Ronald A. Jones
Vice President
New Nuclear Operations

October 25, 2016
NND-16-0425
10 CFR 50.55a

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Subject: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3
Docket Numbers 52-027 and 52-028
Response to Requests for Additional Information related to Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds

Reference: 1. Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 Request for Alternative: Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds, NND-16-0246, dated July 7, 2016.

2. Southern Nuclear Operating Company, Vogtle Electric Generating Plant Units 3 and 4 Response to Requests for Additional Information related to Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds (VEGP 3&4-PSI-ALT-05), ND-16-1968, dated September 30, 2016.

By letter dated July 7, 2016, South Carolina Electric & Gas Company (SCE&G), acting on behalf of itself and the South Carolina Public Service Authority (Santee Cooper), submitted a request for an alternative in accordance with 10 CFR 50.55a for preservice inspection of the Steam Generator Nozzle to Reactor Coolant Pump Casing Welds (Reference 1).

On August 5, 2016, the Nuclear Regulatory Commission (NRC) staff issued two draft requests for additional information [ML16218A439]. A clarification call was held in a public meeting on August 25, 2016 to provide clarification on the requests for additional information.

Enclosures 1 through 3 provide responses to the requests for additional information (RAIs).

Enclosure 2 contains the Non-Proprietary response to the first RAI.

Enclosure 3 contains the Proprietary response to the first RAI and is subject to withholding under 10 CFR 2.390.

Enclosure 4 provides an affidavit from SCE&G supporting withholding the Proprietary information under 10 CFR 2.390.

Enclosure 5 is Westinghouse's Proprietary Information Notice, Copyright Notice, and CAW-16-4491, Application for Withholding Proprietary Information from Public Disclosure and Affidavit. The affidavit sets forth the basis upon which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations. Accordingly, it is

respectfully requested that the information that is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse affidavit should reference CAW-16-4491 and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 3 Suite 310, Cranberry Township, Pennsylvania 16066. Correspondence with respect to proprietary aspects of this letter and its enclosures should also be addressed to April Rice at the contact information within this letter.

The supplemental information provided in this letter does not impact the scope or conclusions of the original alternative.

This letter contains no regulatory commitments. Should you have any questions, please contact April Rice by telephone at (803) 941-9858, or by email at arice@scana.com.

This request is consistent in technical content with Southern Nuclear Operating Company (SNC) Response to Requests for Additional Information related to Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds submitted September 30, 2016 (Reference 2).

I declare under penalty of perjury that the foregoing is true and correct.

Executed on this 25th day of October 2016.

Sincerely,

Ronald A. Jones
Vice President
New Nuclear Operations

BB/RAJ/bb

Enclosure 1: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 – Response to NRC Staff Request for Additional Information (RAI) Regarding Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds

Enclosure 2: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 – Response to Request for Additional Information #1 – LTR-PAFM-16-59-NP, NRC RAI Response Regarding Inspection of *AP1000* Vogtle Units 3 & 4 and V.C. Summer Units 2 & 3 Steam Generator to Reactor Coolant Pump Suction Nozzle Weld (Non-Proprietary)

Enclosure 3: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 – Response to Request for Additional Information #1 – LTR-PAFM-16-59-P, NRC RAI Response Regarding Inspection of *AP1000* Vogtle Units 3 & 4 and V.C. Summer Units 2 & 3 Steam Generator to Reactor Coolant Pump Suction Nozzle Weld **(Proprietary)**

Enclosure 4: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 – Affidavit for Withholding SCE&G's Information Under 10CFR 2.390

Enclosure 5: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 – Westinghouse Application for Withholding Proprietary Information from Public Disclosure CAW-16-4491, accompanying Affidavit, Proprietary Information Notice, and Copyright Notice

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South Carolina Electric & Gas Company

NND-16-0425

Enclosure 1

Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3

Response to NRC Staff Request for Additional Information (RAI) Regarding Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds

(Enclosure consists of 3 pages, including this cover page.)

RAI 1:

Alternative request VEGP3&4-PSI-ALT-05 [SCE&G letter NND-16-0246] describes in detail how the ultrasonic examination of the steam generator nozzle-to-reactor coolant pump casing welds (SG-to-RCP welds) will be done using a procedure and personnel qualified in accordance with the Electric Power Research Institute Performance Demonstration Initiative (EPRI/PDI) program. In this description, the licensee indicates that ultrasonic detection and length sizing qualification was extended to the full thickness of the aforementioned weld and that the examination volume is not limited. The staff notes that this capability would allow the licensee to meet the NRC proposed condition on American Society of Mechanical Engineers (ASME) Code Case N-799 which states, in part, that the examination of dissimilar metal welds between steam generator nozzles and pumps must be full volume.

In lieu of examining the full weld volume as proposed in the condition, the licensee proposes to perform an ultrasonic examination of the inner 1/3 of the weld and a surface examination of the inner and outer weld surfaces. However, there is no technical justification provided to support the licensee's proposal to volumetrically examine only the inner 1/3 of the weld volume. Therefore, the staff is unable to determine whether the proposed alternative examinations provide an acceptable level of quality and safety in accordance with 10 CFR 50.55a(z).

To resolve this issue, the staff requests that the licensee provide additional information or analyses to justify why the proposed examinations are an acceptable alternative to examining the full weld volume. Specifically, the staff requests that the licensee, at a minimum, provide an analysis which considers the size and nature of the largest potential defect which could be expected to be present in the outer 2/3 of the weld as well as the operating loads to which the weld will be subject for the licensed lifetime of the facility. To support the requested alternative, this analysis would be expected to demonstrate that the initiation of active degradation of the weld would not be expected to occur from the postulated defect in the outer 2/3 of the weld over the licensed lifetime of the facility.

SCE&G Response to RAI 1:

Enclosures 2 and 3 provide additional information and analysis that concludes a postulated defect in the outer 2/3 of the weld would not exceed the allowable flaw size over the licensed lifetime of the plant based upon the ASME Boiler & Pressure Vessel Code (B&PVC) Section XI flaw tolerance evaluation and the ASME B&PVC Section III design evaluation. Enclosure 2 contains the Non-Proprietary response. Enclosure 3 contains the Proprietary response subject to withholding under 10 CFR 2.390.

RAI 2:

Alternative request VEGP3&4-PSI-ALT-05 [SCE&G letter NND-16-0246], Figure 2, indicates that the configuration of the SG-to-RCP weld will be a double-sided joint (i.e., double V). However, the figures used to illustrate the examination requirements in ASME Code Case N-799 and ASME Section XI (2013 Edition), IWB-2500-8 are for a single-sided weld joint. The staff requests that the licensee describe why the examination requirements proposed for a single-sided weld are applicable and acceptable for use on the SG-to-RCP weld, which is double-sided weld.

SCE&G Response to RAI 2:

The figures in the ASME B&PVC Code Case N-799 (Figure 1) and ASME B&PVC Section XI, 2013 Edition (Figure IWB-2500-8 (c) – (e)) are illustrative with respect to the weld joint configuration. These figures are intended only to define the examination volume and examination surface extent for similar and dissimilar metal welds in components, nozzles, and piping. It is noted that the examination volume and examination surface extent is defined with respect to the weld (or weld end buttering) edges at the widest part of the weld (and weld end buttering) regardless of whether it is located on the inside or outside surface. For the examination volume, these weld (or weld end buttering) edges are extended to the inside surface and the ¼-inch of adjacent base material is added to both edges to obtain the width extent of the examination volume. The 1/3t examination volume depth is taken from the inside surface. This approach ensures that the entire weld (and weld end buttering) width is captured in the examination volume regardless of the weld preparation configuration.

The Alternative Request in SCE&G letter NND-16-0246, Figure 2, shows that the widest part of the weld (and weld end buttering) is the same on the inside and outside surfaces and it is defined by the edges of the weld end buttering on the Reactor Coolant Pump Casing and the Steam Generator Nozzle. The ¼-inch of adjacent pump casing and nozzle base material is taken from these weld end buttering points and the 1/3t depth is taken from the inside surface. As noted in the Alternative Request, Figure 2, the entire weld and weld end buttering width is captured in the examination volume.

South Carolina Electric & Gas Company

NND-16-0425

Enclosure 2

Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3

Response to Request for Additional Information #1 – LTR-PAFM-16-59-NP, NRC RAI Response Regarding Inspection of *AP1000* Vogtle Units 3 & 4 and V.C. Summer Units 2 & 3 Steam Generator to Reactor Coolant Pump Suction Nozzle Weld (Non-Proprietary)

(Enclosure consists of 19 pages, not including this cover page.)

LTR-PAFM-16-59-NP
Revision 0

NRC RAI Response Regarding Inspection of *AP1000* Vogtle Units 3 & 4 and V. C. Summer Units 2 & 3 Steam Generator to Reactor Coolant Pump Suction Nozzle Weld

September 2016

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**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. These codes are listed with their meanings in WCAP-7211 Revision 8 (September 2015), "Proprietary Information and Intellectual Property Management Policies and Procedures."

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 10CFR2.903. 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-PAFM-16-59-P Revision 0).

1.0 Introduction

The objective of this letter report is to provide responses to the NRC Request for Additional Information (RAI) [1] regarding the *AP1000*® Steam Generator (SG) to Reactor Coolant Pump (RCP) suction nozzle dissimilar metal (DM) weld inspection coverage. The NRC RAI requests additional information or analyses to justify why an ultrasonic examination of the inner 1/3 of the weld thickness and a surface examination of the inner and outer weld surfaces is an acceptable alternative to examining the full weld volume.

The responses to the NRC RAI will be based on two separate assessments that have been performed for the region of interest. The first assessment is based on an ASME Section XI flaw tolerance analysis, and the second assessment is based on the ASME Section III design evaluation.

1.1 ASME Section XI Flaw Tolerance Evaluations for Postulated Outside Surface Flaws

The first evaluation is based on an ASME Section XI flaw tolerance analysis for the DM weld, with the consideration of a surface postulated flaw size in the outer 2/3 of the wall thickness. This flaw evaluation considers a crack growth calculation for 60 years (design life) and the maximum end-of-evaluation flaw size determinations based on limit load analysis, typical of an ASME Section XI flaw evaluation using the rules of Appendix C. The intent is to show that a large postulated outside surface flaw will not grow to the maximum allowable end-of-evaluation period flaw size (i.e., allowable flaw size) after 60 years of growth. The maximum allowable end-of-evaluation period flaw size is calculated based on the ASME IWB-3640 guidelines [2]. The postulated outside surface flaws used in this crack growth analysis are an axial flaw with Aspect Ratio (AR), flaw length/flaw depth, AR = 2, and a circumferential flaw with AR = 6. The evaluation of postulated outside surface flaws conservatively covers evaluations for embedded flaws, as the stress intensity factors for outside surface flaws are more limiting than embedded flaws.

The evaluation of postulated outside surface flaws for 60 years is considered since the DM weld will have an initial full volumetric examination done during fabrication to identify any indications during construction. The fabrication inspections include surface examination of the outside surface, required ASME Section III radiography examinations, and the design required ASME Code Section V ultrasonic testing imposed during component fabrication. The ultrasonic testing includes in-progress inspections of the buttering material on both the steam generator and RCP materials from the end face, and post-weld inspections of the full volume of the weld using multiple angle, four directional angle beam techniques, from both the ID (Inside Diameter) and OD (Outside Diameter) surfaces. The post-weld ultrasonic testing results are evaluated against the ASME Code Section III and Section XI standards for acceptance [3]. In addition to the fabrication inspection, surface examinations are performed on the outside and inside surfaces during the pre-service inspection (PSI), and then every 10 years per the in-service inspection (ISI) schedule [3].

Trademark Note:

The primary crack growth mechanism for flaws within the nozzle welds is Fatigue Crack Growth (FCG). The fatigue crack growth rates as well as the stress intensity factor equations required to complete a FCG analysis are further discussed in Section 2 of this letter report. Crack growth due to Primary Water Stress Corrosion Crack (PWSCC) growth does not need to be investigated since the base metals around the DM weld, the stainless steel buttering, and the Alloy 152/52 DM weld material have a low susceptibility to stress corrosion cracking. Furthermore, the evaluation considered in this letter is for postulated outside surface flaws which are not exposed to the primary coolant, and thus the susceptibility to PWSCC is not of concern. Any potential indications on the inner 1/3 of the dissimilar metal weld wall thickness will be detected by volumetric inspection during the in-service inspections.

1.2 ASME Section III Design Evaluations

In addition to the ASME Section XI flaw tolerance analysis for postulated axial and circumferential flaw on the outside surface of the SG to RCP suction nozzle DM weld, a Section III design evaluation [4] assessment was already completed for the *AP1000* Steam Generator and the adjacent DM weld. The primary goal of the Section III evaluation is to demonstrate acceptable margins to avoid cracks initiating as a result of fatigue cycling. The ASME Section III discussion and results are provided here also to demonstrate that the region of interest (i.e., SG outlet nozzle and DM weld) meet the structural design requirements of the ASME Code. The select results that are provided in Section 3 of this letter aim to demonstrate that the primary and secondary stress analysis, fatigue usage, and non-ductile failure (fracture mechanics) assessment per the ASME Section III code are all satisfied. Therefore, meeting the requirements of ASME Section III further demonstrates the justification that the DM weld location is structurally qualified for the design life of the plant.

2.0 ASME Section XI Flaw Tolerance Analysis for Outside Surface Postulated Flaws

This section provides a brief discussion for the fracture mechanics analysis of outside surface postulated flaws per the ASME Section XI guidelines. The evaluation first calculates the maximum allowable end-of-evaluation period flaw sizes for the two different flaw orientations (axial and circumferential flaws) based on ASME Section XI at the Steam Generator to RCP DM weld location. Next, fatigue crack growth calculations at the dissimilar metal weld are performed for 60 years for large postulated outside surface flaws. The initial postulated outside surface flaw sizes are sufficiently large to ensure detection during the fabrication inspections for this component at this location.

2.1 Maximum Allowable End-of-Evaluation Period Flaw Sizes

The calculation of the maximum allowable end-of-evaluation period flaw sizes for austenitic steel and nickel base alloys is based on limit load analysis. The procedures and acceptance criteria for the limit load analysis in austenitic components and weld metals are contained in paragraph IWB-3640 of ASME Section XI [2]. These criteria were used to determine the maximum allowable end-of-evaluation period flaw size for axial (AR = 2) and circumferential (AR = 6) flaw configurations. The aspect ratio of 2 is reasonable because the axial flaw growth is limited to the width of the DM weld configuration, and an aspect ratio of 6 for postulated circumferential flaw is typical for fracture mechanics analyses. The procedure to evaluate the allowable flaw sizes is based on IWB-3640 and subsequently Appendix C of Section XI of the code.

The maximum end-of-evaluation period flaw sizes determined for both axial and circumferential flaws have incorporated the relevant material properties, nozzle loadings and geometry. Loadings under normal, upset, emergency, and faulted conditions were considered in conjunction with the applicable safety factors for the corresponding service conditions required in the ASME Code Section XI. For circumferential flaws, axial stress due to the [

]a,c,e were considered in the evaluation. As for the axial flaws, hoop stress resulting from pressure loading was used, since none of the other loadings have an impact on such flaws.

Per ASME Section XI, the thermal expansion loads do not need to be considered in the maximum end-of-evaluation period flaw size determination since the nozzle welds are GTAW (Gas Tungsten Arc Weld) and are non-flux welds.

The *AP1000* SG to RCP suction nozzle DM weld dimensions and operating parameters are shown in Table 1. A design temperature of [ ]a,c,e was conservatively used in determining the end-of-evaluation period flaw size and for the fatigue crack growth analysis. The nozzle loads at the SG to RCP suction nozzle weld are based on conservatively bounding both the SG and RCP design specification allowable loads (Table 2). The loads given in Table 2 are in the local coordinate system, where the x-axis is axial along the component centerline, y-axis and z-axis by right-hand-rule. Furthermore, all loads are conservatively applied as absolute values. The design mechanical loads cover normal pump vibration loadings.

Table 1: *AP1000* SG to RCP Suction Nozzle Weld Geometry and Operating Parameters

a,c,e

Table 2: *AP1000* SG to RCP Suction Nozzle Weld Allowable Loads

a,c,e

The maximum end-of-evaluation period allowable flaw sizes are determined based on the weaker of the base metal and weld metal material properties flow strength value (average of the yield and ultimate strengths) at the SG to RCP suction nozzle weld for a maximum temperature of [ ]a,c,e,. The ASME code limiting material properties at the DM weld location are based on the [

]a,c,e

The maximum allowable end-of-evaluation period flaw sizes for the SG to RCP suction nozzle DM weld are shown in Table 3. It should be noted that the maximum end-of-evaluation period allowable flaw sizes are limited to only 75% of the wall thickness in accordance with the requirements of ASME Section XI paragraph IWB-3640 [2]. Next, the fatigue crack growth analyses are performed to determine the largest postulated allowable initial flaw size for 60 years of plant operation such that the final crack growth flaw sizes will not reach the maximum-end-of-evaluation period flaw sizes shown in Table 3.

Table 3: Maximum Allowable End-of-Evaluation Period Flaw Size

Flaw Configuration	Aspect Ratio (flaw length/flaw depth)	Maximum End-of-Evaluation Period Flaw Size (a/t)
Axial Flaw	2	0.75
Circumferential Flaw	6	0.47

The wall thickness, denoted as 't', and the flaw depth and flaw length, denoted as 'a' and 'ℓ' respectively, are shown in Figure 1 for an axial flaw on the outside diameter of the SG to RCP suction nozzle DM weld. A circumferential flaw on the outside diameter has the same denotation for thickness and flaw configuration variables.

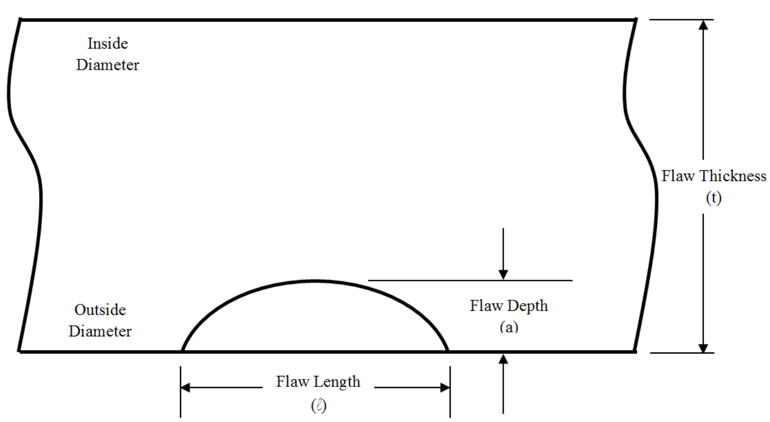

Figure 1: Illustration of SG to RCP Suction Nozzle DM Weld Outside Diameter Axial Flaw

2.2 Crack Growth Evaluations

As discussed in Section 1 of this letter report, the primary crack growth mechanism for flaws within the nozzle welds is fatigue crack growth. Crack growth due to Primary Water Stress Corrosion Crack growth is not applicable since the Alloy 152/52 DM weld material has very low susceptibility to stress corrosion cracking, especially for outside surface flaws which are not exposed to the primary coolant. The fatigue crack growth rate as well as the stress intensity factor equations required to complete a FCG analysis are discussed in this section. The inputs that are used in the crack growth evaluations are the applicable design transients and cycles that contribute significantly to the FCG (see Section 2.2.1), along with the consideration of welding residual stresses to the crack growth analysis. The through-wall transient stresses, along with the residual stresses are used to calculate the stress intensity factor, which will then be used with the cycles to determine the 60 year FCG results for the axial and circumferential flaw.

2.2.1 Transient Stresses

The transient hoop and axial stress data used in the FCG analysis is representative of the stresses at the SG to RCP suction nozzle DM weld. The transients and cycles are listed in Table 4, and these particular transients are considered limiting for use in the FCG analysis. The remaining *AP1000* design transients do not have high fatigue usage factor contributions to the ASME Section III RCP nozzle fatigue evaluation. It is assumed that the fatigue crack growth is also negligible for the other remaining design transients, since the fatigue usage factor contribution for those transients is negligible. It should be noted that the mechanical loadings are included in the transient stresses. A high-cycle pump vibration transient has also been considered, and determined to have stress intensity factor that are below the threshold needed for fatigue crack growth as described later in this report (Section 2.2.5).

Table 4: Limiting Transients Used for the FCG Analysis

a,c,e

2.2.2 Residual Stresses

For the FCG analysis, the welding residual stresses at the SG to RCP suction nozzle DM weld are also considered along with the transient stresses. The inclusion of residual stresses will not change the range of stress intensity factor for the fatigue crack growth calculations; however, it will affect the Load Ratio (R) in the FCG equation (see Section 2.2.5). [

]^{a,c,e}

2.2.3 Fatigue Crack Growth Analysis

In order to determine the growth of a postulated flaw after 60 years, a fatigue crack growth analysis is completed. Fatigue crack growth is the only credible mechanism for crack growth in the material between the SG and RCP since both the weld and the base metals have very low susceptibility to PWSCC, especially since the outside postulated surface flaw is not exposed to the reactor coolant loop environment. The fatigue crack growth analysis procedure involves postulating an initial flaw at the weld region and predicting the growth of that flaw due to an imposed series of loading transients. The input required for a fatigue crack growth analysis is essentially the information necessary to calculate the range of crack tip stress intensity factor, which depends on the crack size and shape, geometry of the structural component where the crack is postulated, and the applied cyclic stresses. Provided below is the methodology used to calculate the stress intensity factor for the axial and circumferential surface flaws.

2.2.4 Generation of Crack Tip Stress Intensity Factors

The FCG analysis in this letter involves calculating growth for a flaw on the outside surface of the SG to RCP suction nozzle DM weld, for an axial (AR = 2) and circumferential (AR = 6) flaw. The aspect ratio of 2 is reasonable because the axial flaw growth is limited to the width of the DM weld configuration, and an aspect ratio of 6 for postulated circumferential flaw is typical for fracture mechanics analyses. The postulated flaws are subjected to cyclic loads due to the transients and residual stresses described previously. The inputs required for the fatigue crack growth analysis is the range in stress intensity factor, ΔK, and the R ratio, K_{min}/K_{max}.

The stress intensity factors expression for surface flaws utilizes a representation of the actual stress profile rather than a linearization between data points. The stress distribution profiles are represented by a cubic polynomial:

$$\sigma(x) = A_0 + A_1 x + A_2 x^2 + A_3 x^3$$

where:

A_0, A_1, A_2, and A_3 are the stress profile curve fitting coefficients,

x is the distance from the wall surface where the crack initiates, and

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

The stress intensity factor expression for semi-elliptical flaw shapes was used. The methodology for calculating the crack tip stress intensity factors is documented in an ASME publication [5] for axial flaws. The stress intensity factor from [5] can also be used conservatively for circumferentially oriented flaws. When evaluating axial and circumferential flaws, semi-elliptical surface flaws with aspect ratios (flaw length/flaw depth) of 2 for axial flaws and 6 for circumferential flaws are considered. Stress intensity factors can be expressed in the general form as follows:

$$K_I = \left(\frac{\pi a}{Q}\right)^{0.5} \sum_{j=0}^{3} G_j\,(a/c, a/t, t/R, \phi)\, A_j\, a^j$$

where:

a:	crack depth
c:	half of the crack length along the surface
t:	wall thickness
R:	inside radius of the component
A_j:	coefficients A_0, A_1, A_2, and A_3 for the stress profile cubic fit
ϕ:	angular position of a point of the crack front (ϕ= 0° at the deepest point; 90° at the surface point)
G_j:	G_0, G_1, G_2, G_3 are boundary correction factors provided in [5] for axial and used conservatively for circumferential flaws
Q:	shape factor of an elliptical crack. Q 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 $a/c > 1$

2.2.5 Fatigue Crack Growth Rate

Once R (load ratio = K_{min}/K_{max}) and ΔK are calculated, the crack growth due to any given stress cycle can be calculated for each transient. This increment of crack growth is then added to the original crack size, and the analysis proceeds to the next transient.

Fatigue crack growth for each transient for a given time interval and number of cycles (N) can be computed using the following equation:

New Crack Depth = Initial Crack Depth + Incremental Crack Depth

with the incremental crack depth, Δa, given by:

$$\Delta a = C\,(\Delta K)^n\, N$$

The procedure is continued in this manner until all the transients known to occur in the period of evaluation have been analyzed. The design transient load cycles used in the analysis for the *AP1000* SG to RCP suction nozzle

weld are listed in Table 4. The above equation is the most fundamental form of fatigue crack growth law, where C and n are material constants.

The general fatigue crack growth rate for materials in air environments is given by the equation of the type:

$$\frac{da}{dN} = F_{weld}\, C(T)\, S(R)\, (\Delta K)^n$$

where:

C(T)	=	Scaling Factor for Temperature Effects
S(R)	=	Scaling Factor for Load Ratio Effects
F_{weld}	=	Factor for Weld Material
ΔK	=	Stress Intensity Factor Range = $K_{max} - K_{min}$
R	=	Load Ratio K_{min} / K_{max}
K_{max}	=	Maximum Stress Intensity Factor
K_{min}	=	Minimum Stress Intensity Factor
da/dN	=	Crack Growth Rate in Environment
n	=	Crack Growth Law Exponent

The fatigue crack growth is performed for the Alloy 152/52 weld material between the SG and RCP suction nozzle. Note that the buttering on the steam generator outlet nozzle is Alloy 152/52, and the weld is Alloy 52. The FCG reference curves for Alloy 152/52 have not been developed in Section XI of the ASME Code; therefore, information available in NUREG/CR-6907 [6] is used. According to [6], in an air environment the Alloy 52 and Alloy 182 weld is approximately 2 times the Alloy 600 FCG rate in air. Due to limited number of test data for Alloy 152 in air environment, Reference [6] concludes that a factor of 2 on the Alloy 600 in air can be used to approximate the Ni-alloy welds, such as Alloy 152/52, FCG rate in air. It should be noted that the buttering on the RCP pump suction nozzle is stainless steel; however, the crack growth results for the Ni-alloy in air are more limiting than the stainless steel material in air (FCG curves for stainless steel based on ASME Section XI Appendix C).

Thus, the crack growth evaluation used herein are based on the FCG rate expression for Alloy 600 in air in SI units with a factor of 2 to represent the Alloy 152/52 weld in air environment [6]:

$$\frac{da}{dN} = F_{weld}\, C(T)\, S(R)\, (\Delta K)^n$$

$$C(T) = 4.835 \text{ X } 10^{-14} + (1.622 \text{ x } 10^{-16})T - (1.490 \text{ x } 10^{-18})T^2 + (4.355 \text{ x } 10^{-21})T^3$$

$$S(R) = (1 - 0.82R)^{-2.2}$$

$$F_{weld} = 2$$

where:

T	= Temperature (°C)
ΔK	= Stress Intensity Factor Range, $K_{max} - K_{min}$, MPa$\sqrt{m}$
K_{max}	= Maximum Stress Intensity Factor, MPa$\sqrt{m}$
K_{min}	= Minimum Stress Intensity Factor, MPa$\sqrt{m}$
n	= Crack Growth Law Exponent (= 4.1)
R	= Load Ratio, K_{min} / K_{max}
$\frac{da}{dN}$	= Crack Growth Rate in Environment, m/Cycle

[

]^{a,c,e} As such, the stress profile and stress range through the DM weld thickness due to RCP vibrations will be small. The stresses that are produced by the vibration are below the endurance limit of the Alloy 152/52 DM weld. Furthermore, the range in stress intensity factors for pump vibrations are less than the $\Delta K_{threshold}$. Therefore, the contribution of RCP vibrations to the FCG analysis would be negligible.

2.2.6 Fatigue Crack Growth Charts

The fatigue crack growth charts (Figures 2 and 3) are constructed by plotting the fatigue crack growth results over a period of 60 years. The flaw depth to through-wall thickness ratio (a/t) is plotted as the ordinate, and time is plotted as the abscissa. The charts are generated for the SG to RCP suction nozzle DM weld for an outside surface axial flaw (AR = 2) and circumferential flaw (AR = 6) as shown in Figures 2 and 3 respectively. The fatigue crack growth results are compared to the maximum allowable end-of-evaluation flaw size. The maximum allowable flaw size is tabulated in Table 3 for the axial and circumferential flaws, and also plotted in Figures 2 and 3. The initial flaw size is a sufficiently large postulated flaw which would not reach the maximum allowable flaw size in 60 years.

As shown in Figure 2 for an axial flaw, even a 60 percent through the wall thickness flaw would not reach the maximum allowable flaw size in 60 years. Figure 3 for circumferential flaws shows that a postulated flaw as large as 30 percent through the wall thickness flaw would not reach the maximum allowable flaw size in 60 years. Any initial axial and circumferential flaw sizes less than the 60 and 30 percent of the wall thickness, respectively, are encompassed by these curves and will not grow to the maximum allowable flaw size in 60 years. The large axial and circumferential flaw sizes described above would have been detected by initial volumetric fabrication inspections and will be detected by the regular ISI surface examinations of the outside surface of the SG to RCP suction nozzle DM weld.

The stress intensity factor correlations for an embedded flaw are lower than that for surface flaws. Therefore, for a given through-wall stress distribution, it can be concluded that the fatigue crack growth for outside surface flaws is more limiting than the embedded flaws due to higher stress intensity factor. Furthermore, the initial volumetric fabrication inspection would detect embedded flaws of the sizes described above.

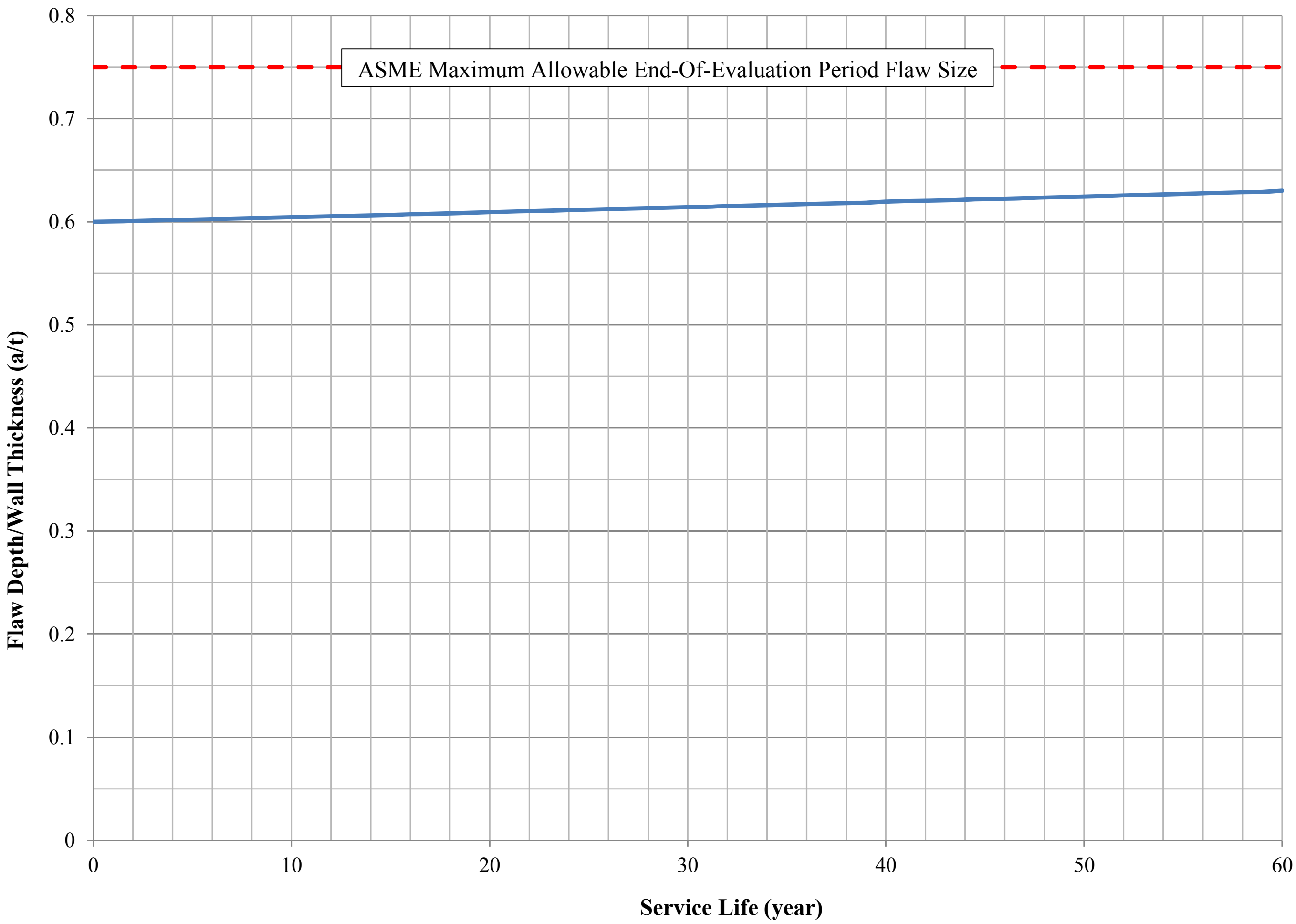

Figure 2: Crack Growth Chart for the *AP1000* Steam Generator to Reactor Coolant Pump Suction Nozzle Dissimilar Metal Weld, Outside Surface Axial Flaw with Aspect Ratio = 2

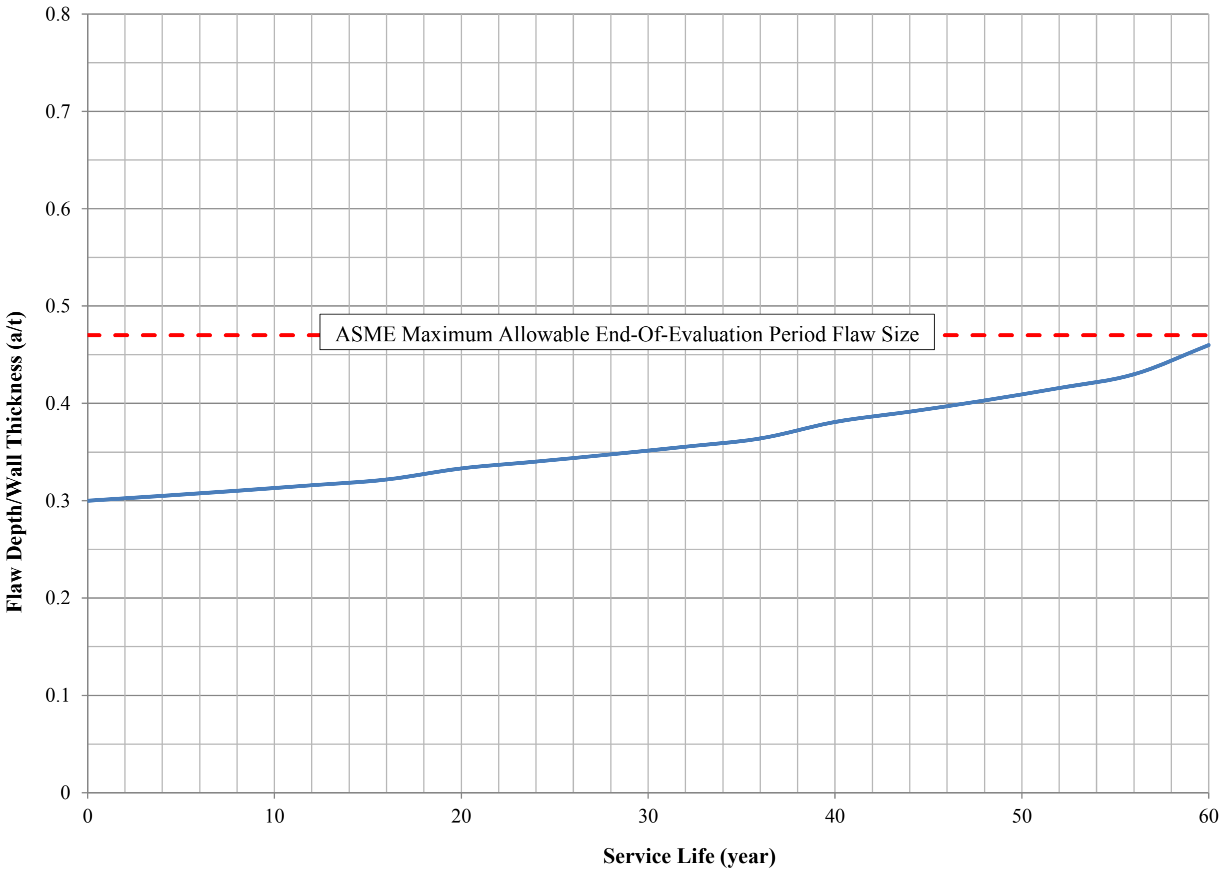

Figure 3: Crack Growth Chart for the *AP1000* Steam Generator to Reactor Coolant Pump Suction Nozzle Dissimilar Metal Weld, Outside Surface Circumferential Flaw with Aspect Ratio = 6

3.0 Section III Design Evaluation for Steam Generator to Pump DM Weld

The goal of the discussion herein on ASME Section III design evaluation [4] is to supplement the primary assessment provided in Section 2 based on ASME Section XI flaw tolerance analysis. The aim here is to provide a brief summary of the primary and secondary stress analyses, including the fatigue usage and ASME Section III Appendix G fracture mechanics (low alloy ferritic steel region) results.

The ASME Section III evaluations for the SG primary outlet nozzle and the SG to RCP suction nozzle DM weld are based on the pressure loads, thermal loads, and external mechanical loads obtained using finite element analysis and also based on strength of materials equations. It should be noted that the loads due to pump fluctuations and vibrations were included in the evaluation for all conditions to determine the fatigue usage factors. Furthermore, the high cycle loading due to pump vibrations was also evaluated separately for an infinite number of cycles to determine the maximum alternating stress. All alternating stress intensities for this high cycle pump loading are below one-half the endurance limits.

Provided in Table 5 below are select results of the ASME Section III allowable stress limits and fatigue usage for the DM weld. Note that all ASME Section III design criteria are satisfied for this region. Furthermore, the low fatigue usage shown in Table 5 demonstrates low susceptibility for any fatigue crack initiations at either inside or outside surfaces.

Table 5: ASME Section III Select Results for DM Weld Location

a,c,e

A non-ductile fracture mechanics evaluation was also performed per ASME Section III Appendix G for the SG nozzle ferritic material adjacent to the DM weld. The non-ductile brittle fracture evaluation per ASME Section III Appendix G can be used as a conservative fracture mechanics assessment of the more ductile Alloy 152/52 weld. The Appendix G results for the ferritic location in the SG next to the DM weld are shown in Table 6 below.

Results from Table 6 can be used to demonstrate the structural stability of the region at and around the DM weld based on a large postulated flaw of 25 percent of the wall thickness with a length-to-depth (aspect ratio) of 6, as required by ASME Section III Appendix G design analysis. Normal, upset, emergency, test, and faulted condition transients were all evaluated. The limiting transients within these service conditions were chosen to be those transients that result in low metal temperatures and high stresses, which would give the worst brittle fracture assessment. The most limiting hoop and axial stresses from either the inside or outside surface were used in the Appendix G evaluation; as a result, the evaluation cover postulated flaws on the inside or outside, and axial or circumferential flaw configurations. The lower bound fracture toughness values were used based on the limiting temperature and material reference nil-ductility temperature (RT_{NDT}) based on the design specification. Table 6 provides the ASME Section III results for the postulated 1/4T flaw for the ferritic steel location adjacent to the DM weld. Based on the results in Table 6, it is demonstrated that the ferritic steel and the adjacent ductile DM weld would be flaw tolerant for large postulated flaws based on the ASME Section III Appendix G non-ductile evaluations.

Table 6: ASME Section III Appendix G Results[1] for SG Nozzle Ferritic Steel Location Adjacent to the DM weld

a,c,e

4.0 Conclusions

The objective of this letter report is to provide responses to the NRC RAI (Reference 1) to support justification of a volumetric inspection of the inner 1/3 of the weld, with a surface examination of the inner and outer weld surfaces, and to demonstrate that this is an acceptable alternative to examining the full weld volume during the ISI. The responses to the NRC RAI were based on two separate assessments that have been performed for this particular region of interest. The first assessment was based on ASME Section XI flaw tolerance analysis, and the second assessment is based on the ASME Section III design evaluation.

The ASME Section XI flaw tolerance evaluation is provided in Section 2 of this report. Postulated outside surface axial and circumferential flaws with aspect ratios of 2 and 6, respectively, were evaluated at the SG to RCP suction nozzle DM weld locations. *AP1000* specific geometry, loadings, and material properties were considered in the maximum end-of-evaluation period flaws and the fatigue crack growth analysis. The fatigue crack growth charts (Figures 2 and 3) demonstrate that it would require very large axial (greater than 60% of the wall thickness with an aspect ratio of 2) or circumferential surface flaw (greater than 30% of the wall thickness with an aspect ratio of 6) on the outside surface of the SG to RCP suction nozzle weld to reach the allowable flaw size in 60 years. Surface examinations of the outside surface at this location would identify flaws much smaller than the initial flaw sizes shown in Figures 2 and 3; furthermore, the full fabrication volumetric examinations would result in repair of any such large flaws. Based on the ASME Code Section III fabrication examination acceptance standards, the largest postulated outside surface axial and circumferential flaws determined in this letter report bound the largest potential outside surface axial and circumferential flaws left behind at fabrication by a substantial margin. This holds true for embedded flaws as well.

Section 3 of this report provides the ASME Section III design evaluation that was performed for the DM weld and the surrounding low alloy steel region. Based on the design criteria, all requirements of the ASME Section III code were met for this region based on the primary and secondary stress analyses, and fatigue usage calculations. The fatigue usage at the DM weld region is very low at both the inside and outside surface, and this region has acceptably low susceptibility to crack initiations for the design life of the plant. The non-ductile ASME Section III Appendix G fracture mechanics evaluation was also performed and shown to be acceptable for the low alloy ferritic steel of the steam generator. The ferritic steel material is considered in the Appendix G evaluation since it is susceptible to brittle fracture, whereas the DM weld is more ductile than the SG base metal, and therefore is not required to be considered in the Appendix G evaluation. Thus, per the design ASME Section III fracture mechanics, it is also demonstrated that the DM weld region is flaw tolerant for large flaws of size 25% of the wall thickness with an aspect ratio of 6.

In conclusion, based on the ASME Section XI and III discussions provided in this report, it is demonstrated that original volumetric and surface examination performed during fabrication, and the outer and inner surface examinations to be performed every ISI are sufficient in lieu of performing a 100% wall thickness volumetric inspection of the DM weld every ISI. This conclusion is based on a fracture mechanics evaluation per ASME Section XI and ASME Section III Appendix G assessments. It was demonstrated that the outer 2/3 of the wall thickness is flaw tolerant for the design life of the plant, and that the initiation of any active degradation of the weld would not be expected to occur over the licensed lifetime of the plant.

5.0 References

1) NRC email from Steven Downey to Chandu Patel, "Requests for Additional Information related to Vogtle Alternative Request VEGP3&4-PSI-ALT-05," dated: August 5, 2016, (NRC ADAMS: ML16218A439).

2) ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 2007 Edition including 2008 Addenda.

3) Request for Alternative Requirement for Preservice Inspection at Vogtle Units 3 & 4 and V.C. Summer Units 2 and 3.

   a. VEGP 3&4-PSI-ALT-05, "Southern Nuclear Operating Company, Vogtle Electric Generating Plant Units 3 and 4 Request for Alternative: Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds," June 24, 2016, (NRC ADAMS: ML16176A312).

   b. NND-16-0246, "Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3, Docket Numbers 52-027 and 52-028, Request for Alternative: Preservice Inspection Requirements for Steam Generator Nozzle to Reactor Coolant Pump Casing Welds," July 7, 2016, (NRC ADAMS: ML16189A312).

4) ASME Code Section III, "Rules for Construction of Nuclear Power Plant Components," 1998 Edition including 2000 Addenda.

5) Raju, I.S. and Newman, J.C., "Stress Intensity Factor Influence Coefficients for Internal and External Surface Cracks in Cylindrical Vessels," ASME Publication PVP, Volume 58, 1982, pp. 37-48.

6) NUREG/CR-6907, ANL-04/3 "Crack Growth Rates of Nickel Alloy Welds in a PWR Environment," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), May 2006.

7) NUREG/CR-6383, ANL-95/37, "Corrosion Fatigue of Alloys 600 and 690 in Simulated LWR Environments," April 1996.

8) Nomura, Y., Yamamoto, K., Hojo, K., ASME PVP2014-28098, "Fatigue Crack Growth Rates for Nickel Base Alloys in Air," Proceedings of ASME 2014 Pressure Vessels & Piping Conference, Anaheim, California, USA, July 20-24, 2014.

9) U.S. Nuclear Regulatory Commission Letter Dated May 19, 2000, License Renewal Issue No. 98-0030, "Thermal Aging Embrittlement of Cast Austenitic Stainless Steel Components."