2 Updated Final Safety Analysis Report (UFSAR) (Reference 5). The RV inlet nozzle geometry and normal operating temperature used in this analysis are summarized in Table 3-1.

The piping reaction loads at the RV inlet nozzle DM weld locations are summarized in Table 3-2. These loads are used in determining the maximum allowable end-of-evaluation period flaw sizes and the PWSCC growth. Both the replacement steam generator (RSG) piping loads and original steam generator (OSG) loads were considered (Reference 6). The most limiting set of loads were based on the RSG, which were used in the crack growth analysis and to determine the maximum allowable end-of-evaluation flaw sizes. The replacement steam generator has not been installed at Beaver Valley Unit 2; however, the RSG piping loads are also conservatively considered in this analysis to bound the RSG program if implemented.

Table 3-1
Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle Geometry and Normal Operating Temperature

	Dimension
Outside Diameter (in)	32.47
Inside Diameter (in)	27.47
Thickness (in)	2.50
RV Inlet Nozzle Normal Operating Temperature = 543.1°F	

Table 3-2
Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle Piping Loads

a,c,e

4.0 Dissimilar Metal Weld Residual Stress Distribution

The plant specific welding residual stresses used in the PWSCC growth analysis are determined from the finite element stress analysis (FEA) in (Reference 7) based on the Beaver Valley Unit 2 RV inlet nozzle DM weld specific configuration. Figure 4-1 shows a sketch of the Beaver Valley Unit 2 inlet nozzle DM weld configuration which reflects the configuration shown in Reference 4.a. The FEA in Reference 7 is based on a two-dimensional axisymmetric model of the inlet nozzle DM weld region. The FEA model geometry includes a portion of the low alloy steel nozzle, the stainless steel safe end, a portion of the stainless steel piping, the DM weld attaching the nozzle to the safe end, and the stainless steel weld attaching the safe end to the piping. The FEA model also assumes a 360° inside surface weld repair with a repair depth of 50% through the DM weld thickness, which is consistent with MRP-287 guidance (Reference 8). The following fabrication sequence was simulated in the FEA and matches the information provided in the reactor vessel nozzle details drawings (Reference 4):

- The inlet nozzle was buttered with weld-deposited Alloy 82/182 material. Nozzle and buttering are post weld heat treated at 1,100°F.
- The inlet nozzle was welded to the safe end ring forging using an Alloy 82/182 weld. The inner diameter of the dissimilar metal weld is machined to finished size.
- An assumed inside surface weld repair 360° around the circumference and 50% through the wall thickness was conservatively simulated in the Alloy 82/182 weld, which is consistent with MRP-287 (Reference 8).
- Shop hydrostatic test was then performed at a pressure of 3110 psig and a temperature of 300°F.
- The safe end was then machined for the piping side weld preparation.
- The machined safe end was welded to a long segment of stainless steel piping using a stainless steel weld.
- A plant hydrostatic test was performed at 2485 psig pressure with a temperature of 300°F.
- After the plant hydrostatic test, normal operating temperature and pressure was uniformly applied three times to consider any shakedown effects, after which the model was set to normal operating conditions.

Based on the FEA model, residual stresses at three different paths (centerline of the DM weld, nozzle side of the DM weld, and safe-end side of the DM weld) in the DM weld were obtained. Additionally, a recommended stress distribution was also provided, which is a representation of the limiting stress from all three paths through the DM weld. The recommended axial and hoop stress profiles were used in the generation of the crack growth charts to determine the maximum allowable initial flaw sizes (Section 7.0). The hoop and axial welding residual stresses for the recommended stress profiles at 100% normal operating conditions (operating pressure and temperature) are shown in Figure 4-2.

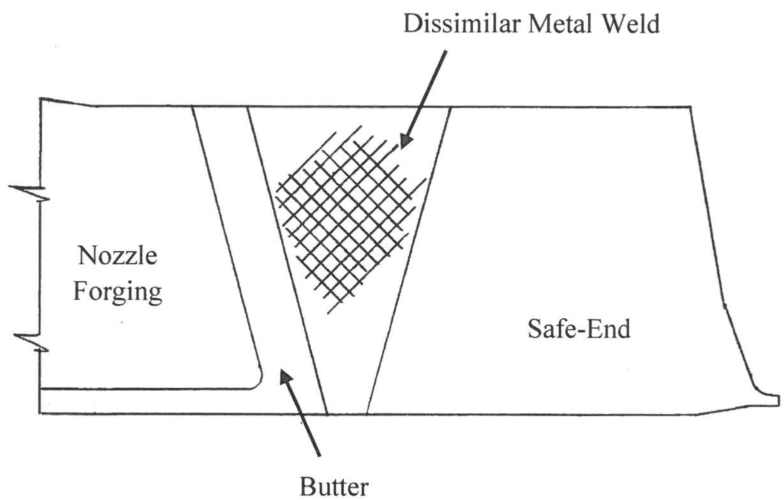

Figure 4-1: Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle DM Weld Configuration

a,c,e

Figure 4-2: Beaver Valley Unit 2 Reactor Vessel Inlet Nozzle DM Weld 100% Normal Operating Residual Stress Profiles Through DM Weld with 50% Inside Surface Weld Repair

5.0 Maximum Allowable End-of-Evaluation Period Flaw Size Determination

In order to develop the technical justification to defer the volumetric examination of the RV inlet nozzle DM welds from the Spring 2020 RFO to the Spring 2023 RFO, the first step is the determination of the maximum allowable end-of-evaluation period flaw sizes. The maximum allowable end-of-evaluation period flaw size is the size to which it is acceptable for an indication to grow prior to the next inspection or evaluation period. This particular flaw size is determined based on the piping loads, geometry and the material properties of the component. The evaluation guidelines and procedures for calculating the maximum allowable end-of-evaluation period flaw sizes are described in paragraph IWB-3640 and Appendix C of the ASME Section XI Code (Reference 2).

Rapid, nonductile failure is possible for ferritic materials at low temperatures, but is not applicable to the nickel-base alloy material. In nickel-base alloy material, the higher ductility leads to two possible modes of failure, plastic collapse or unstable ductile tearing. The second mechanism can occur when the applied J integral exceeds the J_{Ic} fracture toughness, and some stable tearing occurs prior to failure. If this mode of failure is dominant, then the load-carrying capacity is less than that predicted by the plastic collapse mechanism. The maximum allowable end-of-evaluation period flaw sizes of paragraph IWB-3640 for the high toughness materials are determined based on the assumption that plastic collapse would be achieved and would be the dominant mode of failure. However, due to the reduced toughness of the DM welds, it is possible that crack extension and unstable ductile tearing could occur and be the dominant mode of failure. To account for this effect, penalty factors called "Z-factors" were developed in ASME Code Section XI, which are to be multiplied by the loadings at these welds. In the current analysis for Beaver Valley, Z-factors based on MRP-216 (Reference 9) are used in the analysis to provide a more representative approximation of the effects of the DM welds. The Z-factors for Alloy 82/182 from Reference 9 have been incorporated into the ASME Section XI 2013 Edition (Reference 2). The use of Z-factors in effect reduces the maximum allowable end-of-evaluation period flaw sizes for flux welds and thus has been incorporated directly into the evaluation performed in accordance with the procedure and acceptance criteria given in IWB-3640 and Appendix C of ASME Code Section XI. It should be noted that the maximum allowable end-of-evaluation period flaw sizes are limited to only 75% of the wall thickness in accordance with the requirements of ASME Section XI paragraph IWB-3640 (Reference 2).

The maximum allowable end-of-evaluation period flaw sizes determined for both axial and circumferential flaws have incorporated the relevant material properties, pipe loadings, and geometry. Loadings under normal, upset, emergency, and faulted conditions are considered in conjunction with the applicable safety factors for the corresponding service conditions required in the ASME Section XI Code. For circumferential flaws, axial stresses due to the pressure, deadweight, thermal expansion, seismic, and pipe break loads are considered in the evaluation. As for the axial flaws, hoop stress resulting from pressure loading is used.

The maximum allowable end-of-evaluation period flaw sizes for the axial and circumferential flaws at the RV inlet nozzle DM welds are provided in Table 5-1. The maximum allowable end-of-evaluation period axial flaw size was calculated with an assumed aspect ratio (flaw length/flaw depth) of 2. The aspect ratio of 2 is reasonable because the axial flaw growth due to PWSCC is limited to the width of the DM weld configuration. For the circumferential flaw, a conservative aspect ratio of 10 is used.

It should be noted that the resulting maximum allowable end-of-evaluation period flaw sizes were limited by the ASME Code limit of 75% of the weld thickness for both flaw configurations.

Table 5-1
Maximum End-of-Evaluation Period Allowable Flaw Sizes
(Flaw Depth/Wall Thickness Ratio - a/t)

Axial Flaw (Aspect Ratio = 2)	Circumferential Flaw (Aspect Ratio = 10)
0.75	0.75

6.0 PWSCC Growth Analysis

A PWSCC growth analysis was performed to determine the maximum allowable initial flaw size that would be acceptable based on ASME Section XI acceptance criteria (Reference 2) for the operating duration from the Spring 2014 to the Spring 2023 RFOs. The maximum allowable initial flaw size for the given plant operation duration is determined by subtracting the crack growth due to PWSCC for the specific plant operation duration from the maximum allowable end-of-evaluation period flaw size shown in Table 5-1.

Crack growth due to PWSCC is calculated for both axial and circumferential flaws using the normal operating condition steady-state stresses. For axial flaws, the stresses included pressure and residual hoop stresses, while for circumferential flaws, the stresses considered are pressure, 100% power normal thermal expansion, deadweight, and residual axial stresses. The input required for the crack growth analysis is basically the information necessary to calculate the crack tip stress intensity factor (K_I), which depends on the geometry of the crack, its surrounding structure, and the applied stresses. The geometry and loadings for the nozzles of interest are discussed in Section 3.0 and the applicable residual stresses used are discussed in Section 4.0. Once K_I is calculated, PWSCC growth can be calculated using the applicable crack growth rate for the nickel-base alloy material (Alloy 182) from MRP-115 (Reference 3), which is also documented in ASME Section XI (Reference 2). For all inside surface flaws, the governing crack growth mechanism for the RV inlet nozzle is PWSCC.

Using the applicable stresses at the DM welds, the crack tip stress intensity factors can be determined based on the stress intensity factor expressions from API-579 (Reference 10). The through-wall stress distribution profile is represented by a 4th order polynomial:

$$\sigma = \sigma_0 + \sigma_1 \left({}^{x}/_{t}\right) + \sigma_2 \left({}^{x}/_{t}\right)^2 + \sigma_3 \left({}^{x}/_{t}\right)^3 + \sigma_4 \left({}^{x}/_{t}\right)^4$$

Where:

σ_0, σ_1, σ_2, σ_3, and σ_4 are the stress profile curve fitting coefficients;

x = the distance from the wall surface where the crack initiates to the crack tip;

t = the wall thickness; and

σ = the stress perpendicular to the plane of the crack.

The stress intensity factor calculations for semi-elliptical inside surface axial and circumferential flaws are expressed in the general form as follows:

$$K_I = \sqrt{\frac{\pi a}{Q}} \sum_{j=0}^{4} G_j(a/c, a/t, t/R, \Phi)\sigma_j \left(\frac{a}{t}\right)^j$$

Where:

a = Crack depth

c = Half crack length along surface

t = Thickness of cylinder

R = Inside radius

Φ = Angular position of a point on the crack front

G_j = G_j is influence coefficient for j^{th} stress distribution on crack surface (i.e., G_0, G_1, G_2, G_3, G_4)

Q = The shape factor of an elliptical crack is approximated by:

$Q = 1 + 1.464(a/c)^{1.65}$ for $a/c \leq 1$ or $Q = 1 + 1.464(c/a)^{1.65}$ for $a/c > 1$

The influence coefficients at various points on the crack front can be obtained by using an interpolation method. Once the crack tip stress intensity factors are determined, PWSCC growth calculations can be performed using the crack growth rate below with the applicable normal operating temperature.

The PWSCC growth rate used in the crack growth analysis is based on the Electric Power Research Institute (EPRI) recommended crack growth curve for Alloy 182 material (Reference 3):

$$\frac{da}{dt} = \exp\left[-\frac{Q_g}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]\alpha(K)^{\beta}$$

Where:

$\frac{da}{dt}$ = Crack growth rate in m/sec (in/hr)

Q_g = Thermal activation energy for crack growth = 130 kJ/mole (31.0 kcal/mole)

R = Universal gas constant = 8.314×10^{-3} kJ/mole-K (1.103×10^{-3} kcal/mole-°R)

T = Absolute operating temperature at the location of crack, K (°R)

T_{ref} = Absolute reference temperature used to normalize data = 598.15 K (1076.67°R)

α = Crack growth amplitude

= 1.50×10^{-12} at 325°C (2.47×10^{-7} at 617°F)

β = Exponent = 1.6

K = Crack tip stress intensity factor MPa√m (ksi√in)

The normal operating temperature used in the crack growth analysis is 543.1°F at the RV inlet nozzle. It should be noted that the fatigue crack growth mechanism is not considered in the crack growth analysis as it is considered to be small when compared to the crack growth due to the PWSCC growth mechanism at the reactor vessel inlet nozzle for the duration of interest. This is demonstrated by the low fatigue usage factor of 0.00729 at the inlet nozzle location of interest in the reactor vessel analytical report CENC-1247 (Reference 11). There was insignificant change to the fatigue usage factor from any revised transients due to the power uprate program. Therefore, it is not necessary to consider fatigue crack growth in the evaluation.

The PWSCC growth rate is highly dependent on the temperature at the location of the flaw; furthermore, the crack growth rate increases as the temperature increases. Therefore, during periods when the plant is not in operation, such as refueling outages or shutdowns, the temperature at the reactor vessel nozzles is

low such that crack growth due to PWSCC is insignificant. Therefore, the PWSCC growth calculation should be determined for the time interval when the plant is operating at full power. The amount of time when the plant is operating at full power is determined based on previous plant operation data and the anticipated outages scheduled until the next inspections. This operation duration at full power is referred to as Effective Full Power Years (EFPY). However, the analysis herein will conservatively use a 100% capacity factor (i.e. plant operating at full power); thus, the operation duration between the Spring 2014 and the Spring 2023 will be 9 EFPY.

7.0 Technical Justification for Deferring the Volumetric Examination

In accordance with ASME Code Case N-770-2 (Reference 1), the volumetric examination interval for the unmitigated RV inlet nozzle to safe end DM welds must not exceed 7 years. Beaver Valley Unit 2 is seeking relaxation from the ASME Code Case N-770-2 requirement in order to defer the volumetric examination of the reactor vessel inlet nozzle to safe end DM welds from the Spring 2020 to the Spring 2023 RFO. Technical justification can be developed to support deferring the volumetric examination by calculating the maximum allowable initial flaw size that could be left behind in service and remain acceptable between the inspections. This maximum allowable initial flaw size can then be compared to a flaw size which would have been detected during the Spring 2014 RFO inlet nozzle DM weld examination based on the inspection detection capability.

The maximum allowable initial flaw depth is determined by subtracting the amount of PWSCC growth for a duration of 9 effective full power years (EFPY) from the maximum allowable end-of-evaluation period flaw depth shown in Table 5-1. The end-of-evaluation period flaw depth is calculated based on the guidelines given in paragraph IWB-3640 and Appendix C of the ASME Section XI Code (Reference 2). The PWSCC growth at the Alloy 82/182 weld for the postulated axial flaw is calculated based on normal operating welding residual hoop stresses, while for circumferential flaw, the stresses considered normal operating piping loads (deadweight and thermal expansion) and normal operating welding residual axial stresses. The PWSCC crack growth model is based on MRP-115 (Reference 3). The maximum allowable initial flaw depth was calculated for an axial flaw with an aspect ratio of 2. An aspect ratio of 2 is reasonable for the axial flaw due to the DM weld configuration since any PWSCC axial flaw growth is limited to the width of the weld. For the circumferential flaw, a conservative aspect ratio of 10 is used in the crack growth analysis.

The PWSCC growth analysis of the circumferential flaws considered two cases. The first case is normal operating piping loads (deadweight and normal thermal loads) with residual stresses from the profile shown in Figure 4-2. The second case is normal operating piping loads without residual stresses in order to obtain the most limiting crack growth results since a portion of the axial residual stress profile is compressive. It was determined that the case which included normal operating piping loads with residual stresses was limiting for circumferential flaws.

The PWSCC growth curves and the maximum allowable initial flaw sizes for an axial flaw and a circumferential flaw are shown in Figures 7-1 and 7-2, respectively. The horizontal axis displays service life in EFPY, and the vertical axis shows the flaw depth to wall thickness ratio (a/t). The maximum allowable end-of-evaluation period flaw sizes are also shown in these figures for the respective flaw configurations. Based on the crack growth results from Figures 7-1 and 7-2, the maximum allowable initial flaw sizes for the axial and circumferential flaws are tabulated in Table 7-1 for 9 EFPY.

Table 7-1
Beaver Valley Unit 2 Maximum Allowable Initial Flaw Sizes for 9 EFPY

	Axial Flaw (Aspect Ratio = 2)	Circumferential Flaw (Aspect Ratio = 10)
Maximum Allowable Initial Flaw Size (a/t)	0.0402	0.3581
Flaw Depth (in)	0.1004	0.8952
Flaw Length (in)	0.2008	8.9520

Note: Aspect ratio = flaw length/flaw depth
Wall thickness (t) = 2.5 inches

The flaw sizes shown in Table 7-1 are the largest axial and circumferential flaw sizes that could be left behind in service and remain acceptable from the Spring 2014 RFO to the Spring 2023 RFO (9 EFPY with 100% capacity factor) for Beaver Valley Unit 2. In accordance with the Ultrasonic Testing (UT) detection and sizing requirements in ASME Section XI Appendix VIII, Supplement 10 (Reference 2), the minimum required detectable flaw depth is 10% of the wall thickness. Therefore, the maximum allowable initial circumferential flaw sizes are above the minimum flaw depth requirement per the UT detection capabilities, and thus would have been reasonably detected at the previous inspection of the DM welds.

In addition to the required baseline volumetric UT examination of the RV inlet nozzle DM weld, Beaver Valley Unit 2 also conducted Eddy Current Testing (ET) on the RV inlet nozzle DM welds per Reference 12 during the Spring 2014 RFO. The ET examination is an additional means to detecting surface breaking indications on the inside surface of the DM weld.

The Beaver Valley Unit 2 ET inspection procedure (Reference 12) from the Spring 2014 RFO required that an indication with a depth of 0.04" and length of 0.25" or more be recorded. However, during the Spring 2014 inspection, it was possible to identify indications with shorter axial flaw lengths (Reference 13). [

]^{a,c,e}.

WesDyne, a subsidiary of Westinghouse, performed the cold leg DM weld examinations during the Spring 2014 inspection for Beaver Valley Unit 2. WesDyne was requested to re-evaluate the Unit 2 inspection data to support the crack growth evaluation results provided in this letter report per Reference 13. A re-evaluation of the Spring 2014 RFO inspection showed that no indications were observed with axial flaw length sizes larger than 0.16" (Reference 13).

Based on the crack growth evaluation for Beaver Valley Unit 2 performed herein, the maximum initial axial flaw depth is 0.1004" and flaw length is 0.2008" from Table 7-1. These particular flaw dimensions are within the range of Beaver Valley Unit 2 ET detection capability used during the Spring 2014 inspection (Reference 13). Moreover, the re-evaluation of the cold leg DM weld inspection data showed that no indications with the flaw sizes provided in Table 7-1 were present during the Spring 2014 inspection. As a result, the calculated maximum allowable initial axial flaw sizes are large enough to have been detected during the last Spring 2014 RFO examination of the RV inlet nozzle DM welds at Beaver Valley Unit 2.

The supplemental Eddy Current testing was used in a similar justification for South Texas Unit 2 RV inlet nozzle DM weld inservice inspection relief request for axial initial flaw depth less than 10% of the through-wall thickness (Reference 14). Furthermore, the NRC staff in its response to the South Texas

relief request (Reference 15) accepted the use of the licensee's ET qualification process to justify the acceptability for initial flaw sizes less than 10% of the through-wall thickness when supplemented with volumetric examinations performed by UT as required by the ASME Code Case N-770-2.

Therefore, the maximum allowable initial axial and circumferential flaw sizes in Table 7-1 would have been detected during the Spring 2014 RFO inlet nozzle DM weld examination. Since, there were no indications present with the flaw sizes provided in Table 7-1 during the Spring 2014 RFO for the inlet nozzle DM weld (see Reference 13), the technical justification developed in this letter report can be used to defer the volumetric examination for the Beaver Valley Unit 2 RV inlet nozzle DM welds from the Spring 2020 RFO to the Spring 2023 RFO.

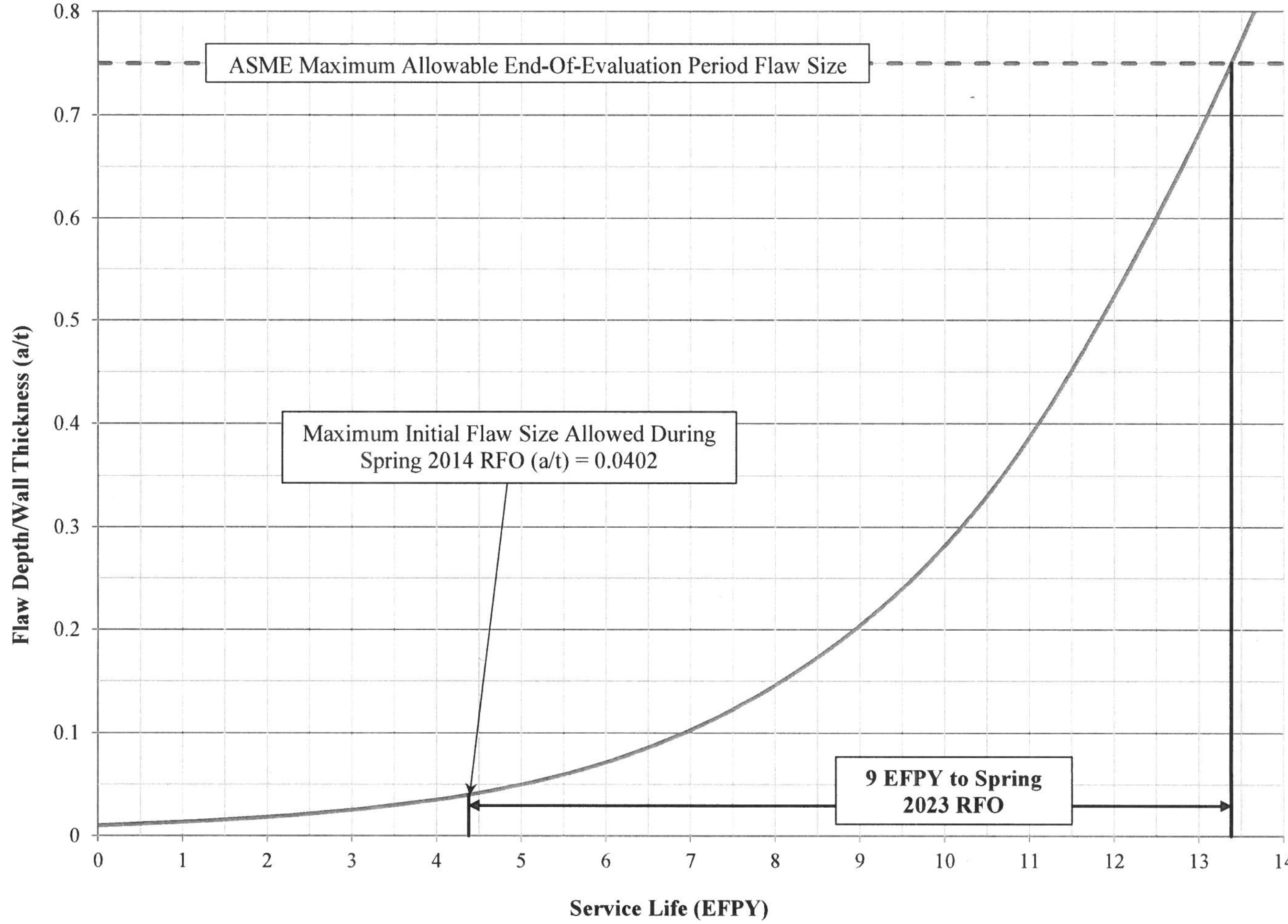

Figure 7-1: PWSCC Growth Curve for Beaver Valley Unit 2 Inlet Nozzle Axial Flaw (DM weld), Aspect Ratio = 2

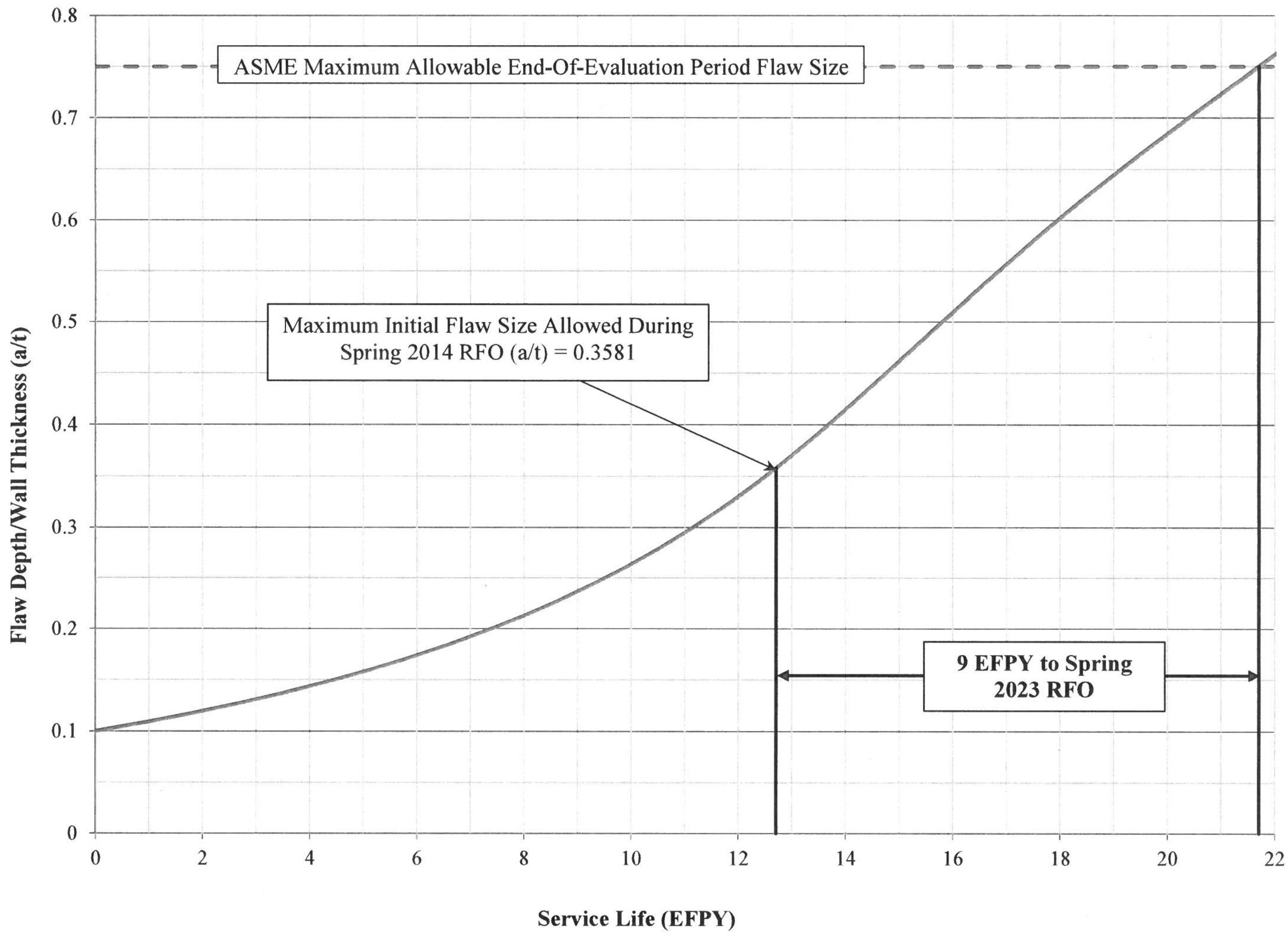

Figure 7-2: PWSCC Growth Curve for Beaver Valley Unit 2 Inlet Nozzle Circumferential Flaw (DM weld), Aspect Ratio = 10

8.0 Summary and Conclusions

A volumetric examination of the reactor vessel inlet nozzle to safe end DM butt welds was performed during the Spring 2014 RFO at Beaver Valley Unit 2. The next required volumetric examination is planned during the Spring 2020 RFO in accordance with ASME Code Case N-770-2 (Reference 1). However, the volumetric examination will be deferred to the Spring 2023 RFO for the reactor vessel inlet nozzle DM welds. Since the time interval between the previous examination and the planned examination exceeds 7 years, which deviates from the Code Case N-770-2 (Reference 1) inspection interval requirements, a flaw tolerance evaluation was completed to defer the volumetric examination of the inlet nozzle DM welds.

This letter report provides technical justification to support the relaxation request by performing a flaw tolerance analysis to determine the largest initial axial and circumferential flaws that could be left behind in service and remain acceptable between the planned examinations. This maximum allowable initial flaw size can then be compared to any flaw size which would have been detected during the previous inlet nozzle DM weld examinations.

Based on the PWSCC growth analysis results from Section 7.0 which is for a duration of 9 EFPY, the maximum allowable initial flaw sizes for the reactor vessel inlet nozzle DM welds are tabulated in Table 8-1 for Beaver Valley Unit 2. These allowable initial axial and circumferential flaw sizes have been shown to be acceptable in accordance with the ASME Section XI IWB-3640 acceptance criteria through the Spring 2023 RFO for Beaver Valley Unit 2 taking into account of potential PWSCC growth since the last volumetric and surface examinations.

In accordance with the Ultrasonic Testing (UT) detection and sizing requirements in ASME Section XI Appendix VIII, Supplement 10 (Reference 2), the minimum required detectable flaw depth is 10% of the wall thickness. In addition to the UT examination of the RV inlet nozzle DM weld, supplemental Eddy Current Testing (ET) was performed on the RV inlet nozzle DM welds for Beaver Valley Unit 2. Based on a re-evaluation of the Spring 2014 RV inlet nozzle dissimilar metal weld inspection data, it was determined that there were no indications present with an axial flaw length larger than 0.16" (Reference 13).

Therefore, based on the Beaver Valley Unit 2 flaw evaluation results in Table 8-1, the calculated maximum allowable initial circumferential flaw size is large enough to have been detected during the last Spring 2014 examination of the RV inlet nozzle DM welds. A re-evaluation of the inlet nozzle DM weld inspection data showed that no indications with the axial flaw sizes provided in Table 8-1 were present during the Spring 2014 inspection (Reference 13). Similar justification was used in the South Texas Unit 2 inlet nozzle DM weld inservice inspection relief request for axial initial flaw sizes less than 10% of the through-wall thickness (Reference 14). Furthermore, the NRC staff in its response to the South Texas relief request (Reference 15) accepted the use of the licensee's ET qualification process to justify the acceptability for initial flaw sizes less than 10% of the through-wall thickness when supplemented with volumetric examinations performed by UT as required by the ASME Code Case N-770-2. Therefore, deferring the volumetric examination for the Beaver Valley Unit 2 RV inlet nozzle DM welds from the Spring 2020 RFO allowed by Code Case N-770-2 to the Spring 2023 RFO is technically justified.

Table 8-1
Beaver Valley Unit 2 Maximum Allowable Initial Flaw Sizes based on 9 EFPY

	Axial Flaw (Aspect Ratio = 2)	Circumferential Flaw (Aspect Ratio = 10)
Maximum Allowable Initial Flaw Size (a/t)	0.0402	0.3581
Flaw Depth (in)	0.1004	0.8952
Flaw Length (in)	0.2008	8.9520

Note: Aspect ratio = flaw length/flaw depth
Wall thickness (t) = 2.5 inches

9.0 References

1. ASME Code Case N-770-2, Section XI Division 1, "Alternative Examination Requirements and Acceptance Standards for Class 1 PWR Piping and Vessel Nozzle Butt Welds Fabricated with UNS N06082 or UNS W86182 Weld Filler Material With or Without Application of Listed Mitigation Activities," Approval Date June 9, 2011.

2. ASME Boiler & Pressure Vessel Code, 2013 Edition, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

3. Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP-115), EPRI, Palo Alto, CA: 2004. 1006696.

4. Drawings for Beaver Valley Unit 2 RV Inlet Nozzles:
    a. Combustion Engineering, Inc. Drawing E-9071-171-001 Revision 2, "Upper Vessel To Lower Vessel Assembly, Westinghouse Electric Corp. 157" I.D. P.W.R."
    b. Combustion Engineering, Inc. Drawing C-9071-131-001 Revision 0, "Nozzle Safe Ends, Westinghouse Electric Corp. 157" I.D. P.W.R."

5. Beaver Valley Unit 2 Updated Final Safety Analysis Report (UFSAR), Revision 23, Table 5.1-1.

6. FENOC Letter BVSES:0222, "Design Input Transmittal for the Beaver Valley Unit 2 RX Vessel Cold Leg Nozzle Fracture Mechanics Analysis – DIT-BVDM-0114-00," August 7, 2018.

7. Dominion Engineering, Inc. Calculation Note, C-8058-00-01, Revision 0, "Welding Residual Stress Calculation for Beaver Valley Unit 2 RPV Inlet Nozzle DMW," July 2018.

8. Materials Reliability Program: Primary Water Stress Corrosion Cracking (PWSCC) Flaw Evaluation Guidance (MRP-287). EPRI, Palo Alto, CA: 2010. 1021023.

9. Materials Reliability Program: Advanced FEA Evaluation of Growth of Postulated Circumferential PWSCC Flaws in Pressurizer Nozzle Dissimilar Metal Welds (MRP-216, Rev. 1): Evaluations Specific to Nine Subject Plants. EPRI, Palo Alto, CA: 2007. 1015400.

10. American Petroleum Institute, API-579-1/ASME FFS-1 (APS 579 Second Edition), "Fitness-For-Service," June 5, 2007.

11. Combustion Engineering, Inc. Report, CENC-1247, "Analytical Report for Duquesne Light Company Beaver Valley Unit No. 2 Reactor Vessel," October 1975.

12. WesDyne Procedure, WDI-STD-146, Revision 12, "ET Examination of Reactor Vessel Pipe Welds Inside Surface," July 10, 2013.

13. WesDyne Letter, WDI-LTR-ENG-18-0021, "2014 Beaver Valley Unit 2 Reactor Vessel Cold Leg Dissimilar Metal Weld Eddy Current Data Review," November 19, 2018.

14. South Texas Project Unit 2 Letter NOC-AE-16003345, "Request for Relief from Code Case N-770-1, Subsection 2400 and Table 1 Inspection Frequency of Reactor Vessel Cold Leg Nozzle to Safe-end Welds with Flaw Analysis (Relief Request RR-ENG-3-20)." (Docket No. STN 50-499), (*Adams Accession Number ML16076A319*)

15. United States Nuclear Regulatory Commission Letter Dated June 30, 2016, "South Texas Project, Unit 2 – Request for Relief No. RR-ENG-3-20 for Extension of the Inspection Frequency of the

Reactor Vessel Cold-Leg Nozzle to Safe-End Welds with Flaw Analysis (CAC No. MF7428)," (*Adams Accession Number ML16174A091*)