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1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the core spray nozzle. Two locations will be analyzed for fatigue acceptance: the blend radius (SA508 Class II) and the safe end (SB 166 N06600). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. A revised fatigue usage will be determined for both locations, the nozzle forging and safe end, respectively. In the end, the environmental fatigue usage factors will be determined for the limiting locations.

2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the core spray nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the core spray nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL), Report [12] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [8]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges may be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, stress indices are not required, as the stresses are calculated by finite element analysis and consider applicable stress concentration factors. In addition, NB-3200 methodology accounts for the different locations within a component where stresses due to thermal, pressure or other mechanical loading are a maximum. This generally results in a net reduction of the stress ranges and consequently, in the calculated fatigue usage. Article 4 [14] methodology was originally used to evaluate the core spray nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original core spray nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more refined CUF.

For the core spray nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [11]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for all thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 8 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 9. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 9. These five step changes produce the five successive stress responses in the lower plot shown in Figure 9. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY core spray nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the two limiting locations (one in the safe end and one in the nozzle forging, representing the two materials of the nozzle assembly) using the Green's Functions developed for these two locations and 60-year projected cycle counts.

Three Structural Integrity utility programs will be used to perform the fatigue analysis. The first two calculate stresses in response to transients. The transients analyzed are those described in the thermal cycle diagrams [2] for the core spray nozzle. These transients are shown in Figure 1– Figure 6. The temperatures and pressures for these transients have been modified to account for power uprate [3]. The power uprate pressures and temperatures were used for this analysis. The last program calculates fatigue based on the stress output. The three programs are STRESS.EXE, P-V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [4] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute K_e per ASME Code, Section III requirements.
- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient definition for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.

The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE, and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., K_e parameters, S_m, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.

3.0 ANALYSIS

The transients analyzed for the core spray nozzle were developed based on the definitions in the original RPV Design Specification [10], as modified for EPU [3], as well as more recent definitions based on BWR operating experience [2] for BWR. The final transients evaluated in the stress and fatigue analyses are shown in Figure 1 thru Figure 6.

The fatigue analysis involves the preparing of input files for, and running of three programs [4]. The programs STRESS.EXE and P-V.EXE are run together through the use of a batch file. The program FATIGUE.EXE is run after processing the output from P_V.EXE.

The steps associated with this process are described in the following sub-sections.

3.1 Transient Definitions (for program STRESS.EXE)

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- Green.dat. There are 8 stress history functions obtained from References [1]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. Both of the blend radius and the safe end have two stress history functions for flow condition of 0% and 100%.
- Green.cfg is configured as described in Reference [4].
- Transnt.inp. These files are created to represent the selected transients obtained from the thermal cycle diagrams [2] and redefined by power uprate [3]. Table 1 and Table 2 contain the loading defined for each transient. Based upon the thermal cycle diagram for the RPV and the core spray nozzle, the transients are split into the following groups based upon flow rate:
    - o Transients 02, 03, 11, 14, 21-23 and 24 are run at 0% flow.
    - o Transient 30 runs at 100% flow rate per [3]. The transient of emergency shutdown is numbered as 30.

The remaining transients are not included in this analysis, as temperature changes from them are considered negligible to have impact on the results.

3.2 Peak and Valley Points of the Stress History (for program P-V.EXE)

The program P-V.exe is then run to extract the peaks and valleys from the STRESS.OUT file produced by the STRESS.EXE program. The only input required for this program is STRESS.OUT and it outputs all the peaks and valleys to P-V.OUT. Columns 2 through 5 of Table 5 (for the blend radius) and Table 6 (for the safe end) show the final peak and valley output. The pressure for column six is then filled in using the thermal cycle diagrams. Pressure and piping loads have to be added to the peak and valley points to calculate the final stress values used for fatigue analysis.

3.3 Pressure Load

The pressure stress associated with a 1000 psi internal pressure was determined in Reference [1]. These values are as follows:

Location	Membrane plus Bending Stress Intensity (psi)	Total Stress Intensity (psi)
Safe End	12,020	12,030
Blend Radius	34,970	35,860

These pressure stress values for each location were linearly scaled according to the pressure of the transient. The actual pressure for column 6 of Table 5 and Table 6 is obtained from Reference [2] and shown in Tables 1 and 2. The scaled pressure stress values are shown in columns 7 and 8 of Table 5 (for the blend radius) and Table 6 (for the safe end).

The pressure stress is combined with the peak and valley points to calculate the final stress values used for fatigue analysis.

3.4 Attached Piping Loads

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 7.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first cut (blend radius) and second cut (safe end) locations using the following equations:

For Cut I:
$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:
$$M_{xy} = \sqrt{(M_x)_1^2 + (M_y)_1^2}$$
$$F_{xy} = \sqrt{(F_x)_1^2 + (F_y)_1^2}$$

For Cut II:
$$M_{xy} = \sqrt{(M_x)_2^2 + (M_y)_2^2}$$
$$F_{xy} = \sqrt{(F_x)_2^2 + (F_y)_2^2}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, PM, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$
$$(P_M)_\theta = \frac{Pa_N}{t_N}$$
$$(P_M)_R = -P$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

or

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

Where:

L_1 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.

L_2 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.
M_{xy} = The maximum bending moment in the xy plane.
F_{yx} = The maximum shear force in the xy plane..
N_z = The normal force per inch of circumference applied to the end of the nozzle in the z direction.
q_N = The shear force per inch of circumference applied to the nozzle.
R_N = The mid-wall nozzle radius.

Because pressure was not considered in this analysis, the equations used for Cut I are valid for Cut II. In addition, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$
$$(P_M)_\theta = 0$$
$$(P_M)_R = 0$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2(\tau_M)_{z\theta}$$
$$or$$
$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}{}^2}$$

Per Reference [5], the core spray nozzle piping loads are as follows:

F_x	=	2,500	lbs	M_x	=	22,000	ft-lb	=	264,000	in-lb
F_y	=	4,600	lbs	M_y	=	7,100	ft-lb	=	85,200	in-lb
F_z	=	1,700	lbs	M_z	=	8,800	ft-lb	=	150,600	in-lb

The location of the nozzle piping loads is assumed to be at the end of the connection of the safe end and the attached pipe. Therefore, the L1 is equal to 30.817 inches and the L2 is equal to 0.303 inches. The calculations for the blend radius and safe end are shown in Table 3 and Table 4. The first cut location is the middle of Green's Function cross section for the blend radius (Node 2181) per [1], and the second cut is from Node 3719 (inside) to Node 3737 (outside). The maximum stress intensities, due to piping loads are 322.52 psi at the blend radius and 6949.94 psi at the safe end, respectively. The piping load sign is set as the same as the thermal stress sign.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F [2]. The scaled piping stress values are shown in columns 9 and 10 of Table 5 and Table 6. Columns 11 and 12 of Table 5 and Table 6 show the summation of all stresses for each thermal peak and valley stress point.

3.5 Fatigue Analysis (for program FATIGUE.EXE)

The number of cycles projected for the 60-year operating life is used for each transient, as obtained from Reference [2]. Column 13 in Table 5 and Table 6 shows the number of cycles associated with each transient.

The program FATIGUE.EXE performs the "ASME Code style" peak event pairing required to calculate a fatigue usage value. The input data for FATIGUE.CFG is as follows:

	Blend Radius (SA508 Class II)	Safe End (N06600)	Piping (Stainless Steel)
Parameters *m* and *n* for Computing K_e	2.0 & 0.2 (low alloy steel) [8]	1.7 & 0.3 [8]	1.7 & 0.3 [8]
Design Stress Intensity Values, S_m	26,700 psi [6] @ 600°F	23,300 psi [6] @ 600°F	17,000 psi [6] @ 600°F
Elastic Modulus from Applicable Fatigue Curve	30.0×10^6 psi [8]	28.3×10^6 psi [8]	28.3×10^6 psi [8]
Elastic Modulus Used in Finite Element Model (300°F)	26.7×10^6 psi [1]	29.8×10^6 psi [1]	27.0×10^6 psi [1]
The Geometric Stress Concentration Factor K_t	1.0	4.0 $^{\text{See Note}}$	1.8 [14]

Note: Conservative bounding value per ASME Code, Section NB-3600 to cover thread and weld regions.

The results of the fatigue analyses are presented in Table 7 through Table 9 for the blend radius, safe end and stainless steel piping for 60 years, respectively.

The Core Spray piping adjacent to the safe end was also analyzed because of its proximity to the maximum safe end thermal stress location. For this fatigue analysis, the stress results of the safe end were used with stainless steel material properties and a value of 1.8 was selected for K_t at the weld location, based on the maximum value given in ASME Code, Section III, table NB-3681(a)-1 [8].

The results described are contained in EXCEL files BRresults.xls and SEresults.xls, which are contained in the computer files.

4.0 FATIGUE USAGE RESULTS

The blend radius Cumulative Usage Factor (CUF) from system cycling is 0.0043 for 60 years. The safe end CUF is 0.0184 and the CUF of stainless steel piping is 0.0005 for 60 years.

5.0 ENVIRONMENTAL FATIGUE ANALYSIS

Per Reference [7], the dissolved Oxygen (DO) calculation shows the overall HWC availability is 47%. It means the pre-HWC is 53%.

The fatigue calculation will be re-performed for the nozzle base material, since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [8]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [9]. Therefore, the cladding will be neglected and EAF assessment of the nozzle base material is performed.

For the blend radius location, the environmental fatigue factors for pre-HWC and post-HWC are 11.14 and 8.82 from Table 4 of Reference [7]. It results in an EAF adjusted CUF of (11.14 x 53% + 8.82 x 47%) x 0.0043 = 0.0432 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 10.05.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are all 1.49 from Reference [13]. It results in an EAF adjusted CUF of 1.49 x 0.0184 = 0.0274 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 1.49.

For the stainless steel piping, the environmental fatigue factors for post-HWC and pre-HWC are all 8.36 from Table 4 of Reference [7]. It results in an EAF adjusted CUF of 8.36 x 0.0005 = 0.00418 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 8.36.

A Fatigue Environmental Multiplier of 1.49 for Ni-Cr-Fe was applied to the safe end fatigue usage and 8.36 for stainless steel to the piping. This results in the safe end being the limiting location for fatigue.

6.0 REFERENCES

1 SI Calculation No. VY-16Q-309, Revision 0, “Core Spray Nozzle Green’s Functions.”

2 “Reactor Thermal Cycles for 60 Years of Operation,” Attachment 1 of Entergy Design Input Record (DIR), Revision 1, EC No. 1773, Revision 0, “Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station,” 7/26/07, SI File No. VY-16Q-209.

3 GE Certified Design Specification No. 26A6019, Revision 1, “Reactor Vessel – Extended Power Uprate,” August 29, 2003, SI File No. VY-05Q-236.

4 Structural Integrity Associates Calculation (Generic) No. SW-SPVF-01Q-301, Revision 0, “STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification.”

5 VY Drawing 5920-0024, Revision 11, Sht. No. 7, “Reactor Vessel,” (GE Drawing No. 919D294), SI File No. VY-05Q-241.

6 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.

7 SI Calculation No. VY-16Q-303, Revision 0, “Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head.”

8 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.

9 NUREG/CR-6260 (INEL-95/0045), “Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components,” March 1995.

10 GE Design Specification No. 21A1115, Revision 4, “Vermont Yankee Reactor Pressure Vessel,” October 21, 1969, SI File No. VY-05Q-210.

11 Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green’s Functions," ASME PVP Conference, Chicago, 1986.

12 NUREG-1801, Revision 1, “Generic Aging Lessons Learned (GALL) Report,” U. S. Nuclear Regulatory Commission, September 2005.

13 EPRI Report No. TR-105759, “An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations,” December 1995.

14 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, Article 4, 1965 Edition with Winter 1966 Addenda.

Table 1: Blend Radius Transients [1, 2, 3]

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)	Flow Rate (GPM)
2. Design HYD Test	—	100	—	0	
				1100	
120 Cycles				50	
3. Startup	0	100		0	0
300 Cycles	16164	549	16164	1010	(0%)
	24164	549	8000	1010	
11. Loss of Feedwater	0	526		1010	0
Pumps	3	526	3	1190	(0%)
10 Cycles	13	526	10	1135	
	233	300	220	1135	
	2213	500	1980	1135	
	2393	300	180	885	
	6893	500	4500	1135	
	7313	300	420	675	
	7613	300	300	675	
	11213	400	3600	240	
	16577	549	5364	1010	
	16637	549	60	1010	
	16638	542	1	1010	
	16698	542	60	1010	
	16699	526	1	1010	
	24699	526	8000	1010	
14. SRV Blowdown	0	526		1010	0
1 Cycle	600	375	600	400	(0%)
	11580	70	10980	50	
	19580	70	8000	50	
21-23. Shutdown	0	549		1010	0
300 Cycles	6264	375	6264	50	(0%)
	6864	330	600	50	
	16224	100	9360	50	
	24224	100	8000	50	
24. Hydrostatic Test	—	100	—	50	
1 Cycle				1563	
				50	
30. Emergency Shut Down	0	549		1010	3200
1 Cycle	10	406	10	250	(100%)
	11	70	1	250	
	8011	70	8000	0	

Note:

1. Instant temperature change is 1 sec.
2. This is due to the length of the Green's Function. The transients are plotted using an 8000 second steady state increment.
3. The number of cycles for 60 years is from Reference [2].

Table 2: Safe End Transients [1, 2, 3]

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)	Flow Rate (GPM)
2. Design HYD Test	---	100	—	0	
120 Cycles				1100	
				50	
3. Startup	0	100		0	0
300 Cycles	16164	549	16164	1010	(0%)
	17164	549	1000	1010	
11. Loss of Feedwater	0	526		1010	0
Pumps	3	526	3	1190	(0%)
10 Cycles	13	526	10	1135	
	233	300	220	1135	
	2213	500	1980	1135	
	2393	300	180	885	
	6893	500	4500	1135	
	7313	300	420	675	
	7613	300	300	675	
	11213	400	3600	240	
	16577	549	5364	1010	
	16637	549	60	1010	
	16638	542	1	1010	
	16698	542	60	1010	
	16699	526	1	1010	
	17699	526	1000	1010	
14. SRV Blowdown	0	526		1010	0
1 Cycle	600	375	600	400	(0%)
	11580	70	10980	50	
	12580	70	1000	50	
21-23. Shutdown	0	549		1010	0
300 Cycles	6264	375	6264	50	(0%)
	6864	330	600	50	
	16224	100	9360	50	
	17224	100	1000	50	
12. Hydrostatic Test	---	100	—	50	
1 cycle				1563	
				50	
30. Emergency Shut Down	0	549		1010	3200
1 Cycle	10	406	10	250	(100%)
	11	70	1	250	
	1011	70	1000	0	

Note:

1. Instant temperature change is 1 sec.
2. The transients are plotted using a 1000 second steady state increment. The difference is due to the length of the Green's Function for the safe end.
3. The number of cycles for 60 years is from Reference [2].

Table 3: Maximum Piping Stress Intensity Calculations for Blend Radius

Blend Radius External Piping Loads		
Parameters		
F_x =	2.50	kips
F_y =	4.60	kips
F_Z =	1.70	kips
M_x =	264.00	in-kips
M_y =	85.20	in-kips
M_Z =	105.60	in-kips
OD=	18.87	in
ID=	11.750	in
R_N =	7.65	in
L =	30.82	in
t_N =	3.56	in
$(M_x)_2$ =	122.24	in-kips
$(M_y)_2$ =	162.24	in-kips
M_{xy} =	203.14	in-kips
F_{xy} =	5.24	kips
N_Z =	1.14	kips/in
q_N =	-0.07	kips/in
Primary Membrane Stress Intensity		
PM_Z =	0.32	ksi
τ =	-0.02	ksi
SI_{max} =	0.32	ksi
SI_{max} =	322.52	psi

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

Table 4: Maximum Piping Stress Intensity Calculations for Safe End

Safe End External Piping Loads		
Parameters		
F_x =	2.50	kips
F_y =	4.60	kips
F_Z =	1.70	kips
M_x =	264.00	in-kips
M_y =	85.20	in-kips
M_Z =	105.60	in-kips
OD=	10.82	in
ID=	9.834	in
R_N =	5.16	in
L =	0.30	in
t_N =	0.49	in
$(M_x)_1$ =	262.60	in-kips
$(M_y)_1$ =	85.96	in-kips
M_{xy} =	276.31	in-kips
F_{xy} =	5.24	kips
N_Z =	3.35	kips/in
q_N =	-0.31	kips/in
Primary Membrane Stress Intensity		
PM_Z =	6.84	ksi
τ =	-0.63	ksi
SI_{max} =	6.95	ksi
SI_{max} =	6949.94	psi

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

Table 5: Blend Radius Stress Summary

1 Transient Number	2 Time (s)	3 Total Stress (psi)	4 M+B Stress (psi)	5 Temperature F	6 Pressure (psig)	7 Total Pressure Stress (psi)	8 M+B Pressure Stress (psi)	9 Total Piping Stress (psi)	10 M+B Piping Stress (psi)	11 Total Total Stress (psi)	12 Total M+B Stress (psi)	13 Number of Cycles (60 years)
2				100	0	0	0	19	19	19	19	120
				100	1100	39446	38467	19	19	39465	38486	120
				100	50	1793	1749	19	19	1812	1768	120
3	0	23700	*12600*	100	*0*	*0*	0	*19*	*19*	23719	12619	*300*
	24164	2100	3180	549	1010	36219	35320	306	306	38625	38806	300
11	0	3209	3644	526	1010	36219	35320	291	291	39719	39255	10
	3	3209	3644	526	1190	42673	41614	291	291	46174	45550	10
	526	10458	5374	330	1135	40701	39691	166	166	51325	45231	10
	2222	5488	1664	490	1122	40235	39236	268	268	45991	41168	10
	2860	11776	7444	321	911	32668	31858	160	160	44605	39462	10
	6903	5435	3621	495	1124	40307	39306	272	272	46013	43199	10
	8012	12577	6791	390	627	22484	21926	204	204	35265	28921	10
	16640	2772	4370	542	1010	36219	35320	301	301	39292	39991	10
	16991	3389	4115	526	1010	36219	35320	291	291	39899	39726	10
	24699	3209	3644	526	1010	36219	35320	291	291	39719	39255	10
14	0	3209	3644	526	1010	36219	35320	291	291	39719	39255	1
	19580	25122	13197	70	50	1793	1749	0	0	26915	14946	1
21-23	0	2103	3161	549	1010	36219	35320	306	306	38628	38787	300
	24224	23680	12568	100	50	1793	1749	19	19	25492	14336	300
24				100	50	1793	1749	19	19	1812	1768	1
				100	1563	56049	54658	19	19	56068	54677	1
				100	50	1793	*1749*	19	19	1812	1768	1
30	0	2040	2950	549	1010	36219	35320	306	306	38565	38576	1
	8011	25700	14900	70	0	0	0	0	0	25700	14900	1

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 1.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 35,860)/1000 [1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 34,970)/1000 [1].
Column 9: Total external stress from calculation in Table 3, 322.52 x (Column 5 -70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

Table 6: Safe End Stress Summary

1	2	3	4	5	6	7	8	9	10	11	12	13
Transient Number	Time (s)	Total Stress (psi)	M+B Stress (psi)	Temperature F	Pressure (psig)	Total Pressure Stress (psi)	M+B Pressure Stress (psi)	Total Piping Stress (psi)	M+B Piping Stress (psi)	Total Total Stress (psi)	Total M+B Stress (psi)	Number of Cycles (60 years)
2				100	0	0	0	413	413	413	413	120
				100	1100	13233	13222	413	413	13646	13635	120
				100	50	602	601	413	413	1014	1014	120
3	0	661	759	100	0	0	0	413	413	1074	1172	300
	17164	9240	10700	549	1010	12150	12140	6592	6592	27982	29432	300
11	0	8802	10236	526	1010	12150	12140	6276	6276	27228	28652	10
	3	8802	10236	526	1190	14316	14304	6276	6276	29393	30815	10
	13	8802	10236	526	1135	13654	13643	6276	6276	28732	30154	10
	164	11645	11598	408	1135	13654	13643	4657	4657	29956	29898	10
	672	4808	5791	344	1135	13654	13643	3775	3775	22237	23209	10
	2374	11140	10841	361	912	10971	10962	4005	4005	26116	25808	10
	2955	4722	5577	325	916	11019	11010	3509	3509	19250	20096	10
	7054	9518	10162	441	959	11537	11527	5100	5100	26155	26789	10
	7930	4491	5276	309	637	7663	7657	3287	3287	15441	16219	10
	16709	9960	11116	526	1010	12150	12140	6276	6276	28386	29532	10
	17699	8802	10236	526	1010	12150	12140	6276	6276	27228	28652	10
14	0	8802	10236	526	1010	12150	12140	6276	6276	27228	28652	1
	152	9499	10570	497	855	10286	10277	5880	5880	25664	26727	1
	12580	91	95	70	50	602	601	0	0	693	696	1
21-23	0	9242	0	549	1010	12150	12140	6592	6592	27984	18732	300
	17224	664	0	100	50	602	601	413	413	1678	1014	300
24				100	50	602	601	413	413	1014	1014	1
				100	1563	18803	18787	413	413	19216	19200	1
				100	50	602	601	413	413	1014	1014	1
30	0	9280	10800	549	1010	12150	12140	6592	6592	28022	29532	1
	13	85600	44694	162	250	3002	3000	1260	1260	89862	48953	1
	1011	-12	-10	70	0	0	0	0	0	-12	-10	1

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 2.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 12,030)/1000.
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 12,020)/1000.
Column 9: Total external stress from calculation in Table 4, 6949.94 x (Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

Table 7: Fatigue Results for Blend Radius (60 Years)

```
      LOCATION = LOCATION NO. 2 -- BLEND RADIUS
 FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 2.0
             n =  .2
            Sm = 26700. psi
        Ecurve = 3.000E+07 psi
     Eanalysis = 2.670E+07 psi
            Kt = 1.00

   MAX      MIN    RANGE  MEM+BEND  Ke     Salt    Napplied  Nallowed     U
======== ======== ======= ======== ===== ======= ========= ========= =======
  56068.      19.  56049.   54658. 1.000  31488. 1.000E+00 1.896E+04   .0001
  51325.      19.  51306.   45212. 1.000  28824. 1.000E+01 2.501E+04   .0004
  46174.      19.  46155.   45531. 1.000  25930. 1.000E+01 3.460E+04   .0003
  46013.      19.  45994.   43180. 1.000  25839. 1.000E+01 3.498E+04   .0003
  45991.      19.  45972.   41149. 1.000  25827. 1.000E+01 3.503E+04   .0003
  44605.      19.  44586.   39443. 1.000  25048. 1.000E+01 3.848E+04   .0003
  39899.      19.  39880.   39707. 1.000  22404. 1.000E+01 5.695E+04   .0002
  39719.      19.  39700.   39236. 1.000  22303. 1.000E+01 5.824E+04   .0002
  39719.      19.  39700.   39236. 1.000  22303. 1.000E+01 5.824E+04   .0002
  39719.      19.  39700.   39236. 1.000  22303. 1.000E+00 5.824E+04   .0000
  39465.      19.  39446.   38467. 1.000  22161. 3.800E+01 6.012E+04   .0006
  39465.    1812.  37653.   36718. 1.000  21153. 8.200E+01 7.572E+04   .0011
  39292.    1812.  37480.   38223. 1.000  21056. 1.000E+01 7.747E+04   .0001
  38628.    1812.  36816.   37019. 1.000  20683. 2.800E+01 8.466E+04   .0003
  38628.    1812.  36816.   37019. 1.000  20683. 1.000E+00 8.466E+04   .0000
  38628.    1812.  36816.   37019. 1.000  20683. 1.000E+00 8.466E+04   .0000
  38628.   23719.  14909.   26168. 1.000   8376. 2.700E+02 5.366E+07   .0000
  38625.   23719.  14906.   26187. 1.000   8374. 3.000E+01 5.375E+07   .0000
  38625.   25492.  13133.   24470. 1.000   7378. 2.700E+02 3.042E+08   .0000
  38565.   25492.  13073.   24240. 1.000   7344. 1.000E+00 3.374E+08   .0000
  35265.   25492.   9773.   14585. 1.000   5490. 1.000E+01 1.000E+20   .0000
  26915.   25492.   1423.     610. 1.000    799. 1.000E+00 1.000E+20   .0000
  25700.   25492.    208.     564. 1.000    117. 1.000E+00 1.000E+20   .0000
                                                                     =======
                                            TOTAL USAGE FACTOR =     .0043
```

Table 8: Fatigue Results for Safe End (60 Years)

```
       LOCATION = LOCATION NO. 1 -- SAFE END
  FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
              m = 1.7
              n =  .3
             Sm = 23300. psi
         Ecurve = 2.830E+07 psi
      Eanalysis = 2.980E+07 psi
             Kt = 4.00

   MAX      MIN     RANGE  MEM+BEND   Ke    Salt    Napplied  Nallowed     U
======== ======== ======= ======== ===== ======= ========= ========= =======
  89862.     -12.  89874.   48963. 1.000 112423. 1.000E+00 1.213E+03  .0008
  29956.     413.  29543.   29485. 1.000  56029. 1.000E+01 1.910E+04  .0005
  29393.     413.  28980.   30402. 1.000  57068. 1.000E+01 1.746E+04  .0006
  28732.     413.  28319.   29741. 1.000  55813. 1.000E+01 1.946E+04  .0005
  28386.     413.  27973.   29119. 1.000  54762. 1.000E+01 2.140E+04  .0005
  28022.     413.  27609.   29119. 1.000  54590. 1.000E+00 2.174E+04  .0000
  27984.     413.  27571.   18319. 1.000  39187. 7.900E+01 1.244E+05  .0006
  27984.     693.  27291.   18036. 1.000  38651. 1.000E+00 1.341E+05  .0000
  27984.    1014.  26970.   17718. 1.000  38045. 1.200E+02 1.460E+05  .0008
  27984.    1014.  26970.   17718. 1.000  38045. 1.000E+00 1.460E+05  .0000
  27984.    1014.  26970.   17718. 1.000  38045. 1.000E+00 1.460E+05  .0000
  27984.    1074.  26910.   17560. 1.000  37792. 9.800E+01 1.514E+05  .0006
  27982.    1074.  26908.   28260. 1.000  53033. 2.020E+02 2.517E+04  .0080
  27982.    1678.  26304.   28418. 1.000  52971. 9.800E+01 2.532E+04  .0039
  27228.    1678.  25550.   27638. 1.000  51502. 1.000E+01 2.919E+04  .0003
  27228.    1678.  25550.   27638. 1.000  51502. 1.000E+01 2.919E+04  .0003
  27228.    1678.  25550.   27638. 1.000  51502. 1.000E+00 2.919E+04  .0000
  26155.    1678.  24477.   25775. 1.000  48339. 1.000E+01 4.021E+04  .0002
  26116.    1678.  24438.   24794. 1.000  46923. 1.000E+01 4.673E+04  .0002
  25664.    1678.  23986.   25713. 1.000  48017. 1.000E+00 4.159E+04  .0000
  22237.    1678.  20559.   22195. 1.000  41379. 1.000E+01 9.257E+04  .0001
  19250.    1678.  17572.   19082. 1.000  35526. 1.000E+01 2.135E+05  .0000
  19216.    1678.  17538.   18186. 1.000  34234. 1.000E+00 2.691E+05  .0000
  15441.    1678.  13763.   15205. 1.000  28195. 1.000E+01 1.001E+06  .0000
  13646.    1678.  11968.   12621. 1.000  23661. 1.200E+02 1.772E+06  .0001
                                                                    =======
                                            TOTAL USAGE FACTOR =     .0184
```

Table 9: Fatigue Results for Stainless Steel Piping (60 Years)

```
       LOCATION = LOCATION NO. 1 -- SS Piping
  FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
              m = 1.7
              n =  .3
             Sm = 17000. psi
         Ecurve = 2.830E+07 psi
      Eanalysis = 2.700E+07 psi
             Kt = 1.80

   MAX       MIN     RANGE   MEM+BEND   Ke     Salt    Napplied  Nallowed     U
======== ======== ======= ======== ===== ======= ========= ========= =======
  89862.     -12.  89874.    48963. 1.000  67629. 1.000E+00 8.006E+03   .0001
  29956.     413.  29543.    29485. 1.000  27845. 1.000E+01 1.042E+06   .0000
  29393.     413.  28980.    30402. 1.000  27934. 1.000E+01 1.031E+06   .0000
  28732.     413.  28319.    29741. 1.000  27310. 1.000E+01 1.110E+06   .0000
  28386.     413.  27973.    29119. 1.000  26868. 1.000E+01 1.171E+06   .0000
  28022.     413.  27609.    29119. 1.000  26678. 1.000E+00 1.198E+06   .0000
  27984.     413.  27571.    18319. 1.000  22130. 7.900E+01 2.272E+06   .0000
  27984.     693.  27291.    18036. 1.000  21864. 1.000E+00 2.392E+06   .0000
  27984.    1014.  26970.    17718. 1.000  21563. 1.200E+02 2.539E+06   .0000
  27984.    1014.  26970.    17718. 1.000  21563. 1.000E+00 2.539E+06   .0000
  27984.    1014.  26970.    17718. 1.000  21563. 1.000E+00 2.539E+06   .0000
  27984.    1074.  26910.    17560. 1.000  21465. 9.800E+01 2.588E+06   .0000
  27982.    1074.  26908.    28260. 1.000  25950. 2.020E+02 1.311E+06   .0002
  27982.    1678.  26304.    28418. 1.000  25700. 9.800E+01 1.354E+06   .0001
  27228.    1678.  25550.    27638. 1.000  24978. 1.000E+01 1.485E+06   .0000
  27228.    1678.  25550.    27638. 1.000  24978. 1.000E+01 1.485E+06   .0000
  27228.    1678.  25550.    27638. 1.000  24978. 1.000E+00 1.485E+06   .0000
  26155.    1678.  24477.    25775. 1.000  23634. 1.000E+01 1.779E+06   .0000
  26116.    1678.  24438.    24794. 1.000  23202. 1.000E+01 1.889E+06   .0000
  25664.    1678.  23986.    25713. 1.000  23351. 1.000E+00 1.850E+06   .0000
  22237.    1678.  20559.    22195. 1.000  20080. 1.000E+01 3.442E+06   .0000
  19250.    1678.  17572.    19082. 1.000  17209. 1.000E+01 7.481E+06   .0000
  19216.    1678.  17538.    18186. 1.000  16816. 1.000E+00 8.600E+06   .0000
  15441.    1678.  13763.    15205. 1.000  13588. 1.000E+01 1.000E+20   .0000
  13646.    1678.  11968.    12621. 1.000  11564. 1.200E+02 1.000E+20   .0000
                                                                      =======
                                            TOTAL USAGE FACTOR =    .0005
```

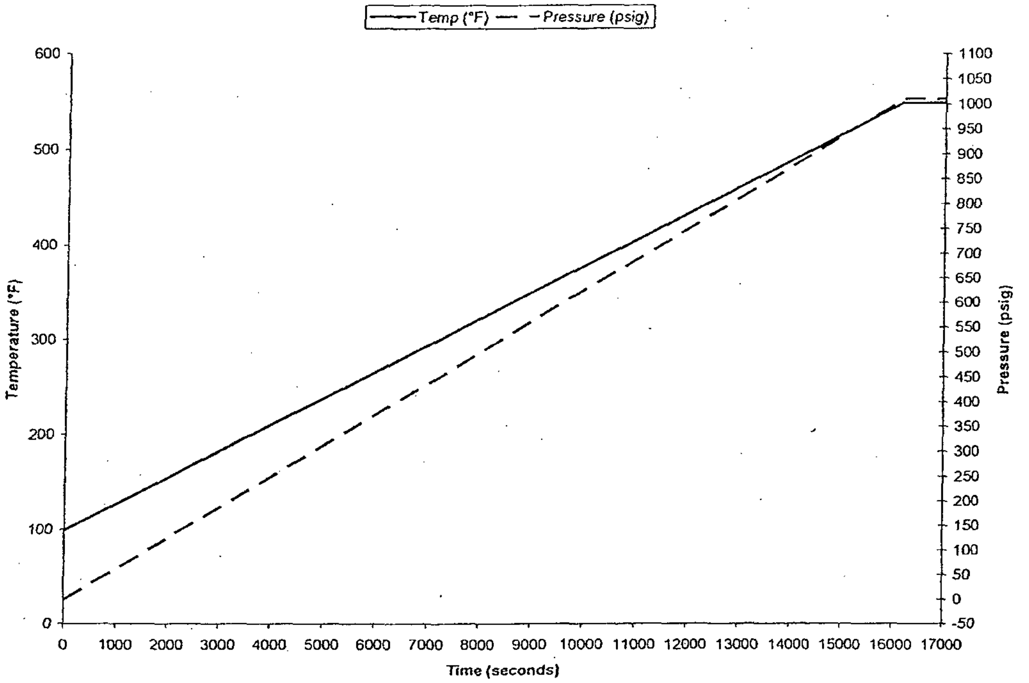

Figure 1: Transient 03: Start Up

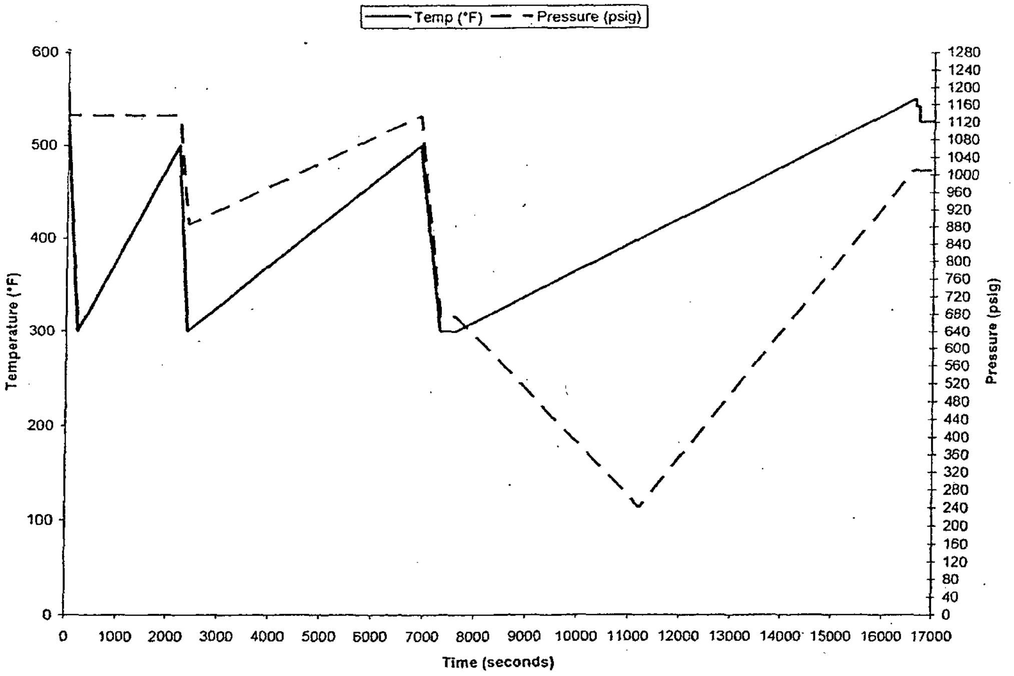

Figure 2: Transient 11: Loss of Feedwater Pumps, Isolation Valves Close

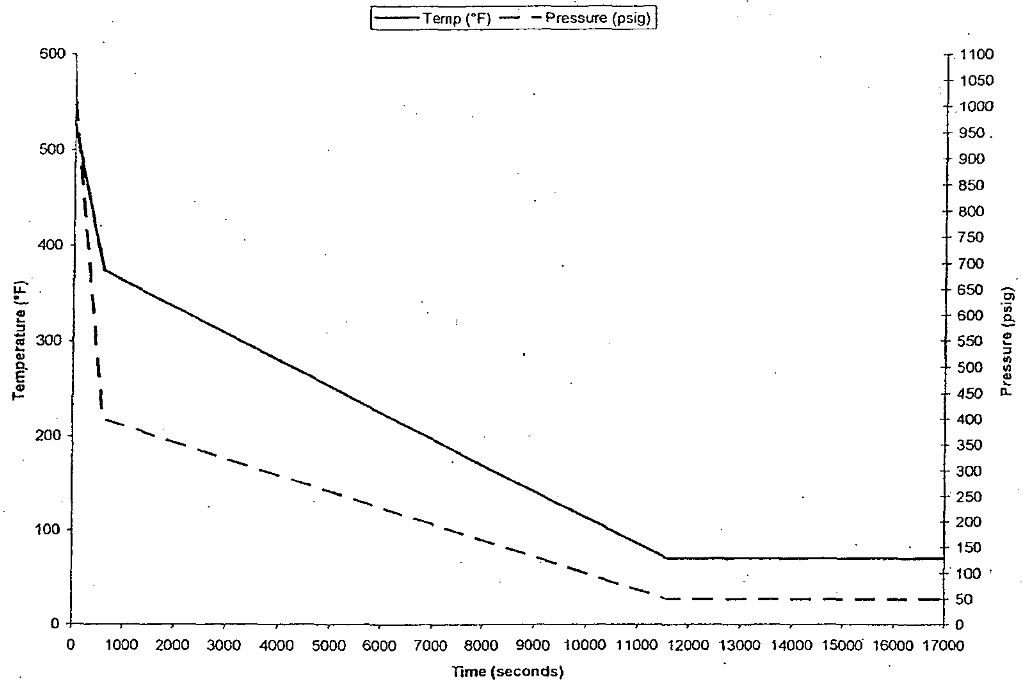

Figure 3: Transient 14: Single Relief of Safety Valve Blow Down

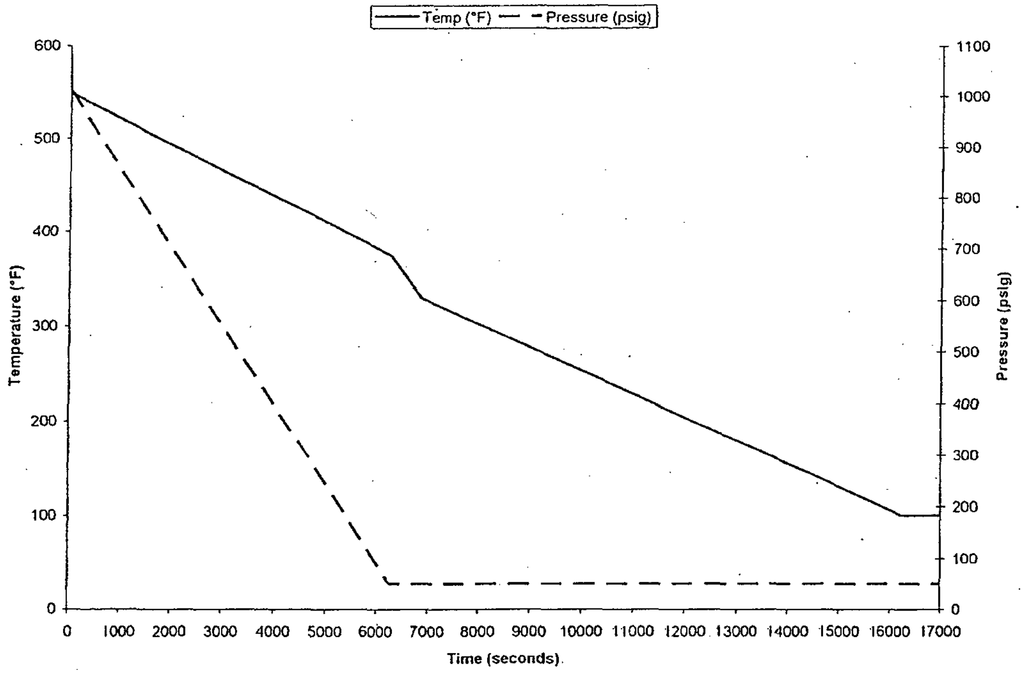

Figure 4: Transient 21-23: Shut Down Vessel Flooding

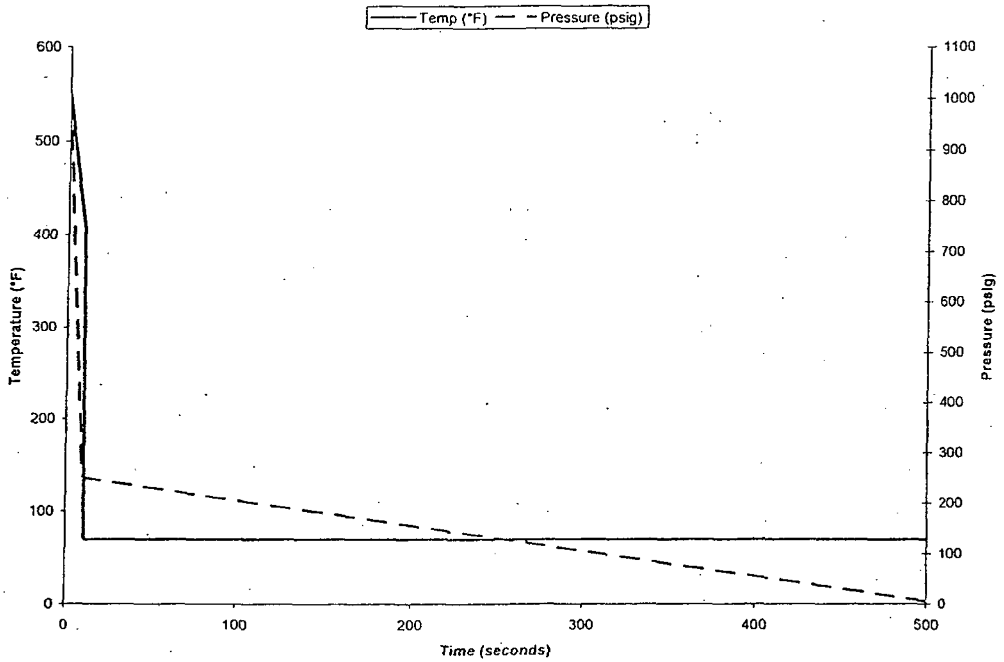

Figure 5: Transient 30: Emergency Shut Down 100% Flow (Safe End)

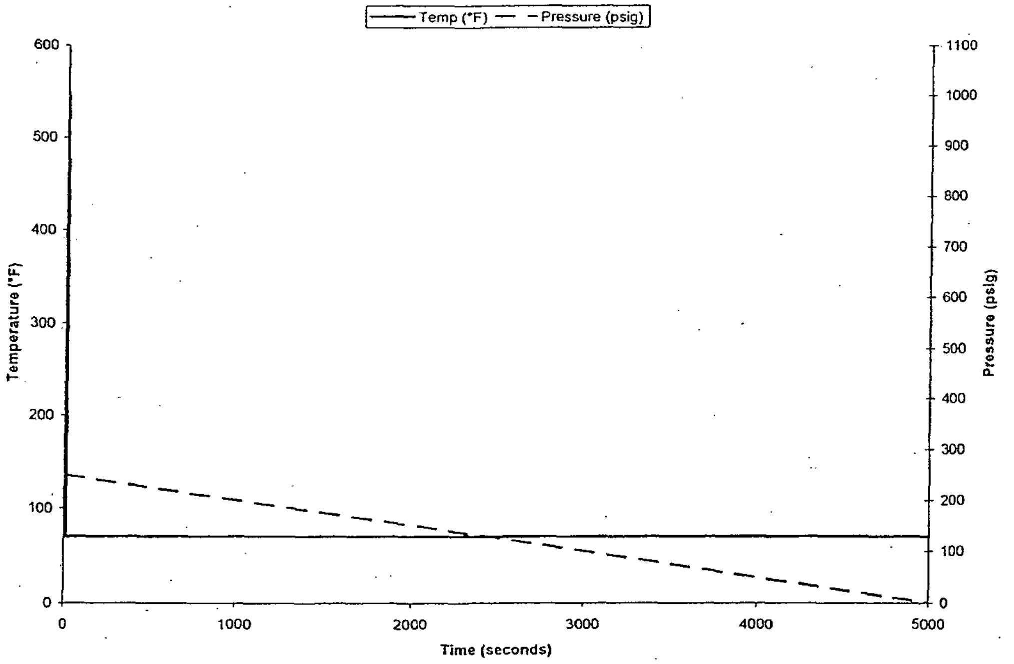

Figure 6: Transient 30: Emergency Shut Down 100% Flow (Blend Radius)

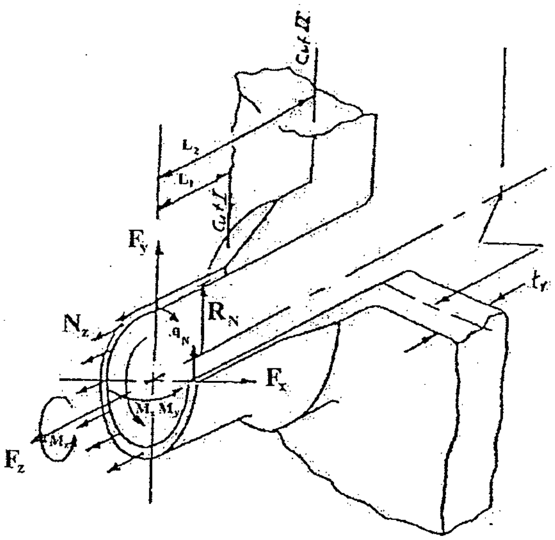

Figure 7: External Forces and Moments on the Core Spray Nozzle

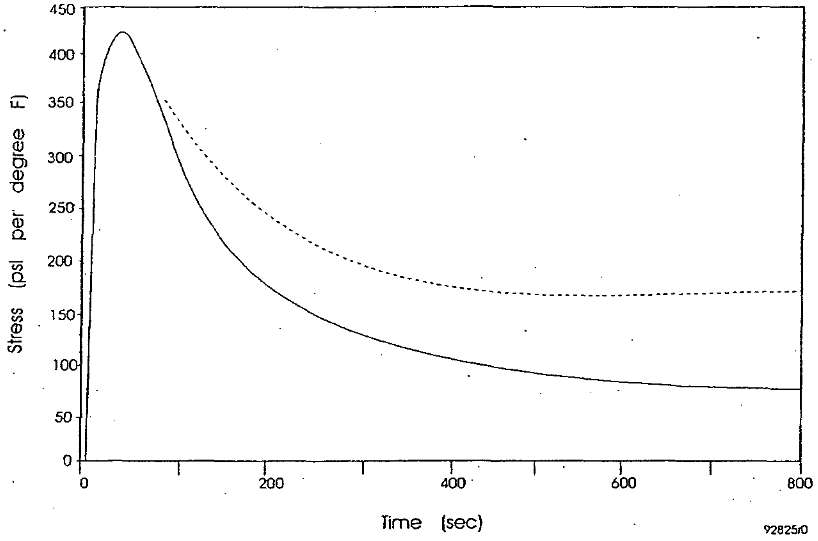

Figure 8: Typical Green's Functions for Thermal Transient Stress

Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

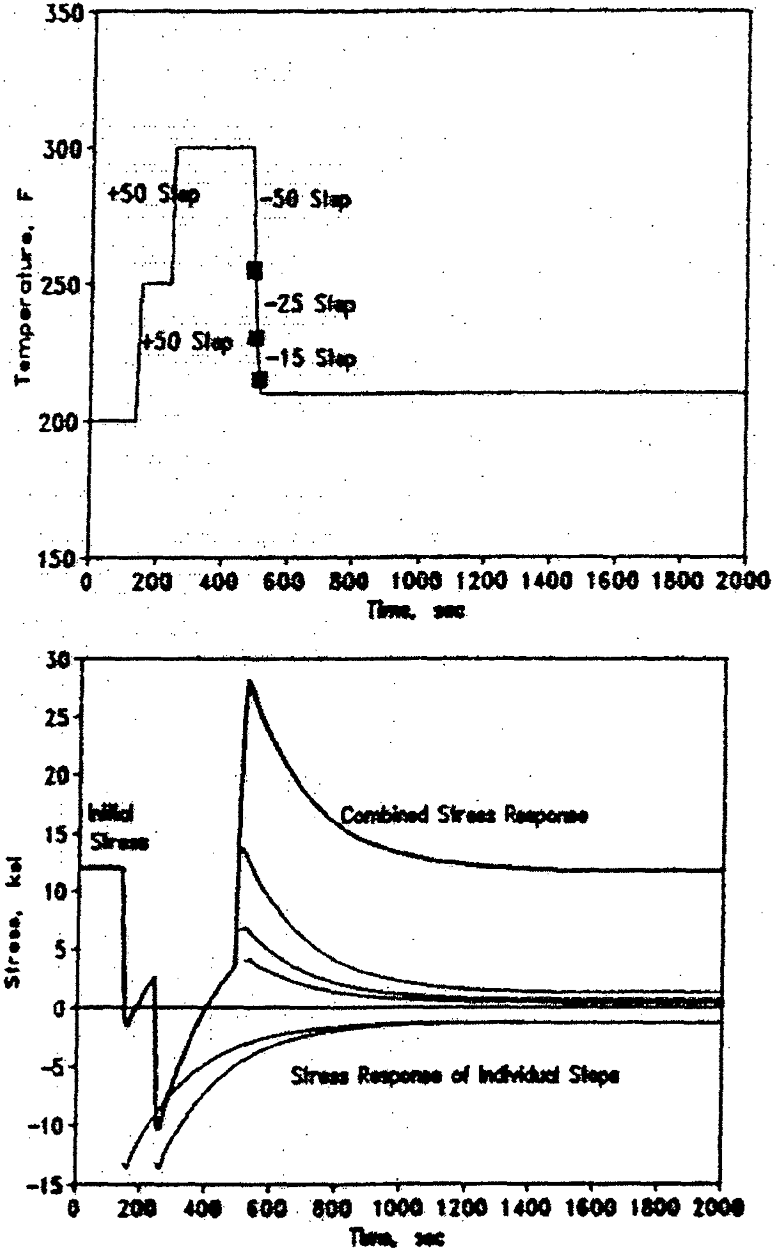

Figure 9: Typical Stress Response Using Green's Functions

APPENDIX A

INPUT AND OUTPUT FILES

Input Files

File Name	Description
TRANSNT_03.INP	Text file describing transient 03 for STRESS.EXE
TRANSNT_11.INP	Text file describing transient 11 for STRESS.EXE
TRANSNT_14.INP	Text file describing transient 14 for STRESS.EXE
TRANSNT_21_22_23.INP	Text file describing transients 21-23 for STRESS.EXE
TRANSNT_30.INP	Text file describing transient 30 for STRESS.EXE

Output Files

File Name	Description
P-V_03.OUT	Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 03
P-V_11.OUT	Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 11
P-V_14.OUT	Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 14
P-V_21_22_23.OUT	Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transients 21-23
P-V_30.OUT	Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 30