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1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the feedwater nozzle. Two locations will be analyzed for fatigue acceptance: the safe end (SA508 Class 1) and the blend radius (SA508 Class 2). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. A revised cumulative fatigue factor (CUF) 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 both locations.

2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the feedwater 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 feedwater 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 [11] 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 [10]. 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 [12] methodology was originally used to evaluate the feedwater 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 feedwater nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more accurate CUF.

For the feedwater 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 [2]. 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 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 1 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 2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 2. These five step changes produce the five successive stress responses in the second plot shown in Figure 2. 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 reactor feedwater 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 thee three feedwater flow conditions 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 [3] for the feedwater nozzle. These transients are shown in Figures 4 – 20. The temperatures and pressures for these transients have been modified to account for power uprate [4]. 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 [5] 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 history 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 fatigue analysis involves the preparing of input files for, and running of three programs verified and described in Reference [5]. 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 12 stress history functions obtained from Reference [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 each of the following flow conditions; 100%, 40%, and 25% flow.
- Green.cfg is configured as described in Reference [5].
- Transnt.inp. These files are created to represent the transients shown on the thermal cycle diagrams and redefined by power uprate. Note that transients 12, 13, and 15 are nearly identical on the thermal cycle diagram [3] and the results from running transient 12 will be used for all three transients. Transient 16, 17 and 18 will not be considered since there is no temperature change. Tables 1 and 2 show the thermal history used to represent each transient. Based upon the thermal cycle diagram for the feedwater nozzle [3], the transients are split into the following groups based upon flow rate:
    - Transients 3, 20, 20A, and 21-23 are run at 25% flow. Although Reference [3] shows 15% flow rate, it is conservative to use 25% flow rate for these transients. Transient 20, Hot Standby, is split up into two parts. The first portion is "Heatup portion" and the second portion is "Feedwater Injection portion" that are defined from Reference [3].
    - Transient 11 is run at 40% flow. Transient 11 starts off and ends at 100% flow.
    - Transients 5, 6, 9, 10, and 19 are run at 100% flow.
    - Transient 4 is run at 100% flow only to obtain the last stress point. The remainder of the stress points for transient 4 is obtained from the 25% flow stress results. The results are pulled from the two flow case results based upon the flow rates defined in the thermal cycle diagram [3].
    - Transients 12, 13, 14 and 15 were run at 100% flow. Heat transfer coefficients were not re-calculated for the 1 minute intervals each of these transients is at 110% flow. The effect of this small flow rate increase for such a relatively short duration should be minor.
    - Transients 1, 2, 24, and 25 are set as no thermal stress due to very small temperature changes (70°F to 100°F) at these transients.

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 Tables 4 (for the blend radius) and 5 (for the safe end) show the final peak and valley output. The pressure for column 6 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:

Pressure stress for the safe end:

- 8693 psi membrane plus bending stress intensity.
- 8891 psi total linearized stress intensity.

Pressure stress for the blend radius:

- 36653 psi membrane plus bending stress intensity.
- 37733 psi total linearized stress intensity.

These pressure stress values for each location were linearly scaled with pressure. The actual pressure for column 6 of Tables 4 and 5 is obtained from Tables 1 and 2. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4 and 5.

The pressure stress is combined with the thermal and piping loads 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 3.

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 and second cut 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, P_M, 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

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

Because pressure was considered separately in this analysis, the equations used for Cut I are valid for Cut II.

where: L_1 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.
L_2 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.
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.

Since the pressure was considered separately in this analysis, 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 [6], the feedwater nozzle piping loads are as follows:

F_x = 3,000 lbs	M_x = 28,000 ft-lb = 336,000 in-lb
F_y = 15,000 lbs	M_y = 13,000 ft-lb = 156,000 in-lb
F_z = 3,200 lbs	M_z = 40,000 ft-lb = 480,000 in-lb

The loads are applied at the connection of the piping and safe end. Therefore, the L_1 is equal to 12.0871 inches and the L_2 is equal to 27.572 inches. The calculations for the safe end and blend radius are shown in Table 3. The first cut location is the same as the Green's Function cross section per [1] at the safe end, and the second cut is from Node 645 (outside) to Node 501 (inside). The maximum stress intensities due to piping loads are 5707.97 psi at the safe end and 265.47 psi at the blend radius, 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. The scaled piping stress values are shown in columns 9 and 10 of Tables 4 and 5. Columns 11 and 12 of Tables 4 and 5 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 [3]:

Column 13 in Tables 4 and 5 shows the number of cycles associated with each transient. The number of cycles for 60 years was obtained from Reference [3].

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	Safe End
Parameters *m* and *n* for Computing K_e	2.0 & 0.2 (low alloy steel) [10]	3.0 & 0.2 (carbon steel) [10]
Design Stress Intensity Values, S_m	26700 psi [8] @ 600°F	17800 psi [8] @ 600°F
Elastic Modulus from Applicable Fatigue Curve	$30.0x10^6$ psi [10]	$30.0x10^6$ psi [10]
Elastic Modulus Used in Finite Element Model	$26.7x10^6$ psi	$28.1x10^6$ psi
The Geometric Stress Concentration Factor K_t	1.0	1.34 [7, page 35 of S4]

The results of the fatigue analyses are presented in Tables 6 and 7 for the blend radius and safe end for 60 years, respectively.

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 0.0636 for 60 years. The safe end CUF is 0.1471 for 60 years.

5.0 ENVIRONMENTAL FATIGUE ANALYSIS

In the response to NRC request for additional information (RAI) 4.3-H-02, VYNPS states that they have conservatively assumed that fatigue cracks may be present in the clad. VYNPS manages this cracking by performing periodic inspections that were implemented in response to Generic Letters 80-095 and

81-11, and NUREG-0619. The inspection frequency is based on the calculated fatigue crack growth of a postulated flaw in the nozzle inner blend radius. The VYNPS fatigue crack growth calculation uses methods in compliance with GE BWR Owners Group Topical Report "Alternate BWR Feedwater Nozzle Inspection Requirements", GE-NE-523-A71-0594, Revision 1, August 1999 and the associated NRC Final Safety Evaluation (TAC No. MA6787) dated March 10, 2000. The NRC has reviewed and approved this approach to handling FW nozzle inner blend radius cracking (Letter D.H. Dorman (USNRC) to D.A. Reid (VYNPC), Subject: Evaluation of Request for Relief from NUREG-0619 for VYNPS dated 2/6/95, (TAC No. M88803)).

The analysis performed for the feedwater nozzle calculated fatigue in the blend radius base metal, not the clad. This is consistent with the VYNPS position stated in the response to RAI 4.3-H-02, and is also consistent with ASME Code methodology since cladding is structurally neglected in fatigue analyses, per ASME Code, Section III, NB-3122.3.

Per Reference [9], the dissolved Oxygen (DO) calculation shows the overall HWC availability is 47%. This means the time ratio under NWC (pre-HWC) is 53%.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are all 1.74 from Table 3 of Reference [9]. It results in an EAF adjusted CUF of 1.74 x 0.1471 = 0.2560 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 1.74.

For the blend radius location, the environmental fatigue factors for post-HWC and pre-HWC are 11.14 and 8.82 from Table 4 of Reference [9]. These results in an EAF adjusted CUF of (11.14 x 53% + 8.82 x 47%) x 0.0636 = 0.6392 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 10.0496.

6.0 REFERENCES

1. SI Calculation No. VY-16Q-301, Revision 0, "Feedwater Nozzle Stress History Development for Green Functions."
2. 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.
3. Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
4. GE Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," SI File No. VY-05Q-236.
5. Structural Integrity Associates Calculation (Generic) No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."
6. GE Drawing No. 919D294, Revision 11, Sht. No. 7, "Reactor Vessel," SI File No. VY-05Q-241.
7. Chicago Bridge & Iron Company Contractor 9-6201, Revision 2, "Section S4, Stress Analysis Feedwater Nozzle Vermont Yankee Reactor Vessel," SI File No. VY-05Q-238.

8. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
9. SI Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head."
10. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.
11. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.
12. 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

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
1. Bolt-up	0	70		0
123 Cycles	10	70	10	0
2. Design	0	70		0
HYD Test	1080	100	1080	0
120 Cycles	1680	100	600	1100
	5280	100	3600	1100
	5880	100	600	50
	10880	100	5000	50
3. Startup	0	100		50
300 Cycles	16164	549	16164	1010
LF_25	21164	549	5000	1010
4. Turbine Roll	0	549		1010
and Increased to	1	100	1	1010
Rated	1801	100	1800	1010
Power	1802	260	1	1010
300 cycles	3602	392	1800	1010
LF_25, HF_100	8602	392	5000	1010
5. Daily	0	392		1010
Reduction	900	310	900	1010
75% Power	2700	310	1800	1010
10,000 Cycles	3600	392	900	1010
HF_100	8600	392	5000	1010
6. Weekly Reduct	0	392		1010
50% Power	1800	280	1800	1010
2,000 Cycles	3600	280	1800	1010
HF_100	5400	392	1800	1010
	10400	392	5000	1010
9. Turbine	0	392		1010
Trip at 25%	1800	265	1800	1010
Power	1980	265	180	1010
10 Cycles	2340	90	360	1010
HF_100	2520	90	180	1010
	3420	265	900	1010
	3600	265	180	1010
	5400	392	1800	1010
	10400	392	5000	1010
10. FW Heater	0	392		1010
Bypass	90	265	90	1010
70 Cycles	1890	265	1800	1010
HF_100	2070	392	180	1010
	7070	392	5000	1010
11. Loss of	0	392		1010
FW Pumps	1	565	1	1010
10 Cycles	3.5	565	2.5	1190
MF_40, HF_100	4.5	50	1	1185
	13.5	50	9	1135
	184.5	50	171	1135
	1564.5	440	1380	1135
	1565.5	565	1	1135
	2165.5	565	600	1135
	2166.5	50	1	1135
	2346.5	50	180	885
	5406.5	440	3060	1055
	5407.5	565	1	1055
	6727.5	565	1320	1135
	6728.5	50	1	1135
	7148.5	50	420	675
	7448.5	300	300	675
	11048.5	400	3600	232
	16411.5	549	5363	885
	16412.5	549	1	1010
	18212.5	549	1800	1010
	18213.5	100	1	1010
	20013.5	100	1800	1010
	20014.5	260	1	1010
	21814.5	392	1800	1010
	26814.5	392	5000	1010
12. Turbine	0	392		1010
Generator Trip	10	392	*10*	1135/1375(2)
60 Cycles	15	392	*5*	1135/1375(2)
13. Reactor	30	392	15	940
Overpressure	90	275	60	940
1 Cycles	990	100	900	940
15. Other	2790	100	1800	940
SCRAMs	2791	260	1	940
228 cycles	3210	291	419	1010
HF_100	4591	392	1381	1010
	9591	392	5000	1010
14. SRV	0	392		1010
Blowdown	60	275	60	885
1 Cycles	960	100	900	50
HF_100	5960	100	5000	50
19. Reduction to 0%	0	392		1010
Power 300 Cycles	1800	265	1800	1010
HF_100	6800	265	5000	1010
20. Hot Standby	0	265		1010
(Heatup Portion)	1	440	1	1010
300 Cycles	3925	549	3924	1010
LF_25	8925	549	5000	1010
20A. Hot Standby	0	549		1010
(FW Injection Portion)	1	100	1	1010
300 Cycles	181	100	180	1010
LF_25	241	290	60	1010
	451	549	210	1010
	5451	549	5000	1010
21-23. Shutdown	0	549		1010
300 Cycles	6264	375	6264	50
LF_25	6864	330	600	50
	15144	100	8280	50
	20144	100	5000	50
24. Hydrostatic	0	100		50
Test	600	100	600	1563
1 Cycles	1200	100	600	1563
	1800	100	600	50
	2400	100	600	50
25. Unbolt	0	100		0
123 Cycles	1080	70	1080	0
	6080	70	5000	0

Note: 1. The indicated time or pressure was assumed.
2. 1375 psi is for Transient 13 only.

Table 2: Safe End Transient

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
1. Bolt-up	0	70		0
123 Cycles	10	70	10	0
2. Design	0	70		0
HYD Test	1080	100	1080	0
120 Cycles	1680	100	600	1100
	5280	100	3600	1100
	5880	100	600	50
	6380	100	500	50
3. Startup	0	100		50
300 Cycles	16164	549	16164	1010
LF_25	16664	549	500	1010
4. Turbine Roll	0	549		1010
and Increased to	1	100	1	1010
Rated	1801	100	1800	1010
Power	1802	260	1	1010
300 cycles	3602	392	1800	1010
LF_25, HF_100	4102	392	500	1010
5. Daily	0	392		1010
Reduction	900	310	900	1010
75% Power	2700	310	1800	1010
10,000 Cycles	3600	392	900	1010
HF_100	4100	392	500	1010
6. Weekly Reduct	0	392		1010
50% Power	1800	280	1800	1010
2,000 Cycles	3600	280	1800	1010
HF_100	5400	392	1800	1010
	5900	392	500	1010
9. Turbine	0	392		1010
Trip at 25%	1800	265	1800	1010
Power	1980	265	180	1010
10 Cycles	2340	90	360	1010
HF_100	2520	90	180	1010
	3420	265	900	1010
	3600	265	180	1010
	5400	392	1800	1010
	5900	392	500	1010
10. FW Heater	0	392		1010
Bypass	90	265	90	1010
70 Cycles	1890	265	1800	1010
HF_100	2070	392	180	1010
	2570	392	500	1010
11. Loss of	0	392		1010
FW Pumps	1	565	1	1010
10 Cycles	3.5	565	2.5	1190
MF_40, HF_100	4.5	50	1	1185
	13.5	50	9	1135
	184.5	50	171	1135
	1564.5	440	1380	1135
	1565.5	565	1	1135
	2165.5	565	600	1135
	2166.5	50	1	1135
	2346.5	50	180	885
	5406.5	440	3060	1055
	5407.5	565	1	1055
	6727.5	565	1320	1135
	6728.5	50	1	1135
	7148.5	50	420	675
	7448.5	300	300	675
	11048.5	400	3600	232
	16411.5	549	5363	885
	16412.5	549	1	1010
	18212.5	549	1800	1010
	18213.5	100	1	1010
	20013.5	100	1800	1010
	20014.5	260	1	1010
	21814.5	392	1800	1010
	22314.5	392	500	1010
12. Turbine	0	392		1010
Generator Trip	10	392	*10*	1135/1375(3)
60 Cycles	15	392	*5*	1135/1375(3)
13. Reactor	30	392	15	940
Overpressure	90	275	60	940
1 Cycles	990	100	900	940
15. Other	2790	100	1800	940
SCRAMs	2791	260	1	940
228 cycles	3210	291	419	1010
HF_100	4591	392	1381	1010
	5091	392	500	1010
14. SRV	0	392		1010
Blowdown	60	275	60	885
1 Cycles	960	100	900	50
HF_100	1460	100	500	50
19. Reduction to 0%	0	392		1010
Power 300 Cycles	1800	265	1800	1010
HF_100	2300	265	500	1010
20. Hot Standby	0	265		1010
(Heatup Portion)	1	440	1	1010
300 Cycles	3925	549	3924	1010
LF_25	4425	549	500	1010
20A. Hot Standby	0	549		1010
(FW Injection Portion)	1	100	1	1010
300 Cycles	181	100	180	1010
LF_25	241	290	60	1010
	451	549	210	1010
	951	549	500	1010
21-23. Shutdown	0	549		1010
300 Cycles	6264	375	6264	50
LF_25	6864	330	600	50
	15144	100	8280	50
	15644	100	500	50
24. Hydrostatic	0	100		50
Test	600	100	600	1563
1 Cycles	1200	100	600	1563
	1800	100	600	50
	2400	100	600	50
25. Unbolt	0	100		0
123 Cycles	1080	70	1080	0
	1580	70	500	0

Note: 1. These transients are the same as in Table 1 with the exception of the 500 second steady state time increment that is used. The transients in Table 1 are plotted using a 5000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend Radius.
2. The indicated time or pressure was assumed.
3. 1375 psi is for Transient 13 only.

Table 3: Maximum Piping Stress Intensity Calculations

Safe End External Piping Loads		
Parameters		
F_x =	3.00	kips
F_y =	15.00	kips
F_Z =	3.20	kips
M_x =	336.00	in-kips
M_y =	156.00	in-kips
M_Z =	480.00	in-kips
OD=	11.86	in
ID=	10.409	in
R_N =	5.57	in
L =	12.09	in
t_N =	0.72	in
$(M_x)_1$ =	154.69	in-kips
$(M_y)_1$ =	192.26	in-kips
M_{xy} =	246.77	in-kips
F_{xy} =	15.30	kips
N_Z =	2.63	kips/in
q_N =	-1.59	kips/in
Primary Membrane Stress Intensity		
PM_Z =	3.63	ksi
τ =	-2.20	ksi
SI_{max} =	5.71	ksi
SI_{max} =	5707.97	psi

Blend Radius External Piping Loads		
Parameters		
F_x =	3.00	kips
F_y =	15.00	kips
F_Z =	3.20	kips
M_x =	336.00	in-kips
M_y =	156.00	in-kips
M_Z =	480.00	in-kips
OD=	22.67	in
ID=	10.750	in
R_N =	8.35	in
L =	27.57	in
t_N =	5.96	in
$(M_x)_2$ =	-77.58	in-kips
$(M_y)_2$ =	238.72	in-kips
M_{xy} =	251.01	in-kips
F_{xy} =	15.30	kips
N_Z =	1.21	kips/in
q_N =	-0.51	kips/in
Primary Membrane Stress Intensity		
PM_Z =	0.20	ksi
τ =	-0.09	ksi
SI_{max} =	0.27	ksi
SI_{max} =	265.47	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: Blend Radius 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)
1	0	0	0	70	0	0	0	0	0	0.00	0.00	123
2	0	0	0	70	0	0	0	0	0	0.00	0.00	120
	1680	0	0	100	1100	41506.3	40318.3	15.77042	15.77042	41522.07	40334.07	120
	10880	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	120
3	0	29166	23676	100	50	1886.65	1832.65	15.77042	15.77042	31068.42	25524.42	300
	16782.8	-3577	-3138	549	1010	38110.33	37019.53	-251.801	-251.801	34281.53	33629.73	300
	21164	-3532	-3138	549	1010	38110.33	37019.53	-251.801	-251.801	34326.53	33629.73	300
4	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	1801.9	29465	22266	244.004	1010	38110.33	37019.53	91.47053	91.47053	67666.80	59377.00	300
	8602	7720	6749	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43937.80	300
5	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10000
	2229.8	13598	11941	311.002	1010	38110.33	37019.53	126.6901	126.6901	51835.02	49087.22	10000
	8600	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10000
6	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	2000
	2820.3	15742	13892	280.691	1010	38110.33	37019.53	110.7562	110.7562	53963.09	51022.29	2000
	10400	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	2000
9	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
	2524	29006	23417	118.311	1010	38110.33	37019.53	25.39616	25.39616	67141.73	60461.93	10
	10400	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
10	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	70
	1632.4	16828	14701	267.399	1010	38110.33	37019.53	103.7688	103.7688	55042.10	51824.30	70
	7070	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	70
11	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
	3.5	6620	6632	565	1190	44902.27	43617.07	260.2119	260.2119	51782.48	50509.28	10
	4.5	6190	6608	50	1185	44713.61	43433.81	10.51361	10.51361	50914.12	50052.32	10
	194.5	31720	21067	109.348	1135	42826.96	41601.16	20.68448	20.68448	74567.64	62688.84	10
	2166.3	-4761	-1859	513.483	972	36676.48	35626.72	-233.1304	-233.1304	31682.35	33534.59	10
	2362.5	31268	22070	102.255	1010	38110.33	37019.53	16.95583	16.95583	69395.29	59106.49	10
	6728.3	-4913	-3149	513.448	1010	38110.33	37019.53	-233.112	-233.112	32964.22	33637.42	10
	7149.9	32114	21472	83.333	1010	38110.33	37019.53	7.0089	7.0089	70231.34	58498.54	10
	18213.3	-3565	-3162	503.978	1010	38110.33	37019.53	-228.1338	-228.1338	34317.20	33629.40	10
	19122.6	29156	23083	100.048	1010	38110.33	37019.53	15.79565	15.79565	67282.13	60118.33	10
	26814.5	7720	6410	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43598.80	10
12	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	60
	10	7720	6752	392	1135	42826.96	41601.16	169.2692	169.2692	50716.22	48522.42	60
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	60
	2033.7	28648	25301	132.007	940	35469.02	34453.82	32.59588	32.59588	64149.62	59787.42	60
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	60
13	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
	10	7720	6752	392	1375	51882.88	50397.88	169.2692	169.2692	59772.14	57319.14	1
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	1
	2033.7	28648	25301	132.007	1010	38110.33	37019.53	32.59588	32.59588	66790.93	62353.13	1
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
14	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
	5960	28487	25650	100	50	1886.65	1832.65	15.77042	15.77042	30389.42	27498.42	1
15	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	228
	10	7720	6752	392	1135	42826.96	41601.16	169.2692	169.2692	50716.22	48522.42	228
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	228
	2033.7	28648	25301	132.007	1010	38110.33	37019.53	32.59588	32.59588	66790.93	62353.13	228
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	228
19	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	300
	6800	16752	14971	265	1010	38110.33	37019.53	102.5077	102.5077	54964.84	52093.04	300
20	0	17151	13815	265	1010	38110.33	37019.53	102.5077	102.5077	55363.84	50937.04	300
	8925	-3531	-3146	549	1010	38110.33	37019.53	-251.801	-251.801	34327.53	33621.73	300
20A	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	183	28102	12153	233	1010	38110.33	37019.53	85.68595	85.68595	66298.02	49258.22	300
	5451	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
21-23	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	20144	29168	23656	100	50	1886.65	1832.65	15.77042	15.77042	31070.42	25504.42	300
24	0	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	1
	600	0	0	100	1563	58976.68	57288.64	15.77042	15.77042	58992.45	57304.41	1
	2400	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	1
25	0	0	0	100	0	0	0	15.77042	15.77042	15.77	15.77	123
	1580	0	0	70	0	0	0	0	0	0.00	0.00	123

Table 4: Blend Radius Stress Summary (Continue)

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 37733)/1000 [Table3, 1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 36653)/1000 [Table 3, 1].
Column 9: Total external stress from calculation in Table 3, 265.47 psi*(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 5: 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)
1	0	0	0	70	0	0	0	0	0	0.00	0.00	**123**
2	0	0	0	70	0	0	0	0	0	0.00	0.00	**120**
	1680	0	0	100	1100	9780.1	9562.3	339.0875	339.0875	10119.19	9901.39	**120**
	6960	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	**120**
3	0	-170	-165	100	50	444.55	434.65	-339.0875	-339.0875	-64.54	-69.44	**300**
	153.2	-235	-212	104.256	50	444.55	434.65	-387.1927	-387.1927	-177.64	-164.54	**300**
	16328.2	2	3	549	1010	8979.91	8779.93	5414.097	5414.097	14396.01	14197.03	**300**
	16664	-1	0	549	1010	8979.91	8779.93	-5414.097	5414.097	3564.81	14194.03	**300**
4	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	**300**
	3.6	44060	30988	100	1010	8979.91	8779.93	339.0875	339.0875	53379.00	40107.02	**300**
	1804.6	-15889	-11224	260.286	1010	8979.91	8779.93	-2150.787	-2150.787	-9059.88	-4594.86	**300**
	4102	21	23	392	1010	8979.91	8779.93	3639.539	3639.539	12640.45	12442.47	**300**
5	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**10000**
	900.1	244	189	310	1010	8979.91	8779.93	2712.7	2712.7	11936.61	11681.63	**10000**
	3600	-169	-110	392	1010	8979.91	8779.93	-3639.539	-3639.539	5171.37	5030.39	**10000**
	3684.4	33	35	392	1010	8979.91	8779.93	3639.539	3639.539	12652.45	12454.47	**10000**
	4100	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**10000**
6	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**2000**
	1800.1	196	159	280	1010	8979.91	8779.93	2373.612	2373.612	11549.52	11312.54	**2000**
	5400.2	-108	-68	392	1010	8979.91	8779.93	-3639.539	-3639.539	5232.37	5072.39	**2000**
	5496.6	29	31	392	1010	8979.91	8779.93	3639.539	3639.539	12648.45	12450.47	**2000**
	5900	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**2000**
9	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**10**
	97.3	180	137	385.135	1010	8979.91	8779.93	3561.945	3561.945	12721.85	12478.87	**10**
	1884.1	63	65	265	1010	8979.91	8779.93	2204.069	2204.069	11246.98	11049.00	**10**
	2059.2	1161	859	226.597	1010	8979.91	8779.93	1770.003	1770.003	11910.91	11408.93	**10**
	3420.1	-334	-211	265	1010	8979.91	8779.93	-2204.069	-2204.069	6441.84	6364.86	**10**
	3490.2	97	98	265	1010	8979.91	8779.93	2204.069	2204.069	11280.98	11082.00	**10**
	5400.1	-126	-80	392	1010	8979.91	8779.93	-3639.539	-3639.539	5214.37	5060.39	**10**
	5470.6	31	32	392	1010	8979.91	8779.93	3639.539	3639.539	12650.45	12451.47	**10**
	5900	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**10**
10	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**70**
	77.1	2308	3188	285.461	1010	8979.91	8779.93	2435.338	2435.338	13723.25	14403.27	**70**
	169.4	-12	-13	265	1010	8979.91	8779.93	-2204.069	-2204.069	6763.84	6562.86	**70**
	1890	74	72	265	1010	8979.91	8779.93	2204.069	2204.069	11257.98	11056.00	**70**
	1968.2	-1069	-1511	322.362	1010	8979.91	8779.93	-2852.427	-2852.427	5058.48	4416.50	**70**
	2147.2	91	90	392	1010	8979.91	8779.93	3639.539	3639.539	12710.45	12509.47	**70**
	2570	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**70**
11	0	-29	-27	392	1010	8979.91	8779.93	-3639.539	-3639.539	5311.37	5113.39	**10**
	2.9	-20317	-13859	565	1147	10197.98	9970.871	-5594.944	-5594.944	-15713.97	-9483.07	**10**
	6.8	42852	29563	565	1172	10420.25	10188.2	5594.944	5594.944	58867.20	45346.14	**10**
	1567.4	-15216	-10526	565	1135	10091.29	9866.555	-5594.944	-5594.944	-10719.66	-6254.39	**10**
	2168.4	60377	41773	50	1134	10082.39	9857.862	-226.0583	-226.0583	70233.34	51404.80	**10**
	5409.4	-14924	-10329	565	1054	9371.114	9162.422	-5594.944	-5594.944	-11147.83	-6761.52	**10**
	6730.4	60377	41773	50	1133	10073.5	9849.169	-226.0583	-226.0583	70224.44	51396.11	**10**
	7243.2	-1965	-1434	128.917	675	6001.425	5867.775	-665.9339	-665.9339	3370.49	3767.84	**10**
	18215.4	52636	36417	100	1010	8979.91	8779.93	339.0875	339.0875	61955.00	45536.02	**10**
	20015.5	-24511	-16189	260.183	1010	8979.91	8779.93	-2149.623	-2149.623	-17680.71	-9558.69	**10**
	22314.5	22	23	392	937	8330.867	8145.341	3639.539	3639.539	11992.41	11807.88	**10**
12	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**60**
	10	23	22	392	1135	10091.29	9866.555	3639.539	3639.539	13753.82	13528.09	**60**
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	**60**
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	**60**
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	**60**
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**60**
13	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**1**
	10	23	22	392	1375	12225.13	11952.88	3639.539	3639.539	15887.66	15614.41	**1**
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	**1**
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	**1**
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	**1**
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**1**

Table 5: Safe End Stress Summary (continue)

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)
14	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**1**
	60	4383	3174	275	885	7868.535	7693.305	2317.098	2317.098	14568.63	13184.40	**1**
	148	420	300	258.492	803	7139.473	6980.479	2130.509	2130.509	9689.98	9410.99	**1**
	960	544	424	100	50	444.55	434.65	339.0875	339.0875	1327.64	1197.74	**1**
	1460	137	139	100	50	444.55	434.65	339.0875	339.0875	920.64	912.74	**1**
15	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**228**
	10	23	22	392	1135	10091.29	9866.555	3639.539	3639.539	13753.82	13528.09	**228**
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	**228**
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	**228**
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	**228**
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	**228**
19	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	**300**
	1800	219	177	265	1010	8979.91	8779.93	2204.069	2204.069	11402.98	11161.00	**300**
	2300	72	74	265	1010	8979.91	8779.93	2204.069	2204.069	11255.98	11058.00	**300**
20	0	-109	-105	265	1010	8979.91	8779.93	-2204.069	-2204.069	6666.84	6470.86	**300**
	4	-17288	-12189	440.106	1010	8979.91	8779.93	-4183.277	-4183.277	-12491.37	-7592.35	**300**
	4425	-2	-1	549	1010	8979.91	8779.93	-5414.097	-5414.097	3563.81	3364.83	**300**
20A	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	**300**
	4	44060	30988	100	1010	8979.91	8779.93	339.0875	339.0875	53379.00	40107.02	**300**
	241	-7461	-5525	290.247	1010	8979.91	8779.93	-2489.433	-2489.433	-970.52	765.50	**300**
	572	128	132	549	1010	8979.91	8779.93	5414.097	5414.097	14522.01	14326.03	**300**
	951	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	**300**
21-23	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	**300**
	138	62	45	545.167	989	8793.199	8597.377	5370.773	5370.773	14225.97	14013.15	**300**
	6264	-5	-20	374.97	50	444.55	434.65	-3447.05	-3447.05	-3007.50	-3032.40	**300**
	6390	104	59	366.172	50	444.55	434.65	3347.607	3347.607	3896.16	3841.26	**300**
	15644	-173	-167	100	50	444.55	434.65	-339.0875	-339.0875	-67.54	-71.44	**300**
24	0	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	**1**
	600	0	0	100	1563	13896.63	13587.16	339.0875	339.0875	14235.72	13926.25	**1**
	2400	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	**1**
25	0	0	0	100	0	0	0	339.0875	339.0875	339.09	339.09	**123**
	1580	0	0	70	0	0	0	0	0	0.00	0.00	**123**

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 8891)/1000 [Table 3, 1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 8693)/1000 [Table3, 1].
Column 9: Total external stress from calculation in Table 3, 5707.97 psi*(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: 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
======== ======== ======= ======== ===== ======= ========= ========= =======
  74568.       0.  74568.   62689. 1.000  41892. 1.000E+01 7.488E+03  .0013
  70231.       0.  70231.   58499. 1.000  39456. 1.000E+01 8.944E+03  .0011
  69395.       0.  69395.   59106. 1.000  38986. 1.000E+01 9.268E+03  .0011
  67667.       0.  67667.   59377. 1.000  38015. 9.300E+01 9.988E+03  .0093
  67667.       0.  67667.   59377. 1.000  38015. 1.200E+02 9.988E+03  .0120
  67667.       0.  67667.   59377. 1.000  38015. 8.700E+01 9.988E+03  .0087
  67282.       0.  67282.   60118. 1.000  37799. 1.000E+01 1.018E+04  .0010
  67142.       0.  67142.   60462. 1.000  37720. 1.000E+01 1.025E+04  .0010
  66791.       0.  66791.   62353. 1.000  37523. 1.000E+00 1.044E+04  .0001
  66791.       0.  66791.   62353. 1.000  37523. 1.500E+01 1.044E+04  .0014
  66791.      16.  66775.   62337. 1.000  37514. 1.230E+02 1.045E+04  .0118
  66791.    1902.  64889.   60505. 1.000  36454. 9.000E+01 1.152E+04  .0078
  66298.    1902.  64396.   47410. 1.000  36177. 3.000E+01 1.182E+04  .0025
  66298.    1902.  64396.   47410. 1.000  36177. 1.000E+00 1.182E+04  .0001
  66298.    1902.  64396.   47410. 1.000  36177. 1.000E+00 1.182E+04  .0001
  66298.   30389.  35909.   21760. 1.000  20173. 1.000E+00 9.581E+04  .0000
  66298.   31068.  35230.   23734. 1.000  19792. 2.670E+02 1.038E+05  .0026
  64150.   31068.  33081.   34263. 1.000  18585. 3.300E+01 1.303E+05  .0003
  64150.   31070.  33079.   34283. 1.000  18584. 2.700E+01 1.303E+05  .0002
  59772.   31070.  28702.   31815. 1.000  16125. 1.000E+00 2.222E+05  .0000
  58992.   31070.  27922.   31800. 1.000  15687. 1.000E+00 2.519E+05  .0000
  55364.   31070.  24293.   25433. 1.000  13648. 2.710E+02 4.757E+05  .0006
  55364.   31682.  23681.   17402. 1.000  13304. 1.000E+01 5.703E+05  .0000
  55364.   32964.  22400.   17300. 1.000  12584. 1.000E+01 9.414E+05  .0000
  55364.   34282.  21082.   17307. 1.000  11844. 9.000E+00 1.912E+06  .0000
  55042.   34282.  20761.   18195. 1.000  11663. 7.000E+01 2.231E+06  .0000
  54965.   34282.  20683.   18463. 1.000  11620. 2.210E+02 2.310E+06  .0001
  54965.   34317.  20648.   18464. 1.000  11600. 1.000E+01 2.348E+06  .0000
  54965.   34327.  20638.   18463. 1.000  11595. 6.900E+01 2.358E+06  .0000
  53963.   34327.  19637.   17393. 1.000  11032. 2.310E+02 3.757E+06  .0001
  53963.   34328.  19636.   17401. 1.000  11031. 3.000E+02 3.758E+06  .0001
  53963.   34329.  19635.   17413. 1.000  11031. 3.000E+02 3.760E+06  .0001
  53963.   34329.  19635.   17413. 1.000  11031. 3.000E+02 3.760E+06  .0001
  53963.   34329.  19635.   17413. 1.000  11031. 3.000E+02 3.760E+06  .0001
  53963.   34329.  19635.   17413. 1.000  11031. 3.000E+02 3.760E+06  .0001
  53963.   41522.  12441.   10688. 1.000   6989. 1.200E+02 1.000E+20  .0000
  53963.   43358.  10605.    9647. 1.000   5958. 6.000E+01 1.000E+20  .0000
  53963.   43358.  10605.    9647. 1.000   5958. 1.000E+00 1.000E+20  .0000
  53963.   43358.  10605.    9647. 1.000   5958. 8.800E+01 1.000E+20  .0000
  51835.   43358.   8477.    7712. 1.000   4762. 1.400E+02 1.000E+20  .0000
  51835.   46000.   5835.    5149. 1.000   3278. 3.000E+02 1.000E+20  .0000
  51835.   46000.   5835.    5146. 1.000   3278. 9.560E+03 1.000E+20  .0000
  51782.   46000.   5783.    6568. 1.000   3249. 1.000E+01 1.000E+20  .0000
```

```
      50914.    46000.    4915.     6112. 1.000   2761. 1.000E+01 1.000E+20   .0000
      50716.    46000.    4717.     4582. 1.000   2650. 6.000E+01 1.000E+20   .0000
      50716.    46000.    4717.     4582. 1.000   2650. 2.280E+02 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.320E+02 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+04 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 2.000E+03 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 2.000E+03 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 7.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 7.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 6.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 6.000E+01 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+00 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+00 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 1.000E+00 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 2.280E+02 1.000E+20   .0000
      46000.    46000.       0.        0. 1.000      0. 2.280E+02 1.000E+20   .0000
                                                                            =======
                                                    TOTAL USAGE FACTOR =    .0636
```

Table 7: Fatigue Results for Safe End (60 Years)

```
        LOCATION = LOCATION NO. 1 -- SAFE END
   FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
               m = 3.0
               n =  .2
              Sm = 17800. psi
          Ecurve = 3.000E+07 psi
       Eanalysis = 2.810E+07 psi
              Kt = 1.34

   MAX      MIN     RANGE  MEM+BEND   Ke    Salt    Napplied  Nallowed    U
======== ======== ======= ======== ===== ======= ========= ========= =======
  70233.   -17681.  87914.    60963. 1.283  74422. 1.000E+01 1.338E+03   .0075
  70224.   -15714.  85938.    60879. 1.280  72869. 1.000E+01 1.415E+03   .0071
  61955.   -12491.  74446.    53128. 1.000  49383. 1.000E+01 4.568E+03   .0022
  58867.   -12491.  71359.    52938. 1.000  47700. 1.000E+01 5.094E+03   .0020
  53379.   -12491.  65870.    47699. 1.000  43819. 2.800E+02 6.552E+03   .0427
  53379.   -11148.  64527.    46869. 1.000  42951. 1.000E+01 6.953E+03   .0014
  53379.   -10720.  64099.    46361. 1.000  42631. 1.000E+01 7.109E+03   .0014
  53379.    -9972.  63351.    58588. 1.194  53087. 6.000E+01 3.628E+03   .0165
  53379.    -9972.  63351.    58588. 1.194  53087. 1.000E+00 3.628E+03   .0003
  53379.    -9972.  63351.    58588. 1.194  53087. 2.280E+02 3.628E+03   .0628
  53379.    -9060.  62439.    44702. 1.000  41444. 1.100E+01 7.731E+03   .0014
  15888.    -9060.  24948.    20209. 1.000  16985. 1.000E+00 1.802E+05   .0000
  14569.    -9060.  23629.    17779. 1.000  15840. 1.000E+00 2.410E+05   .0000
  14522.    -9060.  23582.    18921. 1.000  16022. 2.870E+02 2.287E+05   .0013
  14522.    -3008.  17530.    17358. 1.000  12508. 1.300E+01 9.944E+05   .0000
  14396.    -3008.  17404.    17229. 1.000  12417. 2.870E+02 1.083E+06   .0003
  14396.     -971.  15367.    13432. 1.000  10641. 1.300E+01 5.165E+06   .0000
  14236.     -971.  15206.    13161. 1.000  10506. 1.000E+00 5.563E+06   .0000
  14226.     -971.  15196.    13248. 1.000  10516. 2.860E+02 5.531E+06   .0001
  14226.     -178.  14404.    14178. 1.000  10262. 1.400E+01 6.379E+06   .0000
  13849.     -178.  14026.    15036. 1.000  10216. 6.000E+01 6.547E+06   .0000
  13849.     -178.  14026.    15036. 1.000  10216. 1.000E+00 6.547E+06   .0000
  13849.     -178.  14026.    15036. 1.000  10216. 2.250E+02 6.547E+06   .0000
  13849.      -68.  13916.    14943. 1.000  10141. 3.000E+00 6.837E+06   .0000
  13754.      -68.  13821.    13600. 1.000   9846. 6.000E+01 8.117E+06   .0000
  13754.      -68.  13821.    13600. 1.000   9846. 2.280E+02 8.117E+06   .0000
  13723.      -68.  13791.    14475. 1.000   9989. 9.000E+00 7.465E+06   .0000
  13723.      -65.  13788.    14473. 1.000   9987. 6.100E+01 7.474E+06   .0000
  12722.      -65.  12786.    12548. 1.000   9103. 1.000E+01 1.729E+07   .0000
  12710.      -65.  12775.    12579. 1.000   9102. 7.000E+01 1.730E+07   .0000
  12652.      -65.  12717.    12524. 1.000   9061. 1.590E+02 1.833E+07   .0000
  12652.        0.  12652.    12454. 1.000   9014. 1.230E+02 1.959E+07   .0000
  12652.        0.  12652.    12454. 1.000   9014. 1.200E+02 1.959E+07   .0000
  12652.        0.  12652.    12454. 1.000   9014. 1.230E+02 1.959E+07   .0000
  12652.      339.  12313.    12115. 1.000   8772. 1.230E+02 2.905E+07   .0000
  12652.      784.  11869.    11681. 1.000   8456. 1.200E+02 4.952E+07   .0000
  12652.      784.  11869.    11681. 1.000   8456. 1.000E+00 4.952E+07   .0000
  12652.      784.  11869.    11681. 1.000   8456. 1.000E+00 4.952E+07   .0000
  12652.      921.  11732.    11542. 1.000   8357. 1.000E+00 5.462E+07   .0000
  12652.     1328.  11325.    11257. 1.000   8088. 1.000E+00 7.100E+07   .0000
  12652.     3370.   9282.     8687. 1.000   6531. 1.000E+01 1.000E+20   .0000
  12652.     3563.   9090.     9091. 1.000   6502. 3.000E+02 1.000E+20   .0000
  12652.     3563.   9090.     9091. 1.000   6502. 3.000E+02 1.000E+20   .0000
```

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  12652.    3563.   9090.     9091. 1.000   6502. 3.000E+02 1.000E+20   .0000
  12652.    3563.   9090.     9091. 1.000   6502. 3.000E+02 1.000E+20   .0000
  12652.    3564.   9089.     9090. 1.000   6501. 3.000E+02 1.000E+20   .0000
  12652.    3565.   9088.    -1740. 1.000   4535. 3.000E+02 1.000E+20   .0000
  12652.    3896.   8756.     8613. 1.000   6237. 3.000E+02 1.000E+20   .0000
  12652.    5058.   7594.     8038. 1.000   5513. 7.000E+01 1.000E+20   .0000
  12652.    5171.   7481.     7424. 1.000   5341. 7.048E+03 1.000E+20   .0000
  12650.    5171.   7479.     7421. 1.000   5339. 1.000E+01 1.000E+20   .0000
  12648.    5171.   7477.     7420. 1.000   5338. 2.000E+03 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 7.000E+01 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 7.000E+01 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 6.000E+01 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 6.000E+01 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 1.000E+00 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 1.000E+00 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 2.280E+02 1.000E+20   .0000
  12642.    5171.   7471.     7411. 1.000   5333. 2.280E+02 1.000E+20   .0000
  12641.    5171.   7470.     7412. 1.000   5333. 2.240E+02 1.000E+20   .0000
  12641.    5214.   7427.     7382. 1.000   5304. 1.000E+01 1.000E+20   .0000
  12641.    5232.   7409.     7370. 1.000   5293. 2.000E+03 1.000E+20   .0000
  12641.    5311.   7330.     7329. 1.000   5243. 1.000E+01 1.000E+20   .0000
  12641.    6442.   6200.     6078. 1.000   4412. 1.000E+01 1.000E+20   .0000
  12641.    6667.   5975.     5972. 1.000   4273. 3.000E+02 1.000E+20   .0000
  12641.    6764.   5878.     5880. 1.000   4205. 7.000E+01 1.000E+20   .0000
  12641.    9690.   2951.     3031. 1.000   2126. 1.000E+00 1.000E+20   .0000
  12641.   10119.   2522.     2541. 1.000   1808. 1.200E+02 1.000E+20   .0000
  12641.   11247.   1394.     1393. 1.000    997. 1.000E+01 1.000E+20   .0000
  12641.   11256.   1385.     1384. 1.000    991. 3.000E+02 1.000E+20   .0000
  12641.   11258.   1383.     1386. 1.000    990. 7.000E+01 1.000E+20   .0000
  12641.   11281.   1360.     1360. 1.000    973. 1.000E+01 1.000E+20   .0000
  12641.   11403.   1238.     1281. 1.000    894. 3.000E+02 1.000E+20   .0000
  12641.   11550.   1092.     1130. 1.000    788. 2.000E+03 1.000E+20   .0000
  12641.   11911.    731.     1034. 1.000    578. 1.000E+01 1.000E+20   .0000
  12641.   11937.    705.      761. 1.000    514. 4.555E+03 1.000E+20   .0000
  12641.   11937.    705.      761. 1.000    514. 5.445E+03 1.000E+20   .0000
  12641.   11992.    649.      635. 1.000    462. 1.000E+01 1.000E+20   .0000
  12641.   12020.    621.      610. 1.000    442. 6.000E+01 1.000E+20   .0000
  12641.   12020.    621.      610. 1.000    442. 1.000E+00 1.000E+20   .0000
  12641.   12020.    621.      610. 1.000    442. 2.280E+02 1.000E+20   .0000
  12641.   12640.      1.        0. 1.000      1. 3.000E+02 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 3.956E+03 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 2.000E+03 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 2.000E+03 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 1.000E+01 1.000E+20   .0000
  12641.   12641.      0.        0. 1.000      0. 1.000E+00 1.000E+20   .0000
                                                                    =======
                                                TOTAL USAGE FACTOR =   .1471
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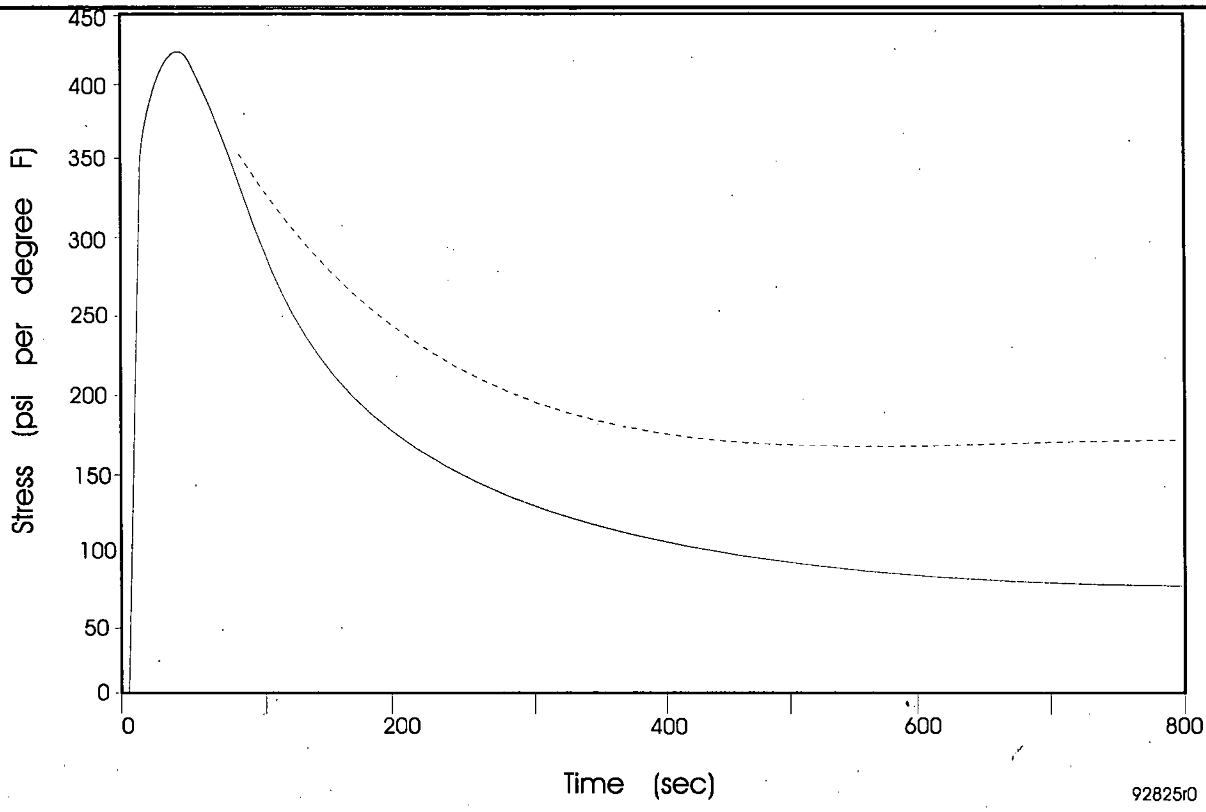


Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

Figure 1: Typical Green's Functions for Thermal Transient Stress

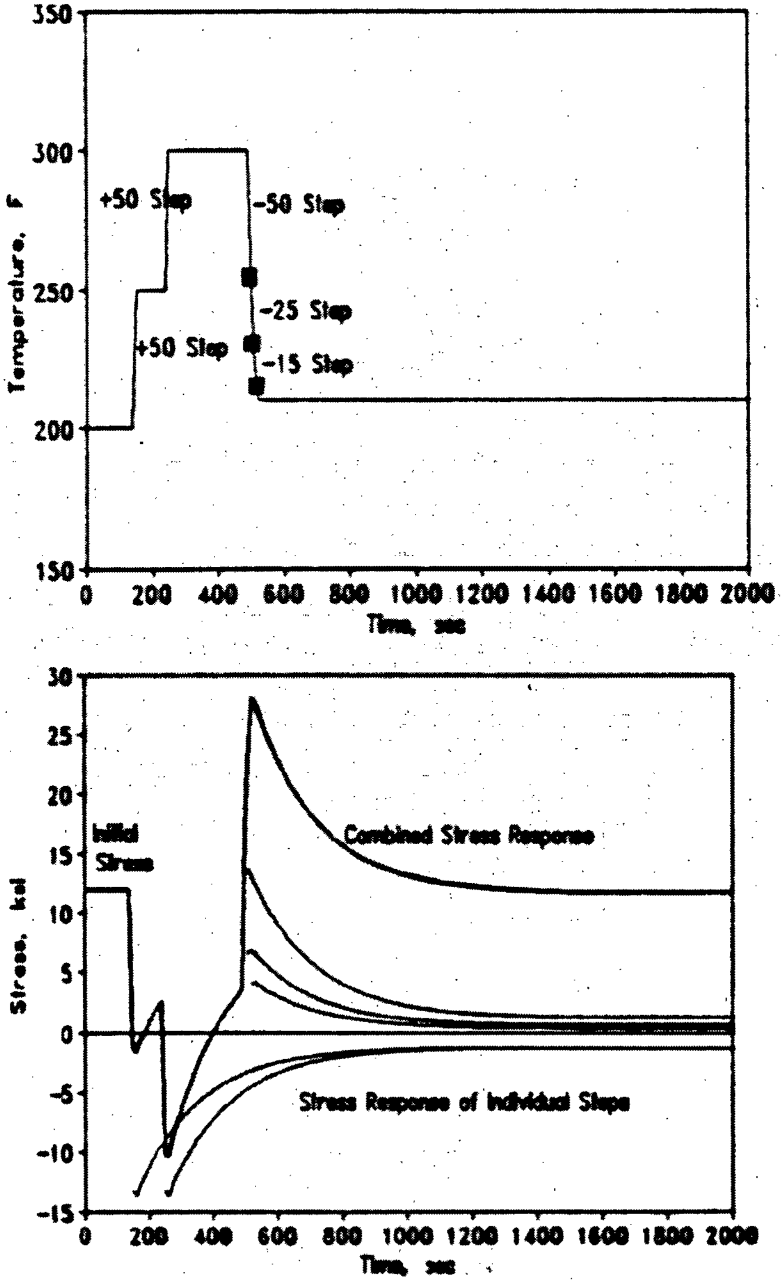


Figure 2: Typical Stress Response Using Green's Functions

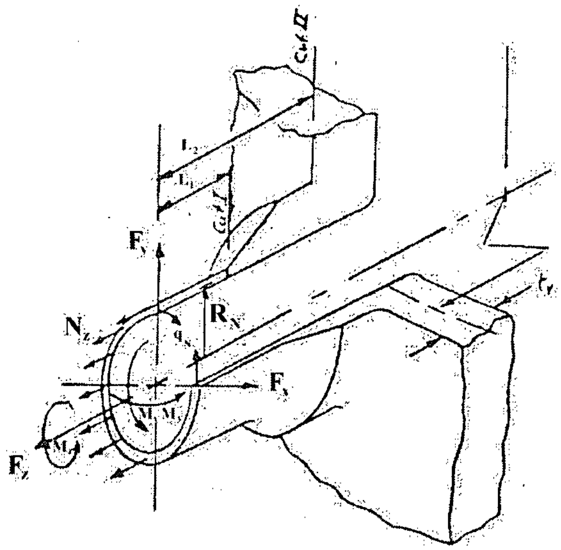
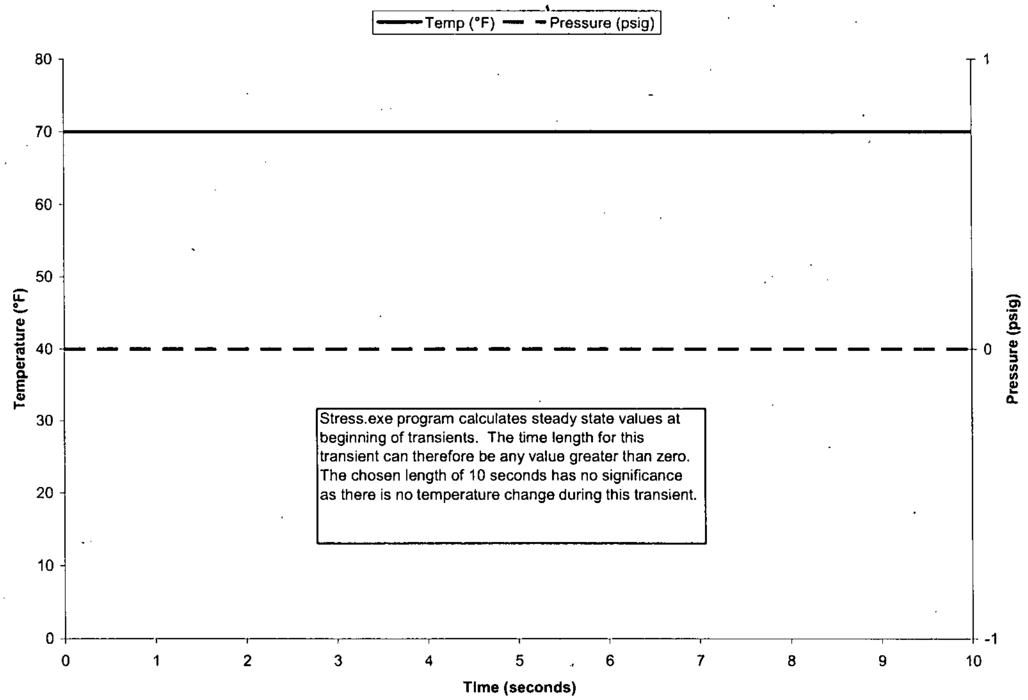
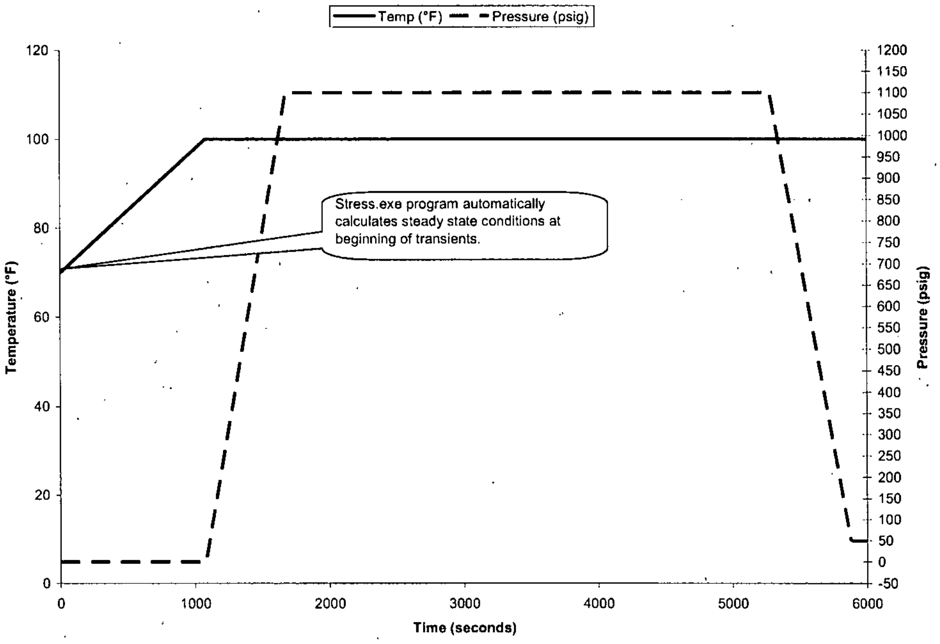


Figure 3: External Forces and Moments on the Feedwater Nozzle



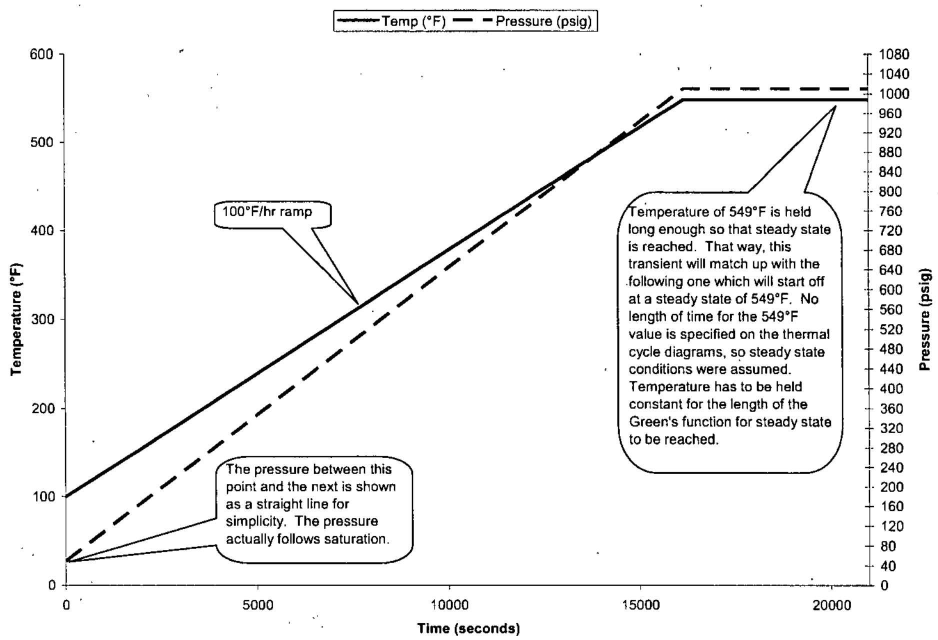
Stress.exe program calculates steady state values at beginning of transients. The time length for this transient can therefore be any value greater than zero. The chosen length of 10 seconds has no significance as there is no temperature change during this transient.

Figure 4: Transient 1, Bolt-up



Stress.exe program automatically calculates steady state conditions at beginning of transients.

Figure 5: Transient 2, Design HYD Test

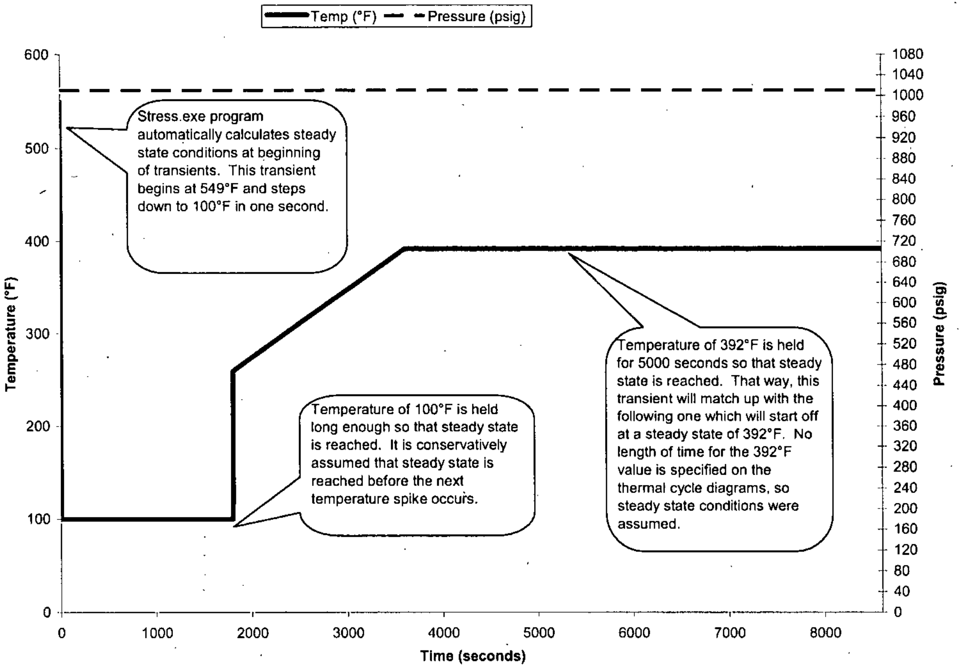


100°F/hr ramp

Temperature of 549°F is held long enough so that steady state is reached. That way, this transient will match up with the following one which will start off at a steady state of 549°F. No length of time for the 549°F value is specified on the thermal cycle diagrams, so steady state conditions were assumed. Temperature has to be held constant for the length of the Green's function for steady state to be reached.

The pressure between this point and the next is shown as a straight line for simplicity. The pressure actually follows saturation.

Figure 6: Transient 3, Startup

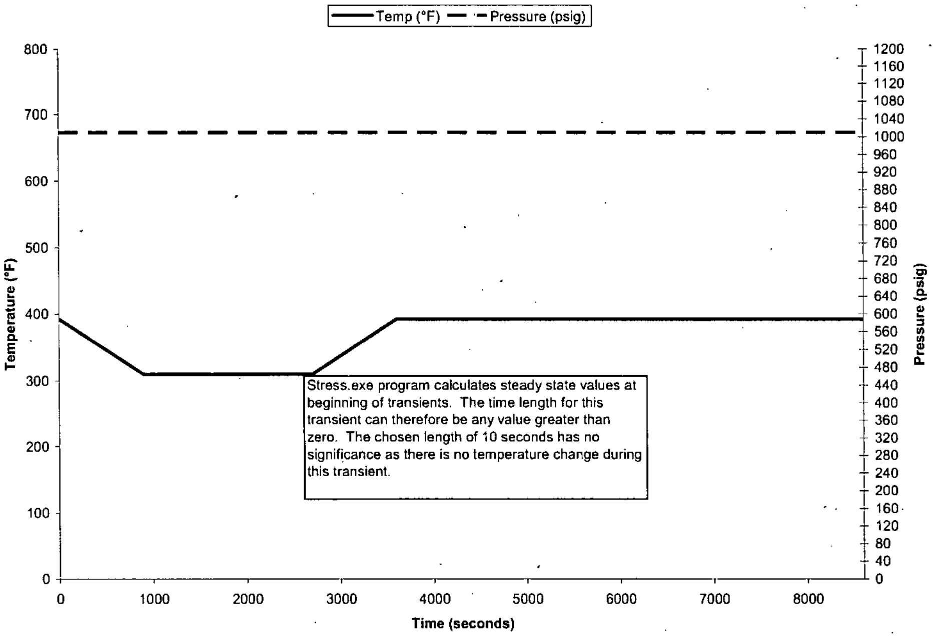


Stress.exe program automatically calculates steady state conditions at beginning of transients. This transient begins at 549°F and steps down to 100°F in one second.

Temperature of 100°F is held long enough so that steady state is reached. It is conservatively assumed that steady state is reached before the next temperature spike occurs.

Temperature of 392°F is held for 5000 seconds so that steady state is reached. That way, this transient will match up with the following one which will start off at a steady state of 392°F. No length of time for the 392°F value is specified on the thermal cycle diagrams, so steady state conditions were assumed.

Figure 7: Transient 4, Turbine Roll and Increased to Rated Power



Stress.exe program calculates steady state values at beginning of transients. The time length for this transient can therefore be any value greater than zero. The chosen length of 10 seconds has no significance as there is no temperature change during this transient.

Figure 8: Transient 5, Daily Reduction 75% Power

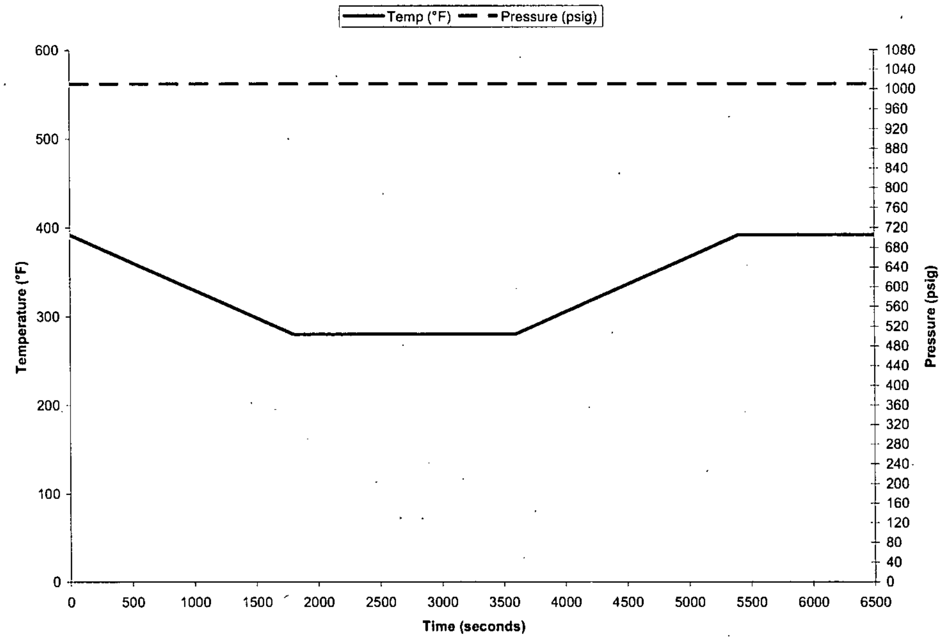


Figure 9: Transient 6, Weekly Reduction 50% Power

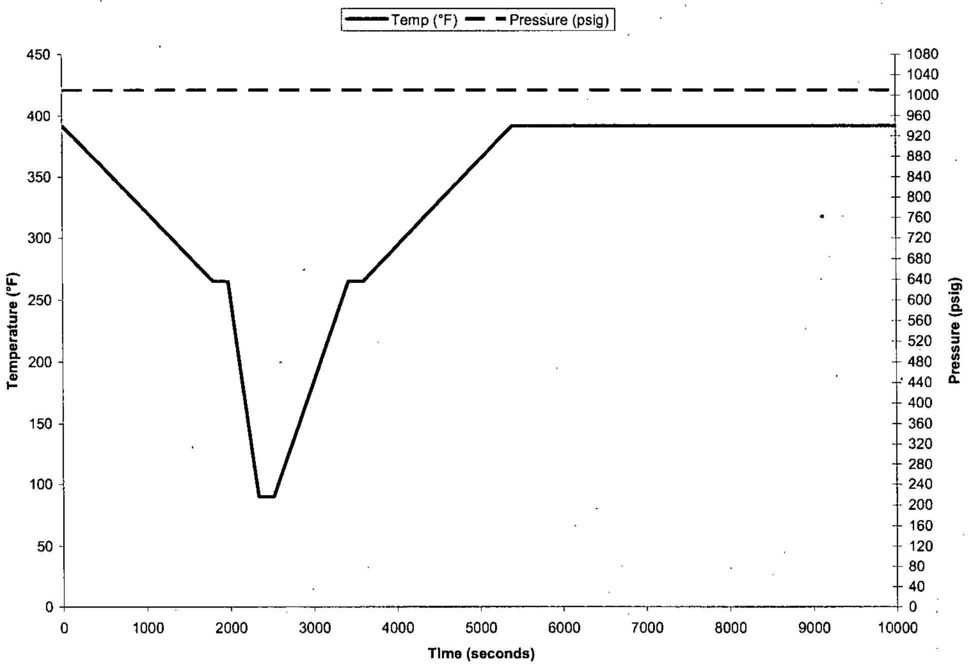


Figure 10: Transient 9, Turbine Trip at 25% Power

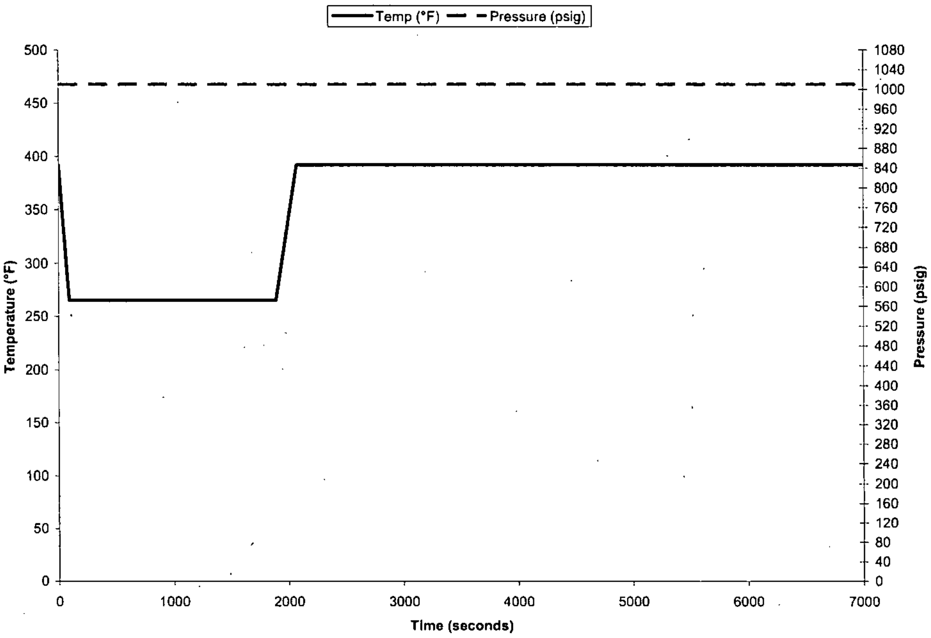
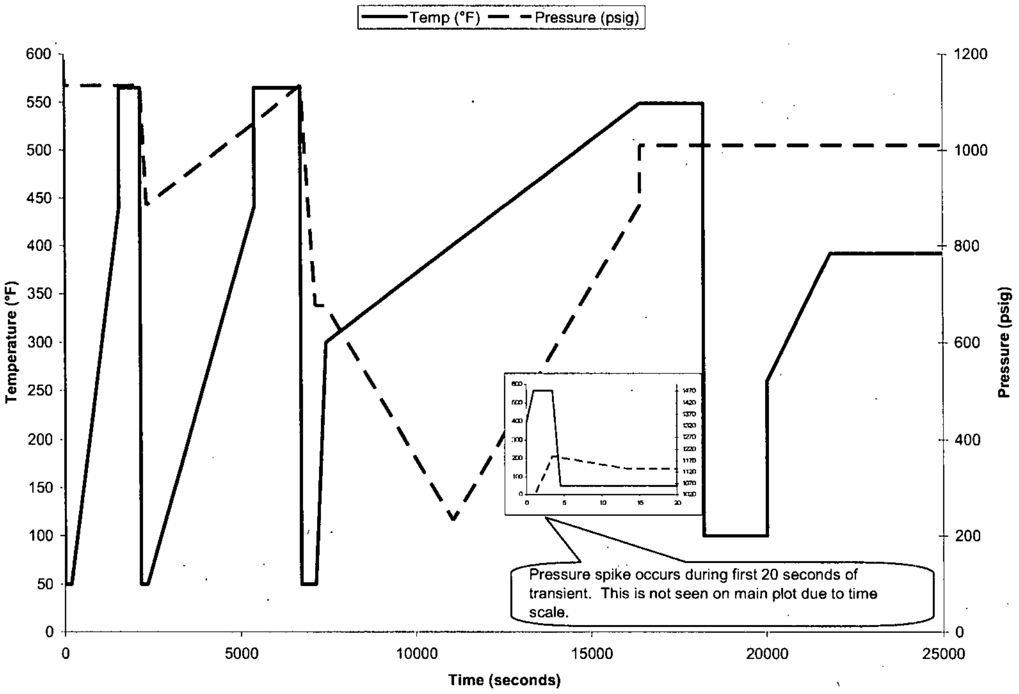
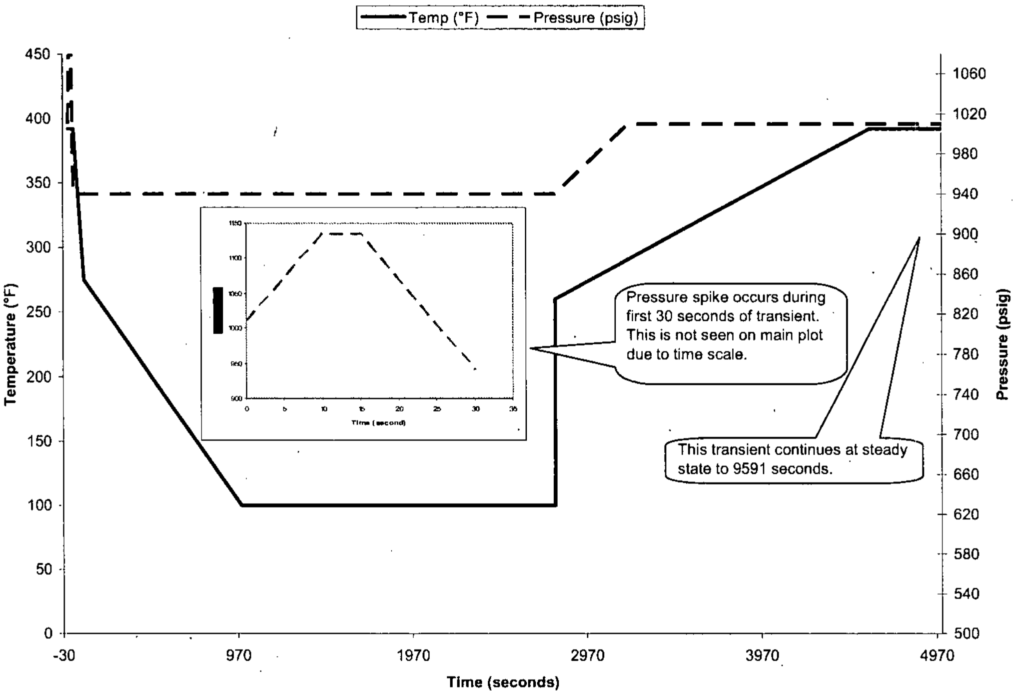


Figure 11: Transient 10, Feedwater Bypass



Pressure spike occurs during first 20 seconds of transient. This is not seen on main plot due to time scale.

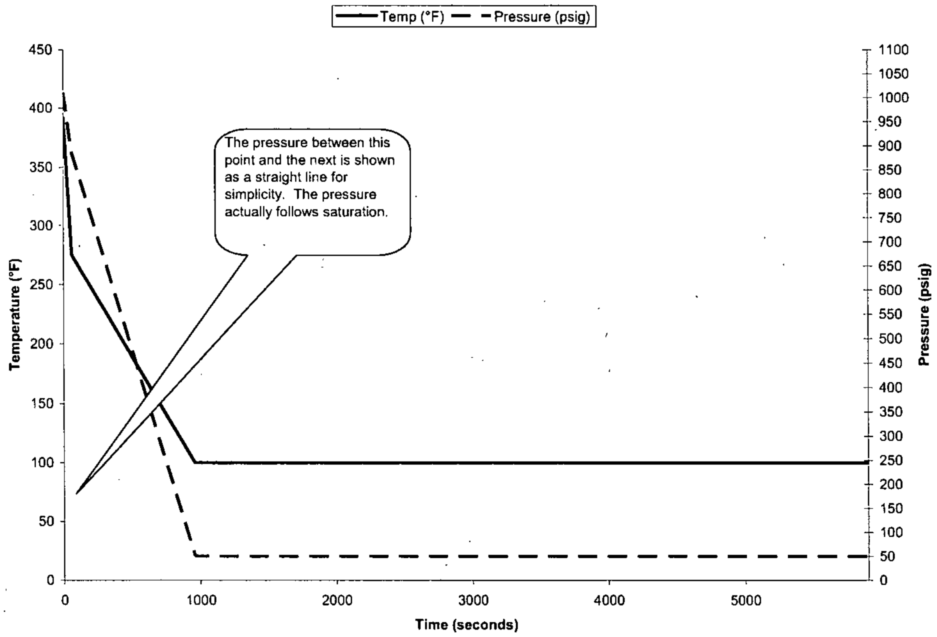
Figure 12: Transient 11, Loss of Feedwater Pumps



Pressure spike occurs during first 30 seconds of transient. This is not seen on main plot due to time scale.

This transient continues at steady state to 9591 seconds.

Figure 13: Transient 12, Turbine Generator Trip



The pressure between this point and the next is shown as a straight line for simplicity. The pressure actually follows saturation.

Figure 14: Transient 14, SRV Blowdown

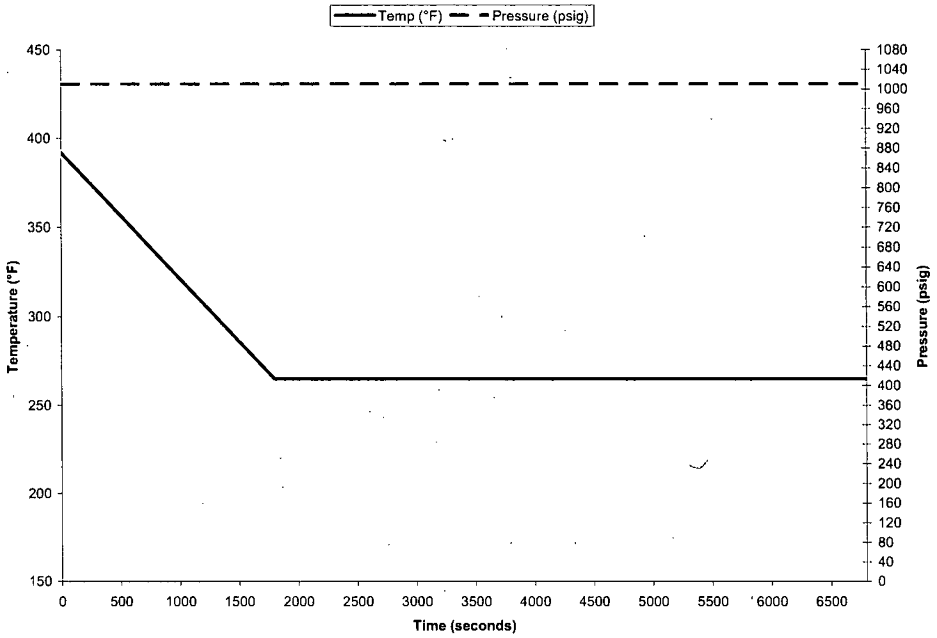


Figure 15: Transient 19, Reduction to 0% Power

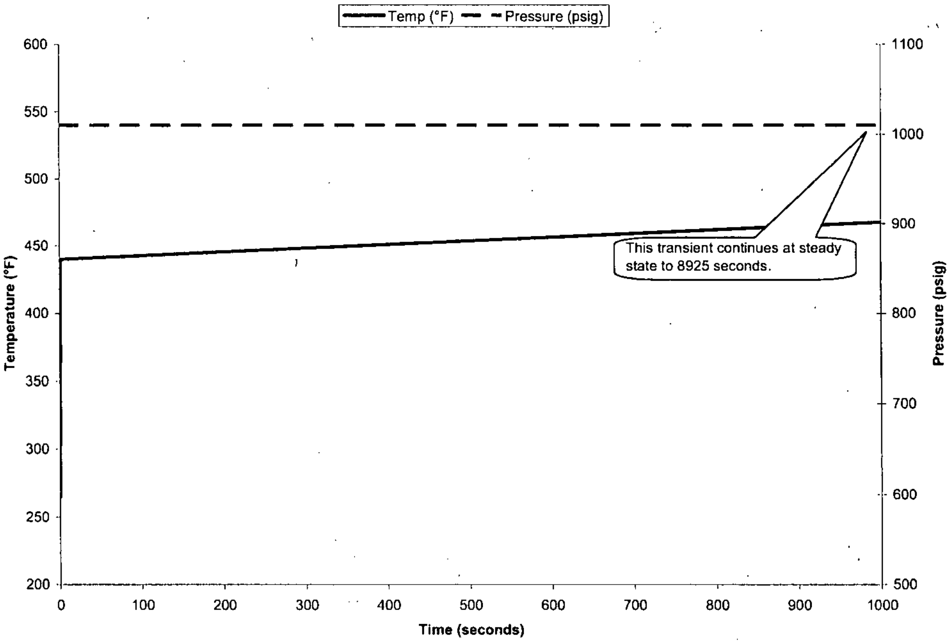


Figure 16: Transient 20, Hot Standby (Heatup Portion)

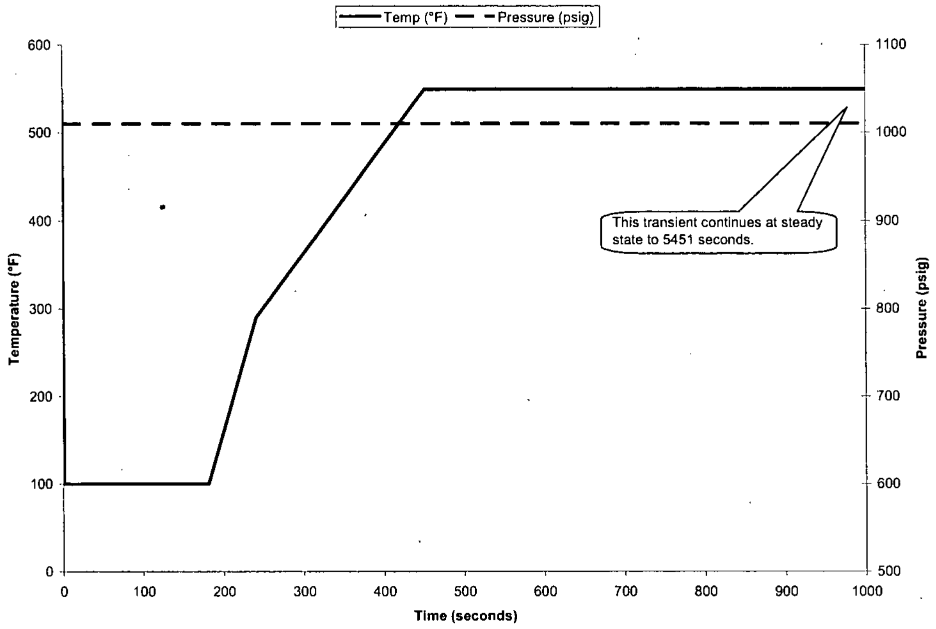


Figure 17: Transient 20A, Hot Standby (Feedwater Injection Portion)

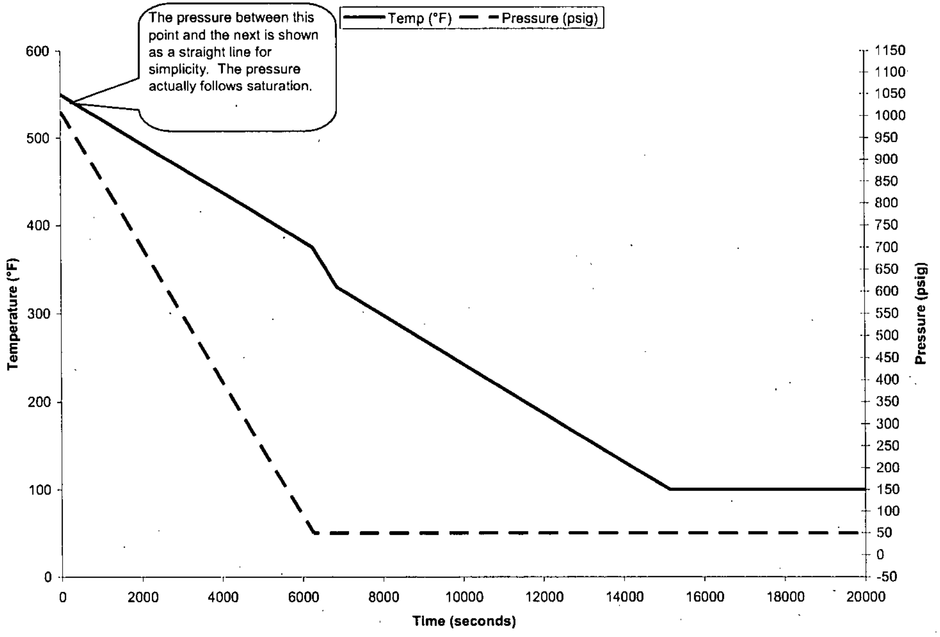


Figure 18: Transient 21-23, Shutdown

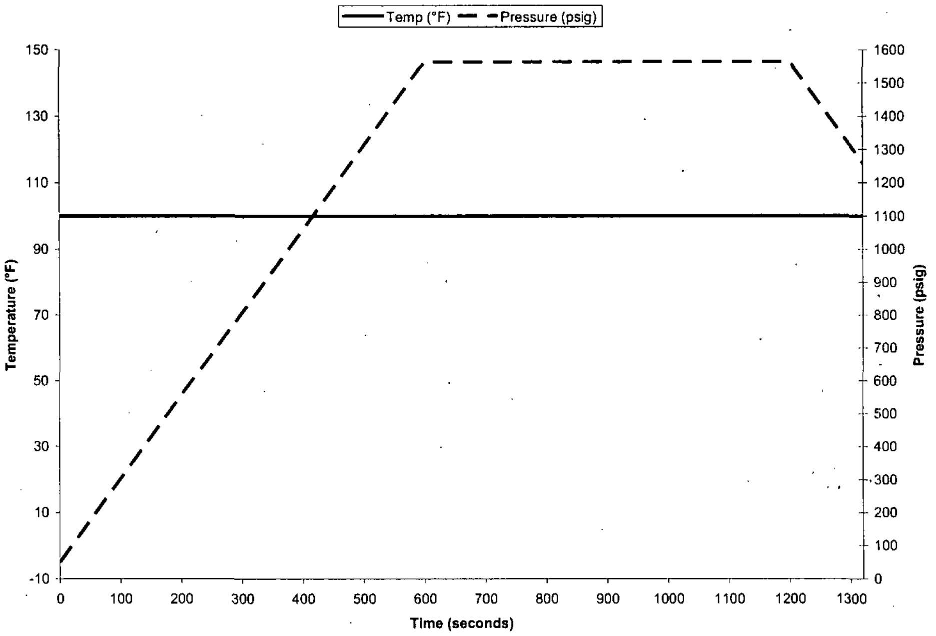


Figure 19: Transient 24, Hydrostatic Test

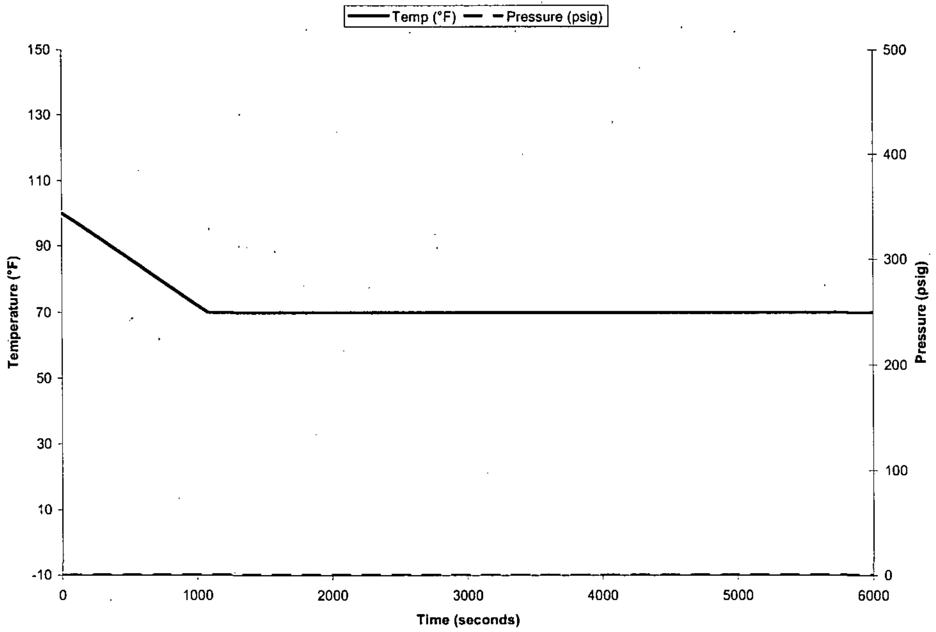


Figure 20: Transient 25, Unbolt

APPENDIX A

SUMMARY OF OUTPUT FILES

Transient Table.xls	Definition of Transients	In Computer files
BRresults.xls	Blend Radius Stress Summary	In Computer files
SEresults.xls	Safe End Stress Summary	In Computer files
TRANSNT_XX.INP	Input File for Each Transient	In Computer files
Green.dat	Input File for Green Functions	In Computer files
P-V_XX.OUT	Output File for Stress Analysis	In Computer files
GREEN.CFG	Input File for Defining Green Function	In Computer files
FATIGUE.CFG	Input File for Defining Fatigue Analysis	In Computer files
FATIGUE.DAT	Input File for Fatigue Curves	In Computer files
FATIGUE.inp	Input file for Fatigue Analysis from BRresults.xls or SEresults.xls	In Computer files
FATIGUE.OUT	Fatigue Output File	In Computer files

Where XX is defined for each transient.