ATTACHMENT 4

Structural Integrity Associates, Inc.® Report

File No. 1400187.301, Revision 1

Finite Element Model Development and Thermal Mechanical Stress Analyses for the Unit 2 N1 Nozzle

(Non-Proprietary)

22 pages follow

Structural Integrity Associates, Inc.® CALCULATION PACKAGE	File No.: 1400187.301
	Project No.: 1400187 Quality Program: ☒ Nuclear ☐ Commercial

PROJECT NAME:
LaSalle N702 Relief Request for 60 Years

CONTRACT NO.:
00517760, Rev 4

CLIENT:	PLANT:
Exelon Generation Company LLC	LaSalle County Generating Station, Units 1 and 2

CALCULATION TITLE:
Finite Element Model Development and Thermal Mechanical Stress Analyses for the Unit 2 N1 Nozzle

NOTE: This document contains ***vendor proprietary information****. Such information has been redacted for public release of this document.*

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 20 A-1 - A-2	Initial Issue	Rich Bax 8/8/14	Preparer: Wilson Wong 8/8/14 Checker: Jagannath Hiremagalur 8/8/14
1	1 - 20 A-1 - A-2	Revised Proprietary Markings	Rich Bax 2/6/15	Preparer: Wilson Wong 2/6/15 Checker: Jagannath Hiremagalur 2/6/15

Table of Contents

List of Tables

List of Figures

1.0 OBJECTIVE

The LaSalle County Generating Station intends to apply the methods of Code Case N-702 [1] using guidance from BWRVIP-108 [2] and BWRVIP-241 [3] to extend their existing inspection relief request for multiple RPV nozzles, specifically the N1, N2, N3, N5, N6, N7, N8, N9, N16, and N18 nozzles. [redacted] [3], a bounding approach will be used to qualify all of the indicated nozzles by analyzing the Unit 2 N1 nozzle with the highest fluence level from all the nozzles for both units.

The objective of this calculation is to develop a Finite Element (FE) model for the LaSalle Unit 2 N1 Recirculation Outlet nozzle, and to determine the stresses caused by thermal transients and internal pressure. Nozzle piping loads are not considered since they have insignificant effects on the thick nozzle-to-vessel weld and nozzle blend radius sections. Through wall stresses at locations of interest are extracted and stored in computer files to be used in a separate Probabilistic Fracture Mechanics (PFM) calculation.

2.0 ASSUMPTIONS

The following assumptions are made in this evaluation:

- The N1 nozzle-to-safe end weld was not specifically modeled. Instead the material instantaneously transitions from the nozzle material to the safe end material. Since the location of stress extraction is at the nozzle-to-vessel weld and nozzle blend radius, the impact of this assumption is minimal.
- All thermal transients are assumed to start from a steady state uniform temperature.
- The stress free reference temperature for the thermal stress calculation is assumed to be 70°F.
- The nozzle is subjected to a conservative high convective heat transfer coefficient (HTC) of 10,000 Btu/hr-ft^2-°F, while the entirety of the outside surface is assumed to be perfectly insulated with no heat transfer to produce a conservative temperature differential through the nozzle body.
- The cladding is assumed to be austenitic stainless steel Type 308L (evaluated as Type 304) based on previous experience.
- The nozzle-to-vessel weld is assumed to have material properties similar to the vessel and nozzle.

3.0 DESIGN INPUTS

3.1 Nozzle Geometry

The reactor pressure vessel inside radius (IR) is 126.5 inches to the clad surface based Reference 4, with a vessel wall thickness of 6.75 inches (includes 0.1875 inch thick cladding). The N1 nozzle has an IR of 10.84375" (includes 0.1875 inch thick cladding), with an outside radius (OR) of 20.03" on the vessel side and 12.375 on the safe end side of the nozzle [4].

3.2 Material Properties

The material component identification for the nozzle of interest is obtained from References 5 and 6. The materials used for the modeled components and their elastic properties are listed in Table 2 and Table 3. The material properties used are in conformance with the 1968 Edition (through Winter 1969 Addenda) of the ASME Boiler and Pressure Vessel Code, Section III [7]. However, since thermal conductivity and specific heat values are not listed in the 1968 Edition, these values were obtained from the 2010 ASME Boiler and Pressure Vessel Code, Section II, Part D [8].

3.3 Thermal Transient Definitions

The thermal transient definitions are obtained from Reference 9. The thermal cycle diagram for the N1 nozzle, Reference 9a, states that all normal and upset transients are identical to the transients specified for Region B of the Reactor Vessel. References 9b and 9c are the thermal cycle diagrams for the reactor vessel, and they are identical. The bounding transients are chosen based on their temperature range and rate of change.

There are two bounding thermal transients analyzed, and they are both tabulated in Table 1. Pressures are not included because they are determined in a separate pressure analysis described in Section 5.1. The stresses determined in the unit pressure analysis will be scaled to the bounding transient pressure and used in a subsequent PFM evaluation.

The Loss of Feedwater Pumps transient produces the greatest temperature rate of change out of all normal and upset transients. There are three internal cycles within the main transient, the last of which occurs after an indefinite time and can be bounded by the TGT-SCRAM transient which has the same rate of change but larger temperature range. Therefore, only the first two internal cycles are considered for the Loss of Feedwater Pump/Isolation Valves Close transient.

In order to achieve a final steady state condition, an arbitrary time of 3,600 seconds was allocated after the last load step, followed by an imposed steady state load step (at an arbitrary 60 seconds after the 3,600 seconds of additional time).

4.0 FINITE ELEMENT MODEL

A three-dimensional (3-D) finite element model is constructed using the ANSYS finite element program [10]. The model will be used for pressure and thermal transient stress analyses. It is developed as a symmetric quarter model using the dimensions given in Reference 4, and includes a local portion of the reactor pressure vessel, the N1 nozzle-to-vessel weld, the N1 nozzle, and a portion of the attached safe end, as shown in Figure 1. The N1 nozzle-to-safe end weld was not modeled because it is not near the region of interest and is assumed to have minimal effect. The model is meshed with the SOLID45 element type from the ANSYS library of elements, for which the thermal equivalent is SOLID70. The mesh used in this calculation is depicted in Figure 2.

5.0 STRESS ANALYSIS

5.1 Unit Internal Pressure

A unit internal pressure, P = 1,000 psi, is applied to the interior surfaces of the model. An end-cap load is applied to the free end of the nozzle piping in the form of tensile axial pressure, as calculated below.

$$P_{ec1} = \frac{P \cdot IR_1^2}{\left(OR_1^2 - IR_1^2\right)} = \frac{1000 \cdot 10.84375^2}{\left(12.375^2 - 10.84375^2\right)} = 3{,}307 \text{ psi}$$

where,

P_{ec1}	=	End cap pressure on attached piping free end (psi)
P	=	Internal unit pressure (psi)
IR_1	=	Inside radius of modeled piping (in) = 10.84375" (with cladding) [4]
OR_1	=	Outside radius of modeled piping (in) =12.375" [4]

The internal pressure also induces an end-cap load on the axial free end of the modeled vessel shell, as calculated below.

$$P_{ec2} = \frac{P \cdot IR_2^2}{\left(OR_2^2 - IR_2^2\right)} = \frac{1000 \cdot 126.5^2}{\left(133.25^2 - 126.5^2\right)} = 9{,}127 \text{ psi}$$

where,

P_{ec2}	=	End cap pressure on vessel shell axial free end (psi)
P	=	Internal unit pressure (psi)
IR_2	=	Inside radius of modeled vessel shell (in) = 126.5" (with cladding) [4]
OR_2	=	Outside radius of modeled vessel shell (in) = 133.25" [4]

Symmetric boundary conditions are applied at the vessel's circumferential free end and the overall model's two planes of symmetry. The free end of the nozzle piping and axial free end of the vessel shell are coupled in their respective axial directions to simulate the remaining portions of the geometry not included in the model. The applied load and boundary conditions for the unit pressure load case are shown in Figure 3.

5.2 Thermal Transient Analyses

The thermal transients to be analyzed for the N1 nozzle are defined in Section 3.3, and are applied as follows.

5.2.1 Thermal Analyses

Bulk fluid temperatures and heat transfer coefficients are applied to the inside surface nodes of the model. The nozzle and inside surface of the vessel are both subjected to a conservatively high convective heat transfer coefficient (HTC) of 10,000 Btu/hr-ft^2-°F, while the entirety of the outside

surface is assumed to be perfectly insulated with no heat transfer. Figure 4 depicts a representative plot of the thermal boundary conditions applied for the transient analyses.

5.2.2 Thermal Stress Analyses

Symmetric boundary conditions are applied at the vessel's circumferential free end and the overall model's two planes of symmetry. The free end of the nozzle piping and axial free end of the vessel shell are coupled in their respective axial directions to simulate the remaining portions of the geometry not included in the model. Figure 5 shows a representative plot of the mechanical boundary conditions applied for the thermal transient stress analyses.

6.0 RESULTS

6.1 Overall Stress and Temperature Results

A representative stress intensity contour plot for the unit pressure analysis is shown in Figure 6. Stress from the thermal transient is calculated. A representative temperature contour and total stress intensity contour plot for the Turbine Generator Trip SCRAM transient is shown in Figure 7 and Figure 8, respectively.

6.2 Through-Wall Stress Extractions

In support of the future PFM analysis, four through-wall stress paths, two each at 0° and 90°, are defined within the region of the N1 nozzle blend radius and nozzle-to-vessel weld, as shown in Figure 9. Since the model is symmetric, these two paths also represent the stress at 180° and 270°, respectively. Stresses from all runs are extracted and saved in *.csv file format which can be imported to an Excel workbook for further processing (see Appendix A for file listings).

7.0 CONCLUSION

Unit pressure and thermal transient stress analyses have been performed. Stress results were extracted from all analyses for through-wall paths at locations of interest along the N1 nozzle blend radius and nozzle-to-vessel weld in support of future PFM calculations. All of the stress results are stored in computer files for later use (see Appendix A for file listings).

8.0 REFERENCES

1. Code Case N-702, "Alternative Requirements for Boiling Water Reactor (BWR) Nozzle Inner Radius and Nozzle-to-Shell Welds, Section XI, Division 1," February 20, 2004.

2. Safety Evaluation of Proprietary EPRI Report, "BWR Vessel and Internal Project, Technical Basis for the Reduction of Inspection Requirements for the Boiling Water Reactor Nozzle-to-Vessel Shell Welds and Nozzle Inner Radius (BWRVIP-108)," December 19, 2007, SI File No. BWRVIP.108P.

3. *BWRVIP-241: BWR Vessel Internal Project, Probabilistic Fracture Mechanics Evaluation for the Boiling Water Reactor Nozzle-to-Vessel Shell Welds and Nozzle Blend Radii*, EPRI, Palo Alto, CA. 1021005. **EPRI PROPRIETARY INFORMATION.**

4. CB&I Drawing No. 72-2046, Revision 5, "Recirculation Outlet Nozzle N1," SI File No. 1400187.214.

5. Unit 1 Form N-1 Manufacturers' Data Report for Nuclear Vessels, Revision 1, Contract 2867, SI File No. 1400187.203.

6. Unit 2 Form N-1A Manufacturers' Data Report for Nuclear Vessels, Contract 72-2046, SI File No. 1400187.204

7. ASME Boiler and Pressure Vessel Code, Section III, Material Properties, 1968 Edition through Winter 1969 Addenda.

8. ASME Boiler and Pressure Vessel Code, Section II, Part D, Material Properties, 2010 Edition.

9. Thermal Cycle Diagrams
   a. General Electric Drawing Number 158B8136, Sheet 1, Revision 6, "Reactor Vessel Nozzle Thermal Cycles," SI File No. 1400187.207
   b. General Electric Drawing Number 731E776, Sheets 1 and 2, Revision 3, "Reactor Vessel Thermal Cycles," LaSalle Unit 1, SI File No. 1400187.205
   c. General Electric Drawing Number 761E581, Sheets 1 and 2, Revision 1, "Reactor Vessel Thermal Cycles," LaSalle Unit 2, SI File No. 1400187.206

10. ANSYS Mechanical APDL and PrepPost, Release 14.5 (w/ Service Pack 1), ANSYS, Inc., September 2012.

Table 1: Bounding Transients for Analysis

Description	Transient Number	Time, sec	T, °F	h, Btu/hr-ft²-°F
Turbine Trip	1	0	528	10000
SCRAM		4392	400	10000
		9648	552	10000
Loss of Feedwater Pumps/	2	0	525	10000
Isolation Valves Close		360	573	10000
		370	561	10000
		1260	561	10000
		1680	490	10000
		2160	573	10000
		2170	561	10000
		3240	561	10000
		3660	485	10000

Note: A total of 3,660 seconds (in addition to the time shown) was added to the end of the transients to capture transient stress lag and to achieve a final transient steady state condition (see Section 3.3 of this calculation).

Table 2: Material Properties for Low Alloy Steel SA-508 Class 2 / SA-533 Grade B, Class 1

Temperature (°F)	Young's Modulus (x10^6 psi)	Mean Thermal Expansion (x10^{-6} in/in/°F)	Thermal Conductivity (x10^{-4} Btu/sec-in-°F)	Specific Heat$^{(1)}$ (Btu/lb-°F)
70	27.9	6.07	5.49	0.106
100	27.9$^{(2)}$	6.13	5.46	0.107
150	27.8$^{(2)}$	6.25	5.44	0.110
200	27.7	6.38	5.44	0.113
250	27.6$^{(2)}$	6.49	5.42	0.116
300	27.4	6.60	5.42	0.119
350	27.2$^{(2)}$	6.71	5.39	0.122
400	27.0	6.82	5.35	0.125
450	26.7$^{(2)}$	6.92	5.32	0.128
500	26.4	7.02	5.25	0.130
550	26.1$^{(2)}$	7.12	5.21	0.133
600	25.7	7.23	5.14	0.135
650	25.3$^{(2)}$	7.33	5.07	0.138
700	24.8	7.41	5.00	0.141

Density (ρ) = 0.283 lb/in^3, assumed temperature independent.
Poisson's Ratio (υ) = 0.3, assumed temperature independent.

Notes:
(1) Specific Heat values are derived from the equation shown in General Note (a) of Table TCD [8], Specific Heat = TC / (TD x density).
(2) Interpolated.

Table 3: Material Properties for Stainless 308L (Treated as Type 304)

Temperature (°F)	Young's Modulus (x10^6 psi)	Mean Thermal Expansion (x10^{-6} in/in/°F)	Thermal Conductivity (x10^{-4} Btu/sec-in-°F)	Specific Heat(1) (Btu/lb-°F)
70	27.4	9.11	1.99	0.116
100	27.3(2)	9.16	2.01	0.117
150	27.2(2)	9.25	2.08	0.120
200	27.1	9.34	2.15	0.122
250	27.0(2)	9.41	2.22	0.124
300	26.8	9.47	2.27	0.125
350	26.6(2)	9.53	2.34	0.127
400	26.4	9.59	2.41	0.129
450	26.2(2)	9.65	2.45	0.130
500	26.0	9.70	2.52	0.132
550	25.7(2)	9.76	2.57	0.132
600	25.4	9.82	2.62	0.133
650	25.2(2)	9.87	2.69	0.134
700	24.9	9.93	2.73	0.135

Density (ρ) = 0.283 lb/in^3, assumed temperature independent.
Poisson's Ratio (υ) = 0.3, assumed temperature independent.

Notes:
(1) Specific Heat values are derived from the equation shown in General Note (a) of Table TCD [8], Specific Heat = TC / (TD x density).
(2) Interpolated.

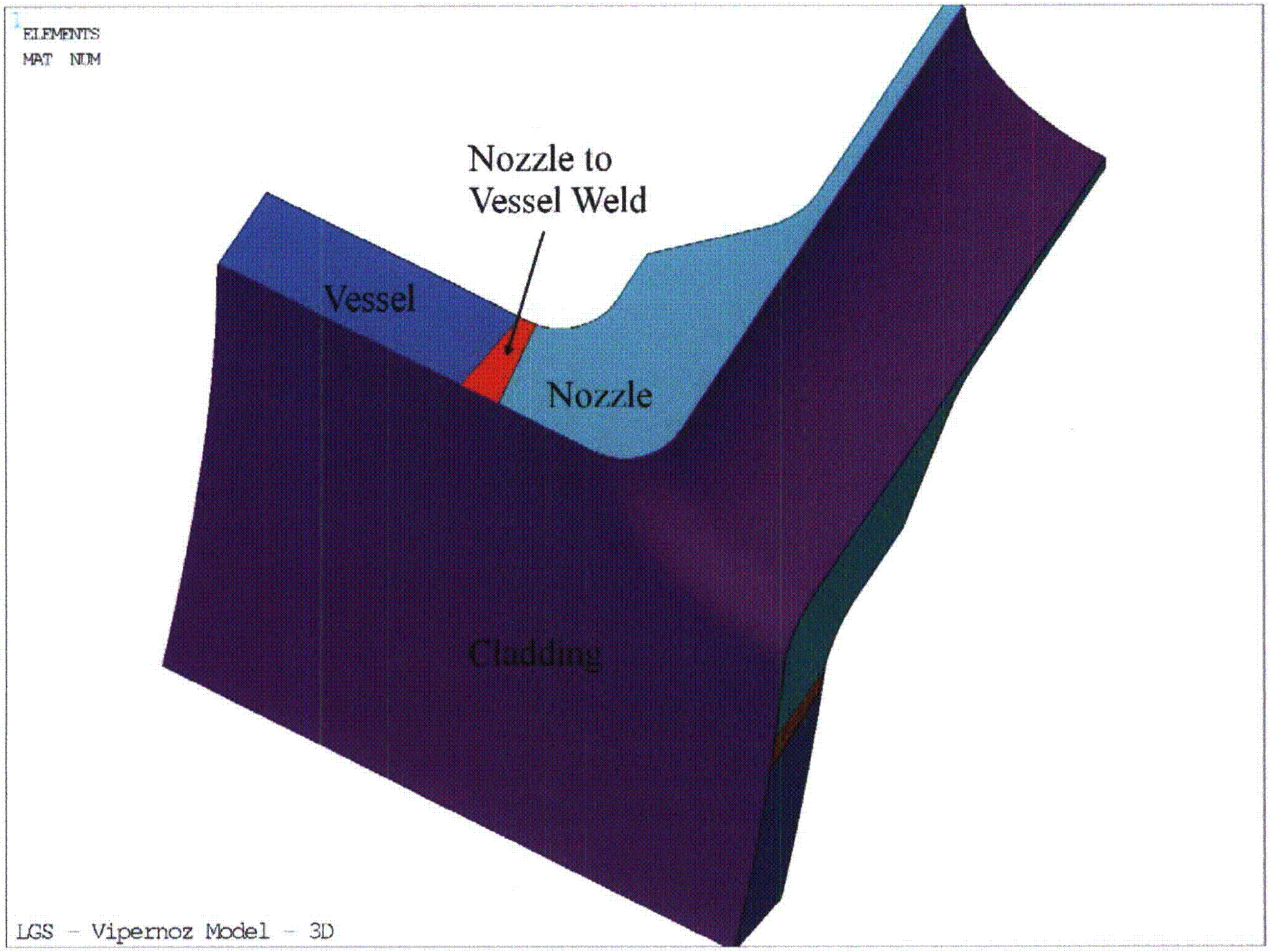


Figure 1: Components Included in the Finite Element Model

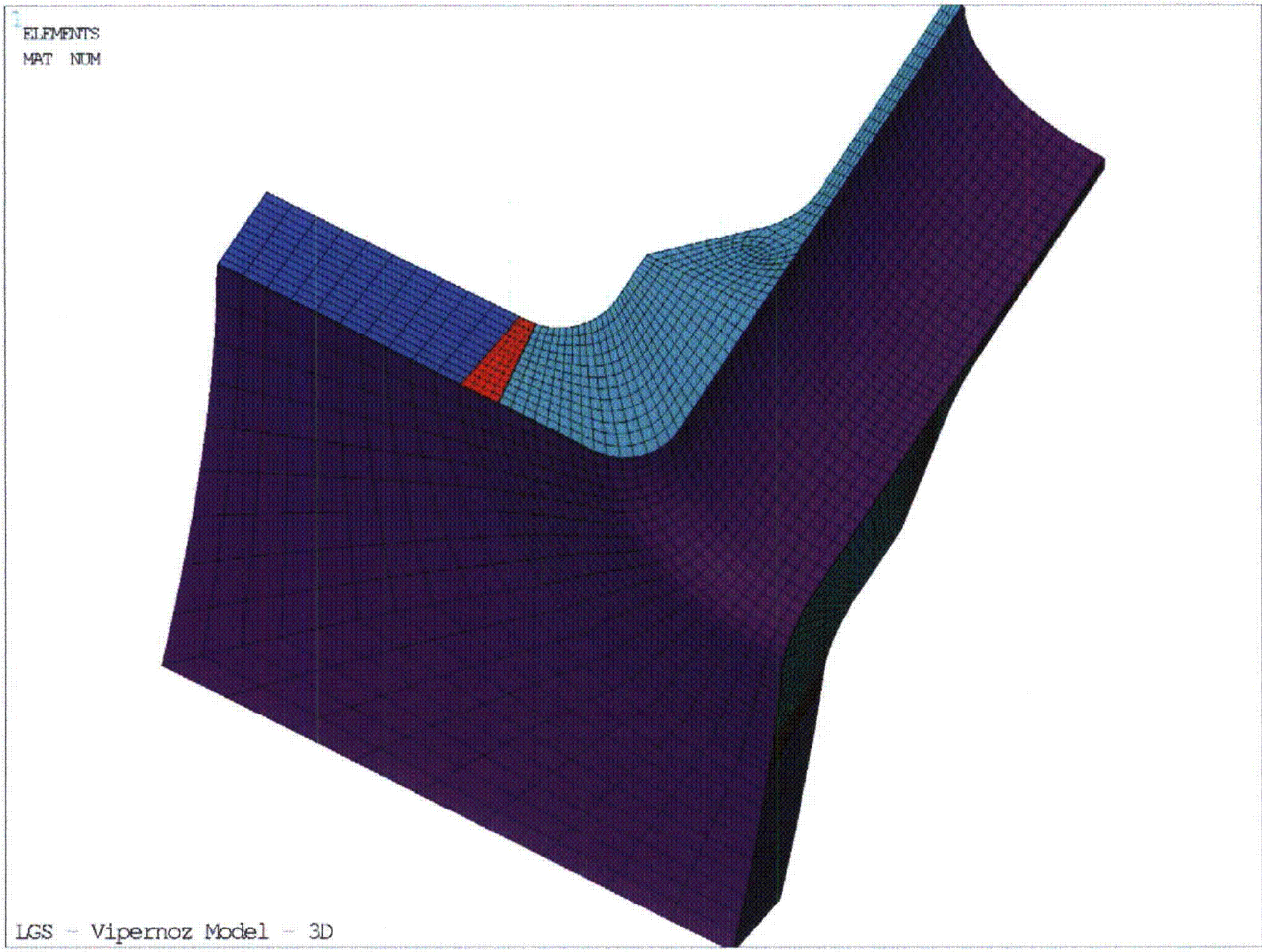


Figure 2: 3-D Finite Element Model Mesh for Analyses

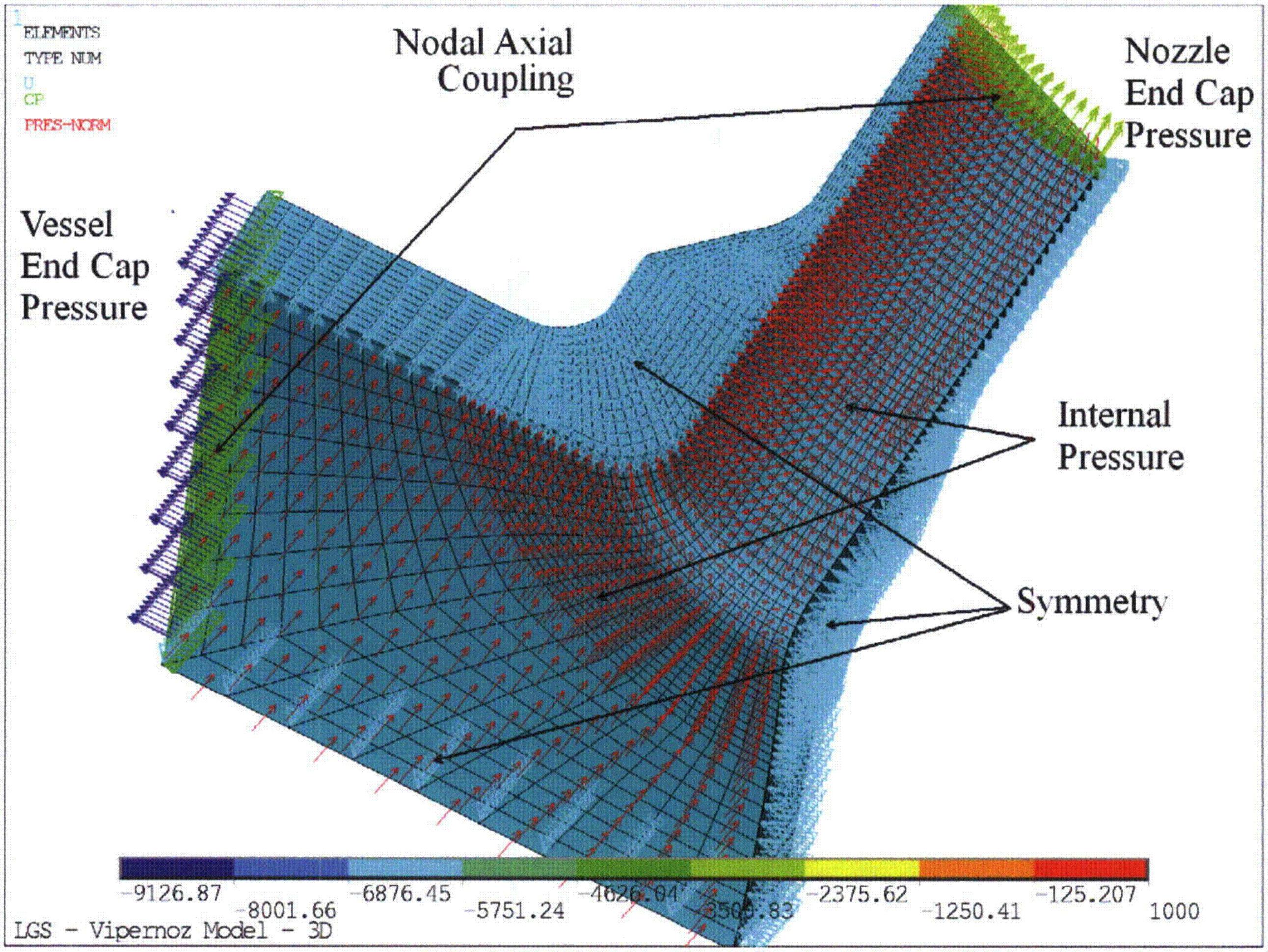
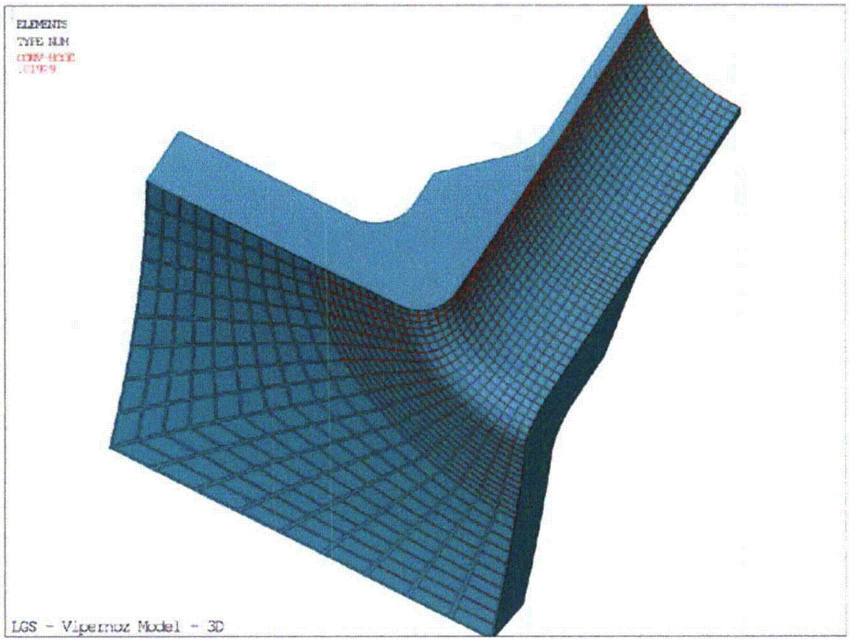
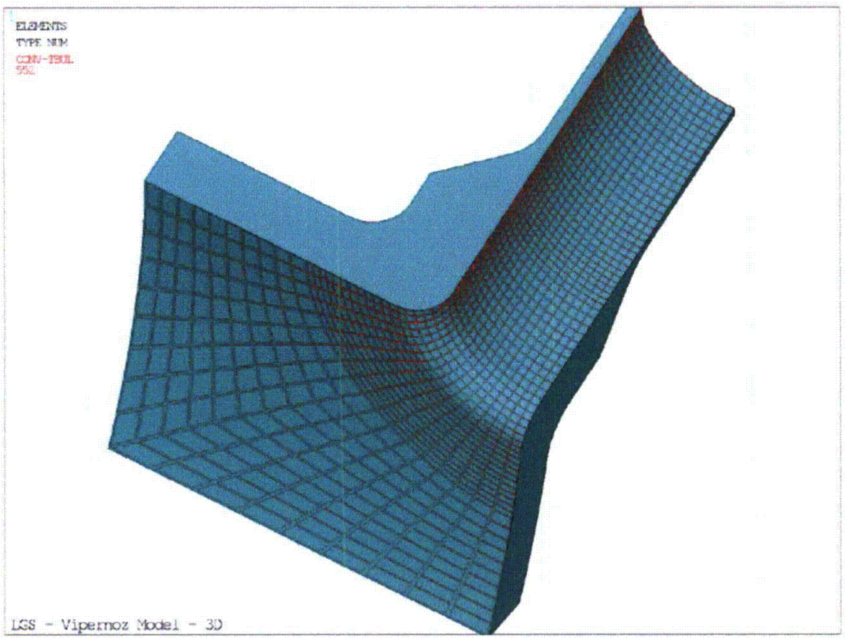


Figure 3: Applied Boundary Conditions and Unit Internal Pressure

(Units for Pressure in terms of psi)



a) Heat transfer coefficient (HTC)



b) Bulk temperature (TBULK)

Figure 4: Applied Thermal Boundary Conditions for Thermal Transient Analyses

(Turbine Generator Trip SCRAM shown, loads applied at end of transient)
(Units for HTC in terms of Btu/sec-in^2-°F, TBULK in °F)

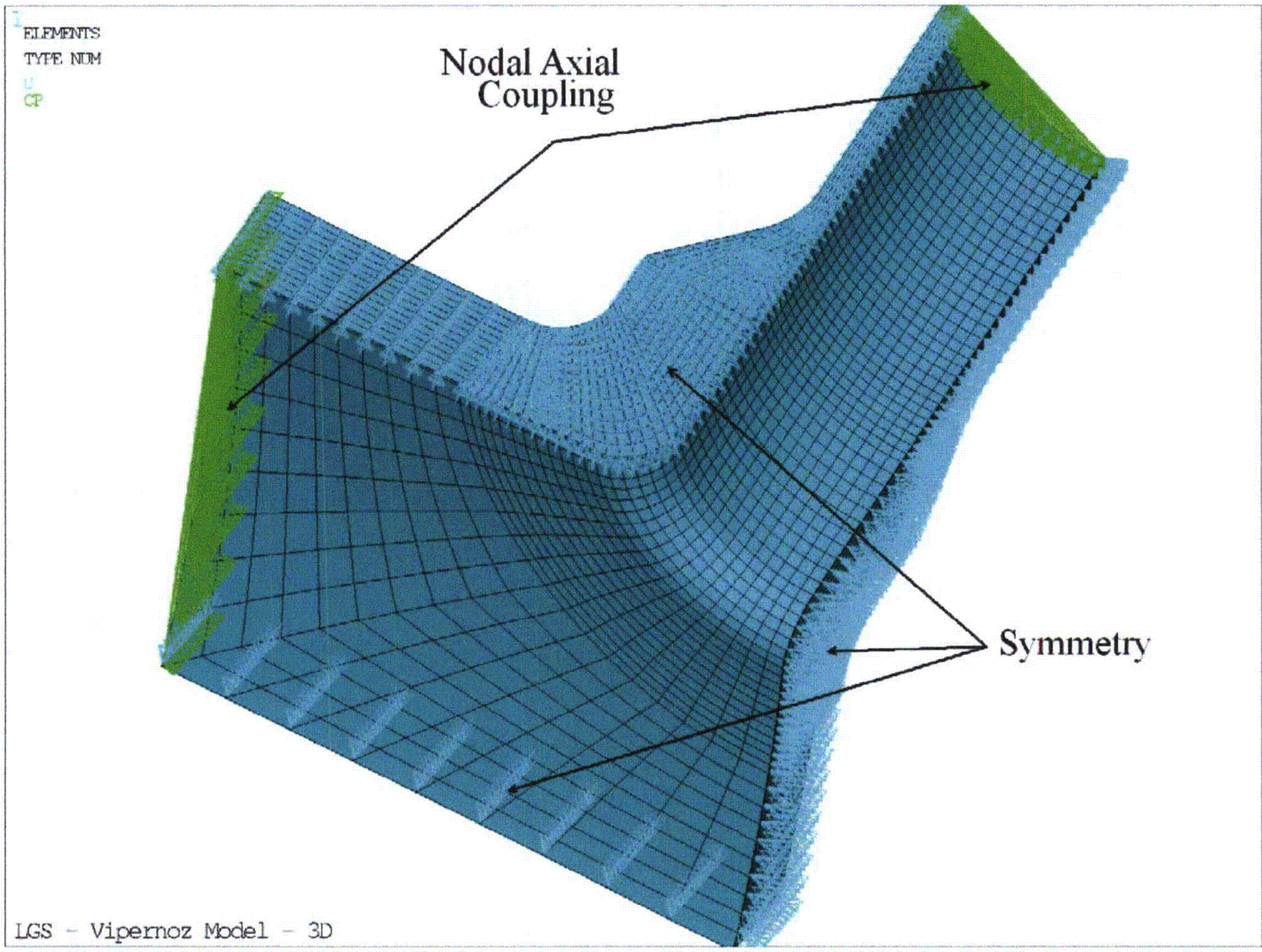


Figure 5: Applied Mechanical Boundary Conditions for Thermal Stress Analyses

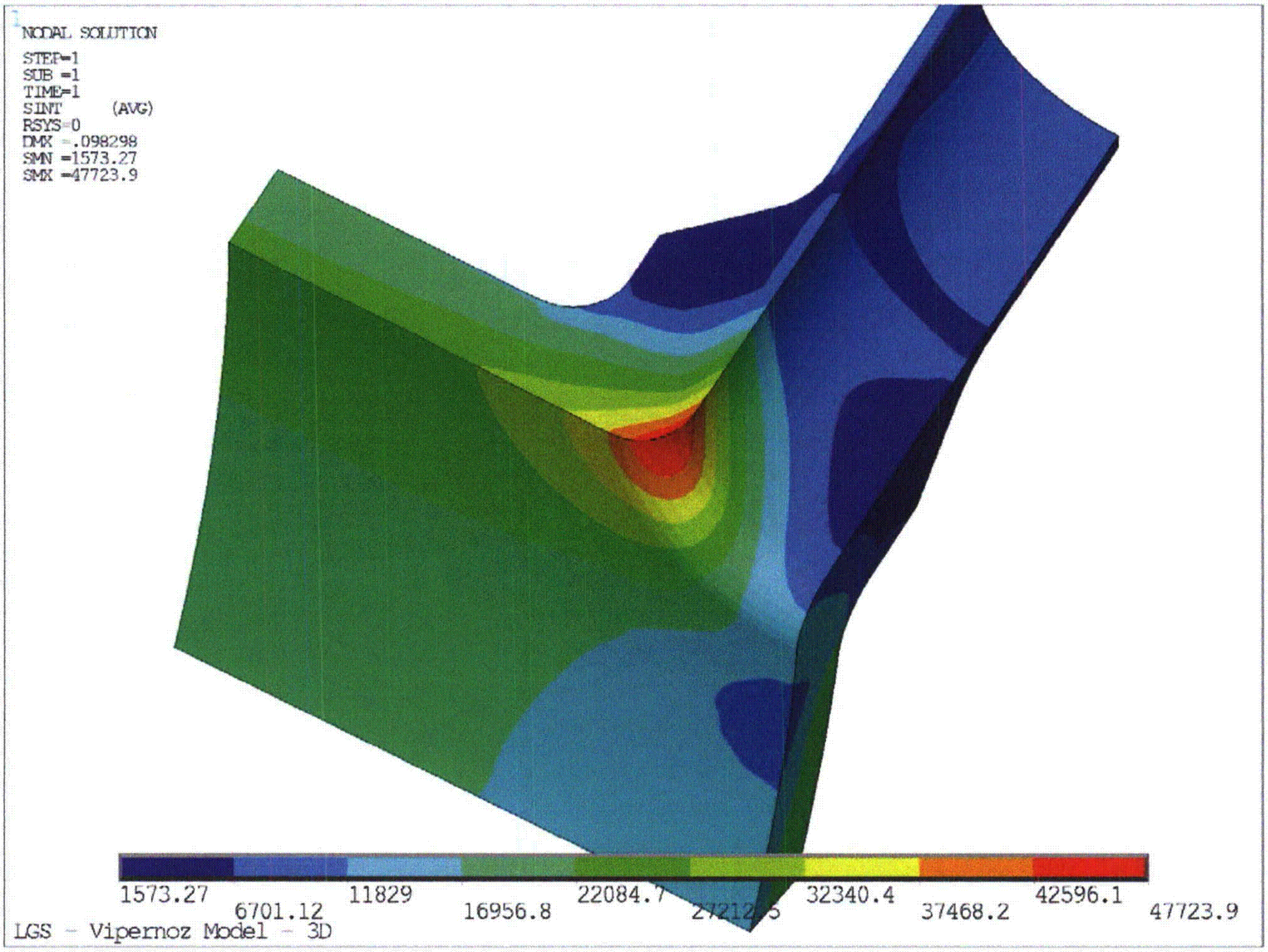


Figure 6: Total Stress Intensity Plot for Unit Internal Pressure

(Units for stress intensity in terms of psi)

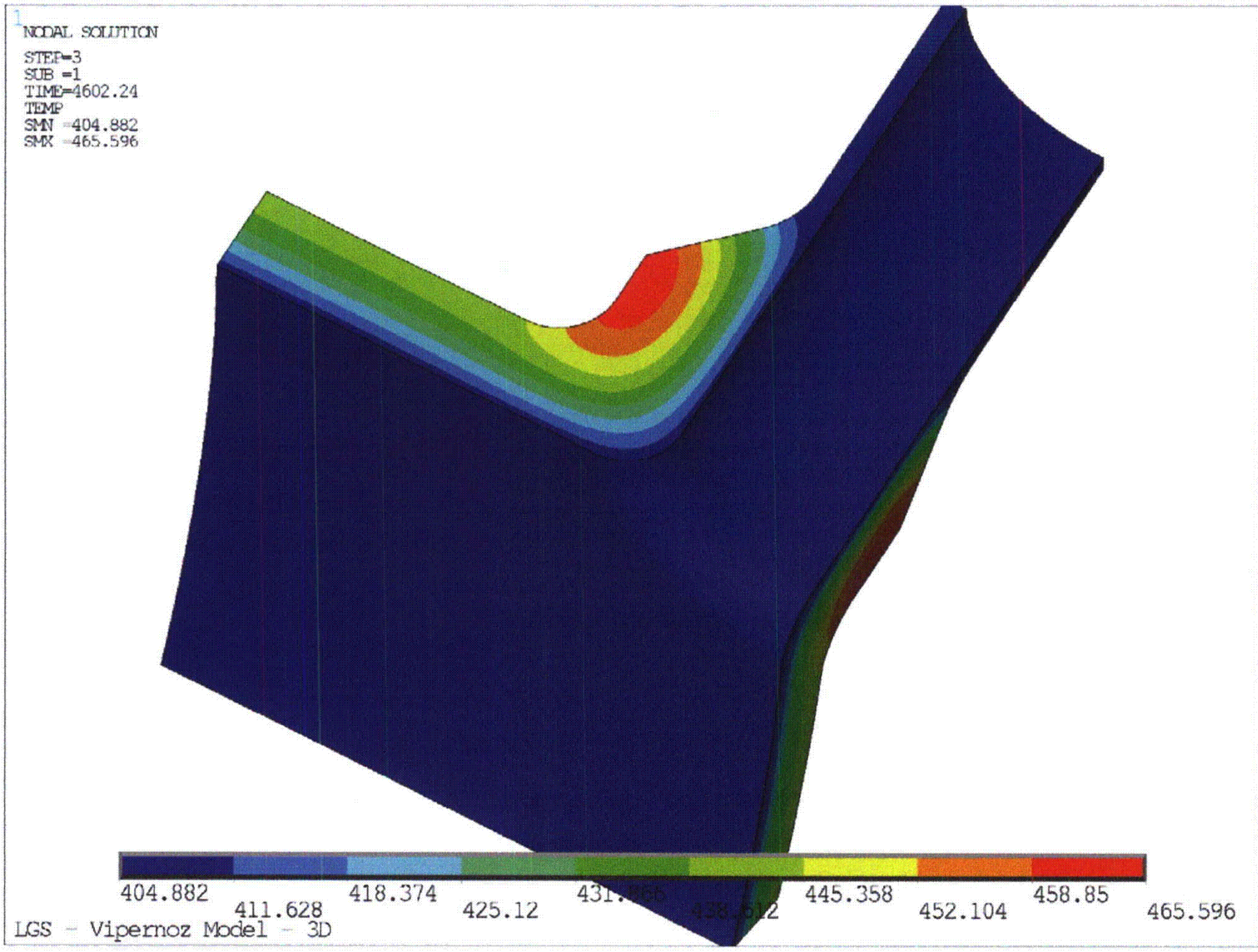


Figure 7: Temperature Contour for Turbine Generator Trip SCRAM at Time=4602.2 sec.

(Units for temperature in terms of °F)

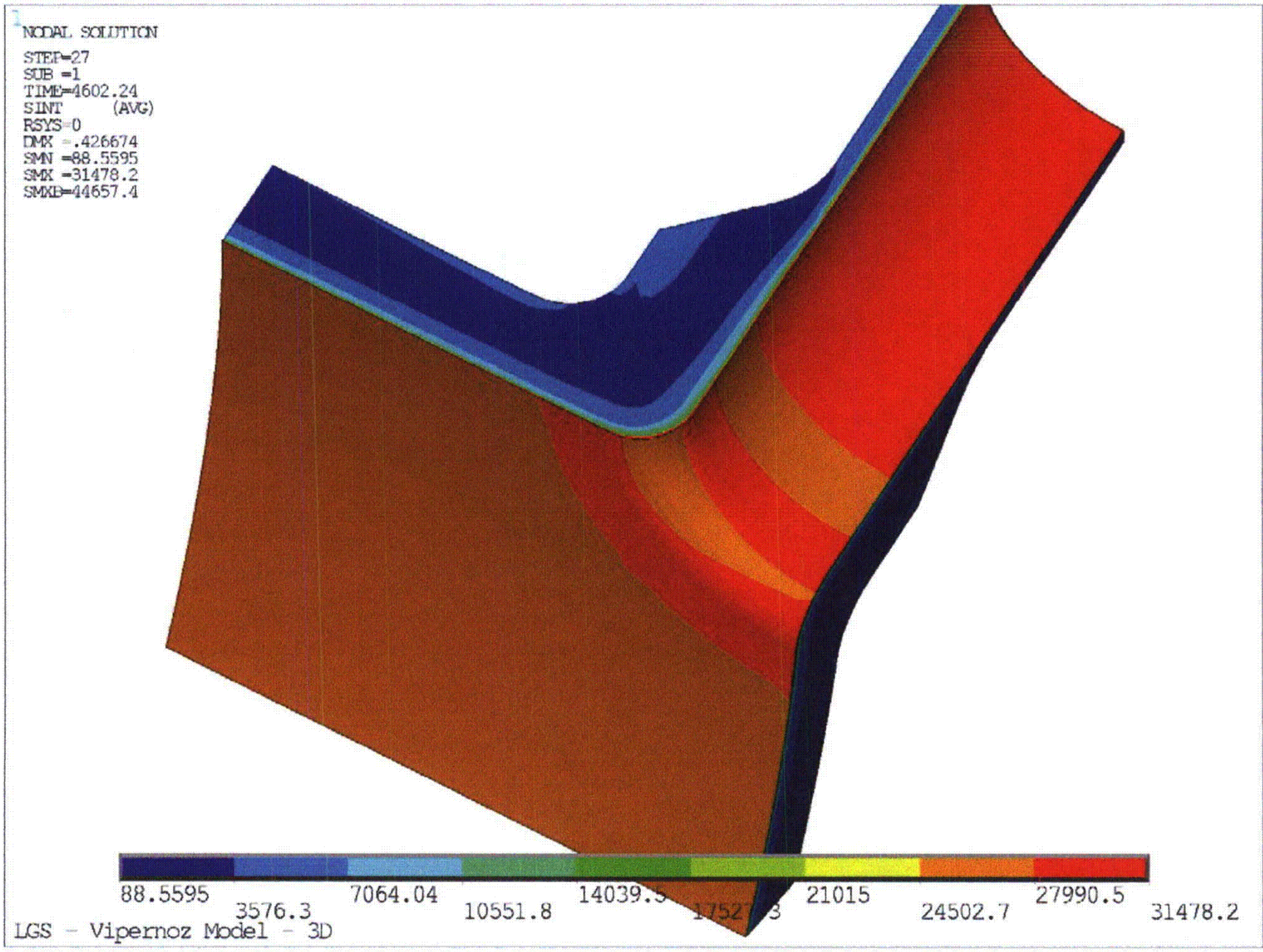


Figure 8: Stress Intensity Plot for Turbine Generator Trip SCRAM at Time=4602.2 sec.

(Units for stress intensity in terms of psi)

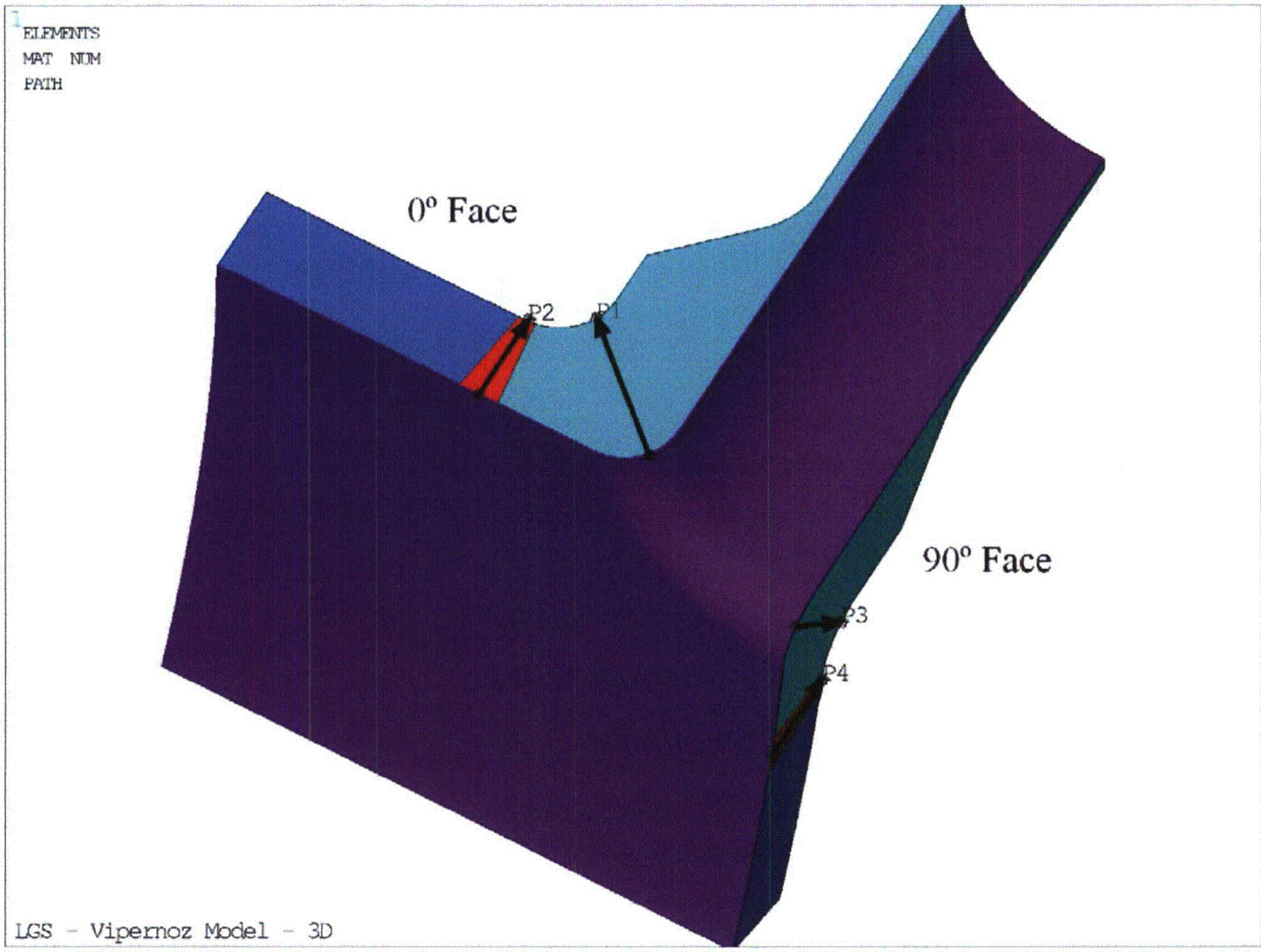


Figure 9: Path Locations for Through-Wall Stress Extractions

APPENDIX A

COMPUTER FILENAMES

File Name	Description
STACK.INP	Controller input file to run thermal and mechanical analyses
LGS.INP	Input file to construct the 3-D model for linear-elastic analysis
MProp_Linear_LGS.INP	Input file of temperature dependent linear elastic material properties
COMPONENTS.INP	Component and boundary conditions definition file
THM_LGS_1.INP	Analysis input file for Transient 1
THM_LGS_2.INP	Analysis input file for Transient 2
LGS_PRESS.INP	Analysis input file for Unit Internal Pressure
THM_*_mntr.inp	Load step definition file from thermal analysis * = LGS_1, LGS_2
CMNTR.MAC	Thermal temperature time history extraction macro file to create THM_*_mntr.inp files
GenStress.mac	Path stress extraction macro file to extract *.CSV files
GETPATH.TXT	Through-wall path definition file
STR_*_COE_P?.CSV	Curve fit coefficients outputs of stresses in tabulated forms * = PRESS, LGS_1, LGS_2 ? = path number 1-10