1.0 OBJECTIVE

Perform the structural analyses of the Energy*Solutions* 3-60B Cask under drop conditions, using a 3-dimensional finite element model.

2.0 INTRODUCTION

Energy*Solutions* 3-60B 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 structural analysis of the 3-60B Cask under various drop conditions required by the code. The analyses in this document are performed using the finite element modeling techniques. A three-dimensional model of the cask that includes all its major components has been employed in the analyses. Temperature dependent material properties of the major components of the cask are used in the analyses.

Analyses of the 3-60B Cask package have been performed for hypothetical accident condition (HAC) and normal condition of transport (NCT) drop test using the methodology developed by Energy*Solutions*. The details of the analyses are documented in the proprietary document of Reference 4. The resultant impact loads during various drop tests are obtained from this document and applied to the detailed finite element model of the cask body. Every component of the cask is evaluated for its integrity during the drop tests by comparing the stress intensities with their corresponding allowable values.

The results of the analyses for various load cases are presented pictorially in stress intensity contour plots as well as in table form, with the corresponding safety factors in each component of the cask body.

3.0 REFERENCES

1. Energy*Solutions* Drawing No. C-002-165024-001, Rev.0, 3-60B Cask General Arrangement and Details.

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.

4. Energy*Solutions* Document No. ST-557, Rev.1, Drop Analyses of the 3-60B Cask Package Using LS-DYNA Program.

5. ASME Boiler & Pressure Vessel Code, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2005.

6. NUREG 0481/SAND77-1872, An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers, Sandia National Laboratories, 1978.

7. U.S. NRC Regulatory Guide 7.6, Revision 1, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, 1978.

8. ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

9. Energy*Solutions* Document No. ST-501, Rev.1, Structural Analyses of the 3-60B Cask under Normal Conditions of Transport.

10. Energy*Solutions* Document TH-022, Rev. 2, Steady State Thermal Analyses of the 3-60B Cask Using a 3-D Finite Element Model.

11. SAND88-0616·UC-71, Numerical and Analytical Methods for Approximating the Eccentric Impact Response (Slapdown) of Deformable Bodies, Sandia National Laboratories, 1988.

4.0 MATERIAL PROPERTIES

Material	Temp. (°F)	Strength (ksi)			Young's Modulus (10^6 psi)	Coefficient of Thermal Expansion (10^{-6} in/in)
		Yield (S_y)	Ultimate (S_u)	Membrane Allowable (S_m)		
		(1)	(1)	(1)	(1)	(1)
ASTM A240 Type 304L	-20	25.0	70.0	16.7	28.8	-
	70	25.0	70.0	16.7	28.3	8.5
	100	25.0	70.0	16.7	-	8.6
	200	21.4	66.1	16.7	27.5	8.9
	300	19.2	61.2	16.7	27.0	9.2
	400	17.5	58.7	15.8	26.4	9.5
	500	16.4	57.5	14.7	25.9	9.7
		(1)	(1)	(1)	(1)	(1)
ASTM A240 Gr. 45 & ASTM A182 Gr. F45	-20	45.0	87.0	24.9	28.8	-
	70	45.0	87.0	24.9	28.3	8.5
	100	45.0	87.0	24.9	-	8.6
	200	37.5	86.4	24.7	27.5	8.9
	300	33.0	81.6	23.3	27.0	9.2
	400	29.9	78.5	22.4	26.4	9.5
	500	27.8	76.4	21.8	25.9	9.7
		(1)	(1)	(1)	(1)	(1)
ASTM A354 Gr. BD (Lid Bolts)	-20	130	150	30	29.7	-
	70	130	150	30	29.2	6.4
	100	130	150	30	-	6.5
	200	119.1	150	30	28.6	6.7
	300	115	150	30	28.1	6.9
	400	111	150	30	27.7	7.1
	500	105.9	150	30	27.1	7.3
		(2)			(2)	(2)
ASTM B29 Lead	-20	-	-	-	2.43	15.65
	70	5	-	-	2.27	16.06
	100	-	-	-	2.21	16.22
	200	-	-	-	2.01	16.70
	300	-	-	-	1.85	17.33
	400	-	-	-	1.70	18.16
	500	-	-	-	1.52	19.12

Notes:

(1) From ASME B&PV Code 2004, Section II, Part D (Reference 5).

(2) From NUREG/CR 0481 (Reference 6)

5.0 ALLOWABLE STRESSES

Material →		ASTM A240 Type 304L	ASTM A182 Gr.F45 & A240 Gr. 45	ASTM A354 Gr. BD
Yield Stress, S_y	(psi)	25,000[(1)]	45,000[(1)]	130,000[(1)]
Ultimate Stress, S_u	(psi)	70,000[(1)]	87,000[(1)]	150,000[(1)]
Design Stress Intensity, S_m	(psi)	16,700[(1)]	24,900[(1)]	30,000[(1)]
Normal Conditions	Membrane Stress	16,700[(2)]	24,900[(2)]	60,000[(2)]
	Mem. + Bending Stress	25,050[(2)]	37,350[(2)]	90,000[(2)]
	Peak Stress	50,100[(3)]	74,700[(3)]	150,000[(3)]
Hypothetical Accident Conditions	Membrane Stress	40,080[(4)]	59,760[(4)]	105,000[(4)]
	Mem. + Bending Stress	60,120[(4)]	87,000[(4)]	150,000[(4)]
	Peak Stress	140,000[(5)]	174,000[(5)]	300,000[(5)]

Notes:

(1) From ASME B&PV Code 2004, Section II, Part D (Reference 5).

(2) Established from Regulatory Guide 7.6 (Reference 7).

(3) Established from Regulatory Guide 7.6, Regulatory Position 4, and ASME, Section III, Division 3, WB-3200 criteria. The limit on this stress component is $3S_m$.

(4) Regulatory Guide 7.6 (Reference 7) does not provide any criteria. ASME B&PV Code, Section III, Appendix F has been used to establish these criteria.

(5) Regulatory Guide 7.6, Regulatory Position 7 and ASME Section III, Division 3, WB-3221.9 criteria of limiting these stresses to $2S_a$ @ 10 cycles results in higher than $2S_u$ allowable values. The limits for peak stresses are conservatively set to be $2S_u$.

6.0 MODEL DESCRIPTION

The structural analyses of the 3-60B Cask under various drop test conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Ref. 8) has been employed to perform the analyses. Since for all the drop orientations (end, side, corner, and slap-down), at least one plane of symmetry exists, a 180° model has been employed in all the analyses. This model has been developed from the 11.25° model developed in References 9 and 10 for the structural and thermal analyses of the cask during normal conditions of transport.

The model of the cask is made using 3-dimensional 8-node structural solid elements (ANSYS SOLID185) to represent the major components of the cask, the cask body, the lid, and the bolts. The fire shield does not provide any structural strength to the cask. Therefore, it is not included in the model.

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 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 that form the lid 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 modeled using these elements.

Figure 1 shows the outline of the model depicting the material numbering. Figure 2 shows the finite element grid of the lid, seal plate, and the bolts. Figure 3 shows the finite element grid of the cask body without the lead and Figure 4 shows that of the lead. The interface between various components of the cask is modeled by target-contact surface definition. Figure 5 shows target surfaces of various contact-target pairs. The printout of the pertinent model quantities is included in Appendix 1.

Boundary Conditions

Since the model of the cask includes 180° geometry, symmetry boundary conditions are used on the cut-plane of the model in all the analyses. Also, the rigid body motion is prevented in the model by restraining it at the locations where such restraints have insignificant effect on the overall behavior of the model. This is necessary since the quasi-static analyses performed for every drop condition will result in a small net force in the plane of symmetry that will give rise to a rigid body motion.

Loading

Applied loading is described for each drop orientation under the corresponding analysis section.

Temperature

The temperature distribution under various drop conditions is obtained from the thermal analyses performed in Reference 10 and is applied as the nodal temperature in the finite element model.

Internal Pressure

The cask internal pressure of 35 psig is applied over the nodes representing the cavity of the cask under various drop conditions in the hot environment. No internal pressures are applied during all drop conditions in the cold environment, with or without the internal decay heat.

Inertia Load

Cask body inertia, under various drop conditions, is applied as a body load. The magnitude of the inertia load is given in the corresponding analysis section. It should be noted that because of the segmentation of arc length in the finite element models, the mass of the model is always lower than the actual mass. To account for this, as well as to include the mass of miscellaneous items not included in the model, an adjustment is made in the value of acceleration due to gravity.

Cask Body Mass = 80,000 – 9,500 – 2×3,800 = 62,900 lb

Mass of the FEM = 2×28,409 = 56,818 lb

Acceleration multiplication factor = 62,900/56,818 = 1.107

7.0 ANALYSES

The finite element model (FEM) described above is analyzed for the accelerations obtained from the EnergySolutions proprietary analyses documented in Reference 4. The distribution of various loading components is described in details in the following sections.

7.1 HAC Drop Tests

7.1.1 End Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions = 3.954×10^6 lb (Table 3 and Figure 56 of Reference 4)

Hot Conditions = 3.083×10^6 lb (Table 3 and Figure 61 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the end drop test the impact limiter reaction is caused by the total mass of the package less the mass of one impact limiter, i.e. 80,000 - 3,800 = 76,200 lb (Reference 3-60B SAR Section 2.1.3). Since the FEM represents only ½ of the package, the total mass is divided by 2 in the calculation of the rigid body acceleration. A factor of 1.1 is used to conservatively increase this reaction in the analyses.

Rigid body acceleration = $1.1\times2\times3.954\times10^6/76{,}200 = 114.2$ » Use 150g

For the quasi-static analysis of the cask under end drop test conditions the inertia loads and reactions are distributed to the cask body as shown in Figure 6.

Impact limiter Inertia

The inertia load of the lower impact limiter is included as the uniform pressure on the surface where the impact limiter contacts the cask.

Mass of each Impact Limiter = 3,800 lb

Inside Radius of the Impact Limiter = 12 in (nearest node in the FEM is at 12.5 in)

Outside Radius of the Cask = 25.5 in

Pressure on the cask due to impact limiter inertia,

$$p_{I.L.} = 150\times3{,}800/[\pi\times(25.5^2 - 12.5^2)] = 367.3 \text{ psi}$$

Payload Inertia

The payload inertia is applied as a uniform surface pressure over the lid inside surface. The lid has a radius of 17.375 in. For 9,500 lb total mass of payload, the magnitude of the pressure is:

$$p_{lid} = 150\times9{,}500/(\pi\times17.375^2) = 1{,}502.5 \text{ psi}$$

Cask Body Inertia

Cask body inertia is applied as the body force. As explained earlier, to account for the total mass of the package a factor of 1.107 is used to increase the FEM mass.

Cask Body Acceleration = $150\times1.107 = 166$ g

Impact Limiter Reaction

The impact limiter reaction is simulated by restraining the nodes at the impact limiter-lid interface in vertical direction.

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 7 through 9 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 10 through 12 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 1 through 3. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

7.1.2 Side Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions $= 1.889\times10^6$ lb (Table 3 and Figure 66 of Reference 4)

Hot Conditions $= 1.636\times10^6$ lb (Table 3 and Figure 71 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the side drop test the impact limiter reaction is caused by the total mass of the package less the mass of the two impact limiters, i.e. 80,000 - 2×3,800 = 72,400 lb (Reference 3-60B SAR Section 2.1.3). Since the FEM represents only ½ of the package and each impact limiter reaction is caused by ½ the participating mass, the total mass is divided by 4 in the calculation of the rigid body acceleration. A factor of 1.1 is used to conservatively increase this reaction in the analyses.

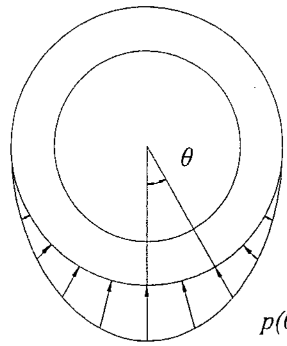
$$\text{Rigid body acceleration} = 1.1\times4\times1.889\times10^6/72{,}400 = 114.8 \quad » \text{ Use 120g}$$

For the quasi-static analysis of the cask under side drop test conditions reactions and the inertia loads are distributed to the cask body as shown in Figure 13.

Impact Limiter Reactions

The impact limiter reactions are applied as surface pressure on the lower half of the impact limiter-cask interface. This pressure is assumed to be uniform along the axis of the cask but varies sinusoidally along the circumference. For such a distribution, the following mathematical derivation is used:

$p(\theta) = p_0 \, Cos\,\theta \qquad -\pi/2 \le \theta \le \pi/2$



$$F_v = \int_{-\pi/2}^{\pi/2} p_0 \cdot Cos\theta \cdot r \cdot d\theta \cdot Cos\theta$$

$$= p_0 \cdot r \int_{-\pi/2}^{\pi/2} Cos^2\theta \, d\theta$$

$$= p_0 \cdot r \int_{-\pi/2}^{\pi/2} \tfrac{1}{2} \cdot (1 + Cos\,2\theta) \cdot d\theta$$

$$= \frac{p_0 \cdot r}{2}\left[\theta + \frac{Sin\ 2\theta}{2}\right]_{-\pi/2}^{\pi/2}$$

$$= \frac{\pi \cdot r \cdot p_0}{2}$$

$$F_h = \int_{-\pi/2}^{\pi/2} p_0 \cdot Cos\theta \cdot r \cdot d\theta \cdot Sin\theta$$

$$= p_0 \cdot r \int_{-\pi/2}^{\pi/2} \tfrac{1}{2} \cdot Sin\ 2\theta \cdot d\theta$$

$$= \frac{p_0 \cdot r}{2}\left[\frac{-Cos\,2\theta}{2}\right]_{-\pi/2}^{\pi/2}$$

$$= 0$$

Reaction of the cask at the two impact limiter locations, 2R = (80,000 - 2×3,800) × 120

Reaction at each impact limiter location, R = ½ × (80,000 - 2×3,800) × 120 = 4.344×10^6 lb

The top impact limiter reaction is applied at the surface that has a radius of 25.5 in and extends in the axial direction over a length of 20.28 in. Thus,

p_0 = (2×4.344×10^6)/(π×25.5×20.28) = 5,348 psi

The bottom impact limiter reaction is applied at the surface that has a radius of 25.5 in and extends in the axial direction over a length of 21.355 in. Thus,

p_0 = (2×4.344×10^6)/(π×25.5×21.355) = 5,078 psi

Payload Inertia

The pay load inertia load is applied as surface pressure on the lower half of the inner shell of the cask. This pressure is assumed to be uniform along the axis of the cask but varies sinusoidally along the circumference. The radius of the inner shell is 17.5 in and its length is 109 inch. Thus,

$$p_0 = (2\times120\times9{,}500)/(\pi\times17.5\times109) = 380.5 \text{ psi}$$

Cask Body Inertia

Cask body inertia is applied as the body force. As explained earlier, to account for the total mass of the package a factor of 1.107 is used to increase the FEM mass.

Cask Body Acceleration = $120\times1.107 = 132.84$ g

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 14 through 16 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 17 through 19 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 4 through 6. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

7.1.3 Corner Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions = 2.080×10^6 lb (Table 3 and Figure 76 of Reference 4)

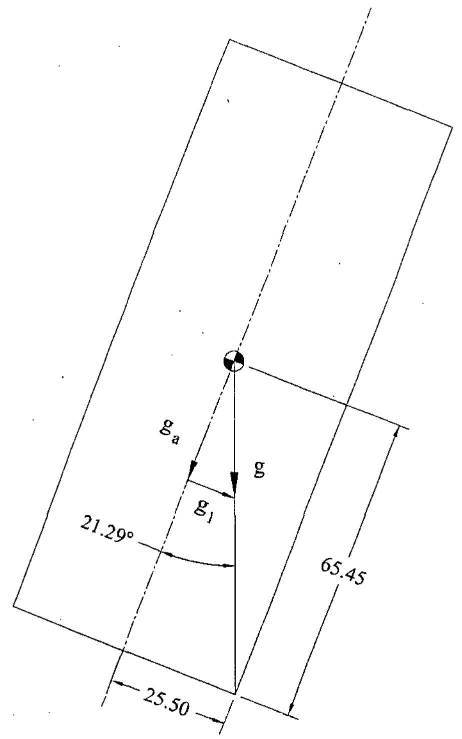
Hot Conditions = 1.847×10^6 lb (Table 3 and Figure 81 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the corner drop test the impact limiter reaction is caused by the total mass of the package less the mass of one impact limiter, i.e. 80,000 - 3,800 = 76,200 lb (Reference 3-60B SAR Section 2.1.3). Since the FEM represents only ½ of the package, the total mass is divided by 2 in the calculation of the rigid body acceleration. A factor of 1.1 is used to conservatively increase this reaction in the analyses.

Rigid body acceleration = $1.1\times2\times2.080\times10^6/76{,}200 = 60.1$ » Use 70g

For the quasi-static analysis of the cask under corner drop test conditions reactions and the inertia loads are distributed to the cask body as shown in Figure 20.

The finite element model of the cask shows that the C.G. of the cask is 65.45 in from the bottom side of the lid. The cask has a radius of 25.5 in. Therefore, for the C.G. to be directly above the corner, the cask axis will be inclined from the vertical axis by an angle,



$$\alpha = \tan^{-1}(25.5/65.45) = 21.29°$$

Thus, the axial acceleration,

$$g_a = 70 \times \text{Cos } 21.29° = 65.22 \text{ g}$$

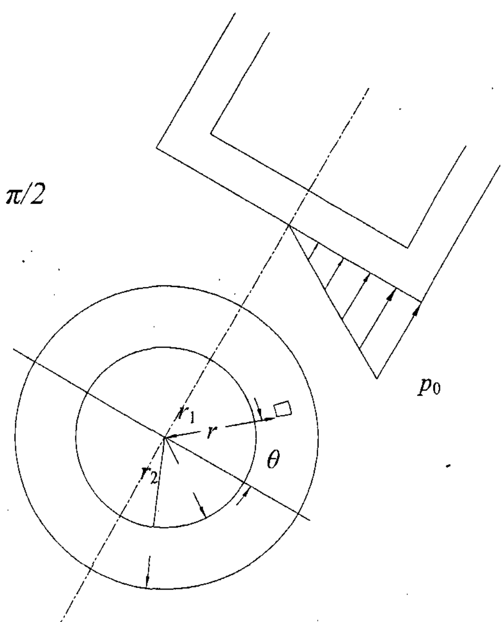
Lateral acceleration,

$$g_l = 70 \times \text{Sin } 21.29° = 25.42 \text{ g}$$

Impact Limiter Reaction

The impact limiter reaction is resolved into an axial and a lateral component. The axial component is applied to the lid surface at the interface with the impact limiter. The pressure is assumed to vary sinusoidally along the tangential direction. Mathematically this pressure may be represented by:

$$p(r,\theta) = p_0 \cdot \frac{r \cdot Cos\theta}{r_2} \cdot r \cdot d\theta \cdot dr \qquad -\pi/2 \le \theta \le \pi/2$$



This distribution results in the total axial load, F that can be calculated by integration as follows:

$$F = \int_{-\pi/2}^{\pi/2} \int_{r_1}^{r_2} \frac{p_0}{r_2} \cdot r \cdot Cos\theta \cdot r \cdot dr \cdot d\theta$$

$$= \frac{p_0}{r_2} \cdot \int_{-\pi/2}^{\pi/2} Cos\theta \cdot d\theta \cdot \int_{r_1}^{r_2} r^2 \cdot dr$$

$$= \frac{2}{3} \cdot \frac{p_0}{r_2} \cdot \left(r_2^{\,3} - r_1^{\,3}\right)$$

The axial component of the impact limiter reaction,

$$R_a = (80{,}000 - 3{,}800) \times 65.22 = 4.97\times10^6 \text{ lb}$$

The reaction is distributed over the lid surface annulus having an inside radius of 15 in and outside radius of 25.5 in. To get the total load R_a on the lid surface, p_0 must be,

$$p_0 = 4.97\times10^6 \cdot \frac{3}{2} \cdot \left(\frac{25.5}{25.5^3 - 15^3}\right) = 14{,}395 \text{ psi}$$

Since the lid has the bolt-hole cut-outs in this region, thereby reducing the area over which this load is applied, adjustment in the above pressure value must be made. This adjustment was manually made using the FEM. To obtain the total load of 4.97×10^6 lb, the value for p_0 was increased to 17,409 psi.

The lateral component of the impact limiter reaction was applied in the manner as described under side drop loading with the exception that the magnitude of the pressure is also varied linearly from the maximum value to zero at the top of the impact limiter edge.

The lateral component of the impact limiter reaction is:

$$R_l = (80{,}000 - 3{,}800) \times 25.42 = 1.937\times10^6 \text{ lb}$$

This reaction is applied at the surface that has a radius of 25.5 in and extends in the axial direction over a length of 20.28 in. Following the derivation under side drop,

$$p_0 = 2\times[(2\times1.937\times10^6)/(\pi\times25.5\times20.28)] = 4{,}769 \text{ psi}$$

Note that a multiplier of 2 is used to account for the axial variation of the pressure.

Impact Limiter Inertia

The upper impact limiter inertia is resolved into an axial component and a lateral component. The axial component is applied in the same manner as described under end drop and the lateral component is applied in the same manner as described for the side drop impact limiter reaction.

Magnitude of the uniform pressure representing the impact limiter axial inertia is:

$$p_{I.L.} = 65.22\times3{,}800/[\pi\times(25.5^2 - 12.5^2)] = 159.7 \text{ psi}$$

Amplitude of the sinusoidally varying pressure, representing the impact limiter lateral inertia,

$$p_0 = (2\times25.42\times3{,}800)/(\pi\times25.5\times21.355) = 112.93 \text{ psi}$$

Payload Inertia

The payload inertia is resolved into an axial component and a lateral component. The axial component is applied to the lid in the same manner as described under the end drop. The lateral component is applied to the lower half of the inner shell as described under side drop.

Magnitude of the uniform pressure representing the payload axial inertia is:

$$p_{lid} = 65.22\times9{,}500/(\pi\times17.375^2) = 653.3 \text{ psi}$$

Amplitude of the sinusoidally varying pressure, representing the payload lateral inertia,

$$p_0 = (2\times25.42\times9{,}500)/(\pi\times17.5\times109) = 80.6 \text{ psi}$$

Cask Body Inertia

Cask body inertia is applied as the body force. As explained earlier, to account for the total mass of the package a factor of 1.107 is used to increase the FEM mass.

Cask Body Axial Acceleration = 65.22×1.107 = 72.2 g

Cask Body Lateral Acceleration = 25.42×1.107 = 28.14 g

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 21 through 23 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 24 through 26 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 7 through 9. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

7.1.4 Shallow Angle Drop

As described in the Reference 4, the 3-60B cask package has also been analyzed for shallow angle drop tests. For these tests, the cask axis makes angles of 7½° and 15° with the horizontal plane. These orientations are referred to as slapdown-1 and slapdown-2, respectively. Under both theses drop conditions the node-end impact limiter makes contact with the rigid target surface first. This is followed by a rotation of the cask and the tail-end impact limiter then strikes the rigid surface. With the four orientations for the drop test addressed in this document the entire spectrum of initial orientations of the cask package for the hypothetical drop test has been covered. The FEM analyses have performed for sufficiently large time durations in which both primary as well as secondary impacts, if any, take place. Thus, the slap-down effect of the shallow angle drop, as well as that during the corner-over-C.G. drop has been included in these analyses.

The results of the shallow angle drop analyses show that the tail-end impact is more severe than the nose-end impact for the 3-60B cask. This result is consistent with the conclusion of Reference 11, which shows that for a slender cask with length-to-radius of gyration ratio larger than 2, the tail-end impact is more severe than the nose-end impact. For both shallow angle orientations (slapdown-1 and slapdown-2), and for both cold and hot environmental conditions, the tail-end impact reactions are larger than nose-end impact limiter reactions (see Figures 86, 91, 96 and 101 of Reference 4).

The largest impact limiter reaction for the slapdown-1 and slapdown-2 and in both cold and hot environment case is:

$R_{\text{shallow-angle}} = 2.009\times10^{6}$ lb (Table 3 and Figure 86 of Reference 4)

The nature of impact limiter reaction in this case is very similar to that of the side drop test. The maximum impact limiter reaction during the side drop test is:

$R_{\text{side-drop}} = 1.889\times10^{6}$ lb (Table 3 and Figure 66 of Reference 4)

Thus, the shallow angle drop test will result in the impact limiter reaction that is larger than that of the side drop test by a factor of:

2.009/1.889 = 1.06

Therefore, a factor of safety of 1.06 or larger in the cask due to HAC side drop loading will ensure that cask will satisfy the design acceptance criteria for the shallow angle drop orientation also. From the examination of results presented in Tables 4 through 6, it is observed that the minimum factor of safety is 1.07, which is larger than 1.06 needed for shallow angle drop test.

7.1.5 Lead Slump Evaluation

Analysis of the 3-60B cask package under HAC drop test has been performed in the side drop orientation with cask top-end down. Since the top end of the cask has a bolted connection between the lid and the cask body, it is more critical than the bottom-end down orientation which includes no bolted connections. However, the cask is most vulnerable, as far as lead slump is concerned, in the bottom end down orientation. To get a conservative estimate of the lead slump, structural analysis of the cask has been performed with the bottom-end down orientation. The most conservative environmental conditions (cold with no decay heat) have been employed in the analysis. Figure 27 shows the displacement plot during this drop test. The largest relative displacement of 0.3172 in is calculated at the bolting ring-lead interface. It should be noted this is the total relative displacement. In considering this to be the lead slump, the elastic recovery of the lead and steel has been neglected.

7.2 NCT Drop Tests

The distribution of the NCT drop test loading on various components of the cask, under all the drop orientations, have been obtained by linearly proportioning the corresponding loading from the HAC drop tests.

7.2.1 End Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions $= 1.338 \times 10^6$ lb (Table 2 and Figure 16 of Reference 4)

Hot Conditions $= 1.103 \times 10^6$ lb (Table 2 and Figure 20 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The NCT end drop rigid body acceleration is:

$$= 2 \times 1.338 \times 10^6 / 76{,}200 = 35.12 \text{ g}$$

The acceleration used in the HAC end drop analyses is 150 g. The mechanical loading applied in the HAC end drop analyses may be proportioned with 35.12 g. The ratio of the two loadings is:

$$R_{end} = 35.12/150 = 0.2341 \quad \text{» For conservatism use } 0.3025$$

Impact limiter Inertia

$$p_{I.L.} = 0.3025 \times 367.3 = 111.11 \text{ psi}$$

Payload Inertia

$$p_{lid} = 0.3025 \times 1{,}502.5 = 454.5 \text{ psi}$$

Cask Body Inertia

Cask Body Acceleration $= 0.3025 \times 166 = 50.2$ g

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 28 through 30 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 31 through 33 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 10 through 12. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

7.2.2 Side Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions = 453,400 lb (Table 2 and Figure 24 of Reference 4)

Hot Conditions = 364,800 lb (Table 2 and Figure 28 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The NCT side drop rigid body acceleration is:

$$= 4 \times 453{,}400/72{,}400 = 25.05 \text{ g}$$

The acceleration used in the HAC side drop analyses is 120 g. The mechanical loading applied in the HAC side drop analyses may be proportioned with 25.05 g. The ratio of the two loadings is:

$$R_{side} = 25.05/120 = 0.209 \quad \text{» For conservatism use } 0.2354$$

Impact Limiter Reactions

Top impact limiter pressure amplitude,

$$p_0 = 0.2354 \times 5{,}348 = 1{,}258.9 \text{ psi}$$

Bottom impact limiter pressure amplitude,

$$p_0 = 0.2354 \times 5{,}078 = 1{,}195.4 \text{ psi}$$

Payload Inertia

Payload inertia pressure amplitude,

$$p_0 = 0.2354 \times 380.5 = 89.57 \text{ psi}$$

Cask Body Inertia

Cask Body Acceleration = $0.2354 \times 132.84 = 31.27$ g

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 34 through 36 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 37 through 39 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 13 through 15. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

7.2.3 Corner Drop

The following impact limiter reactions are obtained from Reference 4.

Cold Conditions = 335,300 lb (Table 2 and Figure 32 of Reference 4)

Hot Conditions = 303,208 lb (Table 2 and Figure 36 of Reference 4)

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The NCT corner drop rigid body acceleration is:

$$= 2\times 335{,}300/76{,}200 = 8.8\text{ g}$$

The acceleration used in the HAC corner drop analyses is 70 g. The mechanical loading applied in the HAC corner drop analyses may be proportioned with 8.8 g. The ratio of the two loadings is:

$$R_{side} = 8.8/70 = 0.126 \quad \text{» For conservatism use } 0.4292$$

Impact Limiter Reactions

Lid pressure magnitude,

$$p_{lid} = 0.4292\times 17{,}409 = 7{,}471.9\text{ psi}$$

Wall pressure amplitude,

$$p_0 = 0.4292\times 4{,}769 = 2{,}046.9\text{ psi}$$

Impact Limiter Inertia

Baseplate pressure magnitude,

$p_{I.L.} = 0.4292 \times 159.7 = 68.54$ psi

Wall pressure amplitude,

$p_0 = 0.4292 \times 112.93 = 48.47$ psi

Payload Inertia

Lid pressure magnitude

$p_{lid} = 0.4292 \times 653.3 = 280.4$ psi

Wall pressure amplitude,

$p_0 = 0.4292 \times 80.6 = 34.6$ psi

Cask Body Inertia

Cask Body Axial Acceleration = $0.4292 \times 72.2 = 30.99$ g

Cask Body Lateral Acceleration = $0.4292 \times 28.14 = 12.1$ g

Model Analyses

The FEM is analyzed under the above loading for hot (Load Case 1), cold with maximum decay heat (Load Case 2), and cold with no decay heat, environmental conditions. The cask body temperature for Load Cases 1 and 2 are obtained from the hot and cold environmental loading conditions of Reference 10. For Load Case 3 (no internal heat), the entire cask is assumed to be at -20°F. Figures 40 through 42 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 43 through 45 show the stress intensity plot in the cask body for the three load cases. Stress intensities are calculated in each major component of the cask and are presented in Tables 16 through 18. These tables also categorize the stresses based on the ASME code and compare them with the corresponding allowable value established in Section 5.0. Factors of safety based on the ratio of allowable stress to the calculated stress are also calculated.

8.0 CONCLUSIONS

The results of the analyses performed in this document show that the 3-60B Cask meets the design requirements during all the drop test scenarios specified in 10 CFR 71 code. Therefore, it is concluded that the cask can withstand the drop test requirements during the normal conditions of transport and the hypothetical accident conditions. It is noted that slight deformation of the cask at certain locations is expected during the hypothetical drop tests. However, the components subjected to deformations during these tests are not on the pressure boundary. Therefore, their deformation in no way can prevent the cask from meeting other requirements of the code. A summary of the expected deformation is as follows:

- The skirt of the bolting ring may be subjected to inelastic bending during the side, corner, and shallow angle drop tests (see Figures 17 and 26 for example). This bending will be confined to a small area near the point of impact. The skirt may bend inward at these locations.

9.0 ANSYS PRINTOUT AND DATA FILES

The printout of the important data from the program is included with this document in electronic form as Appendix 1. The following is the directory of the data on the DVD.

```
Volume in drive F is My Disc
 Volume Serial Number is E35A-63CD

 Directory of F:\

01/04/2008  11:38 AM    <DIR>          1-ft Drop, Corner
12/19/2007  02:52 PM    <DIR>          1-ft Drop, End
01/04/2008  11:15 AM           108,032 1-ft Drop, Result Summary.doc
12/19/2007  02:55 PM    <DIR>          1-ft Drop, Side
01/04/2008  11:44 AM    <DIR>          30-ft Drop, Corner
12/19/2007  02:41 PM    <DIR>          30-ft Drop, End
01/03/2008  04:27 PM           131,584 30-ft Drop, Result Summary.doc
01/03/2008  03:02 PM    <DIR>          30-ft Drop, Side
               2 File(s)        239,616 bytes
               6 Dir(s)               0 bytes free

Directory of F:\1-ft Drop, Corner

01/04/2008  01:42 PM    <DIR>          .
01/04/2008  01:42 PM    <DIR>          ..
10/23/2007  02:10 PM        10,924,071 file.cdb
10/24/2007  05:09 PM       232,390,656 file.rst
10/24/2007  10:18 AM         2,166,410 file.s01
10/24/2007  10:12 AM         2,166,410 file.s02
10/24/2007  10:14 AM           908,444 file.s03
11/20/2007  10:28 AM            97,323 file000.png
11/20/2007  10:30 AM            91,008 file001.png
11/20/2007  10:31 AM            67,746 file002.png
11/20/2007  10:38 AM           153,219 file003.png
11/20/2007  10:39 AM           153,673 file004.png
11/20/2007  10:39 AM           156,392 file005.png
01/03/2008  05:51 PM             3,125 ls1Forging.lis
10/31/2007  10:34 AM             3,125 ls1Inner-Shell.lis
11/01/2007  09:22 AM             3,125 ls1Lid.lis
10/31/2007  10:44 AM             3,125 ls1Outer-Shell.lis
10/29/2007  02:02 PM         3,002,819 ls1post.out
01/03/2008  05:52 PM             3,125 ls2Forging.lis
10/31/2007  10:37 AM             3,125 ls2Inner-Shell.lis
11/01/2007  09:24 AM             3,125 ls2Lid.lis
10/29/2007  02:11 PM         3,002,838 ls2post.out
10/31/2007  12:12 PM             3,125 ls3Baseplates.lis
01/03/2008  05:52 PM             3,125 ls3Forging.lis
10/31/2007  10:38 AM             3,125 ls3Inner-Shell.lis
11/01/2007  09:26 AM             3,125 ls3Lid.lis
```

```
10/31/2007  10:41 AM             3,125 ls3Outer-Shell.lis
10/29/2007  02:15 PM         3,002,836 ls3post.out
12/07/2007  11:14 AM            39,419 Model.txt
              27 File(s)    258,360,764 bytes

Directory of F:\1-ft Drop, End

01/04/2008  01:44 PM    <DIR>          .
01/04/2008  01:44 PM    <DIR>          ..
10/23/2007  02:09 PM        10,782,335 file.cdb
10/26/2007  03:35 PM       470,548,480 file.rst
10/24/2007  10:21 AM         2,025,280 file.s01
10/26/2007  02:52 PM         2,025,322 file.s02
10/26/2007  02:50 PM           767,356 file.s03
11/20/2007  09:08 AM            47,665 file000.png
11/20/2007  09:07 AM            70,202 file001.png
11/20/2007  09:09 AM            41,321 file002.png
11/20/2007  09:23 AM            75,876 file003.png
11/20/2007  09:26 AM            65,404 file004.png
11/20/2007  09:28 AM            63,501 file005.png
10/31/2007  07:33 AM             3,125 ls1Forging.lis
10/31/2007  07:37 AM             3,125 ls1Outer-shell.lis
10/29/2007  01:30 PM         3,002,816 ls1post.out
10/31/2007  08:16 AM             3,125 ls2Forging.lis
10/31/2007  08:18 AM             3,125 ls2Inner-shell.lis
10/29/2007  01:34 PM         3,002,834 ls2post.out
10/31/2007  09:23 AM             3,125 ls3Baseplates.lis
10/31/2007  08:14 AM             3,125 ls3Forging.lis
10/31/2007  09:19 AM             3,125 ls3Inner-shell.lis
10/29/2007  01:39 PM         3,002,833 ls3post.out
12/07/2007  11:22 AM            39,413 Model.txt
              22 File(s)    495,582,513 bytes

Directory of F:\1-ft Drop, Side

01/04/2008  01:46 PM    <DIR>          .
01/04/2008  01:46 PM    <DIR>          ..
10/23/2007  02:08 PM        10,873,221 file.cdb
10/26/2007  12:38 PM       234,946,560 file.rst
10/24/2007  10:30 AM         2,042,171 file.s01
10/26/2007  11:51 AM         2,042,171 file.s02
10/26/2007  11:52 AM           784,205 file.s03
11/20/2007  09:53 AM           137,351 file000.png
11/20/2007  09:55 AM           121,231 file001.png
11/20/2007  09:56 AM            93,363 file002.png
11/20/2007  10:09 AM           154,442 file003.png
11/20/2007  10:11 AM           138,865 file004.png
11/20/2007  10:11 AM           141,508 file005.png
10/31/2007  09:50 AM             3,125 ls1Forging.lis
10/31/2007  09:29 AM             3,125 ls1Inner-Shell.lis
10/31/2007  09:32 AM             3,125 ls1Outer-Shell.lis
10/29/2007  01:45 PM         3,002,817 ls1post.out
10/31/2007  10:07 AM             3,125 ls2Baseplates.lis
10/31/2007  09:52 AM             3,125 ls2Forging.lis
10/31/2007  10:01 AM             3,125 ls2Outer-Shell.lis
```

```
10/29/2007  01:54 PM         3,002,836 ls2post.out
10/31/2007  10:08 AM             3,125 ls3Baseplates.lis
10/31/2007  09:53 AM             3,125 ls3Forging.lis
10/31/2007  10:05 AM             3,125 ls3Outer-Shell.lis
10/29/2007  01:58 PM         3,002,834 ls3post.out
12/07/2007  11:24 AM            40,131 Model.txt
              24 File(s)    260,551,831 bytes

Directory of F:\30-ft Drop, Corner

01/04/2008  01:48 PM    <DIR>          .
01/04/2008  01:48 PM    <DIR>          ..
10/23/2007  02:10 PM        10,924,071 file.cdb
10/24/2007  06:17 PM       232,980,480 file.rst
10/24/2007  12:31 PM         2,166,410 file.s01
10/24/2007  10:45 AM         2,166,410 file.s02
10/24/2007  10:46 AM           908,444 file.s03
10/23/2007  10:52 AM         1,899,466 file.s04
10/23/2007  01:00 PM         1,499,050 file.s05
11/19/2007  05:37 PM            92,321 file000.png
11/19/2007  05:38 PM           108,580 file001.png
11/19/2007  05:39 PM           101,566 file002.png
11/19/2007  05:40 PM            81,406 file003.png
11/19/2007  05:46 PM           140,328 file004.png
11/19/2007  05:47 PM           143,861 file005.png
11/19/2007  05:47 PM           146,377 file006.png
10/23/2007  07:07 AM        82,903,040 ls1.rst
11/01/2007  02:38 PM             3,125 ls1Forging.lis
11/01/2007  11:58 AM             3,125 ls1Lid.lis
10/29/2007  12:47 PM         3,002,820 ls1post.out
11/01/2007  02:40 PM             3,125 ls2Forging.lis
11/01/2007  12:00 PM             3,125 ls2Lid.lis
10/29/2007  12:53 PM         3,002,839 ls2post.out
11/01/2007  02:40 PM             3,125 ls3Forging.lis
11/01/2007  12:00 PM             3,125 ls3Lid.lis
10/29/2007  12:58 PM         3,002,837 ls3post.out
12/07/2007  11:25 AM            39,421 Model.txt
              25 File(s)    345,328,477 bytes

Directory of F:\30-ft Drop, End

01/04/2008  01:50 PM    <DIR>          .
01/04/2008  01:50 PM    <DIR>          ..
10/23/2007  02:09 PM        10,782,335 file.cdb
11/12/2007  12:13 PM       234,881,024 file.rst
10/24/2007  10:50 AM         2,025,304 file.s01
11/12/2007  11:10 AM         2,025,304 file.s02
10/24/2007  10:55 AM           767,338 file.s03
10/17/2007  07:28 AM            81,233 file000.png
11/02/2007  11:27 AM           152,254 file001.png
10/17/2007  09:12 AM           103,068 file002.png
11/19/2007  02:29 PM            59,387 file003.png
11/19/2007  02:31 PM            69,831 file004.png
11/19/2007  02:48 PM           220,493 file005.png
11/19/2007  02:49 PM            95,780 file006.png
```

```
11/19/2007  03:15 PM           135,573 file007.png
11/19/2007  03:40 PM           139,867 file008.png
11/19/2007  03:42 PM           119,828 file009.png
11/19/2007  03:44 PM            89,859 file010.png
11/19/2007  03:53 PM           206,691 file011.png
11/19/2007  03:54 PM           176,300 file012.png
11/19/2007  03:54 PM           173,720 file013.png
11/20/2007  01:18 PM         3,002,775 ls1post.out
10/31/2007  02:25 PM             3,117 ls2Forging.lis
10/31/2007  02:27 PM             3,117 ls2Inner-Shell.lis
11/01/2007  03:16 PM             3,117 ls2Lid.lis
11/20/2007  01:18 PM         3,002,775 ls2post.out
10/31/2007  02:33 PM             3,117 ls3Forging.lis
10/31/2007  02:35 PM             3,117 ls3Inner-Shell.lis
11/01/2007  03:18 PM             3,117 ls3Lid.lis
11/20/2007  01:20 PM         3,002,775 ls3post.out
12/07/2007  11:26 AM            39,714 Model.txt
              29 File(s)    261,371,930 bytes

Directory of F:\30-ft Drop, Side

01/04/2008  01:52 PM    <DIR>          .
01/04/2008  01:52 PM    <DIR>          ..
10/23/2007  02:08 PM        10,873,221 file.cdb
10/24/2007  07:00 PM       235,470,848 file.rst
10/24/2007  10:57 AM         2,042,171 file.s01
11/12/2007  11:03 AM         2,042,171 file.s02
10/24/2007  12:07 PM           784,205 file.s03
11/19/2007  04:25 PM           128,170 file000.png
10/31/2007  04:34 PM           114,190 file001.png
11/19/2007  04:26 PM            94,389 file002.png
11/19/2007  04:21 PM           139,130 file003.png
11/19/2007  04:38 PM           163,220 file005.png
11/19/2007  04:39 PM           162,563 file006.png
11/19/2007  04:39 PM           163,381 file007.png
10/31/2007  02:58 PM             3,125 ls1Forging2.lis
10/31/2007  03:03 PM             3,125 ls1Inner-Shell.lis
11/01/2007  03:23 PM             3,125 ls1Lid.lis
10/31/2007  03:07 PM             3,125 ls1Outer-Shell.lis
10/29/2007  12:25 PM         3,002,818 ls1post.out
10/31/2007  03:20 PM             3,125 ls2Baseplates.lis
10/31/2007  02:58 PM             3,125 ls2Forging2.lis
10/31/2007  03:04 PM             3,125 ls2Inner-Shell.lis
11/01/2007  03:24 PM             3,125 ls2Lid.lis
10/31/2007  03:08 PM             3,125 ls2Outer-Shell.lis
10/29/2007  12:29 PM         3,002,837 ls2post.out
10/31/2007  03:22 PM             3,125 ls3Baseplates.lis
10/31/2007  02:59 PM             3,125 ls3Forging2.lis
10/31/2007  03:05 PM             3,125 ls3Inner-Shell.lis
11/01/2007  03:25 PM             3,125 ls3Lid.lis
10/31/2007  03:09 PM             3,125 ls3Outer-Shell.lis
10/29/2007  12:35 PM         3,002,835 ls3post.out
12/07/2007  11:28 AM            40,559 Model.txt
              30 File(s)    261,270,458 bytes
```

10.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on DVD

Tables

(18 Pages)

Table 1

Stress Intensities in 3-60B Cask under 30-ft End Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	32,855	1.82
	$P_m + P_b$	87,000	32,855	2.65
	F	174,000	32,855	5.30
Inner Shell	P_m	59,760	17,652	3.39
	$P_m + P_b$	87,000	17,652	4.93
	F	174,000	17,652	9.86
Outer Shell	P_m	40,080	31,224	1.28
	$P_m + P_b$	60,120	31,224	1.93
	F	140,000	31,224	4.48
Lid	P_m	40,080	30,311	1.32
	$P_m + P_b$	60,120	30,311	1.98
	F	140,000	30,311	4.62
Base Plates	P_m	40,080	14,924	2.69
	$P_m + P_b$	60,120	14,924	4.03
	F	140,000	14,924	9.38
Seal Plates	$P_m + P_b$	60,120	4,185[3]	14.37
Bolts	P_m	105,000	9,023	11.64
	$P_m + P_b$	150,000	9,023	16.62
	F	300,000	9,023	33.25

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 51,854 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 2

Stress Intensities in 3-60B Cask under 30-ft End Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	50,491	1.18
	$P_m + P_b$	87,000	50,491	1.72
	F	174,000	50,491	3.45
Inner Shell	P_m	59,760	38,207	1.56
	$P_m + P_b$	87,000	38,207	2.28
	F	174,000	38,207	4.55
Outer Shell	P_m	40,080	24,782	1.62
	$P_m + P_b$	60,120	24,782	2.43
	F	140,000	24,782	5.65
Lid	P_m	40,080	33,945	1.18
	$P_m + P_b$	60,120	33,945	1.77
	F	140,000	33,945	4.12
Base Plates	P_m	40,080	24,661	1.63
	$P_m + P_b$	60,120	24,661	2.44
	F	140,000	24,661	5.68
Seal Plates	$P_m + P_b$	60,120	4,187[3]	14.36
Bolts	P_m	105,000	7,592	13.83
	$P_m + P_b$	150,000	7,592	19.76
	F	300,000	7,592	39.52

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 56,497 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 3

Stress Intensities in 3-60B Cask under 30-ft End Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	44,400	1.35
	$P_m + P_b$	87,000	60,610	1.44
	F	174,000	58,779	2.96
Inner Shell	P_m	59,760	43,130	1.39
	$P_m + P_b$	87,000	46,060	1.89
	F	174,000	43,700	3.98
Outer Shell	P_m	40,080	24,687	1.62
	$P_m + P_b$	60,120	24,687	2.44
	F	140,000	24,687	5.67
Lid	P_m	40,080	5,482	7.31
	$P_m + P_b$	60,120	35,126	1.71
	F	140,000	35,126	3.99
Base Plates	P_m	40,080	27,593	1.45
	$P_m + P_b$	60,120	27,593	2.18
	F	140,000	27,593	5.07
Seal Plates	$P_m + P_b$	60,120	4,971[3]	12.09
Bolts	P_m	105,000	7,442	14.11
	$P_m + P_b$	150,000	7,442	20.16
	F	300,000	7,442	40.31

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 57,706 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 4

Stress Intensities in 3-60B Cask under 30-ft Side Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	45,960[3]	1.30
	$P_m + P_b$	87,000	81,730[3]	1.07
	F	174,000	125,360	1.39
Inner Shell	P_m	59,760	36,420	1.64
	$P_m + P_b$	87,000	44,210	1.97
	F	174,000	44,216	3.94
Outer Shell	P_m	40,080	33,800	1.19
	$P_m + P_b$	60,120	44,150	1.36
	F	140,000	44,151	3.17
Lid	P_m	40,080	26,280[4]	1.53
	$P_m + P_b$	60,120	32,940[6]	1.83
	F	140,000	40,684	3.44
Base Plates	P_m	40,080	31,876	1.26
	$P_m + P_b$	60,120	31,876	1.89
	F	140,000	31,876	4.39
Seal Plates	$P_m + P_b$	60,120	45,515[5]	1.32
Bolts	P_m	105,000	57,103	1.84
	$P_m + P_b$	150,000	57,103	2.63
	F	300,000	57,103	5.25

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) Stress intensity in parts other than the skirt. The skirt is expected to deform under HAC side drop.

(4) Average value over the section of maximum stress intensity.

(5) The maximum stress intensity in the seal plates is 104,460 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(6) The reported stress here is the maximum principle stress (tensile).

Table 5

Stress Intensities in 3-60B Cask under 30-ft Side Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[(1)] (psi)	F.S.[(2)]
Bolting Ring	P_m	59,760	45,210[(3)]	1.32
	$P_m + P_b$	87,000	81,460[(3)]	1.07
	F	174,000	127,328	1.37
Inner Shell	P_m	59,760	37,560	1.59
	$P_m + P_b$	87,000	42,230	2.06
	F	174,000	42,230	4.12
Outer Shell	P_m	40,080	35,230	1.14
	$P_m + P_b$	60,120	47,480	1.27
	F	140,000	47,487	2.95
Lid	P_m	40,080	27,640[(4)]	1.45
	$P_m + P_b$	60,120	35,884[(6)]	1.68
	F	140,000	42,435	3.30
Base Plates	P_m	40,080	26,210	1.53
	$P_m + P_b$	60,120	50,500	1.19
	F	140,000	52,020	2.69
Seal Plates	$P_m + P_b$	60,120	46,227[(5)]	1.30
Bolts	P_m	105,000	55,860	1.88
	$P_m + P_b$	150,000	55,860	2.69
	F	300,000	55,860	5.37

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) Stress intensity in parts other than the skirt. The skirt is expected to deform under HAC side drop.

(4) Average value over the section of maximum stress intensity.

(5) The maximum stress intensity in the seal plates is 106,330 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(6) The reported stress here is the maximum principle stress (tensile).

Table 6

Stress Intensities in 3-60B Cask under 30-ft Side Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	44,900[3]	1.33
	$P_m + P_b$	87,000	81,360[3]	1.07
	F	174,000	128,091	1.36
Inner Shell	P_m	59,760	40,200	1.49
	$P_m + P_b$	87,000	43,390	2.01
	F	174,000	43,486	4.00
Outer Shell	P_m	40,080	36,710	1.09
	$P_m + P_b$	60,120	49,360	1.22
	F	140,000	49,364	2.84
Lid	P_m	40,080	27,360[4]	1.46
	$P_m + P_b$	60,120	35,719[6]	1.68
	F	140,000	41,878	3.34
Base Plates	P_m	40,080	29,690	1.35
	$P_m + P_b$	60,120	53,950	1.11
	F	140,000	57,405	2.44
Seal Plates	$P_m + P_b$	60,120	45,153[5]	1.33
Bolts	P_m	105,000	54,432	1.93
	$P_m + P_b$	150,000	54,432	2.76
	F	300,000	54,432	5.51

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) Stress intensity in parts other than the skirt. The skirt is expected to deform under HAC side drop.

(4) Average value over the section of maximum stress intensity.

(5) The maximum stress intensity in the seal plates is 103,850 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(6) The reported stress here is the maximum principle stress (tensile).

Table 7

Stress Intensities in 3-60B Cask under 30-ft Corner Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	41,620	1.44
	$P_m + P_b$	87,000	50,330	1.73
	F	174,000	139,619	1.25
Inner Shell	P_m	59,760	35,571	1.68
	$P_m + P_b$	87,000	35,571	2.45
	F	174,000	35,571	4.89
Outer Shell	P_m	40,080	31,297	1.28
	$P_m + P_b$	60,120	31,297	1.92
	F	140,000	31,297	4.47
Lid	P_m	40,080	27,550	1.45
	$P_m + P_b$	60,120	42,817[4]	1.40
	F	140,000	100,030	1.40
Base Plates	P_m	40,080	10,203	3.93
	$P_m + P_b$	60,120	10,203	5.89
	F	140,000	10,203	13.72
Seal Plates	$P_m + P_b$	60,120	34,765[3]	1.73
Bolts	P_m	105,000	27,642	3.80
	$P_m + P_b$	150,000	27,642	5.43
	F	300,000	27,642	10.85

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 185,160 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(4) The reported stress here is the maximum principle stress (tensile).

Table 8

Stress Intensities in 3-60B Cask under 30-ft Corner Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	44,450	1.34
	$P_m + P_b$	87,000	47,750	1.82
	F	174,000	130,470	1.33
Inner Shell	P_m	59,760	50,708	1.18
	$P_m + P_b$	87,000	50,708	1.72
	F	174,000	50,708	3.43
Outer Shell	P_m	40,080	25,953	1.54
	$P_m + P_b$	60,120	25,953	2.32
	F	140,000	25,953	5.39
Lid	P_m	40,080	26,240	1.53
	$P_m + P_b$	60,120	42,737[4]	1.41
	F	140,000	96,158	1.46
Base Plates	P_m	40,080	16,204	2.47
	$P_m + P_b$	60,120	16,204	3.71
	F	140,000	16,204	8.64
Seal Plates	$P_m + P_b$	60,120	37,369[3]	1.61
Bolts	P_m	105,000	25,437	4.13
	$P_m + P_b$	150,000	25,437	5.90
	F	300,000	25,437	11.79

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 173,420 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(4) The reported stress here is the maximum principle stress (tensile).

Table 9

Stress Intensities in 3-60B Cask under 30-ft Corner Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	59,760	46,380	1.29
	$P_m + P_b$	87,000	52,140	1.67
	F	174,000	126,480	1.38
Inner Shell	P_m	59,760	55,586	1.08
	$P_m + P_b$	87,000	55,586	1.57
	F	174,000	55,586	3.13
Outer Shell	P_m	40,080	26,917	1.49
	$P_m + P_b$	60,120	26,917	2.23
	F	140,000	26,917	5.20
Lid	P_m	40,080	26,050	1.54
	$P_m + P_b$	60,120	42,578[4]	1.41
	F	140,000	95,863	1.46
Base Plates	P_m	40,080	21,989	1.82
	$P_m + P_b$	60,120	21,989	2.73
	F	140,000	21,989	6.37
Seal Plates	$P_m + P_b$	60,120	37,834[3]	1.59
Bolts	P_m	105,000	26,079	4.03
	$P_m + P_b$	150,000	26,079	5.75
	F	300,000	26,079	11.50

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 169,950 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(4) The reported stress here is the maximum principle stress (tensile).

Table 10

Stress Intensities in 3-60B Cask under 1-ft End Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	8,192	3.04
	$P_m + P_b$	37,350	15,310	2.44
	F	74,700	15,342	4.87
Inner Shell	P_m	24,900	4,245	5.87
	$P_m + P_b$	37,350	4,245	8.80
	F	74,700	4,245	17.60
Outer Shell	P_m	16,700	13,760	1.21
	$P_m + P_b$	25,050	15,030	1.67
	F	50,100	15,035	3.33
Lid	P_m	16,700	10,138	1.65
	$P_m + P_b$	25,050	10,138	2.47
	F	50,100	10,138	4.94
Base Plates	P_m	16,700	10,182	1.64
	$P_m + P_b$	25,050	10,182	2.46
	F	50,100	10,182	4.92
Seal Plates	$P_m + P_b$	25,050	16,808	1.49
Bolts	P_m	60,000	6,725	8.92
	$P_m + P_b$	90,000	6,725	13.38
	F	150,000	6,725	22.30

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 11

Stress Intensities in 3-60B Cask under 1-ft End Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	16,850	1.48
	$P_m + P_b$	37,350	22,960	1.63
	F	74,700	22,965	3.25
Inner Shell	P_m	24,900	16,310	1.53
	$P_m + P_b$	37,350	17,040	2.19
	F	74,700	17,043	4.38
Outer Shell	P_m	16,700	7,562	2.21
	$P_m + P_b$	25,050	7,562	3.31
	F	50,100	7,562	6.63
Lid	P_m	16,700	10,320	1.62
	$P_m + P_b$	25,050	10,320	2.43
	F	50,100	10,320	4.85
Base Plates	P_m	16,700	12,590	1.33
	$P_m + P_b$	25,050	12,590	1.99
	F	50,100	12,590	3.98
Seal Plates	$P_m + P_b$	25,050	17,356	1.44
Bolts	P_m	60,000	3,646	16.46
	$P_m + P_b$	90,000	3,646	24.68
	F	150,000	3,646	41.14

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 12

Stress Intensities in 3-60B Cask under 1-ft End Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[(1)] (psi)	F.S.[(2)]
Bolting Ring	P_m	24,900	20,970	1.19
	$P_m + P_b$	37,350	28,920	1.29
	F	74,700	28,928	2.58
Inner Shell	P_m	24,900	20,190	1.23
	$P_m + P_b$	37,350	21,180	1.76
	F	74,700	21,183	3.53
Outer Shell	P_m	16,700	7,467	2.24
	$P_m + P_b$	25,050	7,467	3.35
	F	50,100	7,467	6.71
Lid	P_m	16,700	11,125	1.50
	$P_m + P_b$	25,050	11,125	2.25
	F	50,100	11,125	4.50
Base Plates	P_m	16,700	10,210	1.64
	$P_m + P_b$	25,050	17,040	1.47
	F	50,100	18,208	2.75
Seal Plates	$P_m + P_b$	25,050	19,186	1.31
Bolts	P_m	60,000	5,301	11.32
	$P_m + P_b$	90,000	5,301	16.98
	F	150,000	5,301	28.30

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 13

Stress Intensities in 3-60B Cask under 1-ft Side Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	18,480	1.35
	$P_m + P_b$	37,350	30,410	1.23
	F	74,700	30,441	2.45
Inner Shell	P_m	24,900	14,490	1.72
	$P_m + P_b$	37,350	16,470	2.27
	F	74,700	16,467	4.54
Outer Shell	P_m	16,700	9,915	1.68
	$P_m + P_b$	25,050	20,060	1.25
	F	50,100	20,069	2.50
Lid	P_m	16,700	7,440	2.24
	$P_m + P_b$	25,050	7,440	3.37
	F	50,100	7,440	6.73
Base Plates	P_m	16,700	12,645	1.32
	$P_m + P_b$	25,050	12,645	1.98
	F	50,100	12,645	3.96
Seal Plates	$P_m + P_b$	25,050	5,415[3]	4.63
Bolts	P_m	60,000	24,328	2.47
	$P_m + P_b$	90,000	24,328	3.70
	F	150,000	24,328	6.17

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 22,040 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 14

Stress Intensities in 3-60B Cask under 1-ft Side Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	19,060	1.31
	$P_m + P_b$	37,350	31,240	1.20
	F	74,700	31,247	2.39
Inner Shell	P_m	24,900	13,051	1.91
	$P_m + P_b$	37,350	13,051	2.86
	F	74,700	13,051	5.72
Outer Shell	P_m	16,700	11,240	1.49
	$P_m + P_b$	25,050	14,810	1.69
	F	50,100	14,816	3.38
Lid	P_m	16,700	10,147	1.65
	$P_m + P_b$	25,050	10,147	2.47
	F	50,100	10,147	4.94
Base Plates	P_m	16,700	10,280	1.62
	$P_m + P_b$	25,050	16,960	1.48
	F	50,100	18,373	2.73
Seal Plates	$P_m + P_b$	25,050	9,815[3]	2.55
Bolts	P_m	60,000	21,543	2.79
	$P_m + P_b$	90,000	21,543	4.18
	F	150,000	21,543	6.96

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 26,446 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 15

Stress Intensities in 3-60B Cask under 1-ft Side Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[(1)] (psi)	F.S.[(2)]
Bolting Ring	P_m	24,900	19,340	1.29
	$P_m + P_b$	37,350	31,690	1.18
	F	74,700	31,694	2.36
Inner Shell	P_m	24,900	16,167	1.54
	$P_m + P_b$	37,350	16,167	2.31
	F	74,700	16,167	4.62
Outer Shell	P_m	16,700	12,440	1.34
	$P_m + P_b$	25,050	16,800	1.49
	F	50,100	16,807	2.98
Lid	P_m	16,700	11,179	1.49
	$P_m + P_b$	25,050	11,179	2.24
	F	50,100	11,179	4.48
Base Plates	P_m	16,700	14,290	1.17
	$P_m + P_b$	25,050	22,330	1.12
	F	50,100	24,154	2.07
Seal Plates	$P_m + P_b$	25,050	10,399[(3)]	2.41
Bolts	P_m	60,000	19,916	3.01
	$P_m + P_b$	90,000	19,916	4.52
	F	150,000	19,916	7.53

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The maximum stress intensity in the seal plates is 24,543 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

Table 16

Stress Intensities in 3-60B Cask under 1-ft Corner Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	19,580[6]	1.27
	$P_m + P_b$	37,350	26,170[6]	1.43
	F	74,700	55,516	1.35
Inner Shell[3]	P_L	24,900	13,350	1.87
	$P_L + P_b$	37,350	14,530	2.57
	F	74,700	14,534	5.14
Outer Shell	P_m	16,700	8,248	2.02
	$P_m + P_b$	25,050	16,270	1.54
	F	50,100	16,269	3.08
Lid	P_m	16,700	9,966	1.68
	$P_m + P_b$	25,050	18,347[5]	1.37
	F	50,100	41,359	1.21
Base Plates	P_m	16,700	10,896	1.53
	$P_m + P_b$	25,050	10,896	2.30
	F	50,100	10,896	4.60
Seal Plates	$P_m + P_b$	25,050	12,606[4]	1.99
Bolts	P_m	60,000	18,243	3.29
	$P_m + P_b$	90,000	18,243	4.93
	F	150,000	18,243	8.22

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The stresses in the inner shell under corner drop loading are mostly longitudinal. These stresses are the highest near the impact location and subside greatly away from the plane of impact. Therefore, they are classified as average linearized stress, P_L and not P_m.

(4) The maximum stress intensity in the seal plates is 77,292 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(5) The reported stress here is the maximum principle stress (tensile).

(6) Membrane and membrane plus bending stresses calculated in non-skirt elements.

Table 17

Stress Intensities in 3-60B Cask under 1-ft Corner Drop – Cold Condition (Max. Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.(1) (psi)	F.S.(2)
Bolting Ring	P_m	24,900	21,730(6)	1.15
	$P_m + P_b$	37,350	25,680(6)	1.45
	F	74,700	52,478	1.42
Inner Shell(3)	P_L	37,350	26,480	1.41
	$P_L + P_b$	37,350	27,570	1.35
	F	74,700	27,569	2.71
Outer Shell	P_m	16,700	12,611	1.32
	$P_m + P_b$	25,050	12,611	1.99
	F	50,100	12,611	3.97
Lid	P_m	16,700	9,943	1.68
	$P_m + P_b$	25,050	18,344(5)	1.37
	F	50,100	39,239	1.28
Base Plates	P_m	16,700	11,656	1.43
	$P_m + P_b$	25,050	11,656	2.15
	F	50,100	11,656	4.30
Seal Plates	$P_m + P_b$	25,050	18,934(4)	1.32
Bolts	P_m	60,000	14,026	4.28
	$P_m + P_b$	90,000	14,026	6.42
	F	150,000	14,026	10.69

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The stresses in the inner shell under corner drop loading are mostly longitudinal. These stresses are the highest near the impact location and subside greatly away from the plane of impact. Therefore, they are classified as average linearized stress, P_L and not P_m.

(4) The maximum stress intensity in the seal plates is 71,591 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(5) The reported stress here is the maximum principle stress (tensile).

(6) Membrane and membrane plus bending stresses calculated in non-skirt elements.

Table 18

Stress Intensities in 3-60B Cask under 1-ft Corner Drop – Cold Condition (No Decay Heat)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	23,580[6]	1.06
	$P_m + P_b$	37,350	30,260[6]	1.23
	F	74,700	49,660	1.50
Inner Shell[3]	P_L	37,350	30,150	1.24
	$P_L + P_b$	37,350	32,220	1.20
	F	74,700	32,217	2.32
Outer Shell	P_m	16,700	9,999	1.67
	$P_m + P_b$	25,050	14,390	1.74
	F	50,100	14,387	3.48
Lid	P_m	16,700	9,940	1.68
	$P_m + P_b$	25,050	18,199[5]	1.38
	F	50,100	39,298	1.27
Base Plates	P_m	16,700	10,880	1.53
	$P_m + P_b$	25,050	18,310	1.37
	F	50,100	18,310	2.74
Seal Plates	$P_m + P_b$	25,050	19,456[4]	1.29
Bolts	P_m	60,000	13,725	4.37
	$P_m + P_b$	90,000	13,725	6.56
	F	150,000	13,725	10.93

Notes:

(1) Unless otherwise indicated in this column, the peak stress intensity (F) values have been conservatively reported as P_m and $P_m + P_b$ stress intensities.

(2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

(3) The stresses in the inner shell under corner drop loading are mostly longitudinal. These stresses are the highest near the impact location and subside greatly away from the plane of impact. Therefore, they are classified as average linearized stress, P_L and not P_m.

(4) The maximum stress intensity in the seal plates is 69,165 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The reported stress here is the maximum principal stress (tensile).

(5) The reported stress here is the maximum principle stress (tensile).

(6) Membrane and membrane plus bending stresses calculated in non-skirt elements.

Figures

(45 Pages)

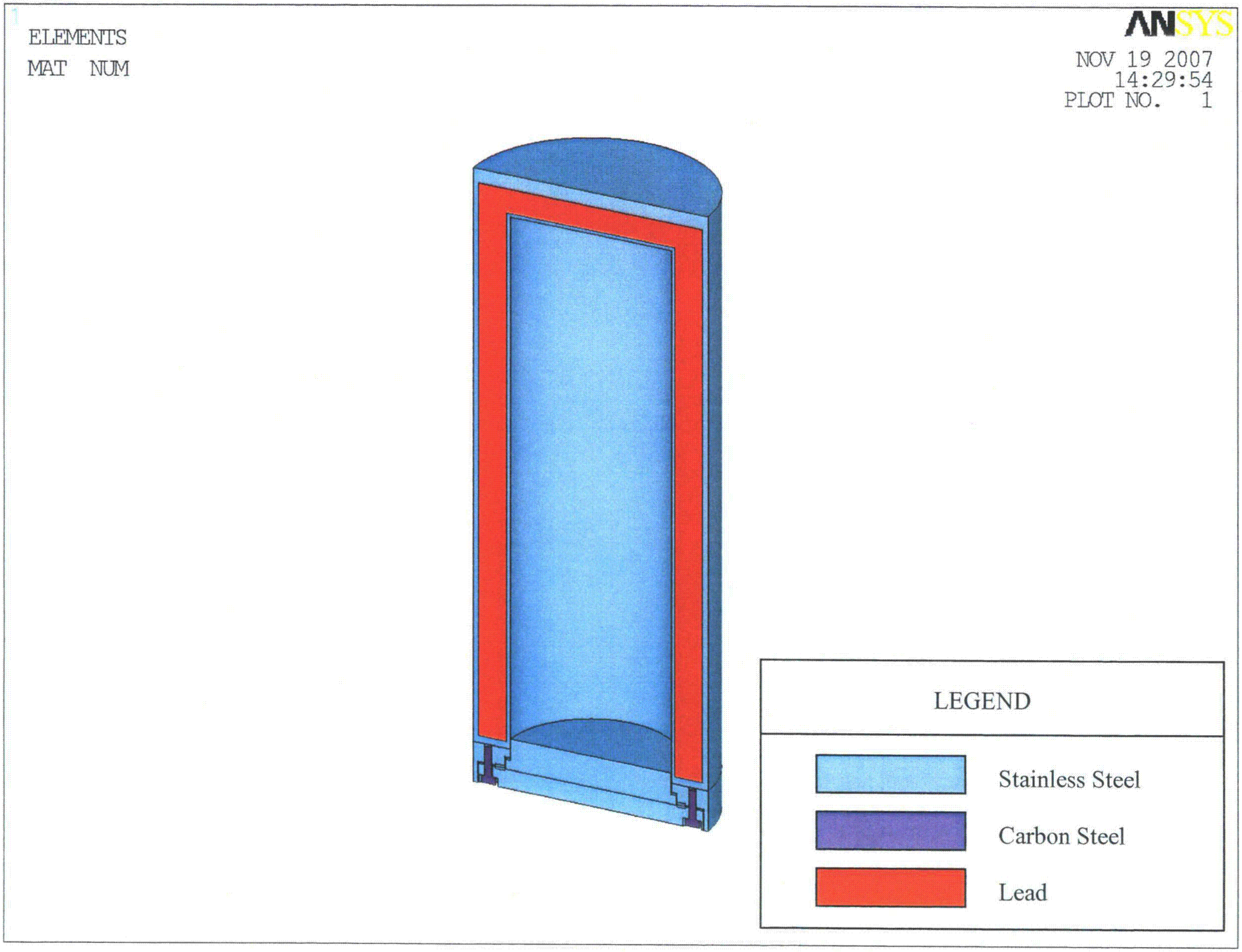


Figure 1

Finite Element Model of the 3-60B Cask Identifying the Cask Components with Material Numbers

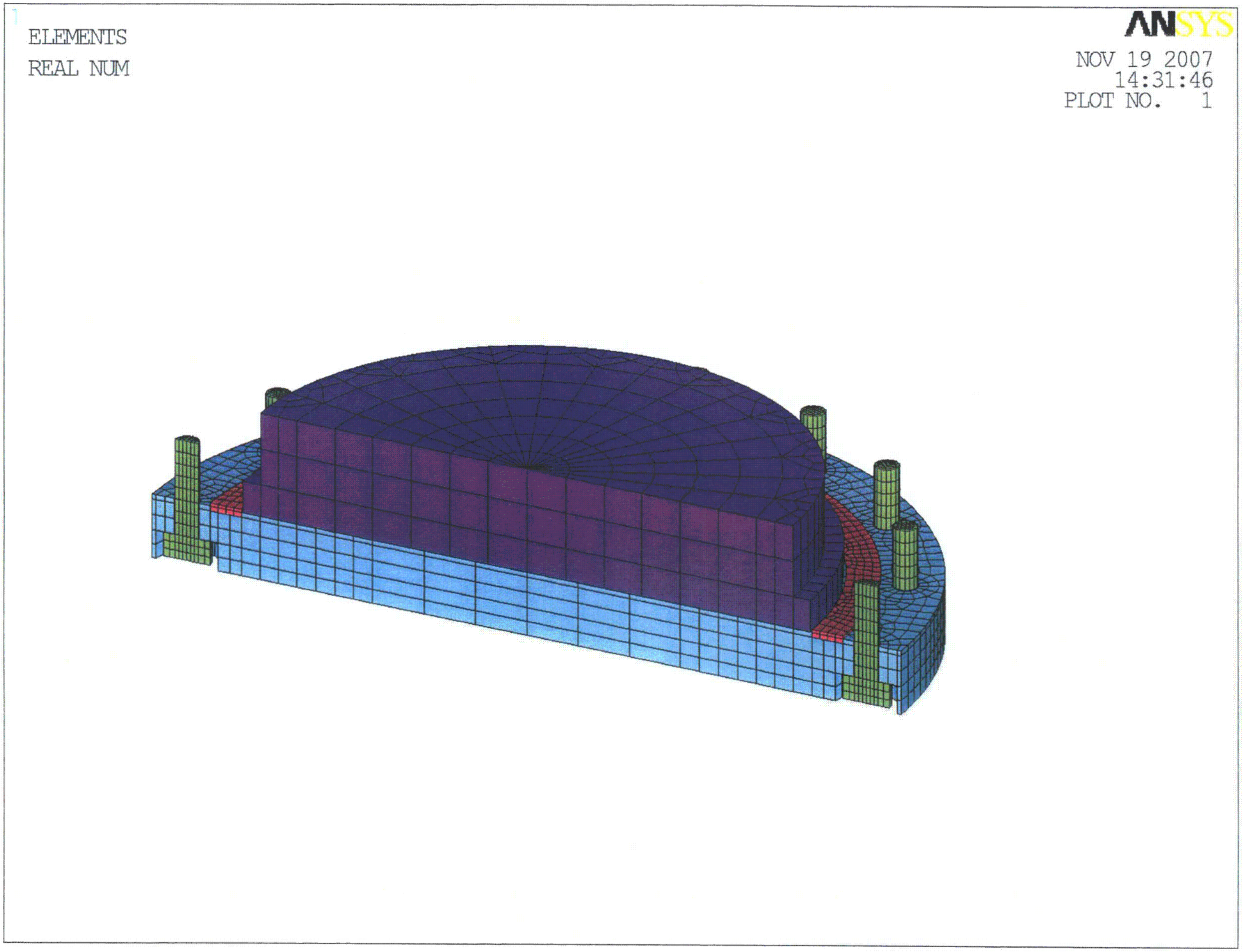


Figure 2
Finite Element Model of the Lid, Seal Plate and Bolts

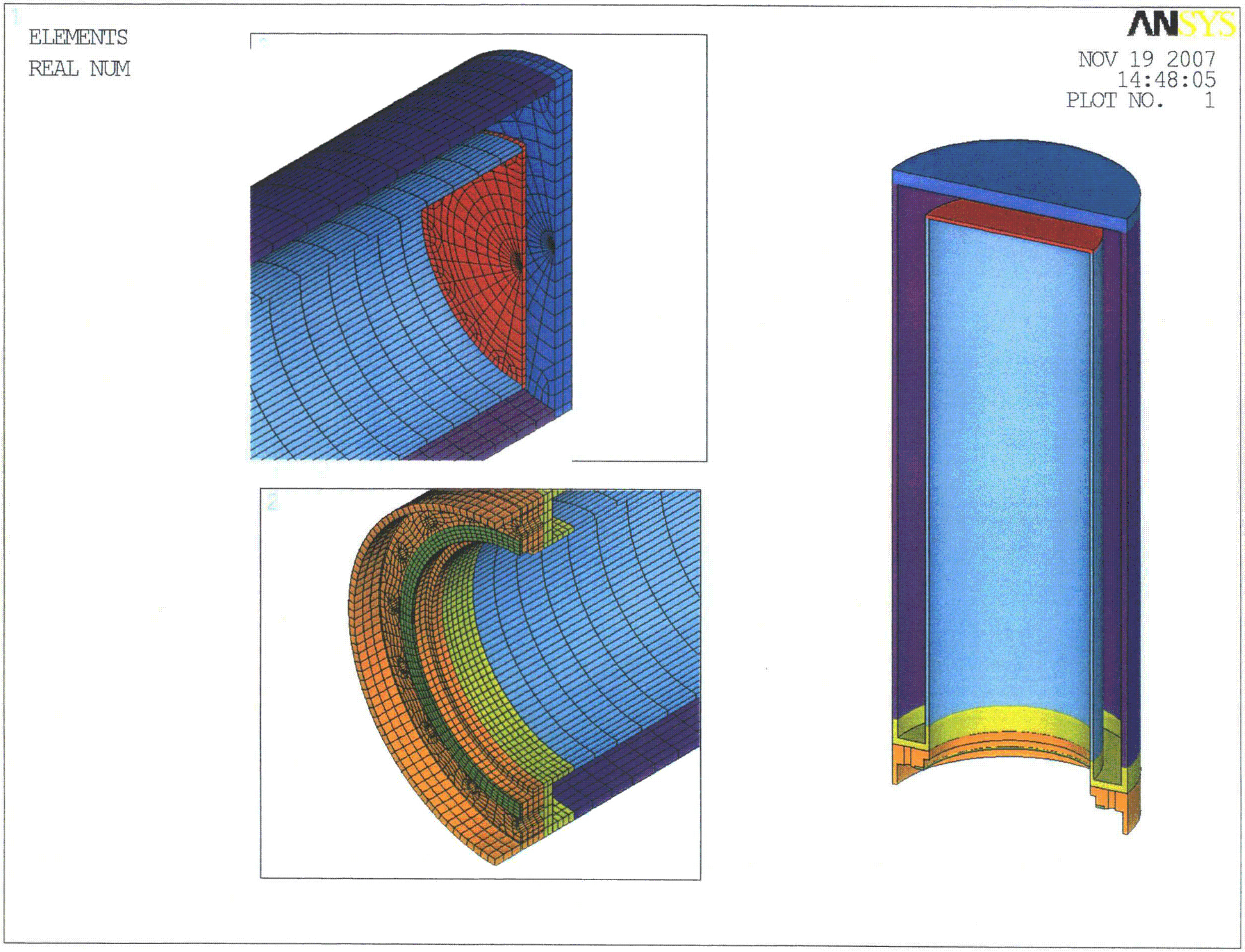


Figure 3
Finite Element Model of the cask Body without the Lead

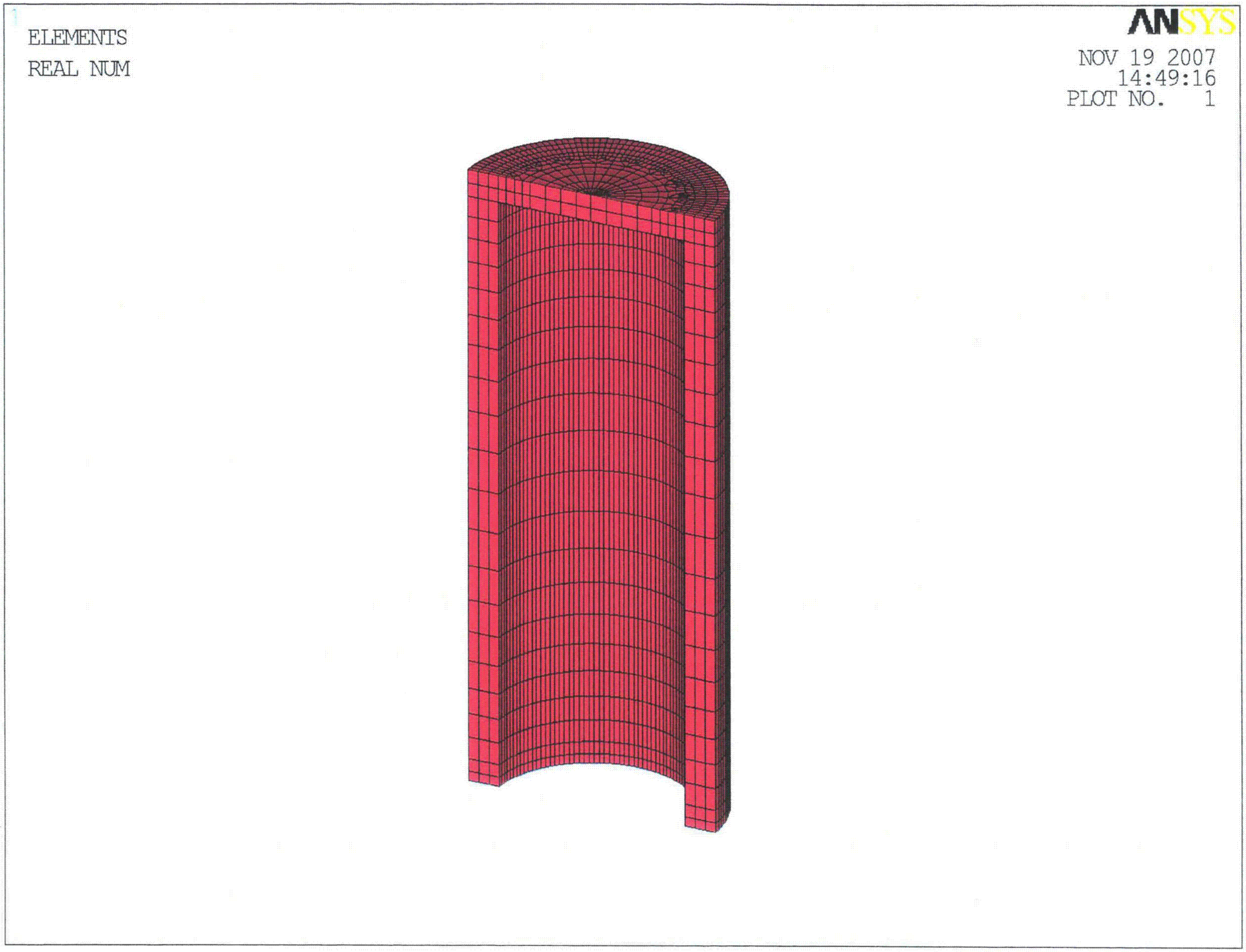


Figure 4

Finite Element Model of the Lead

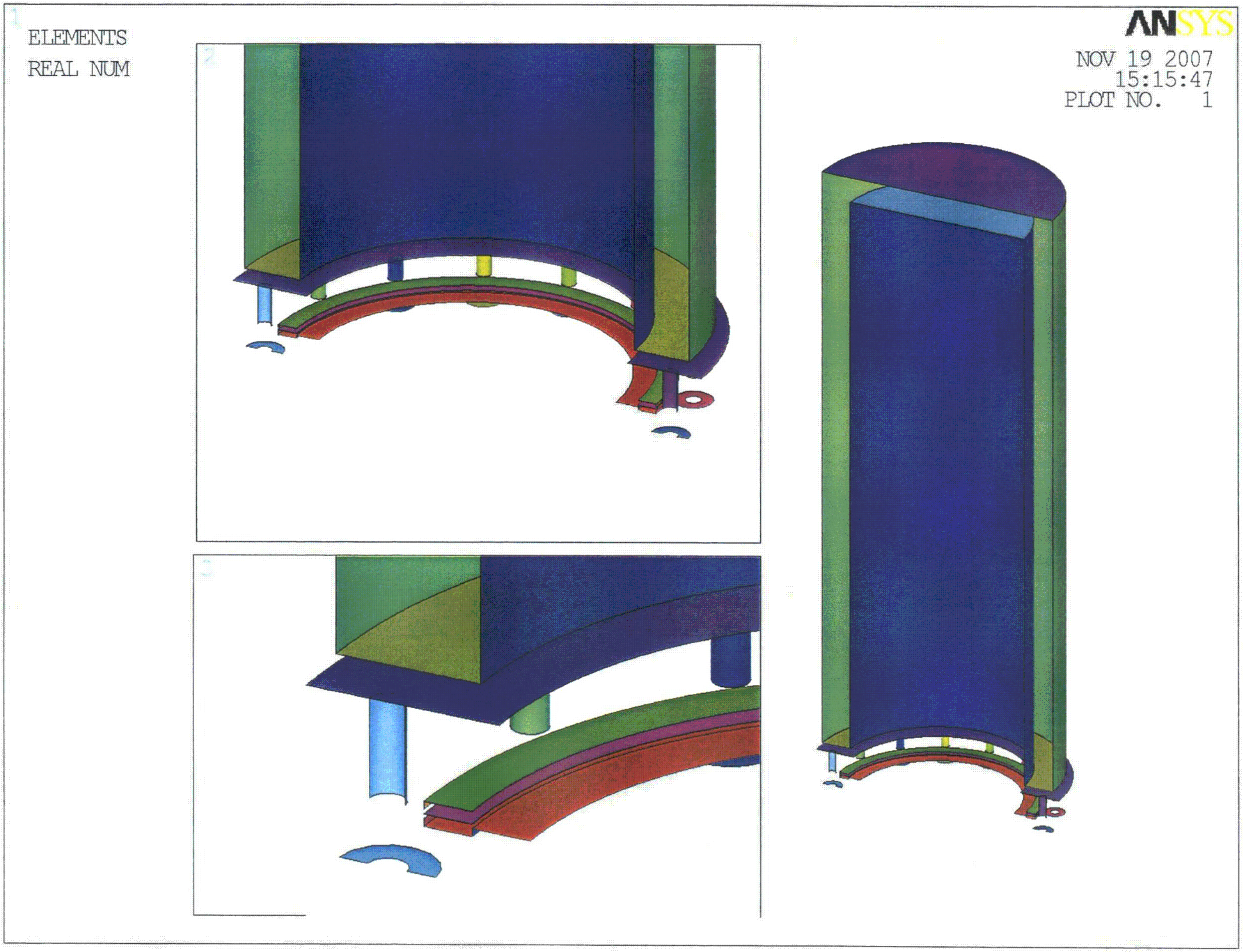


Figure 5

Finite Element Model of the Contact-Target Elements (Only Target Elements Shown)

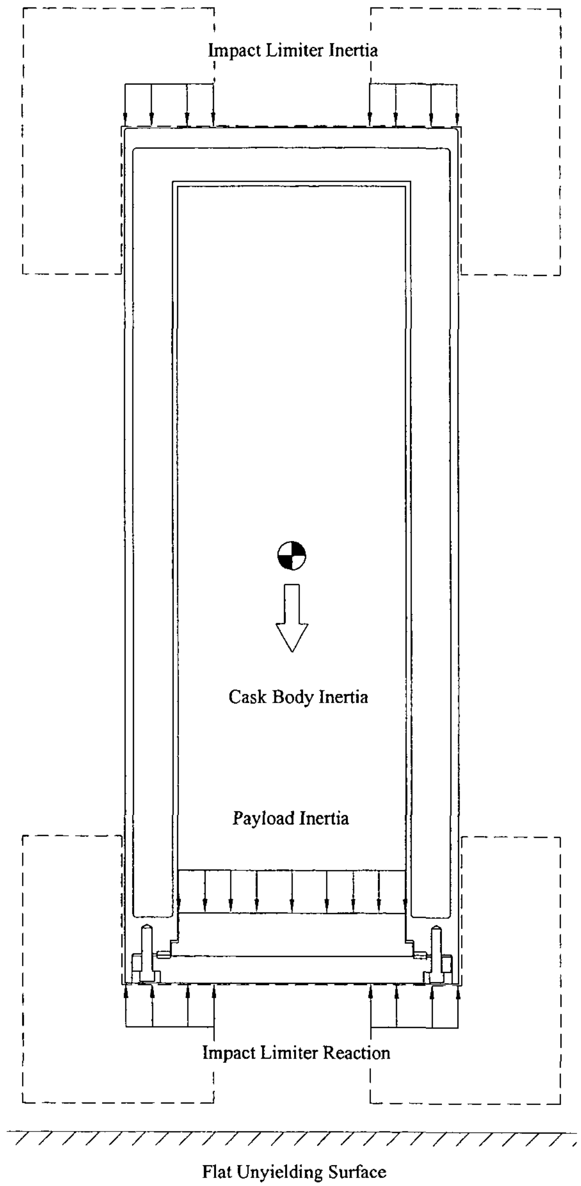


Figure 6

Load Distribution on the Model during End Drop

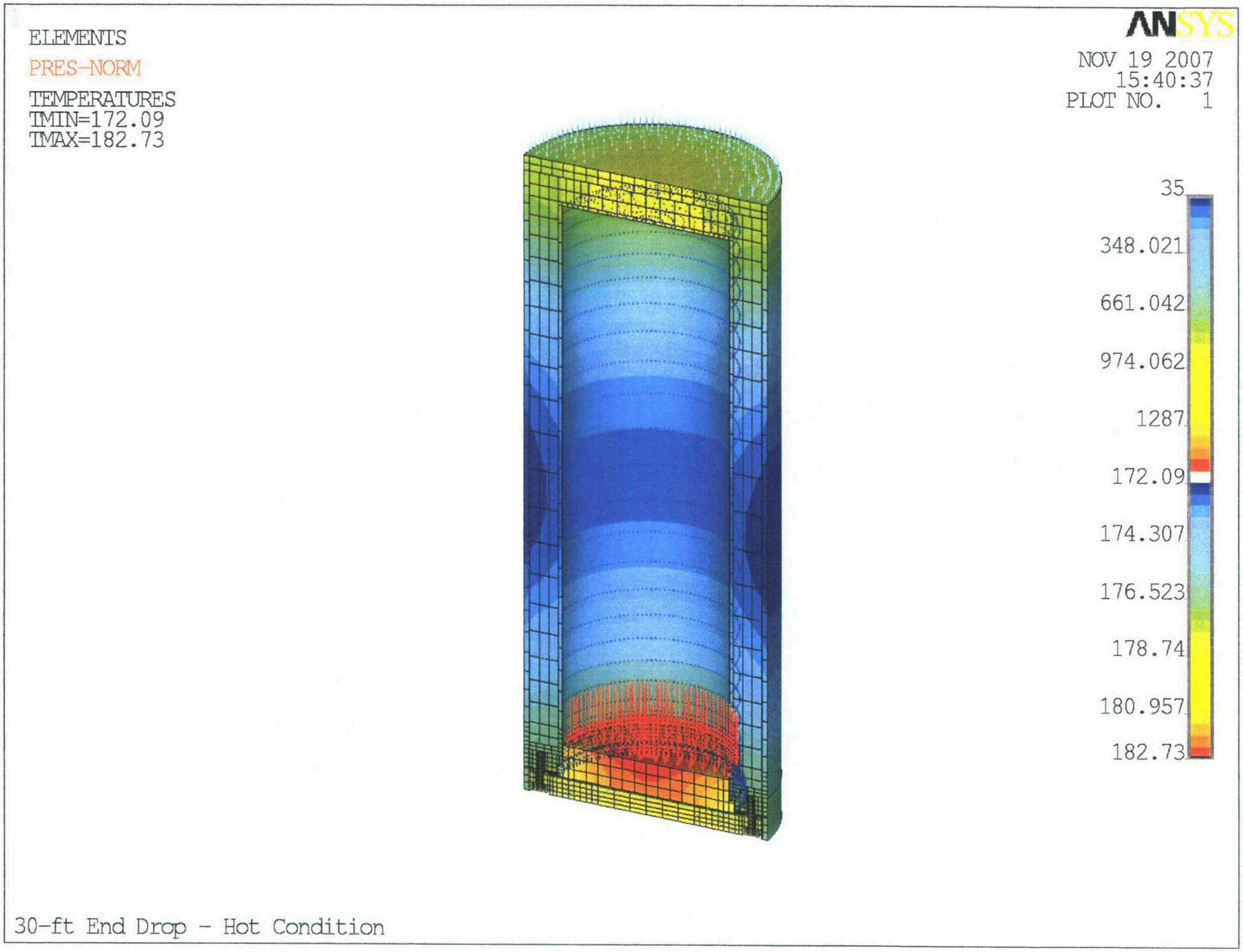


Figure 7

Temperature Profile and Pressure Distribution Used for 30-ft End Drop – Load Combination No.1

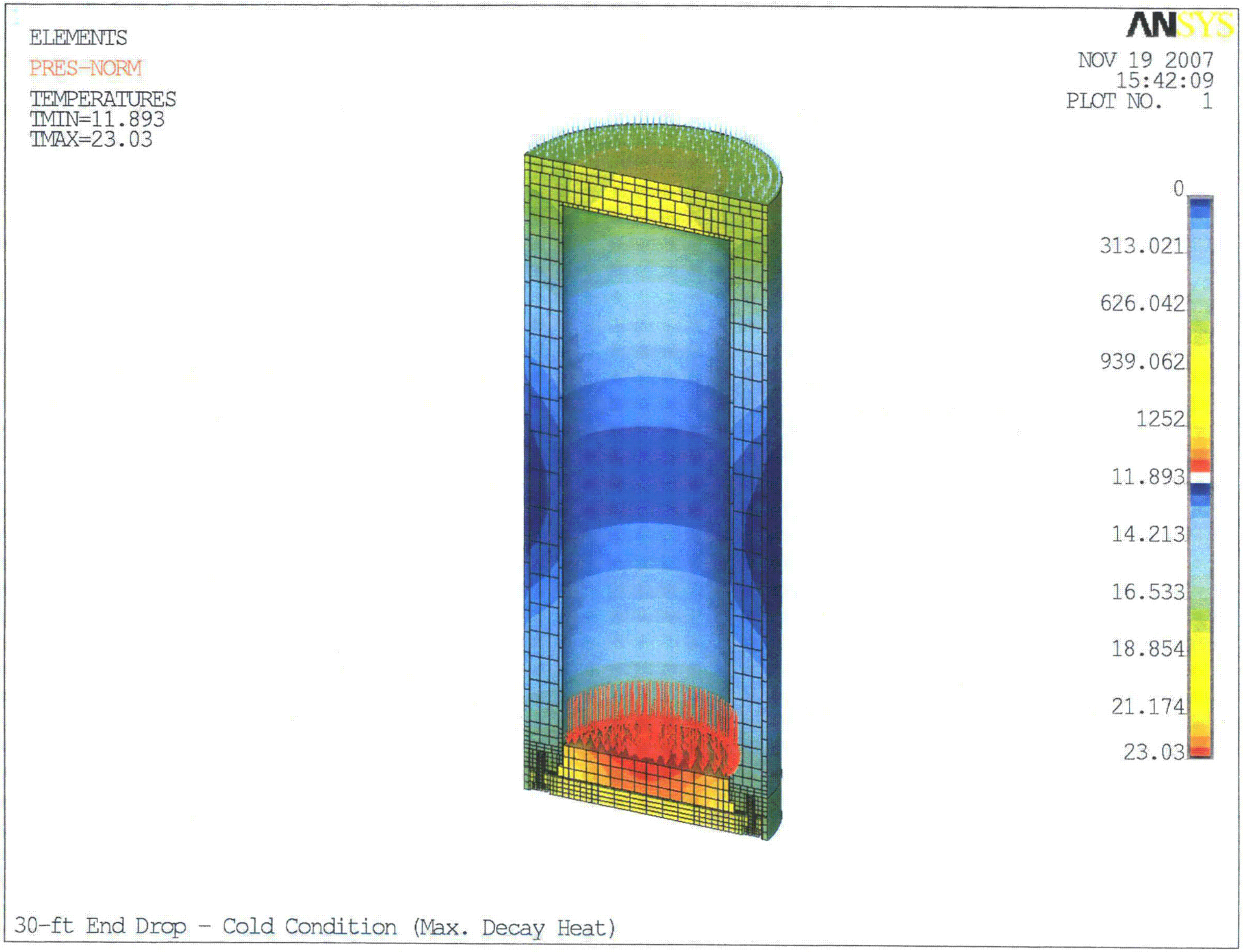


Figure 8

Temperature Profile and Pressure Distribution Used for 30-ft End Drop – Load Combination No.2

Figure 9

Temperature Profile and Pressure Distribution Used for 30-ft End Drop – Load Combination No.3

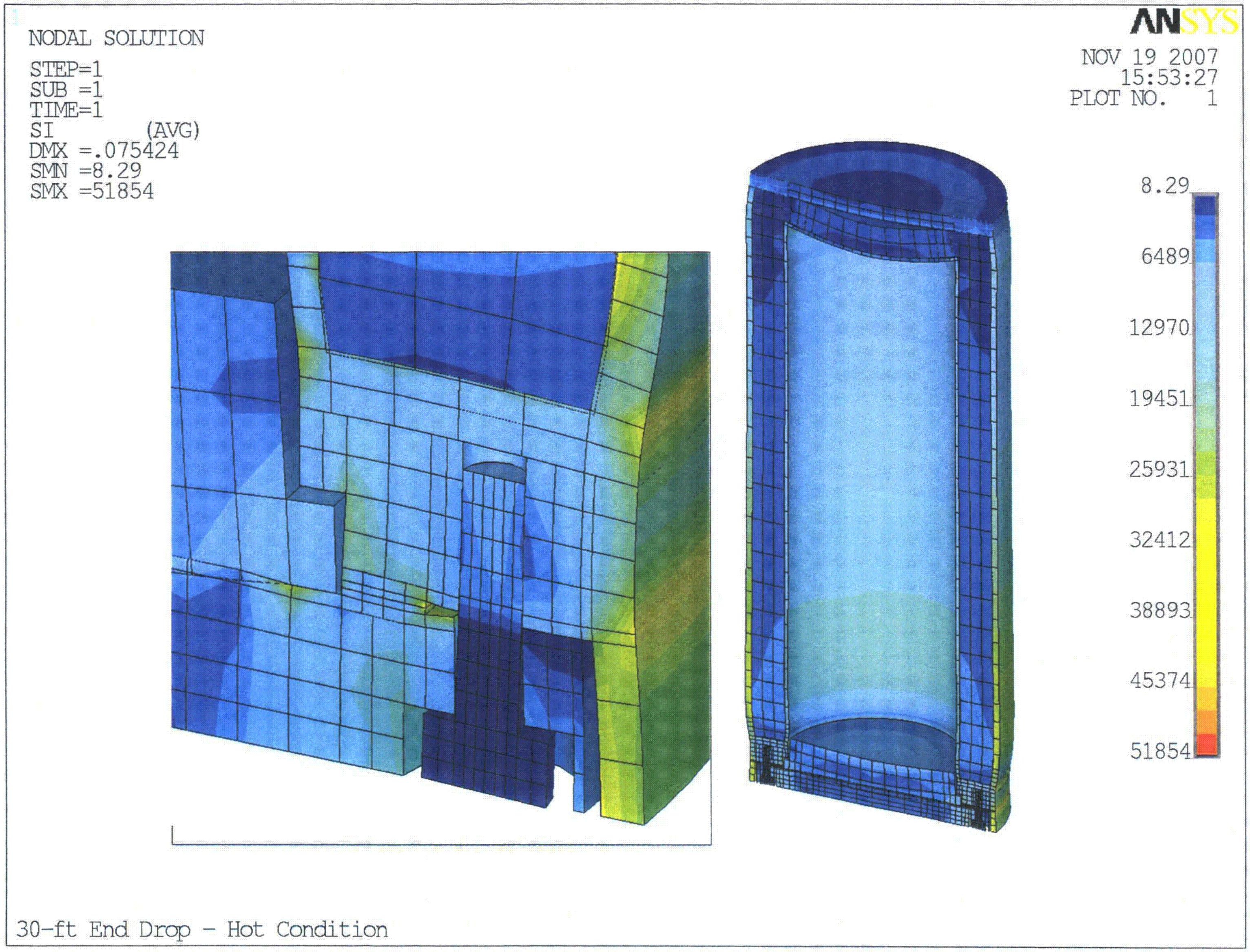


Figure 10

Stress Intensity Plot – 30-ft End Drop – Load Combination No.1

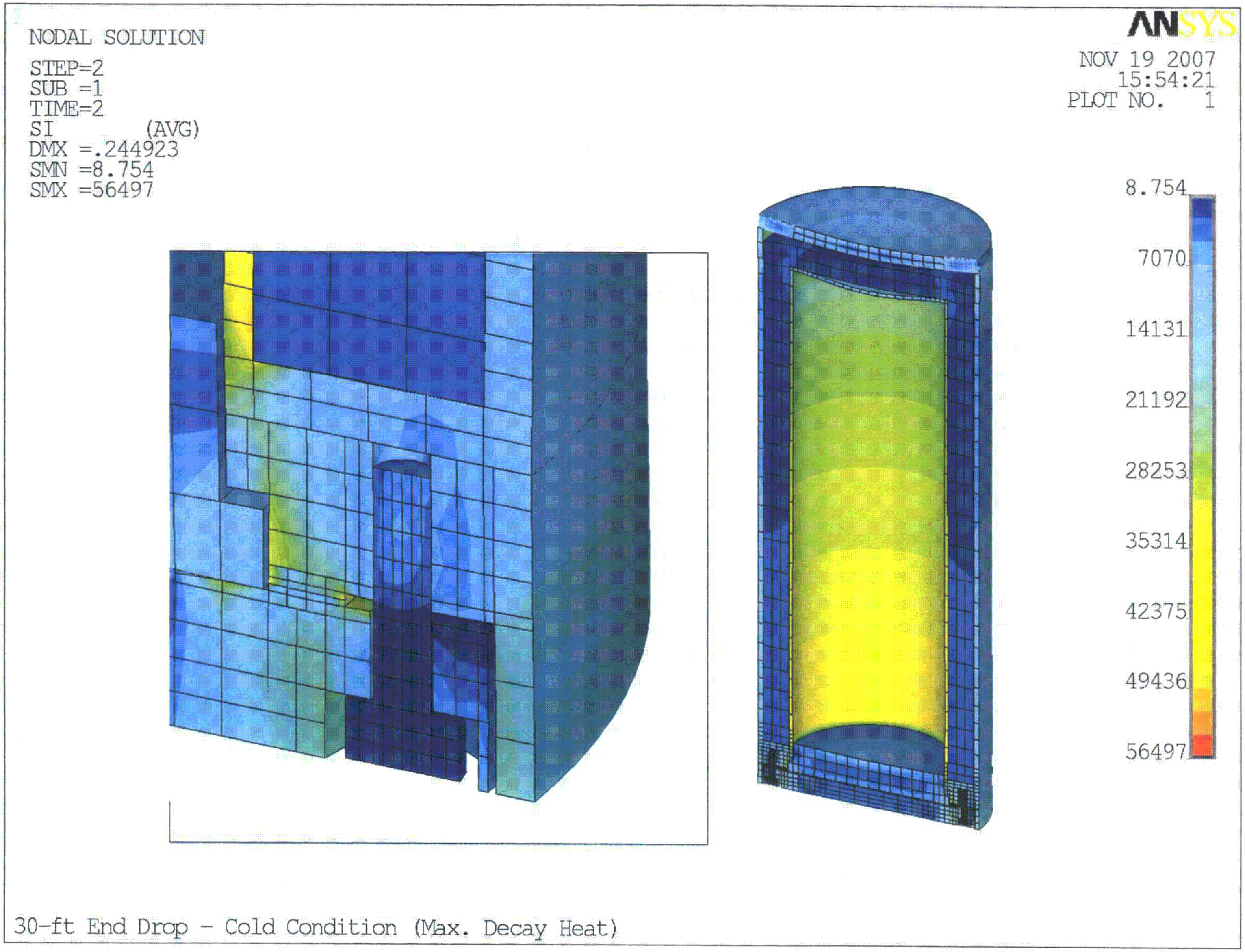


Figure 11

Stress Intensity Plot – 30-ft End Drop – Load Combination No.2

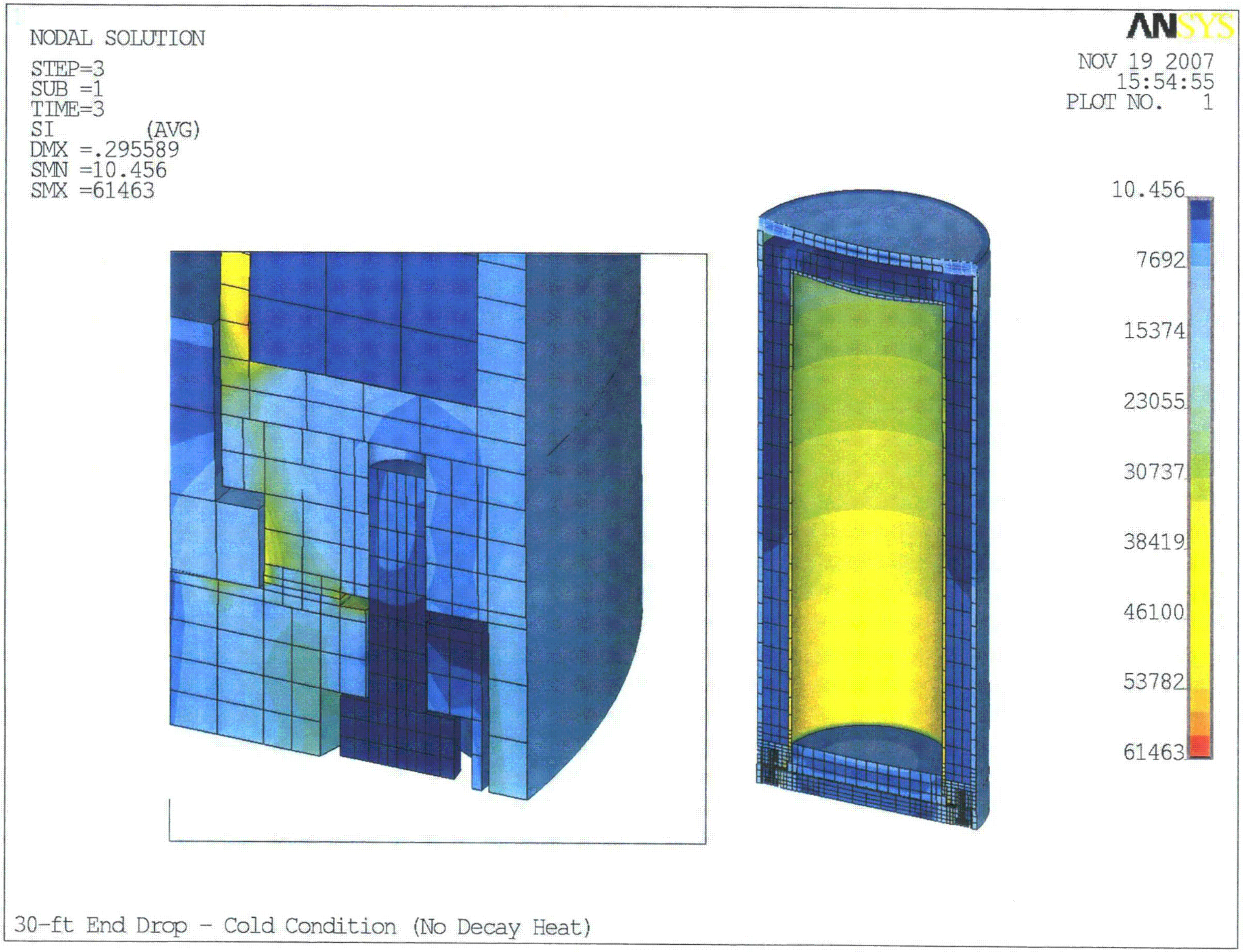


Figure 12

Stress Intensity Plot – 30-ft End Drop – Load Combination No.3

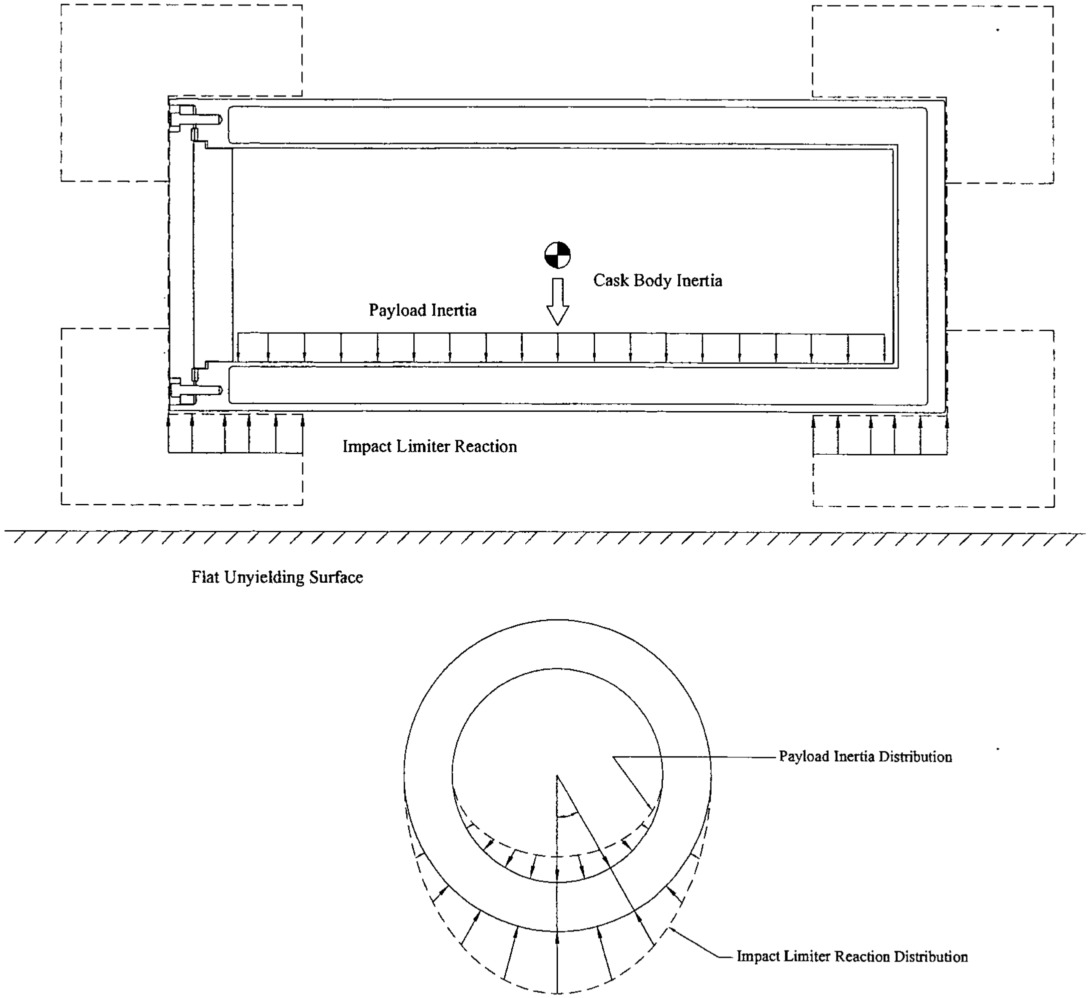


Figure 13

Load Distribution on the Model during Side Drop

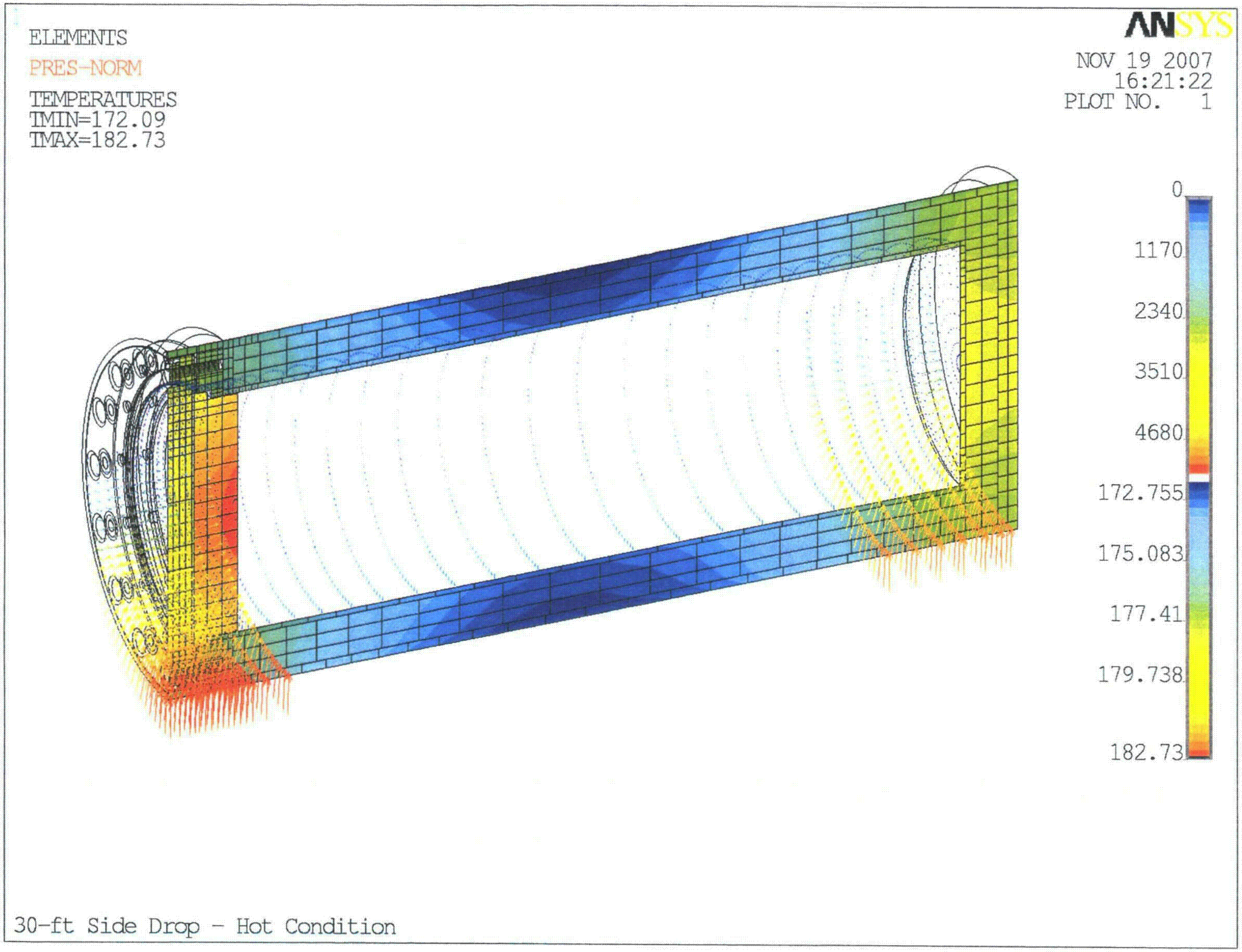


Figure 14

Temperature Profile and Pressure Distribution Used for 30-ft Side Drop – Load Combination No.1

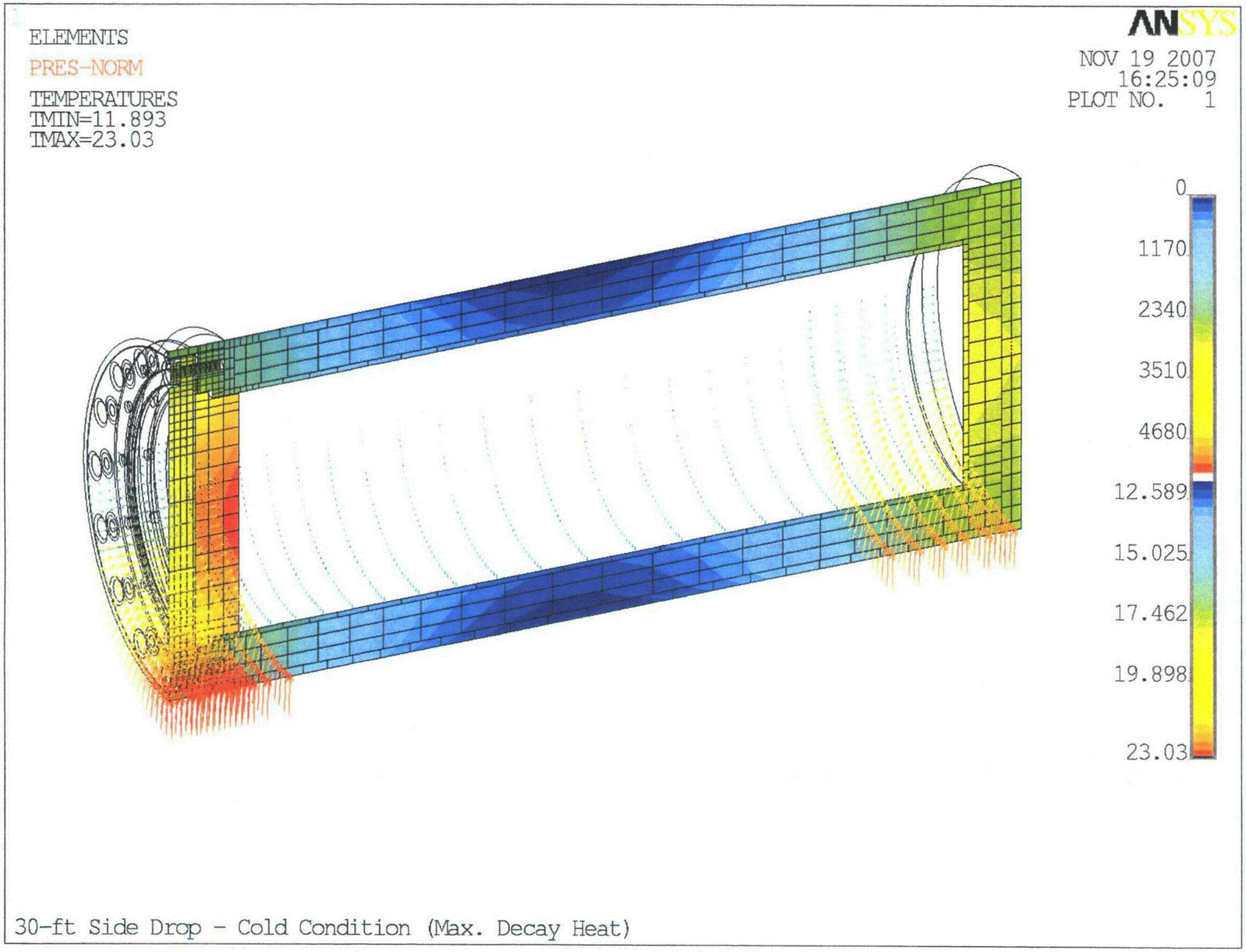


Figure 15

Temperature Profile and Pressure Distribution Used for 30-ft Side Drop – Load Combination No.2

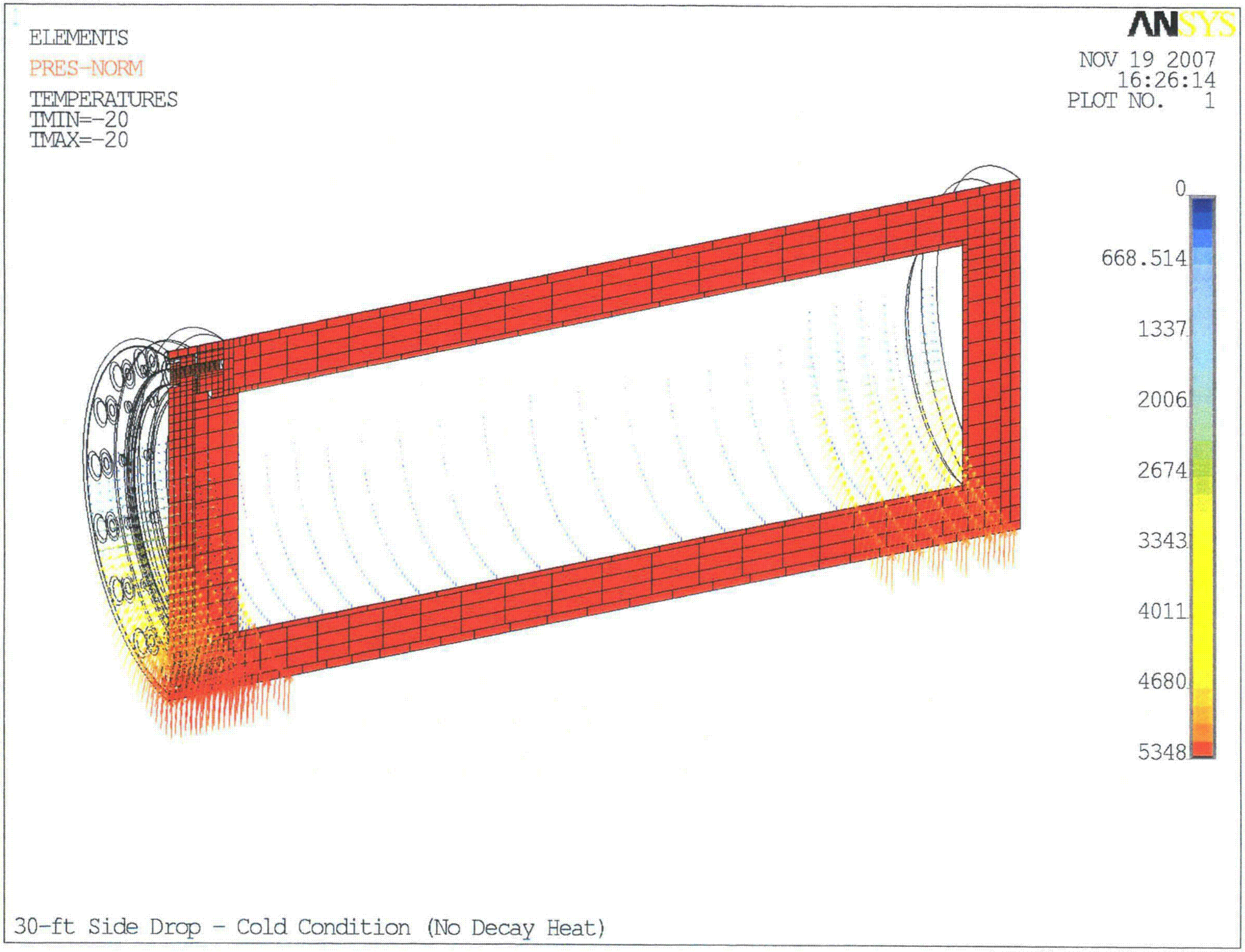


Figure 16

Temperature Profile and Pressure Distribution Used for 30-ft Side Drop – Load Combination No.3

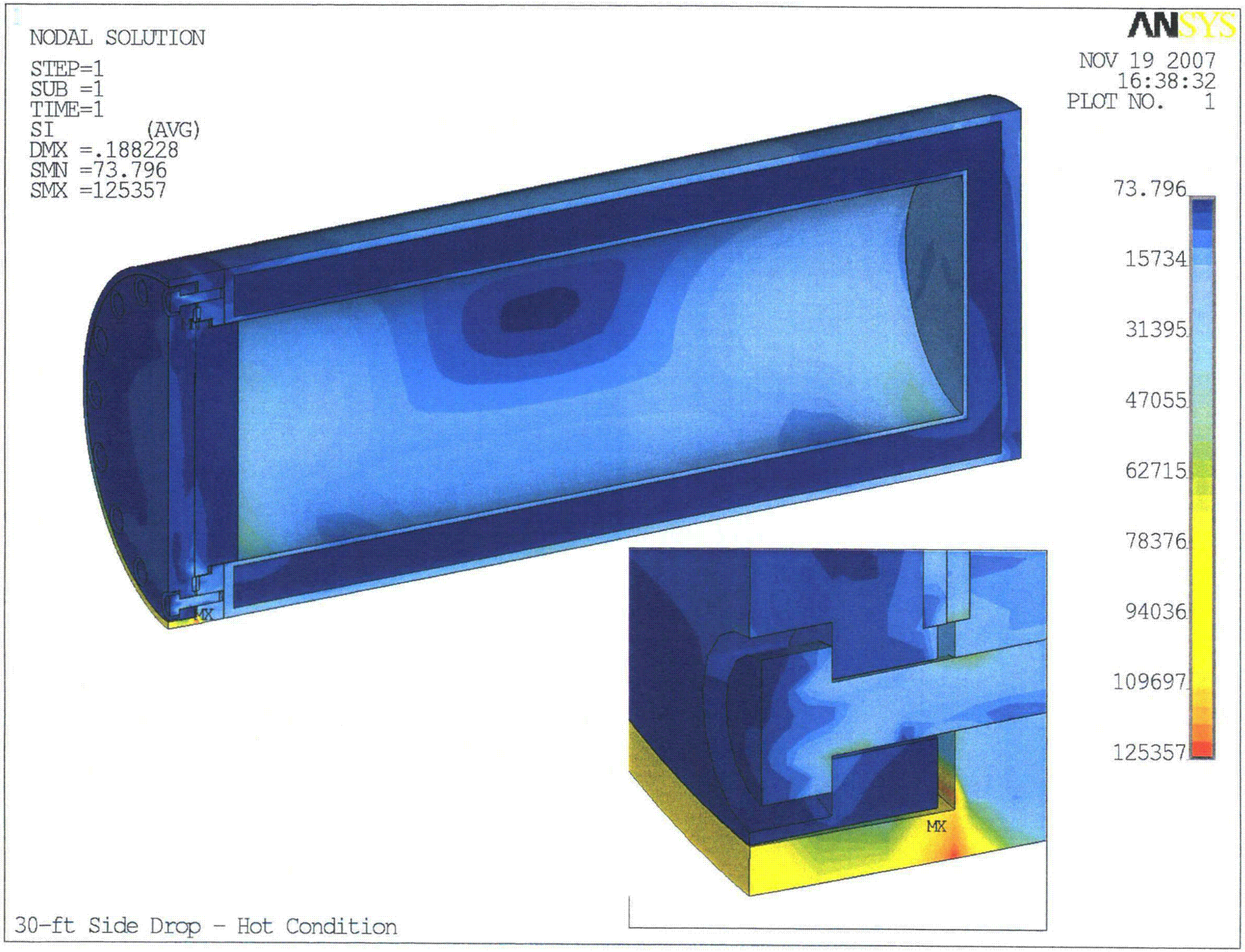


Figure 17

Stress Intensity Plot – 30-ft Side Drop – Load Combination No.1

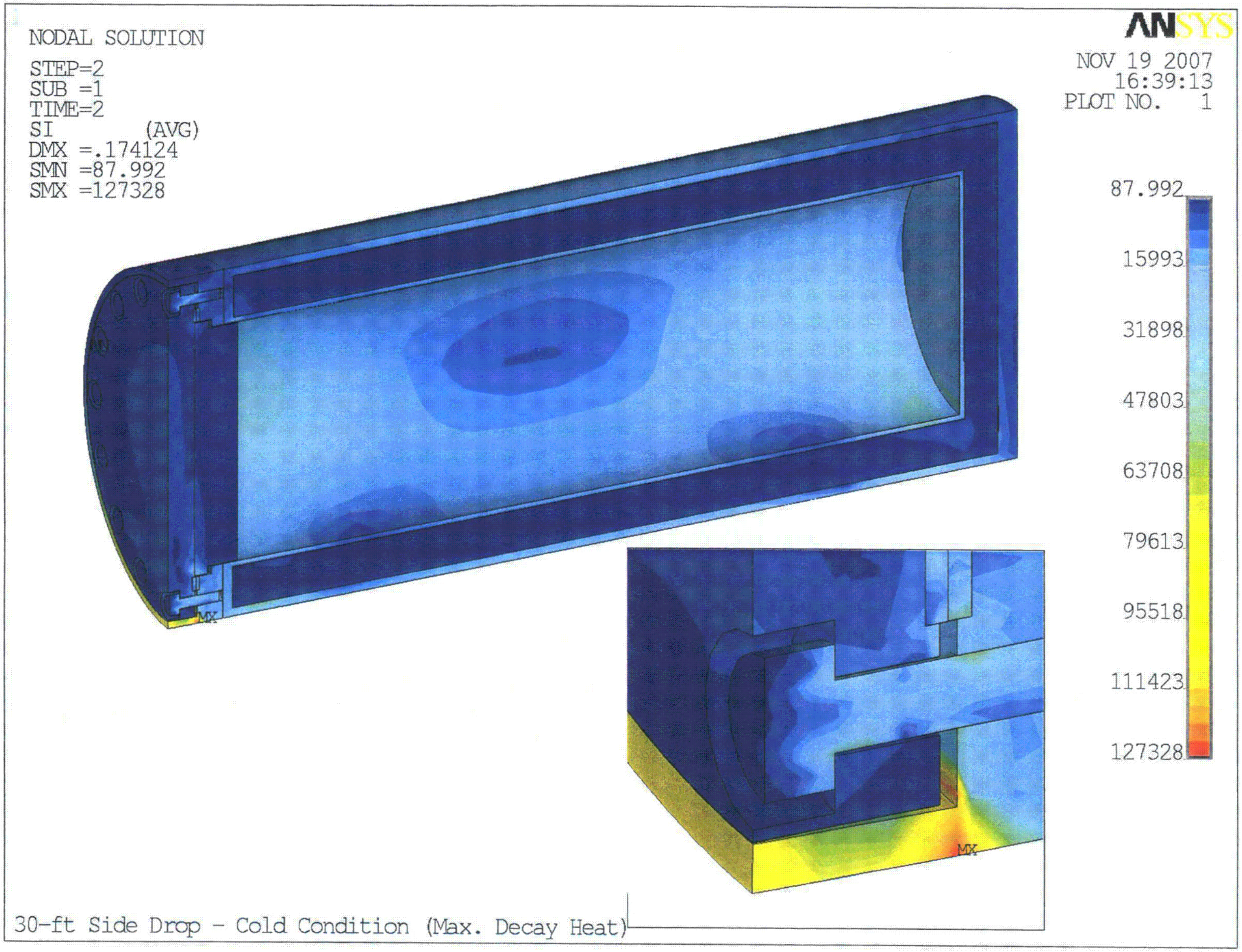


Figure 18

Stress Intensity Plot – 30-ft Side Drop – Load Combination No.2

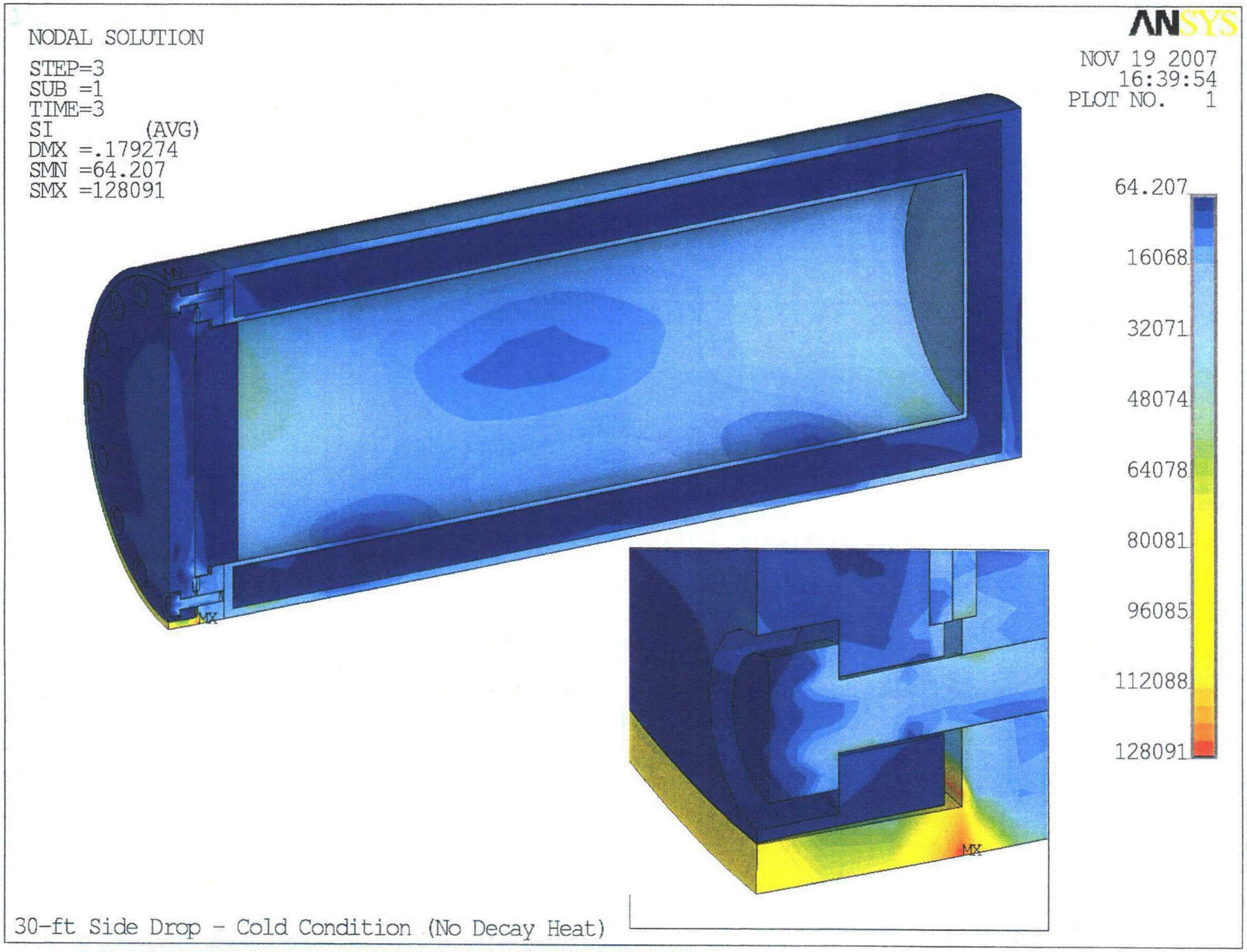


Figure 19

Stress Intensity Plot – 30-ft Side Drop – Load Combination No.3

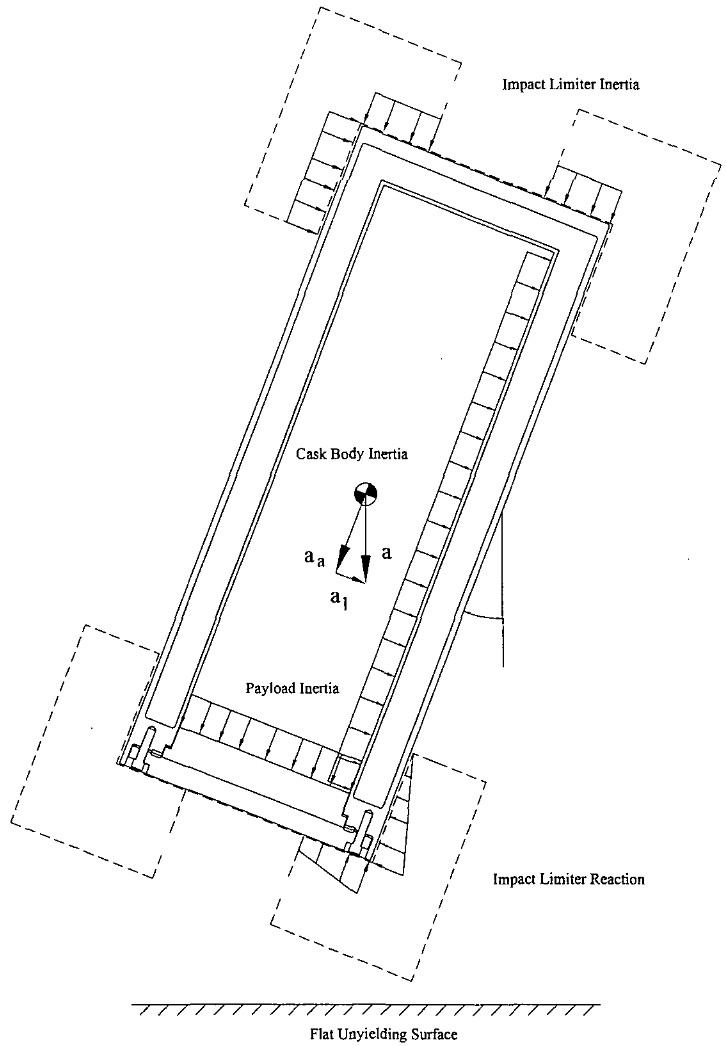


Figure 20

Load Distribution on the Model during Corner Drop

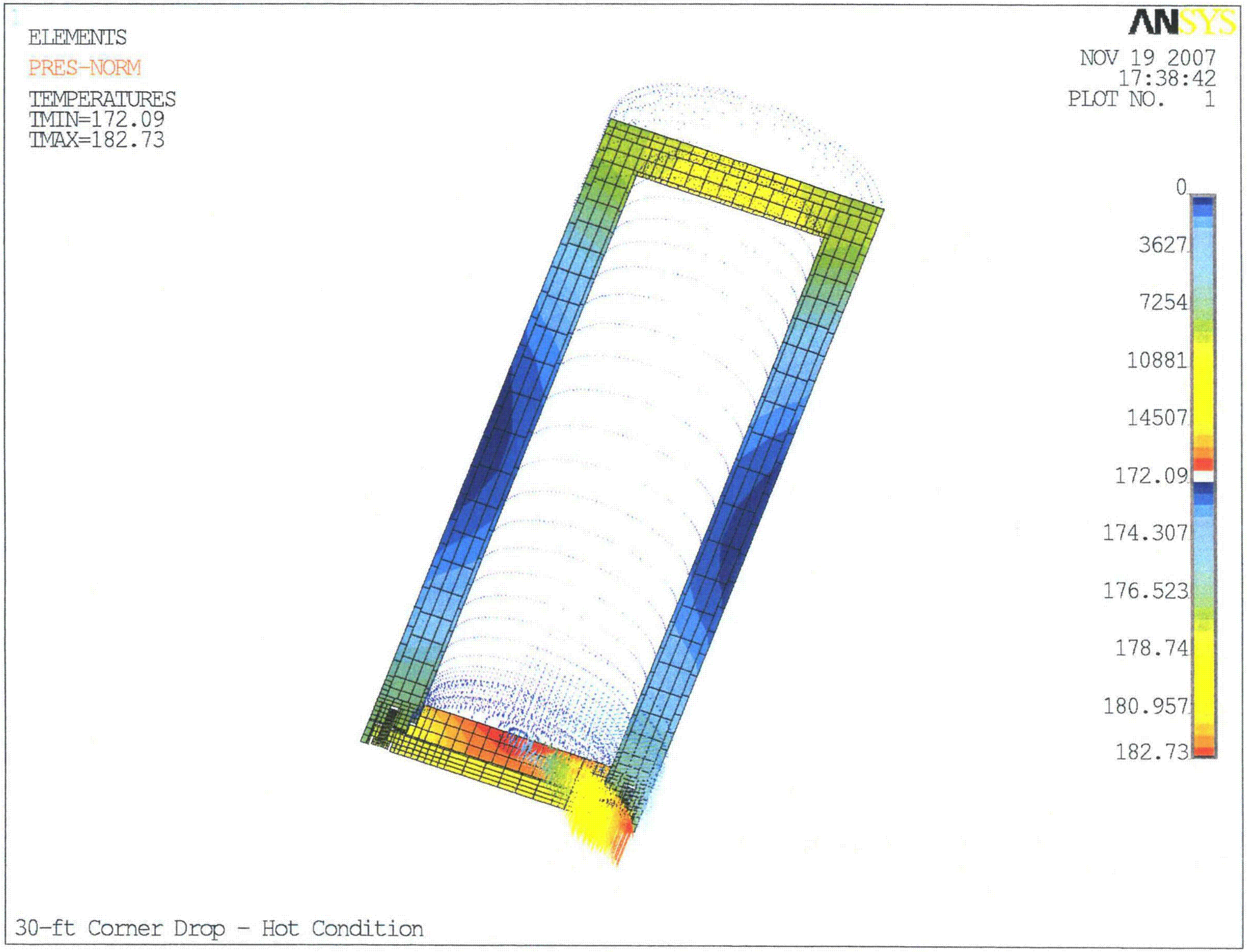


Figure 21

Temperature Profile and Pressure Distribution Used for 30-ft Corner Drop – Load Combination No.1

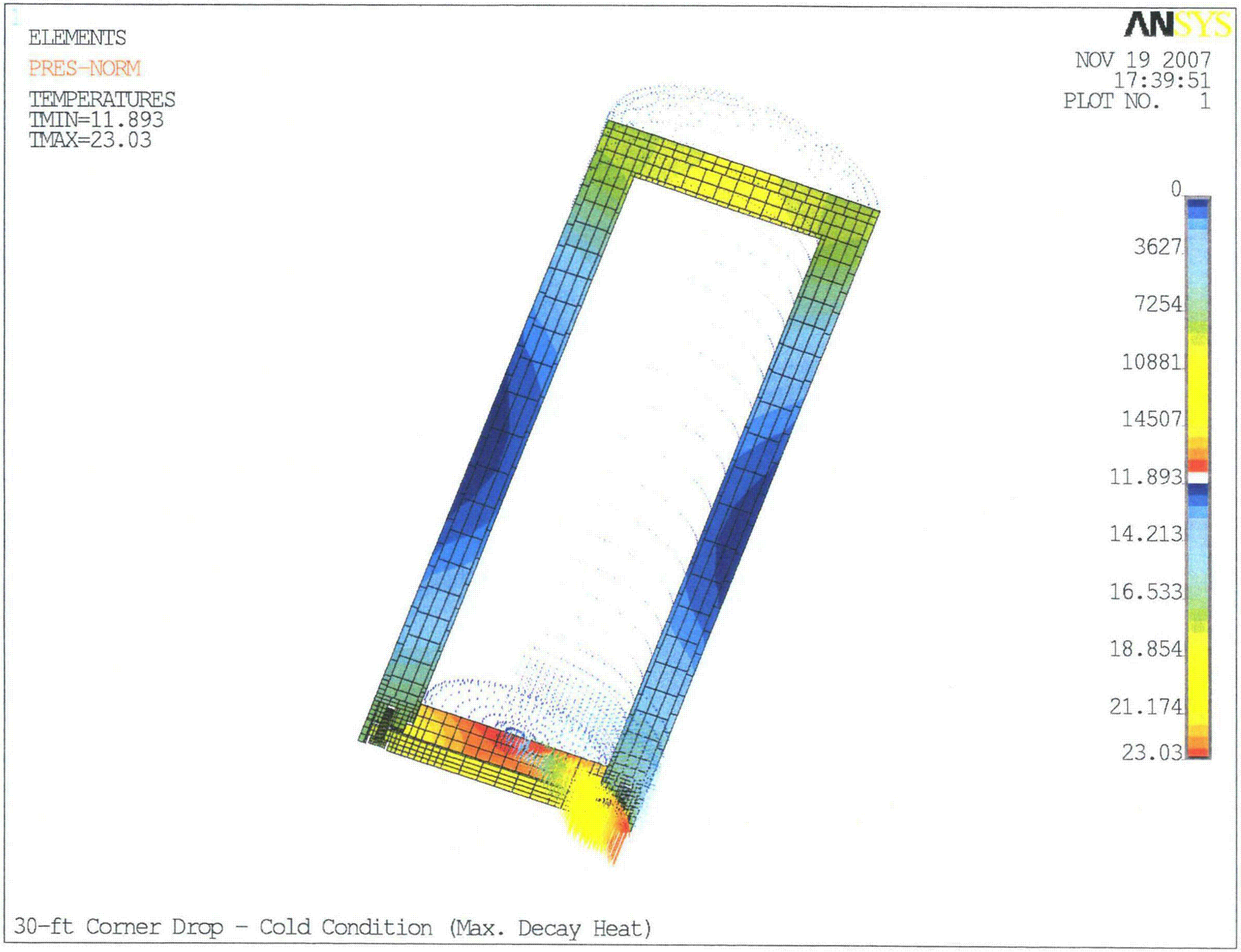


Figure 22

Temperature Profile and Pressure Distribution Used for 30-ft Corner Drop – Load Combination No.2

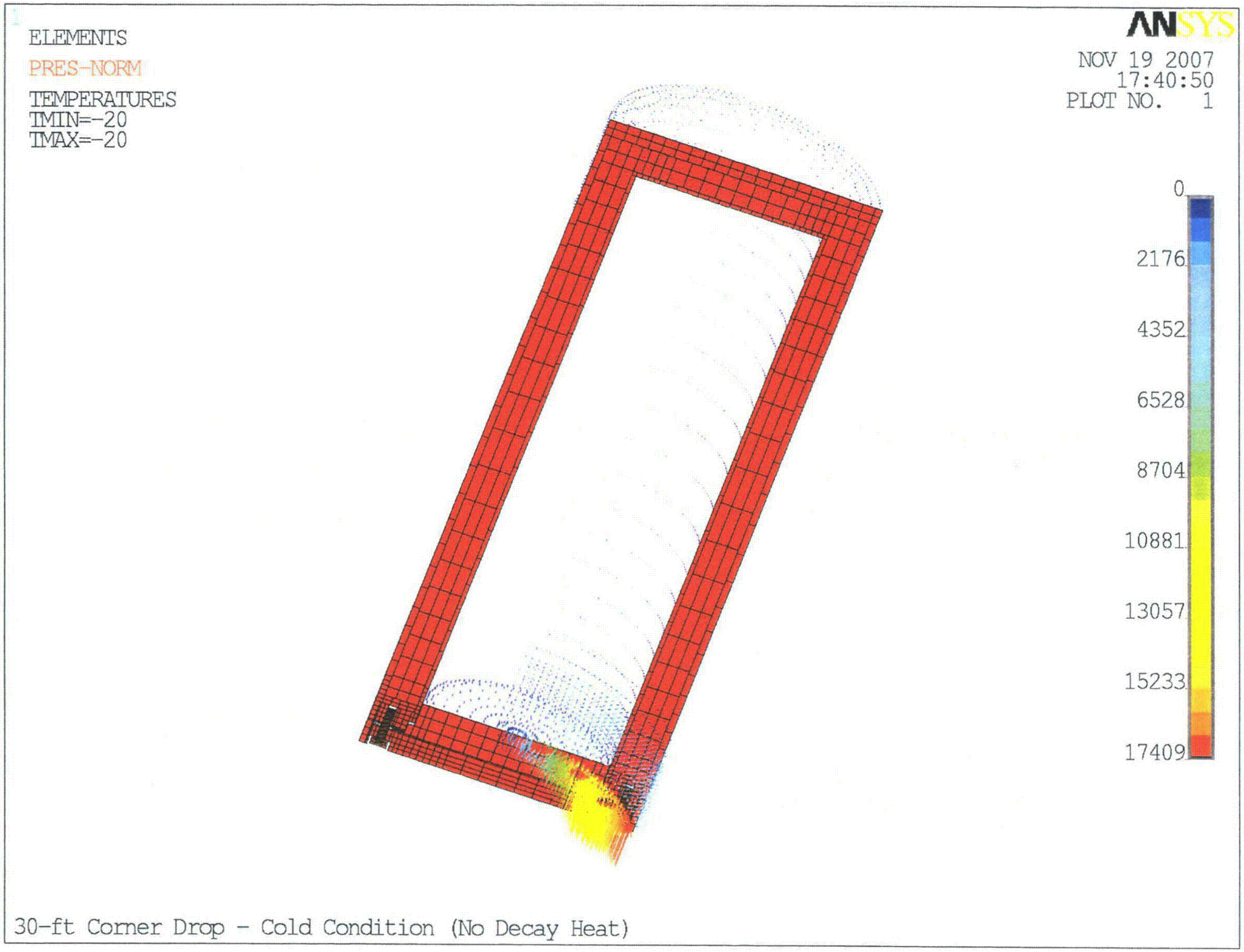


Figure 23

Temperature Profile and Pressure Distribution Used for 30-ft Corner Drop – Load Combination No.3

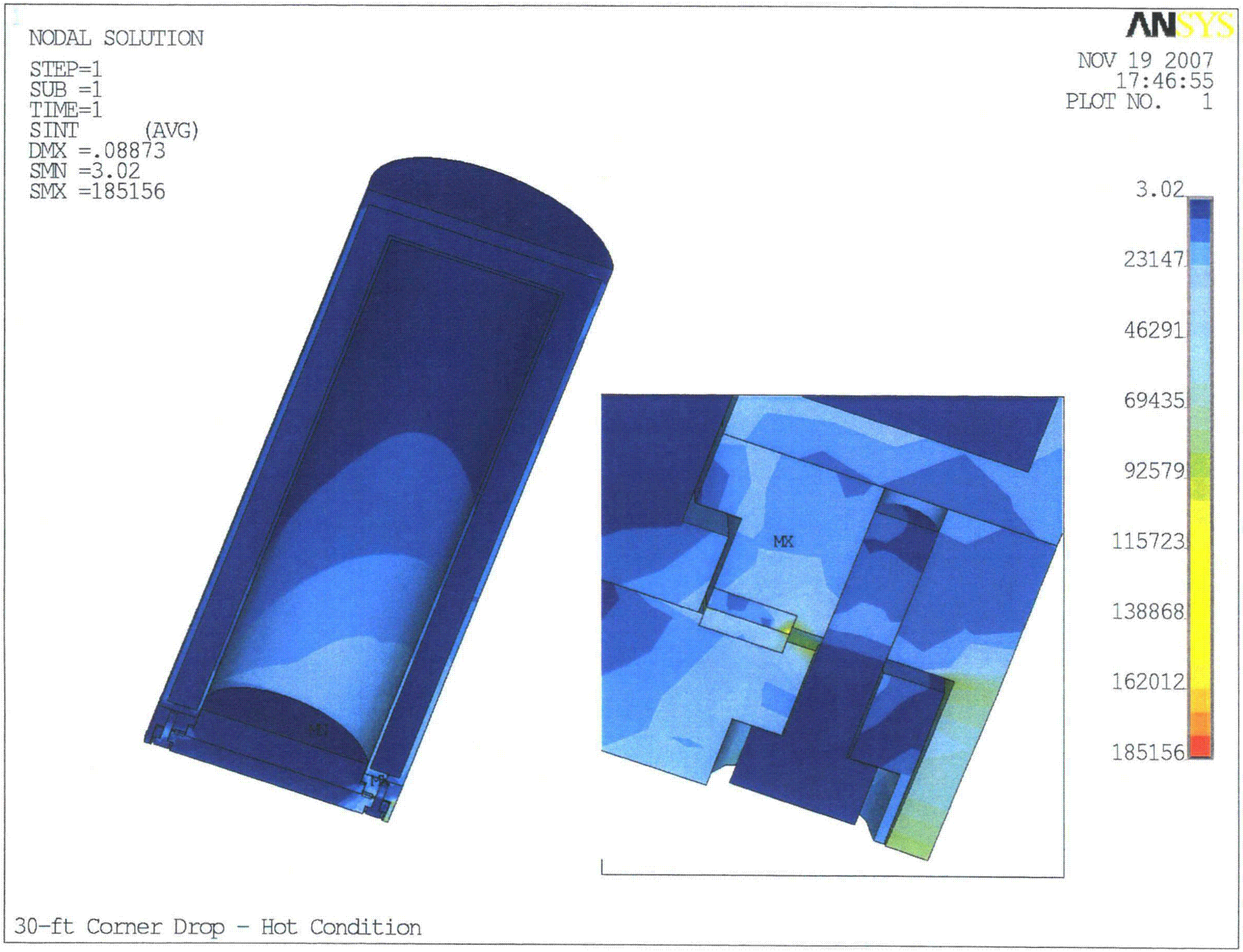


Figure 24

Stress Intensity Plot – 30-ft Corner Drop – Load Combination No.1

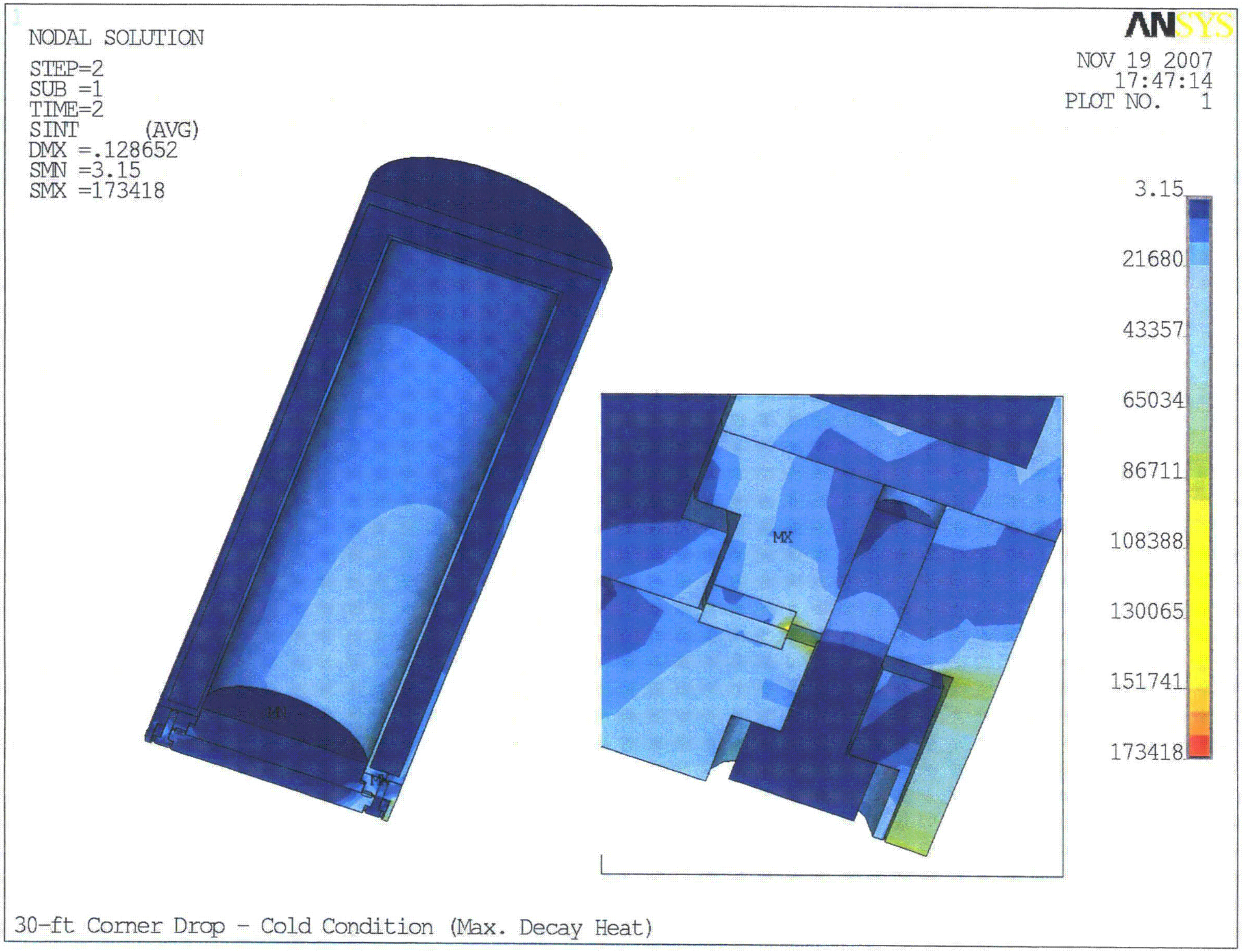


Figure 25

Stress Intensity Plot – 30-ft Corner Drop – Load Combination No.2

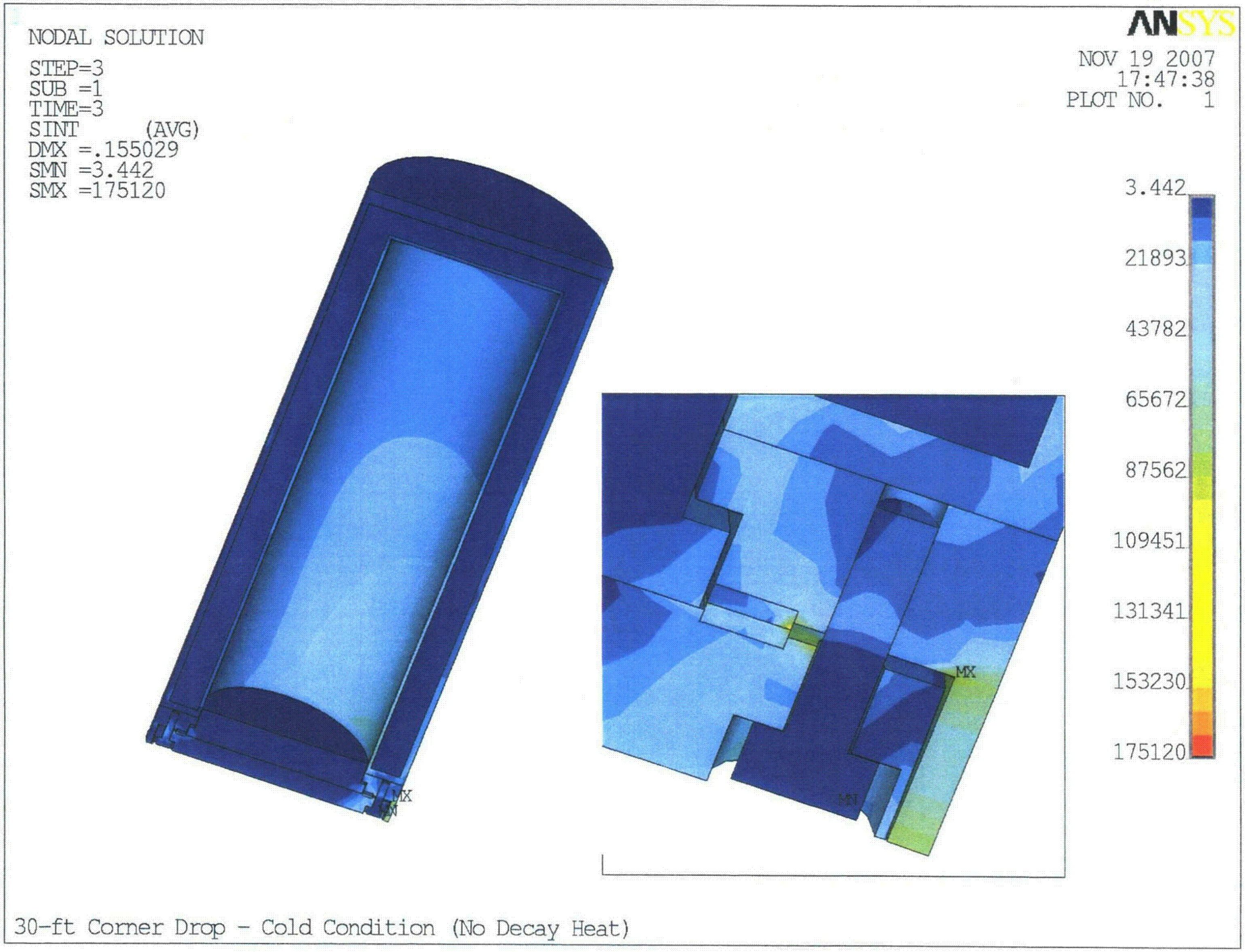


Figure 26

Stress Intensity Plot – 30-ft Corner Drop – Load Combination No.3

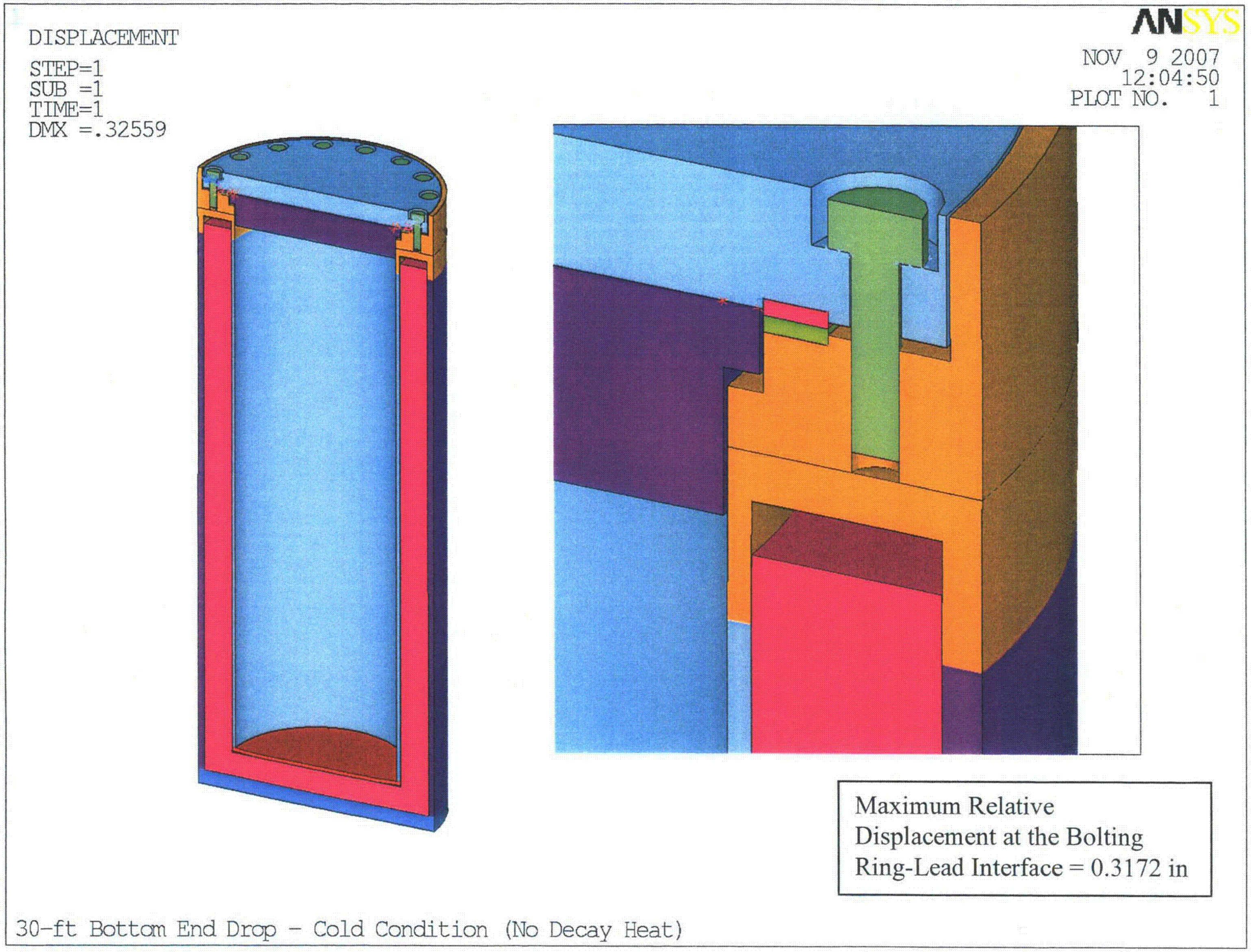


Figure 27

Displacements During 30-ft End Drop on the Bottom

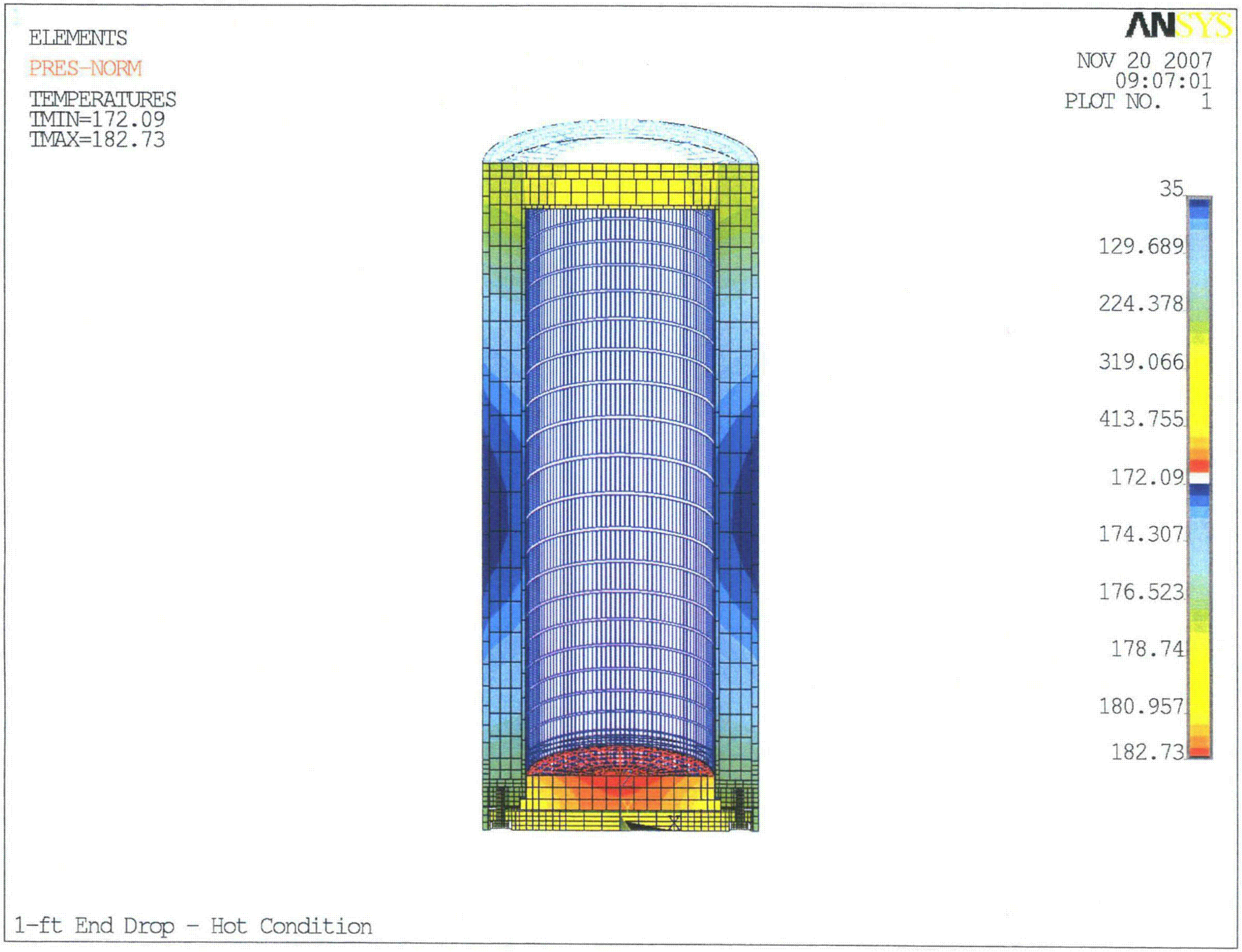


Figure 28

Temperature Profile and Pressure Distribution Used for 1-ft End Drop – Load Combination No.1

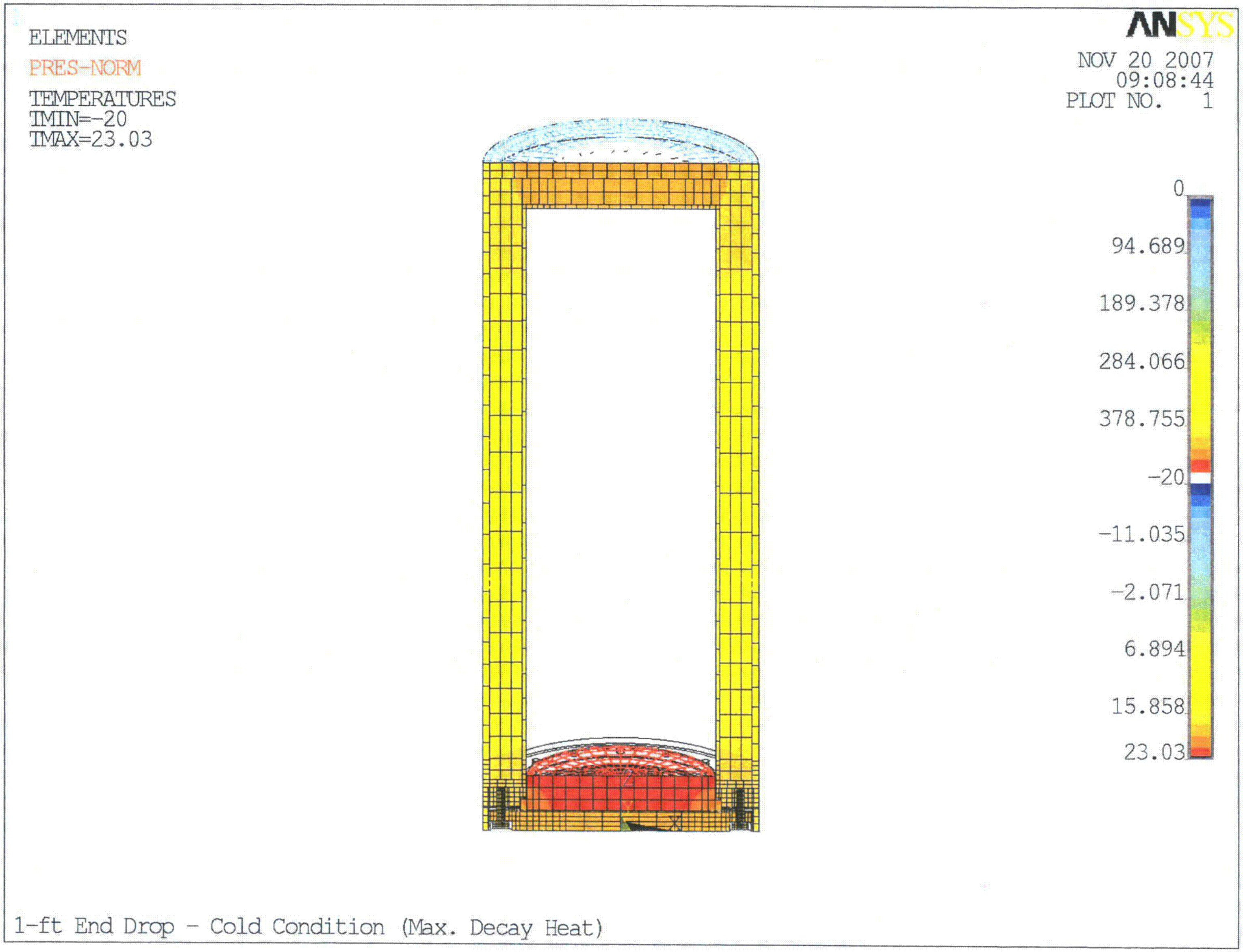


Figure 29

Temperature Profile and Pressure Distribution Used for 1-ft End Drop – Load Combination No.2

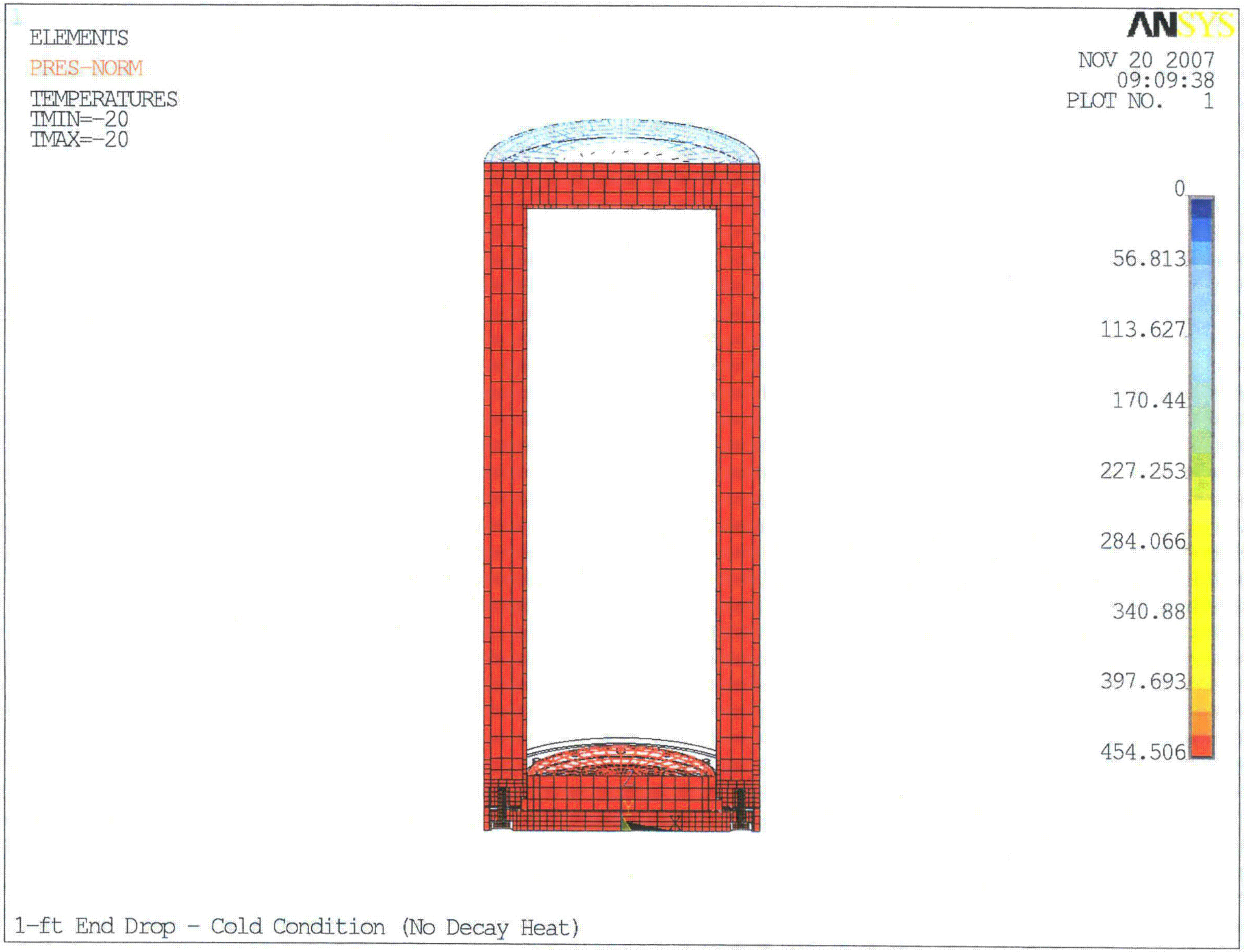


Figure 30

Temperature Profile and Pressure Distribution Used for 1-ft End Drop – Load Combination No.3

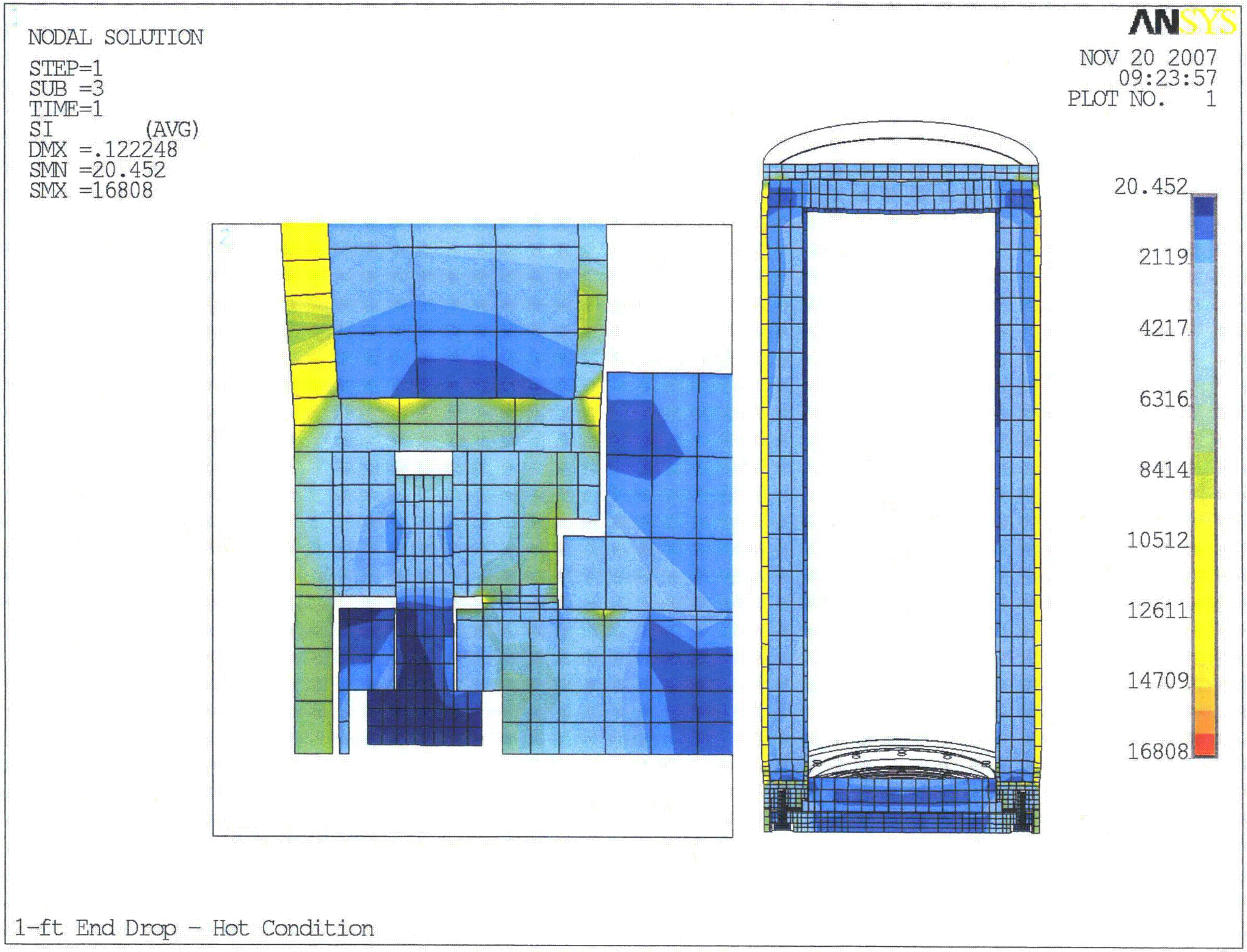


Figure 31

Stress Intensity Plot – 1-ft End Drop – Load Combination No.1

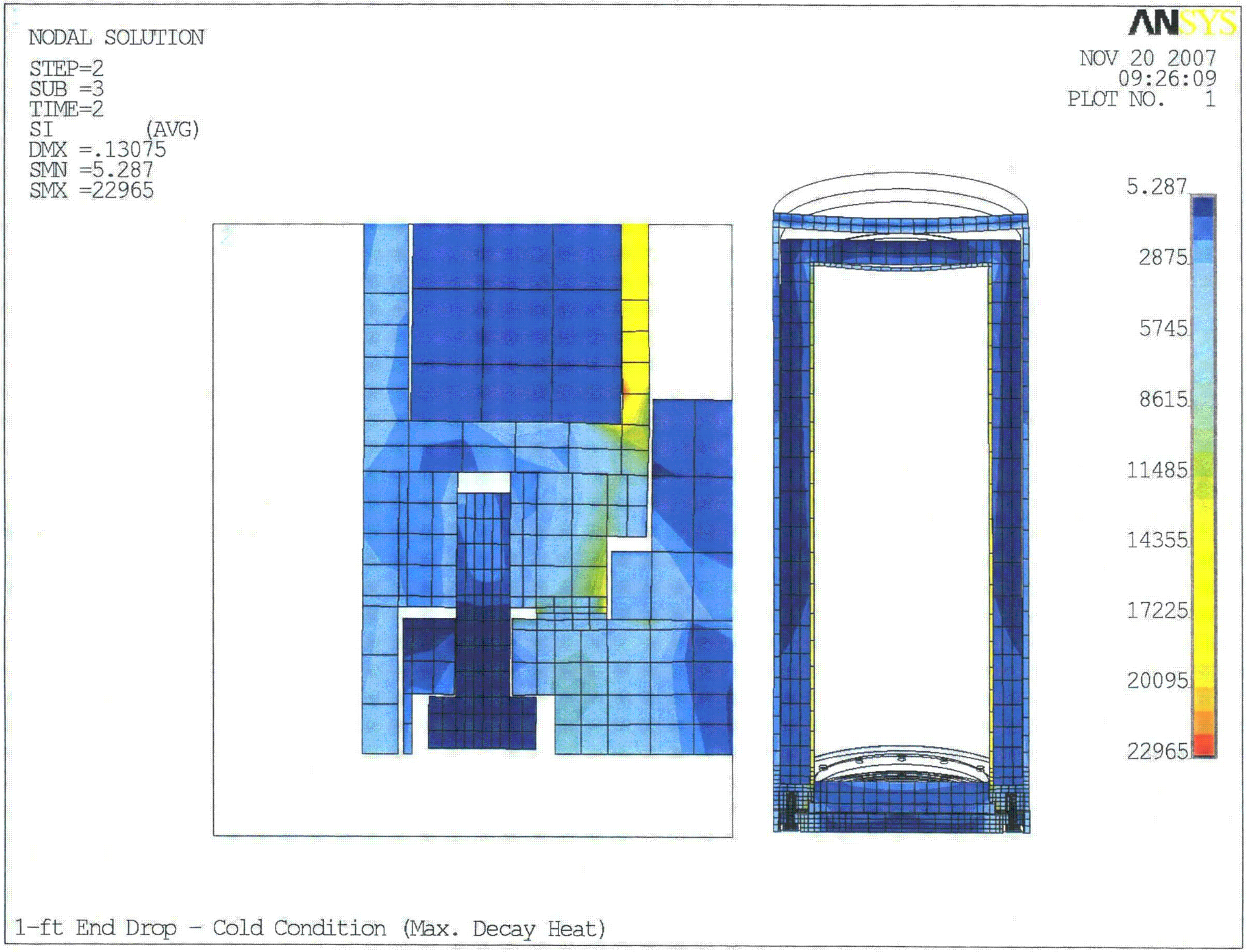


Figure 32

Stress Intensity Plot – 1-ft End Drop – Load Combination No.2

Figure 33

Stress Intensity Plot – 1-ft End Drop – Load Combination No.3

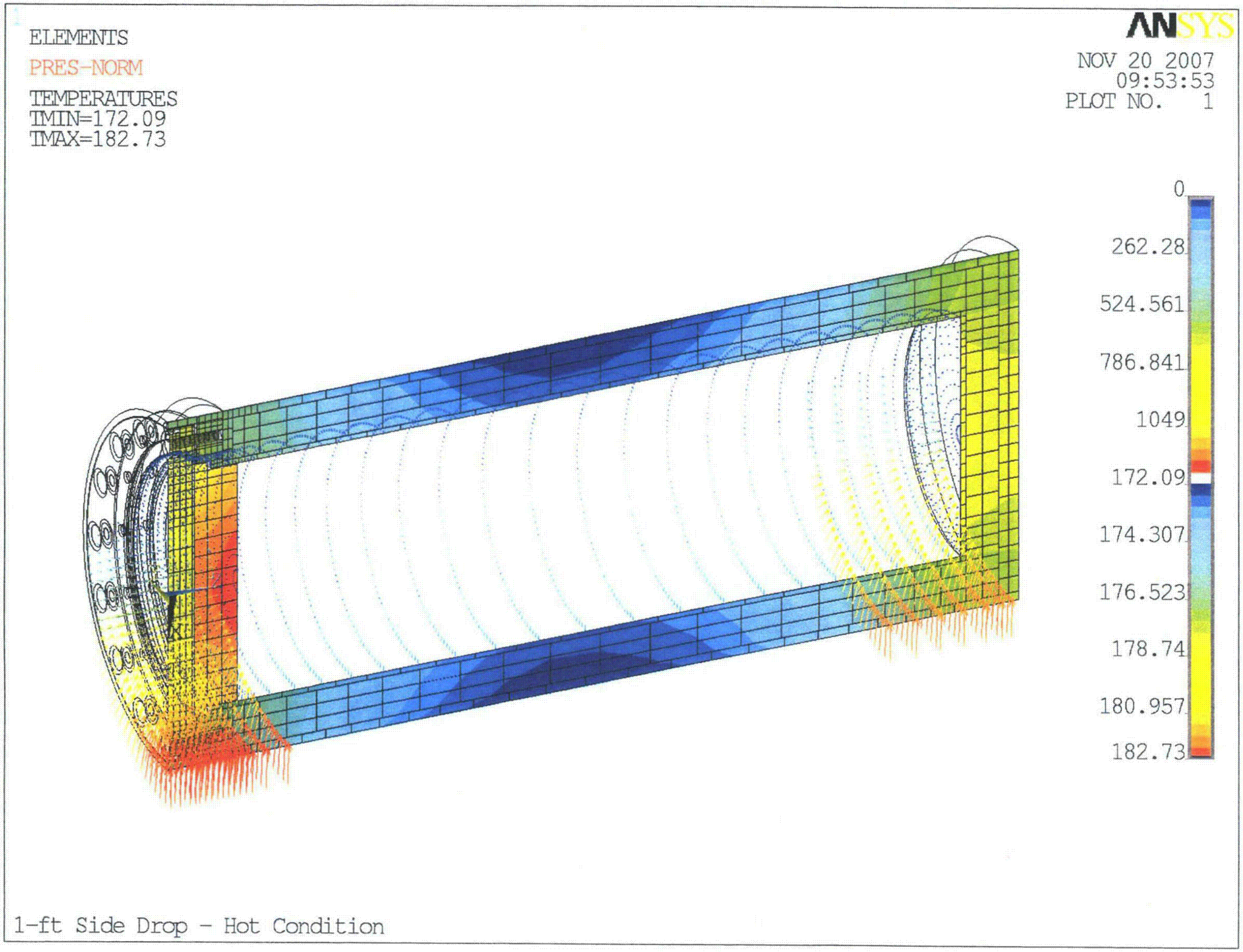


Figure 34

Temperature Profile and Pressure Distribution Used for 1-ft Side Drop – Load Combination No.1

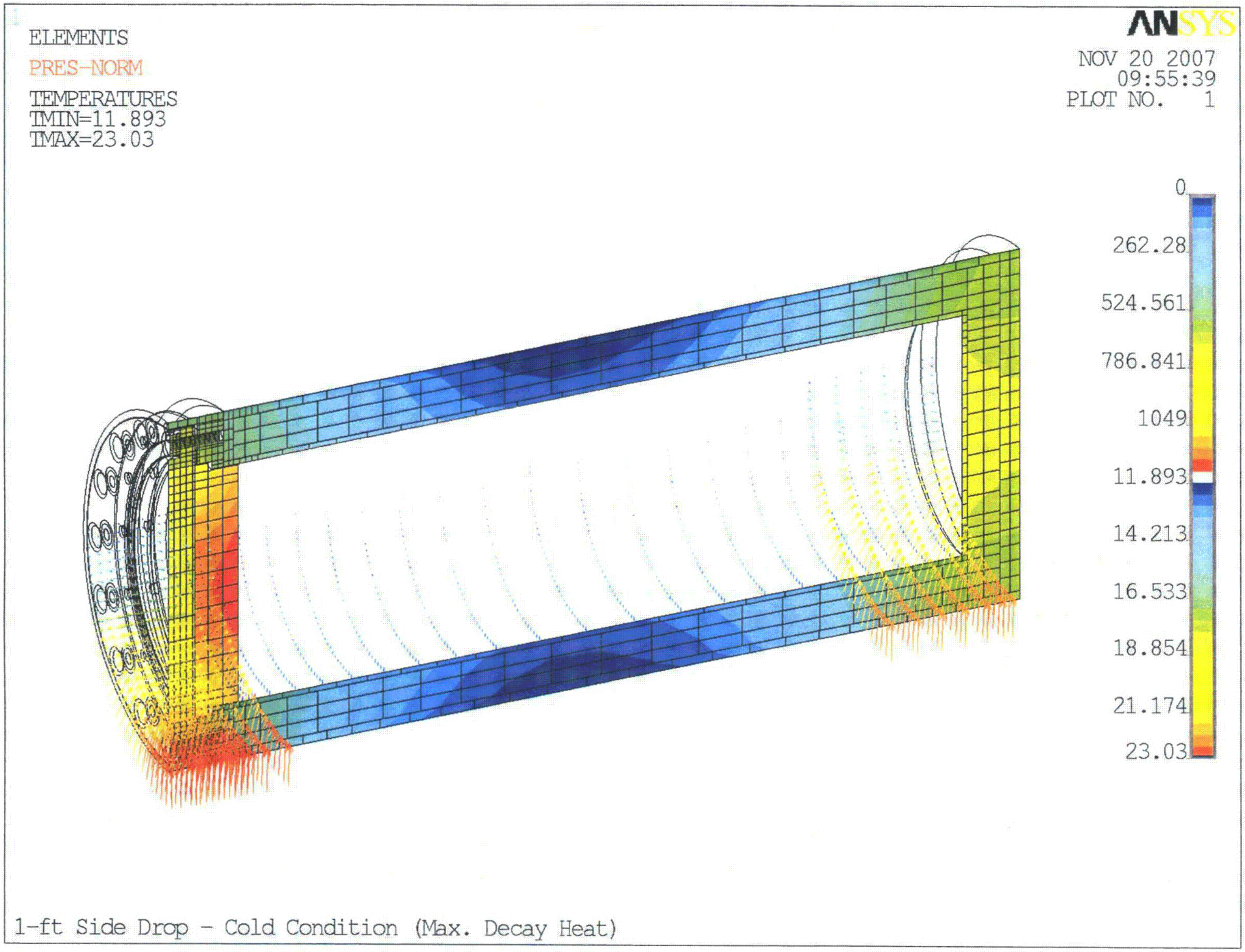


Figure 35

Temperature Profile and Pressure Distribution Used for 1-ft Side Drop – Load Combination No.2

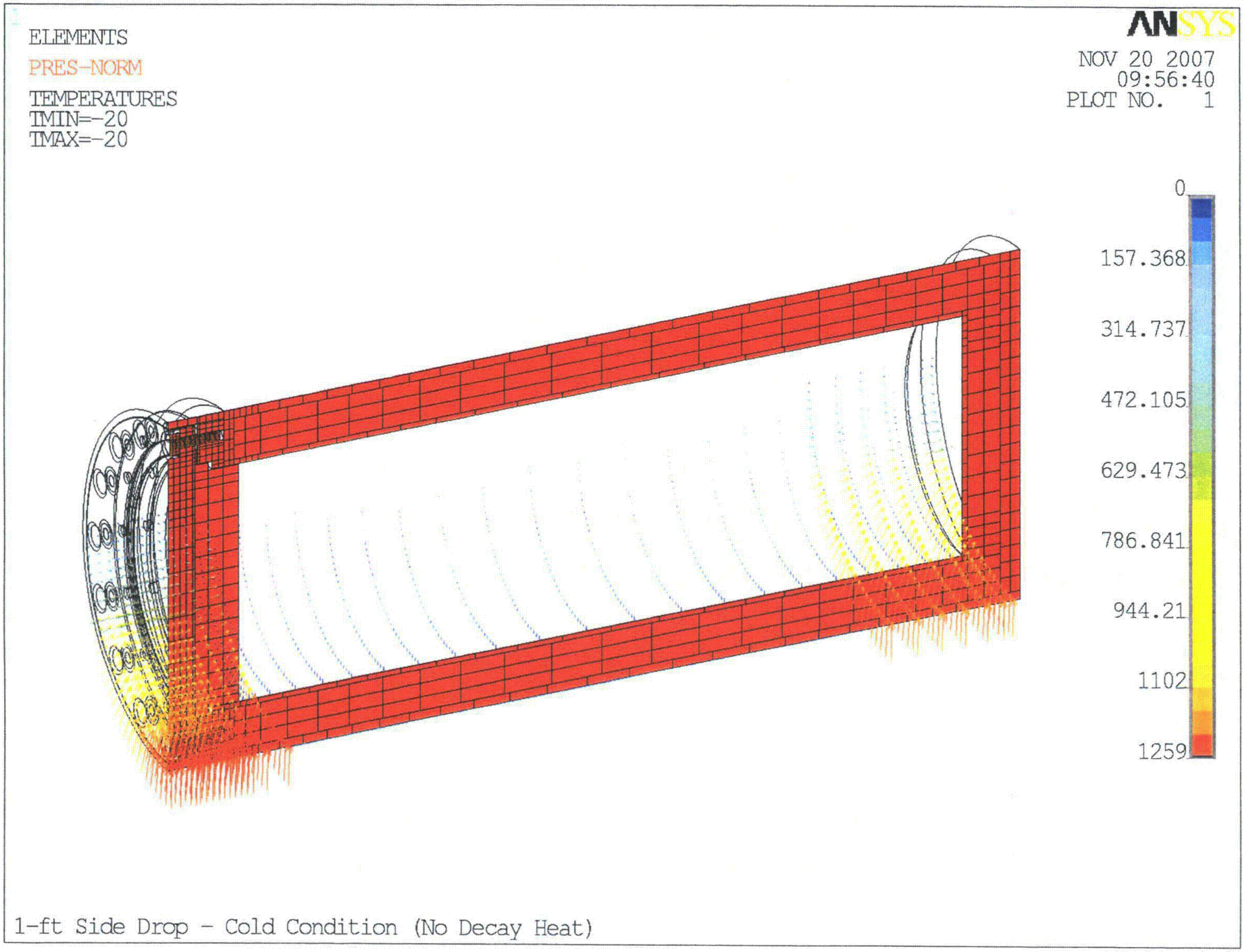


Figure 36

Temperature Profile and Pressure Distribution Used for 1-ft Side Drop – Load Combination No.3

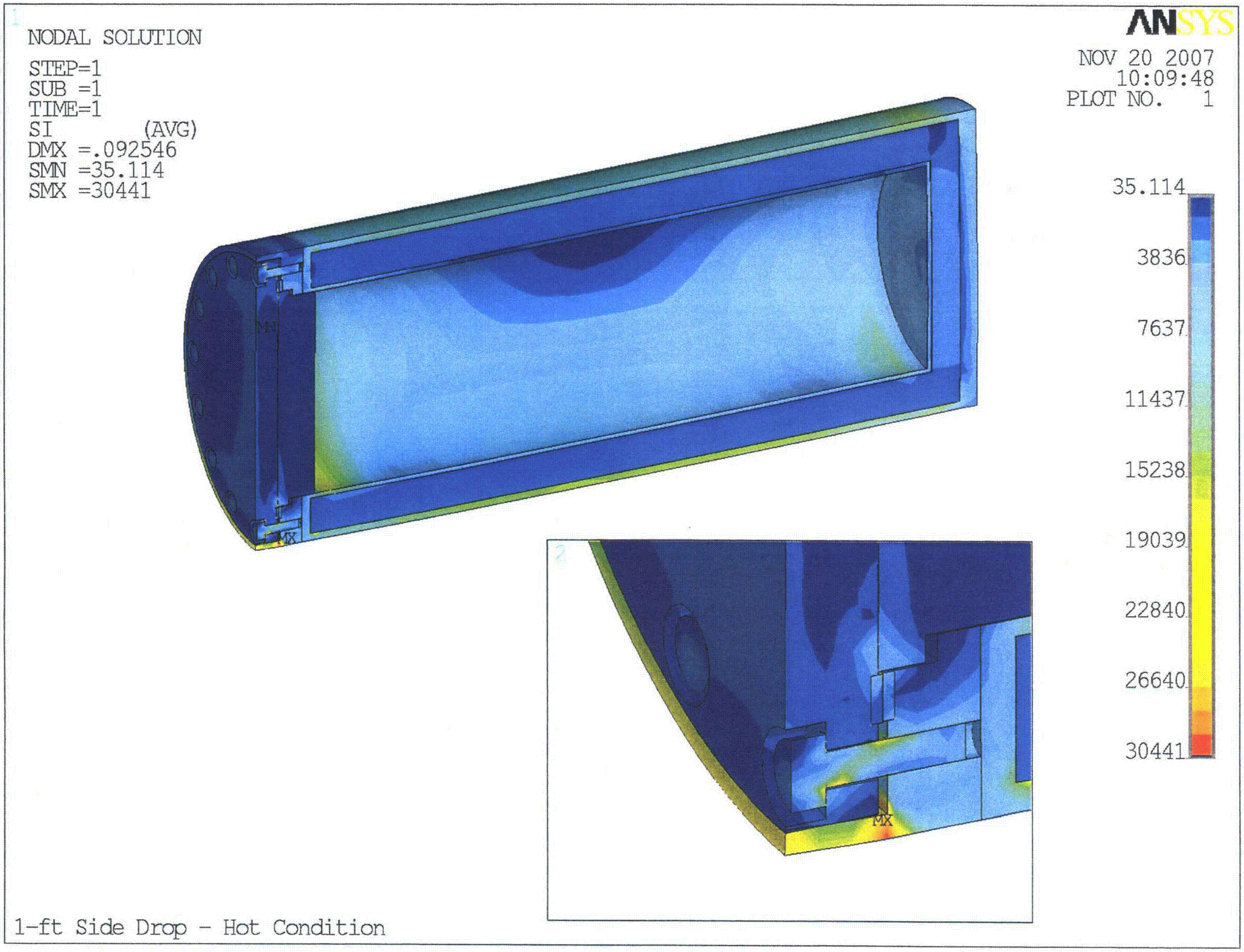


Figure 37

Stress Intensity Plot – 1-ft Side Drop – Load Combination No.1

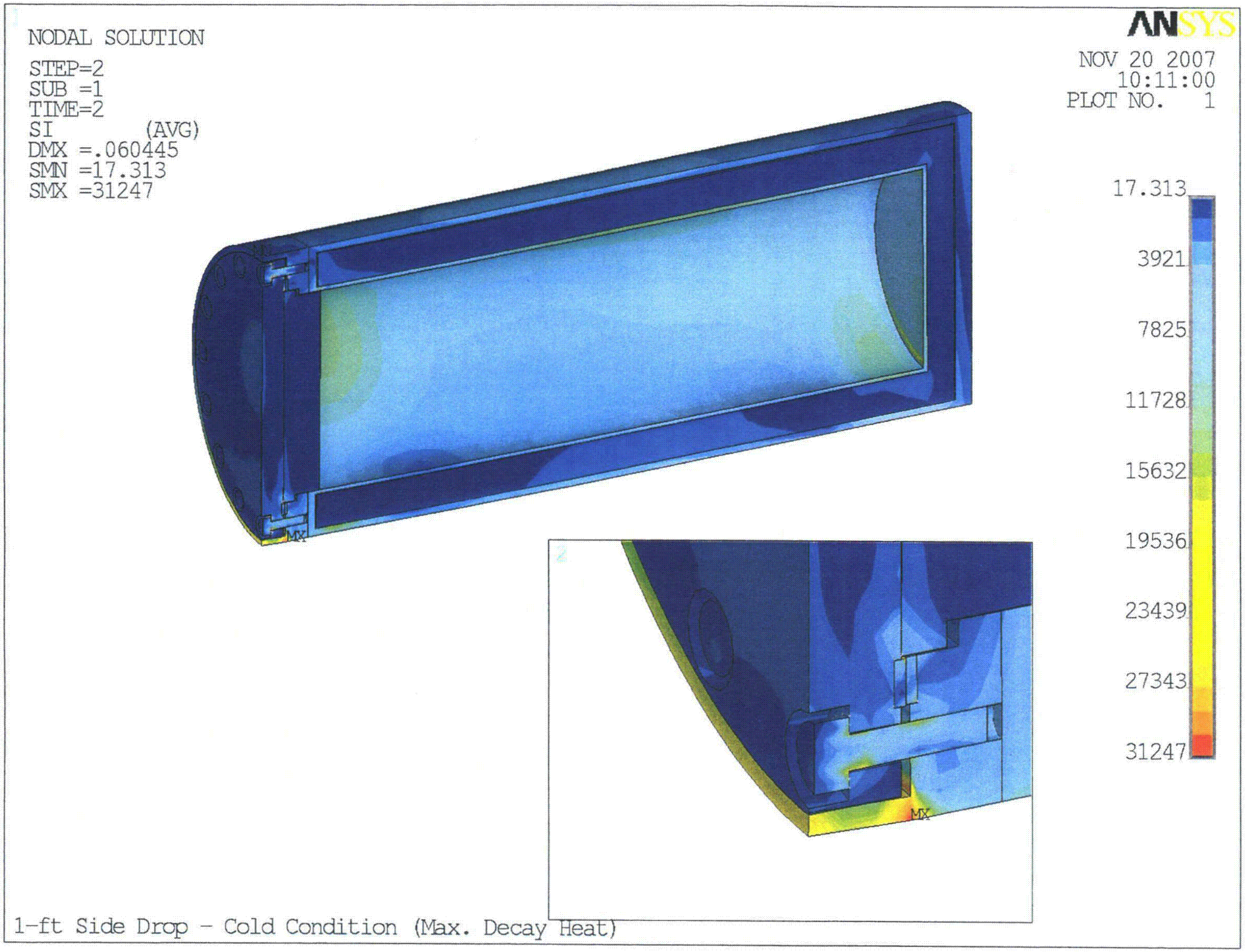


Figure 38

Stress Intensity Plot – 1-ft Side Drop – Load Combination No.2

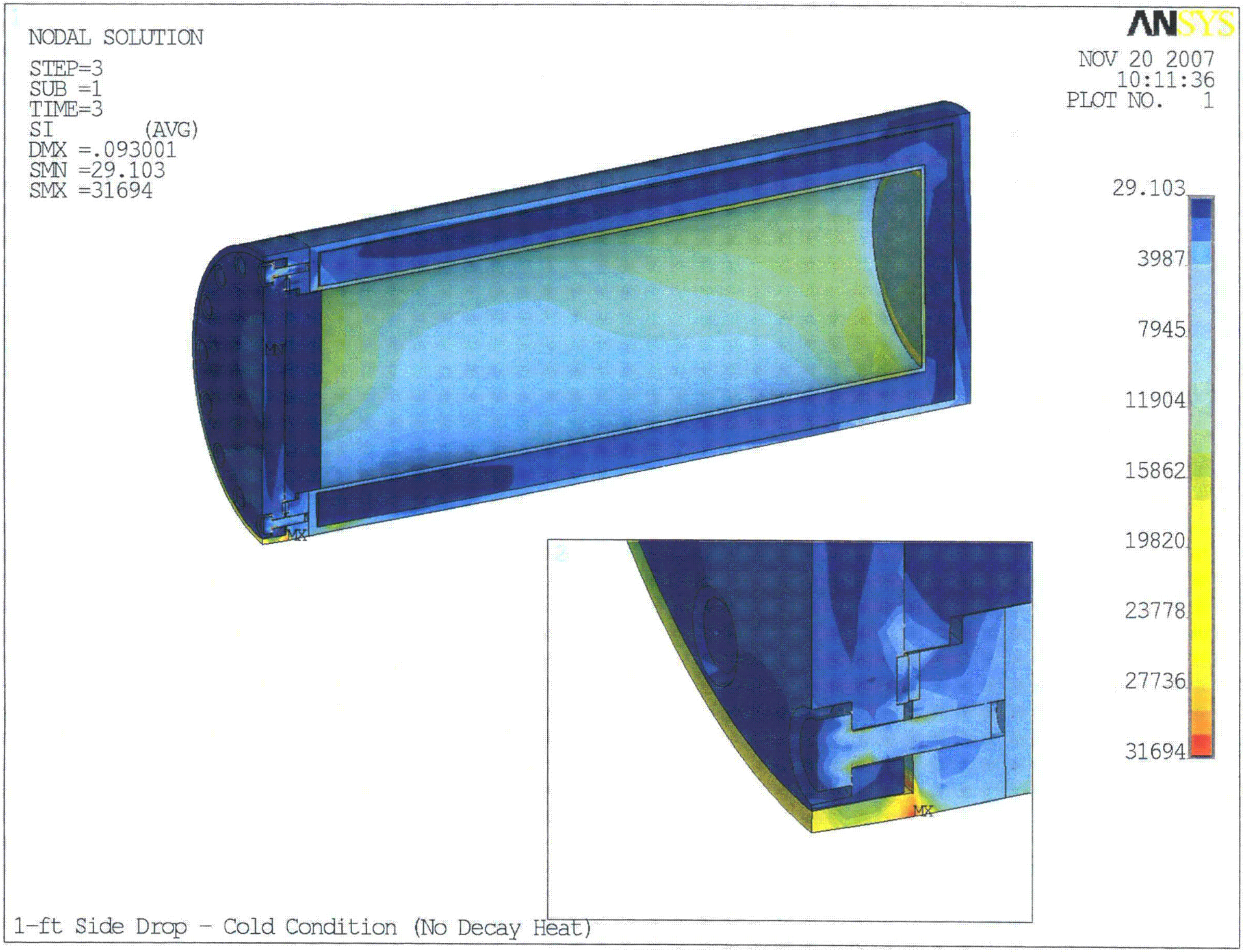


Figure 39

Stress Intensity Plot – 1-ft Side Drop – Load Combination No.3

Title Structural Analyses of the 3-60B Cask Under Drop Conditions

Calc. No. ST-504 (Figures) Rev. 1 Sheet 39 of 45

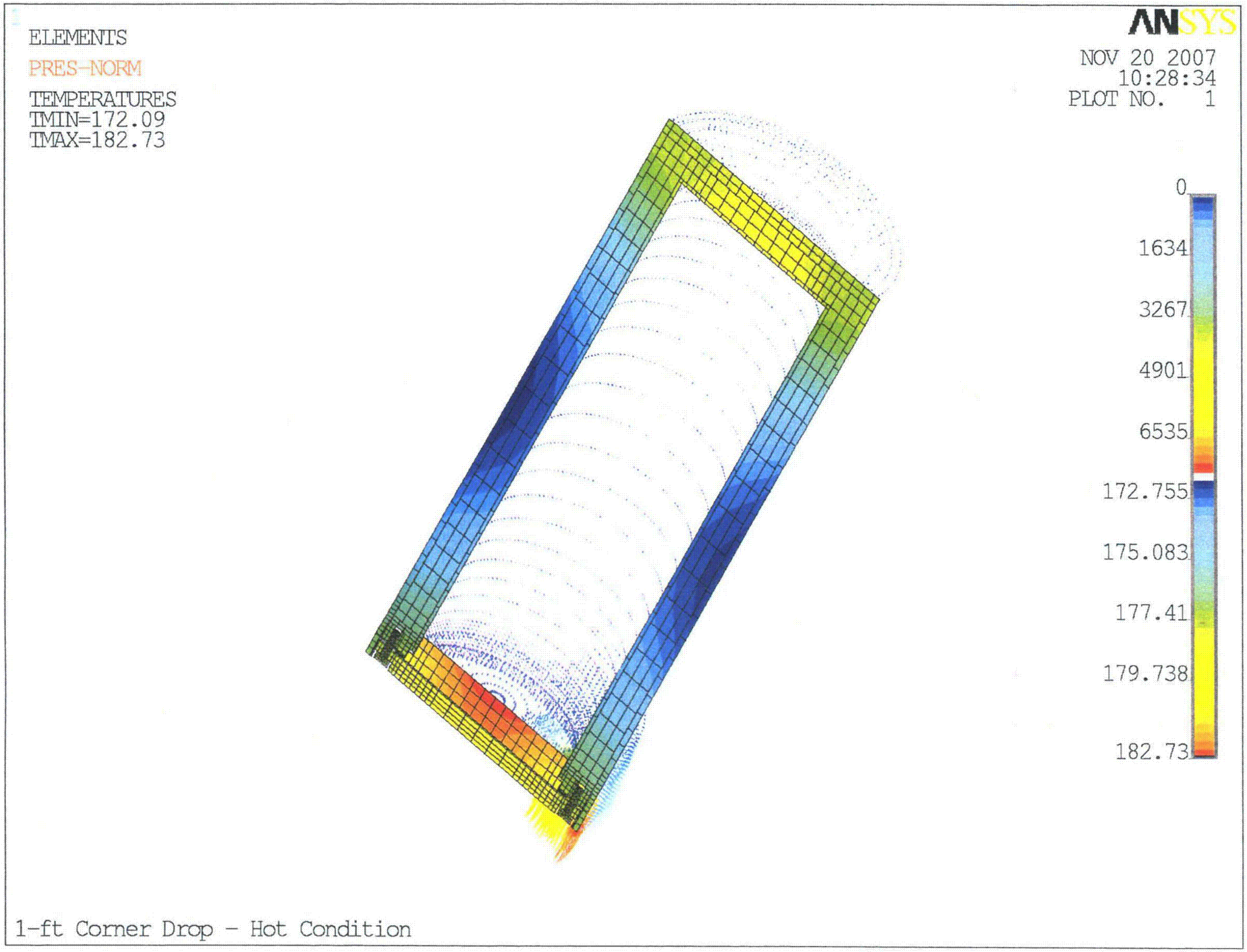


Figure 40

Temperature Profile and Pressure Distribution Used for 1-ft Corner Drop – Load Combination No.1

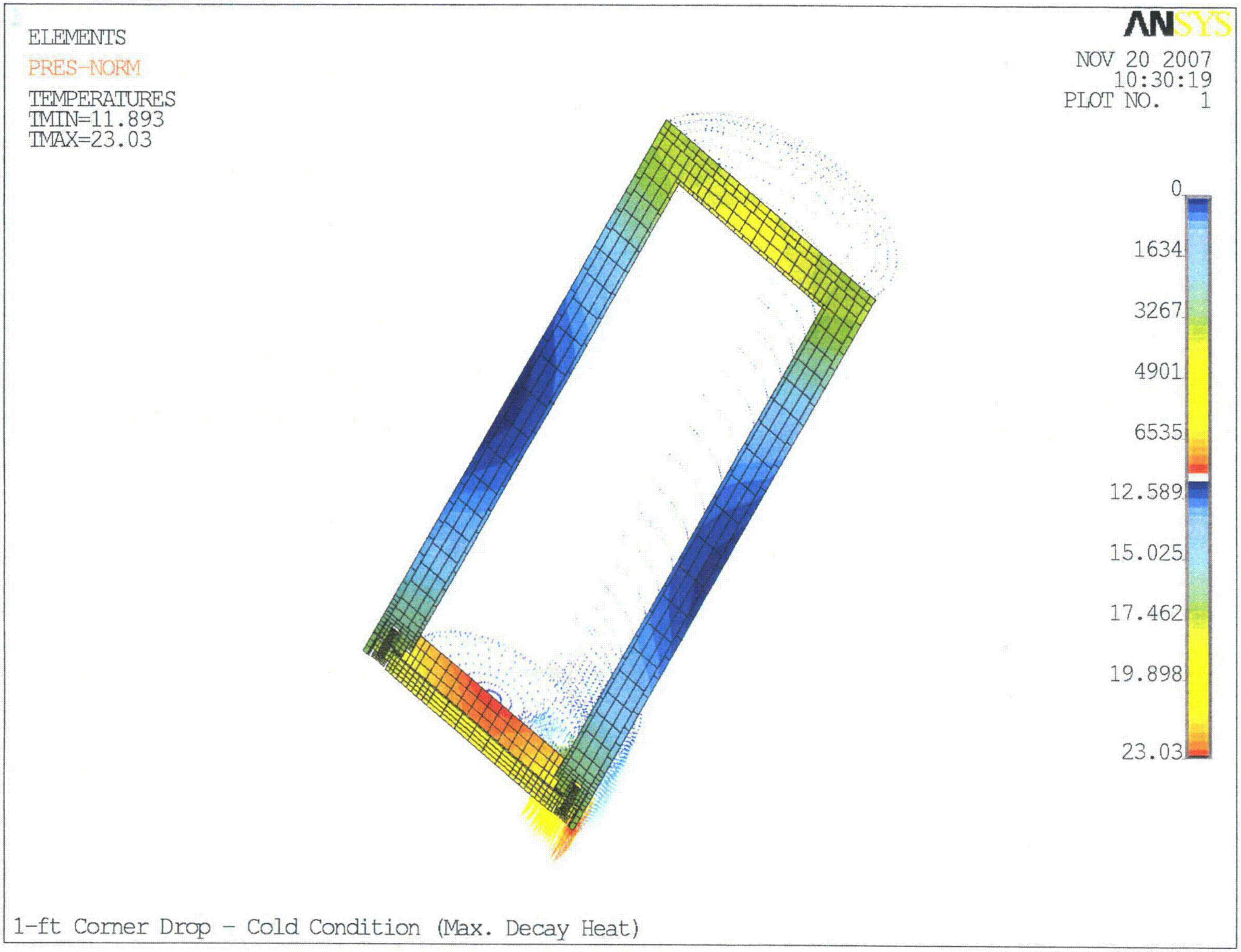


Figure 41

Temperature Profile and Pressure Distribution Used for 1-ft Corner Drop – Load Combination No.2

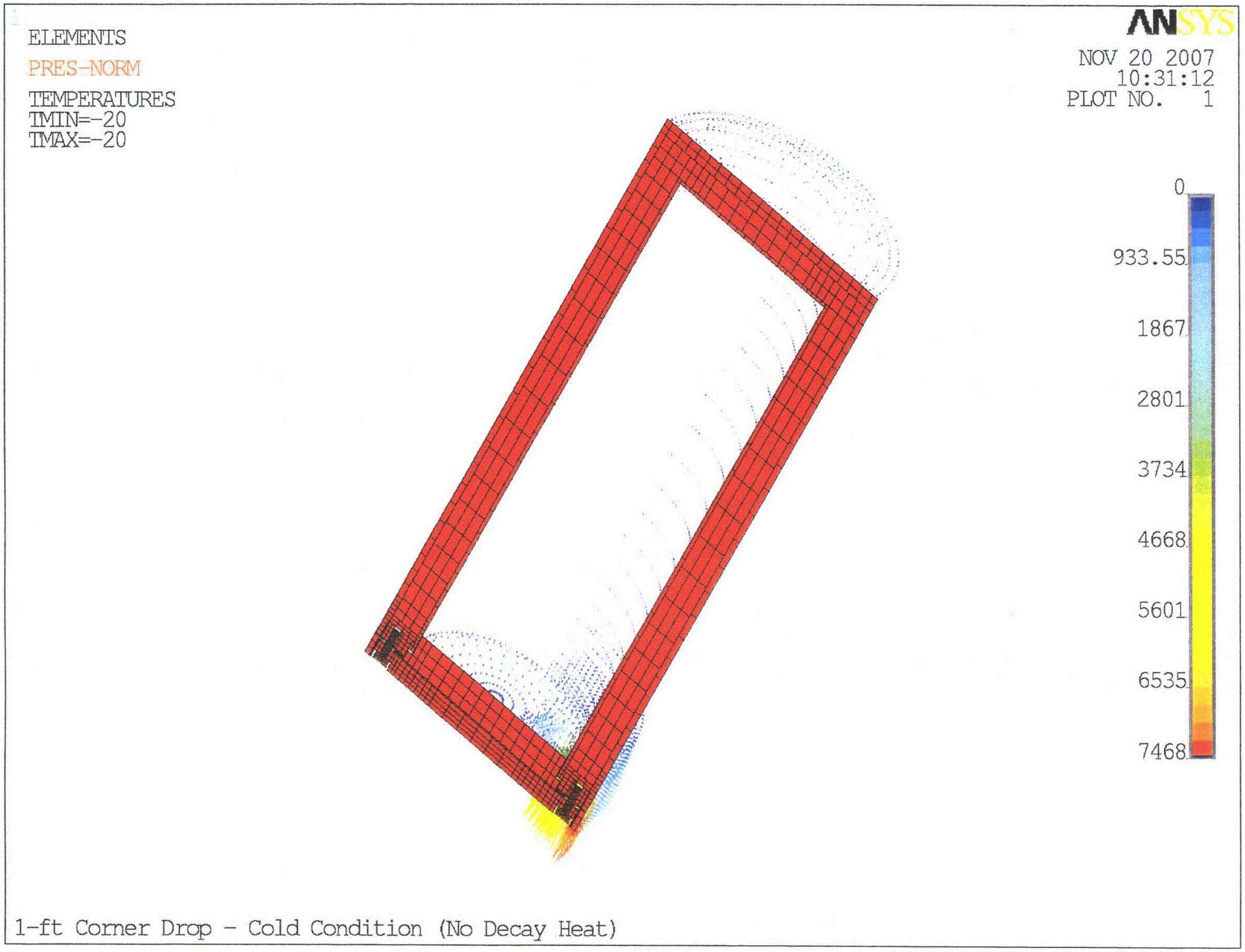


Figure 42

Temperature Profile and Pressure Distribution Used for 1-ft Corner Drop – Load Combination No.3

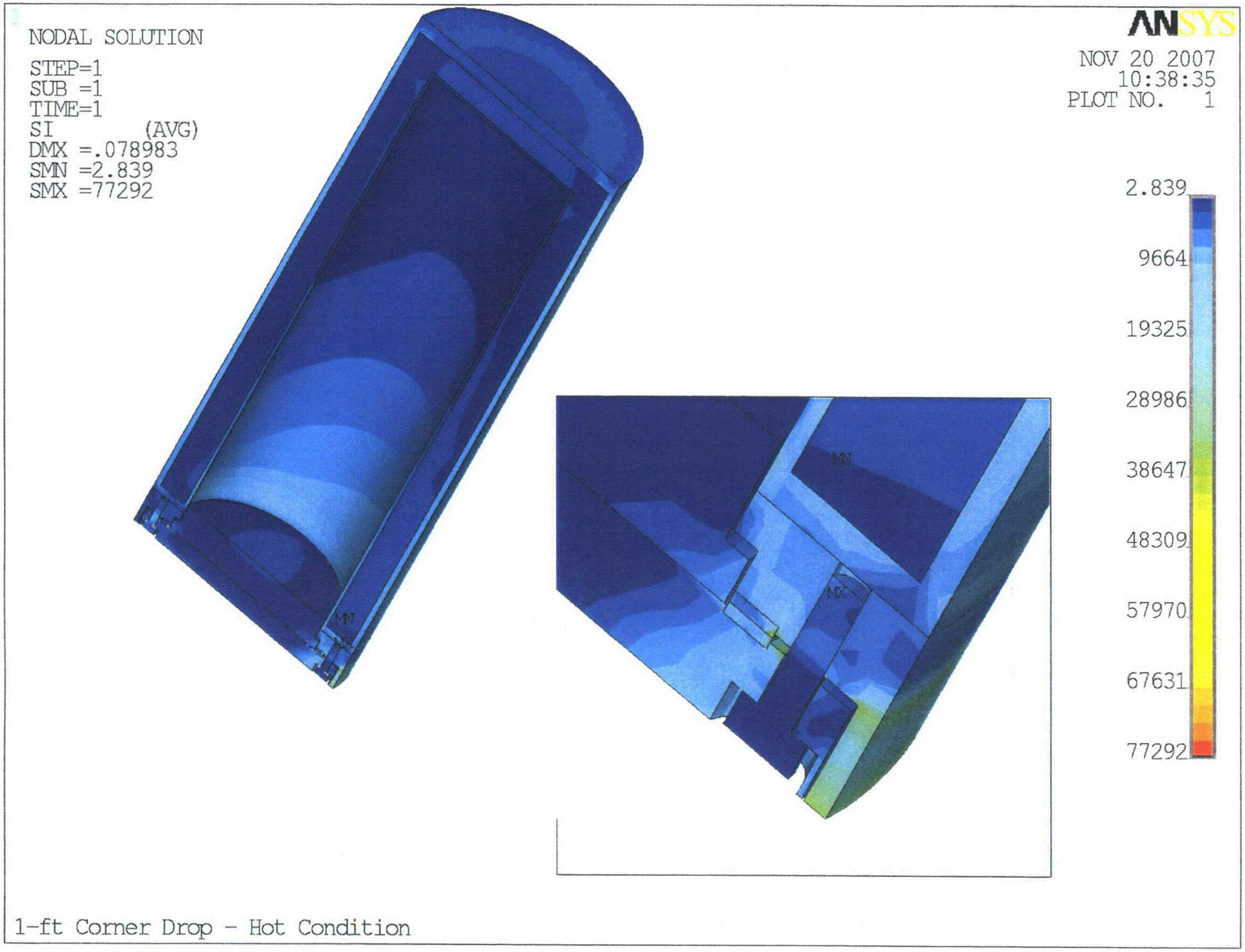


Figure 43

Stress Intensity Plot – 1-ft Corner Drop – Load Combination No.1

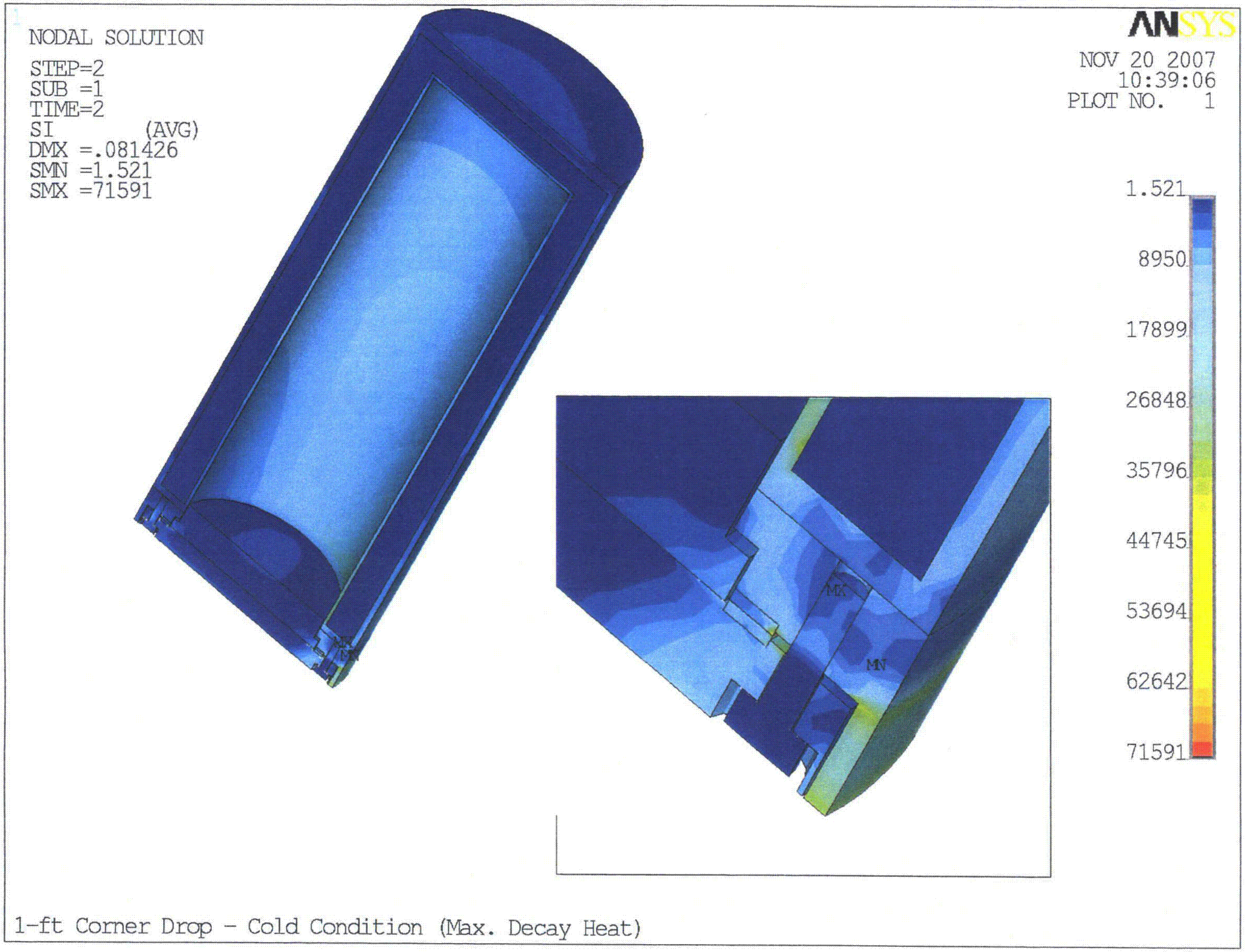


Figure 44

Stress Intensity Plot – 1-ft Corner Drop – Load Combination No.2

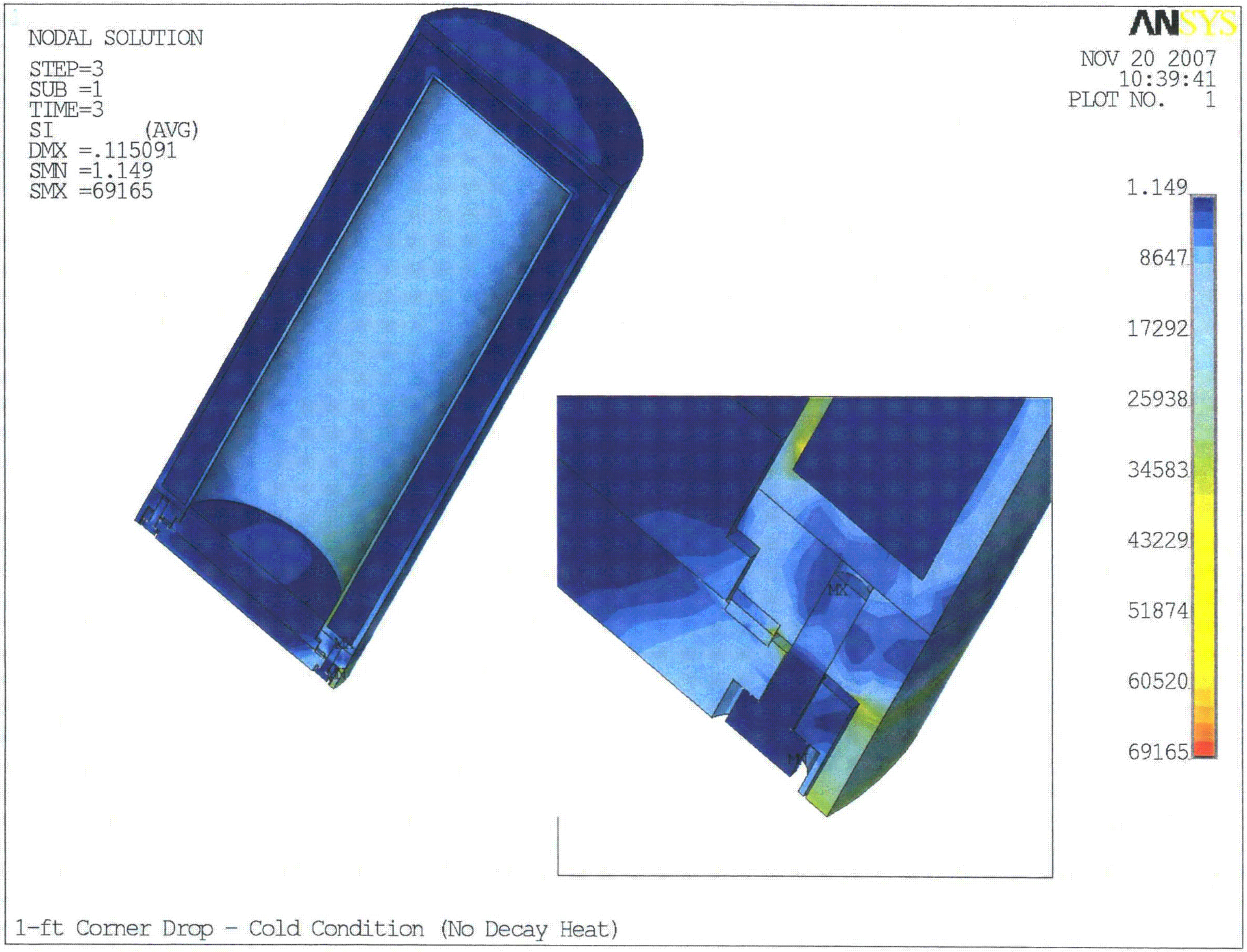


Figure 45

Stress Intensity Plot – 1-ft Corner Drop – Load Combination No.3

Appendix 1

Printout of the ANSYS Model Data

(16 Pages)

3-60B Cask Drop Analyses

By Dr. Mirza I. Baig

Report Generated by ANSYS

Title Listing

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

 *** YOU ARE IN   ANSYS - ENGINEERING ANALYSIS SYSTEM ***
 ANSYS Mechanical/Emag
 RELEASE  11.0SP1   UPDATE 20070830   CUSTOMER  00222442

 INITIAL JOBNAME = file
 CURRENT JOBNAME = file

 Current Working Directory: Y:\30-ft Drop\End

 TITLE= 30-ft End Drop - Cold Condition (No Decay Heat)

 MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans
```

Global Status

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

 ANSYS - Engineering Analysis System             Dec 07, 2007          11:27
 Release 11.0SP1              00222442                   INTEL NT     Version

 Current working directory: Y:\30-ft Drop\End


 MENULIST File: C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-us\UIDL\menulist110.ans

 Product(s) enabled: ANSYS Mechanical/Emag


 Total connect time. . . . .   0 hours  1 minutes
 Total CP usage. . . . . . .   0 hours  0 minutes  4.4 seconds

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

30-ft End Drop - Cold Condition (No Decay Heat)

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

```
 Units . . . . . . . . . . . .unknown

                              Available              Used
 Scratch Memory Space. . . .   256.000 mb          4.919 mb (  1.9%)
 Database space  . . . . . .  65535.750 mb        129.391 mb (  0.2%)

 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-
us\uidl\UIMENU.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-
us\uidl\UIFUNC1.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-
us\uidl\UIFUNC2.GRN
 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\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 . . . . . . . . . . .   47887          36999         36999
 Elements. . . . . . . . . .   37659          37659         24352

 Element types . . . . . . .     69             65           n.a.
 Real constant sets. . . . .     35             31           n.a.
 Material property sets. . .      3              3           n.a.

 Coupling. . . . . . . . . .      0              0           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. . . . . . . . . .   2851
 Constraints on keypoints. . . . . . . .      0
 Constraints on lines. . . . . . . . . .      0
 Constraints on areas. . . . . . . . . .      0

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

 Surface loads on elements . . . . . . .   3216
 Number of element flagged surfaces  . .      0
```

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

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

Temperatures
   Uniform temperature. . . . . . . . . . .   -20.000
   Reference temperature. . . . . . . . . .    70.000
   Offset from absolute scale . . . . . . .     0.000

                                               X            Y            Z
Linear acceleration . . . . . . . . . . . . 0.0000       0.0000       166.00
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 . . . . . . . .  12 (Cartesian)

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

Current element attributes:
   Type number . . . . . . . . . . . . .    69  (CONTA174)
   Real number . . . . . . . . . . . . .    35
   Material number . . . . . . . . . . .     1
   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 . . . . . . . .  12 (Cartesian)

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

Analysis type. . . . . . . . . . . . . .Static (steady-state)

Active options for this analysis type:
   Large deformation effects . . . . . .Not included
   Plasticity. . . . . . . . . . . . . .Not included
   Creep . . . . . . . . . . . . . . . .Not included
   Equation solver to use. . . . . . . .Program Chosen

Results file . . . . . . . . . . . . . .file.rst
```

```
Load step number . . . . . . . . . . .      4

Number of substeps . . . . . . . . . .      1
   Step change boundary conditions . .No
```

Solution Status

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

   PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
   DEGREES OF FREEDOM. . . . . . UX   UY   UZ
   ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
   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. . . . . . . . . . . . . . . .     4
   TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
   NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
   MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
   STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
   TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
   CONVERGENCE CONTROLS. . . . . . . . . . . . . .USE DEFAULTS
   INERTIA LOADS                      X            Y            Z
      ACEL . . . . . . . . . . . . 0.0000       0.0000       166.00
   PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
   DATABASE OUTPUT CONTROLS
      ITEM     FREQUENCY   COMPONENT
      BASI        ALL
```

Element Type Listing

```
 LIST ELEMENT TYPES FROM      1 TO     69 BY      1

 ELEMENT TYPE      1 IS SOLID185     3-D 8-NODE STRUCTURAL SOLID     INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

 ELEMENT TYPE      2 IS SHELL41      MEMBRANE SHELL                  INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

 ELEMENT TYPE      3 IS SOLSH190     3-D 8-NODE SOLID SHELL          INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

 ELEMENT TYPE      4 IS TARGE170     3-D TARGET SEGMENT              INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

 ELEMENT TYPE      5 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
  KEYOPT(1-12)=    0  2  0    0  3  0    0  0  1    2  0  5       0
```

```
ELEMENT TYPE       6 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE       7 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE       8 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE       9 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      10 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      11 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      12 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      13 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      14 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      15 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      16 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      17 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

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

ELEMENT TYPE      19 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      20 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      21 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      22 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0

ELEMENT TYPE      23 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=     0  0  0    0  3  0    0  0  1    2  0  0          0

ELEMENT TYPE      24 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=     0  0  0    0  0  0    0  0  0    0  0  0          0
```

```
ELEMENT TYPE     25 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     26 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     27 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     28 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     29 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     30 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     31 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     32 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     33 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     38 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     39 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     40 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     41 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     42 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     43 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     44 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     45 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5         0

ELEMENT TYPE     46 IS TARGE170      3-D TARGET SEGMENT             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0         0

ELEMENT TYPE     47 IS CONTA174      3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  2  0    2  3  0    0  0  1    2  0  6         0
```

```
ELEMENT TYPE     48 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     49 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  1        0

ELEMENT TYPE     50 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     51 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE     52 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     53 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE     54 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     55 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  1        0

ELEMENT TYPE     56 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     57 IS CONTA175     NODE-TO-SURFACE CONTACT         INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE     58 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     59 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  5        0

ELEMENT TYPE     60 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     61 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  1        0

ELEMENT TYPE     62 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     63 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE     64 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0

ELEMENT TYPE     65 IS CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
 KEYOPT(1-12)=    0  0  0    0  3  0    0  0  1    2  0  0        0

ELEMENT TYPE     66 IS TARGE170     3-D TARGET SEGMENT              INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0        0
```

```
ELEMENT TYPE      67 IS CONTA174     3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=     0  0  0     0  3  0     0  0  1     2  0  0         0

ELEMENT TYPE      68 IS TARGE170     3-D TARGET SEGMENT               INOPR
 KEYOPT(1-12)=     0  0  0     0  0  0     0  0  0     0  0  0         0

ELEMENT TYPE      69 IS CONTA174     3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=     0  0  0     0  3  0     0  0  1     2  0  0         0

CURRENT NODAL DOF SET IS  UX    UY    UZ
 THREE-DIMENSIONAL MODEL
```

Real Constant Listing

```
LIST REAL SETS        1 TO      35 BY        1

 REAL CONSTANT SET       3  ITEMS    1 TO    6
    0.0000       0.0000      1.0000      0.10000       0.0000       0.0000

 REAL CONSTANT SET       3  ITEMS    7 TO   12
    0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

 REAL CONSTANT SET       3  ITEMS   13 TO   18
    0.0000       0.0000      1.0000       0.0000       1.0000      0.50000

 REAL CONSTANT SET       3  ITEMS   19 TO   24
    0.0000       1.0000      1.0000       0.0000       0.0000       1.0000

 REAL CONSTANT SET       3  ITEMS   25 TO   25
    10.000

 REAL CONSTANT SET       4  ITEMS    1 TO    6
    0.0000       0.0000      1.0000      0.10000       0.0000       0.0000

 REAL CONSTANT SET       4  ITEMS    7 TO   12
    0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

 REAL CONSTANT SET       4  ITEMS   13 TO   18
    0.0000       0.0000      1.0000       0.0000       1.0000      0.50000

 REAL CONSTANT SET       4  ITEMS   19 TO   24
    0.0000       1.0000      1.0000       0.0000       0.0000       1.0000

 REAL CONSTANT SET       4  ITEMS   25 TO   25
    10.000

 REAL CONSTANT SET       5  ITEMS    1 TO    6
    0.0000       0.0000      1.0000      0.10000       0.0000       0.0000

 REAL CONSTANT SET       5  ITEMS    7 TO   12
    0.0000       0.0000     0.10000E+21   0.0000       1.0000       0.0000

 REAL CONSTANT SET       5  ITEMS   13 TO   18
    0.0000       0.0000      1.0000       0.0000       1.0000      0.50000
```

```
REAL CONSTANT SET       5  ITEMS  19 TO   24
   0.0000        1.0000       1.0000       0.0000        0.0000        1.0000

REAL CONSTANT SET       5  ITEMS  25 TO   25
   10.000

REAL CONSTANT SET       6  ITEMS   1 TO    6
   0.0000        0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET       6  ITEMS   7 TO   12
   0.0000        0.0000     0.10000E+21    0.0000        1.0000        0.0000

REAL CONSTANT SET       6  ITEMS  13 TO   18
   0.0000        0.0000       1.0000       0.0000        1.0000       0.50000

REAL CONSTANT SET       6  ITEMS  19 TO   24
   0.0000        1.0000       1.0000       0.0000        0.0000        1.0000

REAL CONSTANT SET       6  ITEMS  25 TO   25
   10.000

REAL CONSTANT SET       7  ITEMS   1 TO    6
   0.0000        0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET       7  ITEMS   7 TO   12
   0.0000        0.0000     0.10000E+21    0.0000        1.0000        0.0000

REAL CONSTANT SET       7  ITEMS  13 TO   18
   0.0000        0.0000       1.0000       0.0000        1.0000       0.50000

REAL CONSTANT SET       7  ITEMS  19 TO   24
   0.0000        1.0000       1.0000       0.0000        0.0000        1.0000

REAL CONSTANT SET       7  ITEMS  25 TO   25
   10.000

REAL CONSTANT SET       8  ITEMS   1 TO    6
   0.0000        0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET       8  ITEMS   7 TO   12
   0.0000        0.0000     0.10000E+21    0.0000        1.0000        0.0000

REAL CONSTANT SET       8  ITEMS  13 TO   18
   0.0000        0.0000       1.0000       0.0000        1.0000       0.50000

REAL CONSTANT SET       8  ITEMS  19 TO   24
   0.0000        1.0000       1.0000       0.0000        0.0000        1.0000

REAL CONSTANT SET       8  ITEMS  25 TO   25
   10.000

REAL CONSTANT SET       9  ITEMS   1 TO    6
   0.0000        0.0000       1.0000      0.10000        0.0000        0.0000

REAL CONSTANT SET       9  ITEMS   7 TO   12
   0.0000        0.0000     0.10000E+21    0.0000        1.0000        0.0000
```

```
REAL CONSTANT SET        9  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET        9  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET        9  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET       10  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       10  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       10  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET       10  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       10  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET       11  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       11  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       11  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET       11  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       11  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET       12  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       12  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       12  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000       0.50000

REAL CONSTANT SET       12  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       12  ITEMS  25 TO  25
   10.000

REAL CONSTANT SET       13  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000
```

```
REAL CONSTANT SET       13  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET       13  ITEMS  13 TO  18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET       13  ITEMS  19 TO  24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET       14  ITEMS   1 TO   6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET       14  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET       14  ITEMS  13 TO  18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET       14  ITEMS  19 TO  24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET       15  ITEMS   1 TO   6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET       15  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET       15  ITEMS  13 TO  18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET       15  ITEMS  19 TO  24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET       16  ITEMS   1 TO   6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET       16  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET       16  ITEMS  13 TO  18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET       16  ITEMS  19 TO  24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET       17  ITEMS   1 TO   6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET       17  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET       17  ITEMS  13 TO  18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET       17  ITEMS  19 TO  24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000
```

```
REAL CONSTANT SET       20  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       20  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21  0.0000        1.0000       0.0000

REAL CONSTANT SET       20  ITEMS  13 TO   18
   0.0000       0.0000       1.0000      0.0000        1.0000      0.50000

REAL CONSTANT SET       20  ITEMS  19 TO   24
   0.0000       1.0000       1.0000      0.0000        0.0000       1.0000

REAL CONSTANT SET       21  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       21  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21  0.0000        1.0000       0.0000

REAL CONSTANT SET       21  ITEMS  13 TO   18
   0.0000       0.0000       1.0000      0.0000        1.0000      0.50000

REAL CONSTANT SET       21  ITEMS  19 TO   24
   0.0000       1.0000       1.0000      0.0000        0.0000       1.0000

REAL CONSTANT SET       22  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       22  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21  0.0000        1.0000       0.0000

REAL CONSTANT SET       22  ITEMS  13 TO   18
   0.0000       0.0000       1.0000      0.0000        1.0000      0.50000

REAL CONSTANT SET       22  ITEMS  19 TO   24
   0.0000       1.0000       1.0000      0.0000        0.0000       1.0000

REAL CONSTANT SET       23  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       23  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21  0.0000        1.0000       0.0000

REAL CONSTANT SET       23  ITEMS  13 TO   18
   0.0000       0.0000       1.0000      0.0000        1.0000      0.50000

REAL CONSTANT SET       23  ITEMS  19 TO   24
   0.0000       1.0000       1.0000      0.0000        0.0000       1.0000

REAL CONSTANT SET       24  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       24  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21  0.0000        1.0000       0.0000

REAL CONSTANT SET       24  ITEMS  13 TO   18
   0.0000       0.0000       1.0000      0.0000        1.0000      0.50000
```

```
REAL CONSTANT SET       24  ITEMS  19 TO   24
  0.0000      1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       24  ITEMS  25 TO   30
  10.000      0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       25  ITEMS   1 TO    6
  0.0000      0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       25  ITEMS   7 TO   12
  0.0000      0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       25  ITEMS  13 TO   18
  0.0000      0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       25  ITEMS  19 TO   24
  0.0000      1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       26  ITEMS   1 TO    6
  0.0000      0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       26  ITEMS   7 TO   12
  0.0000      0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       26  ITEMS  13 TO   18
  0.0000      0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       26  ITEMS  19 TO   24
  0.0000      1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       26  ITEMS  25 TO   30
  10.000      0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       27  ITEMS   1 TO    6
  0.0000      0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       27  ITEMS   7 TO   12
  0.0000      0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       27  ITEMS  13 TO   18
  0.0000      0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       27  ITEMS  19 TO   24
  0.0000      1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       27  ITEMS  25 TO   30
  10.000      0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       28  ITEMS   1 TO    6
  0.0000      0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       28  ITEMS   7 TO   12
  0.0000      0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       28  ITEMS  13 TO   18
  0.0000      0.0000       1.0000       0.0000       1.0000      0.50000
```

```
REAL CONSTANT SET       28  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       29  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       29  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       29  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       29  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       29  ITEMS  25 TO   30
   10.000       0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       30  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       30  ITEMS   7 TO   12
   0.0000       0.0000       17320.       0.0000       1.0000       0.0000

REAL CONSTANT SET       30  ITEMS  13 TO   18
   0.0000       0.0000       0.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       30  ITEMS  19 TO   24
   0.0000       0.0000       1.0000       0.0000       0.0000       0.0000

REAL CONSTANT SET       31  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       31  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       31  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       31  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       32  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET       32  ITEMS   7 TO   12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET       32  ITEMS  13 TO   18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET       32  ITEMS  19 TO   24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET       33  ITEMS   1 TO    6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000
```

```
REAL CONSTANT SET      33  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET      33  ITEMS  13 TO   18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET      33  ITEMS  19 TO   24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET      34  ITEMS   1 TO    6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET      34  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET      34  ITEMS  13 TO   18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET      34  ITEMS  19 TO   24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000

REAL CONSTANT SET      35  ITEMS   1 TO    6
   0.0000       0.0000      1.0000        0.10000     0.0000      0.0000

REAL CONSTANT SET      35  ITEMS   7 TO   12
   0.0000       0.0000      0.10000E+21   0.0000      1.0000      0.0000

REAL CONSTANT SET      35  ITEMS  13 TO   18
   0.0000       0.0000      1.0000        0.0000      1.0000      0.50000

REAL CONSTANT SET      35  ITEMS  19 TO   24
   0.0000       1.0000      1.0000        0.0000      0.0000      1.0000
```

Material Properties Listing

```
LIST MATERIALS        1 TO       3 BY       1
  PROPERTY= ALL

 PROPERTY TABLE EX    MAT=        1  NUM. POINTS=  6
   TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
     70.000      0.28300E+08  100.00      0.28100E+08  200.00      0.27600E+08
     300.00      0.27000E+08  400.00      0.26500E+08  500.00      0.25800E+08

 PROPERTY TABLE NUXY  MAT=        1  NUM. POINTS=  6
   TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
     70.000      0.30000      100.00      0.30000      200.00      0.30000
     300.00      0.30000      400.00      0.30000      500.00      0.30000

 PROPERTY TABLE ALPX  MAT=        1  NUM. POINTS=  6   REFERENCE TEMP. =  70.00
   TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE      DATA
     70.000      0.85000E-05  100.00      0.86000E-05  200.00      0.89000E-05
     300.00      0.92000E-05  400.00      0.95000E-05  500.00      0.97000E-05
```

PROPERTY TABLE DENS MAT= 1 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.28300				

PROPERTY TABLE MU MAT= 1 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.30000				

PROPERTY TABLE EX MAT= 2 NUM. POINTS= 6

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.29900E+08	100.00	0.29900E+08	200.00	0.29900E+08
300.00	0.29900E+08	400.00	0.29900E+08	500.00	0.29900E+08

PROPERTY TABLE NUXY MAT= 2 NUM. POINTS= 6

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.30000	100.00	0.30000	200.00	0.30000
300.00	0.30000	400.00	0.30000	500.00	0.30000

PROPERTY TABLE ALPX MAT= 2 NUM. POINTS= 6 REFERENCE TEMP. = 70.00

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.65000E-05	100.00	0.65000E-05	200.00	0.65000E-05
300.00	0.65000E-05	400.00	0.65000E-05	500.00	0.65000E-05

PROPERTY TABLE DENS MAT= 2 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.28300				

PROPERTY TABLE EX MAT= 3 NUM. POINTS= 8

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
-40.000	0.24600E+07	-20.000	0.24300E+07	70.000	0.22700E+07
100.00	0.22100E+07	200.00	0.20100E+07	300.00	0.18500E+07
400.00	0.17000E+07	500.00	0.15200E+07		

PROPERTY TABLE NUXY MAT= 3 NUM. POINTS= 6

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
81.000	0.40000	212.00	0.40000	302.00	0.40000
392.00	0.40000	513.00	0.40000	621.00	0.40000

PROPERTY TABLE ALPX MAT= 3 NUM. POINTS= 8 REFERENCE TEMP. = 70.00

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
-40.000	0.15560E-04	-20.000	0.15650E-04	70.000	0.16060E-04
100.00	0.16220E-04	200.00	0.16700E-04	300.00	0.17330E-04
400.00	0.18160E-04	500.00	0.19120E-04		

PROPERTY TABLE DENS MAT= 3 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.41000				

Appendix 2

Electronic Data on DVD

(1 DVD)