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Diablo Canyon Unit 2 Pressurizer Safety/Relief Nozzle Weld Overlay Structural Analysis – Non-Proprietary

AREVA

CALCULATION SUMMARY SHEET (CSS)

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Safety Related: ☒ Yes ☐ No

Title Diablo Canyon Unit 2 Pressurizer Safety/Relief 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 safety/relief nozzle weld overlay design to the requirements specified in Reference [5].

SUMMARY OF RESULTS:

The calculation demonstrate that the design of the Pressurizer safety/relief nozzle weld overlay for the Diablo Canyon Unit 2 meets the stress and fatigue requirements of the Design Code (Reference [3]).

Based on the loads and cycles specified in References [6] and [8], the conservative fatigue analysis indicates that Pressurizer safety/relief nozzle weld overlay design has the maximum usage factor of **[ ]** for specified number of cycles per Reference [6] compared to the ASME Code allowed maximum value of 1.0.

This document is the Non-Proprietary version of 32-9049114-003.

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

*The 108 pages include pages 1, 1A, 2 through 4, 4A, 5 through 106.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

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THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

☐ YES
☒ NO

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Signature Block

Name and Title (printed or typed)	Signature	P/R/A and LP/LR	Date	Pages/Sections Prepared/Reviewed/Approved
Silvester Noronha Principal Engineer	S Noronha	P	3/26/14	All Pages
Samer Mahmoud Principal Engineer	[signature]	R	3-26-14	All Pages (Detailed Check)
Tim M. Wiger Manager	T.M. Wiger	A	3/27/14	All Pages

Note: P/R/A designates Preparer (P), Reviewer (R), Approver (A);
LP/LR designates Lead Preparer (LP), Lead Reviewer (LR)

Project Manager Approval of Customer References (N/A if not applicable)

Name (printed or typed)	Title (printed or typed)	Signature	Date
N/A	N/A	N/A	N/A

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Table of Contents

Page

SIGNATURE BLOCK 1A
RECORD OF REVISION 2

TABLE OF CONTENTS **3**

LIST OF FIGURES **4**

LIST OF TABLES **5**

1 PURPOSE **7**

2 ANALYTICAL METHODOLOGY **8**

3 KEY ASSUMPTIONS **9**

4 DESIGN INPUT **9**

4.1 GEOMETRY 9
4.2 FINITE ELEMENT MODEL 9
4.3 MATERIALS 11
4.4 BOUNDARY CONDITIONS 15
4.5 LOADS 18
4.5.1 External Loads *18*
4.5.2 Design Conditions *19*
4.5.3 Operational Transient Loads *19*

5 CALCULATION **30**

5.1 DESIGN CONDITION 30
5.2 THERMAL ANALYSIS 32
5.3 STRESS ANALYSIS 53
5.4 ASME CODE CRITERIA 60
5.4.1 ASME Code Primary Stress Intensity (SI) Criteria *60*
5.4.2 ASME Code Primary + Secondary SI Range and Fatigue Usage Criteria *60*

6 RESULTS SUMMARY/CONCLUSIONS **76**

7 REFERENCES **77**

8 COMPUTER OUTPUT FILES **78**

APPENDIX A **82**

A-1 PURPOSE **83**

A-2 STRESS AND TEMPERATURE EVALUATION **83**

APPENDIX B - Comparison of ANSYS 11.0 and 14.0 Results 85
APPENDIX C - Stresses for Safety Nozzle WOL Fracture Mechanics Analysis for Outage 2R17 .. 99

List of Figures

Page

Figure 1 Finite Element Model 10
Figure 2 Finite Element Model Details of Buttering, Nozzle to Safe End Weld, Safe End, Safe End to Pipe Weld and Weld Overlay) 10
Figure 3 Surfaces for Thermal Boundary Conditions (Temperature) 16
Figure 4 Surfaces for Structural Boundary Conditions (Pressure) 17
Figure 5 Deformed Shape vs. Un-Deformed Shape 30
Figure 6 Stress Intensity Contours for Design Condition 31
Figure 7 Locations for Evaluation of Temperature Gradients 33
Figure 8 Temperatures of Selected Locations (HUCD) 34
Figure 9 Thermal Gradients of Selected Locations (HUCD) 35
Figure 10 Temperatures of Selected Locations (LDLI) 36
Figure 11 Thermal Gradients of Selected Locations (LDLI) 37
Figure 12 Temperatures of Selected Locations (LLD) 38
Figure 13 Thermal Gradients of Selected Locations (LLD) 39
Figure 14 Temperatures of Selected Locations (LOL) 40
Figure 15 Thermal Gradients of Selected Locations (LOL) 41
Figure 16 Temperatures of Selected Locations (LOP) 42
Figure 17 Thermal Gradients of Selected Locations (LOP) 43
Figure 18 Temperatures of Selected Locations (LOF) 44
Figure 19 Thermal Gradients of Selected Locations (LOF) 45
Figure 20 Temperatures of Selected Locations (RT) 46
Figure 21 Thermal Gradients of Selected Locations (RT) 47
Figure 22 Temperatures of Selected Locations (TRT) 48
Figure 23 Thermal Gradients of Selected Locations (TRT) 49
Figure 24 Temperatures of Selected Locations (IASA) 50
Figure 25 Thermal Gradients of Selected Locations (IASA) 51
Figure 26 Temperatures of Selected Locations (SVO) 52
Figure 27 Thermal Gradients of Selected Locations (SVO) 53
Figure 28 Path Lines for Stress Analysis 62
Figure 29 Partial Path Lines for Stress Analysis 63
Figure A - 1 Paths Defined for Fracture Mechanics Evaluation 84
Figure B-1 Stress Intensity Contours for Design Condition using ANSYS 14.0 85
Figure B-2 Temperature of Selected Locations (HUCD) using ANSYS 14.0 86
Figure B-3 Thermal Gradients of Selected Locations (HUCD) using ANSYS 14.0 87

List of Figures
(continued)

Page

Figure B-4 Temperature of Selected Locations (LDLI) using ANSYS 14.0 88
Figure B-5 Thermal Gradients of Selected Locations (LDLI) using ANSYS 14.0 89
Figure C-1 Safety Nozzle "A" Indication Plot 99
Figure C-2 Safety Nozzle "B" Indication Plot 100
Figure C-3 Safety Nozzle "C" Indication Plot 100
Figure C-4 Path Lines Defined for Fracture Mechanics Evaluation 101
Figure C-5 Radial Stress at Time [ ] (hr) in HUCD 104
Figure C-6 Shear Stress at Time [ ] (hr) in HUCD 104
Figure C-7 Radial Stress at Time [ ] (hr) in HUCD 105
Figure C-8 Shear Stress at Time [ ] (hr) in HUCD 105
Figure C-9 Radial Stress at Time [ ] (hr) in IASA 106
Figure C-10 Shear Stress at Time [ ] (hr) in IASA 106

List of Tables

Page

Table 1 Pressurizer Upper Head Material Properties 12
Table 2 Safety/Relief Nozzle Material Properties 13
Table 3 Safe End Material Properties 13
Table 4 Safe End to Liner Weld, Nozzle to Safe End Weld and Buttering Material Properties .. 13
Table 5 Safe End to Pipe Weld, Cladding and Liner Material Properties 14
Table 6 Pipe Material Properties 14
Table 7 Weld Overlay Material Properties 14
Table 8 Applicable External Loads 18
Table 9 Summary of External Loads 18
Table 10 Transients for Safety/Relief Nozzles 19
Table 11 Heatup and Cooldown (HUCD) 20
Table 12 Step Load Increase and Decrease (LILD) 21
Table 13 Large Step Load Decrease (LLD) 22
Table 14 Loss of Load (LOL) 23
Table 15 Loss of Power (LOP) 24
Table 16 Loss of Flow (LOF) 25
Table 17 Reactor Trip (RT) 26
Table 18 Turbine Roll Test (TRT) 27
Table 19 Inadvertent Auxiliary Spray Actuation (IASA) 28
Table 20 Safety/Relief Valve Opening Transient (SVO) 29
Table 21 Temperature Gradients of Interest 32
Table 22 Time Points of Interest for the HUCD Transients 54
Table 23 Time Points of Interest for the LDLI Transients 55
Table 24 Time Points of Interest for the LLD Transients 56
Table 25 Time Points of Interest for the LOL Transients 57
Table 26 Time Points of Interest for the LOP Transients 57
Table 27 Time Points of Interest for the LOF Transients 58
Table 28 Time Points of Interest for the RT Transients 58
Table 29 Time Points of Interest for the TRT Transients 58
Table 30 Time Points of Interest for the IASA Transients 59
Table 31 Time Points of Interest for the SVO Transients 59
Table 32 Path Lines for Linearized Stresses 61
Table 33 Geometric Characteristics of Path Line Cross-Section 64
Table 34 Maximum Primary + Secondary SI due to External Loads 65

List of Tables
(continued)

Page

Table 35 Summary of Maximum Primary + Secondary SI Ranges for Membrane + Bending Stresses ... 67
Table 36 PATH9 - outside node of Maximum Primary + Secondary SI Range for Membrane + Bending Stress Components ... 68
Table 37 Stress Category and FSRF in Fatigue Evaluation ... 69
Table 38 Relief/Safety Nozzle, Head Fatigue Usage Calculation ... 70
Table 39 Buttering, Nozzle to Safe End Weld Fatigue Usage Calculation ... 71
Table 40 Safe End Fatigue Usage Calculation ... 72
Table 41 Safe End to Pipe Weld Fatigue Usage Calculation ... 73
Table 42 Pipe Fatigue Usage Calculation ... 74
Table 43 Weld Overlay Fatigue Usage Calculation ... 75
Table 44 Summary of Results ... 76
Table 45 List of Relevant ANSYS Input and Output Files ... 78
Table A - 1 Paths Description ... 83
Table B-1 Computer Files ... 90
Table C-1 Path Lines Description ... 101

1 PURPOSE

It is well recognized that the Alloy 600/82/182 dissimilar metal welds (DMW) are susceptible to the primary water stress corrosion cracking (PWSCC), especially those in high temperature components such as pressurizer nozzles. Pacific Gas and Electric (PG&E) plans to mitigate the pressurizer nozzle Alloy 82/182 dissimilar metal welds (DMW) with structural weld overlays (SWOL) for the Diablo Canyon Unit 2 during the spring 2008 refueling outage for Unit 2.

Since the three safety nozzles have the same dimensions with the relief nozzle (Reference [1]), only one design is created based on the minimum weld overlay design (Reference [11]); the results also bounded maximum weld overlay design (Reference [11]). Detailed sizing calculation of the weld overlay has been documented in Reference [2] for the safety and relief nozzles.

The pressurizer safety/relief nozzles are located on the upper head of the pressurizer. The weld overlay is designed to cover both the Alloy 82/182 DMW and the austenitic stainless weld between the safe end and nozzle or 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 [3], are satisfied for the pressurizer safety/relief 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 piping, stainless steel weld between the safe end and piping, safe end, DMW between the safe end and nozzle, safety/relief nozzle and SWOL. In addition, post-processing of thermal and structural results is performed to provide data for fracture analysis of the safety/relief nozzle (see Appendix A).

It should be noted that the original safety/relief 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 safety/relief 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 safety/relief nozzle's usage prior to SWOL and usage with the SWOL.

The purpose of this calculation is to qualify the weld overlay design to the requirement specified in Reference [8]. The design is qualified to meet the criteria and fatigue requirements of the Reference [3].

The purpose of revision 002 is to provide stress and thermal results of the transient analysis for fracture mechanics of the safety nozzle weld overlay for the indications detected based on the results of 2013 outage (2R17) inservice inspection.

The purpose of revision 003 is to incorporate customer comments.

2 ANALYTICAL METHODOLOGY

The general methodology of the 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 2-D models of the safety/relief nozzle minimum weld overlay and adjacent part of the pressurizer upper head. The model incorporates the geometry (of the adjacent upper head, nozzle, safe end, welds, weld overlay, pipe) of the pressurizer safety/relief nozzle (Reference [1] & [11]), appropriate materials and boundary conditions. The 2-D model is converted into a 2-D finite element model with axisymmetric elements that treat the 2-D model as if it were rotated 360° around the center axis. There are two finite element models consisting of thermal and structural elements, respectively so as to enable the thermal and structural analysis using ANSYS 11.0 (Reference [4])
3) Applying the design conditions of the pressure and temperature 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 the boundary and load conditions.
4) Applying the thermal loads pertaining to the service level transients (in the form of transient temperatures and corresponding heat transfer coefficients versus time). Each of the major service level transients requires a separate run on the thermal finite element model.
5) Reviewing the results of the thermal analysis by examining the magnitude of temperature difference between key locations of the model. The time points of the maximum temperature gradient are those at which the maximum thermal stresses develop.
6) Applying the corresponding mechanical (pressure) and thermal (nodal temperature) loads at each time point identified in step 4 to the structural finite element model. Since the weld overlay configuration contains layers of different materials having different coefficient of expansion, it is possible that one material is in compression and another is in tension due to thermal expansion. The standard method in defining a path is to go from a free surface to a free surface. However, using this method and applying the mathematical equations that ANSYS uses to find the membrane and membrane + bending stresses, may average the stresses at the boundary of the two materials. Since there is no guidance on how to evaluate sections with multiple materials, in addition to the free surface to free surface path, two partial paths (one in each material) are generated at the same location. These paths will be used to check the 3Sm criteria and to obtain the maximum Ke factor. It is recognized that no continuous and progressive displacement can occur in one of the materials without the other material restraining that displacement. Therefore this approach is very conservative.
7) Hand calculating the effects due to nozzle external loads and adding the resulting stresses to the stress results due to pressure and temperature effect.
8) Comparing the results to the ASME Code criteria for acceptability.
9) Documenting stresses and temperatures for the fracture mechanics analysis of the safety/relief 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

The detailed dimensions of the safety/relief nozzle design are shown in Reference [1]. Major dimensions in building the finite element model include: pressurizer upper head inside radius [ ]to base metal) and base metal thickness[ ]nozzle ID[ ]and OD[ ]at nozzle end); pipe at the safe end weld ID[ ]and OD[ ]for safety/relief nozzle.

Two weld overlay configurations are provided for the safety/relief nozzles (Reference [11]) in terms of the overlay size – the minimum and maximum weld overlay. The minimum weld overlay has a thickness of[ ]measured from the nozzle end outside surface, at the Alloy 82/182 DM weld and is tapered on to the pipe covering the weld at the safe end-pipe connection.

4.2 Finite Element Model

One finite element models is built based on the minimum weld overlay design. Model is developed with ANSYS 11.0 (Reference [4]) and documented in the following computer file:

DC2_geo.out

The 2-D model is meshed with the 8-node PLANE183 elements in the structural analysis and all elements are replaced by the equivalent thermal elements PLANE77 in the thermal analysis. The meshed model is shown in Figure 1 and Figure 2.

Finite element model is built with the liner attached to the inside surface of the nozzle. Where in the field the liner is inserted inside of the nozzle and welded at the ends. To study the effect of this discrepancy at the same analysis, the influence is negligible without any effect on final results.

The largest contribution to the stresses is due to a thermal effect. The interface between the inserted liner and the nozzle is considered to have a higher thermal conduction resistance than the fused cladding (modeled configuration). This resistance could be significantly increased during a cool down transient when a separation of the liner and the nozzle could occur, decreasing thermal stresses. A sensitivity study was performed on similar nozzle to simulate the effect on stresses due to heat transfer reduction during the liner separation. The sensitivity study concluded that the fused or inserted liners produced similar stresses (± 2 % difference which is negligible for this type of nozzle).

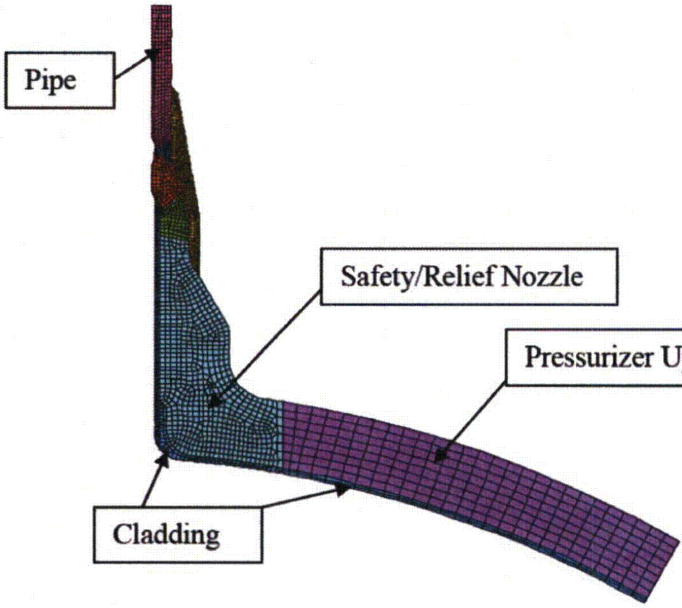

Figure 1 Finite Element Model

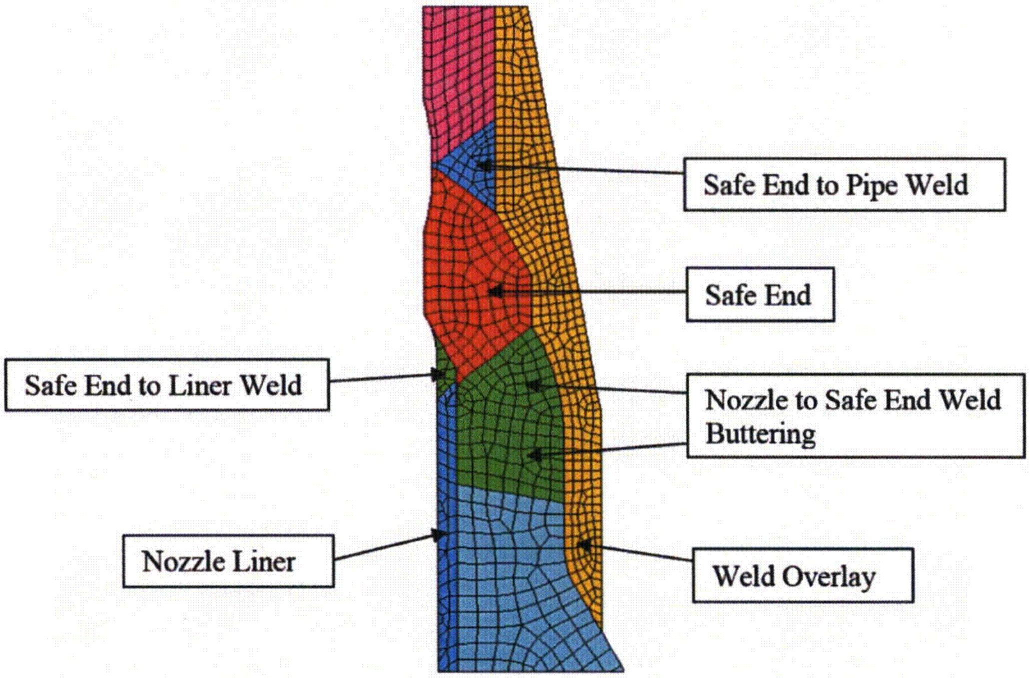

Figure 2 Finite Element Model Details of Buttering, Nozzle to Safe End Weld, Safe End, Safe End to Pipe Weld and Weld Overlay)

4.3 Materials

Reference [5] provides the material designations and properties of the various components. Per the same reference, the material properties for the structural analysis shall be in accordance with ASME Code 1965 Edition including Addenda through Summer 1966 (Reference [12]) for existing material and ASME Code 2001 Edition including Addenda through 2003 (Reference [3]) for weld filler material. Since not all materials and material properties for existing components are provided by Reference [12], later Addenda or Editions of the ASME Code (Reference [13], Reference [14], and Reference [15]) were used to determine the remaining material properties.

Pressurizer Upper Head
Safety/Relief Nozzle
Safe End
Nozzle to Safe End Weld
Buttering Weld
Pipe
Safe End to Pipe Weld
Cladding
Nozzle Liner
Safe End to Liner Weld
Weld Overlay (2)

[ ]

Note (1): Per Ref. [5] par. 4.1.5 and 4.1.7 specifies that the cladding material properties should be equivalent to [ ] weld filler material and the existing pipe to safe end weld is [ ] austenitic stainless steel. These materials are used for welding components with similar chemical composition such as [ ] material. Therefore material [ ] is considered representative of these materials.

Note (2): Per Ref. [5] 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.

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). These pertinent properties (thermal & structural) for the materials are listed in the following tables.

Young's Modulus	E	[10^6 psi]
Poisson's Ratio	μ	[-]
Density	ρ	[lb/in3]
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	S_m	[ksi]
Yield Strength	S_y	[ksi]
Tensile Strength	S_u	[ksi]

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

Note: Values for Coefficient of Thermal Expansion in Table 1 through Table 6 were taken from Reference [13] (ASME Code, 1965 Edition including Addenda through Winter 1967) instead of the main source of the material properties – Reference [12] (ASME Code, 1965 Edition including Addenda through Summer 1966). The small negligible differences have no effect on the results in the documented analysis.

Table 1 Pressurizer Upper Head Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[14]	[14]	[14]

Table 2 Safety/Relief Nozzle Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[13]	[13]	[13]

Table 3 Safe End Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[12]	[12]	[12]

Table 4 Safe End to Liner Weld, Nozzle to Safe End Weld and Buttering Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[13]	[13]	[13]

Table 5 Safe End to Pipe Weld, Cladding and Liner Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[12]	[12]	[12]

Table 6 Pipe Material Properties

Temp	E (1)	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[12]	typical	[16]	[13]	[15]	calculated	[12]	[12]	[12]

Note (1): Small differences in E used in ANSYS input file have negligible impact on the results.

Table 7 Weld Overlay Material Properties

Temp	E	μ	ρ	α	k	C	Sm	Sy	Su
Reference	[3]	typical	[16]	[3]	[3]	calculated	[3]	[3]	[3]

4.4 Boundary Conditions

The model simulates, in 2-D space, a section of the safety/relief nozzle, safe end, related welds, pipe, and part of the adjacent pressurizer upper head.

Thermal Analysis: During operation, the inside surfaces of the Upper Head (INSHEAD), the inside surface of the Nozzle, Nozzle to Safe End Weld, Safe End, Safe End to Pipe Weld and Pipe (INSNOZ) are in contact with the pressurizer steam temperature. An appropriate heat transfer coefficient (HTC) and bulk temperature (BT) versus time is applied on these surfaces (Figure 3). The pressurizer steam temperature varies with time depending upon the service load condition that is being applied and is discussed further in section 4.5.3.

The outside surfaces of the Upper Head, Nozzle, Pipe and Weld Overlay (OUTHEAD) are exposed to the ambient temperature in conjunction with a small HTC. The safety/relief nozzle is assumed to be insulated. A very small HTC of [ ] BTU/hr-in^2-F is used in this calculation.

Structural Analysis: Pressurizer steam pressure is applied to all surfaces of these components: INSHEAD, INSNOZ (Figure 3 and Figure 4). The upper end of the reducer (ENDCAP) has a pressure, p*, applied to represent the hydrostatic end load from the piping closure. The exteriors of the pressurizer head are not loaded by pressure.

Pressure p* is calculated as follows:

$$p^* = -\frac{p \cdot d^2}{D^2 - d^2}$$

Where:
p = actual pressure applied
d = ID of the pipe
D = OD of the pipe

The boundary conditions for the structural analysis are set to have zero displacement in the circumferential direction (CF) (from the nozzle axis) (Figure 4).

[ ]

Figure 3 Surfaces for Thermal Boundary Conditions (Temperature)

[ ]

Figure 4 Surfaces for Structural Boundary Conditions (Pressure)

4.5 Loads

Loads applied to the model include temperatures and heat transfer coefficients for the thermal analysis, and internal pressures for the structural analysis. External forces and moments are evaluated by hand calculation and added to the results from the finite element analysis.

4.5.1 External Loads

The applicable external loads applied at the safe end are defined in Reference [6] and [7]. The Thermal Expansion (TH), OBE and Valve Operating (VO) loads are listed in Table 8 and Table 9 and are further evaluated in Section 5.4.2.1 for primary + secondary SI Ranges.

Table 8 Applicable External Loads

Load Cases	**Axial** [lbs]	**Fy** [lbs]	**Fz** [lbs]	**Torsional** [in-lbs]	**My** [in-lbs]	**Mz** [in-lbs]
Thermal (TH)	[					]
OBE (±)						
Valve Operating (VO)						
External Load Combination per Ref. [6]						
TH+OBE	[					]
TH+VO						
Max. applicable External Loads for Thermal, OBE, Valve Operating						
Max (TH+OBE, TH+VO)	[					]

Note [(1)]: Loads are enveloped from loads on page 8, 9, 10 and 11 of Reference [6]. All other loads are taken from Table 2B of Reference [6].

Table 9 Summary of External Loads

	Axial [lbs]	**Fy** [lbs]	**Fz** [lbs]	**Shear** [(1)] [lbs]	**Torsional** [in-lbs]	**My** [in-lbs]	**Mz** [in-lbs]	**Bending** [(2)] [in-lbs]
Max (TH+OBE, TH+VO)	[							]

Note [(1)]: Shear is calculated as the SRSS of Fy and Fz.

Note [(2)]: Bending is calculated as the SRSS of My and Mz.

4.5.2 Design Conditions

Diablo Canyon Units 1 & 2 pressurizer is designed to satisfy the applicable ASME Code criteria at the design pressure of[ ]psig and temperature of[ ]are assuming. These design conditions are simulated on the model by applying a uniform and reference temperature of[ ] throughout the model (the temperature is used to determine the material properties and not for thermal expansion) and uniform pressure of[ ]psig on all inside surfaces of the model. Equivalent end cap pressure is also applied on the pipe cross-section.

4.5.3 Operational Transient Loads

The safety/relief nozzles are located on top of the pressurizer such that the inside surfaces are subjected to the pressurizer steam region thermal and pressure conditions. The applicable Level A (Normal) and Level B (Upset) transients defined in References [6] and [8] are listed in Table 10 together with the corresponding number of cycles. Some transients such as Steady State Fluctuations and Boron Concentration Equalization are insignificant in fatigue evaluation and are neglected. NB 3226 (e) of ASME Code (Ref. [3]) does not require evaluation for the first ten cycles of Testing Condition and therefore, Primary Hydro Test at 3107 psig (Ref. [6]) is not included in fatigue analysis. The Safety Valve Opening and the Relief Valve Opening transients have the same trend, but Safety Valve Opening transient has higher pressure a temperature. Since both transients cannot occur at the same time, conservatively is used Safety Valve Opening transient to cover also Relief Valve Opening transient. Plant Loading and Unloading transient Reference [8] for safety/relief nozzles have the constant parameters (temperature and pressure); therefore Plant Loading and Unloading transient is a steady state condition for safety/relief nozzles and does not affect present analysis.

Table 10 Transients for Safety/Relief Nozzles

Abbreviation	Transient Name	Design Cycles
HUCD	Heatup at[ ][Normal] Cooldown at[ ][Normal]	[ ]
LDLI	10% Step Load Decrease [Normal] 10% Step Load Increase [Normal]	[ ]
LLD	Large Step Load Decrease [Normal]	[ ]
LOL	Loss of Load [Upset]	[ ]
LOP	Loss of Power [Upset]	[ ]
LOF	Loss of Flow [Upset]	[ ]
RT	Reactor Trip [Upset]	[ ]
TRT	Turbine Roll Test [Test]	[ ]
IASA	Inadvertent Auxiliary Spray Actuation [Normal]	[ ]

SVO/RVO (1)	Safety Valve Opening Transient / Relief Valve Opening Transient	[ ]
LT (2)	Leak Test at 2485 psig [Test]	[ ]
OBE	OBE	[ ]

Note (1) see discussion above Table 10
Note (2) Leak Test at [ ] psig is included in HUCD transient.

The following tables list the time points used in the thermal analysis.

Table 11 Heatup and Cooldown (HUCD)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft²-°F]	

[ ]

Table 12 Step Load Increase and Decrease (LILD)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 13 Large Step Load Decrease (LLD)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Note (1): Small differences in HTC used in ANSYS input file have negligible impact on the results.

Table 14 Loss of Load (LOL)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 15 Loss of Power (LOP)

Index	Time	Temperature[1]	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft²-°F]	

Note [(1)]: The small differences (max. 0.5°F) have negligible impact on the results.

Table 16 Loss of Flow (LOF)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 17 Reactor Trip (RT)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 18 Turbine Roll Test (TRT)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 19 Inadvertent Auxiliary Spray Actuation (IASA)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

Table 20 Safety/Relief Valve Opening Transient (SVO)

Index	Time	Temperature	Pressure	INSHEAD HTC	INSNOZ HTC
	[hrs]	[°F]	[psia]	[Btu/hr-ft^2-°F]	

5 CALCULATION

5.1 Design Condition

Stress analysis of the model under the design pressure provides a basis for verification of the expected behavior of the model, the boundary and load conditions and verifies attenuation of stress effects at regions distant from the nozzle.

The ANSYS output for the design condition is documented in the following file:

DC2_des_pres.out

Figure 5 shows a deformed shape of the model under design pressure along with the un-deformed shape. The stress intensity contours developed in the model under design pressure case are shown in Figure 6.

Figure 5 Deformed Shape vs. Un-Deformed Shape

Figure 6 Stress Intensity Contours for Design Condition

5.2 Thermal Analysis

The ANSYS input files containing the transient definition, as tabulated in Table 11 to Table 20 are:

HUCD_tr.mac
LDLI_tr.mac
LLD_tr.mac
LOL_tr.mac
LOP_tr.mac
LOF_tr.mac
RT_tr.mac
TRT_tr.mac
IASA_tr.mac
SVO_tr.mac

The ANSYS output files are listed as follows:

Thermal analysis:

DC2_HUCD_th.out
DC2_LDLI_th.out
DC2_LLD_th.out
DC2_LOL_th.out
DC2_LOP_th.out
DC2_LOF_th.out
DC2_RT_th.out
DC2_TRT_th.out
DC2_IASA_th.out
DC2_SVO_th.out

Temperature gradients:

DC2_HUCD_dt.out
DC2_LDLI_dt.out
DC2_LLD_dt.out
DC2_LOL_dt.out
DC2_LOP_dt.out
DC2_LOF_dt.out
DC2_RT_dt.out
DC2_TRT_dt.out
DC2_IASA_dt.out
DC2_SVO_dt.out

The results of the thermal analyses are evaluated to identify the maximum and minimum temperature gradients between critical locations in the model and the corresponding time points. These temperature gradients generate maximum and minimum thermal stresses, which in turn contribute to maximum range of stress intensities in the model.

The node numbers corresponding to the two locations for evaluation of temperature gradient are listed in Table 21. The locations are shown in Figure 7.

Table 21 Temperature Gradients of Interest

Gradient Designation	Node Numbers		Description
A1_A2	1487	1600	Nozzle to head conjunction
B1_B2	1235	1483	OD change on nozzle
C1_C2	1324	1452	Safe end weld to weld overlay
D1_D2	1574	1408	Safe end to weld overlay
E1_E2	1790	285	Thickness change from pipe to weld overlay
F1_F2	2145	2171	ID to OD head

[ ]

Figure 7 Locations for Evaluation of Temperature Gradients

The temperatures of selected nodes versus transient time as well as the temperature gradients are shown in Figure 8 to Figure 27. These figures are provided to show the trend and for visual aid only. Specific data is taken from computer output files. Computer file "DC2_inp_dt.mac" contains definition of the node numbers for temperature and gradients calculation.

Figure 8 Temperatures of Selected Locations (HUCD)

Figure 9 Thermal Gradients of Selected Locations (HUCD)

[ ]

Figure 10 Temperatures of Selected Locations (LDLI)

Figure 11 Thermal Gradients of Selected Locations (LDLI)

[ ]

Figure 12 Temperatures of Selected Locations (LLD)

[ ]

Figure 13 Thermal Gradients of Selected Locations (LLD)

Figure 14 Temperatures of Selected Locations (LOL)

[ ]

Figure 15 Thermal Gradients of Selected Locations (LOL)

Figure 16 Temperatures of Selected Locations (LOP)

Figure 17 Thermal Gradients of Selected Locations (LOP)

Figure 18 Temperatures of Selected Locations (LOF)

[

]

Figure 19 Thermal Gradients of Selected Locations (LOF)

Figure 20 Temperatures of Selected Locations (RT)

Figure 21 Thermal Gradients of Selected Locations (RT)

Figure 22 Temperatures of Selected Locations (TRT)

Figure 23 Thermal Gradients of Selected Locations (TRT)

Figure 24 Temperatures of Selected Locations (IASA)

Figure 25 Thermal Gradients of Selected Locations (IASA)

Figure 26 Temperatures of Selected Locations (SVO)

Figure 27 Thermal Gradients of Selected Locations (SVO)

5.3 Stress Analysis

Stress analyses are performed at the time points listed in Table 22 through Table 31. These 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 points is read into the structural model directly from the result file of the thermal analysis. The corresponding pressure is obtained by interpolation from Table 11 through Table 20. The computer output files for structural analyses are:

DC2_HUCD_st.out	DC2_LOF_st.out
DC2_LDLI_st.out	DC2_RT_st.out
DC2_LLD_st.out	DC2_TRT_st.out
DC2_LOL_st.out	DC2_IASA_st.out
DC2_LOP_st.out	DC2_SVO_st.out

Table 22 Time Points of Interest for the HUCD Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Note (1): Leak Test (LT)

Table 23 Time Points of Interest for the LDLI Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Table 24 Time Points of Interest for the LLD Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Table 25 Time Points of Interest for the LOL Transients

Index	Time	Temperature	Pressure
	[hrs]	[°F]	[psia]

Table 26 Time Points of Interest for the LOP Transients

Index	Time	Temperature	Pressure
	[hrs]	[°F]	[psia]

Table 27 Time Points of Interest for the LOF Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Table 28 Time Points of Interest for the RT Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Table 29 Time Points of Interest for the TRT Transients

Index	Time [hrs]	Temperature [°F]	Pressure [psia]

Table 30 Time Points of Interest for the IASA Transients

Index	Time	Temperature	Pressure
	[hrs]	[°F]	[psia]

Table 31 Time Points of Interest for the SVO Transients

Index	Time	Temperature	Pressure
	[hrs]	[°F]	[psia]

5.4 ASME Code Criteria

The ASME Code qualification 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 loadings.

In general, the primary stress intensity criteria of the ASME Code (Reference [3]) assure that the design is adequate for application of design loads.

The ASME Code criteria for cumulative fatigue usage factor assure that the design is adequate for repetitive loadings.

5.4.1 ASME Code Primary Stress Intensity (SI) Criteria

Per NB-3213.8 of References [3], 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 [3] for Design Conditions. The limit of primary stress intensity for Level B (Upset), Level C (Emergency), Level D (Faulted), and Test Condition is specified in NB-3223, NB-3224, NB-3225, and NB-3226 of Reference [3], respectively.

As presented in Reference [2], 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. The overlay further reduces stress concentration by eliminating the outside surface discontinuity. Therefore, the primary stress intensity requirements for the nozzle, welds with overlay, safe end and pipe 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 [3]) and reinforcement area (NB-3330 of Reference [3]), which were addressed in the original nozzle/pressurizer designs. Adding weld overlay will increase the nozzle wall thickness and therefore these requirements are satisfied.

5.4.2 ASME Code Primary + Secondary SI Range and Fatigue Usage Criteria

As stated previously, the stress analysis for transient conditions is required for a component to satisfy the requirements for repetitive loadings. The following discussion describes the fatigue analysis process employed herein for the design.

Computer runs for each transient time point chosen for stress analysis are contained in the ANSYS output files as listed in Section 5.3. The overall stress profile is then reviewed to

determine the critical locations that require detailed stress/fatigue analysis. The objective is to assure that

1) the most severely stressed locations impacted by weld overlay are evaluated;

2) the specified region is quantitatively qualified.

Once the specific locations for detailed stress evaluation are established, the related path 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 [3]).

The path lines selected for primary plus secondary SI range and fatigue failure evaluation are listed in Table 32. The path lines are shown in Figure 28 and Figure 29. A review of the results indicates that these paths include the highest stress locations for the model.

Table 32 Path Lines for Linearized Stresses

Path Line	Node Numbers		Location (See Figure 28 and Figure 29)	Material
PATH2	1235	1483	Nozzle (WOL end location)	
PATH3	1222	1430	Nozzle with WOL	
PATH4	2421	1333	Buttering with WOL	
PATH5	1323	3232	Nozzle to safe end weld with WOL	
PATH6	1576	1405	Safe end with WOL	
PATH7	3635	3293	Pipe weld with WOL	
PATH8	1928	1433	Pipe with WOL	
PATH9	1924	1901	Pipe ID to OD at WOL end	
PATH3A	1222	1461	Same as PATH3 (only nozzle material)	
PATH3B	1461	1430	Same as PATH3 (only WOL material)	
PATH4A	2421	1356	Same as PATH4 (only buttering material)	
PATH4B	1356	1333	Same as PATH4 (only WOL material)	
PATH5A	1323	3247	Same as PATH5 (only nozzle to safe end weld material)	
PATH5B	3247	3232	Same as PATH5 (only WOL material)	
PATH6A	1576	1404	Same as PATH6 (only safe end material)	
PATH6B	1404	1405	Same as PATH6 (only WOL material)	
PATH7A	3635	3244	Same as PATH8 (only pipe weld material)	
PATH7B	3244	3293	Same as PATH8 (only WOL material)	
PATH8A	1928	3276	Same as PATH9 (only pipe material)	
PATH8B	3276	1433	Same as PATH9 (only WOL material)	

[ ]

Figure 28 Path Lines for Stress Analysis

Figure 29 Partial Path Lines for Stress Analysis

5.4.2.1 Maximum Primary + Secondary SI Range, NB-3222.2

External loads (Thermal Expansion, OBE and Valve Operation) that cause periodic stress changes shall also be included in calculating the maximum SI Ranges. The resulting values of this load combination are listed in Table 9.

Except for the path lines PATH1 and PATH10 where the stress variation due to these external loads is negligible, stress intensity due to external loads is calculated at the corresponding cross-section that contains the path lines. The geometric characteristics are listed in Table 33.

Table 33 Geometric Characteristics of Path Line Cross-Section

Location	D	d	I	S_{OD}	S_{ID}	A	L
	[inch]	[inch]	[inch^4]	[inch^3]	[inch^3]	[inch^2]	[inch]
PATH2							
PATH3							
PATH4							
PATH5							
PATH6							
PATH7							
PATH8							
PATH9							

Note [(1)]: For path lines PATH8 and PATH9 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 PATH8 and PATH9 are conservatively reduced to zero

where:

D [inch] – outside diameter of the WOL or pipe

d [inch] – inside diameter of the nozzle, safe end or pipe

$I = \frac{\pi}{64}\left(D^4 - d^4\right)$ [inch^4] – moment of inertia

$S_{OD} = \frac{I}{D/2}$ [inch^3] – section modulus – outside diameter

$S_{ID} = \frac{I}{d/2}$ [inch^3] – section modulus – inside diameter

$A = \frac{\pi}{4}\left(D^2 - d^2\right)$ [inch^2] – cross-section area

L	[inch]	– moment arm – vertical distance from the inside node of path line PATH7 (safe end weld root) to the outside node of the other path

Stress intensity (SI) at the inside and outside nodes of the selected path lines are then calculated and tabulated in Table 34.

Table 34 Maximum Primary + Secondary SI due to External Loads

Location	Axial Stress				Shear Stress			M+B
	σ_{ax_EX}	σ_{ax_BF}	σ_{ax_BM}	σ_{ax_M+B}	τ_{s_Fs}	τ_{s_Mt}	τ_s	S_{int}
	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]
Inside Diameter								
PATH2								
PATH3								
PATH4								
PATH5								
PATH6								
PATH7								
PATH8								
PATH9								
Outside Diameter								
PATH2								
PATH3								
PATH4								
PATH5								
PATH6								
PATH7								
PATH8								
PATH9								

The membrane + bending stress intensities due to external loads in Table 34 are calculated as follows:

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

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

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

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

$\tau_{s\_M_t} = \frac{M_x}{2 \cdot S}$ [ksi] - shear stress due to external torsion moment (M_x)

$\sigma_{ax\_M+B} = \sigma_{ax\_EX} + \sigma_{ax\_BF} + \sigma_{ax\_BM}$ [ksi] - axial membrane + bending stress

$\tau_s = \tau_{s\_F_s} + \tau_{s\_M_t}$ [ksi] - shear stress due to external forces and moments

$S_{int} = \sqrt{\sigma^2_{ax\_M+B} + 4 \cdot \tau_s^2}$ [ksi] - membrane + bending stress intensity

Where F_x, F_y, F_z, M_x, M_y, and M_z are taken from Table 9.

$F_s = (F_y^2+F_z^2)^{1/2}$

$M_b = (M_y^2+M_z^2)^{1/2}$

$S = S_{OD}$ - for outside diameter

$S = S_{ID}$ - for inside diameter

The ANSYS fatigue module is used to calculate the maximum membrane + bending SI range at each node of selected path lines Table 32 for all transients. The module complies with ASME Code Section III, NB-3216.2 in calculating a stress intensity range. Time points are also registered. The ANSYS output files are:

F_M+B_HA[ ]out	F_M+B_HA[ ]A.out
F_M+B_HA[ ]out	F_M+B_HA[ ]A.out
F_M+B_HA[ ]out	F_M+B_HA[ ]A.out
F_M+B_HA[ ]out	F_M+B_HA[ ]A.out
F_M+B_HA[ ]out	F_M+B_HA[ ]A.out
F_M+B_LA[ ]out	F_M+B_LA[ ]A.out

The maximum membrane + bending SI ranges for all nodes along with SIs due to external loads are listed in Table 35.

Table 35 Summary of Maximum Primary + Secondary SI Ranges for Membrane + Bending Stresses

Path Name	Inside Node			3Sm Limit[1]	Outside Node			3Sm Limit[1]
	M+B SI Range	SI due to External Load[2]	(M+B SI Range) +(External Loads SI)		M+B SI Range	SI due to External Load[2]	(M+B SI Range) + (External Loads SI)	
	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]	[ksi]
PATH2				80.10				80.10
PATH3				80.10				69.90
PATH4				69.90				69.90
PATH5				69.90				69.90
PATH6				40.50				69.90
PATH7				45.30				69.90
PATH8				48.60				69.90
PATH9				48.60				48.60
PATH3A				80.10				80.10
PATH3B				69.90				69.90
PATH4A				69.90				69.90
PATH4B				69.90				69.90
PATH5A				69.90				69.90
PATH5B				69.90				69.90
PATH6A				40.50				40.50
PATH6B				69.90				69.90
PATH7A				45.30				45.30
PATH7B				69.00				69.90
PATH8A				48.60				48.60
PATH8B				69.90				69.90

Note (1): Table 32 provides material designation for each defined path line. The Sm values taken from Table 1 through Table 7 are the design stress intensities of material at the maximum transient temperature of [ ] for all path lines.
Note (2): The external loads are calculated in Table 34.
Note (3): The (M+B SI Range) + (External Loads SI) is combined by stress components; see Table 36.

Table 36 PATH9 - outside node of Maximum Primary + Secondary SI Range for Membrane + Bending Stress Components

Location	Membrane + Bending Stress Components						
	Sx	Sy	Sz	Sxy	Syz	Sxz	SI Range
	[psi]	[psi]	[psi]	[psi]	[psi]	[psi]	[ksi]
Event 1 – CD, Time[ ]hrs							
CD	[					]	-
Event 2 – LOL, Time[ ]hrs							
LOL	[					]	-
Event2 – Event 1 (M+B SI Range)							
LOL-CD	[						]
External Loads SI (Table 34)							
PATH9	[					]	-
(M+B SI Range) + (External Loads SI)							
PATH9	[						]

Table 35 lists the maximum membrane + bending stress intensity range obtained by conservatively adding the SI due to external loads to the maximum transient membrane + bending SI range. As shown in Table 35, the stress intensity ranges are within the 3Sm limits for all locations and the ASME Code requirements are met for all locations.

5.4.2.2 Fatigue Usage Factor Criteria (CFUF), NB-3222.4

For consideration of fatigue usage, the Peak Stress Intensity Ranges are calculated. These values must include the 'total' localized stresses. The linearized membrane + bending stress intensity range used in fatigue usage factor calculation may not depict all of the potential peak stresses. Therefore to bind the potential effect of this consideration, the membrane + bending stress intensity range is multiplied by a Fatigue Strength Reduction Factor (FSRF). In general Reference [10] is used for guidance on FSRF for geometric discontinuities in this model. The calculation is performed separately for different materials.

The loads 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 contributions to the fatigue usage factor are included in Table 38 through Table 43.

Based on review of the SI range results, the following locations produce higher fatigue usage factor:

Table 37 Stress Category and FSRF in Fatigue Evaluation

Material	Path Line	Node location	Stress Category	FSRF
[ ](Safety/Relief Nozzle, Head)	PATH3	Inside	M+B	[ ]
[ ](Buttering, Nozzle to Safe End Weld)	PATH5	Inside	Total	[ ]
[ ](Safe End)	PATH6	Inside	M+B	[ ]
[ ](Safe End to Pipe Weld)	PATH7	Inside	M+B	[ ]
[ ](Pipe)	PATH9	Outside	M+B	[ ]
[ ](Weld Overlay)	PATH8B	Outside	M+B	[ ]

PATH8B and PATH9 outside nodes are part of geometric discontinuity. Therefore the maximum membrane + bending SI ranges are multiplied by conservative FSRF of 2.0 to account for geometric discontinuity. Per Reference [10], Chapter 6, it has been reviewed that this value is conservative.

Since the mesh is fine enough and there is no discontinuity at path PATH5 inside node, the 'Total' SI ranges and no FSRF is used for the fatigue usage factor calculation in these locations. Membrane + bending SI ranges at paths PATH1, PATH6 and PATH7 inside nodes are multiplied by conservative FSRF of 2.0.

The membrane + bending stress intensity ranges are documented in the following ANSYS output files:

F_M+B_HA[ ]out F_M+B_HA[ ]A.out
F_M+B_HA[ ]out F_M+B_HA[ ]A.out
F_M+B_HA[ ]out F_M+B_HA[ ]A.out
F_M+B_HA[ ]out F_M+B_HA[ ]A.out
F_M+B_HA[ ]out F_M+B_HA[ ]A.out
F_M+B_LA[ ]out F_M+B_LA[ ]A.out

The total stress intensity ranges are documented in the following ANSYS output files:

F_TOT_HA[ ]out F_TOT_HA[ ]A.out
F_TOT_HA[ ]out F_TOT_HA[ ]A.out
F_TOT_HA[ ]out F_TOT_HA[ ]A.out
F_TOT_HA[ ]out F_TOT_HA[ ]A.out
F_TOT_HA[ ]out F_TOT_HA[ ]A.out
F_TOT_LA[ ]out F_TOT_LA[ ]A.out

Note that only the stress intensity ranges and the corresponding time points are taken from the output files since stress intensities due to external loads are not included in the ANSYS output. The stress intensity due to the external loads is added at each node for each SI range. A review of the results indicates that all CFUF values are well below 1.0.

Table 38 through Table 43 provide the calculation of the cumulative fatigue usage factor based on the loads and cycles specified in Section 4.5. The values of 'E curve' in the following tables are taken from References [3] and [12].

Table 38 Relief/Safety Nozzle, Head Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH3 (inside node)

REFERENCE: F_M+B_LA[ ]out
MATERIAL: [ ]
TYPE: Low-alloy steel
UTS (ksi) = [ ]
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'
1	HU – LOP							
2	HU – LOL							
3	HU – IASA							
4	HU – SVO							
5	CD – LT							
6	HU – LD							
7	CD – LD							
8	LLD - LLD							
9	LD - TRT							
							Total Fatigue Usage Factor =	[ ]

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

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

Note (1): The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH3) are conservatively added to the highest SI range due to transient loads for the first [ ] cycles.
Note (2): [ ] is conservatively used maximum temperature occurring during the plant operation.

Table 39 Buttering, Nozzle to Safe End Weld Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH5 (inside node)

REFERENCE: F_TOT_HA[ ]out
MATERIAL: [ ]
TYPE: High-alloy steel
UTS (ksi) = [ ]
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'
1	HU - LOP							
2	CD - IASA							
3	CD - SVO							
4	HU - LOL							
5	HU - LT							
6	CD - LD							
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'Total' + External Loads[1]

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

Note (1): The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH5) are conservatively added to the highest SI range due to transient loads for the first[ ]cycles.

Note (2): [ ]is conservatively used maximum temperature occurring during the plant operation.

Table 40 Safe End Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH6 (inside node)

REFERENCE: F_M+B_HA[ ]out
MATERIAL: [ ]
TYPE: High-alloy steel
UTS (ksi) = [ ]
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'
1	CD - LOL	[						
2	CD - SVO							
3	CD - LOP							
4	CD - LLD							
5	HU - LLD							
6	HU - LI							
7	LI - IASA							
8	LI - LOF							]

Total Fatigue Usage Factor = [ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) + External Loads(1)

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

Note (1): The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH6) are conservatively added to the highest SI range due to transient loads for the first[ ]cycles.

Note (2): [ ]is conservatively used maximum temperature occurring during the plant operation.

Table 41 Safe End to Pipe Weld Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH7 (inside node)

REFERENCE: F_M+B_HA[ ]out
MATERIAL: [ ]
TYPE: High-alloy steel
UTS (ksi) = [ ]
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'
1	CD - LOL	[						
2	CD - SVO							
3	CD - LOP							
4	CD - LLD							
5	HU - LLD							
6	HU - LD							]
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) + External Loads(1)

For Range 1, 'M+B' SI Range =	[	ksi;	FSRF = 2
For Range 2, 'M+B' SI Range =		ksi;	FSRF = 2
For Range 3, 'M+B' SI Range =		ksi;	FSRF = 2
For Range 4, 'M+B' SI Range =		ksi;	FSRF = 2
For Range 5, 'M+B' SI Range =		ksi;	FSRF = 2
For Range 6, 'M+B' SI Range =	]	ksi;	FSRF = 2

Note (1): The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH7) are conservatively added to the highest SI range due to transient loads for the first[ ]cycles.

Note (2)[ ]is conservatively used maximum temperature occurring during the plant operation.

Table 42 Pipe Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH9 (outside node)								
	REFERENCE: F_M+B_HA[ ]out							
	MATERIAL: [ ]							
	TYPE: High-alloy steel							
	UTS (ksi) = [ ]							
	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'**
1	CD - LOL	[						]
2	CD - SVO							
3	CD - LOP							
4	CD - LLD							
5	HU – LLD							
6	HU – LD							
7	LD - IASA							
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) + External Loads[1]

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

Note [1]: The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH9) are conservatively added to the highest SI range due to transient loads for the first[ ]cycles.

Note [2][ ]is conservatively used maximum temperature occurring during the plant operation.

Table 43 Weld Overlay Fatigue Usage Calculation

EVALUATION TITLE: Diablo Canyon 2- PATH8B (outside node)

REFERENCE: F_M+B_HA[ ]A.out
MATERIAL: [ ]
TYPE: High-alloy steel
UTS (ksi) = [ ]
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'
1	CD - LOL	[						]
2	HU – LOP							
3	HU – SVO							
4	CD – LLD							
5	HU – LLD							
6	HU – LT							
7	IASA - LT							
8	LD - IASA							
							Total Fatigue Usage Factor =	[ ]

The Peak SI Range = 'M+B' x Fatigue Strength Reduction Factor (FSRF) + External Loads(1)

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

Note (1): The stress intensities due to external loads (TH+OBE; TH+VO) calculated in section 5.4.2.1 (Table 34, PATH8) are conservatively added to the highest SI range due to transient loads for the first[ ]cycles.

Note (2)[ ]is conservatively used maximum temperature occurring during the plant operation.

6 RESULTS SUMMARY/CONCLUSIONS

The preceding calculations demonstrate that the design of the safety/relief nozzle weld overlay for the pressurizer of Diablo Canyon Unit 2 meets the stress and fatigue requirements of the Design Code (Reference [3]).

Based on the loads and cycles specified in References [6] and [8] , the conservative fatigue analysis indicates that pressurizer safety/relief nozzle weld overlay design has the maximum usage factor of [ ] for specified number of cycles per Reference [6] compared to the ASME Code allowed maximum value of 1.0.

The results of this analysis cover evaluation of the original design of the pressurizer safety/relief nozzle without weld overlay.

Table 44 Summary of Results

	Max. SI Range P_L+P_b+Q			Fatigue Usage		
	Calculated [ksi]	Limit [ksi]	IR= Cal./Limit	Calculated	Limit	IR= Cal./Limit
Safety/Relief Nozzle		80.10			1	
Buttering, Nozzle to Safe End weld		69.90			1	
Safe End		40.50			1	
Safe End to Pipe Weld		45.30			1	
Pipe		48.60			1	
Weld Overlay		69.90			1	

Note: Primary stresses are bounded by original analysis, see section 5.4.1.

7 REFERENCES

[1] AREVA Drawing 02-8018401C-001, "Diablo Canyon Unit 2 Pressurizer Safety/Relief Nozzle Existing Configuration"

[2] AREVA Document 32-9043545-001, "Diablo Canyon Unit 2, Pressurizer Safety/Relief Nozzle Weld Overlay Sizing Calculation"

[3] ASME Boiler and Pressure Vessel Code, Section III, 2001 Edition including Addenda through 2003

[4] "ANSYS" Finite Element Computer Code, Version 11.0, ANSYS, Inc., Canonsburg, PA

[5] AREVA Document 08-9042937-003, "Diablo Canyon Unit 2 Pressurizer Nozzle Weld Overlays – Certified Design Specification"

[6] AREVA Document 38-9046469-002, "PG&E Design Input Transmittal, Non Proprietary"

[7] AREVA Document 38-2200488-002, "PG&E Design Input Transmittal Proprietary"

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

[9] Not used

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

[11] AREVA Drawing 02-8019311D-001, "Diablo Canyon Pressurizer Safety & Relief Nozzle Weld Overlay Design Input"

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

[13] ASME Boiler and Pressure Vessel Code, Section III, Addenda Winter 1966 through Winter 1967

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

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

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

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

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

8 COMPUTER OUTPUT FILES

The relevant ANSYS input and output files are listed in the following tables. ANSYS program verification tests for the elements used in the analysis are listed at the end of the table. Please note that files listed in Table 45 are listed in the AREVA COLD storage system.

Table 45 List of Relevant ANSYS Input and Output Files

File Name	Date	Description
DC2_geo.out	05/02/2007	Output file to develop finite element model
DC2_geo_WB.mac	05/02/2007	Input file from Ansys Workbench
Mat_prop.mac	04/16/2007	Input file includes material properties
DC2_inp_dt.mac	05/02/2007	Input file defining nodes for temperature and thermal gradient evaluation
Design Condition		
DC2_des_pres.out	05/02/2007	Output file for design Condition
HUCD Transient		
HUCD_tr.mac	05/08/2007	Input file contains definition of HUCD transient
DC2_HUCD_th.out	05/08/2007	Output file for thermal analysis of HUCD
DC2_HUCD_dt.out	05/08/2007	Output file contains thermal gradients of HUCD
DC2_HUCD_st.out	05/08/2007	Output file for stress analysis of HUCD
LDLI Transient		
LDLI_tr.mac	05/01/2007	Input file contains definition of LDLI transient
DC2_LDLI_th.out	05/02/2007	Output file for thermal analysis of LDLI
DC2_LDLI_dt.out	05/02/2007	Output file contains thermal gradients of LDLI
DC2_LDLI_st.out	05/03/2007	Output file for stress analysis of LDLI
LLD Transient		
LLD_tr.mac	05/02/2007	Input file contains definition of LLD transient
DC2_LLD_th.out	05/02/2007	Output file for thermal analysis of LLD
DC2_LLD_dt.out	05/02/2007	Output file contains thermal gradients of LLD
DC2_LLD_st.out	05/03/2007	Output file for stress analysis of LLD
LOL Transient		
LOL_tr.mac	05/02/2007	Input file contains definition of LLD transient
DC2_LOL_th.out	05/02/2007	Output file for thermal analysis of LLD
DC2_LOL_dt.out	05/02/2007	Output file contains thermal gradients of LLD
DC2_LOL_st.out	05/03/2007	Output file for stress analysis of LLD
LOP Transient		
LOP_tr.mac	05/02/2007	Input file contains definition of LOP transient
DC2_LOP_th.out	05/02/2007	Output file for thermal analysis of LOP
DC2_LOP_dt.out	05/02/2007	Output file contains thermal gradients of LOP
DC2_LOP_st.out	05/03/2007	Output file for stress analysis of LOP

Table 44 (continued) List of Relevant ANSYS Input and Output Files

LOF Transient		
LOF_tr.mac	05/02/2007	Input file contains definition of LOF transient
DC2_LOF_th.out	05/02/2007	Output file for thermal analysis of LOF
DC2_LOF_dt.out	05/02/2007	Output file contains thermal gradients of LOF
DC2_LOF_st.out	05/03/2007	Output file for stress analysis of LOF
RT Transient		
RT_tr.mac	05/02/2007	Input file contains definition of RT transient
DC2_RT_th.out	05/02/2007	Output file for thermal analysis of RT
DC2_RT_dt.out	05/02/2007	Output file contains thermal gradients of RT
DC2_RT_st.out	05/03/2007	Output file for stress analysis of RT
TRT Transient		
TRT_tr.mac	05/02/2007	Input file contains definition of TRT transient
DC2_TRT_th.out	05/02/2007	Output file for thermal analysis of TRT
DC2_TRT_dt.out	05/02/2007	Output file contains thermal gradients of TRT
DC2_TRT_st.out	05/03/2007	Output file for stress analysis of TRT
IASA Transient		
IASA_tr.mac	05/02/2007	Input file contains definition of IASA transient
DC2_IASA_th.out	05/02/2007	Output file for thermal analysis of IASA
DC2_IASA_dt.out	05/02/2007	Output file contains thermal gradients of IASA
DC2_IASA_st.out	05/03/2007	Output file for stress analysis of IASA
SVO Transient		
SVO_tr.mac	05/08/2007	Input file contains definition of SVO transient
DC2_SVO_th.out	05/08/2007	Output file for thermal analysis of SVO
DC2_SVO_dt.out	05/08/2007	Output file contains thermal gradients of SVO
DC2_SVO_st.out	05/08/2007	Output file for stress analysis of SVO
Fatigue Usage Factor Calculation		
F_M+B_HA[ ]out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]A.out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]out	05/11/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]A.out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]A.out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]A.out	05/08/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]out	05/09/2007	Stress range results for membrane + bending stresses
F_M+B_HA[ ]A.out	05/09/2007	Stress range results for membrane + bending stresses

Table 44 (continued) List of Relevant ANSYS Input and Output Files

F_M+B_LA[ ]out	05/10/2007	Stress range results for membrane + bending stresses
F_M+B_LA[ ]A.out	05/10/2007	Stress range results for membrane + bending stresses
F_TOT_HA[ ]out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]A.out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]A.out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]A.out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]out	05/10/2007	Stress range results for total stresses
F_TOT_HA[ ]A.out	05/10/2007	Stress range results for total stresses
F_TOT_HA[ ]out	05/09/2007	Stress range results for total stresses
F_TOT_HA[ ]A.out	05/09/2007	Stress range results for total stresses
F_TOT_LA[ ]out	05/10/2007	Stress range results for total stresses
F_TOT_LA[ ]A.out	05/10/2007	Stress range results for total stresses
ANSYS Verification Files		
vm56.out	05/11/2007	2-D 8-node structural element
vm112.out	05/11/2007	2-D 8-node thermal element
Fracture		
DC2_fr_path.out	05/17/07	Output files contains definition for fracture calculation
DC2_HUCD_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for HUCD transient
DC2_LDLI_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for LDLI transient
DC2_LLD_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for LLD transient
DC2_LOL_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for LOL transient

Table 44 (continued) List of Relevant ANSYS Input and Output Files

DC2_LOL_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for LOL transient
DC2_LOP_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for LOP transient
DC2_LOF_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for LOF transient
DC2_RT_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for RT transient
DC2_TRT_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for TRT transient
DC2_IASA_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for IASA transient
DC2_SVO_fr_SY.out	05/17/07	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_SZ.out	05/17/07	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_TH.out	05/17/07	Output file contains temperatures along the fracture paths for SVO transient

APPENDIX A

Stresses used for Safety/Relief Nozzle Weld Overlay Fracture Mechanics Analysis

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 safety/relief nozzle weld overlay.

A-2 STRESS AND TEMPERATURE EVALUATION

The ANSYS Post Processor is used to tabulate the stress and temperature along the predetermined paths. The paths are shown in Figure A - 1 and described in Table A - 1.

The post processor calculation for fracture analysis is contained in computer file:

DC2_fr_path.mac

Table A - 1 Paths Description

Path Line	Node Numbers		Location	Material
FPath1	1211	1425	Buttering with WOL	
FPath2	2419	1424	Buttering with WOL	
FPath3	1323	1410	Nozzle to safe end weld with WOL	
FPath4	3635	3293	Pipe weld with WOL	

Linearized stresses along the path line in the global coordinate system with "y" axis along the nozzle axis are summarized at thirteen points separated by an equal distance from the inside node to the outside node. At each point the axial (Sy) stress, hoop (Sz) stress and the temperature (Th) in the weld or weld overlay are given.

The path point distances from the inside nodes are included in the output file: Fr_PathLocs.out

ANSYS post processing output files are listed in section 8 and the stresses and temperatures output results files for the fracture mechanics are listed below:

DC2_HUCD_fr_SY.out	DC2_LOF_fr_SY.out
DC2_LDLI_fr_SY.out	DC2_RT_fr_SY.out
DC2_LLD_fr_SY.out	DC2_TRT_fr_SY.out
DC2_LOL_fr_SY.out	DC2_IASA_fr_SY.out
DC2_LOP_fr_SY.out	DC2_SVO_fr_SY.out
DC2_HUCD_fr_SZ.out	DC2_LOF_fr_SZ.out
DC2_LDLI_fr_SZ.out	DC2_RT_fr_SZ.out
DC2_LLD_fr_SZ.out	DC2_TRT_fr_SZ.out

DC2_LOL_fr_SZ.out	DC2_IASA_fr_SZ.out
DC2_LOP_fr_SZ.out	DC2_SVO_fr_SZ.out
DC2_HUCD_fr_TH.out	DC2_LOF_fr_TH.out
DC2_LDLI_fr_TH.out	DC2_RT_fr_TH.out
DC2_LLD_fr_TH.out	DC2_TRT_fr_TH.out
DC2_LOL_fr_TH.out	DC2_IASA_fr_TH.out
DC2_LOP_fr_TH.out	DC2_SVO_fr_TH.out

Figure A - 1 Paths Defined for Fracture Mechanics Evaluation

APPENDIX B– COMPARISON OF ANSYS 11.0 AND 14.0 RESULTS

Since the analyses in Rev.001 of this document were performed using ANSYS 11.0 on a Windows NT system, while the analyses in Rev.002 are performed using ANSYS 14.0 on a 64-bit machine, it is unknown whether the results in Rev.001 are still valid for Rev.002. The purpose of this Appendix is to compare the calculated results of ANSYS 11.0 and ANSYS 14.0. The comparisons are made on design condition and selected transients in both temperature and stress. It is concluded from the subsections below that the results from ANSYS 11.0 and 14.0 are the same.

B.1 Design Condition

For the design condition, the stress intensity contour plot using ANSYS 14.0 is illustrated in Figure B-1. By comparing to Figure 6 (using ANSYS 11.0), it can be seen that the results are identical.

Figure B-1: Stress Intensity Contours for Design Condition using ANSYS 14.0

B.2 Temperature

For temperature history, the transients HUCD and LDLI are selected for comparison. The temperatures versus time as well as the temperature gradients for HUCD using ANSYS 14.0 are illustrated in Figure B-2 and Figure B-3 respectively. It is observed that these two figures are identical to the results of ANSYS 11.0 in Figure 8 and Figure 9. The same observation is made on transient LDLI by comparing Figure B-4 to Figure 10, and Figure B-5 to Figure 11. The legends shown in Figure B-2 through Figure B-5 are defined in Table 21 and are depicted in Figure 7.

Figure B-2: Temperature of Selected Locations (HUCD) using ANSYS 14.0

[ ]

Figure B-3: Thermal Gradients of Selected Locations (HUCD) using ANSYS 14.0

Figure B-4: Temperature of Selected Locations (LDLI) using ANSYS 14.0

Figure B-5: Thermal Gradients of Selected Locations (LDLI) using ANSYS 14.0

B.3 Stress

Stress distribution along path lines are compared in this section. The axial stress (SY) and hoop stress (SZ) at four path lines, defined in Figure A-1, during various transients are extracted in Rev.001. These stress data files are listed in Table 45 "Fracture". For comparison, the same path line stresses are extracted in Rev.002 using ANSYS 14.0. The comparisons of stress data are made in Excel file comparison.xlsx in Table B-1. The comparisons were made on selected transients and orientations, which are HUCD_SY, LDLI_SZ, LOL_SY, and LOP_SZ. It is found from the comparison results that the data in ANSYS 11.0 and 14.0 are almost identical at every time point and path line location. The maximum variation between ANSYS 11.0 and 14.0 results is 0.1 psi.

B.4 Software and Hardware

ANSYS Version 14.0 [17] is used for Appendix B and Appendix C. The hardware platform (Service Tag# 5VK16S1) is Intel® Core™ i7-2640M CPU 2.80 GHz, 8.00 GB RAM and Operating System is

Microsoft Windows 7 Enterprise, Copyright © 2009, Service Pack 1. Verification tests listed in Section B.5 (vm56 and vm112) are satisfactory.

B.5 Computer Files

All computer files, including the computer input/output files for the analysis in this document, and the computer program test cases are listed in this section. All files are available in AREVA NP Inc. ColdStor storage \\cold\General-Access\32\32-9000000\32-9049114-002\official.

Test cases vm56 and vm112 from Reference [17] are run to verify that the answers are correct. The files vm56.vrt and vm112.vrt contain output from the test cases. Review of the output files shows that the answers are identical to those contained in Reference [17].

1. Computer program tested: ANSYS Version 14.0
2. Computer hardware used: Intel® Core™ i7-2640M CPU 2.80 GHz Service Tag# 5VK16S1
3. Name of person running test: Pei-Yuan Cheng
4. Date of test: 10-03-2013
5. Results and acceptability: The results in vm56.vrt and vm112.vrt listed in Table B-1 agree exactly with the values in the ANSYS manual [17].

Table B-1: Computer Files

File Name	Checksum	Modified Date Time	Description
dc2_geo.out	11901	Oct 03 2013 15:41:41	Output file to develop finite element model
DC2_geo_WB.mac	03640	Oct 03 2013 15:22:10	Input file from Ansys Workbench
mat_prop.mac	63267	Oct 03 2013 15:22:23	Input file includes material properties
DC2_inp_dt.mac	24910	Oct 03 2013 15:23:00	Input file defining nodes for temperature and thermal gradient evaluation
		Design Condition	
DC2_des_pres.out	41742	Oct 07 2013 14:54:49	Output file for design Condition
		HUCD Transient	
hucd_tr.mac	27643	Oct 03 2013 15:50:51	Input file contains definition of HUCD transient
DC2_HUCD_th.out	57841	Oct 03 2013 17:55:26	Output file for thermal analysis of HUCD
DC2_HUCD_dt.out	46646	Oct 03 2013 17:55:28	Output file contains thermal gradients of HUCD
DC2_HUCD_st.out	16260	Oct 03 2013 17:55:39	Output file for stress analysis of HUCD
		LDLI Transient	
ldli_tr.mac	19186	Oct 03 2013 15:51:02	Input file contains definition of LDLI transient

File Name	Checksum	Modified Date Time	Description
DC2_LDLI_th.out	25006	Oct 03 2013 17:56:19	Output file for thermal analysis of LDLI
DC2_LDLI_dt.out	30133	Oct 03 2013 17:56:21	Output file contains thermal gradients of LDLI
DC2_LDLI_st.out	02521	Oct 03 2013 17:56:35	Output file for stress analysis of LDLI
		LLD Transient	
lld_tr.mac	31823	Oct 03 2013 15:51:21	Input file contains definition of LLD transient
DC2_LLD_th.out	04182	Oct 03 2013 17:57:10	Output file for thermal analysis of LLD
DC2_LLD_dt.out	08066	Oct 03 2013 17:57:12	Output file contains thermal gradients of LLD
DC2_LLD_st.out	25038	Oct 03 2013 17:57:25	Output file for stress analysis of LLD
		LOL Transient	
lol_tr.mac	10419	Oct 03 2013 15:51:31	Input file contains definition of LLD transient
DC2_LOL_th.out	11502	Oct 03 2013 17:57:54	Output file for thermal analysis of LLD
DC2_LOL_dt.out	59140	Oct 03 2013 17:57:56	Output file contains thermal gradients of LLD
DC2_LOL_st.out	08679	Oct 03 2013 17:58:04	Output file for stress analysis of LLD
		LOP Transient	
lop_tr.mac	03421	Oct 03 2013 15:51:37	Input file contains definition of LOP transient
DC2_LOP_th.out	07618	Oct 03 2013 17:58:30	Output file for thermal analysis of LOP
DC2_LOP_dt.out	49056	Oct 03 2013 17:58:32	Output file contains thermal gradients of LOP
DC2_LOP_st.out	47331	Oct 03 2013 17:58:43	Output file for stress analysis of LOP
		LOF Transient	
lof_tr.mac	31206	Oct 03 2013 15:51:26	Input file contains definition of LOF transient
DC2_LOF_th.out	42379	Oct 03 2013 17:59:18	Output file for thermal analysis of LOF
DC2_LOF_dt.out	25101	Oct 03 2013 17:59:21	Output file contains thermal gradients of LOF
DC2_LOF_st.out	32597	Oct 03 2013 17:59:31	Output file for stress analysis of LOF
		RT Transient	
rt_tr.mac	34473	Oct 03 2013 15:51:42	Input file contains definition of RT transient
DC2_RT_th.out	31820	Oct 03 2013 17:59:55	Output file for thermal analysis of RT

File Name	Checksum	Modified Date Time	Description
DC2_RT_dt.out	48885	Oct 03 2013 17:59:57	Output file contains thermal gradients of RT
DC2_RT_st.out	49916	Oct 03 2013 18:00:01	Output file for stress analysis of RT
		TRT Transient	
trt_tr.mac	27728	Oct 03 2013 15:51:52	Input file contains definition of TRT transient
DC2_TRT_th.out	00883	Oct 03 2013 18:00:21	Output file for thermal analysis of TRT
DC2_TRT_dt.out	45034	Oct 03 2013 18:00:22	Output file contains thermal gradients of TRT
DC2_TRT_st.out	23465	Oct 03 2013 18:00:27	Output file for stress analysis of TRT
		IASA Transient	
iasa_tr.mac	05656	Oct 03 2013 15:50:56	Input file contains definition of IASA transient
DC2_IASA_th.out	59663	Oct 03 2013 18:00:52	Output file for thermal analysis of IASA
DC2_IASA_dt.out	55483	Oct 03 2013 18:00:54	Output file contains thermal gradients of IASA
DC2_IASA_st.out	06253	Oct 03 2013 18:01:02	Output file for stress analysis of IASA
		SVO Transient	
svo_tr.mac	13828	Oct 03 2013 15:51:47	Input file contains definition of SVO transient
DC2_SVO_th.out	42410	Oct 03 2013 18:01:18	Output file for thermal analysis of SVO
DC2_SVO_dt.out	29021	Oct 03 2013 18:01:20	Output file contains thermal gradients of SVO
DC2_SVO_st.out	43057	Oct 03 2013 18:01:29	Output file for stress analysis of SVO
		Fatigue Usage Factor Calculation	
F_M+B_HA_[ ].out	29510	Oct 03 2013 18:01:34	Stress range results for membrane + bending stresses
F_M+B_HA_[ ]_A.out	64248	Oct 03 2013 18:02:16	Stress range results for membrane + bending stresses
F_M+B_HA_[ ].out	51428	Oct 03 2013 18:01:45	Stress range results for membrane + bending stresses
F_M+B_HA_[ ]_A.out	47829	Oct 03 2013 18:02:26	Stress range results for membrane + bending stresses
F_M+B_HA_[ ].out	08232	Oct 03 2013 18:01:51	Stress range results for membrane + bending stresses
F_M+B_HA_[ ]_A.out	07596	Oct 03 2013 18:02:32	Stress range results for membrane + bending stresses
F_M+B_HA_[ ].out	01543	Oct 03 2013 18:02:03	Stress range results for membrane + bending stresses
F_M+B_HA_[ ]_A.out	59300	Oct 03 2013 18:02:42	Stress range results for membrane + bending stresses

File Name	Checksum	Modified Date Time	Description
F_M+B_HA_[ ].out	10543	Oct 03 2013 18:01:39	Stress range results for membrane + bending stresses
F_M+B_HA_[ ]_A.out	43573	Oct 03 2013 18:02:21	Stress range results for membrane + bending stresses
F_M+B_LA_[ ].out	19912	Oct 03 2013 18:02:12	Stress range results for membrane + bending stresses
F_M+B_LA_[ ]_A.out	59711	Oct 03 2013 18:02:47	Stress range results for membrane + bending stresses
F_TOT_HA_[ ].out	21086	Oct 03 2013 18:02:52	Stress range results for total stresses
F_TOT_HA_[ ]_A.out	25975	Oct 03 2013 18:03:34	Stress range results for total stresses
F_TOT_HA_[ ].out	35155	Oct 03 2013 18:03:04	Stress range results for total stresses
F_TOT_HA_[ ]_A.out	28171	Oct 03 2013 18:03:44	Stress range results for total stresses
F_TOT_HA_[ ].out	23771	Oct 03 2013 18:03:10	Stress range results for total stresses
F_TOT_HA_[ ]_A.out	41108	Oct 03 2013 18:03:49	Stress range results for total stresses
F_TOT_HA_[ ] out	25709	Oct 03 2013 18:03:21	Stress range results for total stresses
F_TOT_HA_[ ]_A.out	00001	Oct 03 2013 18:03:59	Stress range results for total stresses
F_TOT_HA_[ ].out	44663	Oct 03 2013 18:02:58	Stress range results for total stresses
F_TOT_HA_[ ]_A.out	35064	Oct 03 2013 18:03:39	Stress range results for total stresses
F_TOT_LA_[ ].out	63599	Oct 03 2013 18:03:30	Stress range results for total stresses
F_TOT_LA_[ ]_A.out	36798	Oct 03 2013 18:04:05	Stress range results for total stresses
		ANSYS Verification Files	
vm56.out	41461	Oct 03 2013 16:41:13	2-D 8-node structural element
vm56.vrt	40729	Oct 03 2013 16:41:13	2-D 8-node structural element
vm112.out	11272	Oct 03 2013 16:40:56	2-D 8-node thermal element
vm112.vrt	46559	Oct 03 2013 16:40:56	2-D 8-node thermal element
		Fracture for Appendix A	
DC2_fr_old_path.out	23204	Oct 04 2013 09:31:23	Output files contains definition for fracture calculation
Fr_PathLocs.out	07208	Oct 04 2013 09:31:23	Output files contains path point distances from the inside nodes
DC2_HUCD_fr_SY.out	43320	Oct 04 2013 09:31:23	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_SZ.out	62604	Oct 04 2013 09:31:23	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_TH.out	02629	Oct 04 2013 09:31:23	Output file contains temperatures along

File Name	Checksum	Modified Date Time	Description
			the fracture paths for HUCD transient
DC2_LDLI_fr_SY.out	09561	Oct 04 2013 09:31:15	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_SZ.out	50981	Oct 04 2013 09:31:15	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_TH.out	58283	Oct 04 2013 09:31:15	Output file contains temperatures along the fracture paths for LDLI transient
DC2_LLD_fr_SY.out	08728	Oct 04 2013 09:31:16	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_SZ.out	04504	Oct 04 2013 09:31:16	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_TH.out	41124	Oct 04 2013 09:31:16	Output file contains temperatures along the fracture paths for LLD transient
DC2_LOL_fr_SY.out	15738	Oct 04 2013 09:31:17	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_SZ.out	46249	Oct 04 2013 09:31:17	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_TH.out	09011	Oct 04 2013 09:31:17	Output file contains temperatures along the fracture paths for LOL transient
DC2_LOP_fr_SY.out	47503	Oct 04 2013 09:31:19	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_SZ.out	28046	Oct 04 2013 09:31:19	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_TH.out	49779	Oct 04 2013 09:31:19	Output file contains temperatures along the fracture paths for LOP transient
DC2_LOF_fr_SY.out	25862	Oct 04 2013 09:31:19	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_SZ.out	16865	Oct 04 2013 09:31:19	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_TH.out	65159	Oct 04 2013 09:31:19	Output file contains temperatures along the fracture paths for LOF transient
DC2_RT_fr_SY.out	50489	Oct 04 2013 09:31:20	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_SZ.out	56676	Oct 04 2013 09:31:20	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_TH.out	59558	Oct 04 2013 09:31:20	Output file contains temperatures along the fracture paths for RT transient
DC2_TRT_fr_SY.out	64394	Oct 04 2013 09:31:20	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_SZ.out	38804	Oct 04 2013 09:31:20	Output file contains stress components

File Name	Checksum	Modified Date Time	Description
			along the fracture paths for TRT transient
DC2_TRT_fr_TH.out	16354	Oct 04 2013 09:31:20	Output file contains temperatures along the fracture paths for TRT transient
DC2_IASA_fr_SY.out	43199	Oct 04 2013 09:31:21	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_SZ.out	60834	Oct 04 2013 09:31:21	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_TH.out	45152	Oct 04 2013 09:31:21	Output file contains temperatures along the fracture paths for IASA transient
DC2_SVO_fr_SY.out	50107	Oct 04 2013 09:31:22	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_SZ.out	35035	Oct 04 2013 09:31:22	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_TH.out	56485	Oct 04 2013 09:31:22	Output file contains temperatures along the fracture paths for SVO transient
		ANSYS Comparison	
comparison.xlsx	26601	Oct 04 2013 09:47:58	Stress comparison of ANSYS 11.0 and 14.0
		Fracture for Appendix C	
DC2_fr_new_path.out	13159	Oct 08 2013 11:25:33	Output files contains definition for fracture calculation
Fr_new_PathLocs.out	13999	Oct 08 2013 11:25:33	Output files contains path point distances from the inside nodes
DC2_HUCD_fr_NewPath_SX.out	17800	Oct 08 2013 11:24:53	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_NewPath_SY.out	19076	Oct 08 2013 11:24:53	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_NewPath_SZ.out	38392	Oct 08 2013 11:24:53	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_NewPath_Sh.out	32532	Oct 08 2013 11:24:53	Output file contains stress components along the fracture paths for HUCD transient
DC2_HUCD_fr_NewPath_TH.out	49107	Oct 08 2013 11:24:53	Output file contains temperatures along the fracture paths for HUCD transient
DC2_LDLI_fr_NewPath_SX.out	35915	Oct 08 2013 11:25:01	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_NewPath_SY.out	42153	Oct 08 2013 11:25:01	Output file contains stress components along the fracture paths for LDLI transient

File Name	Checksum	Modified Date Time	Description
DC2_LDLI_fr_NewPath_SZ.out	45742	Oct 08 2013 11:25:01	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_NewPath_Sh.out	40894	Oct 08 2013 11:25:01	Output file contains stress components along the fracture paths for LDLI transient
DC2_LDLI_fr_NewPath_TH.out	16447	Oct 08 2013 11:25:01	Output file contains temperatures along the fracture paths for LDLI transient
DC2_LLD_fr_NewPath_SX.out	59180	Oct 08 2013 11:25:09	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_NewPath_SY.out	41648	Oct 08 2013 11:25:09	Output file contains stress components, along the fracture paths for LLD transient
DC2_LLD_fr_NewPath_SZ.out	24752	Oct 08 2013 11:25:09	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_NewPath_Sh.out	21732	Oct 08 2013 11:25:09	Output file contains stress components along the fracture paths for LLD transient
DC2_LLD_fr_NewPath_TH.out	24282	Oct 08 2013 11:25:09	Output file contains temperatures along the fracture paths for LLD transient
DC2_LOL_fr_NewPath_SX.out	13109	Oct 08 2013 11:25:15	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_NewPath_SY.out	36875	Oct 08 2013 11:25:15	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_NewPath_SZ.out	20482	Oct 08 2013 11:25:15	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_NewPath_Sh.out	26337	Oct 08 2013 11:25:15	Output file contains stress components along the fracture paths for LOL transient
DC2_LOL_fr_NewPath_TH.out	46469	Oct 08 2013 11:25:15	Output file contains temperatures along the fracture paths for LOL transient
DC2_LOP_fr_NewPath_SX.out	18800	Oct 08 2013 11:25:20	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_NewPath_SY.out	33876	Oct 08 2013 11:25:20	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_NewPath_SZ.out	31939	Oct 08 2013 11:25:20	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_NewPath_Sh.out	48017	Oct 08 2013 11:25:20	Output file contains stress components along the fracture paths for LOP transient
DC2_LOP_fr_NewPath_TH.out	00906	Oct 08 2013 11:25:20	Output file contains temperatures along the fracture paths for LOP transient
DC2_LOF_fr_NewPath_SX.out	16427	Oct 08 2013 11:25:24	Output file contains stress components along the fracture paths for LOF

File Name	Checksum	Modified Date Time	Description
			transient
DC2_LOF_fr_NewPath_SY.out	43482	Oct 08 2013 11:25:24	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_NewPath_SZ.out	32519	Oct 08 2013 11:25:24	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_NewPath_Sh.out	48901	Oct 08 2013 11:25:24	Output file contains stress components along the fracture paths for LOF transient
DC2_LOF_fr_NewPath_TH.out	08926	Oct 08 2013 11:25:24	Output file contains temperatures along the fracture paths for LOF transient
DC2_RT_fr_NewPath_SX.out	28079	Oct 08 2013 11:25:25	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_NewPath_SY.out	23652	Oct 08 2013 11:25:25	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_NewPath_SZ.out	12147	Oct 08 2013 11:25:25	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_NewPath_Sh.out	19547	Oct 08 2013 11:25:25	Output file contains stress components along the fracture paths for RT transient
DC2_RT_fr_NewPath_TH.out	39622	Oct 08 2013 11:25:25	Output file contains temperatures along the fracture paths for RT transient
DC2_TRT_fr_NewPath_SX.out	04628	Oct 08 2013 11:25:27	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_NewPath_SY.out	36174	Oct 08 2013 11:25:27	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_NewPath_SZ.out	33574	Oct 08 2013 11:25:27	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_NewPath_Sh.out	06811	Oct 08 2013 11:25:27	Output file contains stress components along the fracture paths for TRT transient
DC2_TRT_fr_NewPath_TH.out	59357	Oct 08 2013 11:25:27	Output file contains temperatures along the fracture paths for TRT transient
DC2_IASA_fr_NewPath_SX.out	07627	Oct 08 2013 11:25:29	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_NewPath_SY.out	24190	Oct 08 2013 11:25:29	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_NewPath_SZ.out	16655	Oct 08 2013 11:25:29	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_NewPath_Sh.out	22483	Oct 08 2013 11:25:29	Output file contains stress components along the fracture paths for IASA transient
DC2_IASA_fr_NewPath_TH.out	02731	Oct 08 2013 11:25:29	Output file contains temperatures along the fracture paths for IASA transient
DC2_SVO_fr_NewPath_SX.out	07270	Oct 08 2013 11:25:33	Output file contains stress components

File Name	Checksum	Modified Date Time	Description
			along the fracture paths for SVO transient
DC2_SVO_fr_NewPath_SY.out	12050	Oct 08 2013 11:25:33	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_NewPath_SZ.out	57834	Oct 08 2013 11:25:33	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_NewPath_Sh.out	08033	Oct 08 2013 11:25:33	Output file contains stress components along the fracture paths for SVO transient
DC2_SVO_fr_NewPath_TH.out	35999	Oct 08 2013 11:25:33	Output file contains temperatures along the fracture paths for SVO transient

APPENDIX C– STRESSES FOR SAFETY NOZZLE WOL FRACTURE MECHANICS ANALYSIS FOR OUTAGE 2R17

C.1 Purpose

During 2013 outage (2R17) inservice inspection indications were detected in the weld overlaid Pressurizer Safety/Relief Nozzles. The indications are described in the Diablo Canyon Power Plant Design Input Transmittal (DIT) summarized in Reference [18]. The purpose of this appendix is to provide stress and thermal results of the transient analysis for fracture mechanics evaluation along pathlines matching the detected indications in the Safety/Relief Nozzles.

C.2 Path Lines Determination

Per Reference [18], rejectable indications are existed in safety nozzles A, B and C as shown in Figure C-1, Figure C-2, and Figure C-3, respectively. The indications in nozzles A and B are located at the interface between WOL and nozzle. For nozzle C, there are two indications; indication C1 is located at the interface of WOL and nozzle while indication C2 is in the WOL near safe end to pipe weld.

Figure C-1: Safety Nozzle "A" Indication Plot

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Figure C-2: Safety Nozzle "B" Indication Plot

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Figure C-3: Safety Nozzle "C" Indication Plot

The path lines determined for fracture mechanics analysis are based on the indications shown above. Note that the stress analysis performed in this calculation uses a finite element model representing all the three Safety Nozzles. The path lines in the finite element model are illustrated in Figure C-4 and described in Table C-1. The first two path lines (A_wol and A_noz) represent the indications A and C1. These two path lines are defined by the same nodes but different materials since the path is located at the interface of two different materials. One of the path lines is using WOL material and second one is

using nozzle material properties by selecting respective materials in the post process analysis. Since the indication A is not a straight line in Figure C-1, the path line is defined by four nodes along the interface between the WOL and nozzle materials.

Similar to the path line for indication A and C1, two path lines (B_wol and B_noz) are defined to represent indication B with different materials assigned. Indication C2 is represented by path line C2_wol, which is completely within the WOL material. Three more path lines (A_pln, B_pln, and C2_pln) are defined to represent any assumed planar component of the existing laminar indications. Note nozzle liner is not included in the planar path lines. Only the indications (#1, #1a) in Nozzle A is found to have any planar component and hence only path line A_pln is used further in the flaw evaluations. B_pln and C2_pln are shown only for information purposes only.

Table C-1: Path Lines Description

Path Line	Node Numbers Start	Intermediate Node Numbers	Node Numbers End	Location	Material
A_wol A_noz	1465	1464,1466	1472	Indications A and C1	
B_wol B_noz	1428	none	1462	Indication B	
C2_wol	275	none	278	Indication C2	
A_pln	1227	none	1467	Planar flaw cross indications A and C1	
B_pln	1220,	none	1459	Planar flaw cross indication B	
C2_pln	1578,	none	1391	Planar flaw cross indication C2	

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Figure C-4: Path Lines Defined for Fracture Mechanics Evaluation

C.3 Stress and Temperature Evaluation

The post processor calculation for fracture analysis is contained in computer file:

DC2_fr_new_path.out

Stresses along the path line in the global coordinate system with "y" axis along the nozzle axis are summarized at thirteen points separated by an equal distance from the inside node to the outside node. At each point the radial (Sx) stress, axial (Sy) stress, hoop (Sz) stress, shear (Sh) stress on XY surface, and the temperature (Th) in the weld or weld overlay are given.

The path point distances from the inside nodes are included in the output file: Fr_new_PathLocs.out

ANSYS post processing output files are listed in Section B.5 and the stresses and temperatures output results files for the fracture mechanics are listed below:

DC2_HUCD_fr_NewPath_SX.out	DC2_LOF_fr_NewPath_SX.out
DC2_LDLI_fr_NewPath_SX.out	DC2_RT_fr_NewPath_SX.out
DC2_LLD_fr_NewPath_SX.out	DC2_TRT_fr_NewPath_SX.out
DC2_LOL_fr_NewPath_SX.out	DC2_IASA_fr_NewPath_SX.out
DC2_LOP_fr_NewPath_SX.out	DC2_SVO_fr_NewPath_SX.out
DC2_HUCD_fr_NewPath_SY.out	DC2_LOF_fr_NewPath_SY.out
DC2_LDLI_fr_NewPath_SY.out	DC2_RT_fr_NewPath_SY.out

DC2_LLD_fr_NewPath_SY.out	DC2_TRT_fr_NewPath_SY.out
DC2_LOL_fr_NewPath_SY.out	DC2_IASA_fr_NewPath_SY.out
DC2_LOP_fr_NewPath_SY.out	DC2_SVO_fr_NewPath_SY.out
DC2_HUCD_fr_NewPath_SZ.out	DC2_LOF_fr_NewPath_SZ.out
DC2_LDLI_fr_NewPath_SZ.out	DC2_RT_fr_NewPath_SZ.out
DC2_LLD_fr_NewPath_SZ.out	DC2_TRT_fr_NewPath_SZ.out
DC2_LOL_fr_NewPath_SZ.out	DC2_IASA_fr_NewPath_SZ.out
DC2_LOP_fr_NewPath_SZ.out	DC2_SVO_fr_NewPath_SZ.out
DC2_HUCD_fr_NewPath_Sh.out	DC2_LOF_fr_NewPath_Sh.out
DC2_LDLI_fr_NewPath_Sh.out	DC2_RT_fr_NewPath_Sh.out
DC2_LLD_fr_NewPath_Sh.out	DC2_TRT_fr_NewPath_Sh.out
DC2_LOL_fr_NewPath_Sh.out	DC2_IASA_fr_NewPath_Sh.out
DC2_LOP_fr_NewPath_Sh.out	DC2_SVO_fr_NewPath_Sh.out
DC2_HUCD_fr_NewPath_TH.out	DC2_LOF_fr_NewPath_TH.out
DC2_LDLI_fr_NewPath_TH.out	DC2_RT_fr_NewPath_TH.out
DC2_LLD_fr_NewPath_TH.out	DC2_TRT_fr_NewPath_TH.out
DC2_LOL_fr_NewPath_TH.out	DC2_IASA_fr_NewPath_TH.out
DC2_LOP_fr_NewPath_TH.out	DC2_SVO_fr_NewPath_TH.out

To investigate the magnitude and distribution of stresses at the existing indications, contour plots at the critical transients and time points are extracted. An example is in transient HUCD where thermal gradients are large at time=13 and 18.6 hrs (see Figure 9). The contour plots of radial stress and shear stress at time=13 in HUCD are illustrated in Figure C-5 and Figure C-6, respectively. The same plots for time=18.6 are illustrated in Figure C-7 and Figure C-8. It is found that stresses are higher at time=13, where the maximum radial stress at all the indications is about 4 ksi (indication A nozzle side) and maximum shear stress is about -6 ksi (indication A nozzle side). From Figure 8 through Figure 27, the maximum thermal gradient is at time=0.1 (hr) in transient IASA (Figure 25). Its radial stress and shear stress contour plots are provided in Figure C-9 and Figure C-10, respectively. The maximum radial stress at all the indications is about 4 ksi (indication A nozzle side) and maximum shear stress is about -6 ksi (indication A nozzle side) and 6 ksi (indication A WOL side).

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Figure C-5: Radial Stress at Time [ ] (hr) in HUCD

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Figure C-6: Shear Stress at Time [ ] (hr) in HUCD

Figure C-7: Radial Stress at Time [ ] (hr) in HUCD

Figure C-8: Shear Stress at Time [ ] (hr) in HUCD

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Figure C-9: Radial Stress at Time [ ] (hr) in IASA

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Figure C-10: Shear Stress at Time [ ] (hr) in IASA