Attachment 13
PG&E Letter DCL-14-028

AREVA Calculation No. 32-9219781-000

Diablo Canyon Unit 2 - Pressurizer Spray Nozzle Weld Overlay Structural Analysis - Non-Proprietary

AREVA

CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9219781 - 000

Safety Related: ☒Yes ☐ No

Title Diablo Canyon Unit 2 - Pressurizer Spray Nozzle Weld Overlay Structural Analysis – Non Proprietary

PURPOSE AND SUMMARY OF RESULTS:

PURPOSE:

The purpose of this calculation is to qualify the Diablo Canyon Unit 2 spray nozzle weld overlay design to the requirements specified in Reference [1]. The analysis was performed using computer program ANSYS version 11.0 and StressRange version 2.0.

SUMMARY OF RESULTS:

The calculation demonstrates that the design of the Pressurizer spray nozzle weld overlay for Diablo Canyon Unit 2 meets the stress and fatigue requirements of the ASME Code (References [14]).

Based on the loads and cycles specified in References [2] and [4], the conservative fatigue analysis indicates that Pressurizer spray nozzle weld overlay design has the maximum usage factor of **[ ]** for specified number of cycles per Reference [2] compared to the ASME Code allowed maximum value of 1.0.

This document is the Non-Proprietary document for 32-9049112-003.

Proprietary information is contained within bold square brackets "**[ ]**".

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
ANSYS 11.0 (Rev. 000) StressRange 2.0 (Rev. 000)	Operating System: Not Known
ANSYS 14.0 (Rev. 002)	Operating System: Win 7

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

☐Yes
☒ No

AREVA

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Diablo Canyon Unit 2 - Pressurizer Spray Nozzle Weld Overlay Structural Analysis – Non Proprietary

Review Method: ☒ Design Review (Detailed Check)

☐ Alternate Calculation

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000	All	Original Release.
000	All	Non-Proprietary document for 32-9049112-003

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1 PURPOSE

1.1 INTRODUCTION

Primary water stress corrosion cracking (PWSCC) of Alloy 600/82/182 materials is a well documented phenomenon in the nuclear power industry. High temperature components, such as those associated with the pressurizer, have risk for PWSCC. Pacific Gas and Electric (PG&E) plans to mitigate the Diablo Canyon Unit 2 pressurizer nozzle Alloy 82/182 dissimilar metal (DM) welds with full structural weld overlays (SWOL) during the spring 2008 2R14 refueling outage for Unit 2. The planned mitigation using SWOL is a preemptive measure to reduce susceptibility of the DM weld and the adjacent pipe to safe end welds to PWSCC.

1.2 SCOPE

The spray nozzle is located on the top of the pressurizer upper head. The nozzle provides a conduit for spray line sprays. The weld overlay is designed to cover both the Alloy 82/182 DM weld and the austenitic stainless weld between the nozzle safe end and the pipe. 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 [14]) are satisfied for the spray 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 spray 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 spray nozzle, SWOL, and the pressurizer upper head. In addition, post-processing of thermal and structural results is performed to provide data for fracture analysis of the spray 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 spray 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 spray 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) Only the minimum SWOL will be modeled and evaluated. Based on past experience, the stresses due to transients had minor differences between the maximum SWOL and minimum SWOL, and the minimum SWOL stresses due to external loads control over the maximum SWOL. Therefore, it is reasonable to evaluate the minimum SWOL only.
2) Building a two-dimensional model of the spray nozzle weld overlay geometry. The model incorporates the geometry (of the adjacent upper head, spray nozzle, spray nozzle safe end, welds, weld overlay and a part of the pipe welded to the spray nozzle safe end), 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.
3) 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.
4) 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.
5) 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.
6) Hand calculating the effects due to the nozzle external loads and adding the resulting stresses to the stress results due to the pressure and temperature effect.
7) Comparing the results to the ASME Code for acceptability.
8) Documenting stresses and temperatures for the fracture mechanics analysis of the spray nozzle weld overlay design.

3 KEY ASSUMPTION

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

4 DESIGN INPUT

4.1 GEOMETRY

Some of the major dimensions (References [11] and [12]) are:

pressurizer upper head inside radius to base metal
pressurizer upper head base metal thickness
pressurizer upper head cladding thickness
spray nozzle ID (to base metal)
spray nozzle OD (near head)
spray nozzle OD (at nozzle to safe end weld)
safe end length (between welds center lines)
safe end ID (minimum)
pipe ID
pipe OD
thermal sleeve OD
thermal sleeve thickness

minimum SWOL configuration:
total SWOL length
SWOL thickness at nozzle
SWOL thickness at pipe

5 FINITE ELEMENT MODEL

The 2D axisymmetric finite element model is built based on the weld overlay minimum design. The model simulates, in two-dimensional space, the spray nozzle, safe end, weld overlay, part of the pipe, thermal sleeve and pressurizer upper head.

The finite element analyses in this document are performed using ANSYS 11.0 (Reference [13]). The model was developed in ANSYS WORKBENCH 11.0 and is shown in Figure 5-1. The element type chosen is the structural element PLANE183 (2-D 8-Node Structural Solid). This element is converted to the thermal element type PLANE77 (2-D 8-Node Thermal Solid) for the thermal analysis. The contact surfaces between the liner and nozzle are modeled by using contact elements TARGE169 (2-D Target Segment) and CONTA172 (2-D 3-Node Surface-to-Surface Contact).

The modeled portion of pressurizer head is sufficient for attenuation of the stresses and thermal gradients. The thermal sleeve is attached by[ ]and it is non-structural weld (Reference [1] and [12]). Therefore, the thermal sleeve is not included in structural runs. Nevertheless, the thermal sleeve is contained in the thermal runs for temperature distribution.

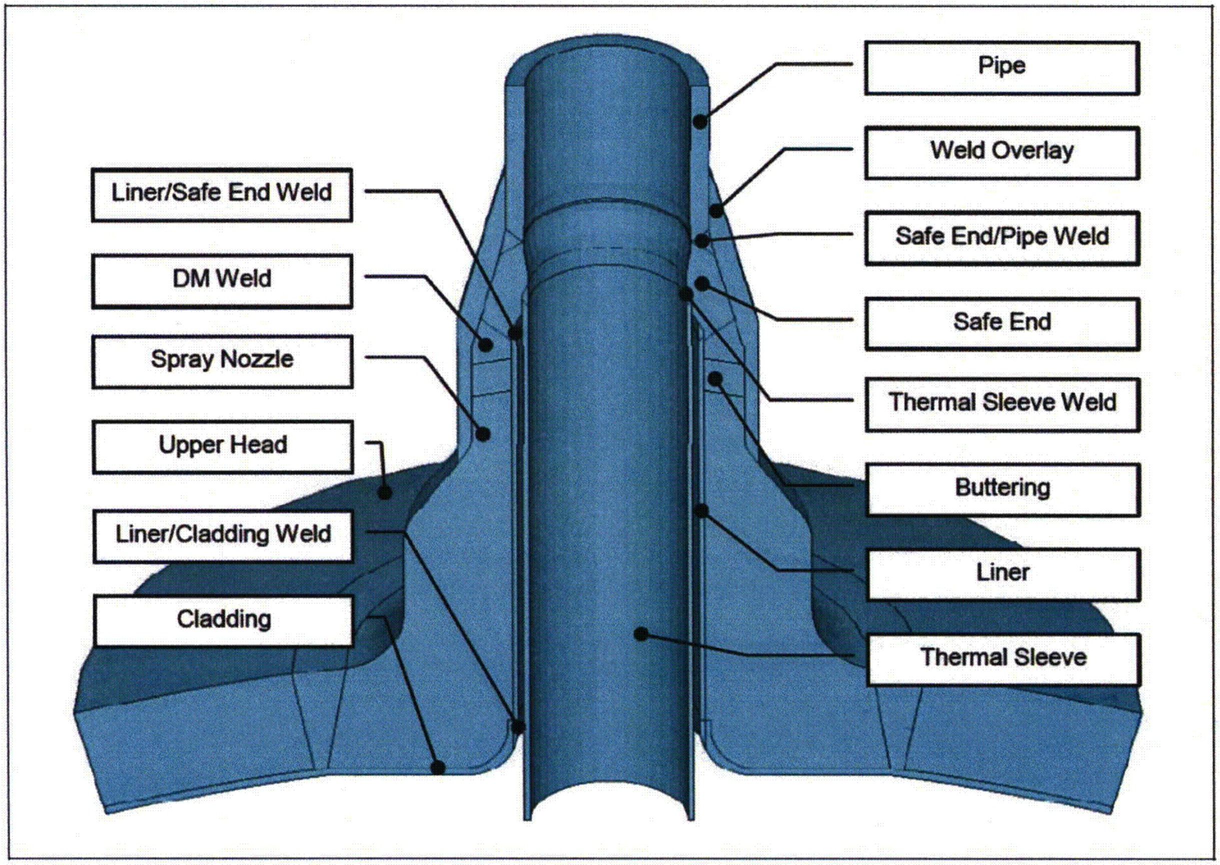

Figure 5-1 Expanded 2-D Axisymmetric Model of the Spray Nozzle with SWOL

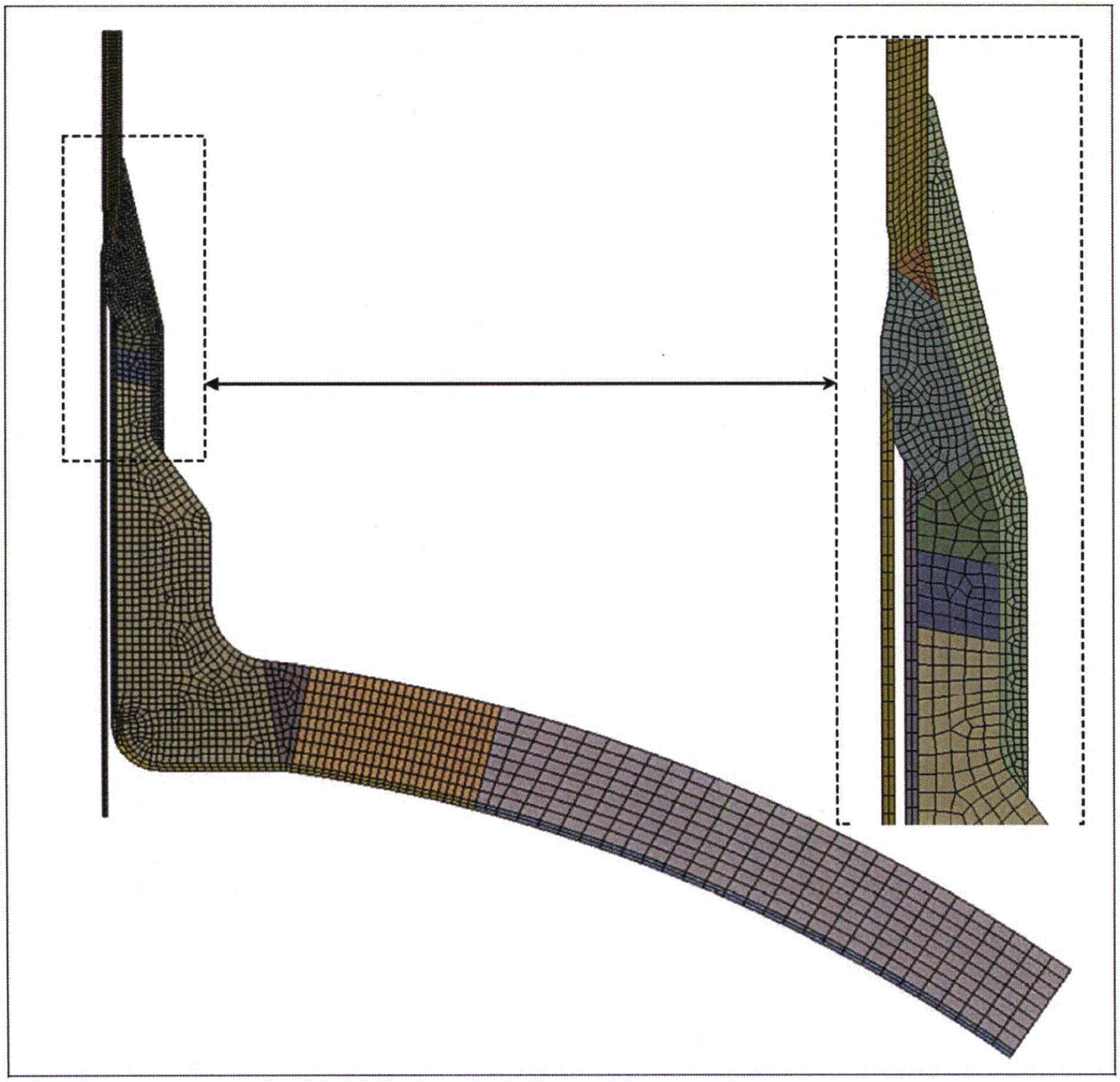

Figure 5-2 Finite Element Model - Mesh

5.1 MATERIALS

Reference [1] and Reference [2] provide the material designations of various components as listed below. Per reference [1], the material properties for the structural analysis shall be in accordance with ASME Code 1965 Edition including Addenda through Summer 1966 (Reference [6]) for existing material and ASME Code 2001 Edition including Addenda through 2003 (Reference [5]) for weld filler material. Since not all materials and material properties for existing components are provided by Reference [6], later Addenda or Editions of the ASME Code (Reference [7], [8] and [9]) were used to determine the remaining material properties.

Table 5-1 Table of Materials

Location	Material
Pressurizer Upper Head	[
Spray Nozzle	
Nozzle to Pressurizer Weld	
Safe End	
Safe End to Nozzle Weld	
Buttering Weld	
Liner to Safe End Weld[1]	
Thermal Sleeve to Safe End Weld	
Thermal Sleeve	
Liner	
Cladding[2]	
Safe End to Pipe Weld[2]	
Liner to Cladding Weld[3]	
Pipe	
Weld Overlay	]

Reference [1], par. 4.2.2 specifies material[ ]for the "Barrier Layer." This very thin layer[ ] Reference [11]) is not modeled in detail in this analysis and is covered by the weld overlay filler material. The effect on the results is negligible.

[1] Material for these welds is specified in Reference [3].

[2] Reference [1], par. 4.1.5 and 4.1.7 specify that the cladding material properties should be equivalent to[ ] weld filler material and the existing pipe to safe end weld is[ ]austenitic stainless steel. This material is used for welding components with similar chemical composition such as[ ]material. Therefore material [ ]is considered representative of this weld material.

[3] The liner to cladding material is specified as[ ]per [3]. This material has similar chemical composition such as[ ]material, and material[ ]is considered representative of this weld material.

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 the following tables. The units of the properties are:

Young's Modulus	E	[10^6 psi]
Poisson's Ratio	μ	[unitless]
Density	ρ	[lb/in^3]
Coefficient of Thermal Expansion	α	[10^{-6} in/in-°F]
Thermal Conductivity	k	[Btu/hr-in-°F]
Specific Heat	C	[Btu/lb-°F]
Design Stress Intensity	Sm	[ksi]
Yield Strength	Sy	[ksi]
Tensile Strength	Su	[ksi]

(C is a calculated value: C = k/(ρ * thermal diffusivity) where thermal diffusivity is taken from the same source as "k")

Table 5-2 Pressurizer Upper Head Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[6]	typical	[10]	[6]	[9]	calculated	[8]	[8]	[8]

Table 5-3 Spray Nozzle and Nozzle to Head Weld Material Properties

			[			]			
Temp	**E**	**μ**	**ρ**	**α**	**k**	**C**	**Sm**	**Sy**	**Su**
[									]
Reference	[6]	typical	[10]	[6]	[9]	calculated	[7]	[7]	[7]

Table 5-4 Safe End Material Properties

			[			]			
Temp	**E**	**μ**	**ρ**	**α**	**k**	**C**	**Sm**	**Sy**	**Su**
[									]
Reference	[6]	typical	[10]	[6]	[9]	calculated	[6]	[6]	[6]

Table 5-5 Safe End to Nozzle Weld, Buttering, Liner/Safe End Weld and Thermal Sleeve to Safe End Weld Material Properties

			[			]			
Temp	**E**	**μ**	**ρ**	**α**	**k**	**C**	**Sm**	**Sy**	**Su**
[									]
Reference	[6]	typical	[10]	[6]	[9]	calculated	[7]	[7]	[7]

Table 5-6 Thermal Sleeve, Liner, Cladding and Safe End to Pipe Weld Material Properties

[ ]									
Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[6]	typical	[10]	[6]	[9]	calculated	[6]	[6]	[6]

Table 5-7 Pipe Material Properties

[ ]									
Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[6]	typical	[10]	[6]	[9]	calculated	[6]	[6]	[6]

Table 5-8 Weld Overlay Material Properties

[ ]									
Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[5]	typical	[10]	[5]	[5]	calculated	[5]	[5]	[5]

5.2 BOUNDARY CONDITION AND LOADS

5.2.1 Thermal Boundary

During operation without spray events, the inside surface of the upper head, the inside bore surfaces of the spray nozzle, pipe, safe end weld, a part of the safe end, and the inside & outside surfaces of the thermal sleeve are in contact with the pressurizer fluid at steam temperature. During spray events, the inside surfaces of the pipe, safe end weld, a part of the safe end, and thermal sleeve are in contact with the spray fluid at spray temperature. An appropriate heat transfer coefficient (HTC) and bulk temperature versus time are applied on these surfaces, which are in contact with the pressurizer steam or spray fluid (Figure 5-3).

Thermal coupling was applied on the surfaces between the safe end and thermal sleeve in the thermal sleeve weld vicinity and between the liner and nozzle (Figure 5-3).

The outside surfaces of the upper head, spray nozzle, pipe and weld overlay are exposed to the ambient temperature in conjunction with a small HTC. Ambient temperature of [ ] is used for all time points in the thermal analysis. The spray nozzle is assumed to be insulated. A very small HTC of [ ] is used.

5.2.2 Structural Boundary

Pressurizer pressure is applied to all inside surfaces which are in contact with steam or fluid. The exteriors of the pressurizer upper head are not loaded by pressure. The upper end of the pipe has an end cap pressure p* applied to represent the hydrostatic end load from the piping closure.

Pressure p* is calculated as follows: $p^* = -\frac{p \cdot d^2}{D^2 - d^2} =$ [ ]

Where p is internal pressure, d is inside diameter of the pipe and D is outside diameter of the pipe.

The displacements of the pressurizer upper head in the circumferential direction are set to be zero (see Figure 5-4).

[ ]

Figure 5-3 Thermal Boundary Conditions

Figure 5-4 Structural Boundary Conditions

6 EXTERNAL LOADS

6.1 APPLICABLE LOADS

Per Reference [1], the external forces and moments acting on the spray nozzle safe end weld location (Figure 6-1) are listed in Table 6-1. These loads are defined in the local coordinate system with the "x" axis oriented along the nozzle axis of symmetry in the nozzle to pipe direction per Reference [3]. The "y" and "z" axes are the horizontal components.

Table 6-1 External Loads

External Load	Axial Force	Shear Force	Shear Force	Torsion	Bending	Bending
	Fx [kips]	Fy [kips]	Fz [kips]	Mx [in-kips]	My [in-kips]	Mz [in-kips]
Thermal	[					]
Pressure[1]						
DW[2]						
Sesimic OBE						
Seismic SSE[2]						
Pipe Rupture[2]						
Pipe Rupture[2](1)						]

The stresses due to OBE and thermal loads are evaluated using hand calculation and they are added to the ANSYS results where appropriate for ASME evaluation in Section 10.

Per Reference [2], the OBE loads hav[ ]cycles[ ]

The thermal expansion loads are considered during the maximum temperature variance in the pressurizer, which corresponds to the heatup-cooldown transient. Much smaller temperature variance occurs during other transients and the loads during these variations are much smaller. Therefore, the thermal expansion is assumed to have same number of cycles as the heatup-cooldown transients fo[ ]

The following Table 6-2 lists the loads used for the SI calculation for the evaluated locations. The total shear force (*Fs*) and total bending moment (*Mb*) by combined as the SRSS method.

---

[1] Pressure load is not used since it is accounted in stress analysis model.

[2] The DW, SSE and Pipe Rupture loads are not evaluate in this document, since the document qualifies only Primary plus Secondary stress intensity range (see Section 10.1); these loads are listed for information purpose only. Dead weight loads act at all time points of all transients, and therefore do not contribute to the SI Ranges.

Table 6-2 External Loads Summary

External Load	Axial Fx [kips]	Shear Fy [kips]	Shear Fz [kips]	Torsion Mx [in-kips]	Bending My [in-kips]	Bending Mz [in-kips]	Total Shear Fs [kips]	Total Bending Mb [in-kips]
OBE								
TH								
OBE +TH								

Figure 6-1 Point of External Loads

Note: The path's numbering starts from the number "2". The pathline "Path1" is not defined.

6.1.1 Nozzle Cross Sections

The cross sectional characteristics are calculated for the path locations as shown in Figure 6-1. These paths correspondent with paths defined in Section 10.2.1 for the stress linearization. The nozzle geometric dimensions are specified in References [11] and [12] and some dimensions are also taken directly from the FE model.

Table 6-3 Nozzle Cross Sectional Characteristics

Pathline	r [in]	R [in]	L [in]	I [in^4]	A [in^2]	Section Modulus S [in^3]	
						S_{inside}	$S_{outside}$
Path2							
Path3							
Path4							
Path5							
Path6							
Path7							
Path8[1]							
Path9[1]							
Path10[1]							

Where: R - outside radius (for the nozzle, WOL or pipe)

r - inside radius (for the nozzle, WOL or pipe)

L - moment arm

$I = \frac{\pi}{4}\left(R^4 - r^4\right)$ - moment of inertia

$A = \pi\left(R^2 - r^2\right)$ - cross-section area at an appropriate location

$S_{outside} = I/R$, $S_{inside} = I/r$ - section modulus

The radii (R, r) are taken at the inside and outside nodes of the paths. Since some of the paths are in slope, the longer moment arm (L) between the safe end weld-root and the further node of the path is conservatively taken into calculation.

[1] For paths Path8, Path9 and Path10, the stress intensity due to axial bending stress from external shear forces would reduce the stress intensity due to transient loads. Therefore, the moment arms for these locations are conservatively reduced to zero.

6.1.2 Stress Intensity Due To External Loads Calculation

The stress components and membrane + bending stress intensities due to external loads and loads combination for inside and outside nodes are calculated based on following formulas and they are listed in Table 6-4 through Table 6-9. The resulting stress intensities will be used along with the transient SI Ranges in the ASME Code Primary plus Secondary Membrane +Bending SI Range qualification in Section 10.2

$\sigma_{ax} = F_x / A$	axial membrane stress due to an external axial force Fx
$\sigma_b = M_b / S$	axial bending stress due to an external moment Mb
$\sigma_{bs} = F_S \cdot L / S$	axial bending stress due to an external shear force Fs
$\tau_T = M_S / (2 \cdot S)$	shear stress due to an external torsion Mx
$\tau_S = F_S / A$	shear stress due to an external shear force Fs
$\sigma_X = \sigma_{ax} + \sigma_b + \sigma_{bS}$	sum of axial stresses
$\tau = \tau_S + \tau_T$	sum of shear stresses
$\sigma_{INT} = \sqrt{\sigma_X^2 + 4 \cdot \tau^2}$	membrane + bending stress intensity

Table 6-4 Summary of the Stress Components – OBE

Pathline	σ_{ax} [ksi]	Shear τ_S [ksi]	Inside σ_b [ksi]	Inside σ_{bs} [ksi]	Inside τ_T [ksi]	Outside σ_b [ksi]	Outside σ_{bs} [ksi]	Outside τ_T [ksi]
Path2								
Path3								
Path4								
Path5								
Path6								
Path7								
Path8								
Path9								
Path10								

Table 6-5 Summary of the Stress Components – Thermal Expansion

Pathline	σ_{ax} [ksi]	Shear τ_S [ksi]	Inside			Outside		
			σ_b [ksi]	σ_{bs} [ksi]	τ_T [ksi]	σ_b [ksi]	σ_{bs} [ksi]	τ_T [ksi]
Path2								
Path3								
Path4								
Path5								
Path6								
Path7								
Path8								
Path9								
Path10								

Table 6-6 Summary of the Stress Components – OBE + Thermal Expansion

Pathline	σ_{ax} [ksi]	Shear τ_S [ksi]	Inside			Outside		
			σ_b [ksi]	σ_{bs} [ksi]	τ_T [ksi]	σ_b [ksi]	σ_{bs} [ksi]	τ_T [ksi]
Path2								
Path3								
Path4								
Path5								
Path6								
Path7								
Path8								
Path9								
Path10								

Table 6-7 Stress Intensity Summary - OBE

Pathline	Inside			Outside		
	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]
Path2						
Path3						
Path4						
Path5						
Path6						
Path7						
Path8						
Path9						
Path10						

Table 6-8 Stress Intensity Summary – Thermal Expansion

Pathline	Inside			Outside		
	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]
Path2	3.923	1.096	4.494	6.193	1.416	6.810
Path3	3.869	1.254	4.611	5.900	1.597	6.709
Path4	3.361	1.254	4.194	5.111	1.597	6.027
Path5	3.551	1.386	4.505	5.451	1.785	6.516
Path6	3.396	1.361	4.352	5.451	1.804	6.537
Path7	3.533	1.511	4.649	5.747	2.034	7.041
Path8	4.967	2.347	6.834	7.094	2.941	9.215
Path9	9.938	4.412	13.290	12.741	5.195	16.440
Path10	13.190	5.747	17.495	16.213	6.591	20.896

Table 6-9 Stress Intensity Summary – OBE + Thermal Expansion

Pathline	Inside			Outside		
	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]	σ_X [ksi]	τ [ksi]	σ_{INT} [ksi]
Path2						
Path3						
Path4						
Path5						
Path6						
Path7						
Path8						
Path9						
Path10						

7 DESIGN CONDITION

It is assumed that the pressurizer assembly was designed to satisfy the ASME Code Criteria at a pressure of[ ]and temperature of[ ]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[ ]The pressure loading is described in detail in Section 5.2.2 . The ANSYS computer output is documented in file "*min_DC.out*".

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. Attenuation of stress effects at regions distant from the nozzle is also verified.

Figure 7-1 shows the deformed shape of the model under the design pressure along with the outline of the un-deformed shape. The stress intensity contours developed in the model under design pressure is shown in Figure 7-2. The contact pressure between the liner and nozzle is shown on Figure 7-3.

[ ]

Figure 7-1 Deformed Shape vs. Un-deformed Outline

[ ]

Figure 7-2 Stress Intensity Contours at Design Condition

[ ]

Figure 7-3 Contact Pressure at Design Condition

8 THERMAL ANALYSIS

The operating thermal loads are defined by the thermal transient conditions as contained in Reference [2] and Reference [4]. The applicable transient data from references are shown in Table 8-1.

Table 8-1 Transients

ASME Code Condition	Transient Name	Cycles	Spray Actuation[1]
Service Level A (Normal)	Heat Up		
	Cool Down		
	Unit Loading at 5% of Full Power/Min		
	Unit Unloading at 5% of Full Power/Min		
	Large Step Decrease in Load With Steam Dump		
	Step Load Increase of 10% of Full Power		
	Step Load Decrease of 10% of Full Power		
	Steady State Fluctuation		
	Boron Concentration Equalization		

Table 8-1 Transients (Continuing)

ASME Code Condition	Transient Name	Cycles	Spray Actuation
Service Level B (Upset)			
Test			

During the heat-up and cool-down transients, the timing for the[ ]spray actuations at a ΔT of [ ]is arbitrary. Therefore, the transients are developed as "*Early Spray*" (ES) and "*Late Spray*" (LS) to investigate all limiting cases of spray occurrences. For cool-down transient, there are the additional[ ]spray actuations with ΔT of[ ]when the pressurizer pressure is below [ ]Therefore, the cool-down is developed as early spray and late spray with temperature drop of[ ]to investigate all limiting cases of spray occurrences. The applicable heat-up and cool-down transients are shown on Figure 8-1.

Unit Loading and Unit Unloading (PLPU) are combined together to form one composite transient. Each transient consists[ ]spray actuations with drop ΔT of[ ]and therefore the composite transient consist[ ]spray actuations.

The spray actuation during Unit Loading/Unloding, Large Step Degrease in Load, Step Load Increase/Decrease of 10% full power and Loss of Load transients starts from the same temperature of[ ]and the same pressure of[ ]with the same temperature rate and same[ ]second duration. Therefore, this spray actuation transient is developed only one time for PLPU and the stresses resulting from this transient bound all spray actuations of rest transients. The total number of cycles of spray actuations is sum of cycles for PLPU and all bounded transients. Therefore, the transient PLPU is considered to occur[ ]times.

[1] Per NB-3226(e), the first[ ]hydrotest cycles need no be considered for the fatigue evaluation.

According to Reference [4], there is small temperature fluctuation during the Steady State Fluctuation transient for the spray nozzle. Per Reference [2], the pressure fluctuation is [ ] These small variations of temperature and pressure create negligible stresses compared to the other transients. Therefore, the steady state fluctuation transient is not contained in spray nozzle analysis.

The leak test comes on at steady state heat-up condition with pressure spikes to [2485 psig] momentarily. Therefore, this transient is modeled by adding a timepoint with pressure of [ ] [ ] during heat-up steady state condition.

[ ]

Figure 8-1 Heat-Up and Cool-Down Early and Late Transients with Spray Actuations

Table 8-2 Summary of Analyzed Transients

Designation	Transient Name	Design Cycles
HU-ES	Heat-up Early Spray	[
HU-LS	Heat-up Late Spray + Leak Test at [ ]	
CD-ES320	Cool-down Early Spray with two [ ] spray actuations.	
CD-LS-320	Cool-down Late Spray with two [ ] spray actuations.	
CD-ES405	Cool-down Early Spray with a [ ] and a [ ] spray actuations.	
CD-LS405	Cool-down Late Spray with a ΔT of 320°F and a ΔT of 405°F spray actuations	
PLPU	Plant Loading and Plant Unloading	
LSL	Large Step Decrease in Load	
SLI	Step Load Increase	
SLD	Step Load Decrease	
BCE	Boron Concentration Equalization	
LOL	Loss of Load	
LOP	Loss of Power	
LOF	Loss of Flow	
RT	Reactor Trip	
IA	Inadvertent Auxiliary Spray	
TRT	Turbine Roll Test	]

The boundary conditions for thermal analysis are described in detail in Section 5.2.1 . The thermal loading was applied to the finite element model in the form of temperatures and HTC versus time on the appropriate surfaces (see Section 5.2.1 , Figure 5-3). The following transient tables (Table 8-3 through Table 8-19) are based on the data from Reference [4] and list the pressure, HTC and temperature values for the time points used in the thermal analysis. Some time-points are omitted from transients that are listed in Reference [4] to simplify the transient definition. The differences between original transients and modified transients are negligible, and they have negligible effect to the results.

[1] Number of spray occurrences is described in detail in Table 8-1.

[2] Leak test with [ ] design cycles is applied at the end of the heat-up transient at steady state condition. Therefore, the leak test is considered as internal cycle of the heat-up transient.

[3] PLPU transient bounds the spray actuations of the others transients as described in text in this section and it results [ ] number of cycles for PLPU.

Table 8-3 Heat-up Early Spray Transient

[ ]

Table 8-4 Heat-up Late Spray Transient

[ ]

Table 8-5 Cool-Down Early Spray with Temperature Drop of[ ]

[ ]

Table 8-6 Cool-Down Late Spray with Temperature Drop of[ ]

[ ]

Table 8-7 Cool-Down Early Spray with Temperature Drop of[ ]

[ ]

Table 8-8 Cool-Down Late Spray with Temperature Drop of[ ]

[ ]

Table 8-9 Unit Loading & Unit Unloading at 5% of Full Power Transients

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[ ]

Table 8-10 Large Step Decrease in Load Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[ ]

Table 8-11 Step Load Increase of 10% of Full Power Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

Table 8-12 Step Load Decrease of 10% of Full Power Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

Table 8-13 Boron Concentration Equalization Transient [1]

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[ ]

Table 8-14 Loss of Load Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[ ]

[1] The pressure variation of [ ] and temperature variation of [ ] from Table 13 of Reference [4] is neglected.

Table 8-15 Loss of Power Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[ ]

Table 8-16 Loss of Flow Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

Table 8-17 Reactor Trip Transient [1]

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

[1] All three reactor trip transients defined in Reference [4] (Table 23 through Table 25) are identical for the spray nozzle.

Table 8-18 Inadvertent Auxiliary Spray Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

Table 8-19 Turbine Roll Test Transient

Time [hr]	TSPR [°F]	TPZR [°F]	PPZR [psia]	HTC Nozzle	HTC Annulus	HTC Head

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:

HU-ES_tr.inp	PLPU_tr.inp	LSL_tr.inp
HU-LS_tr.inp	BCE_tr.inp	SLD_tr.inp
CD-E[ ]tr.inp	IA_tr.inp	SLI_tr.inp
CD-E[ ]tr.inp	LOF_tr.inp	RT_tr.inp
CD-L[ ]tr.inp	LOL_tr.inp	TRT_tr.inp
CD-L[ ]tr.inp	LOP_tr.inp	

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

min_HU-ES_th.out	min_PLPU_th.out	min_LSL_th.out
min_HU-LS_th.out	min_BCE_th.out	min_SLD_th.out
min_CD-E[ ]th.out	min_IA_th.out	min_SLI_th.out
min_CD-E[ ]th.out	min_LOF_th.out	min_RT_th.out
min_CD-L[ ]th.out	min_LOL_th.out	min_TRT_th.out
min_CD-L[ ]th.out	min_LOP_th.out	

The results of the thermal analyses are evaluated by examining the magnitude of temperature differences between key locations of the model (Figure 8-2). The computer input file "*min_dT.mac*" contains definitions of the node numbers for temperature (Table 8-20) and temperature gradients calculation (Table 8-21). The time points of the maximum temperature gradients are those at which the maximum thermal stresses develop. The temperature and temperature gradients are plotted in Figure 8-3 through Figure 8-19. These figures are used only to show the trend. Specific data are taken from the computer output files.

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

min_HU-ES_dt.out	min_PLPU_dt.out	min_LSL_dt.out
min_HU-LS_dt.out	min_BCE_dt.out	min_SLD_dt.out
min_CD-E[ ]dt.out	min_IA_dt.out	min_SLI_dt.out
min_CD-E[ ]dt.out	min_LOF_dt.out	min_RT_dt.out
min_CD-L[ ]dt.out	min_LOL_dt.out	min_TRT_dt.out
min_CD-L[ ]dt.out	min_LOP_dt.out	

Table 8-20 Nodes of Interest for Evaluation of Temperature Gradients

Location	Node Number	Description
2	1660	Pipe
3	262	Weld Overlay
4	1782	Pipe ID
5	1270	Weld Overlay OD at top of the WOL
6	1348	Piping Weld ID at SS weld location
7	1143	Weld Overlay OD near SS weld location
8	1516	Liner to Safe End Weld ID
9	1222	Weld Overlay OD near DM weld
10	7989	Liner ID
11	1289	Weld Overlay OD at bottom of WOL
12	1371	Nozzle/Head Interior Corner (base metal)
13	1421	Nozzle/Head Exterior Corner

Table 8-21 Temperature Gradients of Interest

Gradient Designation	Gradient Location	Gradient Description
21	2 to 3	Pipe to Weld Overlay
22	4 to 5	Pipe ID to Weld Overlay OD
23	6 to 7	Piping Weld ID to Weld Overlay OD
24	8 to 9	Liner to Safe End Weld ID to Weld Overlay OD
25	10 to 11	Liner ID to Weld Overlay OD
26	12 to 13	Head ID (base metal) to Head OD

[ ]

Figure 8-2 Location Numbers for Evaluation of Temperature Gradients

[ ]

Figure 8-3 Heat-Up Early Spray Transient

[ ]

Figure 8-4 Heat-Up Late Spray Transient

[ ]

Figure 8-5 Cool-Down Early Spray with Temperature Drop of[ ]

[ ]

Figure 8-6 Cool-Down Late Spray with Temperature Drop of[ ]

[ ]

Figure 8-7 Cool-Down Early Spray with Temperature Drop of [ ]

[ ]

Figure 8-8 Cool-Down Late Spray with Temperature Drop of[ ]

Figure 8-9 Unit Loading & Unit Unloading at 5% of Full Power Transients

[ ]

Figure 8-10 Large Step Decrease in Load Transient

[ ]

Figure 8-11 Step Load Increase of 10% of Full Power Transient

[ ]

Figure 8-12 Step Load Decrease of 10% of Full Power Transient

[ ]

Figure 8-13 Boron Concentration Equalization Transient

[ ]

Figure 8-14 Loss of Load Transient

Figure 8-15 Loss of Power Transient

[ ]

Figure 8-16 Loss of Flow Transient

[ ]

Figure 8-17 Reactor Trip Transient

[ ]

Figure 8-18 Inadvertent Auxiliary Spray Transient

Figure 8-19 Turbine Roll Test Transient

9 STRUCTURAL ANALYSIS

Stress analyses are performed at the time points listed in Table 9-1 through Table 9-17. The time points include those at which the maximum temperature gradients (maximum thermal stresses) and the maximum and minimum pressures occur, as well as those of analytical interest. 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 from the transient input macros. The computer output files for the structural analyses are:

min_HU-ES_st.out	min_PLPU_st.out	min_LSL_st.out
min_HU-LS_st.out	min_BCE_st.out	min_SLD_st.out
min_CD-E[ ]st.out	min_IA_st.out	min_SLI_st.out
min_CD-E[ ]st.out	min_LOF_st.out	min_RT_st.out
min_CD-L[ ]st.out	min_LOL_st.out	min_TRT_st.out
min_CD-L[ ]st.out	min_LOP_st.out	

Table 9-1 Time Points of Interest - HU-ES

[ ]

Table 9-2 Time Points of Interest - HU-LS

[ ]

Table 9-3 Time Points of Interest - CD-ES[ ]

[ ]

Table 9-4 Time Points of Interest - CD-LS[ ]

[ ]

Table 9-5 Time Points of Interest - CD-ES[ ]

[ ]

Table 9-6 Time Points of Interest - CD-LS[ ]

[ ]

Table 9-7 Time Points of Interest - PLPU

Table 9-8 Time Points of Interest - LSL

[ ]

Table 9-9 Time Points of Interest - SLI

[ ]

Table 9-10 Time Points of Interest - LOL

[ ]

Table 9-11 Time Points of Interest - SLD

[ ]

Table 9-12 Time Points of Interest - BCE

[ ]

Table 9-13 Time Points of Interest - LOP

[ ]

Table 9-14 Time Points of Interest - LOF

Table 9-15 Time Points of Interest - RT

Table 9-16 Time Points of Interest – IA

Table 9-17 Time Points of Interest – TRT

10 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 [14]) 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.

10.1 ASME Code Primary Stress Intensity (SI) Criteria

Per NB-3213.8 of Reference [14], 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 primary stress intensity criteria are specified in: NB-3221 for Design Conditions, NB-3223 for Level B (Upset), NB-3224 for Level C (Emergency), NB-3225 for Level D (Faulted) and NB-3226 for Test Conditions.

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 pipe 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. Therefore, the primary stress intensity requirements for the nozzle, welds, safe end and pipe have been satisfied for all service levels without the need for further evaluation.

Other related criteria include the minimum required pressure thickness (NB-3324 of Reference [14]) and reinforcement area (NB-3330 of Reference [14]), which were addressed in the original nozzle/pressurizer designs. Adding weld overlay will increase the nozzle wall thickness, and therefore, these requirements are satisfied.

10.2 ASME Code Primary + Secondary Stress Intensity (SI) Criteria

The analyses of stresses for transient conditions are required to satisfy the requirements for the secondary SI range and repetitive loadings. The following discussion describes the primary + secondary SI range evaluation and fatigue analysis process employed herein for the design.

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

1) The highly stressed locations affected by implementation of SWOL are evaluated.
2) The specified region is quantitatively qualified.

Once specific locations for detailed stress evaluation are established, the related paths lines can be defined with ANSYS. A post-processing is then conducted to convert the component stresses along the selected path lines into the SI categories (i.e., membrane, membrane + bending, total) that correlate to the criteria of the ASME Code (Reference [14]). For paths that go through two materials partial paths are taken in addition to the free edge to free edge.

10.2.1 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 and peak stress).

The paths are shown in Figure 10-1 and are described in Table 10-1. The stress linearization for all transients is documented in computer file "*min_paths.out*".

Table 10-1 Path Definition

Path Name	Inside Node No.	Outside Node No.
Path1	1371	1421
Path2	1433	1372
Path3	5125	3156
Path3A	5125	1248
Path3B	1248	3156
Path4	1484	3249
Path4A	1484	1188
Path4B	1188	3249
Path5	1317	3209
Path5A	1317	1212
Path5B	1212	3209
Path6	1336	1179
Path6A	1336	1209
Path6B	1209	1179

Path Name	Inside Node No.	Outside Node No.
Path7	1313	3190
Path7A	1313	1165
Path7B	1165	3190
Path8	3765	1136
Path8A	3765	1140
Path8B	1140	1136
Path9	5948	1270
Path9A	5948	3281
Path9B	3281	1270
Path10	5951	1852

Figure 10-1 Stress Paths through the Spray Nozzle Model

Full through thickness paths are taken at the same location as the partial paths (A/B). The partial path name has the letter 'A' or 'B' behind the full path name.

Note: The path's numbering starts from the number "2". The pathline "Path1" is not defined.

10.2.2 Applicable Stress Intensity Due to External Loads

The spray nozzle is exposed to the external loads. The stress intensities applicable for primary + secondary qualification due to these loads were calculated in Section 6. The membrane stress due to internal pressure is not considered here, since this is already included in the ANSYS transient runs.

The OBE + Thermal external loads combination produces highest stress intensities at all evaluated locations. Therefore stress intensities from Table 6-9 has been conservatively added to the maximum transient SI ranges from the ANSYS runs in the following sections.

10.2.3 Maximum Primary + Secondary Stress Intensity Range

The computer program StressRange version 2.0 (Reference [15]) is used to calculate membrane + bending stress intensity range and total stress intensity range based on the method prescribed in paragraph NB-3216.2 of the ASME Code. The computer run containing the results of the stress range calculation for membrane + bending stress for all transient events is "*min_paths(M+B).txt*". A zero stress state (ZSS) is included in this run.

The membrane + bending stress intensity range runs are conservatively combined by hand with the stresses due to external loads (calculated in Section 6). The summary of maximum membrane + bending stress intensity ranges is tabulated in Table 10-2.

10.2.4 Primary + Secondary (P+Q) Stress Intensity Range Qualification (NB 3222.2)

The maximum membrane + bending stress intensity range, as calculated in the stress range run "*min_paths(M+B).txt*", are conservatively combined with the maximum stress intensities due to external loads from Table 6-9 (as discussed in Section 10.2.2). Note, that Table 6-9 lists only SI for the through-wall paths. The SI from outside node of these paths is conservatively used for the partial path – mid-wall locations (outside node of "PathA" and inside node of "PathB").

The sum of the maximum transient SI Range and the stress intensity due to external loads are compared directly to the primary + secondary stress intensities range criteria of the ASME Code.

Table 10-2 provides a summary of the maximum stress intensity ranges and allowable limits along with the material and path designation.

Table 10-2 shows that the 3Sm limit is not met at the following locations:

Inside node of paths: Path5, Path7, Path7A, Path8, Path8A, Path10

Outside node of paths: Path8, Path10

For the remaining locations, the requirement is met.

The load-step combinations for locations which exceed 3Sm limit are shown in Table 10-3.

The ASME Code allows that the 3*Sm limit may be exceeded under special condition, one of them being that the Simplified Elastic-Plastic Analysis (NB-3228.5) is used in the fatigue analysis. See Section 10.2.5 for further qualification.

Table 10-2 Summary of Maximum Primary + Secondary SI Ranges for M + B Stresses

Path	Transient Stresses + External Stresses		Allowable 3Sm limit at 680°F[1] [ksi]		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node	Outside Node	Inside Node	Outside Node
Path2			80.1	80.1		
Path3			80.1	69.9		
Path3A			80.1	80.1		
Path3B			69.9	69.9		
Path4			69.9	69.9		
Path4A			69.9	69.9		
Path4B			69.9	69.9		
Path5			41.1	69.9		
Path5A			41.1	41.1		
Path5B			69.9	69.9		
Path6			41.1	69.9		
Path6A			41.1	41.1		
Path6B			69.9	69.9		
Path7			41.1	69.9		
Path7A			41.1	41.1		
Path7B			69.9	69.9		
Path8			45.6	69.9		
Path8A			45.6	45.6		
Path8B			69.9	69.9		
Path9			49.2	69.9		
Path9A			49.2	49.2		
Path9B[2]			69.9	69.9		
Path10			49.2	49.2		

[1] The Sm values are conservatively taken a[ ](maximum transient temperature)

[2] The entire through thickness section needs to act together in order for ratcheting to occur. Since partial path "Path9A" is much longer and stiffer than Path9B, the behavior of the section is driven by Path9A. Since Path9A material does not ratchet (3Sm limit is satisfied), it can be deduced that the adjacent material Path9B can not ratchet either. Therefore, Path9B is acceptable without satisfying the 3Sm limit.

Table 10-3 Load Step Combinations for the Locations that Exceed 3Sm Limit

Path	Load Step Combination	
	Inside Node	Outside Node
Path5	119 - 301 CD-L[ ]-IA[ ]	-
Path7	135 - 305 CD-E[ ]-IA[ ]	-
Path7A	134-305 CD-E[ ]-IA[ ]	-
Path8	134-237 CD-E[ ]-LOI[ ]	134-237 CD-E[ ]-LOI[ ]
Path8A	134-305 CD-E[ ]-IA[ ]	-
Path10	134-237 CD-E[ ]-LOI[ ]	134-236 CD-E[ ]-LOI[ ]

10.2.5 Simplified Elastic-Plastic Analysis (NB-3228.5)

The maximum primary+secondary stress intensity criterion in Section 10.2.4 is not met for the location at specific load step combinations determinate in Section 10.2.4 . Therefore, the simplified elastic-plastic analysis for these locations is provided in this section.

The primary + secondary stress intensity range may exceed 3*Sm if the requirements of the simplified elestic-plastic analysis are met. The requirements are:

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, shall be ≤ 3*Sm.

The computer program StressRange v2.0 (Reference [15]) is used to calculate primary plus secondary membrane plus bending stress intensity, excluding the thermal bending stress intensity range. The bending stress due to pressure only is determined by multiplying the bending stress obtain from design linearization file "*min_DC_paths.out*" with a pressure ratio. The ratio is the pressure at the time point constituting the maximum membrane + bending SI range, divided by the design pressure of 2485 psig at 680°F. The applied temperature effects only physical material properties, therefore the effect of thermal bending is considered to be negligible. The prorated bending stress is added to the membrane stress and external stress in determining the membrane + bending SI range excluding thermal bending effect. The run containing the results of the stress range calculation is "*min_paths(M+B-ThBend).txt*".

Note that the zero stress state (ZSS) is included in this run. Table 10-4 lists the range of primary plus + secondary membrane plus bending stress intensity, excluding thermal bending for locations and load step combinations where the 3Sm limit was exceeded (see Table 10-3).

Table 10-4 SI Ranges of Maximum Primary + Secondary Membrane Plus Bending Stress Excluding Thermal Bending Stresses

Path	Transient Stresses + External Stresses		Allowable 3Sm limit at 680°F		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node	Outside Node	Inside Node	Outside Node
Path5			41.1	-		
Path7			41.1	-		
Path7A			41.1	-		
Path8			45.6	69.9		
Path8A			45.6	-		
Path10			49.2	49.2		

The SI Ranges of maximum primary + secondary membrane plus bending stress excluding thermal bending stress does not exceed the 3Sm limit at all locations. The criterion is met.

2) Factor Ke (NB-3228.5(b))

The values of Sa 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 [14])

n = 0.3 for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference [14])

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

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

The Ke factor is calculated for each SI Ranges over the 3Sm limit in the fatigue check as documented in Section 10.2.6 .

3) Fatigue Usage Factor (NB-3228.5© and NB-3222.4)

For fatigue usage factor evaluation see Section 10.2.6 .

4) Thermal Stress Ratchet (NB-3228.5(d) and NB-3222.5)

Thermal Ratchet is considered for the locations at specific load step, where the 3Sm limit was not met (see Section 10.2.4)

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 [16], page 207).

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

Table 10-4 determines the maximum allowable ranges of thermal stresses.

NB-3222.5 only requires the SI Range to include thermal SI Ranges. Therefore, the stress analyses due to temperature loads only are performed at all time-points, similar to structural analysis in Section 9, with pressure = 0. The computer output files are:

min_HU-ES_rtch.out	min_PLPU_rtch.out	min_LSL_rtch.out
min_HU-LS_rtch.out	min_BCE_rtch.out	min_SLD_rtch.out
min_CD-E[ ]rtch.out	min_IA_rtch.out	min_SLI_rtch.out
min_CD-E[ ]rtch.out	min_LOF_rtch.out	min_RT_rtch.out
min_CD-L[ ]rtch.out	min_LOL_rtch.out	min_TRT_rtch.out
min_CD-L[ ]rtch.out	min_LOP_rtch.out	

The stress linearization for the transient runs is documented in the file "*min_paths_rtch.out*". The SI ranges for thermal only are obtained from "*min_paths_rtch(M+B).txt*".

The general primary membrane stresses "Pm" due to pressure for load step combinations listed in Table 10-3 are calculated from the general primary membrane stresses at design condition [ ]multiplied by pressure ratios. The pressure ratio for specific load step is given by actual pressure at this load step [psig] divided by design pressure [psig]. The higher "Pm" of two time points is used for determination of the Allowable SI Range. The general primary membrane stresses "Pm" are shown in Table 10-5 and the membrane stresses for all defined paths at design condition are documented in ANSYS output files "*min_DC_paths.out*".

Table 10-5 General Membrane Stress for Critical Locations

Location	Load Step	Pressure [psia]	Pressure Ratio	Pm [ksi] at 2250 psia	Pm [ksi]
Path5 (inside)					
Path7 (inside)					
Path7A (inside)					
Path8 (inside)					
Path8 (outside)					
Path8A (inside)					
Path10 (inside)					
Path10 (outside)					

Table 10-6 Allowable Ranges of Thermal Stresses

Path	SI Range [ksi]	Sm[1] [ksi]	1.5Sm [ksi]	Sy[1] [ksi]	Pm [ksi]	x	y'	Allowable SI Range [ksi]
Path5 (Inside)								
Path7 (Inside)								
Path7a (Inside)								
Path8 (Inside)								
Path8 (Outside)								
Path8a (Inside)								
Path10 (Inside)								
Path10 (Outside)								

Where:

x = maximum general membrane stress due to pressure ("Pm") divided by the max(Sy, 1.5*Sm).

$y' = 1/x$ for $0 < x < 0.5$ and $y' = 4(1-x)$ for $0 \le x \le 0.5$

Allowable SI Range = $y' \cdot \max(1.5S_m, S_y)$

[1] Sm and Sy from Section 5.1 are conservatively taken at 680°F.

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

5) Temperature Limits (NB-3228.5(e))

The maximum temperature of the components is 680°F which does not exceed the maximum allowable temperatures listed in Table NB-3228.5(b)-1, Reference [14].

Therefore, the ASME Code requirement is met.

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 Sy and Su values a[ ]are listed in Section 5.1 .

Table 10-7 Minimum Strength Ratio

Location	Material	Minimum Sy at 70°F [ksi]	Minimum Su at 70°F [ksi]	Sy/Su
Path5 inside, Path7 inside Path7A inside				
Path8 inside Path8A outside				
Path 10 inside Path 10 outside				
Path8 outside				

All materials above have specified minimum yield strength to specified minimum tensile strength ratio less then 0.80, therefore the ASME Code requirement is met.

10.2.6 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 geometric discontinuity.

The following pages contain the calculation of the cumulative fatigue usage factor for the limiting points. The calculation is performed for all materials (except the head material, since the head is not affected by the WOL). The critical locations are listed in Table 10-8. These locations envelop the remaining paths.

The stress category used in fatigue evaluation, along with an appropriate FSRF, for each node is listed in Table 10-8. Due to the geometric discontinuities at the outside nodes of Path2, 10 and inside node of Path4A, M+B stress intensities are used with FSRF for fatigue evaluation. A conservative FSRF o[ ]s chosen based on Reference [17], page 395.

Table 10-8 Stress Category and FSRF in Fatigue Evaluation

Location	Material	Stress Category	FSRF
Path2 outside node	SA-508	M+B	2
Path4A inside node	Alloy 600	M+B	2
Path7 inside node	SA-182	Total	1
Path8A inside node	SA-213	Total	1
Path9B outside node	Alloy 690	Total	1
Path10 outside node	SA-376	M+B	2

The load cases of all transients are combined for the maximum SI range. The number of cycles of the appropriate transient is used in the fatigue usage factor calculation. When combining with other transients, the number of cycles of this transient may be reduced accordingly. All transient combinations with SI Ranges contributing to the fatigue usage factor are included in the following tables. Fatigue curves in the following calculation are defined in Figures I-9.2.1 and I-9.2.2 of Reference [14] for WOL material and Figures N-415(A) and N-415(B) of Reference [6] and [7] for existing materials as specified in Reference [1].

The Inadvertent Auxiliary Spray transient consists of two cycles (see Figure 8-18); therefore, for the fatigue calculations the transient is splitted into two separate transients "IA1" and "IA2" with the same number of cycles of[ ]Transient "IA1" is between time-poin[ ] [ ]Transient "IA2" is betwee[ ] [ ]

The stress intensities due to external loads, as calculated in Section 6.1.2 , are added to the transients SI Ranges where applicable. As already discussed in Section 10.2.2 , the maximum SI due to external loads are given by the load combination: OBE+Thermal Loads. Therefore, the stress intensity due to this combination is conservatively added to the maximum SI Ranges for the first[ ]cycles[ ]cycles is specified for OBE and[ ]cycles for thermal external loads), unless otherwise noted. The notes below the tables with fatigue usage calculations provide detailed description of the used stresses and cycles of the external loads.

The SI Ranges used for the fatigue calculation are documented in the file "*min_paths(M+B).txt*" for membrane + bending stresses and in the file "*min_paths(Total).txt*" for total stresses.

Table 10-9 Nozzle Usage Factor

EVALUATION TITLE: Diablo Canyon, Path2 outside

REFERENCE: min_paths(M+B).txt
MATERIAL: [ ]
TYPE: [ ]
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

RANGE NUM.	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	PEAK SI RANGE	E mat	S alt	(Eratio) x Salt	ALLOWABLE CYCLES 'N'	USAGE FACTOR 'U'
[								]

Total Fatigue Usage Factor = [ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'M+B' SI Range =	[ ]	ksi	FSRF =	[ ]	Ke =	[ ]
For Range 2, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 3, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 4, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 5, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 6, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 7, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 8, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 9, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 10, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 11, 'M+B' SI Range =		ksi	FSRF =		Ke =	
For Range 12, 'M+B' SI Range =		ksi	FSRF =		Ke =	

Usage = [ ] < 1.0. Therefore, the ASME Code requirement is met.

---

[1] The maximum temperature occurring during the plant operation is [ ]. The Young's modulus 'Emat' at [ ] is conservatively used.

[2] Internal cycles

[3] SI of [ ] due to external loads (OBE+Th) is conservatively added to the highest SI Ranges for the first eight combinations, which consist [ ] cycles.

Table 10-10 DM Weld Usage Factor

EVALUATION TITLE: Diablo Canyon, Path4A inside

REFERENCE: min_paths(M+B).txt
MATERIAL: [ ]
TYPE: [ ]
UTS (ksi) = [ ] at T [ ] E curve (psi) [ ]
Emat (psi) = [ ] at T [ ] E ratio = Ecurve/Emat

RANGE NUM.	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	PEAK SI RANGE	E mat	S alt	(Eratio) x Salt	ALLOWABLE CYCLES 'N'	USAGE FACTOR 'U'
[								]

Total Fatigue Usage Factor = [ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'M+B' SI Range = [ ] ksi FSRF = [ ] Ke = [ ]
For Range 2, 'M+B' SI Range = ksi FSRF = Ke =
For Range 3, 'M+B' SI Range = ksi FSRF = Ke =
For Range 4, 'M+B' SI Range = ksi FSRF = Ke =
For Range 5, 'M+B' SI Range = ksi FSRF = Ke =
For Range 6, 'M+B' SI Range = ksi FSRF = Ke =
For Range 7, 'M+B' SI Range = ksi FSRF = Ke =
For Range 8, 'M+B' SI Range = ksi FSRF = Ke =
For Range 9, 'M+B' SI Range = ksi FSRF = Ke =

Usage [ ] < 1.0. Therefore, the ASME Code requirement is met.

---

[1] The maximum temperature occurring during the plant operation is [ ] The Young's modulus 'Emat' at [ ] is conservatively used.

[2] Internal cycles

[3] The external loads do not act during the spray actuations.

[4] SI of [ ] due to external loads (OBE+Th) is conservatively added to the highest SI Ranges for the first six maximum combinations, which consist [ ] cycles.

Table 10-11 Safe End Usage Factor

EVALUATION TITLE: Diablo Canyon, Path7 inside								
REFERENCE: min_paths(Total).txt **MATERIAL:** [ ] **TYPE:** [ ] **UTS (ksi) =** [ ] at T = [ ] E curve (psi) = [ ] **Emat (psi) =** [ ] at T = [ ] E ratio = Ecurve/Emat								
RANGE NUM.	**TRANSIENTS WITH RANGE EXTREMES**	**REQ'D CYCLES**	**PEAK SI RANGE**	**E mat**	**S alt**	**(Eratio) x Salt**	**ALLOWABLE CYCLES 'N'**	**USAGE FACTOR 'U'**

[ ]

Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'Total' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'Total' SI Range =	[ ]	ksi	FSRF =	[ ]	Ke =	[ ]
For Range 2, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 3, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 4, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 5, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 6, 'Total' SI Range =		ksi	FSRF =		Ke[6] =	
For Range 7, 'Total' SI Range =		ksi	FSRF =		Ke[6] =	
For Range 8, 'Total' SI Range =		ksi	FSRF =		Ke[6] =	

Usage = [ ] < 1.0. Therefore, the ASME Code requirement is met.

---

[1] The maximum temperature occurring during the plant operation is [ ]. The Young's modulus 'Emat' at [ ] is conservatively used.

[2] Internal Cycles

[3] The external loads do not act during the spray actuations.

[4] The Young's modulus 'Emat' is taken at average metal temperature for this combination (see Table 10-12).

[5] SI of [ ] due to external loads (OBE+Th) is conservatively added to the highest SI Ranges for the first four combinations, which consist [ ] cycles.

[6] Sm value for Ke factor calculation is taken at average temperature for this calculation (see Table 10-12).

Table 10-12 E and Sm at Average Temperature for Table 10-11 Fatigue Evaluation

Combination	Load Step	T [°F]	T_{avg} [°F	Sm at T_{avg} [°F]	Emat at T_{avg} [psi]

Table 10-13 Safe End to Pipe Weld Usage Factor

EVALUATION TITLE: Diablo Canyon, Path8A inside

REFERENCE: min paths(Total).txt
MATERIAL: [ ]
TYPE: [ ]
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

RANGE NUM.	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	PEAK SI RANGE	E mat	S alt	(Eratio) x Salt	ALLOWABLE CYCLES 'N'	USAGE FACTOR 'U'
[								]

Total Fatigue Usage Factor =[ ]

The Peak SI Range = 'Total' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'Total' SI Range =	[ ] ksi	FSRF = [ ]	Ke[5] =	[ ]
For Range 2, 'Total' SI Range =	ksi	FSRF =	Ke[5] =	
For Range 3, 'Total' SI Range =	ksi	FSRF =	Ke[5] =	
For Range 4, 'Total' SI Range =	ksi	FSRF =	Ke =	
For Range 5, 'Total' SI Range =	ksi	FSRF =	Ke[5] =	
For Range 6, 'Total' SI Range =	ksi	FSRF =	Ke =	
For Range 7, 'Total' SI Range =	ksi	FSRF =	Ke =	

Usage = [ ] < 1.0. Therefore, the ASME Code requirement is met.

[1] The maximum temperature occurring during the plant operation is [ ] The Young's modulus 'Emat' a[ ] is conservatively used.

[2] Internal cycles

[3] The external loads do not act during the spray actuations.

[4] SI o[ ] due to external loads (OBE+Th) is conservatively added for the first four maximum ranges, which consis[ ] cycles.

[5] Ke factor using Sm = [ ]

Table 10-14 Weld Overlay Usage Factor

EVALUATION TITLE: Diablo Canyon, Path9B outside

REFERENCE: min_paths(Total).txt

MATERIAL: [ ]
TYPE: [ ]
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

RANGE NUM.	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES 40 years	PEAK SI RANGE	E mat	S alt	(Eratio) x Salt	ALLOWABLE CYCLES 'N'	USAGE FACTOR 'U'
[								]
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'Total' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'Total' SI Range =	[ ]	ksi	FSRF =	[ ]	Ke =	[ ]
For Range 2, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 3, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 4, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 5, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 6, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 7, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 8, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 9, 'Total' SI Range =		ksi	FSRF =		Ke =	
For Range 10, 'Total' SI Range =		ksi	FSRF =		Ke =	

Usage = [ ] < 1.0. Therefore, the ASME Code requirement is met.

---

[1] The maximum temperature occurring during the plant operation is [ ] The Young's modulus 'Emat' at [ ] is conservatively used.

[2] Internal cycles

[3] The external loads do not act during the spray actuations.

[4] SI of [ ] due to external loads (OBE+Th) is conservatively added to the maximum SI Ranges for first six combinations, which consist from [ ] cycles.

Table 10-15 Pipe Usage Factor

EVALUATION TITLE: Diablo Canyon, Path10 outside

REFERENCE: min_paths(M+B).txt
MATERIAL: [ ]
TYPE: [ ]
UTS (ksi) = [ ] at T [ ] E curve (psi) [ ]
Emat (psi) = [ ] at T [ ] E ratio = Ecurve/Emat

RANGE NUM.	TRANSIENTS WITH RANGE EXTREMES	REQ'D CYCLES	PEAK SI RANGE	E mat	S alt	(Eratio) x Salt	ALLOWABLE CYCLES 'N'	USAGE FACTOR 'U'
[								]
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) x Ke Factor

For Range 1, 'M+B' SI Range =	[	ksi	FSRF = [	Ke[5] =	[
For Range 2, 'M+B' SI Range =		ksi	FSRF =	Ke[5] =	
For Range 3, 'M+B' SI Range =		ksi	FSRF =	Ke[5] =	
For Range 4, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 5, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 6, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 7, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 8, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 9, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 10, 'M+B' SI Range =		ksi	FSRF =	Ke =	
For Range 11, 'M+B' SI Range =	]	ksi	FSRF =]	Ke =	]

Usage = 0.383 < 1.0. Therefore, the ASME Code requirement is met.

---

[1] The maximum temperature occurring during the plant operation is [ ] The Young's modulus 'Emat' at [ ] is conservatively used.

[2] Internal cycles.

[3] The external loads do not act during the spray actuations.

[4] SI of [ ] due to external loads (OBE+Th) is conservatively added in first [400 cycles.]

[5] Ke factor using Sm = [ ]

11 RESULTS SUMMARY/CONSLUSION

Stress analyses of the spray nozzle weld overlay repairs for Diablo Canyon Unit 2 Pressurizer are summarized in this report. Minimum overlay configuration is investigated. The analyses demonstrate that the weld overlay designs satisfy the stress and fatigue requirements of the ASME Code (Reference [14]).

The summary of the maximum primary+secondary membrane plus bending stress intensity ranges and fatigue usage factor are listed in Table 11-1 for each component. The cumulative fatigue usage factors at critical locations investigated are less than 1.0, with the highest usage factor being[ ]The fatigue evaluation is based on the spray nozzle design transient, and for the specified number of cycles per Reference [2].

In conclusion, the spray nozzle with weld overlay satisfies the ASME Code primary plus secondary stress requirements as well as criteria against the fatigue failure. The primary stress criteria are satisfied as described in Section 10.1 .

Table 11-1 Summary of Results

Component	Material	Primary SI	Max. SI Range PL+Pb+Q			Fatigue Usage Factor		
			Calculated [ksi]	Limit [ksi]	IR	Calculated [ksi]	Limit [ksi]	IR
Nozzle	[ ]		[ ]	80.1	[ ]		1.0	[ ]
DM Weld				69.9			1.0	
Safe End		See Section 10.1		41.1			1.0	
Safe End to Pipe Weld				45.6			1.0	
Pipe				49.2			1.0	
Weld Overlay				69.9			1.0	

12 SOFTWARE VERIFICATION

The finite element analyses documented in this report were performed using ANSYS v11.0 software (Reference [13]). The suitability and accuracy of use of ANSYS v11.0 was verified by performing the following verification runs.

Table 12-1 ANSYS Verification Files

File Name	Date	Element	Type
VM211.OUT	5/31/2007	PLANE183	2-D 8-Node Structural Solid
VM112.OUT	5/31/2007	PLANE77	2-D 8-Node Thermal Solid
VM211.OUT	5/31/2007	CONTA172	2-D 3-Node Surface-to-Surface Contact
VM211.OUT	5/31/2007	TARGE169	2-D Target Segment

The Stress Intensity Range calculations, documented in this report, are performed using Stress Range v2.0 program. The suitability and accuracy of the StressRange v2.0 are verified by comparing the calculated SI ranges listed in the files "*SRange_verif_(M+B).txt*" and "*SRange_verif_(Total).txt*" with Tables L3 and L4 in Reference [15].

Table 12-2 StressRange Program v2.0 Verification Files

File Name	Date	Description
SRange_verif_(M+B).txt	6/05/2007	StressRange Program verification file for M+B SI ranges including ZSS
SRange_verif_(Total).txt	6/05/2007	StressRange Program verification file for Total SI ranges including ZSS

13 COMPUTER OUTPUT FILES

Table 13-1 Computer Output and Input Files

File Name	Date	Description
min_geo.mac	5/29/2007	Input file to develop geometry of the spray nozzle
min_geo.out	5/29/2007	Output file to develop geometry of the spray nozzle
min_dT.mac	5/18/2007	Input file defining nodes for temperature and thermal gradient evaluation
min_paths.out	5/30/2007	Output file contains path definition for stress component and contains the linearized stresses along the paths for all transients
min_paths_rtch.out	5/30/2007	Output file for thermal ratchet analysis contains path definition for stress component and contains the linearized stresses along the paths for all transients
Fatigue Stress Range		
min_paths(M+B).txt	5/30/2007	SI Ranges (M+B) for combination of all transients
min_paths(Total).txt	5/30/2007	SI Ranges (Total) for combination of all transients
min_paths(M+B-ThBend).txt	5/30/2007	SI Ranges (M+B) excluding thermal bending for combination of all transients
min_paths_rtch(M+B).txt	5/30/2007	SI Ranges (M+B) with pressure = 0 for combination of all transients
Design Condition		
min_DC.out	5/29/2007	Output file for stress analysis
min_DC_paths.out	5/30/2007	Output file contains stress components along the paths
Heat-up Transients		
HU-ES_tr.inp	5/17/2007	Input file contains definition of heat-up early spray transient
min_HU-ES_th.out	5/29/2007	Output file for thermal analysis
min_HU-ES_dt.out	5/29/2007	Output file contains thermal gradients
min_HU-ES_st.out	5/29/2007	Output file for the stress analysis
min_HU-ES_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
HU-LS_tr.inp	5/17/2007	Input file contains definition of heat-up late spray transient
min_HU-LS_th.out	5/29/2007	Output file for thermal analysis
min_HU-LS_dt.out	5/29/2007	Output file contains thermal gradients
min_HU-LS_st.out	5/29/2007	Output file for the stress analysis
min_HU-LS_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Cool-down Transients		
CD-E[ ]tr.inp	5/17/2007	Input file contains definition of cool-down early spray transient with drop in a temperature o[ ]
min_CD-E[ ]th.out	5/29/2007	Output file for thermal analysis

min_CD-E[ ]dt.out	5/29/2007	Output file contains thermal gradients
min_CD-E[ ]st.out	5/29/2007	Output file for the stress analysis
min_CD-E[ ]rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-L[ ]tr.inp	5/17/2007	Input file contains definition of cool-down late spray transient with drop in a temperature of[ ]
min_CD-E[ ]th.out	5/29/2007	Output file for thermal analysis
min_CD-E[ ]dt.out	5/29/2007	Output file contains thermal gradients
min_CD-E[ ]st.out	5/29/2007	Output file for the stress analysis
min_CD-E[ ]rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-E[ ]tr.inp	5/17/2007	Input file contains definition of cool-down early spray transient with drop in a temperature of[ ]
min_CD-E[ ]th.out	5/29/2007	Output file for thermal analysis
min_CD-E[ ]dt.out	5/29/2007	Output file contains thermal gradients
min_CD-E[ ]st.out	5/29/2007	Output file for the stress analysis
min_CD-E[ ]rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-L[ ]tr.inp	5/17/2007	Input file contains definition of cool-down late spray transient with drop in a temperature of[ ]
min_CD-L[ ]th.out	5/29/2007	Output file for thermal analysis
min_CD-L[ ]dt.out	5/29/2007	Output file contains thermal gradients
min_CD-L[ ]st.out	5/29/2007	Output file for the stress analysis
min_CD-L[ ]rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Plant Loading & Plant Unloading Transient		
PLPU_tr.inp	5/17/2007	Input file contains definition of plant loading and unloading transient
min_PLPU_th.out	5/29/2007	Output file for thermal analysis
min_PLPU_dt.out	5/29/2007	Output file contains thermal gradients
min_PLPU_st.out	5/29/2007	Output file for the stress analysis
min_PLPU_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Step Load Decrease Transient		
SLD_tr.inp	5/17/2007	Input file contains definition of 10% step load decrease transient
min_SLD_th.out	5/29/2007	Output file for thermal analysis
min_SLD_dt.out	5/29/2007	Output file contains thermal gradients
min_SLD_st.out	5/29/2007	Output file for the stress analysis
min_SLD_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Step Load Increase Transient		
SLI_tr.inp	5/17/2007	Input file contains definition of 10% step load increase transient
min_SLI_th.out	5/29/2007	Output file for thermal analysis
min_SLI_dt.out	5/29/2007	Output file contains thermal gradients
min_SLI_st.out	5/29/2007	Output file for the stress analysis
min_SLI_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation

Large Step Load Transient		
LSL_tr.inp	5/17/2007	Input file contains definition of large step load transient
min_LSL_th.out	5/29/2007	Output file for thermal analysis
min_LSL_dt.out	5/29/2007	Output file contains thermal gradients
min_LSL_st.out	5/29/2007	Output file for the stress analysis
min_LSL_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Boron Concentration Equalization		
BCE_tr.inp	5/17/2007	Input file contains definition of boron concentration equalization transient
min_BCE_th.out	5/29/2007	Output file for thermal analysis
min_BCE_dt.out	5/29/2007	Output file contains thermal gradients
min_BCE_st.out	5/29/2007	Output file for the stress analysis
min_BCE_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Loss of Load		
LOL_tr.inp	5/17/2007	Input file contains definition of loss of load transient
min_LOL_th.out	5/29/2007	Output file for thermal analysis
min_LOL_dt.out	5/29/2007	Output file contains thermal gradients
min_LOL_st.out	5/29/2007	Output file for the stress analysis
min_LOL_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Loss of Power		
LOP_tr.inp	5/17/2007	Input file contains definition of loss of power transient
min_LOP_th.out	5/29/2007	Output file for thermal analysis
min_LOP_dt.out	5/29/2007	Output file contains thermal gradients
min_LOP_st.out	5/29/2007	Output file for the stress analysis
min_LOP_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Loss of Flow		
LOF_tr.inp	5/17/2007	Input file contains definition of loss of flow transient
min_LOF_th.out	5/29/2007	Output file for thermal analysis
min_LOF_dt.out	5/29/2007	Output file contains thermal gradients
min_LOF_st.out	5/29/2007	Output file for the stress analysis
min_LOF_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Reactor Trip		
RT_tr.inp	5/17/2007	Input file contains definition of reactor trip transient
min_RT_th.out	5/29/2007	Output file for thermal analysis
min_RT_dt.out	5/29/2007	Output file contains thermal gradients
min_RT_st.out	5/29/2007	Output file for the stress analysis
min_RT_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Turbine Roll Test		
TRT_tr.inp	5/17/2007	Input file contains definition of turbine roll test transient
min_TRT_th.out	5/29/2007	Output file for thermal analysis

min_TRT_dt.out	5/29/2007	Output file contains thermal gradients
min_TRT_st.out	5/29/2007	Output file for the stress analysis
min_TRT_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Inadvertent Auxiliary Spray Actuation		
IA_tr.inp	5/17/2007	Input file contains definition of inadvertent auxiliary spray actuation transient
min_IA_th.out	5/29/2007	Output file for thermal analysis
min_IA_dt.out	5/29/2007	Output file contains thermal gradients
min_IA_st.out	5/29/2007	Output file for the stress analysis
min_IA_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Appendix A: Fracture Mechanics Results		

File Name		Date	Description
min_path_fr.mac		5/31/2007	Input file contains path definition for stress component along the paths for all transients
Fr_PathLocs.out		5/31/2007	Output file contains the path point distances from the inside node
HU-ES_fr_SY	HU-ES_fr_SZ	5/31/2007	Stress results for fracture mechanics
HU-LS_fr_SY	HU-LS_fr_SZ		
CD-E[redacted]fr_SY	CD-E[redacted]fr_SZ		
CD-L[redacted]fr_SY	CD-L[redacted]fr_SZ		
CD-E[redacted]fr_SY	CD-E[redacted]fr_SZ		
CD-L[redacted]fr_SY	CD-L[redacted]fr_SZ		
PLPU_fr_SY	PLPU_fr_SZ		
LSL_fr_SY	LSL_fr_SZ		
SLI_fr_SY	SLI_fr_SZ		
SLD_fr_SY	SLD_fr_SZ		
BCE_fr_SY	BCE_fr_SZ		
LOL_fr_SY	LOL_fr_SZ		
LOP_fr_SY	LOP_fr_SZ		
LOF_fr_SY	LOF_fr_SZ		
RT_fr_SY	RT_fr_SZ		
IA_fr_SY	IA_fr_SZ		
TRT_fr_SY	TRT_fr_SZ		
HU-ES_fr_TH	SLD_fr_TH	5/31/2007	Output file contains temperature results for fracture mechanics
HU-LS_fr_TH	BCE_fr_TH		
CD-E[redacted]fr_TH	LOL_fr_TH		
CD-L[redacted]fr_TH	LOP_fr_TH		
CD-E[redacted]fr_TH	LOF_fr_TH		
CD-L[redacted]fr_TH	RT_fr_TH		
PLPU_fr_TH	IA_fr_TH		
LSL_fr_TH	TRT_fr_TH		
SLI_fr_TH			

14 REFERENCE

[1] AREVA Document 08-9042937-003, "Certified Design Specification for Pressurizer Nozzle Weld Overlays at Pacific Gas and Electric Diablo Canyon Nuclear Power Plant, Unit 2"

[2] AREVA Document 38-9046469-002, "Design Input Transmittal, Non-Proprietary, DIT-A0675765-03-00"

[3] AREVA Document 38-2200488-002, "Design Input Transmittal, Proprietary, DIT – A0675765-04-00, 01 & 03"

[4] AREVA Document 51-9048271-000, "Diablo Canyon 2 PWOL Design Transients"

[5] "ASME Boiler and Pressure Vessel Code", Section II, Part D - Properties, 2001 Edition including Addenda through 2003

[6] "ASME Boiler and Pressure Vessel Code", Section III, 1965 Edition including Addenda through Summer 1966

[7] "ASME Boiler and Pressure Vessel Code", Section III, 1965 Edition including Addenda through Winter 1967

[8] "ASME Boiler and Pressure Vessel Code", Section III, 1968 Edition including Addenda through Winter 1969

[9] "ASME Boiler and Pressure Vessel Code", Section III, 1971 Edition

[10] AREVA Document NPGD-TM-500 rev D, "NPGMAT", NPGD Material Properties Program, User's Manual (03/1985)

[11] AREVA Drawing 02-8019233D-001, "Diablo Canyon Pressurizer Spray Nozzle Weld Overly Design Input"

[12] AREVA Drawing 02-8018400C-002, "Diablo Canyon Unit 2 Pressurizer Spray Nozzle Existing Configuration"

[13] "ANSYS" Finite Element Computer Code, Version 11.0, ANSYS, Inc., Canonsburg, Pa.

[14] "ASME Boiler and Pressure Vessel Code", Section III, Division 1, 2001 Edition including Addenda through 2003

[15] AREVA Document 32-5032987-03, "StressRange Program Verification"

[16] "Companion Guide to the ASME Boiler & Pressure Vessel Code", Volume 1, ASME Press, New York, 2002

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

[18] "ANSYS" Finite Element Computer Code, Version 14.0, ANSYS, Inc., Canonsburg, PA

[19] AREVA Document 38-9200149-001, "DCPP Unit 2 Pressurizer Nozzle NDE Data"

APPENDIX A- Stresses used for Fracture Mechanics Analysis

A-1 Purpose

The purpose of this Appendix is to provide supplemental stress results of the transient analysis for fracture mechanics analysis of the Diablo Canyon Unit 2 spray nozzle weld overlay.

A-2 Stress and Temperature Evaluation

The ANSYS Post Processor is used to tabulate the stresses and temperatures along the predetermined paths. The paths are shown on Figure A-1 and described in Table A-1. Note that all stresses and temperatures are tabulated from the thermal and structural runs output files listed in Section 9.

For post preprocessor calculation, the definitions of these paths are contained in computer file "*min_paths_fr.mac*".

Table A-1 Path Description

Path Name	Inside Node No.	Outside Node No.
FPath1	5349	1246
FPath2	5199	1227
FPath3	5197	1183
FPath4	3765	1143

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, Sy) stress and the corresponding temperature of the nozzle are given. The path point distances from the inside node are included in the output file "*Fr_PathLocs.out*".

Stress and temperature result files are included in output files with "_fr_SY", "_fr_SZ" and "_fr_TH" in their names. They are listed in Section 13.

[ ]

Figure A-1 Paths Defined for Fracture Mechanics Evaluation

APPENDIX B – ADDITIONAL STRESSES USED FOR FRACTURE MECHANICS ANALYSIS

B.1 Purpose

The purpose of this Appendix is to provide additional stress results of the transient analysis for fracture mechanics analysis of the Diablo Canyon Unit 2 spray nozzle weld overlay. Stress results were evaluated for locations that are in close proximity to the indications found in the Spray Nozzle during 2R17.

B.1.1 Stress and Temperature Evaluation

The complete finite element analysis as presented in Rev. 000 was conducted using ANSYS version 11.0 on a 32-bit Windows XP machine. Although the ANSYS results from Rev. 000 are available to extract stress and temperature results at additional path lines, ANSYS 14.0 (Reference [18]) on a 64-bit Windows 7 machine is used for this Appendix and therefore a verification process is performed to ensure all results remain valid under the later version of ANSYS and Windows. Stress and temperature results along the paths defined in Appendix A are first re-produced and then compared with those in Rev. 000. It is verified that all results between two versions of ANSYS (11.0 and 14.0) and Windows (32-bit Windows XP and 64-bit Windows 7) are identical. Detailed ANSYS outputs are listed in Section B.1.2.

The ANSYS post-processing macro used in Appendix A is modified to define different path lines as well as to tabulate the stresses and temperatures along the defined paths in line with the Spray Nozzle NDE indications (see Reference [19]). The paths are shown on Figure B-1 and with node numbers listed in Table B-1.

The definitions of these paths are contained in computer file "min_paths_fr_AppB.mac".

Table B-1 Additional Paths in Appendix B

Path No.	Path Name	Inside Node No.	Outside Node No.	Intermediate Node No.	Material Selected
1	FLine1	5104	3271	none	Nozzle, WOL
2	FLine2	1265	1257	1194, 1259, 1260	Nozzle, WOL
3	FL2_wol	1265	1257	1194, 1259, 1260	WOL only
4	FL2_noz	1265	1257	1194, 1259, 1260	Nozzle only
5	FLine3	3721	3175	none	Safe end, SS weld, WOL
6	FLine4	1145	1141	none	SS weld, WOL
7	FL4_wol	1145	1141	none	WOL only
8	FL4_wld	1145	1141	none	SS weld only

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, Sy) stress, radial stress (Sx), hoop

stress (Sz), shear stress (Sxy), and the corresponding temperature of the nozzle are given. The path point distances from the inside node are included in the output file "Fr_PathLocs_AppB.out".

Stress (Sx, Sy, Sz and Sxy) and temperature result files are included in output files with "_fr_SX_AppB," "_fr_SY_AppB," "_fr_SZ_AppB," "_fr_Sh_AppB" and "_fr_TH" in their names. They are listed in Section B.1.2.

Notes:

- *Only laminar indications are found along pathlines FLine2 and Fline 4.*
- *No planar indications were found. Results along pathlines Flaine1 and Fline3 are provided for* ***Information only*** *in cases they are needed for future evaluations.*
- *FLine2 is path line used to sample results for evaluating laminar indication*
    - *FL2_wol used SWOL material for extracting stresses*
    - *FL2_noz used nozzle material for extracting stresses*
- FLine4 *is path line used to sample results for evaluating laminar indication*
    - FL4_wol *used SWOL material for extracting stresses*
    - FL4_wld *used weld material for extracting stresses*
- *Details A and B show the node numbers used for defining the pathlines as discussed in Table B-1*

Figure B-1 Additional Paths for Fracture Mechanics

Typical stress contour plots at high temperature gradients are shown in Figure B-2 for the overlay region during the transient HU-ES[ ] and in Figure B-3 during the transient CD[ ]

Notes:

- ***Only laminar indications are found along pathlines FLine2 and Fline 4.***
- ***No planar indications were found. Results along pathlines vertical pathlines provided for information only.***

Figure B-2 Stress Plots during HU-ES

[ ]

Notes:

- *Only laminar indications are found along pathlines FLine2 and Fline 4.*
- *No planar indications were found. Results along pathlines vertical pathlines provided for **information only**.*

[ ]

Figure B-3 Stress Plots during CD-ES[ ]

B.1.2 Computer Usage and ANSYS Files

ANSYS Version 14.0 is used in this Appendix. It was tested on the computer used for this Appendix (Computer name: SC-MJEHGTA; OS: Windows 7 with 24GB RAM) on October 14, 2013 by the preparer. The results of the test (as listed in ANSYS output file "VM112.out" and "VM211.out") are acceptable.

All ANSYS input/output files are collected and listed in Table B-2. ANSYS verification output files are also listed. All files are available in AREVA Inc. ColdStor storage \cold\General-Access\32\32-9000000\32-9049112-002\official\. The ColdStor installation date is 10/17/2013 for all files.

Table B-2 Appendix B ANSYS files

<table>
<tr><th colspan="4">Appendix A regenerated. Sub-directory: ..¥App-A-benchmark</th></tr>
<tr><th colspan="2">File Name</th><th>Date and Time</th><th>Description</th></tr>
<tr><td colspan="2">min_path_fr.out</td><td>10/08/2013 3:54pm</td><td>Input file contains path definition in Appendix A</td></tr>
<tr><td colspan="2">Fr_PathLocs.out</td><td>10/08/2013 3:54pm</td><td>Output file contains the path point distances from the inside node</td></tr>
<tr><td>HU-ES_fr_SY</td><td>HU-ES_fr_SZ</td><td rowspan="21">10/08/2013 3:54pm</td><td rowspan="21">Stress results regenerated as in Appendix A</td></tr>
<tr><td>HU-LS_fr_SY</td><td>HU-LS_fr_SZ</td></tr>
<tr><td>CD-ES [ ] _fr_SY</td><td>CD-ES [ ] _fr_SZ</td></tr>
<tr><td>CD-LS [ ] _fr_SY</td><td>CD-LS [ ] _fr_SZ</td></tr>
<tr><td>CD-ES [ ] _fr_SY</td><td>CD-ES [ ] _fr_SZ</td></tr>
<tr><td>CD-LS [ ] _fr_SY</td><td>CD-LS [ ] _fr_SZ</td></tr>
<tr><td>PLPU_fr_SY</td><td>PLPU_fr_SZ</td></tr>
<tr><td>LSL_fr_SY</td><td>LSL_fr_SZ</td></tr>
<tr><td>SLI_fr_SY</td><td>SLI_fr_SZ</td></tr>
<tr><td>SLD_fr_SY</td><td>SLD_fr_SZ</td></tr>
<tr><td>BCE_fr_SY</td><td>BCE_fr_SZ</td></tr>
<tr><td>LOL_fr_SY</td><td>LOL_fr_SZ</td></tr>
<tr><td>LOP_fr_SY</td><td>LOP_fr_SZ</td></tr>
<tr><td>LOF_fr_SY</td><td>LOF_fr_SZ</td></tr>
<tr><td>RT_fr_SY</td><td>RT_fr_SZ</td></tr>
<tr><td>IA_fr_SY</td><td>IA_fr_SZ</td></tr>
<tr><td>TRT_fr_SY</td><td>TRT_fr_SZ</td></tr>
<tr><td>HU-ES_fr_TH</td><td>SLD_fr_TH</td></tr>
<tr><td>HU-LS_fr_TH</td><td>BCE_fr_TH</td></tr>
<tr><td>CD-ES320_fr_TH</td><td>LOL_fr_TH</td></tr>
</table>

CD-LS [ ] _fr_TH	LOP_fr_TH		
CD-ES [ ] _fr_TH	LOF_fr_TH		
CD-LS [ ] _fr_TH	RT_fr_TH		
PLPU_fr_TH	IA_fr_TH		
LSL_fr_TH	TRT_fr_TH		
SLI_fr_TH			

Table B-2 Appendix B ANSYS files (conti.)

Appendix B results. Sub-directory: ..¥App-B			
File Name		**Date**	**Description**
min_path_fr_AppB.out		10/17/2013 1:21pm	Input file contains path definition in Appendix B
Fr_PathLocs_AppB.out		10/17/2013 1:21pm	Output file contains the path point distances from the inside node
HU-ES_fr_SY_AppB	HU-ES_fr_SZ_AppB	10/17/2013 1:21pm	Stress results in Appendix B
HU-ES_fr_SX_AppB	HU-ES_fr_Sh_AppB		
HU-LS_fr_SY_AppB	HU-LS_fr_SZ_AppB		
HU-LS_fr_SX_AppB	HU-LS_fr_Sh_AppB		
CD-ES [ ] _fr_SY_AppB	CD-ES [ ] _fr_SZ_AppB		
CD-ES [ ] _fr_SX_AppB	CD-ES [ ] _fr_Sh_AppB		
CD-LS [ ] _fr_SY_AppB	CD-LS [ ] _fr_SZ_AppB		
CD-LS [ ] _fr_SX_AppB	CD-LS [ ] _fr_Sh_AppB		
CD-ES [ ] _fr_SY_AppB	CD-ES [ ] _fr_SZ_AppB		
CD-ES [ ] _fr_SX_AppB	CD-ES [ ] _fr_Sh_AppB		
CD-LS [ ] _fr_SY_AppB	CD-LS [ ] _fr_SZ_AppB		
CD-LS [ ] _fr_SX_AppB	CD-LS [ ] _fr_Sh_AppB		
PLPU_fr_SY_AppB	PLPU_fr_SZ_AppB		
PLPU_fr_SX_AppB	PLPU_fr_Sh_AppB		
LSL_fr_SY_AppB	LSL_fr_SZ_AppB		
LSL_fr_SX_AppB	LSL_fr_Sh_AppB		
SLI_fr_SY_AppB	SLI_fr_SZ_AppB		
SLI_fr_SX_AppB	SLI_fr_Sh_AppB		
SLD_fr_SY_AppB	SLD_fr_SZ_AppB		
SLD_fr_SX_AppB	SLD_fr_Sh_AppB		
BCE_fr_SY_AppB	BCE_fr_SZ_AppB		

BCE_fr_SX_AppB	BCE_fr_Sh_AppB		
LOL_fr_SY_AppB	LOL_fr_SZ_AppB		
LOL_fr_SX_AppB	LOL_fr_Sh_AppB		
LOP_fr_SY_AppB	LOP_fr_SZ_AppB		
LOP_fr_SX_AppB	LOP_fr_Sh_AppB		
LOF_fr_SY_AppB	LOF_fr_SZ_AppB		
LOF_fr_SX_AppB	LOF_fr_Sh_AppB		
RT_fr_SY_AppB	RT_fr_SZ_AppB		
RT_fr_SX_AppB	RT_fr_Sh_AppB		
IA_fr_SY_AppB	IA_fr_SZ_AppB		
IA_fr_SX_AppB	IA_fr_Sh_AppB		
TRT_fr_SY_AppB	TRT_fr_SZ_AppB		
TRT_fr_SX_AppB	TRT_fr_Sh_AppB		

Table B-2 Appendix B ANSYS files (conti.)

Appendix B results. Sub-directory: ..¥App-B			
File Name		**Date**	**Description**
HU-ES_fr_TH_AppB	SLD_fr_TH_AppB	10/17/2013 1:21pm	Temperature results in Appendix B
HU-LS_fr_TH_AppB	BCE_fr_TH_AppB		
CD-ES [ ] _fr_TH_AppB	LOL_fr_TH_AppB		
CD-LS [ ] _fr_TH_AppB	LOP_fr_TH_AppB		
CD-ES [ ] _fr_TH_AppB	LOF_fr_TH_AppB		
CD-LS [ ] _fr_TH_AppB	RT_fr_TH_AppB		
PLPU_fr_TH_AppB	IA_fr_TH_AppB		
LSL_fr_TH_AppB	TRT_fr_TH_AppB		
SLI_fr_TH_AppB			
VM112.out		10/14/2013 9:28am	ANSYS verification output files
VM211.out		10/14/2013 9:32am	