1.0 OBJECTIVE

Perform the structural analyses of the Energy*Solutions* 3-60B Cask under fire accident test 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 for the hypothetical accident condition (HAC) fire test. 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.

The results of the analyses for various time instants during the fire test are presented pictorially in stress intensity contour plots as well as digital data format.

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. ASME Boiler & Pressure Vessel Code, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2005.
5. NUREG 0481/SAND77-1872, An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers, Sandia National Laboratories, 1978.
6. U.S. NRC Regulatory Guide 7.6, Revision 1, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, 1978.
7. ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.
8. EnergySolutions Document TH-023, Rev.1, Hypothetical Fire Accident Thermal Analyses of the 3-60B Cask Using a 3-D Finite Element Model.

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 4).

(2) From NUREG/CR 0481 (Reference 5)

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$^{(1)}$
Hypothetical Accident Conditions	Membrane Stress	40,080$^{(2)}$	59,760$^{(2)}$	105,000$^{(2)}$
	Mem. + Bending Stress	60,120$^{(2)}$	87,000$^{(2)}$	150,000$^{(2)}$
	Peak Stress	140,000$^{(3)}$	174,000$^{(3)}$	300,000$^{(3)}$

Notes:

(1) From ASME B&PV Code 2004, Section II, Part D (Reference 4).

(2) Regulatory Guide 7.6 (Reference 6) does not provide any criteria. ASME B&PV Code, Section III, Appendix F has been used to establish these criteria.

(3) 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 HAC fire test have been performed using finite element modeling techniques. ANSYS finite element analysis code (Ref. 7) has been employed to perform the analyses. Since the lid of the cask is attached to the body using 16 bolts, the cask geometry has a cyclic symmetry every 11.25° of the circumference. Therefore, an 11.25° 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

For the analyses of the 3-60B Cask under various NCT loading cases, it is assumed that the cask is resting on the upper impact limiter in the vertical orientation, because in this orientation the payload applies deadweight loading, in addition to the internal pressure loading on the lid closure, which is the most vulnerable part of the cask. The model is conservatively restrained in the vertical direction at the skirt instead of the entire bearing surface of the upper impact limiter. Also, since the model represents an 11.25° circumferential symmetry, the nodes on the cut-planes are restrained from displacement normal to these planes.

Loading

The loading on the model include the following, as applicable.

Deadweight

The deadweight of the cask is included in the analyses as the body load in the finite element model subjected to the acceleration due to gravity. The deadweight of the lower impact limiter is included as the uniform pressure on the surface where the impact limiter contacts the cask. The deadweight of the payload is included as the uniform pressure on the lid inside surface.

Mass of each Impact Limiter = 3,800 lb

Inside Radius of the Impact Limiter = 12 in

Outside Radius of the Cask = 25.5 in

Pressure on the cask due to impact limiter weight,

$$p_{I.L.} = 3{,}800/[p\times(25.5^2 - 12^2)] = 2.39 \text{ psi}$$

Payload Mass = 9,500 lb

Lid Radius = 17.5 in

Pressure on the lid surface due to payload weight,

$p_{lid} = 9{,}500/(p \times 17.5^2) = 9.874$ psi

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 = 32×1,775. 6 = 56,819 lb

Use acceleration due to gravity = 62,900/56,819 = 1.107g

Internal Pressure

The cask internal pressure under various HAC fire test (100 psig) is applied as the uniform pressure over the nodes representing the cavity of the cask (Figure 6).

Temperature

The temperature distribution at various time instants during the fire test is obtained from the thermal analyses performed in Reference 8 and is applied as the nodal temperature in the finite element model. Figures 7 through 13 show the temperature profile and the pressure distribution in the cask body at various time instants during the fire test.

7.0 RESULTS

The results obtained from various load case analyses include displacements and stress intensities at the nodal points of the finite element model. The total printout from all the load cases is included in Appendix 2. Stress intensity contour plots are presented in Figures 14 through 28. The stress intensities in various components of the 3-60B Cask under these loading conditions are tabulated in Tables 1 through 7. It should be noted that the maximum stress intensities obtained from the finite element models are peak stresses, as classified by the ASME code. However, these stress intensities are reported as membrane + bending stress intensities and compared with the corresponding allowable values.

It should be noted that under the fire test the cask body undergoes large thermal stresses at the locations where the fire-shield is welded to the cask body. However, these stresses are highly local and a slight local yielding of the material will easily accommodate them. Although these stresses are reported in Tables 2 through 4, they have been excluded in the evaluation of the cask body integrity during the fire test.

The results of the analyses show that the stresses everywhere in the cask body during the fire test are well within the allowable values.

8.0 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 electronic data of the input, output and other files is included in Appendix 2.

9.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on CDROM

Tables

(7 Pages)

Table 1

Stress Intensities in 3-60B Cask HAC Fire (t = 0.1 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	$P_m + P_b$	87,000	11,070	7.86
	F	174,000	11,070	15.72
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	11,070	7.86
	F	174,000	11,070	15.72
Inner Shell	$P_m + P_b$	87,000	4,637	18.76
	F	174,000	4,637	37.52
Outer Shell	$P_m + P_b$	60,120	6,860	8.76
	F	140,000	6,860	20.41
Lid	$P_m + P_b$	60,120	5,437	11.06
	F	140,000	5,437	25.75
Base Plates	$P_m + P_b$	87,000	5,190	16.76
	F	174,000	5,190	33.53
Seal Plates	$P_m + P_b$	60,120	3,560	16.89
	F	140,000	3,560	39.33
Bolts	$P_m + P_b$	150,000	10,593	14.16
	F	300,000	10,593	28.32

See Figure 7 for temperature distribution in the cask body and Figure 14 for stress intensity contour plot.

Notes:

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

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

Table 2

Stress Intensities in 3-60B Cask HAC Fire (t = 1,001 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	$P_m + P_b$	87,000	-[3]	-[3]
	F	174,000	172,140	1.01
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	53,681	1.62
	F	174,000	53,681	3.24
Inner Shell	$P_m + P_b$	87,000	14,035	6.20
	F	174,000	14,035	12.40
Outer Shell	$P_m + P_b$	60,120	39,916	1.51
	F	140,000	39,916	3.51
Lid	$P_m + P_b$	60,120	49,043	1.23
	F	140,000	49,043	2.85
Base Plates	$P_m + P_b$	87,000	80,106	1.09
	F	174,000	80,106	2.17
Seal Plates	$P_m + P_b$	60,120	49,134	1.22
	F	140,000	49,134	2.85
Bolts	$P_m + P_b$	150,000	85,618	1.75
	F	300,000	85,618	3.50

See Figure 8 for temperature distribution in the cask body and Figures 15 & 16 for stress intensity contour plot.

Notes:

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

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

(3) Stress intensity in the skirt of the bolting ring exceeds the $P_m + P_b$ allowable value. However, the stresses are concentrated at the fire-shield weld (see Figure 15). Local yielding at this location will easily accommodate these high stresses. If the skirt is disregarded, the stresses are much lower (see Figure 16).

Table 3

Stress Intensities in 3-60B Cask HAC Fire (t = 1,806 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	$P_m + P_b$	87,000	-[3]	-[3]
	F	174,000	-[3]	-[3]
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	65,848	1.32
	F	174,000	65,848	2.64
Inner Shell	$P_m + P_b$	87,000	19,313	4.50
	F	174,000	19,313	9.01
Outer Shell	$P_m + P_b$	60,120	46,666	1.29
	F	140,000	46,666	3.00
Lid	$P_m + P_b$	60,120	59,543 [4]	1.01
	F	140,000	74,217	1.89
Base Plates	$P_m + P_b$	87,000	80,086	1.09
	F	174,000	80,086	2.17
Seal Plates	$P_m + P_b$	60,120	58,328 [5]	1.03
	F	140,000	65,474	2.14
Bolts	$P_m + P_b$	150,000	131,900	1.14
	F	300,000	131,900	2.27

See Figure 9 for temperature distribution in the cask body and Figures 17 & 18 for stress intensity contour plot.

Notes:

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

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

(3) Stress intensity in the skirt of the bolting ring exceeds the $P_m + P_b$ allowable value. However, the stresses are concentrated at the fire-shield weld (see Figure 17). Local yielding at this location will easily accommodate these high stresses. If the skirt is disregarded, the stresses are much lower (see Figure 18).

(4) Average stress intensity is reported. See Figure 19.

(5) Average stress intensity is reported. See Figure 20.

Table 4

Stress Intensities in 3-60B Cask HAC Fire (t = 1,864 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	$P_m + P_b$	87,000	-[3]	-[3]
	F	174,000	-[3]	-[3]
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	63,726	1.37
	F	174,000	63,726	2.73
Inner Shell	$P_m + P_b$	87,000	19,511	4.46
	F	174,000	19,511	8.92
Outer Shell	$P_m + P_b$	60,120	46,084	1.30
	F	140,000	46,084	3.04
Lid	$P_m + P_b$	60,120	59,242 [4]	1.01
	F	140,000	73,787	1.90
Base Plates	$P_m + P_b$	87,000	69,170	1.26
	F	174,000	69,170	2.52
Seal Plates	$P_m + P_b$	60,120	57,300 [5]	1.05
	F	140,000	64,783	2.16
Bolts	$P_m + P_b$	150,000	132,370	1.13
	F	300,000	132,370	2.27

See Figure 10 for temperature distribution in the cask body and Figures 21 & 22 for stress intensity contour plot.

Notes:

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

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

(3) Stress intensity in the skirt of the bolting ring exceeds the $P_m + P_b$ allowable value. However, the stresses are concentrated at the fire-shield weld (see Figure 21). Local yielding at this location will easily accommodate these high stresses. If the skirt is disregarded, the stresses are much lower (see Figure 22).

(4) Average stress intensity is reported. See Figure 23.

(5) Average stress intensity is reported. See Figure 24.

Table 5

Stress Intensities in 3-60B Cask HAC Fire (t = 4,838 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[(1)] (psi)	F.S.[(2)]
Bolting Ring	$P_m + P_b$	87,000	48,562	1.79
	F	174,000	48,562	3.58
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	48,562	1.79
	F	174,000	48,562	3.58
Inner Shell	$P_m + P_b$	87,000	20,863	4.17
	F	174,000	20,863	8.34
Outer Shell	$P_m + P_b$	60,120	36,829	1.63
	F	140,000	36,829	3.80
Lid	$P_m + P_b$	60,120	52,277[(3)]	1.15
	F	140,000	63,474	2.21
Base Plates	$P_m + P_b$	87,000	27,088	3.21
	F	174,000	27,088	6.42
Seal Plates	$P_m + P_b$	60,120	16,635	3.61
	F	140,000	16,635	8.42
Bolts	$P_m + P_b$	150,000	76,154	1.97
	F	300,000	76,154	3.94

See Figure 11 for temperature distribution in the cask body and Figure 25 for stress intensity contour plot.

Notes:

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

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

(3) Average stress intensity is reported. See Figure 26.

Table 6

Stress Intensities in 3-60B Cask HAC Fire (t = 5,936 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.(1) (psi)	F.S.(2)
Bolting Ring	$P_m + P_b$	87,000	47,484	1.83
	F	174,000	47,484	3.66
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	47,484	1.83
	F	174,000	47,484	3.66
Inner Shell	$P_m + P_b$	87,000	21,080	4.13
	F	174,000	21,080	8.25
Outer Shell	$P_m + P_b$	60,120	37,135	1.62
	F	140,000	37,135	3.77
Lid	$P_m + P_b$	60,120	57,409	1.05
	F	140,000	57,409	2.44
Base Plates	$P_m + P_b$	87,000	26,526	3.28
	F	174,000	26,526	6.56
Seal Plates	$P_m + P_b$	60,120	15,413	3.90
	F	140,000	15,413	9.08
Bolts	$P_m + P_b$	150,000	68,448	2.19
	F	300,000	68,448	4.38

See Figure 12 for temperature distribution in the cask body and Figure 27 for stress intensity contour plot.

Notes:

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

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

Table 7

Stress Intensities in 3-60B Cask HAC Fire (t = 14,000 sec)

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	$P_m + P_b$	87,000	43,574	2.00
	F	174,000	43,574	3.99
Bolting Ring (w/o Skirt)	$P_m + P_b$	87,000	43,574	2.00
	F	174,000	43,574	3.99
Inner Shell	$P_m + P_b$	87,000	19,547	4.45
	F	174,000	19,547	8.90
Outer Shell	$P_m + P_b$	60,120	34,102	1.76
	F	140,000	34,102	4.11
Lid	$P_m + P_b$	60,120	25,297	2.38
	F	140,000	25,297	5.53
Base Plates	$P_m + P_b$	87,000	23,033	3.78
	F	174,000	23,033	7.55
Seal Plates	$P_m + P_b$	60,120	9,585	6.27
	F	140,000	9,585	14.61
Bolts	$P_m + P_b$	150,000	44,073	3.40
	F	300,000	44,073	6.81

See Figure 13 for temperature distribution in the cask body and Figure 28 for stress intensity contour plot.

Notes:

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

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

Figures

(28 Pages)

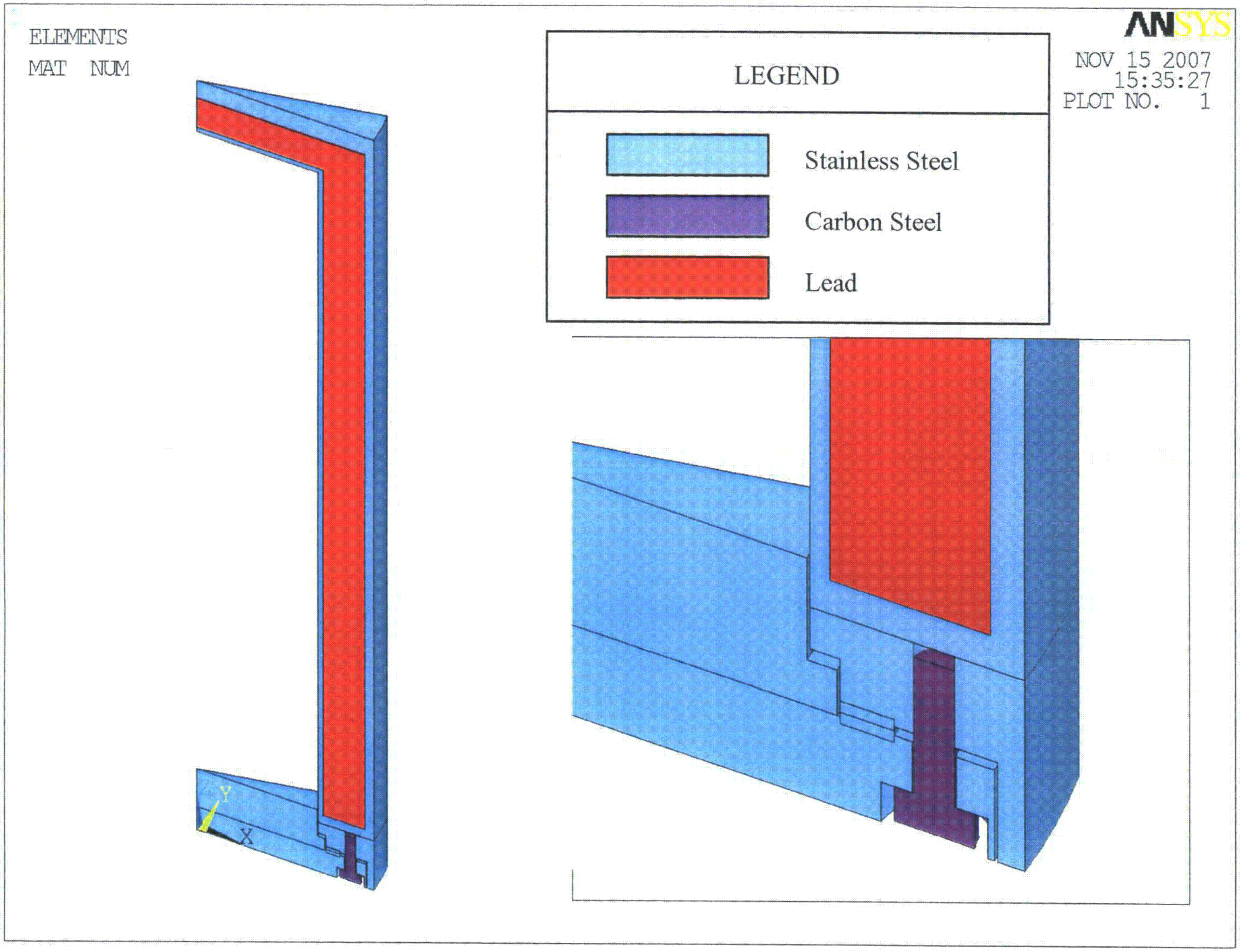

Figure 1
Finite Element Model of the 3-60B Cask Identifying the Components by Material Numbers

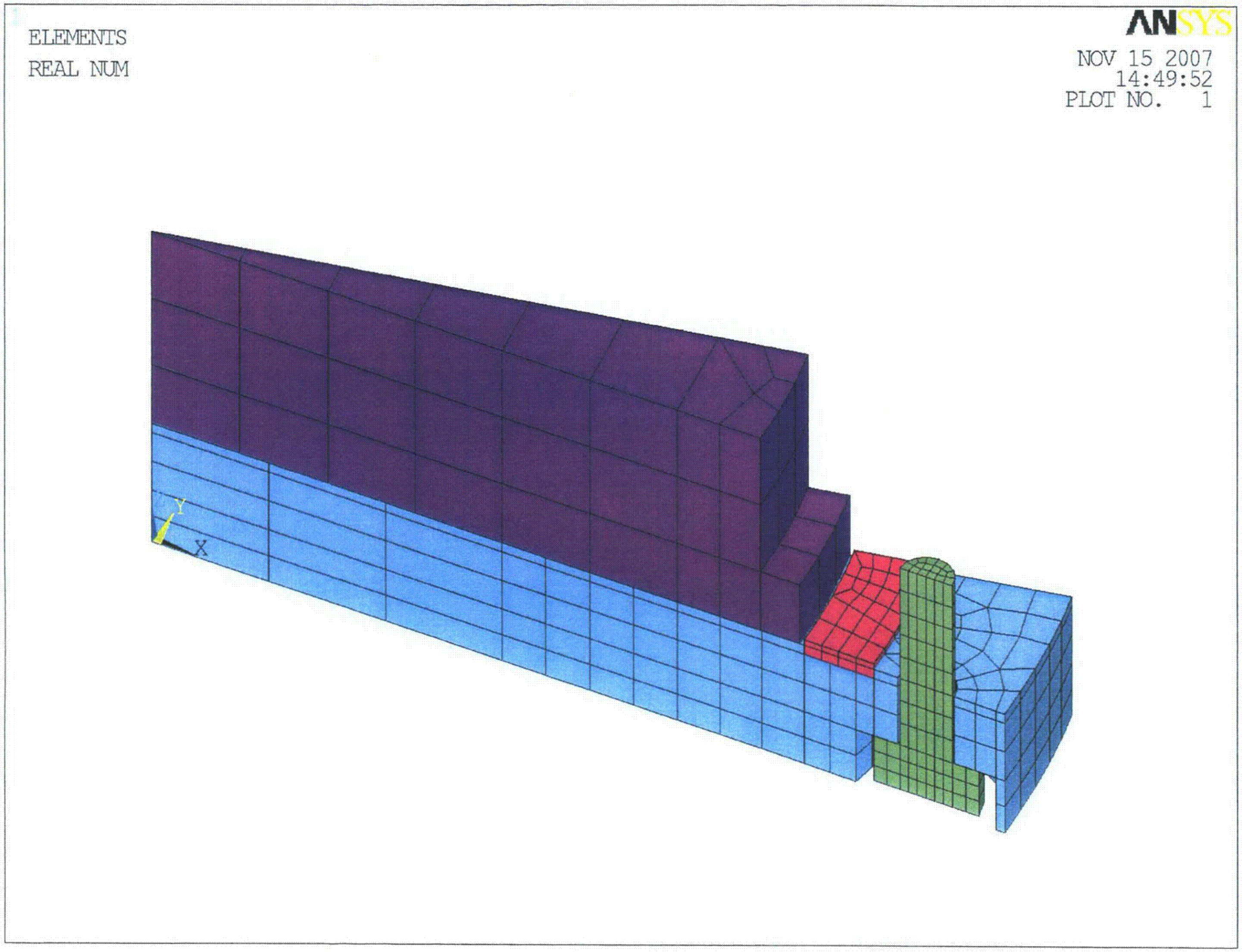

Figure 2

Finite Element Model of the Lid, Seal-Plate and Bolts

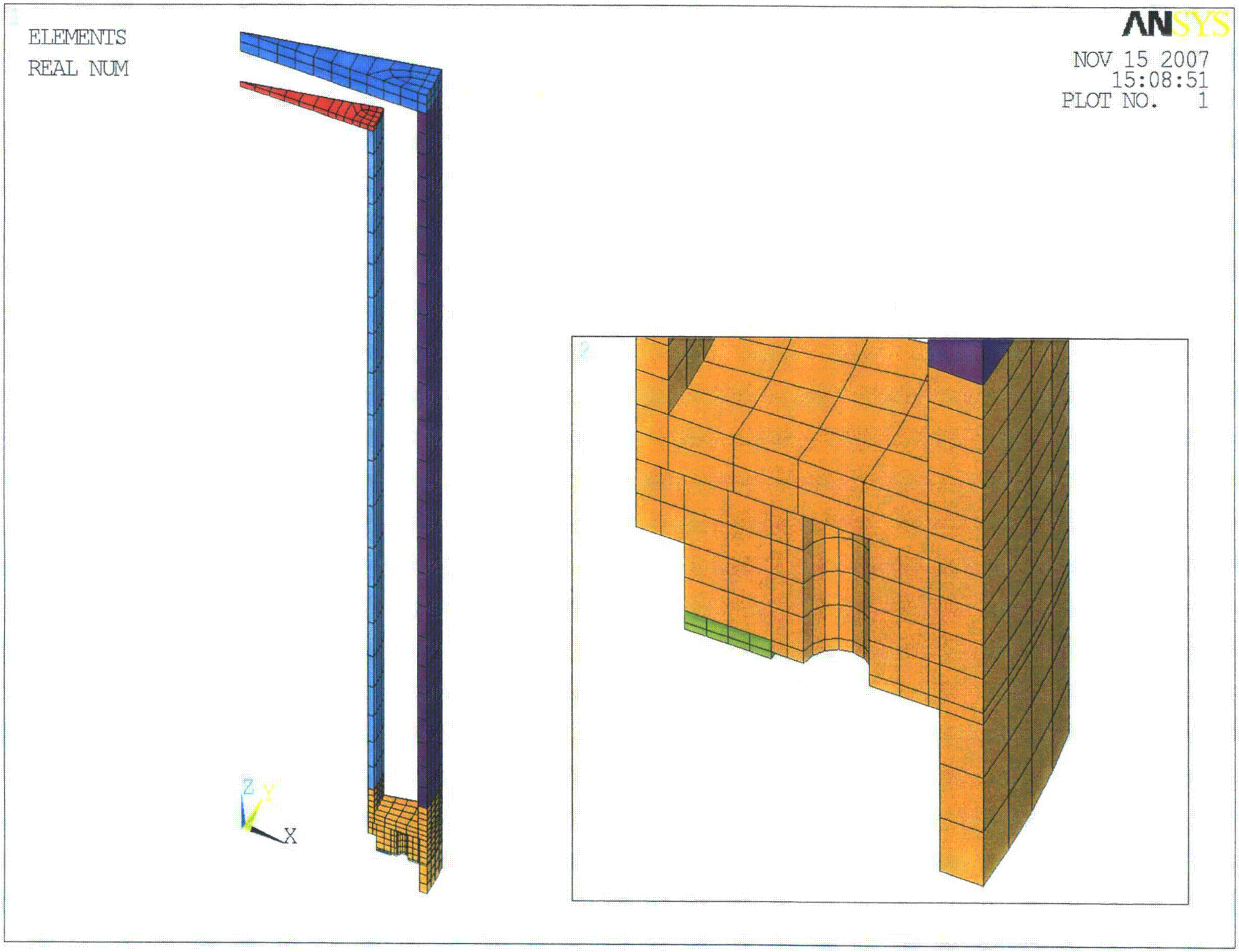

Figure 3
Finite Element Model of the Cask Body without Lead

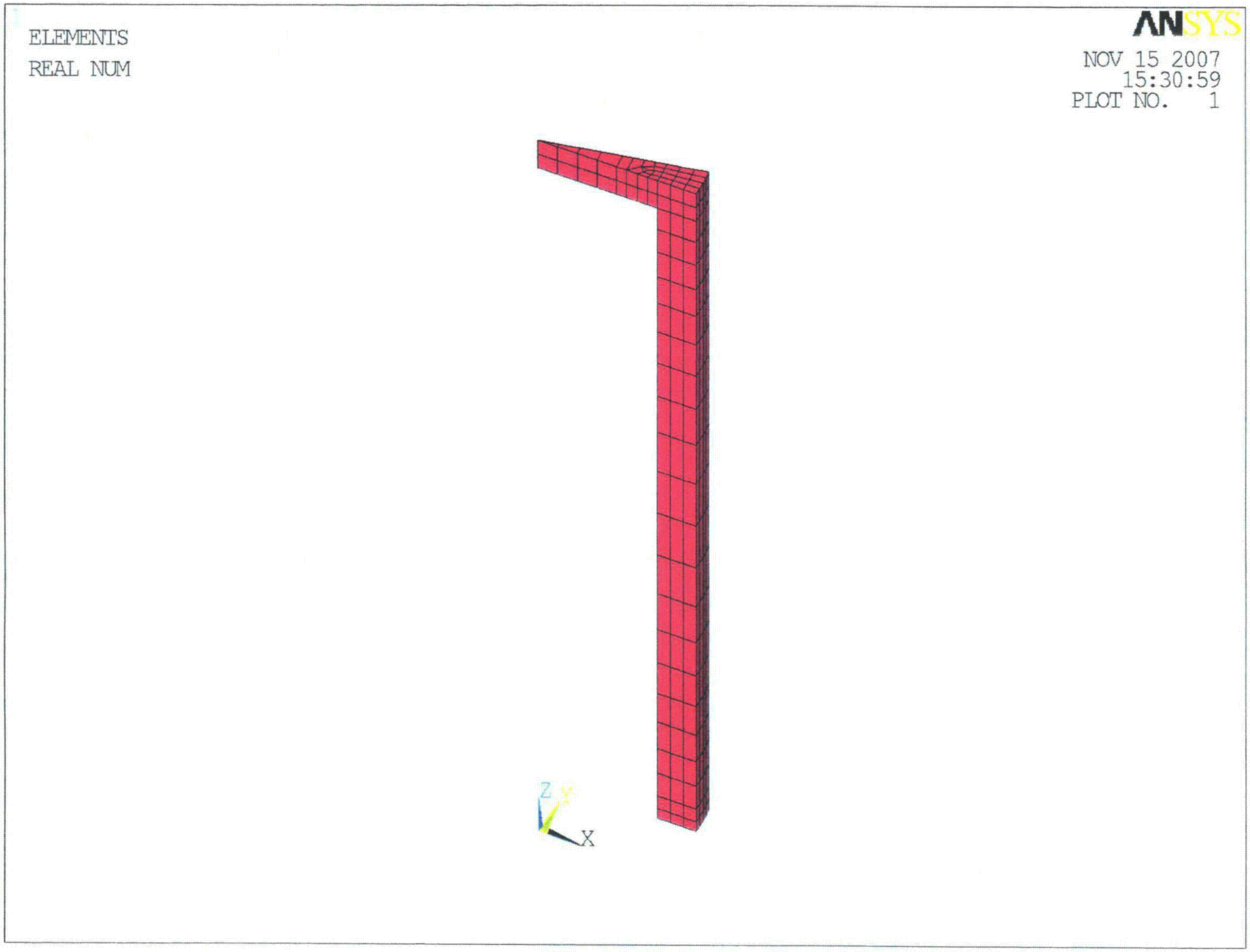

Figure 4
Finite Element Model of the Lead

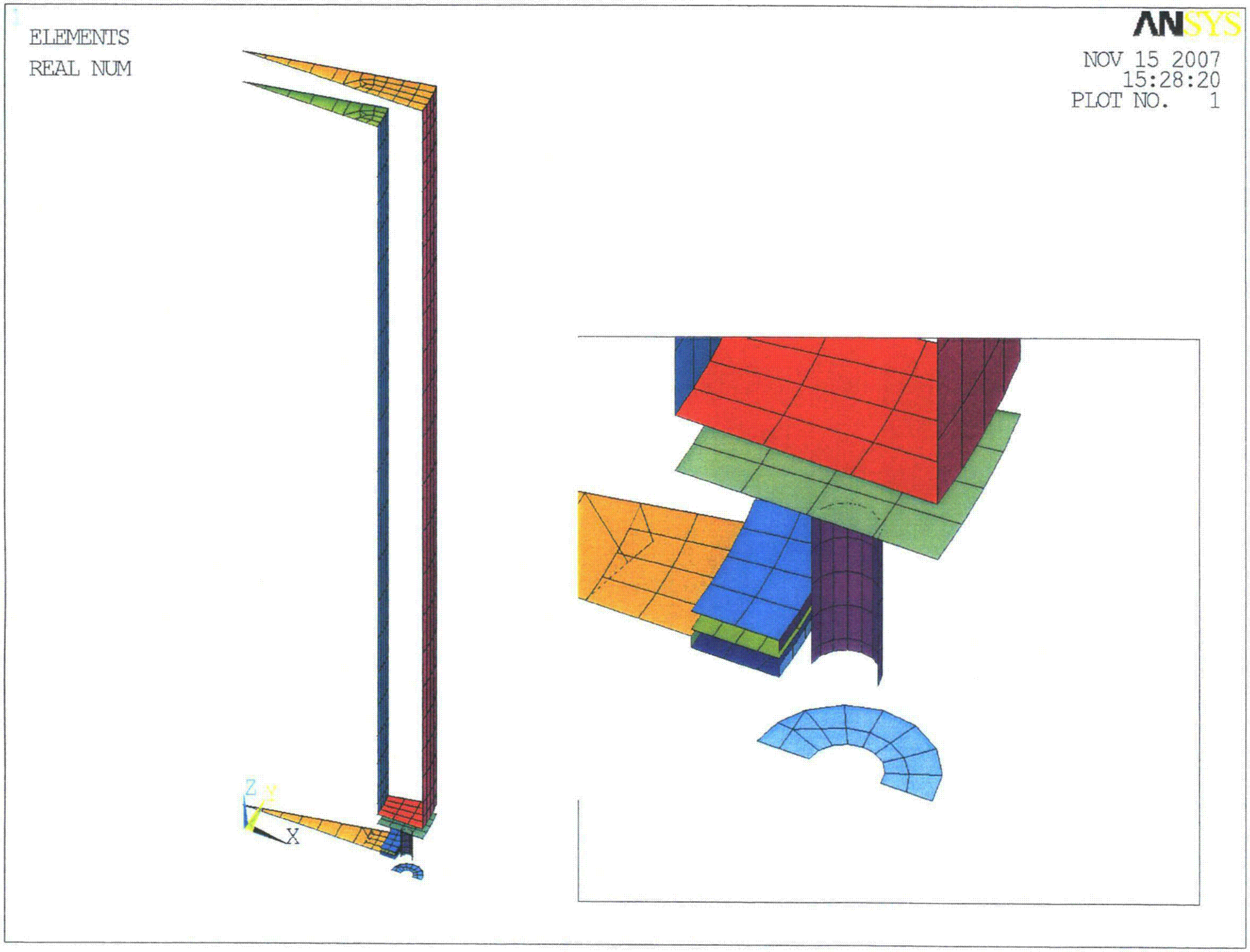

Figure 5

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

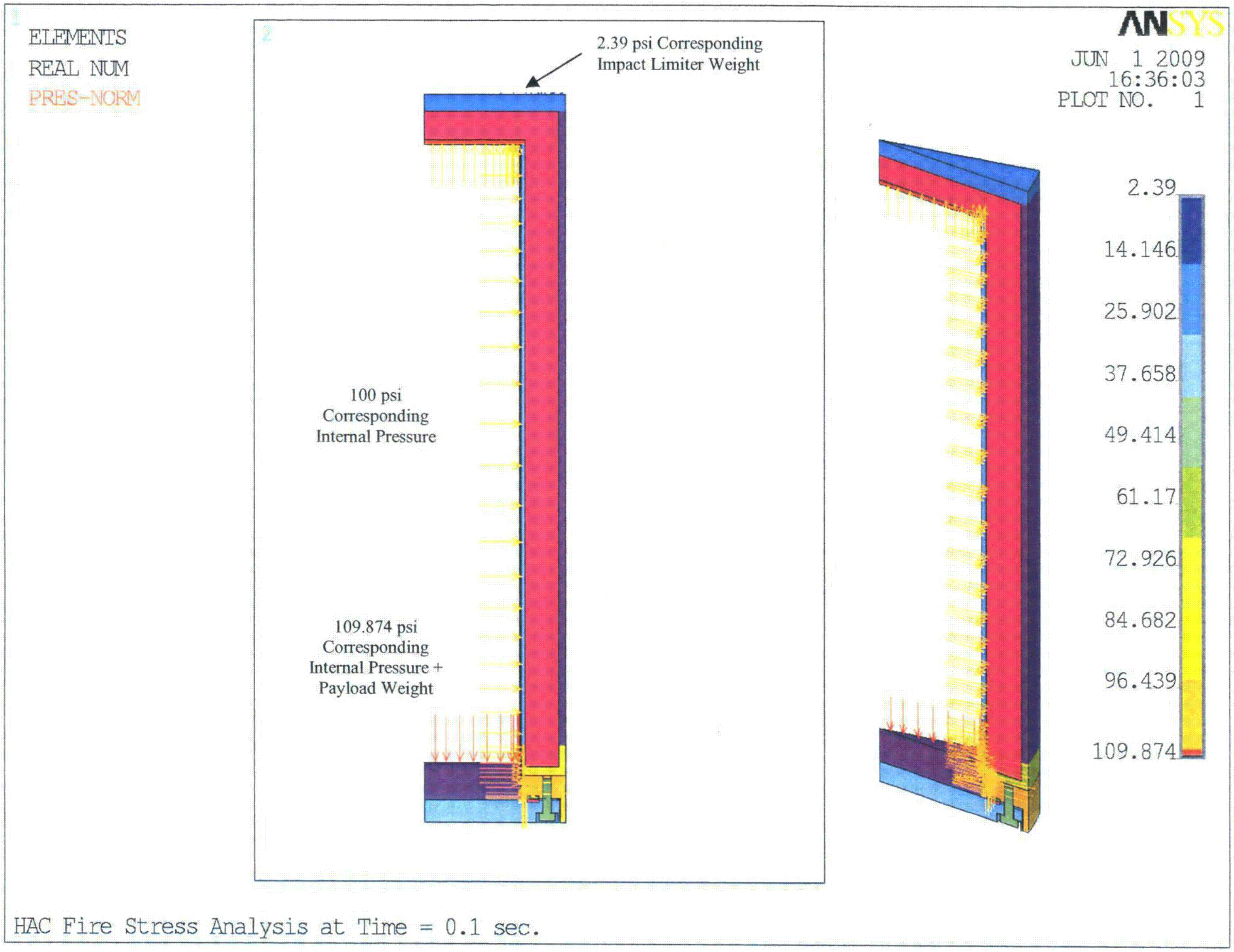

Figure 6
Pressure Distribution Used for All Load Steps

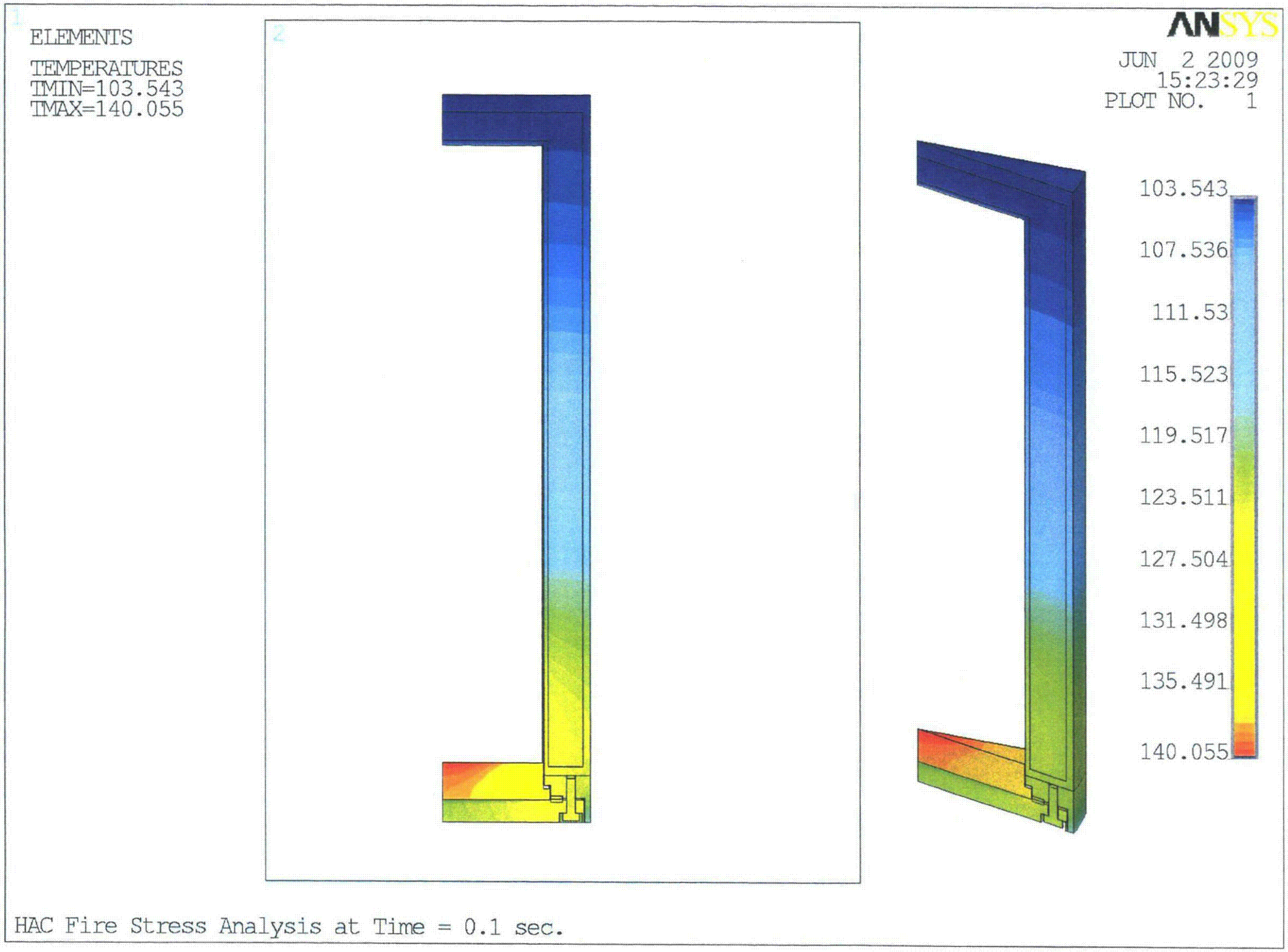

Figure 7
Temperature Profile Used for Load Step No.1 - HAC Thermal Analysis (Time = 0.1 sec)

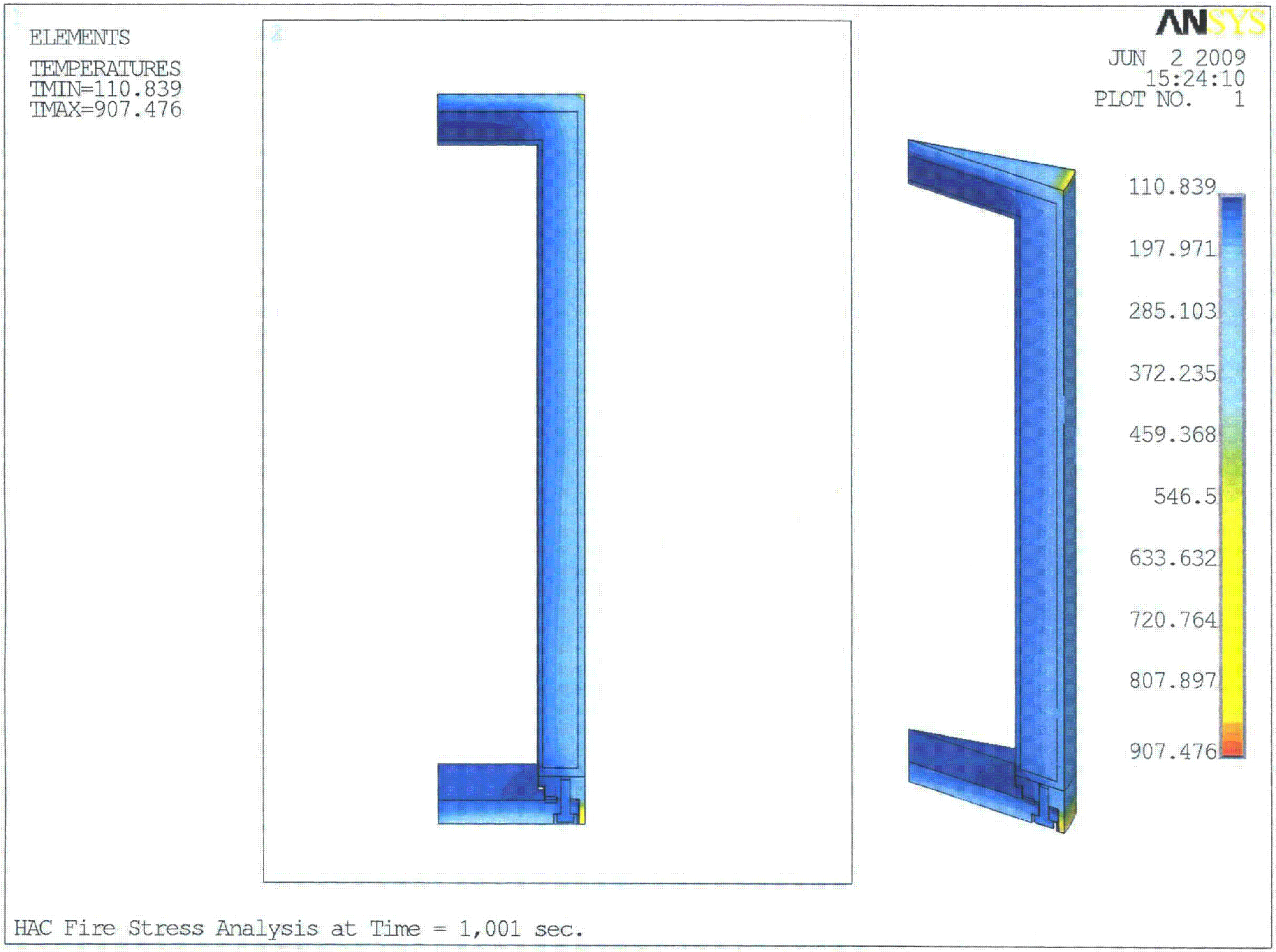

Figure 8

Temperature Profile Used for Load Step No.2 - HAC Thermal Analysis (Time = 1,001 sec)

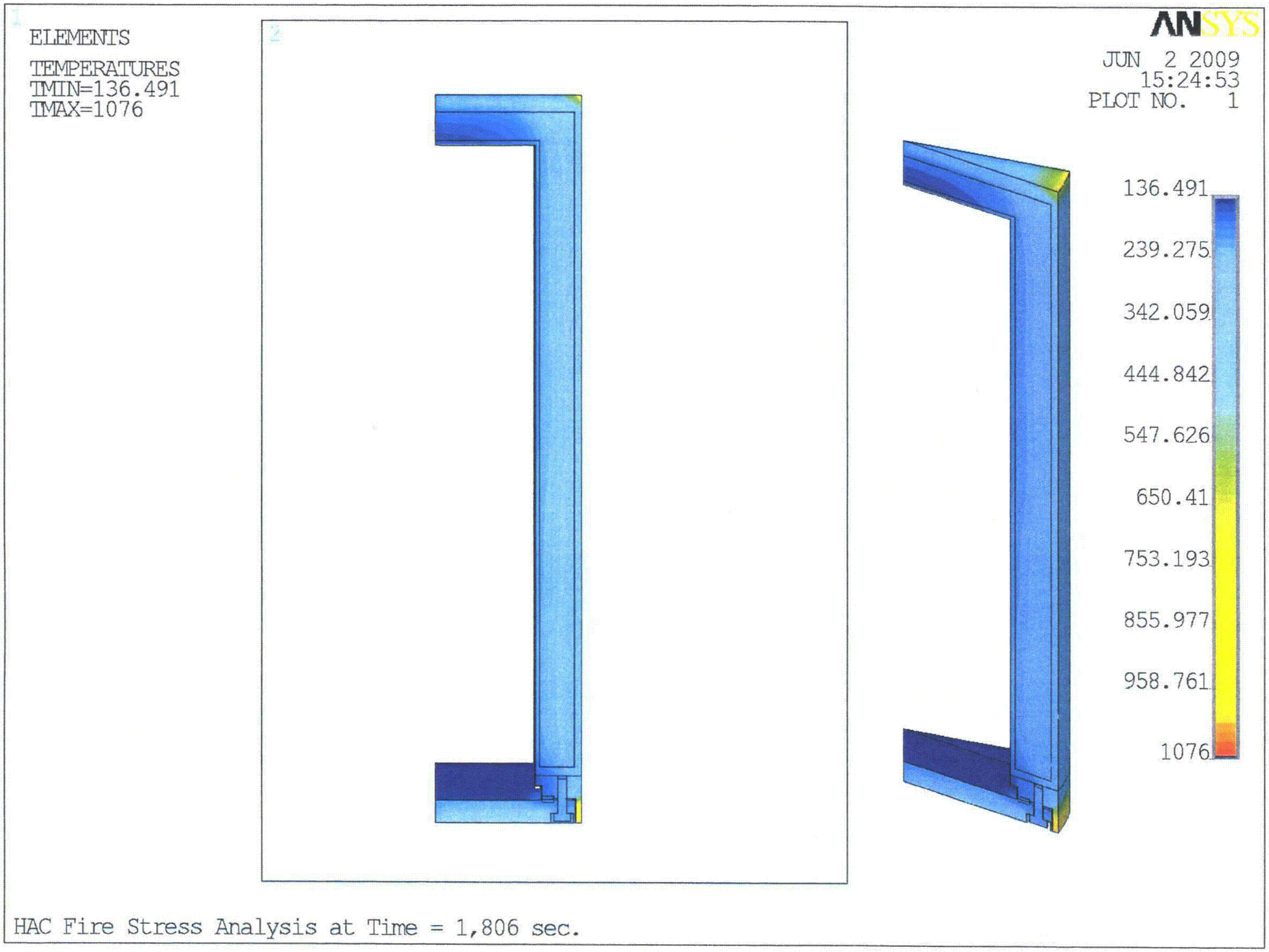

Figure 9

Temperature Profile Used for Load Step No.3 - HAC Thermal Analysis (Time = 1,806 sec)

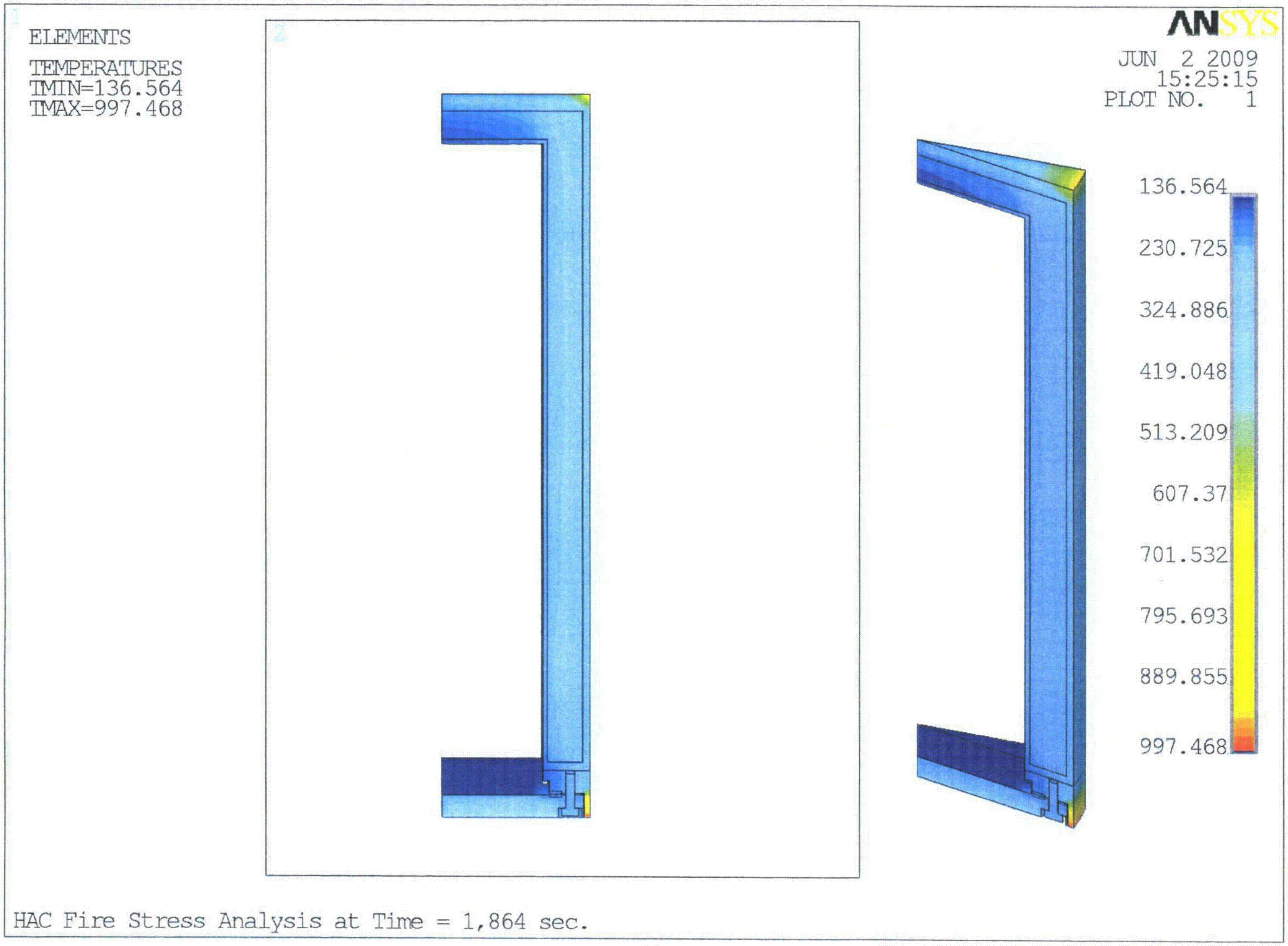

Figure 10
Temperature Profile Used for Load Step No.4 - HAC Thermal Analysis (Time = 1,864 sec)

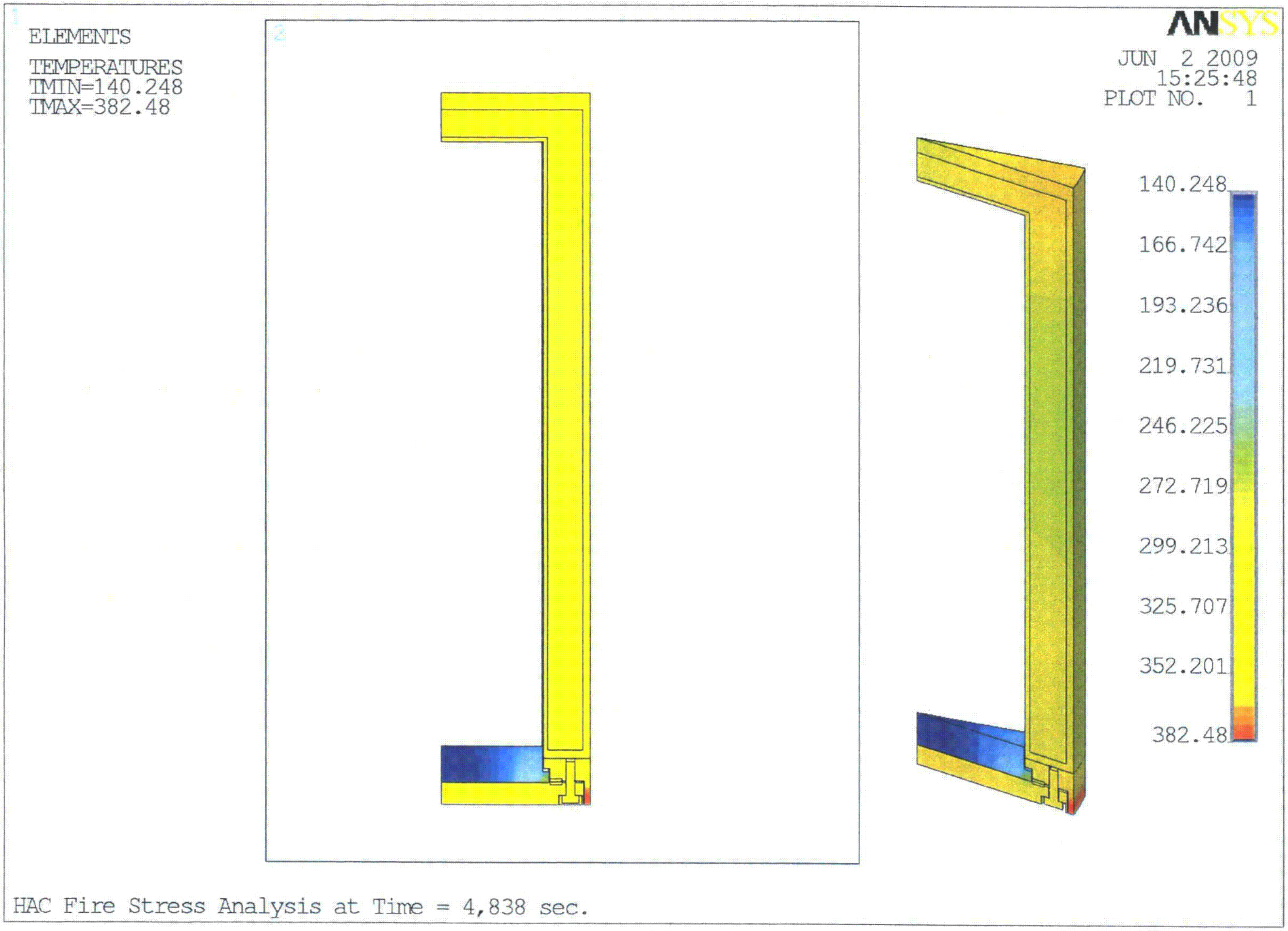

Figure 11

Temperature Profile Used for Load Step No.5 - HAC Thermal Analysis (Time = 4,838 sec)

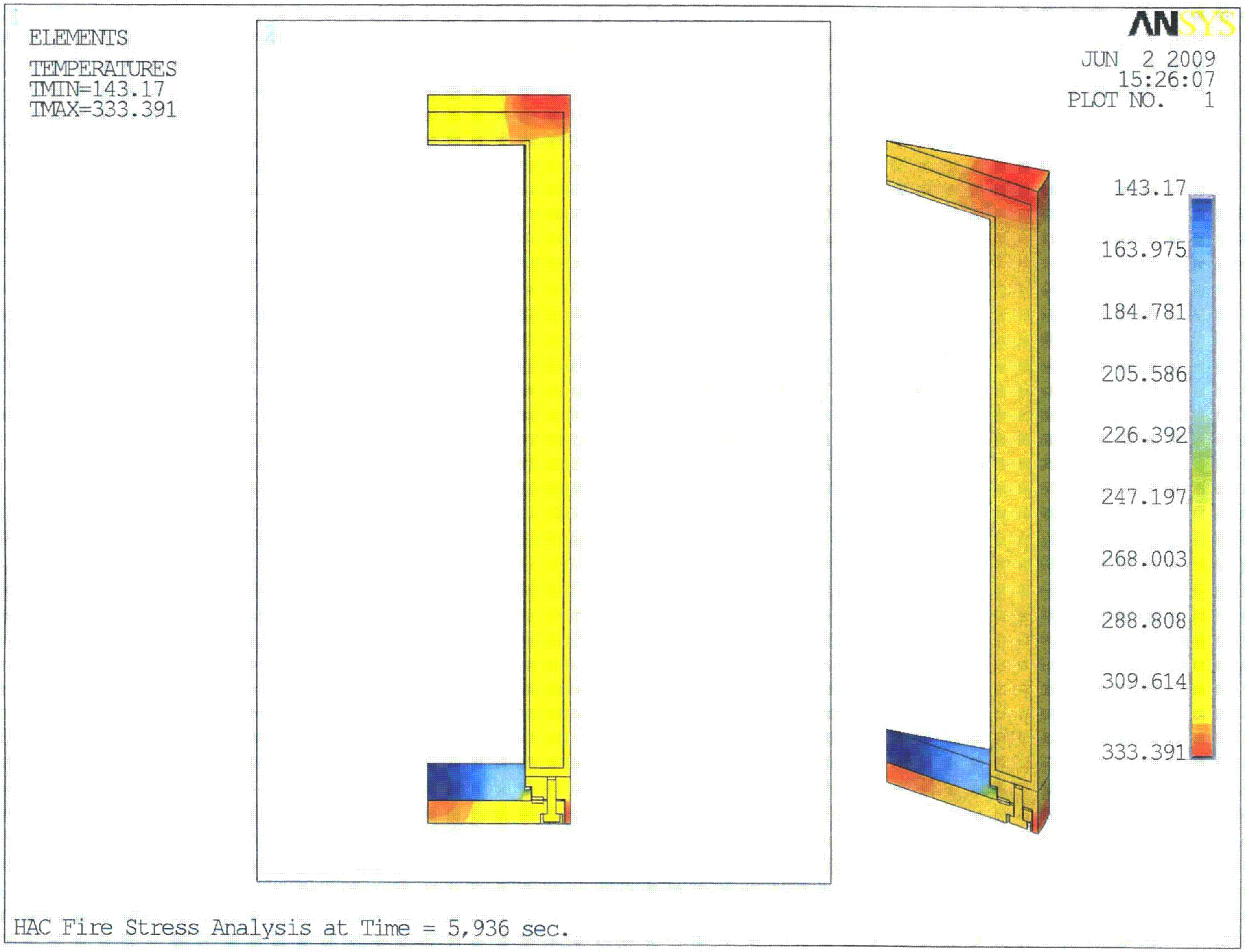

Figure 12

Temperature Profile Used for Load Step No.6 - HAC Thermal Analysis (Time = 5,936 sec)

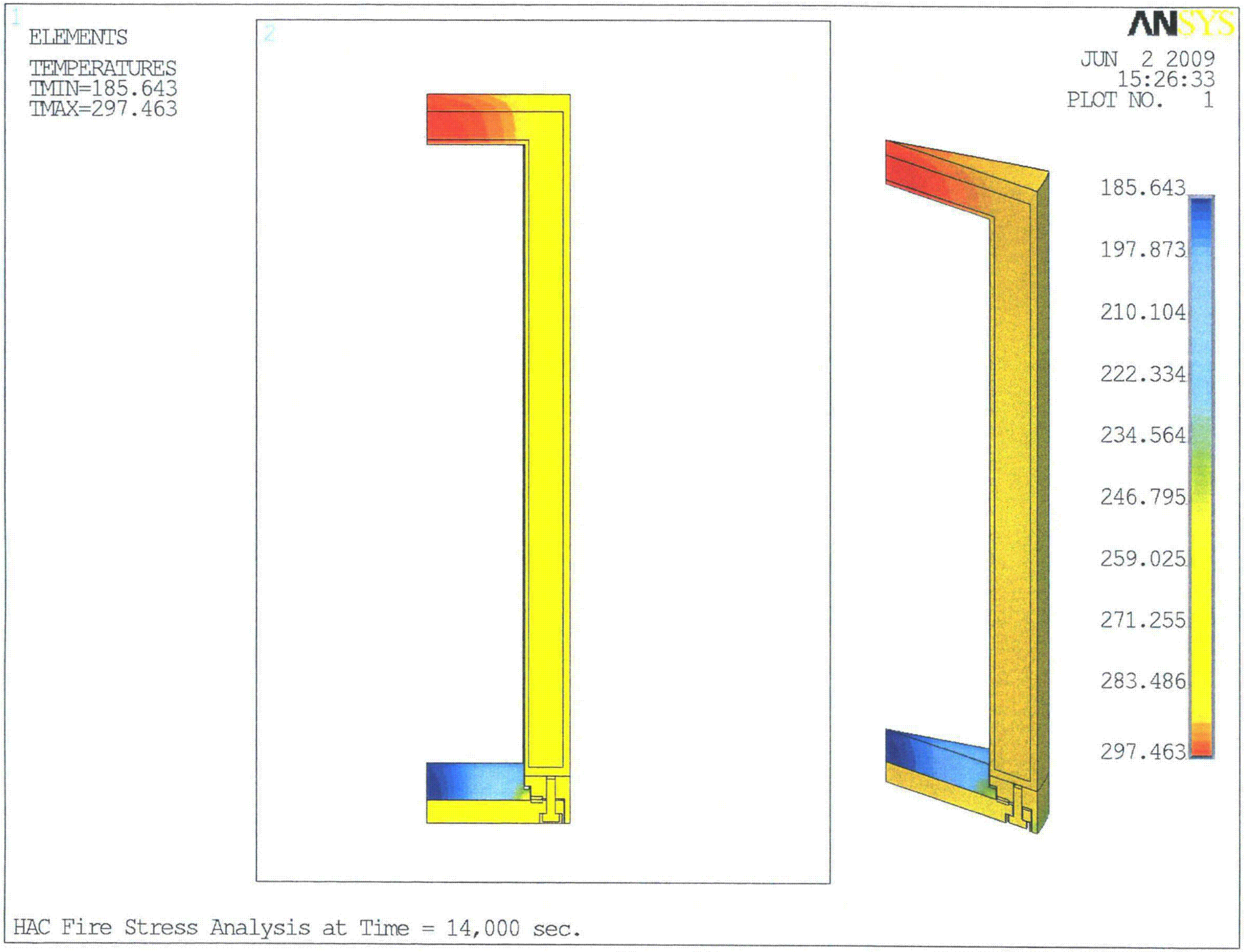

Figure 13

Temperature Profile Used for Load Step No.7 - HAC Thermal Analysis (Time = 14,000 sec)

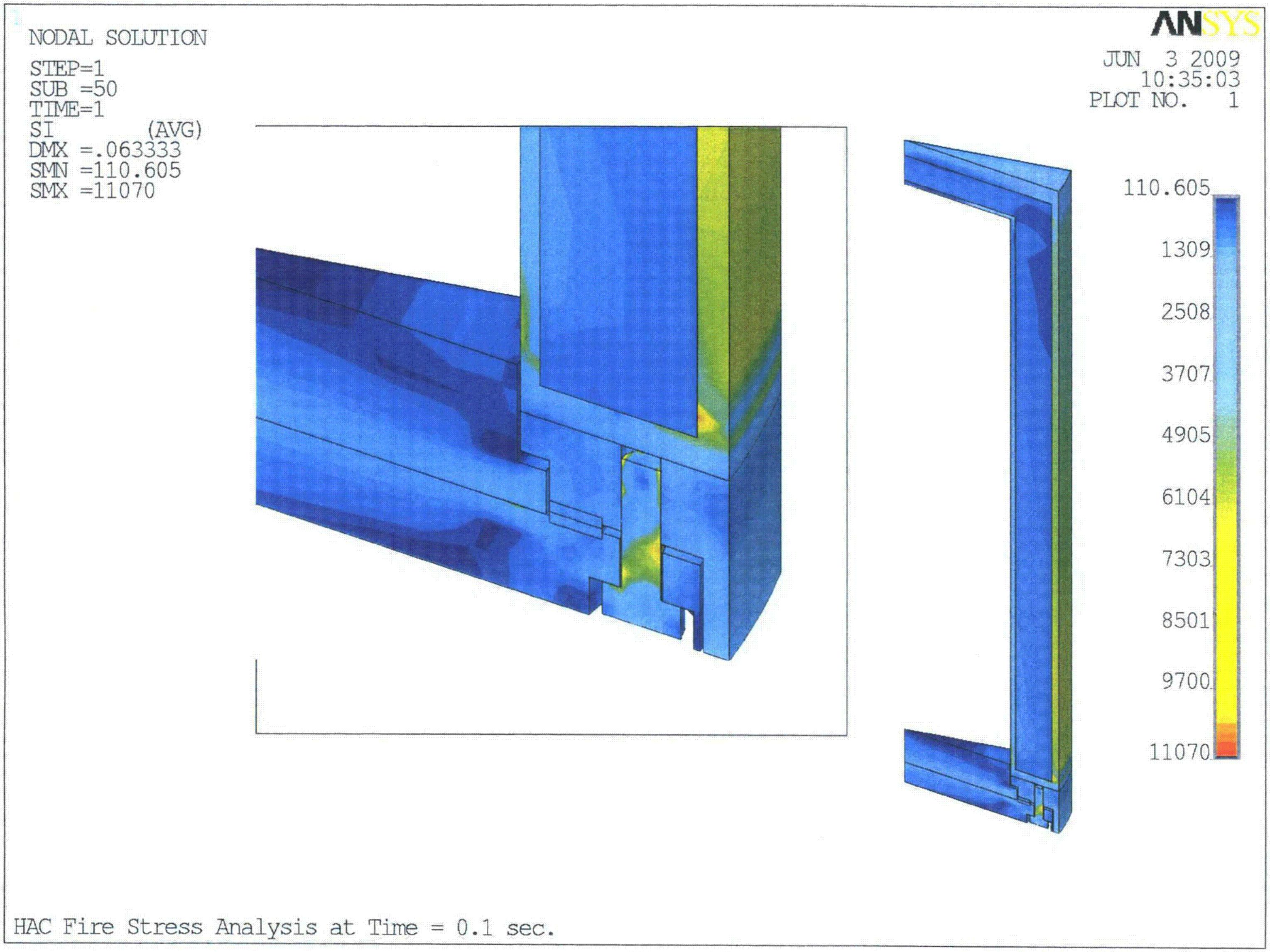

Figure 14

Stress Intensity Contour Plot Cask Body – Load Step No.1

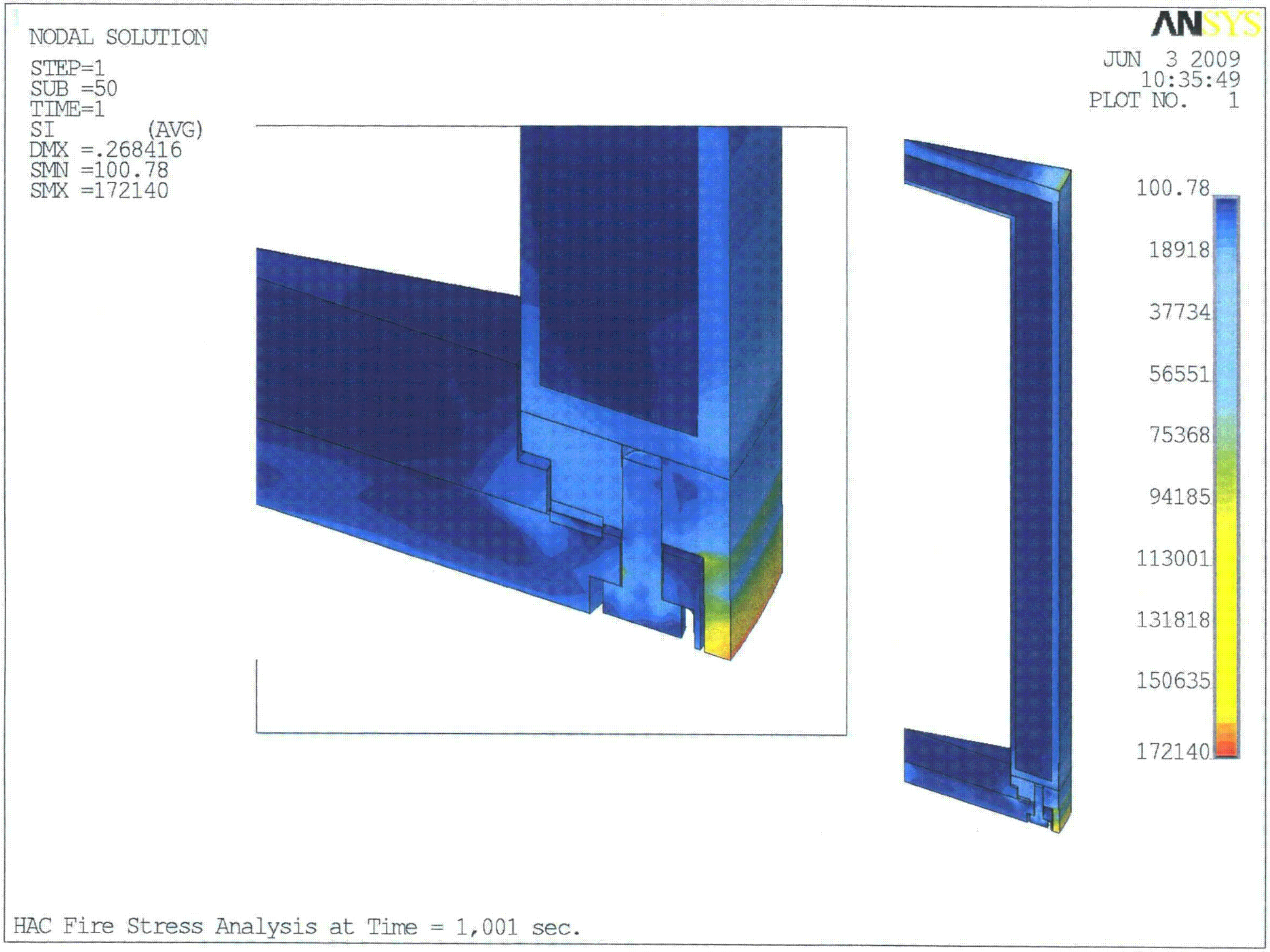

Figure 15

Stress Intensity Contour Plot Cask Body – Load Step No.2

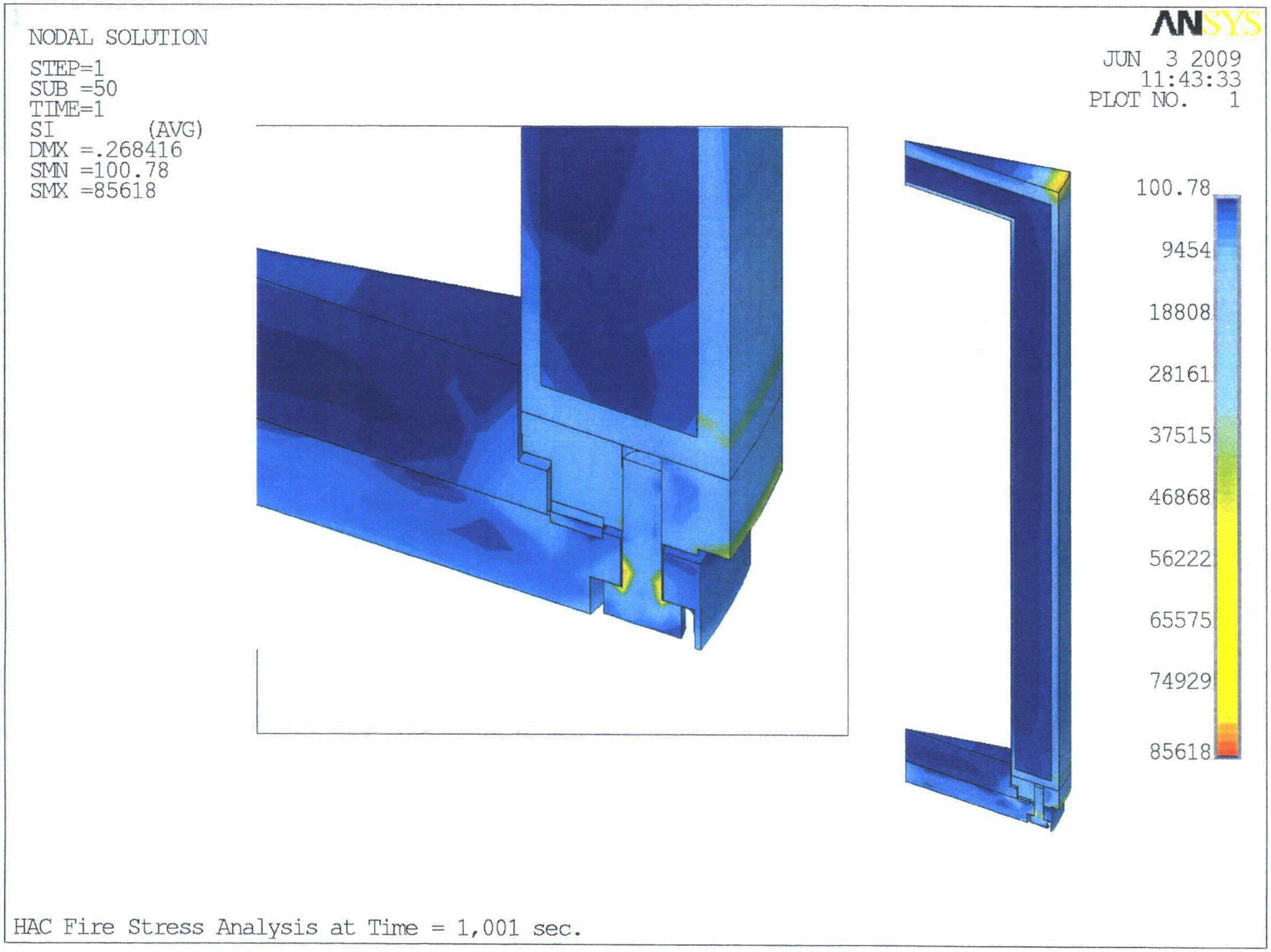

Figure 16

Stress Intensity Contour Plot Cask Body (w/o Skirt) – Load Step No.2

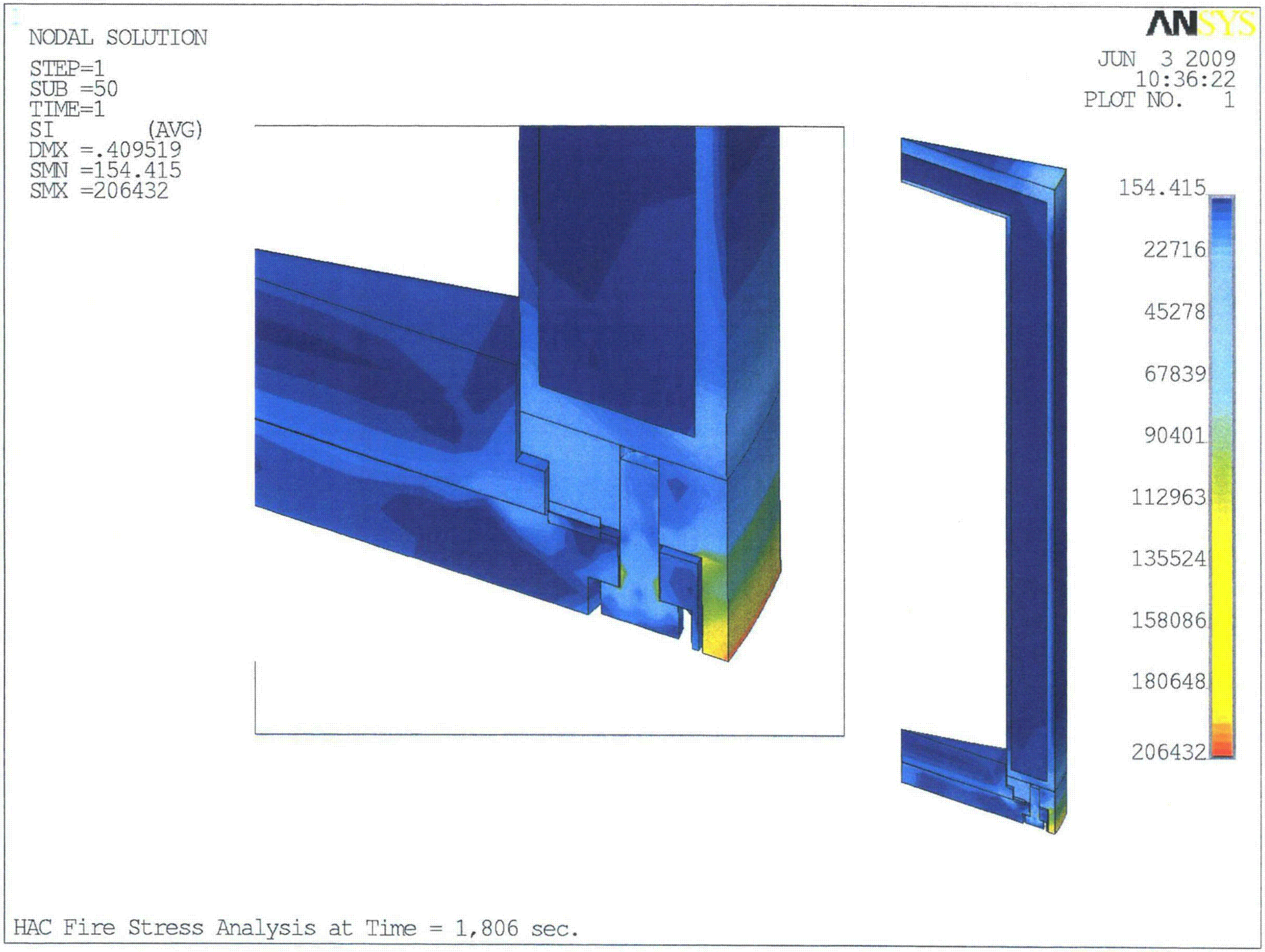

Figure 17

Stress Intensity Contour Plot Cask Body – Load Step No.3

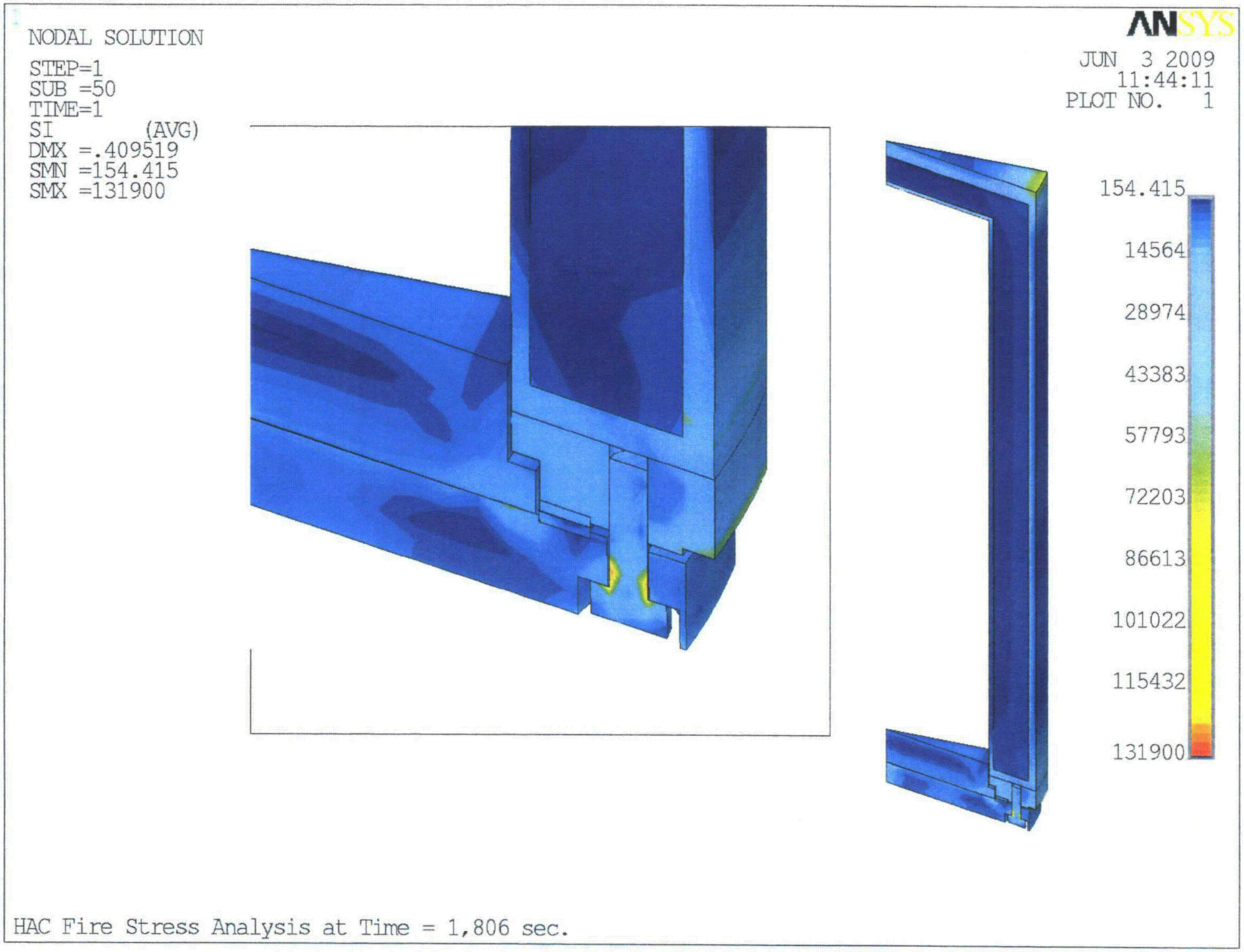

Figure 18

Stress Intensity Contour Plot Cask Body (w/o Skirt) – Load Step No.3

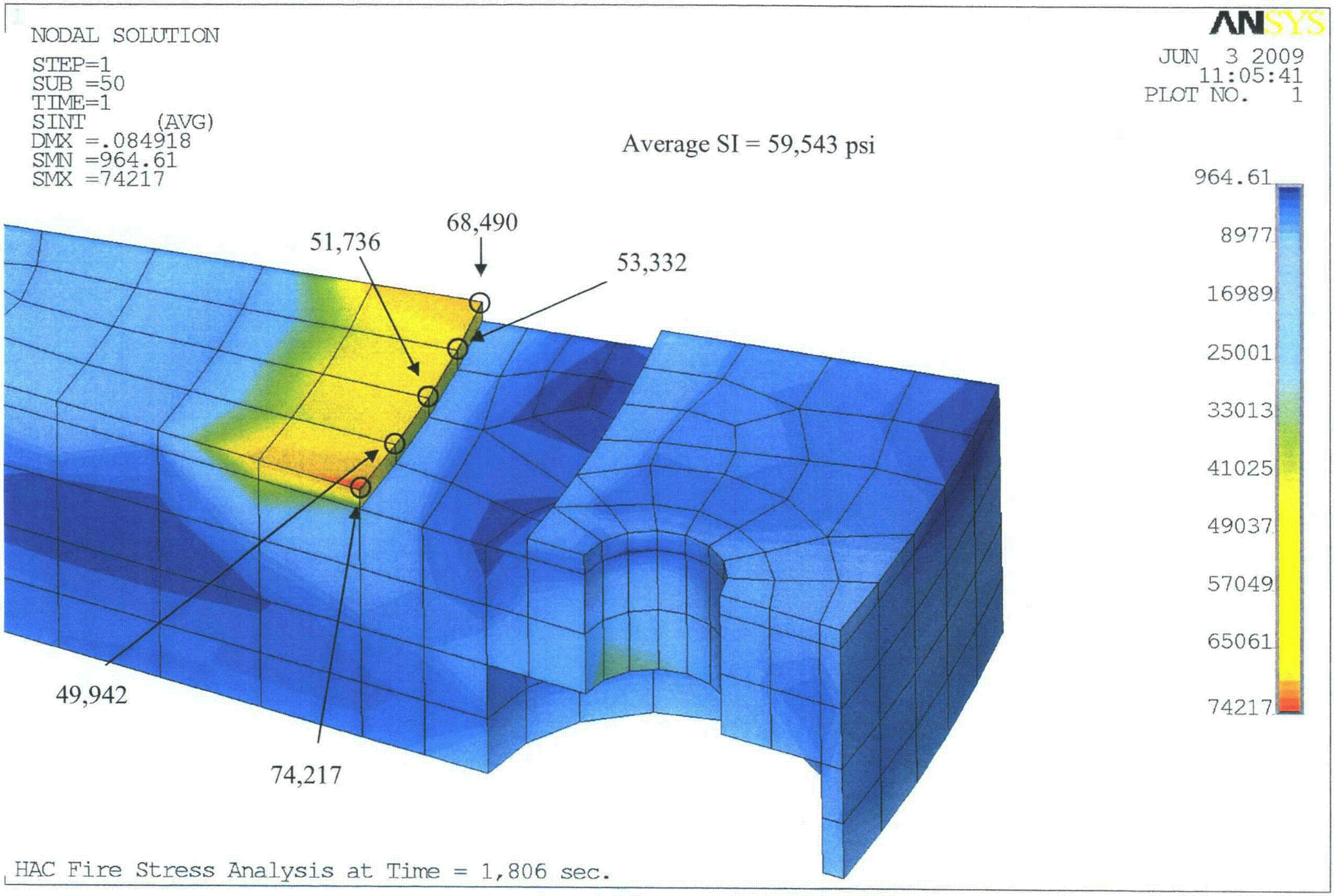

Figure 19
Stress Intensity Averaging in the Lid-Load Step No.3

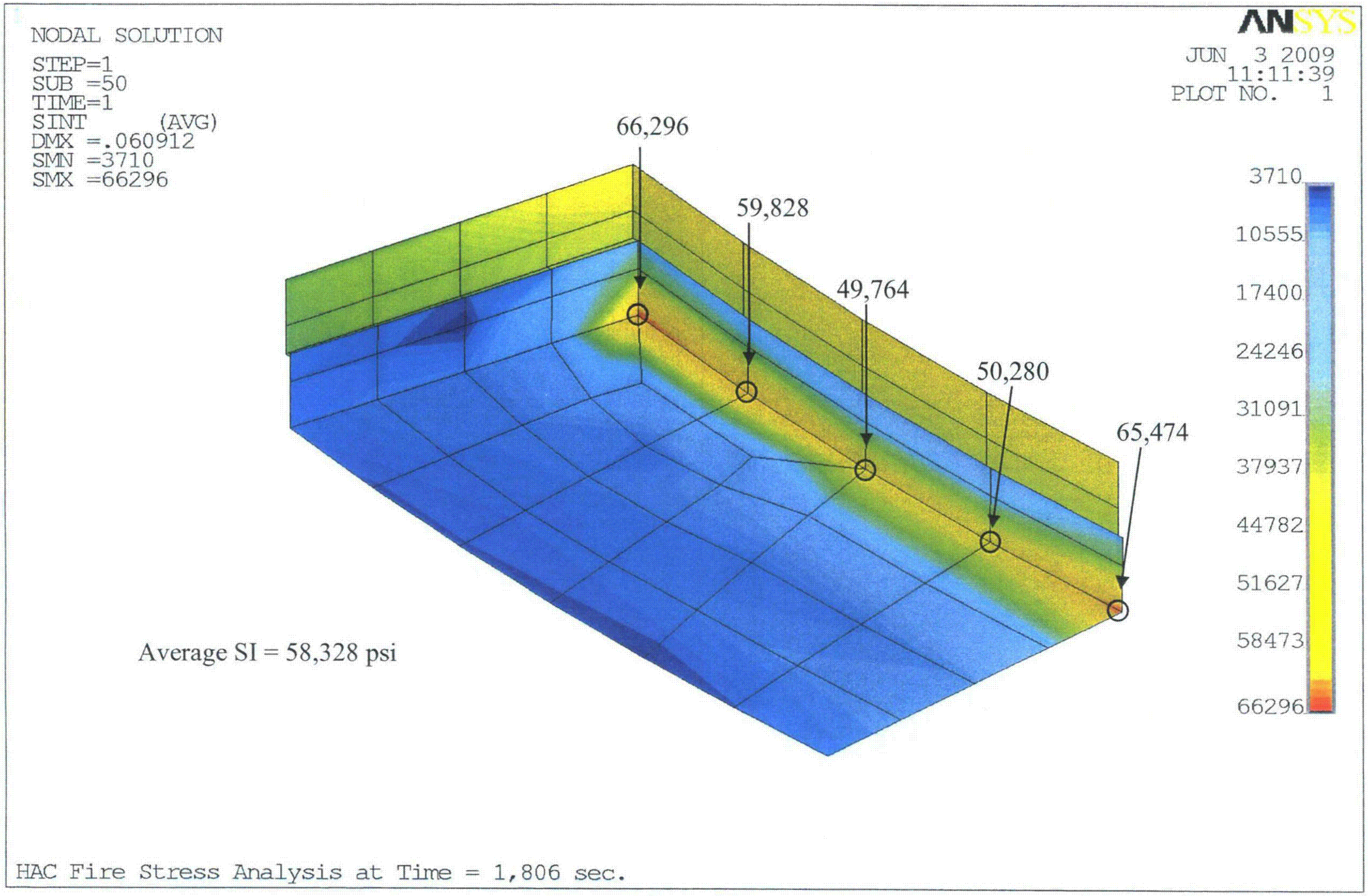

Figure 20

Stress Intensity Averaging in the Seal Plates-Load Step No.3

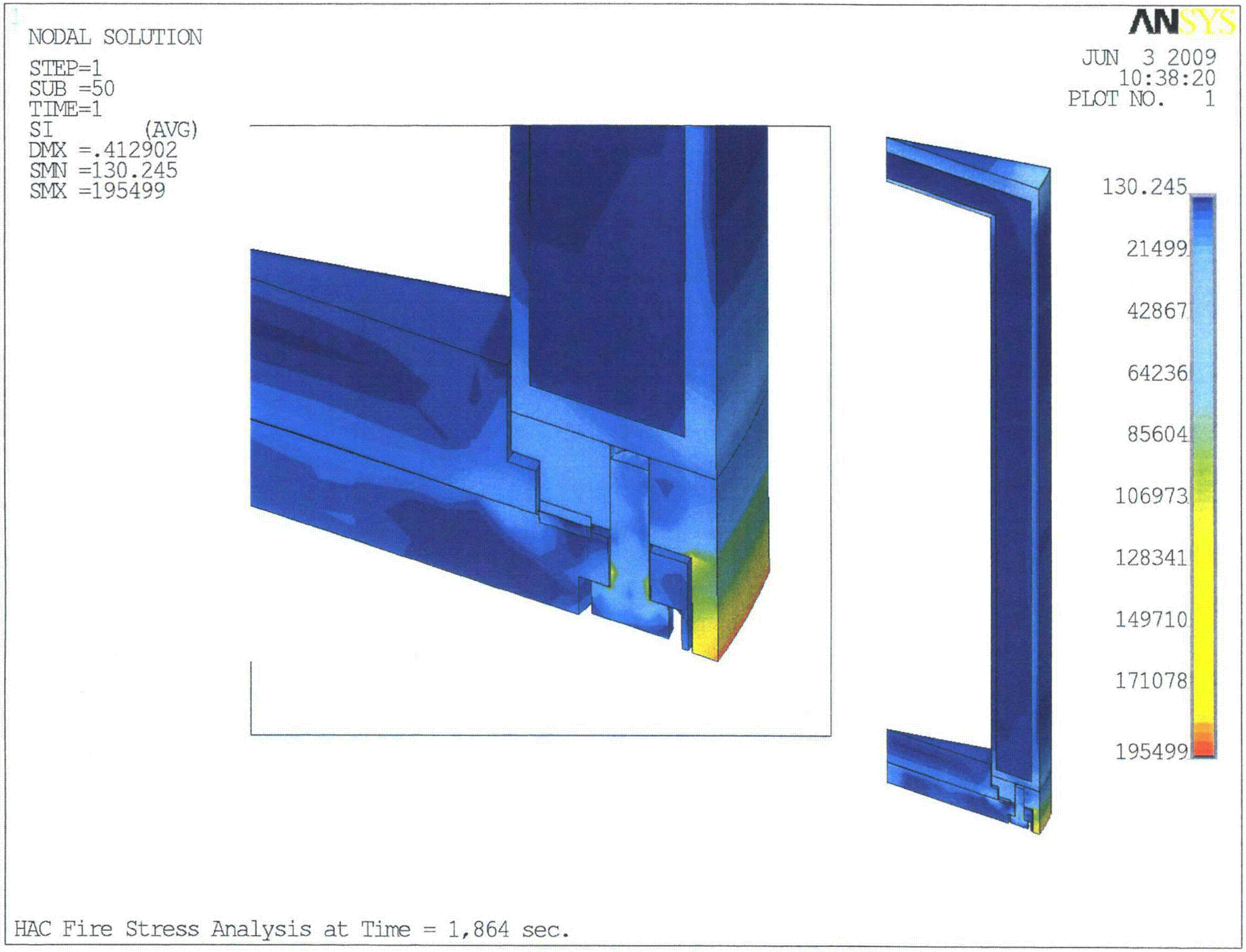

Figure 21
Stress Intensity Contour Plot – Load Step No.4

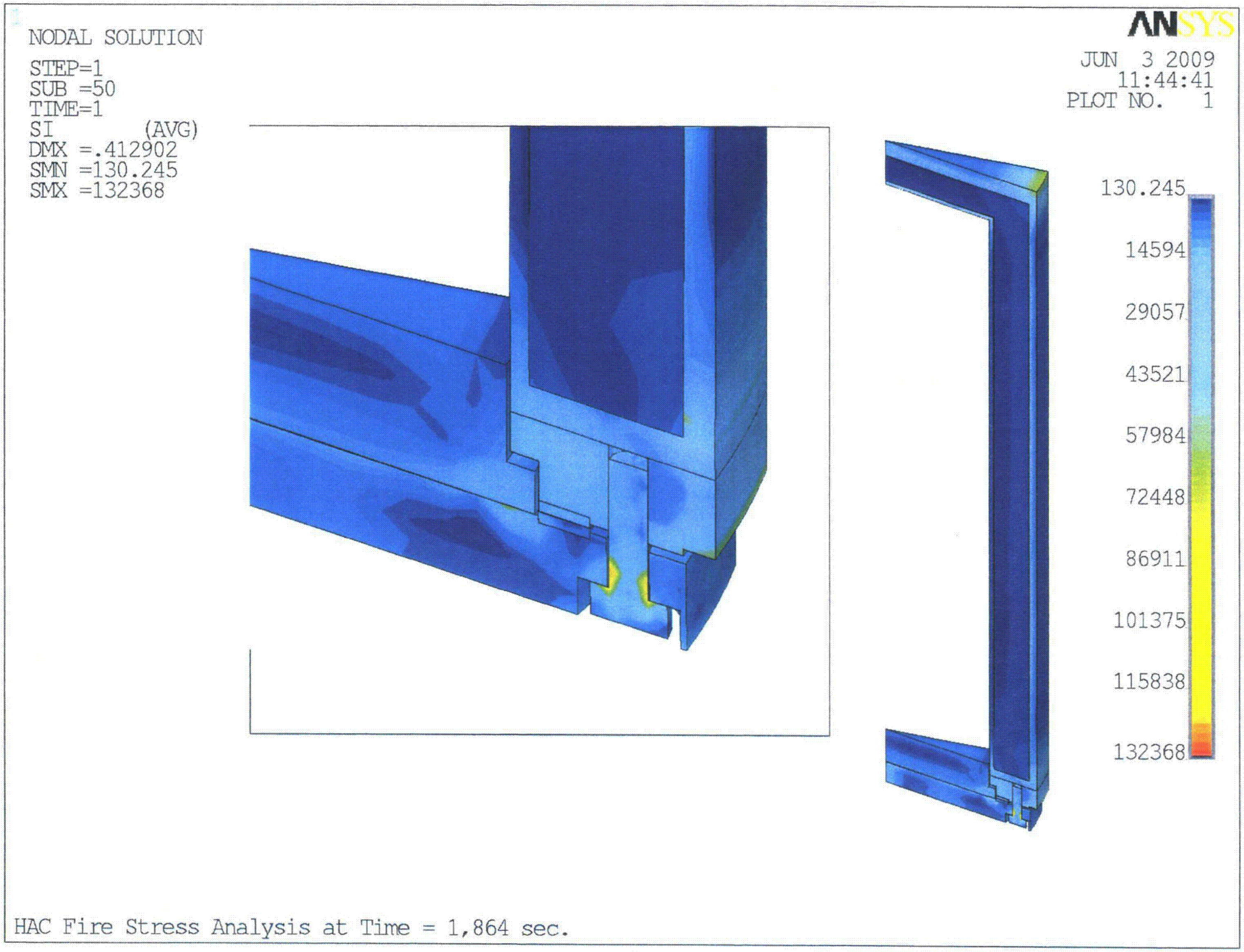

Figure 22

Stress Intensity Contour Plot Cask Body (w/o Skirt) – Load Step No.4

Title Structural Analyses of the 3-60B Cask Under Hypothetical Fire Accident

Calc. No. ST-502 (Figures) Rev. 1 Sheet 22 of 28

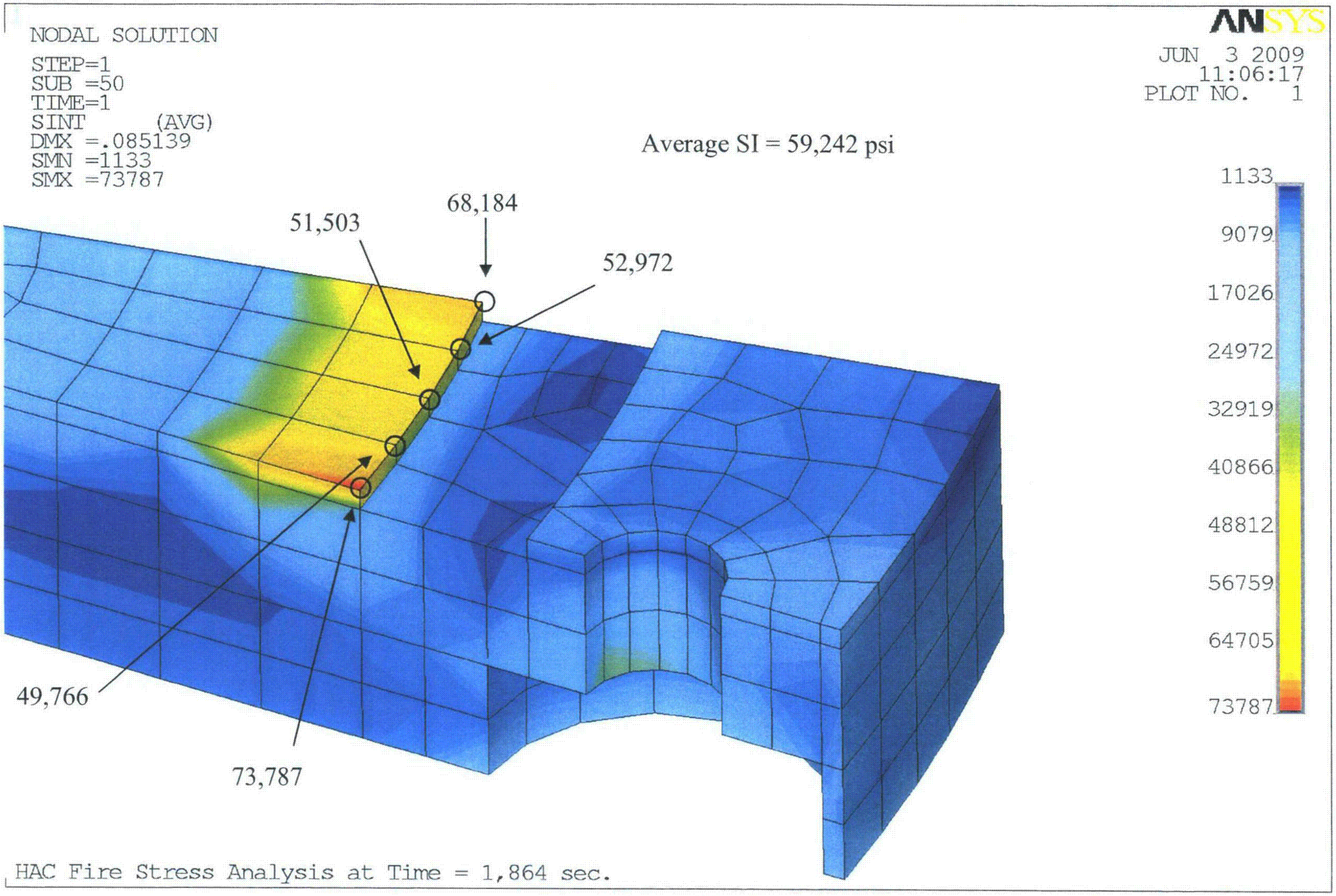

Figure 23

Stress Intensity Averaging in the Lid-Load Step No.4

Title Structural Analyses of the 3-60B Cask Under Hypothetical Fire Accident

Calc. No. ST-502 (Figures) Rev. 1 Sheet 23 of 28

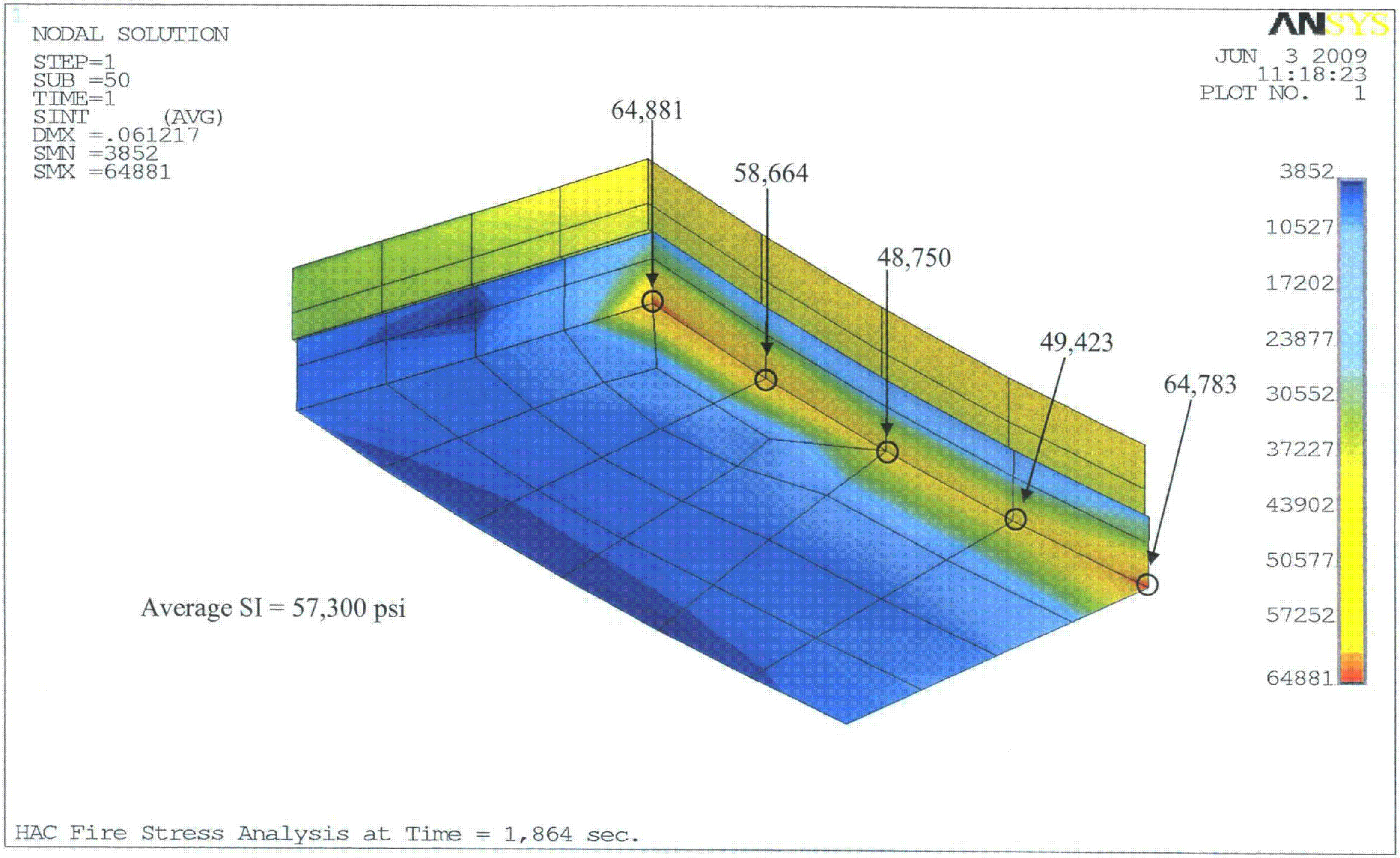

Figure 24

Stress Intensity Averaging in the Seal Plates-Load Step No.4

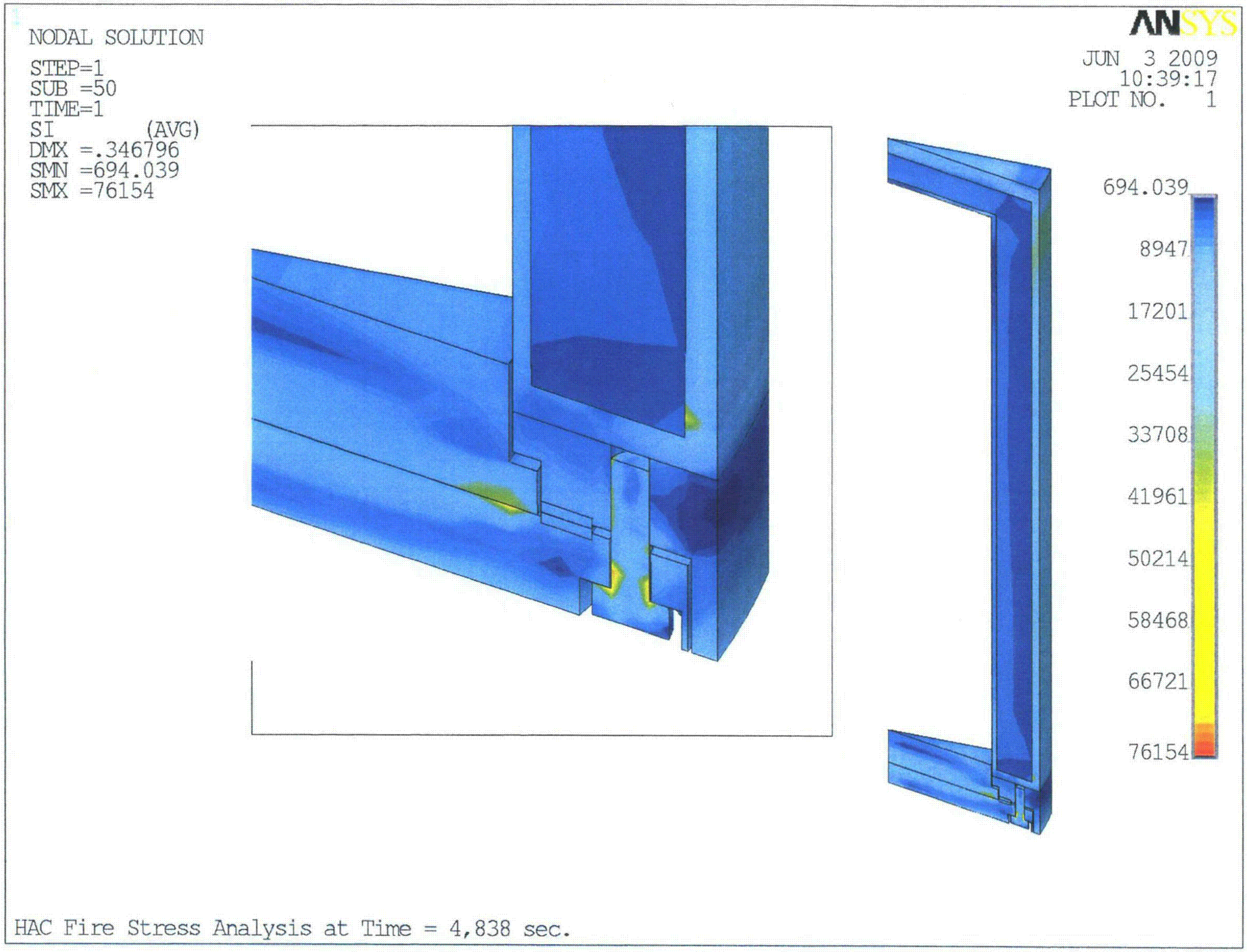

Figure 25

Stress Intensity Contour Plot – Load Step No.5

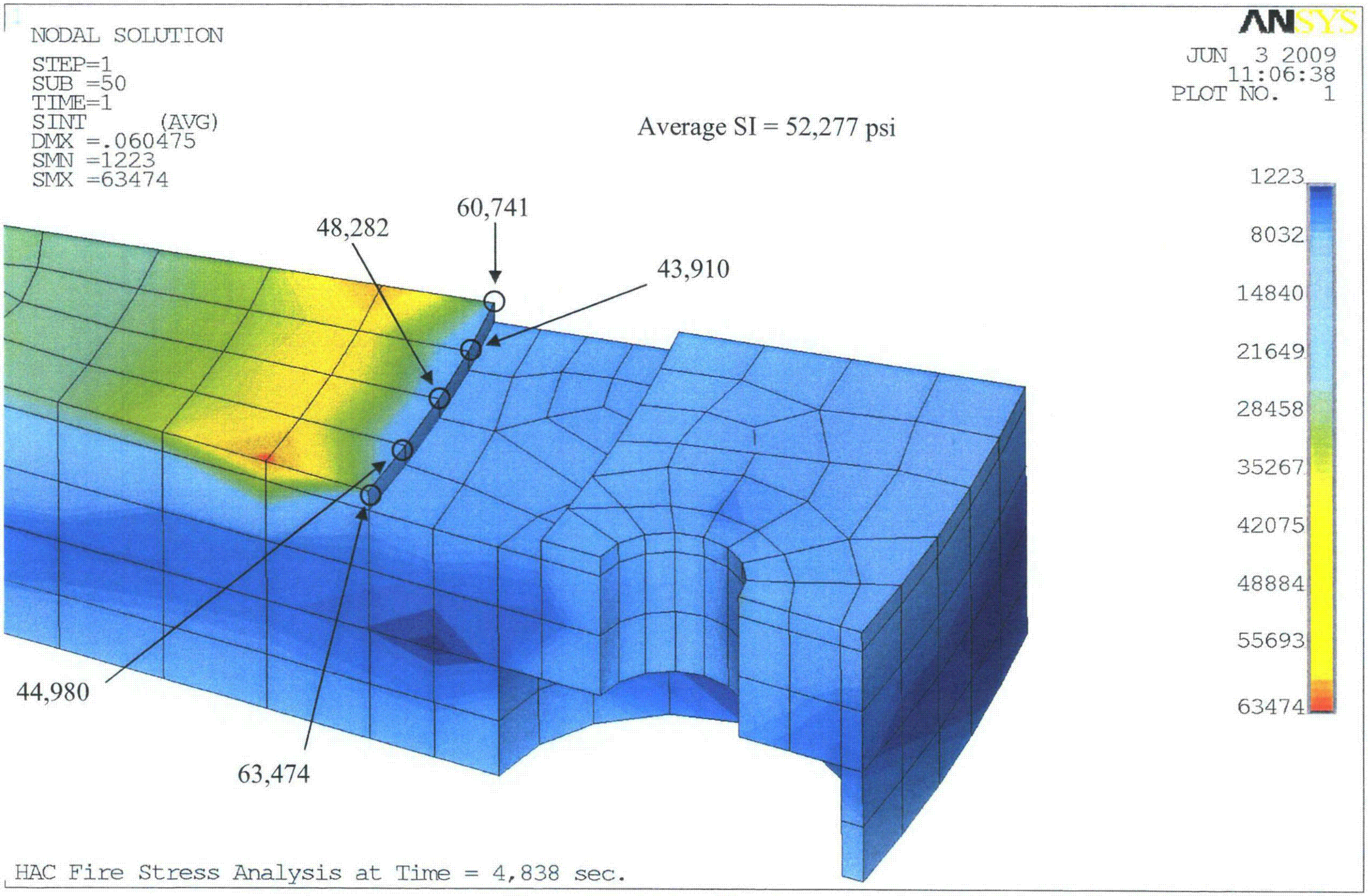

Figure 26

Stress Intensity Averaging in the Lid-Load Step No.5

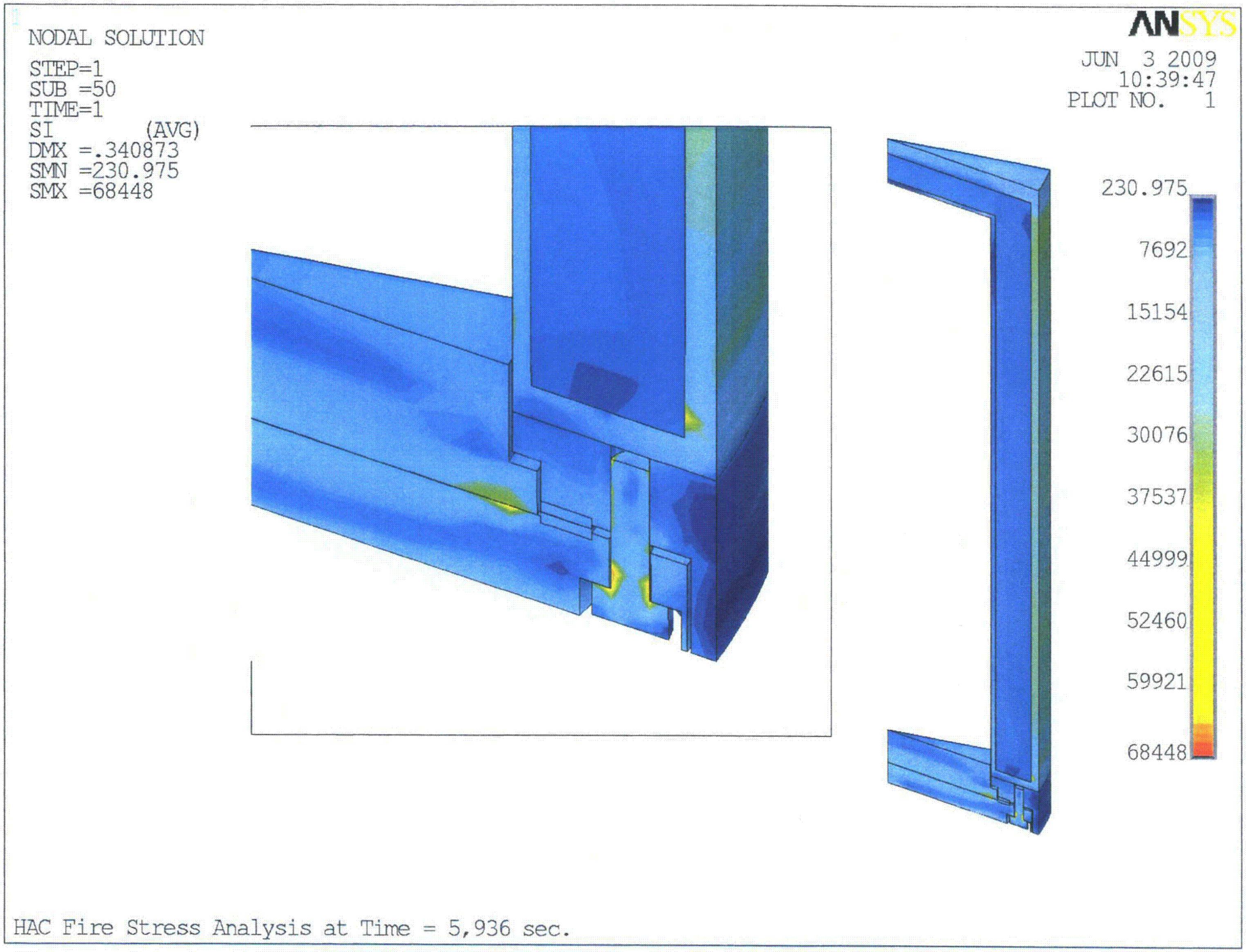

Figure 27
Stress Intensity Contour Plot – Load Step No.6

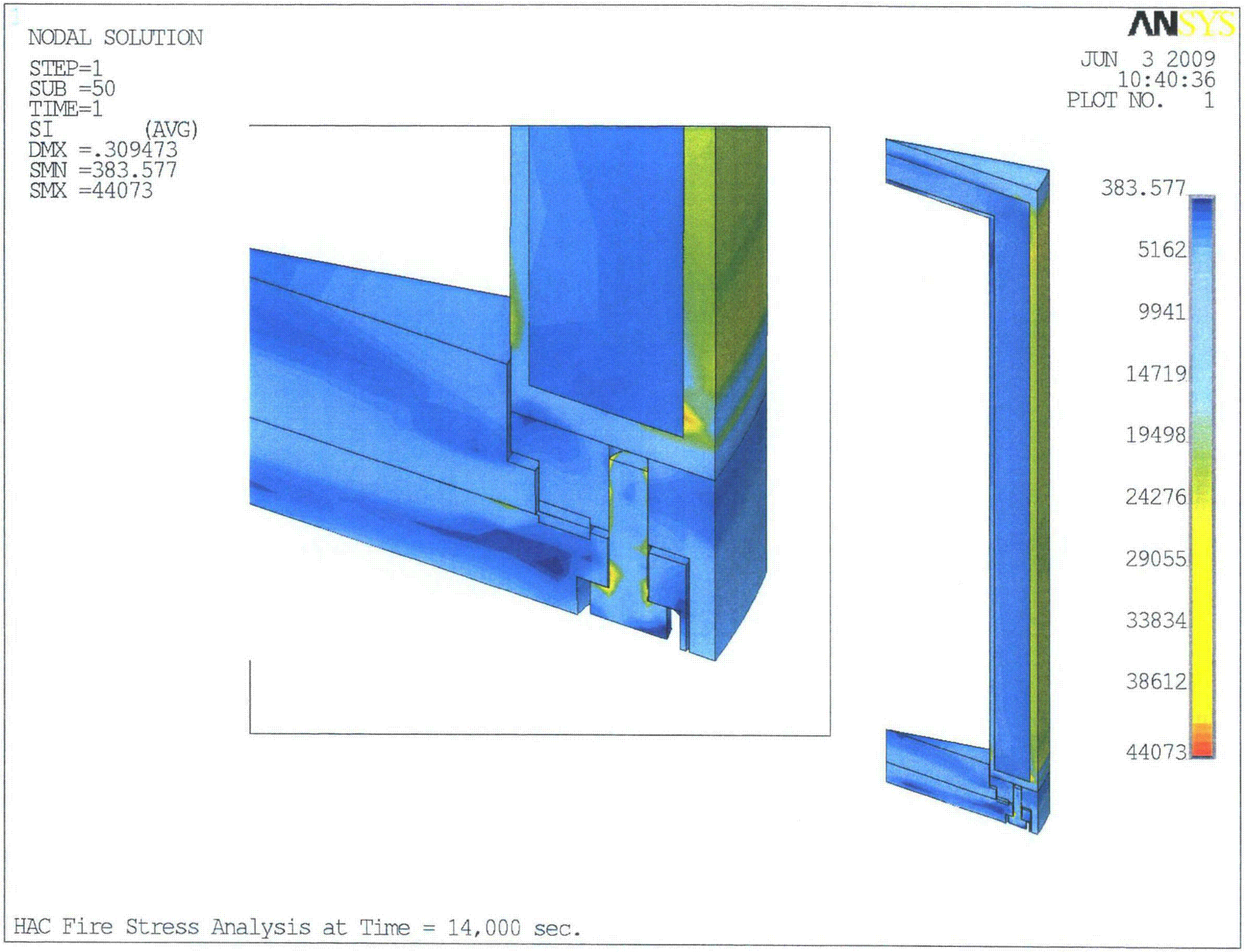

Figure 28
Stress Intensity Contour Plot – Load Step No.7

Appendix 1

Printout of the ANSYS Model Data

(10 Pages)

ANSYS Model Print-Out

```
    ***** 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: D:\Ansys Analyses\3-60B\Thermal\Fire with High Emissivity\Stress

 TITLE= HAC Fire Stress Analysis at Time = 1,864 sec.

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

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

 ANSYS - Engineering Analysis System           Jun 17, 2009          11:47
 Release 11.0SP1              00222442                WINDOWS x64  Version

 Current working directory: D:\Ansys Analyses\3-60B\Thermal\Fire with High Emissivity\Stress


 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  2.4 seconds

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

HAC Fire Stress Analysis at Time = 1,864 sec.

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

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

                                 Available              Used
 Scratch Memory Space. . . .   4796.000 mb          4.280 mb (   0.1%)
 Database space  . . . . . . 1048572.000 mb        10.401 mb (   0.0%)

 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 . . . . . . . . . . .   2895           2868           2868
 Elements. . . . . . . . . .   3949           2368           2368
```

Element types	70	35	n.a.
Real constant sets.	57	28	n.a.
Material property sets. . .	3	3	n.a.
Coupling.	0	0	n.a.
Constraint equations. . . .	267	150	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.	1201
Constraints on keypoints.	0
Constraints on lines.	0
Constraints on areas.	0
Forces on nodes	0
Forces on keypoints	0
Surface loads on elements	197
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	2868
Body loads on keypoints	0
Temperatures	
Uniform temperature.	70.000
Reference temperature.	70.000
Offset from absolute scale	460.000

	X	Y	Z
Linear acceleration	0.0000	0.0000	1.1070
Angular velocity (about global CS). . . .	0.0000	0.0000	0.0000
Angular acceleration (about global CS) . .	0.0000	0.0000	0.0000
Location of reference CS.	0.0000	0.0000	0.0000
Angular velocity (about reference CS) . .	0.0000	0.0000	0.0000
Angular acceleration (about reference CS)	0.0000	0.0000	0.0000

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

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

Active coordinate system . . . .   1 (Cylindrical)

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

Current element attributes:
   Type number 69 (TARGE170)
   Real number   57
   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 . . . .   1 (Cylindrical)

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 . . . . . . . . . .     2

Number of substeps . . . . . . . . .    50
   Step change boundary conditions . .No

                      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   TEMP
  ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
  OFFSET TEMPERATURE FROM ABSOLUTE ZERO . . . . .  460.00
  NEWTON-RAPHSON OPTION . . . . . . . . . . . . .PROGRAM CHOSEN
  GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . .SYMMETRIC

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

  LOAD STEP NUMBER. . . . . . . . . . . . . . . .    2
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
  NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .    50
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS
     LABEL   REFERENCE    TOLERANCE  NORM     MINREF
      F        0.000      0.2000E-01   1      0.000
  INERTIA LOADS                       X            Y            Z
     ACEL . . . . . . . . . . . . 0.0000       0.0000      1.1070
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM      FREQUENCY   COMPONENT
     BASI        ALL


 LIST ELEMENT TYPES FROM      1 TO     70 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     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 CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
  KEYOPT(1-12)=    0  0  0    2  1  0    0  0  1    0  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 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     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 CONTA174     3D 8-NODE SURF-SURF CONTACT     INOPR
```

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

ELEMENT TYPE     53 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     54 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     57 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     58 IS CONTA174      3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0       0

ELEMENT TYPE     61 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     62 IS CONTA174      3D 8-NODE SURF-SURF CONTACT      INOPR
 KEYOPT(1-12)=    0  0  0    2  3  0    0  0  1    2  0  0       0

ELEMENT TYPE     63 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     64 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     65 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     66 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     67 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     68 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     69 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     70 IS CONTA175      NODE-TO-SURFACE 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    TEMP
 THREE-DIMENSIONAL MODEL

LIST REAL SETS       1 TO      57 BY       1

REAL CONSTANT SET      23  ITEMS   1 TO   6
   1.0000      0.33056E-14   0.0000       0.0000        0.0000        0.0000

REAL CONSTANT SET      23  ITEMS   7 TO   12
   0.0000       0.0000       0.0000       0.0000        0.0000        0.0000

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

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

REAL CONSTANT SET      24  ITEMS   7 TO   12
   0.0000       0.0000       0.0000       0.0000        0.0000        0.0000

REAL CONSTANT SET      24  ITEMS  13 TO   18
  0.33300       0.0000       0.0000       0.0000        0.0000        0.0000

REAL CONSTANT SET      27  ITEMS   1 TO   6
   1.0000      0.33056E-14   0.0000       0.0000        0.0000        0.0000

REAL CONSTANT SET      27  ITEMS   7 TO   12
   0.0000       0.0000       0.0000       0.0000        0.0000        0.0000

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

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

REAL CONSTANT SET      28  ITEMS   7 TO   12
   0.0000       0.0000       0.0000       0.0000        0.0000        0.0000

REAL CONSTANT SET      28  ITEMS  13 TO   18
  0.33300       0.0000       0.0000       0.0000        0.0000        0.0000

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

REAL CONSTANT SET      36  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      36  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      36  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      36  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      37  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      37  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      37  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      37  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      38  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      38  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      38  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      38  ITEMS  19 TO  24
   0.0000       1.0000       1.0000       0.0000       0.0000       1.0000

REAL CONSTANT SET      39  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      39  ITEMS   7 TO  12
   0.0000       0.0000     0.10000E+21    0.0000       1.0000       0.0000

REAL CONSTANT SET      39  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000
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REAL CONSTANT SET      39  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      40  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      40  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      40  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      40  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      42  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      42  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      42  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      42  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      43  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      43  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      43  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      43  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      44  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      44  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      44  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      44  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      45  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      45  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      45  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      45  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      46  ITEMS   1 TO   6
   0.0000      0.0000      1.0000      0.10000     0.0000      0.0000

REAL CONSTANT SET      46  ITEMS   7 TO  12
   0.0000      0.0000      0.10000E+21 0.0000      1.0000      0.0000

REAL CONSTANT SET      46  ITEMS  13 TO  18
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   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     46  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     47  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     47  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000

 REAL CONSTANT SET     47  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     47  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     48  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     48  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000

 REAL CONSTANT SET     48  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     48  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     50  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     50  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000

 REAL CONSTANT SET     50  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     50  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     51  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     51  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000

 REAL CONSTANT SET     51  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     51  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     52  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     52  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000

 REAL CONSTANT SET     52  ITEMS  13 TO  18
   0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

 REAL CONSTANT SET     52  ITEMS  19 TO  24
   0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

 REAL CONSTANT SET     53  ITEMS   1 TO   6
   0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

 REAL CONSTANT SET     53  ITEMS   7 TO  12
   0.0000      0.0000    0.10000E+21   0.0000      1.0000      0.0000
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REAL CONSTANT SET      53  ITEMS  13 TO  18
  0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      53  ITEMS  19 TO  24
  0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      54  ITEMS   1 TO   6
  0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

REAL CONSTANT SET      54  ITEMS   7 TO  12
  0.0000      0.0000     0.10000E+21  0.0000      1.0000      0.0000

REAL CONSTANT SET      54  ITEMS  13 TO  18
  0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      54  ITEMS  19 TO  24
  0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      55  ITEMS   1 TO   6
  0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

REAL CONSTANT SET      55  ITEMS   7 TO  12
  0.0000      0.0000     0.10000E+21  0.0000      1.0000      0.0000

REAL CONSTANT SET      55  ITEMS  13 TO  18
  0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      55  ITEMS  19 TO  24
  0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      55  ITEMS  25 TO  30
  10.000      0.0000      0.0000      0.0000      0.0000      0.0000

REAL CONSTANT SET      56  ITEMS   1 TO   6
  0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

REAL CONSTANT SET      56  ITEMS   7 TO  12
  0.0000      0.0000     0.10000E+21  0.0000      1.0000      0.0000

REAL CONSTANT SET      56  ITEMS  13 TO  18
  0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      56  ITEMS  19 TO  24
  0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      56  ITEMS  25 TO  30
  10.000      0.0000      0.0000      0.0000      0.0000      0.0000

REAL CONSTANT SET      57  ITEMS   1 TO   6
  0.0000      0.0000      1.0000     0.10000      0.0000      0.0000

REAL CONSTANT SET      57  ITEMS   7 TO  12
  0.0000      0.0000     0.10000E+21  0.0000      1.0000      0.0000

REAL CONSTANT SET      57  ITEMS  13 TO  18
  0.0000      0.0000      1.0000      0.0000      1.0000      0.50000

REAL CONSTANT SET      57  ITEMS  19 TO  24
  0.0000      1.0000      1.0000      0.0000      0.0000      1.0000

REAL CONSTANT SET      57  ITEMS  25 TO  30
  10.000      0.0000      0.0000      0.0000      0.0000      0.0000

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 EMIS  MAT=        1  NUM. POINTS=  1
  TEMPERATURE      DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    0.0000        0.0000

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 CDROM

(1 Page & 1 CDROM)