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## 1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the Entergy Vermont Yankee (VY) reactor pressure vessel (RPV) recirculation outlet nozzle. Two locations will be analyzed for fatigue acceptance: the safe end (SA182 F316) and the nozzle inner corner blend radius (SA508 Class 2). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. Fatigue usage will be determined for each location, the nozzle forging and safe end, respectively. An environmental fatigue usage factor will also be determined for each of these locations.

## 2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the recirculation outlet 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 recirculation outlet 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 [14] 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 [13]. 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 [17] methodology was originally used to evaluate the recirculation outlet 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 recirculation outlet nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more accurate CUF.

For the recirculation outlet 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 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 [15]. 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 13 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 14. The input transient temperature history contains five step-changes of varying size, as shown in Figure 14. These five step changes produce the five successive stress responses in the second plot shown in Figure 14. 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 recirculation outlet 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 three Recirculation flow conditions and 60-year projected cycle counts.

Three Structural Integrity utility computer programs are used to facilitate the fatigue analysis process: 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.

The 10 transients to be analyzed are described in Reference [2], for the recirculation outlet nozzle. Transients 11 and 12 are hydrostatic tests that have only a small temperature change and are not

modeled. Transients 1 to 10 are shown in Figures 3 – 12. The analysis of transient 9 is an exception to this process because there are two different thermal shocks at the nozzle and vessel regions. Transient 9 is analyzed separately using ANSYS instead of STRESS.EXE and P-V.EXE. The results from ANSYS are input directly into FATIGUE.EXE with the other transient stress results.

## 3.0 ANALYSIS

The fatigue analysis involves preparing the input files and running the three programs. 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 ANSYS results from transient 9 are added to the P-V.EXE results for the other transients and input into FATIGUE.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 (Green's Functions) obtained from Reference [1]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. The blend radius and the safe end have three stress history functions for the 100% flow, 50%, and no-flow conditions.
- GREEN.CFG is configured as described in Reference [5].
- Several TRANSNT.INP files are created to simulate the transients shown on Reference [2]. Tables 2 and 3 show the thermal history used to simulate each transient for the blend radius and safe end locations, respectively. The aforementioned transient information for each location is contained in EXCEL files *Blend_Radius_Transients.xls* and *Safe_End_Transients.xls,* which are contained in the computer files. Transients are split into the following groups based upon flow rate:
    - Transients 2, 3, 5, 6, 7, and 8 are run at 100% flow Green's Function
    - Transients 1 and 10 are run at 50% flow Green's Function
    - Transient 4 is run at no flow, 50% flow, and 100% flow Green's Functions, as shown in Tables 2 and 3.
    - Transient 9 is simulated by ANSYS [11] model and the thermal results are taken from ANSYS directly. See Section 4 for details.
    - Transients 11 and 12 have only small temperature change (70°F to 100°F). Therefore, the thermal stresses for these two transient are ignored. Only the piping load and the pressure load are considered in these two transients.
    - The loss of feedwater heaters (Feedwater Heater Bypass) event has a negligible temperature change (526 °F to 516 °F) associated with it. Therefore this transient is ignored.

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

After STRESS.EXE runs are completed, the program P-V.EXE is run to extract only the peaks and valleys from the STRESS.OUT stress history file produced by the STRESS.EXE program. The only input required for this program is the stress history file (STRESS.OUT), and the program outputs all of the resulting peaks and valleys to output file P-V.OUT. The resulting peak and valley stress summaries for all transients are summarized in Tables 4 and 5 for both locations. Columns 2 through 5 of Tables 4 (for the blend radius) and 5 (for the safe end) show the final peak and valley output. These final peaks and valleys were selected from the total stress and membrane plus bending stress intensities that were calculated by STRESS.EXE and screened with P-V.EXE.

### 3.3 Pressure Load

The pressure stress associated with a 1,000 psi internal pressure was determined in Reference [1]. These values are as follows:

Pressure stress for the safe end:

- 11,350 psi membrane plus bending linearized stress intensity.
- 11,490 psi total stress intensity.

Pressure stress for the blend radius:

- 33,640 psi membrane plus bending linearized stress intensity.
- 31,300 psi total stress intensity.

The pressure stress intensity values for each transient were linearly scaled based on the pressure. The actual pressure for column 6 of Tables 4 and 5 is obtained from Tables 2 and 3, respectively. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4 and 5.

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 1.

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 [7], the recirculation outlet nozzle piping loads (Total thermal, weight and seismic loads) are as follows:

| | |
|---|---|
| $F_x$ = 20,000 lbs | $M_x$ = 2,004,000 in-lb |
| $F_y$ = 20,000 lbs | $M_y$ = 3,000,000 in-lb |
| $F_z$ = 30,000 lbs | $M_z$ = 2,004,000 in-lb |

$L_1$ is equal to 4.25 inches and the $L_2$ is equal to 42.77 inches. The calculations for the safe end and blend radius are shown in Table 1. 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 3829 (inside) to Node 3809 (outside). This gives the maximum ID and minimum OD for the cross section calculation. The maximum stress intensities due to the piping loads are 5708.89 psi at the safe end and 280.16 psi at the blend radius. 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 [6]. 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 [2]:

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 [2] unless otherwise noted.

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) [13] | 1.7 & 0.3 (stainless steel) [13] |
| Design Stress Intensity Values, $S_m$ | 26700 psi [9] @ 600°F | 17000 psi [9] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [13] | $28.3 \times 10^6$ psi [13] |
| Elastic Modulus Used in Finite Element Model | $26.7 \times 10^6$ psi [1] | $27.0 \times 10^6$ psi [1] |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 1.53 [3] |

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 fatigue run inputs described are contained in EXCEL files *BRresults.xls* and *SEresults.xls*, which are contained in the computer files.

## 4.0 CALCULATION OF THERMAL STRESSES FOR TRANSIENT 9

Per Tables 2 and 3, the thermal shocks are from 526°F to 268°F and from 526°F to 130°F at the blend radius and the safe end, respectively. Therefore, the average temperatures for these two locations are about 400°F and 330°F. Since there are two different temperature shocks in the same model, ANSYS [10] will be used to calculate stresses directly. In this section, ANSYS [10] is used to simulate this transient and the results will then be used as input to FATIGUE.EXE, as shown in Tables 4 and 5. This case corresponds to the downhill (RPV) side of the blend radius.

An additional case was also run to simulate the uphill (RPV) side of the blend radius, where the thermal shocks are from 526°F to 130°F at the safe end, and no temperature change at the blend

radius. This case at the uphill side of the blend radius was found to produce lower stresses than the previously mentioned downhill case. Due to this, the downhill case was used for the rest of the analysis in this calculation.

### 4.1 Thermal Load

Since the average temperatures in the blend radius and safe end respectively are 400°F and 330°F, the material properties for 400°F are used for the blend radius, cladding and vessel. Table 8 shows the material properties at 400°F. The flow rate at this transient is 3395.2 GPM (calculated from 12% of max flow rate [2]) and is shown in Tables 2 and 3.

Heat transfer coefficients listed on Reference [4] are for pre power uprate. The heat transfer coefficients can be scaled by power uprate flow rate and diameter to values corresponding to the flow and location conditions. Referring to Figure 2, heat transfer coefficients were applied as follows:

Region 1

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4911 \cdot \left(\frac{2.084}{25}\right)^{0.8} = 672.8 \text{ BTU/hr-ft}^2\text{-°F.}$$

Per [4], the heat transfer coefficient at 100°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$2250 \cdot \left(\frac{2.084}{25}\right)^{0.8} = 308.24 \text{ BTU/hr-ft}^2\text{-°F.}$$

The fluid temperature shock is:

T = 526°F - 130°F - 526°F

Region 2

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4911 \cdot \left(\frac{2.084}{25}\right)^{0.8} \left(\frac{26}{35.49}\right)^{0..2} = 632.21 \text{ BTU/hr-ft}^2\text{-°F.}$$

Per [4], the heat transfer coefficient at 300°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4789 \cdot \left(\frac{2.084}{25}\right)^{0.8} \left(\frac{26}{35.49}\right)^{0..2} = 616.57 \text{ BTU/hr-ft}^2\text{-°F.}$$

The fluid temperature shock is:

T = 526°F - 268°F - 526°F

Region 3

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM flow is

$672.8(0.5) = 336.4$ BTU/hr-ft$^2$-°F.

Per [4], the heat transfer coefficient at 300°F, h, for 3395.2 GPM flow is

$$336.4\left(\frac{4789}{4911}\right) = 328.04 \text{ BTU/hr-ft}^2\text{-°F}.$$

The fluid temperature shock is:

Case 1: T = 526°F - 268°F - 526°F
Case 2: T = 526°F

Region 4

The heat transfer coefficient, h, is 0.4 BTU/hr-ft$^2$-°F [4].

The temperature is:

T = 120°F

## 4.2 Thermal Results

The flow dependent thermal load case outlined in Section 4.1 was run on the finite element model. Appendix A contains the thermal transient input file VY_RON_T_T9.INP for 3395.2 GPM flow rate. The flow dependent input files for the stress run is also included in Appendix A. The stress filename is VY_RON_S_T9.INP for 3395.2 GPM flow rate.

The critical safe end and blend radius locations are defined in Reference [1] at nodes 6395 and 3829, respectively.

The stress time history for the critical paths was extracted during the stress run. This produced two files, T9SE.OUT and T9BR.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses were extracted from these files to produce the files T9SE_Inside.RED and T9BR_Inside.RED, where SE and BR corresponded to the safe end and blend radius locations, respectively.

The data for the stress results is included in the files T9BR_M+B.xls, T9BR_T.xls, T9SE_M+B.xls, and T9SE_T.xls in the project Files. Where SE and BR corresponded to the safe end and blend radius locations, respectively. M+B and T corresponded to membrane plus bending stress and total stress, respectively.

## 5.0 FATIGUE USAGE RESULTS

The blend radius cumulative usage factor (CUF) from system cycling is 0.0108 for 60 years (Table 6). The safe end CUF is 0.0015 for 60 years (Table 7).

## 6.0 ENVIRONMENTAL FATIGUE ANALYSIS

The Recirculation Outlet nozzle has three materials: a Ni-Cr-Fe dissimilar metal weld (DMW), a low alloy steel forging, and a stainless steel safe end. To ensure the maximum CUF considering environmental effects was identified, locations in the safe end and nozzle forging were selected. This selection produces bounding environmental fatigue results for the entire nozzle assembly for the following reasons:

- The highest thermal stresses from the FEM analysis occur in the stainless steel safe end. Stainless steel Fen multipliers are significantly higher than Ni-Cr-Fe multipliers (Fen values are 2.55 or higher for stainless steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [16]). Therefore, evaluation of the safe end bounds the Ni-Cr-Fe weld material.
- The highest pressure stresses from the FEM analysis occur in the low alloy steel nozzle forging. Low alloy steel Fen multipliers are higher than Ni-Cr-Fe multipliers (Fen values are 2.45 or higher for low alloy steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [16]). Therefore, evaluation of the nozzle forging bounds the Ni-Cr-Fe weld material.

Per Reference [12], the dissolved oxygen (DO) calculation shows the overall hydrogen water chemistry (HWC) availability is 47%. This means the time ratio under normal water chemistry (NWC, or pre-HWC) is 53%.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are 15.35 and 8.36 from Table 5 of Reference [12]. These result in an EAF adjusted CUF of (15.35 x 47% + 8.36 x 53%) x 0.0015 = 0.0175 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 11.6453.

For the blend radius location, the environmental fatigue factors for post-HWC and pre-HWC are 2.45 and 12.43 from Table 5 of Reference [12]. These result in an EAF adjusted CUF of (2.45 x 47% + 12.43 x 53%) x 0.0108 = 0.08358 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 7.739.

## 7.0 REFERENCES


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**Table 1: Maximum Piping Stress Intensity Calculations**

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 20.00 | kips |
| $F_y$ = | 20.00 | kips |
| $F_Z$ = | 30.00 | kips |
| $M_x$ = | 2004.00 | in-kips |
| $M_y$ = | 3000.00 | in-kips |
| $M_Z$ = | 2004.00 | in-kips |
| OD= | 55.88 | in |
| ID= | 37.368 | in |
| $R_N$ = | 23.31 | in |
| L = | 42.77 | in |
| $t_N$ = | 9.25 | in |
| $(M_x)_2$ = | 1148.54 | in-kips |
| $(M_y)_2$ = | 3855.46 | in-kips |
| $M_{xy}$ = | 4022.90 | in-kips |
| $F_{xy}$ = | 28.28 | kips |
| $N_Z$ = | 2.56 | kips/in |
| $q_N$ = | -0.20 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 0.28 | ksi |
| $\tau$ = | -0.02 | ksi |
| $SI_{max}$ = | 0.28 | ksi |
| $SI_{max}$ = | 280.16 | psi |

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 20.00 | kips |
| $F_y$ = | 20.00 | kips |
| $F_Z$ = | 30.00 | kips |
| $M_x$ = | 2004.00 | in-kips |
| $M_y$ = | 3000.00 | in-kips |
| $M_Z$ = | 2004.00 | in-kips |
| OD= | 28.38 | in |
| ID= | 25.938 | in |
| $R_N$ = | 13.58 | in |
| L = | 4.25 | in |
| $t_N$ = | 1.22 | in |
| $(M_x)_1$ = | 1919.00 | in-kips |
| $(M_y)_1$ = | 3085.00 | in-kips |
| $M_{xy}$ = | 3633.15 | in-kips |
| $F_{xy}$ = | 28.28 | kips |
| $N_Z$ = | 6.62 | kips/in |
| $q_N$ = | -1.07 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 5.43 | ksi |
| $\tau$ = | -0.88 | ksi |
| $SI_{max}$ = | 5.71 | ksi |
| $SI_{max}$ = | 5708.89 | psi |

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

# Table 2: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 1. Normal Startup with Heatup at 100°F/hr 300 Cycles | 0 | 100 | | 0 | 14147.0 (50%)' |
| | 16164 | 549 | 16164 | 1010 | |
| | 22164 | 549 | 6000 | 1010 | |
| 2. Turbine Roll and Increase to Rated Power 300 Cycles | 0 | 549 | | 1010 | 28294 (100%)' |
| | 1 | 542 | 1 | 1010 | |
| | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 6602 | 526 | 6000 | 1010 | |
| 3. Loss of Feedwater Heaters Turbine Trip 25% Power 10 Cycles | 0 | 526 | | 1010 | 28294 (100%)' |
| | 1800 | 542 | 1800 | 1010 | |
| | 2100 | 542 | 300 | 1010 | |
| | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 12060 | 526 | 6000 | 1010 | |
| 4. Loss of Feedwater Pumps 10 Cycles | 0 | 526 | | 1010 | 0 (0%)' |
| | 3 | 526 | 3 | 1190 | |
| | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1136 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | 14147 (50%) |
| | 7493 | 300 | 300 | 675 | |
| | 11093 | 400 | 3600 | 240 | |
| | 16457 | 549 | 5364 | 1010 | |
| | 16517 | 549 | 60 | 1010 | |
| | 16518 | 542 | 1 | 1010 | 28294 (100%) |
| | 17118 | 542 | 600 | 1010 | |
| | 17119 | 526 | 1 | 1010 | |
| | 23119 | 526 | 6000 | 1010 | |
| 5. Turbine Generator Trip 60 Cycles | 0 | 526 | | 1010 | 28294 (100%)' |
| | 10 | 526 | 10 | 1135 | |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 8912 | 526 | 6000 | 1010 | |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 6. Reactor Overpressure 1 Cycle | 0 | 526 | | 1010 | 28294 (100%)' |
| | 2 | 526 | 2 | 1375 | |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 8914 | 526 | 6000 | 1010 | |
| 7. SRV Blowdown 1 Cycle | 0 | 526 | | 1010 | 28294 (100%)' |
| | 600 | 375 | 600 | 170 | |
| | 11580 | 70 | 10980 | 50 | |
| | 17580 | 70 | 6000 | 50 | |
| 8. SCRAM Other 228 Cycles | 0 | 526 | | 1010 | 28294 (100%)' |
| | 15 | 526 | 15 | 940 | |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 8357 | 526 | 6000 | 1010 | |
| 9. Improper Startup 1 Cycle | 0 | 526 | | 1010 | 3395 (12%)' |
| | 1 | 268 (3) | 1 | 1010 | |
| | 27 | 268 (3) | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 6028 | 526 | 6000 | 1010 | |
| 10. Shutdown 300 Cycles | 0 | 549 | | 1010 | 14147 (50%)' |
| | 6264 | 375 | 6264 | 170 | |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 22224 | 70 | 6000 | 50 | |
| 11. Design Hydrostatic Test 120 cycles | — | 100 | — | 50 | 1981 (7%) |
| | | | | 1563 | |
| | | | | 50 | |
| 12. Hydrostatic Test 1 Cycle | — | 100 | — | 0 | 1981 (7%) |
| | | | | 1100 | |
| | | | | 50 | |

**Notes:**

1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [2].
3. 268°F is the blend radius temperature for this transient. The safe end has a different temperature for Transient 9. [2]

## Table 3: Safe End Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 1. Normal Startup with Heatup at 100°F/hr 300 Cycles | 0 | 100 | | 0 | 14147.0 |
| | 16164 | 549 | 16164 | 1010 | (50%)' |
| | 16864 | 549 | 700 | 1010 | |
| 2. Turbine Roll and Increase to Rated Power 300 Cycles | 0 | 549 | | 1010 | 28294 |
| | 1 | 542 | 1 | 1010 | (100%)' |
| | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 1302 | 526 | 700 | 1010 | |
| 3. Loss of Feedwater Heaters Turbine Trip 25% Power 10 Cycles | 0 | 526 | | 1010 | 28294 |
| | 1800 | 542 | 1800 | 1010 | (100%)' |
| | 2100 | 542 | 300 | 1010 | |
| | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 6760 | 526 | 700 | 1010 | |
| 4. Loss of Feedwater Pumps 10 Cycles | 0 | 526 | | 1010 | 0 |
| | 3 | 526 | 3 | 1190 | (0%)' |
| | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | 14147 |
| | 7493 | 300 | 300 | 675 | (50%)' |
| | 11093 | 400 | 3600 | 240 | |
| | 16457 | 549 | 5364 | 1010 | |
| | 16517 | 549 | 60 | 1010 | |
| | 16518 | 542 | 1 | 1010 | 28294 |
| | 17118 | 542 | 600 | 1010 | (100%)' |
| | 17119 | 526 | 1 | 1010 | |
| | 17819 | 526 | 700 | 1010 | |
| 5. Turbine Generator Trip 60 Cycles | 0 | 526 | | 1010 | 28294 |
| | 10 | 526 | 10 | 1135 | (100%)' |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 3612 | 526 | 700 | 1010 | |
| 6. Reactor Overpressure 1 Cycle | 0 | 526 | | 1010 | 28294 |
| | 2 | 526 | 2 | 1375 | (100%)' |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 3614 | 526 | 700 | 1010 | |
| 7. SRV Blowdown 1 Cycle | 0 | 526 | | 1010 | 28294 |
| | 600 | 375 | 600 | 170 | (100%)' |
| | 11580 | 70 | 10980 | 50 | |
| | 12280 | 70 | 700 | 50 | |
| 8. SCRAM Other 228 Cycles | 0 | 526 | | 1010 | 28294 |
| | 15 | 526 | 15 | 940 | (100%)' |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 3057 | 526 | 700 | 1010 | |
| 9. Improper Startup 1 Cycle | 0 | 526 | | 1010 | 3395 |
| | 1 | 130 (3) | 1 | 1010 | (12%)' |
| | 27 | 130 (3) | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 728 | 526 | 700 | 1010 | |
| 10. Shutdown 300 Cycles | 0 | 549 | | 1010 | 14147 |
| | 6264 | 375 | 6264 | 170 | (50%)' |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 16924 | 70 | 700 | 50 | |
| 11. Design Hydrostatic Test 120 Cycles | — | 100 | — | 0 | 1981 |
| | | | | 1100 | (7%)' |
| | | | | 50 | |
| 12. Hydrostatic Test 1 Cycle | — | 100 | — | 50 | 1981 |
| | | | | 1563 | (7%)' |
| | | | | 50 | |

**Notes:**
1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [2].
3. 130°F is the safe end temperature for this transient. The blend radius has a different temperature for Transient 9. [2]

*Note: These transients are the same as in Table 2 with the exception of the 700 second steady state time increment that is used. The transients in Table 2 are plotted using a 6000 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.*

# 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 | 459 | 388 | 100.00 | 0 | 0 | 0 | 16.64312 | 16.64312 | 475.64 | 404.64 | 300 |
| | 4303 | -3417 | -1594 | 219.53 | 1010 | 31613 | 33976.4 | -82.95209 | -82.95209 | 28113.05 | 32299.45 | 300 |
| | 22164 | 2713 | 2306 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34591.74 | 36548.14 | 300 |
| 2 | 0.00 | 3094 | 1934 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34972.74 | 36176.14 | 300 |
| | 94.30 | 4079 | 2481 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 35953.85 | 36719.25 | 300 |
| | 601.70 | 3683 | 2435 | 538.8 | 1010 | 31613 | 33976.4 | 260.0765 | 260.0765 | 35556.08 | 36671.48 | 300 |
| | 680.10 | 5891 | 3489 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 37756.98 | 37718.38 | 300 |
| | 6602.00 | 2977 | 1859 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34842.98 | 36088.38 | 300 |
| 3 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 10 |
| | 1807.20 | 1834 | 1043 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33708.85 | 35281.25 | 10 |
| | 2491.50 | 4425 | 2667 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36290.98 | 36896.38 | 10 |
| | 3974.40 | 1706 | 1060 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33580.85 | 35298.25 | 10 |
| | 6070.80 | 3971 | 2551 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35836.98 | 36780.38 | 10 |
| | 12060.00 | 2965 | 1852 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34830.98 | 36081.38 | 10 |
| 4 | 0 | 2465 | -703 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | -252.9754 | 34330.98 | 33020.42 | 10 |
| | 3 | 2465 | -703 | 526.00 | 1190 | 37247 | 40031.6 | 252.9754 | -252.9754 | 39964.98 | 39075.62 | 10 |
| | 13 | 2465 | -703 | 526.00 | 1135 | 35525.5 | 38181.4 | 252.9754 | -252.9754 | 38243.48 | 37225.42 | 10 |
| | 435.6 | 18138 | 9690 | 356.38 | 1135 | 35525.5 | 38181.4 | 158.8774 | 158.8774 | 53822.38 | 48030.28 | 10 |
| | 2222.5 | -1169 | -2598 | 489.44 | 1135 | 35525.5 | 38181.4 | -232.6952 | -232.6952 | 34123.80 | 35350.70 | 10 |
| | 2665.5 | 12763 | 6695 | 328.40 | 885 | 27700.5 | 29771.4 | 143.3539 | 143.3539 | 40606.85 | 36609.75 | 10 |
| | 6779.2 | -4008 | -2829 | 497.05 | 1010 | 31613 | 33976.4 | -236.9137 | -236.9137 | 27368.09 | 30910.49 | 10 |
| | 7243.8 | 19275 | 9965 | 302.91 | 1010 | 31613 | 33976.4 | 129.2122 | 129.2122 | 51017.21 | 44070.61 | 10 |
| | 13996 | -2135 | 34 | 542.00 | 1010 | 31613 | 33976.4 | -261.8518 | 261.8518 | 29216.15 | 34272.25 | 10 |
| | 17247 | 3413 | 2074 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35278.98 | 36303.38 | 10 |
| | 23119 | 2971 | 1855 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34836.98 | 36084.38 | 10 |
| 5 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 60 |
| | 10.00 | 2959 | 1849 | 526 | 1135 | 35525.5 | 38181.4 | 252.9754 | 252.9754 | 38737.48 | 40283.38 | 60 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 60 |
| | 2269.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 60 |
| | 3010.10 | 4407 | 2579 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 60 |
| | 8912.00 | 2968 | 1854 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 60 |
| 6 | 0.00 | 2959 | 1849 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 2.00 | 2959 | 1849 | 526.00 | 1375 | 43037.5 | 46255 | 252.9754 | 252.9754 | 46249.48 | 48356.98 | 1 |
| | 32.00 | 2959 | 1849 | 526.00 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 1 |
| | 2271.50 | 111 | 295 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 1 |
| | 3022.00 | 4407 | 2579 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 1 |
| | 8914.00 | 2968 | 1854 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 1 |
| 7 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 615.10 | 20260 | 12980 | 374.581 | 170 | 5321 | 5718.8 | 168.9726 | 168.9726 | 25749.97 | 18867.77 | 1 |
| | 17580.00 | 279 | 179 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1844.00 | 1861.00 | 1 |
| 8 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 228 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 228 |
| | 2254.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 228 |
| | 2491.20 | 3792 | 2234 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35657.98 | 36463.38 | 228 |
| | 8357.00 | 2963 | 1851 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34828.98 | 36080.38 | 228 |
| 9 | 0 | 2058 | 961 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35190.26 | 1 |
| | 0.52 | 1956 | 734 | 525.6 | 1010 | 31613 | 33976.4 | 252.7535 | 252.7535 | 33821.75 | 34963.15 | 1 |
| | 28 | 23747 | 3188 | 504.5 | 1010 | 31613 | 33976.4 | 241.0479 | 241.0479 | 55601.05 | 37405.45 | 1 |
| | 425 | 1520 | 611 | 525.5 | 1010 | 31613 | 33976.4 | 252.698 | 252.698 | 33385.70 | 34840.10 | 1 |
| | 12400 | 2058 | 879 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35108.26 | 1 |
| 10 | 0 | 2767 | 2176 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34645.74 | 36418.14 | 300 |
| | 4240.8 | 6643 | 4158 | 445.775 | 441 | 13803.3 | 14835.24 | 208.469 | 208.469 | 20654.77 | 19201.71 | 300 |
| | 6268 | 6498 | 3675 | 374.7 | 170 | 5321 | 5718.8 | 169.0386 | 169.0386 | 11988.04 | 9562.84 | 300 |
| | 6891.8 | 9282 | 5241 | 329.228 | 88 | 2754.4 | 2960.32 | 143.8121 | 143.8121 | 12180.21 | 8345.13 | 300 |
| | 22224 | 361 | 120 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1926.00 | 1802.00 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 16.64312 | 16.64312 | 16.64 | 16.64 | 120 |
| | | 0 | 0 | 100 | 1100 | 34430 | 37004 | 16.64312 | 16.64312 | 34446.64 | 37020.64 | 120 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 48921.9 | 52579.32 | 16.64312 | 16.64312 | 48938.54 | 52595.96 | 1 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 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 31300)/1000.
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 33640)/1000.
Column 9: Total external stress from calculation in Table 1, 280.16 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 | -925 | -949 | 100.00 | 0 | 0 | 0 | -339.1419 | -339.1419 | -1264.14 | -1288.14 | 300 |
| | 16164 | -4814 | -4433 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 1375.93 | 1615.53 | 300 |
| | 16864 | -3749 | -3705 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2440.93 | 2343.53 | 300 |
| 2 | 0 | -3838 | -3665 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2351.93 | 2383.53 | 300 |
| | 6 | -1664 | -2263 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 4605.07 | 3864.67 | 300 |
| | 601 | -3773 | -3607 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2496.07 | 2520.67 | 300 |
| | 606.6 | 1196 | -403 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17955.86 | 5905.54 | 300 |
| | 1302 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 300 |
| 3 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 10 |
| | 1800.1 | -4165 | -3904 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2104.07 | 2223.67 | 10 |
| | 2460.2 | -1932 | -2200 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 4517.94 | 4108.54 | 10 |
| | 3960.2 | -4537 | -4185 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 1732.07 | 1942.67 | 10 |
| | 6060.2 | -3315 | -3241 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 3134.94 | 3067.54 | 10 |
| | 6760 | -3687 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2762.94 | 2786.54 | 10 |
| 4 | 0.00 | -3756 | -3716 | 526 | 1020 | 11719.8 | 11577 | -5154.958 | -5154.958 | 2808.84 | 2706.04 | 10 |
| | 3.00 | -3756 | -3716 | 526 | 1190 | 13673.1 | 13506.5 | -5154.958 | -5154.958 | 4762.14 | 4635.54 | 10 |
| | 13.00 | -3756 | -3716 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4130.19 | 4011.29 | 10 |
| | 242.30 | 15878 | 10049 | 302.374 | 1135 | 13041.15 | 12882.25 | 2626.926 | 2626.926 | 31546.08 | 25558.18 | 10 |
| | 2213.10 | -6388 | -5428 | 499.889 | 1135 | 13041.15 | 12882.25 | -4859.78 | -4859.78 | 1793.37 | 2594.47 | 10 |
| | 2408.60 | 13203 | 8265 | 301.443 | 885 | 10168.65 | 10044.75 | 2616.401 | 2616.401 | 25988.05 | 20926.15 | 10 |
| | 6773.40 | -4763 | -4312 | 499.809 | 1135 | 13041.15 | 12882.25 | -4858.875 | -4858.875 | 3419.27 | 3711.37 | 10 |
| | 7193.10 | 15374 | 9801 | 300 | 675 | 7755.75 | 7661.25 | 2600.088 | 2600.088 | 25729.84 | 20062.34 | 10 |
| | 16457.50 | -4812 | -5032 | 549 | 240 | 2757.6 | 2724 | -5414.966 | -5414.966 | -7469.37 | -7722.97 | 10 |
| | 16524.70 | -2358 | -2725 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3911.07 | 3402.67 | 10 |
| | 17118.00 | -3778 | -3610 | 541.996 | 1010 | 11604.9 | 11463.5 | -5335.788 | -5335.788 | 2491.11 | 2517.71 | 10 |
| | 17123.60 | 1192 | -406 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17951.86 | 5902.54 | 10 |
| | 17819.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 10 |
| 5 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 60 |
| | 10.00 | -3688 | -3522 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4198.19 | 4205.29 | 60 |
| | 30.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 60 |
| | 2250.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 60 |
| | 2319.90 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 60 |
| | 2911.00 | -3782 | -3613 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 60 |
| | 2916.70 | 1188 | -408 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 60 |
| | 3612.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 60 |
| 6 | 0.00 | -3688 | -3522 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 2.00 | -3688 | -3522 | 5.26E+02 | 1375 | 15798.75 | 15606.25 | -5154.958 | -5154.958 | 6955.79 | 6929.29 | 1 |
| | 32.00 | -3688 | -3522 | 5.26E+02 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 1 |
| | 2252.10 | -6054 | -5337 | 5.49E+02 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 1 |
| | 2322.20 | -2977 | -3123 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 1 |
| | 2913.00 | -3782 | -3613 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 1 |
| | 2918.70 | 1188 | -408 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 1 |
| | 3614.00 | -3670 | -3509 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 1 |
| 7 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 600 | 7773 | 5336 | 375 | 170 | 1953.3 | 1929.5 | 3447.943 | 3447.943 | 13174.24 | 10713.44 | 1 |
| | 1367.9 | -1390 | -1567 | 354.172 | 162 | 1861.38 | 1838.7 | -3212.488 | -3212.488 | -2741.11 | -2940.79 | 1 |
| | 11580.1 | 454 | 190 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 1028.50 | 757.50 | 1 |
| | 12280 | -707 | -689 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -132.50 | -121.50 | 1 |
| 8 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 228 |
| | 15.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 228 |
| | 2235.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 228 |
| | 2305.20 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 228 |
| | 2356.00 | -3183 | -3151 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 3086.08 | 2976.68 | 228 |
| | 2361.50 | 1761 | -28 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 18520.86 | 6280.54 | 228 |
| | 3057.00 | -3667 | -3506 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2782.94 | 2802.54 | 228 |
| 9 | 0 | -2968 | -2837 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3485.22 | 3474.82 | 1 |
| | 27 | 68473 | 45303 | 291.3 | 1010 | 11604.9 | 11463.5 | 2501.737 | 2501.737 | 82579.74 | 59268.34 | 1 |
| | 80.7 | -11546 | -8877 | 518.4 | 1010 | 11604.9 | 11463.5 | -5069.042 | -5069.042 | -5010.04 | -2482.14 | 1 |
| | 5200 | -2967 | -2832 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3486.21 | 3479.78 | 1 |
| 10 | 0 | -3745 | -3709 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2444.93 | 2339.53 | 300 |
| | 6864.2 | 501 | -405 | 329.994 | 170 | 1953.3 | 1929.5 | 2939.162 | -2939.162 | 5393.46 | -1414.66 | 300 |
| | 7455.5 | -1183 | -1528 | 314.325 | 88 | 1011.12 | 998.8 | -2762.029 | -2762.029 | -2933.91 | -3291.23 | 300 |
| | 16224.1 | 334 | -35 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 908.50 | 532.50 | 300 |
| | 16924 | -731 | -763 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -156.50 | -195.50 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 339.1419 | 339.1419 | 339.14 | 339.14 | 120 |
| | | 0 | 0 | 100 | 1100 | 12639 | 12485 | 339.1419 | 339.1419 | 12978.14 | 12824.14 | 120 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 17958.87 | 17740.05 | 339.1419 | 339.1419 | 18298.01 | 18079.19 | 1 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 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 3.

Column 7: Total pressure stress intensity from the quantity (Column 6 x 11490)/1000.

Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 11350)/1000.

Column 9: Total external stress from calculation in Table 1, 5708.89 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 |
|---|---|---|---|---|---|---|---|---|
| 55601. | 17. | 55584. | 37389. | 1.000 | 31227. | 1.000E+00 | 1.951E+04 | .0001 |
| 53822. | 17. | 53806. | 48014. | 1.000 | 30228. | 1.000E+01 | 2.161E+04 | .0005 |
| 51017. | 17. | 51001. | 44054. | 1.000 | 28652. | 1.000E+01 | 2.547E+04 | .0004 |
| 48939. | 17. | 48922. | 52579. | 1.000 | 27484. | 1.000E+00 | 2.894E+04 | .0000 |
| 46249. | 17. | 46233. | 48340. | 1.000 | 25974. | 1.000E+00 | 3.443E+04 | .0000 |
| 40607. | 17. | 40590. | 36593. | 1.000 | 22803. | 1.000E+01 | 5.217E+04 | .0002 |
| 39965. | 17. | 39948. | 39059. | 1.000 | 22443. | 1.000E+01 | 5.647E+04 | .0002 |
| 38737. | 17. | 38721. | 40267. | 1.000 | 21753. | 6.000E+01 | 6.592E+04 | .0009 |
| 38243. | 17. | 38227. | 37209. | 1.000 | 21476. | 1.000E+01 | 7.025E+04 | .0001 |
| 37757. | 17. | 37740. | 37702. | 1.000 | 21202. | 7.000E+00 | 7.486E+04 | .0001 |
| 37757. | 476. | 37281. | 37314. | 1.000 | 20945. | 2.930E+02 | 7.954E+04 | .0037 |
| 36291. | 476. | 35815. | 36492. | 1.000 | 20121. | 7.000E+00 | 9.705E+04 | .0001 |
| 36291. | 1582. | 34709. | 35198. | 1.000 | 19500. | 3.000E+00 | 1.096E+05 | .0000 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 6.000E+01 | 1.098E+05 | .0005 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 1.000E+00 | 1.098E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 5.600E+01 | 1.135E+05 | .0005 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1844. | 34110. | 34858. | 1.000 | 19163. | 1.000E+00 | 1.167E+05 | .0000 |
| 35954. | 1926. | 34028. | 34917. | 1.000 | 19117. | 2.410E+02 | 1.177E+05 | .0020 |
| 35837. | 1926. | 33911. | 34978. | 1.000 | 19051. | 1.000E+01 | 1.191E+05 | .0001 |
| 35658. | 1926. | 33732. | 34661. | 1.000 | 18951. | 4.900E+01 | 1.214E+05 | .0004 |
| 35658. | 11988. | 23670. | 26901. | 1.000 | 13298. | 1.790E+02 | 5.728E+05 | .0003 |
| 35556. | 11988. | 23568. | 27109. | 1.000 | 13240. | 1.210E+02 | 5.955E+05 | .0002 |
| 35556. | 12180. | 23376. | 28326. | 1.000 | 13133. | 1.790E+02 | 6.411E+05 | .0003 |
| 35279. | 12180. | 23099. | 27958. | 1.000 | 12977. | 1.000E+01 | 7.138E+05 | .0000 |
| 34973. | 12180. | 22793. | 27831. | 1.000 | 12805. | 1.110E+02 | 8.050E+05 | .0001 |
| 34973. | 20655. | 14318. | 16974. | 1.000 | 8044. | 1.890E+02 | 7.421E+07 | .0000 |
| 34843. | 20655. | 14188. | 16887. | 1.000 | 7971. | 1.110E+02 | 7.983E+07 | .0000 |
| 34843. | 25750. | 9093. | 17221. | 1.000 | 5108. | 1.000E+00 | 1.000E+20 | .0000 |
| 34843. | 27368. | 7475. | 5178. | 1.000 | 4199. | 1.000E+01 | 1.000E+20 | .0000 |
| 34843. | 28113. | 6730. | 3789. | 1.000 | 3781. | 1.780E+02 | 1.000E+20 | .0000 |
| 34837. | 28113. | 6724. | 3785. | 1.000 | 3777. | 1.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 6.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 1.000E+00 | 1.000E+20 | .0000 |
| 34831. | 28113. | 6718. | 3782. | 1.000 | 3774. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 28113. | 6716. | 3781. | 1.000 | 3773. | 4.100E+01 | 1.000E+20 | .0000 |
| 34829. | 29216. | 5613. | 1808. | 1.000 | 3153. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 6.000E+01 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.000E+00 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.160E+02 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+01 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 6.000E+01 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 4.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 6.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.270E+02 | 1.000E+20 | .0000 |
| 34646. | 32634. | 2012. | 2695. | 1.000 | 1130. | 1.010E+02 | 1.000E+20 | .0000 |
| 34646. | 33386. | 1260. | 1578. | 1.000 | 708. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33581. | 1065. | 1120. | 1.000 | 598. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33709. | 937. | 1137. | 1.000 | 526. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33822. | 824. | 1455. | 1.000 | 463. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1228. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1310. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 34124. | 522. | 1067. | 1.000 | 293. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34331. | 315. | 3398. | 1.000 | 177. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34447. | 199. | -603. | 1.000 | 112. | 1.200E+02 | 1.000E+20 | .0000 |
| 34646. | 34592. | 54. | -130. | 1.000 | 30. | 3.500E+01 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | | TOTAL USAGE FACTOR = | .0108 |

## Table 7: 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 = 17000. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.700E+07 psi
            Kt = 1.53
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 82580. | -7469. | 90049. | 66991. | 2.045 | 134573. | 1.000E+00 | 6.765E+02 | .0015 |
| 31546. | -7469. | 39015. | 33281. | 1.000 | 29691. | 9.000E+00 | 6.857E+05 | .0000 |
| 31546. | -5010. | 36556. | 28040. | 1.000 | 26947. | 1.000E+00 | 1.160E+06 | .0000 |
| 25988. | -2934. | 28922. | 24217. | 1.000 | 21884. | 1.000E+01 | 2.383E+06 | .0000 |
| 25730. | -2934. | 28664. | 23354. | 1.000 | 21509. | 1.000E+01 | 2.566E+06 | .0000 |
| 18521. | -2934. | 21455. | 9572. | 1.000 | 13903. | 2.280E+02 | 9.710E+08 | .0000 |
| 18298. | -2934. | 21232. | 21370. | 1.000 | 17063. | 1.000E+00 | 7.876E+06 | .0000 |
| 17956. | -2934. | 20890. | 9197. | 1.000 | 13502. | 5.100E+01 | 1.000E+20 | .0000 |
| 17956. | -2741. | 20697. | 8846. | 1.000 | 13304. | 1.000E+00 | 1.000E+20 | .0000 |
| 17956. | -1264. | 19220. | 7194. | 1.000 | 12071. | 2.480E+02 | 1.000E+20 | .0000 |
| 17952. | -1264. | 19216. | 7191. | 1.000 | 12068. | 1.000E+01 | 1.000E+20 | .0000 |
| 17948. | -1264. | 19212. | 7189. | 1.000 | 12065. | 4.200E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.800E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.000E+00 | 1.000E+20 | .0000 |
| 13174. | -157. | 13331. | 10909. | 1.000 | 10016. | 1.000E+00 | 1.000E+20 | .0000 |
| 12978. | -157. | 13135. | 13020. | 1.000 | 10500. | 1.200E+02 | 1.000E+20 | .0000 |
| 6956. | -157. | 7112. | 7125. | 1.000 | 5706. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | -157. | 5550. | -1219. | 1.000 | 2570. | 1.590E+02 | 1.000E+20 | .0000 |
| 5393. | -133. | 5526. | -1293. | 1.000 | 2537. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 6.000E+01 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 7.900E+01 | 1.000E+20 | .0000 |
| 4762. | 136. | 4626. | 3924. | 1.000 | 3514. | 1.000E+01 | 1.000E+20 | .0000 |
| 4605. | 136. | 4469. | 3153. | 1.000 | 3218. | 1.390E+02 | 1.000E+20 | .0000 |
| 4605. | 339. | 4266. | 3526. | 1.000 | 3215. | 1.200E+02 | 1.000E+20 | .0000 |
| 4605. | 909. | 3697. | 3332. | 1.000 | 2863. | 4.100E+01 | 1.000E+20 | .0000 |
| 4518. | 909. | 3609. | 3576. | 1.000 | 2885. | 1.000E+01 | 1.000E+20 | .0000 |
| 4198. | 909. | 3290. | 3673. | 1.000 | 2744. | 6.000E+01 | 1.000E+20 | .0000 |
| 4130. | 909. | 3222. | 3479. | 1.000 | 2655. | 1.000E+01 | 1.000E+20 | .0000 |
| 3911. | 909. | 3003. | 2870. | 1.000 | 2371. | 1.000E+01 | 1.000E+20 | .0000 |
| 3486. | 909. | 2578. | 2947. | 1.000 | 2170. | 1.000E+00 | 1.000E+20 | .0000 |
| 3485. | 909. | 2577. | 2942. | 1.000 | 2168. | 1.000E+00 | 1.000E+20 | .0000 |
| 3419. | 909. | 2511. | 3179. | 1.000 | 2199. | 1.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 6.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 9.600E+01 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.200E+02 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 1029. | 2264. | 2247. | 1.000 | 1810. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 1376. | 1916. | 1389. | 1.000 | 1390. | 9.000E+00 | 1.000E+20 | .0000 |
| 3135. | 1376. | 1759. | 1452. | 1.000 | 1325. | 1.000E+01 | 1.000E+20 | .0000 |
| 3086. | 1376. | 1710. | 1361. | 1.000 | 1274. | 2.280E+02 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2809. | 1376. | 1433. | 1091. | 1.000 | 1054. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1376. | 1407. | 1187. | 1.000 | 1067. | 4.300E+01 | 1.000E+20 | .0000 |
| 2783. | 1732. | 1051. | 860. | 1.000 | 790. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1793. | 990. | 208. | 1.000 | 576. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 6.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.000E+00 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.040E+02 | 1.000E+20 | .0000 |
| 2780. | 1958. | 822. | 808. | 1.000 | 655. | 1.240E+02 | 1.000E+20 | .0000 |
| 2780. | 2104. | 676. | 576. | 1.000 | 514. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.660E+02 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 6.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+00 | 1.000E+20 | .0000 |
| 2763. | 2352. | 411. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 4.300E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.700E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 2.280E+02 | 1.000E+20 | .0000 |
| 2496. | 2441. | 55. | 177. | 1.000 | 78. | 5.300E+01 | 1.000E+20 | .0000 |
| 2496. | 2445. | 51. | 181. | 1.000 | 77. | 2.470E+02 | 1.000E+20 | .0000 |
| 2491. | 2445. | 46. | 178. | 1.000 | 74. | 1.000E+01 | 1.000E+20 | .0000 |
| 2487. | 2445. | 42. | 175. | 1.000 | 71. | 4.300E+01 | 1.000E+20 | .0000 |
| 2487. | 2487. | 0. | 0. | 1.000 | 0. | 1.700E+01 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | | TOTAL USAGE FACTOR = | .0015 |

**Table 8: Material Properties (For Transient 9)[1]**

| Material | SA-533 Gr B @400 °F (Mn-1/2Mo-1/2Ni) | SA-508 Cl 2 @400 °F (3/4Ni-1/2Mo-1/3Cr-V) | SA-240 Type 304 @400 °F (18Cr-8Ni) | SA-182 F316 @300 °F (16Cr-12Ni-2Mo) |
|---|---|---|---|---|
| Modulus of Elasticity, $e^{-6}$ psi | 27.4 | 26.1 | 26.5 | 27.0 |
| Coefficient of Thermal Expansion, $e^{-6}$, in/in/°F | 8.0 | 7.7 | 10.2 | 9.8 |
| Thermal Conductivity, Btu/hr-ft-°F | 23.1 | 23.1 | 10.4 | 9.3 |
| Thermal Diffusivity, $ft^2$/hr | 0.378 | 0.378 | 0.165 | 0.150 |
| Specific Heat, Btu/lb-°F[2] | 0.125 | 0.125 | 0.129 | 0.127 |
| Density, lb/$in^3$ | 0.283 | 0.283 | 0.283 | 0.283 |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | 0.3 |

Notes: [1] Material Properties are evaluated at 400°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda, except for density and Poisson's ratio, which are assumed typical values. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. The safe end material properties were used for 300°F, the Code table values closest to the average temperature for the safe end for transient 9.

[2] Calculated as $[k/(\rho d)]/12^3$.

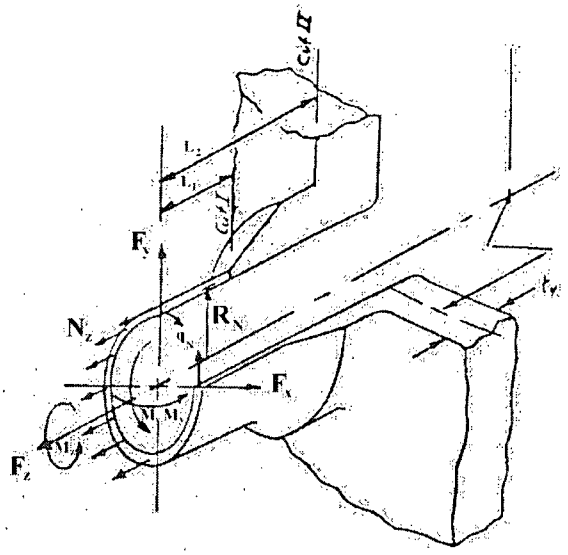



**Figure 1: External Forces and Moments on the Recirculation Outlet Nozzle**

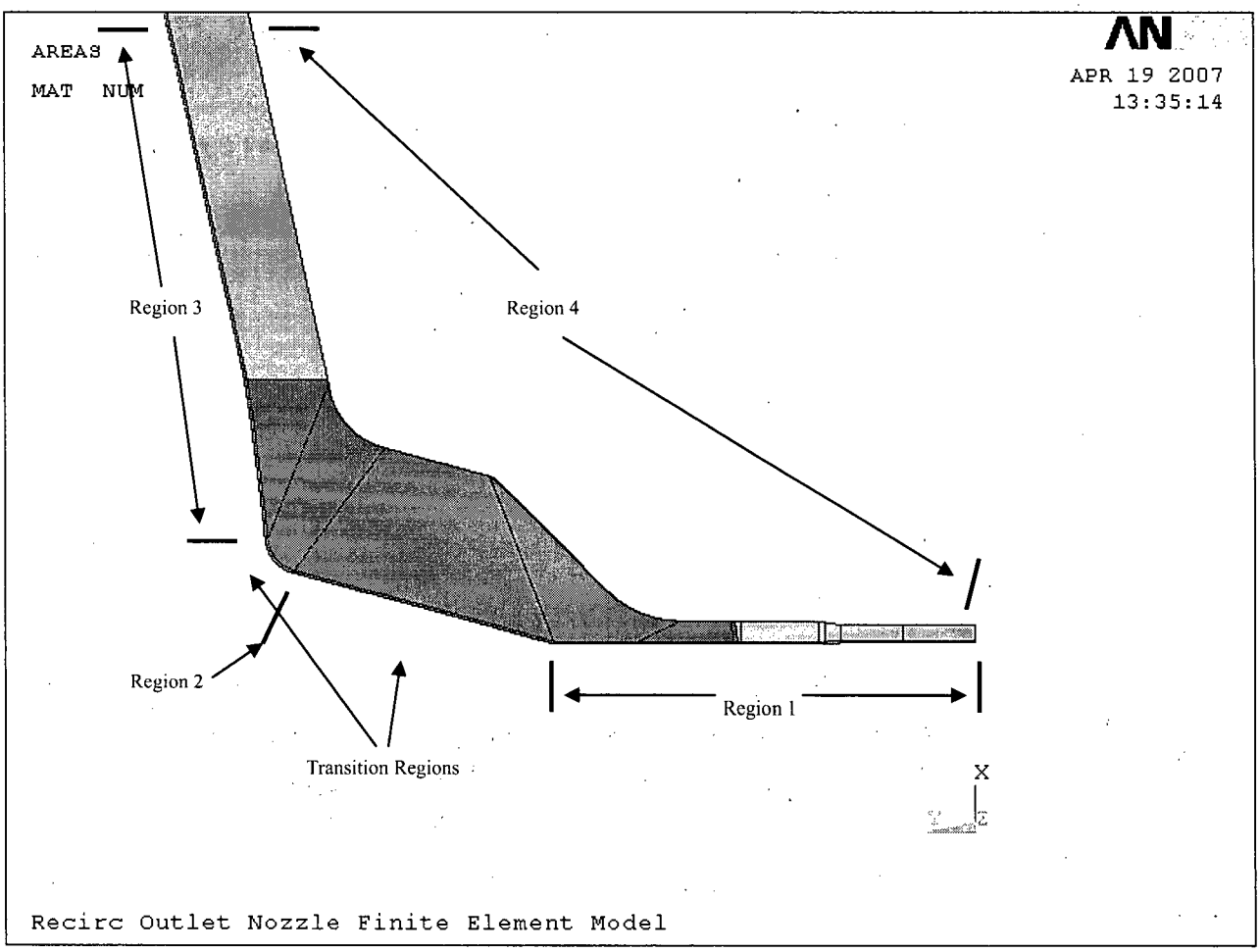



**Figure 2: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries for Transient 9**

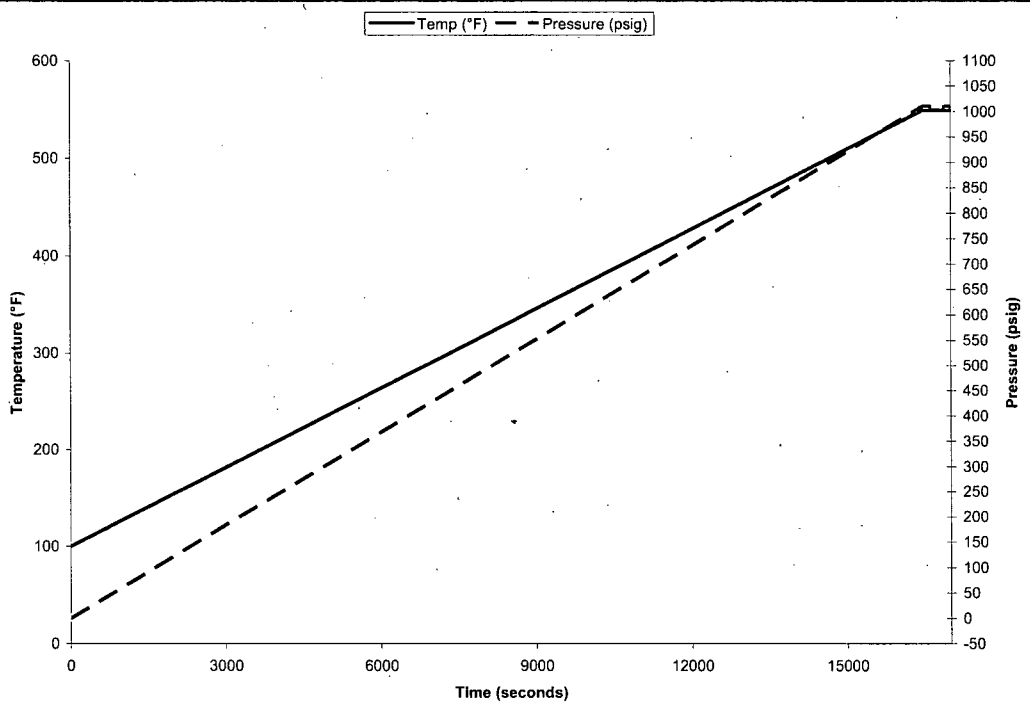



**Figure 3: Transient 1 – Normal Startup at 100°F/hr**

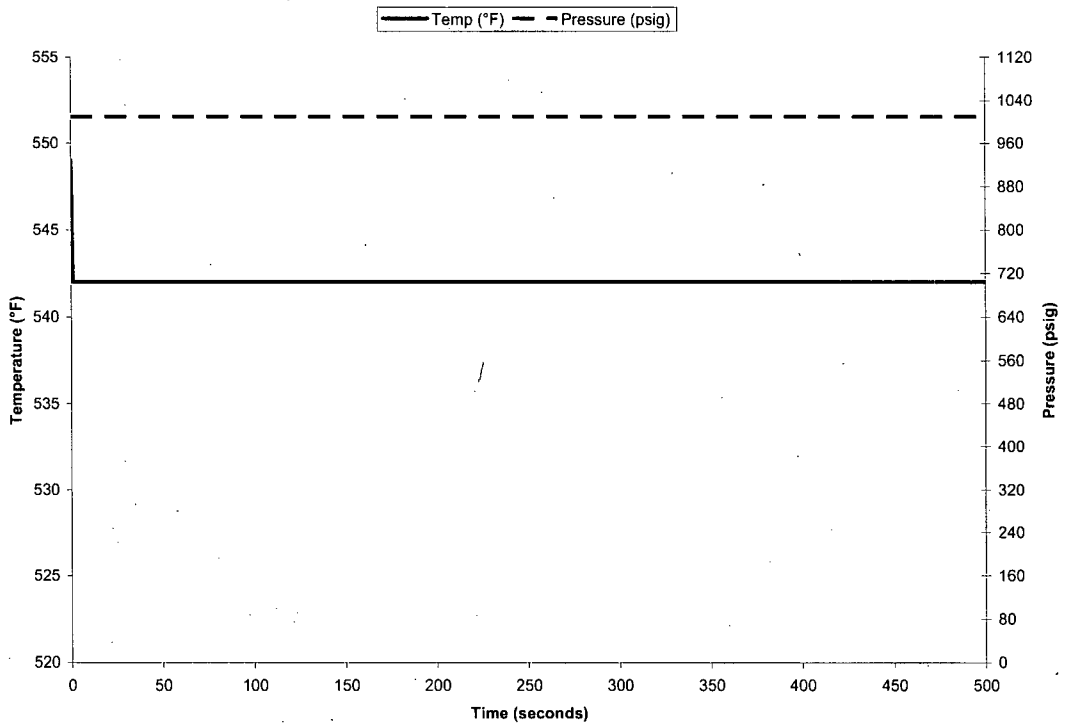



**Figure 4: Transient 2 – Turbine Roll and Increase to Rated Power**

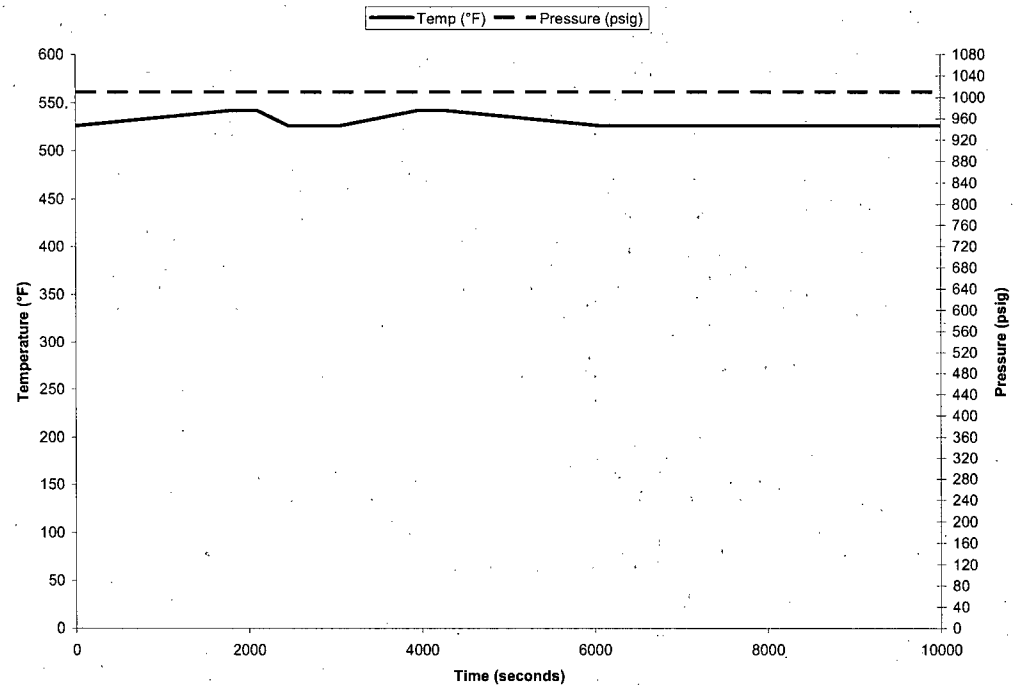



**Figure 5: Transient 3 – Loss of Feedwater Heaters and Turbine Trip 25% Power**

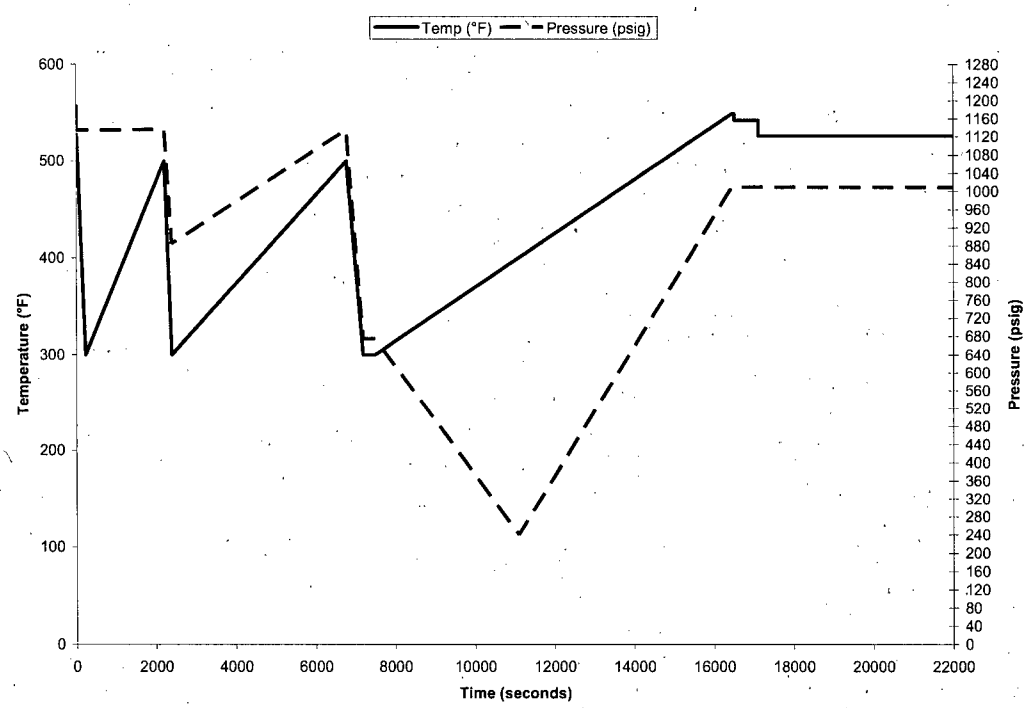



**Figure 6: Transient 4 – Loss of Feedwater Pumps**

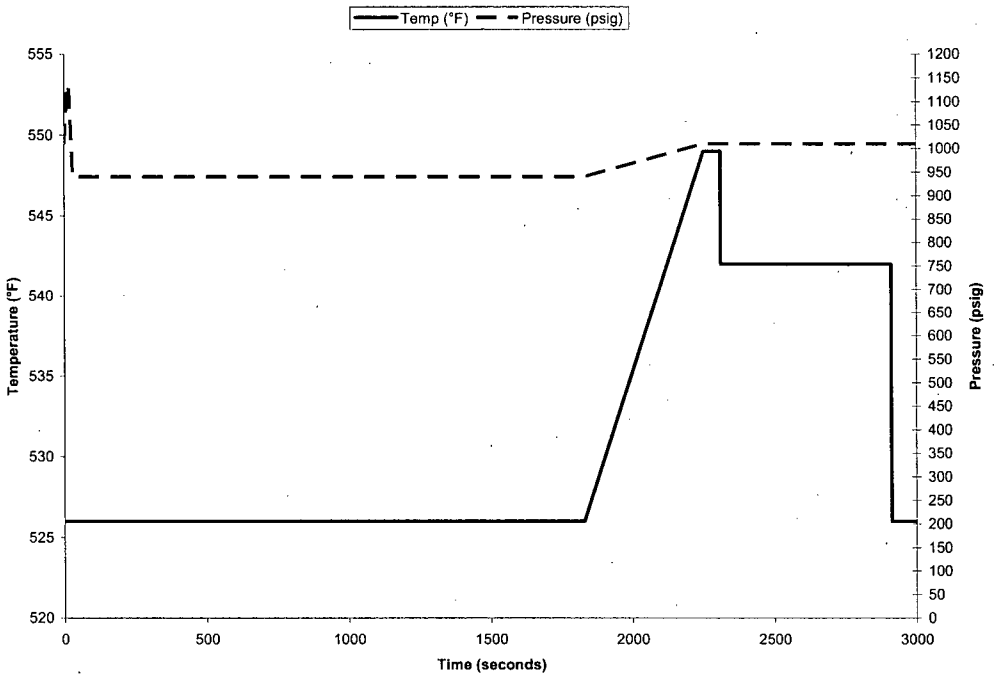



**Figure 7: Transient 5 – Turbine Generator Trip**

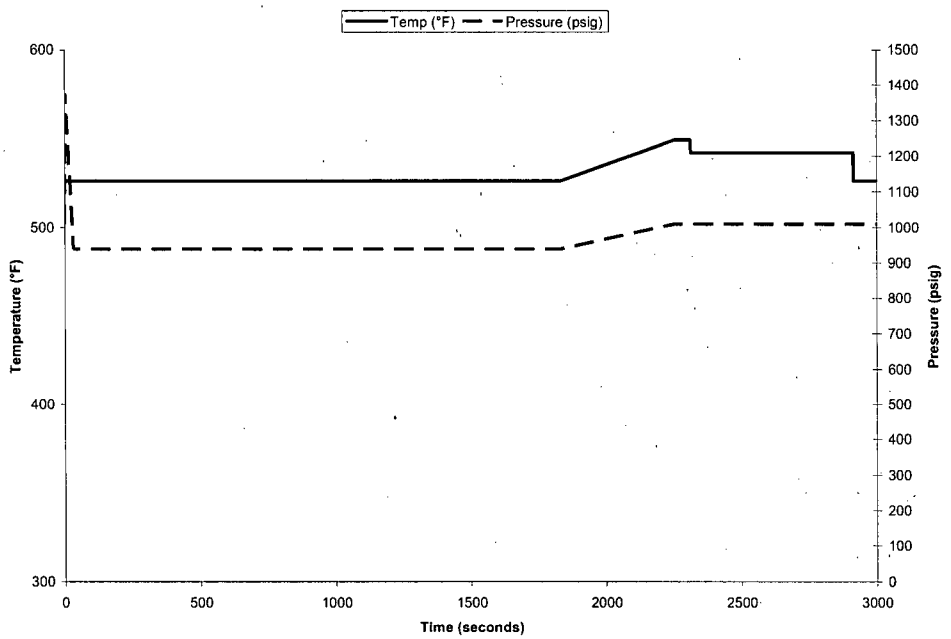



**Figure 8: Transient 6 – Reactor Overpressure**

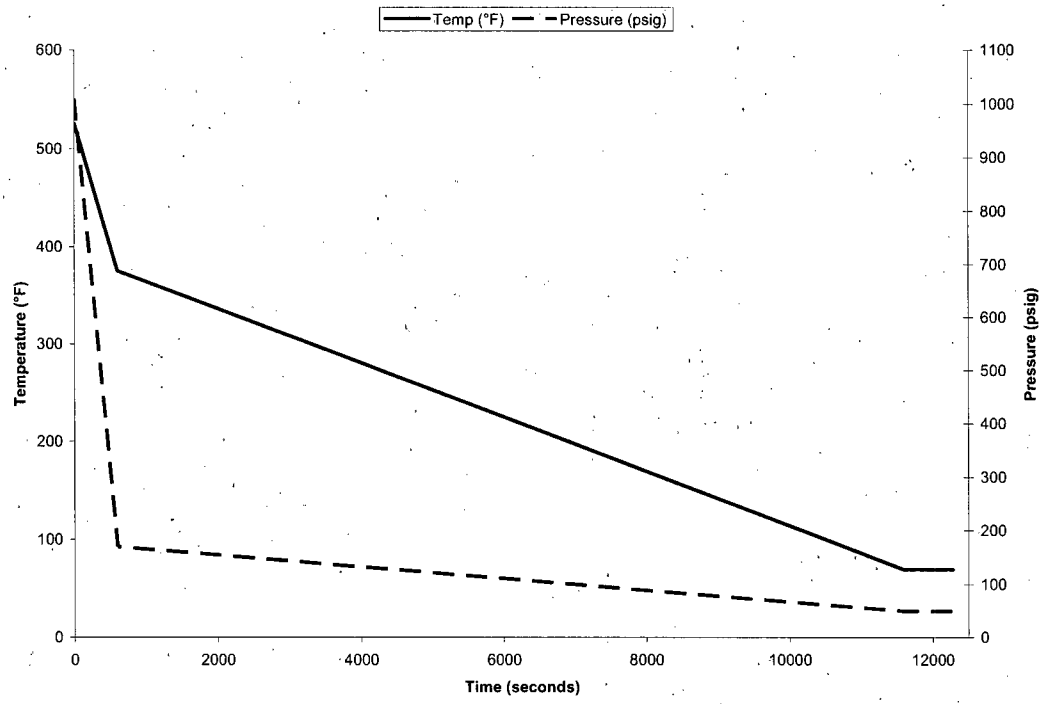



**Figure 9: Transient 7 – SRV Blowdown**

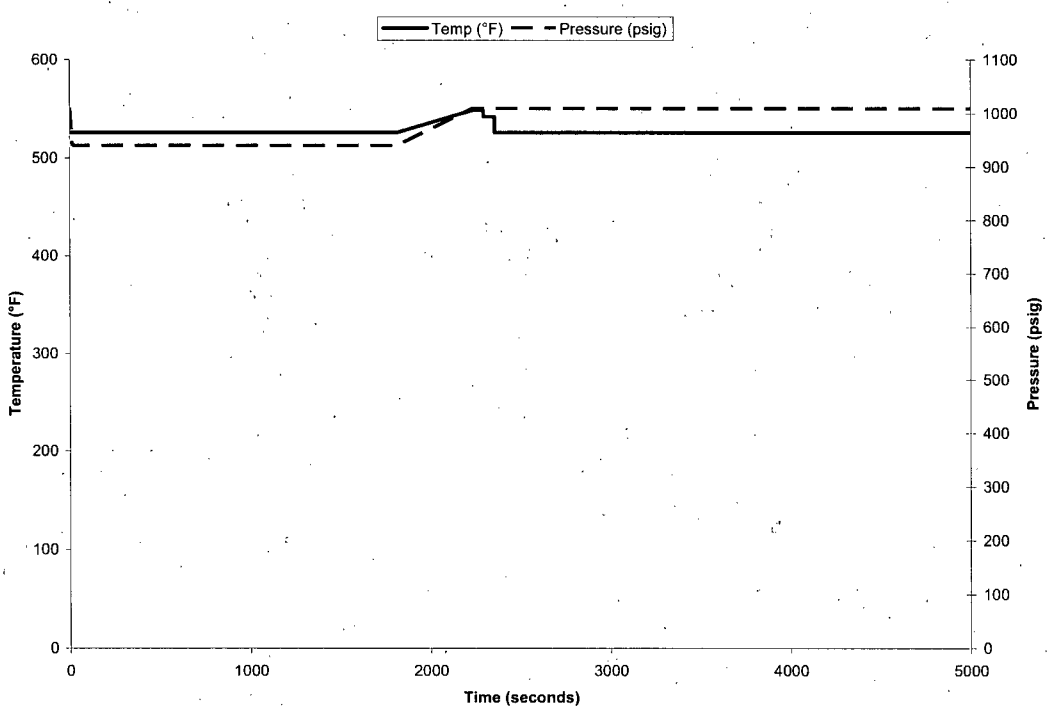



**Figure 10: Transient 8 – SCRAM Other**

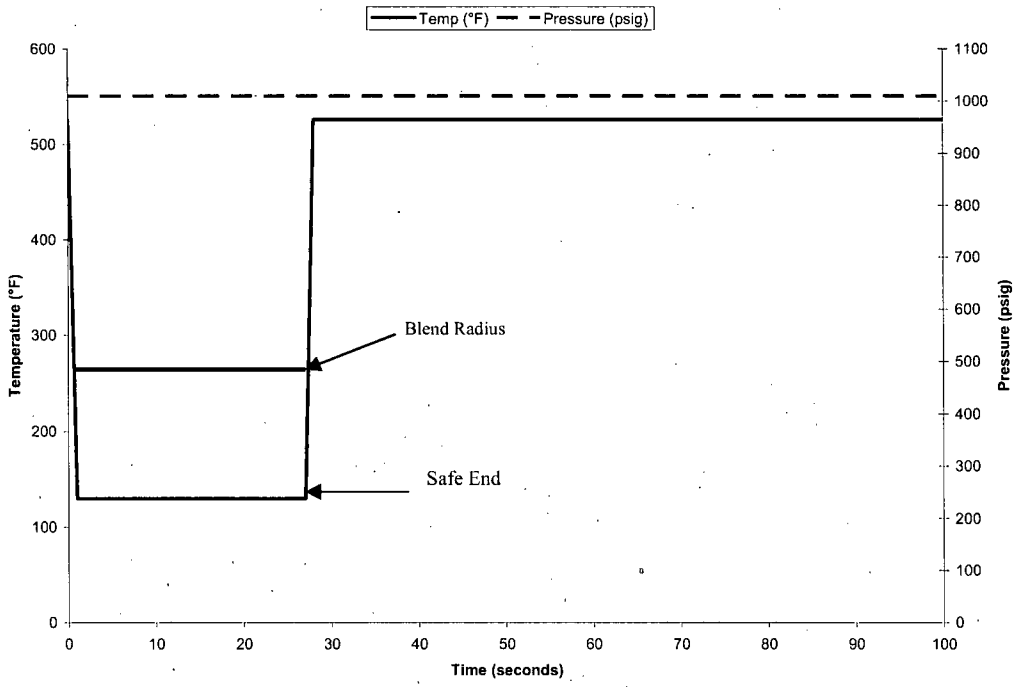



**Figure 11: Transient 9 – Improper Startup**

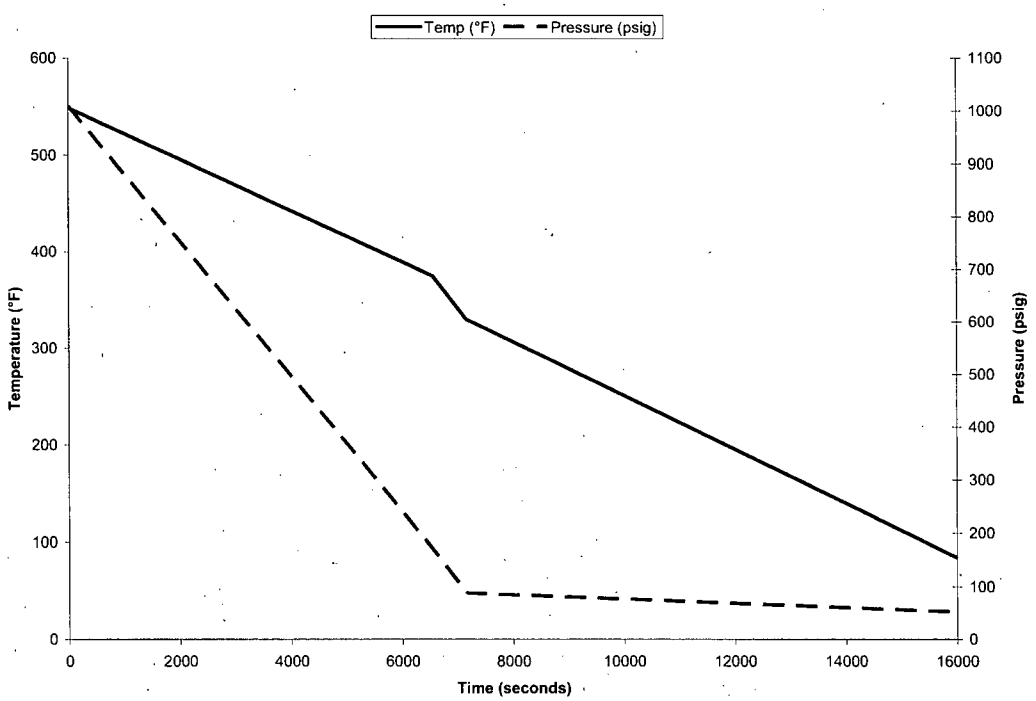
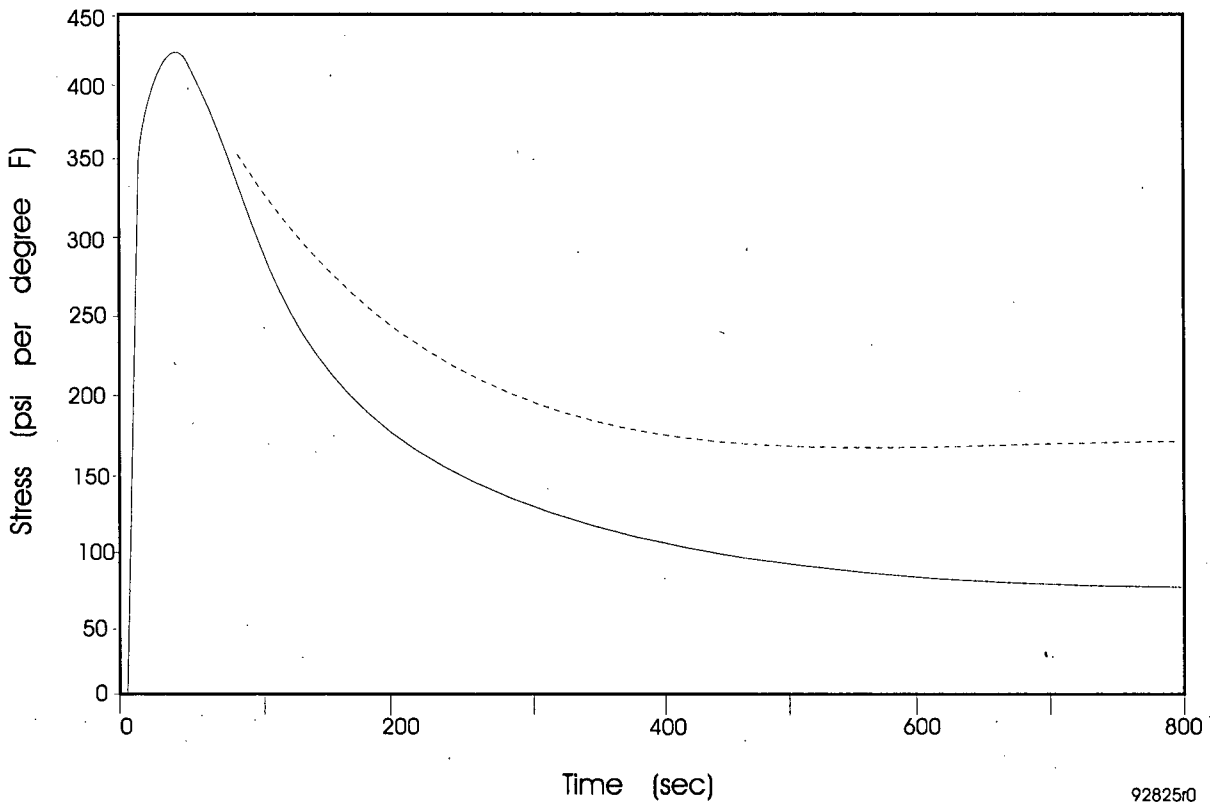



**Figure 12: Transient 10 – Shutdown**




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 13: Typical Green's Functions for Thermal Transient Stress**

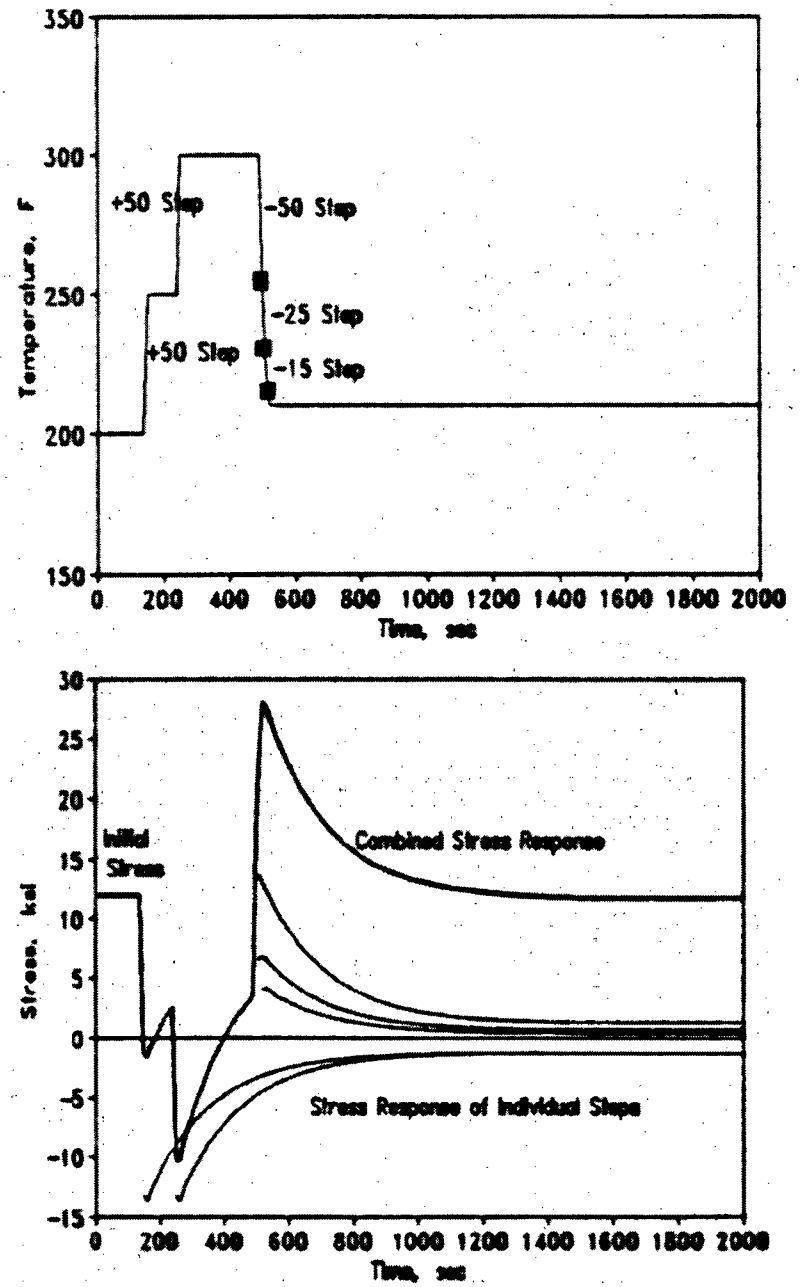



**Figure 14: Typical Stress Response Using Green's Functions**

# APPENDIX A

## SUMMARY OF OUTPUT FILES

| | | |
|---|---|---|
| VY_RON_T_T9.INP | Input File for Transient 9 Thermal Analysis | In Computer files |
| VY_RON_S_T9.INP | Input File for Transient 9 Stress Analysis | In Computer files |
| LFSE.OUT | Stress Output at Safe End | In Computer files |
| LFBR.OUT | Stress Output at Blend Radius | In Computer files |
| LFSE_INSIDE.RED | Stress Extracted at Safe End | In Computer files |
| LFBR_INSIDE.RED | Stress Extracted at Blend Radius | In Computer files |
| LFSE_T.XLS | Stress Results with Total Stress at Safe End | In Computer files |
| LFSE_M+B.XLS | Stress Results with Membrane plus Bending Stress at Safe End | In Computer files |
| LFBR_T.XLS | Stress Results with Total Stress at Blend Radius | In Computer files |
| LFBR_M+B.XLS | Stress Results with Membrane plus Bending Stress at Blend Radius | In Computer files |
| T9SE.OUT | Transient 9 Safe End stress output | In Computer files |
| T9BR.OUT | Transient 9 Blend Radius stress output | In Computer files |
| T9SE_Inside.RED | Transient 9 Stress Extracted at Safe End | In Computer files |
| T9BR_Inside.RED | Transient 9 Stress Extracted at Blend Radius | In Computer files |
| T9BR_M+B.xls | Transient 9 Stress Results with Membrane plus Bending Stress at Blend Radius | In Computer files |
| T9BR_T.xls | Transient 9 Stress Results with Total Stress at Blend Radius | In Computer files |
| T9SE_M+B.xls | Transient 9 Stress Results with Membrane plus Bending Stress at Safe End | In Computer files |
| T9SE_T.xls | Transient 9 Stress Results with Total Stress at Safe End | In Computer files |
| FATIGUE.OUT | Output file from FATIGUE.EXE | In Computer files |
| FATIGUE.inp | Input file for FATIGUE.EXE | In Computer files |
| TRANSNT_XX.inp | Input files for STRESS.EXE | In Computer files |
| P-V_XX.OUT | Output file from P-V.EXE | In Computer files |