Table 8-6 Cool-Down Late Spray with Temperature Drop of 405°F

[ ] [ ]

Table 8-7 Cool-Down Early Spray with Temperature Drop of 320°F

Table 8-8 Cool-Down Late Spray with Temperature Drop of 320°F

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

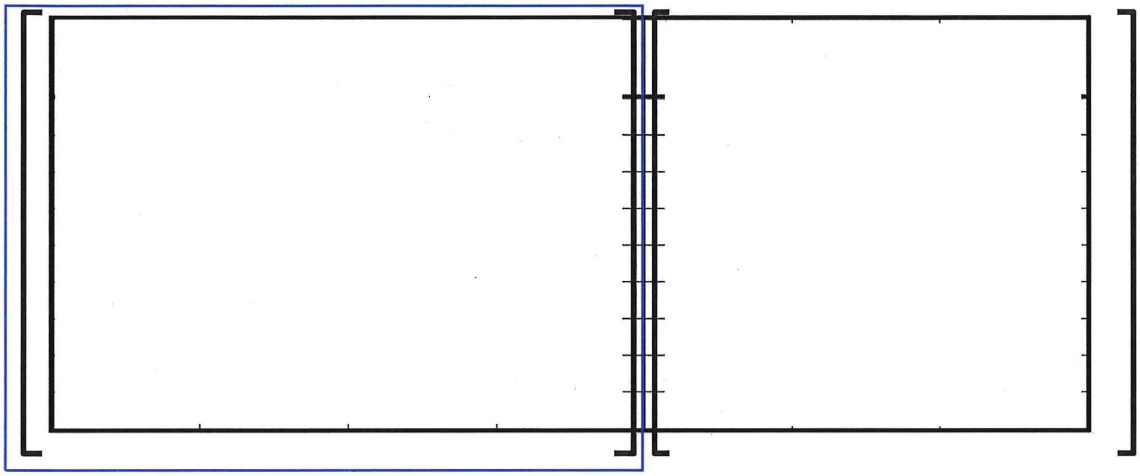


Table 8-10 Large Step Decrease in Load Transient

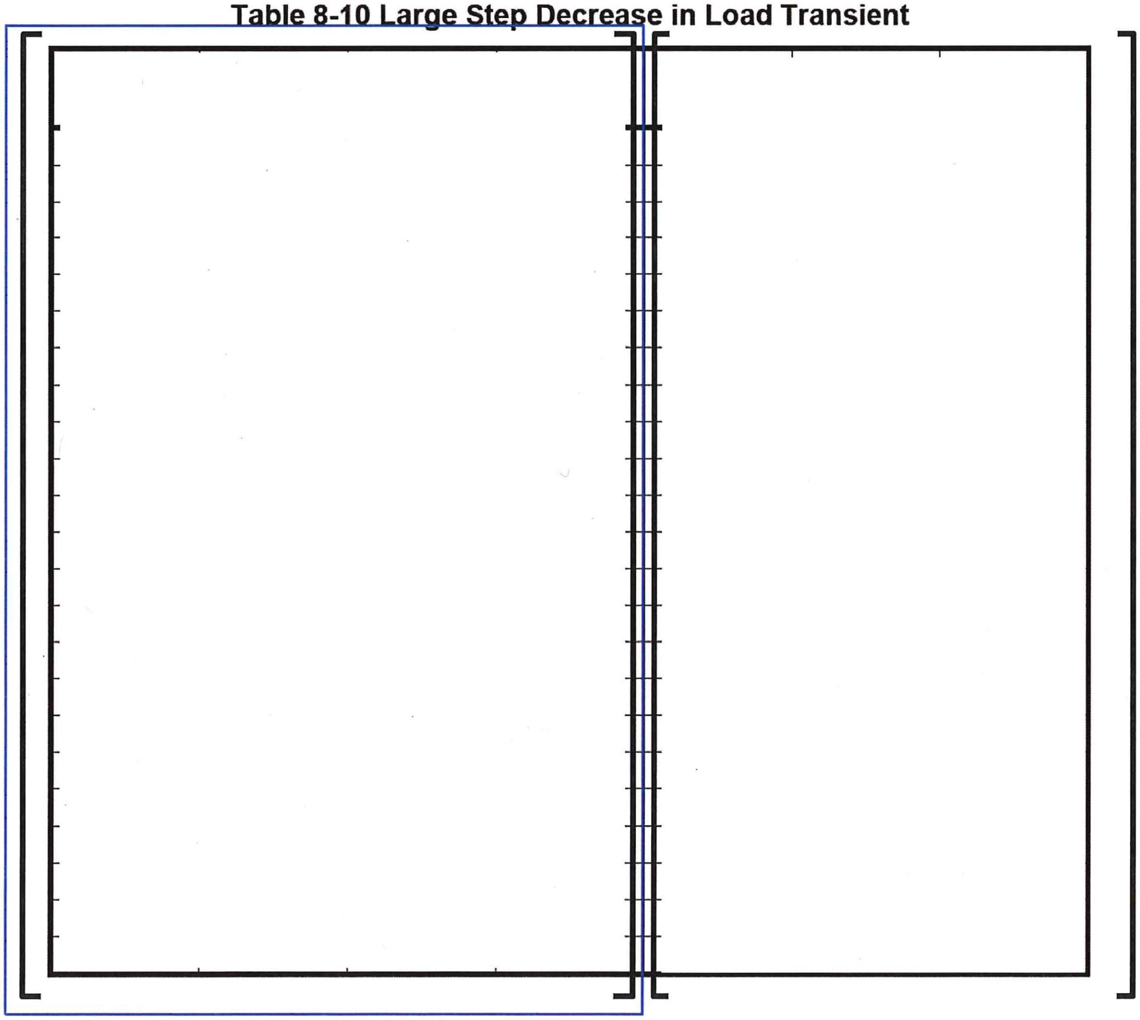


Table 8-11 Step Load Increase of 10% of Full Power Transient

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

Table 8-13 Boron Concentration Equalization Transient [1]

[ ] [ ]

Table 8-14 Loss of Load Transient

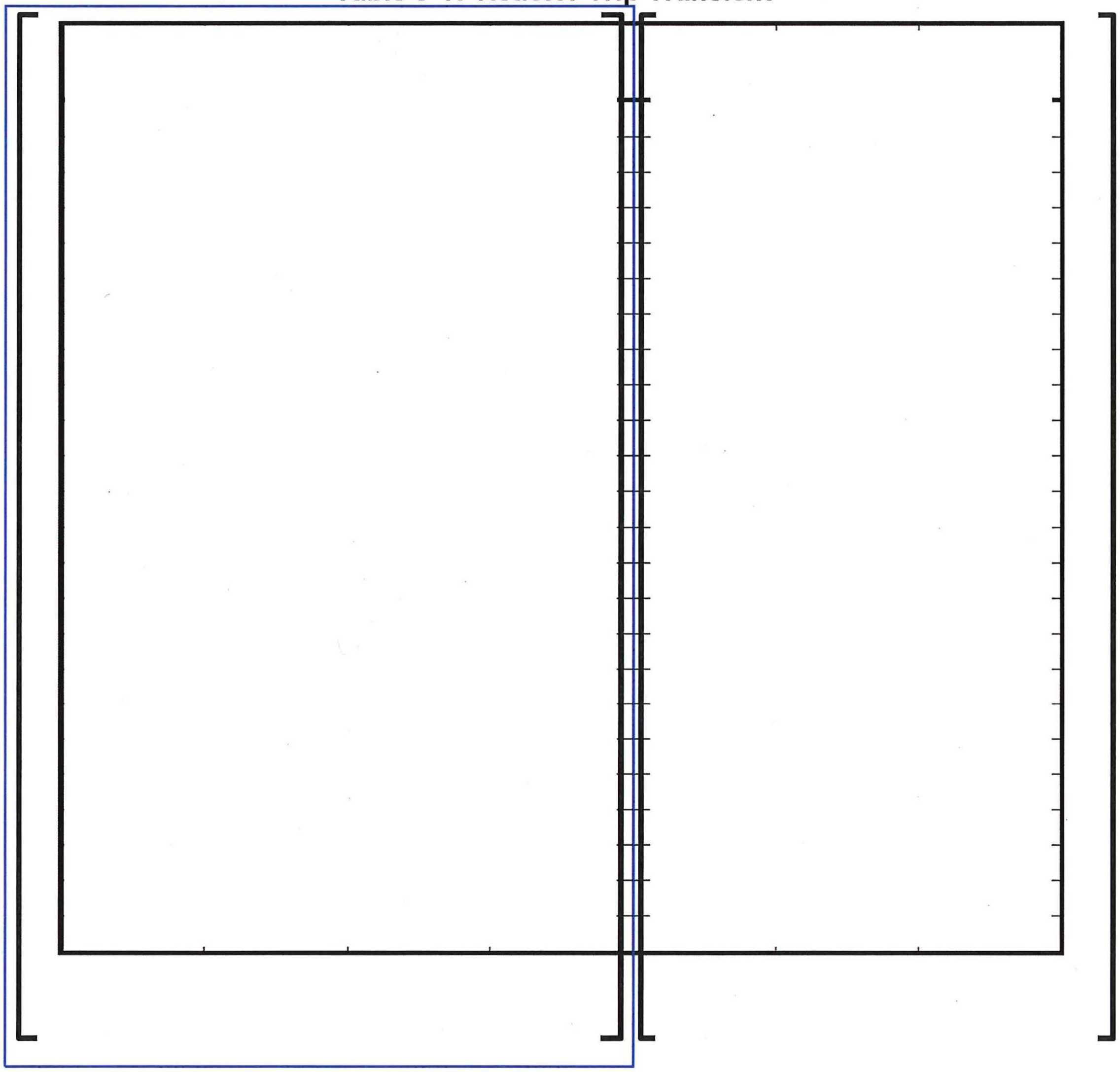
[ ] [ ]

[ ]

Table 8-15 Loss of Power Transient

Table 8-16 Loss of Flow Transient

Table 8-17 Reactor Trip Transient [1]



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

Table 8-18 Inadvertent Auxiliary Spray Transient

Table 8-19 Turbine Roll Test Transient

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

The computer input files containing definition of these transients are:

HU-ES_tr.inp	PLPU_tr.inp	LSL_tr.inp
HU-LS_tr.inp	BCE_tr.inp	SLD_tr.inp
CD-ES320_tr.inp	IA_tr.inp	SLI_tr.inp
CD-ES405_tr.inp	LOF_tr.inp	RT_tr.inp
CD-LS320_tr.inp	LOL_tr.inp	TRT_tr.inp
CD-LS405_tr.inp	LOP_tr.inp	

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

min_HU-ES_th.out	min_PLPU_th.out	min_LSL_th.out
min_HU-LS_th.out	min_BCE_th.out	min_SLD_th.out
min_CD-ES320_th.out	min_IA_th.out	min_SLI_th.out
min_CD-ES405_th.out	min_LOF_th.out	min_RT_th.out
min_CD-LS320_th.out	min_LOL_th.out	min_TRT_th.out
min_CD-LS405_th.out	min_LOP_th.out	

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

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

min_HU-ES_dt.out	min_PLPU_dt.out	min_LSL_dt.out
min_HU-LS_dt.out	min_BCE_dt.out	min_SLD_dt.out
min_CD-ES320_dt.out	min_IA_dt.out	min_SLI_dt.out
min_CD-ES405_dt.out	min_LOF_dt.out	min_RT_dt.out
min_CD-LS320_dt.out	min_LOL_dt.out	min_TRT_dt.out
min_CD-LS405_dt.out	min_LOP_dt.out	

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

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

Table 8-21 Temperature Gradients of Interest

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

Figure 8-2 Location Numbers for Evaluation of Temperature Gradients

Figure 8-3 Heat-Up Early Spray Transient

Figure 8-4 Heat-Up Late Spray Transient

Figure 8-5 Cool-Down Early Spray with Temperature Drop of 405°F

Figure 8-6 Cool-Down Late Spray with Temperature Drop of 405°F

Figure 8-7 Cool-Down Early Spray with Temperature Drop of 320°F

Figure 8-8 Cool-Down Late Spray with Temperature Drop of 320°F

[ ]

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

Figure 8-10 Large Step Decrease in Load Transient

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

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

[ ]

Figure 8-13 Boron Concentration Equalization Transient

Figure 8-14 Loss of Load Transient

Figure 8-15 Loss of Power Transient

Figure 8-16 Loss of Flow Transient

Figure 8-17 Reactor Trip Transient

Figure 8-18 Inadvertent Auxiliary Spray Transient

Figure 8-19 Turbine Roll Test Transient

9 STRUCTURAL ANALYSIS

Stress analyses are performed at the time points listed in Table 9-1 through Table 9-17. The time points include those at which the maximum temperature gradients (maximum thermal stresses) and the maximum and minimum pressures occur, as well as those of analytical interest. The nodal temperature at the particular time point is read into the structural model directly from the result file of the thermal analysis. The corresponding pressure is obtained from the transient input macros. The computer output files for the structural analyses are:

min_HU-ES_st.out
min_HU-LS_st.out
min_CD-ES320_st.out
min_CD-ES405_st.out
min_CD-LS320_st.out
min_CD-LS405_st.out
min_PLPU_st.out
min_BCE_st.out
min_IA_st.out
min_LOF_st.out
min_LOL_st.out
min_LOP_st.out
min_LSL_st.out
min_SLD_st.out
min_SLI_st.out
min_RT_st.out
min_TRT_st.out

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

[ ]

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

[ ]

Table 9-3 Time Points of Interest - CD-ES405

[ ]

Table 9-4 Time Points of Interest - CD-LS405

[ ]

Table 9-5 Time Points of Interest - CD-ES320

[ ]

Table 9-6 Time Points of Interest - CD-LS320

[ ]

Table 9-7 Time Points of Interest - PLPU

Table 9-8 Time Points of Interest - LSL

[ ]

Table 9-9 Time Points of Interest - SLI

[ ]

Table 9-10 Time Points of Interest - LOL

[ ]

Table 9-11 Time Points of Interest - SLD

[ ]

Table 9-12 Time Points of Interest - BCE

[ ]

Table 9-13 Time Points of Interest - LOP

[ ]

Table 9-14 Time Points of Interest - LOF

Table 9-15 Time Points of Interest - RT

Table 9-16 Time Points of Interest – IA

Table 9-17 Time Points of Interest – TRT

10 ASME CODE CRITERIA

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

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

In general, the primary stress intensity criteria of the ASME Code (Reference [14]) assure that the design is adequate for application of design loads.

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

10.1 ASME Code Primary Stress Intensity (SI) Criteria

Per NB-3213.8 of Reference [14], the primary stresses are those normal or shear stresses developed by an imposed loading such as internal pressure and external loadings. A thermal stress is not classified as a primary stress. The primary stress intensity criteria are specified in: NB-3221 for Design Conditions, NB-3223 for Level B (Upset), NB-3224 for Level C (Emergency), NB-3225 for Level D (Faulted) and NB-3226 for Test Conditions.

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

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

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

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

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

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

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

10.2.1 Path Stress Evaluation

The ANSYS Post Processor is used to tabulate the stresses along predetermined paths and classify them in accordance with the ASME Code Criteria (i.e., membrane, membrane plus bending, total and peak stress).

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

Table 10-1 Path Definition

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

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

Figure 10-1 Stress Paths through the Spray Nozzle Model

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

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

10.2.2 Applicable Stress Intensity Due to External Loads

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

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

10.2.3 Maximum Primary + Secondary Stress Intensity Range

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

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

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

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

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

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

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

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

Outside node of paths: Path8, Path10

For the remaining locations, the requirement is met.

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

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

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

Path	Transient Stresses + External Stresses		Allowable 3Sm limit at 680°F[1] [ksi]		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node	Outside Node	Inside Node	Outside Node
Path2			80.1	80.1	SA-508	SA-508
Path3			80.1	69.9	SA-508	Alloy690
Path3A			80.1	80.1	SA-508	SA-508
Path3B			69.9	69.9	Alloy690	Alloy690
Path4			69.9	69.9	Alloy600	Alloy690
Path4A			69.9	69.9	Alloy600	Alloy600
Path4B			69.9	69.9	Alloy690	Alloy690
Path5			41.1	69.9	SA-182	Alloy690
Path5A			41.1	41.1	SA-182	SA-182
Path5B			69.9	69.9	Alloy690	Alloy690
Path6			41.1	69.9	SA-182	Alloy690
Path6A			41.1	41.1	SA-182	SA-182
Path6B			69.9	69.9	Alloy690	Alloy690
Path7			41.1	69.9	SA-182	Alloy690
Path7A			41.1	41.1	SA-182	SA-182
Path7B			69.9	69.9	Alloy690	Alloy690
Path8			45.6	69.9	SA-213	Alloy690
Path8A			45.6	45.6	SA-213	SA-213
Path8B			69.9	69.9	Alloy690	Alloy690
Path9			49.2	69.9	SA-376	Alloy690
Path9A			49.2	49.2	SA-376	SA-376
Path9B[2]			69.9	69.9	Alloy690	Alloy690
Path10			49.2	49.2	SA-376	SA-376

[1] The Sm values are conservatively taken at 680°F (maximum transient temperature)

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

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

Path	Load Step Combination	
	Inside Node	Outside Node
Path5	119 - 301 CD-LS320 (7.643 hr) – IA (2.239 hr)	-
Path7	135 - 305 CD-ES405 (2.19267 hr) – IA (2.3499 hr)	-
Path7A	134-305 CD-ES405 (2.191 hr) – IA (2.3499 hr)	-
Path8	134-237 CD-ES405 (2.191 hr) – LOL (0.005235 hr)	134-237 CD-ES405 (2.191 hr) – LOL (0.005235 hr)
Path8A	134-305 CD-ES405 (2.191 hr) – IA (2.3499 hr)	-
Path10	134-237 CD-ES405 (2.191 hr) – LOL (0.005235 hr)	134-236 CD-ES405 (2.191 hr) – LOL (0.003512 hr)

10.2.5 Simplified Elastic-Plastic Analysis (NB-3228.5)

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

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

1) Primary + Secondary SI Range (Excluding thermal bending stresses), NB-3228.5(a)

The range of primary + secondary membrane + bending stress intensity, excluding thermal bending, shall be ≤ 3*Sm.

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

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

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

Path	Transient Stresses + External Stresses		Allowable 3Sm limit at 680°F		Material	
	SI Range Inside Node [ksi]	SI Range Outside Node [ksi]	Inside Node	Outside Node	Inside Node	Outside Node
Path5					SA-182	-
Path7					SA-182	-
Path7A					SA-182	-
Path8					SA-213	Alloy690
Path8A					SA-213	-
Path10					SA-376	SA-376

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

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

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

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

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

m = 1.7 for austenitic stainless steel from Table NB-3228.5 (b)-1 (Reference [14])

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

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

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

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

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

For fatigue usage factor evaluation see Section 10.2.6 .

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

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

Some of these locations are parts of the local geometric discontinuities. The ASME Code requirements for thermal ratcheting are considered accurately only for cylindrical shells without discontinuities. On the other hand, the requirements for thermal ratcheting at discontinuities are considered to be "probably overly conservative" (Reference [16], page 207).

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

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

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

min_HU-ES_rtch.out	min_PLPU_rtch.out	min_LSL_rtch.out
min_HU-LS_rtch.out	min_BCE_rtch.out	min_SLD_rtch.out
min_CD-ES320_rtch.out	min_IA_rtch.out	min_SLI_rtch.out
min_CD-ES405_rtch.out	min_LOF_rtch.out	min_RT_rtch.out
min_CD-LS320_rtch.out	min_LOL_rtch.out	min_TRT_rtch.out
min_CD-LS405_rtch.out	min_LOP_rtch.out	

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

The general primary membrane stresses "Pm" due to pressure for load step combinations listed in Table 10-3 are calculated from the general primary membrane stresses at design condition (2485 psig) multiplied by pressure ratios. The pressure ratio for specific load step is given by actual pressure at this load step [psig] divided by design pressure [psig]. The higher "Pm" of two time points is used for determination of the Allowable SI Range. The general primary membrane stresses "Pm" are shown in Table 10-5 and the membrane stresses for all defined paths at design condition are documented in ANSYS output files "*min_DC_paths.out*".

Table 10-5 General Membrane Stress for Critical Locations

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

Table 10-6 Allowable Ranges of Thermal Stresses

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

Where:

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

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

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

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

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

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

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

Therefore, the ASME Code requirement is met.

6) Minimum Strength Ratio (NB-3228.5(f))

The material shall have specified minimum yield strength to specified minimum tensile strength ratio of less then 0.80. The Sy and Su values at 70°F are listed in Section 5.1 .

Table 10-7 Minimum Strength Ratio

Location	Material	Minimum Sy at 70°F [ksi]	Minimum Su at 70°F [ksi]	Sy/Su
Path5 inside, Path7 inside Path7A inside	SA-182, F316L	25	65	0.38
Path8 inside Path8A outside	SA-213, TP304	30	75	0.40
Path 10 inside Path 10 outside	SA-376, TP316	30	75	0.40
Path8 outside	Alloy 690	35	85	0.41

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

10.2.6 Fatigue Usage Factor Calculation

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

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

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

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

Table 10-8 Stress Category and FSRF in Fatigue Evaluation

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

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

The Inadvertent Auxiliary Spray transient consists of two cycles (see Figure 8-18); therefore, for the fatigue calculations the transient is splitted into two separate transients "IA1" and "IA2" with the same number of cycles of 12. Transient "IA1" is between time-point 0.0001 [hr] (load step 284) and time-point 1.5417 [hr] (load step 297). Transient "IA2" is between time-point 2.01342 [hr] (load step 298) and time-point 3.00 [hr] (load step 309).

The stress intensities due to external loads, as calculated in Section 6.1.2 , are added to the transients SI Ranges where applicable. As already discussed in Section 10.2.2 , the maximum SI due to external loads are given by the load combination: OBE+Thermal Loads. Therefore, the stress intensity due to this combination is conservatively added to the maximum SI Ranges for the first 400 cycles (20x20 cycles is specified for OBE and 250 cycles for thermal external loads), unless otherwise noted. The notes below the tables with fatigue usage calculations provide detailed description of the used stresses and cycles of the external loads.

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

Table 10-9 Nozzle Usage Factor

EVALUATION TITLE: Diablo Canyon, Path2 outside

REFERENCE:	min_paths(M+B).txt		
MATERIAL:	SA-508, Class 2		
TYPE:	C, 1/2Mo, Cr, Ni		
UTS (ksi) =	[ ]	at T = [ ]	E curve (psi) = [ ]
Emat (psi) =	[ ]	at T = [ ]	E ratio = Ecurve/Emat

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

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

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

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

---

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

2 Internal cycles

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

Table 10-10 DM Weld Usage Factor

EVALUATION TITLE: Diablo Canyon, Path4A inside

REFERENCE:	min_paths(M+B).txt
MATERIAL:	Alloy 600
TYPE:	SB166 (Ni-Cr-Fe)
UTS (ksi) =	[ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) =	[ ] at T = [ ] E ratio = Ecurve/Emat

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

Total Fatigue Usage Factor = [ ]

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

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

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

---

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

[2] Internal cycles

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

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

Table 10-11 Safe End Usage Factor

EVALUATION TITLE: Diablo Canyon, Path7 inside

REFERENCE: min_paths(Total).txt
MATERIAL: SA-182
TYPE: F316L (17Cr-12Ni-2Mo)
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

[

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

]

Total Fatigue Usage Factor = [ ]

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

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

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

---

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

[2] Internal Cycles

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

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

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

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

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

[

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

]

Table 10-13 Safe End to Pipe Weld Usage Factor

EVALUATION TITLE: Diablo Canyon, Path8A inside

REFERENCE: min_paths(Total).txt
MATERIAL: SA-213
TYPE: TP316 (16Cr-13Ni-3Mo)
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

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

Total Fatigue Usage Factor = [ ]

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

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

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

---

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

[2] Internal cycles

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

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

[5] Ke factor using Sm = [ ]

Table 10-14 Weld Overlay Usage Factor

EVALUATION TITLE: Diablo Canyon, Path9B outside

REFERENCE: min_paths(Total).txt

MATERIAL: Alloy690
TYPE: SB-166 (Ni-Cr-Fe)
UTS (ksi) = [ ] at T = [ ] E curve (psi) = [ ]
Emat (psi) = [ ] at T = [ ] E ratio = Ecurve/Emat

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

Total Fatigue Usage Factor = [ ]

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

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

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

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

[2] Internal cycles

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

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

Table 10-15 Pipe Usage Factor

EVALUATION TITLE: Diablo Canyon, Path10 outside

REFERENCE:	min_paths(M+B).txt		
MATERIAL:	SA-376		
TYPE:	TP316 (16Cr-13Ni-3Mo)		
UTS (ksi) =	[ ]	at T = [ ]	E curve (psi) = [ ]
Emat (psi) =	[ ]	at T = [ ]	E ratio = Ecurve/Emat

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

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

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

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

---

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

2 Internal cycles.

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

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

5 Ke factor using Sm = [ ]

11 RESULTS SUMMARY/CONSLUSION

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

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

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

Table 11-1 Summary of Results

Component	Material	Primary SI	Max. SI Range PL+Pb+Q			Fatigue Usage Factor		
			Calculated [ksi]	Limit [ksi]	IR	Calculated [ksi]	Limit [ksi]	IR
Nozzle	SA-508	See Section 10.1						
DM Weld	Alloy 600							
Safe End	SA-182							
Safe End to Pipe Weld	SA-213							
Pipe	SA-376							
Weld Overlay	Alloy 690							

12 SOFTWARE VERIFICATION

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

Table 12-1 ANSYS Verification Files

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

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

Table 12-2 StressRange Program v2.0 Verification Files

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

13 COMPUTER OUTPUT FILES

Table 13-1 Computer Output and Input Files

File Name	Date	Description
min_geo.mac	5/29/2007	Input file to develop geometry of the spray nozzle
min_geo.out	5/29/2007	Output file to develop geometry of the spray nozzle
min_dT.mac	5/18/2007	Input file defining nodes for temperature and thermal gradient evaluation
min_paths.out	5/30/2007	Output file contains path definition for stress component and contains the linearized stresses along the paths for all transients
min_paths_rtch.out	5/30/2007	Output file for thermal ratchet analysis contains path definition for stress component and contains the linearized stresses along the paths for all transients
Fatigue Stress Range		
min_paths(M+B).txt	5/30/2007	SI Ranges (M+B) for combination of all transients
min_paths(Total).txt	5/30/2007	SI Ranges (Total) for combination of all transients
min_paths(M+B-ThBend).txt	5/30/2007	SI Ranges (M+B) excluding thermal bending for combination of all transients
min_paths_rtch(M+B).txt	5/30/2007	SI Ranges (M+B) with pressure = 0 for combination of all transients
Design Condition		
min_DC.out	5/29/2007	Output file for stress analysis
min_DC_paths.out	5/30/2007	Output file contains stress components along the paths
Heat-up Transients		
HU-ES_tr.inp	5/17/2007	Input file contains definition of heat-up early spray transient
min_HU-ES_th.out	5/29/2007	Output file for thermal analysis
min_HU-ES_dt.out	5/29/2007	Output file contains thermal gradients
min_HU-ES_st.out	5/29/2007	Output file for the stress analysis
min_HU-ES_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
HU-LS_tr.inp	5/17/2007	Input file contains definition of heat-up late spray transient
min_HU-LS_th.out	5/29/2007	Output file for thermal analysis
min_HU-LS_dt.out	5/29/2007	Output file contains thermal gradients
min_HU-LS_st.out	5/29/2007	Output file for the stress analysis
min_HU-LS_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Cool-down Transients		
CD-ES320_tr.inp	5/17/2007	Input file contains definition of cool-down early spray transient with drop in a temperature of 320°F
min_CD-ES320_th.out	5/29/2007	Output file for thermal analysis

min_CD-ES320_dt.out	5/29/2007	Output file contains thermal gradients
min_CD-ES320_st.out	5/29/2007	Output file for the stress analysis
min_CD-ES320_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-LS320_tr.inp	5/17/2007	Input file contains definition of cool-down late spray transient with drop in a temperature of 320°F
min_CD-ES320_th.out	5/29/2007	Output file for thermal analysis
min_CD-ES320_dt.out	5/29/2007	Output file contains thermal gradients
min_CD-ES320_st.out	5/29/2007	Output file for the stress analysis
min_CD-ES320_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-ES405_tr.inp	5/17/2007	Input file contains definition of cool-down early spray transient with drop in a temperature of 405°F
min_CD-ES405_th.out	5/29/2007	Output file for thermal analysis
min_CD-ES405_dt.out	5/29/2007	Output file contains thermal gradients
min_CD-ES405_st.out	5/29/2007	Output file for the stress analysis
min_CD-ES405_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
CD-LS405_tr.inp	5/17/2007	Input file contains definition of cool-down late spray transient with drop in a temperature of 405°F
min_CD-LS405_th.out	5/29/2007	Output file for thermal analysis
min_CD-LS405_dt.out	5/29/2007	Output file contains thermal gradients
min_CD-LS405_st.out	5/29/2007	Output file for the stress analysis
min_CD-LS405_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Plant Loading & Plant Unloading Transient		
PLPU_tr.inp	5/17/2007	Input file contains definition of plant loading and unloading transient
min_PLPU_th.out	5/29/2007	Output file for thermal analysis
min_PLPU_dt.out	5/29/2007	Output file contains thermal gradients
min_PLPU_st.out	5/29/2007	Output file for the stress analysis
min_PLPU_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Step Load Decrease Transient		
SLD_tr.inp	5/17/2007	Input file contains definition of 10% step load decrease transient
min_SLD_th.out	5/29/2007	Output file for thermal analysis
min_SLD_dt.out	5/29/2007	Output file contains thermal gradients
min_SLD_st.out	5/29/2007	Output file for the stress analysis
min_SLD_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation
Step Load Increase Transient		
SLI_tr.inp	5/17/2007	Input file contains definition of 10% step load increase transient
min_SLI_th.out	5/29/2007	Output file for thermal analysis
min_SLI_dt.out	5/29/2007	Output file contains thermal gradients
min_SLI_st.out	5/29/2007	Output file for the stress analysis
min_SLI_rtch.out	5/29/2007	Output file for the thermal ratcheting calculation