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1.0 INTRODUCTION

Nuclear Regulatory Commission (NRC) Generic Letter (GL) 96-03 allows plants to relocate their pressure-temperature (P-T) curves and numerical values of the other P-T limits (such as heatup/cooldown) from Technical Specifications in to a Pressure Temperature Limits Report (PTLR). The Structural Integrity licensing Topical Report (LTR) SIR-05-044-A, which was reviewed and approved by the NRC in April 2007, can be referenced by any boiling water reactor (BWR) licensee, who supported development of the LTR, in a license amendment request to adopt NRC GL 96-03 requirements for a PTLR.

The LTR addresses forged nozzle configurations in that it provides a fracture mechanics solution for these nozzle designs and requires that all such nozzles in the beltline, and extended beltline due to exposure to neutron fluence, be considered as a part of P-T curve development. However, a more recent finding associated with reactor pressure vessel (RPV) instrumentation nozzles is not addressed in the LTR. The partial penetration style nozzle configuration of the RPV instrumentation nozzles is different than traditional forged nozzle designs. These nozzles have been determined to be located in the beltline plate material (or have become part of the extended beltline) where fluence exceeds $1x10^{17}$ n/cm^2 in many BWRs. As a result, the NRC has been providing Requests for Additional Information to all applicants developing PTLRs in accordance with the LTR asking for the instrument nozzles to be addressed.

The purpose of this calculation package is to introduce a fracture mechanics solution for the partial penetration style RPV instrumentation nozzles, and to calculate stress intensity factors associated with pressure and through-wall thermal gradient for a plant specific nozzle configuration in a 238 inch diameter BWR. Future calculations will determine a generic approach for addressing RPV instrumentation nozzles in P-T curve development. The generic approach will be compared to the plant specific evaluation herein to demonstrate the bounding nature of the generic approach.

2.0 METHODOLOGY

A finite element model (FEM) of the instrument nozzle is constructed, and hoop stress results are extracted along a limiting path for various loading conditions. As required by ASME Section XI, Appendix G [1], a ¼ thickness postulated flaw at the J-groove weld is assumed as shown in Figure 1. A fracture mechanics model is introduced, and a stress intensity factor is calculated for each load case.

The following topics are described separately below:

- Method of stress analysis
- Model geometry
- Load cases
- Stress extraction path
- Heat transfer coefficients
- Fracture mechanics solution

2.1 Method of Stress Analysis

A three dimensional (3-D) linear elastic finite element analysis (FEA) of the instrument nozzle is performed to obtain the nozzle stress distribution resulting from the applied load cases. The ANSYS FEA software [2] is used for all thermo-elastic stress analyses. A quarter symmetric (90°) model is used.

2.2 Model Geometry

Dimensional information given in Section 3.0, *Design Inputs,* is used to create the FEM geometry. The FEM includes a portion of the low alloy steel RPV shell, stainless steel RPV clad, stainless steel nozzle, Inconel J-groove weld, and Inconel weld butter. The extent of the RPV shell is defined such that the FEM boundaries do not introduce non-representative end effects at the location of interest.

2.3 Load Cases

The following load cases are considered:

1. Internal pressure
2. Thermal transient
3. Pipe reaction loads

2.3.1 Internal Pressure Load Case

An internal pressure of 1,000 psig is applied to the inside surfaces of the RPV and the instrument nozzle. Membrane (or cap) loads are applied to the end of the attached piping, and to the edges of the vessel shell. Since the results of the pressure load case are linear, the evaluated pressure is a "unit" loading, the results of which are scaled by the actual pressure.

2.3.2 Thermal Transient

The bounding Normal Operating thermal transients identified in the instrument nozzle stress report [3] are selected for evaluation. RPV fluid temperatures and convection coefficients are applied to the inside (wetted) surfaces on the RPV and instrument nozzle. An assumed temperature and convection coefficient are applied to the outside surfaces of the RPV and instrument nozzle (see Section 4.0, Assumption #1).

2.3.3 Pipe Reaction Loads

The load path between the instrument nozzle and the RPV passes through the J-groove weld, which is at the same location as the postulated flaw required for P-T curve analysis. Therefore, the pipe reaction loads are evaluated.

2.4 Stress Extraction Path

A linear stress path, the orientation of which is shown in Figure 1, is chosen for extracting hoop stress results. The path begins from the nozzle inner corner surface at the inside radius of the low alloy steel RPV. The path extends to the outside surface of the RPV, oriented at a 45° angle with respect to the nozzle centerline. The orientation of this path is consistent with the necessary inputs for the fracture mechanics solution for the nozzle corner crack in Section 2.6. An angle slightly less than 45° may be chosen if the nodes within the FEM may not allow a path at exactly 45°. This slight reduction in path angle does not significantly affect the results.

The pressure stress at the postulated crack location typically bounds the thermal and attached piping load stresses, often by a significant margin. The pressure stress in a cylinder is highest in the hoop direction. Therefore, the limiting postulated crack is perpendicular to both the RPV and nozzle hoop directions. That is, the limiting postulated crack lies on a plane coincident with the RPV axis and the nozzle axis. The limiting path also lies on this plane. In addition, the thermal stress results are essentially constant around the axis of symmetry of the nozzle. Therefore, any crack oriented perpendicular to the nozzle hoop direction will have essentially equal thermal stress results. A single, limiting path may be chosen for pressure and thermal stress extraction rather than extracting stresses from a unique path for each load case and combining the results. The limiting location due to the attached piping load may require selecting an additional path for stress extraction. If the stress due to the attached piping load is significant, the stress results for each load case will be analyzed as if they were pulled from a single, limiting path.

2.5 Heat Transfer Coefficients

Convection heat transfer between the RPV coolant or drywell air and the structure is considered along both the inside and outside surfaces of the RPV and nozzle. Heat transfer across the air gap is also considered.

2.5.1 Convection Heat Transfer

A forced convection coefficient is calculated in Reference [3] for the wetted surface of the vessel wall (see Section 3.0) for each thermal transient. Since there is no bulk flow in the instrument nozzle, the only fluid flow is due to natural convection and mixing near the RPV inside surface. Because the relative fluid velocities of each of these flows are small when compared to the core flow, a heat transfer coefficient based on either flow will be less than the forced convection coefficient at the inner surface of the RPV. Therefore, the RPV inside convection coefficient is conservatively applied to the inside surface of the instrument nozzle.

A convection coefficient of 0.2 Btu/hr-ft^2-°F is applied to the external surfaces of the RPV and instrument nozzle (see Section 3.0); this value considers the effect of radiation from the exterior surfaces of the insulation (see Section 4.0, Assumption #2).

2.5.2 Air Gap Heat Transfer

Convection heat transfer is not modeled in the air gap. The air gap is very narrow, approximately 0.01 inches (see Section 3.0), and does not experience forced flow. This suggests that viscous effects would tend to restrain air flow driven by a fluid density gradient between the nozzle and RPV surfaces.

Radiation heat transfer across the air gap can be estimated by assuming the sides of the air gap are two infinite plates. Both sides can be considered gray surfaces, and the radiation heat transfer rate between the plates can be calculated by [4]:

$$q_{12,net} = A \cdot F_{12} \sigma \left(T_1^4 - T_2^4 \right) \quad (1)$$

$$F_{12} = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \quad (2)$$

where:

A = Area of each plate, ft^2
F_{12} = View factor
σ = Stephan-Boltzmann constant = 0.1713×10^{-8} Btu/hr-ft^2-°R^4
T_1 = Surface temperature of hot component, °R
T_2 = Surface temperature of cool component, °R
$\varepsilon_1, \varepsilon_2$ = Material emissivity

A temperature difference ($T_1 - T_2$) of 50°F is assumed for an initial comparison with the heat transfer rate for conduction across the air gap. Because the temperature terms in Equation 1 are raised to the fourth power, the maximum possible radiation heat transfer rate for a 50°F temperature difference occurs when T_1 is at the maximum temperature of any of the analyzed thermal transients (552°F = 1,012°R, see Section 3.0). The limit of Equation 2 is one, and can be conservatively used in the analysis. The radiation heat transfer rate per unit area can be calculated from Equation1 as:

$$\frac{q_{12,net}}{A} = \sigma\left(T_1^4 - T_2^4\right) = 329 \text{ Btu/hr-ft}^2$$

Because the radial distance across the air gap is relatively small compared to the radius of the air gap, the conduction heat transfer can be approximated as conduction across a flat plate. The heat transfer rate per unit area across the air gap due to conduction is calculated as follows [4]:

$$\frac{q}{A} = \frac{k_{air}}{w_{gap}}\left(T_1 - T_2\right) \quad (3)$$

where:

k_{air} = Thermal conductivity of air, Btu/hr-ft-°F
w_{gap} = width of air gap, ft

The temperature difference is again chosen as 50°F for the initial comparison. The thermal conductivity of air is linearly interpolated at the average temperature (maximum temperature of any of the analyzed thermal transients minus half the temperature difference = 527°F), which is 0.0236 Btu/hr-ft-°F (see Section 3.0 for design inputs). The air gap width, calculated from Figure 2, is 0.01 inch = 8.3×10^{-4} ft. Solving Equation 3 then yields a value of 1,416 Btu/hr-ft^2, which is relatively constant for all $T_1 - T_2$ values equal to 50°F. By comparison, the maximum possible radiation heat transfer rate for the same temperature difference is approximately 23% of that for conduction. The effects of radiation may influence the results, and should be considered in the thermal analysis.

2.6 Fracture Mechanics Solution

For the instrument nozzle, as a minimum, the stress concentration effect of the nozzle on the plate material should be addressed as part of P-T curve development. This can be accomplished with the use of a fracture mechanics model that applies to the partial penetration style nozzle. Calculation of the stress intensity factor, K_I, is based on a quarter circular crack in an infinite quarter space [5]. The fracture mechanics model and associated equation used to calculate K_I are shown in Figure 3 [5]. The K_I equation is reproduced here:

$$K_I = \sqrt{\pi a}\left(0.723A_0 + 0.551A_1\frac{2a}{\pi} + 0.462A_2\frac{a^2}{2} + 0.408A_3\frac{4a^3}{3\pi}\right) \quad (4)$$

where:

a	=	¼ through-wall postulated flat depth, in
A_0,A_1, A_2,A_3	=	pressure or thermal stress polynomial coefficients, obtained from a curve-fit of the extracted hoop stresses from an FEM analysis

The nozzle is made of austenitic stainless steel (see Section 3.0) and is not a concern for brittle fracture [1]. Therefore, analysis of the nozzle material is not required.

3.0 DESIGN INPUTS

Dimensional data for the 2-inch instrument nozzle are taken from References [6], [7], and [8]. Figure 2 and Figure 4 illustrate the nozzle dimensions. The major dimensions of the model are:

Nozzle inner diameter (ID)	=	0.968 in [7]
Nozzle outer diameter (OD)	=	2.397 in [6]
	=	2.617 in [6]
Vessel penetration IDs	=	2.417 in [6]
	=	2.637 in [6]
Vessel base metal thickness	=	6 in [8]
Vessel base metal inside radius	=	120 3/16 in [8]
Vessel clad thickness	=	3/16 in [6]

The materials of the various components included in the instrument nozzle FEM are listed here and in Table 1.

RPV Shell:	SA-533 Gr. B Class 1 [3]
RPV Cladding:	Stainless Steel Type 304 (see Section 4.0, Assumption #3)
Nozzle Forging:	SA-336 F8 [3], use Stainless Steel Type 304 (see Section 4.0, Assumption #4)
Weld Butter:	Inconel [3], use Alloy 600 (see Section 4.0, Assumption #5)
Weld:	Inconel [3], use Alloy 600 (see Section 4.0, Assumption #5)

The material property data for the structural materials (Young's Modulus, E, thermal expansion coefficient, α, thermal conductivity, k, and specific heat, c_p) are obtained from Reference [9]. The Inconel material properties are assumed to be equivalent to those of Alloy 600 (see Section 4.0, Assumption # 5). These properties are presented in Table 2 through Table 4. The thermal property data for dry air (thermal conductivity, k_{air}, specific heat, c_{p_air}, and density, ρ_{air}) are obtained from Reference [10, Appendix 35.C] and shown in Table 5. The supporting file, *MATPROPS.INP*, is created for use in the ANSYS analysis; it is discussed further in Appendix A and reproduced in Appendix B.

Reference [3] identifies four limiting Normal and Upset thermal transients. The Safety Valve Blowdown transient is typically a scram event, and would normally be classified as an Upset event. As a result, it is beyond the scope of analysis for P-T Curve evaluation. The remaining three Normal Opertating transients that need to be considered are:

1. Design Hydrotest
2. Startup and Turbine Roll
3. Shutdown and Vessel Flooding

The design hydrotest involves a temperature step change from 100°F to 60°F for the nozzle fluid, but the RPV temperature remains constant at 100°F. Because the step change is relatively small, and is isolated to the instrument nozzle, the design hydrotest is not expected to produce significant stresses in the area of interest. The startup and turbine roll transient consists mainly of a 100°F/hr increase from 100°F to 552°F. After one hour at operating temperature, there is a small step change followed by a 30 minute cool down at 32°F/hr; the final temperature is 528°F. Assuming that there is no ramp, and the total temperature decrease is due to a step change, the resulting step change is only a decrease of 24°F. Therefore, the last portion of the startup transient is not expected to produce significant stresses in the area of interest. The shutdown and vessel flooding transient consists mainly of a -100°F/hr cool down ramp. In this case, the shutdown transient bounds the startup because the cooling effect produces tensile stresses at the RPV inner surface, which in turn produces a higher thermal stress intensity factor at the postulated crack location. In addition, there is a ten minute period in the shut down transient where the cooling rate exceeds -100°F/hr. Therefore, the shut down transient bounds all other Normal Operating transients and is the only transient that requires analysis.

Reference [3] lists the heat transfer coefficients at the RPV for the shutdown and vessel flooding transient. Bounding heat transfer coefficients are used in the analysis. The resulting boundary conditions are shown in Table 6. Note that 10,000 seconds is assumed after the transient for the model to reach steady state. Figure 5 graphically demonstrates the shutdown and vessel flooding transient temperature. As stated in Section 2.5.1, the boundary conditions of the wetted RPV surface are conservatively applied to the inside surface of the instrument nozzle.

The heat transfer coefficient for the RPV and nozzle external surfaces is given as 0.2 Btu/hr-ft2°F [3]. An ambient temperature of 100°F is assumed for all times during the transient (see Section 4.0, Assumption #1).

4.0 ASSUMPTIONS

The following assumptions are used in the analysis.

1. The heat transfer coefficient of all external surfaces is given as 0.2 Btu/hr-ft^2-°F [3]. The ambient temperature is assumed to be 100°F. The assumed temperature does not have a significant effect on the results of the analysis since the heat transfer coefficients, shown in Table 6, at the internal surfaces are more than three orders of magnitude greater than the external surface heat transfer coefficient of 0.2 Btu/hr-ft^2-°F.
2. The external convection coefficient in Assumption 1 is an overall heat transfer coefficient and accounts for the effect of insulation and radiation from the exterior surface of the insulation.
3. Reference [3, sht 3] identifies the RPV cladding material as "Stainless – SA 304." It is assumed that the intent of this designation is Stainless, Type 304 (18Cr-8Ni). This is supported by the fact that the RPV cladding and instrument nozzle forging have identical material properties in Reference [3]. The instrument nozzle forging material is 18Cr-8Ni (see Assumption # 4 below).
4. The instrument nozzle forging is identified as SA-336 F8 in Reference [3]. However, this material designation does not exist in the 2004 Edition of the ASME Code [9]. A previous version of the ASME Code, Section II, Part A [11] identifies SA-336 F8 as an austenitic stainless steel forging, with material properties that fall within the Type 304 specification range. Therefore, SA-336 F8 is assumed to have material properties identical to stainless steel Type 304 (18Cr-8Ni).
5. Material properties for the weld components listed in Table 1 are assumed based on practices established in the ASME Boiler and Pressure Vessel (B&PV) Code, Section IX [12]. Weld material properties are based on weld procedure qualifications. Testing is the only way to verify the properties. In general, the failure location is in the base metal during material failure tests. Therefore, applying the weaker base metal properties instead of weld material properties is typically considered conservative. Since the chemical composition of Alloy 600 (N06600) is close to that of Inconel, Alloy 600 material properties are used for Alloy 82/182.
6. The residual stresses due to the application of austenitic cladding are insignificant at or near normal operating temperature, for both the cladding and the RPV base metal [13]. Therefore, a stress free temperature of 550°F is assumed for all materials in this evaluation. The choice of stress free temperature will affect the magnitude of the differential thermal expansion stresses induced in the nozzle assembly.
7. Density and Poisson's ratio are assumed temperature independent for all materials. In addition, typical values are assumed for these values.

5.0 FINITE ELEMENT MODEL

A 3-D FEM is constructed in ANSYS [2] using the dimensions shown in Figure 2 and Figure 4. Three dimensional SOLID45 elements are used for structural analyses, and 3-D SOLID70 elements are used for thermal analyses. Results are reviewed to ensure that there is no contact between the instrument nozzle and RPV bore. Figure 6 illustrates the quarter symmetric model. Figure 7 shows a close-up view of the as-modeled nozzle forging, J-groove weld, and RPV clad.

The stainless steel RPV clad, Inconel J-groove weld, Inconel butter, and stainless steel instrument nozzle are modeled as separate materials. The air in the gap between the instrument nozzle and RPV shell is modeled for the thermal analysis only.

6.0 INSTRUMENT NOZZLE LOAD CASES

The applied loads and boundary conditions for each load case are described below.

6.1 Internal Pressure Load Case

A uniform internal pressure of 1,000 psig is applied along the inside surface of the instrument nozzle and RPV wall. Consistent with the intent of ASME Code, Section III [14], the RPV clad is not considered for the pressure load case. Pressure on the crack face is not simulated; this is consistent with ASME XI, Appendix G [1]. For this load case, the clad elements are removed and the internal pressure is applied directly to the low alloy steel RPV shell. To eliminate any potential differential thermal expansion stresses, the analysis is run at the stress free temperature (see Section 4.0, Assumption #6).

In addition, membrane or "cap" loads are applied to the end of the nozzle and to the RPV shell to account for closed-end effects of the attached piping and vessel. The membrane loads were calculated as follows:

$$P_{CAP} = \frac{P \cdot R_i^2}{R_o^2 - R_i^2} \quad (5)$$

where:

P = Internal pressure (P = 1,000 psig)
R_i = Inner radius of cylindrical section, in
R_o = Outer radius of cylindrical section, in

Using Equation 5, the nozzle membrane load is 195 psi (with P = 1,000 psi, R_i = 0.968/2, R_o = 2.397/2). This membrane load is applied such that it acts as a tensile load on the instrument nozzle. The nodes on the free end of the nozzle are coupled in the nozzle axial degree of freedom to ensure equal axial displacement of the end of the nozzle in response to the membrane load to simulate the effects of the attached piping.

Using Equation 5, the RPV shell membrane load is 9,772 psi (with P = 1,000 psi, R_i = 120 3/16, R_o = 126 3/16). The nodes on the end of the RPV are coupled in the longitudinal degree of freedom of the RPV to ensure equal axial displacement of the end of the RPV.

Symmetry boundary conditions are applied to both lateral boundaries of the FEM, as well as to the RPV shell opposite the applied membrane load.

Figure 8 and Figure 9 illustrate the applied loads and boundary conditions for the pressure load case.

The following ANSYS input files for the pressure load case are discussed in Appendix A and reproduced in Appendix B:

MATPROPS.INP:	Material properties
IN.INP:	Geometry input file
IN_PRESS.INP:	Pressure load case

6.2 Thermal Transient

As shown in Section 3.0, the bounding Normal Operating thermal transient from Reference [3] is the shutdown and vessel flooding transient. The boundary conditions for this transient are given in Section 3.0, and are shown in Table 6.

Adiabatic conditions are applied to the boundaries of the RPV shell; this is consistent with the symmetry structural boundary conditions and prevents heat flow across the areas where symmetry is expected. On the other two boundaries the adiabatic condition is reasonable because they are far from the instrument nozzle, and a large axial thermal gradient is not expected in the RPV during the thermal transient.

The SOLID70 element type is used for thermal analysis and the SOLID45 element type is used for subsequent stress analysis. During the thermal analysis, the air elements between the nozzle and the vessel bore are activated to simulate the conduction heat transfer between the two surfaces. These elements are unselected during the subsequent stress analysis. The RPV clad is considered in both the thermal and stress analyses so that the differential thermal expansion stresses induced by the cladding are captured.

The thermal stress analysis is performed in two parts. First, a thermal run is completed using SOLID70 elements. A temperature solution is output from the thermal run. A stress run is then completed using SOLID45 elements. The stress run uses the temperature solution from the thermal run as input. The temperatures are applied to the model for each time step, and thermal stresses are calculated. As stated previously, symmetric boundary conditions are applied to the symmetry faces of the instrument nozzle model, and the nodes at the end of the nozzle are coupled in the axial direction to simulate the effects of the attached piping.

Section 2.5.2 specifies that the effects of radiation should be considered in the analysis. Because the air gap is modeled as a solid to account for conduction heat transfer, the thermal conductivity of the air can be increased to account for radiation heat transfer. This is consistent with the analysis conducted in Reference [3]. Based on the calculations in Section 2.5.2, radiation heat transfer can be as much as 23% of the heat transfer due to conduction. Therefore, the thermal conductivity of air in Table 5 is increased by 23%. Although accounting for radiation in this method introduces a time component to the heat transfer, it can be seen by the temperature value and temperature difference that the heat flux due to radiation is small. This methodology is valid as long as the temperature difference between the nozzle and RPV bore is less than 50°F.

Figure 10 illustrates the applied loads and boundary conditions for the thermal transient analysis. The structural boundary conditions for the stress solution of the thermal transient are identical to that shown in Figure 9.

The following ANSYS input files for the thermal analyses are discussed in Appendix A and reproduced in Appendix B:

MATPROPS.INP:	Material properties
IN.INP:	Geometry input file
IN-HTBC.INP:	Heat transfer boundary conditions
SHUTDOWN-T.INP:	Shut down, thermal analysis
SHUTDOWN-T_mntr.INP:	Shut down, thermal monitoring file
SHUTDOWN-S.INP:	Shut down, stress analysis

6.3 Pipe Reaction Load Case

Table 7 summarizes the design mechanical pipe reaction loads identified in the Design Report [8]. Only a small design moment loading is specified; a hand calculation will be performed to show that the resulting stress is negligible.

7.0 THERMAL, PRESSURE, AND PIPING LOAD RESULTS

This section presents the results of each load case, separately.

The stress extraction path for all load cases is chosen starting from the instrument nozzle corner at the vessel inner diameter (Node 34,651) in the axial direction along the vessel. This path then travels at a 45° angle through the thickness of the vessel base metal (Node 9,852). Figure 11 shows this path on the FEM.

7.1 Internal Pressure Load Case

Figure 12 through Figure 14 illustrates the radial, axial, and circumferential stress distributions from the pressure load case, respectively. For this case and the thermal transient load case, the radial, axial, and circumferential directions refer to a cylindrical coordinate system whose axial direction is along the axis of the instrumentation nozzle. The "11" shown in the figures represents the origin of this coordinate system. Note that the radial and axial stress distributions are presented for completeness, since only the circumferential, or hoop, stresses are used in calculation of the stress intensity factors. The contour scales for Figure 12 through Figure 14 have been truncated to exclude the peak stresses at the nozzle to RPV shell discontinuity. Since the analysis is linear elastic, and because the FEM includes the small gap between the instrument nozzle and RPV with a fine mesh in this region, the stress solution exhibits a large elastic pseudo-stress adjacent to the geometric discontinuity. The contour scale selected for the plot excludes these peak stresses such that the stress distribution throughout the remainder of the instrument nozzle is more clearly illustrated.

Figure 18 shows the path hoop stress distribution for the internal pressure load case. As can be seen in Figure 18, several data points are heavily influenced by the proximity of the air gap. Inclusion of these points artificially lowers the stress intensity factor due to pressure. Therefore, these points are conservatively excluded from the polynomial curve fit. Applying the polynomial coefficients from Figure 18, along with the ¼ path postulated crack length of 2.121 inches, to Equation 4 yields a stress intensity factor due to unit pressure, $K_{Ip\text{-}applied}$, of 69.4 ksi√in. The stress intensity factor is shown in Table 8.

7.2 Thermal Transient Load Case

Section 2.5.2 presents a comparison of heat transfer due to conduction and the heat transfer due to radiation across the air gap. As stated previously, heat transfer due to radiation is accounted for by an increase in the thermal conductivity in the air gap. The limit of applicability is a temperature difference between the nozzle and RPV of less than 50°F. The temperature difference is monitored at the location shown in Figure 11. Examination of the results shows that the 50°F condition has been met.

The hoop stresses are extracted for all time steps along the path shown in Figure 11. A third order polynomial curve fit is then conducted for each time step. Applying the polynomial coefficients and the ¼ path postulated crack length of 2.121 inches to Equation 4, a thermal stress intensity factor is calculated for all time steps. The maximum K_{IT} of 38.6 ksi√in occurs at time t=11,542 seconds and is shown in Table 8. Figure 15 through Figure 17 illustrates the radial, axial, and circumferential stress distributions for this load case at time t = 11,542 seconds. Figure 19 shows the path hoop stress distribution for the shutdown transient at time t = 11,542 seconds. Note that the effect of the air gap on the thermal hoop stresses is not nearly as pronounced as the effect on the pressure hoop stresses. As a result, all data points in Figure 19 are used in the polynomial curve fit.

7.3 Pipe Reaction Load Case

The stress due to the attached piping loads, shown in Table 7, was calculated using the following formula:

$$\sigma = \frac{M \cdot c}{I} \qquad (6)$$

where:

M	=	Moment acting on nozzle due to attached piping, in-kips
c	=	distance from neutral axis, equal to outer radius of nozzle, in
I	=	Moment of inertia of instrument nozzle, in^4

Using Equation 6, the stress in the nozzle is less than 1.5 ksi. The stress at the ¼ thickness postulated flaw location would be much small than that calculated for the nozzle. Therefore, the piping loads are insignificant and are not considered in the analysis.

8.0 DISCUSSIONS

The Structural Integrity licensing Topical Report (LTR) SIR-05-044-A is being revised to address the partial penetration style configuration of the RPV instrumentation nozzles. The LTR may be referenced by any BWR licensee, who supported development of the LTR, in a license amendment request to adopt NRC GL 96-03 requirements for a PTLR. The current LTR addresses forged nozzle configurations, but not the partial penetration style instrumentation nozzles. This calculation develops stress intensity factors due to unit pressure and thermal transients for an instrument nozzle in a 238 inch diameter BWR. The attached piping loads are small, and have been shown to create insignificant stresses in the area of interest.

There are no specific stress intensity factor limits that apply to this calculation. Rather, the stress intensity factors developed herein are used to address the partial penetration style configuration of the RPV instrumentation nozzles when developing P-T curves. The resulting stress intensity factors are summarized in Table 8.

9.0 REFERENCES

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14. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components," 2004 Edition with no Addenda.

Table 1: List of Component Materials.

Component	Material	Reference
RPV Shell	SA-533 Gr. B Class 1	[3]
RPV Cladding	Stainless Steel Type 304(1)	[3]
Nozzle Forging	SA-336 F8 (use Stainless Steel Type 304)(2)	[3]
Weld Butter	Inconel (use N06600)(3)	[3]
Weld	Inconel (use N06600)(3)	[3]

Notes:
1. See Section 4.0, Assumption #3.
2. See Section 4.0, Assumption #4.
3. See Section 4.0, Assumption #5.

Table 2: Material Properties for SA-533, Grade B, Class 1 (Mn-1/2Mo-1/2Ni) [9].

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Mean Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/ lb_m -°F)
70	29.0	7.0	23.7	0.106
200	28.5	7.3	23.5	0.113
300	28.0	7.4	23.4	0.119
400	27.6	7.6	23.1	0.125
500	27.0	7.7	22.7	0.130
600	26.3	7.8	22.2	0.135

Density (ρ) = 0.283 lbm/in^3, assumed temperature independent (see Section 4.0, Assumption #7).
Poisson's Ratio (υ) = 0.3, assumed temperature independent (see Section 4.0, Assumption #7).

Table 3: Material Properties for Stainless Steel, Type 304 (18Cr-8Ni) [9].

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Mean Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/ lb_m -°F)
70	28.3	8.5	8.6	0.114
200	27.5	8.9	9.3	0.119
300	27.0	9.2	9.8	0.122
400	26.4	9.5	10.4	0.126
500	25.9	9.7	10.9	0.129
600	25.3	9.8	11.3	0.130

Density (ρ) = 0.29 lbm/in^3, assumed temperature independent (see Section 4.0, Assumption #7).
Poisson's Ratio (υ) = 0.3, assumed temperature independent (see Section 4.0, Assumption #7).

Table 4: Material Properties for Alloy 600 (UNS6600) [9].

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Mean Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/ lb_m -°F)
70	31.0	6.8	8.6	0.108
200	30.3	7.1	9.1	0.113
300	29.9	7.3	9.6	0.116
400	29.4	7.5	10.1	0.118
500	29.0	7.6	10.6	0.120
600	28.6	7.8	11.1	0.122

Density (ρ) = 0.300 lbm/in^3, assumed temperature independent (see Section 4.0, Assumption #7).
Poisson's Ratio (υ) = 0.3, assumed temperature independent (see Section 4.0, Assumption #7).

Table 5: Dry Air Properties [10, Appendix 35.C].

Temperature (°F)	Density (lb_m/ft^3)	Thermal Conductivity (Btu/hr-ft-°F)	Modified Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lb_m-°F)
32	0.081	0.014	0.0172	0.240
100	0.071	0.0154	0.0189	0.240
200	0.060	0.0174	0.0214	0.241
300	0.052	0.0193	0.0237	0.243
400	0.046	0.0212	0.0261	0.245
500	0.0412	0.0231	0.0284	0.247
600	0.0373	0.0250	0.0308	0.250

Table 6: Shutdown and Vessel Flooding Transient [3].

Transient	Time (s)	Fluid Temperature (°F)	Heat Transfer Coefficient (Btu/hr-ft^2-°F)		
			Vessel	Nozzle	Outside
Shutdown	0	552	650	650	0.2
	10,872	250	450	450	0.2
	11,472	205	400	400	0.2
	15,252	100	275	275	0.2
	25,252[(1)]	100	275	275	0.2

1. 10,000 seconds assumed for steady state conditions to be reached

Table 7: Piping Loads [8].

F (kips)	M (in-kips)
0	2.560

Table 8: Summary of Stress Intensity Factors.

Unit Pressure Stress Intensity Factor(1)	69.4 ksi√in
Maximum Thermal Stress Intensity Factor(2)	38.6 ksi√in

1. 1000 psig internal pressure load case.
2. Shutdown and Vessel Flooding Thermal Transient.

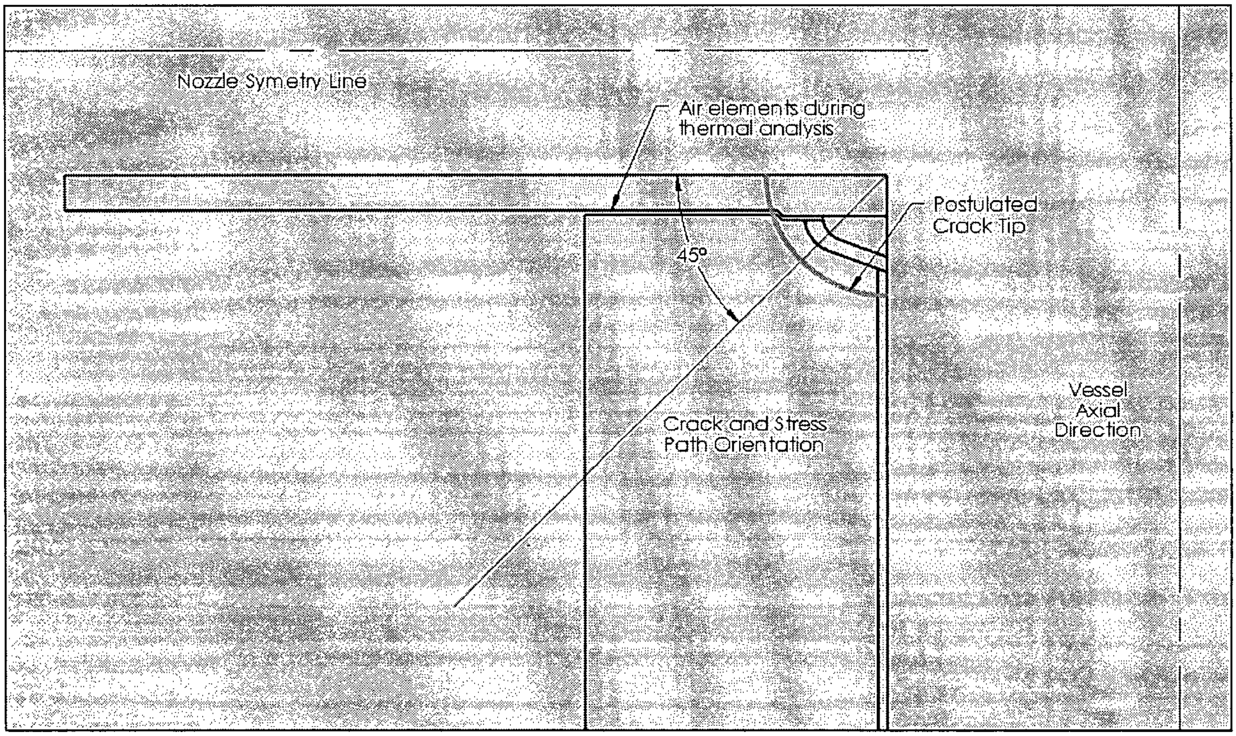


Figure 1: Stress Path and Postulated Flaw Orientation.

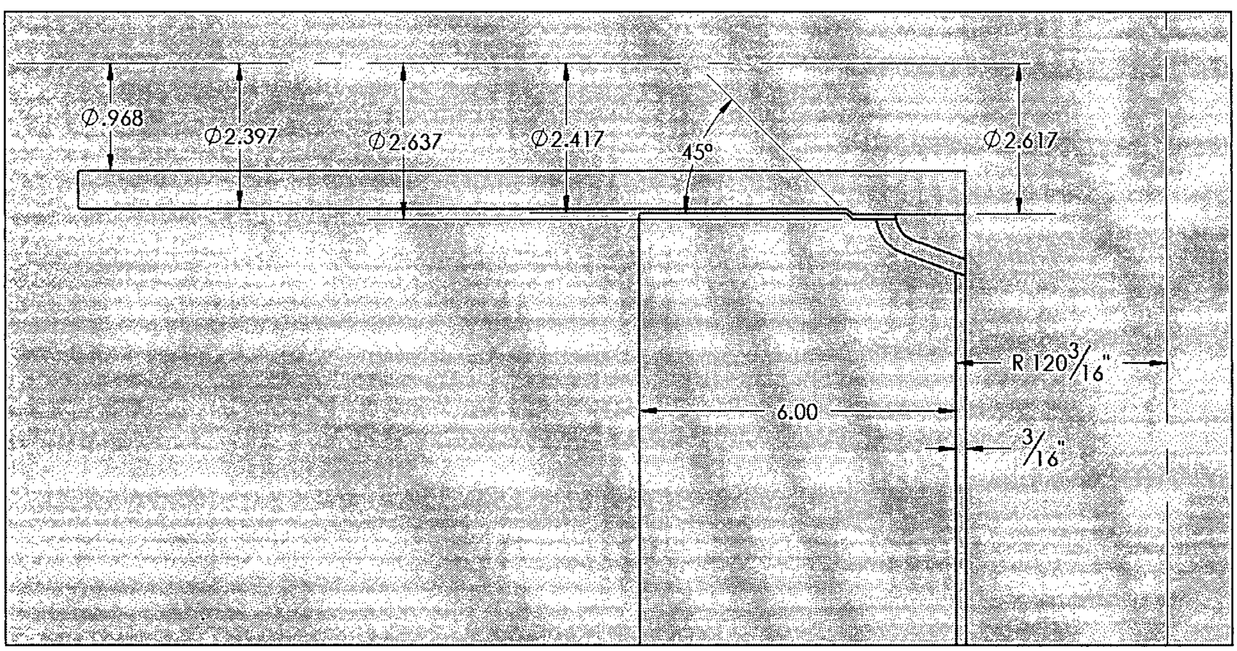
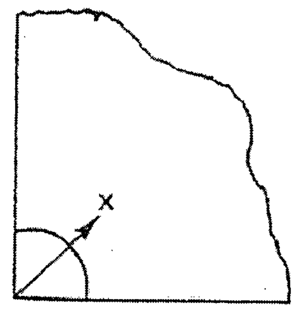


Figure 2: Instrument Nozzle Dimensions.



QUARTER-CIRCULAR CRACK IN AN INFINITE QUARTER-SPACE

$$K_I = \sqrt{\pi a}\left[0.723A_0 + 0.551A_1\left(\frac{2a}{\pi}\right) + 0.462A_2\left(\frac{a^2}{2}\right) + 0.408A_3\left(\frac{4a^3}{3\pi}\right)\right]$$

Figure 3: Fracture Mechanics Solution for Instrument Nozzle Evaluation.

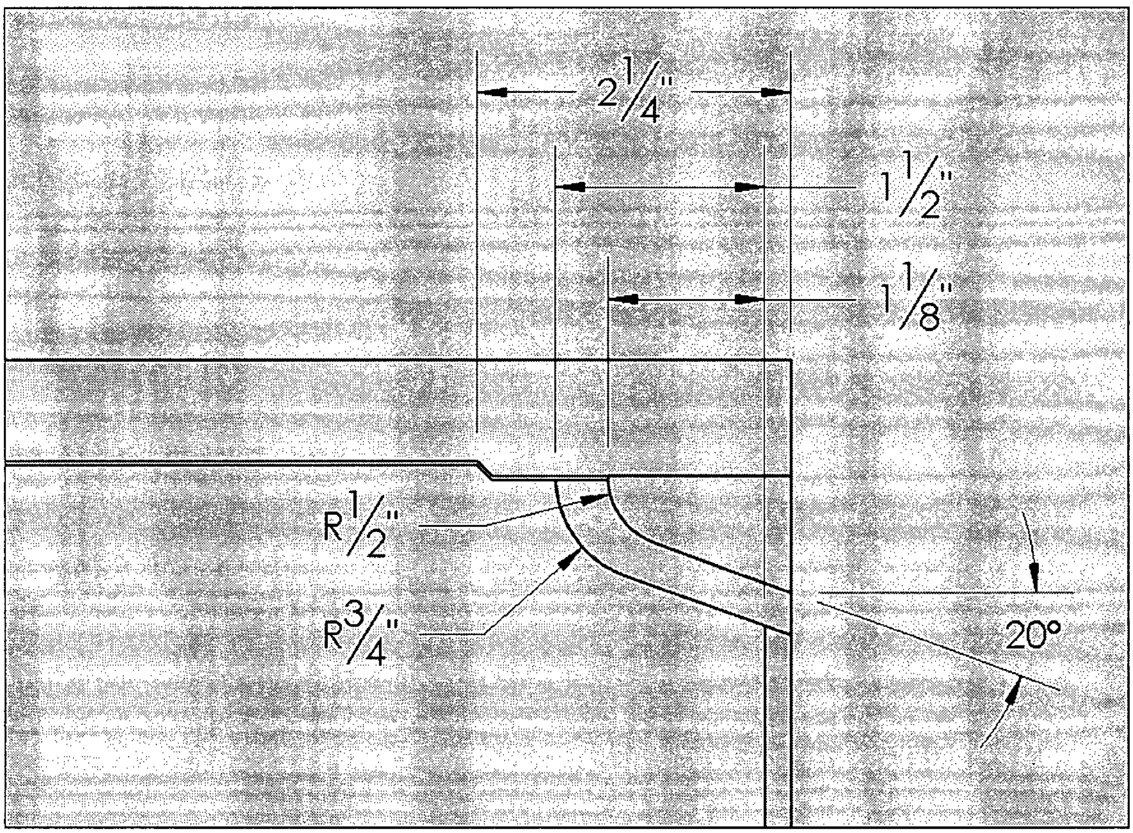


Figure 4: Detail View of Instrument Nozzle Weld Prep [6].

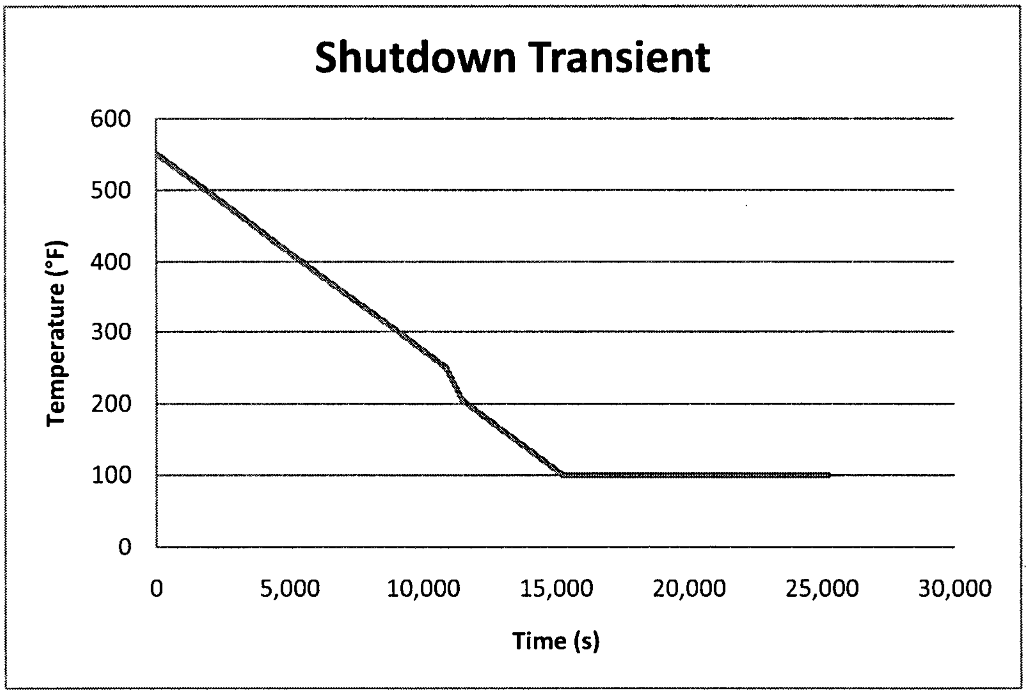


Figure 5: Shutdown and Vessel Flooding Thermal Transient [3].

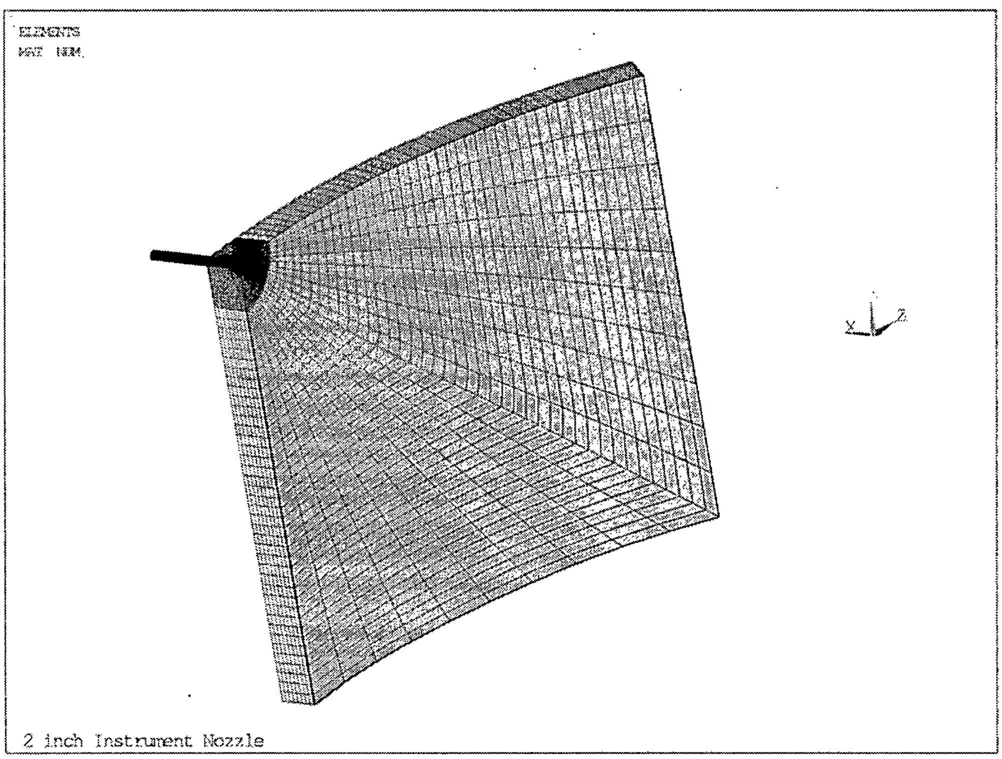


Figure 6: Quarter Model Instrument Nozzle and Reactor Pressure Vessel FEM.

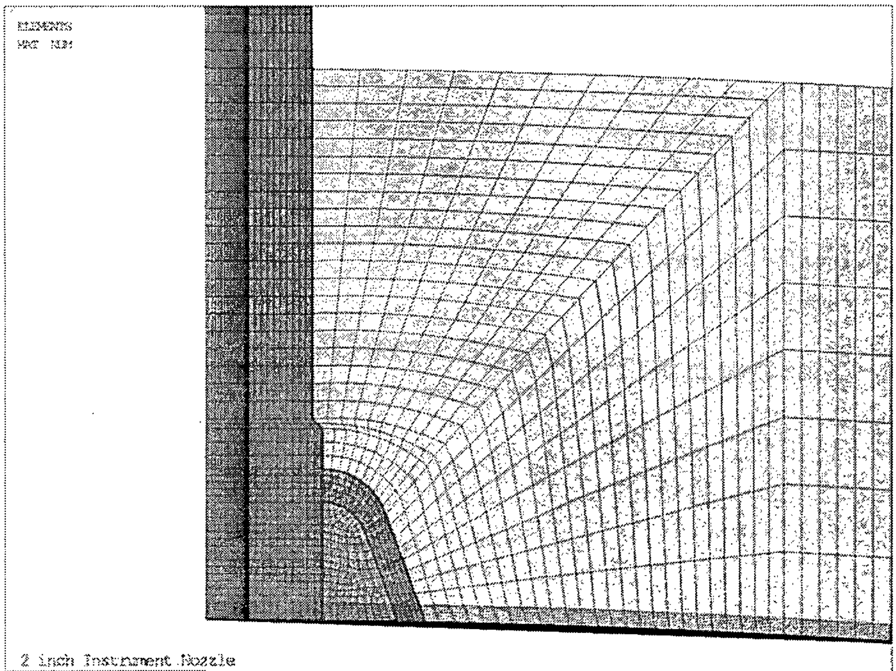


Figure 7: Close-Up View of As-Modeled Nozzle Forging.

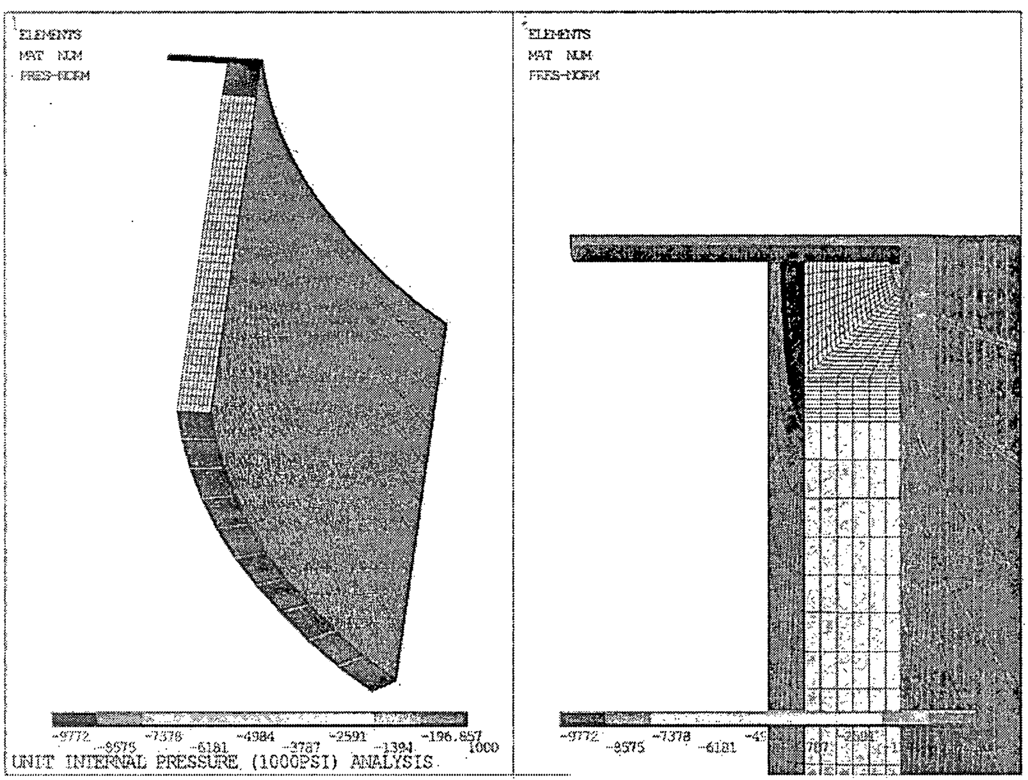


Figure 8: Element Plot of Applied Internal Pressure Load to As-Modeled Instrument Nozzle.

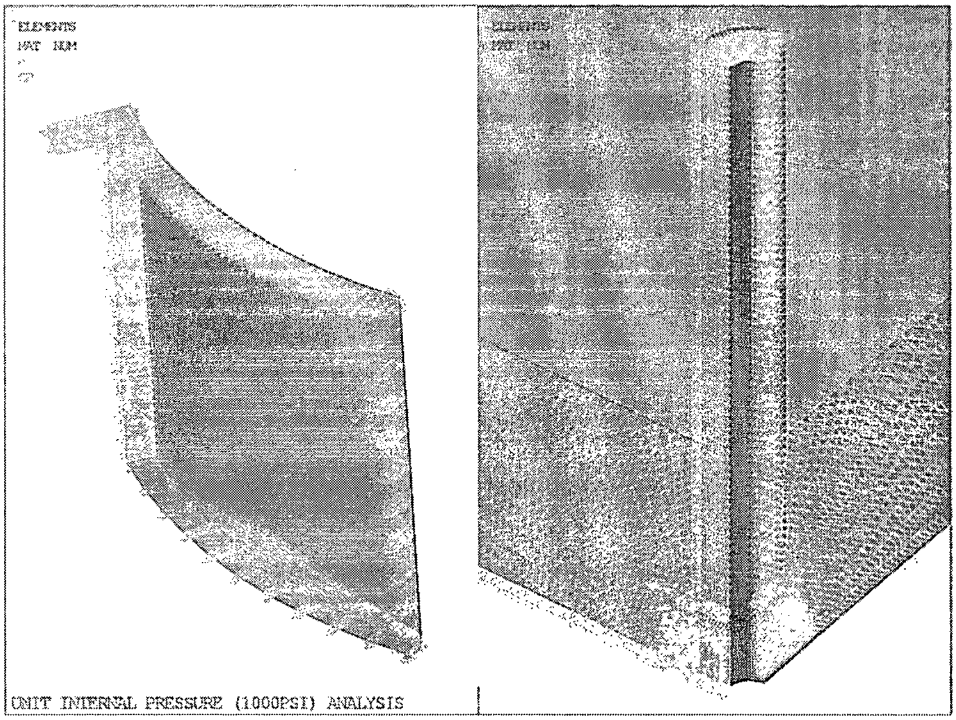


Figure 9: Applied Structural Boundary Conditions to As-Modeled Instrument Nozzle FEM.

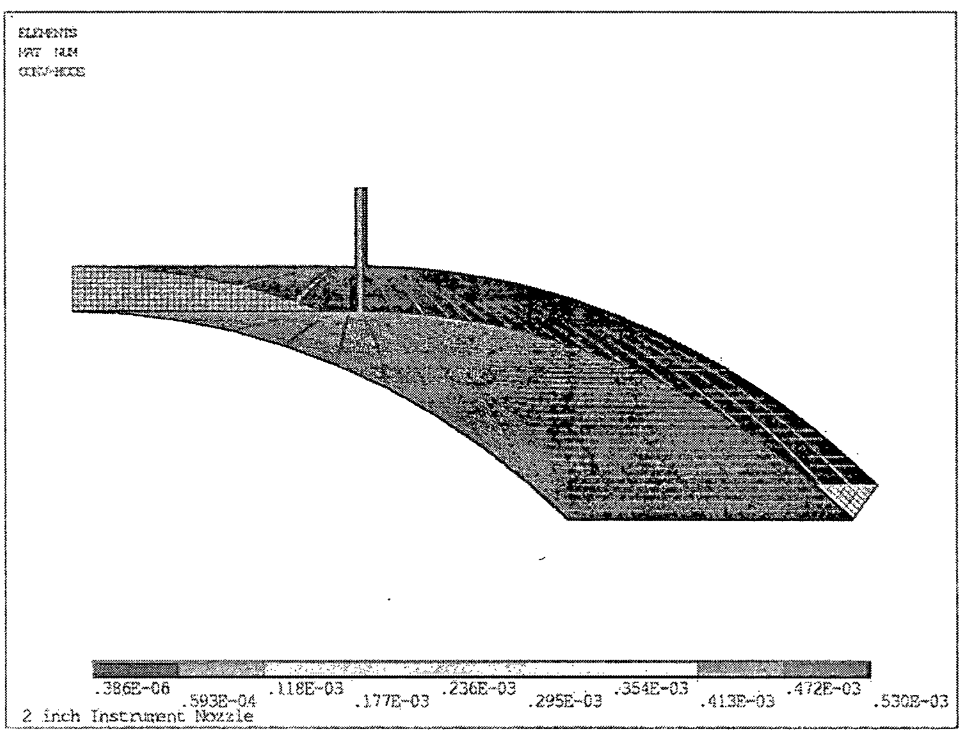


Figure 10: Applied Thermal Loads and Boundary Conditions.

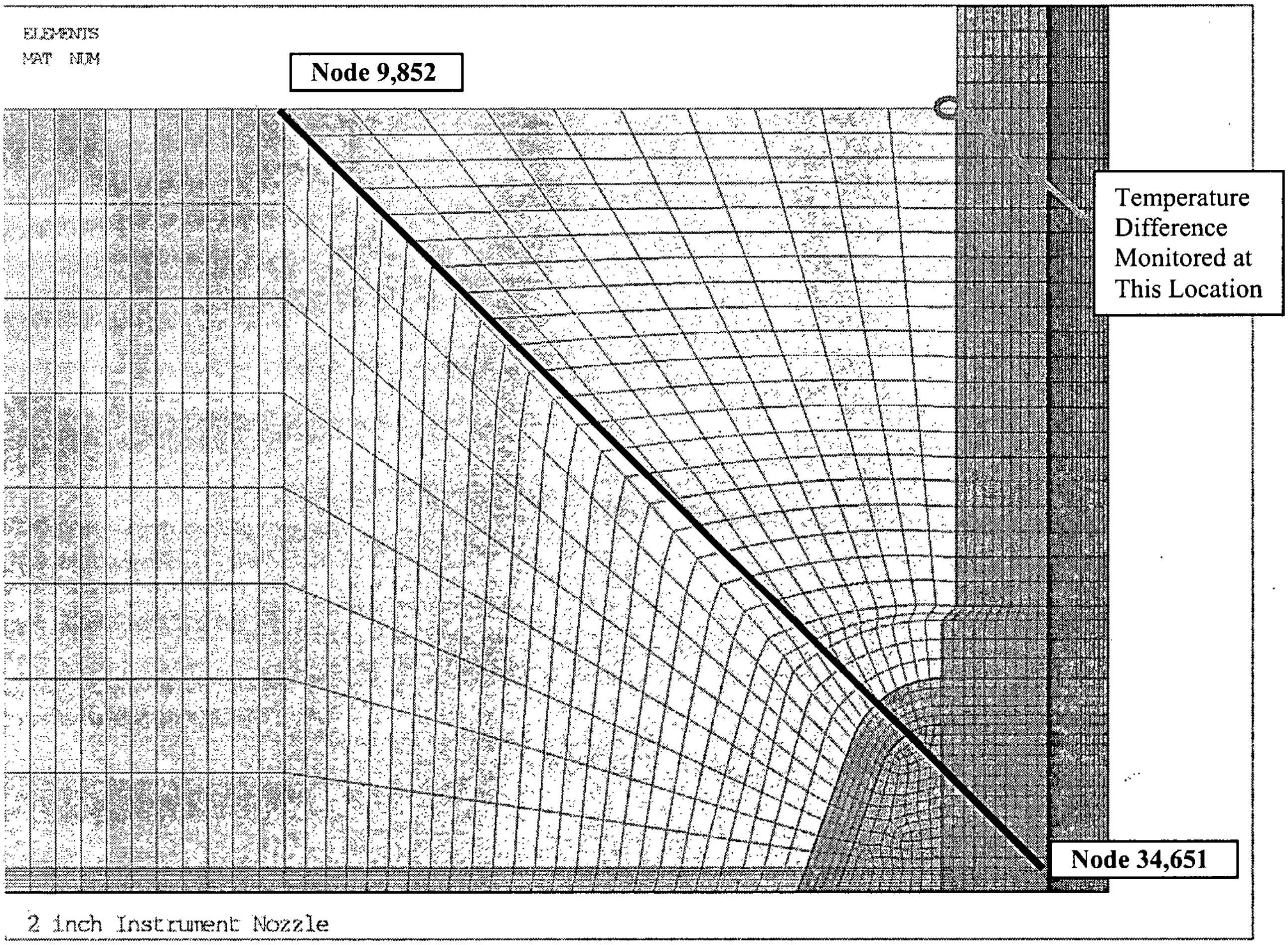


Figure 11: Stress Extraction Path.

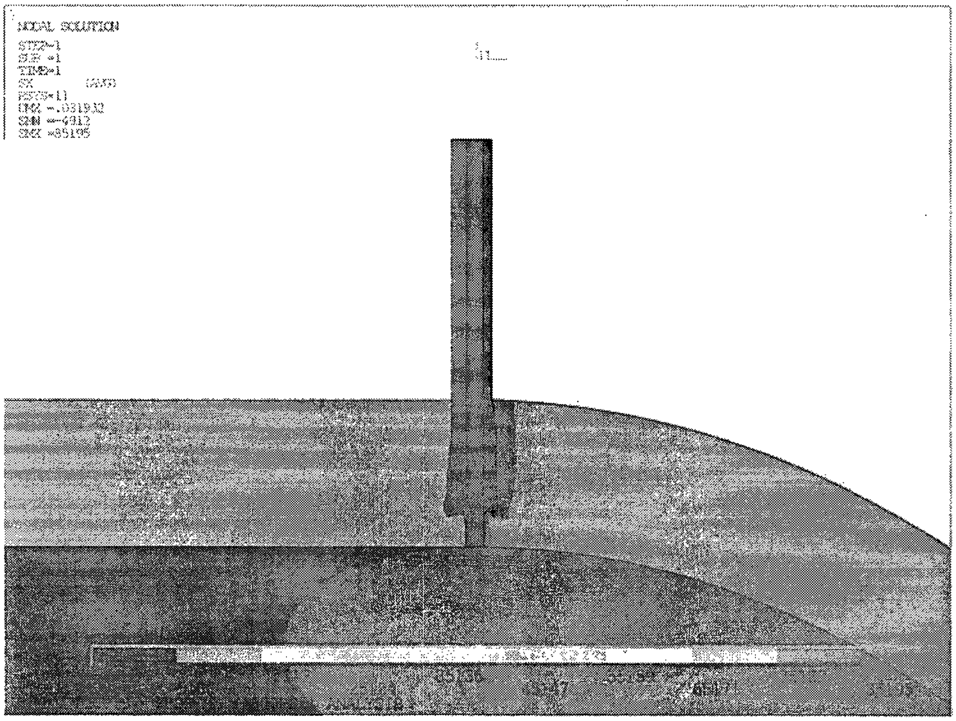


Figure 12: Radial Stress Distribution for the Unit Pressure Load Case.
Note: The "11" included in this figure is an identifier for a local coordinate system

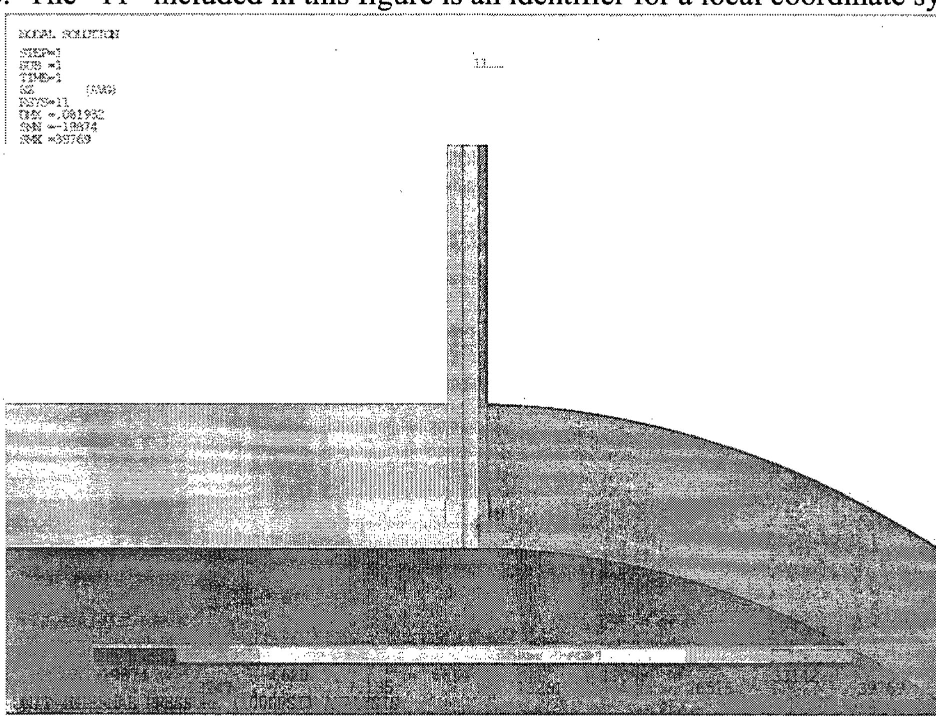


Figure 13: Axial Stress Distribution for the Unit Pressure Load Case.
Note: The "11" included in this figure is an identifier for a local coordinate system

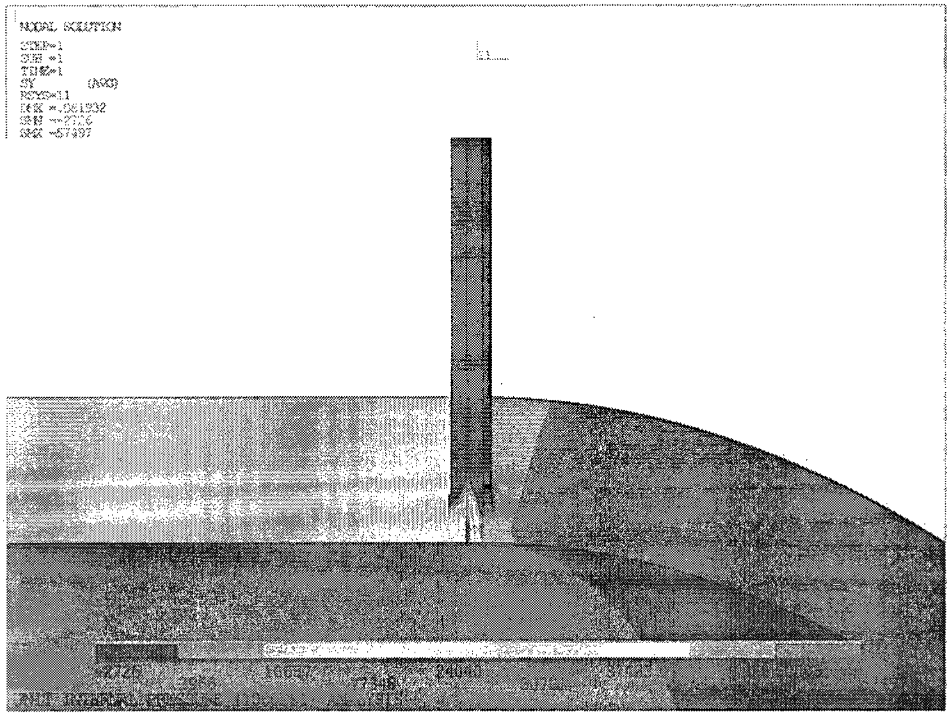


Figure 14: Circumferential Stress Distribution for the Unit Pressure Load Case.
Note: The "11" included in this figure is an identifier for a local coordinate system

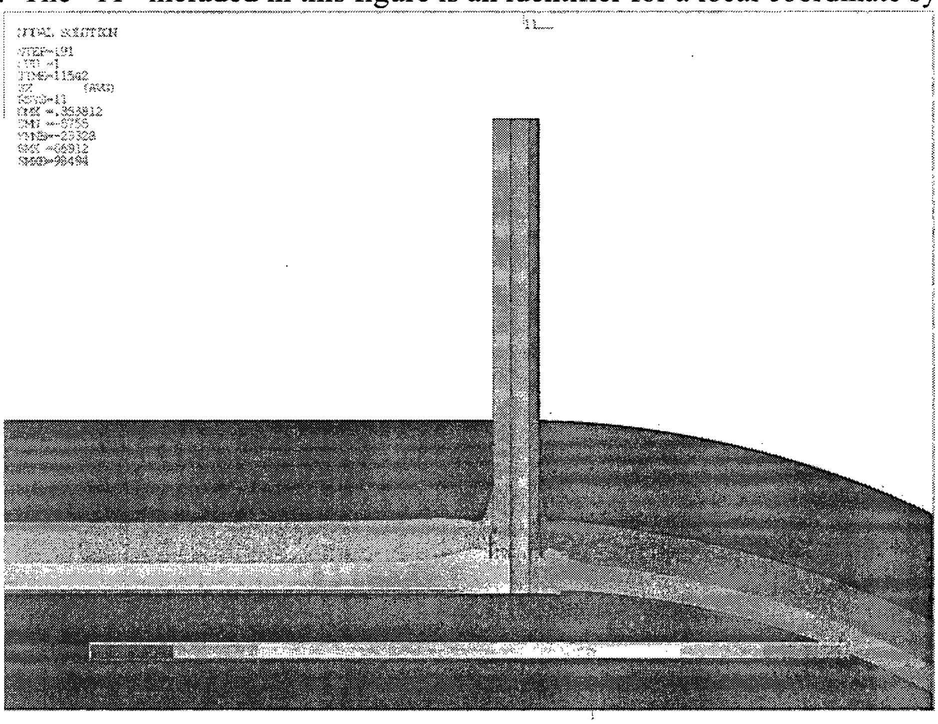


Figure 15: Radial Stress Distribution for Shutdown Transient, t = 11,542 seconds.
Note: The "11" included in this figure is an identifier for a local coordinate system

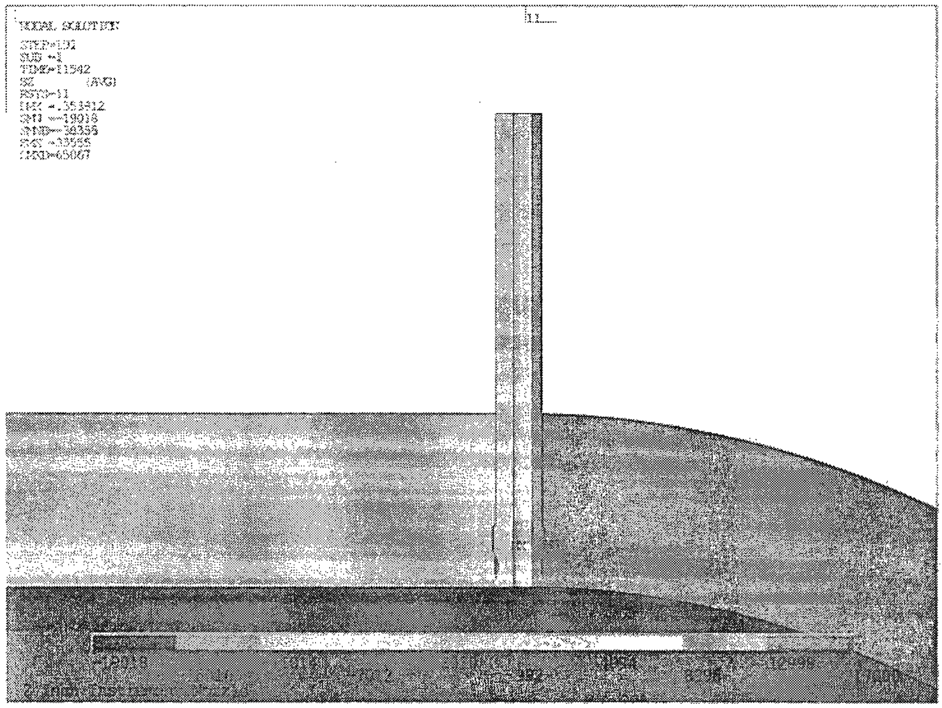


Figure 16: Axial Stress Distribution for Shutdown Transient, t = 11,542 seconds.
Note: The "11" included in this figure is an identifier for a local coordinate system

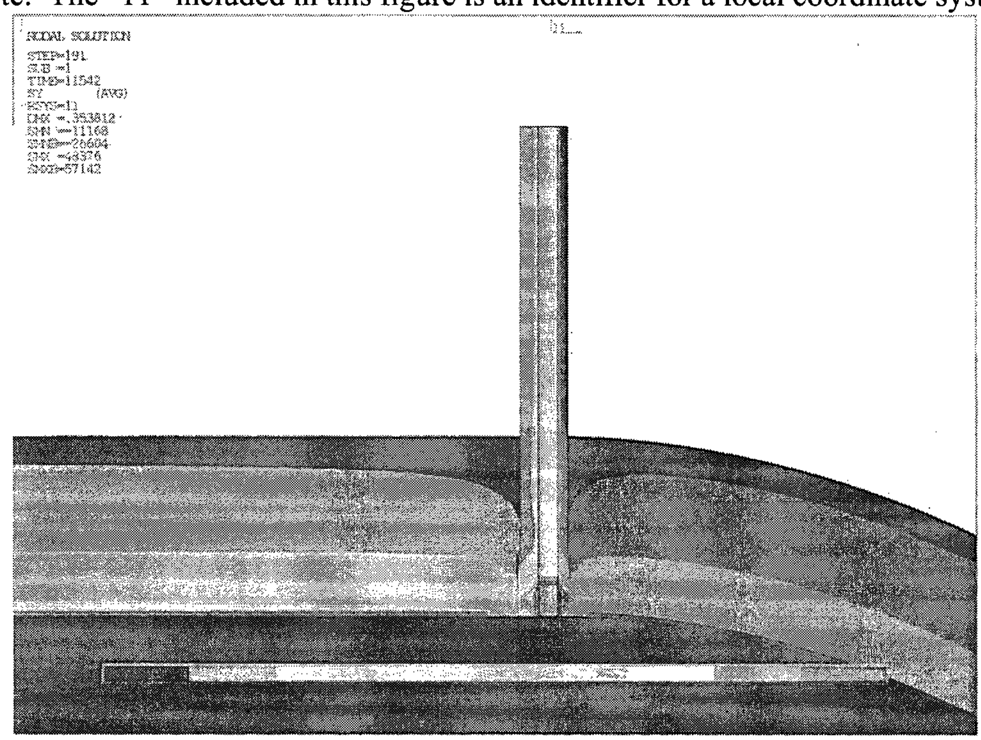
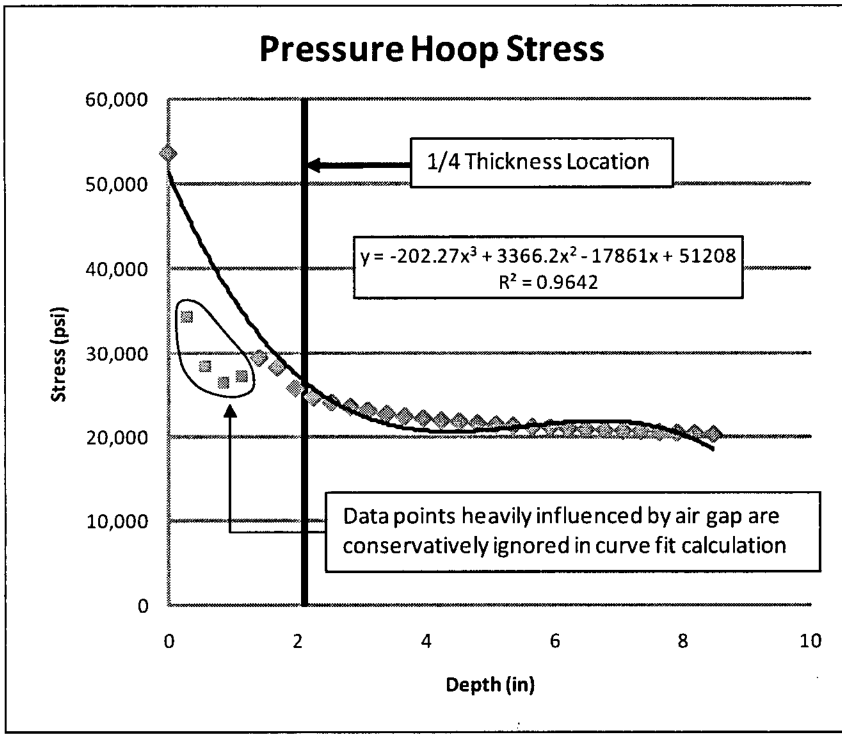
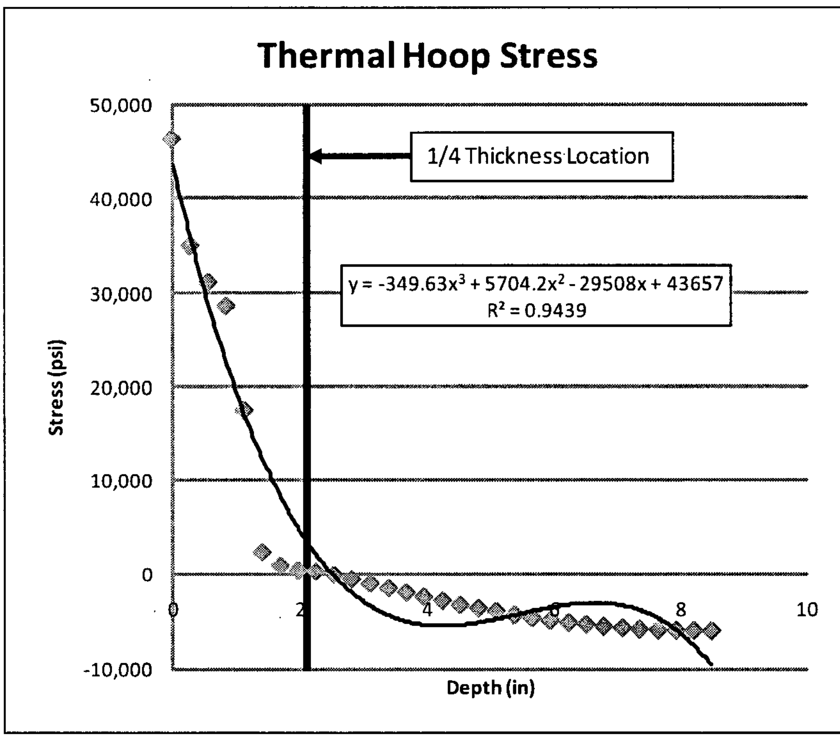


Figure 17: Circumferential Stress Distribution for Shutdown Transient, t = 11,542 seconds.
Note: The "11" included in this figure is an identifier for a local coordinate system



Depth (in)	Hoop Stress (psi)
0	53,501
0.283	34,266
0.566	28,431
0.849	26,400
1.131	27,217
1.414	29,318
1.697	28,218
1.980	25,672
2.263	24,622
2.546	23,974
2.828	23,428
3.111	23,000
3.394	22,636
3.677	22,328
3.960	22,064
4.243	21,842
4.526	21,651
4.808	21,482
5.091	21,331
5.374	21,194
5.657	21,069
5.940	20,955
6.223	20,850
6.505	20,754
6.788	20,664
7.071	20,581
7.354	20,504
7.637	20,431
7.920	20,363
8.202	20,298
8.485	20,226

Figure 18: Pressure Load Case Path Stress Distribution.



Depth (in)	Hoop Stress (psi)
0	46,320
0.283	34,954
0.566	31,137
0.849	28,704
1.131	17,575
1.414	2,410
1.697	978
1.980	439
2.263	329
2.546	-62
2.828	-513
3.111	-983
3.394	-1,471
3.677	-1,950
3.960	-2,413
4.243	-2,851
4.525	-3,262
4.808	-3,646
5.091	-4,003
5.374	-4,331
5.657	-4,629
5.940	-4,898
6.223	-5,138
6.505	-5,347
6.788	-5,528
7.071	-5,679
7.354	-5,802
7.637	-5,896
7.920	-5,963
8.202	-6,003
8.485	-6,017

Figure 19: Thermal Transient Load Case Path Stress Distribution, t = 11,542 seconds.

Appendix A

ANALYSIS FILE DESCRIPTION

The following files were created for this calculation:

ANSYS Input Files

IN.INP	- Input deck with geometry and mesh definition.
MATPROPS.INP	- Material property input deck.
IN-HTBC.INP	- Input deck that applies the convection coefficients to the model.
IN-PRESS.INP	- Input deck that runs the unit pressure load case.
SHUTDOWN-T.INP	- Input deck that runs the shutdown thermal transient.
SHUTDOWN-T_mntr.inp	- Input deck created from SHUTDOWN-T.mntr. Used as input in the thermal stress run.
SHUTDOWN-S.INP	- Input deck that runs the thermal stress case.

ANSYS ASCII Output Files

PRESS_STR.OUT	- Contains the hoop stress results for the unit pressure load case along the selected path.
SHUTDOWN_THMSTR.OUT	- Contains the hoop stress results for the thermal transient load case, for all time steps, along the selected path.

Excel Files

StrIntFactors.xlsx	- Excel 2007 file used to calculate the stress intensity factors due to unit pressure and shut down thermal transient.

Figure A-1 illustrates the information flow-path for the thermal, structural, and output files of this analysis; it depicts the information given below.

I. Thermal Solution

Run File:	SHUTDOWN-T.inp
Required Inputs called by Run File:	IN.INP, MATPROPS.INP, IN-HTBC.INP
Critical Output Files:	SHUTDOWN-T_mntr.inp

II. Structural Solution

Run File:	SHUTDOWN-S.INP
Required Inputs called by Run File:	IN.INP, MATPROPS.INP, SHUTDOWN-T_mntr.inp
Critical Output Files:	SHUTDOWN_THMSTR.OUT
Run File:	IN_PRESS.INP
Required Inputs called by Run File:	IN.INP, MATPROPS.INP
Critical Output Files:	PRESS_STR.OUT

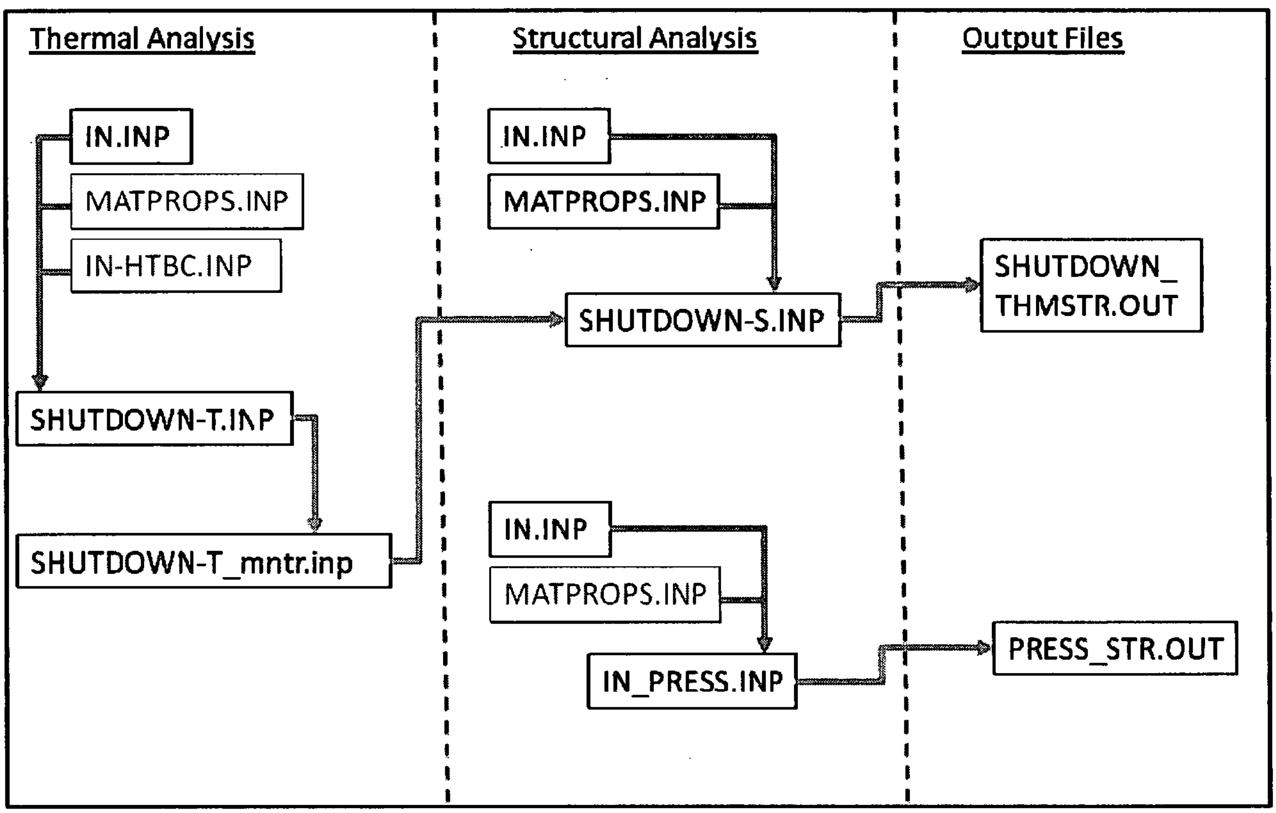


Figure A-1: Analysis Input / Output File Flow Chart

Appendix B

ANSYS SUPPORTING FILES

IN.INP

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/clear,start
/CONFIG,NPROC,2
/CONFIG,NRES,100000
/filn,IN,1
/prep7
/NUMBER,1
/PNUM,MAT,1
/PLOPTS,DATE,0
/title, 2 inch Instrument Nozzle

/com, define element type
et,1,solid45

:READ

/com, Dimensions
*AFUN,DEG

!Sensitive factor
Sf= 1

!Vessel inner radius to clad
ri=120

!Vessel clad thickness
tc=3/16

!Vessel thickness excluding clad
Vth = 6

!Vessel outer radius
ro=ri+tc+Vth

!Safe End outer radius
ro1=2.397/2

!Safe End and Nozzle inner radius
ri1=0.968/2

!Nozzle outer radius
ro2=ro1

!Vessel Hole inner radius
ri3 =2.417/2

!Vessel pad outer radius
ro4= Vth+ri1+1

!length of SE before the step
l1= 2    !if no step input 2 inch

!angle at the SE
af= 0  !if no step input 0

!length of SE step
l2 = 1/2 !if no step input 0.5 inch

!length of SE
l3=       4

!weld length
l4=                 1/2
```

```
!total of length of SE and Nozzle
l5=                  137.5-ri+l3+l4+(ro2-ri1)*tan(af)

!length of end of SE to vessle CL
l=ri+l5

!Pad thickness
td=        1

!Butter top to the vessel inner surface
l6=        1.5+tc

!Butter bottom to the vessel inner surface
l7=        1.125+tc

!Angle of butter with vessel surface
af1= 20

!Angle of the pad
af2= 45

!Angle of weld at safe end
af3= 45

!2 times Angle of Vessel that you want to build
af4= 80

!Butter outer radius
R1= .75

!Butter inner radius
R2= 1/2

!Vessel Hole larger inner radius
ri6 = 2.637/2  !if there is no step using ri3

!Nozzle larger outer radius
ro6= 2.617/2        !if there is no step using ro2

!Butter curve Center point to OD of nozzle
l8=        RI6-RO6

!length of the inner step
ls = ri6-ri3        !if there is no step using 1/16 inch

!distance from inside of vessel wall to the start of normal nozzle outer radius
ds =  2+1/4         !if there is no step using Vth/2 inch

!clad inner radius
ro7 =  vth+ri1      !if the clad is at the same level of butter using ro4-1 inch

Tol=0.15

!ri5=R2*tan(45-af1/2)+(l7+Tol)*tan(af1)+l8+ro6
!ro5=R1*tan(45-af1/2)+(l6+Tol)*tan(af1)+l8+ro6

RI5 = RO6 + L8 + R2*COS(AF1) + (L7-R2+R2*SIN(AF1)+TOL)*TAN(AF1)
RO5 = RO6 + L8 + R1*COS(AF1) + (L6-R1+R1*SIN(AF1)+TOL)*TAN(AF1)


/INP,MATPROPS,INP

/com, Create Model
k,1,l,ri1,0
k,2,l,ro1,0
k,3,l-l1,ri1,0
k,4,l-l1,ro1,0
```

```
k,5,l-l1-l2,ri1,0
k,6,l-l1-l2,ro2,0
k,7,l-l3,ri1,0
k,8,l-l3+(ro2-ri1)*tan(af3),ro2,0
k,9,l-l3-l4,ri1,0
k,10,l-l3-l4-(ro2-ri1)*tan(af3),ro2,0
k,11,ri+ds,ri1,0
k,12,ri+ds,ro2,0
k,13,ri+ds-ls,ri1,0
k,14,ri+ds-ls,ro6,0
k,15,ri+l6,ri1,0
k,16,ri+l6,ro6,0
k,17,ri+l7,ri1,0
k,18,ri+l7,ro6,0
k,19,ri-Tol,ri1,0
k,20,ri-Tol,ro6,0
k,21,ri-Tol,ri5,0
k,22,ri-Tol,ro5,0

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LSTR,   16,   23

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FITEM,2,33
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!*
LFILLT,34,35,R1, ,
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FITEM,2,8
FITEM,2,10
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FITEM,2,11
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FITEM,2,-13
FLST,8,2,3
FITEM,8,1001
FITEM,8,1000
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K,200,0,-ro4-70,0
K,201, ri,-ro4-70,0
K,202, ri+tc,-ro4-70,0
K,203, ro,-ro4-70,0
k,204, ro+td,-ro4-70,0

K,205, ri*cos(af4/2),-ro4-70,ri*sin(af4/2)
K,206, (ri+tc)*cos(af4/2),-ro4-70,(ri+tc)*sin(af4/2)
K,207, ro*cos(af4/2),-ro4-70,ro*sin(af4/2)
k,208, (ro+td)*cos(af4/2),-ro4-70,(ro+td)*sin(af4/2)

K,209, ri*cos(af4/2),-ro4-70,-ri*sin(af4/2)
K,210, (ri+tc)*cos(af4/2),-ro4-70,-(ri+tc)*sin(af4/2)
K,211, ro*cos(af4/2),-ro4-70,-ro*sin(af4/2)
k,212, (ro+td)*cos(af4/2),-ro4-70,-(ro+td)*sin(af4/2)

!*
LARC,205,201,200,ri,
!*
LARC,201,209,200,ri,
!*
LARC,206,202,200,ri+tc,
!*
LARC,202,210,200,ri+tc,
!*
LARC,207,203,200,ro,
!*
```

```
LARC,203,211,200,ro,
!*
LARC,208,204,200,ro+td,
!*
LARC,204,212,200,ro+td,

LSTR,    205,   206
LSTR,    206,   207
LSTR,    209,   210
LSTR,    210,   211
LSTR,    201,   202
LSTR,    202,   203

FLST,2,4,4
FITEM,2,258
FITEM,2,260
FITEM,2,267
FITEM,2,269
AL,P51X
FLST,2,4,4
FITEM,2,257
FITEM,2,259
FITEM,2,269
FITEM,2,265
AL,P51X
FLST,2,4,4
FITEM,2,266
FITEM,2,261
FITEM,2,270
FITEM,2,259
AL,P51X
FLST,2,4,4
FITEM,2,260
FITEM,2,262
FITEM,2,268
FITEM,2,270
AL,P51X
FLST,2,4,5,ORDE,2
FITEM,2,205
FITEM,2,-208
VEXT,P51X, , ,0,ro4+70,0,,,,

FLST,2,41,6,ORDE,5
FITEM,2,1
FITEM,2,-26
FITEM,2,40
FITEM,2,-53
FITEM,2,56
VDELE,P51X, , ,1
LDELE,    264, , ,1

K,300,0,-ro4-td,0
K,301,0,0,ro4+td

LARC,300,301,1000,ro4+td,

LSTR,    301,   1000
LSTR,    300,   1000

FLST,2,3,4
FITEM,2,3
FITEM,2,1
FITEM,2,2
AL,P51X
FLST,2,1,5,ORDE,1
FITEM,2,1
FLST,8,2,3
```

```
FITEM,8,1000
FITEM,8,1001
!*
VOFFST,1,l, ,

FLST,3,1,3,ORDE,1
FITEM,3,208
KGEN,2,P51X, , ,ro4+70, , ,0
LSTR,    208,     4
ADRAG,    263, , , , , ,     10
VSBA,      1,     6
VDELE,      3, , ,1

FLST,2,3,6,ORDE,3
FITEM,2,2
FITEM,2,55
FITEM,2,54
VPTN,P51X
VDELE,      1, , ,1

K,1000,0,0,0
K,400,0,0,ri6
K,401,0,-ri6,0
K,402,ri+ds-ls,-ri6,0
K,403,ri+ds,-ri3,0
K,404,l,-ri3,0

LARC,400,401,1000,ri6,

LSTR,    401,    402
LSTR,    402,    403
LSTR,    403,    404
FLST,2,3,4,ORDE,3
FITEM,2,2
FITEM,2,-3
FITEM,2,7
ADRAG,P51X, , , , , ,      1
FLST,2,5,6,ORDE,4
FITEM,2,3
FITEM,2,-5
FITEM,2,36
FITEM,2,39
FLST,3,3,5,ORDE,3
FITEM,3,1
FITEM,3,3
FITEM,3,-4
VSBA,P51X,P51X
FLST,2,3,6,ORDE,3
FITEM,2,1
FITEM,2,-2
FITEM,2,12
VDELE,P51X, , ,1

FLST,2,5,6,ORDE,5
FITEM,2,9
FITEM,2,11
FITEM,2,13
FITEM,2,37
FITEM,2,-38
VPTN,P51X
FLST,2,2,6,ORDE,2
FITEM,2,3
FITEM,2,14
VDELE,P51X, , ,1
ADRAG,    257, , , , , ,    282
FLST,2,2,6,ORDE,2
FITEM,2,35
```

```
FITEM,2,10
VSBA,P51X,    12
FLST,2,2,6,ORDE,2
FITEM,2,3
FITEM,2,11
VDELE,P51X, , ,1
ADRAG,    259, , , , , ,    283
FLST,2,2,6,ORDE,2
FITEM,2,9
FITEM,2,13
VSBA,P51X,    12

K,500,0,-ro4,0
K,501,0,0,ro4

LARC,500,501,1000,ro4,
LSTR,    1000,    1001

ADRAG,    39, , , , , ,    41
VDELE,    8
FLST,2,2,5,ORDE,2
FITEM,2,36
FITEM,2,-37
ADELE,P51X
ASBA,    35,    12

FLST,2,2,5,ORDE,2
FITEM,2,13
FITEM,2,36
ADELE,P51X, , ,1
LSTR,     3,    42
LSTR,     5,    43

FLST,2,4,4
FITEM,2,91
FITEM,2,44
FITEM,2,54
FITEM,2,16
AL,P51X
FLST,2,4,4
FITEM,2,16
FITEM,2,13
FITEM,2,20
FITEM,2,90
AL,P51X
FLST,2,4,4
FITEM,2,55
FITEM,2,20
FITEM,2,100
FITEM,2,45
AL,P51X
FLST,2,6,5,ORDE,6
FITEM,2,12
FITEM,2,-13
FITEM,2,28
FITEM,2,34
FITEM,2,-35
FITEM,2,37
VA,P51X

!Create clading location for special plant such as HC

K,600,0,-ro7,0
K,601,0,0,ro7

LARC,600,601,1000,ro7,
```

```
ADRAG,    22,,,,,,     41
FLST,2,3,6,ORDE,3
FITEM,2,1
FITEM,2,8
FITEM,2,16
VSBA,P51X,    36

KGEN,2,16,,,,-ky(16),,,0
KGEN,2,18,,,,-ky(18),,,0
LSTR,    16,     7
LSTR,    18,     8
LSTR,     7,    15
LSTR,     8,    17
FLST,2,3,4
FITEM,2,2
FITEM,2,7
FITEM,2,40
AL,P51X
FLST,2,3,4
FITEM,2,8
FITEM,2,4
FITEM,2,43
AL,P51X
FLST,3,2,5,ORDE,2
FITEM,3,1
FITEM,3,-2
VSBA,    31,P51X

!CREATE AIR GAP
LSTR,    51,    16
LSTR,    77,    18
LSTR,    15,    71
LSTR,    17,    97
LSTR,    64,   403
LSTR,    66,   402
LSTR,    90,    13
LSTR,    92,    12

FLST,2,4,4
FITEM,2,40
FITEM,2,2
FITEM,2,100
FITEM,2,7
AL,P51X
FLST,2,4,4
FITEM,2,43
FITEM,2,4
FITEM,2,160
FITEM,2,8
AL,P51X
FLST,2,4,4
FITEM,2,19
FITEM,2,126
FITEM,2,194
FITEM,2,165
AL,P51X
FLST,2,4,4
FITEM,2,17
FITEM,2,128
FITEM,2,199
FITEM,2,166
AL,P51X
FLST,2,4,4
FITEM,2,45
FITEM,2,2
FITEM,2,162
FITEM,2,4
```

```
AL,P51X
FLST,2,4,4
FITEM,2,44
FITEM,2,7
FITEM,2,164
FITEM,2,8
AL,P51X
FLST,2,4,4
FITEM,2,72
FITEM,2,4
FITEM,2,148
FITEM,2,126
AL,P51X
FLST,2,4,4
FITEM,2,154
FITEM,2,8
FITEM,2,71
FITEM,2,165
AL,P51X
FLST,2,4,4
FITEM,2,133
FITEM,2,126
FITEM,2,3
FITEM,2,128
AL,P51X
FLST,2,4,4
FITEM,2,18
FITEM,2,165
FITEM,2,197
FITEM,2,166
AL,P51X
FLST,2,4,4
FITEM,2,83
FITEM,2,128
FITEM,2,138
FITEM,2,153
AL,P51X
FLST,2,4,4
FITEM,2,82
FITEM,2,166
FITEM,2,202
FITEM,2,217
AL,P51X
FLST,2,6,5,ORDE,6
FITEM,2,1
FITEM,2,-2
FITEM,2,28
FITEM,2,98
FITEM,2,100
FITEM,2,-101
VA,P51X
FLST,2,6,5,ORDE,6
FITEM,2,2
FITEM,2,50
FITEM,2,64
FITEM,2,85
FITEM,2,102
FITEM,2,-103
VA,P51X
FLST,2,6,5,ORDE,6
FITEM,2,3
FITEM,2,85
FITEM,2,99
FITEM,2,104
FITEM,2,106
FITEM,2,139
VA,P51X
```

```
FLST,2,6,5,ORDE,6
FITEM,2,62
FITEM,2,99
FITEM,2,107
FITEM,2,-108
FITEM,2,143
FITEM,2,155
VA,P51X

!DELETE ATTACHED PIPING
K,450,KX(62),0,0

LSTR,   450,    62
LSTR,   450,    88

FLST,2,3,4
FITEM,2,190
FITEM,2,189
FITEM,2,192
AL,P51X
FLST,2,1,6,ORDE,1
FITEM,2,1
VSBA,P51X,110
FLST,2,5,6,ORDE,3
FITEM,2,25
FITEM,2,27
FITEM,2,-30
VDELE,P51X, , ,1

NUMMRG,KP, , , ,LOW

!ASSIGN RPV MATERIAL
FLST,5,5,6,ORDE,4
FITEM,5,7
FITEM,5,13
FITEM,5,18
FITEM,5,-20
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,     1, ,   1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!ASSIGN CLADDING MATERIAL
FLST,5,3,6,ORDE,3
FITEM,5,6
FITEM,5,9
FITEM,5,17
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,     6, ,   1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!ASSIGN NOZZLE MATERIAL
FLST,5,8,6,ORDE,7
FITEM,5,8
```

```
FITEM,5,10
FITEM,5,-11
FITEM,5,16
FITEM,5,26
FITEM,5,32
FITEM,5,-34
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,    2, ,  1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!ASSIGN BUTTER MATERIAL
FLST,5,3,6,ORDE,3
FITEM,5,4
FITEM,5,-5
FITEM,5,15
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,    3, ,  1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!ASSIGN WELD MATERIAL
FLST,5,4,6,ORDE,4
FITEM,5,2
FITEM,5,-3
FITEM,5,12
FITEM,5,14
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,    4, ,  1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!ASSIGN AIR MATERIAL
FLST,5,5,6,ORDE,3
FITEM,5,21
FITEM,5,-24
FITEM,5,36
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CMSEL,S,_Y
!*
CMSEL,S,_Y1
VATT,    7, ,  1,     0
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1

!*************************************
```

```
!BEGIN MESH
!*************************************

!CIRC MESH DENSITY, NOZZLE,WELD,AIR
FLST,5,32,4,ORDE,32
FITEM,5,5
FITEM,5,9
FITEM,5,17
FITEM,5,19
FITEM,5,21
FITEM,5,36
FITEM,5,40
FITEM,5,43
FITEM,5,48
FITEM,5,51
FITEM,5,65
FITEM,5,69
FITEM,5,85
FITEM,5,91
FITEM,5,93
FITEM,5,100
FITEM,5,159
FITEM,5,-160
FITEM,5,189
FITEM,5,193
FITEM,5,-194
FITEM,5,198
FITEM,5,-199
FITEM,5,203
FITEM,5,-204
FITEM,5,208
FITEM,5,-209
FITEM,5,214
FITEM,5,218
FITEM,5,-219
FITEM,5,223
FITEM,5,-224
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,20*Sf, , , , ,1

!NOZZLE RADIAL MESH DENSITY
FLST,5,18,4,ORDE,18
FITEM,5,42
FITEM,5,56
FITEM,5,66
FITEM,5,81
FITEM,5,84
FITEM,5,92
FITEM,5,127
FITEM,5,132
FITEM,5,137
FITEM,5,142
FITEM,5,149
FITEM,5,155
FITEM,5,191
FITEM,5,196
FITEM,5,201
FITEM,5,206
FITEM,5,211
FITEM,5,213
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
```

```
LESIZE,_Y1, , ,10*Sf, , , , ,1

!CIRC MESH DENSITY, OD WELD PAD
FLST,5,8,4,ORDE,8
FITEM,5,6
FITEM,5,13
FITEM,5,25
FITEM,5,80
FITEM,5,90
FITEM,5,101
FITEM,5,110
FITEM,5,124
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,20*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE FREE END
FLST,5,4,4,ORDE,4
FITEM,5,39
FITEM,5,55
FITEM,5,225
FITEM,5,-226
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,48*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE AND WELD PAD
FLST,5,10,4,ORDE,8
FITEM,5,16
FITEM,5,20
FITEM,5,44
FITEM,5,-45
FITEM,5,115
FITEM,5,120
FITEM,5,161
FITEM,5,-164
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,5*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE AFTER STEP
FLST,5,6,4,ORDE,6
FITEM,5,71
FITEM,5,-72
FITEM,5,147
FITEM,5,-148
FITEM,5,150
FITEM,5,154
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,20*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE BEFORE STEP
FLST,5,6,4,ORDE,6
FITEM,5,82
FITEM,5,-83
FITEM,5,136
FITEM,5,138
FITEM,5,200
```

```
FITEM,5,202
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,3*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE STEP
FLST,5,6,4,ORDE,6
FITEM,5,3
FITEM,5,18
FITEM,5,131
FITEM,5,133
FITEM,5,195
FITEM,5,197
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,2*Sf, , , , ,1

!MESH DENSITY, BUTTER THICKNESS
FLST,5,12,4,ORDE,12
FITEM,5,47
FITEM,5,49
FITEM,5,78
FITEM,5,-79
FITEM,5,141
FITEM,5,143
FITEM,5,152
FITEM,5,157
FITEM,5,205
FITEM,5,207
FITEM,5,216
FITEM,5,221
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,5*Sf, , , , ,1

!MESH DENSITY, NOZZLE/WELD/BUTTER AT CLAD
FLST,5,10,4,ORDE,10
FITEM,5,11
FITEM,5,-12
FITEM,5,37
FITEM,5,-38
FITEM,5,46
FITEM,5,53
FITEM,5,58
FITEM,5,62
FITEM,5,88
FITEM,5,-89
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,8*Sf, , , , ,1

!AXIAL MESH DENSITY, NOZZLE AT WELD
FLST,5,6,4,ORDE,4
FITEM,5,76
FITEM,5,-77
FITEM,5,94
FITEM,5,-97
CM,_Y,LINE
LSEL, , , ,P51X
```

```
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,14*Sf, , , , ,1

!MESH DENSITY, BUTTER RADIUS
FLST,5,4,4,ORDE,4
FITEM,5,156
FITEM,5,158
FITEM,5,220
FITEM,5,222
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,10*Sf, , , , ,1

!MESH DENSITY, BUTTER ANGLE
FLST,5,4,4,ORDE,3
FITEM,5,50
FITEM,5,73
FITEM,5,-75
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,8*Sf, , , , ,1

!RADIAL MESH DENSITY, WELD AT CLAD
FLST,5,4,4,ORDE,4
FITEM,5,14
FITEM,5,-15
FITEM,5,23
FITEM,5,-24
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,10*Sf, , , , ,1

!RADIAL MESH DENSITY, AIR/WELD
FLST,5,16,4,ORDE,16
FITEM,5,2
FITEM,5,4
FITEM,5,7
FITEM,5,-8
FITEM,5,59
FITEM,5,-60
FITEM,5,63
FITEM,5,67
FITEM,5,126
FITEM,5,128
FITEM,5,151
FITEM,5,153
FITEM,5,165
FITEM,5,-166
FITEM,5,215
FITEM,5,217
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,1, , , , ,1

!RADIAL MESH DENS, INNER WELD PAD
FLST,5,8,4,ORDE,7
FITEM,5,57
FITEM,5,70
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```
FITEM,5,86
FITEM,5,-87
FITEM,5,140
FITEM,5,144
FITEM,5,-146
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,10*Sf, , , , ,1

!RADIAL MESH DENS, OUTER WELD PAD
FLST,5,8,4,ORDE,8
FITEM,5,108
FITEM,5,-109
FITEM,5,114
FITEM,5,119
FITEM,5,125
FITEM,5,129
FITEM,5,-130
FITEM,5,134
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,10*Sf, , , , ,1

!MESH DENS, RPV THICKNESS
FLST,5,6,4,ORDE,6
FITEM,5,28
FITEM,5,-29
FITEM,5,135
FITEM,5,139
FITEM,5,270
FITEM,5,284
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,8*Sf, , , , ,1

!MESH DENS, RPV LONG EDGE OPPOSITE NOZZLE
FLST,5,6,4,ORDE,6
FITEM,5,257
FITEM,5,259
FITEM,5,261
FITEM,5,282
FITEM,5,-283
FITEM,5,287
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,10*Sf, , , , ,1

!MESH DENS, RPV LONG EDGE NEAR NOZZLE
FLST,5,6,4,ORDE,2
FITEM,5,30
FITEM,5,-35
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,40*Sf, , , , ,1

!MESH DENS, CLAD THICKNESS
FLST,5,7,4,ORDE,7
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```
FITEM,5,26
FITEM,5,-27
FITEM,5,102
FITEM,5,107
FITEM,5,265
FITEM,5,269
FITEM,5,281
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,8*Sf, , , , ,1

!RPV CORNER, OPPOSITE NOZZLE
FLST,5,1,4,ORDE,1
FITEM,5,266
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,8*Sf, , , , ,1

!RE-MESHES CLAD AT INNER WELD PAD LOC
FLST,5,4,4,ORDE,4
FITEM,5,57
FITEM,5,70
FITEM,5,86
FITEM,5,-87
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
LESIZE,_Y1, , ,25*Sf, , , , ,1

!DELETE EXTRA LINES
FLST,2,3,4,ORDE,3
FITEM,2,1
FITEM,2,10
FITEM,2,41
LDELE,P51X, , ,1

!MESH NOZZLE, WELD PAD, CLADDING
FLST,5,14,6,ORDE,10
FITEM,5,8
FITEM,5,-9
FITEM,5,13
FITEM,5,16
FITEM,5,-19
FITEM,5,21
FITEM,5,-24
FITEM,5,26
FITEM,5,32
FITEM,5,-33
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CHKMSH,'VOLU'
CMSEL,S,_Y
MSHAPE,0,3d
MSHKEY,1
VMESH,_Y1
MSHKEY,0
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2

!MESH VOLUMES AROUND WELD
```

```
FLST,5,10,6,ORDE,8
FITEM,5,2
FITEM,5,-5
FITEM,5,10
FITEM,5,-11
FITEM,5,14
FITEM,5,-15
FITEM,5,34
FITEM,5,36
CM,_Y,VOLU
VSEL, , , ,P51X
CM,_Y1,VOLU
CHKMSH,'VOLU'
CMSEL,S,_Y
MSHAPE,0,3d
MSHKEY,1
VMESH,_Y1
MSHKEY,0
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2

!MESH WELD
CM,_Y,VOLU
VSEL, , , ,      12
CM,_Y1,VOLU
CHKMSH,'VOLU'
CMSEL,S,_Y
VSWEEP,_Y1
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2

!MESH PRV AT WELD PAD
ET,2,MESH200
KEYOPT,2,1,6
KEYOPT,2,2,0
MSHAPE,0,2D
MSHKEY,1
AMAP,91,17,100,25,45
CM,_Y,VOLU
VSEL, , , ,      20
CM,_Y1,VOLU
CHKMSH,'VOLU'
CMSEL,S,_Y
VSWEEP,_Y1
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
ACLEAR,      91

!MESH CLAD
AMAP,23,1,201,109,2
CM,_Y,VOLU
VSEL, , , ,      6
CM,_Y1,VOLU
CHKMSH,'VOLU'
CMSEL,S,_Y
VSWEEP,_Y1
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2

!MESH RPV
CM,_Y,VOLU
VSEL, , , ,      7
CM,_Y1,VOLU
```

```
CHKMSH,'VOLU'
CMSEL,S,_Y
VSWEEP,_Y1
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2

!CLEAR EXCESS
ACLEAR,    23
ETDEL,2

FLST,2,3,6,ORDE,3
FITEM,2,13
FITEM,2,19
FITEM,2,21
VCLEAR,P51X
FLST,2,3,6,ORDE,3
FITEM,2,13
FITEM,2,19
FITEM,2,21
VDELE,P51X, , ,1

SAVE
```

MATPROPS.INP

```
/COM,************************************************************
/COM, Material Properties
/COM,************************************************************
! MAT 1: Vessel (SA-533 GR.B CL 1)
! MAT 2: Nozzle (SA-336 F8, USE TYP 304 STAINLESS)
! MAT 3: BUTTER (use Alloy 600)
! MAT 4: Weld (use Alloy 600)
! MAT 5: SAFE END - NOT USED
! MAT 6: CLADDING "STAINLESS - SA 304", USE TYP 304 STAINLESS)
! MAT 7: Air

MPTEMP, 1, 70,200,300,400,500, 600
tmp = 3600*12      ! hr-ft to sec-in
vm  = 12**3        !ft3 to in3

/com, VESSEL, SA-533 Gr. B Cl 1 (Mn-1/2Mo-1/2Ni)
        MPDATA,EX ,1, 1, 29.0e6,  28.5e6,  28.0e6,  27.6e6,  27.0e6, 26.3e6
        MPDATA,ALPX,1, 1, 7.0e-6,  7.3e-6,  7.4e-6,  7.6e-6,  7.7e-6, 7.8e-6
        MPDATA, KXX,1, 1, 23.7/tmp, 23.5/tmp, 23.4/tmp, 23.1/tmp, 22.7/tmp, 22.2/tmp
        MPDATA,  C,1, 1, 0.106,  0.113,  0.119,  0.125,  0.130, 0.135
        MP,DENS,  1,      0.283
        MP,NUXY,  1,      0.3
        MP,REFT,          1,        550
        MPAMOD,                          1,        70


/COM, NOZZLE, SA-336 F8 (USE TYP 304 STAINLESS)
        MPDATA,EX ,2, 1, 28.3e6,  27.5e6,  27.0e6,  26.4e6,            25.9e6,           25.3e6
        MPDATA,ALPX,2, 1, 8.5e-6,  8.9e-6,  9.2e-6,  9.5e-6,  9.7e-6,  9.8e-6
        MPDATA, KXX,2, 1, 8.6/tmp,  9.3/tmp,  9.8/tmp,  10.4/tmp, 10.9/tmp, 11.3/tmp
        MPDATA,  C,2, 1, 0.114,  0.119,  0.122,  0.126,  0.129,            0.130
        MP,DENS,  2,      0.300
        MP,NUXY,  2,      0.3
        MP,REFT,          2,        550
        MPAMOD,                          2,        70

/COM, BUTTER, INCONEL (use N06600)
        MPDATA,EX ,3, 1, 31.0e6,  30.3e6,  29.9e6,  29.4e6,  29.0e6, 28.6e6
        MPDATA,ALPX,3, 1, 6.8e-6,  7.1e-6,  7.3e-6,  7.5e-6,  7.6e-6, 7.8e-6
        MPDATA, KXX,3, 1, 8.6/tmp,  9.1/tmp,  9.6/tmp,  10.1/tmp, 10.6/tmp, 11.1/tmp
        MPDATA,  C,3, 1, 0.108,  0.113,  0.116,  0.118,  0.120, 0.122
        MP,DENS,  3,      0.300
        MP,NUXY,  3,      0.3
        MP,REFT,          3,        550
        MPAMOD,                          3,        70

/COM, WELD, INCONEL (use N06600)
        MPDATA,EX ,4, 1, 31.0e6,  30.3e6,  29.9e6,  29.4e6,  29.0e6, 28.6e6
        MPDATA,ALPX,4, 1, 6.8e-6,  7.1e-6,  7.3e-6,  7.5e-6,  7.6e-6, 7.8e-6
        MPDATA, KXX,4, 1, 8.6/tmp,  9.1/tmp,  9.6/tmp,  10.1/tmp, 10.6/tmp, 11.1/tmp
        MPDATA,  C,4, 1, 0.108,  0.113,  0.116,  0.118,  0.120, 0.122
        MP,DENS,  4,      0.300
        MP,NUXY,  4,      0.3
        MP,REFT,          4,        550
        MPAMOD,                          4,        70

/COM, CLADDING, "SA-304" (USE STAINLESS, TYPE 304)
        MPDATA,EX ,6, 1, 28.3e6,  27.5e6,  27.0e6,  26.4e6,            25.9e6,           25.3e6
        MPDATA,ALPX,6, 1, 8.5e-6,  8.9e-6,  9.2e-6,  9.5e-6,  9.7e-6,  9.8e-6
        MPDATA, KXX,6, 1, 8.6/tmp,  9.3/tmp,  9.8/tmp,  10.4/tmp, 10.9/tmp, 11.3/tmp
        MPDATA,  C,6, 1, 0.114,  0.119,  0.122,  0.126,  0.129,            0.130
        MP,DENS,  6,      0.290
        MP,NUXY,  6,      0.3
        MP,REFT,          6,        550
```

```
        MPAMOD,                        6,        70

/COM, AIR
        MPTEMP, 1, 32,100,200,300,400,500
        MPDATA,KXX,  7,  1, 0.0172/tmp,  0.0189/tmp,  0.0214/tmp,  0.0237/tmp,  0.0261/tmp, 0.0284/tmp
        MPDATA,C,    7,  1,     0.24,       0.24,       0.241,      0.243,      0.245,      0.247
        MPDATA,DENS, 7,  1,  0.081/vm,    0.071/vm,    0.060/vm,    0.052/vm,    0.046/vm, 0.0412/vm

        MPTEMP, 7,600
        MPDATA,KXX,  7,  7, 0.0308/tmp
        MPDATA,C,    7,  7,    0.250
        MPDATA,DENS, 7,  7,  0.0373/vm
```

IN-HTBC.INP

```
!APPLY HTC NOZZLE ID
FLST,2,8,5,ORDE,8
FITEM,2,49
FITEM,2,63
FITEM,2,66
FITEM,2,96
FITEM,2,135
FITEM,2,137
FITEM,2,141
FITEM,2,145
/GO
SFA,P51X,1,CONV,h1,Tnoz

!APPLY HTC VESSEL ID
FLST,2,7,5,ORDE,6
FITEM,2,7
FITEM,2,23
FITEM,2,39
FITEM,2,-41
FITEM,2,56
FITEM,2,75
/GO
SFA,P51X,1,CONV,h2,Tves

!APPLY HTC OUTSIDE
FLST,2,5,5,ORDE,5
FITEM,2,27
FITEM,2,34
FITEM,2,58
FITEM,2,86
FITEM,2,98
/GO
SFA,P51X,1,CONV,h3,Tout
```

IN-PRESS.INP

```
finish
/clear,start
/CONFIG,NPROC,2
/CONFIG,NRES,100000
/FILNAME,IN-PRESS,1
/TITLE,UNIT INTERNAL PRESSURE (1000PSI) ANALYSIS
/NUMBER,1
/PNUM,MAT,1
/PLOPTS,DATE,0
/PREP7

et,1,solid45

/INP,IN,INP,,:read

!DELETE CLADDING AND AIR
FLST,2,11,6,ORDE,10
FITEM,2,2
FITEM,2,-3
FITEM,2,6
FITEM,2,9
FITEM,2,-10
FITEM,2,15
FITEM,2,17
FITEM,2,22
FITEM,2,-24
FITEM,2,36
VCLEAR,P51X
FLST,2,11,6,ORDE,10
FITEM,2,2
FITEM,2,-3
FITEM,2,6
FITEM,2,9
FITEM,2,-10
FITEM,2,15
FITEM,2,17
FITEM,2,22
FITEM,2,-24
FITEM,2,36
VDELE,P51X, , ,1

ALLSEL,ALL

CSYS,0
!ADD END CAP PRESSURES
P = 1000

PCAP = P*ri1**2/(ro1**2-ri1**2)

PCAPV = P*(ri+tc)**2/(ro**2-(ri+tc)**2)

SFA,114,1,PRES,-PCAP, ,
SFA,207,1,PRES,-PCAPV, ,

!ADD SYMMETRY TO THE SYMMETRY FACE
FLST,2,14,5,ORDE,14
FITEM,2,25
FITEM,2,32
FITEM,2,37
FITEM,2,52
FITEM,2,65
FITEM,2,68
FITEM,2,80
FITEM,2,91
```

```
FITEM,2,95
FITEM,2,133
FITEM,2,140
FITEM,2,144
FITEM,2,148
FITEM,2,160
DA,P51X,SYMM

FLST,2,14,5,ORDE,14
FITEM,2,26
FITEM,2,31
FITEM,2,36
FITEM,2,51
FITEM,2,54
FITEM,2,67
FITEM,2,82
FITEM,2,89
FITEM,2,-90
FITEM,2,93
FITEM,2,-94
FITEM,2,97
FITEM,2,109
FITEM,2,115
DA,P51X,SYMM

DA,    219,SYMM

!Coupling end of vessel
ASEL,S, , ,207
NSLA,S,1
CP,next,UY,ALL
ALLSEL,ALL

!COUPLE THE ENDS OF THE PIPING
ASEL,S, , ,114
NSLA,S,1
CP,NEXT,UX,ALL
ALLSEL,ALL

!ADD INTERNAL PRESSURE
FLST,2,14,5,ORDE,14
FITEM,2,8
FITEM,2,19
FITEM,2,24
FITEM,2,42
FITEM,2,45
FITEM,2,-46
FITEM,2,63
FITEM,2,66
FITEM,2,76
FITEM,2,96
FITEM,2,135
FITEM,2,137
FITEM,2,141
FITEM,2,145
/GO
SFA,P51X,1,PRES,P

/COM, CONTACT PAIR CREATION - START
        !IF NEEDED
/COM, CONTACT PAIR CREATION - END

TUNIF,550

/SOLU

ANTYPE,STATIC,NEW
```

```
SOLVE

SAVE

!CREATE LOCAL COORDINATE SYSTEM - CSYS11
/PREP7
K,1000,140
K,1001,140,1
K,1002,140,,1
CSKP,11,1,1000,1001,1002

/POST1
!-- DEFINE PATHS -----------------------------------------------------
        CSYS,0
        PATH_01_ID = NODE(KX(40),KY(40),KZ(40))        ! INSIDE NODE PATH 1
        PATH_01_OD = NODE(KX(47),KY(47),KZ(47))        ! OUTSIDE NODE PATH 1

        FLST,2,2,1
        FITEM,2,PATH_01_ID
        FITEM,2,PATH_01_OD
        PATH,PTH1,2,30,30,
        PPATH,P51X,1

!WRITE STRESS TO OUTPUT FILES
/OUT,PRESS_STR,OUT
RSYS,11
PATH,STAT
PATH,PTH1
                /COM,
        /COM,******************************************************
        /COM, HOOP STRESS OUTPUTS
        /COM,******************************************************
                *GET,Tcurr,ACTIVE,0,SET,TIME
                /COM,
                /COM, TIME = %Tcurr%
                PDEF,SY,S,Y,AVG
                /PBC,PATH, ,0
                PRPATH,SY
/OUT

FINISH
```

SHUTDOWN-T.INP

```
FINISH
/clear,start
/CONFIG,NPROC,2
/CONFIG,NRES,100000
/filn,SHUTDOWN-T,1
/prep7
/NUMBER,1
/PNUM,MAT,1
/PLOPTS,DATE,0
/title, 2 inch Instrument Nozzle

/com, ****************************
/com, ELEMENT TYPES
/com, ****************************

ET,1,solid70

/INPUT,IN,inp,,:read

/SOLU
!******************************
/com, Set Thermal Boundary Conditions
!*****************************
TUNIF, 100

Tout=100            !Outside temperature
Tves=552     !Vessel temperature
Tnoz=552                !Nozzle temperature
/com, *** Heat Transfer Coefficients ***
h1=650/(3600*144)      !Nozzle
h2=650/(3600*144)      !Vessel
h3=0.2/(3600*144)                 !Outside
/INPUT,IN-HTBC,INP

!*****************
/com, Perform Run, Steady State
!*****************
ANTYPE,TRANS
allsel, all
outres,nsol,all
outpr,nsol,last
TIMINT,OFF
TIME,1e-10
SOLVE

/COM, LOAD STEP 2
Tves=250     !FLUID TEMP
Tnoz=250                !FLUID TEMP
/com, *** Heat Transfer Coefficients ***
h1=450/(3600*144)  !Nozzle
h2=450/(3600*144)  !Vessel
/INPUT,IN-HTBC,INP
kbc,0        !ramp
TIMINT,ON
AUTOTS,ON
deltim,5,5,500,off
TIME,10872
SOLVE

/COM, LOAD STEP 3
Tves=205     !FLUID TEMP
Tnoz=205                !FLUID TEMP
/com, *** Heat Transfer Coefficients ***
h1=400/(3600*144)  !Nozzle
```

```
h2=400/(3600*144)  !Vessel
/INPUT,IN-HTBC,INP
kbc,0         !ramp
TIMINT,ON
deltim,5,5,500,off
TIME,11472
SOLVE

/COM, LOAD STEP 4
Tves=100     !FLUID TEMP
Tnoz=100                          !FLUID TEMP
/com, *** Heat Transfer Coefficients ***
h1=275/(3600*144)  !Nozzle
h2=275/(3600*144)  !Vessel
/INPUT,IN-HTBC,INP
kbc,0         !ramp
TIMINT,ON
deltim,5,5,500,off
TIME,15252
SOLVE

/COM, RUN TO STEADY STATE
kbc,0         !ramp
TIMINT,ON
deltim,100,100,10,off
TIME,25252
SOLVE

SAVE

/POST1
*GET,NSet,ACTIVE,,SET,NSET
*IF,NSet,LT,1,THEN
 /EOF
*ENDIF
MN=
*DIM,MN,ARRAY,NSet,4
*GET,DBname,ACTIVE,,JOBNAM
/POST26
LINES,1000000
SOLU,2,NCMLS,,LOADSTEP
STORE,MERGE
SOLU,3,NCMSS,,SUBSTEP
STORE,MERGE
SOLU,4,MXDVL,,TMAX
STORE,MERGE
/FORMAT,7,F,12,5
/OUT,DBname,TXT
 PRVAR,2,3,4
/OUT
FINISH
*VREAD,MN(1,1),DBname,TXT,,JIK,4,NSet,,6
(4F14.5)
*IF,MN(1,1),LT,0.0001,THEN
 *MSG,WARN
 Time for loadstep 1 is trivial (<0.0001). It is set at TIME=0.0001
 MN(1,1) = 0.0001
*ENDIF
*CFOPEN,%DBname%_mntr,inp
*VWRITE
NSUBST,1,10,1
*VWRITE
OUTRES,ALL,LAST
*VWRITE
RESCONTROL,DEFINE NONE ! Disable multi-frame restart option
*VWRITE
(' ')
```

```
*VWRITE,MN(1,2),MN(1,3),DBname,MN(1,1),MN(1,4)
LDREAD,TEMP,%6I,%6I,,,%C,rth $TIME,%13.5F $SOLVE !Tmx=%8.2F
*CFCLOS
/DELETE,DBname,TXT
MN=
*MSG,UI,DBname
Converted thermal pass load step data has been saved to%/&
%C_mntr.inp
```

SHUTDOWN-T_mntr.inp

```
NSUBST,1,10,1
OUTRES,ALL,LAST
RESCONTROL,DEFINE NONE ! Disable multi-frame restart option

LDREAD,TEMP,  1,  1,,,SHUTDOWN-T,rth $TIME,  0.00010 $SOLVE !Tmx= 551.99
LDREAD,TEMP,  2,  1,,,SHUTDOWN-T,rth $TIME,  5.00092 $SOLVE !Tmx= 551.91
LDREAD,TEMP,  2,  2,,,SHUTDOWN-T,rth $TIME,  10.00092 $SOLVE !Tmx= 551.85
LDREAD,TEMP,  2,  3,,,SHUTDOWN-T,rth $TIME,  15.00092 $SOLVE !Tmx= 551.79
LDREAD,TEMP,  2,  4,,,SHUTDOWN-T,rth $TIME,  20.00092 $SOLVE !Tmx= 551.74
LDREAD,TEMP,  2,  5,,,SHUTDOWN-T,rth $TIME,  25.00092 $SOLVE !Tmx= 551.70
LDREAD,TEMP,  2,  6,,,SHUTDOWN-T,rth $TIME,  30.00092 $SOLVE !Tmx= 551.66
LDREAD,TEMP,  2,  7,,,SHUTDOWN-T,rth $TIME,  35.00092 $SOLVE !Tmx= 551.63
LDREAD,TEMP,  2,  8,,,SHUTDOWN-T,rth $TIME,  40.00092 $SOLVE !Tmx= 551.60
LDREAD,TEMP,  2,  9,,,SHUTDOWN-T,rth $TIME,  45.00092 $SOLVE !Tmx= 551.56
LDREAD,TEMP,  2,  10,,,SHUTDOWN-T,rth $TIME,  50.00092 $SOLVE !Tmx= 551.52
LDREAD,TEMP,  2,  11,,,SHUTDOWN-T,rth $TIME,  55.00092 $SOLVE !Tmx= 551.48
LDREAD,TEMP,  2,  12,,,SHUTDOWN-T,rth $TIME,  60.22762 $SOLVE !Tmx= 551.43
LDREAD,TEMP,  2,  13,,,SHUTDOWN-T,rth $TIME,  65.78305 $SOLVE !Tmx= 551.37
LDREAD,TEMP,  2,  14,,,SHUTDOWN-T,rth $TIME,  71.67459 $SOLVE !Tmx= 551.31
LDREAD,TEMP,  2,  15,,,SHUTDOWN-T,rth $TIME,  77.90989 $SOLVE !Tmx= 551.24
LDREAD,TEMP,  2,  16,,,SHUTDOWN-T,rth $TIME,  84.49670 $SOLVE !Tmx= 551.16
LDREAD,TEMP,  2,  17,,,SHUTDOWN-T,rth $TIME,  91.44283 $SOLVE !Tmx= 551.11
LDREAD,TEMP,  2,  18,,,SHUTDOWN-T,rth $TIME,  98.75607 $SOLVE !Tmx= 551.05
LDREAD,TEMP,  2,  19,,,SHUTDOWN-T,rth $TIME,  106.44414 $SOLVE !Tmx= 551.00
LDREAD,TEMP,  2,  20,,,SHUTDOWN-T,rth $TIME,  114.51465 $SOLVE !Tmx= 550.96
LDREAD,TEMP,  2,  21,,,SHUTDOWN-T,rth $TIME,  122.97511 $SOLVE !Tmx= 550.91
LDREAD,TEMP,  2,  22,,,SHUTDOWN-T,rth $TIME,  131.83288 $SOLVE !Tmx= 550.86
LDREAD,TEMP,  2,  23,,,SHUTDOWN-T,rth $TIME,  141.09520 $SOLVE !Tmx= 550.81
LDREAD,TEMP,  2,  24,,,SHUTDOWN-T,rth $TIME,  150.76917 $SOLVE !Tmx= 550.76
LDREAD,TEMP,  2,  25,,,SHUTDOWN-T,rth $TIME,  160.86178 $SOLVE !Tmx= 550.70
LDREAD,TEMP,  2,  26,,,SHUTDOWN-T,rth $TIME,  171.37991 $SOLVE !Tmx= 550.65
LDREAD,TEMP,  2,  27,,,SHUTDOWN-T,rth $TIME,  182.33039 $SOLVE !Tmx= 550.60
LDREAD,TEMP,  2,  28,,,SHUTDOWN-T,rth $TIME,  193.72000 $SOLVE !Tmx= 550.55
LDREAD,TEMP,  2,  29,,,SHUTDOWN-T,rth $TIME,  205.55552 $SOLVE !Tmx= 550.49
LDREAD,TEMP,  2,  30,,,SHUTDOWN-T,rth $TIME,  217.84380 $SOLVE !Tmx= 550.44
LDREAD,TEMP,  2,  31,,,SHUTDOWN-T,rth $TIME,  230.59184 $SOLVE !Tmx= 550.38
LDREAD,TEMP,  2,  32,,,SHUTDOWN-T,rth $TIME,  243.80679 $SOLVE !Tmx= 550.33
LDREAD,TEMP,  2,  33,,,SHUTDOWN-T,rth $TIME,  257.49611 $SOLVE !Tmx= 550.27
LDREAD,TEMP,  2,  34,,,SHUTDOWN-T,rth $TIME,  271.66761 $SOLVE !Tmx= 550.21
LDREAD,TEMP,  2,  35,,,SHUTDOWN-T,rth $TIME,  286.32957 $SOLVE !Tmx= 550.15
LDREAD,TEMP,  2,  36,,,SHUTDOWN-T,rth $TIME,  301.49079 $SOLVE !Tmx= 550.09
LDREAD,TEMP,  2,  37,,,SHUTDOWN-T,rth $TIME,  317.16073 $SOLVE !Tmx= 550.03
LDREAD,TEMP,  2,  38,,,SHUTDOWN-T,rth $TIME,  333.34958 $SOLVE !Tmx= 549.97
LDREAD,TEMP,  2,  39,,,SHUTDOWN-T,rth $TIME,  350.06838 $SOLVE !Tmx= 549.90
LDREAD,TEMP,  2,  40,,,SHUTDOWN-T,rth $TIME,  367.32906 $SOLVE !Tmx= 549.84
LDREAD,TEMP,  2,  41,,,SHUTDOWN-T,rth $TIME,  385.14457 $SOLVE !Tmx= 549.77
LDREAD,TEMP,  2,  42,,,SHUTDOWN-T,rth $TIME,  403.52895 $SOLVE !Tmx= 549.70
LDREAD,TEMP,  2,  43,,,SHUTDOWN-T,rth $TIME,  422.49737 $SOLVE !Tmx= 549.62
LDREAD,TEMP,  2,  44,,,SHUTDOWN-T,rth $TIME,  442.06623 $SOLVE !Tmx= 549.54
LDREAD,TEMP,  2,  45,,,SHUTDOWN-T,rth $TIME,  462.25317 $SOLVE !Tmx= 549.45
LDREAD,TEMP,  2,  46,,,SHUTDOWN-T,rth $TIME,  483.07716 $SOLVE !Tmx= 549.35
LDREAD,TEMP,  2,  47,,,SHUTDOWN-T,rth $TIME,  504.55847 $SOLVE !Tmx= 549.25
LDREAD,TEMP,  2,  48,,,SHUTDOWN-T,rth $TIME,  526.71876 $SOLVE !Tmx= 549.14
LDREAD,TEMP,  2,  49,,,SHUTDOWN-T,rth $TIME,  549.58103 $SOLVE !Tmx= 549.02
LDREAD,TEMP,  2,  50,,,SHUTDOWN-T,rth $TIME,  573.16964 $SOLVE !Tmx= 548.89
LDREAD,TEMP,  2,  51,,,SHUTDOWN-T,rth $TIME,  597.51030 $SOLVE !Tmx= 548.75
LDREAD,TEMP,  2,  52,,,SHUTDOWN-T,rth $TIME,  622.63005 $SOLVE !Tmx= 548.59
LDREAD,TEMP,  2,  53,,,SHUTDOWN-T,rth $TIME,  648.55718 $SOLVE !Tmx= 548.43
LDREAD,TEMP,  2,  54,,,SHUTDOWN-T,rth $TIME,  675.32123 $SOLVE !Tmx= 548.24
LDREAD,TEMP,  2,  55,,,SHUTDOWN-T,rth $TIME,  702.95291 $SOLVE !Tmx= 548.04
LDREAD,TEMP,  2,  56,,,SHUTDOWN-T,rth $TIME,  731.48398 $SOLVE !Tmx= 547.82
LDREAD,TEMP,  2,  57,,,SHUTDOWN-T,rth $TIME,  760.94721 $SOLVE !Tmx= 547.59
LDREAD,TEMP,  2,  58,,,SHUTDOWN-T,rth $TIME,  791.37628 $SOLVE !Tmx= 547.33
LDREAD,TEMP,  2,  59,,,SHUTDOWN-T,rth $TIME,  822.80560 $SOLVE !Tmx= 547.05
```

```
LDREAD,TEMP,  2,  60,,,SHUTDOWN-T,rth $TIME,  855.27023 $SOLVE !Tmx= 546.75
LDREAD,TEMP,  2,  61,,,SHUTDOWN-T,rth $TIME,  888.80570 $SOLVE !Tmx= 546.42
LDREAD,TEMP,  2,  62,,,SHUTDOWN-T,rth $TIME,  923.44787 $SOLVE !Tmx= 546.07
LDREAD,TEMP,  2,  63,,,SHUTDOWN-T,rth $TIME,  959.23275 $SOLVE !Tmx= 545.69
LDREAD,TEMP,  2,  64,,,SHUTDOWN-T,rth $TIME,  996.19628 $SOLVE !Tmx= 545.28
LDREAD,TEMP,  2,  65,,,SHUTDOWN-T,rth $TIME, 1034.37417 $SOLVE !Tmx= 544.84
LDREAD,TEMP,  2,  66,,,SHUTDOWN-T,rth $TIME, 1073.80169 $SOLVE !Tmx= 544.37
LDREAD,TEMP,  2,  67,,,SHUTDOWN-T,rth $TIME, 1114.51340 $SOLVE !Tmx= 543.86
LDREAD,TEMP,  2,  68,,,SHUTDOWN-T,rth $TIME, 1156.54297 $SOLVE !Tmx= 543.33
LDREAD,TEMP,  2,  69,,,SHUTDOWN-T,rth $TIME, 1199.92293 $SOLVE !Tmx= 542.76
LDREAD,TEMP,  2,  70,,,SHUTDOWN-T,rth $TIME, 1244.68445 $SOLVE !Tmx= 542.16
LDREAD,TEMP,  2,  71,,,SHUTDOWN-T,rth $TIME, 1290.85708 $SOLVE !Tmx= 541.51
LDREAD,TEMP,  2,  72,,,SHUTDOWN-T,rth $TIME, 1338.46855 $SOLVE !Tmx= 540.82
LDREAD,TEMP,  2,  73,,,SHUTDOWN-T,rth $TIME, 1387.54451 $SOLVE !Tmx= 540.09
LDREAD,TEMP,  2,  74,,,SHUTDOWN-T,rth $TIME, 1438.10834 $SOLVE !Tmx= 539.31
LDREAD,TEMP,  2,  75,,,SHUTDOWN-T,rth $TIME, 1490.18097 $SOLVE !Tmx= 538.48
LDREAD,TEMP,  2,  76,,,SHUTDOWN-T,rth $TIME, 1543.78066 $SOLVE !Tmx= 537.61
LDREAD,TEMP,  2,  77,,,SHUTDOWN-T,rth $TIME, 1598.92284 $SOLVE !Tmx= 536.68
LDREAD,TEMP,  2,  78,,,SHUTDOWN-T,rth $TIME, 1655.61999 $SOLVE !Tmx= 535.71
LDREAD,TEMP,  2,  79,,,SHUTDOWN-T,rth $TIME, 1713.88152 $SOLVE !Tmx= 534.68
LDREAD,TEMP,  2,  80,,,SHUTDOWN-T,rth $TIME, 1773.71368 $SOLVE !Tmx= 533.60
LDREAD,TEMP,  2,  81,,,SHUTDOWN-T,rth $TIME, 1835.11949 $SOLVE !Tmx= 532.47
LDREAD,TEMP,  2,  82,,,SHUTDOWN-T,rth $TIME, 1898.09874 $SOLVE !Tmx= 531.28
LDREAD,TEMP,  2,  83,,,SHUTDOWN-T,rth $TIME, 1962.64797 $SOLVE !Tmx= 530.03
LDREAD,TEMP,  2,  84,,,SHUTDOWN-T,rth $TIME, 2028.76051 $SOLVE !Tmx= 528.73
LDREAD,TEMP,  2,  85,,,SHUTDOWN-T,rth $TIME, 2096.42656 $SOLVE !Tmx= 527.37
LDREAD,TEMP,  2,  86,,,SHUTDOWN-T,rth $TIME, 2165.63305 $SOLVE !Tmx= 525.96
LDREAD,TEMP,  2,  87,,,SHUTDOWN-T,rth $TIME, 2236.35804 $SOLVE !Tmx= 524.48
LDREAD,TEMP,  2,  88,,,SHUTDOWN-T,rth $TIME, 2308.57846 $SOLVE !Tmx= 522.95
LDREAD,TEMP,  2,  89,,,SHUTDOWN-T,rth $TIME, 2382.27718 $SOLVE !Tmx= 521.37
LDREAD,TEMP,  2,  90,,,SHUTDOWN-T,rth $TIME, 2457.43195 $SOLVE !Tmx= 519.72
LDREAD,TEMP,  2,  91,,,SHUTDOWN-T,rth $TIME, 2534.01068 $SOLVE !Tmx= 518.02
LDREAD,TEMP,  2,  92,,,SHUTDOWN-T,rth $TIME, 2611.99042 $SOLVE !Tmx= 516.27
LDREAD,TEMP,  2,  93,,,SHUTDOWN-T,rth $TIME, 2691.34232 $SOLVE !Tmx= 514.46
LDREAD,TEMP,  2,  94,,,SHUTDOWN-T,rth $TIME, 2772.03124 $SOLVE !Tmx= 512.60
LDREAD,TEMP,  2,  95,,,SHUTDOWN-T,rth $TIME, 2854.02588 $SOLVE !Tmx= 510.68
LDREAD,TEMP,  2,  96,,,SHUTDOWN-T,rth $TIME, 2937.29312 $SOLVE !Tmx= 508.71
LDREAD,TEMP,  2,  97,,,SHUTDOWN-T,rth $TIME, 3021.79748 $SOLVE !Tmx= 506.70
LDREAD,TEMP,  2,  98,,,SHUTDOWN-T,rth $TIME, 3107.50419 $SOLVE !Tmx= 504.63
LDREAD,TEMP,  2,  99,,,SHUTDOWN-T,rth $TIME, 3194.37749 $SOLVE !Tmx= 502.51
LDREAD,TEMP,  2, 100,,,SHUTDOWN-T,rth $TIME, 3282.38172 $SOLVE !Tmx= 500.35
LDREAD,TEMP,  2, 101,,,SHUTDOWN-T,rth $TIME, 3371.48123 $SOLVE !Tmx= 498.14
LDREAD,TEMP,  2, 102,,,SHUTDOWN-T,rth $TIME, 3461.64057 $SOLVE !Tmx= 495.89
LDREAD,TEMP,  2, 103,,,SHUTDOWN-T,rth $TIME, 3552.82471 $SOLVE !Tmx= 493.59
LDREAD,TEMP,  2, 104,,,SHUTDOWN-T,rth $TIME, 3644.99919 $SOLVE !Tmx= 491.25
LDREAD,TEMP,  2, 105,,,SHUTDOWN-T,rth $TIME, 3738.13024 $SOLVE !Tmx= 488.88
LDREAD,TEMP,  2, 106,,,SHUTDOWN-T,rth $TIME, 3832.18484 $SOLVE !Tmx= 486.46
LDREAD,TEMP,  2, 107,,,SHUTDOWN-T,rth $TIME, 3927.13080 $SOLVE !Tmx= 484.01
LDREAD,TEMP,  2, 108,,,SHUTDOWN-T,rth $TIME, 4022.93686 $SOLVE !Tmx= 481.52
LDREAD,TEMP,  2, 109,,,SHUTDOWN-T,rth $TIME, 4119.57273 $SOLVE !Tmx= 479.00
LDREAD,TEMP,  2, 110,,,SHUTDOWN-T,rth $TIME, 4217.00916 $SOLVE !Tmx= 476.44
LDREAD,TEMP,  2, 111,,,SHUTDOWN-T,rth $TIME, 4315.21797 $SOLVE !Tmx= 473.85
LDREAD,TEMP,  2, 112,,,SHUTDOWN-T,rth $TIME, 4414.17210 $SOLVE !Tmx= 471.23
LDREAD,TEMP,  2, 113,,,SHUTDOWN-T,rth $TIME, 4513.84561 $SOLVE !Tmx= 468.58
LDREAD,TEMP,  2, 114,,,SHUTDOWN-T,rth $TIME, 4614.21374 $SOLVE !Tmx= 465.90
LDREAD,TEMP,  2, 115,,,SHUTDOWN-T,rth $TIME, 4715.25287 $SOLVE !Tmx= 463.20
LDREAD,TEMP,  2, 116,,,SHUTDOWN-T,rth $TIME, 4816.94055 $SOLVE !Tmx= 460.46
LDREAD,TEMP,  2, 117,,,SHUTDOWN-T,rth $TIME, 4919.25546 $SOLVE !Tmx= 457.71
LDREAD,TEMP,  2, 118,,,SHUTDOWN-T,rth $TIME, 5022.17744 $SOLVE !Tmx= 454.93
LDREAD,TEMP,  2, 119,,,SHUTDOWN-T,rth $TIME, 5125.68745 $SOLVE !Tmx= 452.12
LDREAD,TEMP,  2, 120,,,SHUTDOWN-T,rth $TIME, 5229.76752 $SOLVE !Tmx= 449.30
LDREAD,TEMP,  2, 121,,,SHUTDOWN-T,rth $TIME, 5334.40079 $SOLVE !Tmx= 446.45
LDREAD,TEMP,  2, 122,,,SHUTDOWN-T,rth $TIME, 5439.57142 $SOLVE !Tmx= 443.58
LDREAD,TEMP,  2, 123,,,SHUTDOWN-T,rth $TIME, 5545.26458 $SOLVE !Tmx= 440.69
LDREAD,TEMP,  2, 124,,,SHUTDOWN-T,rth $TIME, 5651.46646 $SOLVE !Tmx= 437.78
LDREAD,TEMP,  2, 125,,,SHUTDOWN-T,rth $TIME, 5758.16415 $SOLVE !Tmx= 434.86
LDREAD,TEMP,  2, 126,,,SHUTDOWN-T,rth $TIME, 5865.34554 $SOLVE !Tmx= 431.91
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LDREAD,TEMP,  2, 127,,,SHUTDOWN-T,rth $TIME,  5972.99268 $SOLVE !Tmx= 428.95
LDREAD,TEMP,  2, 128,,,SHUTDOWN-T,rth $TIME,  6081.07889 $SOLVE !Tmx= 425.97
LDREAD,TEMP,  2, 129,,,SHUTDOWN-T,rth $TIME,  6189.60500 $SOLVE !Tmx= 422.98
LDREAD,TEMP,  2, 130,,,SHUTDOWN-T,rth $TIME,  6298.55210 $SOLVE !Tmx= 419.97
LDREAD,TEMP,  2, 131,,,SHUTDOWN-T,rth $TIME,  6407.91961 $SOLVE !Tmx= 416.94
LDREAD,TEMP,  2, 132,,,SHUTDOWN-T,rth $TIME,  6517.69964 $SOLVE !Tmx= 413.91
LDREAD,TEMP,  2, 133,,,SHUTDOWN-T,rth $TIME,  6627.88259 $SOLVE !Tmx= 410.86
LDREAD,TEMP,  2, 134,,,SHUTDOWN-T,rth $TIME,  6738.46366 $SOLVE !Tmx= 407.79
LDREAD,TEMP,  2, 135,,,SHUTDOWN-T,rth $TIME,  6849.43633 $SOLVE !Tmx= 404.71
LDREAD,TEMP,  2, 136,,,SHUTDOWN-T,rth $TIME,  6960.79660 $SOLVE !Tmx= 401.62
LDREAD,TEMP,  2, 137,,,SHUTDOWN-T,rth $TIME,  7072.53971 $SOLVE !Tmx= 398.52
LDREAD,TEMP,  2, 138,,,SHUTDOWN-T,rth $TIME,  7184.66059 $SOLVE !Tmx= 395.40
LDREAD,TEMP,  2, 139,,,SHUTDOWN-T,rth $TIME,  7297.16510 $SOLVE !Tmx= 392.27
LDREAD,TEMP,  2, 140,,,SHUTDOWN-T,rth $TIME,  7410.05311 $SOLVE !Tmx= 389.13
LDREAD,TEMP,  2, 141,,,SHUTDOWN-T,rth $TIME,  7523.32069 $SOLVE !Tmx= 385.97
LDREAD,TEMP,  2, 142,,,SHUTDOWN-T,rth $TIME,  7636.96444 $SOLVE !Tmx= 382.81
LDREAD,TEMP,  2, 143,,,SHUTDOWN-T,rth $TIME,  7750.98148 $SOLVE !Tmx= 379.63
LDREAD,TEMP,  2, 144,,,SHUTDOWN-T,rth $TIME,  7865.36942 $SOLVE !Tmx= 376.44
LDREAD,TEMP,  2, 145,,,SHUTDOWN-T,rth $TIME,  7980.12629 $SOLVE !Tmx= 373.23
LDREAD,TEMP,  2, 146,,,SHUTDOWN-T,rth $TIME,  8095.25057 $SOLVE !Tmx= 370.02
LDREAD,TEMP,  2, 147,,,SHUTDOWN-T,rth $TIME,  8210.74111 $SOLVE !Tmx= 366.79
LDREAD,TEMP,  2, 148,,,SHUTDOWN-T,rth $TIME,  8326.59716 $SOLVE !Tmx= 363.56
LDREAD,TEMP,  2, 149,,,SHUTDOWN-T,rth $TIME,  8442.81833 $SOLVE !Tmx= 360.31
LDREAD,TEMP,  2, 150,,,SHUTDOWN-T,rth $TIME,  8559.40454 $SOLVE !Tmx= 357.05
LDREAD,TEMP,  2, 151,,,SHUTDOWN-T,rth $TIME,  8676.35608 $SOLVE !Tmx= 353.78
LDREAD,TEMP,  2, 152,,,SHUTDOWN-T,rth $TIME,  8793.67352 $SOLVE !Tmx= 350.50
LDREAD,TEMP,  2, 153,,,SHUTDOWN-T,rth $TIME,  8911.35774 $SOLVE !Tmx= 347.21
LDREAD,TEMP,  2, 154,,,SHUTDOWN-T,rth $TIME,  9029.40992 $SOLVE !Tmx= 343.90
LDREAD,TEMP,  2, 155,,,SHUTDOWN-T,rth $TIME,  9147.83147 $SOLVE !Tmx= 340.59
LDREAD,TEMP,  2, 156,,,SHUTDOWN-T,rth $TIME,  9266.62411 $SOLVE !Tmx= 337.27
LDREAD,TEMP,  2, 157,,,SHUTDOWN-T,rth $TIME,  9385.78979 $SOLVE !Tmx= 333.93
LDREAD,TEMP,  2, 158,,,SHUTDOWN-T,rth $TIME,  9505.33088 $SOLVE !Tmx= 330.58
LDREAD,TEMP,  2, 159,,,SHUTDOWN-T,rth $TIME,  9625.25834 $SOLVE !Tmx= 327.23
LDREAD,TEMP,  2, 160,,,SHUTDOWN-T,rth $TIME,  9745.59736 $SOLVE !Tmx= 323.86
LDREAD,TEMP,  2, 161,,,SHUTDOWN-T,rth $TIME,  9866.32832 $SOLVE !Tmx= 320.48
LDREAD,TEMP,  2, 162,,,SHUTDOWN-T,rth $TIME,  9987.41392 $SOLVE !Tmx= 317.09
LDREAD,TEMP,  2, 163,,,SHUTDOWN-T,rth $TIME, 10108.88521 $SOLVE !Tmx= 313.69
LDREAD,TEMP,  2, 164,,,SHUTDOWN-T,rth $TIME, 10230.72816 $SOLVE !Tmx= 310.27
LDREAD,TEMP,  2, 165,,,SHUTDOWN-T,rth $TIME, 10352.95388 $SOLVE !Tmx= 306.85
LDREAD,TEMP,  2, 166,,,SHUTDOWN-T,rth $TIME, 10475.56274 $SOLVE !Tmx= 303.42
LDREAD,TEMP,  2, 167,,,SHUTDOWN-T,rth $TIME, 10598.55819 $SOLVE !Tmx= 299.98
LDREAD,TEMP,  2, 168,,,SHUTDOWN-T,rth $TIME, 10721.94451 $SOLVE !Tmx= 296.52
LDREAD,TEMP,  2, 169,,,SHUTDOWN-T,rth $TIME, 10796.97225 $SOLVE !Tmx= 294.42
LDREAD,TEMP,  2, 170,,,SHUTDOWN-T,rth $TIME, 10872.00000 $SOLVE !Tmx= 292.32
LDREAD,TEMP,  3,   1,,,SHUTDOWN-T,rth $TIME, 10877.00000 $SOLVE !Tmx= 292.18
LDREAD,TEMP,  3,   2,,,SHUTDOWN-T,rth $TIME, 10882.00000 $SOLVE !Tmx= 292.04
LDREAD,TEMP,  3,   3,,,SHUTDOWN-T,rth $TIME, 10897.00000 $SOLVE !Tmx= 291.62
LDREAD,TEMP,  3,   4,,,SHUTDOWN-T,rth $TIME, 10931.12033 $SOLVE !Tmx= 290.67
LDREAD,TEMP,  3,   5,,,SHUTDOWN-T,rth $TIME, 10965.84514 $SOLVE !Tmx= 289.69
LDREAD,TEMP,  3,   6,,,SHUTDOWN-T,rth $TIME, 11002.43191 $SOLVE !Tmx= 288.65
LDREAD,TEMP,  3,   7,,,SHUTDOWN-T,rth $TIME, 11041.35825 $SOLVE !Tmx= 287.53
LDREAD,TEMP,  3,   8,,,SHUTDOWN-T,rth $TIME, 11082.82853 $SOLVE !Tmx= 286.32
LDREAD,TEMP,  3,   9,,,SHUTDOWN-T,rth $TIME, 11126.98053 $SOLVE !Tmx= 285.00
LDREAD,TEMP,  3,  10,,,SHUTDOWN-T,rth $TIME, 11173.93760 $SOLVE !Tmx= 283.55
LDREAD,TEMP,  3,  11,,,SHUTDOWN-T,rth $TIME, 11223.82883 $SOLVE !Tmx= 281.95
LDREAD,TEMP,  3,  12,,,SHUTDOWN-T,rth $TIME, 11276.79811 $SOLVE !Tmx= 280.18
LDREAD,TEMP,  3,  13,,,SHUTDOWN-T,rth $TIME, 11333.00817 $SOLVE !Tmx= 278.23
LDREAD,TEMP,  3,  14,,,SHUTDOWN-T,rth $TIME, 11392.64223 $SOLVE !Tmx= 276.07
LDREAD,TEMP,  3,  15,,,SHUTDOWN-T,rth $TIME, 11432.32111 $SOLVE !Tmx= 274.59
LDREAD,TEMP,  3,  16,,,SHUTDOWN-T,rth $TIME, 11472.00000 $SOLVE !Tmx= 273.07
LDREAD,TEMP,  4,   1,,,SHUTDOWN-T,rth $TIME, 11477.00000 $SOLVE !Tmx= 272.88
LDREAD,TEMP,  4,   2,,,SHUTDOWN-T,rth $TIME, 11482.00000 $SOLVE !Tmx= 272.69
LDREAD,TEMP,  4,   3,,,SHUTDOWN-T,rth $TIME, 11497.00000 $SOLVE !Tmx= 272.11
LDREAD,TEMP,  4,   4,,,SHUTDOWN-T,rth $TIME, 11542.00000 $SOLVE !Tmx= 270.31
LDREAD,TEMP,  4,   5,,,SHUTDOWN-T,rth $TIME, 11677.00000 $SOLVE !Tmx= 264.70
LDREAD,TEMP,  4,   6,,,SHUTDOWN-T,rth $TIME, 11898.03025 $SOLVE !Tmx= 255.54
LDREAD,TEMP,  4,   7,,,SHUTDOWN-T,rth $TIME, 12125.67674 $SOLVE !Tmx= 246.37
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LDREAD,TEMP,  4,  8,,,SHUTDOWN-T,rth $TIME, 12348.61662 $SOLVE !Tmx= 237.73
LDREAD,TEMP,  4,  9,,,SHUTDOWN-T,rth $TIME, 12571.55651 $SOLVE !Tmx= 229.42
LDREAD,TEMP,  4, 10,,,SHUTDOWN-T,rth $TIME, 12794.49640 $SOLVE !Tmx= 221.42
LDREAD,TEMP,  4, 11,,,SHUTDOWN-T,rth $TIME, 13017.43629 $SOLVE !Tmx= 213.68
LDREAD,TEMP,  4, 12,,,SHUTDOWN-T,rth $TIME, 13240.37617 $SOLVE !Tmx= 206.18
LDREAD,TEMP,  4, 13,,,SHUTDOWN-T,rth $TIME, 13463.31606 $SOLVE !Tmx= 198.88
LDREAD,TEMP,  4, 14,,,SHUTDOWN-T,rth $TIME, 13686.25595 $SOLVE !Tmx= 191.76
LDREAD,TEMP,  4, 15,,,SHUTDOWN-T,rth $TIME, 13909.19584 $SOLVE !Tmx= 184.79
LDREAD,TEMP,  4, 16,,,SHUTDOWN-T,rth $TIME, 14132.13572 $SOLVE !Tmx= 177.95
LDREAD,TEMP,  4, 17,,,SHUTDOWN-T,rth $TIME, 14355.07561 $SOLVE !Tmx= 171.22
LDREAD,TEMP,  4, 18,,,SHUTDOWN-T,rth $TIME, 14578.01550 $SOLVE !Tmx= 164.59
LDREAD,TEMP,  4, 19,,,SHUTDOWN-T,rth $TIME, 14800.95539 $SOLVE !Tmx= 158.04
LDREAD,TEMP,  4, 20,,,SHUTDOWN-T,rth $TIME, 15023.89527 $SOLVE !Tmx= 151.57
LDREAD,TEMP,  4, 21,,,SHUTDOWN-T,rth $TIME, 15137.94764 $SOLVE !Tmx= 148.27
LDREAD,TEMP,  4, 22,,,SHUTDOWN-T,rth $TIME, 15252.00000 $SOLVE !Tmx= 144.99
LDREAD,TEMP,  5,  1,,,SHUTDOWN-T,rth $TIME, 15257.00000 $SOLVE !Tmx= 144.85
LDREAD,TEMP,  5,  2,,,SHUTDOWN-T,rth $TIME, 15262.00000 $SOLVE !Tmx= 144.70
LDREAD,TEMP,  5,  3,,,SHUTDOWN-T,rth $TIME, 15277.00000 $SOLVE !Tmx= 144.27
LDREAD,TEMP,  5,  4,,,SHUTDOWN-T,rth $TIME, 15322.00000 $SOLVE !Tmx= 142.98
LDREAD,TEMP,  5,  5,,,SHUTDOWN-T,rth $TIME, 15457.00000 $SOLVE !Tmx= 139.25
LDREAD,TEMP,  5,  6,,,SHUTDOWN-T,rth $TIME, 15862.00000 $SOLVE !Tmx= 130.19
LDREAD,TEMP,  5,  7,,,SHUTDOWN-T,rth $TIME, 16362.00000 $SOLVE !Tmx= 121.90
LDREAD,TEMP,  5,  8,,,SHUTDOWN-T,rth $TIME, 16862.00000 $SOLVE !Tmx= 115.84
LDREAD,TEMP,  5,  9,,,SHUTDOWN-T,rth $TIME, 17362.00000 $SOLVE !Tmx= 111.45
LDREAD,TEMP,  5, 10,,,SHUTDOWN-T,rth $TIME, 17862.00000 $SOLVE !Tmx= 108.27
LDREAD,TEMP,  5, 11,,,SHUTDOWN-T,rth $TIME, 18362.00000 $SOLVE !Tmx= 105.97
LDREAD,TEMP,  5, 12,,,SHUTDOWN-T,rth $TIME, 18862.00000 $SOLVE !Tmx= 104.31
LDREAD,TEMP,  5, 13,,,SHUTDOWN-T,rth $TIME, 19362.00000 $SOLVE !Tmx= 103.11
LDREAD,TEMP,  5, 14,,,SHUTDOWN-T,rth $TIME, 19862.00000 $SOLVE !Tmx= 102.24
LDREAD,TEMP,  5, 15,,,SHUTDOWN-T,rth $TIME, 20362.00000 $SOLVE !Tmx= 101.62
LDREAD,TEMP,  5, 16,,,SHUTDOWN-T,rth $TIME, 20862.00000 $SOLVE !Tmx= 101.17
LDREAD,TEMP,  5, 17,,,SHUTDOWN-T,rth $TIME, 21362.00000 $SOLVE !Tmx= 100.84
LDREAD,TEMP,  5, 18,,,SHUTDOWN-T,rth $TIME, 21862.00000 $SOLVE !Tmx= 100.61
LDREAD,TEMP,  5, 19,,,SHUTDOWN-T,rth $TIME, 22362.00000 $SOLVE !Tmx= 100.44
LDREAD,TEMP,  5, 20,,,SHUTDOWN-T,rth $TIME, 22862.00000 $SOLVE !Tmx= 100.31
LDREAD,TEMP,  5, 21,,,SHUTDOWN-T,rth $TIME, 23362.00000 $SOLVE !Tmx= 100.23
LDREAD,TEMP,  5, 22,,,SHUTDOWN-T,rth $TIME, 23862.00000 $SOLVE !Tmx= 100.16
LDREAD,TEMP,  5, 23,,,SHUTDOWN-T,rth $TIME, 24362.00000 $SOLVE !Tmx= 100.12
LDREAD,TEMP,  5, 24,,,SHUTDOWN-T,rth $TIME, 24862.00000 $SOLVE !Tmx= 100.08
LDREAD,TEMP,  5, 25,,,SHUTDOWN-T,rth $TIME, 25252.00000 $SOLVE !Tmx= 100.07
```

SHUTDOWN-S.INP

```
FINISH
/clear,start
/CONFIG,NPROC,2
/CONFIG,NRES,100000
/filn,SHUTDOWN-S,1
/prep7
/NUMBER,1
/PNUM,MAT,1
/PLOPTS,DATE,0
/title, 2 inch Instrument Nozzle

/com, ****************************
/com, ELEMENT TYPES
/com, ****************************

ET,1,SOLID45

/INPUT,IN,INP,,:READ

!DELETE AIR
FLST,2,4,6,ORDE,3
FITEM,2,22
FITEM,2,-24
FITEM,2,36
VCLEAR,P51X
FLST,2,4,6,ORDE,3
FITEM,2,22
FITEM,2,-24
FITEM,2,36
VDELE,P51X, , ,1

ALLSEL,ALL

!ADD SYMMETRY TO THE SYMMETRY FACE
FLST,2,21,5,ORDE,21
FITEM,2,10
FITEM,2,15
FITEM,2,22
FITEM,2,25
FITEM,2,32
FITEM,2,37
FITEM,2,44
FITEM,2,48
FITEM,2,52
FITEM,2,61
FITEM,2,65
FITEM,2,68
FITEM,2,79
FITEM,2,-80
FITEM,2,91
FITEM,2,95
FITEM,2,133
FITEM,2,140
FITEM,2,144
FITEM,2,148
FITEM,2,160
DA,P51X,SYMM

FLST,2,21,5,ORDE,21
FITEM,2,9
FITEM,2,14
FITEM,2,21
FITEM,2,26
FITEM,2,31
```

```
FITEM,2,36
FITEM,2,43
FITEM,2,47
FITEM,2,51
FITEM,2,54
FITEM,2,60
FITEM,2,67
FITEM,2,78
FITEM,2,82
FITEM,2,89
FITEM,2,-90
FITEM,2,93
FITEM,2,-94
FITEM,2,97
FITEM,2,109
FITEM,2,115
DA,P51X,SYMM

DA,   219,SYMM

!Coupling end of vessel
FLST,5,2,5,ORDE,2
FITEM,5,206
FITEM,5,-207
ASEL,S, , ,P51X
NSLA,S,1
CP,next,UY,ALL
ALLSEL,ALL

!COUPLE THE ENDS OF THE PIPING
ASEL,S, , ,114
NSLA,S,1
CP,NEXT,UX,ALL
ALLSEL,ALL

/SOLU
OUTRES,BASIC,LAST
OUTPR,BASIC,LAST
ANTYPE,STATIC

ALLSEL,ALL

/INPUT, SHUTDOWN-T_MNTR,INP

SAVE

!CREATE LOCAL COORDINATE SYSTEM - CSYS11
/PREP7
K,1000,140
K,1001,140,1
K,1002,140,,1
CSKP,11,1,1000,1001,1002

/POST1
*GET,NUMSET,ACTIVE,0,set,NSET

!-- DEFINE PATHS -----------------------------------------------------
        CSYS,0
        PATH_01_ID = NODE(KX(40),KY(40),KZ(40))        ! INSIDE NODE PATH 1
        PATH_01_OD = NODE(KX(47),KY(47),KZ(47))        ! OUTSIDE NODE PATH 1

        FLST,2,2,1
        FITEM,2,PATH_01_ID
        FITEM,2,PATH_01_OD
        PATH,PTH1,2,30,30,
        PPATH,P51X,1
```

```
!WRITE STRESS TO OUTPUT FILES
/OUT,SHUTDOWN_THMSTR,OUT
RSYS,11
PATH,STAT
PATH,PTH1
*DO,I,1,NUMSET,1
            SET,I
            /COM,
    /COM,******************************************************
    /COM, HOOP STRESS OUTPUTS
    /COM,******************************************************
            *GET,Tcurr,ACTIVE,0,SET,TIME
            /COM,
            /COM, TIME = %Tcurr%
            PDEF,SY,S,Y,AVG
            /PBC,PATH, ,0
            PRPATH,SY
*ENDDO
/OUT

FINISH
```