Appendix 3.5.5 Thermal Stress Evaluation of the Polyurethane Plug Insert

At the request of USNRC, a thermal stress evaluation was completed for the polyurethane plug (part 62 described in Table 3.5.1-1) that is utilized within the payload cavity. An equivalent part was not utilized in the Champion package fire test (presented as additional performance information, see Appendix 3.5.3); this finite element analysis provides the equivalent data.

ALGOR Release 18.1 was used for the evaluation. The parts, nodes, and elements of the model described in Appendix 3.5.1 and shown in Figures 3.5.1-1 through 3.5.1-15 were used to generate a thermal stress model, and the results from the fire and cooldown model described in Section 3 were imposed on the thermal stress model.

The evaluation utilized static stress conditions with linear material models, and the thermal and mechanical material properties utilized in the model are provided in Tables 3.5.5-1, 3.5.5-2 and 3.5.5-3. The polyurethane compressive modulus varies, depending on the direction of foam rise during its fabrication. Additionally, the compressive modulus is temperature-sensitive. For purposes of bounding the expected performance, the compressive modulus of the polyurethane plug was selected conservatively to produce the highest thermal stress. To confirm the correct selection, a sensitivity case was run.

The evaluation assumes that continuity is maintained at the planes of symmetry of the quarter-model, as shown in Figure 3.5.5-1. Also, a single node at the center of the packaging base (also shown in Figure 3.5.5-1) was constrained against translation in the x-, y- and z-directions.

The temperature condition producing the highest thermal stress in the polyurethane plug is the condition where the steel packaging components are at a low temperature in comparison with the polyurethane plug, since the thermal expansion coefficient of the polyurethane plug is larger than that of the encasing steel components. This maximum thermal differential occurs at 150 minutes (0 minutes is at the start of the fire event) for the VersaPac evaluation. Thus, the thermal stress evaluation was completed utilizing the packaging and contents temperature distribution corresponding to 150 minutes. This distribution is illustrated in Figure 3.5.5-2.

The maximum evaluated stress in the polyurethane plug is 78 psi and is much less than the compressive strength of the material; however, it should be noted that the polyurethane plug is not a structural component of the package, and is considered to be a sacrificial component in the event of a fire.

Table 3.5.5- 1 Material Properties for Versa-Pac Components, excluding Polyurethane Foam

Material	Density (lb / ft^3)	Modulus of Elasticity (psi)	Poison's Ratio	Thermal Expansion Coefficient (in/in/◦F)	Source
Isotropic steel	2.836E-01	2.9E+7	0.29	6.5E-6	ALGOR material library (Mechanics of Materials, 2nd Ed., F.P Beer and E.R. Johnston, Jr.)
8 pcf Temperature dependent isotropic alumina silica	All alumina silica insulation conservatively modeled as 6pcf polyurethane for the thermal stress evaluation (temperatures generated in the fire and cooldown model)				
Fiberglass – Extren525 Isophthalic polyester resin	6.192E-02	8.0E+6	0.3	1.0E-5	Century Industries SOP6.13, also "Typical Properties – FRP Structural Shapes", Enduro Systems, Inc., www.endurocomposites.com
Air	4.225E-05	5000*	0.3*	1E-16*	*Mechanical properties selected such that the air doesn't impose or carry load.
Contents 1, wood	Contents modeled as solid steel to maximize thermal expansion (temperatures generated in the fire and cooldown model)				
Contents 2, void	Contents modeled as solid steel to maximize thermal expansion (temperatures generated in the fire and cooldown model)				
Contents 3, solid steel	2.836E-01	2.9E+7	0.29	6.5E-6	ALGOR material library (Mechanics of Materials, 2nd Ed., F.P Beer and E.R. Johnston, Jr.)

Table 3.5.5- 2 6 pcf Polyurethane Foam Material Properties

Source: General Plastics Manufacturing Company, www.generalplastics.com accessed 1/31/2010.
Nominal Physical Property Data for **LAST-A-FOAM® FR-3700 Rigid Foam** at **6** pounds per cubic foot density

Property	English	Metric
Density (pcf) (kg/m^3)	6	96
Compressive Strength (psi) (kPa) Parallel to Rise		
@ -65° F	243	1675
@ 75° F	154	1063
@ 200° F	102	704
@ 250° F	74	509
Perpendicular to Rise		
@ -65° F	198	1367
@ 75° F	139	955
@ 200° F	82	564
@ 250° F	64	440
Compressive Modulus (psi) (kPa) Parallel to Rise		
@ -65° F	5418*	37357
@ 75° F	4253	29322
@ 200° F	3261	22486
@ 250° F	2383	16428
Perpendicular to Rise		
@ -65° F	4308	29701
@ 75° F	3437	23701
@ 200° F	2465	16998
@ 250° F	2064	14231
Tensile Strength (psi) (kPa)		
Parallel to Rise	182	1252
Perpendicular to Rise	174	1200

Source: General Plastics Manufacturing Company, www.generalplastics.com accessed 1/31/2010.
Nominal Physical Property Data for **LAST-A-FOAM® FR-3700 Rigid Foam** at **6** pounds per cubic foot density

Property	English	Metric
Tensile Modulus (psi) (kPa)		
Parallel to Rise	5947	41008
Perpendicular to Rise	5662	39037
Shear Strength (psi) (kPa)		
Rise Parallel to Specimen Width	116	799
Rise Parallel to Specimen Thick	116	798
CTE: (in/in/°F) (K^-1)	~3.4x10^-5	~6.1x10^-5
Poisson's Ratio	~0.3	~0.3

* Bounding value used in FEA model.
Values used in the model are shown in red

Table 3.5.5- 3 10 pcf Polyurethane Foam Material Properties

Source: General Plastics Manufacturing Company, www.generalplastics.com accessed 1/31/2010.
Nominal Physical Property Data for **LAST-A-FOAM® FR-3700 Rigid Foam** at **10** pounds per cubic foot density

Property	English	Metric
Density (pcf) (kg/m^3)	10	160
Compressive Strength (psi) (kPa) Parallel to Rise		
@ -65° F	552	3809
@ 75° F	350	2415
@ 200° F	215	1485
@ 250° F	143	988
Perpendicular to Rise		
@ -65° F	527	3630
@ 75° F	325	2238
@ 200° F	209	1440
@ 250° F	146	1008
Compressive Modulus (psi) (kPa) Parallel to Rise		
@ -65° F	11306*	77955
@ 75° F	10156	70028
@ 200° F	7250	49986
@ 250° F	5797	39969
Perpendicular to Rise		
@ -65° F	10958	75557
@ 75° F	8759	60390
@ 200° F	6365	43888
@ 250° F	5797	39969
Tensile Strength (psi) (kPa)		
Parallel to Rise	319	2202
Perpendicular to Rise	313	2155

Source: General Plastics Manufacturing Company, www.generalplastics.com accessed 1/31/2010. Nominal Physical Property Data for **LAST-A-FOAM® FR-3700 Rigid Foam** at **10** pounds per cubic foot density		
Property	English	Metric
Tensile Modulus (psi) (kPa)		
Parallel to Rise	11855	81742
Perpendicular to Rise	12489	86111
Shear Strength (psi) (kPa)		
Rise Parallel to Specimen Width	249	1719
Rise Parallel to Specimen Thick	242	1670
CTE: (in/in/°F) (K^-1)	~3.4x10^-5	~6.1x10^-5
Poisson's Ratio	~0.3	~0.3

*** Bounding value used in FEA model.**

Values used in the model are shown in red

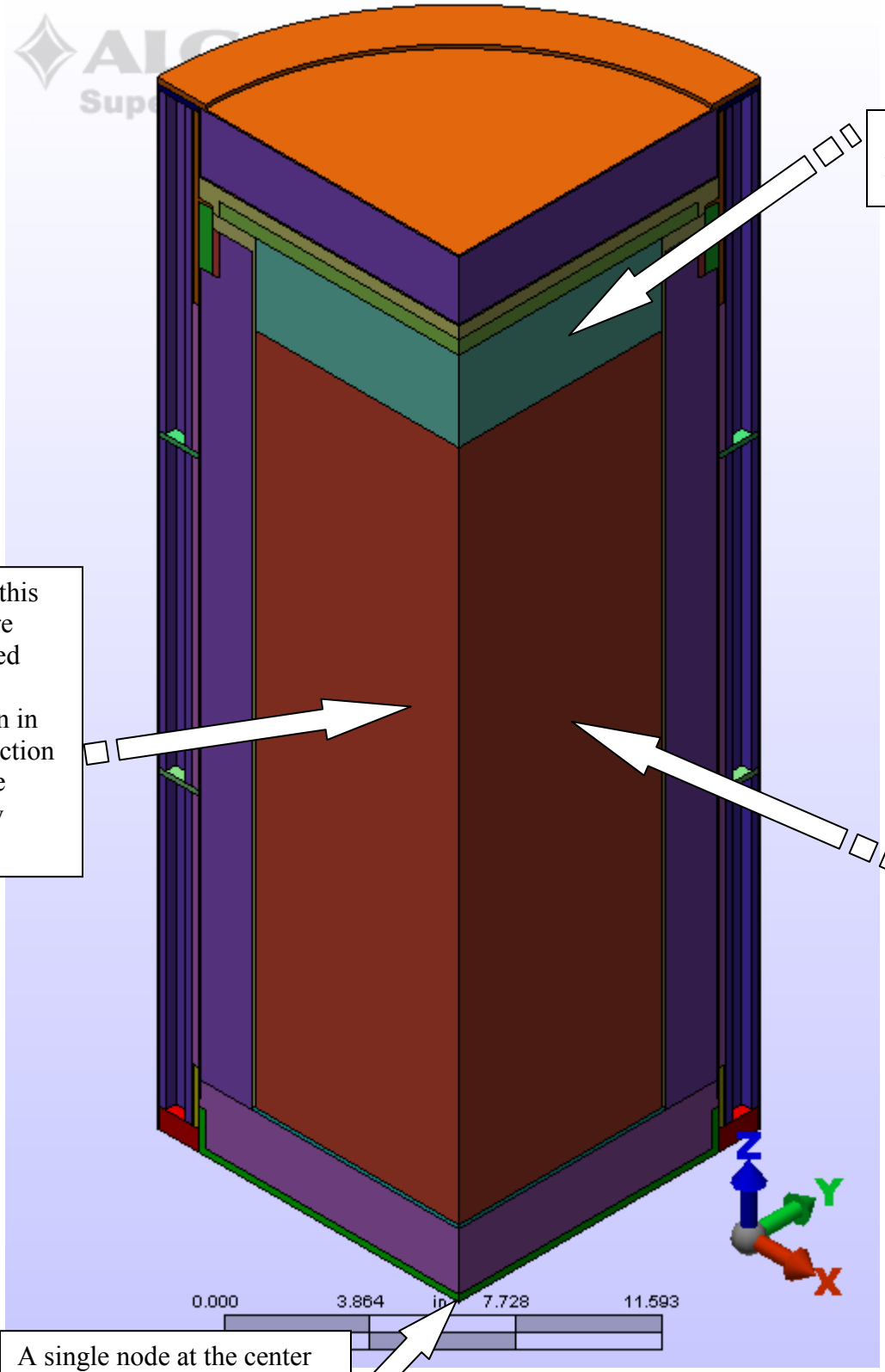

Figure 3.5.5- 1 FEA Model and boundary conditions

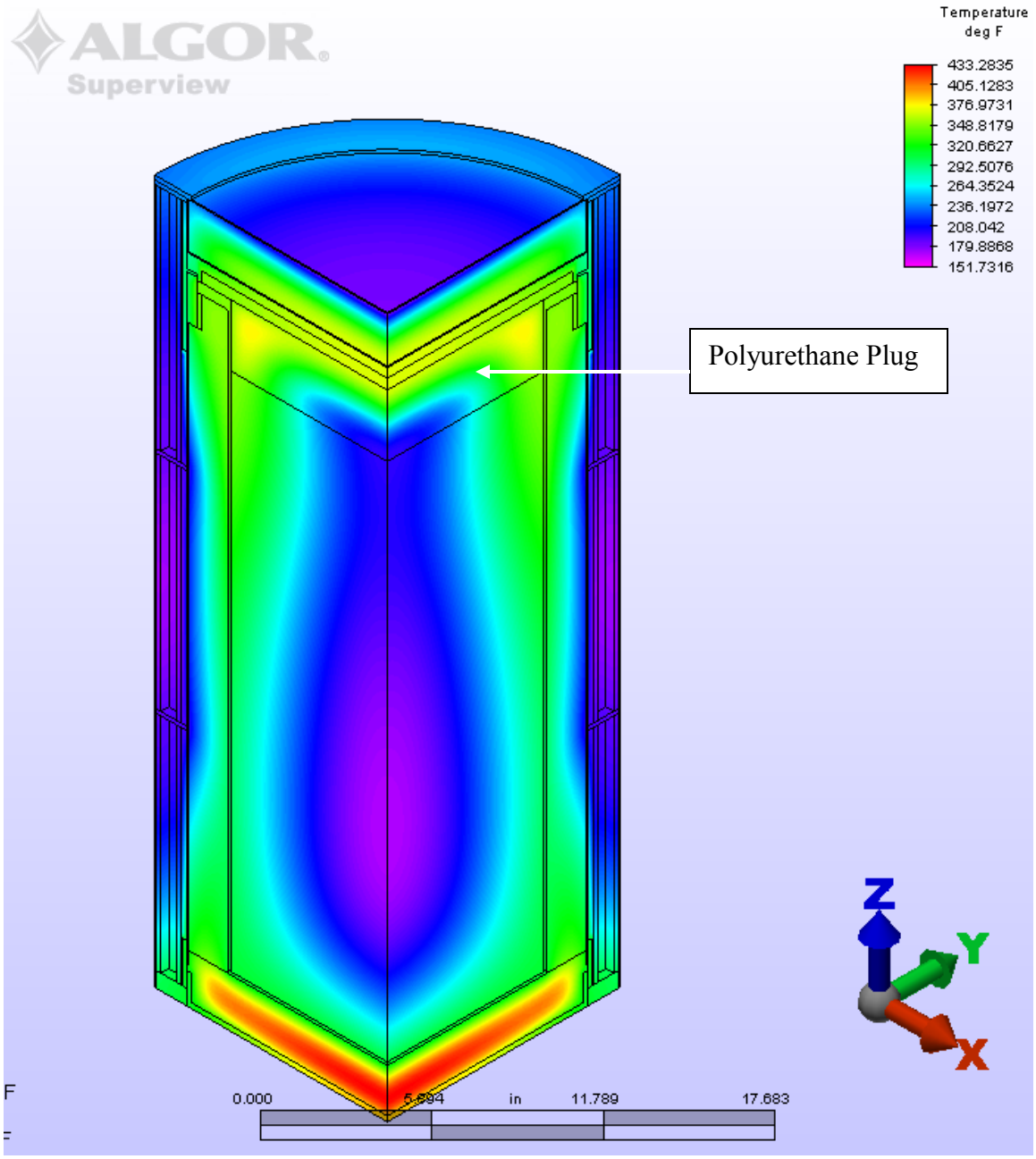

Figure 3.5.5- 2 Imposed Temperature Distribution

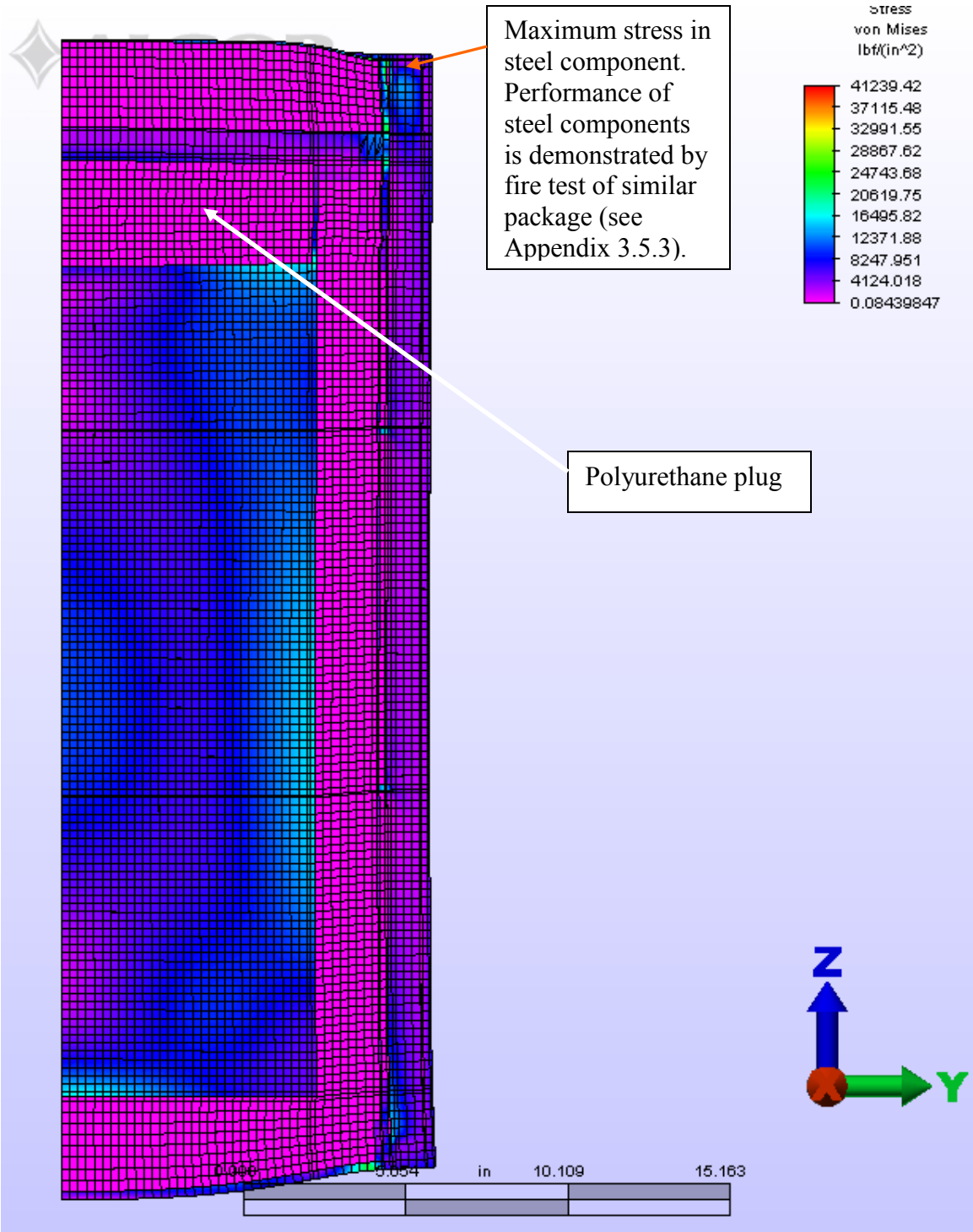

Figure 3.5.5- 3 Side View of Thermal Expansion at 150 minutes, Von Mises Stress Distribution Shown

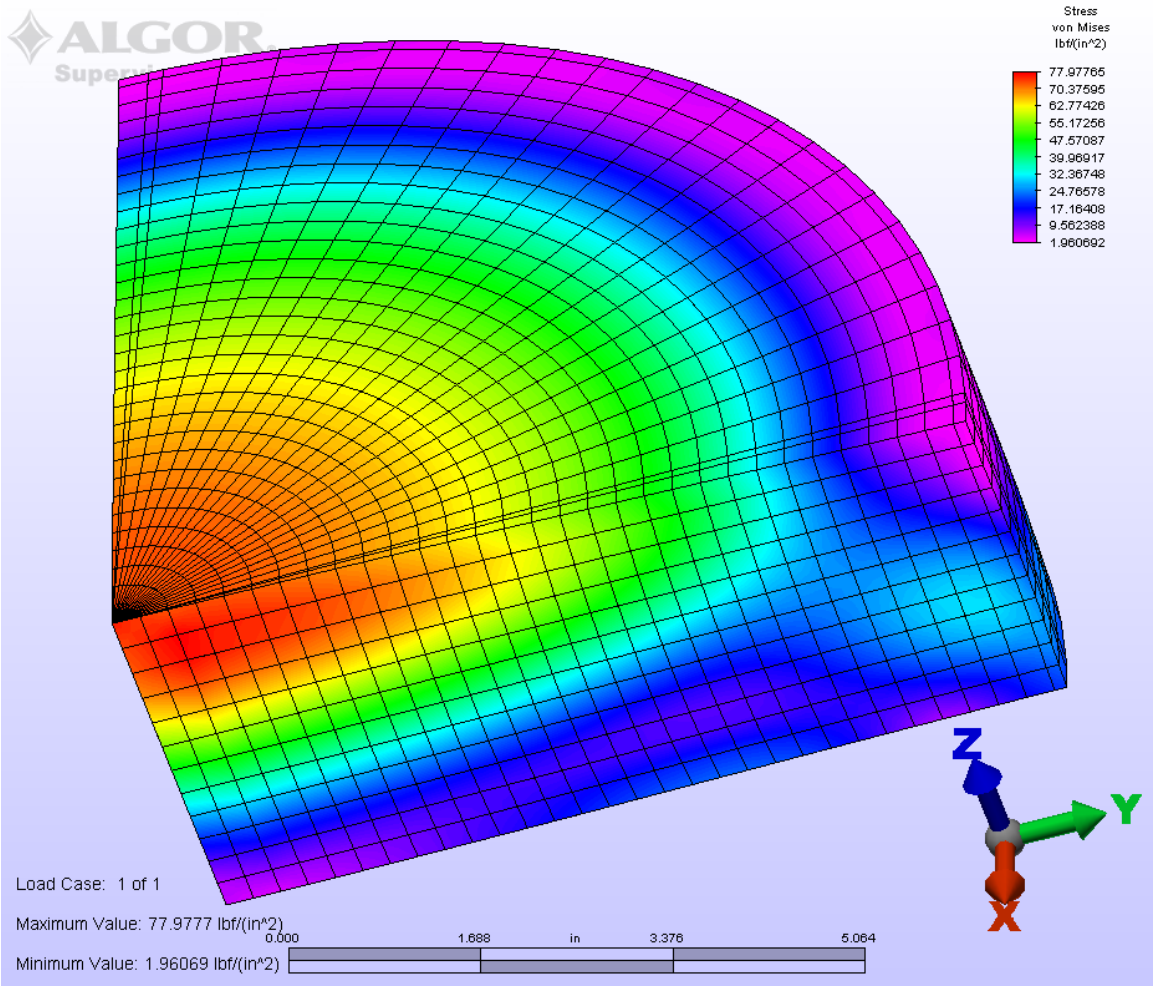

Figure 3.5.5- 4 Thermal Stress on the Polyurethane Plug (Von Mises) at 150 minutes

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