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CALCULATION SUMMARY SHEET (CSS)

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Title North Anna Units 1&2, Pressurizer Surge Nozzle Weld Overlay Analysis

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		METHOD: ☒ DETAILED CHECK ☐ INDEPENDENT CALCULATION	
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PURPOSE AND SUMMARY OF RESULTS:

Purpose:

This document is a non-proprietary version of AREVA NP Document 32-9038239-002. The proprietary information removed from 32-9038239-002 is indicated by a pair of square brackets "[ ]." The geometry and operating condition are Dominion Power proprietary. The purpose of this calculation is to qualify the North Anna Units 1 & 2 Pressurizer Surge Nozzle Weld Overlay Design to the requirements specified in Reference 13.7.

The purpose of Revision 001 is to update non-proprietary version of AREVA NP Document 32-9038239-002.

Conclusion:

The calculations demonstrate that the design of the Surge Nozzle Weld Overlay for the North Anna Units 1 & 2 Pressurizer has met the stress and fatigue requirements of the Design Code (Reference 13.1).
Based on the loads and cycles specified in References 13.8 and 13.16, the conservative fatigue analysis indicates that the Pressurizer Surge Nozzle has a maximum fatigue usage factor of[ ]Years of operation (Reference 13.7) compared to the ASME Code allowed maximum value of 1.0.

Revision 001 is complete revision.
The total number of pages is 254 which are consisted of pages 1 to 250 and 4 inserted pages, 4a, 8a, 10a and 243a.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV

THE DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK

☐ YES
☒ NO

RECORD OF REVISIONS

Revision	Date	Pages/Sections Changed	Brief Description
000	02/2007	All	Original Release
001	12/2007	All Pages	Update non-proprietary version of AREVA NP Document 32-9038239-002.

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1. PURPOSE

1.1 INTRODUCTION

Primary water stress corrosion cracking (PWSCC) of Alloy 82/182 materials is a well-documented phenomenon in the nuclear power. High temperature components, such as those associated with the pressurizer, have risk for PWSCC. Dominion Generation (Dominion) plans to mitigate the North Anna Units 1 and 2 pressurizer nozzle Alloy 82/182 dissimilar metal welds (DMW) with full structural weld overlays (SWOL) during the fall 2007 and spring 2007 refueling outages for Units 1 and 2, respectively. The planned mitigation using SWOL is a preemptive measure to reduce susceptibility of the DMW and the adjacent pipe/fitting to safe end welds to PWSCC.

1.2 SCOPE

The surge nozzle is located on the bottom of the pressurizer as a conduit for the surge line insurges and outsurges. The weld overlay is designed to cover both the Alloy 82/182 DM region and the austenitic stainless weld between the nozzle safe end and the piping. Application of weld overlays alters the local stress distribution. A detailed finite element analysis (FEA) is therefore conducted to investigate stress conditions under various operational transients. The results are summarized in this report to certify that criteria per ASME Code Section III for Class 1 components, Reference 13.1, are satisfied for the surge nozzle with weld overlays.

The analysis is focused on the overlaid region for requirements on both stress distribution and fatigue failure criterion. The main scope of the analysis includes the surge line piping, the stainless steel weld between the safe end and the piping, the safe end, the DM weld between the safe end and the nozzle, the surge nozzle, SWOL, and the pressurizer lower head. In addition, post-processing of thermal and structural results is performed to provide data for fracture analysis of the surge nozzle (see Appendix A).

It should be noted that the original nozzle configuration without the Weld Overlay is not analyzed in this calculation. The application of the SWOL will increase the secondary stress due to thermal gradients and added discontinuities at the SWOL to Pipe, and SWOL to Nozzle junctures. The cumulative fatigue usage factors calculated in this document assume the Surge Nozzle SWOL has been in place since the plant conception. Therefore, the usage factors calculated will be higher than the actual usage factors based on summing Surge Nozzle's usage prior to SWOL and usage with the SWOL.

2. ANALYTICAL METHODOLOGY

The general methodology of model development and stress analysis consists of:

1) Building a two-dimensional axisymmetric model of the Pressurizer Surge Nozzle. The model incorporates the geometry (of the adjacent lower head, nozzle, safe end, welds, weld overlay, and piping), appropriate materials, and boundary conditions. The 2-D Solid model is converted into a 2-D finite element model. There are two finite element models consisting of thermal and structural elements, respectively, to enable the thermal and structural analysis.
2) Applying the design conditions of pressure and temperature (as temperature affects the material properties only) to the structural finite element model and obtaining the deformation and stresses in the model. The deformation field is used to verify the correct behavior of the model and correct modeling of boundary and load conditions.
3) Applying the thermal loads resulting from the plant operating transients (in the form of transient temperatures and corresponding heat transfer coefficients versus time). Evaluating the results of the thermal analysis by examining the magnitude of temperature differences between key locations of the model. The time points of the maximum temperature gradient are those at which the maximum thermal stresses develop.
4) Applying the corresponding pressure and thermal loads (nodal temperature) at each time point identified in step 3 and other time points of analytical interest on the structural finite element model and obtaining the stress results.
5) Hand calculating the effects due to nozzle external loads and adding the resulting stresses to the stress results due to pressure and temperature effect.
6) Comparing the results to the ASME Code for acceptability.
7) Documenting stresses and temperatures for the fracture mechanics analysis of the surge nozzle weld overlay design.

3. KEY ASSUMPTIONS

There are no major assumptions for this calculation. Minor assumptions are noted where applicable.

4. DESIGN INPUT

4.1 GEOMETRY

Major parts of the Surge Nozzle Weld Overlay are shown in Figure 4-1. The detailed dimensions of the surge nozzle design are shown in References 13.5 and 13.6 as noted.

Pressurizer Lower Head Inside Radius to Base Metal =
Pressurizer Lower Head Base Metal Thickness =
Pressurizer Lower Head and Nozzle Cladding Thickness =
Pipe ID =
Pipe OD =
Safe End Top OD =
Safe End Top ID =
Thermal Sleeve Weld ID =
Thermal Sleeve ID =
Thermal Sleeve OD =
Surge Nozzle ID =
Surge Nozzle OD at Weld =
Nozzle OD (near head) =
Nozzle OD (at nozzle to head weld) =
Max Weld Overlay Length =
Max Weld Overlay Thickness (at nozzle side) =
Min Weld Overlay Length =
Min Weld Overlay Thickness (at nozzle side) =

The model shown in Figure 4-1 simulates, in two-dimensional space, the surge nozzle, surge nozzle safe end, and part of adjacent pressurizer vessel closure head. Since the surge nozzle is radial with respect to the spherical head, an axisymmetric model is used. The modeled portion of pressurizer head extends to 30 degrees from the axis of symmetry. This is considered sufficient for the stresses and thermal gradients to attenuate.

Figure 4-1 Surge Nozzle Geometry with Weld Overlay

4.2 FINITE ELEMENT MODEL

The finite element analysis in this document is performed using ANSYS 10.0 (Reference 13.10). The model was developed in ANSYSWORKBENCH 10.0 and is shown in Figure 4-2 and Figure 4-3. The output files documenting the Nozzle geometry are listed in Section 12. The element type chosen is the structural element PLANE183 (2-D 8-Node Structural Solid). This element type is converted to element PLANE77 (2-D 8-Node Thermal Solid) for the thermal analysis.

Figure 4-2 Finite Element Model of Surge Nozzle with Weld Overlay (Maximum WOL Shown)

Figure 4-3 Finite Element Model – Detail View of SWOL Region (Maximum Configuration Shown)

4.3 MATERIALS

Reference 13.7 provides the component material designations of various components:

Pressurizer Lower Head
Surge Nozzle
Nozzle to Upper Head Weld
Safe End
Nozzle to Safe End Weld
Buttering Weld
Thermal Sleeve
Pipe
Safe End to Pipe Weld
Head Internal Cladding
Weld Overlay

The analysis herein uses the thermal properties – mean coefficient of thermal expansion (α), specific heat (C), thermal conductivity (k), and the mechanical properties – modulus of elasticity (E), Poisson's ratio (μ), density (ρ). The pertinent properties (thermal & structural) for these materials are listed in Reference 13.15.

4.4 BOUNDARY CONDITIONS AND LOADS

4.4.1 Thermal analysis

During operation, the inside surfaces of the Pressurizer and the inside bore surfaces of the Surge Line Nozzle are in contact with the reactor coolant. Appropriate heat transfer coefficients and bulk temperatures versus time for each region shown in Figure 4-4 are applied on these surfaces. The reactor coolant temperature varies with time depending upon the service load condition that is being applied and has been defined thoroughly in Reference 13.16.

The outside surface of pressurizer head and surge nozzle is exposed to the ambient temperature in conjunction with a small HTC. An ambient temperature of 70°F is conservatively used for all time points in the thermal analysis. Reference 13.16 specifies that a small HTC of[ ] [ ]be used in the analysis.

4.4.2 Structural Analysis

Pressure is applied to all exposed interior surfaces of the Pressurizer Lower Head and Nozzle. The exterior surfaces of the Pressurizer Lower Head and Nozzle are not loaded by pressure. End Cap pressure is applied to the upper end of the Piping to represent the hydrostatic end load from the piping closure.

End Cap Pressure is calculated by multiplying Pressurizer Pressure by the quantity $\left(-\frac{d^2}{D^2-d^2}\right)$.

Where:
d = ID of the piping
D = OD of the piping

The boundary conditions for the structural analysis are set to have zero displacement in the circumferential direction (from the nozzle axis) and at the plane of symmetry.

Coupling is not used in the structural analysis between the Safe End and Thermal Sleeve in the Thermal Sleeve Weld vicinity. Internal pressure, as discussed in Section 8, is applied to either side of the interface.

Figure 4-4 Surfaces for Thermal Boundary Conditions

5. EXTERNAL LOADS

Per Reference 13.16, the external forces and moments acting on the Surge Nozzle Safe End Weld location (Figure 5-1) are listed in Table 5-1. Table 5-2 lists the external loads due to Thermal Stratification only per Reference 13.8. These loads are defined in the local coordinate system with the "y" axis oriented along the nozzle axis of symmetry in the nozzle to pipe direction.

Table 5-1 Applicable External Loads

OBE + Thermal(1)	Fy (Axial) *lbs*	Fx *lbs*	Fz *lbs*	Fs (Shear)(2) *lbs*	Mtx (Torsional) *in-lbs*	Mx *in-lbs*	Mz *in-lbs*	Mb (Bending)(3) *in-lbs*
Unit 1 Piping								
Unit 2 Piping								
Vessel Spec.								
Enveloped Loads								

Note (1): DW loads are not included in the tabulated values since this calculation is for the P+Q evaluation of the stress intensity range. Deadweight loads act at all time points of all transients, and therefore do not contribute to the stress intensity ranges. Hence their omission is appropriate

Note (2): Shear is calculated as the SRSS of Fx and Fz.

Note (3): Bending is calculated as the SRSS of Mx and Mz.

These loads are evaluated using hand calculation and the stresses due to these loads are added to the ANSYS results where appropriate for ASME evaluation.

Table 5-2 Applicable Loads Due to Thermal Stratification

Thermal Load Cases[1]	Plant Unit	Fy (Axial) *lbs*	Fx *lbs*	Fz *lbs*	Fs (Shear)[2] *lbs*	Mtx (Torsional) *in-lbs*	Mx *in-lbs*	Mz *in-lbs*	Mb (Bending)[3] *in-lbs*

Note [1]: Per Reference 13.8

Note [2]: Shear is calculated as the SRSS of Fx and Fz.

Note [3]: Bending is calculated as the SRSS of Mx and Mz.

5.1 NOZZLE CROSS SECTION CHARACTERISTICS

The nozzle geometric dimensions are specified in References 13.5 and 13.6. Based on these dimensions, the cross sectional characteristics (Table 5-3 and Table 5-4) are calculated for the locations depicted in Figure 5-1.

Table 5-3 Nozzle Cross Sectional Characteristics (Maximum WOL)

Path Name	D	d	I	SOD	SID	A	L
	[in]	[in]	$[in^4]$	$[in^3]$	$[in^3]$	$[in^2]$	[in]
PipeL							
P_Wol							
SEU_Weld							
SEU_Wol							
SEL_Wol							
SEL_Weld							
N_Wol							
Noz							

Note [(1)]: For path lines PipeL and P_Wol, the stress intensity due to axial bending stress from external shear forces would reduce the stress intensity due to transient loads. Therefore, the vertical distances from path line SEU_Weld to PipeL and P_Wol are conservatively reduced to zero.

Table 5-4 Nozzle Cross Sectional Characteristics (Minimum WOL)

Path Name	D	d	I	SOD	SID	A	L
	[in]	[in]	$[in^4]$	$[in^3]$	$[in^3]$	$[in^2]$	[in]
PipeL							
P_Wol							
SEU_Weld							
SEU_Wol							
SEL_Wol							
SEL_Weld							
N_Wol							
Noz							

Note [(1)]: For path lines PipeL and P_Wol, the stress intensity due to axial bending stress from external shear forces would reduce the stress intensity due to transient loads. Therefore, the vertical distances from path line SEU_Weld to PipeL and P_Wol are conservatively reduced to zero.

Where:

D	– outside diameter
d	– inside diameter
$I = \frac{\pi}{64}\left(D^4 - d^4\right)$	– moment of inertia
$S_{OD} = \frac{I}{D/2}$	– section modulus of the nozzle – outside diameter
$S_{ID} = \frac{I}{d/2}$	– section modulus of the nozzle – inside diameter
$A = \frac{\pi\left(D^2 - d^2\right)}{4}$	– cross-section area of the nozzle
L	– moment arm

[ ]

Figure 5-1 Path Definitions for External Loading

5.2 APPLICABLE STRESS INTENSITY DUE TO EXTERNAL LOADS FOR PRIMARY + SECONDARY QUALIFICATION

The Surge Nozzle Weld Overlay is exposed to the external loads. The total stress intensities applicable for primary + secondary qualification due to these loads are calculated here.

The membrane stress due to internal pressure is not considered here, since this is already included in the ANSYS transient run. Thus only OBE and thermal operating external loads (TH) are applicable for calculation in this section.

The membrane + bending stress intensities due to external loads from Table 5-1 and due to thermal stratification only from Table 5-2 are calculated as follows:

$\sigma_{ax\_EX} = \frac{F_y}{A}$ - axial membrane stress due to external axial force (F_y)

$\sigma_{ax\_BM} = \frac{M_b}{S}$ - axial bending stress due to external bending moment (M_b)

$\sigma_{ax\_BF} = \frac{F_s \cdot L}{S}$ - axial bending stress due to external shear force (F_s)

$\tau_{s\_F_s} = \frac{F_s}{A}$ - shear stress due to external shear force (F_s)

$\tau_{s\_M_t} = \frac{M_{tx}}{2 \cdot S}$ - shear stress due to external torsion moment (M_{tx})

$\text{Sint} = \sqrt{\sigma_{ax\_M+B}^2 + 4 \cdot \tau_s^2}$ - membrane + bending stress intensity range

where:

$\sigma_{ax\_M+B} = \sigma_{ax\_EX} + \sigma_{ax\_MB} + \sigma_{ax\_BF}$ - axial membrane + bending stress

$\tau_s = \tau_{s\_F_s} + \tau_{s\_M_t}$ - shear stress due to external shear force and torsion moment

The maximum stress intensities due to external loads (Thermal, OBE) are listed together with the stress components in Table 5-5 (Maximum WOL) and Table 5-6 (Minimum WOL). These stress intensities will be used in the ASME Code evaluation for primary + secondary stresses and fatigue in the nozzle regions (Section 9). Additional stress intensities due to thermal stratification only are listed together with the stress components in Tables 5-7 through 5-16 for each load case. These stress intensities will be included to account for subcycles of thermal stratification during fatigue evaluation (Section 9.2.4).

Table 5-5 Primary + Secondary SI Due to External Loads (Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diam								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-6 Primary + Secondary SI Due to External Loads (Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diame								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-7 Primary + Secondary SI Due to Thermal Stratification Load Case HU-( )(Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diar								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-8 Primary + Secondary SI Due to Thermal Stratification Load Case HU-[ ](Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diam								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-9 Primary + Secondary SI Due to Thermal Stratification Load Case HU-[ ] (Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diam								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-10 Primary + Secondary SI Due to Thermal Stratification Load Case HU-( ) (Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diar								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-11 Primary + Secondary SI Due to Thermal Stratification Load Case HU-( ) (Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diar								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-12 Primary + Secondary SI Due to Thermal Stratification Load Case HU-( ) (Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diam								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-13 Primary + Secondary SI Due to Thermal Stratification Load Case HU-( )(Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diam								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-14 Primary + Secondary SI Due to Thermal Stratification Load Case HU-[ ](Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Dia								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-15 Primary + Secondary SI Due to Thermal Stratification Load Case OP-( ) (Max WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diar								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

Table 5-16 Primary + Secondary SI Due to Thermal Stratification Load Case OP-[ ](Min WOL)

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
Inside Diameter								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								
Outside Diar								
PipeL								
P_Wol								
SEU_Weld								
SEU_Wol								
SEL_Wol								
SEL_Weld								
N_Wol								
Noz								

6. DESIGN CONDITION

The pressurizer assembly was designed to satisfy the ASME Code Criteria when operating at a pressure of [ ] at temperature of [ ] (Reference 13.8). These design conditions were simulated by setting a uniform temperature of [ ] throughout the model (this temperature is only used to define material properties and not thermal expansion) and a uniform pressure of [ ] on all inside surfaces. The Lower end of the Surge Nozzle Piping has the pressure applied to represent the hydrostatic end load. Also, pressure is applied to the assumed boundary edge at the end of Surge Line Piping. The ANSYS output file for the design condition stress analysis is [ ] for maximum and minimum WOL respectively.

Stress analysis of the model under design pressure case served two important purposes. It provides a basis for verification of the correct behavior of the model as well as boundary conditions. Stresses from the design pressure run are used to evaluate the primary stresses in the model in Section 9. Attenuation of stress effects at regions distant from the nozzle is also verified.

Figure 6-1 shows the deformed shape of the Maximum WOL model under the design pressure along with the outline of the un-deformed shape. The stress intensity contours developed in the Maximum WOL model under design pressure are shown in Figure 6-2 and Figure 6-3.

Figure 6-1 Deformed Shape versus Un-deformed Outline

Figure 6-2 Stress Intensity Contours at Design Condition (Maximum WOL Shown)

Figure 6-3 Stress Intensity Contours at Design Condition Boundaries (Maximum WOL Shown)

7. THERMAL ANALYSIS

The operating thermal loads are defined by the thermal transient conditions as contained in Reference 13.16. A summary of the applicable Service Level A (Normal) and Service Level B (Upset) transients including the applicable design cycles, is shown below in Table 7-1. The numbers of cycles listed below correspond to 60 years of pressurizer design life.

Table 7-1 Transients

Transient ID Number	Operating Cycle	Name Abbreviation	Occurrences	Operating Condition
1	Unit heatup at HL surge nozzle			
2	Unit cooldown at HL surge nozzle			
3	Plant Loading at 5% power per minute			
4	Plant Unloading at 5% power per minute			Normal
5	10% step load increase			
6	10% step load decrease			
7	Large step decrease in load			
8	Loss of load			
9	Loss of power			Upset
10	Loss of flow in one loop			
11	Feedwater cycling at hot shutdown			Normal
12	Boron Concentration Equalization			
13	Reactor trip with no cooldown			
14	Reactor trip with cooldown but no safety injection			
15	Reactor trip with cooldown and safety injection			
16	Inadvertent reactor coolant system depressurization			Upset
17	Inadvertent startup of an inactive loop			
18	Control rod drop			
19	Inadvertent safety injection actuation			
20	Steady state fluctuations [(1)]			Normal
21	Turbine roll test			Test
22	Loop out of service normal loop shutdown			Normal
23	Loop out of service normal loop startup			Normal
24	RCS cold overpressurization			Upset
25	Heatup and Cooldown Surge Flow Details H1-H6 and C1-C7, Subcycles of Heatup and Cooldown			Normal
26	Thermal Stratifications			Normal

Note: [(1)] These small fluctuations create small stresses that are negligible compared to other transients.

The Cooldown Transient was combined with the Heatup Transient. Only the times were changed to set zero mark at 27 hours for Cooldown. Similarly, the Plant Unloading transient was combined with Plant Loading with its start time set to 0.4444 hours. The detailed thermal loading due to these transients were applied to the thermal finite element model in the form of fluid and steam temperatures and HTC versus time.

The computer input files containing definition of these transients are:

[ ]

The computer output files for the thermal analyses of the transients are:

[ ]

The results of the thermal analyses are evaluated by examining the magnitude of temperature differences between key locations of the model (see Figure 7-1). The time points of the maximum temperature gradient are those at which the maximum thermal stresses develop.

The computer output files that provide the temperatures at the selected locations are:

( )

Added transients for insurge and outsurge are defined in Attachment 12 of Reference 13.8. The two added transients, IOSurge and IOSurge110 are described in Appendix D. All files and supporting information are presented in Section D.2.

The temperature gradients between these key locations (See Figure 7-1) are also listed in the above output files. The Thermal gradient for each transient are plotted in Figure 7-2 through

Figure 7-22 for the maximum WOL configuration only. The minimum configuration thermal plots look very similar to those of the maximum. These figures are used only to show the trend. Specific data are taken from the computer output files.

Table 7-2 Nodes of Interest for Evaluation of Temperature Gradients

Location Designation in ANSYS DT Files	Max WOL Node No.	Min WOL Node No.	Location Description
2	3145	2412	Mid thickness in Piping lower than SWOL region
3	3774	3480	Mid thickness in lower SWOL
4 & 6	6350	6105	Inside surface of Piping in SWOL Region
5	6193	5950	Outer surface of lower SWOL
7	6159	6001	Outer surface of SWOL horizontal with Pipe-to Safe End Weld
8	5135	4968	Inside surface of Nozzle above the Safe End-to-Nozzle Weld
9	6134	6073	Outer surface of SWOL horizontal with Location 8
10	5179	Not Analyzed	Inside surface of Nozzle at Mouth
11	4969	Not Analyzed	Outer surface of Nozzle at Nozzle-to-Head Transition

Table 7-3 Temperature Gradients of Interest

Gradient Designation in ANSYS DT Files	Gradient Location	Gradient Description
21	2 to 3	Lower Piping to SWOL
22	4 to 5	Inside Piping to Outer SWOL
23	7 to 6	Inside Piping to Outer mid-SWOL
24	9 to 8	Outer SWOL to Nozzle Annulus Surface
25	11 to 10	Outer Nozzle-to-Head Transition to Inside Surface Nozzle Mouth

Note: Nodes were not selected at the nozzle mouth region in Minimum Weld Overlay. That area is far enough away from the weld overlay region

Figure 7-1 Location of Node Numbers for Evaluation of Temperature Gradients

Figure 7-2 Temperature and Temperature Gradients for Surge Plant Heatup/Cooldown Transients for Maximum WOL Configuration

Figure 7-3 Temperature and Temperature Gradients for Surge Plant Loading/Unloading Transients for Maximum WOL Configuration

[ ]

Figure 7-4 Temperature and Temperature Gradients for Surge 10% Step Load Increase Transient for Maximum WOL Configuration

Figure 7-5 Temperature and Temperature Gradients for Surge 10% Step Load Decrease Transient for Maximum WOL Configuration

Figure 7-6 Temperature and Temperature Gradients for Surge Large Step Decrease in Load for Maximum WOL Configuration

Figure 7-7 Temperature and Temperature Gradients for Surge Loss of Load for Maximum WOL Configuration

Figure 7-8 Temperature and Temperature Gradients for Surge Loss of Power Transient for Maximum WOL Configuration

[ ]

Figure 7-9 Temperature and Temperature Gradients for Surge Loss of Flow Transient for Maximum WOL Configuration

[ ]

Figure 7-10 Temperature and Temperature Gradients for Surge Feedwater Cycling at Hot Shutdown Transient for Maximum WOL Configuration

[ ]

Figure 7-11 Temperature and Temperature Gradients for Surge Boron Concentration Equalization Transient for Maximum WOL Configuration

Figure 7-12 Temperature and Temperature Gradients for Surge Reactor Trip with No Cooldown Transient for Maximum WOL Configuration

[ ]

Figure 7-13 Temperature and Temperature Gradients for Surge Reactor Trip with Cooldown but no Safety Injection Transient for Maximum WOL Configuration

Figure 7-14 Temperature and Temperature Gradients for Surge Reactor Trip with Cooldown and Safety Injection Transient for Maximum WOL Configuration

[ ]

Figure 7-15 Temperature and Temperature Gradients for Surge Inadvertent Reactor Coolant System Depressurization Transient for Maximum WOL Configuration

[ ]

Figure 7-16 Temperature and Temperature Gradients for Surge Control Rod Drop Transient for Maximum WOL Configuration

Figure 7-17 Temperature and Temperature Gradients for Surge Inadvertent Startup of an Inactive Loop Transient for Maximum WOL Configuration

Figure 7-18 Temperature and Temperature Gradients for Surge Inadvertent Safety Injection Actuation Transient for Maximum WOL Configuration

Figure 7-19 Temperature and Temperature Gradients for Surge Turbine Roll Test Transient for Maximum WOL Configuration

[ ]

Figure 7-20 Temperature and Temperature Gradients for Surge Loop Out of Service Normal Loop Shutdown Transient for Maximum WOL Configuration

Figure 7-21 Temperature and Temperature Gradients for Surge Loop Out of Service Normal Loop Startup Transient for Maximum WOL Configuration

Figure 7-22 Temperature and Temperature Gradients for Surge RCS Cold Overpressurization for Maximum WOL Configuration

8. STRUCTURAL ANALYSIS

Stress analyses are performed at those time points which the maximum temperature gradients (maximum thermal stresses) in addition to those defining the transient in Reference 13.16. The nodal temperature at the particular time point is read into the structural model directly from the result file of the thermal analysis. The corresponding pressure is obtained through linear interpolation from appropriate tables listed in Reference 13.16. All time points of interest are also listed in Appendix B. The computer output files for the structural analyses are:

Added files for IOSurge and IOSurge110 transients added to account for the insurge and outsurge are documented in Appendix D, Section D.3.

9. ASME CODE CRITERIA

The ASME Code stress analysis involves two basic sets of criteria:

1. Assure that failure does not occur due to application of the design loads.
2. Assure that failure does not occur due to repetitive loading.

In general, the Primary Stress Intensity criteria of the ASME Code (Reference 13.1) assure that the design is adequate for application of design loads.

Also, the ASME Code criteria for cumulative fatigue usage factor assure that the design is adequate for repetitive loading.

9.1 ASME CODE PRIMARY STRESS INTENSITY (SI) CRITERIA

Per NB-3213.8 of Reference 13.1, the primary stresses are those normal or shear stresses developed by an imposed loading such as internal pressure and external loadings. A thermal stress is not classified as a primary stress. The classification as well as the limit of primary stress intensity is specified in NB-3221 of Reference 13.1 for Design Conditions. The limit of primary stress intensity for Level B (Upset), Level C (Emergency), and Level D (Faulted) is specified in NB-3223, NB-3224, and NB-3225 of Reference 13.1, respectively.

As presented in Reference 13.14, the primary stress intensity criteria are the basic requirements in calculating the weld overlay size, which is under the assumption that a 360° circumferential flaw has grown completely through the original weld. Loading conditions in each service level have been considered in the weld overlay sizing calculation. The nozzle to piping region has been reinforced by the weld overlay since adding materials to the nozzle outside region relieves primary stress burden resulting from internal pressure and external loads. The overlay further reduces stress concentration by eliminating the outside surface discontinuity. Therefore, the primary stress intensity requirements for the surge nozzle, welds with overlay, safe end and piping have been satisfied for all service level loadings without the need for further evaluation.

Other related criteria include the minimum required pressure thickness (NB-3324 of Reference 13.1) and reinforcement area (NB-3330 of Reference 13.1), which were addressed in the original nozzle/pressurizer designs. Adding weld overlay will increase the nozzle wall thickness and therefore these requirements are satisfied.

9.2 ASME CODE PRIMARY+SECONDARY STRESS INTENSITY (SI) CRITERIA

As stated previously, the analyses of stresses for transient conditions are required to satisfy the requirements for the repetitive loadings. The following discussion describes the fatigue analysis process employed herein for the design.

Overall stress levels are reviewed and assessed to determine which model locations require detailed stress/fatigue analysis. The objective is to assure that:

1. The most severely stressed locations are evaluated.
2. The specified region is quantitatively qualified.

9.2.1 Path Stress Evaluation

The ANSYS Post Processor is used to tabulate the stresses along predetermined paths and classify them in accordance with the ASME Code Criteria (i.e., membrane, membrane plus bending, total). For paths that go through 2 materials partial paths are taken in addition to the free edge to free edge.

The paths are shown in Figure 9-1 and Figure 9-2 and are described in Table 9-1. For post processor calculation, the definitions of these paths are contained in the computer input files as follows:

Table 9-1 Path Descriptions

Path Name	Maximum Weld Overlay		Minimum Weld Overlay	
	Inside Node	Outside Node	Inside Node	Outside Node
PipeL	6289	6340	6172	6103
P_Wol	6290	6203	6216	5986
P_Wola	6290	6205	6216	5988
P_Wolb	6205	6203	5988	5986
SEU_Weld	6426	6157	6244	6001
SEU_Welda	6426	6161	6244	16050
SEU_Weldb	6161	6157	16050	6001
SEU_Wol	6472	6213	6292	5947
SEU_Wola	6472	6209	6292	6012
SEU_Wolb	6209	6213	6012	5947
SEL_Wol	5230	6228	5060	5958
SEL_Wola	5230	6226	5060	6038
SEL_Wolb	6226	6228	6038	5958
SEL_Weld	6437	6243	6255	6052
SEL_Welda	6437	6240	6255	6054
SEL_Weldb	6240	6243	6054	6052
N_Wol	4935	6133	4803	6072
N_Wola	4935	5206	4803	5037
N_Wolb	5206	6133	5037	6072
Noz	4899	5039	4985	4868
NozL	5179	4969	NA	NA
Sleeve	5246	5249	5078	5081

Note: The full path is taken at the same location as the partial paths. The partial path name has the letter "a" or a "b" behind the full path name.

Figure 9-1 Path Locations in SWOL Region used for Stress Evaluation

Note: Due to the distance from the WOL region, NozL was only evaluated in the maximum configuration computer files

Figure 9-2 Path Locations in Nozzle used for Stress Evaluation

9.2.2 Primary + Secondary Stress Intensity Range Qualification (NB 3222.2)

The ANSYS Post Processor was used to find the membrane + bending Stress Intensity Ranges and total Stress Intensity Ranges based on the method prescribed in paragraph NB-3216.2 of the ASME Code. The computer runs containing the results of the stress ranges calculation for membrane + bending, total stresses and associated usage factors are listed below. Additional transients added (IOSurge and IOSurge 110) are incorporated into computer runs listed in Appendix D, Section D.4.2.2. The Primary + Secondary qualifications presented in Appendix D supersede that presented in this and the following sections.

[ ]

The membrane + bending stress ranges as determined in the stress range runs are conservatively combined by hand with the stresses due to external loads (calculated in Section 5.2) where appropriate. The maximum membrane + bending Stress Intensity Ranges are compared directly to the Primary + Secondary Stress Intensity Range criteria of the ASME Code. The summary of maximum membrane + bending Stress Intensity Ranges for maximum and minimum WOL configurations are tabulated in Table 9-2 through Table 9-6.

Note that the Zero Stress State (ZSS) is included in the ANSYS runs listed above.

Table 9-2 Summary of Maximum Primary + Secondary SI Ranges for Membrane + Bending Stresses (Maximum WOL)

Path	Transient Stresses		Applicable External Stresses	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Maximum SI Inside Node [ksi]	Minimum SI Outside Node [ksi]
PipeL				
P_Wol				
P_Wola				
P_Wolb				
SEU_Weld				
SEU_Welda				
SEU_Weldb				
SEU_Wol				
SEU_Wola				
SEU_Wolb				
SEL_Wol				
SEL_Wola				
SEL_Wolb				
SEL_Weld				
SEL_Welda				
SEL_Weldb				
N_Wol				
N_Wola				
N_Wolb				
Noz				
NozL				
Sleeve				

[ ]

Table 9-3 Comparison of Maximum SI Range including External Loads to ASME Code 3*Sm Criteria (Maximum WOL)

Path	Transient + External Stresses		Allowable M+B SI Range 3*Sm[1]		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node [ksi]	Outside Node [ksi]	Inside Node	Outside Node
PipeL						
P_Wol						
P_Wola						
P_Wolb						
SEU_Weld						
SEU_Welda						
SEU_Weldb						
SEU_Wol						
SEU_Wola						
SEU_Wolb						
SEL_Wol						
SEL_Wola						
SEL_Wolb						
SEL_Weld						
SEL_Welda						
SEL_Weldb						
N_Wol						
N_Wola						
N_Wolb						
Noz						
NozL						
Sleeve						

[ ]

Table 9-4 External Stress Added by Components (Maximum WOL)

Table 9-4 (Continued) External Stress Added by Components (Maximum WOL)

Table 9-5 Summary of Maximum Primary + Secondary SI Ranges for Membrane + Bending Stresses (Minimum WOL)

Path	Transient Stresses		Applicable External Stresses	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]
PipeL				
P_Wol				
P_Wola				
P_Wolb				
SEU_Weld				
SEU_Welda				
SEU_Weldb				
SEU_Wol				
SEU_Wola				
SEU_Wolb				
SEL_Wol				
SEL_Wola				
SEL_Wolb				
SEL_Weld				
SEL_Welda				
SEL_Weldb				
N_Wol				
N_Wola				
N_Wolb				
Noz				
Sleeve				

Table 9-6 Comparison of Maximum SI Range including External Loads to ASME Code 3*Sm Criteria (Minimum WOL)

Path	Transient + External Stresses		Allowable M+B SI Range 3*Sm(1)		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node [ksi]	Outside Node [ksi]	Outside Node	Inside Node
PipeL						
P_Wol						
P_Wola						
P_Wolb						
SEU_Weld						
SEU_Welda						
SEU_Weldb						
SEU_Wol						
SEU_Wola						
SEU_Wolb						
SEL_Wol						
SEL_Wola						
SEL_Wolb						
SEL_Weld						
SEL_Welda						
SEL_Weldb						
N_Wol						
N_Wola						
N_Wolb						
Noz						
Sleeve						

[ ]

Table 9-7 External Stress Added by Components (Minimum WOL)

Table 9-7 (Continued) External Stress Added by Components (Minimum WOL)

[ ]

9.2.2.1 Summary of Stress Intensity Range Qualification

Tables 9-3, 9-4, 9-6 and 9-7 show the maximum SI Range calculated and the allowable limits for both maximum and minimum weld overlay configurations. The following path locations for both configurations exceeded the allowable 3*Sm limit:

PipeL - inside and outside nodes (maximum and minimum WOL)

Sleeve - inside node (maximum WOL)

The ASME Code allows the 3*Sm limit to be exceeded under special conditions, one of them being that Simplified Elastic-Plastic Analysis (NB 3228.5) is used for fatigue analysis. See Section 9.2.3 for further qualifications.

9.2.3 Simplified Elastic-Plastic Analysis (NB-3228.5)

The maximum Primary + Secondary Stress Intensity criteria in Section 9.2.2 is not met for the locations determined in the Section 9.2.2.1. Therefore, the simplified elastic-plastic analysis for these locations is provided in this section.

The Primary + Secondary Stress Intensity range in the model may exceed $3*S_m$ if the requirements of the simplified elastic-plastic analysis are met. The requirements are:

9.2.3.1 ***Primary + Secondary SI Range (Excluding thermal bending stresses) (NB-3228.5(a))***

The range of Primary + Secondary membrane + bending stress intensity, excluding thermal bending stresses, shall be ≤ 3*Sm.

The SI ranges excluding thermal bending are calculated for the locations identified in Section 9.2.2.1. The membrane + bending ANSYS output files listed in Section 9.2.2 are used to find the stress components for membrane stress due to pressure and thermal conditions.

The bending stress due to pressure only is determined by multiplying the bending stress obtained from design linearization output files [ ] with a pressure ratio. The ratio is based on the transient pressure at the time point of interest and design pressure. The ratioed bending stress is added to the membrane stress and external stress for determination of SI range without thermal bending effect.

The design condition is [ ] The applied temperature affects only physical material properties, therefore the effect of thermal bending is considered to be negligible.

Tables 9-8 and 9-9 present the calculations and results for the maximum primary + secondary SI Ranges for membrane + bending – thermal bending stresses per NB-3228.5(a) for the maximum and minimum WOLs.

Table 9-8 Maximum WOL SI Ranges Minus Thermal Bending

Table 9-8 (Continued) Maximum WOL SI Ranges Minus Thermal Bending

Table 9-9 Minimum WOL SI Ranges Minus Thermal Bending

All SI Ranges listed in Tables 9-8 and 9-9 are less than the allowable stress, therefore the requirement of ASME NB-3228.5(a) has been met on all locations.

9.2.3.2 *Factor Ke (NB-3228.5(b))*

The values of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where

$$K_e = 1.0 + \frac{1-n}{n \cdot (m-1)} \cdot \left(\frac{S_n}{3 \cdot S_m} - 1 \right) \quad \text{for } 3 \cdot S_m < S_n < 3 \cdot m \cdot S_m$$

$$K_e = 1.0 / n \quad \text{for } S_n \geq 3 \cdot m \cdot S_m$$

m = 1.7 for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference 13.1)

n = 0.3 for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference 13.1)

S_m [ksi] @ average temperature of the metal at the critical time points

S_n [ksi] Primary + Secondary membrane plus bending SI Range

The K_e factor is calculated for each SI Ranges over the $3S_m$ limit in the fatigue evaluation as documented in Section 9.2.4.

9.2.3.3 *Fatigue Usage Factor (NB-3228.5(c) and NB-3222.4)*

For fatigue usage factor evaluation see Section 9.2.4.

9.2.3.4 *Thermal Stress Ratchet (NB-3228.5(d) and NB-3222.5)*

Thermal Ratchet is considered for the locations listed in Section 9.2.2.1.

Some of these locations are parts of the local geometric discontinuities. The ASME Code requirements for thermal ratcheting are considered accurately only for cylindrical shells without discontinuities. On the other hand, the requirements for thermal ratcheting at discontinuities are considered to be "probably overly conservative" (Reference 13.12, page 207).

Maximum Allowable Range of Thermal Stress (NB-3222.5):

Tables 9-10 and 9-11 determine the maximum allowable ranges of thermal stresses in the piping and thermal sleeve. The values of allowable stresses are conservatively calculated based on the membrane stresses due to the design pressure[ ].

The "SINT" values are obtained from ANSYS output files [ ] and [ ].

NB-3222.5 only requires the SI Range to include thermal SI Ranges and those from the output files also contain pressure effects. The Thermal SI Ranges are calculated in Tables 9-12 and 9-13.

Table 9-10 Allowable Ranges of Thermal Stresses for Maximum WOL

Path	SI Range[3] [ksi]	Average Temperature [°F]	Sm [ksi]	1.5*Sm [ksi]	Sy [ksi]	SINT [ksi]	x	y'	Allowable SI Range [ksi]

Note [1]: See Table 9-4
Note [2]: See Table 9-3
Note [3]: See Table 9-12

Table 9-11 Allowable Ranges of Thermal Stresses for Minimum WOL

Path	SI Range[2] [ksi]	Average Temperature [°F]	Sm [ksi]	1.5*Sm [ksi]	Sy [ksi]	SINT [ksi]	x	y'	Allowable SI Range [ksi]

Note [1]: See Table 9-7
Note [2]: See Table 9-13

Where:

x = max. general membrane stress due to pressure ("SINT") divided by the yield strength S_y [1]

$y' = \frac{1}{x}$ for $0.0 < x < 0.5$; $y' = 4(1 - x)$ for $0.5 < x < 1.0$

Maximum allowable range of thermal stress = $y' * S_y$ [1]

Note [1]: $1.5S_m$ is used instead of S_y. Per NB-3222.5, note 11, it is permissible to use $1.5S_m$ in this equation whenever it is greater than S_y.

The maximum SI Ranges of thermal stresses are less than the allowable stresses; therefore the requirement has been met.

Table 9-12 Thermal M+B SI Range for Maximum WOL

Table 9-12 (Continued) Thermal M+B SI Range for Maximum WOL

Table 9-13 Thermal M+B SI Range for Minimum WOL

[ ]

9.2.3.5 ***Temperature Limits (NB-3228.5(e))***

The maximum temperature of the components is [ ] which does not exceed the maximum allowable temperatures listed in Table NB-3228.5(b)-1, Reference 13.1.

Therefore, the ASME Code requirement is met.

9.2.3.6 ***Minimum Strength Ratio (NB-3228.5(f))***

The material shall have specified minimum yield strength to specified minimum tensile strength ratio of less then 0.80.

The S_y and S_u values at 70°F are obtained from Reference 13.15.

For Thermal Sleeve, Path 'Sleeve', [ ]
Specified minimum yield strength, S_y = 30 ksi @70°F
Specified minimum tensile strength, S_u = 75 ksi @70°F
Ratio of S_y/S_u = 0.4

For Piping, Path 'PipeL', [ ]
Specified minimum yield strength, S_y = 30 ksi @70°F
Specified minimum tensile strength, S_u = 75 ksi @70°F
Ratio of S_y/S_u = 0.4

Therefore, the ASME Code requirement is met.

9.2.4 Fatigue Usage Factor Calculation

For consideration of fatigue usage, the Peak Stress Intensity Ranges are calculated. These values must include the total localized stresses.

The fatigue usage factor at a location is usually calculated based on the actual stress intensity range. However, at a geometric or material discontinuity, an unrealistic peak stress may result from the modeling approach, element type and mesh sizes. The total stress obtained from the finite element analysis may not be able to capture the actual stress condition. To account for the possible modeling inaccuracies, an FSRF is usually applied to the M+B stress intensity range for location experiencing the discontinuity.

The stress category used in fatigue evaluation, along with an appropriate FSRF, for each node is listed in Table 9-14. For path lines nearby the thermal sleeve weld (i.e., crevice), M+B stresses with a FSRF of 4.0 are applied. Per Reference 13.13 (p. 395), the FSRF for node on the inside and outside of the safe end component, outer nozzle, and pipe near WOL junction are based on a bounding taper angle.

Table 9-14 Stress Category and FSRF in Fatigue Evaluation

Path Name	Inside Node		Outside Node	
	Stress Category	FSRF	Stress Category	FSRF
PipeL	TOTAL		M+B	
P_Wol	M+B		TOTAL	
P_Wola	M+B		TOTAL	
P_Wolb	TOTAL		TOTAL	
SEU_Weld	M+B		TOTAL	
SEU_Welda	M+B		M+B	
SEU_Weldb	M+B		TOTAL	
SEU_Wol	M+B		TOTAL	
SEU_Wola	M+B		M+B	
SEU_Wolb	M+B		TOTAL	
SEL_Wol	M+B		TOTAL	
SEL_Wola	M+B		M+B	
SEL_Wolb	M+B		TOTAL	
SEL_Weld	M+B		TOTAL	
SEL_Welda	M+B		M+B	
SEL_Weldb	M+B		TOTAL	
N_Wol	TOTAL		TOTAL	
N_Wola	TOTAL		TOTAL	
N_Wolb	TOTAL		TOTAL	
Noz	TOTAL		M+B	
NozL	M+B		M+B	
TS	TOTAL		M+B	

For the location determined to be critical, the corresponding external loads from Table 5-5 through Table 5-16 have been incorporated in the fatigue calculation. Using the SI ranges and cycles taken from the "fatigue" output files (see Section 12.0), the bounding external SI (including thermal stratification) have been added manually to the first [ ] cycles and the fatigue usage factor then recalculated. This method of adding the external SI to the transient SI is a conservative method as shown in the previous sections.

As stated in Table 5-30 of Reference 13.16, within the Heatup and Cooldown cycles there exist sub-cycles (minor cycles) at the beginning and end of the transients (major cycles) respectively.

[ ]

The thermal stratification external loads are included in the fatigue calculation as independent sub-cycles. For each case the usage factor calculation is based upon the SI specified in Table 5-7 through Table 5-16 and the number of cycles for each case as stated in Reference 13.8.

The following pages contain the calculation of the cumulative fatigue usage factor for the points of interest. The usage factor includes Transients loading and all applicable external loadings. The calculation is performed separately for seven materials and different parts of model.

The critical locations are:

[ ]

Path Name PipeL (outside) Maximum Weld Overlay **Output File:** [ ]

Node [ ]

MATERIAL: **FSRF=** [ ]

TYPE: High Alloy

UTS (psi) = **3Sm=** 49.1

E matl (psi) = [ ] **E ratio** =('E curve' / 'E analysis')=1.14

Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ext. Load	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	HU/RT_CDSI								
2	HU/RCOP								
3	HU/CD								
4	CD/SIA								
5	RCSD/SIA								
6	SIA/SUIL								
7	CRD/SIA								
8	CRD/LOP								
9	CRD/LOSLSD								
10	LOSLSD/RT_CDnSI								
11	LOL/RT_CDnSI								
12	RT_CDnSI/RT_noCD								
13	FCHSD/RT_noCD								
14	FCHSD/LOF								
15	FCHSD/PL								
16	PL/PL								
17	LSDL/LSDL								
18	10SLdec/10SLdec								
19	BCE/TRT								
20	BCE/UL								
21	10SLinc/BCE								
22	BCE/LOSLSU								
23	BCE/BCE								
24	HU-340								
25	HU-200								
26	HU-100								
27	HU-147								
28	OP-43								
	Sub-Cycle within HUCD								

Path Name SEU_Welda (inside) Minimum Weld Overlay **Output File:** [ ]

Node [ ] **FSRF=** [ ]

MATERIAL: **TYPE:** High Alloy

UTS (psi) = **3Sm=** 49.3

E matl (psi) = [ ] [ ] **E ratio** =('E curve' / 'E analysis')=1.14

Salt=(Total+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	Total SI	Ext. Load	Ke(1)	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	RCSD/SUIL								
2	RCSD/RT_CDSI								
3	RCOP/SIA								
4	HU/RT_CDnSI								
5	HU/LOSLSD								
6	LOSLSD/SIA								
7	CRD/SIA								
8	CRD/LOL								
9	LOF/LOL								
10	LOF/RT_noCD								
11	FCHSD/RT_noCD								
12	FCHSD/RT_noCD								
13	FCHSD/LSDL								
14	10SLDec/FCHSD								
15	10SLDec/CD								
16	10SLDec/LOP								
17	10SLDec/PL								
18	PL/PL								
19	BCE/UL								
20	10SLInc/BCE								
21	BCE/LOSLSU								
22	BCE/TRT								
23	BCE/BCE								
24	HU-340								
25	HU-200								
26	HU-100								
27	HU-147								
28	OP-43								
	Sub-Cycle within HUCD								

Note (1): Ke factor calculation for this location is based on Total Stress. This is conservative because the Total stress range is higher than Membrane+Bending, resulting in a large usage factor.

Path Name SEL_Wola (inside) Maximum Weld Overlay **Output File:** [ ]
Node [ ] **FSRF=** [ ]
MATERIAL: **TYPE:** High Alloy
UTS (psi) = **3Sm=** 40.7
E matl (psi) = [ ] **E ratio** =('E curve' / 'E analysis')=1.14
Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ext. Load	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	HU/RT_CDSI								
2	HU/SIA								
3	HU/SUIL								
4	HU/CD								
5	CD/RCSD								
6	CD/RT_CDnSI								
7	CRD/RT_CDnSI								
8	FCHSD/RT_CDnSI								
9	FCHSD/LOL								
10	FCHSD/RT_noCD								
11	FCHSD/RT_noCD								
12	FCHSD/LOF								
13	FCHSD/LSDL								
14	FCHSD/LOSLSD								
15	FCHSD/PL								
16	PL/RCOP								
17	PL/PL								
18	10SLdec/LOP								
19	10SLdec/10SLdec								
20	BCE/UL								
21	10SLinc/BCE								
22	BCE/LOSLSU								
23	BCE/TRT								
24	BCE/BCE								
25	HU-340								
26	HU-200								
27	HU-100								
28	HU-147								
29	OP-43								
	Sub-Cycle within HUCD								

Path Name SEL_Welda (inside) Minimum Weld Overlay **Output File:** [ ]
Node [ ] **FSRF=** [ ]
MATERIAL: **TYPE:** High Alloy
UTS (psi) = **3Sm=** 69.9
E matl (psi) = [ ] [ ] **E ratio** =('E curve' / 'E analysis')=1.00
Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ext. Load	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	HU/LOP								
2	BCE/HU								
3	BCE/CD								
4	BCE/RCOP								
5	LOL/RT_CDSI								
6	LOL/SIA								
7	FCHSD/RCSD								
8	FCHSD/LOL								
9	FCHSD/RT_CDnSI								
10	CRD/FCHSD								
11	FCHSD/LOF								
12	FCHSD/LOSLSD								
13	FCHSD/LSDL								
14	FCHSD/RT_noCD								
15	10SLdec/FCHSD								
16	10SLdec/SUIL								
17	10SLdec/PL								
18	PL/PL								
19	10SLinc/BCE								
20	BCE/LOSLSU								
21	UL/TRT								
22	BCE/UL								
23	BCE/BCE								
24	HU-340								
25	HU-200								
26	HU-100								
27	HU-147								
28	OP-43								
	Sub-Cycle within HUCD								

Path Name N_Wolb (outside) Minimum Weld Overlay **Output Files:** [ ]
Node [ ]
FSRF= [ ]
MATERIAL: [ ] **TYPE:** High Alloy
UTS (psi) = [ ] **3Sm=** 69.9
E matl (psi) = [ ] [ ] **E ratio** =('E curve' / 'E analysis')=1.02
Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ext. Load	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	HU/RT_CDSI								
2	HU/CD								
3	CD/LOP								
4	LOP/RCSD								
5	LOP/RCOP								
6	LOSLSD/SIA								
7	CRD/LOSLSD								
8	CRD/PL								
9	FCHSD/PL								
10	FCHSD/PL								
11	PL/SUIL								
12	PL/RT_CDnSI								
13	PL/PL								
14	10SLdec/LOF								
15	10SLdec/RT_noCD								
16	10SLdec/TRT								
17	10SLdec/LOL								
18	10SLdec/UL								
19	BCE/UL								
20	10SLinc/BCE								
21	BCE/LOSLSU								
22	BCE/LSDL								
23	BCE/BCE								
24	HU-340								
25	HU-200								
26	HU-100								
27	HU-147								
28	OP-43								
	Sub-Cycle within HUCD								

Path Name NozL (inside) Maximum Weld Overlay **Output File:** [ ]
Node [
MATERIAL:
UTS (psi) =
E matl (psi) =] [ ]
FSRF= [ ]
TYPE: Low Alloy
3Sm= 80.1
E ratio = ('E curve' / 'E analysis')= 1.21
Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	HU/SIA	[						
2	FCHSD/HU							
3	FCHSD/CD							
4	LOL/RCOP							
5	LOL/RCSD							
6	RT_CDnSI/RT_CDSI							
7	FCHSD/RT_CDnSI							
8	CRD/FCHSD							
9	FCHSD/LOL							
10	FCHSD/LOF							
11	FCHSD/RT_noCD							
12	FCHSD/TRT							
13	FCHSD/LSDL							
14	FCHSD/FCHSD							
15	LOP/SUIL							
16	LOP/LOSLSD							
17	LOSLSD/LOSLSD							
18	10SLdec/PL							
19	PL/PL							
20	BCE/UL							
21	BCE/BCE							
22	10SLinc/LOSLSU							
23	10SLinc/10SLinc							
	Sub-Cycle within HUCD							]

Path Name Sleeve (outside) Maximum Weld Overlay **Output File:** [ ]
Node [
MATERIAL:
UTS (psi) =
E matl (psi) =]
FSRF= [ ]
TYPE: High Alloy
3Sm= 45.5
[ ] **E ratio** = ('E curve' / 'E analysis')= 1.00
Salt=(M+B+Ext. Load)*FSRF/2

RANGE	TRANSIENTS WITH	REQ'D CYCLES	M+B SI	Ke	Salt	Ke x (E ratio) x S alt ksi	ALLOWABLE CYCLES	USAGE FACTOR
1	RCSD/RT_CDSI	[						
2	RCSD/RCSD							
3	HU/SUIL							
4	RCOP/RT_CDnSI							
5	HU/CD							
6	CD/RT_CDnSI							
7	LOSLSD/RT_CDnSI							
8	RT_CDnSI/RT_CDnSI							
9	LOF/SIA							
10	FCHSD/LOF							
11	CRD/FCHSD							
12	FCHSD/RT_noCD							
13	FCHSD/LOL							
14	FCHSD/LOP							
15	FCHSD/LSDL							
16	FCHSD/PL							
17	PL/PL							
18	10SLinc/UL							
19	LOSLSU/UL							
20	UL/UL							
21	10SLdec/10SLdec							
22	BCE/TRT							
23	BCE/BCE							
	Sub-Cycle within HUCD							
								]

10. RESULTS SUMMARY/CONCLUSION

The fatigue calculation assumes that the Surge Nozzle WOL configuration has existed from the beginning of plant operation. The preceding calculations demonstrate that the design of the Surge Nozzle Maximum and Minimum Weld Overlay for the North Anna Units 1 & 2 Pressurizers have met the stress and fatigue requirements of the Design Code (Reference 13.1).

Based on the loads and cycles specified in References 13.8 and 13.16, the conservative fatigue analysis indicated that the Pressurizer Surge Nozzle Weld Overlay design has a maximum fatigue factor of [ ] compared to the ASME Code allowed maximum value of 1.0. Therefore, the total usage for the Surge Nozzle is less than the allowable value of 1.0 for the total of 60 years of operation.

Table 10-1 Summary of Results(1)

	Nozzle			Safe End to Nozzle Weld			Safe End		
	Calculated	Limit	IR(2)	Calculated	Limit	IR(2)	Calculated	Limit	IR(2)
Primary SI	Bounded by original analysis, see Section 9.1								
Max. SI Range PL+Pb+Q [ksi]	[								
Fatigue Usage									]
	Thermal Sleeve			**Safe End to Pipe Weld**			**Pipe**		
	Calculated	Limit	IR(2)	Calculated	Limit	IR(2)	Calculated	Limit	IR(2)
Primary SI	Bounded by original analysis, see Section 9.1								
Max. SI Range PL+Pb+Q [ksi]	[								
Fatigue Usage									]
	Weld Overlay								
	Calculated	Limit	IR(1)						
Primary SI	Bounded by original analysis, see Section 9.1								
Max. SI Range PL+Pb+Q [ksi]	[								
Fatigue Usage			]						

Note (1): Results from Appendix D and E qualifications that incorporate added insurge and outsurge transients replacing previous qualifications in Section 9.
Note (2): IR- Interaction Ration is defined as (Calculated Value / Limit)
Note (3): See Table D-8.
Note (4): See Table D-7.

11. SOFTWARE VERIFICATION

The finite element analyses documented in this report were performed using ANSYS v10.0 software (Reference 13.10). The suitability and accuracy of use of ANSYS v10.0 was verified by performing the following verification runs (Table 11-1).

Table 11-1 Software Verification Files

[ ]

12. COMPUTER OUTPUT FILES

For list of fracture mechanics output files, see Appendix A.

For list of output files for justification of insufficient Weld Overlay length, see Appendix C.

For list of output files for Insurge/Outsurge Elastic Analysis, see Appendix D.

For list of output files for Elastic-Plastic Analysis, see Appendix E.

Table 12-1 Computer Output and Input Files

[ ]

[ ]

13. REFERENCES

13.1 ASME Code, Section III, Division 1, "Boiler and Pressure Vessel Code", 2001 Edition including Addenda through 2003.

13.2 Oak Ridge National Laboratory Report ORNL/NUREG/TM-57, "Heat-to-Heat Variations of Total Strain (to 5%) at Discrete Stress Levels in Types 316 and 304 Stainless Steel from 24 to 316°C", prepared for the US NRC.

13.3 J. L. Rempe et al., "Light Water Reactor Lower Head Failure Analysis," NUREG/CR-5642 (EGG-2618), October 1993.

13.4 Not Used

13.5 AREVA Drawing 02-8016831C-003, "North Anna Pressurizer Surge Nozzle Design."

13.6 AREVA Drawing 02-8017167D-000, "North Anna Pressurizer Surge Nozzle Weld Overlay Design."

13.7 AREVA Document 51-9031151-003, "North Anna Pressurizer Nozzle Weld Overlays – Technical Requirements."

13.8 AREVA Document 38-9034638-003, "Required Engineering Input for North Anna Pressurizer Weld Overlays, North Anna Power Station Units 1 & 2."

13.9 ANSYS Finite Element Computer Code, Version 10.0 Help Manual

13.10 "ANSYS" Finite Element Computer Code, Version 10.0, ANSYS, Inc. Canonsburg, Pa.

13.11 AREVA Document 38-9042859-000, Code Case N-740-1 (2-07-2007 Draft), "Dissimilar Metal Weld Overlay for Repair of Class 1, 2, and 3 Items, Section XI, Division 1." (Revision 000 of this document is the applicable revision for this project. This Code Case is not yet accepted by the NRC.)

13.12 "Companion Guide to the ASME Boiler & Pressure Vessel Code", Volume 1, ASME Press, New York, 2002.

13.13 John F. Harvey, "Theory and Design of Pressure Vessels," Second Edition, Van Nostran Reinhold, 1991.

13.14 AREVA Document 32-9034323-003, "North Anna Units 1 & 2 Pressurizer Weld Overlay Sizing Calculation – Surge Nozzle."

13.15 AREVA Document 51-9038545-002, "Material Properties for North Anna Units 1 & 2 Pressurizer Nozzles."

13.16 AREVA Document 51-9036969-004, "Pressurizer Bounding Transients for North Anna Units 1 & 2."

13.17 ANSYS Finite Element Computer Code, Version 11.0 Help Manual

13.18 "ANSYS" Finite Element Computer Code, Version 11.0, ANSYS, Inc. Canonsburg, Pa.

APPENDIX A

PATH STRESSES FOR FRACTURE MECHANICS

A.1 PURPOSE

The purpose of this appendix is to provide supplemental stress and thermal results of the transient analysis for a Fracture Mechanics Analysis of the surge nozzle weld overlay. The focus of the analysis is crack initiation and growth through both the Pipe to Safe End Weld and Nozzle to Safe End Weld. The Minimum Weld overlay represents the worst case scenario with a through-weld crack, therefore only the minimum WOL is included in this appendix.

A.2 STRESS AND TEMPERATURE EVALUATION

The ANSYS Post Processor is used to tabulate the stresses and temperatures along the predetermined paths for the Minimum Weld Overlay Configuration only. The paths are shown in Figure A-1 and described in Table A-1.

The definitions of these paths and post processing commands are contained in computer output file named, [ ]. All output files used for fracture mechanics evaluation are listed in Table A-2.

Table A- 1 Paths Description Min WOL

Output File Path No.	Path Name	Inside Node No.	Outside Node No.
1	SEUWELD	6244	6001
2	SELWELD	6255	6052
3	SEBUT	6297	15955

Figure A- 1 Paths Defined for Fracture Mechanics Evaluation

Stresses along the path line are summarized at twelve points separated by an equal distance from the inside node to the outside node. At each point, the axial (longitudinal, S_y) stress and the temperature of the nozzle are given. The path point distances from the inside node are included in the output files listed in Table A-2 with "_PathLocs" in their names. The stress and temperature result files for these locations are listed on Table A-2.

In addition, files with "_PathDisc" in their names, listed in Table A-2, provide path point distances from the inside node including the location at the dissimilar material interface for each path (two path points, one just before and one just after the material discontinuity, define the location of the material interface). No post processing are obtained at these path points; this information is provides for reference only.

Table A- 2 Stress and Temperature Result Files for Fracture Mechanics Evaluation

[ ]

APPENDIX B

STRUCTURAL TIME POINTS OF INTEREST

B.1 TIME POINTS OF INTEREST USED FOR STRUCTURAL ANALYSIS

The following tables list all transient time points analyzed in the structural analysis of the Surge Nozzle. The time points have been selected based on localized extreme thermal gradients tabulated at the end of all "...Dt.out" thermal post processing computer files. The thermal extreme time points were merged with all time points defining the transients for the structural analysis. In the following tables, those time points marked with asterisks have been taken directly from the transient definition; all other points represent temperature gradient extreme time points.

Table B-1 Structural Time Points of Interest for Plant Heatup and Cooldown-MAX WOL

Time	Temperature [°F]	Press [psi]	Time	Temperature [°F]	Press [psi]	Time	Temperature [°F]	Press [psi]
0.00010*			23.69330*			31.00240*		
1.22290*			23.69334			31.00244		
1.31209			23.69343			31.00250		
1.40128			23.69360*			31.00270*		
2.11480*			23.71239			31.02136		
4.00000*			23.72780			31.03677		
4.00030*			23.73125			31.04029		
4.04183			23.73470*			31.04380*		
4.08335			23.73500*			31.04410*		
4.16640*			24.15024			31.54330*		
4.16670*			24.56548			31.73559		
7.44280*			25.81120*			32.31246		
7.44310*			25.81124			33.46620*		
7.48463			25.81150*			33.46650*		
7.52615			25.83022			33.50881		
7.60920*			25.84563			33.52957		
7.60950*			25.84912			33.55033		
7.96808			25.85260*			33.63260*		
8.20713			25.85290*			33.63290*		
8.92428			26.31174			34.38500*		
10.00000*			26.69411			34.38530*		
18.00000*			27.00000*			34.41852		
19.00000*			27.00003			34.45174		
19.55320*			27.00010*			34.55140*		
19.55324			27.00014			34.55170*		
19.55333			27.00020			34.87490*		
19.55350*			27.00040*			34.87520*		
19.57239			27.01913			34.87550*		
19.58266			27.03454			35.09710*		
19.59120			27.03802			35.09716		
19.59460*			27.04150*			35.09720		
19.59490*			27.04180*			35.09740*		
20.23744			27.43804			35.40100*		
21.73670*			27.83428			40.93120*		
21.73674			29.02300*			40.93126		
21.73683			29.02304			40.93150*		
21.73700*			29.02310			40.93153		
21.75585			29.02330*			40.93166		
21.76613			29.04351			40.93180*		
21.77468			29.05995			41.15340*		
21.77810*			29.06440*			41.15370*		
21.77840*			29.06470*			41.76480*		
22.54436			29.45224			42.33220*		
22.92734			29.83978			43.00000*		

Table B- 2 Structural Time Points of Interest for Plant Loading and Unloading-MAX WOL

Time	Temperature [°F]	Press [psi]	Time	Temperature [°F]	Press [psi]
0.00010*			0.46540*		
0.00013			0.46541		
0.00020*			0.46545		
0.02780*			0.46549		
0.03058			0.46550*		
0.03927			0.47110		
0.04170*			0.49350*		
0.04530			0.52160*		
0.05970*			0.52250*		
0.05980*			0.55233		
0.07640*			0.58215		
0.09720*			0.76110*		
0.09894			0.77610*		
0.10068			0.78622		
0.10852			0.79255		
0.11375			0.79697		
0.11810*			0.80140*		
0.22780*			0.84430*		
0.30560*			0.84432		
0.31368			0.84432		
0.31714			0.84433		
0.32407			0.84438		
0.33330*			0.84439		
0.33331			0.84440*		
0.33340*			0.87950*		
0.37500*			0.88570*		
0.38888			0.88844		
0.44440*			0.89006		
0.44447			0.89087		
0.44450*			0.89490		
0.44460*			0.89700*		
0.45580*			0.89762		
0.45840*			0.90320*		

Table B- 3 Structural Time Points of Interest for 10% Step Load Increase-MAX WOL

Time	Temperature [F]	Press [psi]
0 00010*		
0 00310*		
0.00421		
0.00500*		
0.00592		
0.00628		
0.00720*		
0.00730*		
0.00869		
0.00910*		
0.01970*		
0.02140*		
0.02313		
0.02690*		
0.03579		
0.04376		
0 04727		
0.04880*		
0.05350*		
0.05360*		
0.05510*		
0.05558		
0 05650*		
0.06850		
0.09250*		

Table B- 4 Structural Time Points of Interest for 10% Step Load Decrease-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00310*		
0.00480*		
0.00696		
0.00760*		
0.00770*		
0.00785		
0.00790*		
0.00925		
0.00987		
0.01017		
0.01220*		
0.01240*		
0.01430*		
0.03203		
0.04250*		
0.04320		
0.04690		
0.04950*		
0.08310*		
0.08393		
0.08460		
0.08561		
0.08680*		
0.08728		
0.08776		
0.08982		
0.09160*		
0.09460*		
0.09470*		
0.09694		
0.10590*		

Table B- 5 Structural Time Points of Interest for Large Step Decrease In Load-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00011		
0.00012		
0.00013		
0.00015		
0.00020*		
0.00210*		
0.00240*		
0.00294		
0.00510*		
0.00520*		
0.00619		
0.00730*		
0.00830*		
0.00998		
0.01358		
0.01478		
0.01670*		
0.01732		
0.01794		
0.02290*		
0.02353		
0 02686		
0.02920*		
0.03184		
0.03340*		
0.04173		
0.09590*		
0.21160*		
0.22720*		
0.24080*		
0.26890*		
0.32624		
0.55560*		

Table B- 6 Structural Time Points of Interest for Loss of Load-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00180		
0.00190*		
0.00210*		
0.00483		
0.00866		
0.01030*		
0.01059		
0.01130*		
0.01140*		
0.01180*		
0.01688		
0.01760*		
0.01850*		
0.02270*		
0.05376		
0.33330*		

Table B- 7 Structural Time Points of Interest for Loss of Power-MAX WOL

Time	Temperature [F]	Press [psi]
0.00010*		
0.00020*		
0.00110*		
0.00188		
0.00270*		
0.00280*		
0.00404		
0.00420*		
0.01674		
0.01870*		
0.02480*		
0.02481		
0.02482		
0.02487		
0.02490*		
0.04309		
0.04538		
0.05000*		
0.05259		
0.05435		
0.05788		
0.06940*		
0.08162		
0.08436		
0.08983		
0.09950*		
0.09960*		
0.14030*		
0.14819		
0.16735		
0.21920*		
0.28060*		
0.37620*		
0.43387		
0.49154		
0.77990*		
0.80690*		

Table B- 8 Structural Time Points of Interest for Loss of Flow-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00023		
0.00030		
0.00070*		
0.00083		
0.00100*		
0.00110*		
0.00114		
0.00118		
0.00170*		
0.00203		
0.00217		
0.00250*		
0.00533		
0.00930*		
0.01047		
0.01210*		
0.01220*		
0.01274		
0.01400*		
0.01588		
0.01684		
0.01840*		
0.01954		
0.02070*		
0.02100*		

Table B- 9 Structural Time Points of Interest for Feedwater Cycling at Hot Shutdown-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.42780*		
0.42790*		
0.44710*		
0.45432		
0.46514		
0.47055		
0.47597		
0.49040*		
0.63460*		
0.64410*		
0.64415		
0.64418		
0.64420*		
0.65870*		
0.66830		
0.67516		
0.68887		
0.69573		
0.70670*		
0.74040*		
1.20190*		
1.24357		
1.26440*		
1.26450*		
1.26920*		
1.27724		
1.28046		
1.28850*		
2.00000*		

Table B- 10 Structural Time Points of Interest for Boron Concentration Equalization-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00013		
0.00020*		
0.01686		
0.03353		
0.05019		
1.00000*		
1.00010*		

Table B- 11 Structural Time Points of Interest for Reactor Trip with No Cooldown-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00180*		
0.00358		
0.00700*		
0.00804		
0.00846		
0.00950*		
0.00960*		
0.01033		
0.01200*		
0.01240*		
0.01410*		
0.01414		
0.01420*		
0.01428		
0.01540*		
0.02780*		

Table B- 12 Structural Time Points of Interest for Reactor Trip with Cooldown but no Safety Injection-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00190*		
0.00509		
0.00550*		
0.00750*		
0.01380*		
0.01387		
0.01444		
0.01480*		
0.01500*		
0.01588		
0.01784		
0.01800*		
0.01810*		
0.01818		
0.01830*		
0.02020		
0.02780*		

Table B- 13 Structural Time Points of Interest for Reactor Trip with Cooldown and Safety Injection-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00149		
0.00190*		
0.00537		
0.00745		
0.00953		
0.01230*		
0.01390*		
0.01420*		
0.02150*		
0.02850*		
0.11960		
0.12947		
0.13934		
0.16670*		

Table B- 14 Structural Time Points of Interest for Inadvertent Reactor Coolant System Depressurization-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00840*		
0.00960*		
0.00969		
0.00970*		
0.00974		
0.01030*		
0.01060		
0.01135		
0.01371		
0.01390*		
0.01467		
0.02310*		
0.02311		
0.02314		
0.02320*		
0.02364		
0.02450*		
0.03220*		
0.03990*		
0.05990		
0.27990*		
0.28134		
0.28483		
0.28541		
0.28630*		
0.29301		
0.33330*		

Table B-15 Structural Time Points of Interest for Control Rod Drop-MAX WOL

Time	Temperature [F]	Press [psi]
0.00007		
0.00010*		
0.00016		
0.00022		
0.00100*		
0.00266		
0.00290*		
0.00593		
0.00810*		
0.00870*		
0.01140*		
0.01193		
0.01320*		
0.01330*		
0.01379		
0.01700*		
0.02710		
0.02840*		
0.03111		
0.03331		
0.03771		
0.04050*		
0.04140*		
0.04150*		
0.04183		
0.04215		
0.04410*		

Table B- 16 Structural Time Points of Interest for Inadvertent Startup of an Inactive Loop-MAX WOL

Time	Temperature [°F]	Press [psi]	Time	Temperature [°F]	Press [psi]
0.00010*			0.02074		
0.00020*			0.02120		
0.00160*			0.02211		
0.00340*			0.02293		
0.00400*			0.02330*		
0.00406			0.02397		
0.00410*			0.02447		
0.00480*			0.02597		
0.00510*			0.02730*		
0.00551			0.02806		
0.00571			0.02899		
0.00580*			0.02930		
0.00730*			0.03070*		
0.00770*			0.03104		
0.00870			0.03187		
0.01241			0.03410*		
0.01270*			0.03486		
0.01323			0.03551		
0.01360			0.03616		
0.01505			0.03670*		
0.01670*			0.03693		
0.01850*			0.03716		
0.01860*			0.03749		
0.01890			0.03900*		
0.02010*			0.03910*		

Table B- 17 Structural Time Points of Interest for Inadvertent Safety Injection Actuation-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00260*		
0.00466		
0.01186		
0.01340*		
0.01341		
0.01344		
0.01349		
0.01350*		
0.01420*		
0.01423		
0.01480*		
0.02780*		
0.03411		
0.03862		
0.04763		
0.05665		
0.09090*		
0.28620*		
0.28625		
0.28629		
0.28630*		
0.28841		
0.29016		
0.29080*		
0.29718		
0.31790		
0.32398		
0.33330*		

Table B- 18 Structural Time Points of Interest for Turbine Roll Test-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.01510*		
0.01868		
0.03249		
0.05090*		
0 27780*		
0.28298		
0.29594		
0.30372		
0.31149		
0.34000*		

Table B- 19 Structural Time Points of Interest for Loop Out of Service Normal Loop Shutdown-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00260*		
0.00268		
0.00372		
0.00380*		
0.00390*		
0.00510*		
0.00558		
0.01090*		
0.01560*		
0.02362		
0.02697		
0.03633		
0.03900*		
0.04250		
0.05650*		
0.05660*		
0.06770*		
0.07082		
0.07305		
0.07528		
0 08131		
0 08330*		

Table B- 20 Structural Time Points of Interest for Loop Out of Service Normal Loop Startup-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00012		
0.00020*		
0.00029		
0.00130*		
0.00260*		
0.00270*		
0.00275		
0.00330*		
0.00331		
0.00340*		
0.00365		
0.00720*		
0.01050*		
0.01341		
0.01900*		
0.01929		
0.01999		
0.02190*		
0.02200*		
0.02243		
0.02840*		
0.05000*		
0.07334		
0.09001		
0.10668		
0.16670*		

Table B- 21 Structural Time Points of Interest for RCS Cold Overpressurization-MAX WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00025		
0.00140*		
0.00150*		
0.00160*		
0.00161		
0.00170*		
0.00180*		
0.00181		
0.00190*		
0.00196		
0.00200*		
0.00210*		
0.00220*		
0.00225		
0.00230*		
0.00240*		
0.00250*		
0.00259		
0.00260*		
0.00270*		
0.00280*		
0.00290*		
0.00300*		
0.00310*		
0.00320*		
0.00330*		
0.00340*		
0.00350*		
0.00360*		
0.00370*		
0.00380*		
0.00385		
0.00390*		

Table B- 22 Structural Time Points of Interest for Plant Heatup and Cooldown-MIN WOL

Time	Temp [°F]	Press [psi]	Time	Temp [°F]	Press [psi]	Time	Temp [°F]	Press [psi]
0.00010*			23.70726			31.04380*		
0.06124			23.71240			31.04410*		
1.22290*			23.71754			31.06906		
1.31209			23.73126			31.54330*		
2.11480*			23.73470*			31.92788		
4.00000*			23.73500*			33.46620*		
4.00030*			23.94262			33.46626		
4.04183			24.15024			33.46630		
4.16640*			25.39596			33.46650*		
4.16670*			25.81120*			33.50913		
4.82192			25.81150*			33.63260*		
5.47714			25.81698			33.63290*		
7.44280*			25.82509			33.85853		
7.44310*			25.83023			34.38500*		
7.48463			25.83537			34.38503		
7.60920*			25.85260*			34.38509		
7.60950*			25.85290*			34.38530*		
7.84855			26.08232			34.41852		
7.96808			26.31174			34.55140*		
8.68523			27.00000*			34.55170*		
10.00000*			27.00010*			34.74562		
10.40000			27.00040*			34.87490*		
18.00000*			27.00588			34.87520*		
18.20000			27.01400			34.87526		
19.00000*			27.01914			34.87529		
19.55320*			27.02427			34.87550*		
19.55350*			27.04150*			34.96539		
19.55898			27.04180*			35.09710*		
19.56726			27.23992			35.09716		
19.57754			27.43804			35.09740*		
19.58268			28.62676			35.37832		
19.59460*			29.02300*			35.40100*		
19.59490*			29.02330*			36.50704		
19.80908			29.02741			40.93120*		
20.02326			29.03571			40.93123		
21.73670*			29.04357			40.93126		
21.73700*			29.05179			40.93130		
21.74248			29.06440*			40.93150*		
21.75073			29.06470*			40.93180*		
21.75587			29.25847			40.97612		
21.76100			29.45224			41.15340*		
21.77128			30.22732			41.15356		
21.77810*			30.61486			41.15370*		
21.77840*			31.00240*			41.39814		
21.96989			31.00270*			41.76480*		
22.16138			31.00818			41.99176		
23.69330*			31.01623			42.33220*		
23.69360*			31.02137			43.00000*		

23.69908	[ ]	31.02651	[ ]

Table B- 23 Structural Time Points of Interest for Plant Loading and Unloading-MIN WOL

Time	Temperature [°F]	Press [psi]	Time	Temperature [°F]	Press [psi]
0.00010*			0.46540*		
0.00015			0.46549		
0.00020*			0.46550*		
0.00572			0.49350*		
0.02283			0.50236		
0.02780*			0.52160*		
0.03336			0.52250*		
0.04170*			0.55233		
0.05970*			0.62192		
0.05980*			0.76110*		
0.07087			0.77610*		
0.07640*			0.78116		
0.09720*			0.78622		
0.09894			0.79255		
0.10330			0.80140*		
0.11810*			0.84430*		
0.22780*			0.84432		
0.23428			0.84432		
0.30560*			0.84433		
0.31022			0.84438		
0.31368			0.84440*		
0.31714			0.86646		
0.33330*			0.87950*		
0.33331			0.88012		
0.33340*			0.88570*		
0.34033			0.88844		
0.37500*			0.88925		
0.44440*			0.89006		
0.44443			0.89167		
0.44450*			0.89700*		
0.44460*			0.89762		
0.45580*			0.89824		
0.45840*			0.90320*		
0.46124					

Table B- 24 Structural Time Points of Interest for 10% Step Load Increase-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00310*		
0.00421		
0.00500*		
0.00528		
0.00628		
0.00720*		
0.00730*		
0.00910*		
0.01437		
0.01970*		
0.02140*		
0.02263		
0.02690*		
0.02836		
0.02982		
0.04880*		
0.05350*		
0.05360*		
0.05510*		
0.05558		
0.05650*		
0.06850		
0.08050		
0.09250*		

Table B- 25 Structural Time Points of Interest for 10% Step Load Decrease-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00310*		
0.00441		
0.00480*		
0.00760*		
0.00768		
0.00770*		
0.00785		
0.00790*		
0.01220*		
0.01240*		
0.01430*		
0.02800		
0.03605		
0.03928		
0.04250*		
0.04950*		
0.08310*		
0.08359		
0.08393		
0.08460		
0.08680*		
0.08728		
0.09050		
0.09160*		
0.09460*		
0.09470*		
0.09694		
0.10590*		

Table B- 26 Structural Time Points of Interest for Large Step Decrease In Load-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00011		
0.00012		
0.00013		
0.00020*		
0.00210*		
0.00240*		
0.00294		
0.00329		
0.00510*		
0.00520*		
0.00730*		
0.00830*		
0.00914		
0.00998		
0.01358		
0.01616		
0.01670*		
0.01732		
0.01794		
0.01856		
0.02290*		
0.02686		
0.02920*		
0.03340*		
0.09590*		
0.21160*		
0.22720*		
0.22856		
0.24080*		
0.26007		
0.26890*		
0.32624		
0.55560*		

Table B- 27 Structural Time Points of Interest for Loss of Load-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00012		
0.00014		
0.00020*		
0.00170		
0.00190*		
0.00210*		
0.00702		
0.00866		
0.01030*		
0.01130*		
0.01140*		
0.01180*		
0.01398		
0.01760*		
0.01775		
0.01798		
0.01850*		
0.02270*		
0.05376		
0.08482		
0.33330*		

Table B- 28 Structural Time Points of Interest for Loss of Power-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00014		
0.00020*		
0.00110*		
0.00188		
0.00270*		
0.00280*		
0.00294		
0.00308		
0.00420*		
0.00783		
0.01674		
0.01870*		
0.02480*		
0.02484		
0.02485		
0.02490*		
0.02825		
0.04081		
0.04309		
0.04765		
0.05000*		
0.06940*		
0.07341		
0.08162		
0.08436		
0.08710		
0.09950*		
0.09960*		
0.10774		
0.14030*		
0.14819		
0.21920*		
0.28060*		
0.35435		
0.37620*		
0.77990*		
0.79709		
0.80690*		

Table B- 29 Structural Time Points of Interest for Loss of Flow-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00070*		
0.00083		
0.00100*		
0.00110*		
0.00118		
0.00140		
0.00170*		
0.00203		
0.00217		
0.00250*		
0.00420		
0.00533		
0.00930*		
0.01012		
0.01117		
0.01210*		
0.01220*		
0.01400*		
0.01610		
0.01685		
0.01716		
0.01840*		
0.02070*		
0.02100*		

Table B- 30 Structural Time Points of Interest for Feedwater Cycling at Hot Shutdown-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.42780*		
0.42790*		
0.43310		
0.44710*		
0.45071		
0.45432		
0.45973		
0.48138		
0.49040*		
0.63460*		
0.64410*		
0.64415		
0.64420*		
0.65141		
0.65870*		
0.66350		
0.66830		
0.67516		
0.70670*		
0.74040*		
0.95137		
1.20190*		
1.22013		
1.24357		
1.26440*		
1.26444		
1.26450*		
1.26920*		
1.27403		
1.27724		
1.28046		
1.28368		
1.28850*		
1.43080		
2.00000*		

Table B- 31 Structural Time Points of Interest for Boron Concentration Equalization-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00014		
0.00020*		
0.01686		
0.03353		
0.07400		
1.00000*		
1.00010*		

Table B- 32 Structural Time Points of Interest for Reactor Trip with No Cooldown-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00007*		
0.00010		
0.00180*		
0.00232		
0.00358		
0.00700*		
0.00804		
0.00930		
0.00950*		
0.00960*		
0.01200*		
0.01240*		
0.01392		
0.01410*		
0.01420*		
0.01428		
0.01469		
0.01540*		
0.02284		
0.02780*		

Table B- 33 Structural Time Points of Interest for Reactor Trip with Cooldown but no Safety Injection-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00190*		
0.00226		
0.00509		
0.00550*		
0.00750*		
0.01380*		
0.01387		
0.01480*		
0.01500*		
0.01588		
0.01767		
0.01800*		
0.01810*		
0.01818		
0.01830*		
0.02780*		

Table B- 34 Structural Time Points of Interest for Reactor Trip with Cooldown and Safety Injection-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00133		
0.00190*		
0.00259		
0.00606		
0.00745		
0.01230*		
0.01390*		
0.01420*		
0.01481		
0.02150*		
0.02850*		
0.11149		
0.11974		
0.12961		
0.16670*		

Table B- 35 Structural Time Points of Interest for Inadvertent Reactor Coolant System Depressurization-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00007		
0.00010*		
0.00012		
0.00012		
0.00020*		
0.00353		
0.00840*		
0.00960*		
0.00961		
0.00962		
0.00970*		
0.00974		
0.00989		
0.01030*		
0.01180		
0.01371		
0.01390*		
0.02310*		
0.02313		
0.02320*		
0.02450*		
0.02714		
0.03220*		
0.03990*		
0.16990		
0.27990*		
0.28483		
0.28541		
0.28630*		
0.33330*		

Table B- 36 Structural Time Points of Interest for Control Rod Drop-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00100*		
0.00266		
0.00290*		
0.00507		
0.00810*		
0.00870*		
0.01140*		
0.01193		
0.01238		
0.01320*		
0.01330*		
0.01700*		
0.01814		
0.02579		
0.02840*		
0.03111		
0.03221		
0.04050*		
0.04140*		
0.04150*		
0.04183		
0.04215		
0.04410*		

Table B- 37 Structural Time Points of Interest for Inadvertent Startup of an Inactive Loop-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00160*		
0.00340*		
0.00400*		
0.00401		
0.00410*		
0.00442		
0.00480*		
0.00510*		
0.00571		
0.00580*		
0.00730*		
0.00770*		
0.00870		
0.01013		
0.01270*		
0.01323		
0.01360		
0.01642		
0.01670*		
0.01850*		
0.01860*		
0.01875		
0.02010*		
0.02120		
0.02211		
0.02330*		
0.02397		
0.02730*		
0.02806		
0.02930		
0.03070*		
0.03187		
0.03324		
0.03410*		
0.03486		
0.03583		
0.03670*		
0.03716		
0.03749		
0.03900*		
0.03910*		

Table B- 38 Structural Time Points of Interest for Inadvertent Safety Injection Actuation-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00186		
0.00260*		
0.00466		
0.01243		
0.01340*		
0.01349		
0.01350*		
0.01420*		
0.01480*		
0.01889		
0.02780*		
0.03096		
0.03411		
0.03862		
0.04312		
0.09090*		
0.14992		
0.28620*		
0.28625		
0.28630*		
0.28648		
0.28841		
0.28991		
0.29016		
0.29080*		
0.30882		
0.33330*		

Table B- 39 Structural Time Points of Interest for Turbine Roll Test-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00319		
0.01510*		
0.01868		
0.02226		
0.02737		
0.04272		
0.05090*		
0.27780*		
0.28298		
0.28817		
0.34000*		

Table B- 40 Structural Time Points of Interest for Loop Out of Service Normal Loop Shutdown-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00260*		
0.00268		
0.00372		
0.00380*		
0.00390*		
0.00439		
0.00510*		
0.01090*		
0.01560*		
0.02362		
0.03031		
0.03900*		
0.05650*		
0.05660*		
0.06514		
0.06770*		
0.07082		
0.07305		
0.07528		
0.08330*		

Table B- 41 Structural Time Points of Interest for Loop Out of Service Normal Loop Startup-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00007		
0.00010*		
0.00012		
0.00020*		
0.00130*		
0.00260*		
0.00270*		
0.00275		
0.00310		
0.00330*		
0.00331		
0.00340*		
0.00365		
0.00391		
0.00460		
0.00720*		
0.00753		
0.01050*		
0.01220		
0.01341		
0.01803		
0.01900*		
0.02190*		
0.02200*		
0.02840*		
0.03272		
0.05000*		
0.06167		
0.07334		
0.16670*		

Table B- 42 Structural Time Points of Interest for RCS Cold Overpressurization-MIN WOL

Time	Temperature [°F]	Press [psi]
0.00010*		
0.00020*		
0.00025		
0.00030		
0.00140*		
0.00150*		
0.00160*		
0.00170*		
0.00180*		
0.00181		
0.00190*		
0.00194		
0.00200*		
0.00210*		
0.00220*		
0.00230*		
0.00240*		
0.00250*		
0.00260*		
0.00270*		
0.00277		
0.00280*		
0.00289		
0.00290*		
0.00300*		
0.00310*		
0.00320*		
0.00330*		
0.00340*		
0.00350*		
0.00351		
0.00360*		
0.00370*		
0.00380*		
0.00390*		

APPENDIX C

JUSTIFICATION OF INSUFFICIENT LENGTH OF WELD OVERLAY

C.1 PURPOSE

The purpose of this Appendix is to examine stress distribution in the North Anna Surge Nozzle components and to justify the deficient length of weld overlay on the nozzle side as it is calculated in Reference 13.14.

C.2 ANALYTICAL METHODOLOGY

By AREVA Document 38-9042859-000, Reference 13.11, the length of the weld overlay should extend at least $0.75\sqrt{(Rt_n)}$ beyond each end of the observed crack, where R and t_n are the outside radius and nominal wall thickness of the pipe prior to depositing the weld overlay. This requirement is to make sure that enough length is provided to attenuate stresses in case of stress concentration due to crack initiation. Because of the existing short length of the Surge Nozzle analyzed in the main body of this document, the above requirement was not satisfied and therefore shorter length for the weld overlay was used. The main focus of this Appendix is to look closely at the stress distribution for the Surge Nozzle thin weld overlay configuration under the conservative assumption of the total loss of buttering and weld between nozzle and safe end.

For this sake the finite element model for the thin weld overlay created in the main body of this document was tested under design pressure and external applied loads listed in Tables 6-7 through 6-9, Reference 13.16. The dead weight loads were taken from Table 1 of Reference 13.14. All the elements pertain to the weld and buttering between the safe end and nozzle body were eliminated. The modified geometry for this analysis is documented in these files: [ ](Table 12-1). Also, it is important to note that since the model created in the main body of this document uses 2-D axisymmetric elements and some of the applied external loads are non-axisymmetric, special 2-D elements were needed to address this issue. Consequently, all the elements were changed to PLANE 83 which allows the application of non-axisymmetric loads on an axisymmetric model. The detailed description of this element is listed in ANSYS Manual, Reference 13.9.

C.3 BOUNDARY CONDITIONS

The geometric boundary conditions for the model remained the same as it is described in the main body of this document. The external loads are conservatively assumed to be applied at the top of the external pipe and their application to the model is described as follows:

First, unit loads are applied on the model, and in the second step, the unit loads are scaled and combined such that they are representative of the different external loads (DW, Design Pressure, Thermal (TH), and OBE) reported in Reference 13.16, Tables 6-7 through 6-9. Five different unit load cases are evaluated for the thin weld overlay configuration. 1) Unit, 1 kip, axial load, 2) Unit, 1 kip-in, torsion, 3) Unit, 1 kip, shear, 4) Unit, 1 kip-in, bending, 5) Unit, 1 ksi, pressure. All unit loads are applied at the end of the modeled external surge piping with an exception of the unit pressure load applied on the internal surfaces.

The unit axial, unit torsion and unit pressure load cases can be represented by the constant term of a harmonic function series in particular the Fourier series, Reference 13.9. The unit shear and unit bending load cases can be represented by the first harmonic, either symmetric cosine or antisymmetric sine function of the Fourier series Reference 13.9. While the unit bending moment can be described by a single harmonic load applied perpendicular to the cross section, the unit shear uniform lateral load is composed of two harmonic components applied in two perpendicular directions in the plane of the cross section, Reference 13.9. Since all load cases considered can be exactly represented by either the constant or first harmonic terms of the Fourier series, no Fourier series expansion of the non-axisymmetric loads is necessary. The ANSYS output of the unit external loads is contained in the output file [ ].

Due to the axisymmetry of the geometries only two load combinations need to be defined for each model (DW + Design Pressure + TH + OBE) and (DW + Design Pressure + TH - OBE). The shear and bending moment components are combined using the square root of the sum of the squares Fs= $\sqrt{(F_x^2 + F_z^2)}$ and for moment Mb= $\sqrt{(M_x^2 + M_z^2)}$ and since the first load combination produces higher stresses the stress intensity contour plot for this load combination is shown in Figure C-1. It is important to mention that the axial load here is considered to be Fy aligned to the axis of axisymmetry y. The stress output for the aforementioned load combinations is contained in output file [ ].

C.4 RESULTS AND CONCLUSIONS

It is clear from Figure C-1 that the existing length of the weld overlay provides enough material to attenuate the stresses (due to design pressure and external loads) effectively. It is important to note that the comparison with ASME Code limits are documented in the main body of this document and this Appendix is intended to only verify the stress attenuation under conservative assumption of losing the entire weld between safe end and nozzle.

Table C- 1 Computer Output Files For Appendix C

( )

Figure C- 1 Stress Intensity Contour for the Thin Weld Overlay Configuration

APPENDIX D

RE-ANALYSIS WITH INSURGE AND OUTSURGE TRANSIENT

D.1 PURPOSE

The purpose of this Appendix is to incorporate the addition of an Insurge and Outsurge Transient to the analysis. The methodology, design input, external loads, Design Condition, and all existing transients presented in the main body of this calculation still remain valid.

This evaluation is limited to minimum weld overlay configuration only based on the review of the stress results between maximum and minimum configurations. The final results are very similar between the two configurations, and therefore, only minimum weld overlay configuration is used.

The elastic or simplified elastic-plastic approach is used in this Appendix. An elastic-plastic approach will be implemented at those locations not qualified in this Appendix, and the evaluation will be documented in Appendix E.

D.2 THERMAL ANALYSIS

All transients described in Section 7 are still applicable. The added transients for insurge and outsurge is defined in Attachment 12 of Reference 13.8. The insurge and outsurge transitions can be separated into two groups. One group is during HUCD Transient, and the other is during transients other than HUCD. The first group has a maximum temperature drop of [ ], and the second group has maximum temperature drop of [ ] The number of cycles are conservatively added for all the possible events and separated into these two groups as shown in the Table below.

Table D-1 Insurge & Outsurge Transients

Transient ID Number	Operating Cycle	Name Abbreviation	Occurrences	Operating Condition
27	Insurge/Outsurge Transient	[	]	Normal (HUCD)
28	Insurge/Outsurge Transient			Normal & Upset (Non-HUCD)

Note (1): This transient only occurs during the HUCD Transient, and therefore it can only range with all other transients for [ ] cycles. The rest will only range within itself as subcycles.

The temperature and pressure profile of the two surge transients are developed based on Reference 13.8 and using the same approach to determine the HTC as Reference 13.16.

Table D-2 IOSurge Transient (Δt =[ ]

Time	Time	Fluid Temp Pzr	Fluid Temp Noz	Pressure	Flow Rate	HTC_{noz}	$HTC_{annulus\_eff}$	HTC_{pzr}
hr	*min*	*°F*	*°F*	*psia*	*gpm*	*Btu/hr·ft²·°F*	*Btu/hr·ft²·°F*	*Btu/hr·ft²·°F*
0.0001	0.001							
0.0500	3.000							
0.05001	3.001							
0.0667	4.000							
0.3167	19.000							
0.3333	20.000							
0.3334	20.001							
0.5000	30.000							
1.0000	60.000							
2.0000	120.000							

Table D-3 IOSurge110 Transient (Δt =[ ]

Time	Time	Fluid Temp Pzr	Fluid Temp Noz	Pressure	Flow Rate	HTC_{noz}	$HTC_{annulus\_eff}$	HTC_{pzr}
hr	*min*	*°F*	*°F*	*psia*	*gpm*	*Btu/hr·ft²·°F*	*Btu/hr·ft²·°F*	*Btu/hr·ft²·°F*
0.0000	0.001							
0.0500	3.000							
0.0500	3.001							
0.0667	4.000							
0.3167	19.000							
0.3333	20.000							
0.3334	20.001							
0.5000	30.000							
1.0000	60.000							
2.0000	120.000							

The detailed thermal loading due to these transients were applied to the thermal finite element model in the form of fluid and steam temperatures and HTC versus time.

The computer input files containing definition of these transients are:

[ ]

The computer output files for the thermal analyses of the transients are:

[ ]

The points on interests for temperature gradients are the same as illustrated in Table 7-2 and Figure 7-1. The results of the thermal analyses are evaluated by examining the magnitude of temperature differences between key locations of the model (see Figure 7-1). The time points of the maximum temperature gradient are those at which the maximum thermal stresses develop.

The computer output files that provide the temperatures at the selected locations are:

[ ]

Figure D-1 Temperature and Temperature Gradient for IOSurge Transient

Figure D-2 Temperature and Temperature Gradient for IOSurge110 Transient

D.3 STRUCTURAL ANALYSIS

Stress analyses are performed at those time points which the maximum temperature gradients (maximum thermal stresses) in addition to those defining the transient in Tables D-2 and D-3. The time points of interest are listed in the Tables below. In the following tables, those time points marked with asterisks have been taken directly from the transient definition; all other points represent temperature gradient extreme time points.

Table D-4 Structural Time Points of Interest for Insurge/Outsurge Transient with Temperature Drop of[ ]

Time	Temperature [°F]	Press [psi]
0.000100*		
0.050000*		
0.050100*		
0.050653		
0.066700*		
0.096707		
0.316700*		
0.333300*		
0.333400*		
0.500000*		
1.000000*		
2.000000*		

Table D-5 Structural Time Points of Interest for Insurge/Outsurge Transient with Temperature Drop of[ ]

Time	Temperature [°F]	Press [psi]
0.000100*		
0.050000*		
0.050100*		
0.051207		
0.053128		
0.066700*		
0.083669		
0.316700*		
0.333300*		
0.333400*		
0.500000*		
1.000000*		
2.000000*		

The nodal temperature at the particular time point is read into the structural model directly from the result file of the thermal analysis. The corresponding pressure is obtained through linear interpolation from appropriate tables listed in Tables D-2 and D-3. The computer output files for the structural analyses of the Insurge/Outsurge Transients are:

[ ]

D.4 ASME CODE CRITERIA

The ASME Code stress analysis involves two basic sets of criteria:

1. Assure that failure does not occur due to application of the design loads.
2. Assure that failure does not occur due to repetitive loading.

In general, the Primary Stress Intensity criteria of the ASME Code (Reference 13.1) assure that the design is adequate for application of design loads.

Also, the ASME Code criteria for cumulative fatigue usage factor assure that the design is adequate for repetitive loading.

D.4.1 ASME CODE PRIMARY STRESS INTENSITY (SI) CRITERIA

As explained in Section 9.1, the nozzle configuration with structural weld overlay is qualified for primary stress consideration. Therefore, no primary stress evaluation is included in this Appendix.

D.4.2 ASME CODE PRIMARY+SECONDARY STRESS INTENSITY (SI) CRITERIA

As stated previously, the analyses of stresses for transient conditions are required to satisfy the requirements for the repetitive loadings. The following discussion describes the fatigue analysis process employed herein for the design.

Overall stress levels are reviewed and assessed to determine which model locations require detailed stress/fatigue analysis. The objective is to assure that:

1. The most severely stressed locations are evaluated.
2. The specified region is quantitatively qualified.

D.4.2.1 Path Stress Evaluation

The ANSYS Post Processor is used to tabulate the stresses along predetermined paths and classify them in accordance with the ASME Code Criteria (i.e., membrane, membrane plus bending, total). For paths that go through 2 materials partial paths are taken in addition to the free edge to free edge.

For this analysis, the same paths for the minimum WOL are analyzed. The paths are shown in Figure 9-1 and Figure 9-2 and are described in Table 9-1.

D.4.2.2 Primary+Secondary Stress Intensity Range Qualification

The ANSYS Post Processor was used to find the membrane + bending Stress Intensity Ranges and total Stress Intensity Ranges based on the method prescribed in paragraph NB-3216.2 of the ASME Code. The computer runs containing the results of the stress ranges calculation for membrane + bending, total stresses and associated usage factors are listed below.

( )

The membrane + bending stress ranges as determined in the stress range runs are conservatively combined by hand with the stresses due to external loads (calculated in Section 5.2 of the main document) where appropriate. The maximum membrane + bending Stress Intensity Ranges are compared directly to the Primary + Secondary Stress Intensity Range criteria of the ASME Code. The summary of maximum membrane + bending Stress Intensity Ranges for the minimum WOL configuration is tabulated in Table D-6 through Table D-8.

Note that the Zero Stress State (ZSS) is included in the ANSYS runs listed above.

Table D-6 Summary of Maximum Primary + Secondary SI Ranges for Membrane + Bending Stresses (Minimum WOL)

Path	Transient Stresses w/ Surge		Applicable External Stresses	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]
PipeL				
P_Wol				
P_Wola				
P_Wolb				
SEU_Weld				
SEU_Welda				
SEU_Weldb				
SEU_Wol				
SEU_Wola				
SEU_Wolb				
SEL_Wol				
SEL_Wola				
SEL_Wolb				
SEL_Weld				
SEL_Welda				
SEL_Weldb				
N_Wol				
N_Wola				
N_Wolb				
Noz				
Sleeve				

Note (1): External stress at outside node of full path is conservatively used for the partial path node located at material interface.

Table D-7 Comparison of Maximum SI Range including External Loads to ASME Code 3*Sm Criteria (Minimum WOL)

Path	Transient + External Stresses		Allowable M+B SI Range 3*Sm(1)		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node [ksi]	Outside Node [ksi]	Outside Node	Inside Node
PipeL						
P_Wol						
P_Wola						
P_Wolb						
SEU_Weld						
SEU_Welda						
SEU_Weldb						
SEU_Wol						
SEU_Wola						
SEU_Wolb						
SEL_Wol						
SEL_Wola						
SEL_Wolb						
SEL_Weld						
SEL_Welda						
SEL_Weldb						
N_Wol						
N_Wola						
N_Wolb						
Noz						
Sleeve						

Table D-8 External Stress Added by Components (Minimum WOL)

Table D-8 (Continued) External Stress Added by Components (Minimum WOL)

Table D-8 (Continued) External Stress Added by Components (Minimum WOL)

Table D-8 (Continued) External Stress Added by Components (Minimum WOL)

Table D-8 (Continued) External Stress Added by Components (Minimum WOL)

D.4.2.2.1 Summary of Stress Intensity Range Qualification

Tables D-7 and D-8 show the maximum SI Range calculated and the allowable limits for both maximum and minimum weld overlay configurations. The following path locations for both configurations exceeded the allowable 3*Sm limit:

- PipeL – inside and outside nodes
- SEU_Welda – outside node
- SEU_Wol – inside node
- SEU_Wola – inside and outside nodes
- SEL_Wola – inside node
- Sleeve – inside and outside node

The ASME Code allows the 3*Sm limit to be exceeded under special conditions, one of them being that Simplified Elastic-Plastic Analysis (NB 3228.5) is used for fatigue analysis. See Section D.4.2.3 for further qualifications.

D.4.2.3 Simplified Elastic-Plastic Analysis (NB-3228.5)

The maximum Primary + Secondary Stress Intensity criterion in Section D.4.2.2 is not met for the locations determined in the Section D.4.2.2.1. Therefore, the simplified elastic-plastic analysis for these locations is provided in this section.

The Primary + Secondary Stress Intensity range in the model may exceed $3*S_m$ if the requirements of the simplified elastic-plastic analysis are met. The requirements are:

D.4.2.3.1 Primary + Secondary SI Range (Excluding thermal bending stresses) (NB-3228.5(a))

The range of Primary + Secondary membrane + bending stress intensity, excluding thermal bending stresses, shall be ≤ 3*Sm.

The SI ranges excluding thermal bending are calculated for the locations identified in Section D.4.2.2.1. The membrane + bending ANSYS output files listed in Section D.4.2.2 are used to find the stress components for membrane stress due to pressure and thermal conditions.

The bending stress due to pressure only is determined by multiplying the bending stress obtained from design linearization output files [ ] with a pressure ratio. The ratio is based on the transient pressure at the time point of interest and design pressure. The ratioed bending stress is added to the membrane stress and external stress for determination of SI range without thermal bending effect.

The design condition is [ ] The applied temperature affects only physical material properties, therefore the effect of thermal bending is considered to be negligible.

Tables D-9 presents the calculations and results for the maximum primary + secondary SI Ranges for membrane + bending – thermal bending stresses per NB-3228.5(a) for the minimum WOL.

Table D-9 Minimum WOL SI Ranges Minus Thermal Bending

Table D-9 (Continued) Minimum WOL SI Ranges Minus Thermal Bending

Table D-9 (Continued) Minimum WOL SI Ranges Minus Thermal Bending

Table D-9 (Continued) Minimum WOL SI Ranges Minus Thermal Bending

Table D-9 (Continued) Minimum WOL SI Ranges Minus Thermal Bending

All SI Ranges listed in Tables D-4 are less than the allowable stress, therefore the requirement of ASME NB-3228.5(a) has been met on all locations.

D.4.2.3.2 Factor Ke (NB-3228.5(b))

The values of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where

$$K_e = 1.0 + \frac{1-n}{n \cdot (m-1)} \cdot \left(\frac{S_n}{3 \cdot S_m} - 1 \right) \qquad \text{for } 3 \cdot S_m < S_n < 3 \cdot m \cdot S_m$$

$$K_e = 1.0 / n \qquad \text{for } S_n \geq 3 \cdot m \cdot S_m$$

m = 1.7	for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference 13.1)
n = 0.3	for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference 13.1)
S_m [ksi]	@ average temperature of the metal at the critical time points
S_n [ksi]	Primary + Secondary membrane plus bending SI Range

The K_e factor is calculated for each SI Ranges over the $3xS_m$ limit in the fatigue evaluation as documented in Section D.4.2.4.

D.4.2.3.3 Fatigue Usage Factor (NB-3228.5(c) and NB-3222.4)

For fatigue usage factor evaluation see Section D.4.2.4.

D.4.2.3.4 Thermal Stress Ratchet (NB-3228.5(d) and NB-3222.5)

Thermal Ratchet is considered for the locations listed in Section D.4.2.2.1.

Some of these locations are parts of the local geometric discontinuities. The ASME Code requirements for thermal ratcheting are considered accurately only for cylindrical shells without discontinuities. On the other hand, the requirements for thermal ratcheting at discontinuities are considered to be "probably overly conservative" (Reference 13.12, page 207).

Maximum Allowable Range of Thermal Stress (NB-3222.5):

Tables D-10 determines the maximum allowable ranges of thermal stresses in the piping and thermal sleeve. The values of allowable stresses are conservatively calculated based on the membrane stresses due to the design pressure[ ].

The "S1" values are obtained from ANSYS output files [ ] and [ ].

NB-3222.5 only requires the SI Range to include thermal SI Ranges and those from the output files also contain pressure effects. The Thermal SI Ranges are calculated in Tables D-11.

Table D-10 Allowable Ranges of Thermal Stresses for Minimum WOL

Path	SI Range[1]	Maximum Temperature [2] [3]	Sm	1.5*Sm	Sy	S1	x	y'	Allowable SI Range
	[ksi]	[°F]	[ksi]	[ksi]	[ksi]	[ksi]			[ksi]

Note [1]: See Table D-11
Note [2]: See Table D-7
Note [3]: See Table D-8

Where:

x = max. general membrane stress due to pressure ("S1") divided by the yield strength S_y [1]

$y' = \frac{1}{x}$ for $0.0 < x < 0.5$; $y' = 4(1-x)$ for $0.5 < x < 1.0$.

Maximum allowable range of thermal stress = y' * S_y [1]

Note [1]: $1.5S_m$ is used instead of S_y. Per NB-3222.5, note 11, it is permissible to use $1.5S_m$ in this equation whenever it is greater than S_y.

The maximum SI Ranges of thermal stresses are less than the allowable stresses; therefore the requirement has been met.

Table D-11 Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

Table D-11 (Continued) Thermal M+B SI Range for Minimum WOL

D.4.2.3.5 Thermal Only External Loading

Seismic external loads are assumed to only occur during the steady state transient. Because the two transients ranging to create the maximum stress intensity are not the steady state condition, the OBE external loads can be excluded from the total stress intensity range. When the steady state condition (PLUL) ranges with another transient, the stress state is significantly less than the maximum stress intensity range such that even if OBE and Thermal external loads were combined with it, the total stress intensity would not govern. From Reference 13.16, the enveloped external loads due to Thermal loads only are:

Table D-12 Thermal External Loads

Thermal Loads	Fy (Axial) *kip*	Fx *kip*	Fz *kip*	Fs (Shear)(1) *kip*	Mtx (Torsional) *in- kip*	Mx *in- kip*	Mz *in- kip*	Mb (Bending)(2) *in- kip*
[								]

Note (1): Shear is calculated as the SRSS of Fx and Fz.

Note (2): Bending is calculated as the SRSS of Mx and Mz.

Using the dimensions and equations in presented in Section 5.1 and 5.2, the following external loads are found for path PipeL, outside diameter:

Table D-13 Thermal External Loads

Loading	Axial Stress				Shear Stress			M+B
	σ_{ax_EX} [ksi]	σ_{ax_BF} [ksi]	σ_{ax_BM} [ksi]	σ_{ax_M+B} [ksi]	τ_{s_Fs} [ksi]	τ_{s_Mt} [ksi]	τ_s [ksi]	Sint [ksi]
[								]

D.4.2.3.5 Temperature Limits (NB-3228.5(e))

The maximum temperature of the components is [ ] which does not exceed the maximum allowable temperatures listed in Table NB-3228.5(b)-1, Reference 13.1.

Therefore, the ASME Code requirement is met.

D.4.2.3.7 Minimum Strength Ratio (NB-3228.5(f))

The material shall have specified minimum yield strength to specified minimum tensile strength ratio of less then 0.80.

The S_y and S_u values at 70°F are obtained from Reference 13.15.

For [ ]
Specified minimum yield strength, S_y = 30 ksi @70°F
Specified minimum tensile strength, S_u = 75 ksi @70°F
Ratio of S_y/S_u = 0.40

[ ]
Specified minimum yield strength, S_y = 30 ksi @70°F
Specified minimum tensile strength, S_u = 75 ksi @70°F
Ratio of S_y/S_u = 0.40

[ ]
Specified minimum yield strength, S_y = 25 ksi @70°F
Specified minimum tensile strength, S_u = 65 ksi @70°F
Ratio of S_y/S_u = 0.38

[ ]
Specified minimum yield strength, S_y = 30 ksi @70°F
Specified minimum tensile strength, S_u = 75 ksi @70°F
Ratio of S_y/S_u = 0.40

Therefore, the ASME Code requirement is met.

D.4.2.4 Fatigue Usage Factor Calculation

For consideration of fatigue usage, the Peak Stress Intensity Ranges are calculated. These values must include the total localized stresses.

The fatigue usage factor at a location is usually calculated based on the actual stress intensity range. However, at a geometric or material discontinuity, an unrealistic peak stress may result from the modeling approach, element type and mesh sizes. The total stress obtained from the finite element analysis may not be able to capture the actual stress condition. To account for the possible modeling inaccuracies, an FSRF is usually applied to the M+B stress intensity range for location experiencing the discontinuity.

The stress category used in fatigue evaluation, along with an appropriate FSRF, for each node is listed in Table D-12. For path lines nearby the thermal sleeve weld (i.e., crevice), M+B stresses with a FSRF of 4.0 are applied. Per Reference 13.13 (p. 395), the FSRF for node on the inside and outside of the safe end component, outer nozzle, and pipe near WOL junction are based on a bounding taper angle.

Table D-12 Stress Category and FSRF in Fatigue Evaluation

Path Name	Inside Node		Outside Node	
	Stress Category	FSRF	Stress Category	FSRF
PipeL	TOTAL		M+B	
P_Wol	M+B		TOTAL	
P_Wola	M+B		TOTAL	
P_Wolb	TOTAL		TOTAL	
SEU_Weld	M+B		TOTAL	
SEU_Welda	M+B		M+B	
SEU_Weldb	M+B		TOTAL	
SEU_Wol	M+B		TOTAL	
SEU_Wola	M+B		M+B	
SEU_Wolb	M+B		TOTAL	
SEL_Wol	M+B		TOTAL	
SEL_Wola	M+B		M+B	
SEL_Wolb	M+B		TOTAL	
SEL_Weld	M+B		TOTAL	
SEL_Welda	M+B		M+B	
SEL_Weldb	M+B		TOTAL	
N_Wol	TOTAL		TOTAL	
N_Wola	TOTAL		TOTAL	
N_Wolb	TOTAL		TOTAL	
Noz	TOTAL		M+B	
TS	TOTAL		M+B	

For the location determined to be critical, the corresponding external loads from Table 5-5 through Table 5-16 have been incorporated in the fatigue calculation. Using the SI ranges and cycles taken from the "fatigue" output files (see Section 12), the bounding external SI (including thermal stratification) have been added manually to the first( )cycles and the fatigue usage factor then recalculated. This method of adding the external SI to the transient SI is a conservative method as shown in the previous sections.

( )

The thermal stratification external loads are included in the fatigue calculation as independent sub-cyles. For each case the usage factor calculation is based upon the SI specified in Table 5-7 through Table 5-16 and the number of cycles for each case as stated in Reference 13.8.

The following pages contain the calculation of the cumulative fatigue usage factor for the points of interest. The usage factor includes Transient loading and all applicable external loadings. The calculation is performed separately for seven materials and different parts of model.

The critical locations are:

( )

Table D-13 PipeL Usage Factor Calculation

Evaluation Title: North Anna - PZR Surge Nozzle Weld Overlay Analysis - PipeL (Outside Node, 6103)
Reference Files:
Material:
Type:
UTS (ksi) =
E matl (psi) =

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'SIA'-'IOSurge_1'							
2	'HUCD_1'-'IOSurge_1'							
3	'HUCD_1'-'RT_CDSI'							
4	'HUCD_1'-'RCOP'							
5	'HUCD_1'-'HUCD_2'							
6	'HUCD_2'-'IOSurge110_2'							
7	'RCSD'-'IOSurge_2'							
8	'SUIL'-'IOSurge110_2'							
9	'RT_CDnSI-'IOSurge_2'							
10	'RT_CDnSI-'IOSurge_2'							
11	'CRD'-'IOSurge110_2'							
12	'IOSurge_2'-'IOSurge110_2'							
13	'FCHSD'-'IOSurge110_2'							
14	'LOSLSD'-'IOSurge110_2'							
15	'LOF'-'IOSurge110_2'							
16	'IOSurge110_1'-'IOSurge110_2'							
17	'LOP'-'IOSurge110_1'							
18	'LOL'-'IOSurge110_1'							
19	'RT_noCD'-'IOSurge110_1'							
20	'PLUL_1'-'IOSurge110_1'							
21	'PLUL_1'-'PLUL_1'							
22	'LSDL'-'LSDL'							
23	'10SLdec'-'10SLdec'							
24	'BCE'-'TRT'							
25	'BCE'-'PLUL_2'							
26	'10SLinc'-'BCE'							
27	'BCE'-'LOSLSU'							
28	'BCE'-'BCE'							
29	HU-340							
30	HU-200							
31	HU-100							
32	HU-147							

Table D-13 (Continued) PipeL Usage Factor Calculation

33	OP-43
34	IO Surge Sub-Cycles
35	Sub-Cycle within HUCD

The 'Peak SI Range' = 'Memb + Bend' SI Range
Range 1, 'Memb + Bend' SI Range =
Range 2, 'Memb + Bend' SI Range =
Range 3, 'Memb + Bend' SI Range =
Range 4, 'Memb + Bend' SI Range =
Range 5, 'Memb + Bend' SI Range =
Range 6, 'Memb + Bend' SI Range =
Range 7, 'Memb + Bend' SI Range =
Range 8, 'Memb + Bend' SI Range =
Range 9, 'Memb + Bend' SI Range =
Range 10, 'Memb + Bend' SI Range =
Range 11, 'Memb + Bend' SI Range =
Range 12, 'Memb + Bend' SI Range =
Range 13, 'Memb + Bend' SI Range =
Range 14, 'Memb + Bend' SI Range =
Range 15, 'Memb + Bend' SI Range =
Range 16, 'Memb + Bend' SI Range =
Range 17, 'Memb + Bend' SI Range =
Range 18, 'Memb + Bend' SI Range =
Range 19, 'Memb + Bend' SI Range =
Range 20, 'Memb + Bend' SI Range =
Range 21, 'Memb + Bend' SI Range =
Range 22, 'Memb + Bend' SI Range =
Range 23, 'Memb + Bend' SI Range =
Range 24, 'Memb + Bend' SI Range =
Range 25, 'Memb + Bend' SI Range =
Range 26, 'Memb + Bend' SI Range =
Range 27, 'Memb + Bend' SI Range =
Range 28, 'Memb + Bend' SI Range =
Range 29, 'Memb + Bend' SI Range =
Range 30, 'Memb + Bend' SI Range =
Range 31, 'Memb + Bend' SI Range =
Range 32, 'Memb + Bend' SI Range =
Range 33, 'Memb + Bend' SI Range =

Table D-13 (Continued) PipeL Usage Factor Calculation

Location	M+B Transient SI Range	Temp 1	Temp 2	Max. Temp.	Sm	External SI	Transient + External SI Range	EQ 1 (3)	EQ 2 (3)	Ke Factor
	ksi	°F	°F	°F	ksi	ksi	ksi			

Note (1): Max. Temperature used to find the Ematl value.

Note (2): Thermal only external loads. See Section D.4.2.3.5.

Note (3): Equation 1 and 2 for Ke values are presented in Section D.4.2.3.2.

Table D-14 SEU_Weld Usage Factor Calculation

Evaluation Title: North Anna - PZR Surge Nozzle Weld Overlay Analysis - SEU_Weld (Inside Node, 6244)
Reference Files:
Material:
Type:
UTS (ksi) =
E matl (psi) =

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'RCSD'-'IOSurge_1'							
2	'LOL'-'IOSurge_1'							
3	'RT_CDnSI-'IOSurge_1'							
4	'RT_CDnSI-'RT_CDSI'							
5	'HUCD_1'-'RT_CDnSI							
6	'CRD'-'HUCD_1'							
7	'HUCD_1'-'HUCD_1'							
8	'HUCD_2'-'SIA'							
9	'HUCD_2'-'RT_noCD'							
10	'HUCD_2'-'RT_noCD'							
11	'RCOP'-'RT_noCD'							
12	'RT_noCD'-'IOSurge_2'							
13	'LOF'-'IOSurge_2'							
14	'LSDL'-'IOSurge_2'							
15	'LSDL'-'SUIL'							
16	'FCHSD'-'LSDL'							
17	'FCHSD'-'LOSLSD'							
18	'FCHSD'-'LOP'							
19	'10SLdec'-'FCHSD'							
20	'10SLdec'-'IOSurge110_1'							
21	'BCE'-'IOSurge110_1'							
22	'TRT'-'IOSurge110_1'							
23	'PLUL_1'-'IOSurge110_1'							
24	'PLUL_1'-'PLUL_1'							
25	'PLUL_2'-'IOSurge110_2'							
26	'10SLinc'-'IOSurge110_2'							
27	'IOSurge110_2'-'IOSurge110_2'							
28	'LOSLSU'-'LOSLSU'							
29	HU-340							
30	HU-200							
31	HU-100							
32	HU-147							
33	OP-43							

Table D-14 (Continued) SEU_Weld Fatigue Usage Factor Calculation

34	IOSurge Sub-Cycles
35	Sub-Cycle within HUCD

The 'Peak SI Range' = 'Memb + Bend' SI Ran
Range 1, 'Memb + Bend' SI Range =
Range 2, 'Memb + Bend' SI Range =
Range 3, 'Memb + Bend' SI Range =
Range 4, 'Memb + Bend' SI Range =
Range 5, 'Memb + Bend' SI Range =
Range 6, 'Memb + Bend' SI Range =
Range 7, 'Memb + Bend' SI Range =
Range 8, 'Memb + Bend' SI Range =
Range 9, 'Memb + Bend' SI Range =
Range 10, 'Memb + Bend' SI Range =
Range 11, 'Memb + Bend' SI Range =
Range 12, 'Memb + Bend' SI Range =
Range 13, 'Memb + Bend' SI Range =
Range 14, 'Memb + Bend' SI Range =
Range 15, 'Memb + Bend' SI Range =
Range 16, 'Memb + Bend' SI Range =
Range 17, 'Memb + Bend' SI Range =
Range 18, 'Memb + Bend' SI Range =
Range 19, 'Memb + Bend' SI Range =
Range 20, 'Memb + Bend' SI Range =
Range 21, 'Memb + Bend' SI Range =
Range 22, 'Memb + Bend' SI Range =
Range 23, 'Memb + Bend' SI Range =
Range 24, 'Memb + Bend' SI Range =
Range 25, 'Memb + Bend' SI Range =
Range 26, 'Memb + Bend' SI Range =
Range 27, 'Memb + Bend' SI Range =
Range 28, 'Memb + Bend' SI Range =
Range 29, 'Memb + Bend' SI Range =
Range 30, 'Memb + Bend' SI Range =
Range 31, 'Memb + Bend' SI Range =
Range 32, 'Memb + Bend' SI Range =
Range 33, 'Memb + Bend' SI Range =

Table D-14 (Continued) SEU_Weld Fatigue Usage Factor Calculation

Location	M+B Transient SI Range	Temp 1	Temp 2	Max. Temp.	Sm	External SI	Transient + External SI Range	EQ 1 (1)	EQ 2 (1)	Ke Factor
	ksi	*°F*	*°F*	*°F*	*ksi*	*ksi*	*ksi*			

Note [1]: Equation 1 and 2 for Ke values are presented in Section D.4.2.3.2.

Table D-15 SEL_Wola Usage Factor Calculation

Evaluation Title:	North Anna - PZR Surge Nozzle Weld Overlay Analysis - SEL_Wola (Inside Node, 5060)
Reference Files:	
Material:	
Type:	
UTS (ksi) =	
E matl (psi) =	

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'HUCD_1'-'IOSurge_1'							
2	'RCSD'-'RT_CDSI'							
3	'RCSD'-'SUIL'							
4	'SIA'-'IOSurge_2'							
5	'CRD'-'IOSurge_2'							
6	'FCHSD'-'IOSurge_2'							
7	'FCHSD'-'RT_CDnSI							
8	'FCHSD'-'RT_CDnSI							
9	'FCHSD'-'LOL'							
10	'FCHSD'-'RT_noCD'							
11	'FCHSD'-'LOF'							
12	'FCHSD'-'LSDL'							
13	'FCHSD'-'LOSLSD'							
14	'FCHSD'-'PLUL_1'							
15	'HUCD_2'-'PLUL_1'							
16	'PLUL_1'-'RCOP'							
17	'PLUL_1'-'IOSurge110_1'							
18	'10SLdec'-'IOSurge110_1'							
19	'BCE'-'IOSurge110_1'							
20	'BCE'-'LOP'							
21	'PLUL_2'-'IOSurge110_2'							
22	'10SLinc'-'BCE'							
23	'BCE'-'LOSLSU'							
24	'TRT'-'IOSurge110_2'							
25	'BCE'-'IOSurge110_2'							
26	'IOSurge110_2'-'IOSurge110_2'							
27	HU-340							
28	HU-200							
29	HU-100							
30	HU-147							
31	OP-43							

Table D-15 (Continued) SEL_Wola Usage Factor Calculation

34	IO Surge Sub-Cycles [2]
35	Sub-Cycle within HUCD

The 'Peak SI Range' = 'Memb + Bend' SI Ra
Range 1, 'Memb + Bend' SI Range =
Range 2, 'Memb + Bend' SI Range =
Range 3, 'Memb + Bend' SI Range =
Range 4, 'Memb + Bend' SI Range =
Range 5, 'Memb + Bend' SI Range =
Range 6, 'Memb + Bend' SI Range =
Range 7, 'Memb + Bend' SI Range =
Range 8, 'Memb + Bend' SI Range =
Range 9, 'Memb + Bend' SI Range =
Range 10, 'Memb + Bend' SI Range =
Range 11, 'Memb + Bend' SI Range =
Range 12, 'Memb + Bend' SI Range =
Range 13, 'Memb + Bend' SI Range =
Range 14, 'Memb + Bend' SI Range =
Range 15, 'Memb + Bend' SI Range =
Range 16, 'Memb + Bend' SI Range =
Range 17, 'Memb + Bend' SI Range =
Range 18, 'Memb + Bend' SI Range =
Range 19, 'Memb + Bend' SI Range =
Range 20, 'Memb + Bend' SI Range =
Range 21, 'Memb + Bend' SI Range =
Range 22, 'Memb + Bend' SI Range =
Range 23, 'Memb + Bend' SI Range =
Range 24, 'Memb + Bend' SI Range =
Range 25, 'Memb + Bend' SI Range =
Range 26, 'Memb + Bend' SI Range =
Range 27, 'Memb + Bend' SI Range =
Range 28, 'Memb + Bend' SI Range =
Range 29, 'Memb + Bend' SI Range =
Range 30, 'Memb + Bend' SI Range =
Range 31, 'Memb + Bend' SI Range =

Table D-15 (Continued) SEL_Wola Usage Factor Calculation

Location	M+B Transient SI Range	Temp 1	Temp 2	Max Temp.	Sm	External SI	Transient + External SI Range	EQ 1 (3)	EQ 2 (3)	Ke Factor
	ksi	°F	°F	°F	ksi	ksi	ksi			
[										]

Note (1): Max. Temperature used to find the E matl value.

Note (2): Plastic analysis is used to find the CFUF associated with the Insurge/Outsurge Subcycles. See Appendix E.

Note (3): Equations 1 and 2 for Ke values are presented in Section D.4.2.3.2.

Note (4): IOSurge Transient contributes a partial usage factor of [ ] when this transient ranges within itself (i.e., sub-cycles), see Section D.4.2.4 (last paragraph).

Because the total usage factor of [ ] is above the allowable value 1.0, plastic analysis is performed for IOSurge Transient at this location (SEL_Wola) in Appendix E.

Table D-16 SEL_Welda Usage Factor Calculation

Evaluation Title: North Anna - PZR Surge Nozzle Weld Overlay Analysis - SEL_Welda (Inside Node, 6103)
Reference Files:
Material:
Type:
UTS (ksi) =
E matl (psi) =

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'HUCD_1'-'LOP'							
2	'BCE'-'HUCD_1'							
3	'BCE'-'HUCD_2'							
4	'LOL'-'IOSurge_1'							
5	'RT_CDnSI-'IOSurge_1'							
6	'RT_CDnSI-'IOSurge_1'							
7	'BCE'-'IOSurge_2'							
8	'BCE'-'RCOP'							
9	'RT_CDnSI-'RT_CDSI'							
10	'RT_CDnSI-'SIA'							
11	'RCSD'-'SIA'							
12	'CRD'-'SIA'							
13	'CRD'-'FCHSD'							
14	'FCHSD'-'LOF'							
15	'FCHSD'-'LOSLSD'							
16	'FCHSD'-'LSDL'							
17	'FCHSD'-'RT_noCD'							
18	'10SLdec'-'FCHSD'							
19	'10SLdec'-'IOSurge110_1'							
20	'PLUL_1'-'IOSurge110_1'							
21	'BCE'-'IOSurge110_1'							
22	'BCE'-'SUIL'							
23	'PLUL_2'-'IOSurge110_2'							
24	'BCE'-'IOSurge110_2'							
25	'10SLinc'-'TRT'							
26	'LOSLSU'-'IOSurge110_2'							
27	'10SLinc'-'IOSurge110_2'							
28	'IOSurge110_2'-'IOSurge110_2'							
29	HU-340							
30	HU-200							
31	HU-100							
32	HU-147							

Table D-16 (Continued) SEL_Welda Usage Factor Calculation

33	OP-43	
34	IO Surge Sub-Cycles	
35	Sub-Cycle within HUCD	

The 'Peak SI Range' = 'Memb + Bend' SI Ra

Range 1, 'Memb + Bend' SI Range =
Range 2, 'Memb + Bend' SI Range =
Range 3, 'Memb + Bend' SI Range =
Range 4, 'Memb + Bend' SI Range =
Range 5, 'Memb + Bend' SI Range =
Range 6, 'Memb + Bend' SI Range =
Range 7, 'Memb + Bend' SI Range =
Range 8, 'Memb + Bend' SI Range =
Range 9, 'Memb + Bend' SI Range =
Range 10, 'Memb + Bend' SI Range =
Range 11, 'Memb + Bend' SI Range =
Range 12, 'Memb + Bend' SI Range =
Range 13, 'Memb + Bend' SI Range =
Range 14, 'Memb + Bend' SI Range =
Range 15, 'Memb + Bend' SI Range =
Range 16, 'Memb + Bend' SI Range =
Range 17, 'Memb + Bend' SI Range =
Range 18, 'Memb + Bend' SI Range =
Range 19, 'Memb + Bend' SI Range =
Range 20, 'Memb + Bend' SI Range =
Range 21, 'Memb + Bend' SI Range =
Range 22, 'Memb + Bend' SI Range =
Range 23, 'Memb + Bend' SI Range =
Range 24, 'Memb + Bend' SI Range =
Range 25, 'Memb + Bend' SI Range =
Range 26, 'Memb + Bend' SI Range =
Range 27, 'Memb + Bend' SI Range =
Range 28, 'Memb + Bend' SI Range =
Range 29, 'Memb + Bend' SI Range =
Range 30, 'Memb + Bend' SI Range =
Range 31, 'Memb + Bend' SI Range =
Range 32, 'Memb + Bend' SI Range =
Range 33, 'Memb + Bend' SI Range =

Table D-17 P_Wol Fatigue Usage Factor Calculation

Evaluation Title: North Anna - PZR Surge Nozzle Weld Overlay Analysis - P_Wol (Outside Node, 5986)
Reference Files:
Material:
Type:
UTS (ksi) =
E matl (psi) =

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'LOP'-'IOSurge_1'							
2	'HUCD_1'-'IOSurge_1'							
3	'HUCD_1'-'HUCD_1'							
4	'HUCD_2'-'LOSLSD'							
5	'BCE'-'HUCD_2'							
6	'BCE'-'RT_CDSI'							
7	'BCE'-'RCOP'							
8	'BCE'-'IOSurge_2'							
9	'BCE'-'IOSurge_2'							
10	'BCE'-'RCSD'							
11	'BCE'-'SIA'							
12	'BCE'-'CRD'							
13	'BCE'-'FCHSD'							
14	'BCE'-'IOSurge110_1'							
15	'10SLdec'-'IOSurge110_1'							
16	'LOL'-'IOSurge110_1'							
17	'LSDL'-'IOSurge110_1'							
18	'PLUL_1'-'IOSurge110_1'							
19	'PLUL_1'-'SUIL'							
20	'PLUL_1'-'RT_CDnSI							
21	'PLUL_1'-'PLUL_1'							
22	'PLUL_2'-'TRT'							
23	'LOF'-'PLUL_2'							
24	'PLUL_2'-'RT_noCD'							
25	'PLUL_2'-'IOSurge110_2'							
26	'10SLinc'-'IOSurge110_2'							
27	'LOSLSU'-'IOSurge110_2'							
28	'IOSurge110_2'-'IOSurge110_2'							
29	HU-340							
30	HU-200							
31	HU-100							
32	HU-147							

Table D-17 (Continued) P Wol Fatigue Usage Factor Calculation

33	OP-43
34	IOSurge Sub-Cycles
35	Sub-Cycle within HUCD

The 'Peak SI Range' = 'Total' SI Range x Fatig

Range 1, 'Total' SI Range =
Range 2, 'Total' SI Range =
Range 3, 'Total' SI Range =
Range 4, 'Total' SI Range =
Range 5, 'Total' SI Range =
Range 6, 'Total' SI Range =
Range 7, 'Total' SI Range =
Range 8, 'Total' SI Range =
Range 9, 'Total' SI Range =
Range 10, 'Total' SI Range =
Range 11, 'Total' SI Range =
Range 12, 'Total' SI Range =
Range 13, 'Total' SI Range =
Range 14, 'Total' SI Range =
Range 15, 'Total' SI Range =
Range 16, 'Total' SI Range =
Range 17, 'Total' SI Range =
Range 18, 'Total' SI Range =
Range 19, 'Total' SI Range =
Range 20, 'Total' SI Range =
Range 21, 'Total' SI Range =
Range 22, 'Total' SI Range =
Range 23, 'Total' SI Range =
Range 24, 'Total' SI Range =
Range 25, 'Total' SI Range =
Range 26, 'Total' SI Range =
Range 27, 'Total' SI Range =
Range 28, 'Total' SI Range =
Range 29, 'Total' SI Range =
Range 30, 'Total' SI Range =
Range 31, 'Total' SI Range =
Range 32, 'Total' SI Range =
Range 33, 'Total' SI Range =

Table D-18 Noz Fatigue Usage Factor Calculation

Evaluation Title:	**North Anna - PZR Surge Nozzle Weld Overlay Analysis - Noz (Outside Node, 4868)**
Reference Files:	
Material:	
Type:	
UTS (ksi) =	
E matl =	

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'HUCD_1'-'IOSurge_1'							
2	'HUCD_2'-'LOP'							
3	'HUCD_2'-'IOSurge110_2'							
4	'RCOP'-'IOSurge110_2'							
5	'RT_CDSI'-'IOSurge_2'							
6	'RCSD'-'IOSurge_2'							
7	'SIA'-'IOSurge_2'							
8	'IOSurge_2'-'IOSurge110_2'							
9	'FCHSD'-'IOSurge110_2'							
10	'CRD'-'IOSurge110_2'							
11	'IOSurge110_1'-'IOSurge110_2'							
12	'LOSLSD'-'IOSurge110_1'							
13	'PLUL_1'-'IOSurge110_1'							
14	'PLUL_1'-'PLUL_1'							
15	'10SLdec'-'SUIL'							
16	'10SLdec'-'RT_CDnSI							
17	'10SLdec'-'TRT'							
18	'10SLdec'-'LOF'							
19	'10SLdec'-'RT_noCD'							
20	'10SLdec'-'PLUL_2'							
21	'PLUL_2'-'PLUL_2'							
22	'BCE'-'LOL'							
23	'10SLinc'-'BCE'							
24	'BCE'-'LOSLSU'							
25	'BCE'-'LSDL'							
26	'BCE'-'BCE'							
27	HU-340							
28	HU-200							
29	HU-100							
30	HU-147							

Table D-18 (Continued) Noz Fatigue Usage Factor Calculation

31	OP-43	
32	IO Surge Sub-Cycles	
33	Sub-Cycle within HUCD	

The 'Peak SI Range' = 'Total' SI Range x Ke (a

Range 1, 'Total' SI Range =
Range 2, 'Total' SI Range =
Range 3, 'Total' SI Range =
Range 4, 'Total' SI Range =
Range 5, 'Total' SI Range =
Range 6, 'Total' SI Range =
Range 7, 'Total' SI Range =
Range 8, 'Total' SI Range =
Range 9, 'Total' SI Range =
Range 10, 'Total' SI Range =
Range 11, 'Total' SI Range =
Range 12, 'Total' SI Range =
Range 13, 'Total' SI Range =
Range 14, 'Total' SI Range =
Range 15, 'Total' SI Range =
Range 16, 'Total' SI Range =
Range 17, 'Total' SI Range =
Range 18, 'Total' SI Range =
Range 19, 'Total' SI Range =
Range 20, 'Total' SI Range =
Range 21, 'Total' SI Range =
Range 22, 'Total' SI Range =
Range 23, 'Total' SI Range =
Range 24, 'Total' SI Range =
Range 25, 'Total' SI Range =
Range 26, 'Total' SI Range =
Range 27, 'Total' SI Range =
Range 28, 'Total' SI Range =
Range 29, 'Total' SI Range =
Range 30, 'Total' SI Range =
Range 31, 'Total' SI Range =

Table D-19 Sleeve Fatigue Usage Factor Calculation

Evaluation Title: North Anna - PZR Surge Nozzle Weld Overlay Analysis - TS (Outside Node, 5081)
Reference Files:
Material:
Type:
UTS (ksi) =
E matl (psi) =

RANGE NUMBER	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	E matl	PEAK SI RANGE	S alt	(E ratio) x S alt	ALLOWABLE CYCLES "N"	USAGE FACTOR "U"
1	'RCSD'-'IOSurge_1'							
2	'HUCD_1'-'IOSurge_1'							
3	'HUCD_1'-'RT_CDSI'							
4	'HUCD_1'-'SUIL'							
5	'RCOP'-'IOSurge_2'							
6	'HUCD_2'-'IOSurge_2'							
7	'HUCD_2'-'RT_CDnSI							
8	'LOSLSD'-'SIA'							
9	'LOSLSD'-'RT_CDnSI							
10	'RT_CDnSI-'RT_CDnSI							
11	'FCHSD'-'LOL'							
12	'CRD'-'FCHSD'							
13	'FCHSD'-'IOSurge110_2'							
14	'RT_noCD'-'IOSurge110_2'							
15	'LOF'-'IOSurge110_1'							
16	'IOSurge110_1'-'IOSurge110_2'							
17	'LOP'-'IOSurge110_1'							
18	'LSDL'-'IOSurge110_1'							
19	'PLUL_1'-'IOSurge110_1'							
20	'PLUL_1'-'PLUL_1'							
21	'10SLinc'-'PLUL_2'							
22	'LOSLSU'-'PLUL_2'							
23	'PLUL_2'-'PLUL_2'							
24	'10SLdec'-'10SLdec'							
25	'BCE'-'TRT'							
26	'BCE'-'BCE'							
27	IOSurge Sub-Cycles(1)							
28	Sub-Cycle within HUCD							

Table D-19 (Continued) Sleeve Fatigue Usage Factor Calculation

The 'Peak SI Range' = 'Memb + Bend' SI Range x Fatigue Strength Reduction Factor (FSRF) x Ke (as needed)

Range 1, 'Memb + Bend' SI Range =
Range 2, 'Memb + Bend' SI Range =
Range 3, 'Memb + Bend' SI Range =
Range 4, 'Memb + Bend' SI Range =
Range 5, 'Memb + Bend' SI Range =
Range 6, 'Memb + Bend' SI Range =
Range 7, 'Memb + Bend' SI Range =
Range 8, 'Memb + Bend' SI Range =
Range 9, 'Memb + Bend' SI Range =
Range 10, 'Memb + Bend' SI Range =
Range 11, 'Memb + Bend' SI Range =
Range 12, 'Memb + Bend' SI Range =
Range 13, 'Memb + Bend' SI Range =
Range 14, 'Memb + Bend' SI Range =
Range 15, 'Memb + Bend' SI Range =
Range 16, 'Memb + Bend' SI Range =
Range 17, 'Memb + Bend' SI Range =
Range 18, 'Memb + Bend' SI Range =
Range 19, 'Memb + Bend' SI Range =
Range 20, 'Memb + Bend' SI Range =
Range 21, 'Memb + Bend' SI Range =
Range 22, 'Memb + Bend' SI Range =
Range 23, 'Memb + Bend' SI Range =
Range 24, 'Memb + Bend' SI Range =
Range 25, 'Memb + Bend' SI Range =
Range 26, 'Memb + Bend' SI Range =

Location	M+B Transient SI Range	Temp 1	Temp 2	Max. Temp.	Sm	Transient + External SI Range	EQ 1 (2)	EQ 2 (2)	Ke Factor
	ksi	*°F*	*°F*	*°F*	*ksi*	*ksi*			

Note [1]: Plastic analysis is used to find the CFUF associated with the Insurge/Outsurge Subcycles. See Appendix E.

Note [2]: Equations 1 and 2 for Ke values are presented in Section D.4.2.3.2.

Note [3]: IOSurge Transient contributes a partial usage factor of [ ] when this transient ranges within itself (i.e., sub-cycles), see Section D.4.2.4 (last paragraph).

Because the total usage factor [ ] is above allowable value 1.0, plastic analysis is performed for IOSurge Transient at this location (Thermal Sleeve path TS) in Appendix E.

D.5 SOFTWARE VERIFICATION

The finite element analyses documented in this report were performed using ANSYS v11.0 software (References 13.17 and 13.18). The suitability and accuracy of use of ANSYS v11.0 was verified by performing the following verification runs (Table D-20).

Table D-20 Software Verification Files

[ ]

D.6 COMPUTER OUTPUT FILES

Table D-21 Computer Output and Input Files

( )

APPENDIX E

NON-LINEAR ELASTIC-PLASTIC ANALYSIS

E.1 PURPOSE

The purpose of this Appendix is to analyze several points on the Surge Nozzle using Non-Linear Elastic-Plastic Analysis that could not be qualified with Simplified Elastic-Plastic Analysis presented in Appendix D.

E.2 NON-LINEAR ELASTIC-PLASTIC ANALYSIS (NB-3228.4)

The analysis is based on the requirements and procedures specified in NB-3228.4 of Reference 13.1. As mentioned in Section D.4.2.4, the elastic-plastic analysis is performed for IOSurge Transient (Δt =[ ] for all the sub-cycles, and the locations which do not meet the ASME Section III elastic or simplified elastic-plastic criteria (Reference 13.1) are then evaluated in accordance with par. NB-3228.4 - Shakedown Analysis. The path locations evaluated with elastic-plastic approach are: SEL_Wola inside, and Sleeve outside.

Par. NB-3228.4 of Reference 13.1, states that the limits on Thermal Stress Ratchet in Shell (NB-3222.5) and Progressive Distortion of Non-Integral Connections (NB-3227.3) need not be satisfied at a specific location, if, at the location, the procedures of (a) through (c) are used. The shakedown of a structure is defined by NB-3213.34 of the same reference as the deformation response of the structure that after a few cycles of load application, ratcheting ceases and the subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent.

NB-3228.4(a): In evaluating stresses for comparison with the remaining stress limits, the stresses shall be calculated on an elastic basis.

Since the stresses for comparison with the remaining stress limits are calculated on elastic basis as presented in previous sections. This requirement is satisfied.

NB-3228.4(b): In lieu of satisfying the specific requirements of NB-3221.2, NB-3222.2, NB-3222.5, and NB-3227.3 at a specific location, the structural action shall be calculated on a plastic basis, and the design shall be considered to be acceptable if the shakedown occurs (as opposed to continuing deformation).

A detailed finite element analysis is performed to verify that shakedown occurs when the surge nozzle is exposed to the IOSurge Transient along with the applicable external loads.

E.2.1 FINITE ELEMENT MODEL FOR ELASTIC-PLASTIC ANALYSIS

Since the plastic behavior of the material is time dependent, the external loads have to be applied directly to the FE model along with the thermal transient and pressure loads. The 2-D axisymmetric ANSYS FE model does not have 2-D elements for non-symmetric external loads application in the elastic-plastic analysis, therefore the 2-D model built in ANSYS WORKBENCH 11.0 was expanded into 180° symmetric 3-D model to perform the elastic-plastic analysis, as shown in Figure E-1.

The boundary conditions and the surface loading are similar to 2-D FE model (see Section 4.4) except symmetry boundary condition at the front face of the 180° FE model. The symmetry boundary condition is modeled by setting zero displacement normal to the plane of symmetry (UZ = 0). The FE model is meshed using the structural element SOLID186 (3-D 20-Node Structural Solid Element). This element is converted to the thermal element SOLID90 (3-D 20-Node Thermal Solid Element) for the thermal analysis.

Figure E-1 3-D Finite Element Model

The 3-D FE model including the elastic material properties obtained from Reference 13.15 is same as the 2-D FE model and is documented in the output file ( ).

For the following elastic-plastic structural analysis, the plastic material properties have to be added at the critical locations. The elastic-plastic material definition is documented in the output file ( ).

E.2.2 DESIGN CONDITION ANALYSIS

To verify the correct behavior of the model as well as the correct settings of the boundary conditions, the structural run with Design pressure [ ] and Design temperature [ ] was performed and compared with the results of 2-D analysis (see Figure 6-2, Section 6). The stress intensity contour plot for the 3-D model under the Design Conditions is shown in Figure E-2. This Design Condition run is documented in the output file: [ ].

[ ]

Figure E-2 Stress Intensity Contours for 3-D Design Pressure Run

E.2.3 THERMAL TRANSIENT ANALYSIS FOR IOSURGE TRANSIENT

The thermal loads and boundary conditions as described and specified in detail in Section 7 and Section D.2 were applied to the 3-D finite element model. Note that only transient IOSurge are evaluated in the elastic-plastic analysis. The thermal run of this transient is documented in the output file: [ ].

The thermal results were evaluated by examining the magnitude of temperature differences between key locations of the model. The approximately same node locations as shown in Figure 7-1 were selected for the thermal gradient determination. The output file documenting these nodal temperatures and temperature gradients: [ ]. Based on the results documented in this file and temperature and temperature gradient plots (Figure E-3), it has been confirmed that 3-D model gives the same results as 2-D model. These corresponding results provide other verification between the 2-D and 3-D model behavior.

Figure E-3 Temperature and Temperature Gradients for IOSurge Transient

E.2.4 ELASTIC-PLASTIC MATERIAL PROPERTIES

Since the total SI ranges are below the $3S_m$ limit at locations in the surge nozzle material, the nozzle (and head) is still modeled with elastic material properties as before. Part of the pipe, remote from the weld overlay area, is also modeled with elastic material properties. The true

[ ]

Multilinear Kinematic Hardening (KINH) material model was used. KINH options use the Besseling model, also called the sub-layer or overlay model, so that the Bauschinger effect is included. The ANSYS options of KINH allow to define enough stress-strain curves (total 40, 8 used) as well as the number of points per curve (total 20, 16 used). Note that only part of the surge nozzle assembly subjected to plastic deformation is modeled with elastic-plastic material properties, as shown in Figure E-4.

[ ]

Figure E-4 Elastic-Plastic Region of the Model

Table E-1 lists the data for the stress-strain curves for the [ ] materials at various temperatures given by Reference 13.2. Table E-2 tabulates the first strain values of the curve based on the Young's modulus taken from Reference 13.15.

Table E-1 Elastic-Plastic Material Properties of [ ]

Strain [-]	Stress [psi]							
	700°F	600°F	500°F	400°F	300°F	200°F	100°F	70°F
[ ]								

Table E-2 First Strain Values for Table E-1

Temperature	700°F	600°F	500°F	400°F	300°F	200°F	100 °F	70°F
Strain	[ ]							

Table E-3 lists three sets of Young's modulus, coefficients of thermal expansion and data of the stress-strain curves for [ ] per Reference 13.3.

Table E-3 Elastic-Plastic Material Properties of [ ]

Temperature [°F]	75°F		620°F		980°F	
E [psi]	[ ]					
α [10^{-6} in/in-°F]						
	Strain [-]	Stress [psi]	Strain [-]	Stress [psi]	Strain [-]	Stress [psi]
	[ ]					

E.2.5 EXTERNAL LOADS

External loads defined at the end of the safe end are transformed to the end of the modeled pipe as shown in Figure E-5. The transformed local loads are listed in Table E-4.

Figure E-5 External Loads Coordinate System

The following formulae are used in transforming the loads into the local coordinate system:

$F_{xL} = F_x$

$F_{yL} = F_y$

$F_{zL} = F_z$

$M_{xL} = M_x - F_z \cdot L$

$M_{yL} = M_y$

$M_{zL} = M_z + F_x \cdot L$

where:

$L = 10.9$ in. is taken from the ANSYS FE model

The loads applied at the safe end are obtained from Reference 13.8 with proper transformation of coordinate systems and directions. The Dead Weight loadings are conservatively taken from Attachment 11 of Reference 13.8. The Thermal loadings under normal operation condition are taken from the UNSTR Condition in Attachment 9, page 7, of the same reference. The

The enveloped loads are considered as the corresponding component forces and moments to the maximum resultant moment applied at the end of pipe among all stratification cases.

The resulting loads applied to the FE model are shown in Figure E-6. These local loads are applied to the model via surface-based constraints. The forces and moments are applied on a pilot node. This pilot node is the only target segment (TARGE170 element) on the target surface side. It is the master node of the MPC (multipoint constraint approach) equations. The bottom pipe cross-section area is the contact surface and contains the contact elements (CONTA174). The nodes of these elements are the slave nodes of the MPC equations. Options of these contact elements are for a force-distributed surface constraint. Since the FE model contains symmetry boundary conditions, the torsional moment, shear force in the "z" direction and bending moment in the "x" direction are not applicable. All three moments are then conservatively summed by SRSS as the bending moment acting in the "–z" direction as follows:

Shear force applied at the pilot node in the +x direction: $F_{shear} = \sqrt{F_{xL}^2 + F_{zL}^2}$

Bending moment applied at the pilot node in the –z direction: $M_{bending} = \sqrt{M_{xL}^2 + M_{yL}^2 + M_{zL}^2}$

Table E-4 External Loads

Loads (absolute values)	F_{xL} [lbs]	F_{yL} [lbs]	F_{zL} [lbs]	M_{xL} [in-lbs]	M_{yL} [in-lbs]	M_{zL} [in-lbs]
Dead Weight						
Thermal						
Stratification						

Since only half of the geometry is modeled with symmetry condition, the above loads are divided by 2 when input in ANSYS.

Figure E-6 External Loads at Pilot Node

The external loads are not constant during the evaluated transient time points. The evaluated transient time points along with the applied external loads are listed in Table E-5. Note that OBE is typically assumed to occur during the normal operating conditions at full power and therefore is not considered in these transients, which do not contain such as conditions. The Stratification (STR) loads are not applied at the time period during the Insurge/Outsurge. Dead Weight (DW) and Thermal (TH) loads are applied to all time points. The applied external loads and load combination is documented in the following iput file: [ ].

Table E-5 Time Points of Interest for 'IOSurge' Structural Elastic-Plastic Analysis

Load Case	Time [hr]	Comment	External Load Combination
1	0.0001		DW+TH+STR
2	0.0500		DW+TH+STR
3	0.050653		DW+TH
4	0.0667		DW+TH
5	0.08413		DW+TH
6	0.09663		DW+TH
7	0.2		DW+TH
8	0.3167		DW+TH
9	0.3333		DW+TH
10	0.35		DW+TH
11	0.40		DW+TH
12	0.5		DW+TH+STR
13	0.783333		DW+TH+STR
14	1.0000		DW+TH+STR

E.2.6 RESULTS OF THE ELASTIC-PLASTIC ANALYSIS

The shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. In order to inspect the shakedown of the surge nozzle, the new elastic-plastic IOSurge Transient was analyzed for 10 cycles in the structural runs. The stress analyses are performed for each cycle with time points of interest listed in Table E-5. Selected time points include time points corresponding to the critical parts of IOSurge Transient, maximum thermal gradients, and other intermediate time points. The number of time points in one cycle is adequate to ensure that the elastic-plastic analysis results are accurate and to ensure numerical stability in the model. The nodal temperature at the particular time point is read into the structural model directly from the result file of the thermal analysis. The FE model of the surge nozzle is then loaded by the internal pressure and external loads. The ANSYS output file documenting the structural run is: [ ]

Figure E-7 Nodes for Post-Processing of Elastic-Plastic Analysis

The figure below is extracted from Figure 9-1 for 2-D elastic analysis in the main document, and the nodes corresponding to the same locations are selected in the 3-D elastic-plastic analysis, as illustrated in Figure E-7. During the post-processing, the time histories of total strains are investigated at four locations. Two selected nodes are at the locations of the inside node of Path SEL_Wola and outside node of Path Sleeve. Nodes 180° from these two locations are also selected to ensure the worst conditions are captured due to the applied external loads.

Figure E-7 (continued) Nodes for Post-Processing of Elastic-Plastic Analysis

The maximum principal total strain ranges of each calculated cycle are listed in Table E-6. The principal total strain range calculation follows the same approach prescribed in NB-3216.2 of Reference 13.1 for total stress ranges. The total strain $\varepsilon_{ij}^{(t)}$ is the summation of elastic $\varepsilon_{ij}^{(e)}$ and plastic $\varepsilon_{ij}^{(p)}$ strains: $\varepsilon_{ij}^{(t)} = \varepsilon_{ij}^{(e)} + \varepsilon_{ij}^{(p)}$. Let ε_1 be the algebraically largest and ε_3 the algebraically smallest strain ($\varepsilon_1 \geq \varepsilon_2 \geq \varepsilon_3$), the numerically (absolute) maximum principal strain is defined by $\varepsilon_{max} = \max(|\varepsilon_1|, |\varepsilon_3|)$. The maximum total principal strain range is then $\Delta\varepsilon^t_{max} = \max(|\Delta\varepsilon_1|, |\Delta\varepsilon_3|)$, where the range is taken between the components of the total strain. The principal strain range is calculated "after" taking the strain component range. The post-processing is documented in the output files: [ ] and the output files containing the calculated strain ranges for the selected nodes are the following:

[ ]

Table E-6 Maximum Principal Total Strain Ranges

Strain Ranges for IOSurge Transient				
Cycle	Node # 12507	Node # 18610	Node # 18719	Node # 18575
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

A review of the strain time history indicates shakedown occurs at all investigated locations. Typical curves of the displacement and strain components versus time (node #12507 and #18575) are shown in Figure E-8 through Figure E-11. Stability of the structural response can be observed from these figures. The file documenting these printed outputs is: [ ]

The UZ, ε_{yz}, and ε_{xz} components are not shown since all selected nodes are located on the plane of symmetry where UZ displacement in the horizontal direction (see Figure E-6) is equal to zero and shear strains are relatively small in comparison with normal strains (ε_x, ε_y, and ε_z).

Figure E-8 Strain Plots for Node #12507 and IOSurge Transient

Figure E-9 Displacement Plots for Node #12507 and IOSurge Transient

Figure E-10 Strain Plots for Node #18575 and IOSurge Transient

Figure E-11 Displacement Plots for Node #18575 and IOSurge Transient

NB-3228.4(c): In evaluating stresses for comparison with fatigue allowable, the numerically maximum principal total strain range shall be multiplied by one-half the modulus of elasticity of the material (Young's modulus) at the mean value of the temperature of the cycle. Since the internal cycles of the IOSurge Transient is excluded in the previous elastic analysis of inside node of Path SEL_Wola and outside node of Path Sleeve, the principal stress intensity ranges calculated from the total strain ranges in the elastic-plastic analysis shall be additionally considered for fatigue evaluation at these locations. In order to obtain the principal stress intensity ranges, the principal total strain ranges shall be multiplied by the factor $E_t \cdot (E_c/E_t) = E_c$, where E_t is the Young's modulus at the mean temperature of the cycle and E_c is the referenced Young's modulus of the fatigue curve ($28.3 \cdot 10^6$ psi for high alloy steel per Reference 13.1). The highest stress intensity ranges at the selected nodes within the 10 loading cycles during the elastic-plastic analysis are obtained and reviewed, and Table E-7 summarizes the maximum strain and stress results.

Table E-7 Maximum Principal Strain Ranges and Calculated SI Ranges

Node #	Maximum Strain Range from Selected Nodes (Table E-6, Path SEL_Wola, Inside)	SI Range [ksi]
12507	[ ]	[ ]
18719		
Node #	Maximum Strain Range from Selected Nodes (Table E-6, Sleeve, outside)	SI Range [ksi]
18610	[ ]	[ ]
18575		

The maximum SI Ranges of [ ] are used in the fatigue usage calculation in Table E-8 and E-9. Since IOSurge Transient is critical only when it is ranging within itself, the number of sub-cycles accounted for in the elastic-plastic analysis is [ ] as discussed in Table D-1. The remaining [ ] can range with other transients and are accounted for in the elastic analysis in Appendix D.

Table E-8 Fatigue Usage Factor Calculation for Safe End

EVALUATION TITLE: North Anna - PZR Surge Nozzle Weld Overlay Analysis - SEL_Wola (Inside)

Table E-9 Fatigue Usage Factor Calculation for Thermal Sleeve

EVALUATION TITLE: North Anna - PZR Surge Nozzle Weld Overlay Analysis - Sleeve (outside)

See Table 10-1 in the main body of the calculation for summary of the total fatigue usage factors for all evaluated materials using elastic or elastic-plastics analysis.

E.3 SOFTWARE VERIFICATION

The finite element analyses documented in this report were performed using ANSYS v11.0 software (References 13.17 and 13.18). The suitability and accuracy of use of ANSYS v11.0 was verified by performing the following verification runs (Table E-10).

Table E-10 Software Verification Files

E.4 COMPUTER OUTPUT FILES

Table E-11 Computer Output and Input Files

[ ]