Attachment 1

LTR-PAFM-16-11-NP Revision 0, Technical Justification to Support Extended Volumetric Examination Interval for South Texas Unit 2 Reactor Vessel Inlet Nozzle to Safe End Dissimilar Metal Welds, March 2016 (Non-Proprietary).

LTR-PAFM-16-11-NP Revision 0

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

March 2016

Author: Alexandria M. Carolan*, Piping Analysis and Fracture Mechanics

Verifier: Anees Udyawar*, Piping Analysis and Fracture Mechanics

Approved: John L. McFadden*, Manager, Piping Analysis and Fracture Mechanics

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1.0 Introduction

Service induced cracking of the nickel-base alloy components and weldments have been occurring more and more frequently in recent years, resulting in the need to repair and/or replace these components. Such cracking and leakage have been observed in the reactor vessel upper and bottom head penetration nozzles as well as the dissimilar metal (DM) butt welds of the pressurizer and reactor vessel nozzles exposed to the high reactor coolant temperatures. These Pressurized Water Reactor (PWR) power plant field experiences and the potential for Primary Water Stress Corrosion Cracking (PWSCC) require reassessment of the examination frequency as well as the overall examination strategy for nickel-base alloy components and weldments. Code Case N-770-1 (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 Code Case N-770-1 guidelines, volumetric examinations are required for the unmitigated DM butt welds at the Reactor Vessel (RV) inlet nozzles every second inspection period not exceeding 7 years. A volumetric examination was previously performed for the South Texas Unit 2 reactor vessel inlet nozzle to safe end DM butt welds during the Spring 2010 Re-Fueling Outage (RFO). The next required volumetric examination for the reactor vessel inlet nozzle DM welds is planned during the Fall 2016 RFO in accordance with Code Case N-770-1. The fracture mechanics evaluation in this report will determine the impact of performing the volumetric examination on South Texas Unit 2 during the Fall 2019 RFO. The time interval between the previous Unit 2 examination during the Spring 2010 RFO and the planned examination during the Fall 2019 RFO is 9.5 years, rather than the 7 years allowed by Code Case N-770-1. Therefore, South Texas is seeking relaxation from the ASME Code Case N-770-1 examination requirement to be able to defer the volumetric examination to the Fall 2019 RFO. The technical justification to support this relief 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 2010 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 Code Case N-770-1.

2.0 Methodology

In order to support the technical justification for deferring the volumetric examination from the Fall 2016 to Fall 2019 RFO for South Texas Unit 2, it is necessary to demonstrate the structural integrity of the RV inlet nozzle DM welds subjected to the PWSCC crack growth mechanism. To demonstrate the structural integrity of the DM welds, it is essential to determine the maximum allowable initial flaw size that would be acceptable in the DM welds for the duration between examinations. This maximum allowable initial flaw size would be the largest flaw size that would remain acceptable until the Fall 2019 RFO. The maximum allowable initial flaw size for a given plant operation duration can be determined by subtracting the PWSCC crack 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).

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 latest piping loads at the reactor vessel inlet nozzle DM weld locations are based on WCAP-9135 (Reference 3). 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 that given in MRP-115 for Alloy 182 weld material (Reference 4). The nozzle geometry and piping loads used in the fracture mechanics analysis are shown in Section 3.0. A discussion of the plant specific 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 crack 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 Code Case N-770-1 guidelines by deferring the volumetric inspection of the RV inlet nozzle DM welds from the Fall 2016 to Fall 2019 RFO.

3.0 Nozzle Geometry and Loads

The DM weld geometry for the South Texas Unit 2 Reactor Vessel inlet nozzles is based on the nozzle detail drawings (Reference 5). The operating temperature of the reactor vessel inlet nozzles is based on customer correspondence. The RV inlet nozzle geometry and normal operating temperature used in the analysis are summarized in Table 3-1.

The piping reaction loads at the RV inlet nozzle DM weld locations are based on WCAP-9135 (Reference 3) and 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.

Table 3-1
South Texas Unit 2 Reactor Vessel Inlet Nozzle Geometry and Normal Operating Temperature

	Dimension
Outside Diameter (in.)	33.05
Inside Diameter (in.)	27.47
Thickness (in.)	2.79
Safe End length (in.)	4.06
RV Inlet Nozzle Normal Operating Temperature = 563°F	

Table 3-2
South Texas Unit 2 Reactor Vessel Inlet Nozzle Piping Loads

Loading	Forces (kips)	Moments (in-kips)		
	Fx (Axial)	Mx (Torsion)	My (Bending)	Mz (Bending)
Deadweight	-0.2	-151.1	38.9	-371.2
Pressure*	1333.5			
Normal Thermal	20.1	-3253.0	-862.0	-8436.7
Upset Thermal	204.5	-4174.3	-2113.9	-9258.8
OBE (Operational Basis Earthquake)	326.1	1226.1	2326.2	1802.5
SSE (Safe Shutdown Earthquake)	535.6	2688.7	5674.6	5114.7
Maximum Pipe Break	1300.2	984.0	12351.1	2387.1

*Axial force due to normal operating pressure of 2.25 ksi

4.0 Dissimilar Metal Weld Residual Stress Distribution

The welding residual stresses used in the PWSCC crack growth analysis are determined from the finite element stress analysis (FEA) in Reference 6 based on the South Texas Unit 2 Reactor Vessel inlet nozzle DM weld specific configuration. Figure 4-1 shows a sketch of the South Texas inlet nozzle DM weld configuration. The FEA in Reference 6 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 7). The following fabrication sequence was simulated in the FEA and matches the information provided in the reactor vessel nozzle details drawings (Reference 5):

- The inlet nozzle was buttered with weld-deposited Alloy 82/182 material. Nozzle and buttering are post weld heat treated (PWHT) 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 50% inside surface weld repair 360° around the circumference was conservatively simulated in the Alloy 82/182 weld, which is consistent with MRP-287 (Reference 7).
- 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. The final length of the safe end after machining is 4.06" (Table 3-1).
- 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 then 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 condition (operating temperature and pressure) are shown in Figure 4-2. The hoop and axial welding residual stresses at ambient conditions (room temperature, no pressure) and operating conditions (operating temperature and pressure) at the DM weld centerline is provided as well in Figure 4-3 for information purposes.

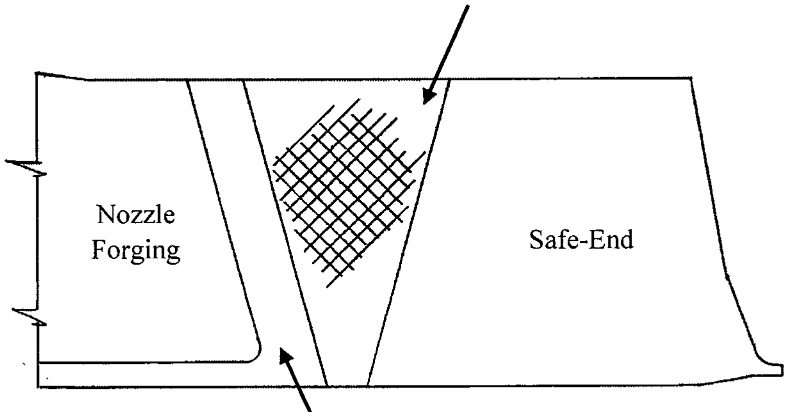

Figure 4-1: South Texas Unit 2 Reactor Vessel Inlet Nozzle DM Weld Configuration

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Figure 4-2: Reactor Vessel Inlet Nozzle DM Weld Recommended Residual Stress Profiles Through DM Weld at 100% Normal Operating Condition

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Figure 4-3: Reactor Vessel Inlet Nozzle DM Weld Residual Stress Profiles At Ambient Conditions (room temperature, no pressure) and Normal Operating conditions (operating temperature and pressure) at Centerline of the DM Weld (For Information Purposes)

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 Fall 2016 to Fall 2019 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 an indication is allowed to grow to until 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 South Texas, Z factors based on Reference 8 are used in the analysis to provide a more representative approximation of the effects of the DM welds. 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 stress 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 Crack Growth Analysis

A PWSCC crack 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 2010 to the Fall 2019 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 stresses, while for circumferential flaws, the stresses considered are pressure, 100% power normal thermal expansion, deadweight and residual 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 4). 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 9). The through-wall stress distribution profile is represented by a 4^{th} 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 is the distance from the wall surface where the crack initiates;

t is the wall thickness; and

σ is 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. The through-wall stress intensity factors (K_I) for axial and circumferential flaws are shown in Figure 6-1 and 6-2 respectively. The axial flaw stress intensity factors in Figure 6-1 were determined based on the 100% normal operating hoop welding residual stresses (Figure 4-2). The circumferential flaw stress intensity factors in Figure 6-2 are calculated based on 100% normal operating axial welding residual stresses condition (Figure 4-2), and includes normal operating piping loads (deadweight and normal thermal). Also given in Figure 6-2 are the circumferential flaw stress intensity factors with the consideration of only normal operating loads (pressure, deadweight, and normal thermal) without the normal operating axial residual stresses, which are compressive through certain portions of the wall thickness (Figure 4-2). The exclusion of axial residual stresses is conservative for the circumferential crack growth evaluation. The axial and circumferential flaw stress intensity factors in Figures 6-1 and 6-2 include the effect of crack-face pressure on the crack front. Furthermore, the stress intensity factors in these two figures are based on the deepest point along the crack front, which provide conservative results for the crack growth results.

Once the crack tip stress intensity factors are determined, PWSCC crack growth calculations can be performed using the crack growth rate below with the applicable normal operating temperature. The PWSCC crack growth rate used in the crack growth analysis is based on the EPRI recommended crack growth curve for Alloy 182 material (Reference 4):

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

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 563°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 crack growth mechanism at the reactor vessel inlet nozzle for the duration of interest. This is demonstrated by the low fatigue usage factor of 0.00973 at the inlet nozzle location of interest in the reactor vessel analytical report CENC-1354 (Reference 10). Therefore, it is not necessary to consider fatigue crack growth in the evaluation.

The PWSCC crack 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, PWSCC crack 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 Days (EFPD), or Effective Full Power Years (EFPY). Plant operation data and projected future outage dates and durations were provided for South Texas Unit 2 and are used to estimate the EFPD, or EFPY, between the Spring 2010 to the Fall 2019 RFOs.

The determination of the EFPY based on plant operating data is shown in Table 6-1 for South Texas Unit 2. It should be noted that the EFPD calculation for future outages conservatively includes startup and coast down days. Therefore, based on Table 6-1, for the time interval between the Spring 2010 RFO and Fall 2019 RFO, South Texas Unit 2 is estimated to operate at full power for 8.3 EFPY. The values in Table 6-1 are rounded for reporting purposes; the impact of rounding on PWSCC growth is insignificant. The calculated EFPY values will be used in the determination of the maximum allowable initial flaw sizes in Section 7.0.

Table 6-1
Effective Full Power Year Estimation for South Texas Unit 2

Cycle	Operation Start	Operation End	EFPD
15	5/3/2010 (Spring 2010 RFO)	10/29/2011	517*
16A	11/21/2011	11/28/2011	6*
16B	4/23/2012	1/7/2013	256*
16C	4/23/2013	11/16/2013	207*
17	12/22/2013	3/28/2015	494*
18	5/9/2015	10/8/2016	522**
19	11/12/2016	3/24/2018	506**
20	4/17/2018	10/4/2019 (Fall 2019 RFO)	535**
		Cumulative EFPD	3042
		Cumulative EFPY	8.3

Notes: *Based on plant operation data.

**Estimated based on anticipated outages. Conservatively include startup and coast down days.

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Figure 6-1: Through-Wall Axial Flaw Stress Intensity Factors at the Reactor Vessel Inlet Nozzle DM weld, Aspect Ratio = 2

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Figure 6-2: Through-Wall Circumferential Flaw Stress Intensity Factors at the Reactor Vessel Inlet Nozzle DM weld, Aspect Ratio = 10

7.0 Technical Justification for Deferring the Volumetric Examination

In accordance with ASME Code Case N-770-1 (Reference 1), the volumetric examination interval for the unmitigated reactor vessel inlet nozzle to safe end DM welds must not exceed 7 years. South Texas Unit 2 is seeking relaxation from the ASME Code Case N-770-1 requirement in order to defer the volumetric examination of the reactor vessel inlet nozzle to safe end DM welds from the Fall 2016 to Fall 2019 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 2010 RFO inlet nozzle DM weld examination based on the inspection detection capability.

The maximum allowable initial flaw depth is determined by subtracting the PWSCC crack growth for a plant operation duration of 8.3 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 crack growth at the Alloy 82/182 weld is calculated based on the normal operating condition, piping loads, and the welding residual stresses at the DM weld as well as the crack growth model in MRP-115 (Reference 4). The maximum allowable initial flaw depth was calculated for an axial flaw with an assumed 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 crack growth analysis of the circumferential flaws considered two cases. The first case is normal operating axial residual stresses from the recommended profile (shown in Figure 4-2) plus normal operating piping loads. 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 only piping loads and no residual stresses was limiting for circumferential flaws. The exclusion of residual stresses in the evaluation is conservative for the circumferential flaw evaluation.

The PWSCC crack 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 Effective Full Power Years, 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.

Table 7-1
South Texas Unit 2 Maximum Allowable Initial Flaw Sizes

	Axial Flaw (Aspect Ratio = 2)	Circumferential Flaw (Aspect Ratio = 10)
Maximum Allowable Initial Flaw Size (a/t)	0.035	0.325
Flaw Depth (inches)	0.098	0.907
Flaw Length (inches)	0.196	9.07

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 2010 to Fall 2019 RFO for South Texas 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 size is 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, South Texas also conducted Eddy Current Testing (ET) on the RV inlet nozzle DM welds. The ET examination is an additional means to detecting surface breaking indications on the inside surface of the DM weld. The South Texas qualification process for the ET procedure is the same as that of the qualification procedures used for ET used at Farley, which followed the details discussed in Reference 11. Per Reference 11, the qualification process and practical trial for the ET procedure is in accordance with European Network for Inspection Qualification (ENIQ) guidelines. More details are provided in Reference 11, which is a NRC RAI response provided by Farley for justification of their ET procedure.

The South Texas ET inspection procedure (Reference 13) from Spring 2010 required that an indication with a depth of 0.08" and length of 0.28" or more be recorded. However, during the Spring 2010 inspection, it was possible to identify indications with shorter axial flaw lengths. Circumferential ET scan looking for axial defects would allow axial flaw lengths in the range of 0.16" to 0.32" to be detected. It should be noted that much smaller axial flaw lengths less than 0.16" could also be evaluated and detected with the eddy current detection capability.

WesDyne, a subsidiary of Westinghouse, performed the cold leg DM weld examinations during Spring 2010 inspection for South Texas 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. A re-evaluation of the 2010 South Texas Unit 2 reactor vessel cold leg dissimilar welds showed that no indications were observed in the axial flaw length size range of 0.16" to 0.32" (Reference 14).

Based on the crack growth evaluation for South Texas Unit 2 performed in this letter, the maximum initial axial flaw depth is 0.098" and flaw length is 0.196" from Table 7-1. These

particular flaw dimensions are within the range of South Texas ET detection capability used during Spring 2010 inspection. As a result, the calculated maximum allowable initial axial flaw size is large enough to have been detected during the last Spring 2010 RFO examination of the RV inlet nozzle DM welds at South Texas Unit 2. 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 2010 inspection.

The supplemental Eddy Current testing was used in a similar justification for the J.M. Farley Units 1 and 2 and South Texas Unit 1 RV inlet nozzle DM weld alternate inservice inspection relief request for axial initial flaw depth less than 10% of the through-wall thickness. Furthermore, the NRC staff in its response to the Farley relief request (Reference 12) and for the South Texas Unit 1 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-770-1.

Therefore, the maximum allowable initial axial and circumferential flaw sizes in Table 7-1 would have been detected during the Spring 2010 RFO inlet nozzle DM weld examination. Since, there were no indications found during the Spring 2010 RFO for the inlet nozzle DM weld, the technical justification developed in this letter report can be used to defer the volumetric examination for the South Texas Unit 2 RV inlet nozzle DM welds from the Fall 2016 RFO to the Fall 2019 RFO.

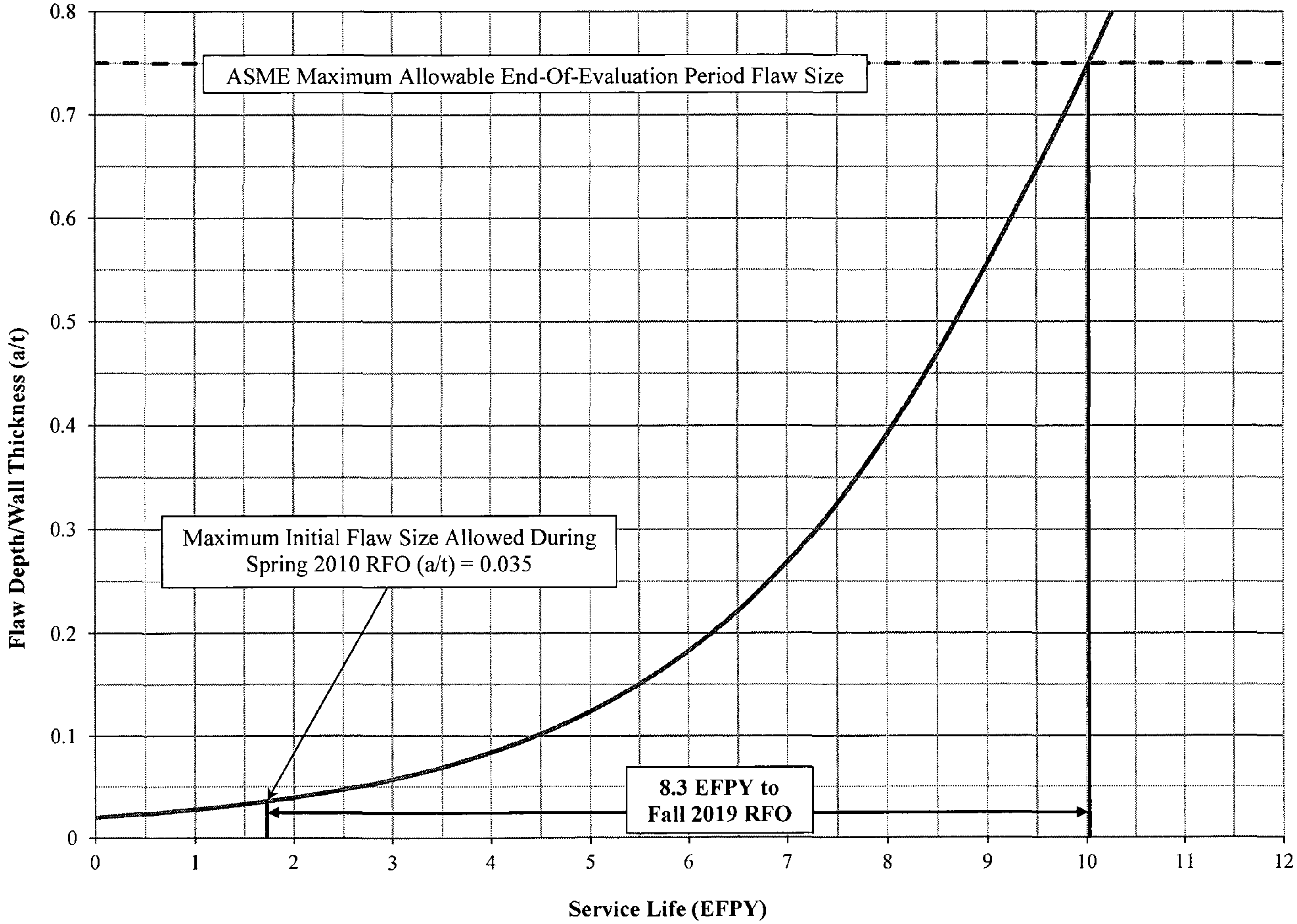

Figure 7-1: PWSCC Crack Growth Curve for South Texas Unit 2 Inlet Nozzle Axial Flaw (DM weld), Aspect Ratio = 2

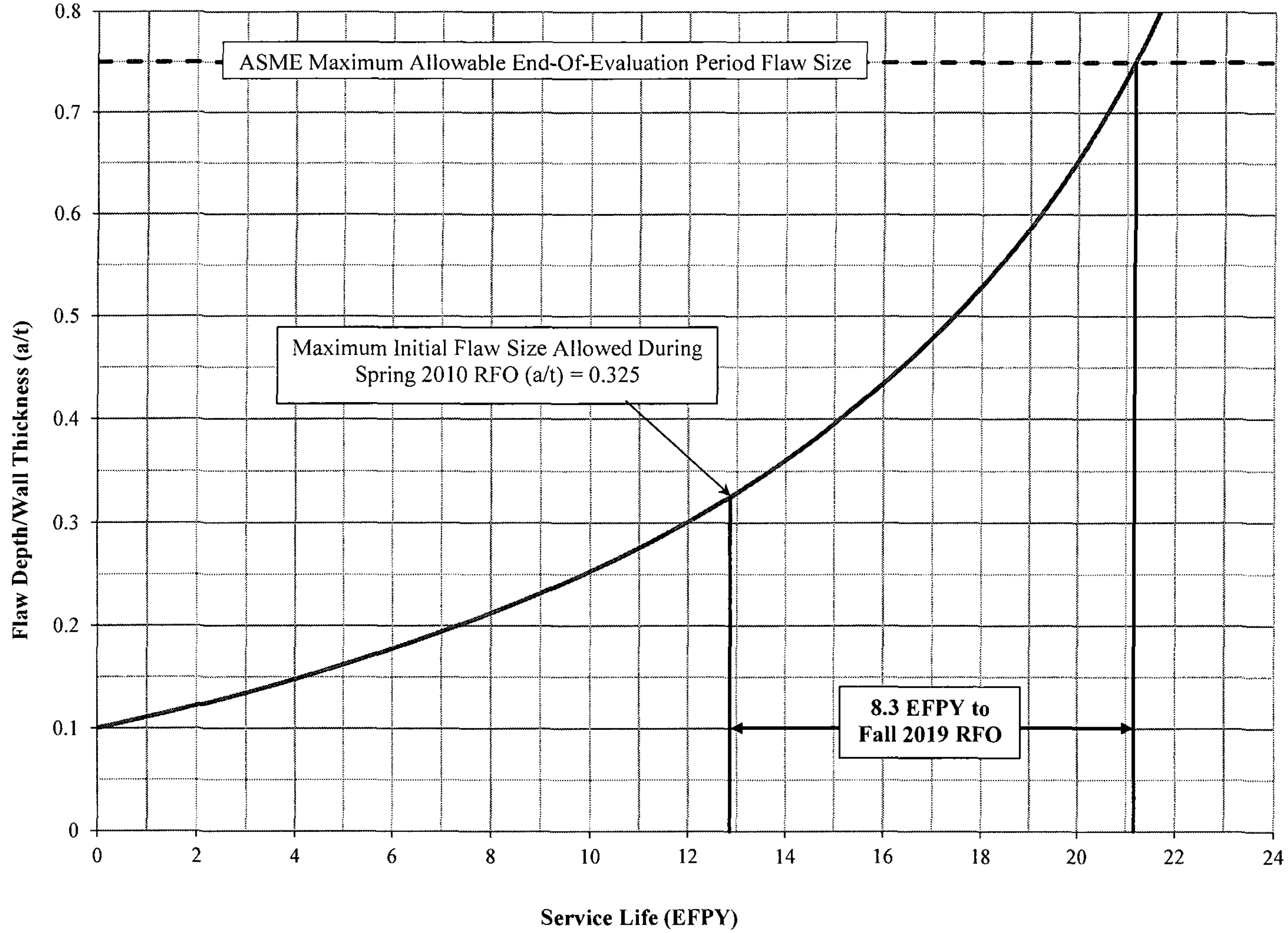

Figure 7-2: PWSCC Crack Growth Curve for South Texas Unit 2 Inlet Nozzle Circumferential Flaw (DM weld), Aspect Ratio = 10

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 2010 RFO at South Texas Unit 2. The next required volumetric examination will be during the Fall 2016 RFO in accordance with Code Case N-770-1. However, the volumetric examination will be deferred to the Fall 2019 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-770-1 inspection interval requirements, a relief request will be submitted to the Nuclear Regulatory Commission (NRC) seeking relaxation from the ASME Code Case N-770-1 examination requirement 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 crack growth analysis results from Section 7.0, the maximum allowable initial flaw sizes for the reactor vessel inlet nozzle DM welds are tabulated in Table 8-1 for South Texas 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 Fall 2019 RFO for South Texas Unit 2 taking into account of potential PWSCC crack 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 South Texas Unit 2. Based on a re-evaluation of the Spring 2010 RV inlet nozzle dissimilar metal weld inspection data, it was determined that there were no indication present with axial depth more than 0.08" and flaw lengths in the range of 0.16" to 0.32" (Reference 14).

Therefore, based on the South Texas Unit 2 flaw evaluation results in Table 8-1, the calculated maximum allowable initial axial flaw size is large enough to have been detected during the last Spring 2010 RFO 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 flaw sizes provided in Table 8-1 were present during the Spring 2010 inspection. Similar justification was used in the J.M. Farley Units 1 and 2 and South Texas Unit 1 RV inlet nozzle DM weld alternate inservice inspection relief request for axial initial flaw sizes less than 10% of the through-wall thickness. Furthermore, the NRC staff in its response to the Farley relief request (Reference 12) and the South Texas Unit 1 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-770-1. Therefore, deferring the volumetric examination for the South Texas Unit 2 RV inlet nozzle DM welds from the Fall 2016 RFO allowed by Code Case N-770-1

to the Fall 2019 RFO is technically justified.

Table 8-1
South Texas Unit 2 Maximum Allowable Initial Flaw Sizes

	Axial Flaw (Aspect Ratio = 2)	Circumferential Flaw (Aspect Ratio = 10)
Maximum Allowable Initial Flaw Size (a/t)	0.035	0.325
Flaw Depth (inches)	0.098	0.907
Flaw Length (inches)	0.196	9.07

Note: Aspect ratio = flaw length/flaw depth

9.0 References

1. ASME Code Case N-770-1, 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 December 25, 2009.
2. ASME Boiler & Pressure Vessel Code, 2004, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.
3. Westinghouse Report WCAP-9135, Volume 1, Rev. 4, "Structural Analysis of the Reactor Coolant Loop for the South Texas Project Units 1 and 2 Volume 1 Analysis of the Reactor Coolant Loop Piping (Units 1 & 2 RSG)," January 2003.
4. 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.
5. Drawings for South Texas Unit 2 RV inlet nozzles:
    a. Combustion Engineering, Inc. Drawing D-12173-128-002, Rev. 1, "Inlet Nozzle Cladding and Machining."
    b. Combustion Engineering, Inc. Drawing C-12173-131-001, Rev. 0, "Nozzle Safe Ends."
    c. Combustion Engineering, Inc. Drawing, E-12173-161-001, Rev. 3, "Material Identification Vessel."
    d. Combustion Engineering, Inc. Drawing, E-12173-121-003, Rev. 0, "Upper Vessel Machining."
6. Dominion Engineering, Inc. Document C-8891-00-01, Rev. 0, "Welding Residual Stress Calculation for South Texas Project Units 1 and 2 RPV Inlet Nozzle DMW."
7. Materials Reliability Program: Primary Water Stress Corrosion Cracking (PWSCC) Flaw Evaluation Guidance (MRP-287). EPRI, Palo Alto, CA: 2010. 1021023.
8. 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.
9. American Petroleum Institute, API 579-1/ASME FFS-1 (API 579 Second Edition), "Fitness-For-Service," June 2007.
10. Combustion Engineering, Inc. Report CENC-1354, "Analytical Report for South Texas Project No. 2 Houston Lighting and Power Company," January 1979.
11. Southern Nuclear Company, Inc. Letter NL-14-1193, "Joseph M. Farley Nuclear Plant Response to Request for Additional Information Regarding Proposed Alternative to Inservice Inspection Requirements of ASME Code Case N-770-1," Docket Nos. 50-348 and 50-364, Dated August 1, 2014. (*ADAMS Accession Number ML14213A484*)

12. United States Nuclear Regulatory Commission Letter Dated December 5, 2014, "Joseph M. Farley, Units 1 and 2, (FNP-ISI-ALT-15, Version 1) Alternative to Inservice Inspection Regarding Reactor Pressure Vessel Cold-Leg Nozzle Dissimilar Metal Welds (TAC Nos. MF 3687 and MF3688)." *(ADAMS Accession Number ML14262A317)*

13. WesDyne WDI-STD-146, Rev. 9. "ET Examination of Reactor Vessel Pipe Welds Inside Surface," December 2008.

14. WesDyne WDI-LTR-ENG-16-0002, Revision 1, "2010 STP Unit 2 Reactor Vessel Cold Leg Dissimilar Metal Weld Eddy Current Data Review," February 12, 2016.

15. United States Nuclear Regulatory Commission Letter Dated August 21, 2015, "South Texas Project, Unit 1 – Request for Relief No. RR-ENG-3-17 for Extension of the Inspection Frequency of the Reactor Vessel Cold-Leg Nozzle to Safe-End Welds with Flaw Analysis (Tac No. MF6174)." *(ADAMS Accession Number ML15218A367)*