1.0 OBJECTIVE

Perform the thermal analyses of the Energy*Solutions* 8-120B Cask under hypothetical fire accident conditions, using a 3-dimensional finite element model.

2.0 REFERENCES

1. Energy*Solutions* Drawing No. C-110-E-0007, Rev. 14, 8-120B Shipping Cask.
2. Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material, January 2003.
3. U.S. NRC Regulatory Guide 7.8, Revision 1, March 1989, Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material.
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9. ANSYS, Release 13.0, ANSYS Inc., Canonsburg, PA, 2010.
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3.0 INTRODUCTION

Energy*Solutions* 8-120B Cask (Reference 1) is designed as a Type B radioactive-material shipping package. To be certified by the U.S.N.R.C., the cask needs to meet the requirements of 10 CFR 71 (Reference 2) and follow the guidelines of U.S.N.R.C. Regulatory Guide 7.8 (Ref. 3).

This document presents the thermal load analysis of the 8-120B Cask for the hypothetical accident conditions (HAC) fire test. The normal conditions of transport (NCT) analyses have been performed in a separate document. The analyses in this document are performed using the finite element modeling techniques. Models of the cask that includes all its major components have been employed in the analyses. Temperature dependent material properties of the major components of the cask are used in the analyses.

The effect of HAC fire test on the waste contents of the 8-120B cask has been included in this document. It has also been shown that after the puncture drop test if the fire-shield looses the air gap separation, the HAC fire test will not cause a melting of the lead at this location.

The results of the analyses for various load cases are presented pictorially in temperature contour plots as well as digital data format, suitable for use with a structural finite element model to obtain the thermal stresses.

4.0 MATERIAL PROPERTIES

Temperature-Independent Metal Thermal Properties

Material	Property	Reference: Page	Value
Steel	Density	4: 536	0.2824 lb/in^3
	ε (Outside)	2: 648	0.8
	ε (Inside)	5:133	0.15
Lead	Density	4: 535	0.4109 lb/in^3
	Spec. Heat	4: 535	0.0311 Btu/lb-°F
	Melting Point	6: B-29	621.5 °F

Temperature-Dependent Metal Thermal Properties

Temp. (°F)	**Stainless Steel** (Ref. 7)		**Carbon Steel** (Ref.7)		**Lead** (Ref.8)
	Sp. Heat Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Sp. Heat** Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F
70	0.117	0.199	0.104	0.813	0.465
100	0.117	0.201	0.106	0.803	0.461
150	0.120	0.208	0.109	0.789	0.455
200	0.122	0.215	0.113	0.778	0.448
250	0.125	0.222	0.115	0.762	0.441
300	0.126	0.227	0.118	0.748	0.435
350	0.128	0.234	0.122	0.731	0.428
400	0.129	0.241	0.124	0.715	0.422
450	0.130	0.245	0.126	0.701	0.415
500	0.131	0.252	0.128	0.677	0.409
550	0.132	0.257	0.131	0.667	0.402
600	0.133	0.262	0.133	0.648	0.395
650	0.134	0.269	0.135	0.632	0.389
700	0.135	0.273	0.139	0.616	0.389
750	0.136	0.278	0.142	0.600	0.389
800	0.136	0.282	0.146	0.583	0.389
900	0.138	0.294	0.154	0.551	0.389
1,000	0.139	0.306	0.163	0.519	0.389
1,100	0.141	0.315	0.172	0.484	0.389
1,200	0.141	0.324	0.184	0.451	0.389

Temperature-Dependent Air Thermal Properties

Temp. (°F)	**Air** (Ref.4)		
	Density $\times 10^{-5}$ lb/in^3	**Sp. Heat** Btu/lb-°F	**Conductivity** $\times 10^{-7}$ Btu/sec-in-°F
70	4.3507	0.2402	3.4491
100	4.1117	0.2404	3.5787
150	3.7517	0.2408	3.9028
200	3.4676	0.2414	4.1759
250	3.2361	0.2421	4.4468
300	3.0307	0.2429	4.7037
350	2.8310	0.2438	4.9560
400	2.6730	0.2450	5.2037
450	2.5220	0.2461	5.4491
500	2.3964	0.2474	5.6875
550	2.2778	0.2490	5.9213
600	2.1684	0.2511	6.1435
650	2.0706	0.2527	6.3634
700	1.9803	0.2538	6.5810
750	1.8981	0.2552	6.7894
800	1.8177	0.2568	6.9954
900	1.6898	0.2596	7.4097
1,000	1.5712	0.2628	7.8032
1,100	1.4722	0.2659	8.1759
1,200	1.3848	0.2689	8.5440
1,300	1.3044	0.2717	8.8981
1,400	1.2350	0.2742	9.2847
1,500	1.1707	0.2766	9.7060

5.0 MODEL DESCRIPTION

The thermal analyses of the 8-120B Cask under hypothetical fire accident test conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Ref. 9) has been employed to perform the analyses.

Two finite element models have been employed in performing the HAC thermal analyses. A three-dimensional and a 2-d axisymmetric model were used in the analyses. For the structural analyses of the loading conditions where the bolt loadings are non-uniform a three dimensional finite element model, in which the primary and secondary lid bolts can be appropriately modeled, is needed. To obtain the temperature distribution for these loading conditions a three-dimensional thermal model is used. To obtain the temperature distribution in the cask where the bolt loadings have no effect on the results, a two-dimensional axisymmetric finite element model has been used.

3-Dimensional Finite Element Model

The cask is symmetrical about a vertical plane. Therefore, a one-half model of the cask is employed in the three-dimensional model. Figure 1 shows the finite element model used in various thermal load analyses. Figures 2 and 3 are detailed views of various regions of the finite element model. Figure 4 shows the material property model numbers of various components of the cask.

The finite element model is made of 3-dimensional thermal solid elements (ANSYS SOLID70) that represent the major components of the cask, the cask body, the lid, the bolts, and the fire shield. The interstitial air gaps between the impact limiter plates and the cask end as well as that between the fire-shield and the cask body are modeled by 3-dimensional thermal solid elements.

The poured lead in the body is not bonded to the steel. It is free to slide over the steel surface. Therefore, the interface between the lead and the steel is modeled by pairs of 3-d 8 node thermal contact element (CONTA174) and 3-d target segment (TARGE170) elements. These elements allow the lead to slide over the steel at the same time prevent it from penetrating the steel surface. The interface between the two plates of the lid at the weld location is also modeled by the contact-target pairs. The transition from a coarser mesh to a finer mesh, as well as bondage between various parts of the model, is also achieved by using these elements. Figure 5 shows the contact-target pair elements used in the finite element model.

The heat transfer by radiation between the fire-shield and the ambient air is modeled by 3-d thermal surface (ANSYS SURF152). The radiation between the outer shell and the fire-shield is modeled by superelements (ANSYS MATRIX50). These elements are formed by modeling the radiating surfaces with thermal shells (ANSYS SHELL57) and specifying the appropriate emissivity of the surfaces and the Stefan-Boltzmann constant. The heat transfer by natural convection between the fire-shield and the ambient air is simulated by 3-d thermal surface (ANSYS SURF152). The outer surfaces of the impact limiter plates, which are covered by foam, are considered to be totally insulated.

For the HAC fire the foam of the impact limiters is assumed to provide complete thermal insulation. Therefore, only the area of the model not covered by the impact limiter is subjected to the fire in the analysis.

The real constants used in the ANSYS finite element model, to define the characteristic of various finite elements to simulate the heat transfer by convection and radiation, are based on the derivation in the following section. The heat flux representing the internal heat load and the solar insolation is also presented in the following section.

2-Dimensional Axisymmetric Finite Element Model

The 2-d axisymmetric FEM uses the same modeling techniques as described under the 3-dimensional model, except that it uses the corresponding 2-dimensional elements. Figure 6 shows the 2-dimensional axisymmetric model.

A print-out of the model data is included in Appendix 1.

5.1 Natural Convection Modeling

The convective heat transfer per unit area between the cask and the atmosphere, q, is governed by the equation:

$$q = hA\left(T_s - T_a\right)$$

where:

h = Heat transfer coefficient (Btu/hr-ft^2-°F)

A = Area (sq ft)

T_s = cask surface temperature (°F)

T_a = ambient temperature (°F)

The heat transfer coefficient for the natural convection is given by the following relationship (see for example Ref. 5, page 135).

$$h = C\left(T_s - T_a\right)^{1/3}$$

where, for horizontal cask,

C = 0.18 (Btu/hr-ft^2-°F$^{4/3}$)

= 3.4722×10^{-7} (Btu/sec-in^2-°F$^{4/3}$)

5.2 Forced Convection Modeling

The heat transfer coefficient for the forced convection during the fire is based on the explanatory material for the IAEA regulations in Safety Series No.37 (Ref. 10), the pool fire gas velocity is taken to be 10 m/sec (32.8 ft/sec). The forced convection heat transfer coefficient for large casks, according to Ref. 10, is:

$$h = 10\ \frac{W}{m^2\,°C}$$

For conversion, using,

1 W = 9.4804×10^{-4} Btu/sec

1 m = 39.37 inch

1°C = 1.8°F

Therefore,

$$h = \frac{10 \times 9.4804 \times 10^{-4}}{39.37^2 \times 1.8} = 3.398 \times 10^{-6}\ \frac{Btu}{sec-in^2-°F}$$

The heat transfer coefficients for forced convection are also obtained from additional sources and compared with the IAEA recommended value. It is shown that the value calculated above is larger than the values calculated from other sources. Therefore, the IAEA recommended

value will result in a conservative prediction of the cask temperatures during the HAC fire test.

A comprehensive heat transfer coefficient formula for a horizontal cylinder, which is applicable over a large range of Reynolds number values, is listed in Reference 4. This formula is referred to as Churchill-Bernstein formula, which relates Reynolds and Prandtl number with Nusselt number as follows:

$$Nu_d = 0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1+\left(\frac{0.4}{\mathrm{Pr}}\right)^{2/3}\right]^{3/4}}\left[1+\left(\frac{\mathrm{Re}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

........Equation (1)

Where, Re = Reynolds Number $= \dfrac{\rho_f u_\infty d}{\mu_f}$

ρ_f = Air density at film temperature (1475ºF use 1500ºF)

= 1.1707×10^{-5} lb/in^3 (see Table in Section 4.0)

u_∞ = Air velocity = 32.8 ft/sec = 394 in/sec

d = diameter of the cylinder = 73.2 in

μ_f = Air viscosity at film temperature

= 91.75×10^{-8} lb_f-sec/ft^2 (Reference Mark's Handbook)

= 246.2×10^{-8} lb/(in-sec)

Therefore,

$$\mathrm{Re} = \frac{\left(1.1707\times10^{-5}\,\frac{lb}{in^3}\right)\times\left(394\,\frac{in}{\sec}\right)\times(73.2in)}{246.2\times10^{-8}\,\frac{lb}{in\cdot\sec}} = 137{,}140$$

Also, Pr = Prandtl Number $= \dfrac{\mu_f C_{pf}}{k_f}$

C_{pf} = Specific heat of the air at constant pressure at film temperature

= 0.2766 Btu/lb-ºF (see Table in Section 4.0)

k_f = Conductivity of air at film temperature

= 9.706×10^{-7} Btu/sec-in-ºF

Therefore,

$$\Pr = \frac{\left(246.2\times10^{-8}\ \frac{lb}{in\cdot\sec}\right)\times\left(0.2766\ \frac{Btu}{lb\cdot\deg F}\right)}{9.706\times10^{-7}\ \frac{Btu}{\sec\cdot in\cdot\deg F}} = 0.7$$

Substitution of these values in Equation 1 results in:

$$Nu_d = 0.3 + \frac{0.62\times(137{,}140)^{1/2}\times(0.7)^{1/3}}{\left[1+\left(\frac{0.4}{0.7}\right)^{2/3}\right]^{3/4}}\left[1+\left(\frac{137{,}140}{282{,}000}\right)^{5/8}\right]^{4/5} = 0.3 + \left(\frac{203.86}{1.481}\times\left[1+0.6373\right]^{4/5}\right)$$

$$= 0.3 + \left[(137.65)\times(1.4836)\right] = 204.5 \approx 205$$

Where, Nu_d = Nusselt Number = $\frac{hd}{k_f}$

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{205\times\left(9.706\times10^{-7}\right)}{73.2} = 2.718\times10^{-6}\ \frac{\text{Btu}}{\sec\cdot\text{in}^2\cdot\text{degF}}$$

......Equation 2

For vertical cylinders Reference 11 gives the following equation relating the Reynolds number, Prandtl number and Nusselt number as follows.

$$Nu = (0.664)\times(\text{Re}_L)^{0.5}\times(\Pr)^{1/3}$$

......Equation 3

The limits of applicability of this equation is:

$\text{Re}_L < 5\times10^5$ and $\Pr > 0.1$

Where the Reynolds number Re_L is based on the cylinder length,

$L = 87.0$ in

$$\text{Re}_L = \frac{\left(1.1707\times10^{-5}\right)\times(394)\times(87.0)}{246.2\times10^{-8}} = 162{,}995 \approx 1.63\times10^5$$

Substitution of values in Equation 3 gives,

$$Nu = (0.664)\times(\text{Re}_L)^{0.5}\times(\Pr)^{1/3} = (0.664)\times\left(1.63\times10^5\right)^{0.5}\times(0.7)^{1/3} = 238.03$$

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{(238.03)\times\left(9.706\times10^{-7}\right)}{87} = 2.656\times10^{-6}\ \frac{\text{Btu}}{\sec\cdot\text{in}^2\cdot\text{degF}}$$

The forced convection heat transfer coefficient for both horizontal and vertical cylinders calculated above are both smaller than IAEA recommended value for the 8-120B cask geometry. Therefore, in order to predict the cask temperature conservatively during the HAC fire test, the IAEA recommended value has been used in all the analyses.

5.3 Radiation Modeling

The heat transfer by radiation between two nodes of a finite element model is governed by the following equation (see for example Ref. 4).

$$q = \sigma\ \varepsilon\ F\ A \left(T_I^4 - T_J^4\right)$$

where:

q = heat flow rate (Btu/hr)

σ = Stefan-Boltzmann Constant

= 1.7136×10^{-9} (Btu/hr-ft^2-R^4)

= 3.3056×10^{-15} (Btu/sec-in^2-R^4)

ε = emissivity

F = geometric form factor

A = area (sq ft)

T = temperature (°R)

I = first node number

J = second node number

Two radiation heat transfer systems are modeled: (1) radiation heat transfer between the fire shield outside surface and the environment, and (2) radiation between the fire shield inside surface and the cask shell outside surface and radiation between the cask ends and the impact limiter plates. Emissivity, area, and geometric form factors are defined in both systems.

The overall emissivity for radiation heat transfer between the fire shield and the environment is set equal to the overall emissivity, ε, for heat transfer between two infinite parallel planes as given by the following equation (Ref. 4, page 336).

$$\varepsilon = \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_2 + \varepsilon_1 - \varepsilon_1 \varepsilon_2}$$

Where: ε = overall emissivity

ε_1 = surface 1 emissivity

ε_2 = surface 2 emissivity

The regulations (Article 71.73 of Reference 2) require that an average environment emissivity coefficient of 0.9 must be used for HAC fire test. It also requires that for purpose of calculation, the surface absorptivity coefficient must be either that which the package may be

expected to possess if exposed to fire specified or 0.8, whichever is greater. It is conservatively assumed in the analyses that the package has an absorptivity of 1.0. Therefore, an emissivity coefficient of 0.9 has been conservatively specified for all the elements that radiate heat to the environment. Form factor value of 1.0 is used and the area of the surface is automatically calculated by the computer program.

The radiation between the outer shell and the fire-shield is modeled by superelements (ANSYS MATRIX50). These elements are formed by modeling the radiating surfaces with thermal shells (ANSYS SHELL57). The thermal shield forms an air annulus between itself and the cask body. This annulus is formed by separating the two components with the help of helically wound 5/32" steel wires. The ends of the fire-shield are seal welded to the cask body. Thus, the two surfaces forming the annulus will remain in polished condition throughout the operating life of the cask. The emissivity coefficient of the as-received steel is 0.15 (see Section 4.0). Therefore, the emissivity coefficient of 0.15 is used for the heat transfer between the inside surface of the fire shield and the outside surface of the outer shell.

5.4 Solar Insolation Modeling

The total insolation is required to be 400 gcal/cm^2 for a 12-hour period for curved surfaces according to the Code of Federal Regulations 10CFR71.71 (Ref 2). The total insolation of 400 gcal/cm^2 is divided by 12 hours of assumed sunlight to yield an average insolation rate. The average insolation rate is then multiplied by the surface emissivity of 0.7347 (See Reference 12) yielding an insolation rate of 1.742×10^{-4} Btu/sec-in^2. This insolation heat load is applied to the outside surface of the fire shield.

5.5 Internal Heat Loading

The internal heat load content of the 8-120B Cask has been represented in the finite element models by two different ways. In the first, the heat load is implicitly represented by a uniform heat flux over the cask cavity. In the second, it is explicitly represented by the finite element model of the waste container and the cavity air. The heat load in this case is applied as a constant heat flux over the waste container wall.

5.5.1 Implicit Internal Heat Load Modeling

The 200-Watt decay heat load is modeled as a constant heat flux over the exposed sidewall inner surface of the cask.

$$\text{Internal heat load, } q = 200\text{ W} = 200\times9.4804\times10^{-4} = 0.1896\text{ Btu/sec}$$

The cask inside diameter is 61.8" and the cavity height is 75". Thus, the heat flux on the inside surface of the cask is:

$$q_s = 0.1896/\left(\pi\times61.8\times75 + 2\times\pi/4\times61.8^2\right)$$

$$= 9.2216\times10^{-6}\text{ Btu/(sec-in}^2)$$

5.5.2 Explicit Internal Heat Load Modeling

In order to obtain the temperature of the waste container and the cavity air during the NCT, they are explicitly represented in the 2-d axisymmetric finite element model with appropriate material properties. The waste container is conservatively assumed to be a cylindrical shell

having the diameter and length to be approximately ½ of the corresponding cavity dimensions.

Waste Container Outside Diameter = 31", Length = 37.5", Wall Thickness = 1.0"

Container Inside Surface Area = $\pi \times (31-2) \times (37.5-2) + 2 \times [\pi \times (31-2)^2/4] = 4{,}555$ in^2

The heat flux is applied on the inside surface of the waste container. Its magnitude is:

$$q_w = 0.1896/4{,}555 = 4.163 \times 10^{-5} \text{ Btu/sec-in}^2$$

The cavity air is conservatively assumed to be stagnant - no convective heat transfer is assumed to take place between the waste container and the cask cavity. Thus, the heat transfer between these components takes place by means of conduction through the air and radiation between the two bodies. The air conduction is accounted for by the appropriate material properties of the finite elements representing it. The heat transfer by radiation is achieved by the ANSYS radiation sub-matrix method. Since the objective of this analysis is to obtain the waste temperature conservatively, the coefficients of emissivity for both the surfaces are assigned lower than actual values. The inside surface of the cask is either carbon steel (emissivity 0.6 to 0.7) or, if it has a liner, stainless steel (emissivity 0.54 to 0.63). For both kinds of surfaces the emissivity is assumed to be 0.2. The waste containers are made of painted carbon steel (emissivity 0.8 to 0.9), stainless steel (emissivity 0.54 to 0.63), or plastic (emissivity 0.8 to 0.9). The assumed value of the emissivity of the waste container surface is 0.4. Please note that the emissivity values quoted here have been obtained from Reference 4. The form-factor is automatically calculated by the computer program from the geometry of the two bodies. The finite element model of the cask with explicit internal heat load modeling is shown in Figure 6.

5.6 Puncture Drop Damage Modeling

During the regulatory puncture drop test specified in Article 71.73(c)(3) of Reference 2, the structural analyses have shown that no damage to the cask body will occur. However, the fire-shield which is separated from the cask body with the help of helically-wound wires, may jam into the cask body at the puncture bar contact location. An analysis of the 8-120B cask has been performed assuming that such a contact occurred at the exposed location closest to the top of the fire-shield. The 2-d axisymmetric model is used for this analysis, which conservatively makes the contact area in shape of a circular ring having a width equal to the contact diameter instead of a circle. Full thermal contact is assumed between the fire-shield and the outer shell of the cask at the assumed location of the puncture drop. In other words, the outer shell is assumed to be directly exposed to the fire at this location.

6.0 ANALYSES

The finite element model described in Section 5.0 is analyzed in the following manner:

1. The initial temperature condition is obtained by running the finite element model with the following boundary conditions:
    - Internal heat load – 200 W
    - Solar insolation - yes

- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

2. The fire transient is run with the body temperature resulting from the above initial conditions. The fire transient is run for 30 minutes (1,800 sec) with the following boundary conditions:
   - Internal heat load – 200 W
   - Solar insolation - no
   - Heat Transfer to the ambient by radiation – yes
   - Heat transfer to the ambient by forced convection – yes
   - Ambient air temperature - 1475°F
3. The end of fire analysis of the model is performed with the body temperature resulting from the above fire transient to 1801 sec with the following boundary conditions:
   - Internal heat load – 200 W
   - Solar insolation - no
   - Heat Transfer to the ambient by radiation – yes
   - Heat transfer to the ambient by natural convection – yes
   - Ambient air temperature - 100°F
4. The cool-down analysis of the model is performed with the body temperature resulting from the above fire transient to 14,000 sec with the following boundary conditions:
   - Internal heat load – 200 W
   - Solar insolation - yes
   - Heat Transfer to the ambient by radiation – yes
   - Heat transfer to the ambient by natural convection – yes
   - Ambient air temperature - 100°F

Figure 7 shows the boundary conditions used during the fire transient analysis.

The finite element models are analyzed to obtain the limiting thermal loading on the 8-120B cask. The internal heat load has been modeled implicitly for the cask body temperature evaluation. It has been demonstrated in the NCT thermal analysis that this model predicts the cask temperature conservatively.

7.0 RESULTS

7.1 Cask Temperature Results

As described earlier the model representing the internal heat load implicitly is used for obtaining the cask body temperature. From the transient analyses of the finite element model, using the loading described in Section 6.0, a time-history data of the temperature in various

components of the cask is obtained. The fire shield, outer shell, inner shell, lead, and seal were considered as the critical components of the cask. The temperatures at representative nodes in these locations are monitored during the entire fire and cool down transient analysis. The nodes that are monitored at these critical components are shown in Figure 8.

Figure 9 gives the plot of the time-history data at the representative nodes of the cask components. Figure 10 gives the same data in cask components that are not directly exposed to the fire. Figure 11 shows the time-history plot of the waste container temperature at a node where the temperature attains a maximum value (Node 2,013 of the 2-d model).

The ANSYS printout of the modeling is provided in Appendix 1 and the summary of the time-history data are provided in Appendix 2.

Table 1 summarizes the maximum temperature of various components of the cask during the entire analysis period.

To capture the maximum stresses in the cask components during the fire accident test conditions, the structural finite element model, with identical node numbers, needs to be run at some critical time instances. From the time-history plot several critical time instants were identified. The criterion used for determining these time instants was that one of the components achieved the highest temperature during the fire transient. Figure 10 identifies these time instants. These time instants are identified as 0.1, 1,800.3, 1,810, 5,000, 7,500, 12,500, and 22,500 seconds after the start of the fire test. The temperature profiles at these time instants are shown in Figures 12 through 18.

7.2 Cavity Air Temperature Results

The temperature profile at the nodes located on the inside (cavity) of the cask is shown in Figure 19. The maximum value of the temperature in the cavity is 320.5°F. The entire cask cavity volume is conservatively considered to be at 320.5°F.

The temperature profile of the cask with the implicit waste modeling (2-d model) at the time when the waste attains a maximum value during the HAC fire (t = 40,289 sec) is shown in Figure 20. The waste attains a maximum temperature of 239.7°F.

7.3 Puncture Drop Damage Results

The temperature profile of the cask obtained from the finite element model with damaged fire shield at the location of puncture drop is shown in Figure 21. From this figure it is observed that due to the assumed damage to the fire shield the temperature increase in the cask body under HAC fire is highly localized. The temperature plot in the lead column near the assumed damage location is shown in Figure 22. A maximum value of 617.7° is attained by the lead column.

Table 1

Summary of Maximum Hypothetical Fire Temperatures

Component	Maximum Calculated Temp.			Maximum Allowable Temperature (°F)
	Location (Node Nos.)	Time (Sec.)	Value (°F)	
Fire Shield	42,910	1,800	1,392	N.A
Outer Shell	12,531	1,800.3	464.4	800
Inner Shell	8,015	4,461.7	295.5	800
Lead	14,338	4,461.7	295.8	622(1)
Baseplate	2,430	936.48	206.3	800
Primary Lid	37,675	612.66	202.9	800
Secondary Lid	27,023	1,566.13	192.6	800
Primary Lid Seals	25,430	18,225	212.4	235(2)
Secondary Lid Seals	37,678	24,000	202.9	235(2)
Vent Seal	34,802	24,000	206.9	235(2)
Impact Limiter	27,594	24,000	205.1	500(4)
Cask Cavity	(3)	1,800	320.5	(5)
Waste Contents	2,013	40,289	239.7	(6)

NOTES:

(1) Lead melting point temperature.

(2) Established based on 110% of the maximum seal temperatures.

(3) Obtained from the temperature contour plot. See Figure 19.

(4) Temperature at which the foam material shows 0% thermal decomposition. Obtained from the General Plastics' sales brochure.

(5) Temperature used for calculating the cavity pressure.

(6) Waste contents temperature is obtained for reference purpose.

8.0 ANSYS PRINTOUT AND DATA FILES

The print-out of the model data is included in Appendix 1. Appendix 2 included the print-out of the results from the analyses presented in this document.

The complete electronic data of the input and output of all the analyses are included on a CDROM in Appendix 2.

9.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data

Appendix 2 Print-out of the results

Appendix 3 Electronic data on CDROM

Figures

(22 Pages)

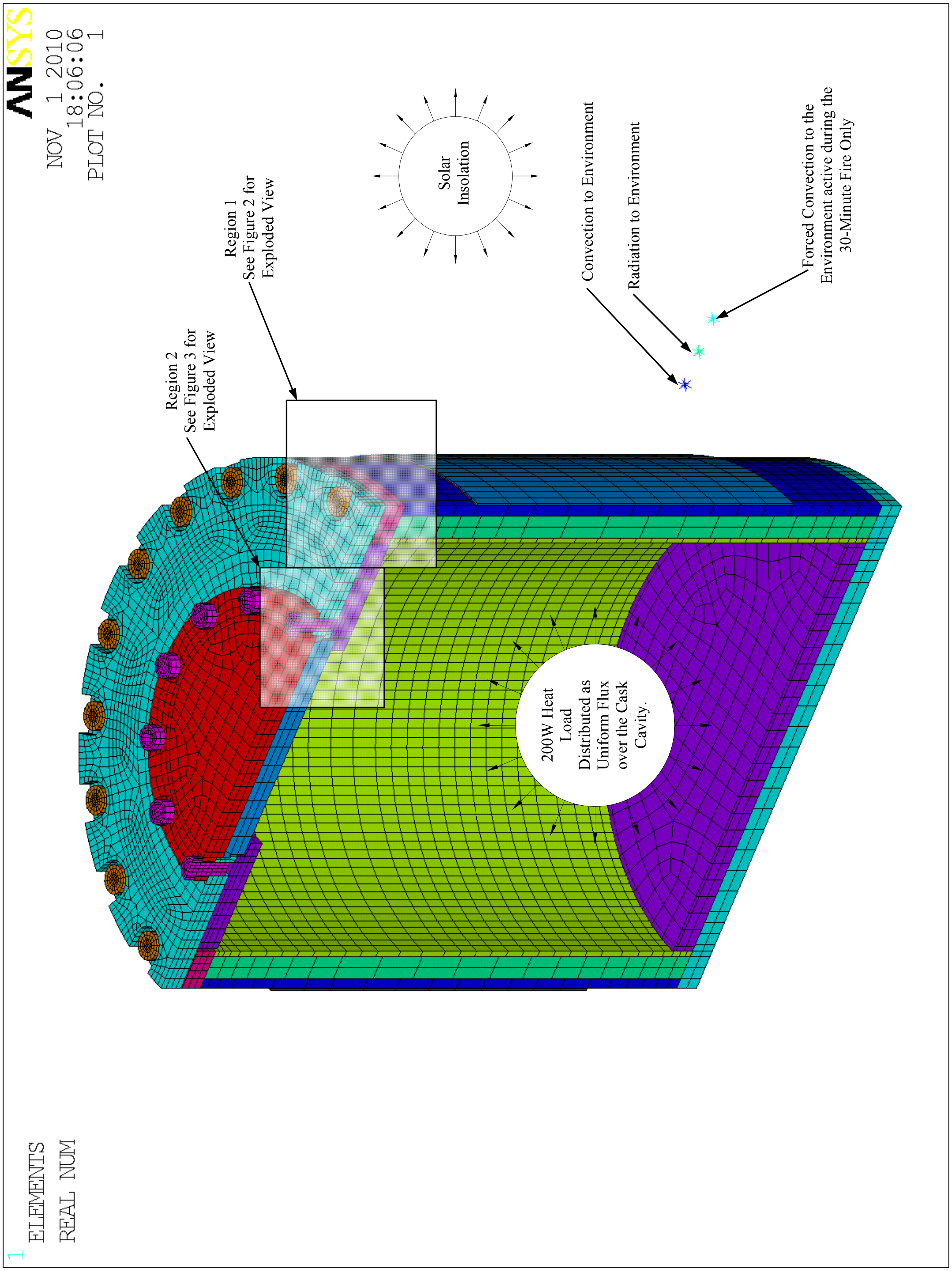

Figure 1 – 3-D Finite Element Model of the 8-120B Cask Used for the Thermal Analyses

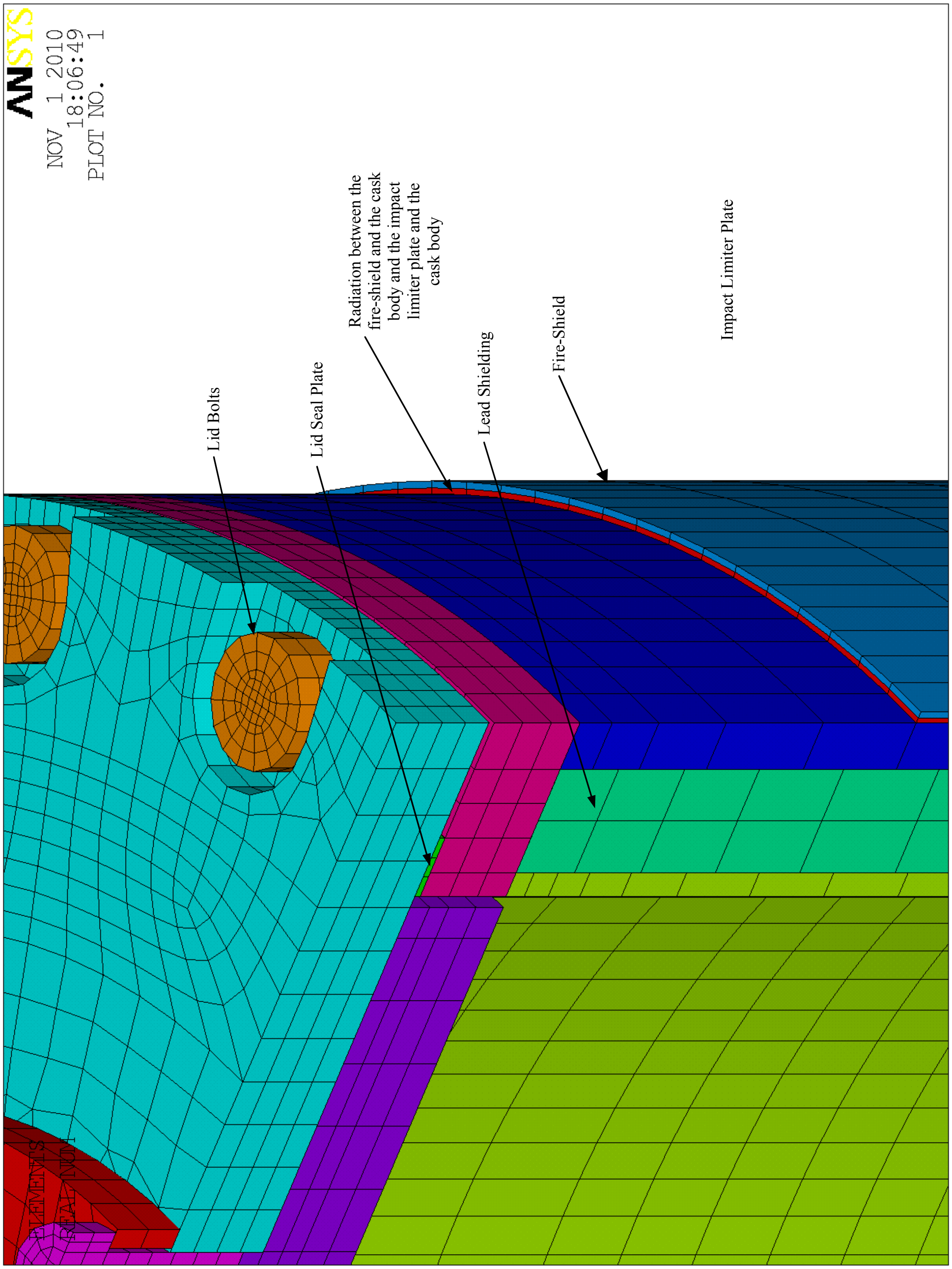

Figure 2 – Exploded View of Region 1 of Figure 1

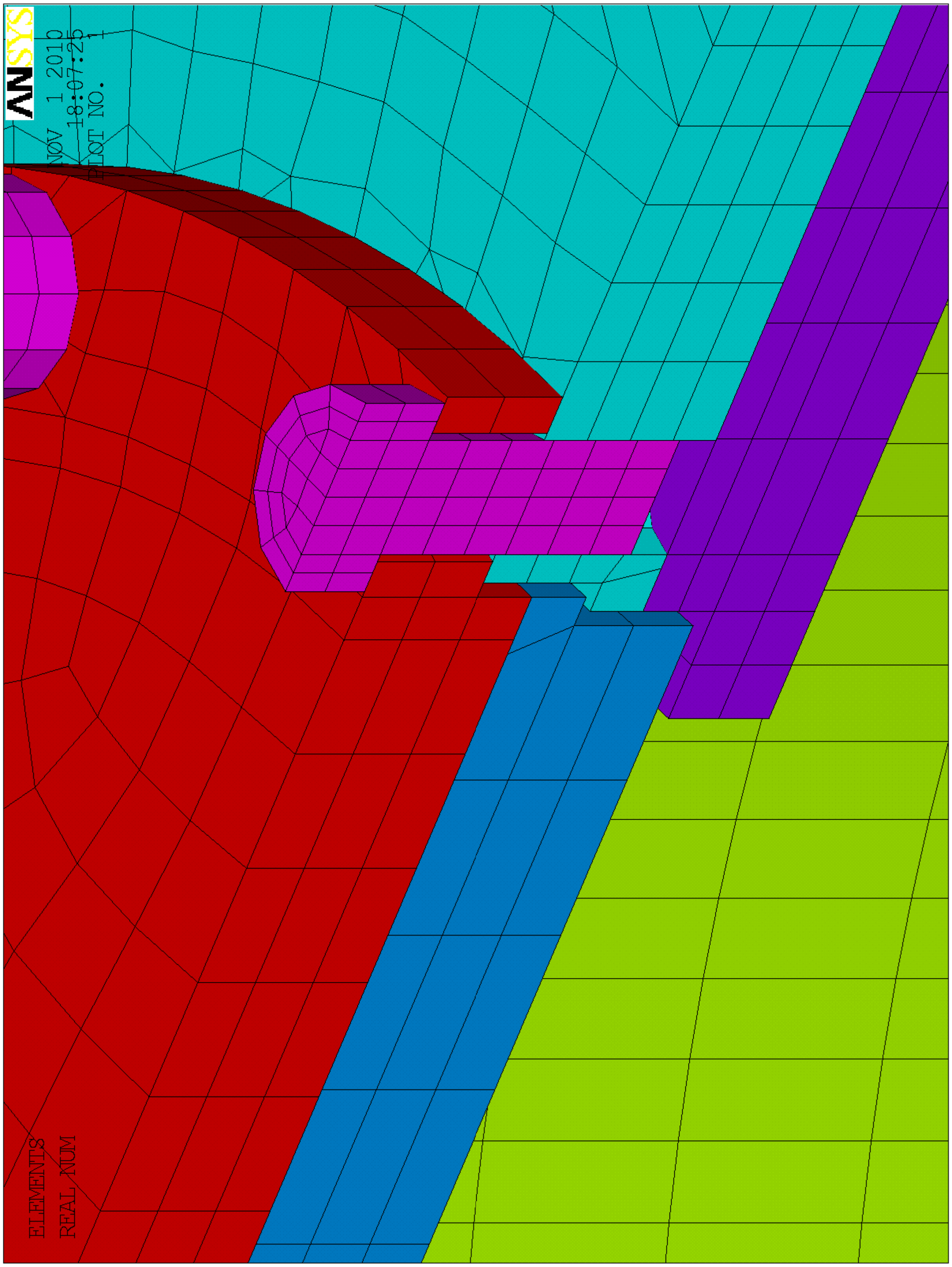

Figure 3 – Exploded View of Region 2 of Figure 1

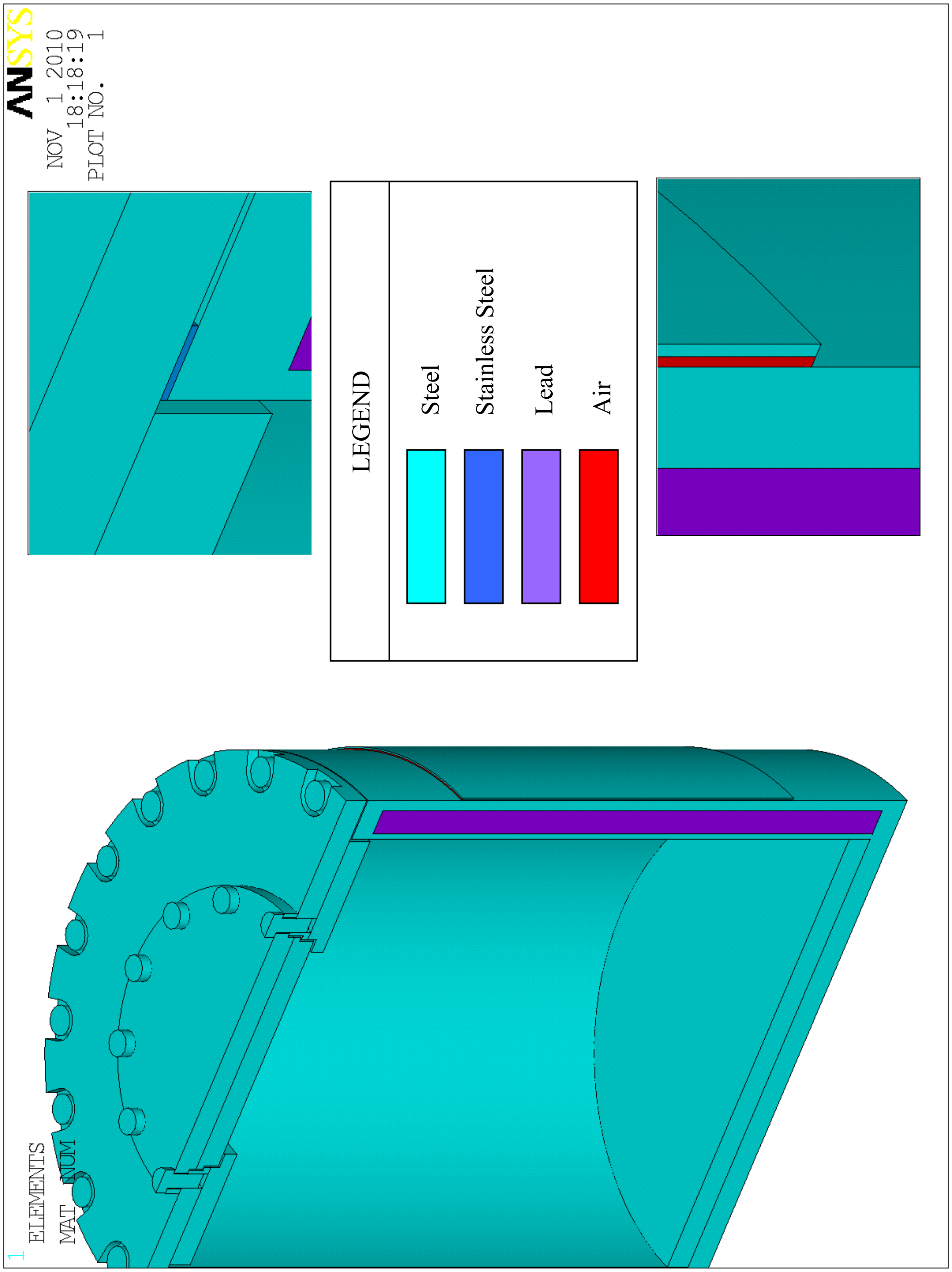

Figure 4 – Materials Used in the Finite Element Model

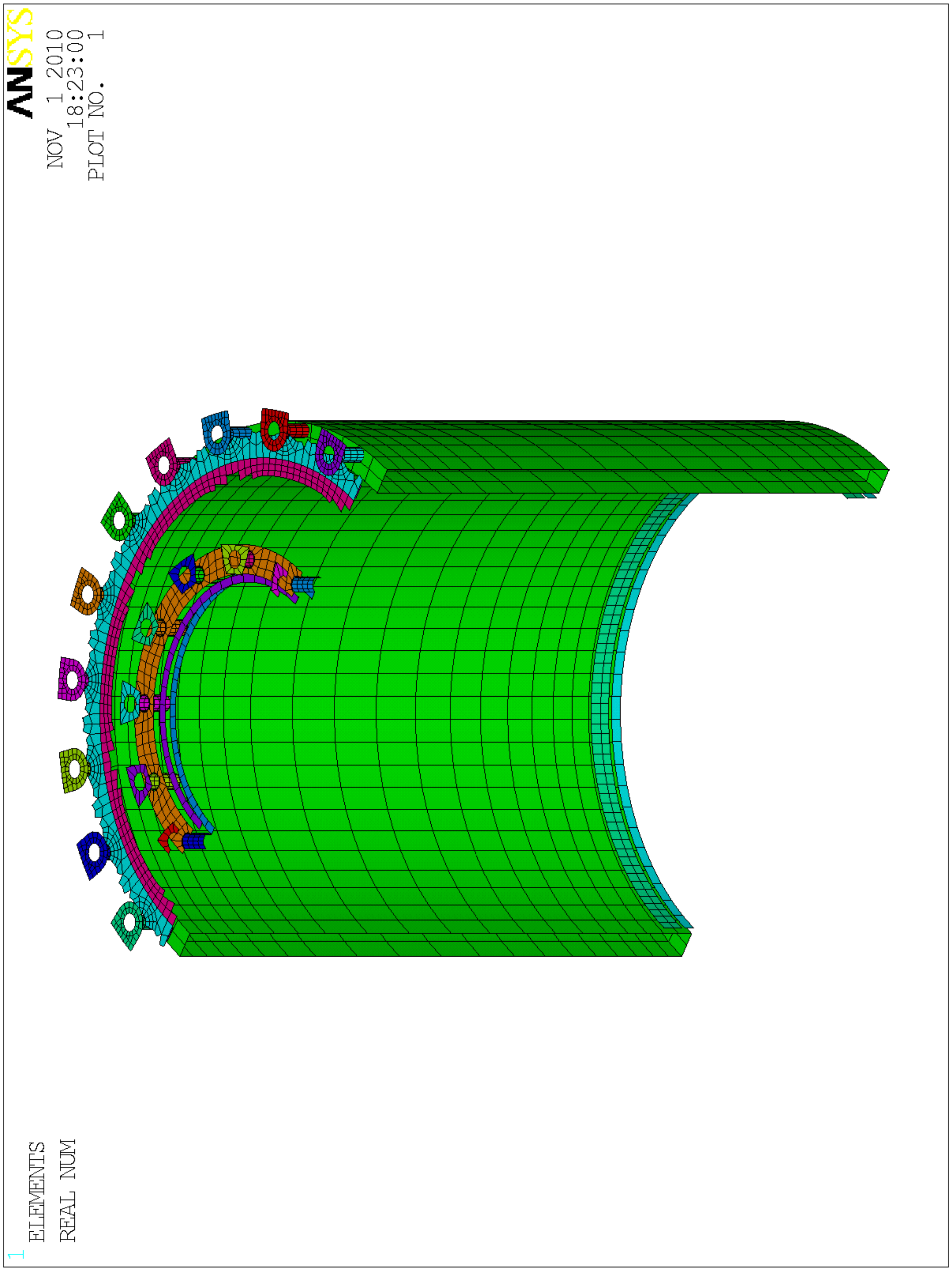

Figure 5 – Contact-Target Pair Elements (Only Target Elements Shown for Clarity)

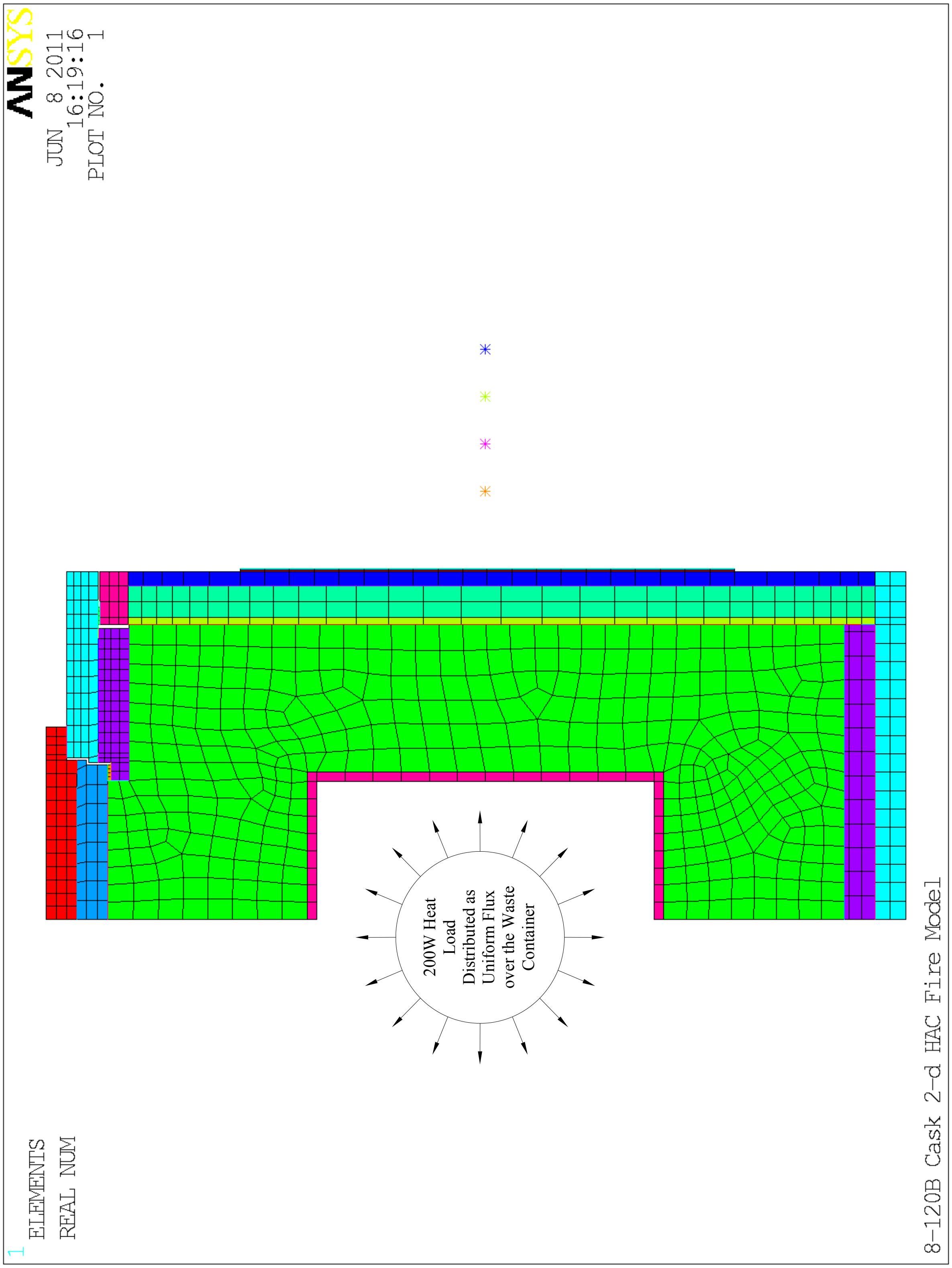

Figure 6 – 2-D Finite Element Model of the 8-120B Cask Used for the Thermal Analyses

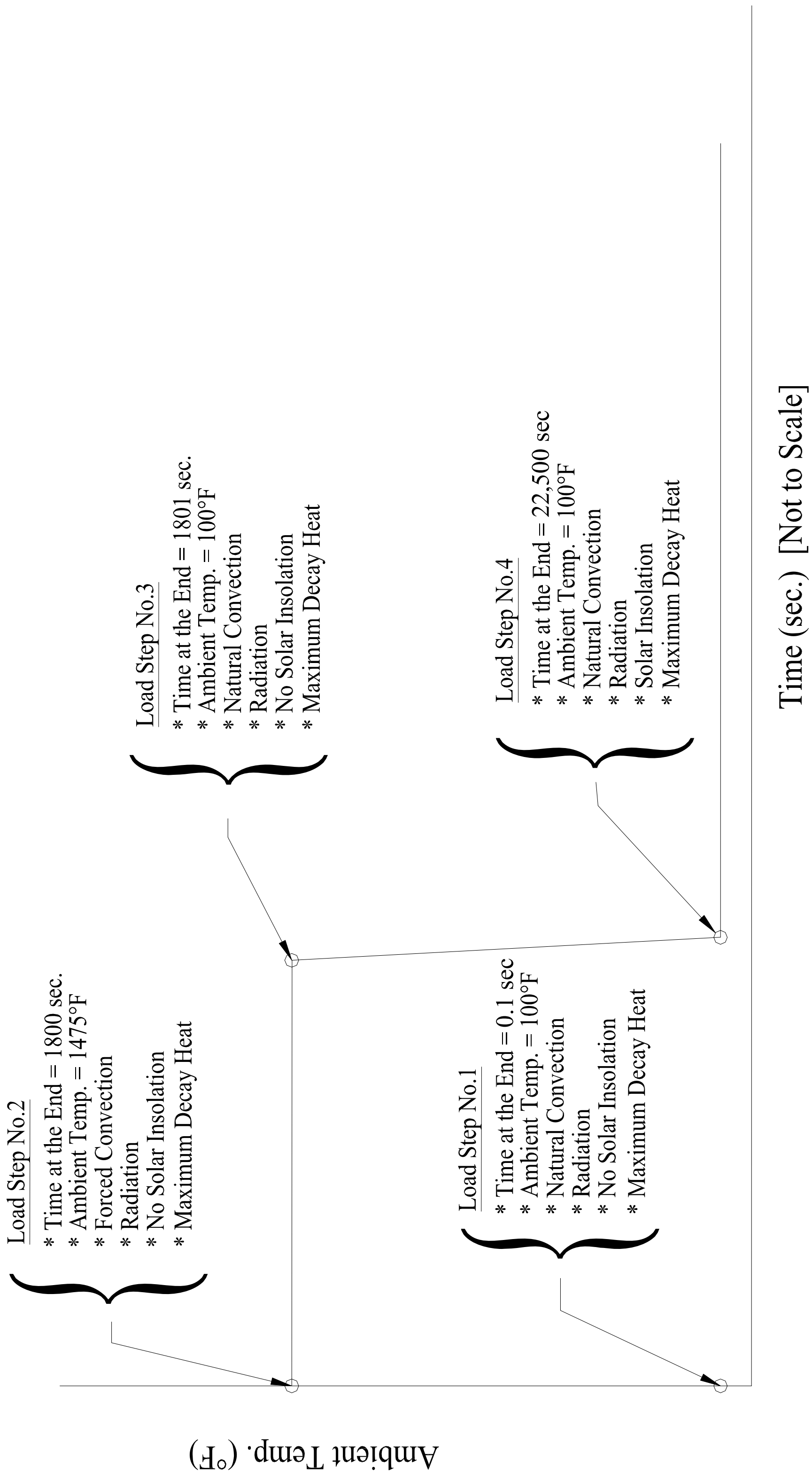

Figure 7 – HAC Fire Analysis Load Steps and Boundary Conditions

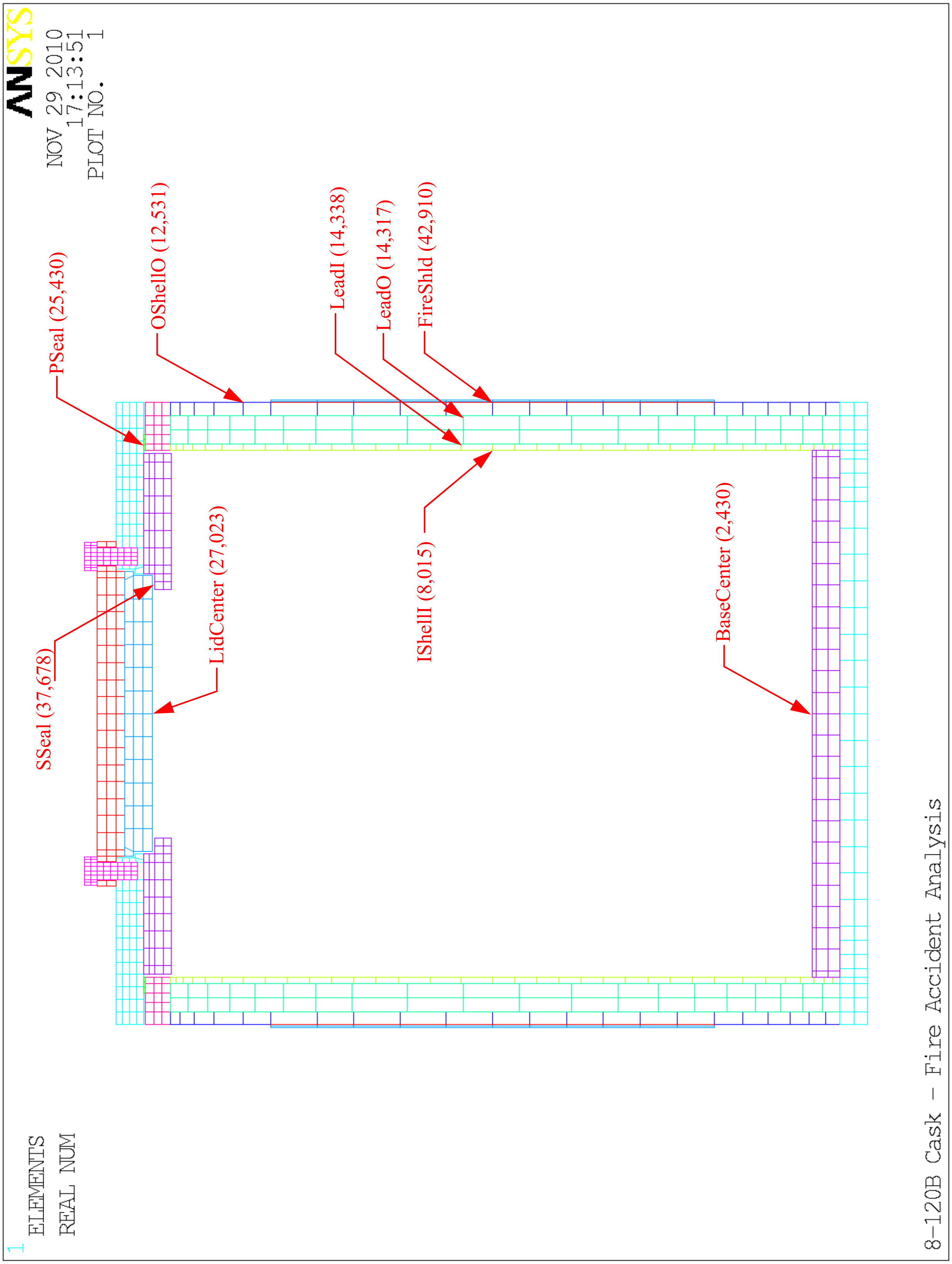

Figure 8 – Identification of the Nodes where Time-History is Monitored

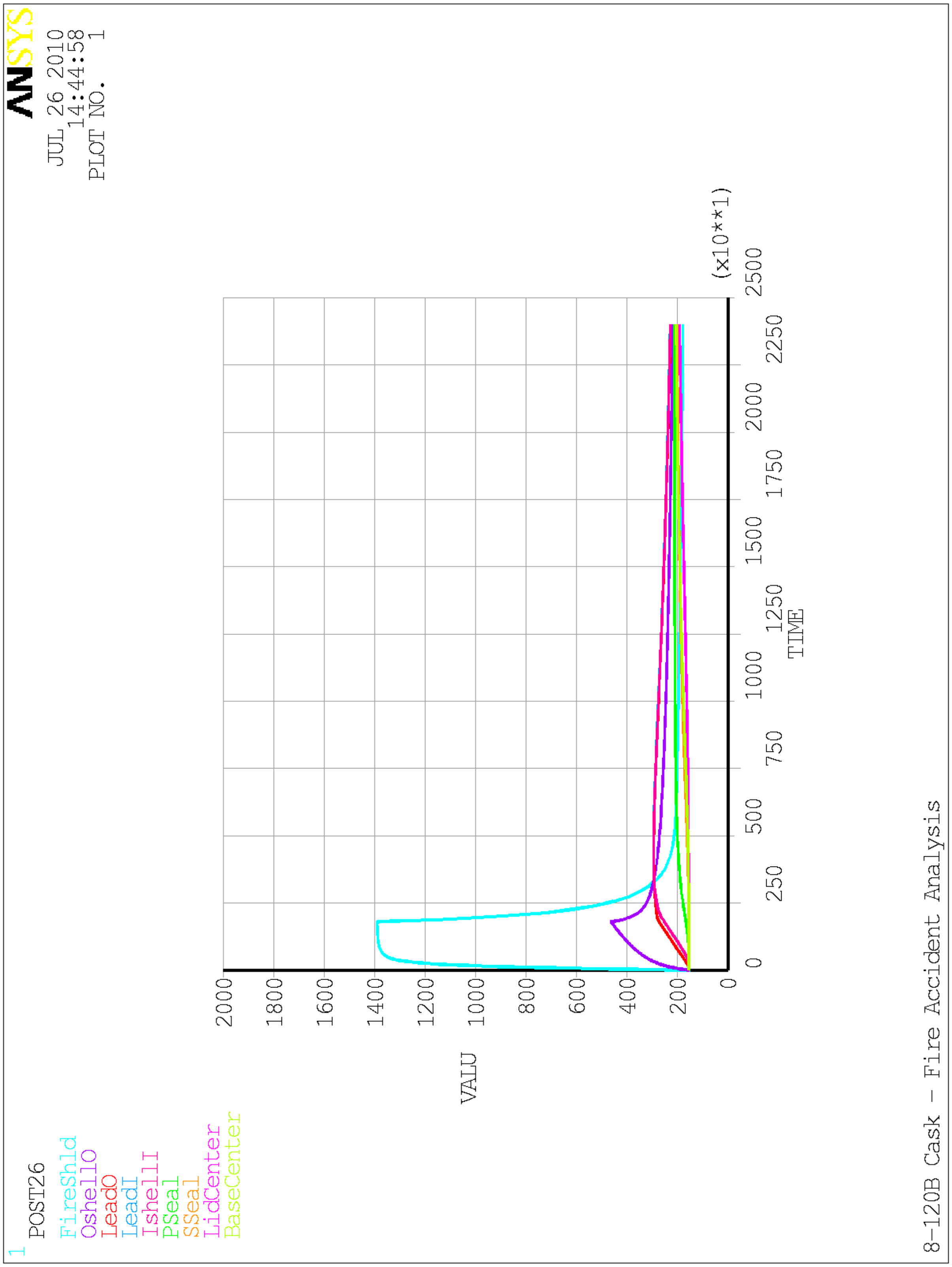

Figure 9 –Temperature Plot of Nodes Directly Exposed to Fire

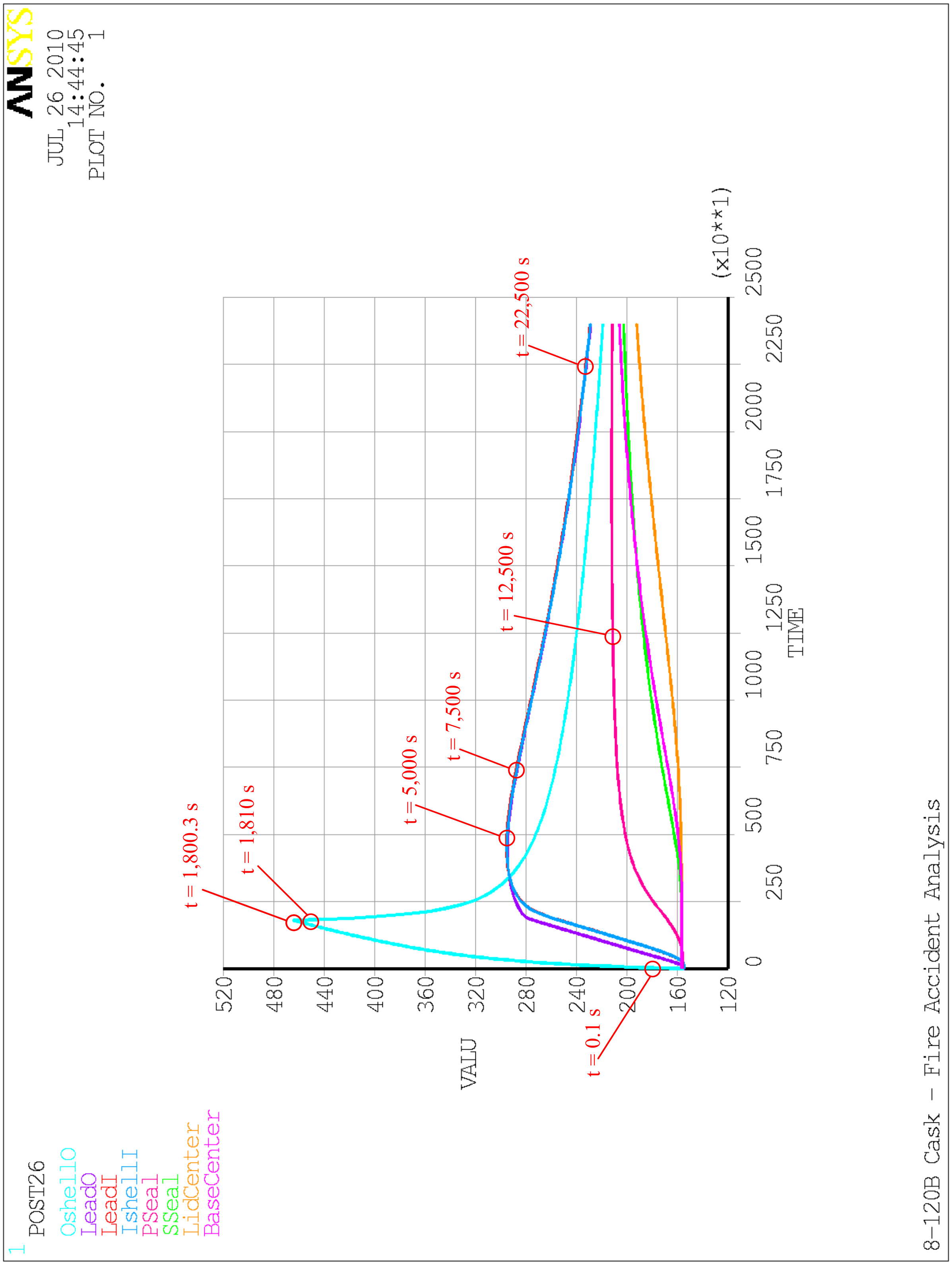

Figure 10 –Temperature Plot of Nodes not Directly Exposed

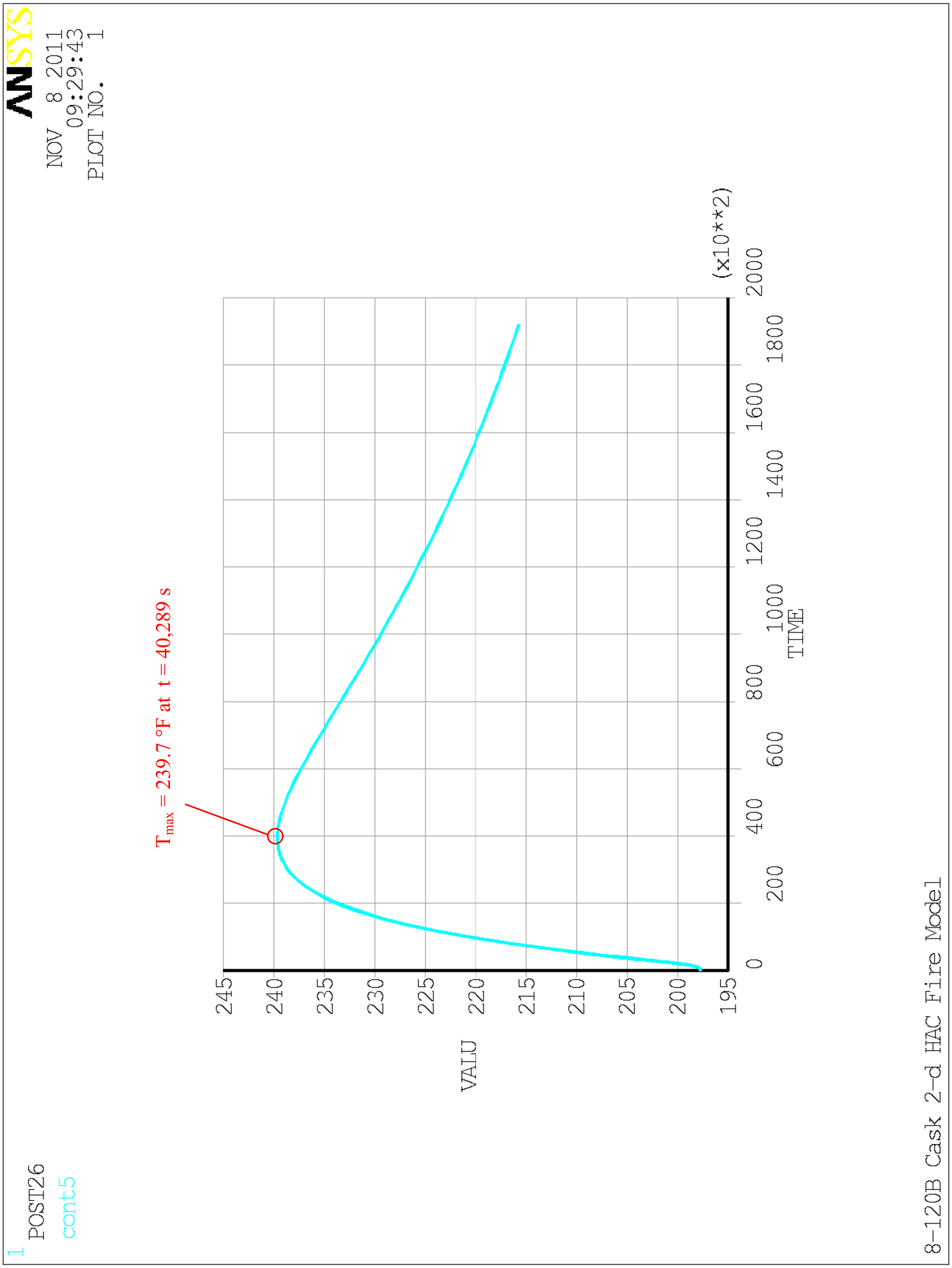

Figure 11 –Time-History Plot of the Waste Container Temperature during the HAC Fire (from the 2-D Model)

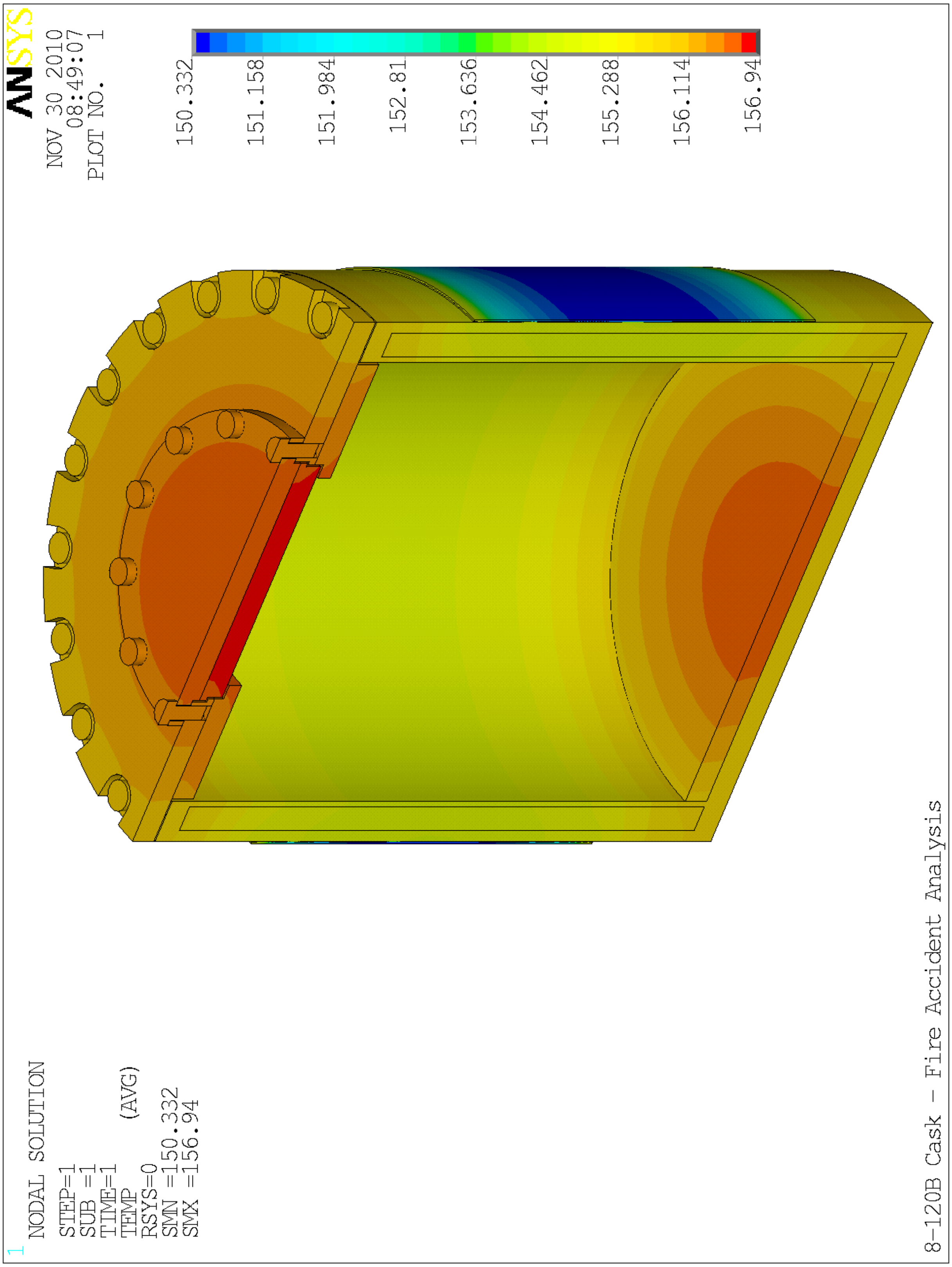

Figure 12 - Temperature Distribution – 0.1 Sec. After the Start of the Fire

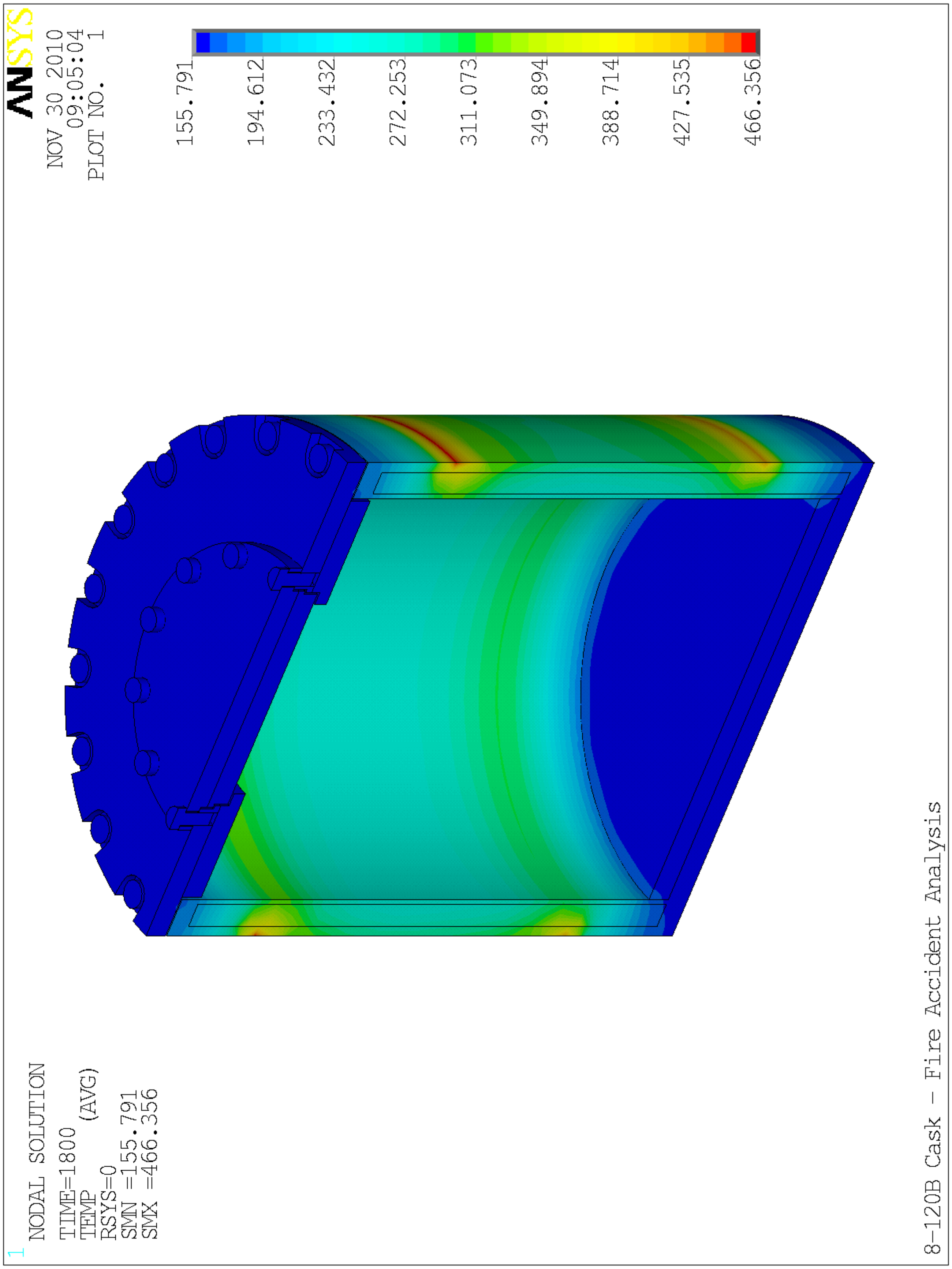

Figure 13 - Temperature Distribution – 1,800.3 Sec. After the Start of the Fire

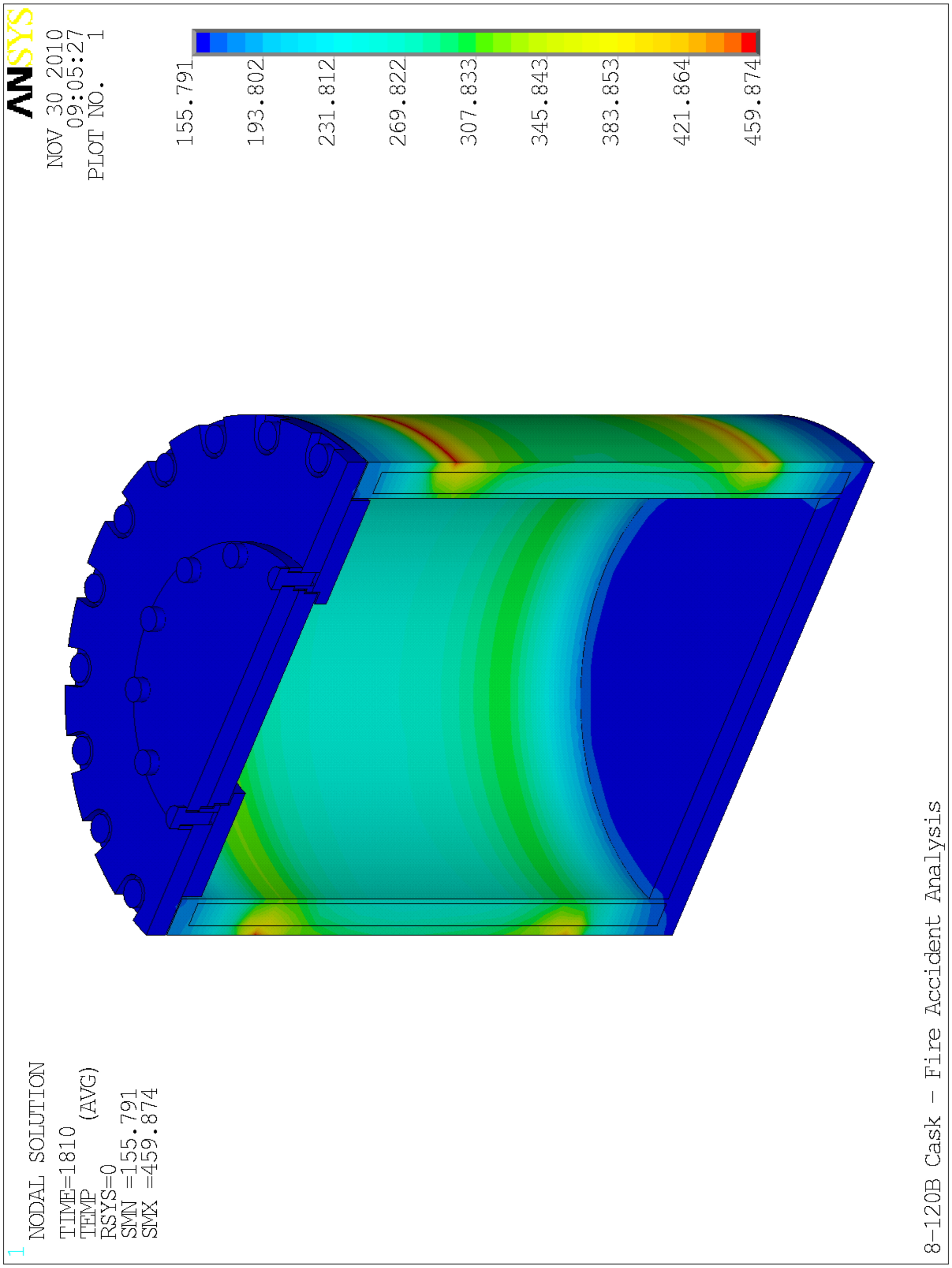

Figure 14 - Temperature Distribution – 1,810 Sec. After the Start of the Fire

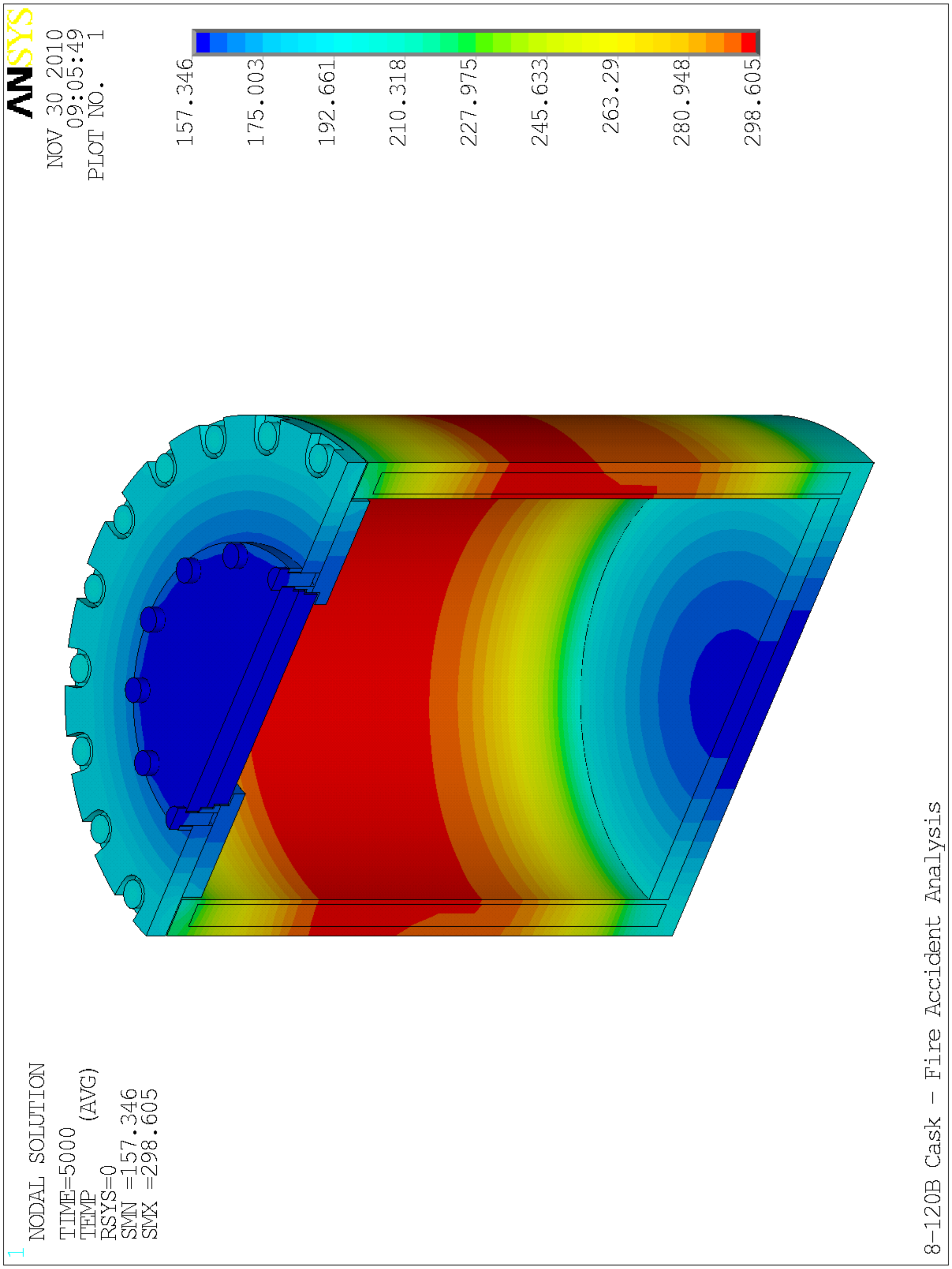

Figure 15 - Temperature Distribution – 5,000 Sec. After the Start of the Fire

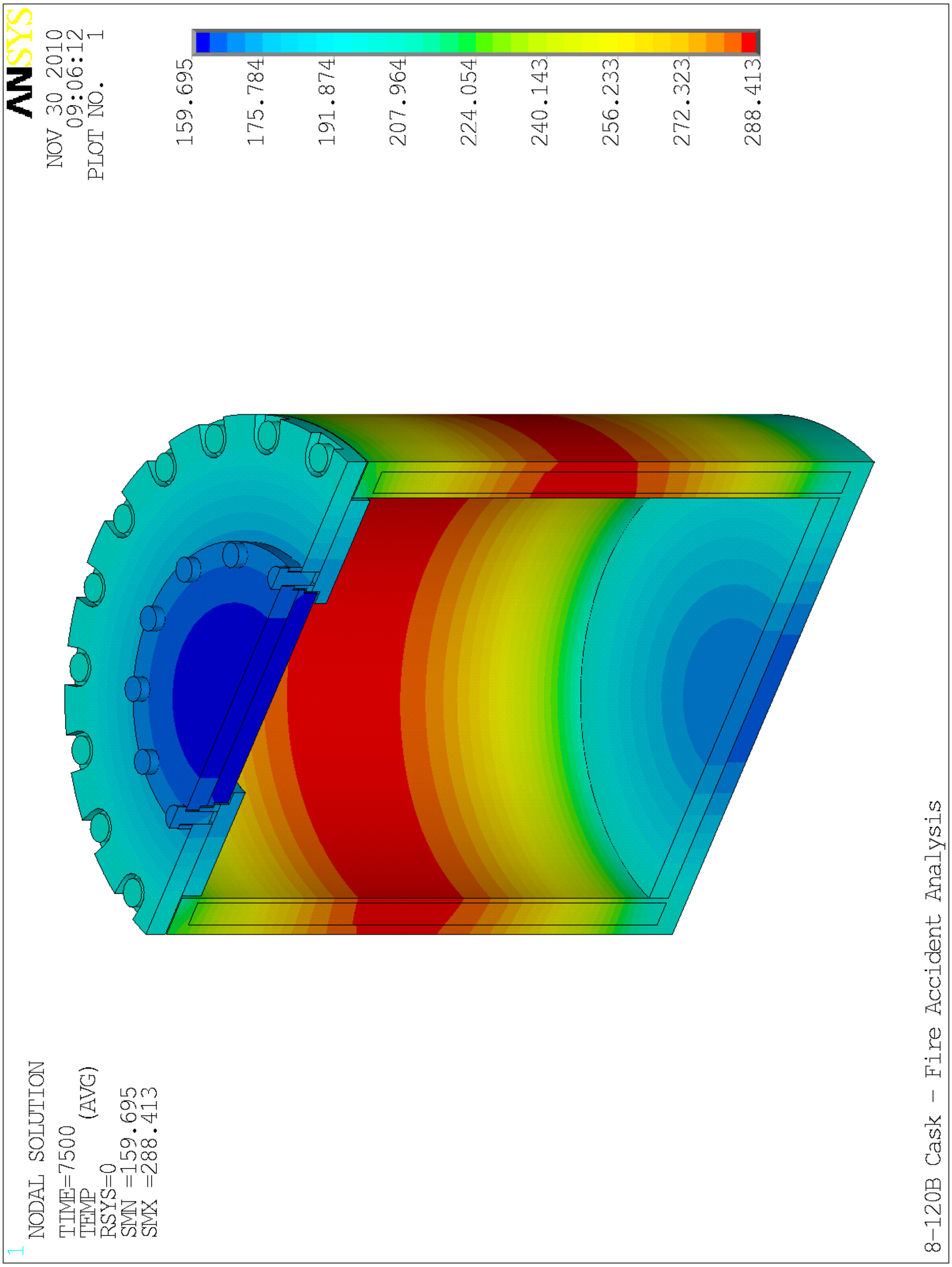

Figure 16 - Temperature Distribution – 7,500 Sec. After the Start of the Fire

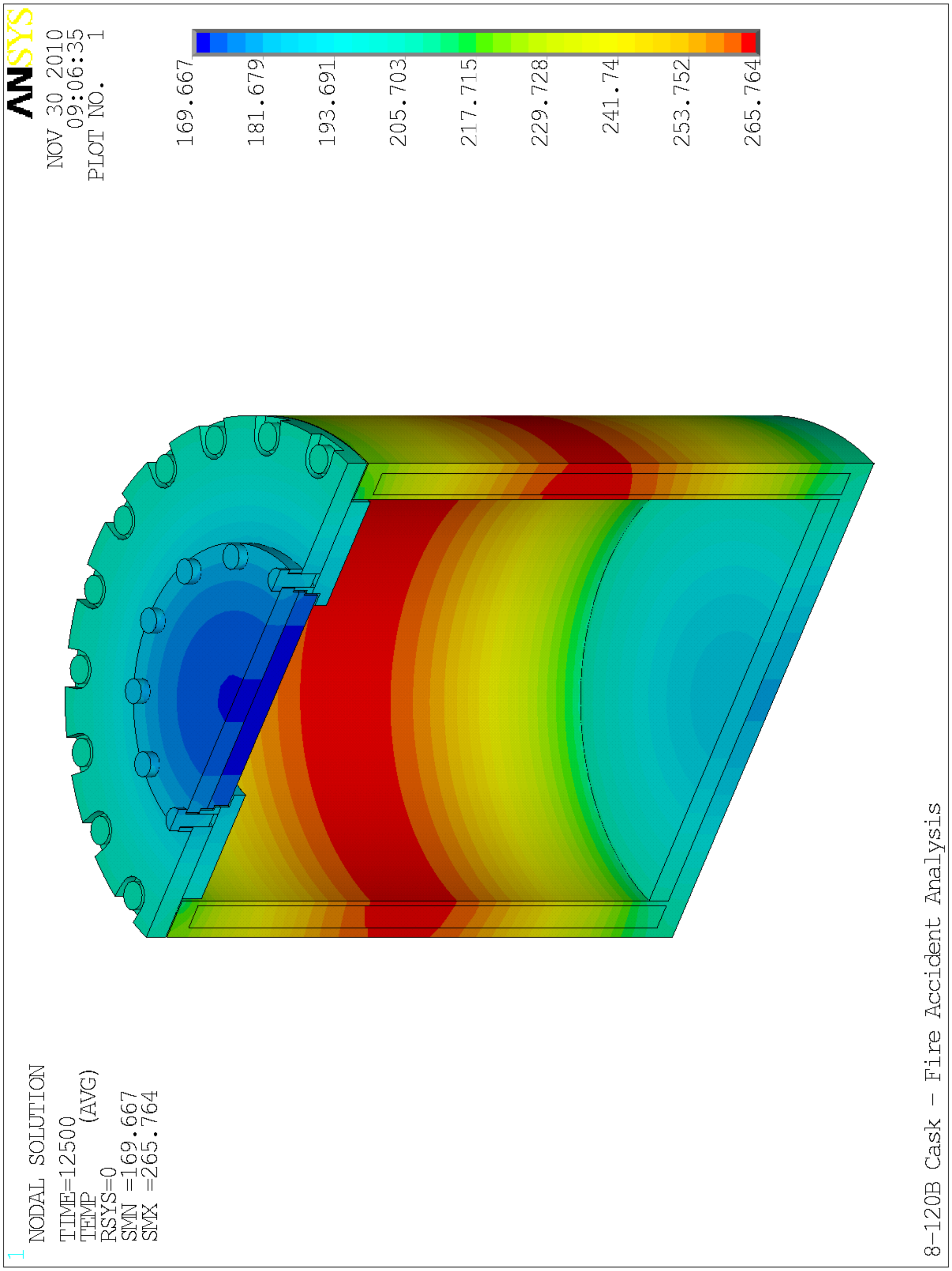

Figure 17 - Temperature Distribution – 12,500 Sec. After the Start of the Fire

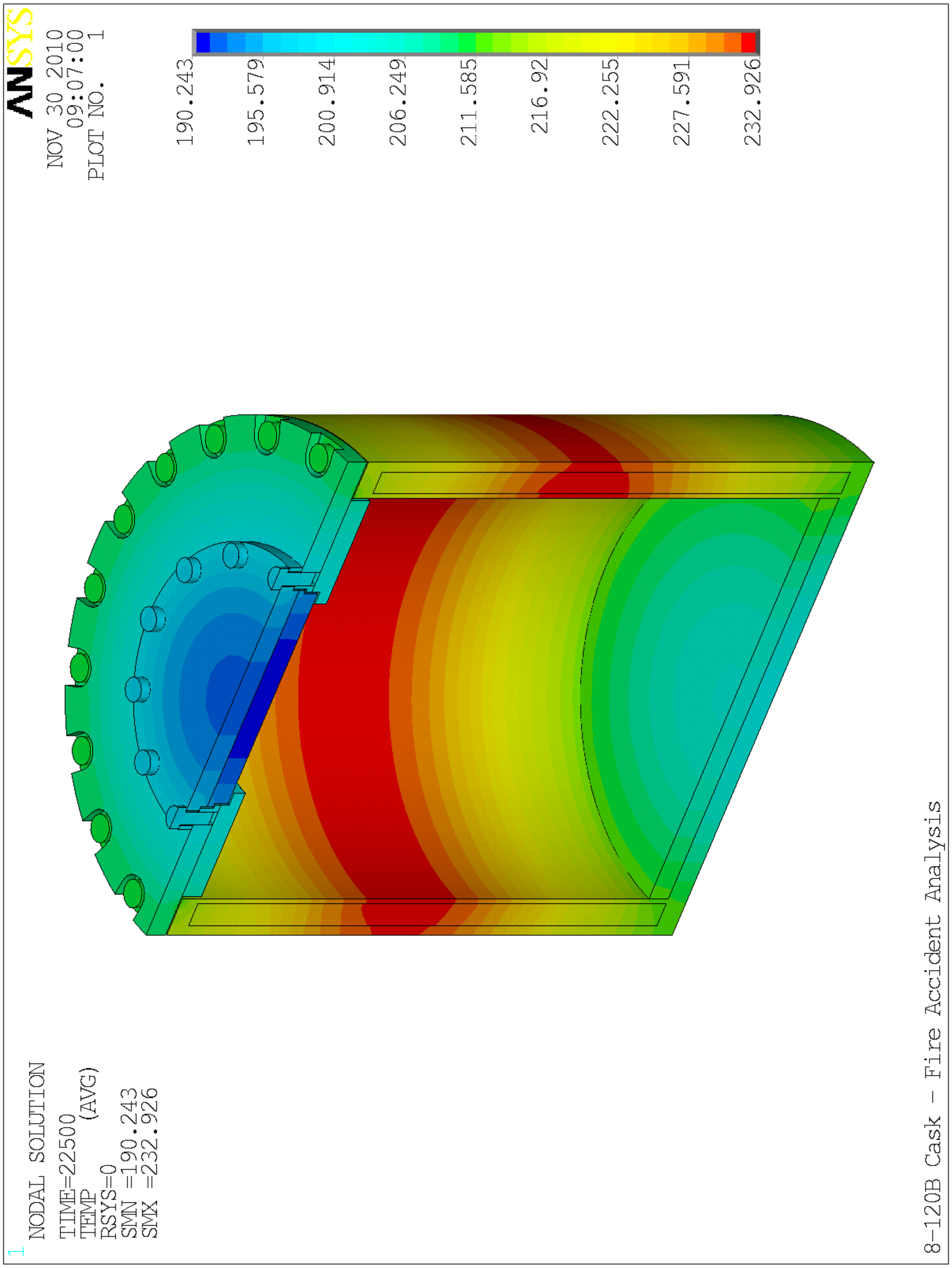

Figure 18 - Temperature Distribution – 22,500 Sec. After the Start of the Fire

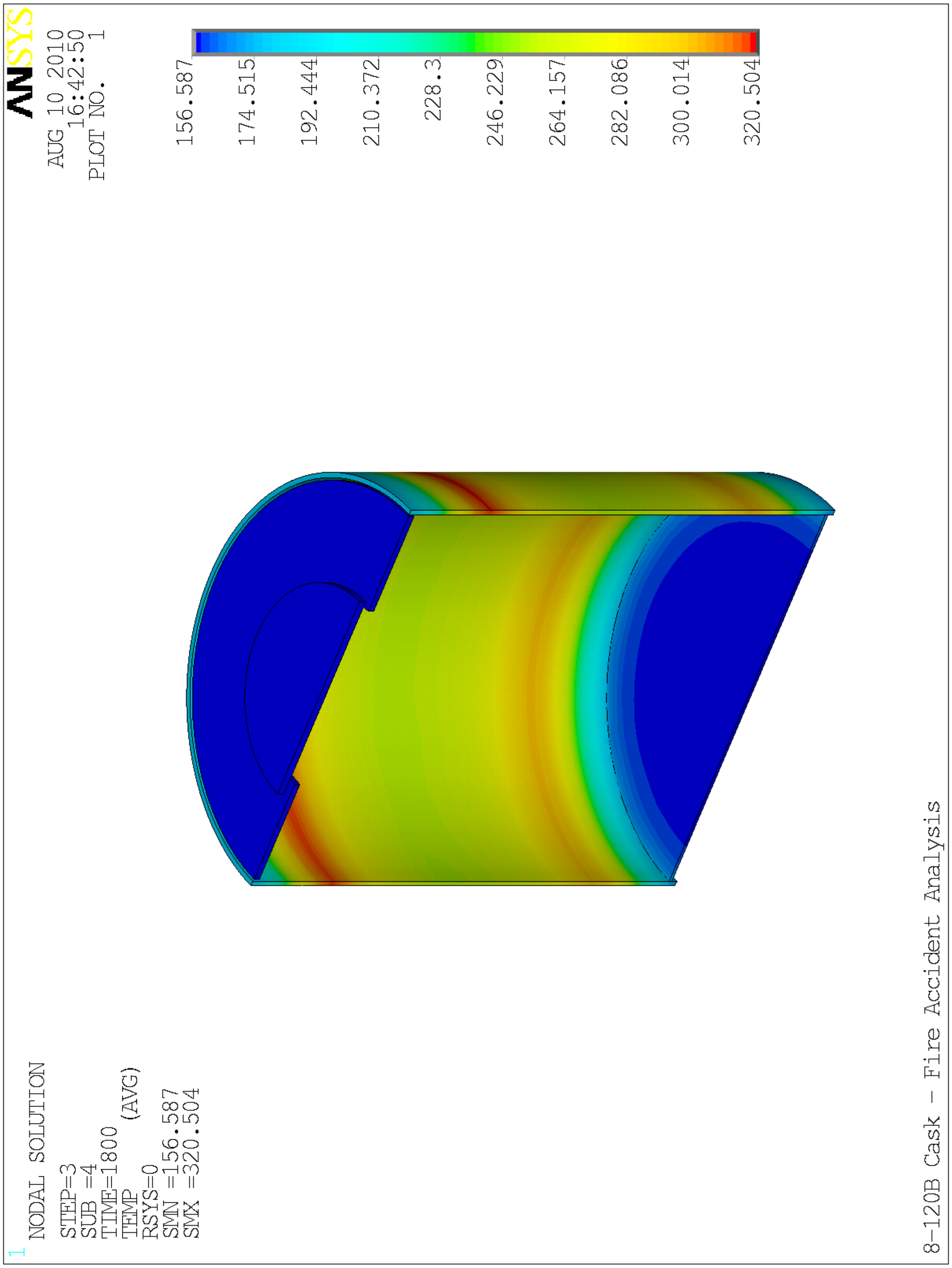

Figure 19 - Temperature Profile of the Cavity Surface

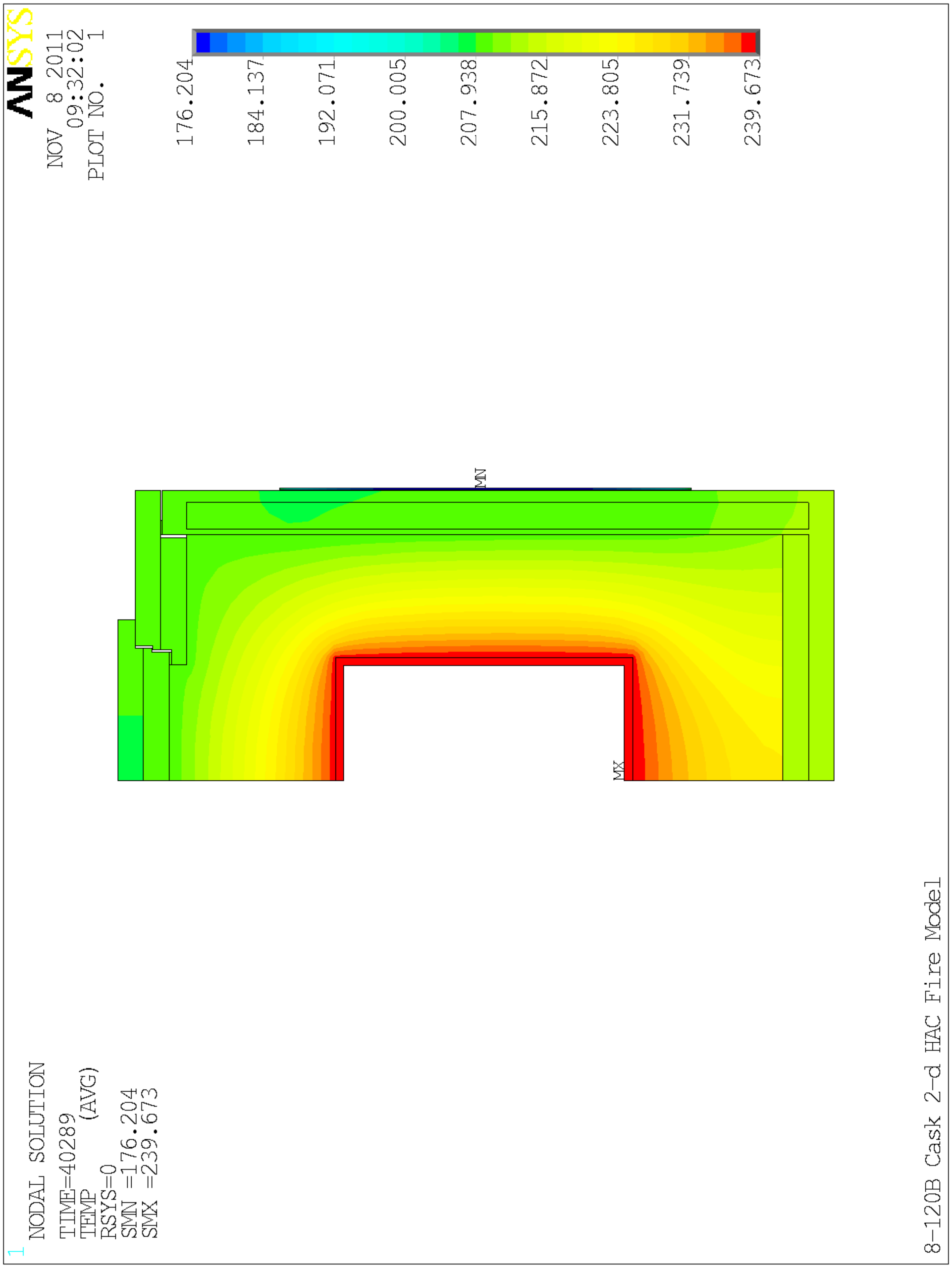

Figure 20 - Temperature Profile of the Cask at time when the Waste Container Temperature Peaks (from the 2-D Model)

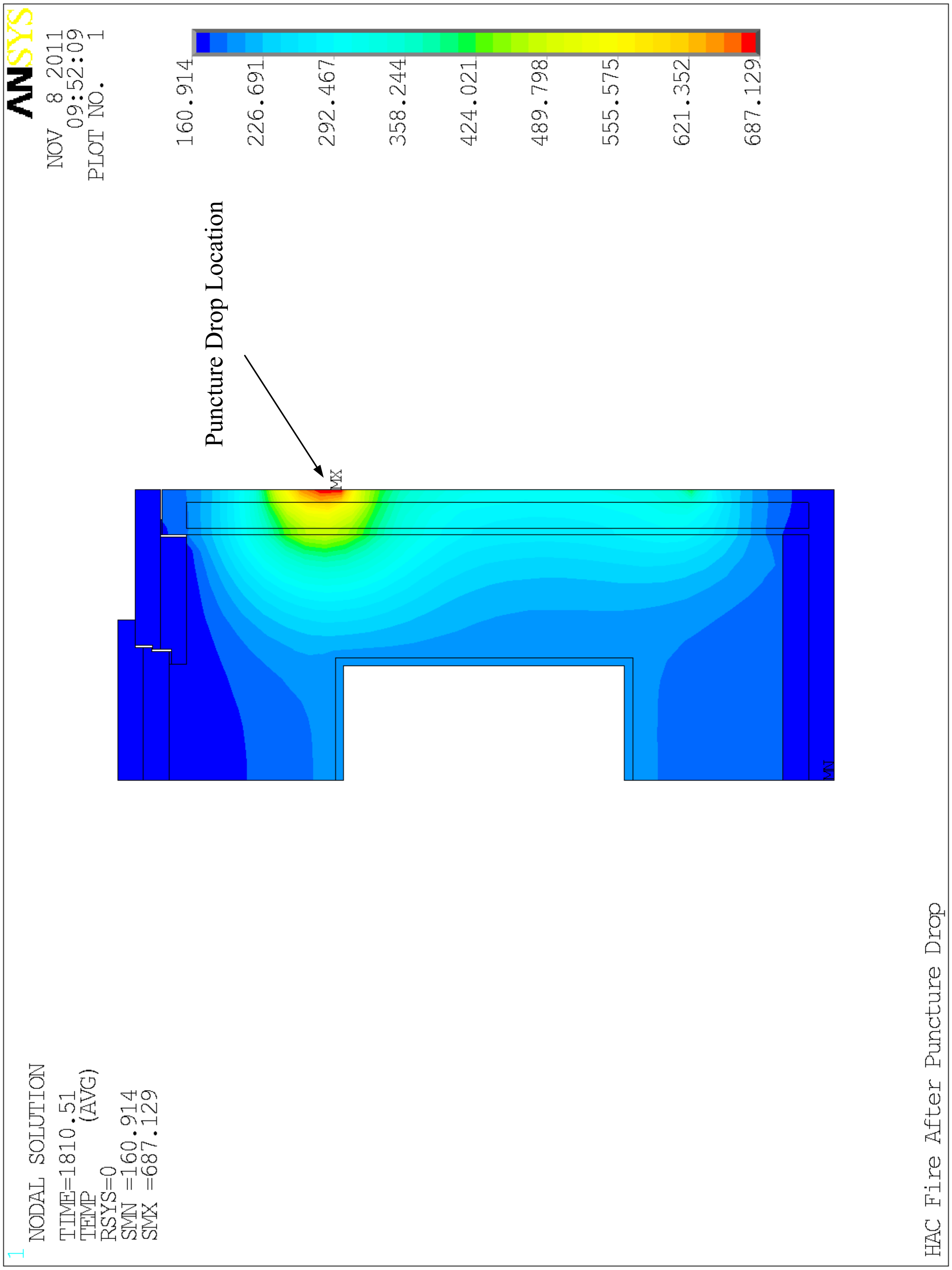

Figure 21 –Temperature Distribution in the Cask with Puncture Drop Damage (from the 2-D Model)

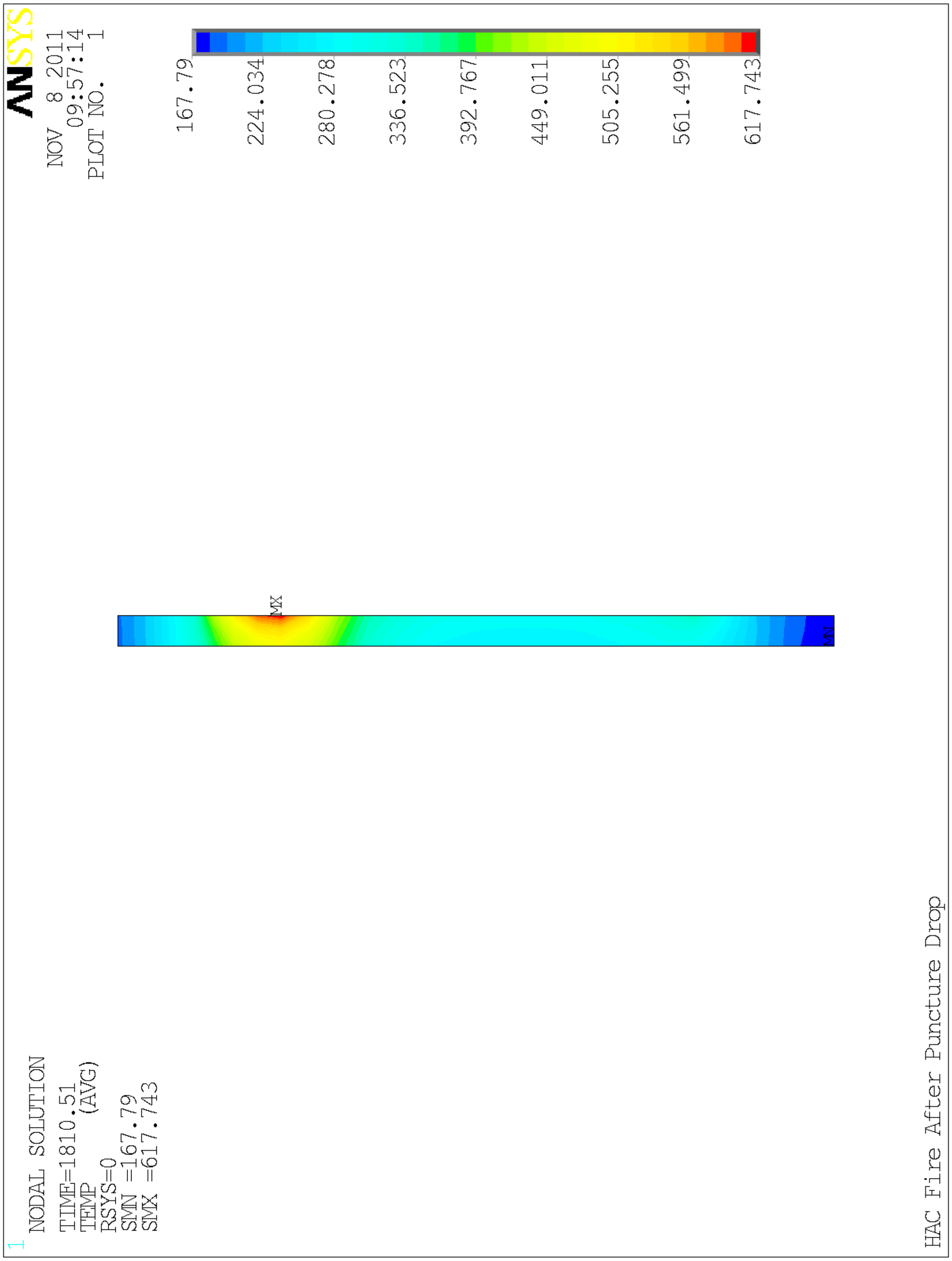

Figure 22 –Temperature Distribution in the Lead Column with Puncture Drop Damage (from the 2-D Model)

Appendix 1

Print-out of the ANSYS model data

(33 Pages)

ANSYS Finite Element Model Partial Printout

3-d Finite Element Model Data

(Note: The complete data printout is included on the file "3d Model\model.out", which is included on the electronic media included in the package)

```
     ***** TITLES *****

 *** YOU ARE IN   ANSYS - ENGINEERING ANALYSIS SYSTEM ***
 ANSYS Mechanical
 RELEASE  12.1      UPDATE 20091102   CUSTOMER  00222442

 INITIAL JOBNAME = file
 CURRENT JOBNAME = file

 Current Working Directory: D:\ANSYS Analyses\8-120B\Thermal\HAC

 TITLE= 8-120B Cask - Fire Accident Analysis

 MENULIST File: C:\Program Files\ANSYS Inc\v121\ANSYS\gui\en-
us\UIDL\menulist121.ans

                           G L O B A L   S T A T U S

 ANSYS - Engineering Analysis System            Nov 01, 2010           11:42
 Release 12.1                    00222442               WINDOWS x64  Version

 Current working directory: D:\ANSYS Analyses\8-120B\Thermal\HAC


 MENULIST File: C:\Program Files\ANSYS Inc\v121\ANSYS\gui\en-
us\UIDL\menulist121.ans

 Product(s) enabled: ANSYS Mechanical


 Total connect time. . . . .   0 hours  1 minutes
 Total CP usage. . . . . . .   0 hours  0 minutes  2.5 seconds

 J O B   I N F O R M A T I O N -----------------------------------------------

8-120B Cask - Fire Accident Analysis

 Current jobname . . . . . .file
 Initial jobname . . . . . .file

 Units . . . . . . . . . . .unknown

                                 Available               Used
 Scratch Memory Space. . . .     512.000 mb            6.839 mb (  1.3%)
 Database space  . . . . . .   65535.750 mb          107.485 mb (  0.2%)

 User menu file in use . . .%ANSYS121_DIR%\gui\en-us\UIDL\UIMENU.GRN
 User menu file in use . . .%ANSYS121_DIR%\gui\en-us\UIDL\UIFUNC1.GRN
```

```
User menu file in use . . .%ANSYS121_DIR%\gui\en-us\UIDL\UIFUNC2.GRN
User menu file in use . . .%ANSYS121_DIR%\gui\en-us\UIDL\MECHTOOL.AUI
Beta features . . . . . . .are not shown in the user interface

M O D E L   I N F O R M A T I O N ---------------------------------------------

Solid model summary:

                              Largest         Number        Number
                               Number         Defined       Selected
Keypoints . . . . . . . . .        0               0             0
Lines . . . . . . . . . . .        0               0             0
Areas . . . . . . . . . . .        0               0             0
Volumes . . . . . . . . . .        0               0             0

Finite element model summary:

                              Largest         Number        Number
                               Number         Defined       Selected
Nodes . . . . . . . . . . .    50005           39845         39845
Elements. . . . . . . . . .    52666           40315         40315

Element types . . . . . . .      150             101          n.a.
Real constant sets. . . . .       92              51          n.a.
Material property sets. . .        6               6          n.a.

Coupling. . . . . . . . . .      162             162          n.a.
Constraint equations. . . .        0               0          n.a.
Master DOFs . . . . . . . .        0               0          n.a.
Dynamic gap conditions. . .        0               0          n.a.

B O U N D A R Y   C O N D I T I O N   I N F O R M A T I O N ------------------

                                           Number
                                          Defined
Constraints on nodes. . . . . . . . . . .       2
Constraints on keypoints. . . . . . . . .       0
Constraints on lines. . . . . . . . . . .       0
Constraints on areas. . . . . . . . . . .       0

Forces on nodes . . . . . . . . . . . . .       0
Forces on keypoints . . . . . . . . . . .       0

Surface loads on elements . . . . . . . .    5838
Number of element flagged surfaces  . . .       0
Surface loads on lines. . . . . . . . . .       0
Surface loads on areas. . . . . . . . . .       0

Body loads on elements. . . . . . . . . .       0
Body loads on areas . . . . . . . . . . .       0
Body loads on lines . . . . . . . . . . .       0
Body loads on nodes . . . . . . . . . . .       0
Body loads on keypoints . . . . . . . . .       0

Temperatures
   Uniform temperature. . . . . . . . . .     0.000
   Offset from absolute scale . . . . . .   460.000
```

```
                                              X           Y           Z
Linear acceleration . . . . . . . . . . . .  0.0000      0.0000      0.0000
Angular velocity (about global CS). . . .  0.0000      0.0000      0.0000
Angular acceleration (about global CS). .  0.0000      0.0000      0.0000
Location of reference CS. . . . . . . . .  0.0000      0.0000      0.0000
Angular velocity (about reference CS) . .  0.0000      0.0000      0.0000
Angular acceleration (about reference CS)  0.0000      0.0000      0.0000

R O U T I N E   I N F O R M A T I O N ---------------------------------------

Current routine. . . . . . . . . . . . .Preprocessing (PREP7)

Active coordinate system . . . . . . .   1 (Cylindrical)

Display coordinate system. . . . . . .   0 (Cartesian)

Current element attributes:
   Type number . . . . . . . . . . . .     5  (MATRIX50)
   Real number . . . . . . . . . . . .    94
   Material number . . . . . . . . . .     5
   Element coordinate system number. .     0

Current mesher type. . . . . . . . . .based on default element shape

Current element meshing shape 2D . . .use default element shape.

Current element meshing shape 3D . . .use default element shape.

SmrtSize Level  . . . . . . . . . . . . OFF

Global element size. . . . . . . . .     0 divisions per line

Active coordinate system . . . . . . .   1 (Cylindrical)

Display coordinate system. . . . . . .   0 (Cartesian)

Analysis type. . . . . . . . . . . . .Transient

Active options for this analysis type:
   Solution method . . . . . . . . . .Full
   Equation solver to use. . . . . . .Sparse

Results file . . . . . . . . . . . . .file.rth

Load step number . . . . . . . . . .     2

Number of substeps:
   Starting number of substeps . . . .   5000
   Maximum number of substeps. . . . .   5000
   Minimum number of substeps. . . . .    100
   Step change boundary conditions . .Yes

                      S O L U T I O N   O P T I O N S

  PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
  DEGREES OF FREEDOM. . . . . . TEMP
```

```
  ANALYSIS TYPE . . . . . . . . . . . . . . . . . . . .TRANSIENT
     SOLUTION METHOD. . . . . . . . . . . . . . . . . .FULL
  OFFSET TEMPERATURE FROM ABSOLUTE ZERO . . . . .  460.00
  EQUATION SOLVER OPTION. . . . . . . . . . . . . .SPARSE
  NEWTON-RAPHSON OPTION . . . . . . . . . . . . . .PROGRAM CHOSEN
  GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . . .SYMMETRIC

                   L O A D   S T E P   O P T I O N S

  LOAD STEP NUMBER. . . . . . . . . . . . . . . .       2
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  24001.
  AUTOMATIC TIME STEPPING . . . . . . . . . . . .     ON
     INITIAL NUMBER OF SUBSTEPS . . . . . . . . .  5000
     MAXIMUM NUMBER OF SUBSTEPS . . . . . . . . .  5000
     MINIMUM NUMBER OF SUBSTEPS . . . . . . . . .   100
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .   YES
  TRANSIENT (INERTIA) EFFECTS
     THERMAL DOFS . . . . . . . . . . . . . . . .    ON
  TRANSIENT INTEGRATION PARAMETERS
     THETA. . . . . . . . . . . . . . . . . . . .  1.0000
     OSCILLATION LIMIT CRITERION. . . . . . . . . 0.50000
     TOLERANCE. . . . . . . . . . . . . . . . . .  0.0000
  PRESSURE LOAD STIFFNESS . . . . . . . . . . . . .NEVER USED
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS. . . . . . . . . . . . . . .USE DEFAULTS
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     BASI        ALL


LIST ELEMENT TYPES FROM      1 TO    150 BY      1

ELEMENT TYPE      2 IS SOLID70      3-D THERMAL SOLID
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      4 IS SHELL57      THERMAL SHELL
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      5 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)
 KEYOPT( 1- 6)=        1      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      7 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      8 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
```

```
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     11 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     12 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     17 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     18 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     19 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     20 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     21 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     22 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     23 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     24 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     25 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0
```

```
ELEMENT TYPE     26 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     27 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     28 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     29 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     30 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     31 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     32 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     33 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     34 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     35 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     36 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     37 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
```

```
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     38 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     39 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     40 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     41 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     42 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     43 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     44 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     45 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     46 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     47 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     48 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0
```

```
ELEMENT TYPE      49 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      50 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       2      0        2       0       0
 KEYOPT( 7-12)=        0       0      0        2       0       5
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      51 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      52 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       2      0        2       0       0
 KEYOPT( 7-12)=        0       0      0        2       0       5
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      53 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      54 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       2      0        2       0       0
 KEYOPT( 7-12)=        0       0      0        2       0       5
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      55 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      56 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       2      0        2       0       0
 KEYOPT( 7-12)=        0       0      0        2       0       5
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      57 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      58 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       2      0        2       0       0
 KEYOPT( 7-12)=        0       0      0        2       0       5
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      59 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0      0        0       0       0
 KEYOPT( 7-12)=        0       0      0        0       0       0
 KEYOPT(13-18)=        0       0      0        0       0       0

ELEMENT TYPE      60 IS CONTA174     3D 8-NODE THERMAL CONTACT
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```
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     61 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     62 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     63 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     64 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     65 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     66 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     67 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     68 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     69 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     70 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     71 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
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 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      72 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      73 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=         0       0       0         0       0       0
 KEYOPT( 7-12)=         0       0       0         0       0       0
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      74 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      75 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=         0       0       0         0       0       0
 KEYOPT( 7-12)=         0       0       0         0       0       0
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      76 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      77 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=         0       0       0         0       0       0
 KEYOPT( 7-12)=         0       0       0         0       0       0
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      78 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      79 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=         0       0       0         0       0       0
 KEYOPT( 7-12)=         0       0       0         0       0       0
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      80 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      81 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=         0       0       0         0       0       0
 KEYOPT( 7-12)=         0       0       0         0       0       0
 KEYOPT(13-18)=         0       0       0         0       0       0

ELEMENT TYPE      82 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=         2       2       0         2       0       0
 KEYOPT( 7-12)=         0       0       0         2       0       5
 KEYOPT(13-18)=         0       0       0         0       0       0
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ELEMENT TYPE     83 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     84 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
 KEYOPT( 7-12)=       0      0      0        2      0      5
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     85 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     86 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
 KEYOPT( 7-12)=       0      0      0        2      0      5
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     89 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     90 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
 KEYOPT( 7-12)=       0      0      0        2      0      5
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     91 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     92 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
 KEYOPT( 7-12)=       0      0      0        2      0      5
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     93 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     94 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
 KEYOPT( 7-12)=       0      0      0        2      0      5
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     95 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=       0      0      0        0      0      0
 KEYOPT( 7-12)=       0      0      0        0      0      0
 KEYOPT(13-18)=       0      0      0        0      0      0

ELEMENT TYPE     96 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=       2      2      0        2      0      0
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 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     97 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     98 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     99 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    100 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    101 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    102 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    103 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    104 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    105 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    106 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    109 IS TARGE170     3-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0
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ELEMENT TYPE    110 IS CONTA174     3D 8-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    147 IS SURF152      3-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      0        1      1      0
 KEYOPT( 7-12)=        0      0      1        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    148 IS SURF152      3-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      0        1      1      0
 KEYOPT( 7-12)=        1      4      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    149 IS SURF152      3-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      0        1      1      0
 KEYOPT( 7-12)=        0      4      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE    150 IS SURF152      3-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      0        1      0      0
 KEYOPT( 7-12)=        0      1      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

CURRENT NODAL DOF SET IS  TEMP
 THREE-DIMENSIONAL MODEL

LIST MATERIALS       1 TO       6 BY       1
 PROPERTY= ALL

MATERIAL NUMBER       1

     TEMP        DENS
              0.2830000

     TEMP        KXX
    70.000     0.81300E-03
    100.00     0.80300E-03
    200.00     0.77800E-03
    300.00     0.74800E-03
    400.00     0.71500E-03
    500.00     0.67700E-03
    600.00     0.64800E-03
    700.00     0.61600E-03
    800.00     0.58300E-03
    900.00     0.55100E-03
    1000.0     0.51900E-03
    1100.0     0.48400E-03
    1200.0     0.45100E-03
    1300.0     0.41700E-03
    1400.0     0.38000E-03
    1500.0     0.36300E-03

     TEMP        C
    70.000     0.10330
```

100.00	0.10530
200.00	0.11210
300.00	0.11770
400.00	0.12340
500.00	0.12780
600.00	0.13220
700.00	0.13810
800.00	0.14520
900.00	0.15350
1000.0	0.16240
1100.0	0.17100
1200.0	0.18290
1300.0	0.20450
1400.0	0.40100
1500.0	0.19820

MATERIAL NUMBER 2

TEMP	DENS
70.000	0.41090
100.00	0.41090
150.00	0.41090
200.00	0.41090
250.00	0.41090
300.00	0.41090
350.00	0.41090
400.00	0.41090
450.00	0.41090
500.00	0.41090
550.00	0.41090
600.00	0.41090
650.00	0.41090
700.00	0.41090
750.00	0.41090
800.00	0.41090
900.00	0.41090
1000.0	0.41090
1100.0	0.41090
1200.0	0.41090
1300.0	0.41090
1400.0	0.41090
1500.0	0.41090

TEMP	KXX
70.000	0.46500E-03
100.00	0.46100E-03
150.00	0.45500E-03
200.00	0.44800E-03
250.00	0.44100E-03
300.00	0.43500E-03
350.00	0.42800E-03
400.00	0.42200E-03
450.00	0.41500E-03
500.00	0.40900E-03
550.00	0.40200E-03
600.00	0.39500E-03
650.00	0.38900E-03

700.00	0.38900E-03
750.00	0.38900E-03
800.00	0.38900E-03
900.00	0.38900E-03
1000.0	0.38900E-03
1100.0	0.38900E-03
1200.0	0.38900E-03
1300.0	0.38900E-03
1400.0	0.38900E-03
1500.0	0.38900E-03

TEMP	C
70.000	0.31050E-01
100.00	0.31050E-01
150.00	0.31050E-01
200.00	0.31050E-01
250.00	0.31050E-01
300.00	0.31050E-01
350.00	0.31050E-01
400.00	0.31050E-01
450.00	0.31050E-01
500.00	0.31050E-01
550.00	0.31050E-01
600.00	0.31050E-01
650.00	0.31050E-01
700.00	0.31050E-01
750.00	0.31050E-01
800.00	0.31050E-01
900.00	0.31050E-01
1000.0	0.31050E-01
1100.0	0.31050E-01
1200.0	0.31050E-01
1300.0	0.31050E-01
1400.0	0.31050E-01
1500.0	0.31050E-01

MATERIAL NUMBER 3

TEMP	DENS
70.000	0.43510E-04
100.00	0.41120E-04
150.00	0.37520E-04
200.00	0.34680E-04
250.00	0.32360E-04
300.00	0.30310E-04
350.00	0.28310E-04
400.00	0.26730E-04
450.00	0.25220E-04
500.00	0.23960E-04
550.00	0.22780E-04
600.00	0.21680E-04
650.00	0.20710E-04
700.00	0.19800E-04
750.00	0.18980E-04
800.00	0.18180E-04
900.00	0.16900E-04
1000.0	0.15710E-04

1100.0	0.14720E-04
1200.0	0.13850E-04
1300.0	0.13040E-04
1400.0	0.12350E-04
1500.0	0.11710E-04

TEMP	KXX
70.000	0.34490E-06
100.00	0.36210E-06
150.00	0.39030E-06
200.00	0.41770E-06
250.00	0.44460E-06
300.00	0.47040E-06
350.00	0.49570E-06
400.00	0.52040E-06
450.00	0.54480E-06
500.00	0.56880E-06
550.00	0.59210E-06
600.00	0.61430E-06
650.00	0.63630E-06
700.00	0.65810E-06
750.00	0.67900E-06
800.00	0.69960E-06
900.00	0.74090E-06
1000.0	0.78040E-06
1100.0	0.81750E-06
1200.0	0.85450E-06
1300.0	0.88970E-06
1400.0	0.92850E-06
1500.0	0.97070E-06

TEMP	C
70.000	0.24020
100.00	0.24040
150.00	0.24080
200.00	0.24140
250.00	0.24210
300.00	0.24290
350.00	0.24380
400.00	0.24500
450.00	0.24610
500.00	0.24740
550.00	0.24900
600.00	0.25110
650.00	0.25270
700.00	0.25380
750.00	0.25520
800.00	0.25680
900.00	0.25960
1000.0	0.26280
1100.0	0.26590
1200.0	0.26890
1300.0	0.27170
1400.0	0.27420
1500.0	0.27660

MATERIAL NUMBER 4

TEMP	DENS
70.000	0.28240
100.00	0.28240
150.00	0.28240
200.00	0.28240
250.00	0.28240
300.00	0.28240
350.00	0.28240
400.00	0.28240
450.00	0.28240
500.00	0.28240
550.00	0.28240
600.00	0.28240
650.00	0.28240
700.00	0.28240
750.00	0.28240
800.00	0.28240
900.00	0.28240
1000.0	0.28240
1100.0	0.28240
1200.0	0.28240
1300.0	0.28240
1400.0	0.28240
1500.0	0.28240

TEMP	KXX
70.000	0.19900E-03
100.00	0.20100E-03
150.00	0.20800E-03
200.00	0.21500E-03
250.00	0.22200E-03
300.00	0.22700E-03
350.00	0.23400E-03
400.00	0.24100E-03
450.00	0.24500E-03
500.00	0.25200E-03
550.00	0.25700E-03
600.00	0.26200E-03
650.00	0.26900E-03
700.00	0.27300E-03
750.00	0.27800E-03
800.00	0.28200E-03
900.00	0.29400E-03
1000.0	0.30600E-03
1100.0	0.31500E-03
1200.0	0.32400E-03
1300.0	0.33600E-03
1400.0	0.34500E-03
1500.0	0.35400E-03

TEMP	C
70.000	0.11700
100.00	0.11700
150.00	0.12000
200.00	0.12200
250.00	0.12500

```
     300.00      0.12600
     350.00      0.12800
     400.00      0.12900
     450.00      0.13000
     500.00      0.13100
     550.00      0.13200
     600.00      0.13300
     650.00      0.13400
     700.00      0.13500
     750.00      0.13600
     800.00      0.13600
     900.00      0.13800
     1000.0      0.13900
     1100.0      0.14100
     1200.0      0.14100
     1300.0      0.14300
     1400.0      0.14400
     1500.0      0.14500

 MATERIAL NUMBER        5

      TEMP         EMIS
                0.1500000

 MATERIAL NUMBER        6

      TEMP         EMIS
                0.9000000
```

2-d Finite Element Model Data

(Note: The complete data printout is included on the file "3d Model\model.out", which is included on the electronic media included in the package)

```
                           G L O B A L   S T A T U S

 ANSYS - Engineering Analysis System            Nov 08, 2011           10:02
 Release 13.0                   00222442                WINDOWS x64   Version

 Current working directory: D:\ANSYS Analyses\8-120B\Thermal\Rev2\2-d
Analyses\HAC


 MENULIST File: C:\Program Files\ANSYS Inc\v130\ANSYS\gui\en-
us\UIDL\menulist130.ans

 Product(s) enabled: ANSYS Mechanical


 Total connect time. . . . .    0 hours  0 minutes
 Total CP usage. . . . . . .    0 hours  0 minutes   2.0 seconds

 J O B   I N F O R M A T I O N -----------------------------------------------

8-120B Cask 2-d HAC Fire Model
```

```
Current jobname . . . . . .file
Initial jobname . . . . . .file

Units . . . . . . . . . . .unknown

                                Available              Used
Scratch Memory Space. . . .    9600.000 mb        517.840 mb (  5.4%)
Database space  . . . . . .   65535.750 mb          2.748 mb (  0.0%)

User menu file in use . . .%ANSYS130_DIR%\gui\en-us\UIDL\UIMENU.GRN
User menu file in use . . .%ANSYS130_DIR%\gui\en-us\UIDL\UIFUNC1.GRN
User menu file in use . . .%ANSYS130_DIR%\gui\en-us\UIDL\UIFUNC2.GRN
User menu file in use . . .%ANSYS130_DIR%\gui\en-us\UIDL\MECHTOOL.AUI
Beta features . . . . . . .are not shown in the user interface

M O D E L   I N F O R M A T I O N --------------------------------------------

Solid model summary:

                              Largest         Number         Number
                               Number        Defined        Selected
Keypoints . . . . . . . . .     101            101              18
Lines . . . . . . . . . . .     136            136              23
Areas . . . . . . . . . . .      43             43               6
Volumes . . . . . . . . . .       0              0               0

Finite element model summary:

                              Largest         Number         Number
                               Number        Defined        Selected
Nodes . . . . . . . . . . .    2443           1074            1068
Elements. . . . . . . . . .    1350           1210             823

Element types . . . . . . .      65             46            n.a.
Real constant sets. . . . .      60             24            n.a.
Material property sets. . .      14             10            n.a.

Coupling. . . . . . . . . .       2              2            n.a.
Constraint equations. . . .       0              0            n.a.
Master DOFs . . . . . . . .       0              0            n.a.
Dynamic gap conditions. . .       0              0            n.a.

B O U N D A R Y   C O N D I T I O N   I N F O R M A T I O N ------------------

                                          Number
                                         Defined
Constraints on nodes. . . . . . . . . . .      4
Constraints on keypoints. . . . . . . . .      0
Constraints on lines. . . . . . . . . . .      0
Constraints on areas. . . . . . . . . . .      0

Forces on nodes . . . . . . . . . . . . .      0
Forces on keypoints . . . . . . . . . . .      0

Surface loads on elements . . . . . . . .     88
Number of element flagged surfaces  . . .      0
```

```
Surface loads on lines. . . . . . . . . .       0
Surface loads on areas. . . . . . . . . .       0

Body loads on elements. . . . . . . . . .       0
Body loads on areas . . . . . . . . . . .       0
Body loads on lines . . . . . . . . . . .       0
Body loads on nodes . . . . . . . . . . .       0
Body loads on keypoints . . . . . . . . .       0

Temperatures
   Uniform temperature. . . . . . . . . .    70.000
   Offset from absolute scale . . . . . .   460.000

                                              X           Y           Z
Linear acceleration . . . . . . . . . . .  0.0000      0.0000      0.0000
Angular velocity (about global CS). . . .  0.0000      0.0000      0.0000
Angular acceleration (about global CS). .  0.0000      0.0000      0.0000
Location of reference CS. . . . . . . . .  0.0000      0.0000      0.0000
Angular velocity (about reference CS) . .  0.0000      0.0000      0.0000
Angular acceleration (about reference CS)  0.0000      0.0000      0.0000

R O U T I N E   I N F O R M A T I O N --------------------------------------

Current routine. . . . . . . . . . . .Preprocessing (PREP7)

Active coordinate system . . . . . . .   0 (Cartesian)

Display coordinate system. . . . . . .   0 (Cartesian)

Current element attributes:
   Type number . . . . . . . . . . . .    50  (MATRIX50)
   Real number . . . . . . . . . . . .    50
   Material number . . . . . . . . . .     8
   Element coordinate system number. .     0

Current mesher type. . . . . . . . . .free mesher

Current element meshing shape 2D . . .use default element shape.

Current element meshing shape 3D . . .use default element shape.

SmrtSize Level  . . . . . . . . . . . . OFF

Global element size. . . . . . . . . .     0 divisions per line

Active coordinate system . . . . . . .   0 (Cartesian)

Display coordinate system. . . . . . .   0 (Cartesian)

Analysis type. . . . . . . . . . . . .Transient

Active options for this analysis type:
   Solution method . . . . . . . . . .Full
   Equation solver to use. . . . . . .Sparse

Results file . . . . . . . . . . . . .file.rth
```

```
Load step number . . . . . . . . . . .     1

Number of substeps:
   Starting number of substeps . . . .  40000
   Maximum number of substeps. . . . .  40000
   Minimum number of substeps. . . . .    100
   Step change boundary conditions . .Yes


                         Analysis Options


   New, Restart, or Expansion Pass:  NEW ANALYSIS
  Discipline (based on active DOF):  THERMAL
                     Analysis type:  TRANSIENT
                   Analysis method:  FULL


               Newton-Raphson option     PROGRAM CHOOSES
     Newton-Raphson adaptive descent     DO NOT USE ADAPT DESCENT

        Equation solver to be used  SPARSE DIRECT SOLVER

Difference (in degrees) between absolute zero and
   the temperature system being used   460.00

LIST ELEMENT TYPES FROM      1 TO     65 BY      1

ELEMENT TYPE      1 IS PLANE55      AXI. THERMAL SOLID
 KEYOPT( 1- 6)=        0      0      1        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      2 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      3 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      4 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      5 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      0      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      6 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0
```

```
ELEMENT TYPE      7 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        2      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      8 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE      9 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     10 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     11 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     12 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     13 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     14 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     15 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     16 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     17 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      0      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     18 IS TARGE169     2-D TARGET SEGMENT
```

```
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     19 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     20 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     21 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     22 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     23 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     24 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     25 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     26 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     27 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      2      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     28 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     29 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      0      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
```

```
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     49 IS LINK33       3-D CONDUCTION BAR
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     50 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)
 KEYOPT( 1- 6)=        1      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     51 IS SURF151      2-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      1        1      1      0
 KEYOPT( 7-12)=        1      4      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     52 IS SURF151      2-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      1        1      1      0
 KEYOPT( 7-12)=        0      0      1        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     53 IS SURF151      2-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      1        1      1      0
 KEYOPT( 7-12)=        0      4      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     54 IS SURF151      2-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      1        1      1      0
 KEYOPT( 7-12)=        0      0      1        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     55 IS SURF151      2-D THERMAL SURFACE
 KEYOPT( 1- 6)=        0      0      1        1      0      0
 KEYOPT( 7-12)=        0      1      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     56 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     57 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      0      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     58 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0      0      0        0      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      0
 KEYOPT(13-18)=        0      0      0        0      0      0

ELEMENT TYPE     59 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2      0      0        2      0      0
 KEYOPT( 7-12)=        0      0      0        0      0      5
 KEYOPT(13-18)=        0      0      0        0      0      0
```

```
ELEMENT TYPE     60 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0       0         0       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       0
 KEYOPT(13-18)=        0       0       0         0       0       0

ELEMENT TYPE     61 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       0       0         2       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       5
 KEYOPT(13-18)=        0       0       0         0       0       0

ELEMENT TYPE     62 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0       0         0       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       0
 KEYOPT(13-18)=        0       0       0         0       0       0

ELEMENT TYPE     63 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       0       0         2       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       5
 KEYOPT(13-18)=        0       0       0         0       0       0

ELEMENT TYPE     64 IS TARGE169     2-D TARGET SEGMENT
 KEYOPT( 1- 6)=        0       0       0         0       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       0
 KEYOPT(13-18)=        0       0       0         0       0       0

ELEMENT TYPE     65 IS CONTA171     2D 2-NODE THERMAL CONTACT
 KEYOPT( 1- 6)=        2       0       0         2       0       0
 KEYOPT( 7-12)=        0       0       0         0       0       5
 KEYOPT(13-18)=        0       0       0         0       0       0

CURRENT NODAL DOF SET IS  TEMP
 THREE-DIMENSIONAL MODEL

LIST MATERIALS       1 TO      14 BY       1
 PROPERTY= ALL

MATERIAL NUMBER       1

     TEMP        DENS
    70.000     0.28180
    100.00     0.28180
    150.00     0.28180
    200.00     0.28180
    250.00     0.28180
    300.00     0.28180
    350.00     0.28180
    400.00     0.28180
    450.00     0.28180
    500.00     0.28180
    550.00     0.28180
    600.00     0.28180
    650.00     0.28180
    700.00     0.28180
    750.00     0.28180
    800.00     0.28180
    900.00     0.28180
    1000.0     0.28180
```

1100.0	0.28180
1200.0	0.28180
1300.0	0.28180
1400.0	0.28180
1500.0	0.28180

TEMP	MU
	0.000000

TEMP	KXX
70.000	0.81300E-03
100.00	0.80300E-03
150.00	0.78900E-03
200.00	0.77800E-03
250.00	0.76200E-03
300.00	0.74800E-03
350.00	0.73100E-03
400.00	0.71500E-03
450.00	0.70100E-03
500.00	0.68300E-03
550.00	0.66700E-03
600.00	0.64800E-03
650.00	0.63200E-03
700.00	0.61600E-03
750.00	0.60000E-03
800.00	0.58300E-03
900.00	0.55100E-03
1000.0	0.51900E-03
1100.0	0.48400E-03
1200.0	0.45100E-03
1300.0	0.41700E-03
1400.0	0.38000E-03
1500.0	0.36300E-03

TEMP	C
70.000	0.10400
100.00	0.10600
150.00	0.10900
200.00	0.11300
250.00	0.11500
300.00	0.11800
350.00	0.12200
400.00	0.12400
450.00	0.12600
500.00	0.12800
550.00	0.13100
600.00	0.13300
650.00	0.13500
700.00	0.13900
750.00	0.14200
800.00	0.14600
900.00	0.15400
1000.0	0.16300
1100.0	0.17200
1200.0	0.18400
1300.0	0.20500
1400.0	0.41100

```
    1500.0     0.19900

     TEMP        EMIS
               0.000000

MATERIAL NUMBER       2

     TEMP        DENS
    70.000     0.28240
    100.00     0.28240
    150.00     0.28240
    200.00     0.28240
    250.00     0.28240
    300.00     0.28240
    350.00     0.28240
    400.00     0.28240
    450.00     0.28240
    500.00     0.28240
    550.00     0.28240
    600.00     0.28240
    650.00     0.28240
    700.00     0.28240
    750.00     0.28240
    800.00     0.28240
    900.00     0.28240
    1000.0     0.28240
    1100.0     0.28240
    1200.0     0.28240
    1300.0     0.28240
    1400.0     0.28240
    1500.0     0.28240

     TEMP        MU
               0.000000

     TEMP        KXX
    70.000     0.19900E-03
    100.00     0.20100E-03
    150.00     0.20800E-03
    200.00     0.21500E-03
    250.00     0.22200E-03
    300.00     0.22700E-03
    350.00     0.23400E-03
    400.00     0.24100E-03
    450.00     0.24500E-03
    500.00     0.25200E-03
    550.00     0.25700E-03
    600.00     0.26200E-03
    650.00     0.26900E-03
    700.00     0.27300E-03
    750.00     0.27800E-03
    800.00     0.28200E-03
    900.00     0.29400E-03
    1000.0     0.30600E-03
    1100.0     0.31500E-03
    1200.0     0.32400E-03
    1300.0     0.33600E-03
```

1400.0	0.34500E-03
1500.0	0.35400E-03

TEMP	C
70.000	0.11700
100.00	0.11700
150.00	0.12000
200.00	0.12200
250.00	0.12500
300.00	0.12600
350.00	0.12800
400.00	0.12900
450.00	0.13000
500.00	0.13100
550.00	0.13200
600.00	0.13300
650.00	0.13400
700.00	0.13500
750.00	0.13600
800.00	0.13600
900.00	0.13800
1000.0	0.13900
1100.0	0.14100
1200.0	0.14100
1300.0	0.14300
1400.0	0.14400
1500.0	0.14500

MATERIAL NUMBER 3

TEMP	DENS
70.000	0.41090
100.00	0.41090
150.00	0.41090
200.00	0.41090
250.00	0.41090
300.00	0.41090
350.00	0.41090
400.00	0.41090
450.00	0.41090
500.00	0.41090
550.00	0.41090
600.00	0.41090
650.00	0.41090
700.00	0.41090
750.00	0.41090
800.00	0.41090
900.00	0.41090
1000.0	0.41090
1100.0	0.41090
1200.0	0.41090
1300.0	0.41090
1400.0	0.41090
1500.0	0.41090

TEMP	KXX
70.000	0.46500E-03

```
     100.00     0.46100E-03
     150.00     0.45500E-03
     200.00     0.44800E-03
     250.00     0.44100E-03
     300.00     0.43500E-03
     350.00     0.42800E-03
     400.00     0.42200E-03
     450.00     0.41500E-03
     500.00     0.40900E-03
     550.00     0.40200E-03
     600.00     0.39500E-03
     650.00     0.38900E-03
     700.00     0.38900E-03
     750.00     0.38900E-03
     800.00     0.38900E-03
     900.00     0.38900E-03
     1000.0     0.38900E-03
     1100.0     0.38900E-03
     1200.0     0.38900E-03
     1300.0     0.38900E-03
     1400.0     0.38900E-03
     1500.0     0.38900E-03

      TEMP         C
     70.000     0.31050E-01
     100.00     0.31050E-01
     150.00     0.31050E-01
     200.00     0.31050E-01
     250.00     0.31050E-01
     300.00     0.31050E-01
     350.00     0.31050E-01
     400.00     0.31050E-01
     450.00     0.31050E-01
     500.00     0.31050E-01
     550.00     0.31050E-01
     600.00     0.31050E-01
     650.00     0.31050E-01
     700.00     0.31050E-01
     750.00     0.31050E-01
     800.00     0.31050E-01
     900.00     0.31050E-01
     1000.0     0.31050E-01
     1100.0     0.31050E-01
     1200.0     0.31050E-01
     1300.0     0.31050E-01
     1400.0     0.31050E-01
     1500.0     0.31050E-01

 MATERIAL NUMBER       4

      TEMP         DENS
     70.000     0.43510E-04
     100.00     0.41120E-04
     150.00     0.37520E-04
     200.00     0.34680E-04
     250.00     0.32360E-04
     300.00     0.30310E-04
```

350.00	0.28310E-04
400.00	0.26730E-04
450.00	0.25220E-04
500.00	0.23960E-04
550.00	0.22780E-04
600.00	0.21680E-04
650.00	0.20710E-04
700.00	0.19800E-04
750.00	0.18980E-04
800.00	0.18180E-04
900.00	0.16900E-04
1000.0	0.15710E-04
1100.0	0.14720E-04
1200.0	0.13850E-04
1300.0	0.13040E-04
1400.0	0.12350E-04
1500.0	0.11710E-04

TEMP	KXX
70.000	0.34490E-06
100.00	0.36210E-06
150.00	0.39030E-06
200.00	0.41770E-06
250.00	0.44460E-06
300.00	0.47040E-06
350.00	0.49570E-06
400.00	0.52040E-06
450.00	0.54480E-06
500.00	0.56880E-06
550.00	0.59210E-06
600.00	0.61430E-06
650.00	0.63630E-06
700.00	0.65810E-06
750.00	0.67900E-06
800.00	0.69960E-06
900.00	0.74090E-06
1000.0	0.78040E-06
1100.0	0.81750E-06
1200.0	0.85450E-06
1300.0	0.88970E-06
1400.0	0.92850E-06
1500.0	0.97070E-06

TEMP	C
70.000	0.24020
100.00	0.24040
150.00	0.24080
200.00	0.24140
250.00	0.24210
300.00	0.24290
350.00	0.24380
400.00	0.24500
450.00	0.24610
500.00	0.24740
550.00	0.24900
600.00	0.25110
650.00	0.25270

```
    700.00     0.25380
    750.00     0.25520
    800.00     0.25680
    900.00     0.25960
    1000.0     0.26280
    1100.0     0.26590
    1200.0     0.26890
    1300.0     0.27170
    1400.0     0.27420
    1500.0     0.27660

MATERIAL NUMBER       5

     TEMP        EMIS
            0.1500000

MATERIAL NUMBER       6

     TEMP        EMIS
            0.1500000

MATERIAL NUMBER       7

     TEMP        EMIS
            0.2000000

MATERIAL NUMBER       8

     TEMP        EMIS
            0.4000000

MATERIAL NUMBER      12

     TEMP        EMIS
            0.7347000

MATERIAL NUMBER      14

     TEMP        EMIS
            0.9000000

LIST DATA TABLE  ALL   FOR ALL MATERIALS

*** WARNING ***                         CP =       1.981   TIME= 10:02:49
The requested ALL table data for ALL materials does not exist.  The
TBLIST command is ignored.


                       General load step options


       Automatic time stepping     USE AUTOMATIC TIME STEPPING
            Number of substeps       40000
       Minimum number substeps         100
       Maximum number substeps       40000
      Time at end of load step     TIME =  0.19200E+06
```

```
Stiffness matrix reuse options     PROGRAM DECIDES
       Step boundary condition     STEP BOUNDARY KEY =  1 (STEP)
         Reference temperature     TREF=  70.000

*** NOTE ***                            CP =       1.981   TIME= 10:02:49
No nodal body forces to list.

                      Inertia load options

           Acceleration vector     GLOBAL CARTESIAN COMPONENTS ARE:
                                     0.0000      0.0000      0.0000
       Angular velocity vector     GLOBAL CARTESIAN COMPONENTS ARE:
                                     0.0000      0.0000      0.0000
                                   SPIN SOFTENING NOT ACTIVATED
   Angular acceleration vector     GLOBAL CARTESIAN COMPONENTS ARE:
                                     0.0000      0.0000      0.0000
Reference coord. system origin     ORIGIN =  0.0000      0.0000      0.0000
       Angular velocity vector     REFERENCE COORDINATE COMPONENTS ARE:
                                     0.0000      0.0000      0.0000
   Angular acceleration vector     REFERENCE COORDINATE COMPONENTS ARE:
                                     0.0000      0.0000      0.0000
                Inertia relief     NO INERTIA RELIEF
Translational acceleration vector on components    NONE
Angular velocity vector on components    NONE
Angular acceleration vector on components    NONE

LIST CONSTRAINTS FOR SELECTED NODES         1 TO     2443 BY        1
CURRENTLY SELECTED DOF SET= TEMP

*** NOTE ***                            CP =       1.981   TIME= 10:02:49
No nodal forces to list.

LIST ELEM PRESS FOR SELECTED ELEMENTS IN RANGE       1 TO    1350 BY       1

LIST NODAL SURFACE LOAD HFLU FOR ALL SELECTED NODES


ELEMENT  LKEY     FACE NODES       HEAT FLUX
    740     3        2013           4.163000000E-05
                     2014           4.163000000E-05
    741     3        2014           4.163000000E-05
                     2015           4.163000000E-05
    742     3        2015           4.163000000E-05
                     2016           4.163000000E-05
    743     3        2016           4.163000000E-05
                     2017           4.163000000E-05
    744     3        2017           4.163000000E-05
                     2018           4.163000000E-05
    745     3        2018           4.163000000E-05
                     2019           4.163000000E-05
    746     3        2019           4.163000000E-05
                     2020           4.163000000E-05
    747     3        2020           4.163000000E-05
                     2012           4.163000000E-05
    749     4        2012           4.163000000E-05
                     2046           4.163000000E-05
    750     4        2046           4.163000000E-05
```

		2045	4.163000000E-05

ELEMENT	LKEY	FACE NODES	HEAT FLUX
751	4	2045	4.163000000E-05
		2044	4.163000000E-05
752	4	2044	4.163000000E-05
		2043	4.163000000E-05
753	4	2043	4.163000000E-05
		2042	4.163000000E-05
754	4	2042	4.163000000E-05
		2041	4.163000000E-05
755	4	2041	4.163000000E-05
		2040	4.163000000E-05
756	4	2040	4.163000000E-05
		2039	4.163000000E-05
757	4	2039	4.163000000E-05
		2038	4.163000000E-05
758	4	2038	4.163000000E-05
		2037	4.163000000E-05
759	4	2037	4.163000000E-05
		2036	4.163000000E-05
760	4	2036	4.163000000E-05
		2035	4.163000000E-05

ELEMENT	LKEY	FACE NODES	HEAT FLUX
762	1	2050	4.163000000E-05
		2049	4.163000000E-05
763	1	2051	4.163000000E-05
		2050	4.163000000E-05
764	1	2052	4.163000000E-05
		2051	4.163000000E-05
765	1	2053	4.163000000E-05
		2052	4.163000000E-05
766	1	2054	4.163000000E-05
		2053	4.163000000E-05
767	1	2055	4.163000000E-05
		2054	4.163000000E-05
768	1	2056	4.163000000E-05
		2055	4.163000000E-05
769	1	2035	4.163000000E-05
		2056	4.163000000E-05

Appendix 2

Print-out of the Results

(2 Pages)

ANSYS Finite Element Model Partial Printout

3-d Finite Element Model Results

(The complete print-out of the time-history of the following nodal temperatures is available on the file "3d model\prvar1.lis" included on the DVD in Appendix 3)

POST26 SUMMARY OF VARIABLE EXTREME VALUES

NAME	ELEMENT	NODE	MINIMUM	AT TIME	MAXIMUM	AT TIME
FireShld		42910	150.332	1	1392.01	1800
OshellO		12531	154.965	1	464.422	1800.3
LeadO		14317	154.688	1	295.127	4461.67
LeadI		14338	154.763	1	295.845	4461.67
IshellI		8015	154.767	8.196	295.455	4461.67
PSeal		25430	155.938	1	212.385	18225.1

(The complete print-out of the time-history of the following nodal temperatures is available on the file "3d model\prvar2.lis" included on the DVD in Appendix 3)

POST26 SUMMARY OF VARIABLE EXTREME VALUES

NAME	ELEMENT	NODE	MINIMUM	AT TIME	MAXIMUM	AT TIME
SSeal		37678	156.538	594.67	202.867	24000
LidCenter		27023	156.94	1566.13	192.57	24000
BaseCente		2430	156.715	936.48	206.255	24000

(The complete print-out of the time-history of the following nodal temperatures is available on the file "3d model\prvar3.lis" included on the DVD in Appendix 3)

POST26 SUMMARY OF VARIABLE EXTREME VALUES

NAME	ELEMENT	NODE	MINIMUM	AT TIME	MAXIMUM	AT TIME
PLid		37675	156.552	612.66	202.876	24000
VSeal		34802	156.211	1	206.878	24000
IL		27594	156.28	1	205.084	24000

2-d Finite Element Model HAC fire Results

(The complete print-out of the time-history of the following nodal temperatures is available on the file "2d model\prvar1.lis" included on the DVD in Appendix 3)

POST26 SUMMARY OF VARIABLE EXTREME VALUES

NAME	ELEMENT	NODE	MINIMUM	AT TIME	MAXIMUM	AT TIME
cav1		2057	197.591	54.97	239.047	40289
cav2		2023	197.282	54.97	238.819	38387
cav3		2029	197.865	72.96	239.629	38387
cav4		2021	197.301	54.97	239.212	38387
cav5		2003	197.694	54.97	239.622	40289
cav6		2098	160.971	4.598	302.278	3643.22

(The complete print-out of the time-history of the following nodal temperatures is available on the file “2d model\prvar2.lis” included on the DVD in Appendix 3)

POST26 SUMMARY OF VARIABLE EXTREME VALUES

NAME	ELEMENT	NODE	MINIMUM	AT TIME	MAXIMUM	AT TIME
cont1		2049	197.642	72.96	239.099	40289
cont2		2035	197.329	72.96	238.864	38387
cont3		2041	197.915	72.96	239.679	38387
cont4		2012	197.405	72.96	239.314	38387
cont5		2013	197.745	72.96	239.673	40289

Appendix 3

(Electronic Data - 1 DVD)

```
Volume in drive E is TH-028
 Volume Serial Number is 3C05-E9B0

 Directory of E:\

11/08/2011  01:49 PM    <DIR>          2-D Model
11/08/2011  01:52 PM    <DIR>          3-D Model
               0 File(s)              0 bytes

 Directory of E:\2-D Model

11/08/2011  01:49 PM    <DIR>          .
11/08/2011  02:28 PM    <DIR>          ..
11/08/2011  02:03 PM    <DIR>          Fire
11/08/2011  02:04 PM    <DIR>          Puncture
               0 File(s)              0 bytes

 Directory of E:\2-D Model\Fire

11/08/2011  02:03 PM    <DIR>          .
11/08/2011  01:49 PM    <DIR>          ..
10/31/2011  12:16 PM            65,536 annulus-sub.sub
10/31/2011  12:16 PM            59,964 ansub.out
10/31/2011  03:06 PM           131,072 cavity-sub.sub
10/31/2011  03:06 PM           337,229 cavsub.out
11/08/2011  09:27 AM               596 EXTREME-1.lis
11/08/2011  09:27 AM               518 EXTREME-2.lis
11/08/2011  11:06 AM         5,111,808 file.db
11/08/2011  11:06 AM       175,308,800 file.rth
11/08/2011  09:29 AM            20,637 file000.png
11/08/2011  09:32 AM            27,119 file001.png
11/08/2011  10:59 AM           179,461 model.out
11/08/2011  09:27 AM            27,224 PRVAR-1.lis
11/08/2011  09:28 AM            23,542 PRVAR-2.lis
              13 File(s)    181,293,506 bytes

 Directory of E:\2-D Model\Puncture

11/08/2011  02:04 PM    <DIR>          .
11/08/2011  01:49 PM    <DIR>          ..
10/31/2011  12:16 PM            65,536 annulus-sub.sub
10/31/2011  12:16 PM            59,964 ansub.out
10/31/2011  03:06 PM           131,072 cavity-sub.sub
10/31/2011  03:06 PM           337,229 cavsub.out
11/08/2011  09:54 AM               206 EXTREME.lis
11/08/2011  11:08 AM         5,111,808 file.db
11/08/2011  11:08 AM       173,867,008 file.rth
11/08/2011  09:52 AM            28,140 file001.png
11/08/2011  09:57 AM            21,603 file002.png
11/08/2011  10:59 AM           208,098 model.out
11/08/2011  09:54 AM             8,752 PRVAR.lis
```

```
               11 File(s)    179,839,416 bytes

 Directory of E:\3-D Model

11/08/2011  01:52 PM    <DIR>          .
11/08/2011  02:28 PM    <DIR>          ..
07/23/2010  04:55 PM        30,474,240 annulus15.sub
11/29/2010  04:20 PM               596 EXTREME1.lis
11/29/2010  04:21 PM               364 EXTREME2.lis
06/07/2011  01:37 PM               362 EXTREME3.lis
11/30/2010  09:15 AM        65,339,392 file.db
08/10/2010  03:42 PM           143,251 file001.png
07/26/2010  01:44 PM            28,688 file002.png
07/26/2010  01:44 PM            24,448 file003.png
11/29/2010  05:13 PM            17,017 file004.png
11/30/2010  08:49 AM           152,049 file005.png
11/30/2010  09:05 AM           151,666 file006.png
11/30/2010  09:05 AM           152,857 file007.png
11/30/2010  09:05 AM           167,156 file008.png
11/30/2010  09:06 AM           167,539 file009.png
11/30/2010  09:06 AM           164,579 file010.png
11/30/2010  09:07 AM           157,256 file011.png
11/01/2010  10:42 AM         2,893,815 model.out
11/29/2010  04:18 PM            29,960 PRVAR1.lis
11/29/2010  04:19 PM            18,606 PRVAR2.lis
06/07/2011  01:37 PM            17,822 PRVAR3.lis
               20 File(s)    100,101,663 bytes

     Total Files Listed:
               44 File(s)    461,234,585 bytes
               12 Dir(s)               0 bytes free
```