Reference 2-6 (ST-551) is a proprietary document. It is provided on the media marked "PROPRIETARY".

1.0 OBJECTIVE

To evaluate the 3-60B Cask trunnion assembly under various loading conditions.

2.0 INTRODUCTION

The 3-60B cask is equipped with four identical trunnions to help the lifting, handling and transportation of the cask. The details of the trunnions are shown in Reference 1 drawing. Analyses of the trunnion assemblies and the cask body are provided in this document to show that the trunnion design meets the applicable requirements of 10 CFR Part 71 (Reference 2).

The following load cases have been addressed.

Lifting

The loaded cask is lifted using the two upper trunnions as shown in Figure 1.

Handling

The cask is designed to be supported on the two pairs of the trunnions during transportation. The trunnions are used when the cask is down-ended and lowered unto the supporting structure. See Figure 1 for the trunnion loading during the handling process.

Regulatory/Transportation Requirement

Trunnions are used for the tie-down of the 3-60B Cask package during transportation. The transportation of the packages in the United States is controlled under the provisions of 49 CFR 393 (Reference 3). Loadings are specified by 49 CFR 393.102 for minimum performance criteria for cargo securement devices and systems. However, 10 CFR 71.45(b) requires that:

> "If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times weight of the package with contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents."

Since the 10CFR71 loading on the tie-down system is much more severe than the 49CFR393 loading, it is used for the evaluation of the 3-60 Cask package for the transportation conditions.

Enveloping loading conditions on the trunnions are developed from the above load cases. For these load cases, analyses of the trunnion assembly and the cask body have been performed using ANSYS finite element models (Reference 4).

3.0 REFERENCES

1. Energy*Solutions* Drawing C-002-165024-001, Rev. 0, "3-60B Cask General Arrangement and Details."

2. Code of Federal Regulations 10 CFR PART 71- Packaging and Transportation of Radioactive Material.
3. Code of Federal Regulations 49 CFR PART 393 - Transportation.
4. ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

4.0 MATERIAL PROPERTIES

Cask Shell

Specification: ASTM A-240 Type 304L

Minimum Yield Strength, S_y = 25,000 psi

Minimum Ultimate Strength, S_u = 70,000 psi

Trunnions

Specification: ASTM A-240 Type 304 (or Equivalent)

Minimum Yield Strength, S_y = 30,000 psi

Minimum Ultimate Strength, S_u = 75,000 psi

5.0 ALLOWABLE STRESSES

The load cases described in Section 2.0 of this document require that the materials of the cask package do not yield under specified factored loads. Thus the following stress criteria are set for the factored loads:

Normal stress allowable = yield strength of the material (S_y)

Shear stress allowable = 0.6×Normal stress allowable = $0.6S_y$

Material Type	Normal Stress Allowable, psi	Shear Stress Allowable, psi
ASTM A-240 Type 304L	25,000	15,000
ASTM A-240 Type 304	30,000	18,000

The allowable stresses in the weld are conservatively taken to be the same as the base metal.

6.0 DESIGN LOADING

Weight of the package with its content, W = 80,000 lb

Lifting:

According to 10 CFR 71.45(a), the design of the lifting attachment must provide a safety factor of 3 against yield when used to lift the package in the intended manner. The 3-60B Cask is designed to be lifted with the help of a lifting yoke that utilizes the two upper trunnions. Depending on the crane characteristics, a dynamic load amplification may result due to such lifting. The dynamic load factor for a typical crane is between 1.0 and 1.1. For conservatism a dynamic load factor of 1.3 is used for the evaluation of the trunnions under lifting conditions.

The stresses are calculated for the amplified load including the safety factor and are compared with the yield stress.

Amplified load = 1.3×3.0×W = 1.3×3.0×80,000 = 312,000 lb

Each trunnion will be subjected to half of the amplified load. Therefore, load on each trunnion,

F = ½×312,000 = 156,000 lb

Under lifting conditions, the maximum loads on a trunnion along the three orthogonal directions are:

Longitudinal Load = 156,000 lb

Lateral Load = 0

Radial Load = 0

Handling:

The cask is downended from the vertical orientation to the horizontal orientation with the help of all the four trunnions. During this process, the maximum loads on a trunnion along the three orthogonal directions are (see Figure 1):

Longitudinal Load = 0.25×W = 0.25×80,000 = 20,000 lb

Lateral Load = 0.25×W = 0.25×80,000 = 20,000 lb

Radial Load = 0

Regulatory/Transportation:

The cask is transported in horizontal orientation. All the four trunnions are utilized during the transportation.

As shown in Figure 1, under the transportation loading, enveloped by the 10CFR71 loading, a typical trunnion is subjected to the following maximum loads along the three orthogonal directions:

Longitudinal Load = 2.5×W = 2.5×80,000 = 200,000 lb

Lateral Load = 0.5×W = 0.5×80,000 = 40,000 lb

Radial Load = 2.5×W = 2.5×80,000 = 200,000 lb

Analyzed Load Cases

To fully envelope the above loading conditions, the following load cases have been analyzed using the finite element models described in Section 7.0.

Load Case 1 Longitudinal Load = 2.5×W = 2.5×80,000 = 200,000 lb

Load Case 2 Radial Load = 2.5×W = 2.5×80,000 = 200,000 lb

Load Case 3 Lateral Load = 0.5×W = 0.5×80,000 = 40,000 lb

Load Case 4 Combined load of Load Cases 1 through 3.

Load Case 5 Longitudinal Load = 156,000 lb

7.0 MODEL DESCRIPTION

The trunnion assembly is modeled using ANSYS finite element program (Reference 4) and evaluated for the load cases described above. This model is a half-symmetry solid model representing the trunnion assembly, including the 3 ½" thick back-up plate, a portion of the cask inner and outer shells, and the lead material in between the cask inner and outer shells. The model uses 3-D, 8-Node structural solid elements (SOLID 185) for the trunnion, backing plate and the lead. 3-D, 8-Node solid shell elements (SOLSH 190) are used for the cask inner and outer shells. Various components of the model are tied together with the contact and target surface combinations. The model is shown in Figures 2 and 3, and it is analyzed for the five load cases described in Section 6.0.

The model uses symmetry boundary conditions on the cut-plane and fixed boundary conditions on the two ends. It should be noted that these boundaries are located far away from the trunnion assembly and do not have significant effect on the stresses in the trunnion assembly.

For each load case the applied loading plot, the stress intensity contour plot, stress intensity contour plot in the shell, and stress intensity contour plot in the trunnion assembly are provided. These plots for Load Cases 1 through 5 are shown in Figures 4-7, 8-11, 12-15, 16-19 and 20-23, respectively.

Summary print-out of the finite element model, used in the analyses, is included in Appendix 1. The electronic data generated for the analyses are included in Appendix 2.

8.0 RESULTS & CONCLUSIONS

The stress intensity results obtained from the analyses of the FEM, described above, for various load cases are listed in Table 1. The stress intensities in the trunnion assembly and the cask outer shell, under lifting and regulatory/transportation conditions, are summarized in Table 2. These stress intensities are also compared with their corresponding allowable values in Table 2. The stresses under handling conditions are enveloped by the regulatory/transportation conditions and are not explicitly listed in this document.

It should be noted that the welds in the trunnion assemblies have been explicitly included in the finite element model. Therefore, the stresses in the welds have been implicitly analyzed. They are also subjected to stresses below their allowable values.

It has been demonstrated by the analyses presented in this document that the 3-60B Cask trunnion assemblies have a sufficient margin of safety in its design to be safely lifted, it could safely be downended to a horizontal orientation with the help of a pair of trunnions provided in the lower part of the cask and also meets the regulatory requirements of 10CFR71.45 (b).

10.0 APPENDICES

Appendix 1 Summary print-out of the ANSYS model data

Appendix 2 Electronic data on CDROM

Table 1

Summary of Stress Intensities in Various Components of the Trunnion Assembly

Load Case	Component	S.I. (psi)	Reference
1	Cask Outer Shell	14,651	Figure 6
	Trunnion Assembly	27,952	Figure 7
2	Cask Outer Shell	9,446	Figure 10
	Trunnion Assembly	14,026	Figure 11
3	Cask Outer Shell	3,695	Figure 14
	Trunnion Assembly	5,430	Figure 15
4	Cask Outer Shell	14,887	Figure 18
	Trunnion Assembly	29,671	Figure 19
5	Cask Outer Shell	10,920	Figure 22
	Trunnion Assembly	21,108	Figure 23

Table 2

Comparison of S.I. with the Allowable Values for Various Loading Conditions

Loading Condition	Component	Max S.I. (psi)	Allowable S.I. (psi)	F.S.(3)
Lifting(1)	Cask Outer Shell	10,920	25,000	2.29
	Trunnion Assembly	21,108	30,000	1.42
Regulatory/ Transportation(2)	Cask Outer Shell	14,887	25,000	1.68
	Trunnion Assembly	29,671	30,000	1.01

NOTES:

(1) Load Case 5 of Table 1.

(2) Load Case 4 of Table 1.

(3) Factor of Safety, F.S. = (Allowable S.I.)/(Max S.I.)

Figures

(23 Pages)

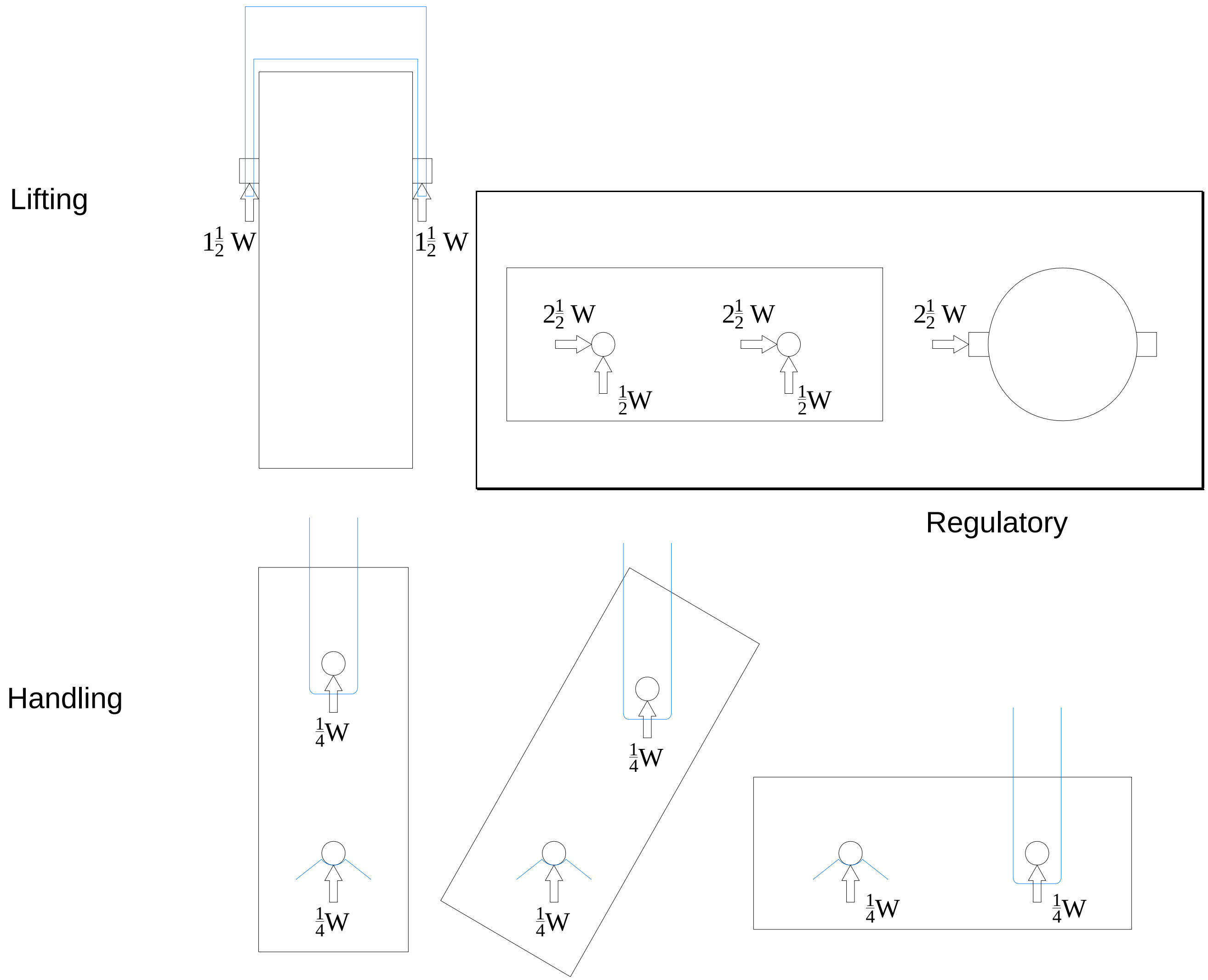


Figure 1

Loads on the Trunnions during Lifting and Handling Operation and per the Regulatory Requirement

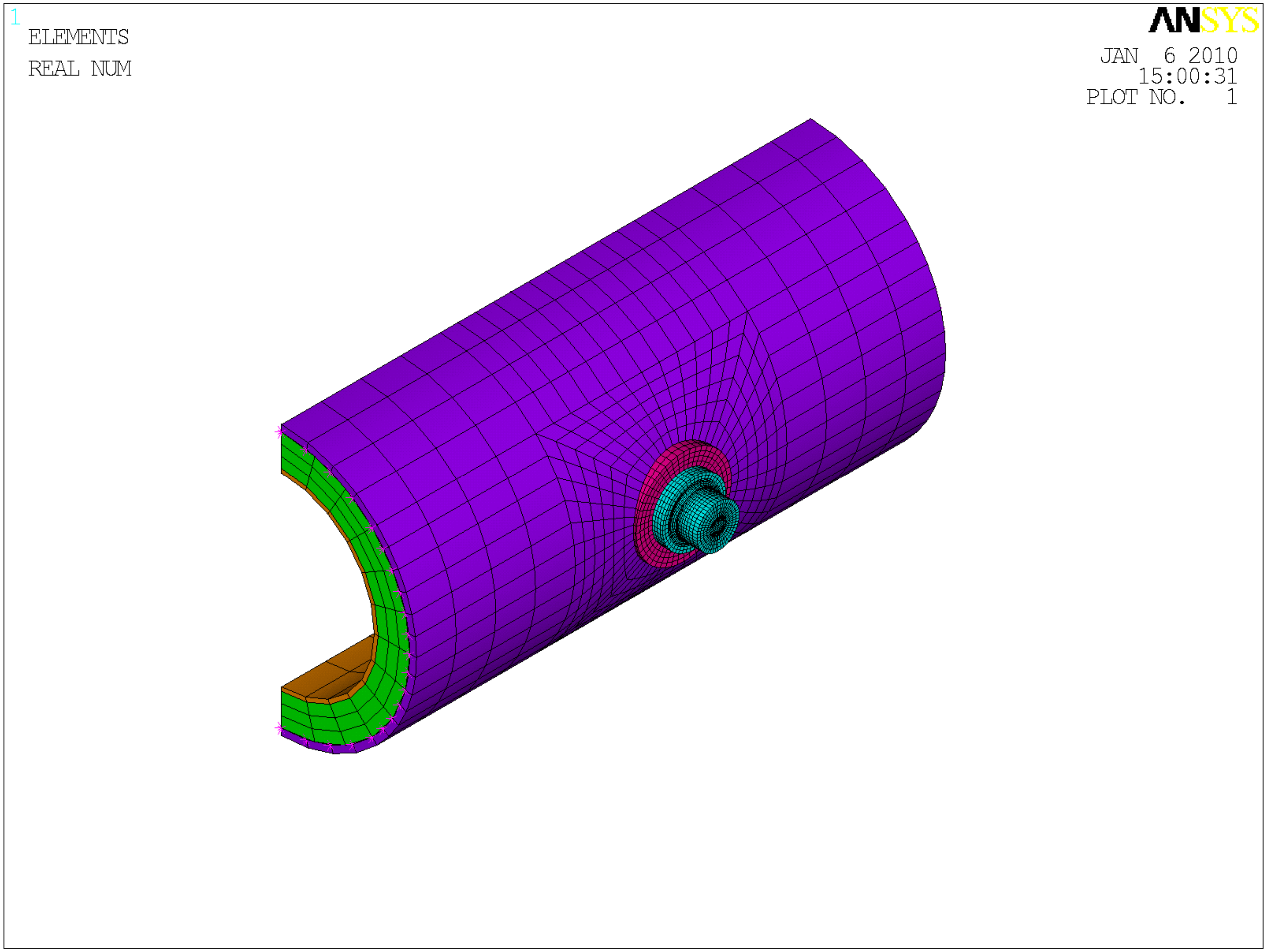
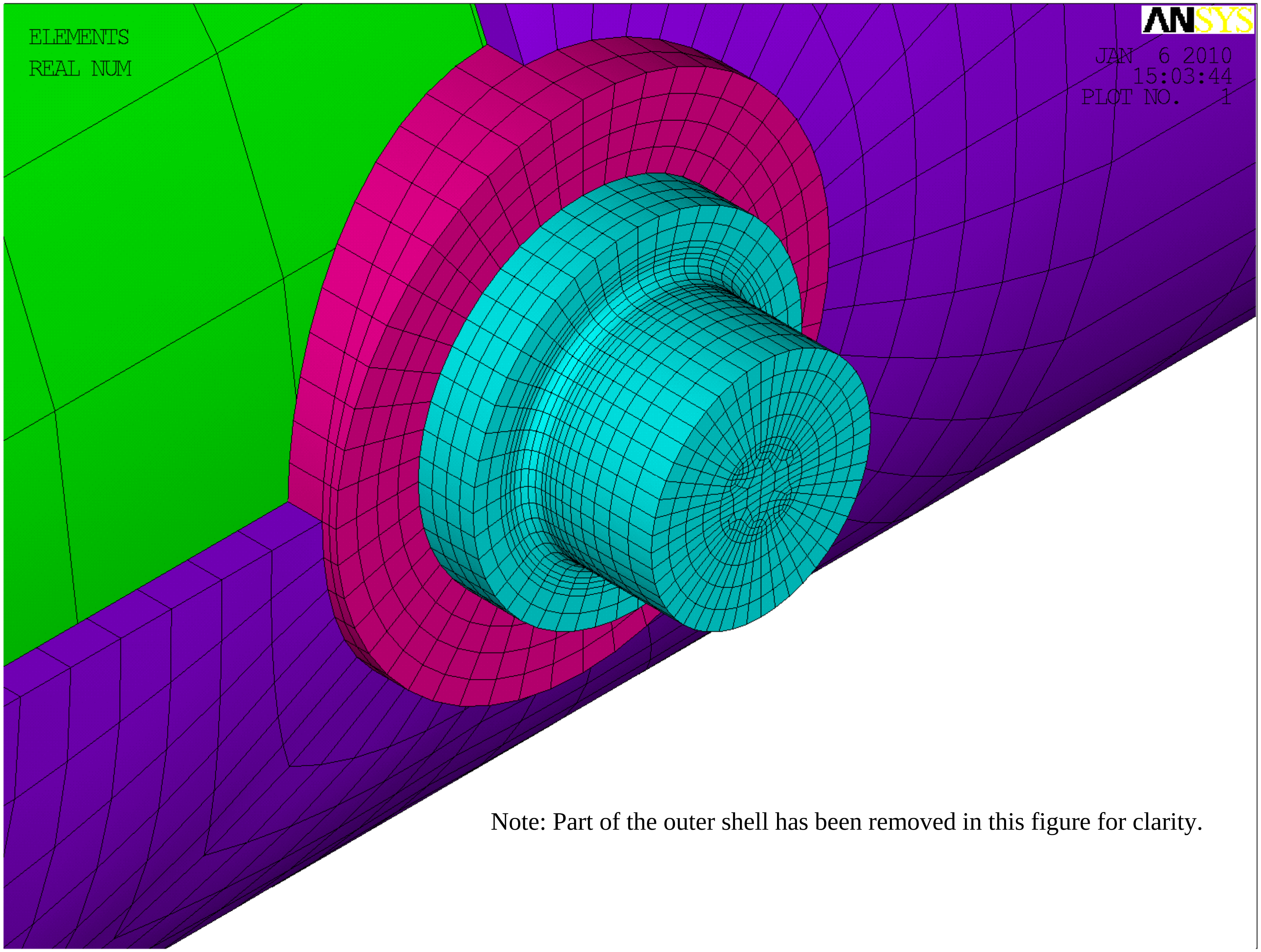


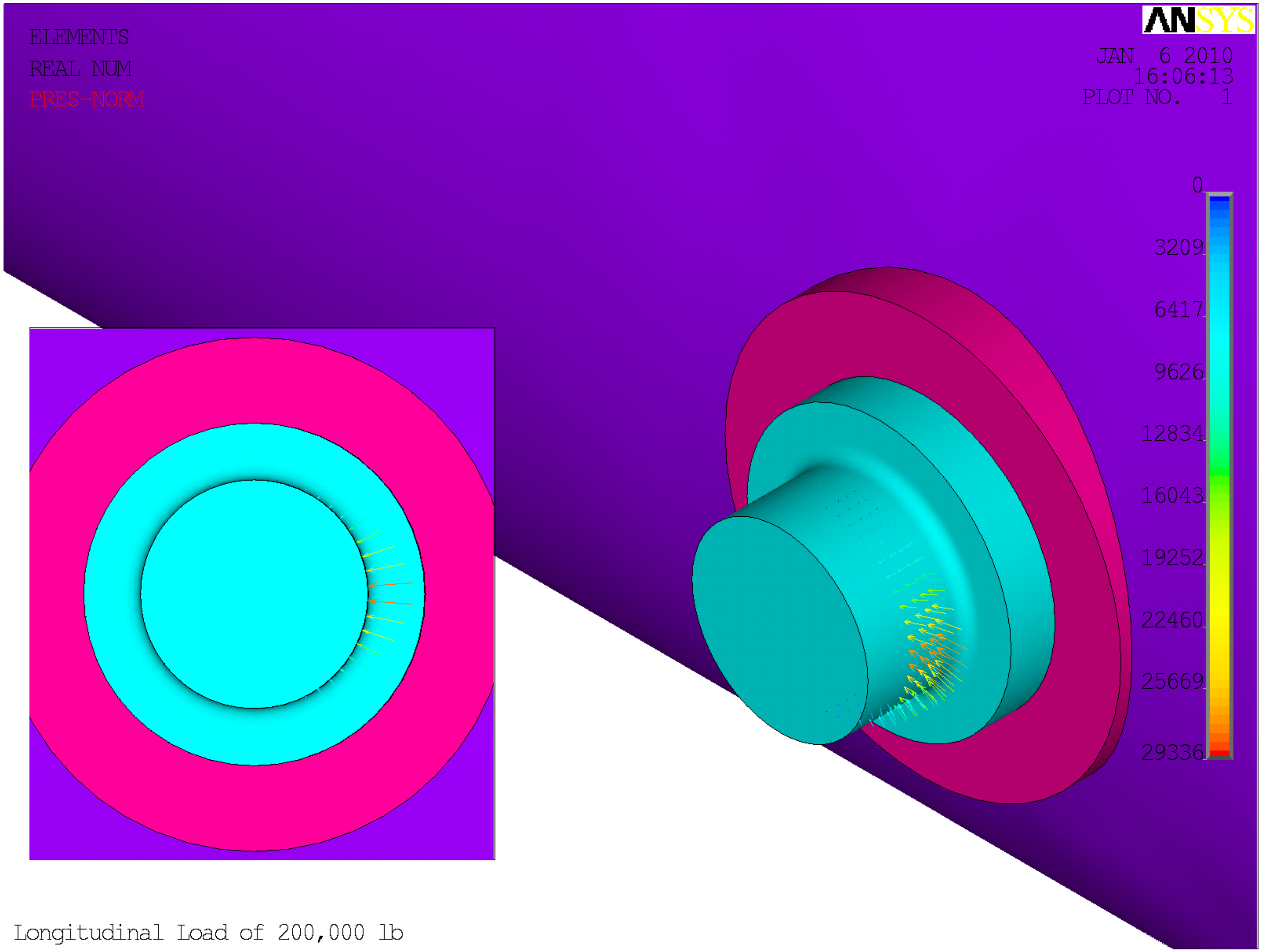
Figure 2

Finite Element Model of the 3-60B Cask Trunnion & its Vicinity



Note: Part of the outer shell has been removed in this figure for clarity.

Figure 3
Finite Element Model Close-Up of the Trunnion



Longitudinal Load of 200,000 lb

Figure 4
Finite Element Model Analysis Load Step 1 – Applied Loading

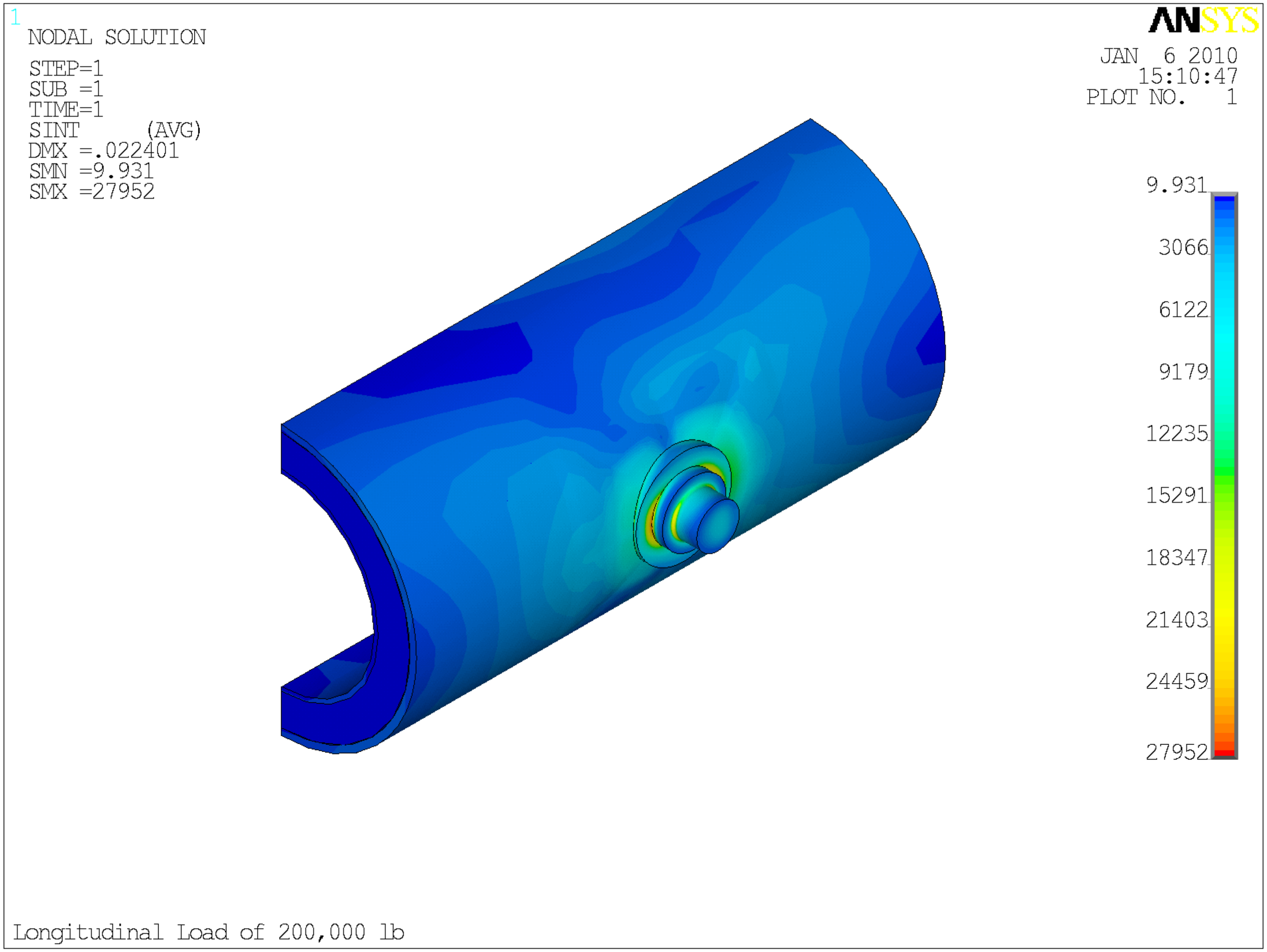


Figure 5
Load Step 1 – Stress Intensity Plot

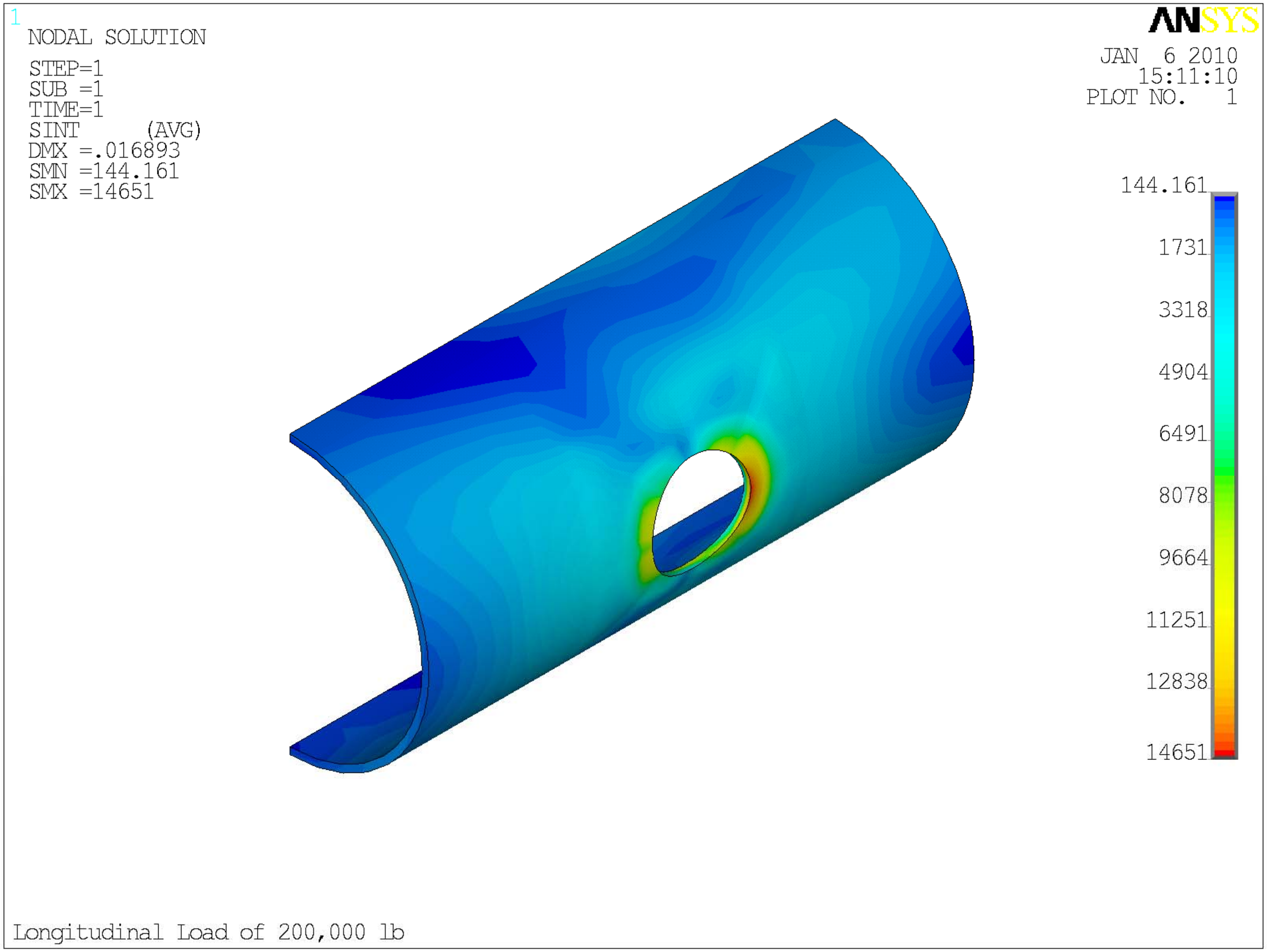


Figure 6

Load Step 1 – Stress Intensity in the Shell

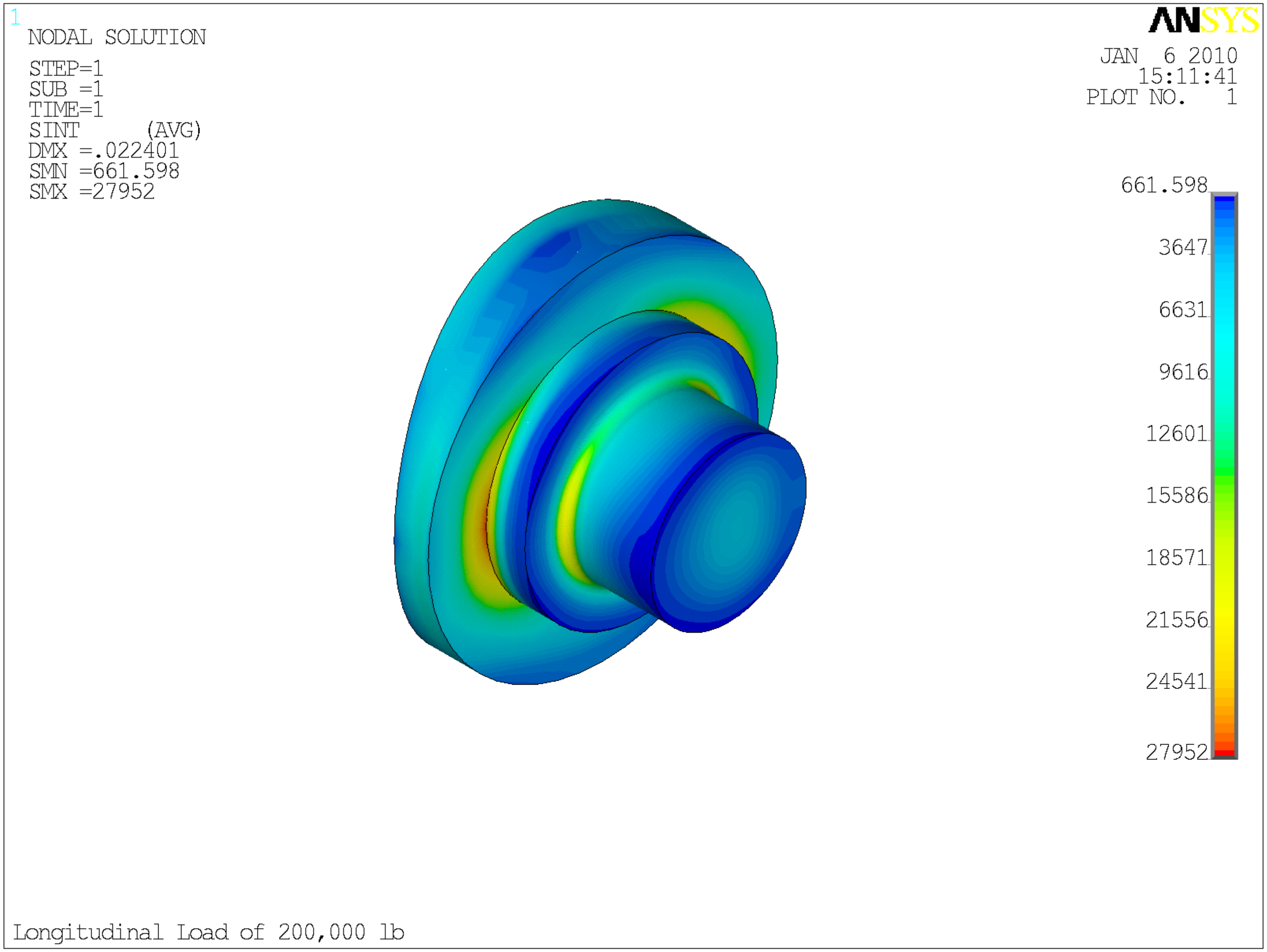
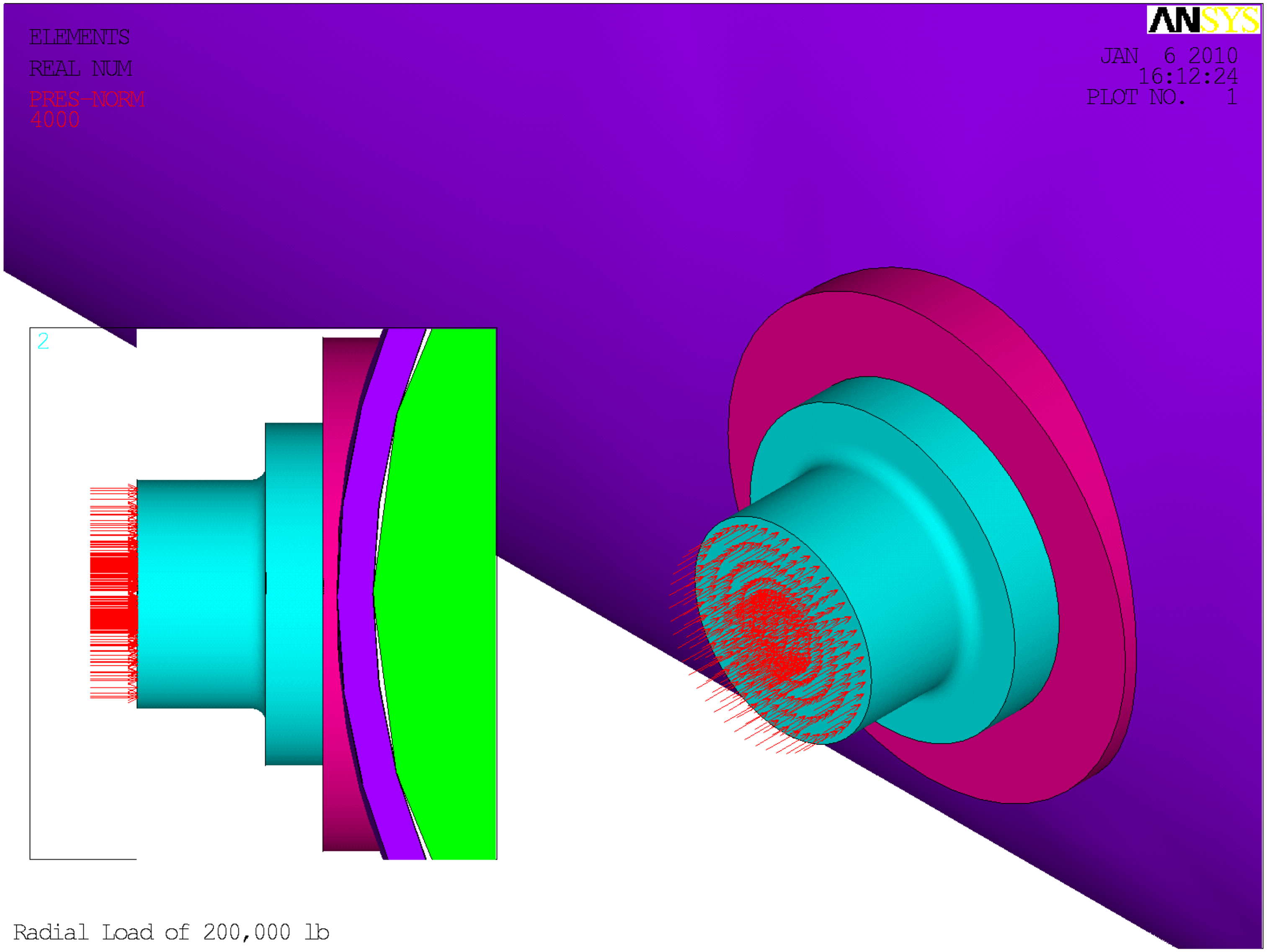


Figure 7

Load Step 1 – Stress Intensity in the Trunnion



Radial Load of 200,000 lb

Figure 8

Finite Element Model Analysis Load Step 2 – Applied Loading

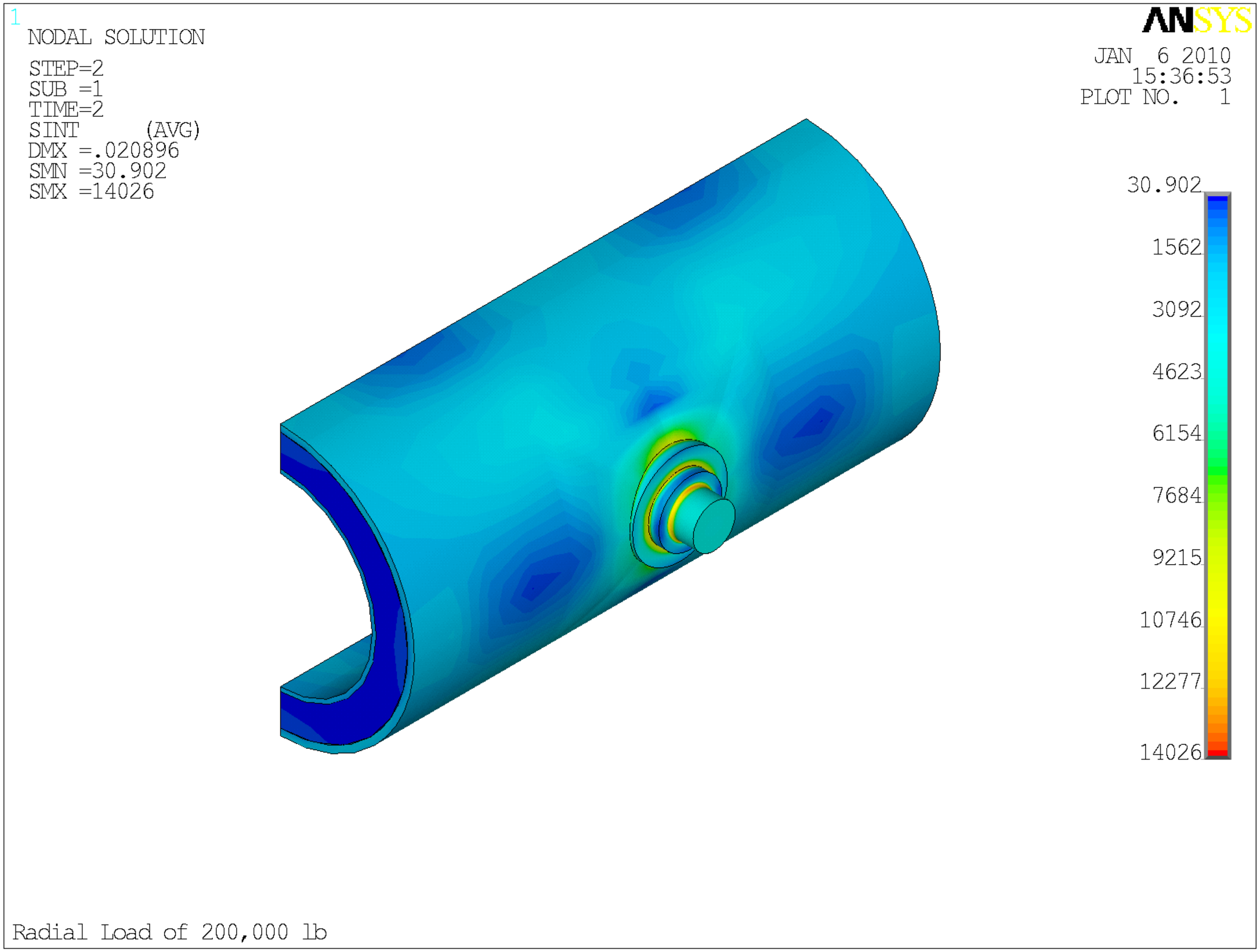


Figure 9
Load Step 2 – Stress Intensity Plot

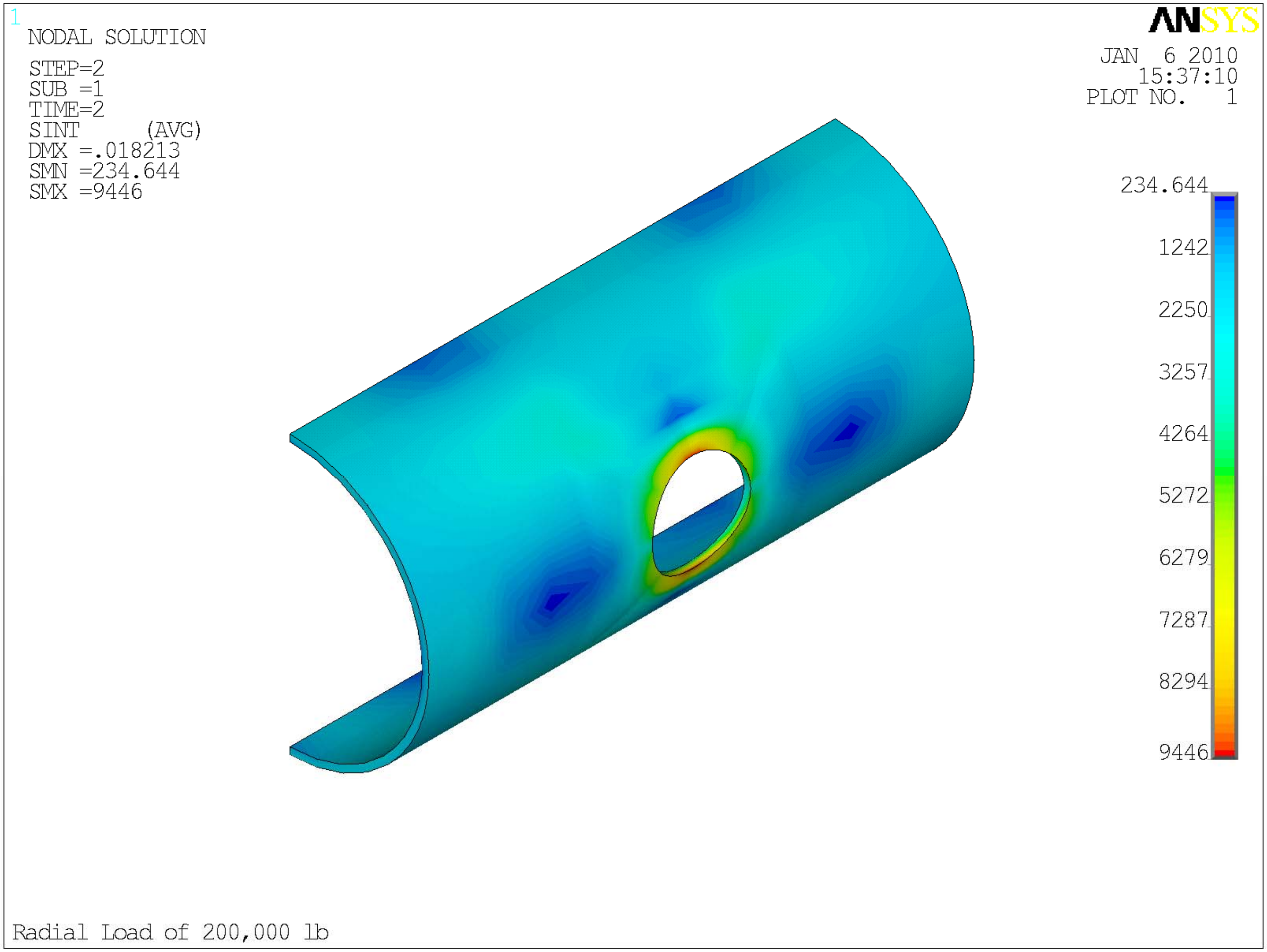


Figure 10

Load Step 2 – Stress Intensity in the Shell

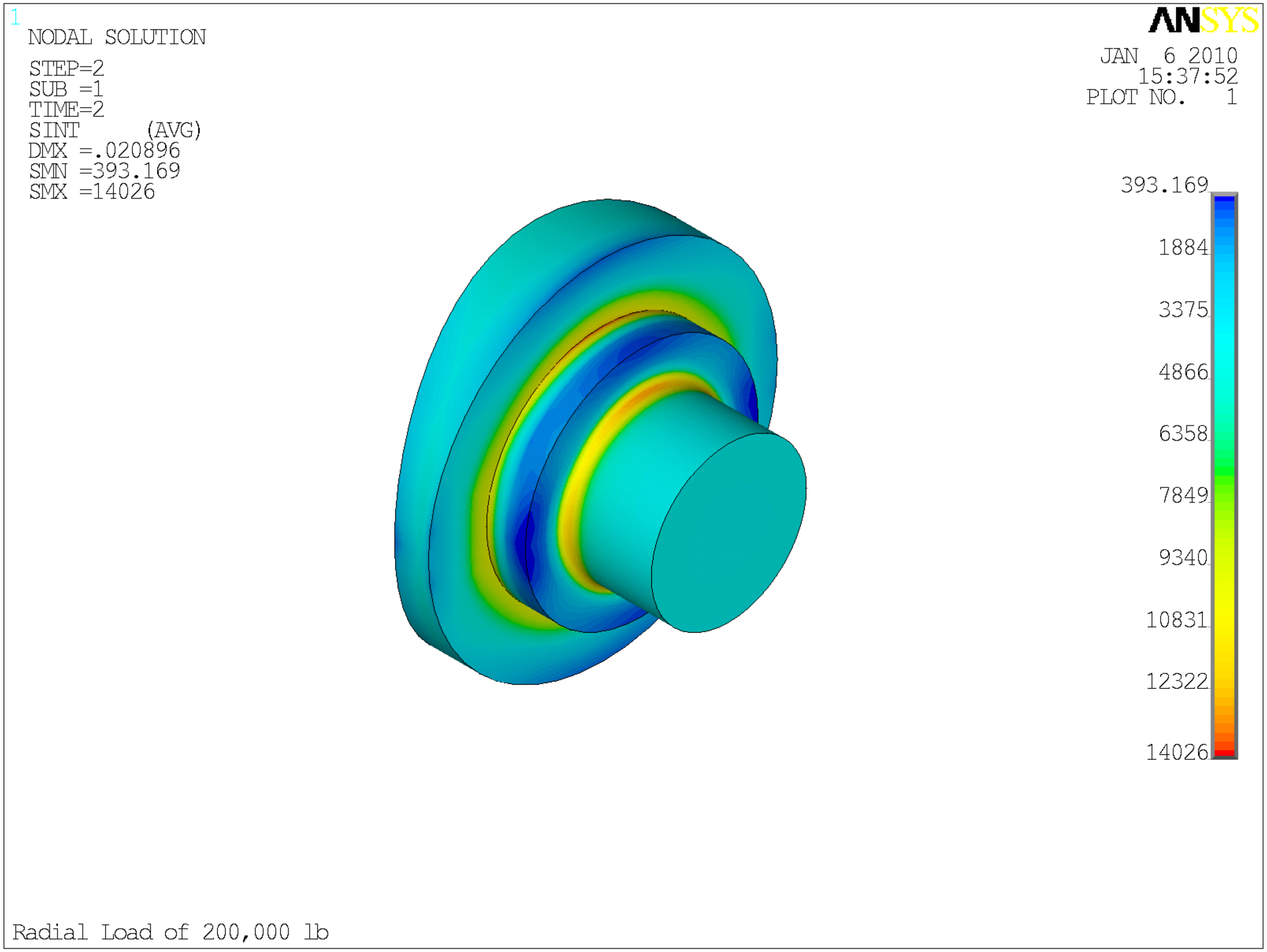


Figure 11

Load Step 2 – Stress Intensity in the Trunnion

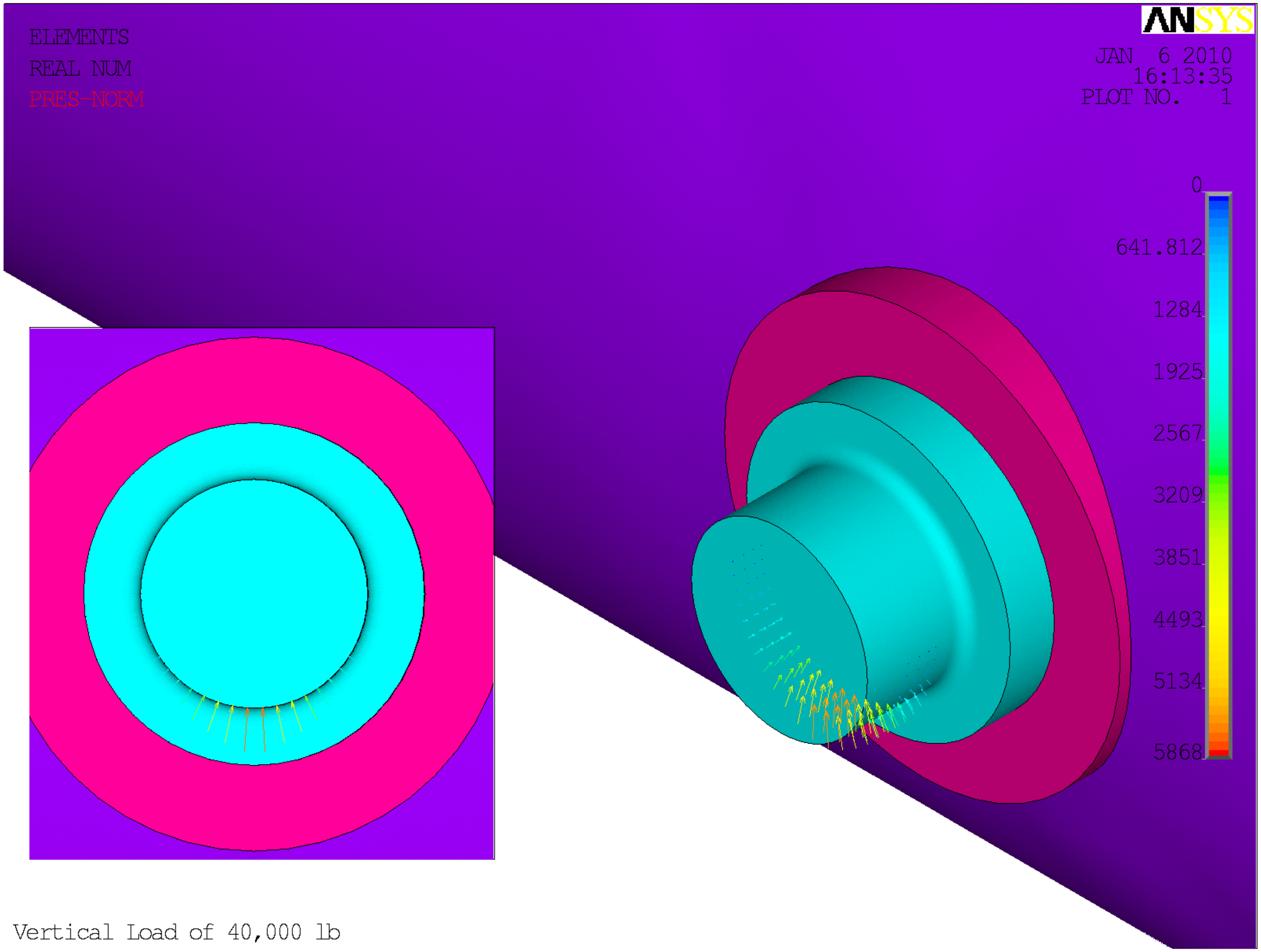


Figure 12

Finite Element Model Analysis Load Step 3 – Applied Loading

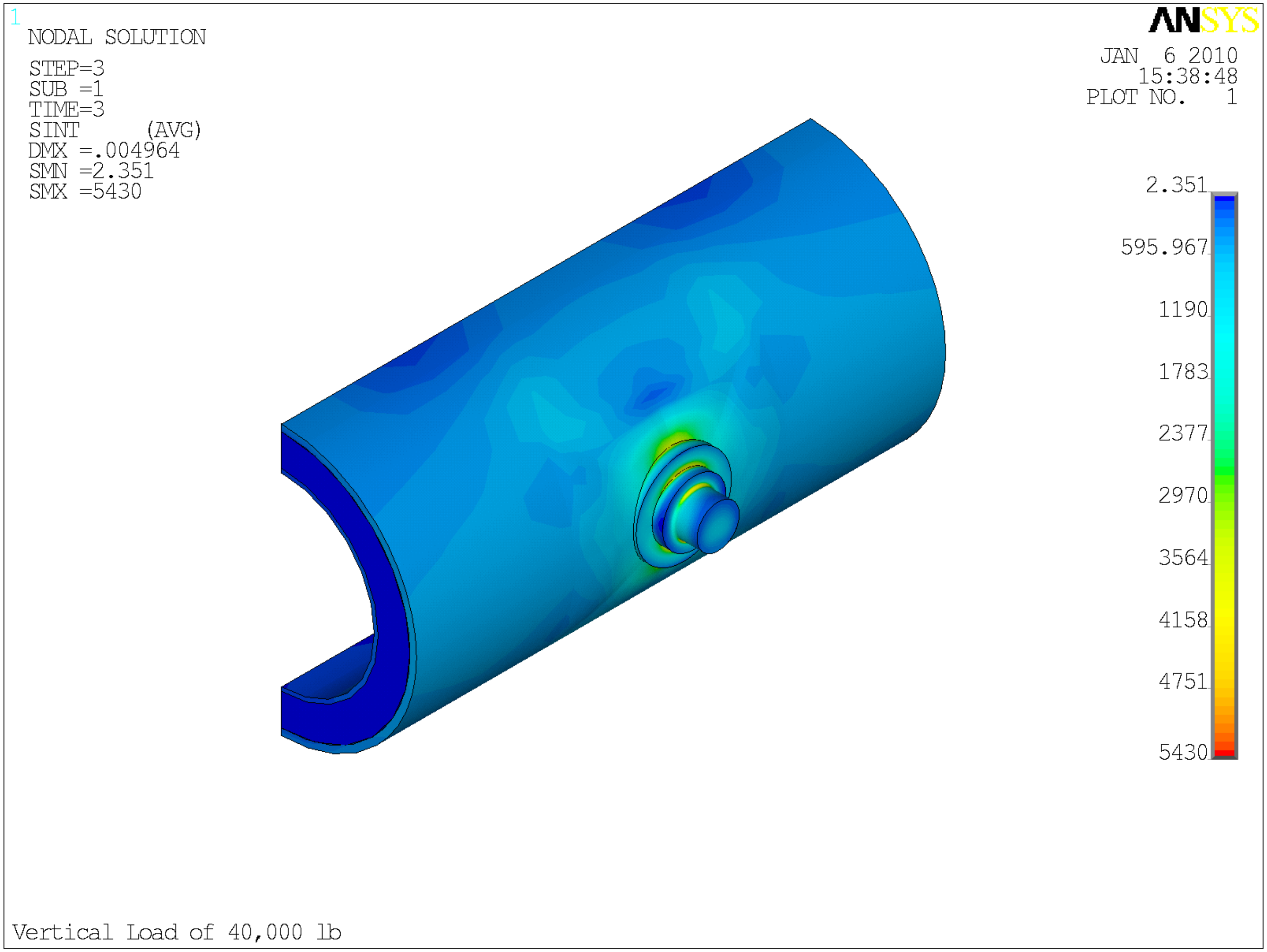


Figure 13

Load Step 3 – Stress Intensity Plot

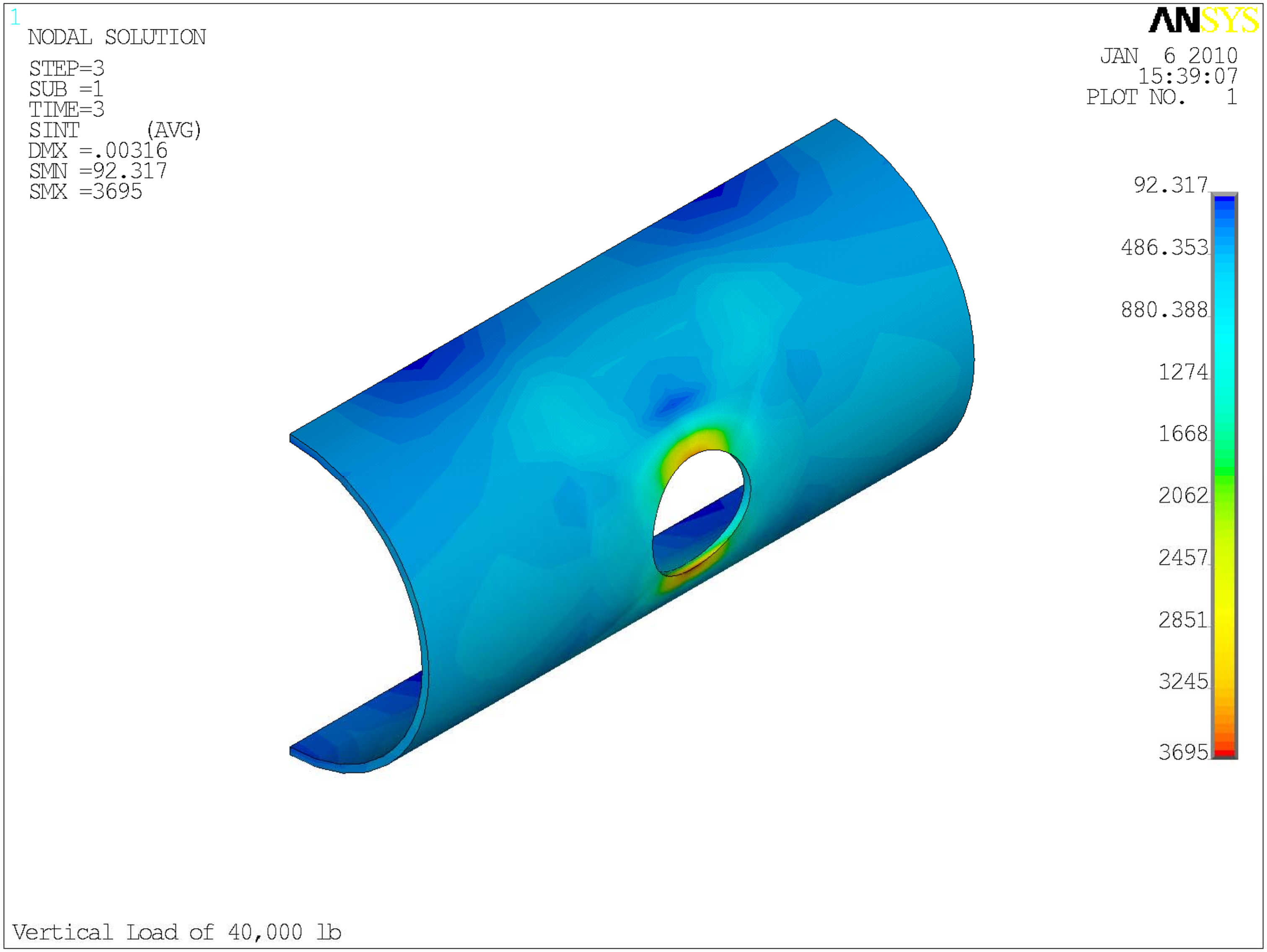


Figure 14

Load Step 3 – Stress Intensity in the Shell

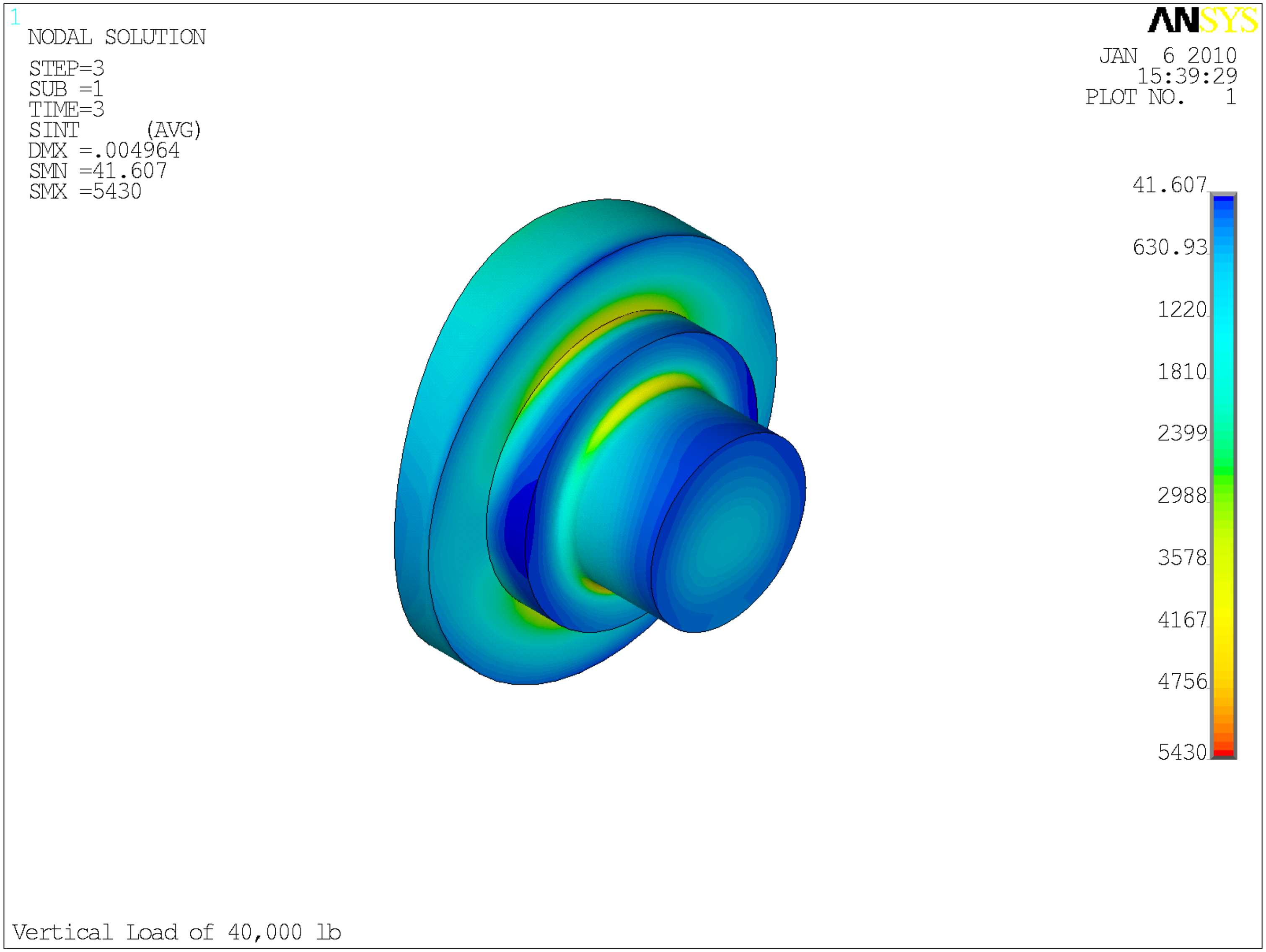


Figure 15

Load Step 3 – Stress Intensity in the Trunnion

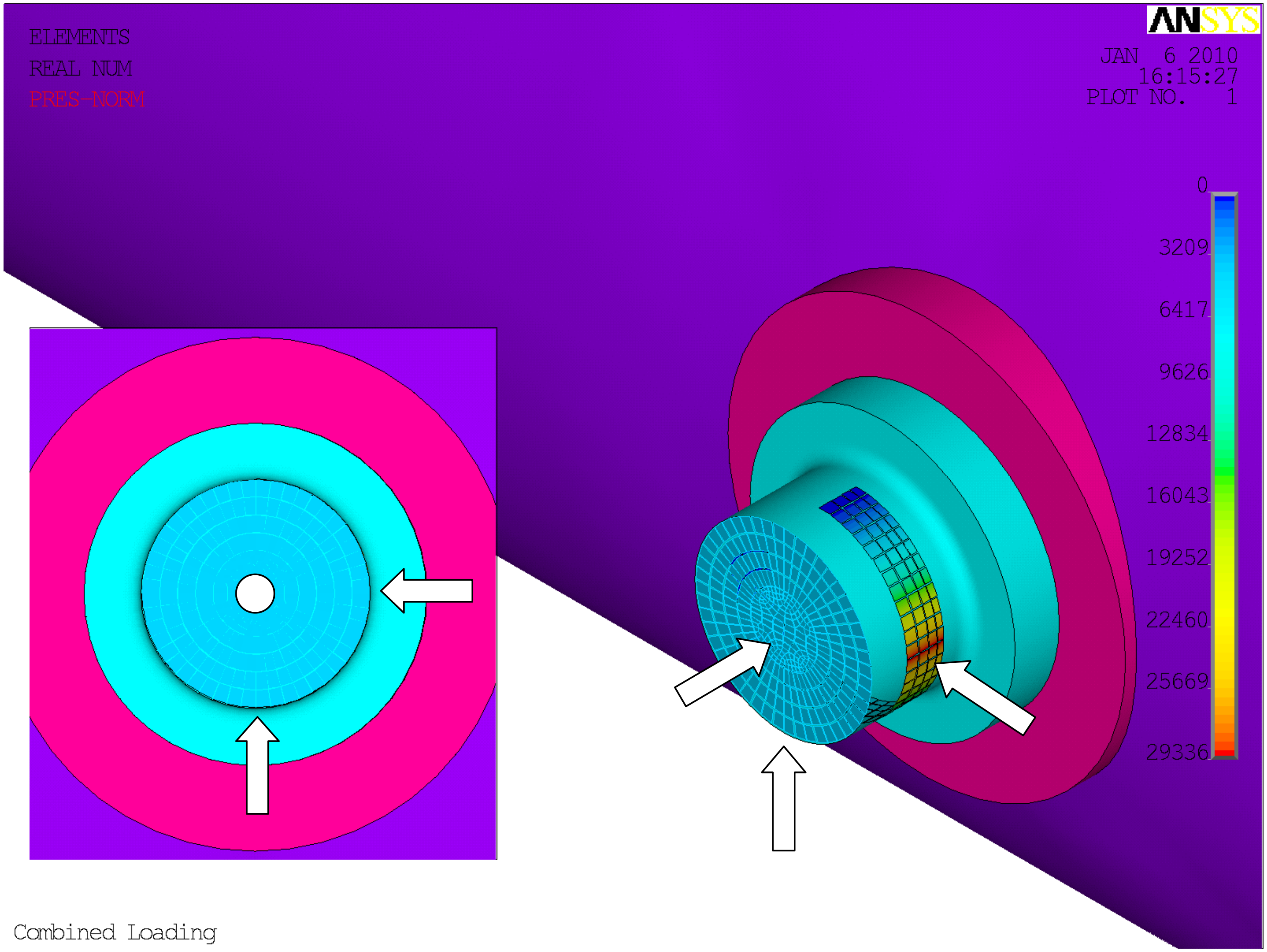


Figure 16

Finite Element Model Analysis Load Step 4 – Applied Loading

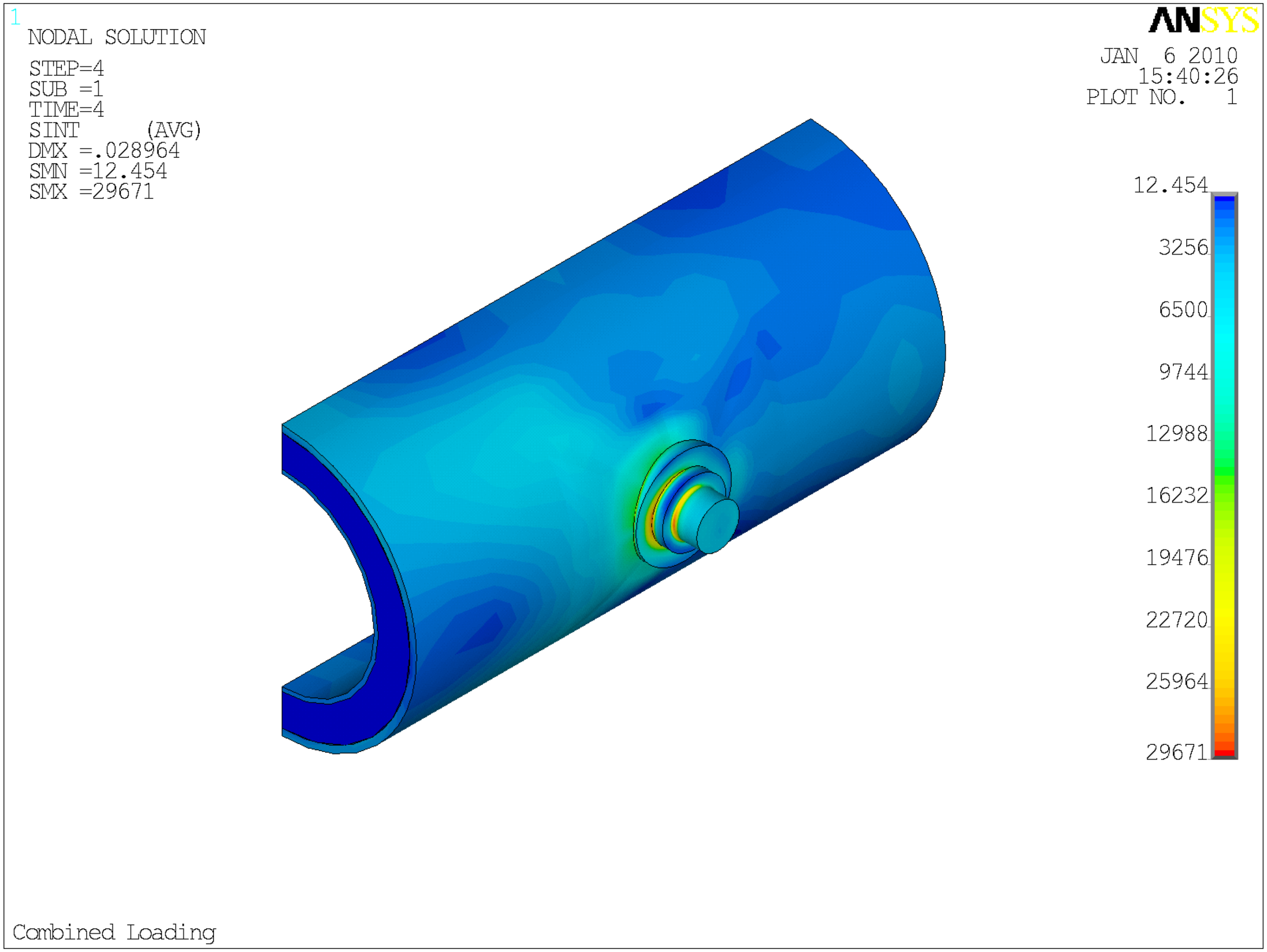


Figure 17

Load Step 4 – Stress Intensity Plot

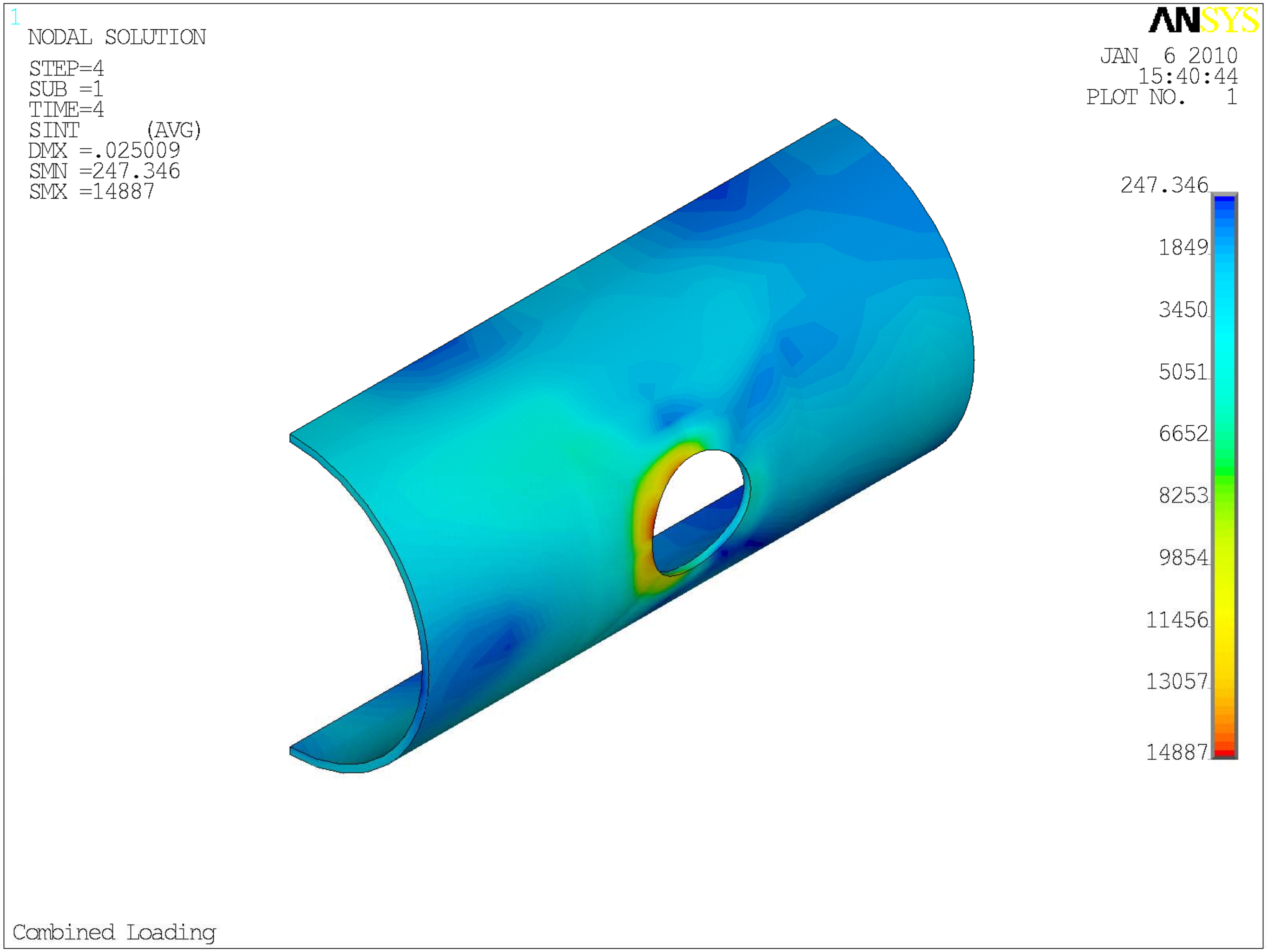


Figure 18

Load Step 4 – Stress Intensity in the Shell

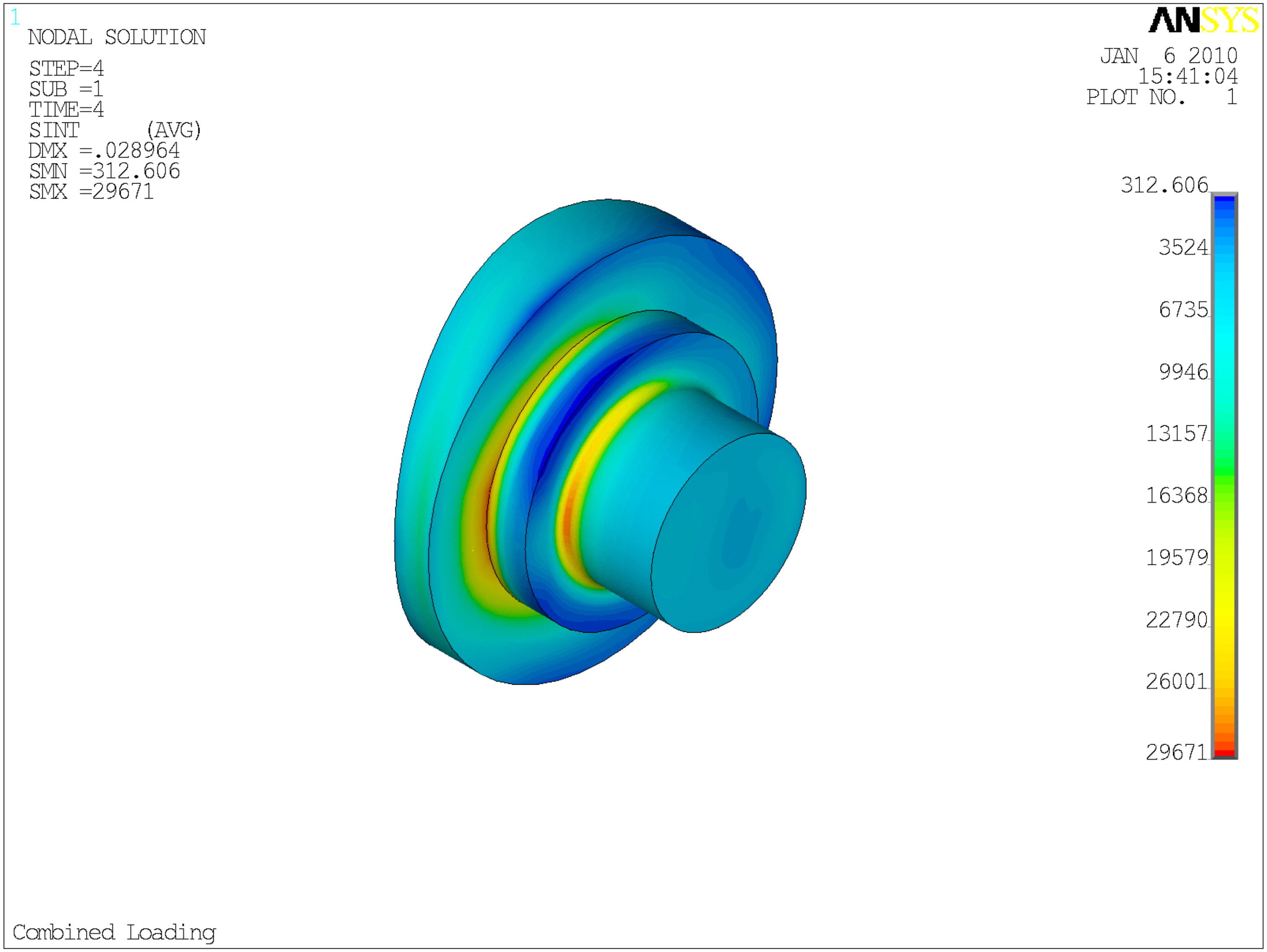


Figure 19

Load Step 4 – Stress Intensity in the Trunnion

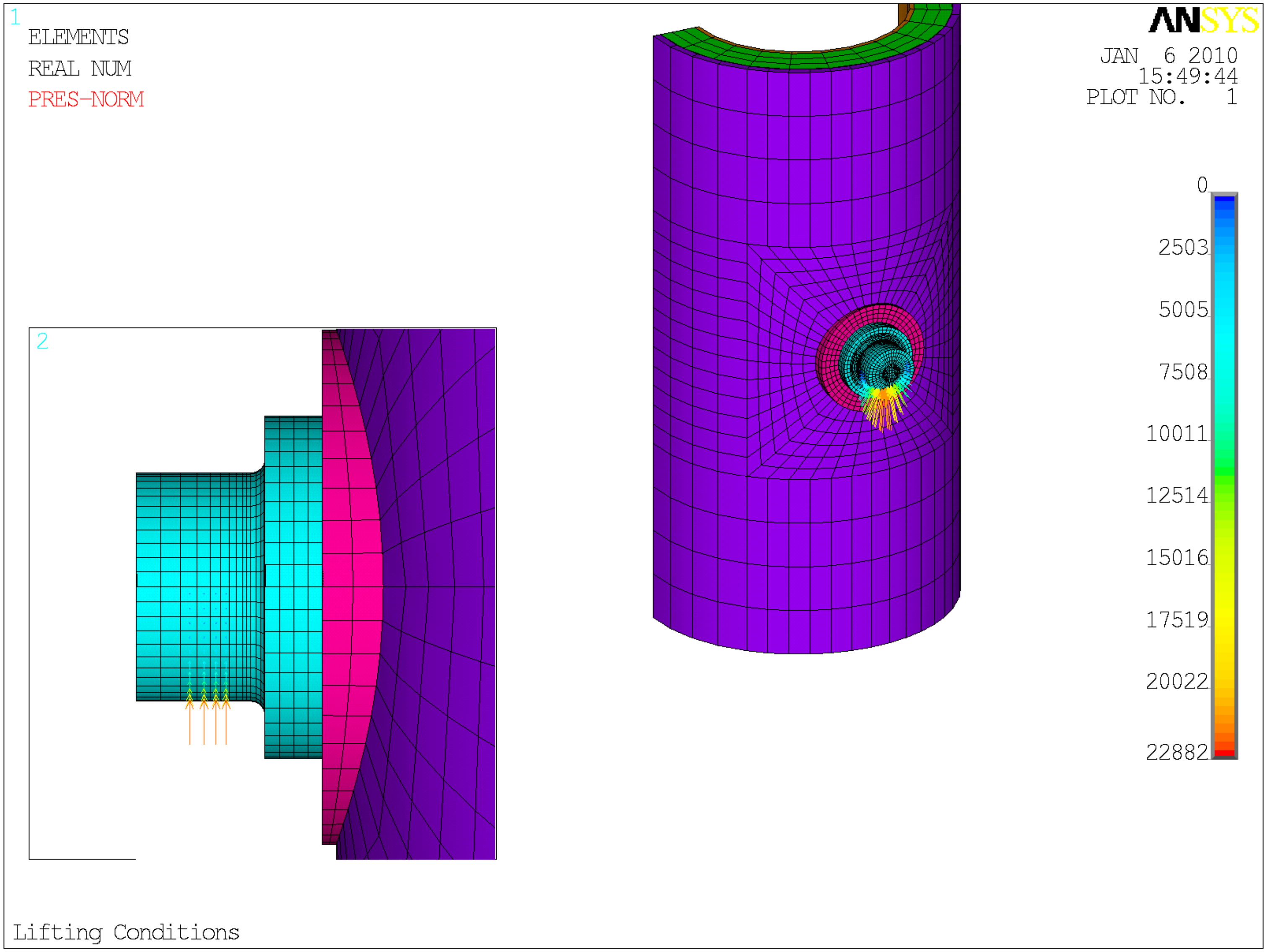


Figure 20

Finite Element Model Analysis Load Stop 5 – Applied Loading

Title Trunnion Analyses of the 3-60B Cask under Various Loading Conditions

Calc. No. ST-503 (Figures) Rev. 1 Sheet 20 of 23

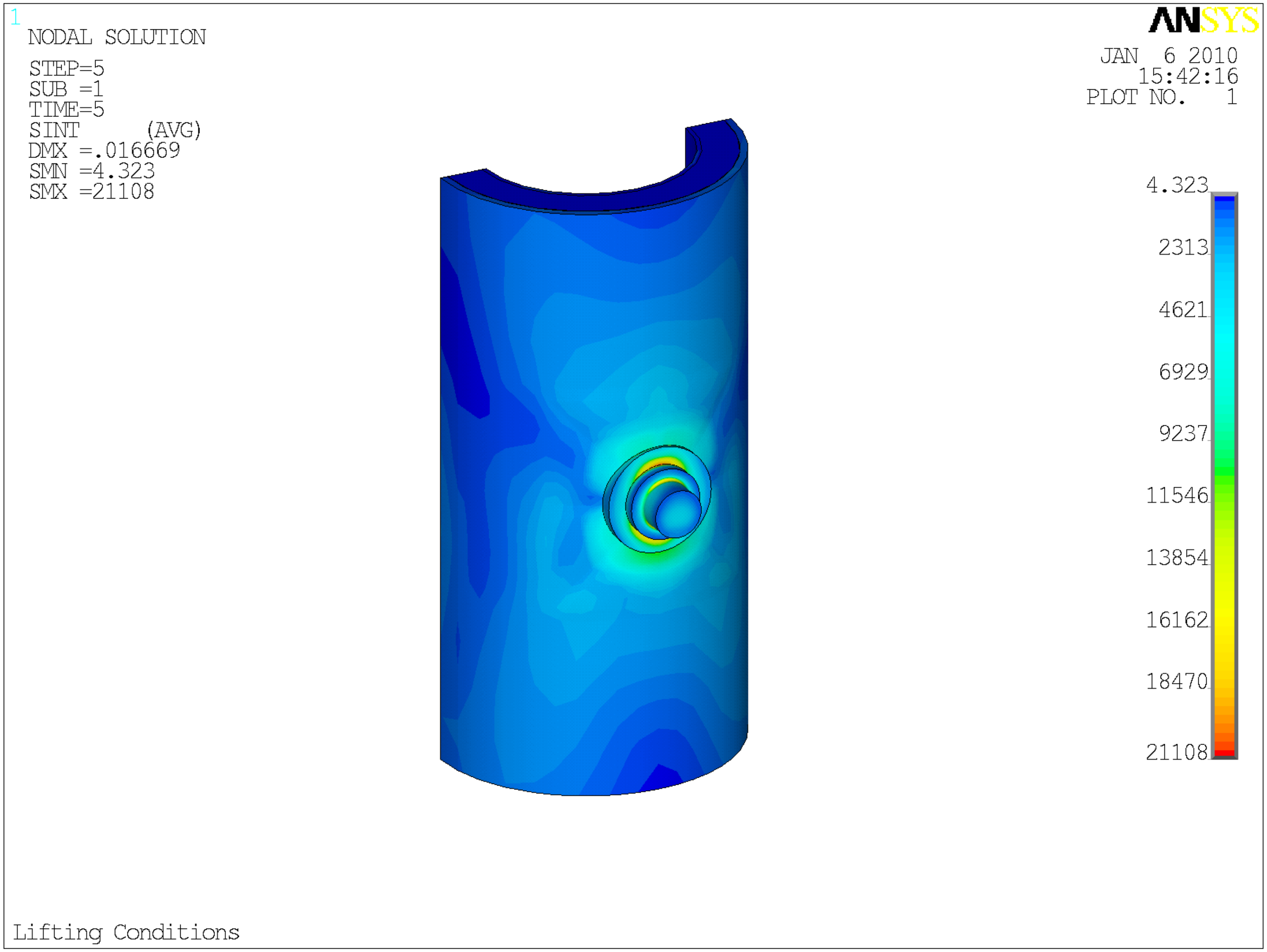


Figure 21

Load Step 5 – Stress Intensity Plot

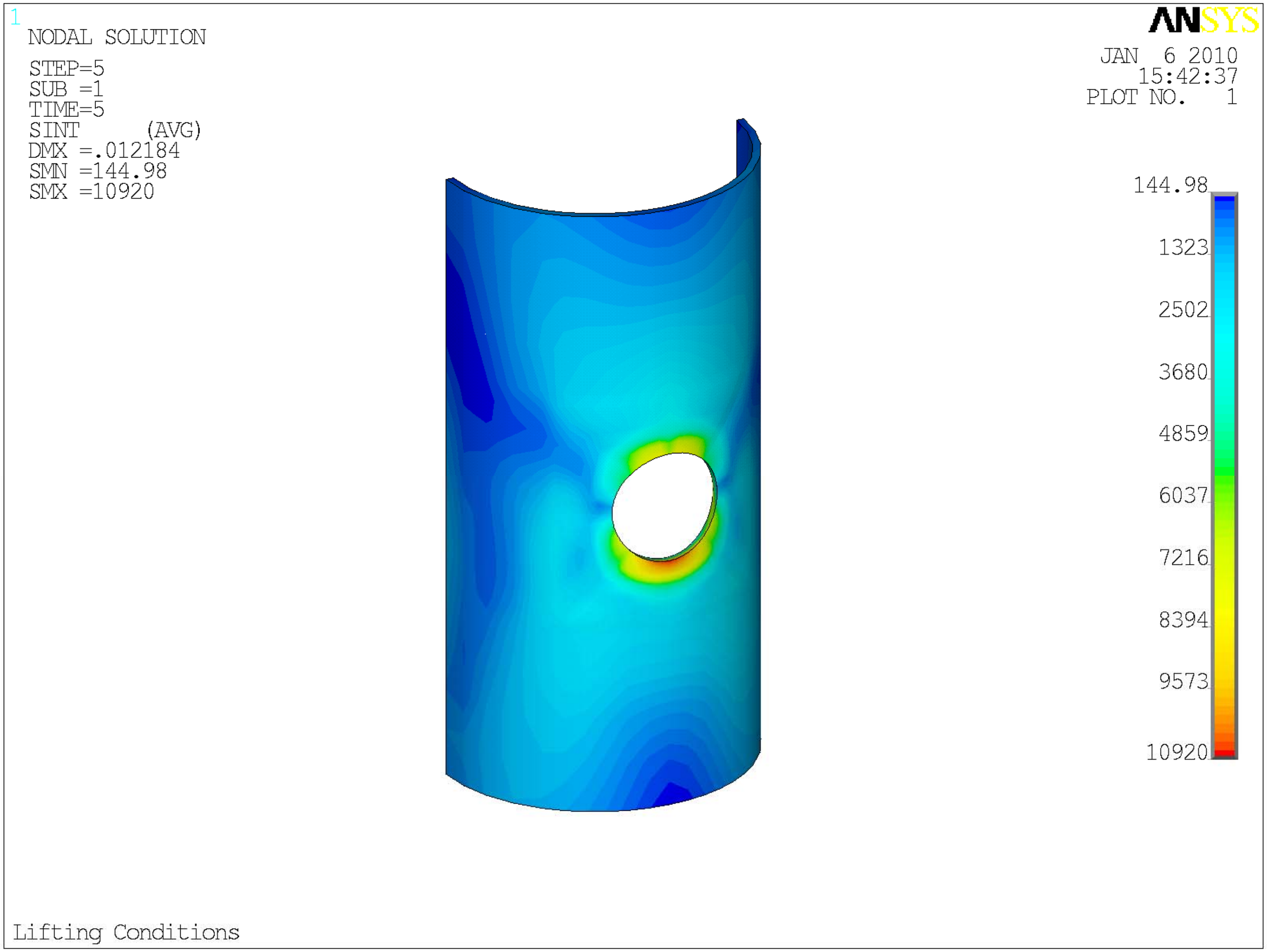


Figure 22

Load Step 5 – Stress Intensity in the Shell

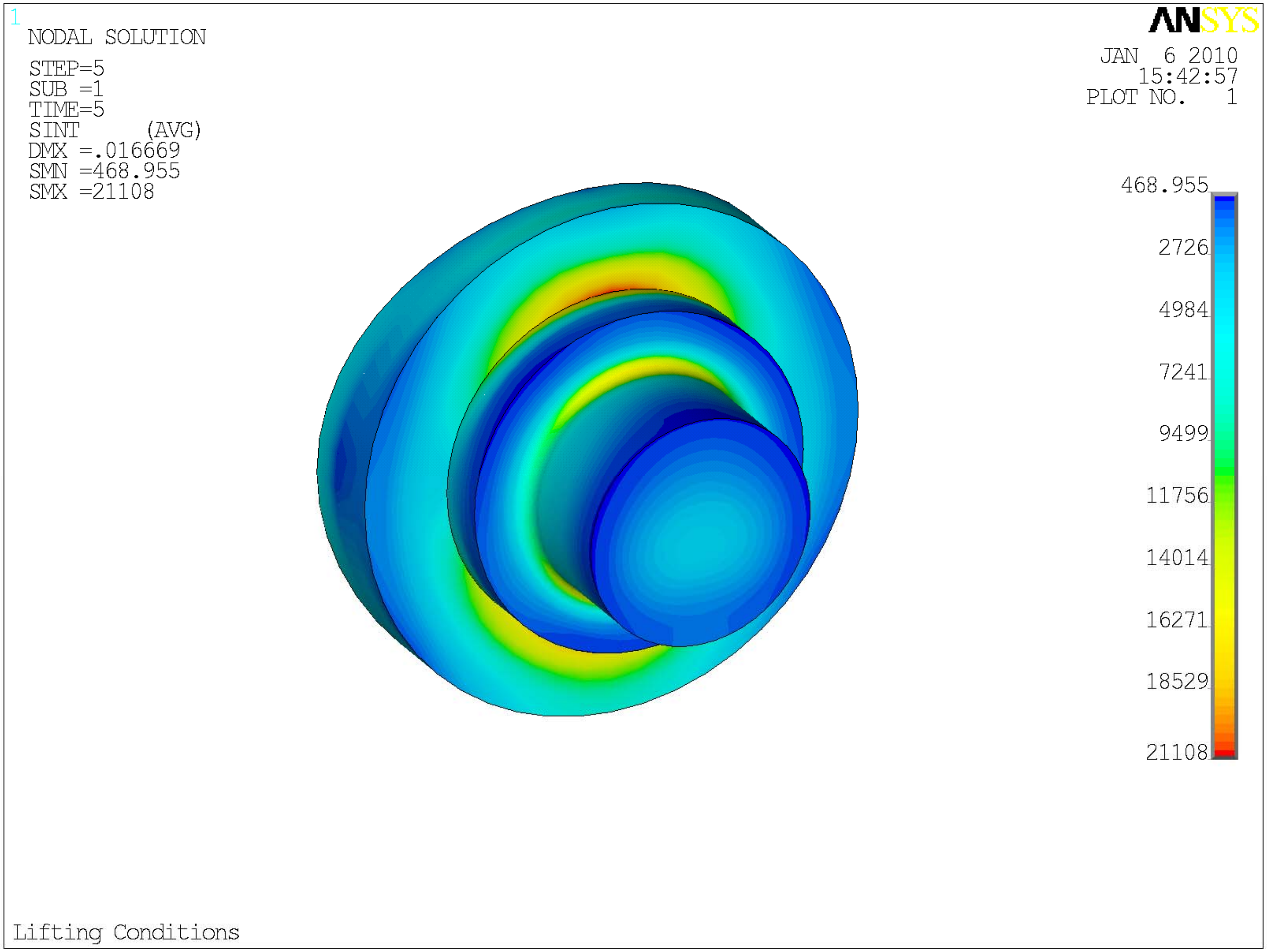


Figure 23

Load Step 5 – Stress Intensity in the Trunnion

Appendix 1

Printout of the ANSYS Model Data

(5 Pages)

3-60B Cask Trunnion Analyses

By Mirza I. Baig

January 07, 2010

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: D:\Ansys Analyses\3-60B\RAI-1 Analyses\Trunnion Analyses

 TITLE= Lifting Conditions

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

Global Status

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

 ANSYS - Engineering Analysis System           Jan 07, 2010           13:26
 Release 11.0SP1             00222442                 WINDOWS x64  Version

 Current working directory: D:\Ansys Analyses\3-60B\RAI-1 Analyses\Trunnion Analyses


 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 12 minutes
 Total CP usage. . . . . . .   0 hours  0 minutes 11.4 seconds

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

Lifting Conditions

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

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

                                Available             Used
 Scratch Memory Space. . . .    4796.000 mb           5.204 mb (  0.1%)
 Database space  . . . . . . 1048572.000 mb          37.701 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 . . . . . . . . .      32            24            24
 Lines . . . . . . . . . . .      56            36            36
 Areas . . . . . . . . . . .      28            16            16
 Volumes . . . . . . . . . .       3             2             2

 Finite element model summary:

                              Largest         Number        Number
                               Number        Defined       Selected
 Nodes . . . . . . . . . . .   22230         12268         12268
 Elements. . . . . . . . . .   32839          9870          9870

 Element types . . . . . . .      30            14           n.a.
 Real constant sets. . . . .       8             6           n.a.
 Material property sets. . .       2             2           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. . . . . . . . . . .     928
Constraints on keypoints. . . . . . . . .       0
Constraints on lines. . . . . . . . . . .       0
Constraints on areas. . . . . . . . . . .       0

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

Surface loads on elements . . . . . . . .     478
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. . . . . . . . . .     0.000
   Reference temperature. . . . . . . . .     0.000
   Offset from absolute scale . . . . . .     0.000

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

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

Current routine. . . . . . . . . . . .General Postprocessor (POST1)

Active coordinate system . . . . . . .  11 (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 . . . . . . . . . .     6

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

Results coordinate system. . . . . . .   0 (Global Cartesian)

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

Output options:
   Shell layer. . . . . . .Top
   Force type . . . . . . .Total

Current results correspond to:
   Results file . . . . . .file.rst
   Load step. . . . . . . .     5
   Substep. . . . . . . . .     1
   Cumulative iteration . .    32
   Time . . . . . . . . . .  5.0000
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Solution Status

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                    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   ROTX ROTY ROTZ
  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. . . . . . . . . . . . . . . .     6
  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
  COPY INTEGRATION POINT VALUES TO NODE . . . . .   YES
  PRINT OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     RSOL       NONE
  DATABASE OUTPUT CONTROLS
```

```
     ITEM     FREQUENCY   COMPONENT
      ALL        ALL
```

Element Type Listing

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  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

 ELEMENT TYPE      2 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     19 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     20 IS CONTA174     3D 8-NODE SURF-SURF CONTACT    INOPR
  KEYOPT(1-12)=    0  0  0    0  3  0    0  0  0    2  0  0       0

 ELEMENT TYPE     21 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     22 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     23 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     24 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     25 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     26 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     27 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     28 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     29 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     30 IS CONTA175     NODE-TO-SURFACE CONTACT        INOPR
  KEYOPT(1-12)=    0  0  0    0  0  0    0  0  1    2  0  0       0

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

Real Constant Listing

```
 LIST REAL SETS       1 TO       8 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       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       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       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       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  30
   10.000       0.0000       0.0000       0.0000       0.0000       0.0000

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  30
   10.000       0.0000       0.0000       0.0000       0.0000       0.0000
```

Material Properties Listing

```
LIST MATERIALS       1 TO       2 BY       1
 PROPERTY= ALL

PROPERTY TABLE EX    MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.30000E+08

PROPERTY TABLE NUXY  MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.30000

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      0.0000

PROPERTY TABLE EMIS  MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.78886E-30

PROPERTY TABLE EX    MAT=       2  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.22700E+07

PROPERTY TABLE NUXY  MAT=       2  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.45000
```

Listing of Reactions

```
c***
```

```
USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

 SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     7
   TIME/FREQUENCY=  1.0000
 TITLE= Longitudinal Load of 200,000 lb

 ***** SUMMATION OF TOTAL    FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  0.4787353E-08
  FY  =  0.2615146E-05
  FZ  =   200017.1
  MX  = -0.3180321E-06
  MY  =  -820270.0
  MZ  =  0.1073431E-04

 SUMMATION POINT=  26.000      0.0000      0.0000


 USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

 SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    13
   TIME/FREQUENCY=  2.0000
 TITLE= Radial Load of 200,000 lb

 ***** SUMMATION OF TOTAL    FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  -200488.2
  FY  =  0.1455192E-10
  FZ  = -0.8640200E-11
  MX  =  0.4074536E-09
  MY  = -0.1600711E-09
  MZ  = -0.1025910E-08

 SUMMATION POINT=  26.000      0.0000      0.0000


 USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

 SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    21
   TIME/FREQUENCY=  3.0000
 TITLE= Vertical Load of 40,000 lb

 ***** SUMMATION OF TOTAL    FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  0.5386482E-09
  FY  =   40008.87
  FZ  =  0.4012177E-05
  MX  =  0.2796878E-07
  MY  = -0.1645576E-04
  MZ  =   164076.4

 SUMMATION POINT=  26.000      0.0000      0.0000


 USE LOAD STEP     4  SUBSTEP     0  FOR LOAD CASE 0

 SET COMMAND GOT LOAD STEP=     4  SUBSTEP=     1  CUMULATIVE ITERATION=    26
   TIME/FREQUENCY=  4.0000
 TITLE= Combined Loading

 ***** SUMMATION OF TOTAL    FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  -200488.2
  FY  =   40008.87
  FZ  =   200017.1
  MX  = -0.2891175E-06
  MY  =  -820270.0
  MZ  =   164076.4

 SUMMATION POINT=  26.000      0.0000      0.0000


 USE LOAD STEP     5  SUBSTEP     0  FOR LOAD CASE 0

 SET COMMAND GOT LOAD STEP=     5  SUBSTEP=     1  CUMULATIVE ITERATION=    32
   TIME/FREQUENCY=  5.0000
 TITLE= Lifting Conditions

 ***** SUMMATION OF TOTAL    FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  0.3769628E-08
  FY  =  0.1323480E-05
  FZ  =   156013.3
  MX  = -0.2466695E-06
  MY  =  -639810.6
  MZ  =  0.5436420E-05

 SUMMATION POINT=  26.000      0.0000      0.0000
```

Appendix 2

Electronic Data on CDROM

(1 Page & 1 CDROM)

Directory of the CD-ROM

```
 Volume in drive F is ST-503 Rev1 App2
 Volume Serial Number is 7447-86B2

 Directory of F:\

01/07/2010  01:15 PM         2,998,783 file.cdb
01/07/2010  01:46 PM        39,780,352 file.db
01/06/2010  02:41 PM        83,623,936 file.rst
09/24/2007  07:53 AM            65,949 file.s01
09/24/2007  07:56 AM           112,121 file.s02
09/24/2007  09:59 AM            65,949 file.s03
12/14/2009  05:08 PM           140,057 file.s04
01/06/2010  02:10 PM            65,949 file.s05
01/06/2010  03:00 PM           116,164 file000.png
01/06/2010  03:03 PM           267,456 file001.png
01/06/2010  03:07 PM           234,924 file002.png
01/06/2010  03:10 PM           122,578 file003.png
01/06/2010  03:11 PM           133,948 file004.png
01/06/2010  03:11 PM           144,710 file005.png
01/06/2010  03:36 PM           139,256 file006.png
01/06/2010  03:37 PM           153,412 file007.png
01/06/2010  03:37 PM           142,420 file008.png
01/06/2010  03:38 PM           120,145 file009.png
01/06/2010  03:39 PM           124,294 file010.png
01/06/2010  03:39 PM           142,338 file011.png
01/06/2010  03:40 PM           125,305 file012.png
01/06/2010  03:40 PM           137,816 file013.png
01/06/2010  03:41 PM           143,333 file014.png
01/06/2010  03:42 PM           127,486 file015.png
01/06/2010  03:42 PM           128,795 file016.png
01/06/2010  03:42 PM           188,556 file017.png
01/06/2010  03:49 PM           172,560 file018.png
01/06/2010  04:06 PM           184,401 file019.png
01/06/2010  04:12 PM           176,939 file020.png
01/06/2010  04:13 PM           180,879 file021.png
01/06/2010  04:15 PM           204,484 file022.png
01/07/2010  01:15 PM         1,895,891 model.out
01/07/2010  01:24 PM             2,721 reactions.out
              33 File(s)    132,363,907 bytes

     Total Files Listed:
              33 File(s)    132,363,907 bytes
               0 Dir(s)               0 bytes free
```

1.0 OBJECTIVE

Perform the structural analyses of the Energy*Solutions* 3-60B Cask under normal conditions of transport (NCT), 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 normal conditions of transport (NCT). 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 load cases 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-022, Rev.1, Steady State Thermal Analyses of the 3-60B Cask Using a 3-D Finite Element Model.

4.0 MATERIAL PROPERTIES

Material	Temp. (°F)	Strength (ksi) Yield (S_y)	Strength (ksi) Ultimate (S_u)	Strength (ksi) Membrane Allowable (S_m)	Young's Modulus (10^6 psi)	Coefficient of Thermal Expansion (10^{-6} in/in)
ASTM A240 Type 304L		(1)	(1)	(1)	(1)	(1)
	-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
ASTM A240 Gr. 45 & ASTM A182 Gr. F45		(1)	(1)	(1)	(1)	(1)
	-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
ASTM A354 Gr. BD (Lid Bolts)		(1)	(1)	(1)	(1)	(1)
	-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
ASTM B29 Lead		(2)			(2)	(2)
	-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)
Normal Conditions	Membrane Stress	16,700(2)	24,900(2)	60,000(3)
	Mem. + Bending Stress	25,050(2)	37,350(2)	90,000(3)
Hypothetical Accident Conditions	Membrane Stress	40,080(4)	59,760(4)	105,000(5)
	Mem. + Bending Stress	60,120(4)	87,000(4)	150,000(5)

Notes:

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

(2) Established from Regulatory Guide 7.6 (Reference 6), Position 2.

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

(4) Established from Regulatory Guide 7.6 (Reference 6), Position 6.

(5) 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.

5.0 MODEL DESCRIPTION

The structural analyses of the 3-60B Cask under NCT 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 shell components of the cask - the inner and outer shells, and the baseplates have been represented in the finite element model by SOLSH190 elements.

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 of the cask 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 a pair of contact (CONTA174) and target (TARGE170) elements. These elements allow the lead to slide over the steel at the same time prevent it from penetrating the steel surface.

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

For various NCT loading cases, 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,

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

Payload Mass = 9,500 lb

Lid Radius = 17.5 in

Pressure on the lid surface due to payload weight,

$p_{lid} = 9{,}500/(\pi\times17.5^2) = 9.874$ 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 NCT loading conditions is applied as the uniform pressure over the nodes representing the cavity of the cask. The external pressure, if applicable, is applied over the nodes representing the entire exterior surface of the cask.

Temperature

The temperature distribution under various NCT loading conditions is obtained from the thermal analyses performed in Reference 8 and is applied as the nodal temperature in the finite element model.

6.0 ANALYSES

The finite element model described in Section 5.0 is analyzed for the following loading conditions:

1. Hot Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (1). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	Load Case 1
Internal Pressure	35 psi
External Pressure	No

See Figure 6 for the plot of the temperature profile and pressure distribution used for this load step.

2. Cold Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (2). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	Load Case 2

Internal Pressure	35 psi
External Pressure	No

See Figure 7 for the plot of the temperature profile and pressure distribution used for this load step.

3. Normal Hot - This load case is based on the requirements of 10 CFR 71.71 (b). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	Load Case 3
Internal Pressure	35 psi
External Pressure	No

See Figure 8 for the plot of the temperature profile and pressure distribution used for this load step.

4. Normal Cold - This load case is based on the requirements of 10 CFR 71.71 (b). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	Load Case 4
Internal Pressure	35 psi
External Pressure	No

See Figure 9 for the plot of the temperature profile and pressure distribution used for this load step.

5. Maximum Normal Operating Pressure - This load case is analyzed to obtain the load-controlled stresses in the cask under MNOP. The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	70°F
Internal Pressure	35 psi
External Pressure	No

See Figure 10 for the plot of the temperature profile and pressure distribution used for this load step.

6. Reduced External Pressure - This load case is based on the requirements of 10 CFR 71.71 (c)(3). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	Load Case 3
Internal Pressure	50 psi
External Pressure	No

See Figure 11 for the plot of the temperature profile and pressure distribution used for this load step.

7. Increased External Pressure & Immersion - This load case is based on the requirements of 10 CFR 71.71 (c)(4). This load case also envelopes the requirement of 10 CFR 71.73(c)(6). The finite element model is subjected to the following loading:

Cask Deadweight	✓
Upper Impact Limiter Deadweight	✓
Payload Deadweight	✓
Temperature from Reference 8	-20°F
Internal Pressure	No

External Pressure	25 psi

See Figure 12 for the plot of the temperature profile and pressure distribution used for this load step.

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 summary results of the stress quantities, obtained from the post-processing of each load case, are provided in Appendix 2. The total printout from all the load cases is included in Appendix 3. Stress intensity contour plots are presented in Figures 13 through 19. 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. If the magnitude of these S.I.s are smaller than the membrane stress allowable values for the material, the peak stress values from the finite element model results are reported as membrane and membrane plus bending as well. However, if these values are larger than the membrane stress allowable values, stresses are linearized over the cross-section, per ASME code, and the results obtained from this operation are listed in Tables 1 through 7. The stress intensity values are also compared with the corresponding allowable values in these tables. A factor of safety is calculated for every component for each load case. A factor of safety value of 1.0 or larger indicates that the stress intensity is acceptable for the loading considered.

The results of the analyses show that the stresses for all the normal operating load cases are well within the allowable values.

8.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Stress Summary Print-out

Appendix 3 Electronic data on CDROM

Tables

(7 Pages)

Table 1

Stress Intensities in 3-60B Cask under Hot Environment Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	17,334	1.44
	$P_m + P_b$	37,350	17,334	2.15
Bolting Ring Shell Extension	P_m	24,900	14,050[3]	1.77
	$P_m + P_b$	37,350	24,070[3]	1.55
Bolting Ring Skirt	P_m	24,900	3,762	6.62
	$P_m + P_b$	37,350	3,762	9.93
Inner Shell	P_m	24,900	7,558	3.30
	$P_m + P_b$	37,350	7,558	4.94
Outer Shell	P_m	16,700	9,727[4]	1.72
	$P_m + P_b$	25,050	17,720[4]	1.41
Lid	P_m	16,700	4,699	3.55
	$P_m + P_b$	25,050	4,699	5.33
Base Plates	P_m	16,700	12,237	1.36
	$P_m + P_b$	25,050	12,237	2.05
Seal Plates	$P_m + P_b$	25,050	12,223	2.05
Bolts	P_m	60,000	20,871	2.87
	$P_m + P_b$	90,000	20,871	4.31

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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) See Figure 20 for the location of the section over which the stresses are linearized.

(4) See Figure 21 for the location of the section over which the stresses are linearized.

Table 2

Stress Intensities in 3-60B Cask under Cold Environment Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	13,838	1.80
	$P_m + P_b$	37,350	13,838	2.70
Bolting Ring Shell Extension	P_m	24,900	9,477[3]	2.63
	$P_m + P_b$	37,350	16,420[3]	2.27
Bolting Ring Skirt	P_m	24,900	4,139	6.02
	$P_m + P_b$	37,350	4,139	9.02
Inner Shell	P_m	24,900	9,713	2.56
	$P_m + P_b$	37,350	9,713	3.85
Outer Shell	P_m	16,700	1,731	9.65
	$P_m + P_b$	25,050	1,731	14.47
Lid	P_m	16,700	7,346	2.27
	$P_m + P_b$	25,050	7,346	3.41
Base Plates	P_m	16,700	11,264	1.48
	$P_m + P_b$	25,050	11,264	2.22
Seal Plates	$P_m + P_b$	25,050	12,696	1.97
Bolts	P_m	60,000	9,941	6.04
	$P_m + P_b$	90,000	9,941	9.05

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as Pm and Pm + Pb stress intensities.

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

(3) See Figure 22 for the location of the section over which the stresses are linearized.

Table 3

Stress Intensities in 3-60B Cask under Normal Hot Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	9,392	2.65
	$P_m + P_b$	37,350	9,392	3.98
Bolting Ring Shell Extension	P_m	24,900	13,574	1.83
	$P_m + P_b$	37,350	13,574	2.75
Bolting Ring Skirt	P_m	24,900	2,581	9.65
	$P_m + P_b$	37,350	2,581	14.47
Inner Shell	P_m	24,900	4,078	6.11
	$P_m + P_b$	37,350	4,078	9.16
Outer Shell	P_m	16,700	9,789	1.71
	$P_m + P_b$	25,050	9,789	2.56
Lid	P_m	16,700	2,700	6.19
	$P_m + P_b$	25,050	2,700	9.28
Base Plates	P_m	16,700	6,982	2.39
	$P_m + P_b$	25,050	6,982	3.59
Seal Plates	$P_m + P_b$	25,050	7,065	3.55
Bolts	P_m	60,000	10,976	5.47
	$P_m + P_b$	90,000	10,976	8.20

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 4

Stress Intensities in 3-60B Cask under Normal Cold Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	10,658	2.34
	$P_m + P_b$	37,350	10,658	3.50
Bolting Ring Shell Extension	P_m	24,900	12,421	2.00
	$P_m + P_b$	37,350	12,421	3.00
Bolting Ring Skirt	P_m	24,900	3,388	7.35
	$P_m + P_b$	37,350	3,388	11.02
Inner Shell	P_m	24,900	7,273	3.42
	$P_m + P_b$	37,350	7,273	5.14
Outer Shell	P_m	16,700	1,298	12.87
	$P_m + P_b$	25,050	1,298	19.30
Lid	P_m	16,700	5,863	2.85
	$P_m + P_b$	25,050	5,863	4.27
Base Plates	P_m	16,700	8,131	2.05
	$P_m + P_b$	25,050	8,131	3.08
Seal Plates	$P_m + P_b$	25,050	9,810	2.55
Bolts	P_m	60,000	7,900	7.59
	$P_m + P_b$	90,000	7,900	11.39

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 5

Stress Intensities in 3-60B Cask under Maximum Normal Operating Pressure

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	1,579	15.77
	$P_m + P_b$	37,350	1,579	23.75
Bolting Ring Shell Extension	P_m	24,900	501	49.70
	$P_m + P_b$	37,350	501	74.55
Bolting Ring Skirt	P_m	24,900	608	40.95
	$P_m + P_b$	37,350	608	61.43
Inner Shell	P_m	24,900	426	58.45
	$P_m + P_b$	37,350	426	87.68
Outer Shell	P_m	16,700	273	61.17
	$P_m + P_b$	25,050	273	91.76
Lid	P_m	16,700	1,019	16.39
	$P_m + P_b$	25,050	1,019	24.58
Base Plates	P_m	16,700	901	18.53
	$P_m + P_b$	25,050	901	27.80
Seal Plates	$P_m + P_b$	25,050	2,103	11.91
Bolts	P_m	60,000	648	92.59
	$P_m + P_b$	90,000	648	138.89

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 6

Stress Intensities in 3-60B Cask under Reduced External Pressure

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	7,851	3.17
	$P_m + P_b$	37,350	7,851	4.76
Bolting Ring Shell Extension	P_m	24,900	13,169	1.89
	$P_m + P_b$	37,350	13,169	2.84
Bolting Ring Skirt	P_m	24,900	2,356	10.57
	$P_m + P_b$	37,350	2,356	15.85
Inner Shell	P_m	24,900	6,420	3.88
	$P_m + P_b$	37,350	6,420	5.82
Outer Shell	P_m	16,700	9,404	1.78
	$P_m + P_b$	25,050	9,404	2.66
Lid	P_m	16,700	2,515	6.64
	$P_m + P_b$	25,050	2,515	9.96
Base Plates	P_m	16,700	11,544	1.45
	$P_m + P_b$	25,050	11,544	2.17
Seal Plates	$P_m + P_b$	25,050	5,882	4.26
Bolts	P_m	60,000	10,962	5.47
	$P_m + P_b$	90,000	10,962	8.21

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 7

Stress Intensities in 3-60B Cask under Increased External Pressure and Immersion

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.[1] (psi)	F.S.[2]
Bolting Ring	P_m	24,900	15,915	1.56
	$P_m + P_b$	37,350	15,915	2.35
Bolting Ring Shell Extension	P_m	24,900	11,610[3]	2.14
	$P_m + P_b$	37,350	19,860[3]	1.88
Bolting Ring Skirt	P_m	24,900	4,213	5.91
	$P_m + P_b$	37,350	4,213	8.87
Inner Shell	P_m	24,900	11,890	2.09
	$P_m + P_b$	37,350	11,890	3.14
Outer Shell	P_m	16,700	2,406	6.94
	$P_m + P_b$	25,050	2,406	10.41
Lid	P_m	16,700	6,925	2.41
	$P_m + P_b$	25,050	6,925	3.62
Base Plates	P_m	16,700	10,510[4]	1.59
	$P_m + P_b$	25,050	15,070[4]	1.66
Seal Plates	$P_m + P_b$	25,050	13,854	1.81
Bolts	P_m	60,000	10,044	5.97
	$P_m + P_b$	90,000	10,044	8.96

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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) See Figure 23 for the location of the section over which the stresses are linearized.

(4) See Figure 24 for the location of the section over which the stresses are linearized.

Figures

(24 Pages)

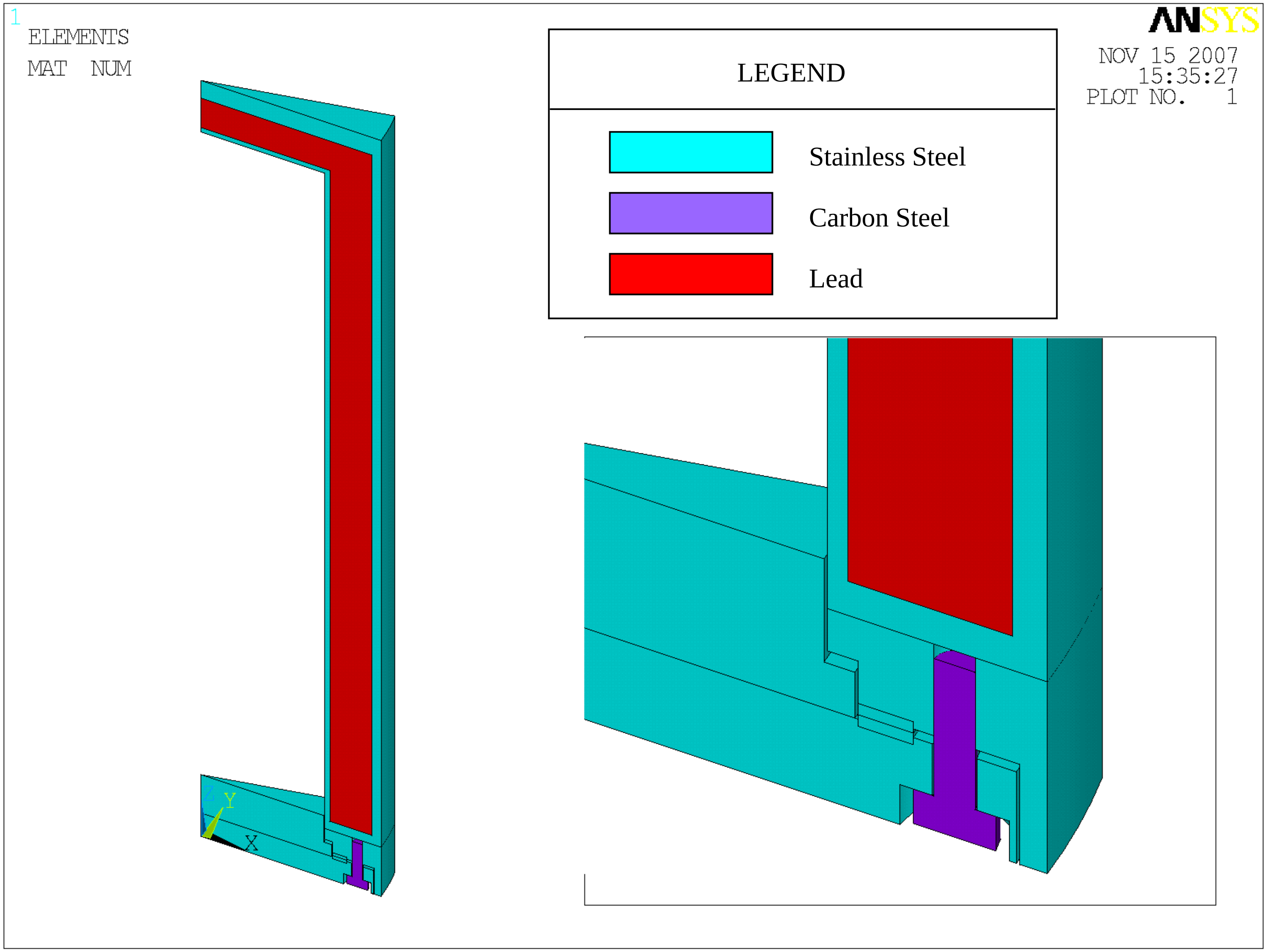

Figure 1
Finite Element Model of the 3-60B Cask Identifying the Components by Material Numbers

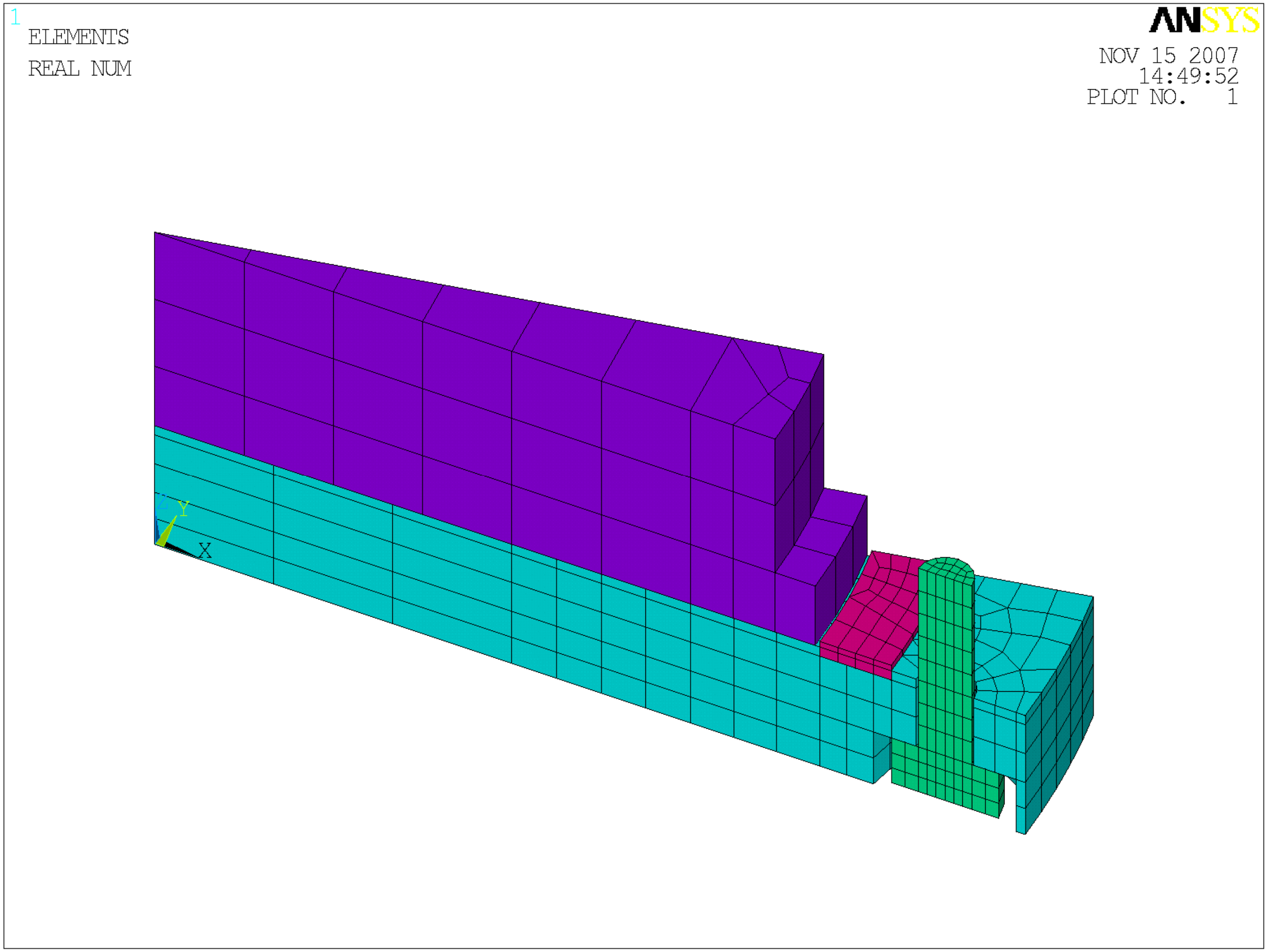

Figure 2
Finite Element Model of the Lid, Seal-Plate and Bolts

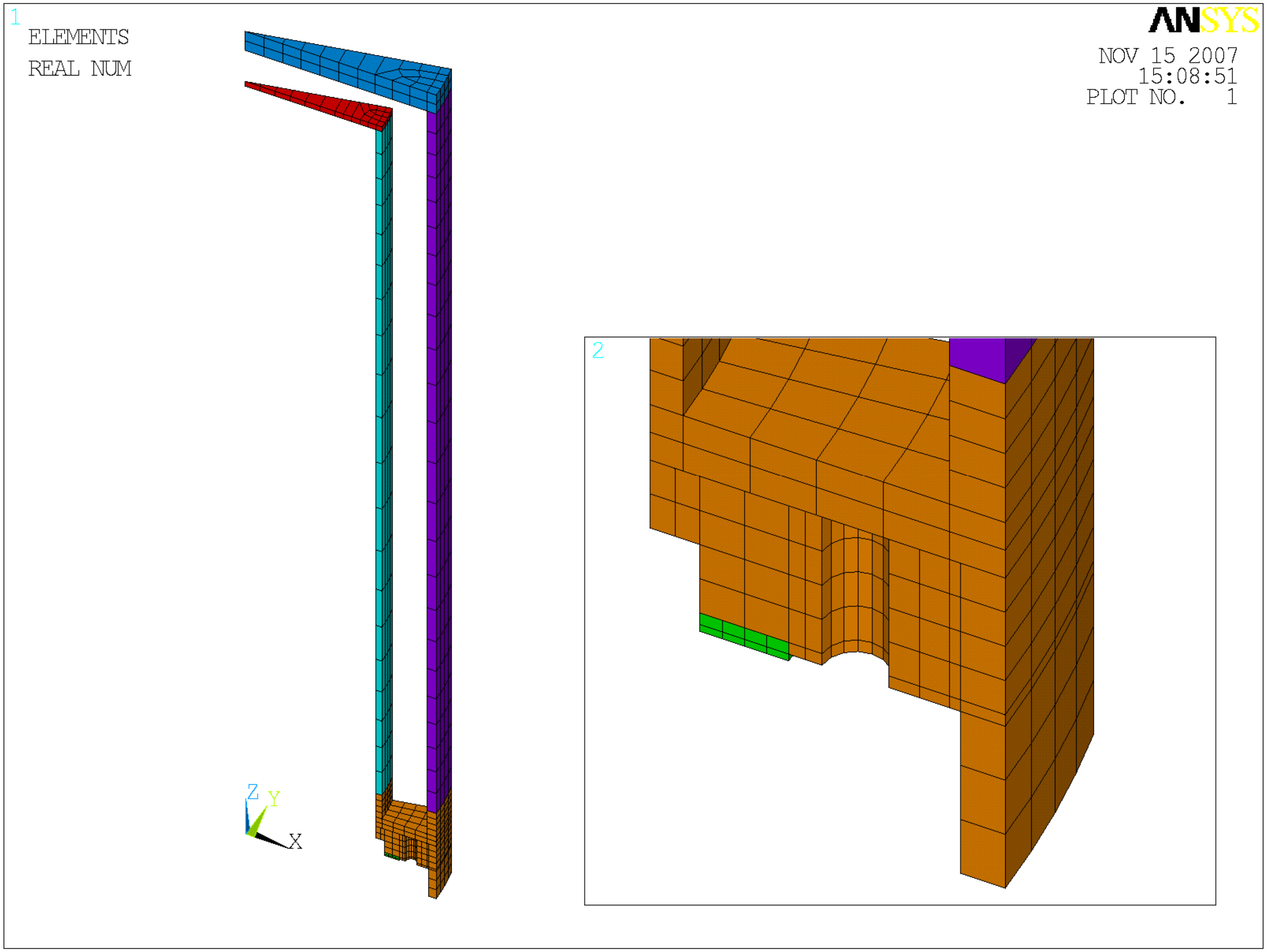

Figure 3
Finite Element Model of the Cask Body without Lead

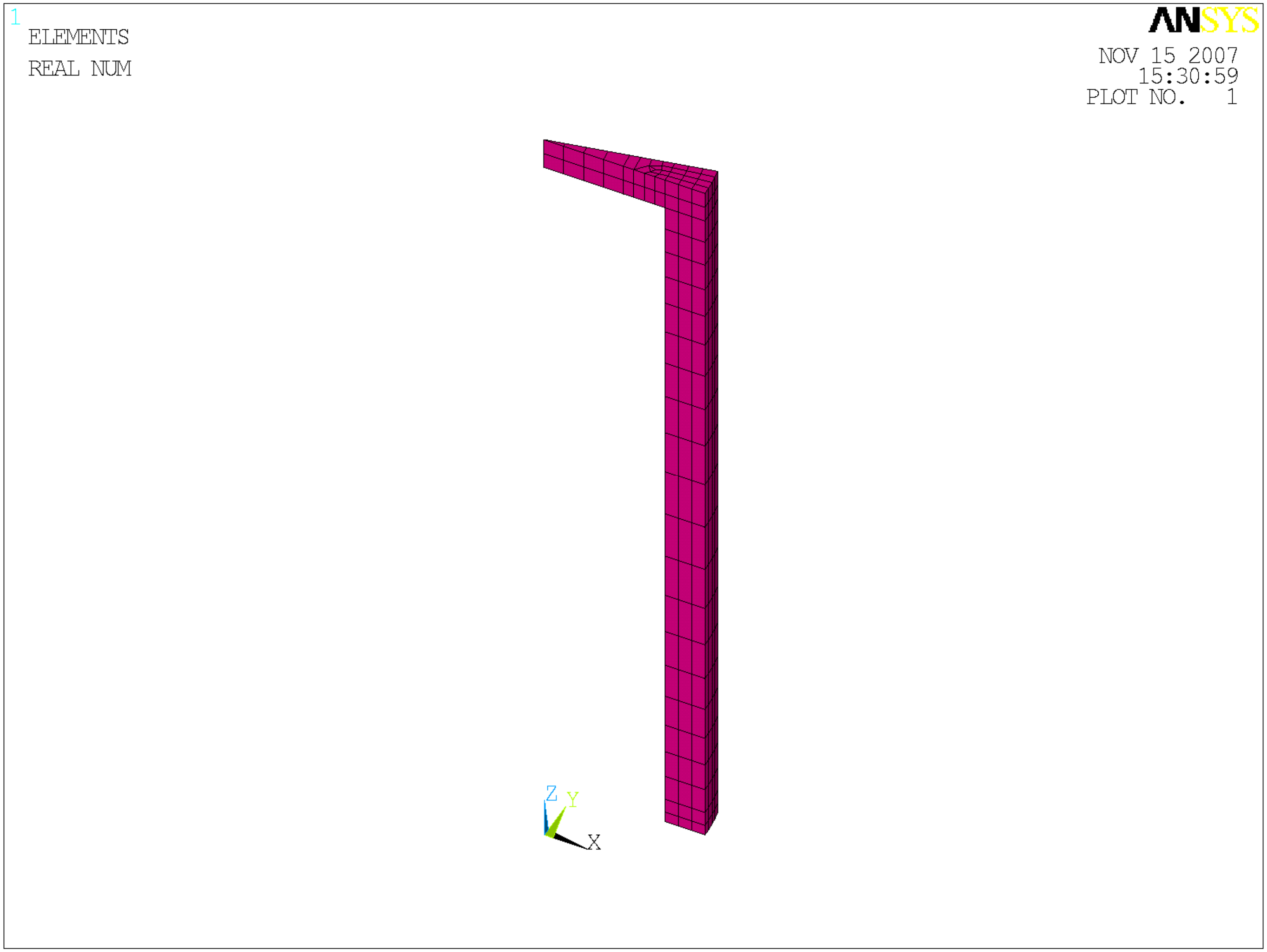

Figure 4
Finite Element Model of the Lead

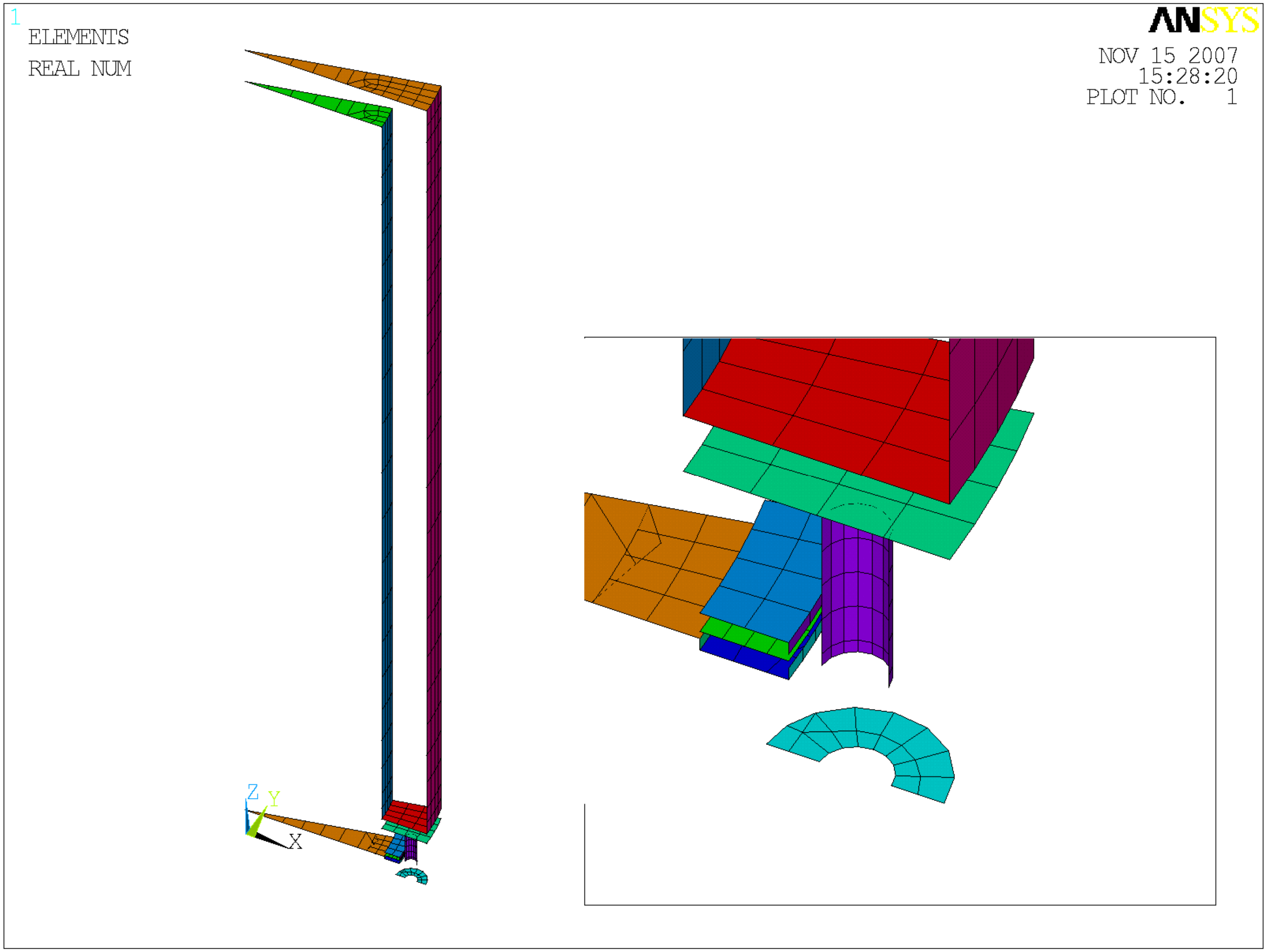

Figure 5

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

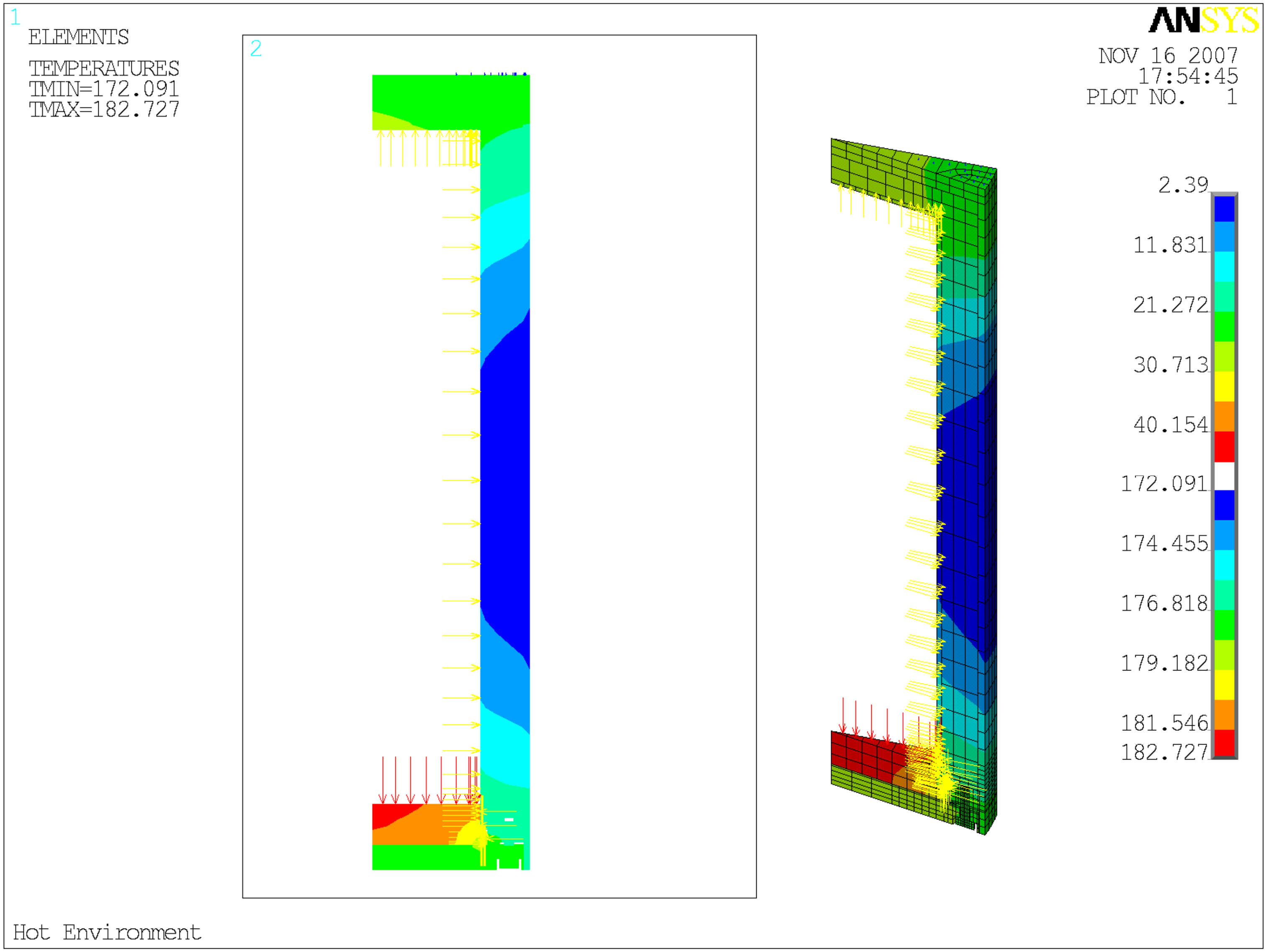

Figure 6

Temperature Profile and Pressure Distribution used for Load Step No.1

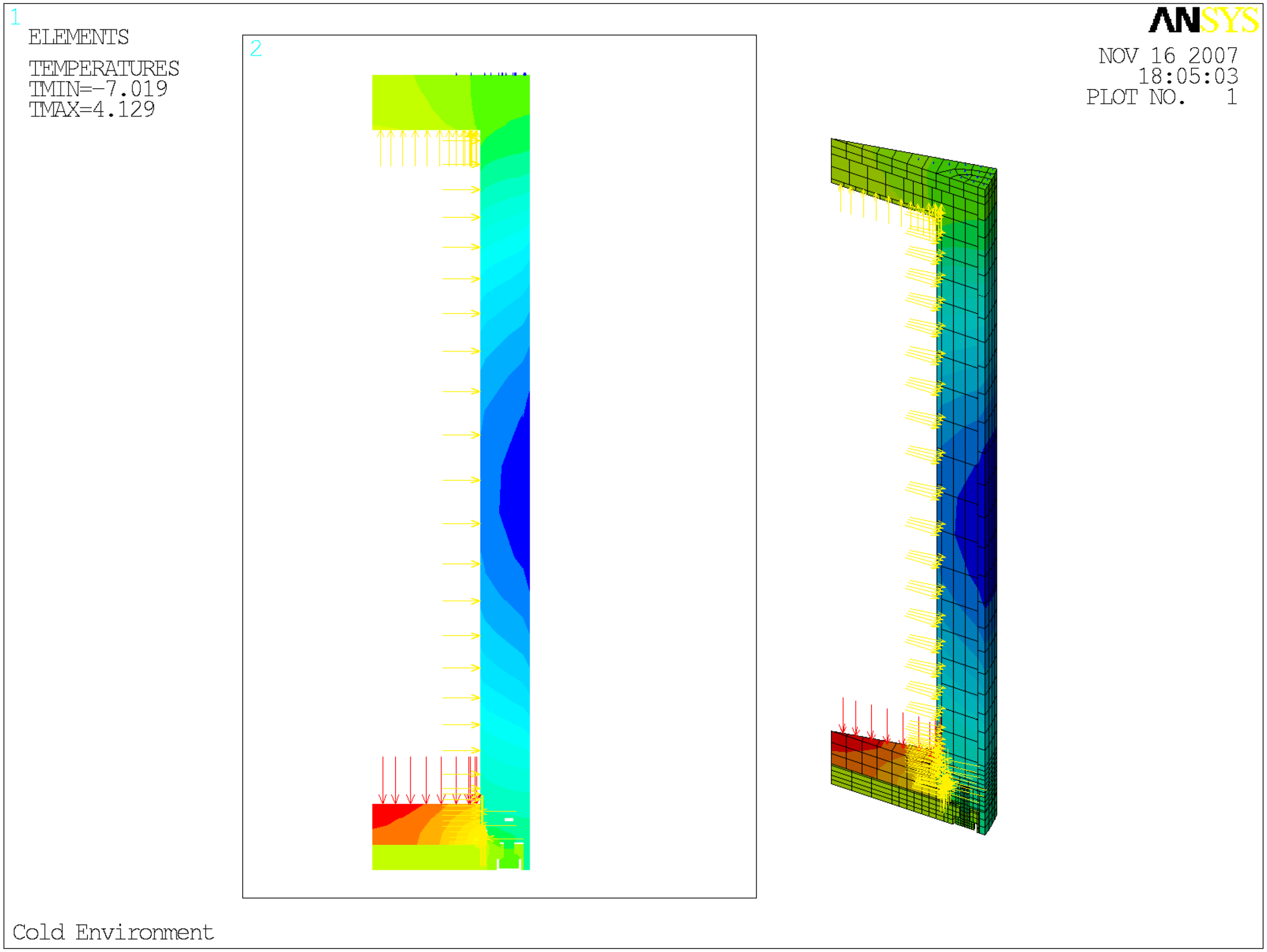

Figure 7
Temperature Profile and Pressure Distribution used for Load Step No.2

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

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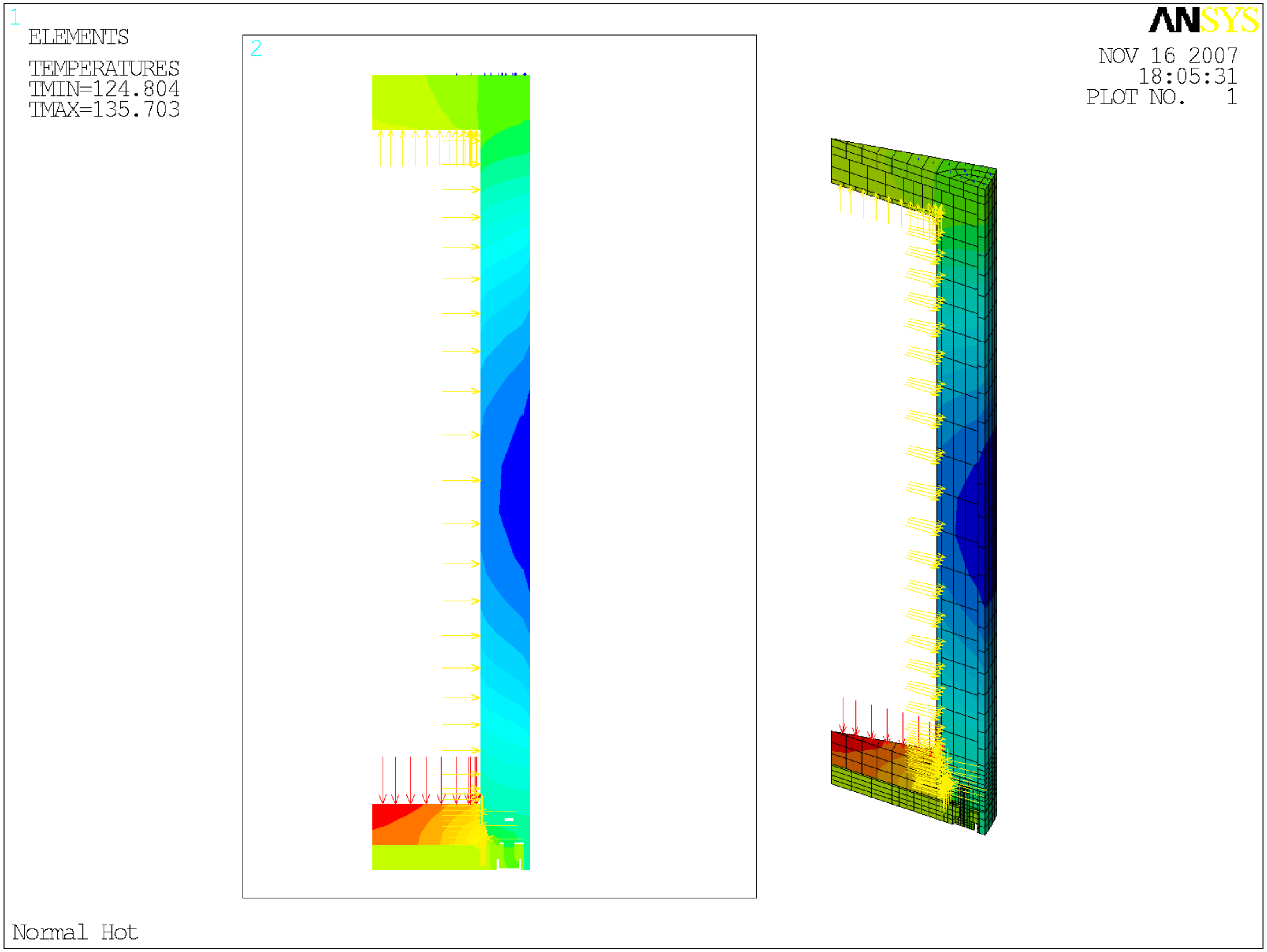

Figure 8

Temperature Profile and Pressure Distribution used for Load Step No.3

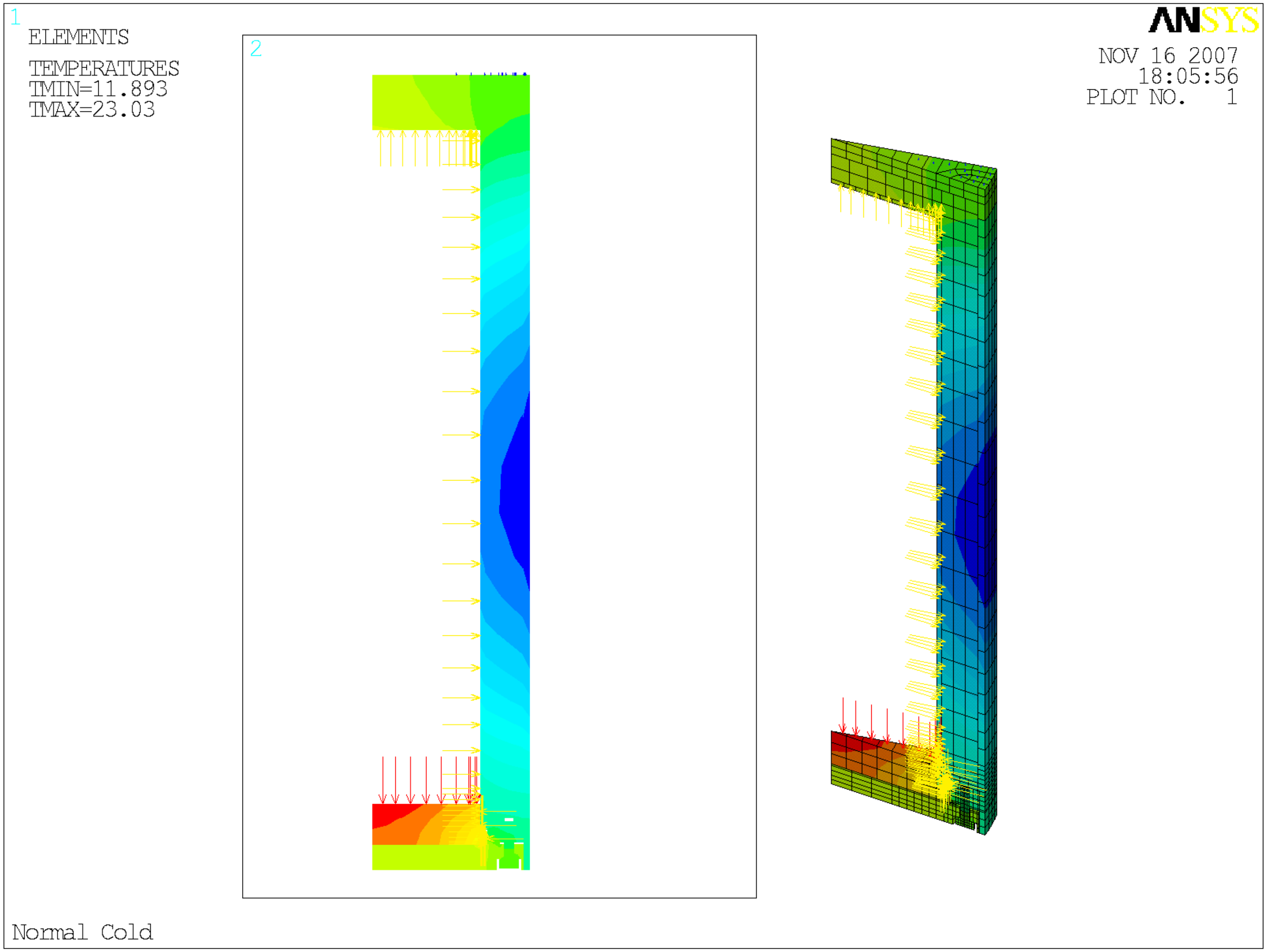

Figure 9

Temperature Profile and Pressure Distribution used for Load Step No.4

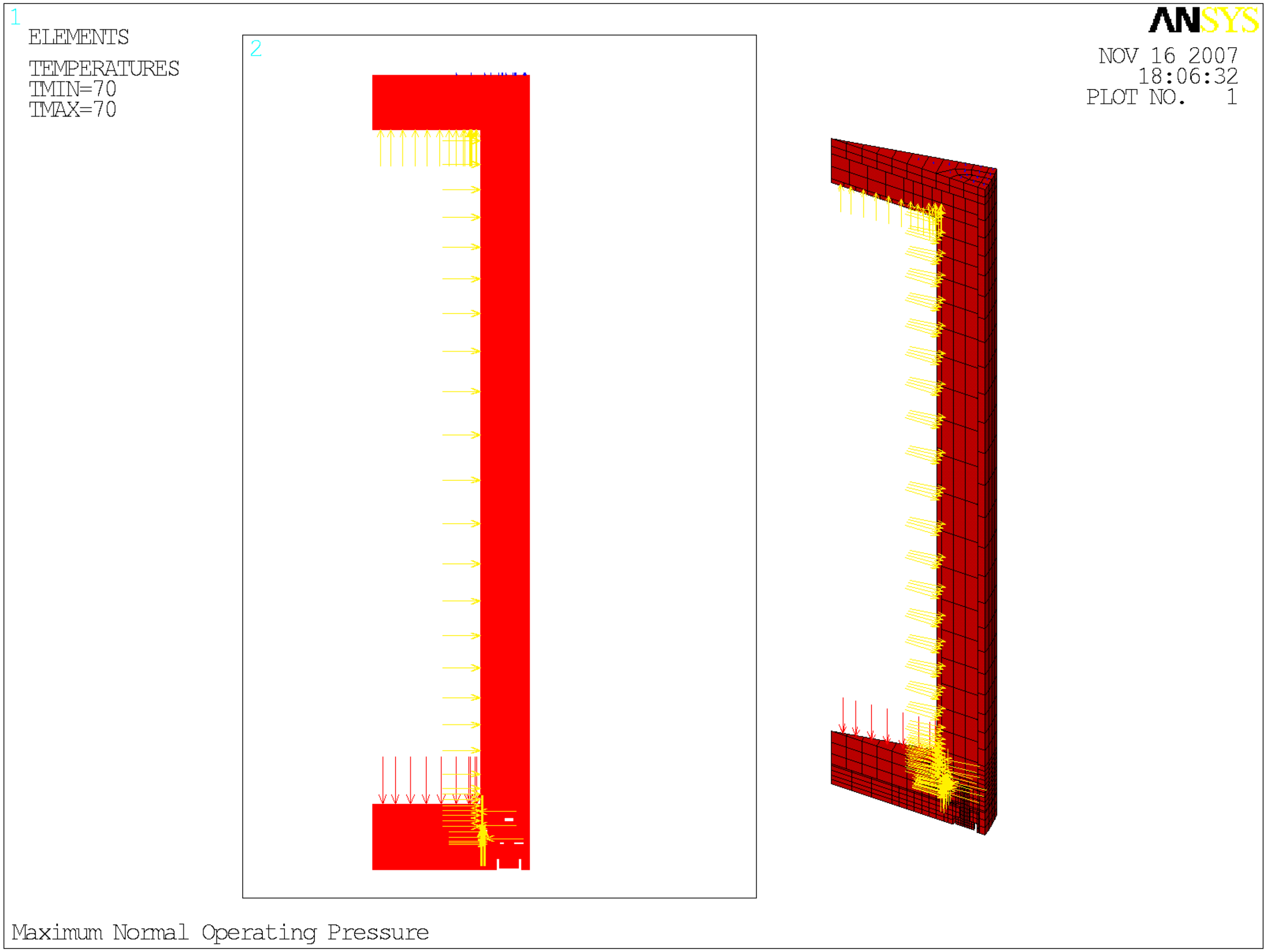

Figure 10

Temperature Profile and Pressure Distribution used for Load Step No.5

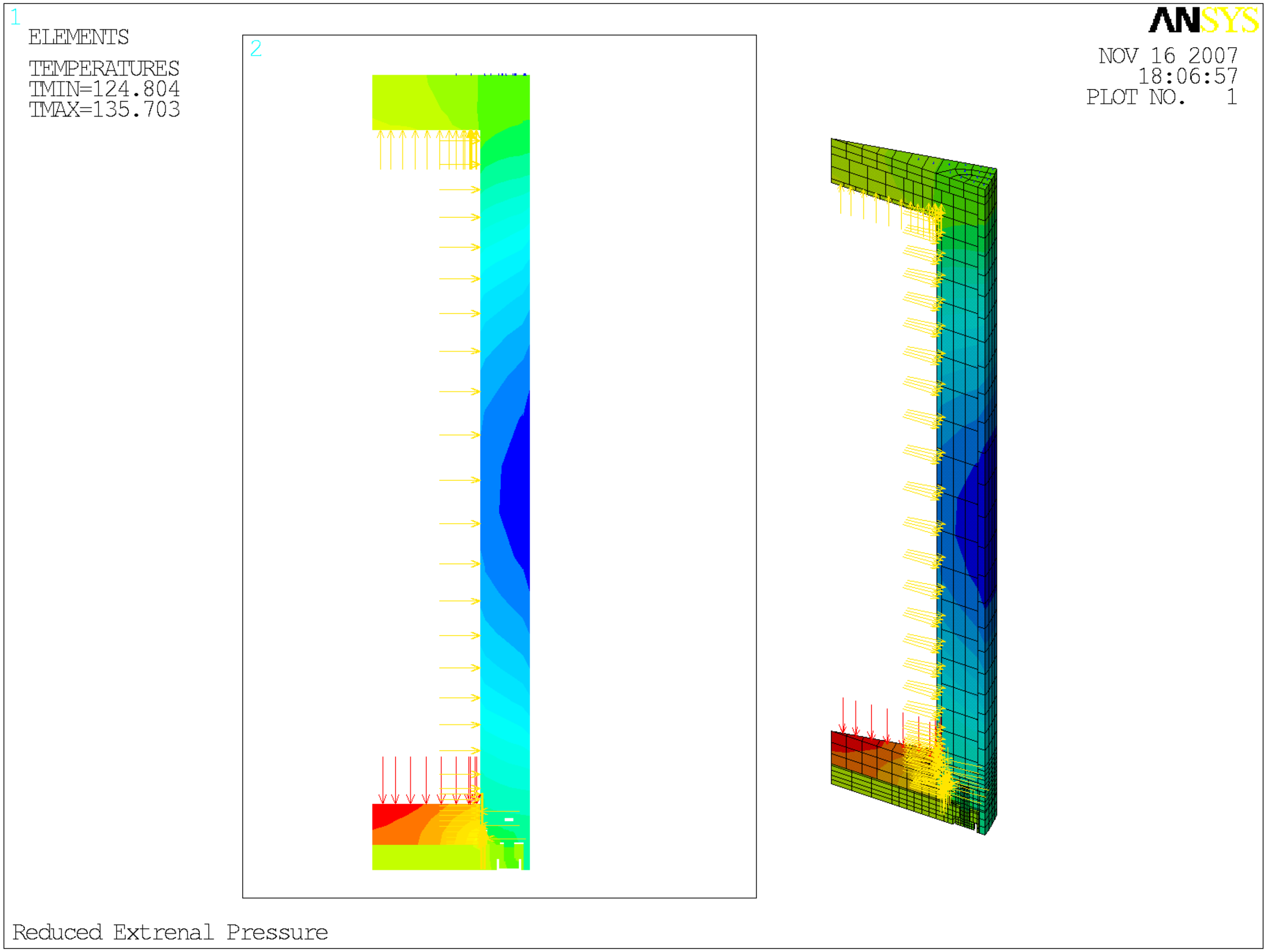

Figure 11

Temperature Profile and Pressure Distribution used for Load Step No.6

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

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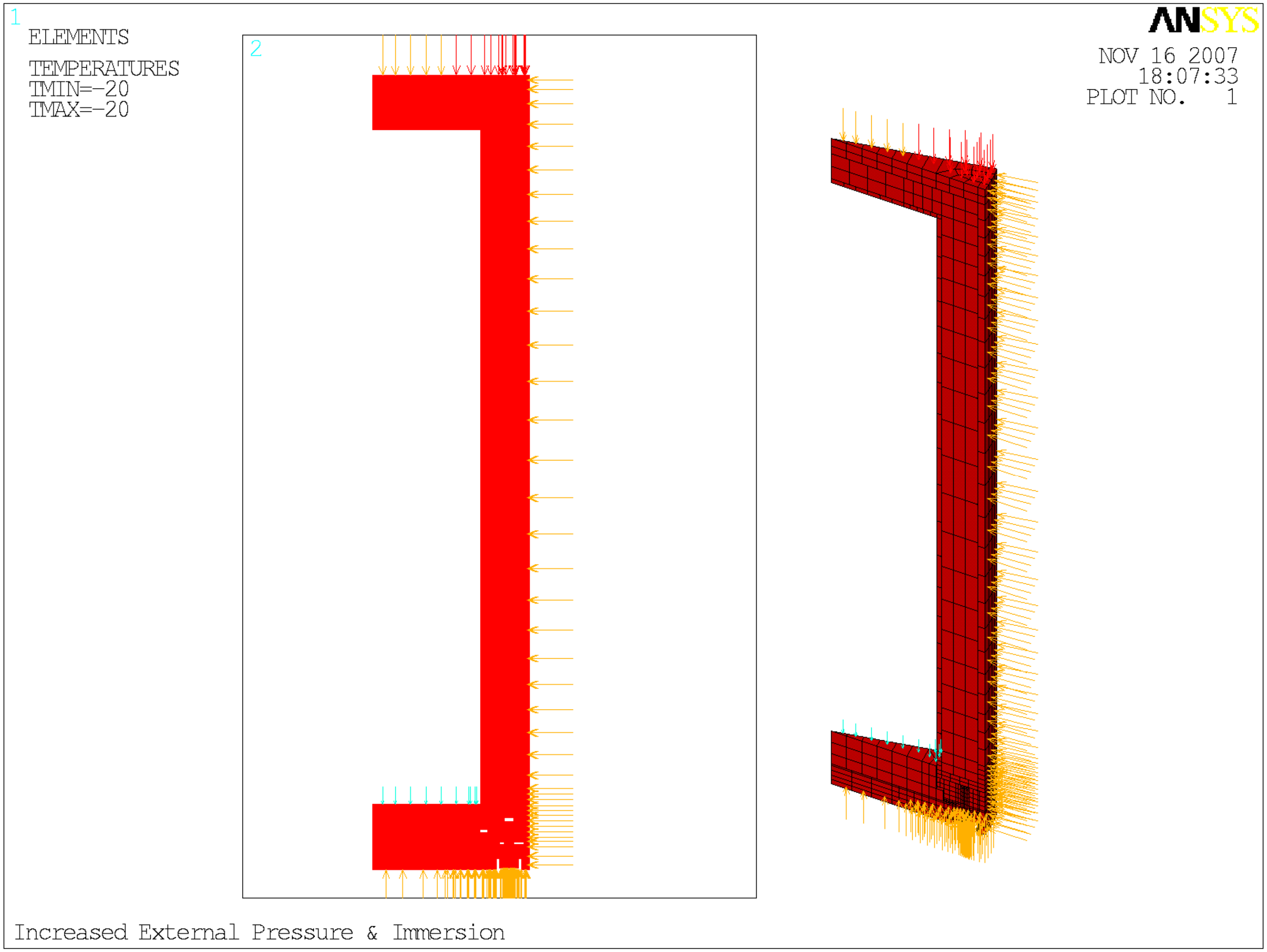

Figure 12

Temperature Profile and Pressure Distribution used for Load Step No.7

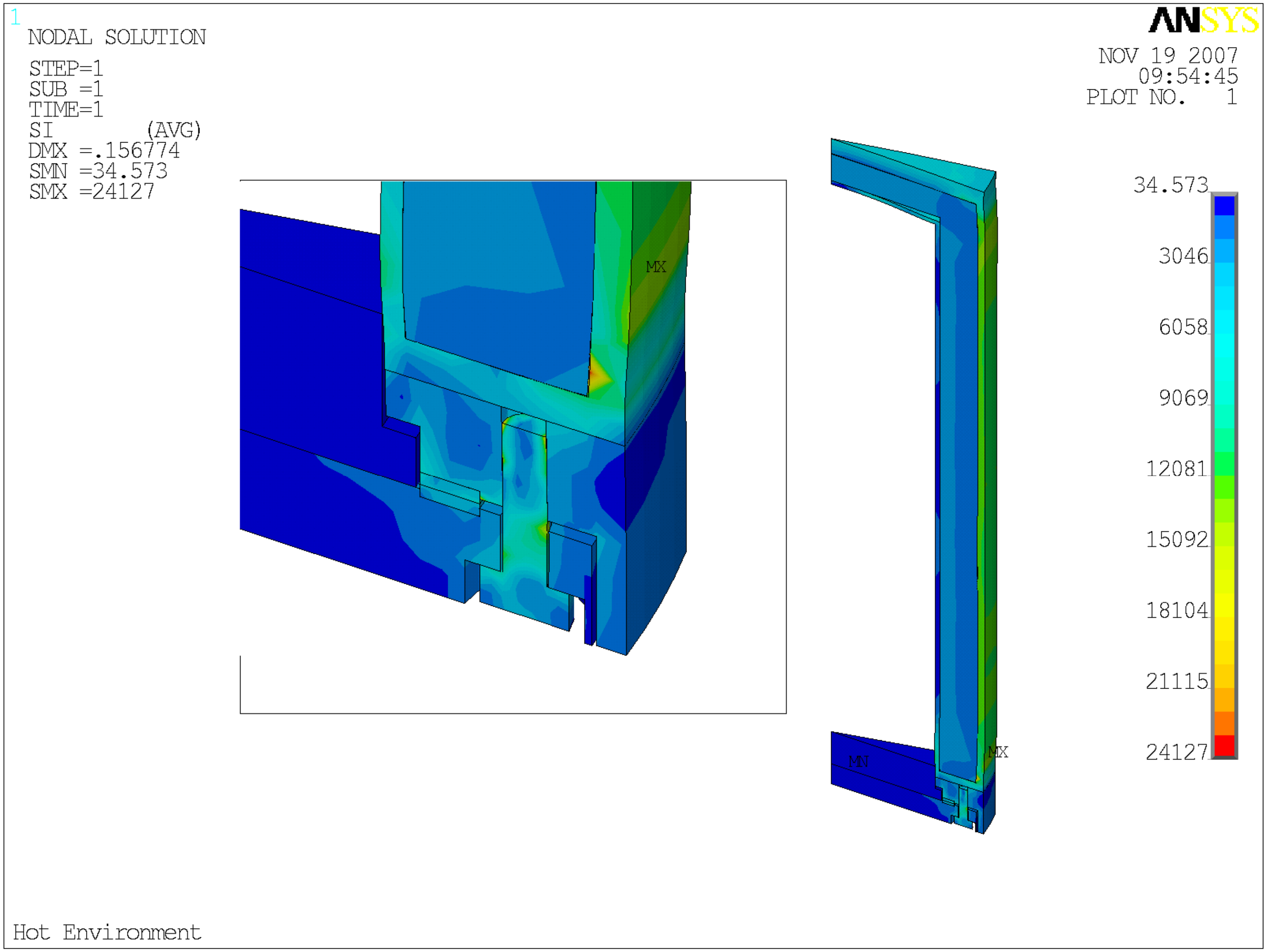

Figure 13

Stress Intensity Contour Plot – Load Step No.1

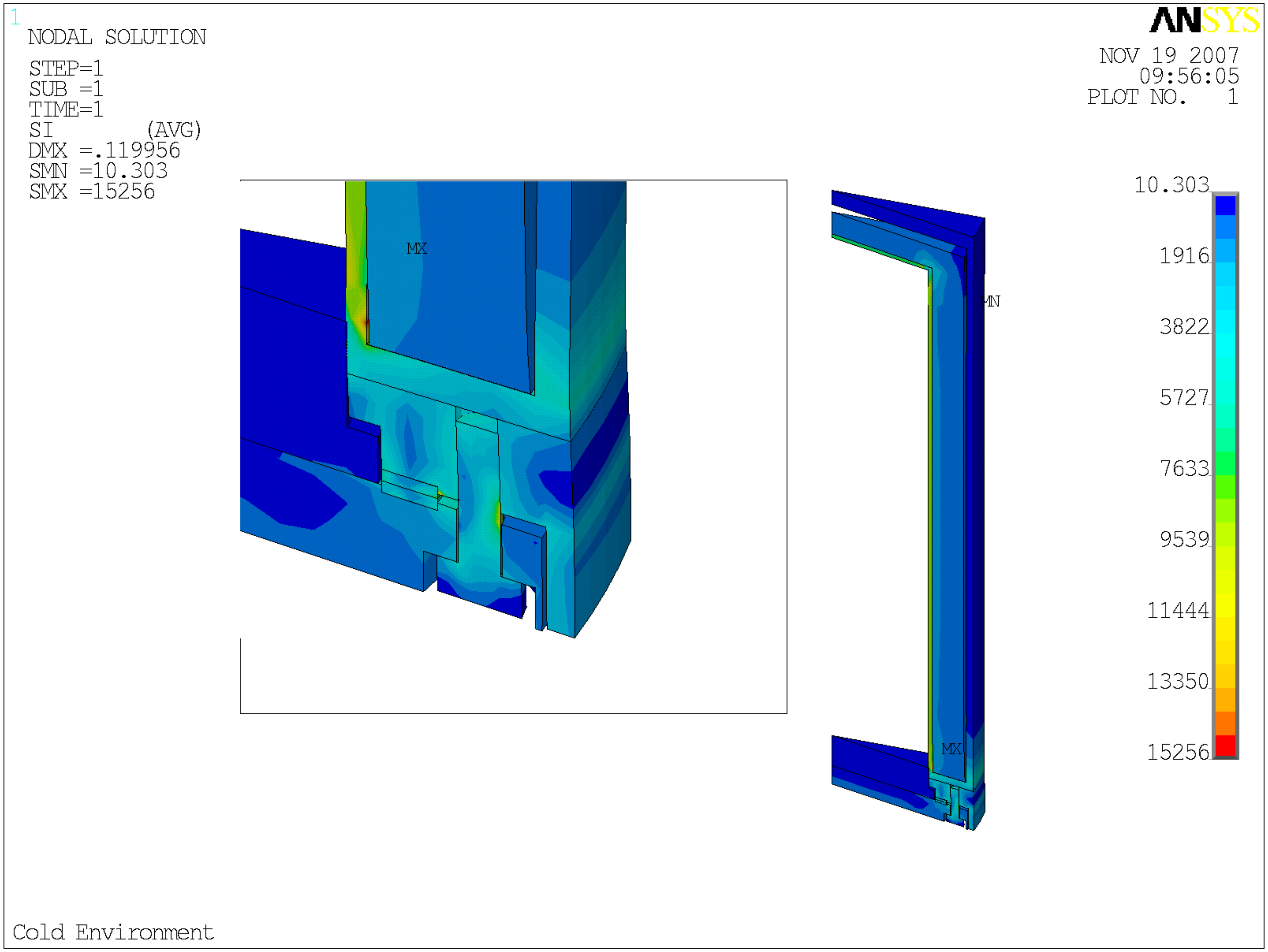

Figure 14

Stress Intensity Contour Plot – Load Step No.2

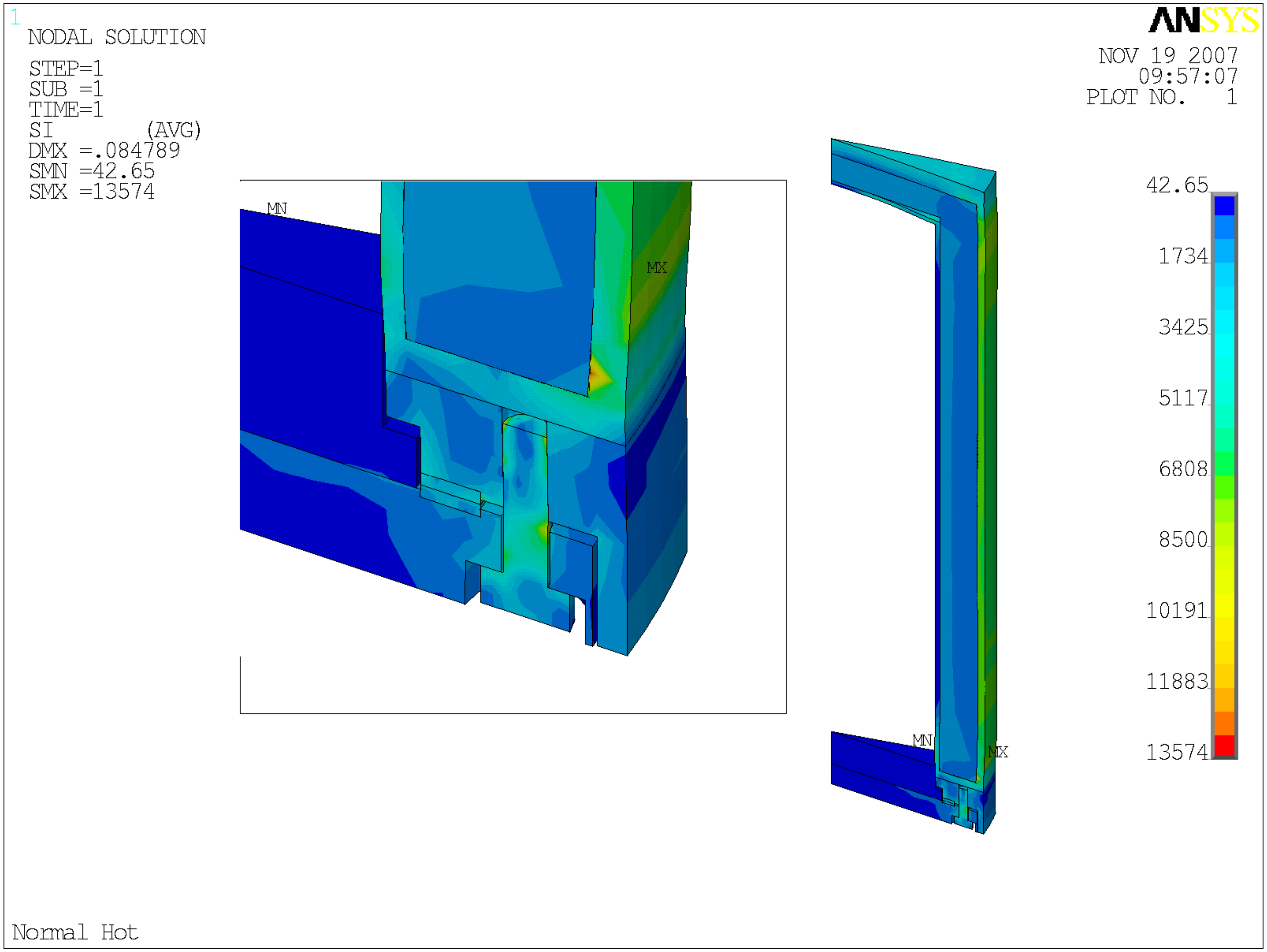

Figure 15

Stress Intensity Contour Plot – Load Step No.3

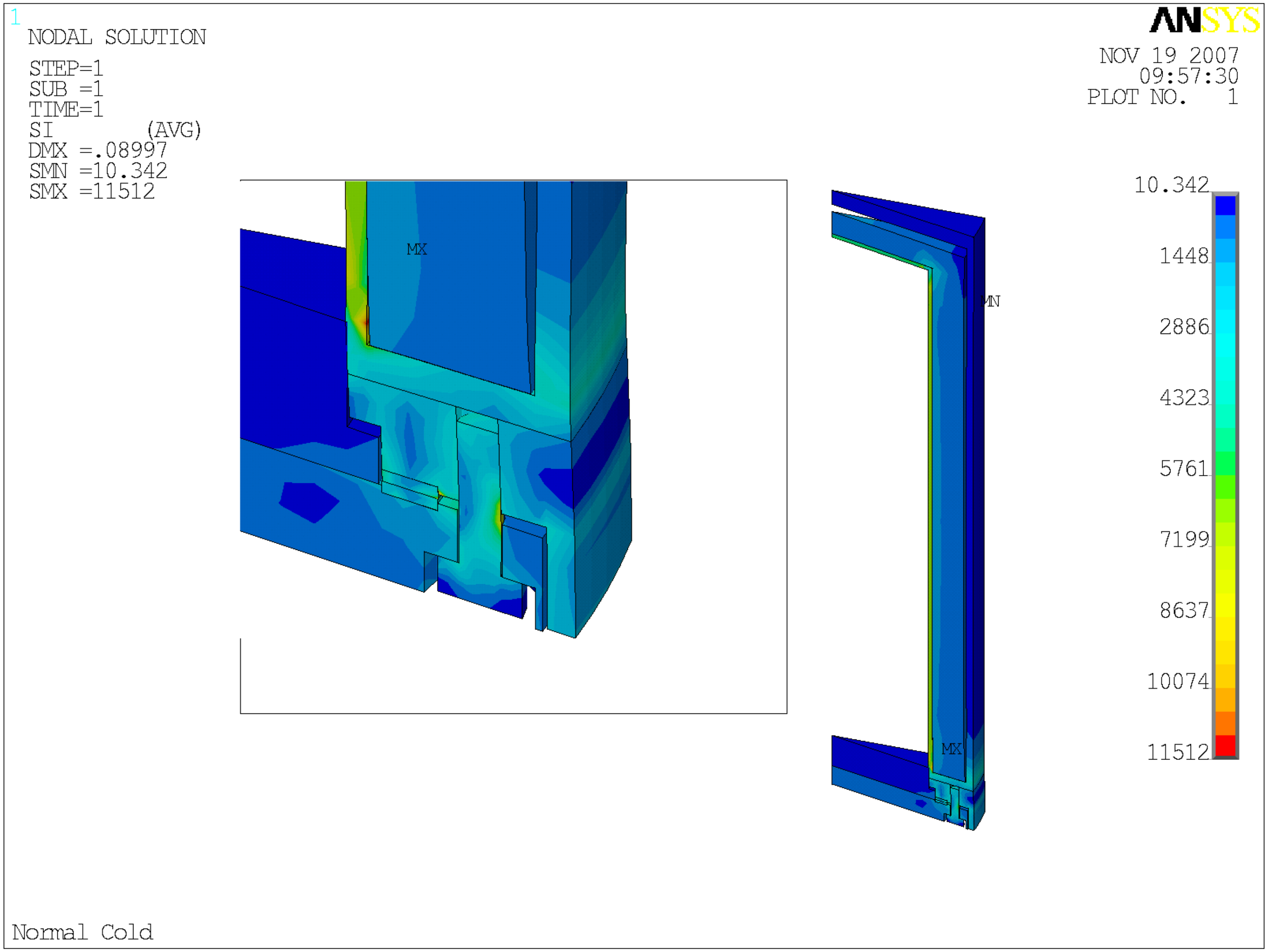

Figure 16
Stress Intensity Contour Plot – Load Step No.4

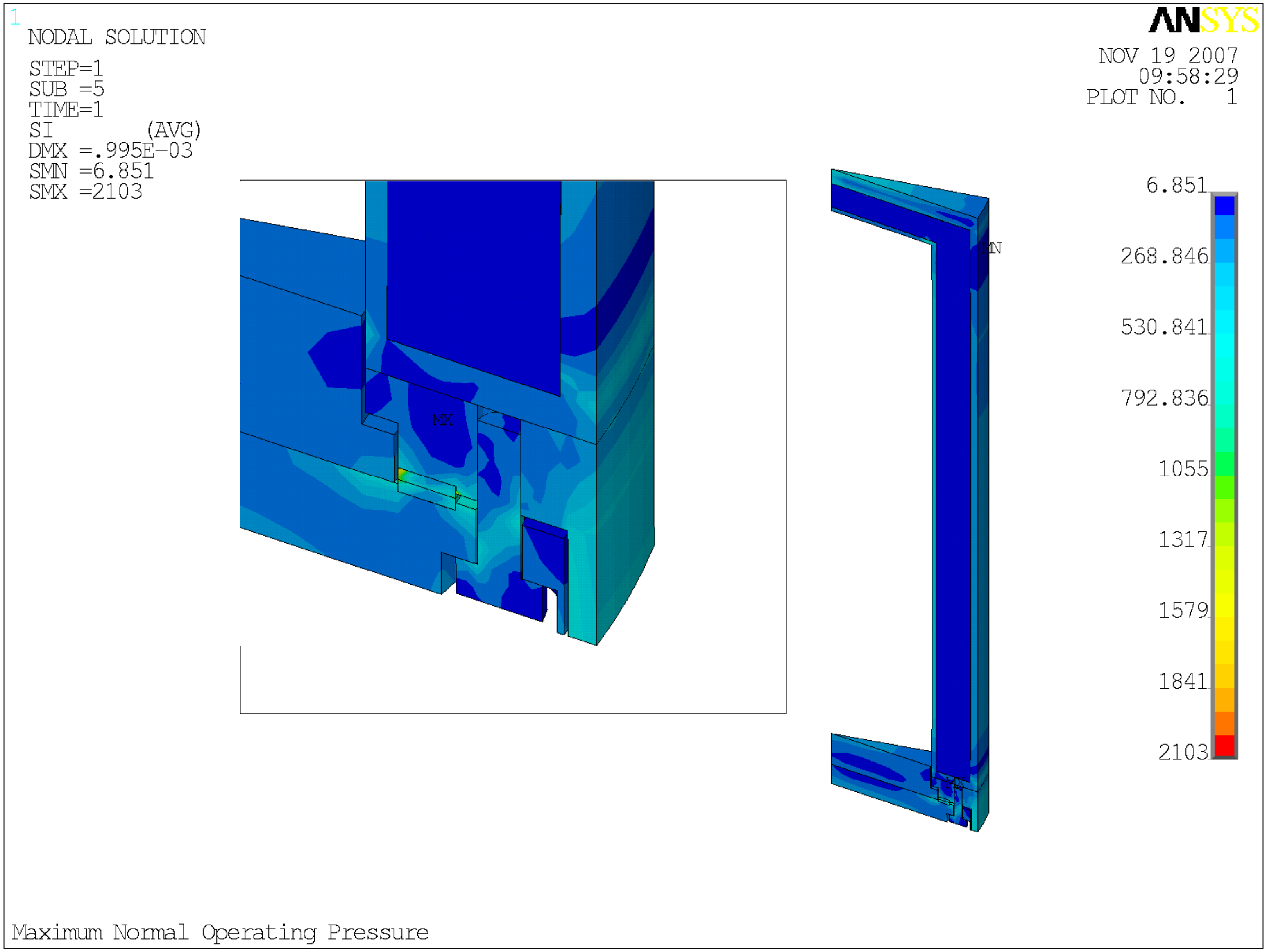

Figure 17

Stress Intensity Contour Plot – Load Step No.5

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

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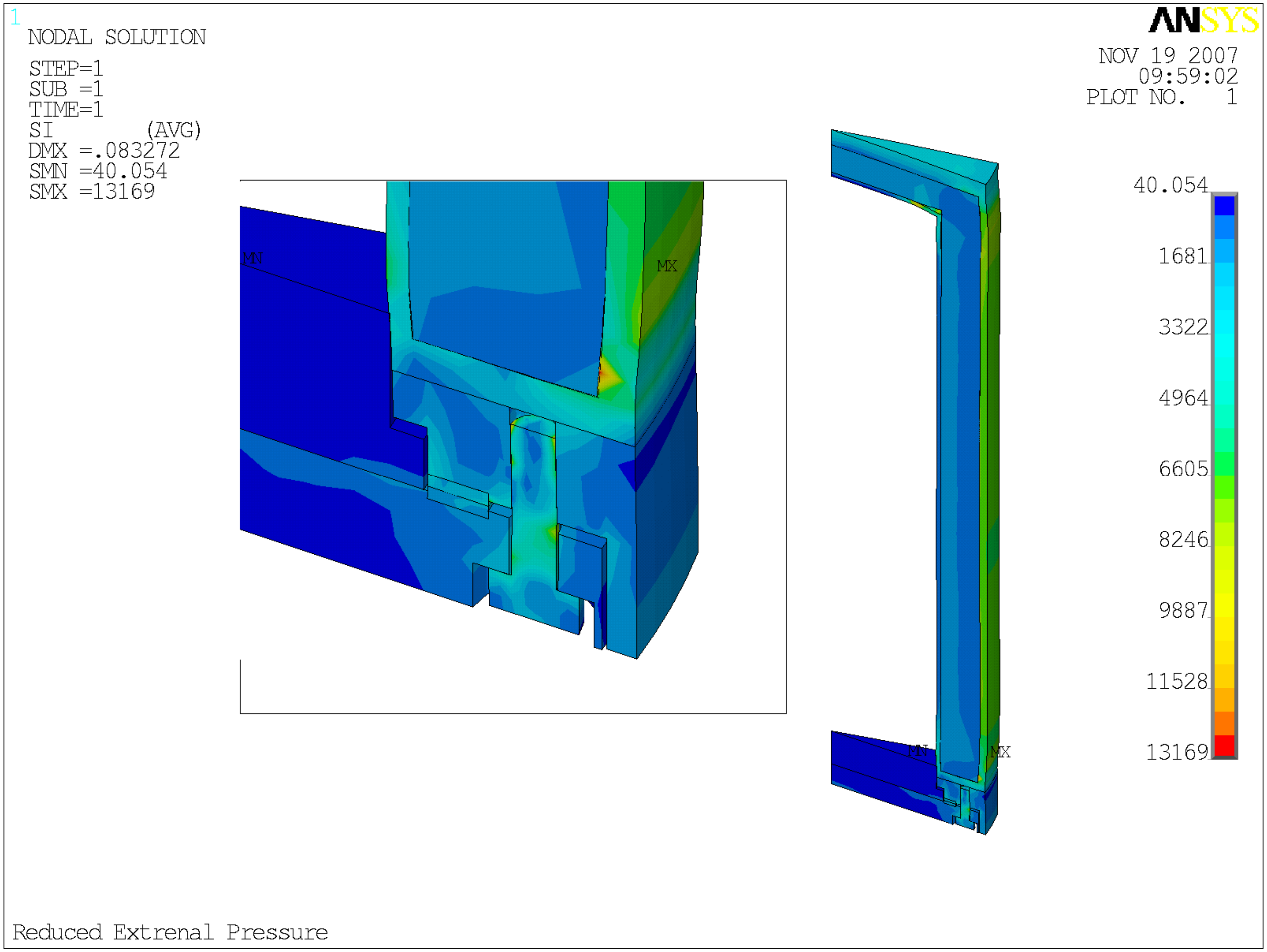

Figure 18

Stress Intensity Contour Plot – Load Step No.6

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

Calc. No. ST-501 (Figures) Rev. 2 Sheet 18 of 24

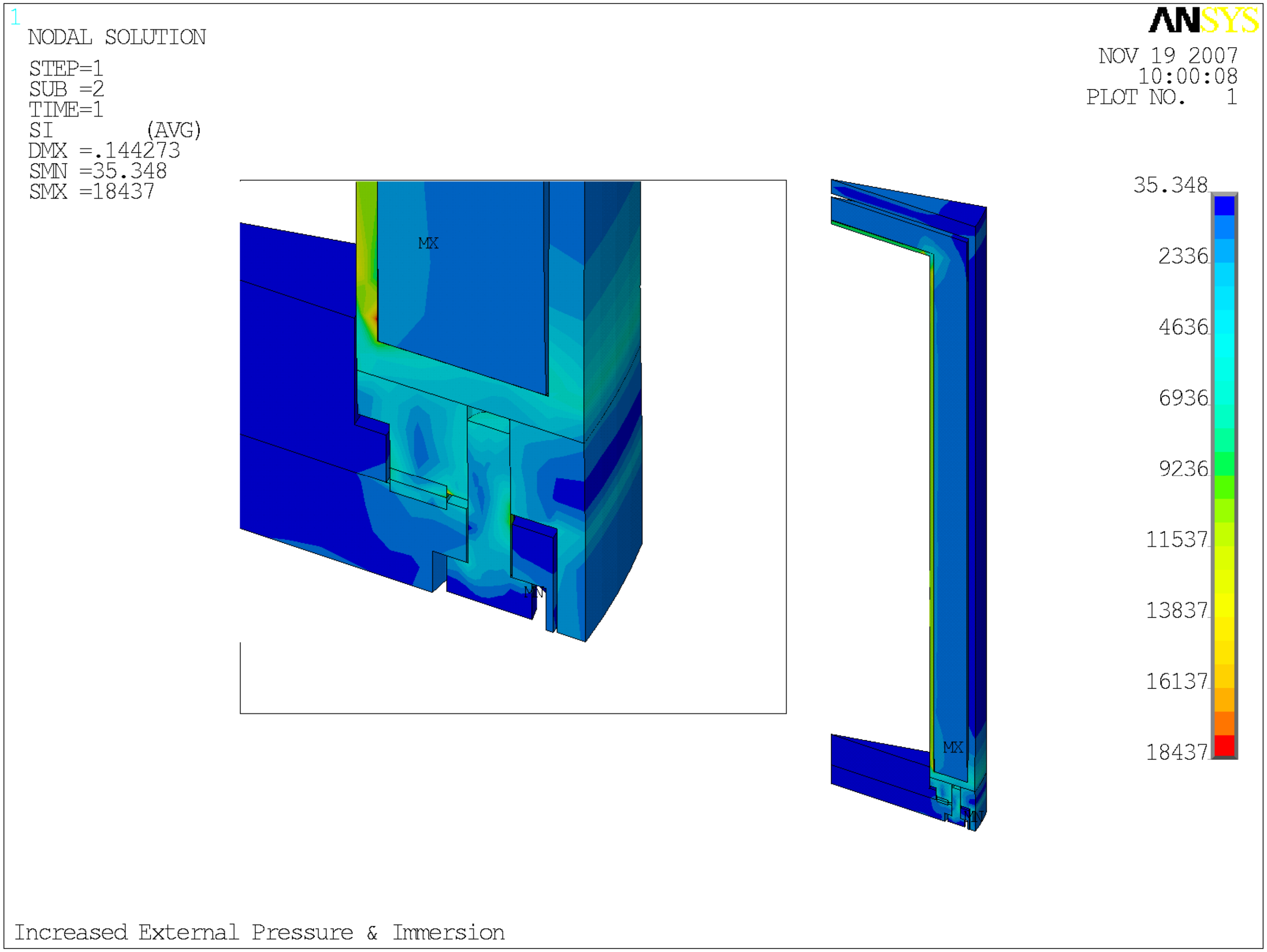

Figure 19
Stress Intensity Contour Plot – Load Step No.7

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

Calc. No. ST-501 (Figures) **Rev.** 2 **Sheet** 19 of 24

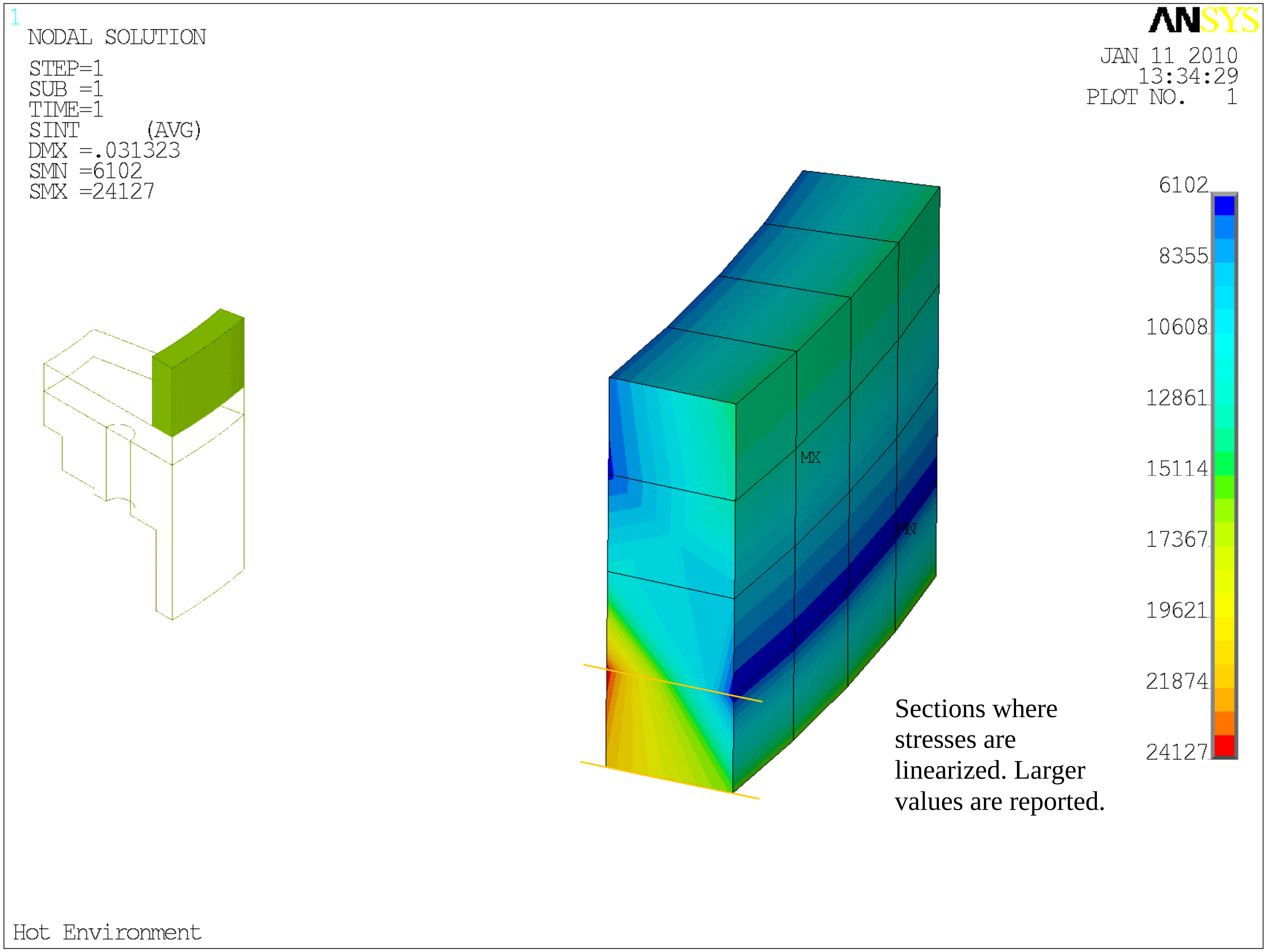

Figure 20

Stress Linearization – Load Step No.1 - Bolting Ring

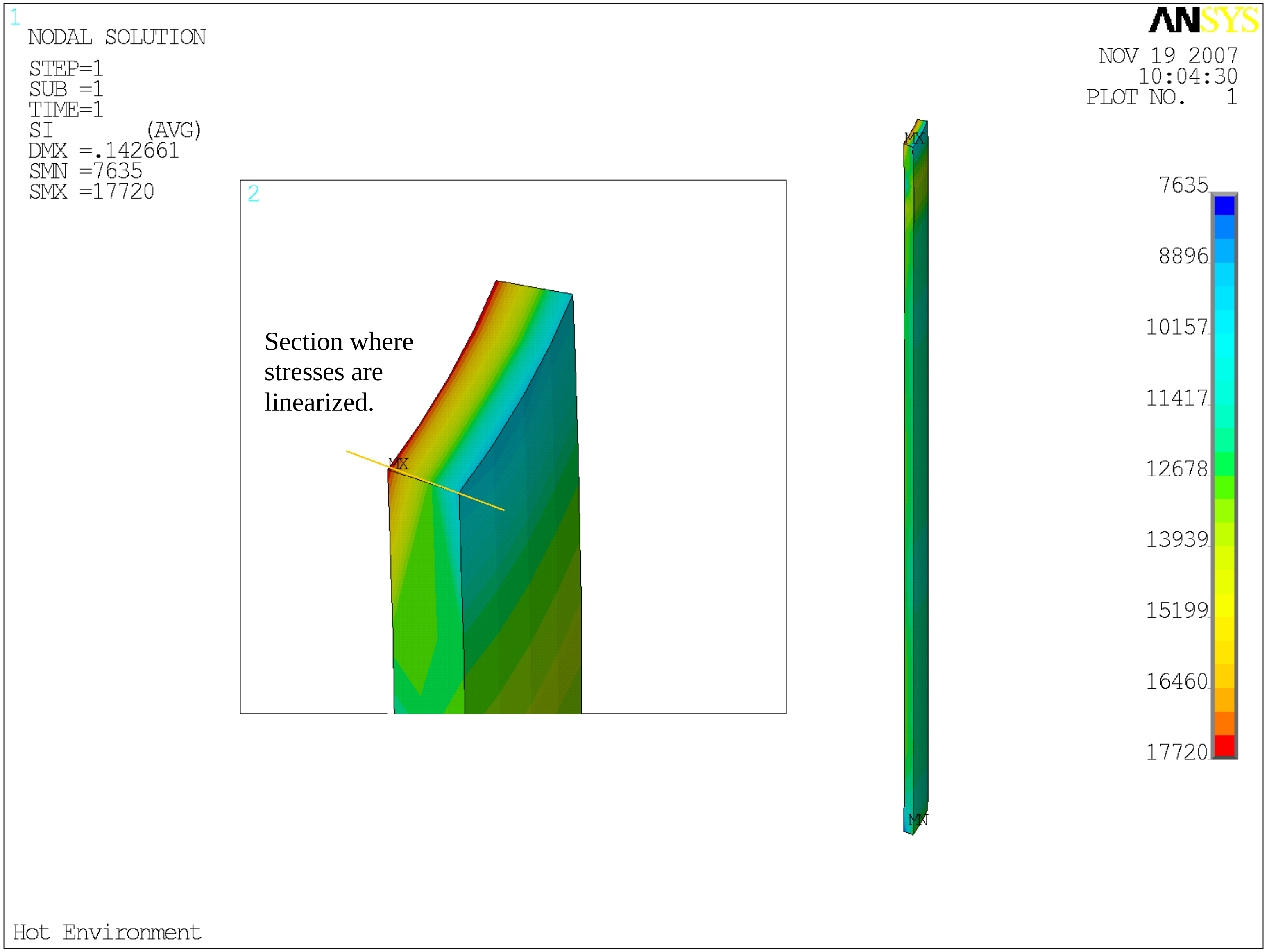

Figure 21

Stress Linearization – Load Step No.1 – Outer Shell

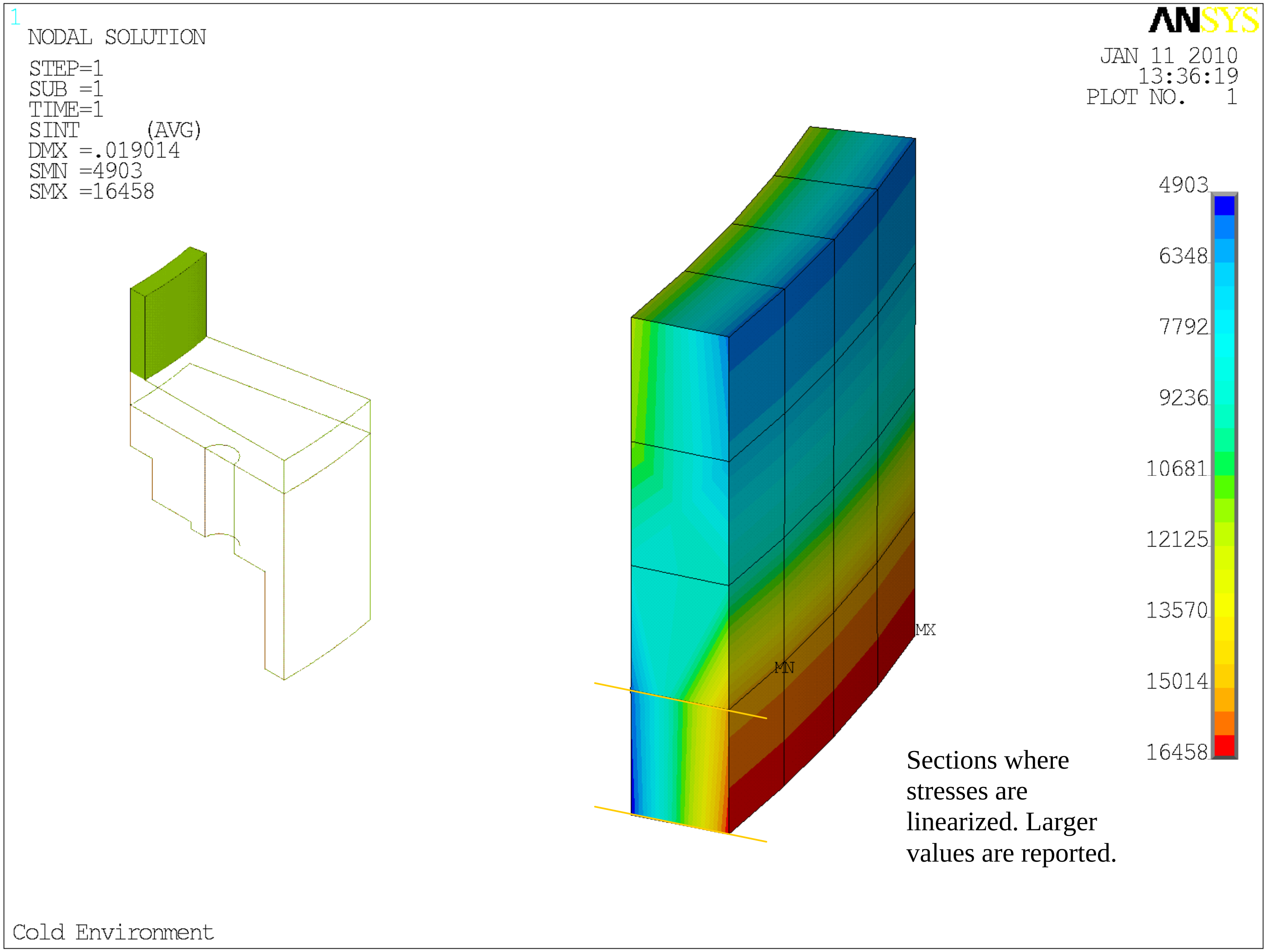

Figure 22

Stress Linearization – Load Step No.2 - Bolting Ring

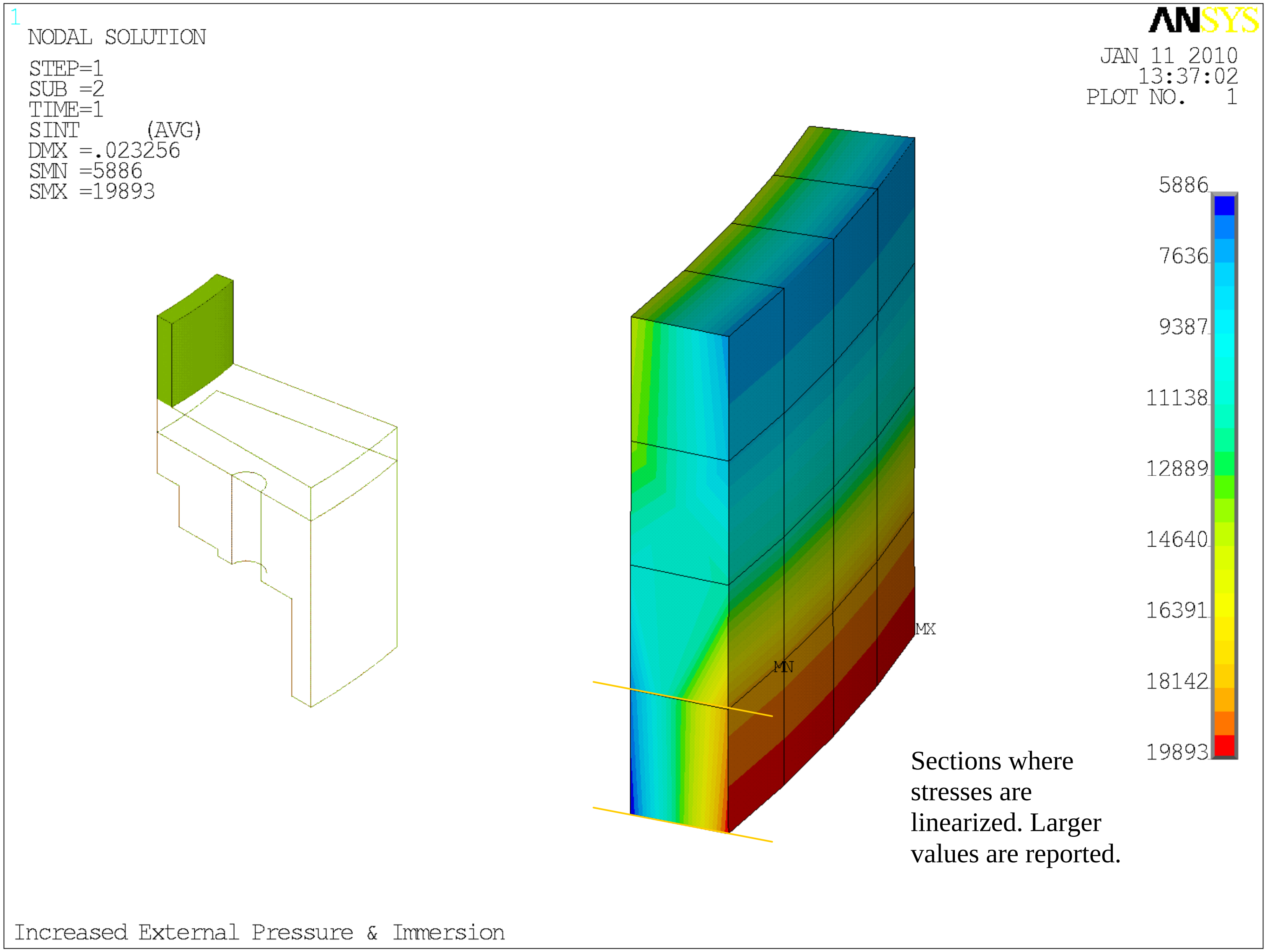

Figure 23

Stress Linearization – Load Step No.7 - Bolting Ring

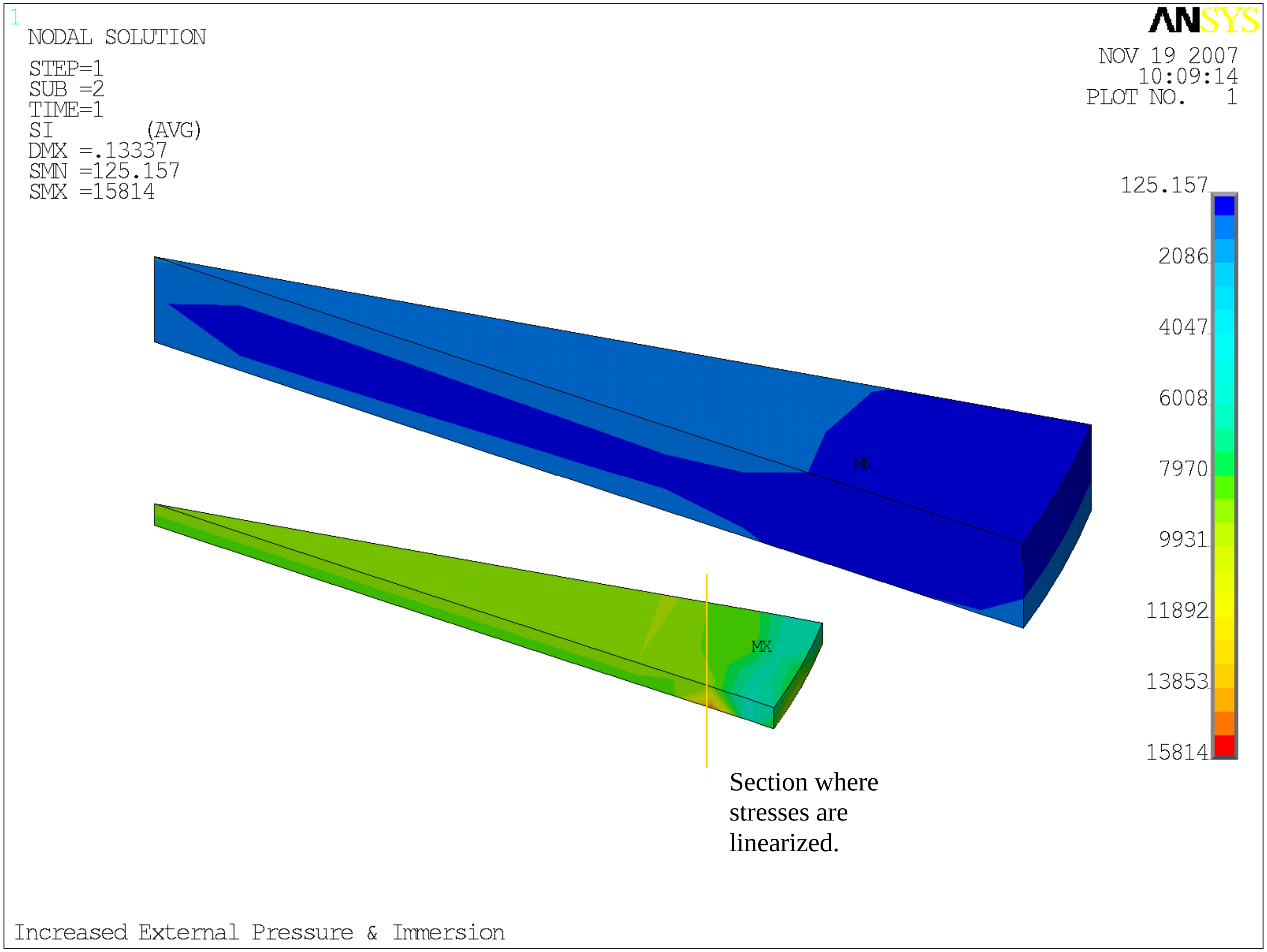

Figure 24

Stress Linearization – Load Step No.7 - Baseplates

Appendix 1

Printout of the ANSYS Model Data

(16 Pages)

ANSYS Finite Element 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: Y:\Thermal\NCT\Stress

 TITLE= Hot Environment

 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            Dec 07, 2007
11:33
 Release 11.0SP1              00222442                 INTEL NT
Version

 Current working directory: Y:\Thermal\NCT\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  0 minutes
 Total CP usage. . . . . . .   0 hours  0 minutes  2.3 seconds

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

Hot Environment

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

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

                                 Available              Used
 Scratch Memory Space. . . .     256.000 mb           3.980 mb (  1.6%)
 Database space  . . . . . .   65535.750 mb           9.866 mb (  0.0%)

 User menu file in use . . .C:\Program Files\ANSYS Inc\v110\ANSYS\gui\en-
us\uidl\UIMENU.GRN
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```
 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          2878          2878
 Elements. . . . . . . . . .    3945          2368          1522

 Element types . . . . . . .      70            35          n.a.
 Real constant sets. . . . .      57            28          n.a.
 Material property sets. . .       3             3          n.a.

 Coupling. . . . . . . . . .      82            30          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. . . . . . . . . . . .    1205
 Constraints on keypoints. . . . . . . . . .       0
 Constraints on lines. . . . . . . . . . . .       0
 Constraints on areas. . . . . . . . . . . .       0

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

 Surface loads on elements . . . . . . . . .     322
 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 . . . . . . . . . . .    2878
Body loads on keypoints . . . . . . . . .       0

Temperatures
   Uniform temperature. . . . . . . . . .   100.000
   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 . . . . . . . .  12 (Cartesian)

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 . . . . . . . .  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 . . . . . . . . . . .     1

Number of substeps . . . . . . . . . .     1
   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. . . . . . . . . . . . . . . .     1
  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
     LABEL   REFERENCE    TOLERANCE  NORM     MINREF
      F       0.000       0.1000E-02   2      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  1       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  1       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  5       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

 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
    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

 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      0.0000

 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

Stress Summary Print-Out

(9 Pages)

ANSYS Analyses Result Summary

APDL file that was used to create this result summary is included in Appendix 3 and is named "summary-nct.in". The quantities marked with (*) are linearized over the cross-section for reporting purpose. The linearization results are included in this appendix.

Hot Environment

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	17334.	14562.	1015.
Shell Extension	24127.(*)	27074.	5368.
Bolting Ring Skirt	3762.	1854.	-294.
Inner Shell	7558.	4183.	748.
Outer Shell	17720.(*)	20987.	3270.
Lid	4699.	2764.	314.
Baseplates	12237.	8747.	1715.
Seal Plates	12223.	11362.	1307.
Bolts	20871.	14539.	4860.

Cold Environment

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	13838.	12719.	391.
Shell Extension	16458.(*)	4873.	-243.
Bolting Ring Skirt	4139.	1727.	-249.
Inner Shell	9713.	468.	-8334.
Outer Shell	1731.	580.	6.
Lid	7346.	5601.	278.
Baseplates	11264.	1627.	7.
Seal Plates	12696.	12995.	1170.
Bolts	9940.	9485.	250.

Normal Hot

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	9392.	8119.	816.
Shell Extension	13574.	15200.	3068.
Bolting Ring Skirt	2581.	1204.	-250.
Inner Shell	4077.	2993.	526.
Outer Shell	9789.	11607.	1820.
Lid	2700.	1779.	294.
Baseplates	6982.	5051.	1257.
Seal Plates	7065.	6763.	859.
Bolts	10976.	8609.	2716.

Normal Cold

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	10658.	9755.	339.
Shell Extension	12421.	3675.	-144.
Bolting Ring Skirt	3388.	1385.	-206.
Inner Shell	7273.	328.	-6221.
Outer Shell	1298.	425.	6.
Lid	5863.	4516.	98.
Baseplates	8131.	1192.	7.
Seal Plates	9810.	10042.	976.
Bolts	7900.	7545.	232.

Maximum Normal Operating

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	1579.	1479.	66.
Shell Extension	501.	338.	99.
Bolting Ring Skirt	608.	71.	-417.
Inner Shell	426.	400.	92.
Outer Shell	273.	233.	49.
Lid	1019.	623.	48.
Baseplates	901.	735.	203.
Seal Plates	2103.	1940.	113.
Bolts	648.	608.	164.

Reduced External Pressure

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	7851.	6749.	763.
Shell Extension	13169.	14777.	3002.
Bolting Ring Skirt	2356.	1101.	-258.
Inner Shell	6420.	7310.	1103.
Outer Shell	9404.	11153.	1750.
Lid	2515.	1684.	150.
Baseplates	11544.	11210.	1958.
Seal Plates	5882.	5443.	645.
Bolts	10962.	7687.	2617.

Increased External Pressure

	Max. S.I.	Max. Sig1	Max. Sig3
Bolting Ring	15915.	14793.	285.
Shell Extension	19893.(*)	5122.	-804.
Bolting Ring Skirt	4213.	1731.	-272.
Inner Shell	11890.	668.	-10268.
Outer Shell	2406.	1547.	40.
Lid	6925.	5084.	31.
Baseplates	15814.(*)	2150.	433.
Seal Plates	13854.	14112.	1011.
Bolts	10044.	9548.	112.

Stress Linearization - Hot Environment - Bolting Ring Shell Extension - Section-1

```
          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =   1519     OUTSIDE NODE =   1612

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

              ** MEMBRANE **
     SX           SY           SZ           SXY          SYZ          SXZ
   6098.        4764.        9476.        29.97        102.2        3809.
     S1           S2           S3           SINT         SEQV
  0.1196E+05   4764.        3620.        8335.        7826.

              ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
 I  -91.68       4990.      0.1686E+05  -124.9       -8.634      -112.1
 C   0.000       0.000       0.000       0.000        0.000       0.000
 O   91.68      -4990.     -0.1686E+05   124.9        8.634       112.1
     S1           S2           S3           SINT         SEQV
 I  0.1686E+05   4993.      -95.49      0.1696E+05  0.1507E+05
 C   0.000       0.000       0.000       0.000       0.000
 O   95.49      -4993.     -0.1686E+05  0.1696E+05  0.1507E+05

              ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
 I   6007.       9755.      0.2634E+05  -94.94        93.53       3697.
 C   6098.       4764.       9476.       29.97        102.2       3809.
 O   6190.      -226.1      -7388.       154.9        110.8       3921.
     S1           S2           S3           SINT         SEQV
 I  0.2699E+05   9757.       5353.      0.2164E+05  0.1981E+05
 C  0.1196E+05   4764.       3620.       8335.       7826.
 O   7245.      -229.8      -8439.      0.1568E+05  0.1359E+05

              ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
 I -0.3981E-01   2.167       7.323     -0.5423E-01 -0.3749E-02 -0.4867E-01
 C  0.9095E-12  0.9095E-12 -0.1819E-11  0.3908E-13  0.8527E-13  0.4547E-12
 O  0.3981E-01  -2.167      -7.323      0.5423E-01  0.3749E-02  0.4867E-01
     S1           S2           S3           SINT         SEQV
 I   7.323       2.168     -0.4146E-01   7.364        6.546
 C  0.1011E-11  0.8842E-12 -0.1895E-11  0.2906E-11  0.2845E-11
 O  0.4146E-01  -2.168      -7.323       7.364        6.546

              ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
 I   6007.       9757.      0.2635E+05  -94.99        93.53       3697.
 C   6098.       4764.       9476.       29.97        102.2       3809.
 O   6190.      -228.2      -7395.       154.9        110.8       3921.
     S1           S2           S3           SINT         SEQV         TEMP
 I  0.2700E+05   9759.       5353.      0.2165E+05  0.1981E+05   176.4
 C  0.1196E+05   4764.       3620.       8335.       7826.
 O   7245.      -231.9      -8446.      0.1569E+05  0.1359E+05   176.4
```

Stress Linearization - Hot Environment - Bolting Ring Shell Extension - Section-2

```
         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1623     OUTSIDE NODE =   1644

 LOAD STEP     1  SUBSTEP=     1
 TIME=    1.0000         LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY           SZ          SXY          SYZ          SXZ
 -3395.       2998.        9417.      -158.9        77.43        2881.
     S1           S2           S3          SINT         SEQV
 0.1003E+05   3002.       -4017.       0.1405E+05  0.1217E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I   56.64        3394.       0.1059E+05  -82.01       -2.311        42.94
C   0.000        0.000        0.000        0.000        0.000        0.000
O  -56.64       -3394.      -0.1059E+05   82.01        2.311       -42.94
     S1           S2           S3          SINT         SEQV
I  0.1059E+05   3396.        54.45       0.1053E+05   9324.
C   0.000        0.000        0.000        0.000        0.000
O  -54.45       -3396.      -0.1059E+05  0.1053E+05   9324.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -3338.        6391.       0.2001E+05  -240.9        75.12        2924.
C  -3395.        2998.        9417.      -158.9        77.43        2881.
O  -3451.       -395.8       -1172.      -76.84        79.75        2838.
     S1           S2           S3          SINT         SEQV
I  0.2037E+05   6397.       -3705.       0.2407E+05  0.2094E+05
C  0.1003E+05   3002.       -4017.       0.1405E+05  0.1217E+05
O   747.2       -393.9      -5373.        6120.        5637.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  0.2460E-01   1.474        4.598      -0.3561E-01 -0.1004E-02  0.1865E-01
C  0.1637E-10  0.2274E-10  0.6548E-10 -0.1990E-12  0.1421E-13   0.000
O -0.2460E-01  -1.474       -4.598       0.3561E-01  0.1004E-02 -0.1865E-01
     S1           S2           S3          SINT         SEQV
I   4.598        1.474       0.2364E-01   4.574        4.049
C  0.6548E-10  0.2274E-10  0.1636E-10  0.4912E-10  0.4626E-10
O -0.2364E-01  -1.474       -4.598        4.574        4.049

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -3338.        6393.       0.2001E+05  -240.9        75.12        2924.
C  -3395.        2998.        9417.      -158.9        77.43        2881.
O  -3451.       -397.2       -1177.      -76.81        79.75        2838.
     S1           S2           S3          SINT         SEQV         TEMP
I  0.2037E+05   6399.       -3705.       0.2408E+05  0.2094E+05   176.3
C  0.1003E+05   3002.       -4017.       0.1405E+05  0.1217E+05
O   744.1       -395.3      -5374.        6118.        5635.        176.3
```

Stress Linearization - Cold Environment - Bolting Ring Shell Extension - Section-1

```
          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =   1609     OUTSIDE NODE =   1504

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

              ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  -1822.      -6677.      -8791.       117.8       29.27       1103.
     S1          S2          S3          SINT        SEQV
  -1649.      -6679.      -8962.       7313.       6481.

              ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I   10.96       2640.       9286.      -64.61      -2.767      -85.85
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O  -10.96      -2640.      -9286.       64.61       2.767       85.85
     S1          S2          S3          SINT        SEQV
 I   9287.       2642.       8.578       9278.       8282.
 C   0.000       0.000       0.000       0.000       0.000
 O  -8.578      -2642.      -9287.       9278.       8282.

              ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -1811.      -4037.       494.8       53.22       26.50       1017.
 C  -1822.      -6677.      -8791.       117.8       29.27       1103.
 O  -1833.      -9317.     -0.1808E+05   182.4       32.03       1189.
     S1          S2          S3          SINT        SEQV
 I   879.8      -2195.      -4038.       4918.       4303.
 C  -1649.      -6679.      -8962.       7313.       6481.
 O  -1742.      -9321.     -0.1816E+05  0.1642E+05  0.1424E+05

              ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  0.4759E-02   1.146       4.032     -0.2805E-01 -0.1202E-02 -0.3728E-01
 C -0.1137E-11 -0.1637E-10 -0.5093E-10  0.3695E-12  0.1776E-13  0.6821E-12
 O -0.4759E-02  -1.146      -4.032      0.2805E-01  0.1202E-02  0.3728E-01
     S1          S2          S3          SINT        SEQV
 I   4.033       1.147      0.3725E-02   4.029       3.596
 C -0.1119E-11 -0.1638E-10 -0.5094E-10  0.4982E-10  0.4421E-10
 O -0.3725E-02  -1.147      -4.033       4.029       3.596

              ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -1811.      -4035.       498.9       53.19       26.50       1017.
 C  -1822.      -6677.      -8791.       117.8       29.27       1103.
 O  -1833.      -9318.     -0.1808E+05   182.5       32.04       1189.
     S1          S2          S3          SINT        SEQV        TEMP
 I   883.3      -2195.      -4037.       4920.       4305.      -2.294
 C  -1649.      -6679.      -8962.       7313.       6481.
 O  -1742.      -9322.     -0.1817E+05  0.1643E+05  0.1424E+05  -2.410
```

Stress Linearization - Cold Environment - Bolting Ring Shell Extension - Section-2

```
         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1658     OUTSIDE NODE =   1679

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000         LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  476.5      -6309.      -8817.       166.6       24.12       915.9
     S1          S2          S3          SINT        SEQV
  570.1      -6313.      -8906.       9477.       8483.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I   1.330       1555.       5832.      -38.16      0.6019       31.43
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O  -1.330      -1555.      -5832.       38.16     -0.6019      -31.43
     S1          S2          S3          SINT        SEQV
 I   5832.       1556.      0.2241       5832.       5231.
 C   0.000       0.000       0.000       0.000       0.000
 O -0.2241      -1556.      -5832.       5832.       5231.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I   477.9      -4754.      -2985.       128.4       24.72       947.3
 C   476.5      -6309.      -8817.       166.6       24.12       915.9
 O   475.2      -7864.     -0.1465E+05   204.7       23.51       884.5
     S1          S2          S3          SINT        SEQV
 I   723.2      -3227.      -4757.       5480.       4898.
 C   570.1      -6313.      -8906.       9477.       8483.
 O   531.8      -7869.     -0.1470E+05  0.1523E+05  0.1321E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  0.5777E-03  0.6752       2.532     -0.1657E-01  0.2614E-03  0.1365E-01
 C -0.3979E-12 -0.1819E-11 -0.1637E-10  0.1137E-12 -0.7105E-14 -0.4547E-12
 O -0.5777E-03 -0.6752      -2.532      0.1657E-01 -0.2614E-03 -0.1365E-01
     S1          S2          S3          SINT        SEQV
 I   2.532      0.6756      0.9731E-04   2.532       2.271
 C -0.3760E-12 -0.1828E-11 -0.1638E-10  0.1601E-10  0.1533E-10
 O -0.9731E-04 -0.6756      -2.532       2.532       2.271

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I   477.9      -4753.      -2982.       128.4       24.72       947.4
 C   476.5      -6309.      -8817.       166.6       24.12       915.9
 O   475.2      -7865.     -0.1465E+05   204.8       23.51       884.5
     S1          S2          S3          SINT        SEQV        TEMP
 I   723.4      -3225.      -4757.       5480.       4897.      -2.294
 C   570.1      -6313.      -8906.       9477.       8483.
 O   531.8      -7870.     -0.1470E+05  0.1523E+05  0.1322E+05  -2.335
```

Stress Linearization - Increased External Pressure - Bolting Ring Shell Extension - Section-1

```
          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =   1609     OUTSIDE NODE =   1504

  LOAD STEP     1  SUBSTEP=     2
  TIME=    1.0000         LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  -2035.      -8386.     -0.1082E+05   155.6       32.49       1270.
     S1          S2          S3          SINT        SEQV
  -1851.      -8390.     -0.1100E+05   9150.       8163.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I   25.03       3103.       0.1090E+05  -75.62      -2.911      -100.7
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O  -25.03      -3103.     -0.1090E+05   75.62       2.911       100.7
     S1          S2          S3          SINT        SEQV
 I  0.1091E+05   3105.       22.24      0.1088E+05   9716.
 C   0.000       0.000       0.000       0.000       0.000
 O  -22.24      -3105.     -0.1091E+05  0.1088E+05   9716.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -2010.      -5283.       83.50       79.95       29.58       1169.
 C  -2035.      -8386.     -0.1082E+05   155.6       32.49       1270.
 O  -2060.     -0.1149E+05 -0.2173E+05   231.2       35.40       1371.
     S1          S2          S3          SINT        SEQV
 I   606.8      -2531.      -5285.       5892.       5106.
 C  -1851.      -8390.     -0.1100E+05   9150.       8163.
 O  -1959.     -0.1149E+05 -0.2182E+05  0.1986E+05  0.1720E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  0.1087E-01   1.347       4.735     -0.3284E-01 -0.1264E-02 -0.4374E-01
 C -0.1364E-11 -0.2001E-10 -0.6366E-10  0.4547E-12  0.2132E-13   0.000
 O -0.1087E-01  -1.347      -4.735      0.3284E-01  0.1264E-02  0.4374E-01
     S1          S2          S3          SINT        SEQV
 I   4.735       1.348      0.9659E-02   4.726       4.219
 C -0.1353E-11 -0.2002E-10 -0.6366E-10  0.6231E-10  0.5539E-10
 O -0.9659E-02  -1.348      -4.735       4.726       4.219

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -2010.      -5281.       88.23       79.91       29.58       1169.
 C  -2035.      -8386.     -0.1082E+05   155.6       32.49       1270.
 O  -2060.     -0.1149E+05 -0.2173E+05   231.2       35.40       1371.
     S1          S2          S3          SINT        SEQV        TEMP
 I   610.8      -2531.      -5283.       5894.       5108.      -20.00
 C  -1851.      -8390.     -0.1100E+05   9150.       8163.
 O  -1959.     -0.1150E+05 -0.2183E+05  0.1987E+05  0.1721E+05  -20.00
```

Stress Linearization - Increased External Pressure - Bolting Ring Shell Extension - Section-2

```
         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1658     OUTSIDE NODE =   1679

 LOAD STEP     1  SUBSTEP=     2
 TIME=    1.0000         LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  555.8      -7979.     -0.1085E+05   209.6       27.09       1060.
     S1          S2          S3          SINT        SEQV
  658.6      -7984.     -0.1095E+05  0.1161E+05  0.1044E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -14.54       1823.       6879.      -45.15      0.6383       36.33
C   0.000       0.000       0.000       0.000       0.000       0.000
O   14.54      -1823.      -6879.       45.15     -0.6383      -36.33
     S1          S2          S3          SINT        SEQV
I   6879.       1825.      -15.83       6895.       6184.
C   0.000       0.000       0.000       0.000       0.000
O   15.83      -1825.      -6879.       6895.       6184.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   541.3      -6155.      -3970.       164.5       27.72       1096.
C   555.8      -7979.     -0.1085E+05   209.6       27.09       1060.
O   570.4      -9802.     -0.1773E+05   254.8       26.45       1023.
     S1          S2          S3          SINT        SEQV
I   797.5      -4222.      -6159.       6957.       6219.
C   658.6      -7984.     -0.1095E+05  0.1161E+05  0.1044E+05
O   633.7      -9808.     -0.1779E+05  0.1842E+05  0.1600E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.6311E-02  0.7918       2.987     -0.1960E-01  0.2771E-03  0.1577E-01
C -0.2274E-12 -0.4547E-11 -0.1819E-10  0.1421E-12 -0.3553E-14   0.000
O  0.6311E-02 -0.7918      -2.987      0.1960E-01 -0.2771E-03 -0.1577E-01
     S1          S2          S3          SINT        SEQV
I   2.987      0.7923     -0.6876E-02   2.994       2.685
C -0.2227E-12 -0.4552E-11 -0.1819E-10  0.1797E-10  0.1624E-10
O  0.6876E-02 -0.7923      -2.987       2.994       2.685

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   541.3      -6154.      -3967.       164.5       27.72       1096.
C   555.8      -7979.     -0.1085E+05   209.6       27.09       1060.
O   570.4      -9803.     -0.1773E+05   254.8       26.45       1023.
     S1          S2          S3          SINT        SEQV        TEMP
I   797.6      -4219.      -6158.       6956.       6218.      -20.00
C   658.6      -7984.     -0.1095E+05  0.1161E+05  0.1044E+05
O   633.7      -9809.     -0.1779E+05  0.1842E+05  0.1600E+05  -20.00
```

Stress Linearization - Increased External Pressure - Baseplates

```
         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   2140     OUTSIDE NODE =   2167

  LOAD STEP     1  SUBSTEP=     2
  TIME=    1.0000         LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  -8339.      -8013.       2022.       22.75      -259.3       842.0
     S1          S2          S3          SINT        SEQV
   2096.      -8014.      -8412.      0.1051E+05  0.1031E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -4609.      -1318.      0.8674E-10   41.44      -0.7123E-09 -0.8470E-11
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O   4609.       1318.     -0.8674E-10  -41.44       0.7123E-09  0.8470E-11
     S1          S2          S3          SINT        SEQV
 I   0.000      -1318.      -4610.       4610.       4112.
 C   0.000       0.000       0.000       0.000       0.000
 O   4610.       1318.       0.000       4610.       4112.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1295E+05  -9331.       2022.       64.18      -259.3       842.0
 C  -8339.      -8013.       2022.       22.75      -259.3       842.0
 O  -3730.      -6694.       2022.      -18.69      -259.3       842.0
     S1          S2          S3          SINT        SEQV
 I   2074.      -9335.     -0.1300E+05  0.1507E+05  0.1362E+05
 C   2096.      -8014.      -8412.      0.1051E+05  0.1031E+05
 O   2150.      -3851.      -6702.       8852.       7826.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I  -2.001     -0.5724      0.2501E-11  0.1799E-01 -0.3411E-12  0.1137E-11
 C   0.000     -0.8185E-11  0.2501E-11  0.1421E-13 -0.1705E-12  0.1364E-11
 O   2.001      0.5724      0.000      -0.1799E-01  0.2274E-12  0.7958E-12
     S1          S2          S3          SINT        SEQV
 I   0.000     -0.5721      -2.002       2.002       1.786
 C  0.3103E-11 -0.5993E-12 -0.8188E-11  0.1129E-10  0.9970E-11
 O   2.002      0.5721       0.000       2.002       1.786

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1295E+05  -9331.       2022.       64.20      -259.3       842.0
 C  -8339.      -8013.       2022.       22.75      -259.3       842.0
 O  -3728.      -6694.       2022.      -18.71      -259.3       842.0
     S1          S2          S3          SINT        SEQV        TEMP
 I   2074.      -9335.     -0.1300E+05  0.1507E+05  0.1362E+05  -20.00
 C   2096.      -8014.      -8412.      0.1051E+05  0.1031E+05
 O   2150.      -3849.      -6702.       8852.       7825.      -20.00
```

Appendix 3

Electronic Data on CDROM

(1 CDROM)

```
 Volume in drive F is ST-501 Rev2 App3
 Volume Serial Number is FFC5-CA46

 Directory of F:\

01/14/2010  05:04 PM           824,906 file.cdb
01/11/2010  01:43 PM        11,730,944 file.db
11/16/2007  12:06 PM           211,002 file.s01
11/16/2007  12:09 PM           211,002 file.s02
11/16/2007  12:12 PM           211,002 file.s03
11/16/2007  12:14 PM           211,002 file.s04
11/16/2007  12:51 PM           113,150 file.s05
11/16/2007  04:08 PM           211,002 file.s06
11/16/2007  12:59 PM           163,396 file.s07
11/16/2007  12:06 PM         5,570,560 ls1.rst
01/11/2010  01:29 PM             3,125 ls1BringSec-1.lis
01/11/2010  01:30 PM             3,125 ls1BringSec-2.lis
11/16/2007  04:38 PM             3,125 ls1Outer-shell.lis
11/16/2007  04:10 PM           243,321 ls1post.out
11/16/2007  12:10 PM         5,439,488 ls2.rst
01/11/2010  01:40 PM             3,125 ls2BringSec-1.lis
01/11/2010  01:40 PM             3,125 ls2BringSec-2.lis
11/16/2007  04:10 PM           240,152 ls2post.out
11/16/2007  12:13 PM         5,570,560 ls3.rst
11/16/2007  04:10 PM           240,152 ls3post.out
11/16/2007  12:15 PM         5,439,488 ls4.rst
11/16/2007  04:10 PM           240,152 ls4post.out
11/16/2007  12:50 PM        15,204,352 ls5.rst
11/16/2007  04:10 PM           240,152 ls5post.out
11/16/2007  04:09 PM         5,636,096 ls6.rst
11/16/2007  04:30 PM           238,440 ls6post.out
11/16/2007  12:58 PM         8,060,928 ls7.rst
11/16/2007  05:12 PM             3,125 ls7Baseplates.lis
01/11/2010  01:42 PM             3,125 ls7BringSec-1.lis
01/11/2010  01:43 PM             3,125 ls7BringSec-2.lis
11/16/2007  04:11 PM           241,009 ls7post.out
12/07/2007  11:32 AM            32,821 Model.txt
01/14/2010  01:56 PM            18,819 summary-nct.in
01/14/2010  01:56 PM             5,390 summary.out
              34 File(s)     66,574,286 bytes

     Total Files Listed:
              34 File(s)     66,574,286 bytes
               0 Dir(s)               0 bytes free
```

Reference 2-17 (ST-557) is a proprietary document. It is provided on the media marked "PROPRIETARY".

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 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.
12. Energy*Solutions* Document ST-609, Rev.0, 3-60B Cask Inelastic Analyses of the Bolting Ring Skirt under HAC Drop Loadings.

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)		
ASTM A240 Type 304L		(1)	(1)	(1)	(1)	(1)
	-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
ASTM A240 Gr. 45 & ASTM A182 Gr. F45		(1)	(1)	(1)	(1)	(1)
	-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
ASTM A354 Gr. BD (Lid Bolts)		(1)	(1)	(1)	(1)	(1)
	-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
ASTM B29 Lead		(2)			(2)	(2)
	-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(3)
	Mem. + Bending Stress	25,050(2)	37,350(2)	90,000(3)
Hypothetical Accident Conditions	Membrane Stress	40,080(4)	59,760(4)	105,000(5)
	Mem. + Bending Stress	60,120(4)	87,000(4)	150,000(5)

Notes:

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

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

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

(4) Established from Regulatory Guide 7.6 (Reference 7), Position 6.

(5) 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.

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 bolting ring, the lid, and the bolts. The shell components of the cask - the inner and outer shells, and the baseplates have been represented in the finite element model by SOLSH190 elements.

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,

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

$p_{lid} = 150 \times 9{,}500/(\pi \times 17.375^2) = 1{,}502.5$ 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 = 150×1.107 = 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. Figure 10 shows the displacement boundary conditions used to represent the impact limiter reaction.

Figures 11 through 13 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 = 1.889×10^6 lb (Table 3 and Figure 66 of Reference 4)

Hot Conditions = 1.636×10^6 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.

Rigid body acceleration = $1.1 \times 4 \times 1.889 \times 10^6/72{,}400 = 114.8$ » 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 14.

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:

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

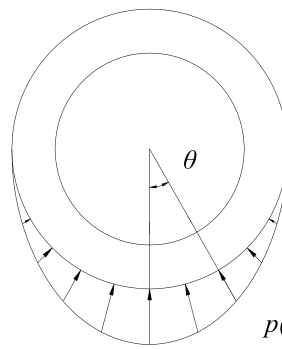
$$F_v = \int_{-\pi/2}^{\pi/2} p_0 \cdot Cos\theta \cdot r \cdot d\theta \cdot Cos\theta$$

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

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

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

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



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

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

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

$$= 0$$

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,

$p_0 = (2 \times 4.344 \times 10^6)/(\pi \times 25.5 \times 20.28) = 5{,}348$ 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,

$p_0 = (2 \times 4.344 \times 10^6)/(\pi \times 25.5 \times 21.355) = 5{,}078$ 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 = 120×1.107 = 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 15 through 17 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3. Figure 18 shows the displacement boundary conditions used to prevent the rigid body motion of the cask.

Figures 19 through 21 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)

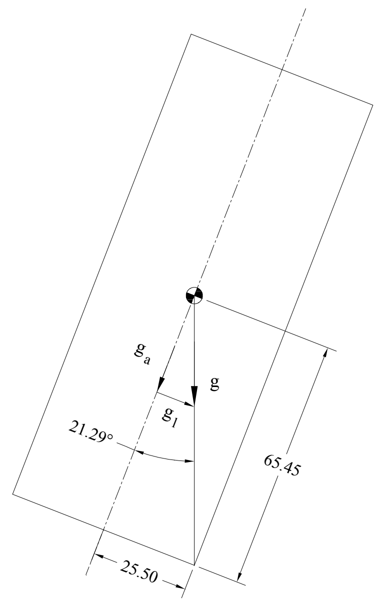
Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the corner drop test the 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 22.

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,

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

Lateral acceleration,

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

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:

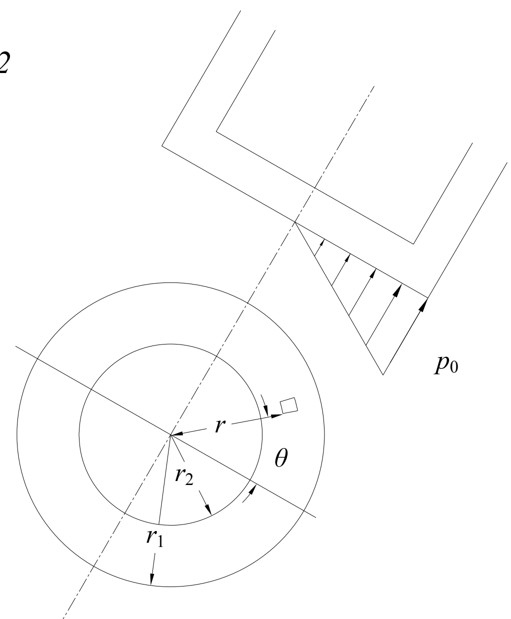
$$p(r,\theta) = p_0 \cdot \frac{r \cdot Cos\theta}{r_2} \cdot r \cdot d\theta \cdot dr \qquad -\pi/2 \le \theta \le \pi/2$$

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,

$$R_a = (80{,}000 - 3{,}800) \times 65.22 = 4.97 \times 10^6 \text{ lb}$$

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 23 through 25 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3. Figure 26 shows the displacement boundary conditions used to prevent the rigid body motion of the cask.

Figures 27 through 29 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 7½º 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 1.09, 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 30 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 $= 1.338\times10^6$ lb (Table 2 and Figure 16 of Reference 4)

Hot Conditions $= 1.103\times10^6$ 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:

$$= 2\times1.338\times10^6/76{,}200 = 35.12 \text{ g}$$

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:

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

Impact limiter Inertia

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

Payload Inertia

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

Cask Body Inertia

Cask Body Acceleration = 0.3025×166 = 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 31 through 33 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 34 through 36 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:

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

Impact Limiter Reactions

Top impact limiter pressure amplitude,

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

Bottom impact limiter pressure amplitude,

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

Payload Inertia

Payload inertia pressure amplitude,

$p_0 = 0.2354\times380.5 = 89.57$ psi

Cask Body Inertia

Cask Body Acceleration = 0.2354×132.84 = 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 37 through 39 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 40 through 42 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 = 303,280 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:

= 2×335,300/76,200 = 8.8 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:

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

Impact Limiter Reactions

Lid pressure magnitude,

$p_{\text{lid}} = 0.4292\times17{,}409 = 7{,}471.9$ psi

Wall pressure amplitude,

$p_0 = 0.4292\times4{,}769 = 2{,}046.9$ psi

Impact Limiter Inertia

Baseplate pressure magnitude,

$p_{I.L.}$ = 0.4292×159.7 = 68.54 psi

Wall pressure amplitude,

p_0 = 0.4292×112.93 = 48.47 psi

Payload Inertia

Lid pressure magnitude

p_{lid} = 0.4292×653.3 = 280.4 psi

Wall pressure amplitude,

p_0 = 0.4292×80.6 = 34.6 psi

Cask Body Inertia

Cask Body Axial Acceleration = 0.4292×72.2 = 30.99 g

Cask Body Lateral Acceleration = 0.4292×28.14 = 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 43 through 45 show the cask body temperature profile and the pressure distributions used in the FEM for Load Cases 1 through 3.

Figures 46 through 48 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. It has been shown in Reference 12 by inelastic analyses that the bolting ring skirt that is subjected to plastic deformation during the side drop and corner drop tests cannot impart enough loading to the closure bolts which could compromise the sealing of the cask. It has been shown in Reference 12 by inelastic analyses that the bolting ring skirt that is subjected to plastic deformation during the side drop and corner drop tests cannot impart enough loading to the closure bolts which could compromise the sealing of the cask. 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 3. The printout of the important data from the program is included with this document in electronic form as Appendix 3.

10.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Summary Print-Out of the ANSYS Results and Stress Linearization

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	$P_m + P_b$	87,000	32,803	2.65
Bolting Ring Shell Extension	P_m	59,760	32,727	1.83
	$P_m + P_b$	87,000	32,727	2.66
Bolting Ring Skirt	P_m	59,760	30,895	1.93
	$P_m + P_b$	87,000	30,895	2.82
Inner Shell	P_m	59,760	17,652	3.39
	$P_m + P_b$	87,000	17,652	4.93
Outer Shell	P_m	40,080	31,224	1.28
	$P_m + P_b$	60,120	31,224	1.93
Lid	P_m	40,080	30,311	1.32
	$P_m + P_b$	60,120	30,311	1.98
Base Plates	P_m	40,080	14,924	2.69
	$P_m + P_b$	60,120	14,924	4.03
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	34,141	2.55
Bolting Ring Shell Extension	P_m	59,760	52,643	1.14
	$P_m + P_b$	87,000	52,643	1.65
Bolting Ring Skirt	P_m	59,760	21,036	2.84
	$P_m + P_b$	59,760	21,036	2.84
Inner Shell	P_m	59,760	38,207	1.56
	$P_m + P_b$	87,000	38,207	2.28
Outer Shell	P_m	40,080	24,782	1.62
	$P_m + P_b$	60,120	24,782	2.43
Lid	P_m	40,080	33,945	1.18
	$P_m + P_b$	60,120	33,945	1.77
Base Plates	P_m	40,080	24,661	1.63
	$P_m + P_b$	60,120	24,661	2.44
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	35,803	2.43
Bolting Ring Shell Extension	P_m	59,760	43,220[3]	1.38
	$P_m + P_b$	87,000	61,390[3]	1.42
Bolting Ring Skirt	P_m	59,760	19,504	3.06
	$P_m + P_b$	59,760	19,504	3.06
Inner Shell	P_m	59,760	43,700	1.37
	$P_m + P_b$	87,000	43,700	1.99
Outer Shell	P_m	40,080	24,687	1.62
	$P_m + P_b$	60,120	24,687	2.44
Lid	P_m	40,080	35,126	1.14
	$P_m + P_b$	60,120	35,126	1.71
Base Plates	P_m	40,080	27,593	1.45
	$P_m + P_b$	60,120	27,593	2.18
Seal Plates	$P_m + P_b$	60,120	4,971[4]	12.09
Bolts	P_m	105,000	7,442	14.11
	$P_m + P_b$	150,000	7,442	20.16

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(4) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- (3)	-
Bolting Ring Shell Extension	P_m	59,760	45,723	1.31
	$P_m + P_b$	87,000	45,723	1.90
Bolting Ring Skirt	P_m	59,760	- (3)	-
	$P_m + P_b$	59,760	- (3)	-
Inner Shell	P_m	59,760	36,420(4)	1.64
	$P_m + P_b$	87,000	44,210(4)	1.97
Outer Shell	P_m	40,080	33,800(4)	1.19
	$P_m + P_b$	60,120	44,150(4)	1.36
Lid	P_m	40,080	26,280(4)	1.53
	$P_m + P_b$	60,120	40,680(4)	1.48
Base Plates	P_m	40,080	31,876	1.26
	$P_m + P_b$	60,120	31,876	1.89
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.

(4) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- [3]	-
Bolting Ring Shell Extension	P_m	59,760	48,347	1.24
	$P_m + P_b$	87,000	48,347	1.80
Bolting Ring Skirt	P_m	59,760	- [3]	-
	$P_m + P_b$	59,760	- [3]	-
Inner Shell	P_m	59,760	37,560[4]	1.59
	$P_m + P_b$	87,000	42,230[4]	2.06
Outer Shell	P_m	40,080	35,230	1.14
	$P_m + P_b$	60,120	47,480	1.27
Lid	P_m	40,080	27,640[4]	1.45
	$P_m + P_b$	60,120	42,430[4]	1.42
Base Plates	P_m	40,080	26,210[4]	1.53
	$P_m + P_b$	60,120	50,500[4]	1.19
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.

(4) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(5) The maximum stress intensity in the seal plates is 106,333 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- [3]	-
Bolting Ring Shell Extension	P_m	59,760	52,021	1.15
	$P_m + P_b$	87,000	52,021	1.67
Bolting Ring Skirt	P_m	59,760	- [3]	-
	$P_m + P_b$	59,760	- [3]	-
Inner Shell	P_m	59,760	43,486	1.37
	$P_m + P_b$	87,000	43,486	2.00
Outer Shell	P_m	40,080	36,710	1.09
	$P_m + P_b$	60,120	49,360	1.22
Lid	P_m	40,080	27,360[4]	1.46
	$P_m + P_b$	60,120	41,870[4]	1.44
Base Plates	P_m	40,080	29,690	1.35
	$P_m + P_b$	60,120	53,950	1.11
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.

(4) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(5) The maximum stress intensity in the seal plates is 103,855 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- [3]	-
Bolting Ring Shell Extension	P_L[4]	87,000	47,453	1.83
	$P_L + P_b$	87,000	47,453	1.83
Bolting Ring Skirt	P_m	59,760	- [3]	-
	$P_m + P_b$	59,760	- [3]	-
Inner Shell	P_m	59,760	35,571	1.68
	$P_m + P_b$	87,000	35,571	2.45
Outer Shell	P_m	40,080	31,297	1.28
	$P_m + P_b$	60,120	31,297	1.92
Lid	P_m	40,080	27,550[5]	1.45
	$P_m + P_b$	60,120	42,817[6]	1.40
Base Plates	P_m	40,080	10,203	3.93
	$P_m + P_b$	60,120	10,203	5.89
Seal Plates	$P_m + P_b$	60,120	34,765[7]	1.73
Bolts	P_m	105,000	27,642	3.80
	$P_m + P_b$	150,000	27,642	5.43

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.

(4) The stresses in the inner shell 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.

(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

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

(7) The maximum stress intensity in the seal plates is 185,156 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- [3]	-
Bolting Ring Shell Extension	P_L[4]	87000	54,420[5]	1.60
	$P_L + P_b$	87,000	71,870[5]	1.21
Bolting Ring Skirt	P_m	59,760	- [3]	-
	$P_m + P_b$	59,760	- [3]	-
Inner Shell	P_L[4]	87,000	50,708	1.72
	$P_L + P_b$	87,000	50,708	1.72
Outer Shell	P_m	40,080	25,953	1.54
	$P_m + P_b$	60,120	25,953	2.32
Lid	P_m	40,080	26,240[5]	1.53
	$P_m + P_b$	60,120	42,737[6]	1.41
Base Plates	P_m	40,080	16,204	2.47
	$P_m + P_b$	60,120	16,204	3.71
Seal Plates	$P_m + P_b$	60,120	37,369[7]	1.61
Bolts	P_m	105,000	25,437	4.13
	$P_m + P_b$	150,000	25,437	5.90

Notes:
(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.
(4) The stresses in the inner shell 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.
(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.
(6) The reported stress here is the maximum principal stress (tensile).
(7) The maximum stress intensity in the seal plates is 173,418 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	87,000	- [3]	-
Bolting Ring Shell Extension	P_L[4]	87,000	58,930[5]	1.48
	$P_L + P_b$	87,000	80,750[5]	1.08
Bolting Ring Skirt	P_m	59,760	- [3]	-
	$P_m + P_b$	59,760	- [3]	-
Inner Shell	P_L[4]	87,000	55,586	1.57
	$P_L + P_b$	87,000	55,586	1.57
Outer Shell	P_m	40,080	26,917	1.49
	$P_m + P_b$	60,120	26,917	2.23
Lid	P_m	40,080	26,050[5]	1.54
	$P_m + P_b$	60,120	42,578[6]	1.41
Base Plates	P_m	40,080	21,989	1.82
	$P_m + P_b$	60,120	21,989	2.73
Seal Plates	$P_m + P_b$	60,120	37,834[7]	1.59
Bolts	P_m	105,000	26,079	4.03
	$P_m + P_b$	150,000	26,079	5.75

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.

(4) The stresses in the inner shell 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.

(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

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

(7) The maximum stress intensity in the seal plates is 169,949 psi. However, the plates are under compression and the maximum stress intensity may be categorized as bearing stress. The maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	14,825	2.52
Bolting Ring Shell Extension	P_m	24,900	9,477(3)	2.63
	$P_m + P_b$	37,350	18,420(3)	2.03
Bolting Ring Skirt	P_m	24,900	7,951	3.13
	$P_m + P_b$	37,350	7,951	4.70
Inner Shell	P_m	24,900	4,244	5.87
	$P_m + P_b$	37,350	4,244	8.80
Outer Shell	P_m	16,700	13,760(3)	1.21
	$P_m + P_b$	25,050	15,030(3)	1.67
Lid	P_m	16,700	10,138	1.65
	$P_m + P_b$	25,050	10,138	2.47
Base Plates	P_m	16,700	10,182	1.64
	$P_m + P_b$	25,050	10,182	2.46
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

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	$P_m + P_b$	37,350	13,602	2.75
Bolting Ring Shell Extension	P_m	24,900	15,120[3]	1.65
	$P_m + P_b$	37,350	24,100[3]	1.55
Bolting Ring Skirt	P_m	24,900	5,097	4.89
	$P_m + P_b$	37,350	5,097	7.33
Inner Shell	P_m	24,900	17,043	1.46
	$P_m + P_b$	37,350	17,043	2.19
Outer Shell	P_m	16,700	7,562	2.21
	$P_m + P_b$	25,050	7,562	3.31
Lid	P_m	16,700	10,320	1.62
	$P_m + P_b$	25,050	10,320	2.43
Base Plates	P_m	16,700	12,590	1.33
	$P_m + P_b$	25,050	12,590	1.99
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

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	$P_m + P_b$	37,350	16,002	2.33
Bolting Ring Shell Extension	P_m	24,900	18,410[3]	1.35
	$P_m + P_b$	37,350	30,400[3]	1.23
Bolting Ring Skirt	P_m	24,900	4,370	5.70
	$P_m + P_b$	37,350	4,370	8.55
Inner Shell	P_m	24,900	21,183	1.18
	$P_m + P_b$	37,350	21,183	1.76
Outer Shell	P_m	16,700	7,467	2.24
	$P_m + P_b$	25,050	7,467	3.35
Lid	P_m	16,700	11,125	1.50
	$P_m + P_b$	25,050	11,125	2.25
Base Plates	P_m	16,700	10,210[3]	1.64
	$P_m + P_b$	25,050	17,040[3]	1.47
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

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

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	$P_m + P_b$	37,350	21,532	1.73
Bolting Ring Shell Extension	P_m	24,900	12,960[3]	1.92
	$P_m + P_b$	37,350	21,690[3]	1.72
Bolting Ring Skirt	P_L[4]	37,350	28,830[3]	1.30
	$P_L + P_b$	37,350	33,680[3]	1.11
Inner Shell	P_m	24,900	16,467	1.51
	$P_m + P_b$	37,350	16,467	2.27
Outer Shell	P_m	16,700	9,915	1.68
	$P_m + P_b$	25,050	20,060	1.25
Lid	P_m	16,700	7,439	2.24
	$P_m + P_b$	25,050	7,439	3.37
Base Plates	P_m	16,700	12,645	1.32
	$P_m + P_b$	25,050	12,645	1.98
Seal Plates	$P_m + P_b$	25,050	5,415[5]	4.63
Bolts	P_m	60,000	24,328	2.47
	$P_m + P_b$	90,000	24,328	3.70

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(4) The stresses in the bolting skirt 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.

(5) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	22,153	1.69
Bolting Ring Shell Extension	P_m	24,900	18,408	1.35
	$P_m + P_b$	37,350	18,408	2.03
Bolting Ring Skirt	P_L[4]	37,350	29,629[3]	1.26
	$P_L + P_b$	37,350	34,600[3]	1.08
Inner Shell	P_m	24,900	13,051	1.91
	$P_m + P_b$	37,350	13,051	2.86
Outer Shell	P_m	16,700	14,816	1.13
	$P_m + P_b$	25,050	14,816	1.69
Lid	P_m	16,700	10,147	1.65
	$P_m + P_b$	25,050	10,147	2.47
Base Plates	P_m	16,700	10,280[3]	1.62
	$P_m + P_b$	25,050	16,960[3]	1.48
Seal Plates	$P_m + P_b$	25,050	9,851[5]	2.54
Bolts	P_m	60,000	21,543	2.79
	$P_m + P_b$	90,000	21,543	4.18

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(4) The stresses in the bolting skirt 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.

(5) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	22,443	1.66
Bolting Ring Shell Extension	P_m	24,900	12,450[3]	2.00
	$P_m + P_b$	37,350	19,130[3]	1.95
Bolting Ring Skirt	P_L[4]	37,350	30,040[3]	1.24
	$P_L + P_b$	37,350	35,100[3]	1.06
Inner Shell	P_m	24,900	16,167	1.54
	$P_m + P_b$	37,350	16,167	2.31
Outer Shell	P_m	16,700	12,440[3]	1.34
	$P_m + P_b$	25,050	16,800[3]	1.49
Lid	P_m	16,700	11,179	1.49
	$P_m + P_b$	25,050	11,179	2.24
Base Plates	P_m	16,700	14,290[3]	1.17
	$P_m + P_b$	25,050	22,330[3]	1.12
Seal Plates	$P_m + P_b$	25,050	10,399[5]	2.41
Bolts	P_m	60,000	19,916	3.01
	$P_m + P_b$	90,000	19,916	4.52

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.

(4) The stresses in the bolting skirt 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.

(5) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	- [3]	-
Bolting Ring Shell Extension	P_L[4]	37,350	26,202	1.43
	$P_L + P_b$	37,350	26,202	1.43
Bolting Ring Skirt	P_m	24,900	- [3]	-
	$P_m + P_b$	37,350	- [3]	-
Inner Shell	P_m	24,900	14,534	1.71
	$P_m + P_b$	37,350	14,534	2.57
Outer Shell	P_m	16,700	8,248	2.02
	$P_m + P_b$	25,050	16,270	1.54
Lid	P_m	16,700	9,966[5]	1.68
	$P_m + P_b$	25,050	18,347[6]	1.37
Base Plates	P_m	16,700	10,896	1.53
	$P_m + P_b$	25,050	10,896	2.30
Seal Plates	$P_m + P_b$	25,050	12,606[7]	1.99
Bolts	P_m	60,000	18,243	3.29
	$P_m + P_b$	90,000	18,243	4.93

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.
(4) The stresses in the inner shell 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.
(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.
(6) The reported stress here is the maximum principle stress (tensile).
(7) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	- [3]	-
Bolting Ring Shell Extension	P_L[4]	37,350	27,610[5]	1.35
	$P_L + P_b$	37,350	30,010[5]	1.24
	Q	74,700	41,030[5]	1.82
Bolting Ring Skirt	P_m	24,900	- [3]	-
	$P_m + P_b$	37,350	- [3]	-
Inner Shell	P_L	37,350	27,569	1.35
	$P_L + P_b$	37,350	27,569	1.35
Outer Shell	P_m	16,700	12,611	1.32
	$P_m + P_b$	25,050	12,611	1.99
Lid	P_m	16,700	9,943[5]	1.68
	$P_m + P_b$	25,050	18,344[6]	1.37
Base Plates	P_m	16,700	11,656	1.43
	$P_m + P_b$	25,050	11,656	2.15
Seal Plates	$P_m + P_b$	25,050	18,934[7]	1.32
Bolts	P_m	60,000	14,026	4.28
	$P_m + P_b$	90,000	14,026	6.42

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.
(4) The stresses in the inner shell 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. Stresses at the discontinuity are classified as Q and away from it are classified as $P_L + P_b$.
(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.
(6) The reported stress here is the maximum principle stress (tensile).
(7) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

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	$P_m + P_b$	37,350	- [3]	-
Bolting Ring Shell Extension	P_L[4]	37,350	31,460[5]	1.19
	$P_L + P_b$	37,350	34,720[5]	1.08
	Q	74,700	49,500[5]	1.51
Bolting Ring Skirt	P_m	24,900	- [3]	-
	$P_m + P_b$	37,350	- [3]	-
Inner Shell	P_L	37,350	32,217	1.16
	$P_L + P_b$	37,350	32,217	1.16
Outer Shell	P_m	16,700	9,999[5]	1.67
	$P_m + P_b$	25,050	14,390[5]	1.74
Lid	P_m	16,700	9,940[5]	1.68
	$P_m + P_b$	25,050	18,199[6]	1.38
Base Plates	P_m	16,700	10,880[5]	1.53
	$P_m + P_b$	25,050	18,310[5]	1.37
Seal Plates	$P_m + P_b$	25,050	19,456[7]	1.29
Bolts	P_m	60,000	13,725	4.37
	$P_m + P_b$	90,000	13,725	6.56

Notes:

(1) Unless otherwise indicated in this column, the maximum stress intensity 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 bolting ring skirt experiences inelastic deformation. Analyses of Reference 12 have been used to qualify these components.
(4) The stresses in the inner shell 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. Stresses at the discontinuity are classified as Q and away from it are classified as $P_L + P_b$.
(5) The stress intensity has been linearized over the cross-section. Print-out of the stress linearization is included in Appendix 2.
(6) The reported stress here is the maximum principle stress (tensile).
(7) 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 maximum principal stress (tensile) has been used for the seal plate's qualification.

Figures

(48 Pages)

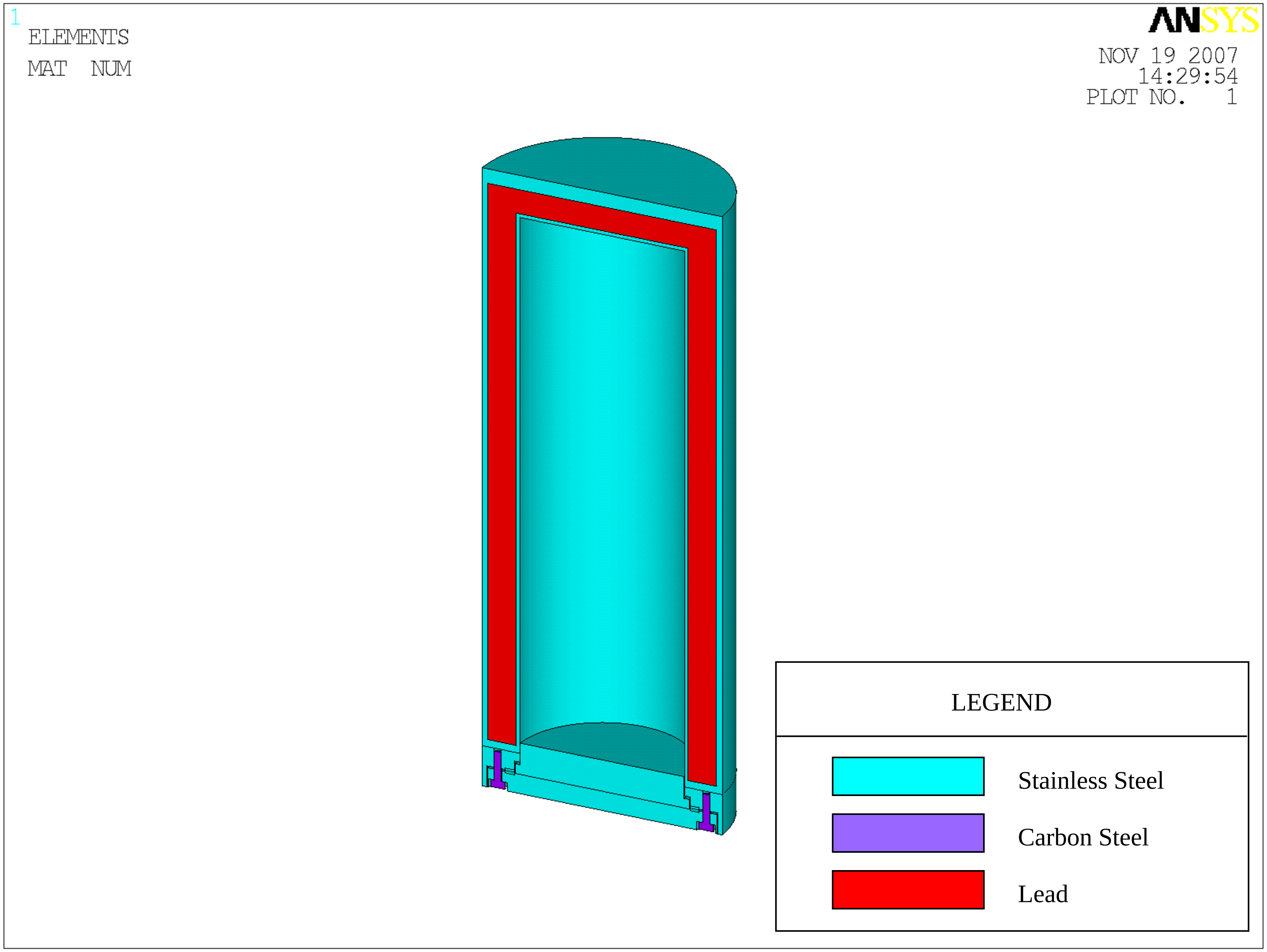


Figure 1

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

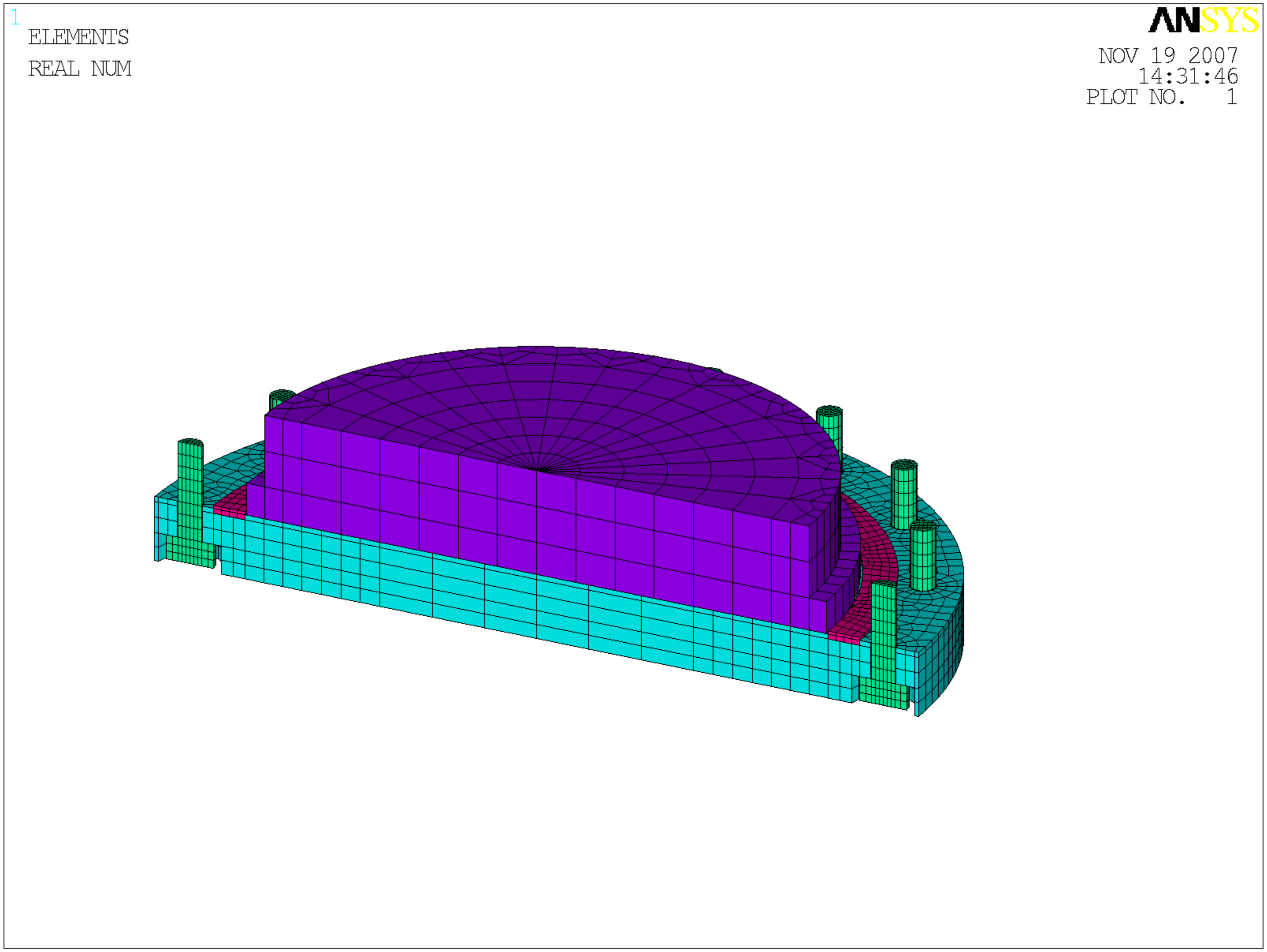


Figure 2
Finite Element Model of the Lid, Seal Plate and Bolts

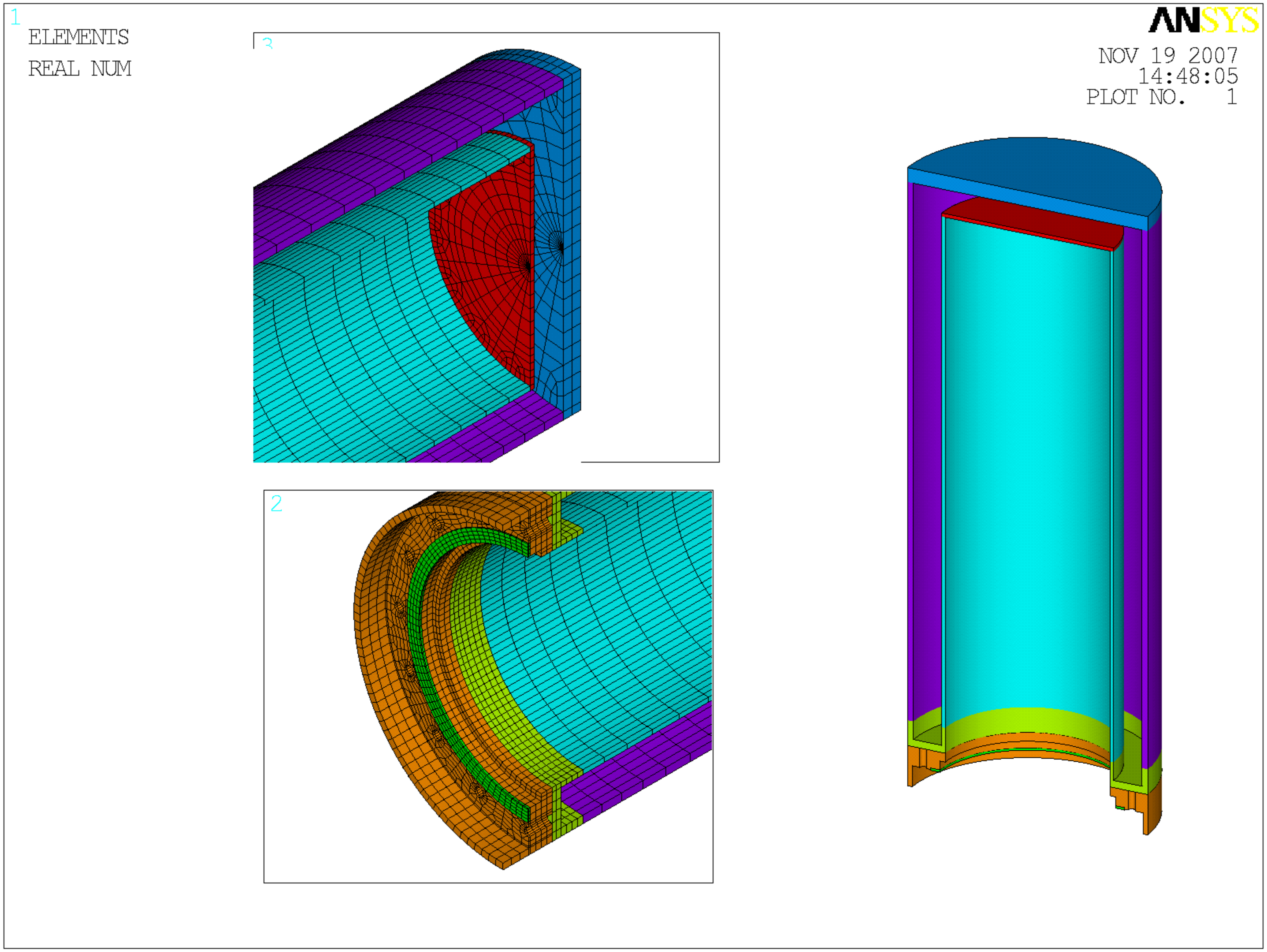


Figure 3
Finite Element Model of the cask Body without the Lead

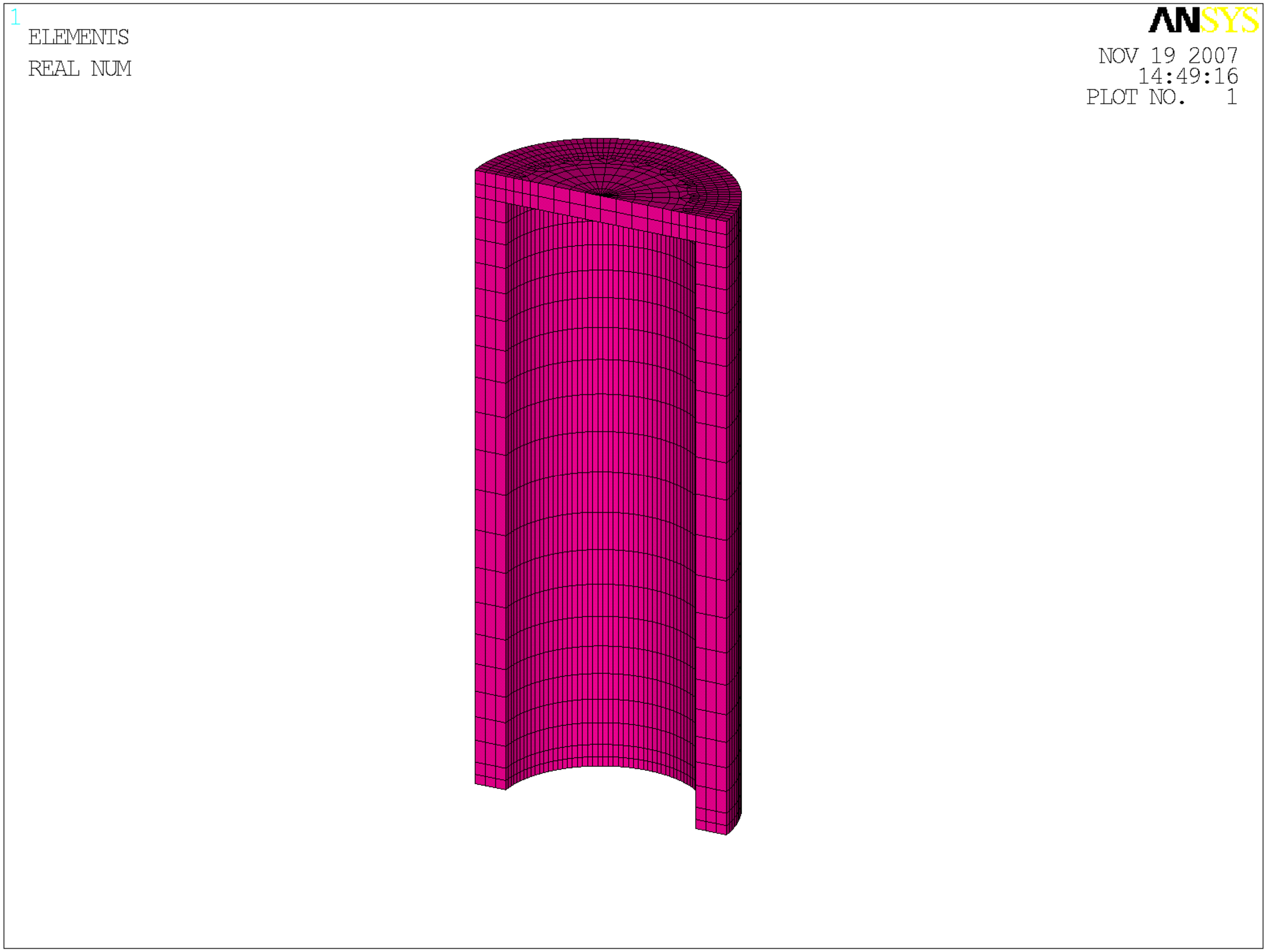


Figure 4

Finite Element Model of the Lead

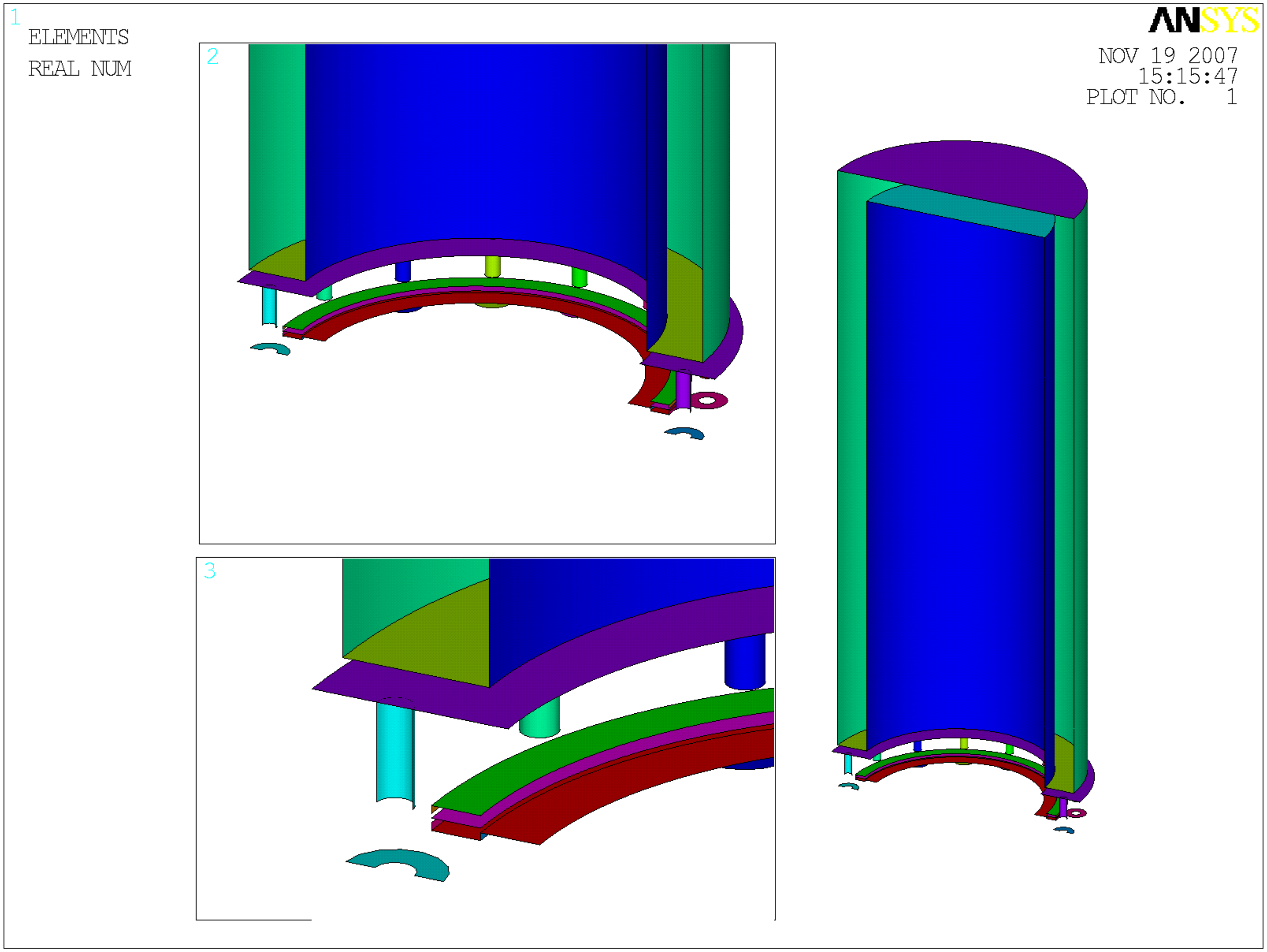


Figure 5

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

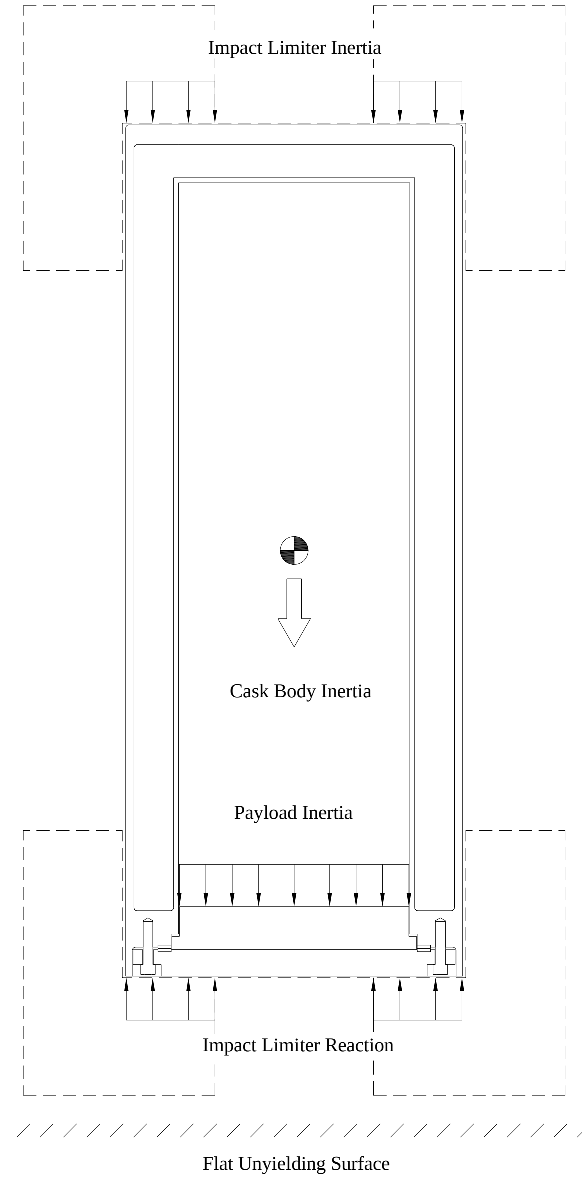


Figure 6

Load Distribution on the Model during End Drop

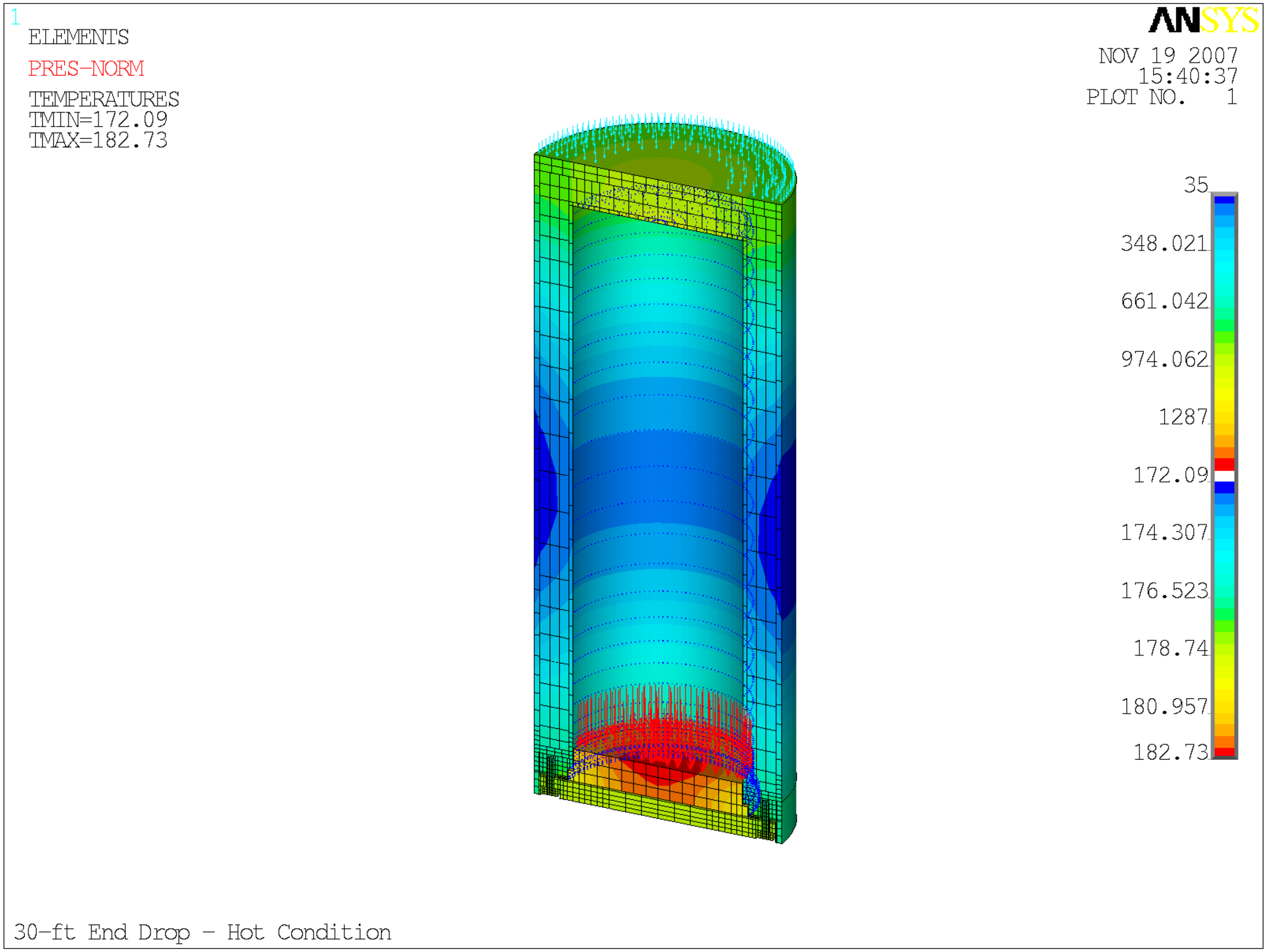


Figure 7

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

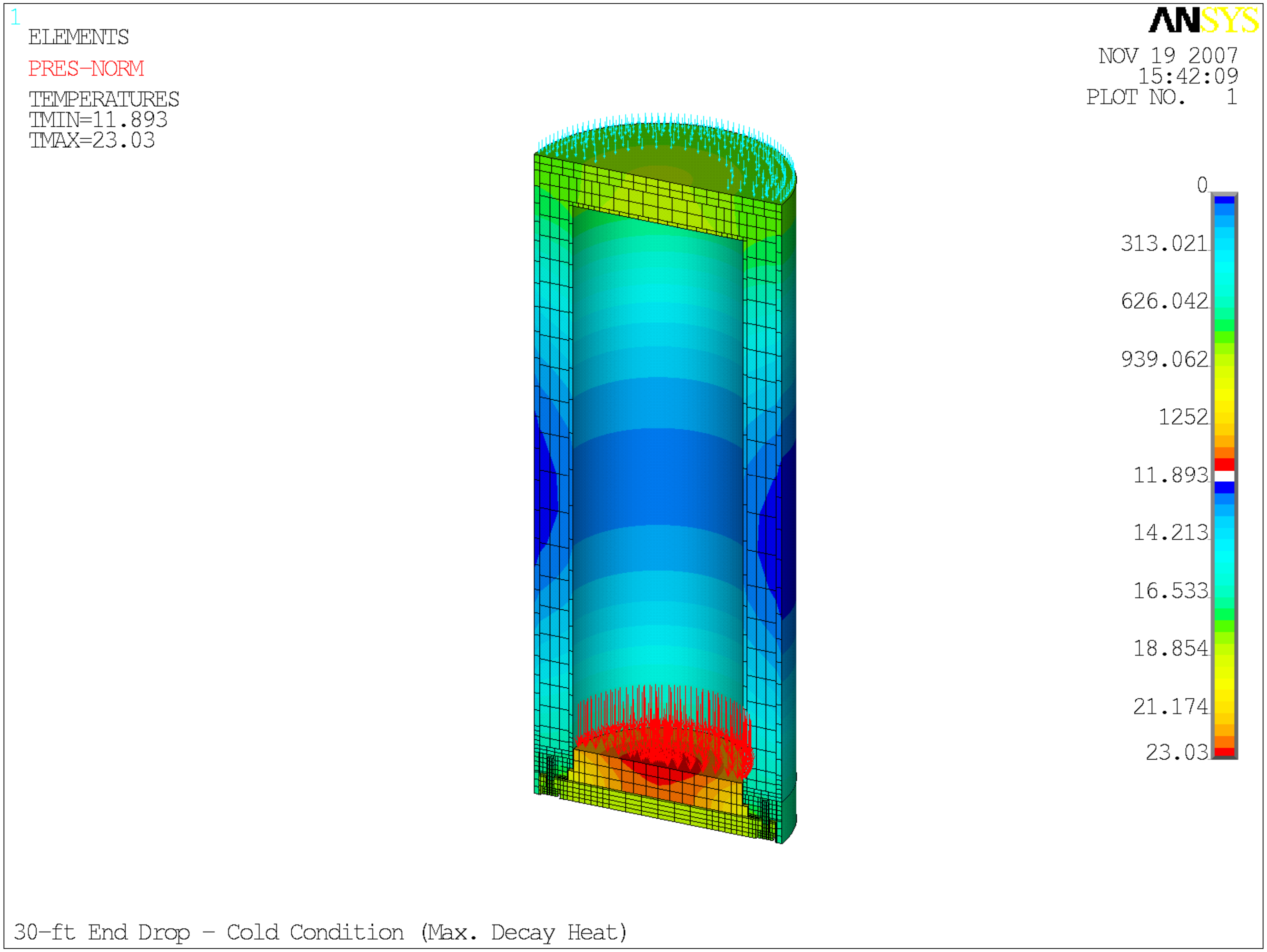


Figure 8

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

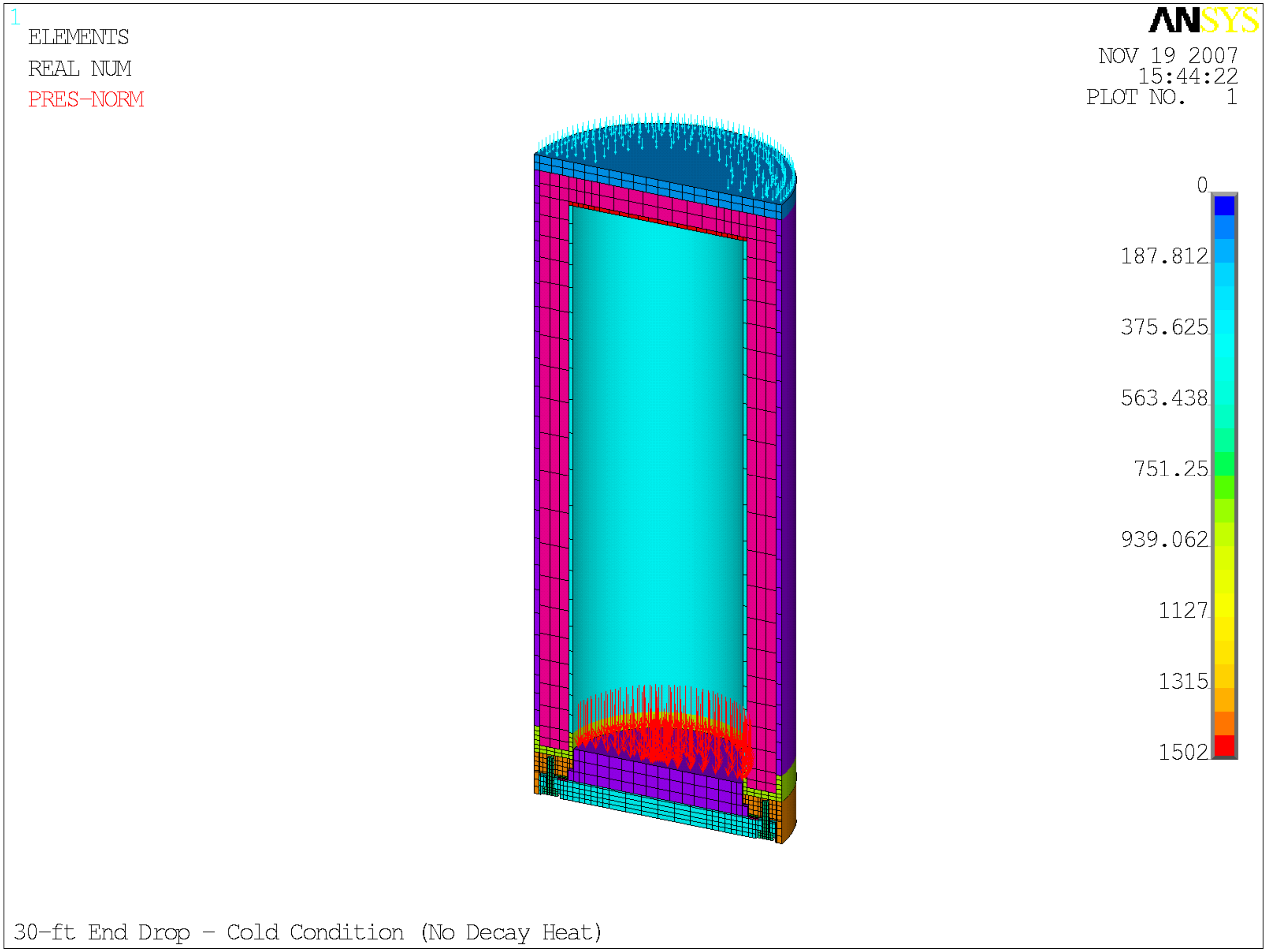


Figure 9

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

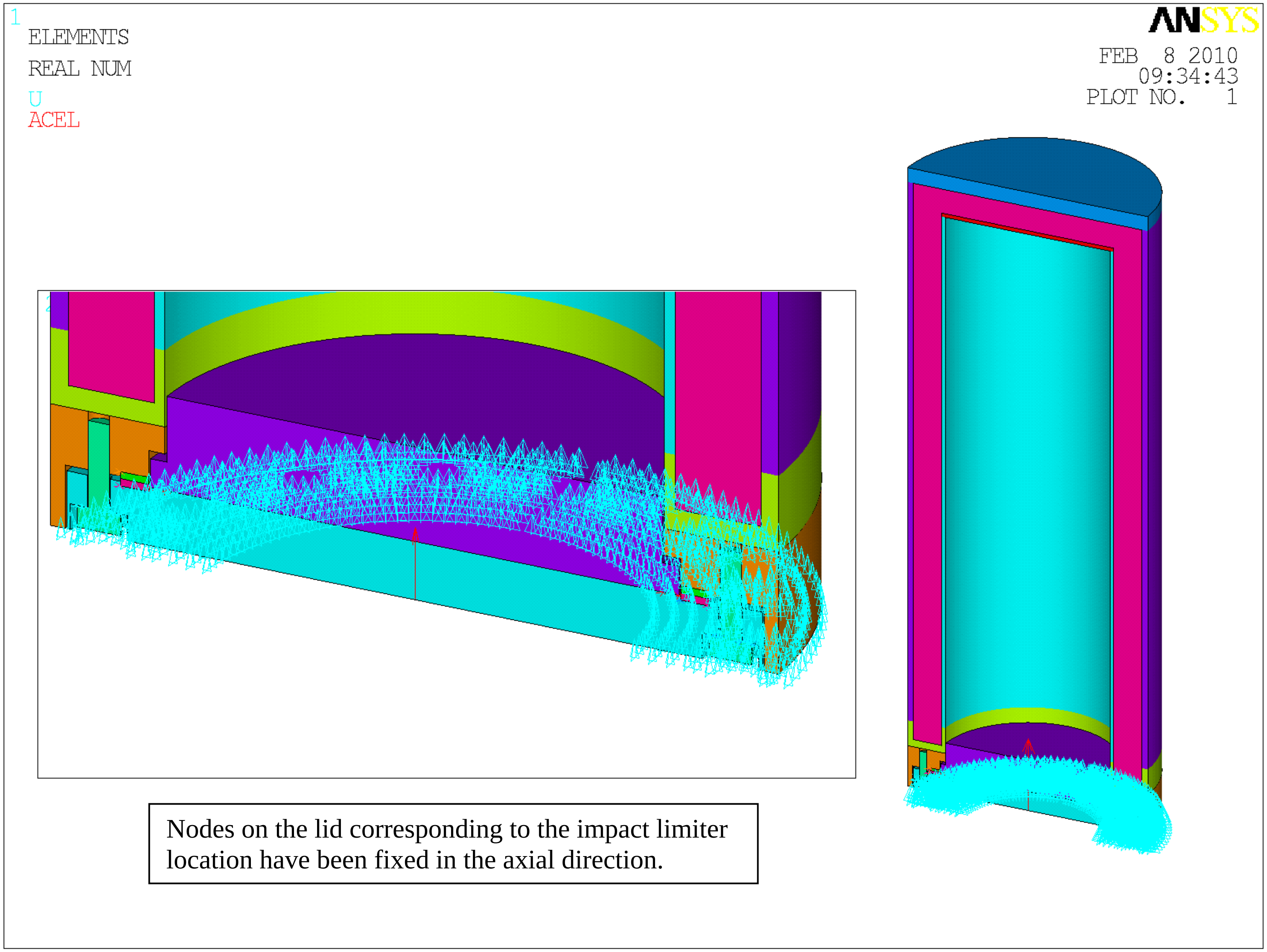


Figure 10

Stress Intensity Plot – 30-ft End Drop – Displacement Boundary Conditions Used to Represent the Impact Limiter

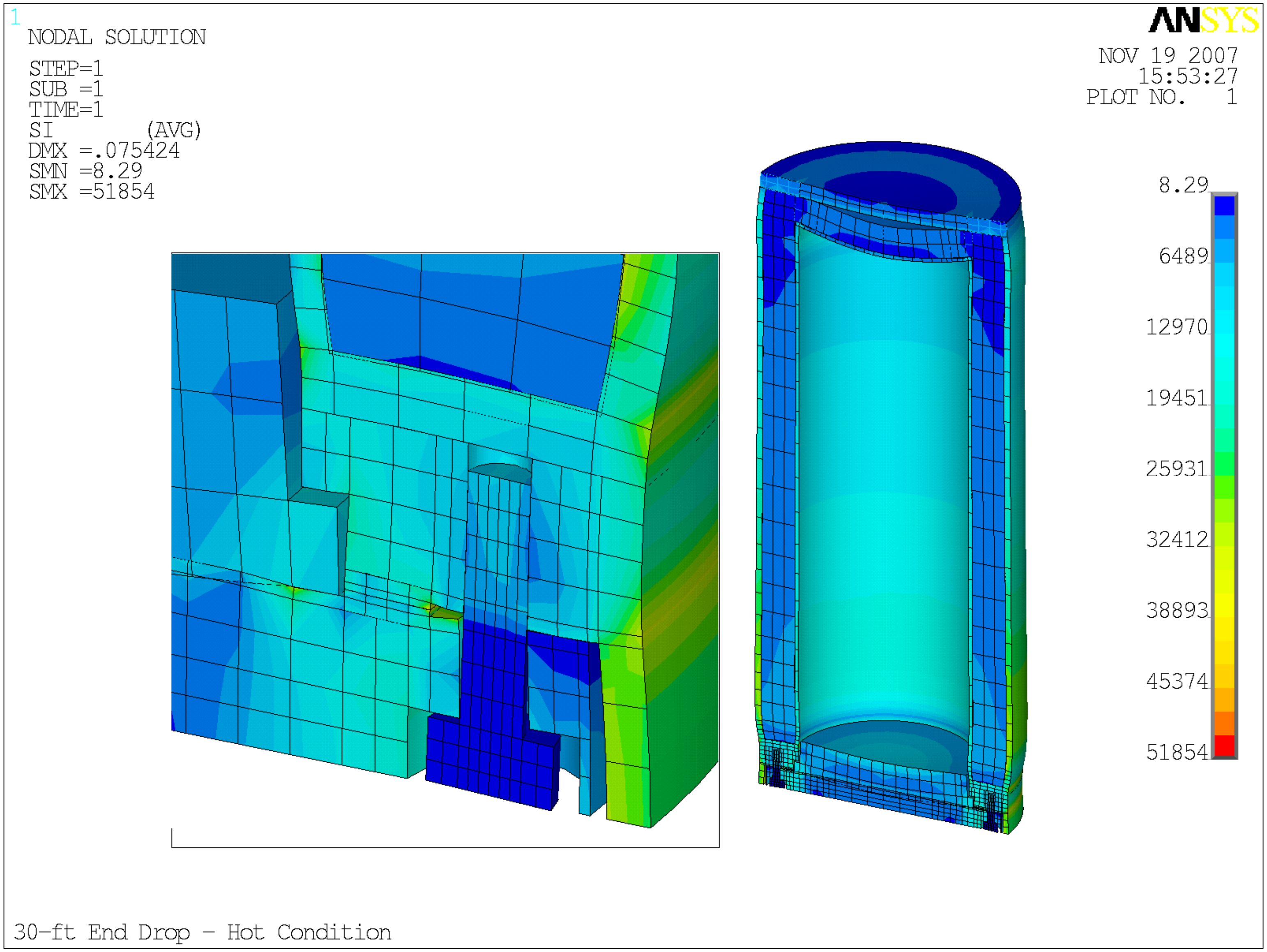


Figure 11

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

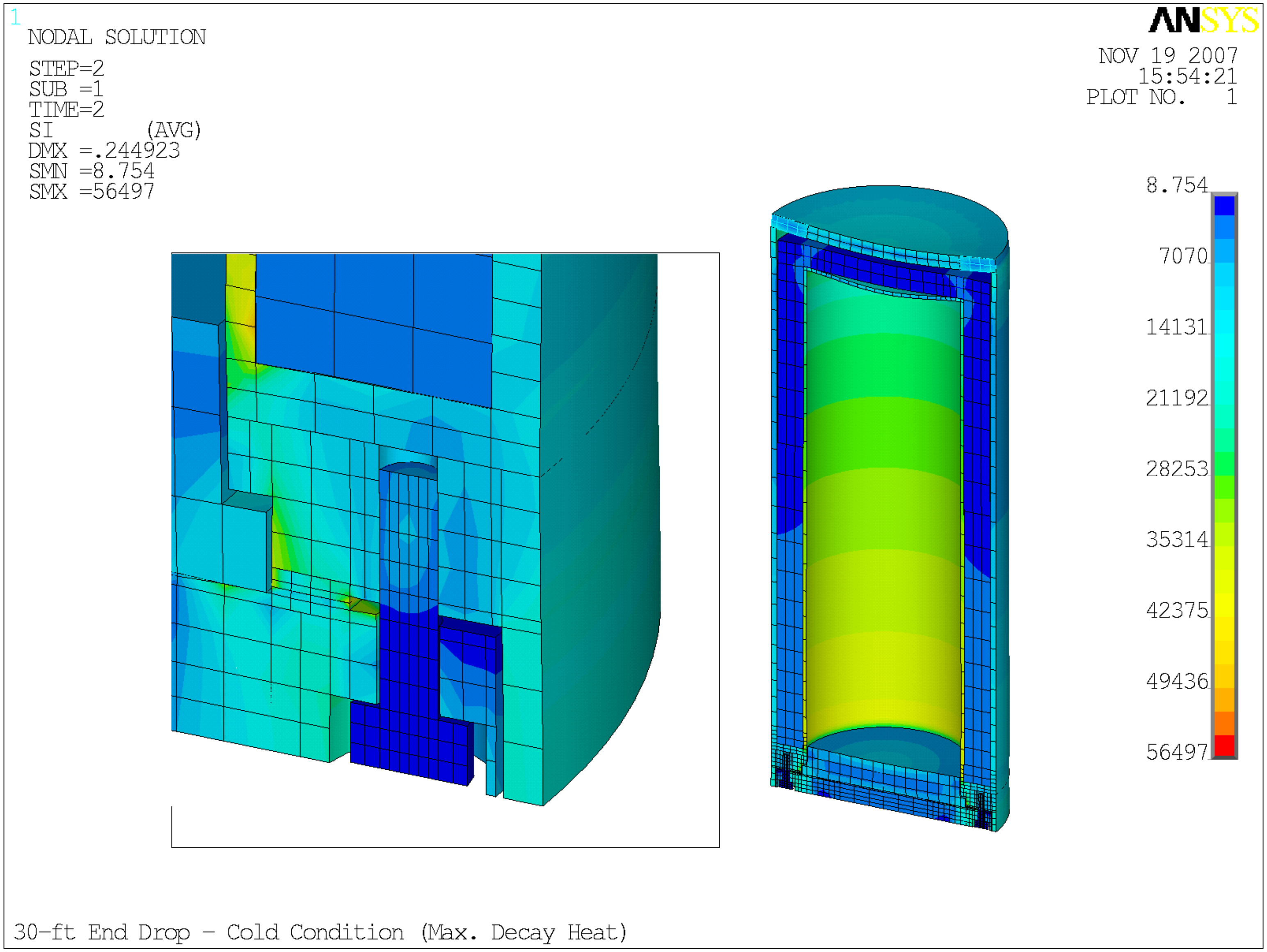


Figure 12

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

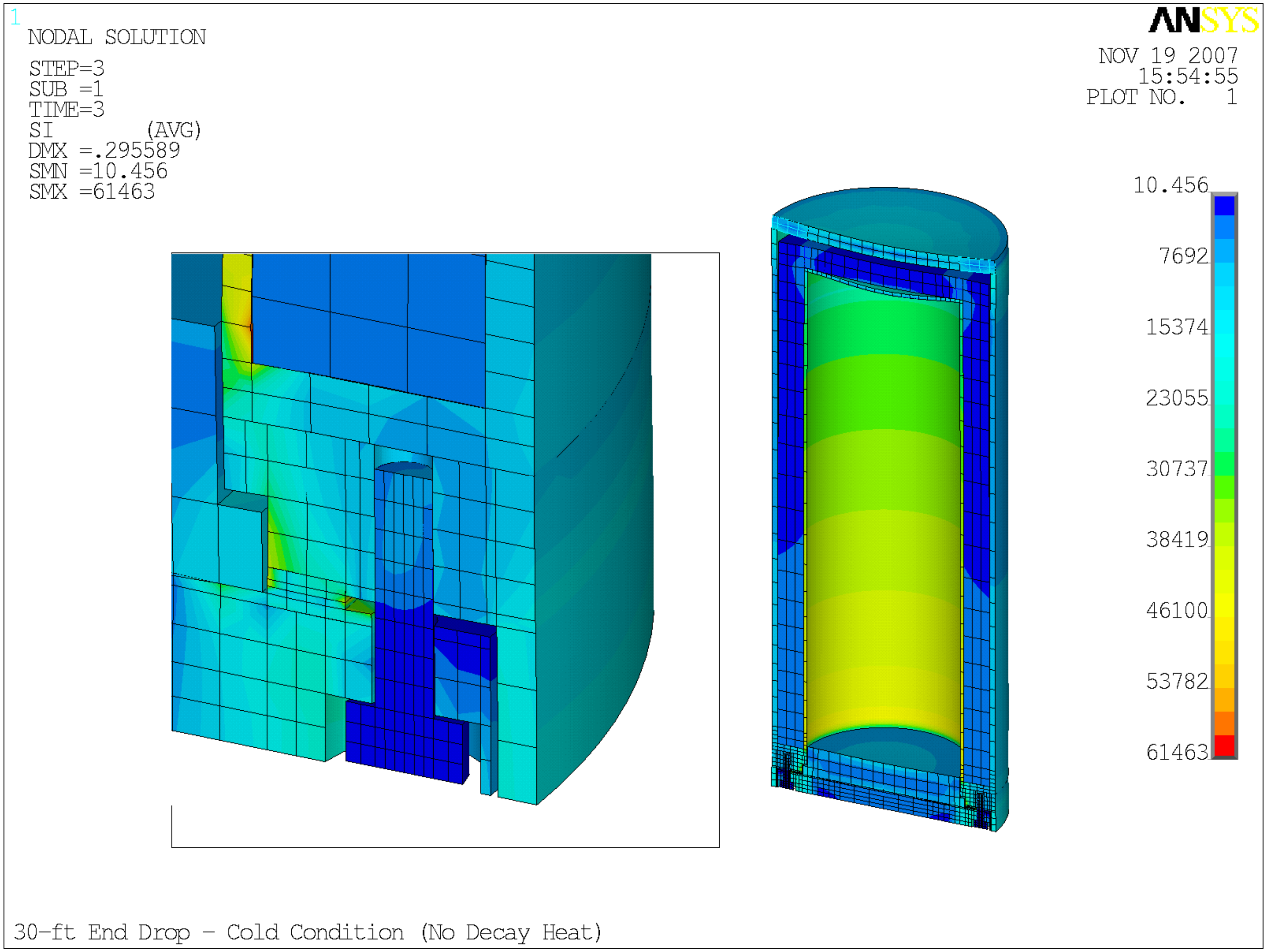


Figure 13

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

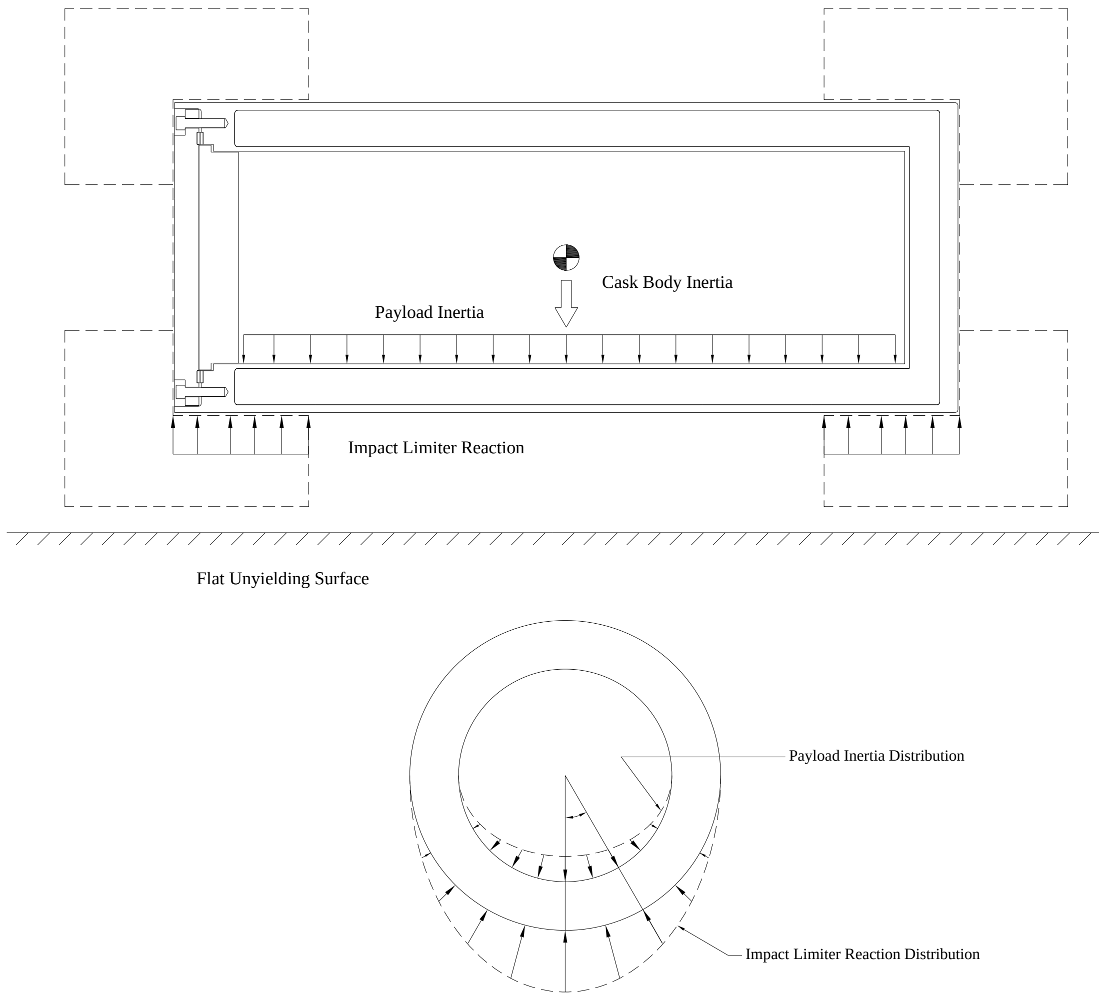
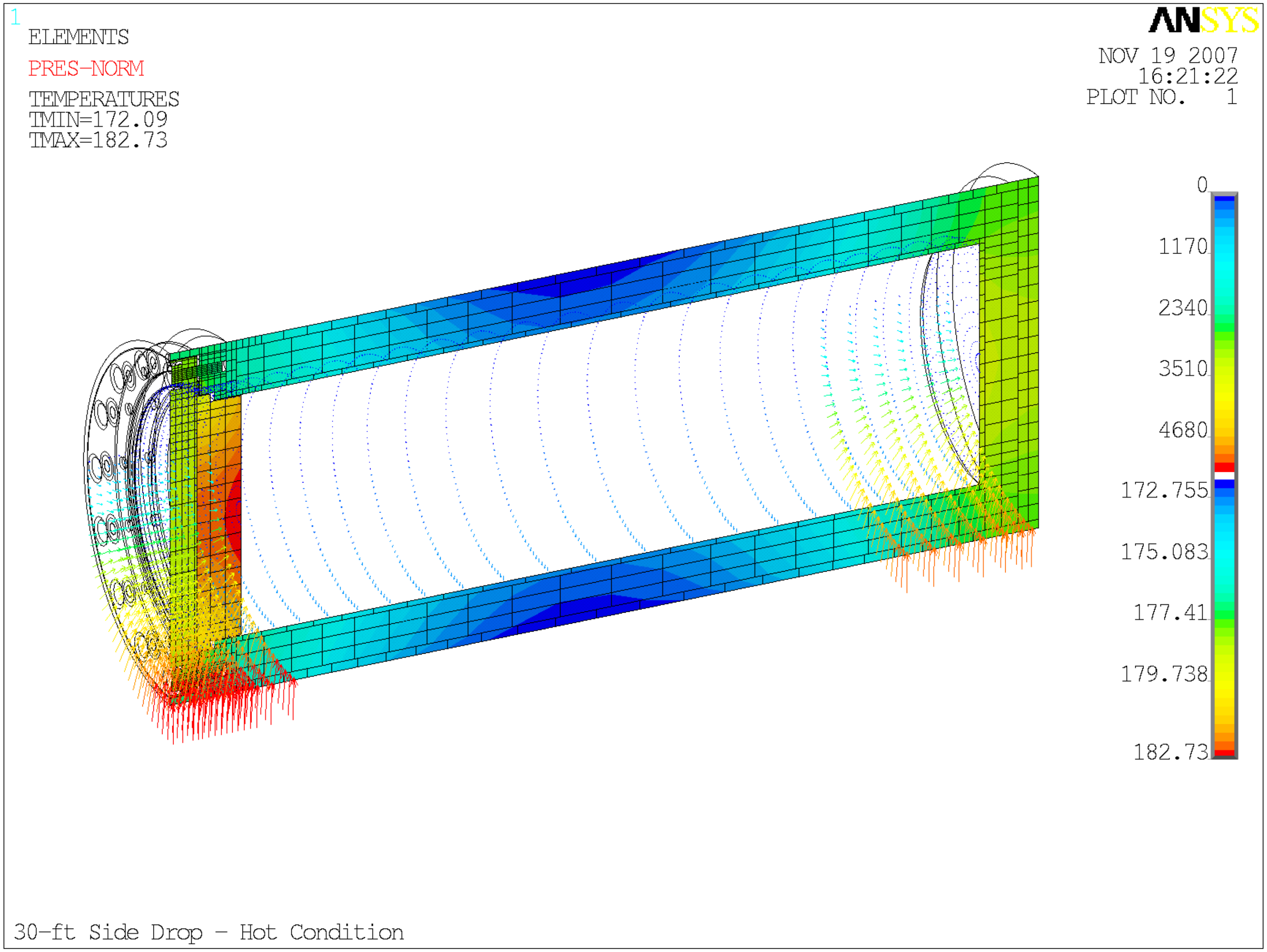


Figure 14

Load Distribution on the Model during Side Drop



<u>Figure 15</u>

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

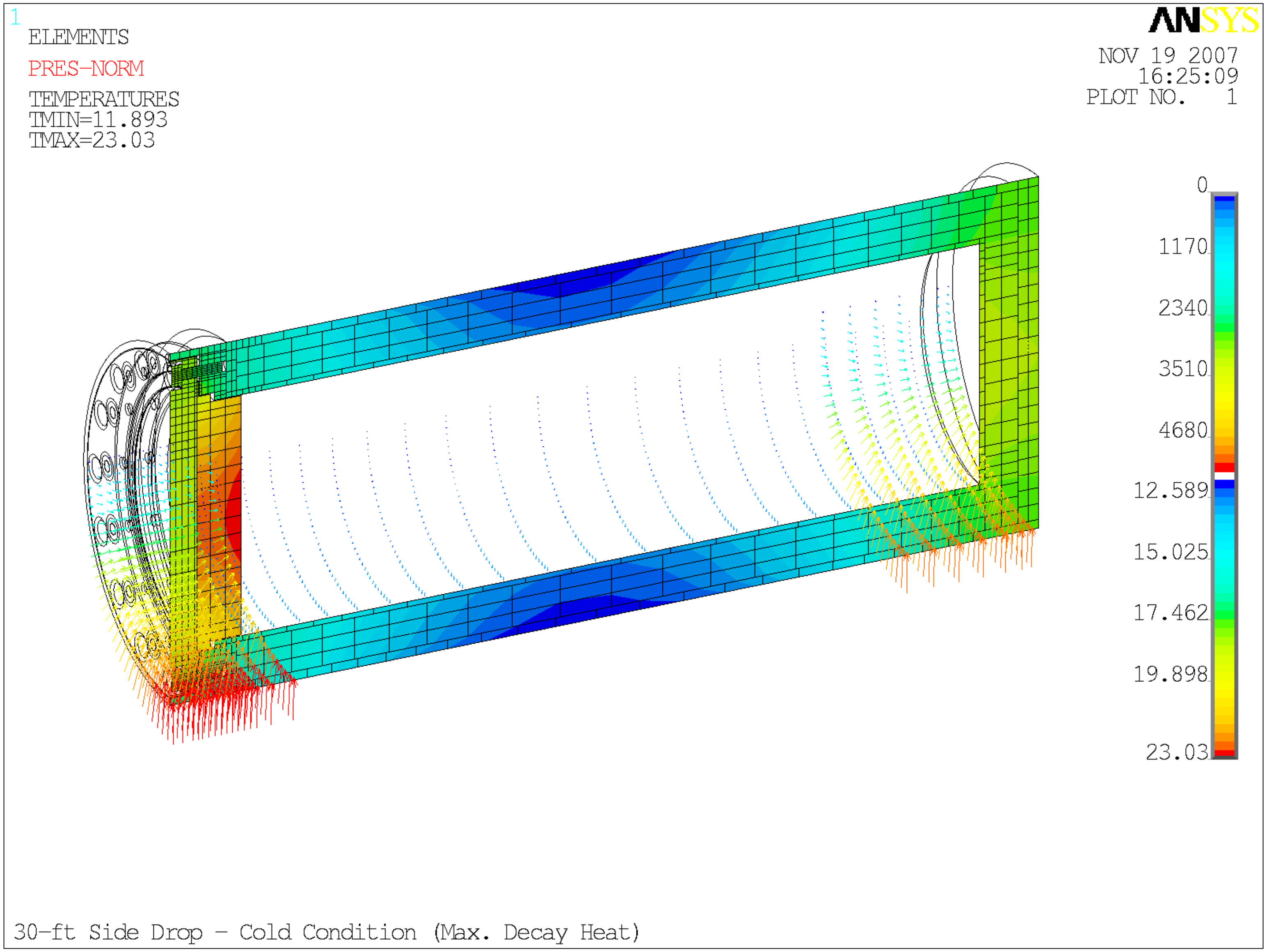


Figure 16

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

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

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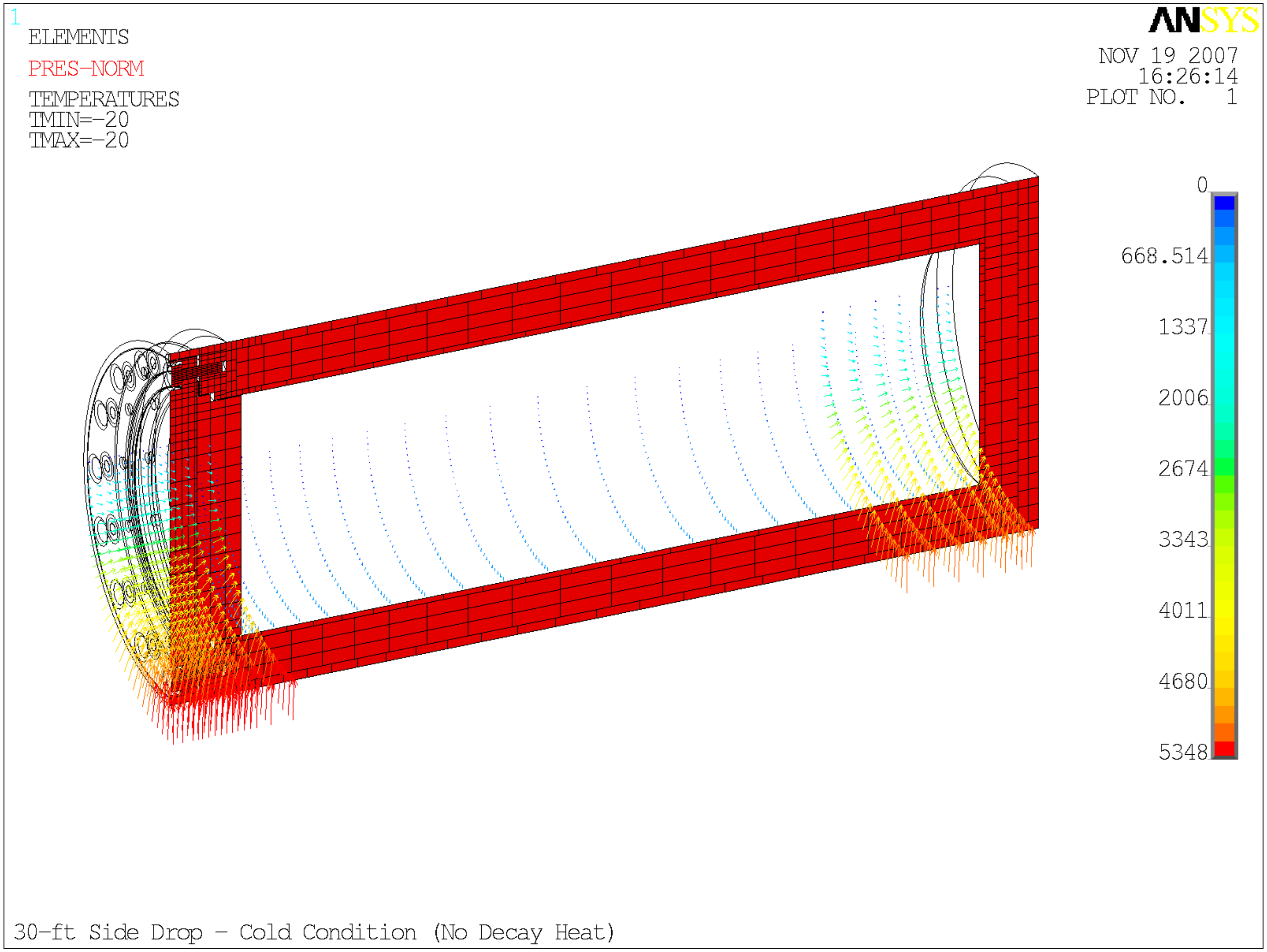

Figure 17

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

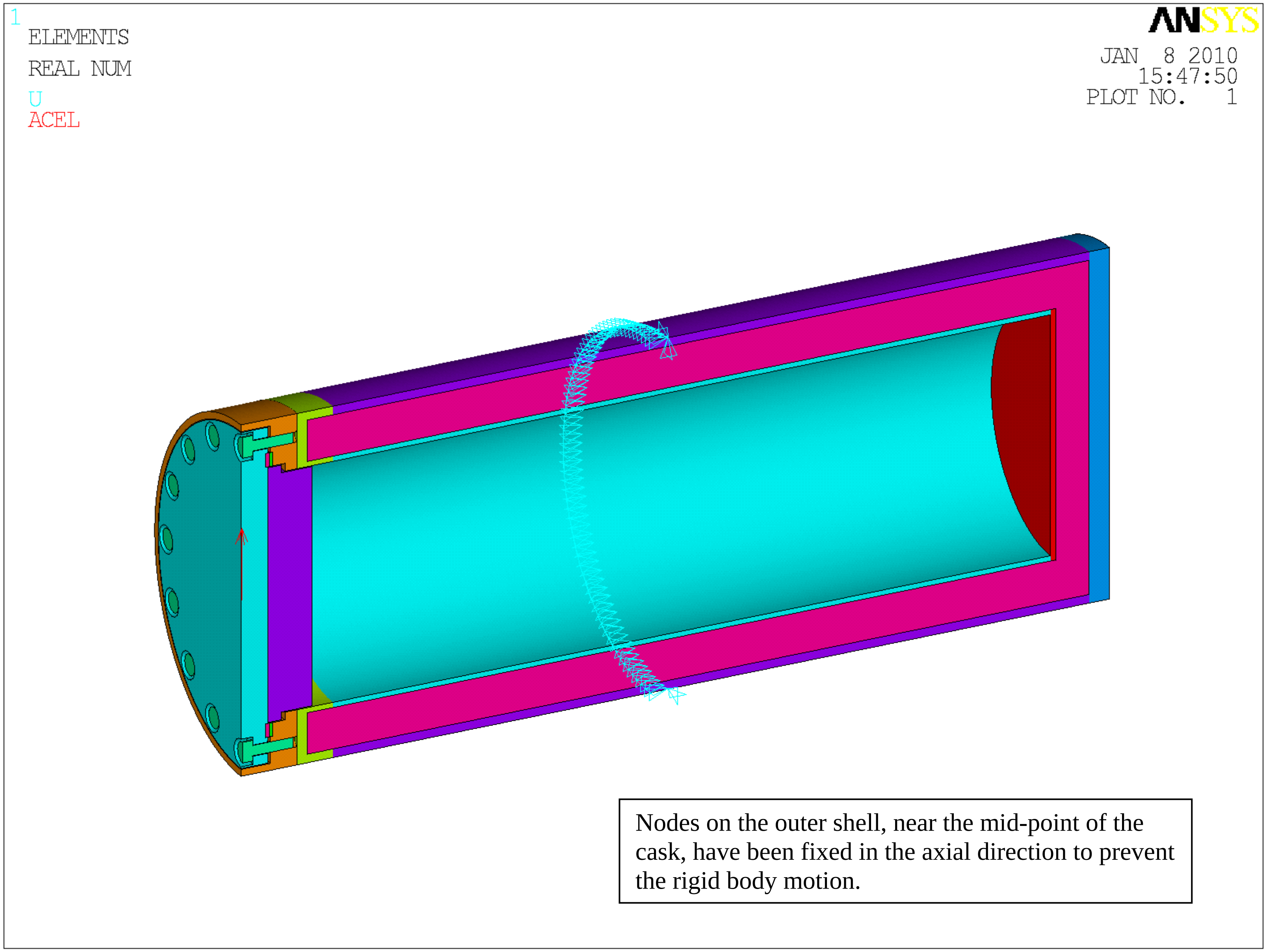

Figure 18

Stress Intensity Plot – 30-ft Side Drop – Displacement Boundary Conditions Used to Prevent Rigid Body Motion

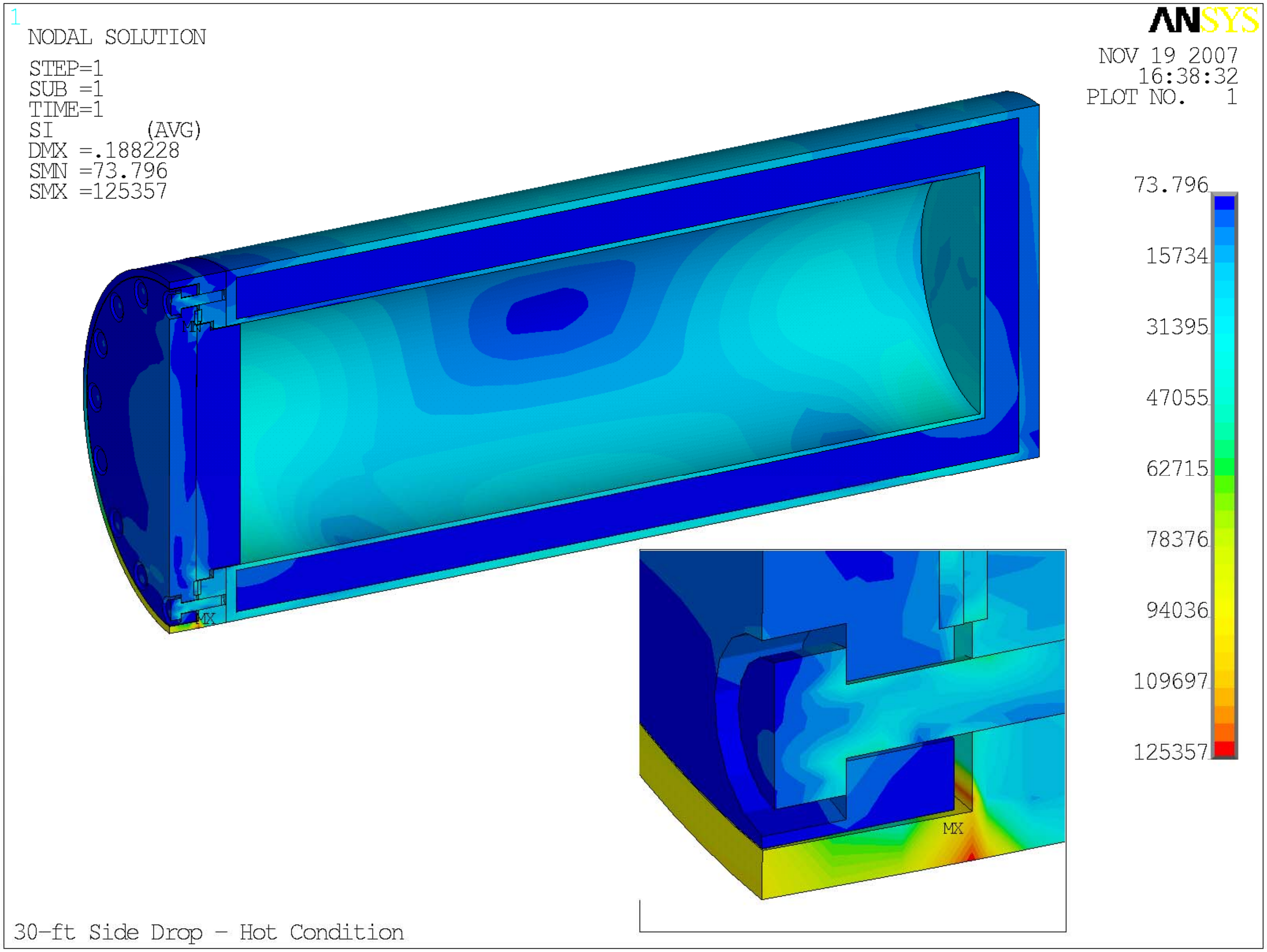

Figure 19

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

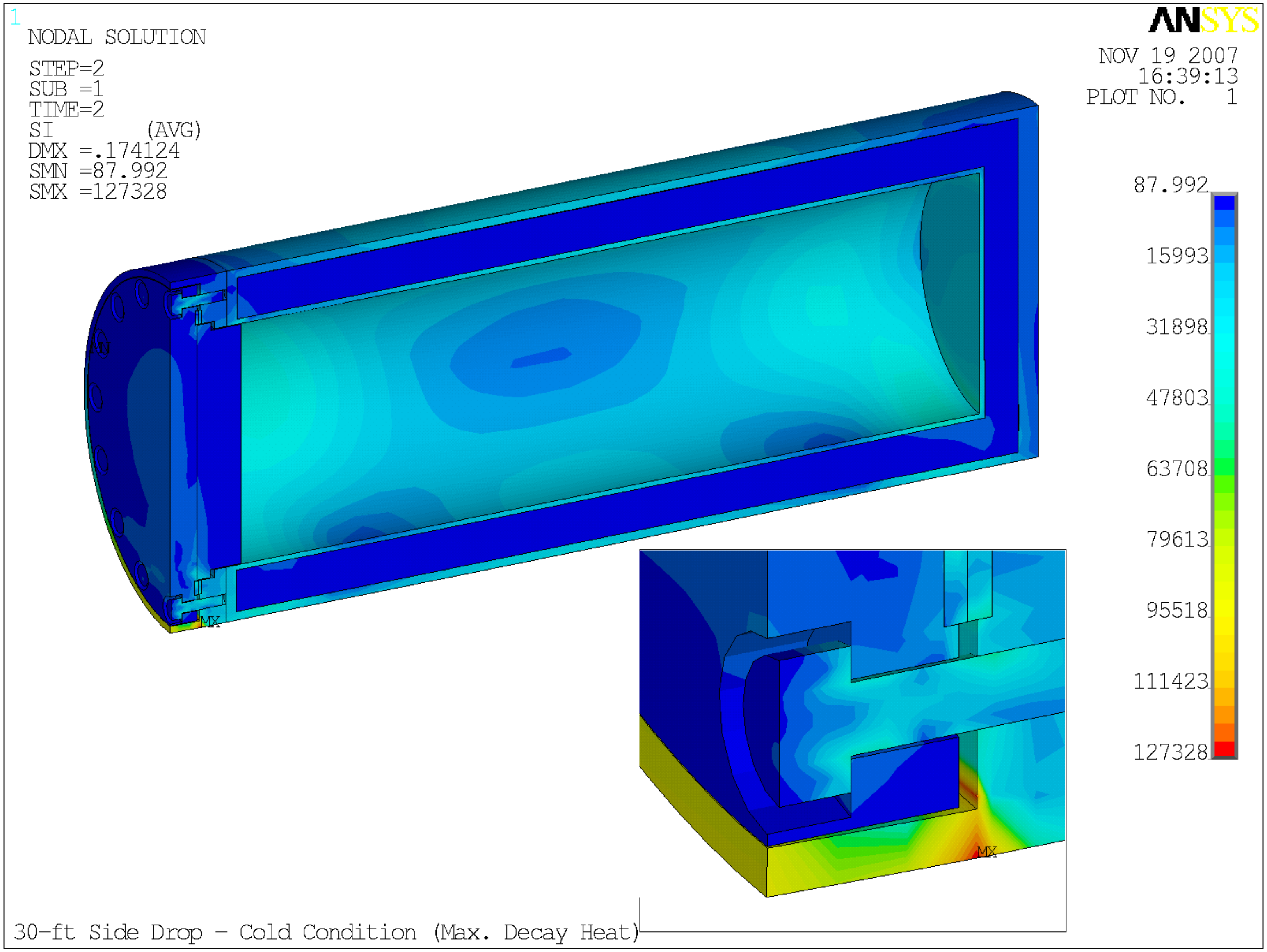

Figure 20

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

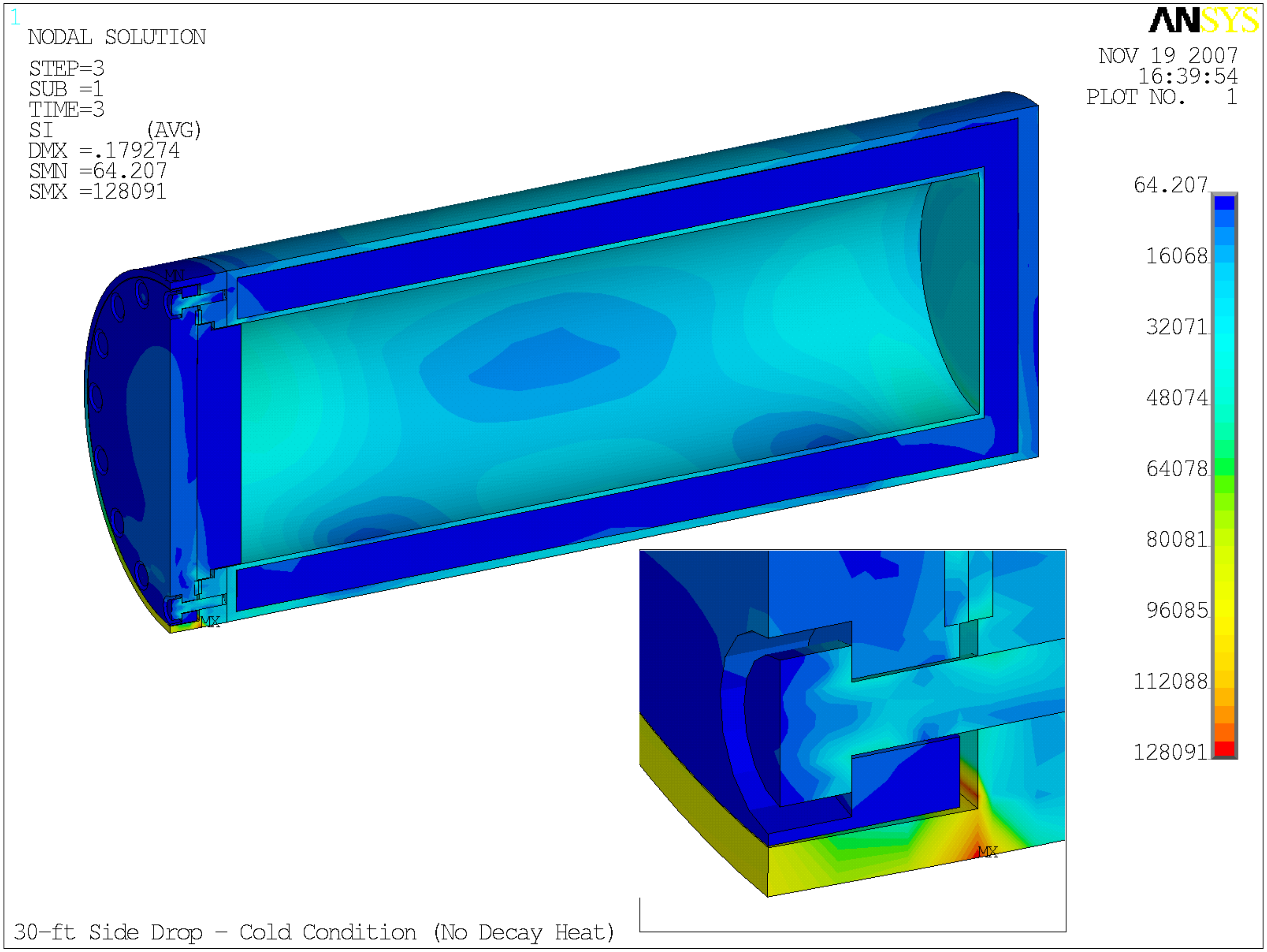

Figure 21

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

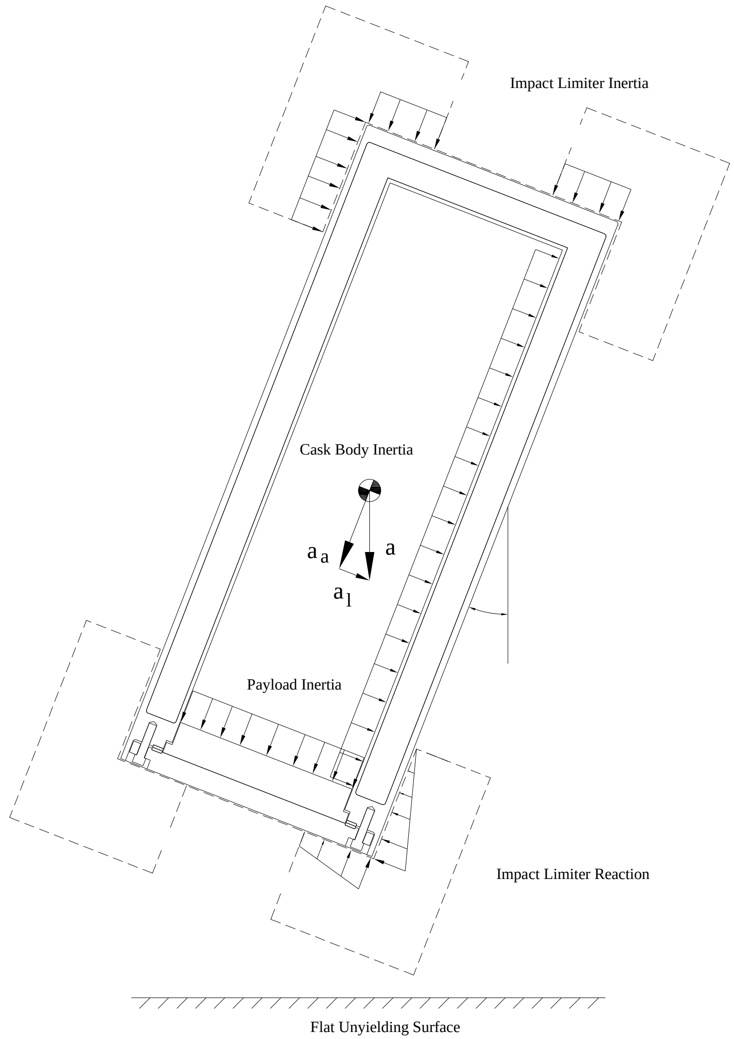

Figure 22

Load Distribution on the Model during Corner Drop

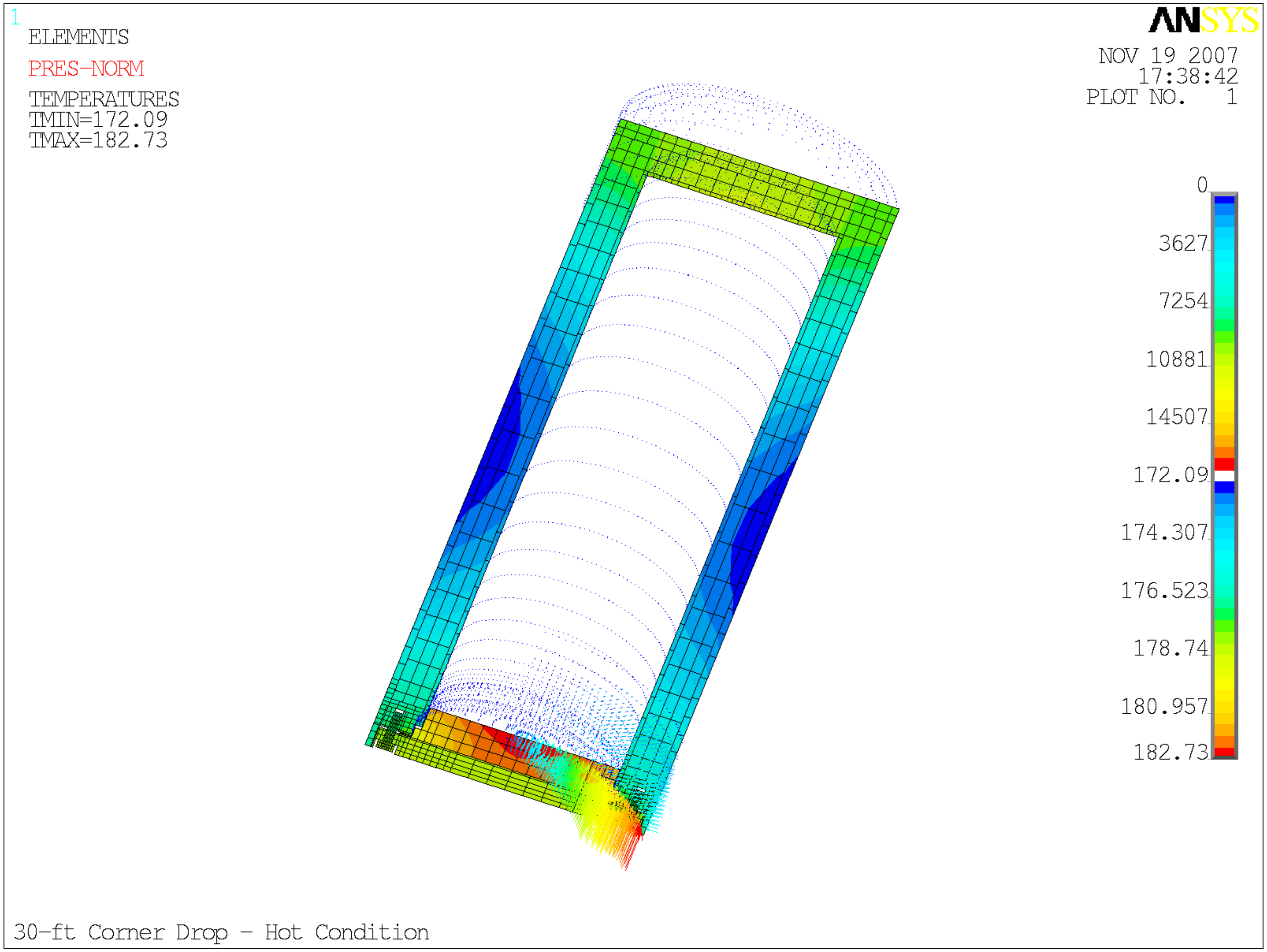

Figure 23

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

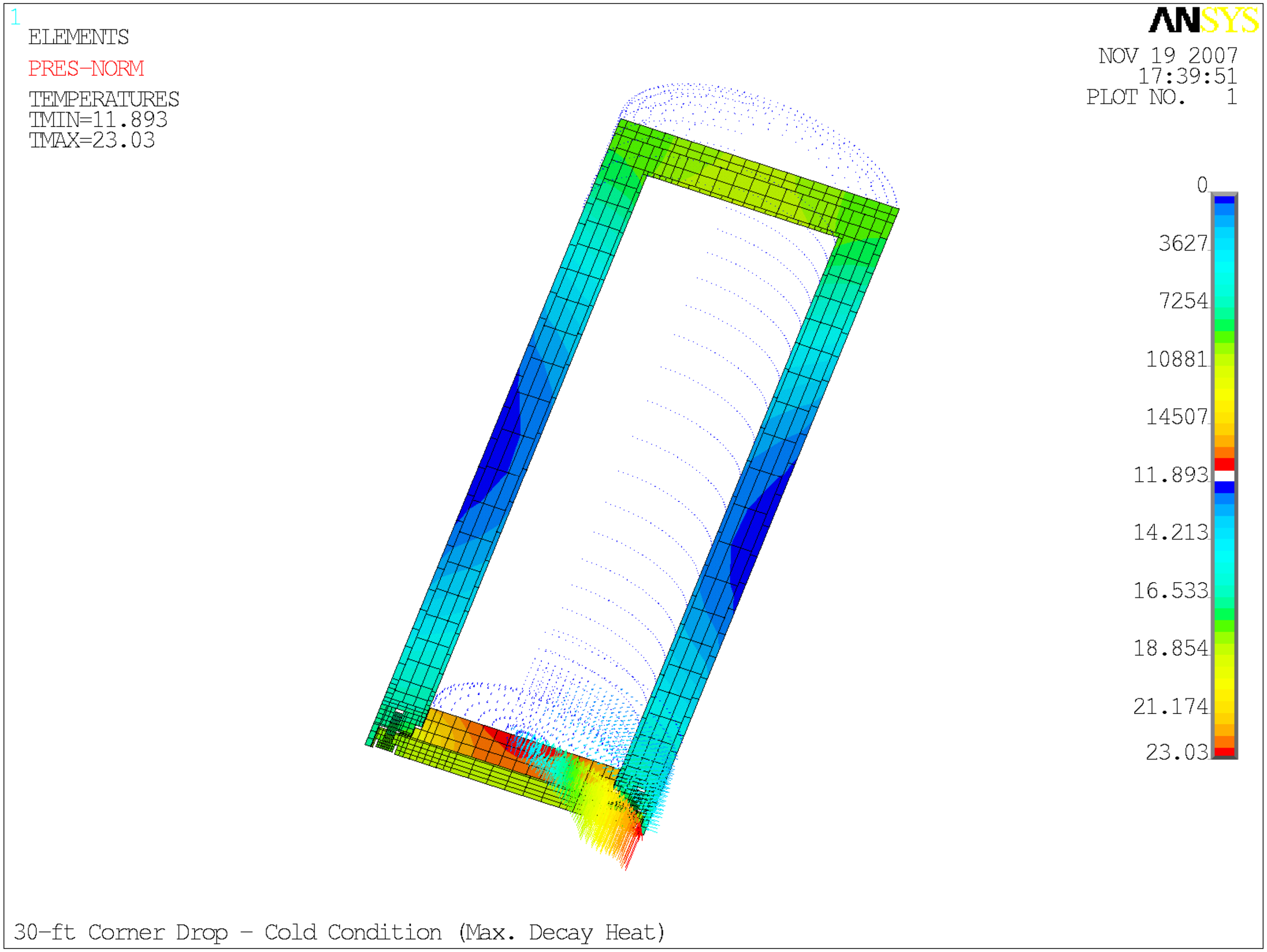

Figure 24

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

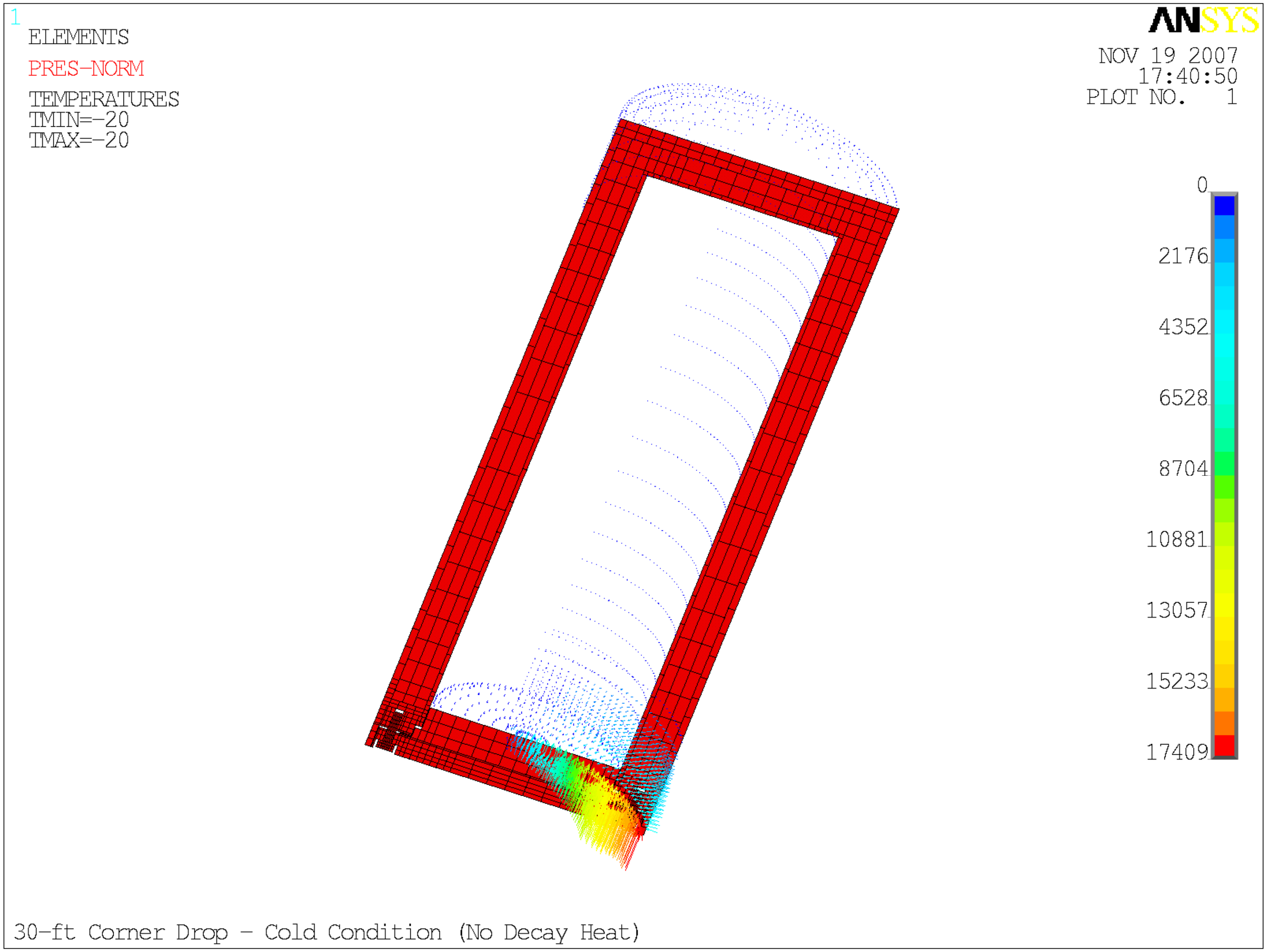

Figure 25

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

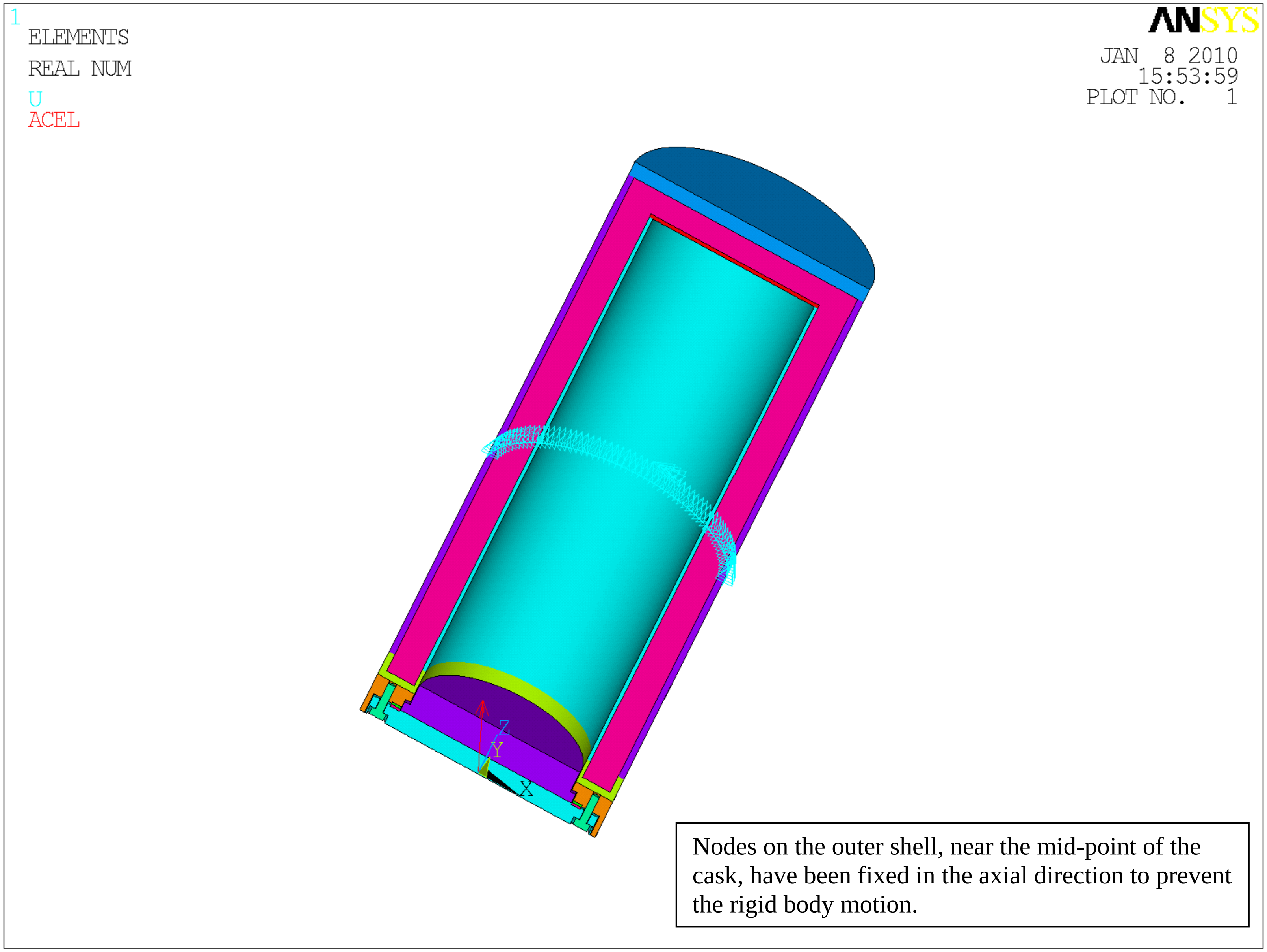

Figure 26
Stress Intensity Plot – 30-ft Corner Drop – Displacement Boundary Conditions Used to Prevent Rigid Body Motion

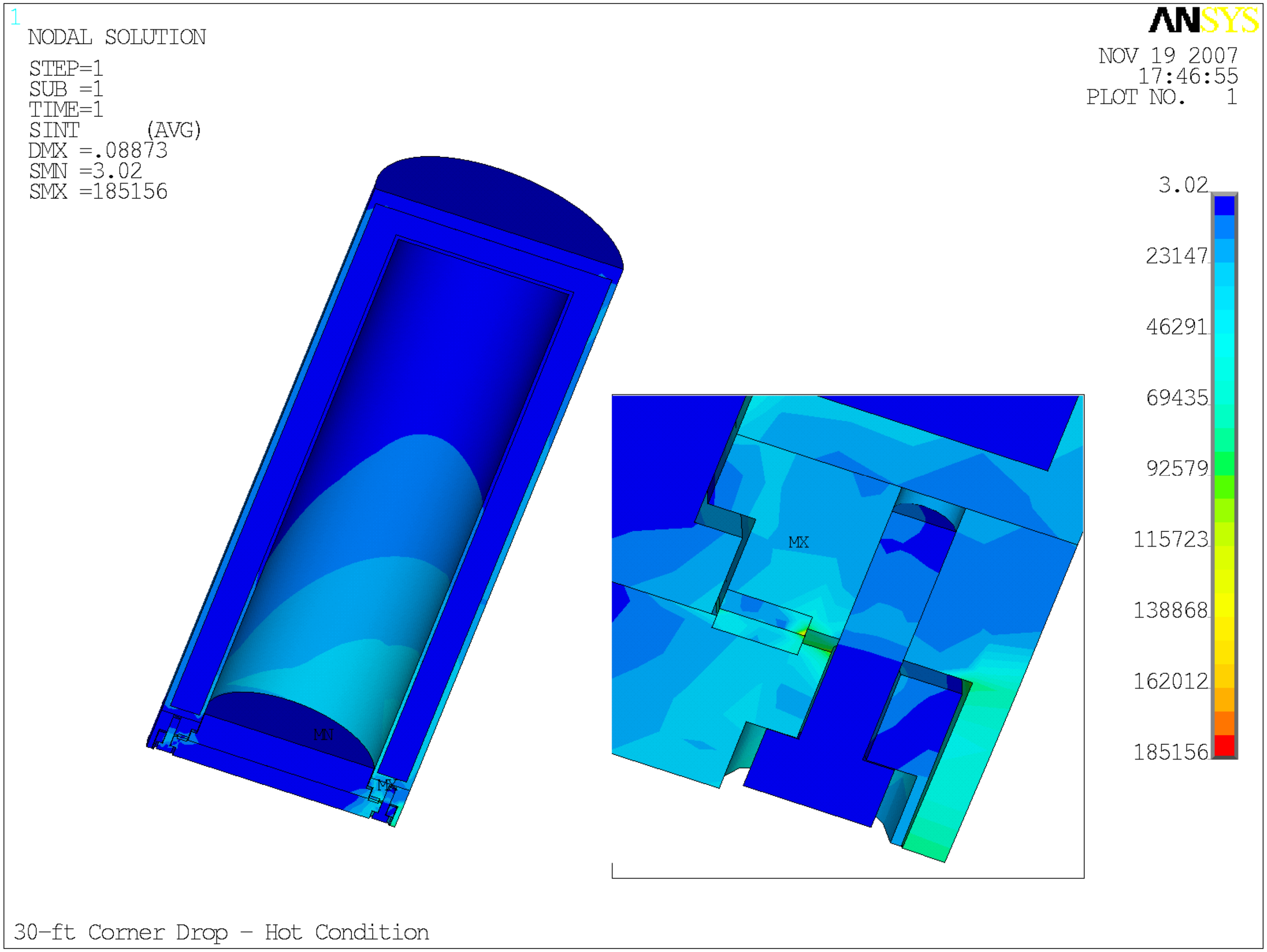

Figure 27

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

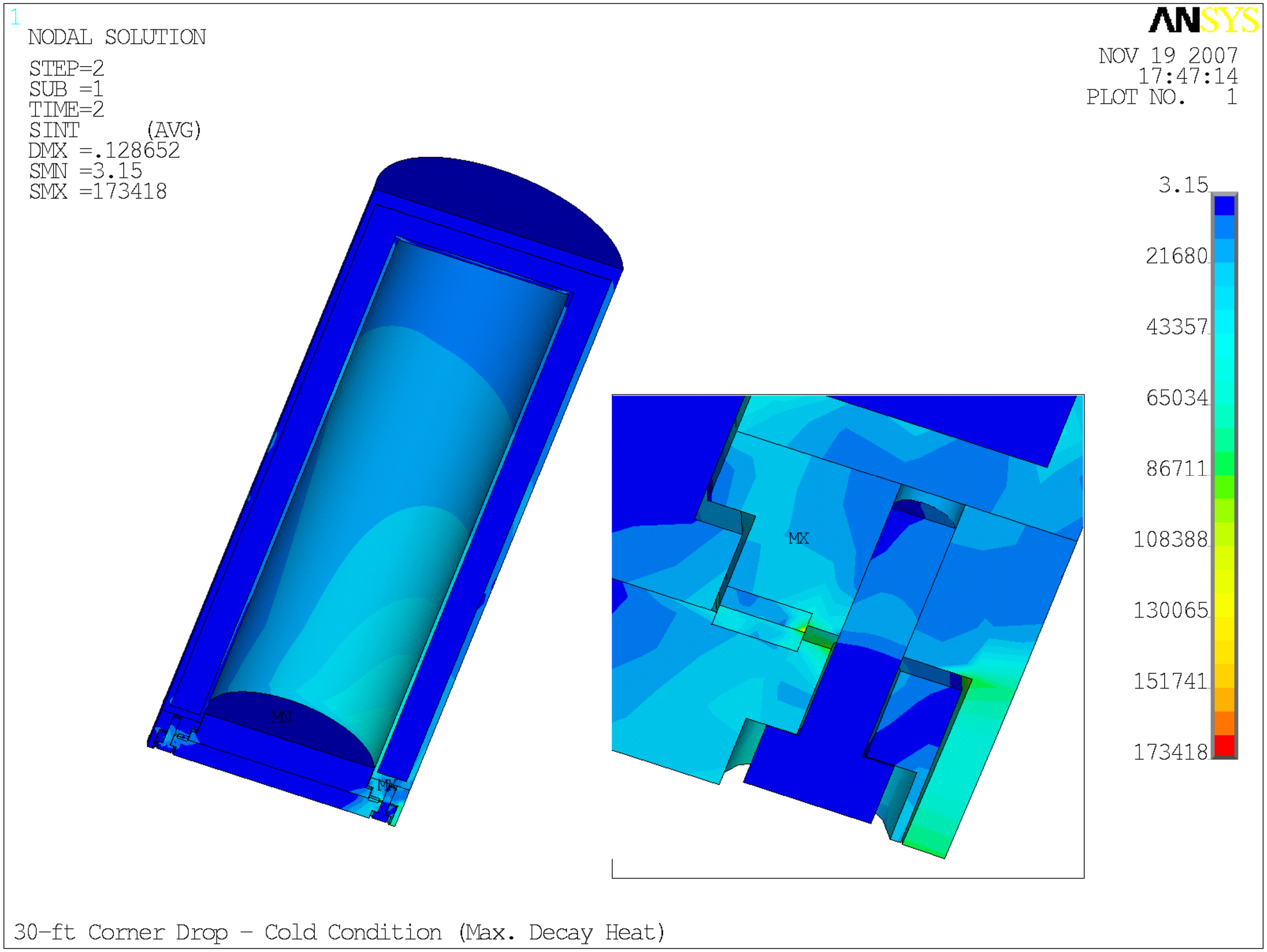

Figure 28

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

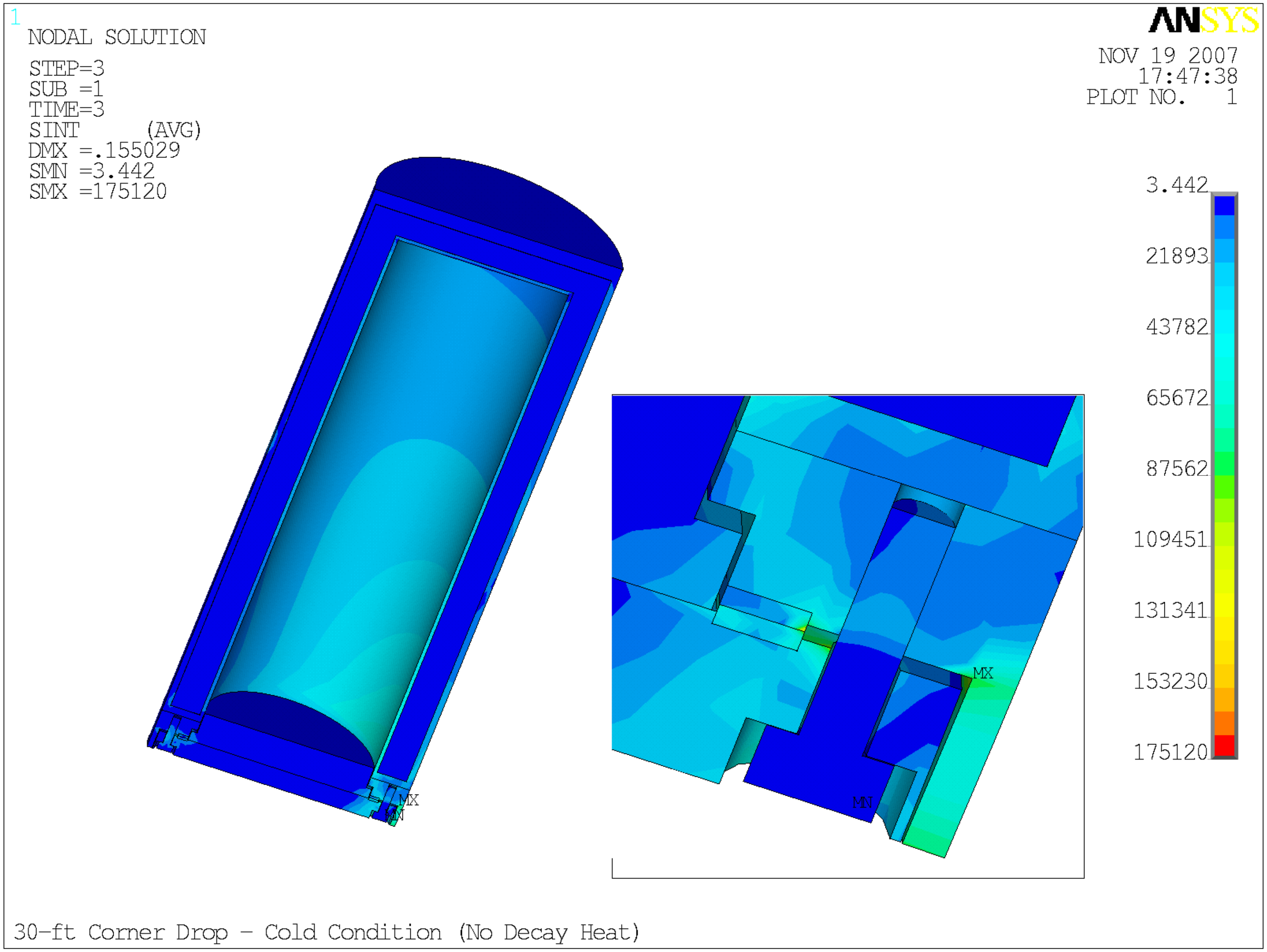

Figure 29

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

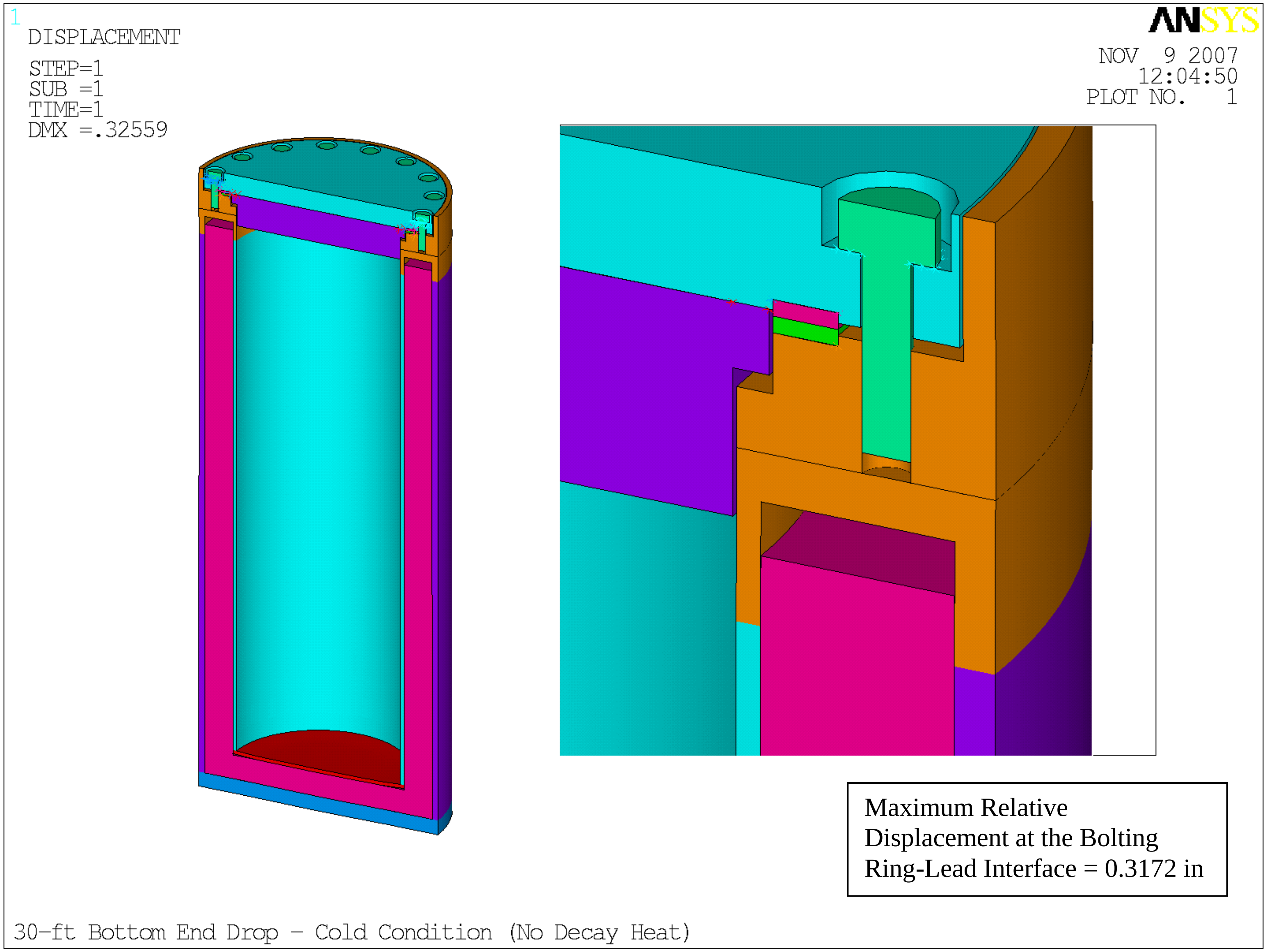

Figure 30

Displacements During 30-ft End Drop on the Bottom

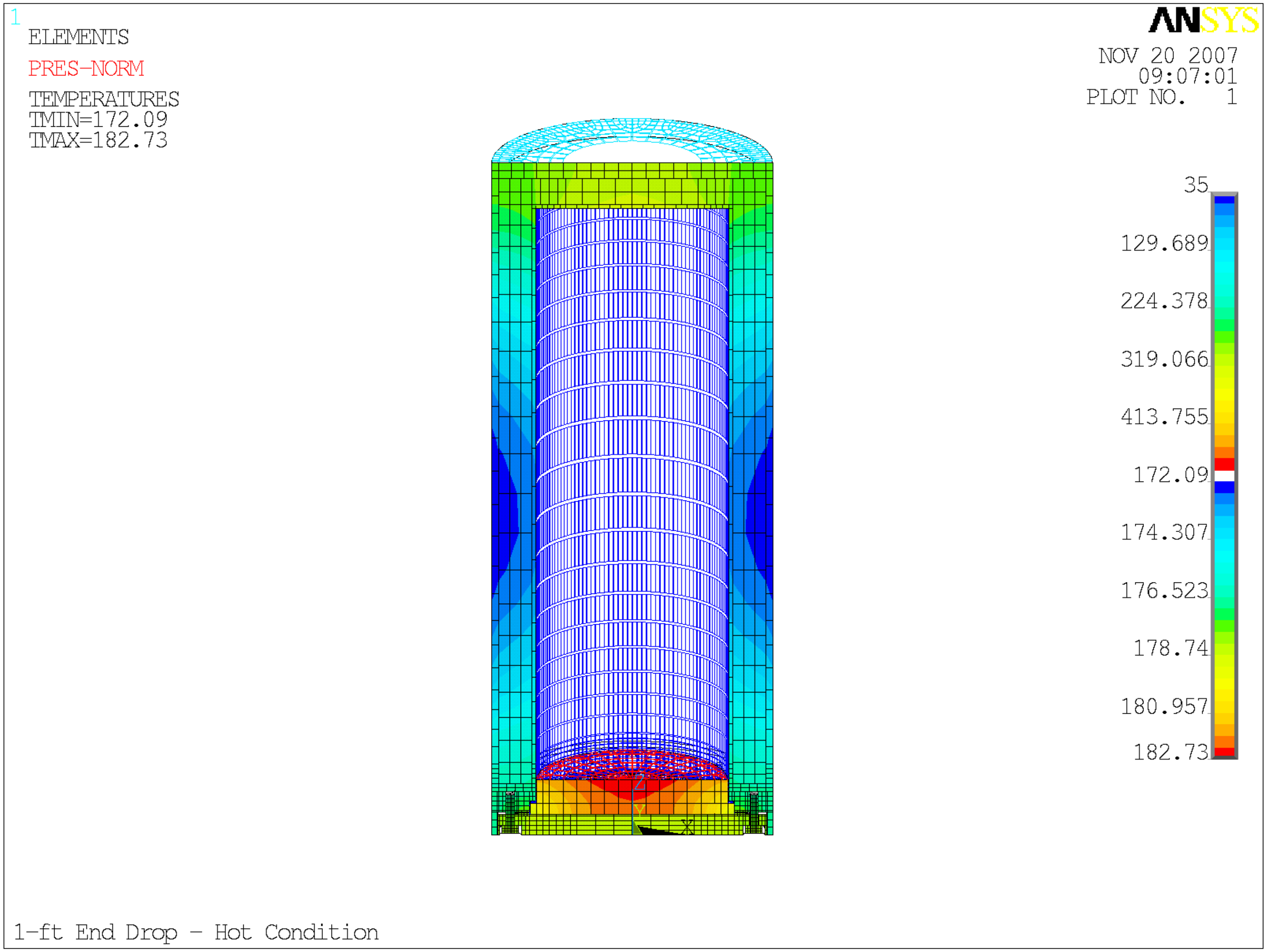

Figure 31

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

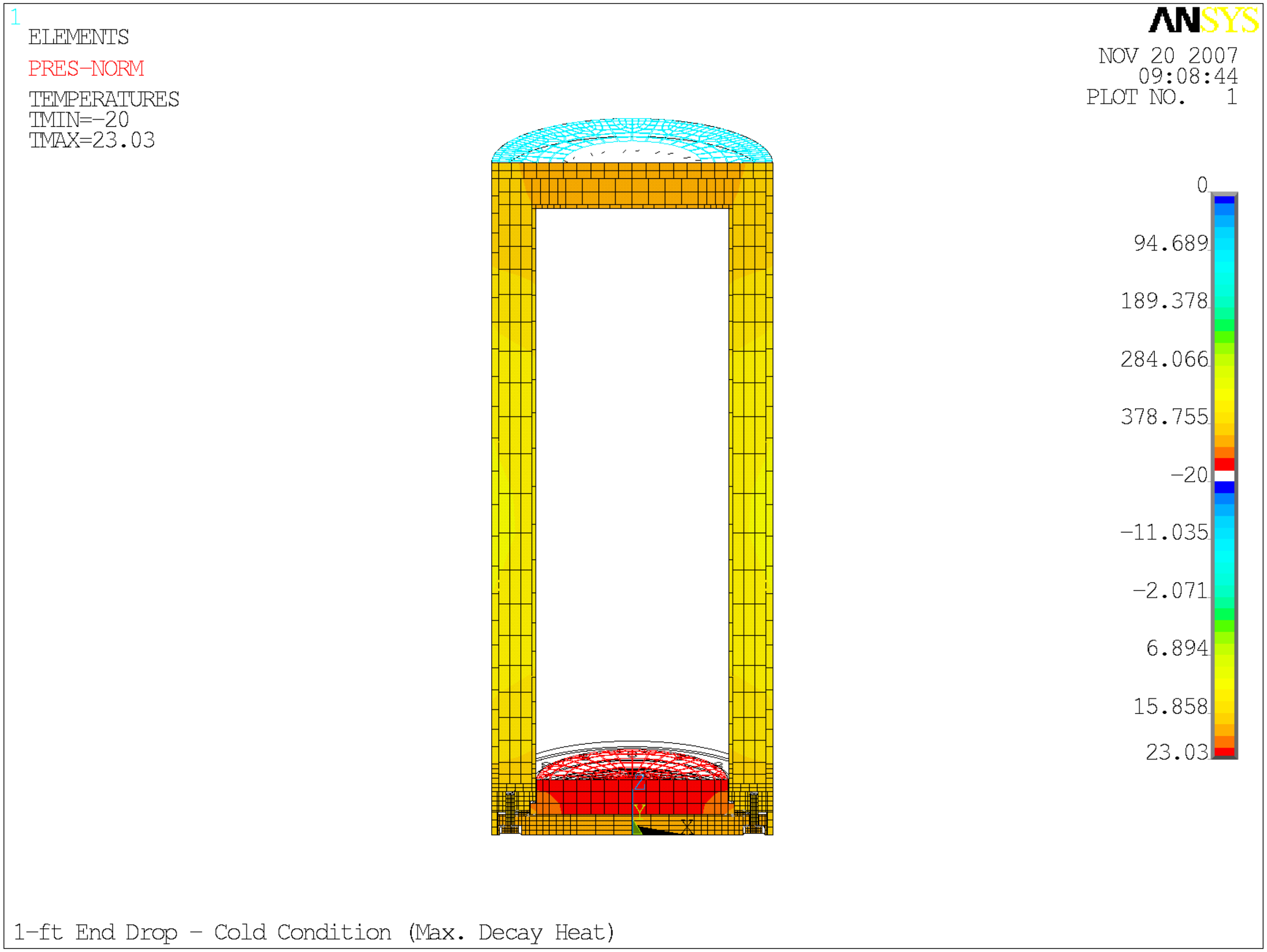

Figure 32

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

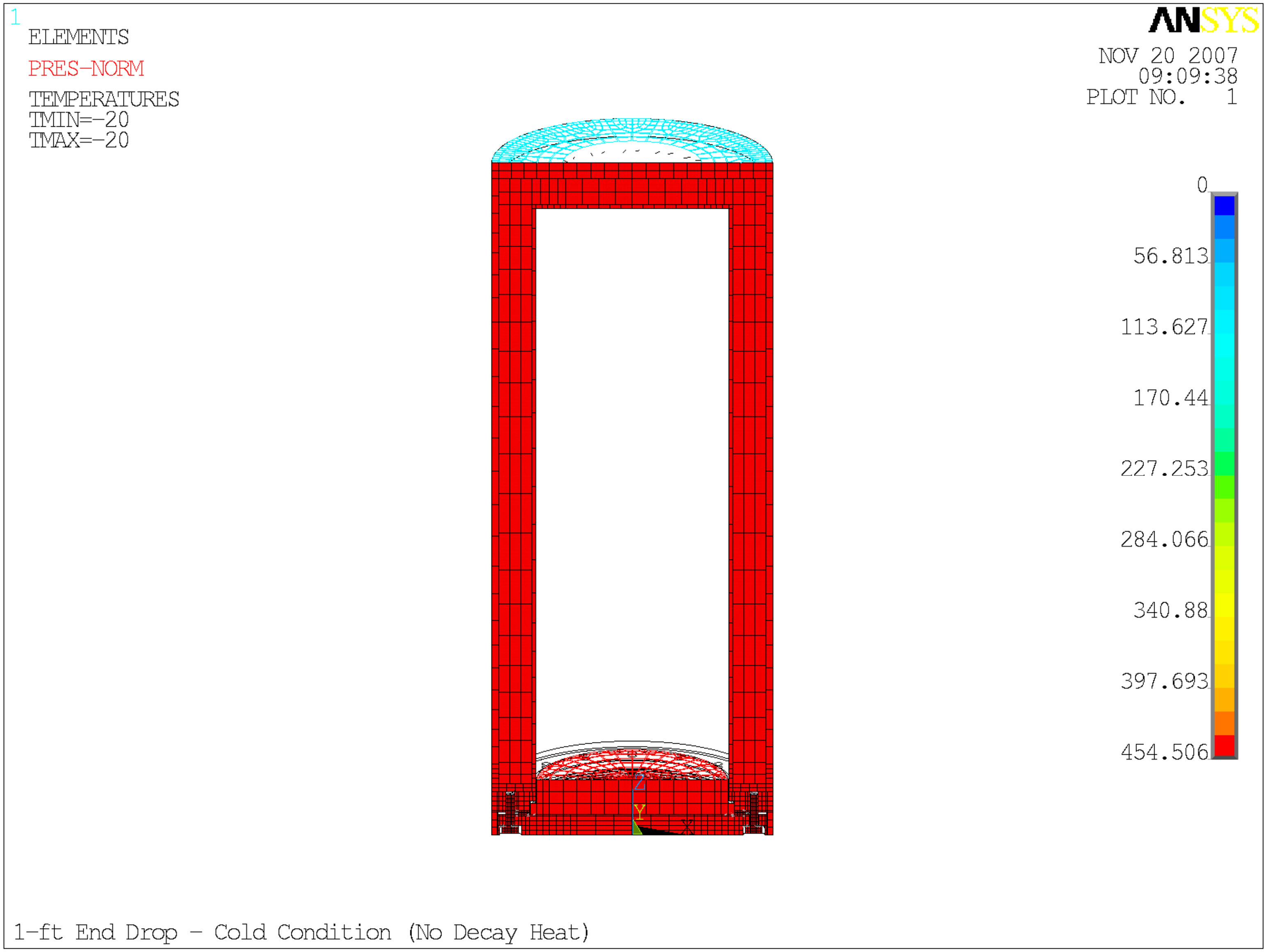

Figure 33

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

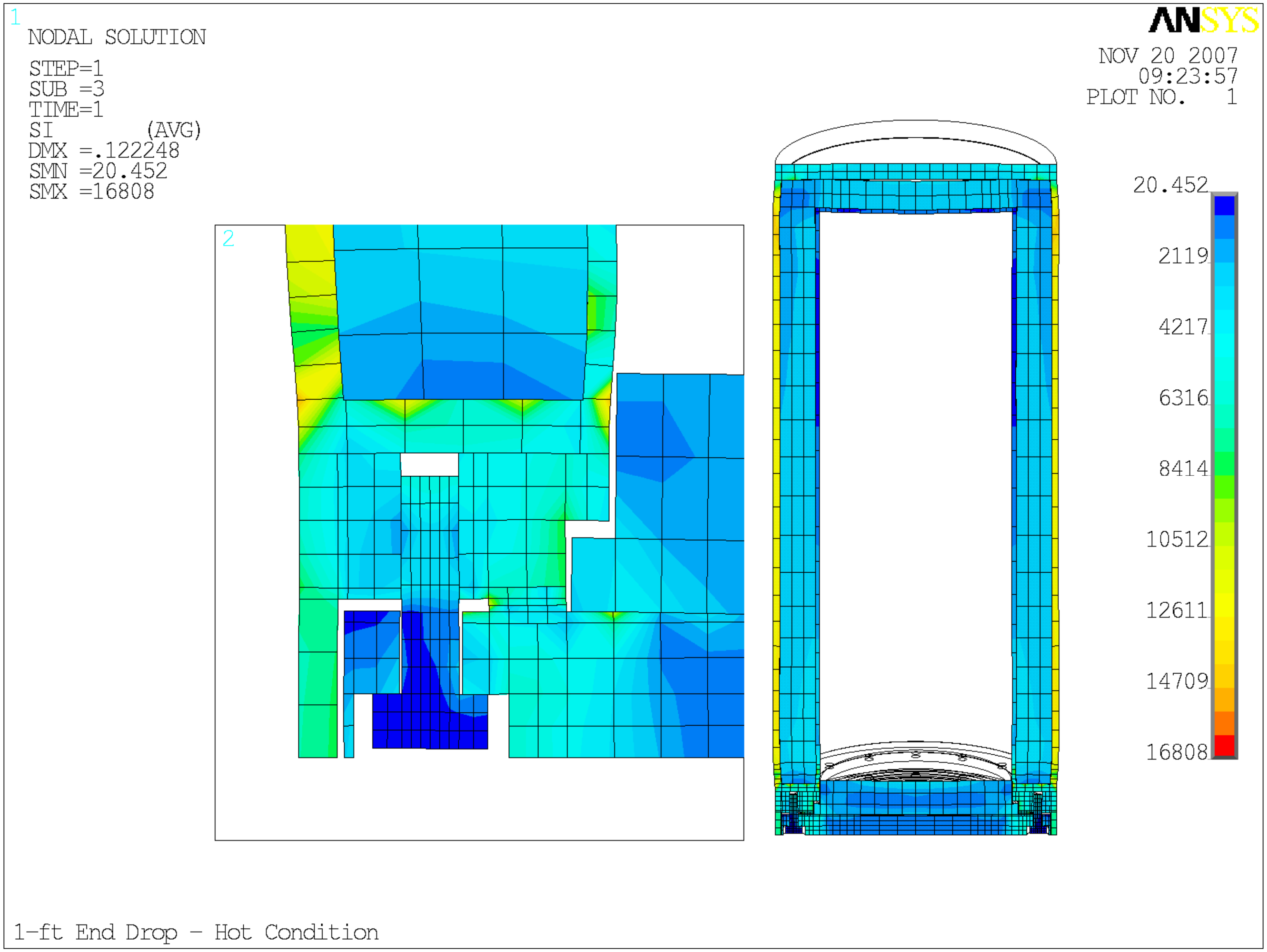

Figure 34

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

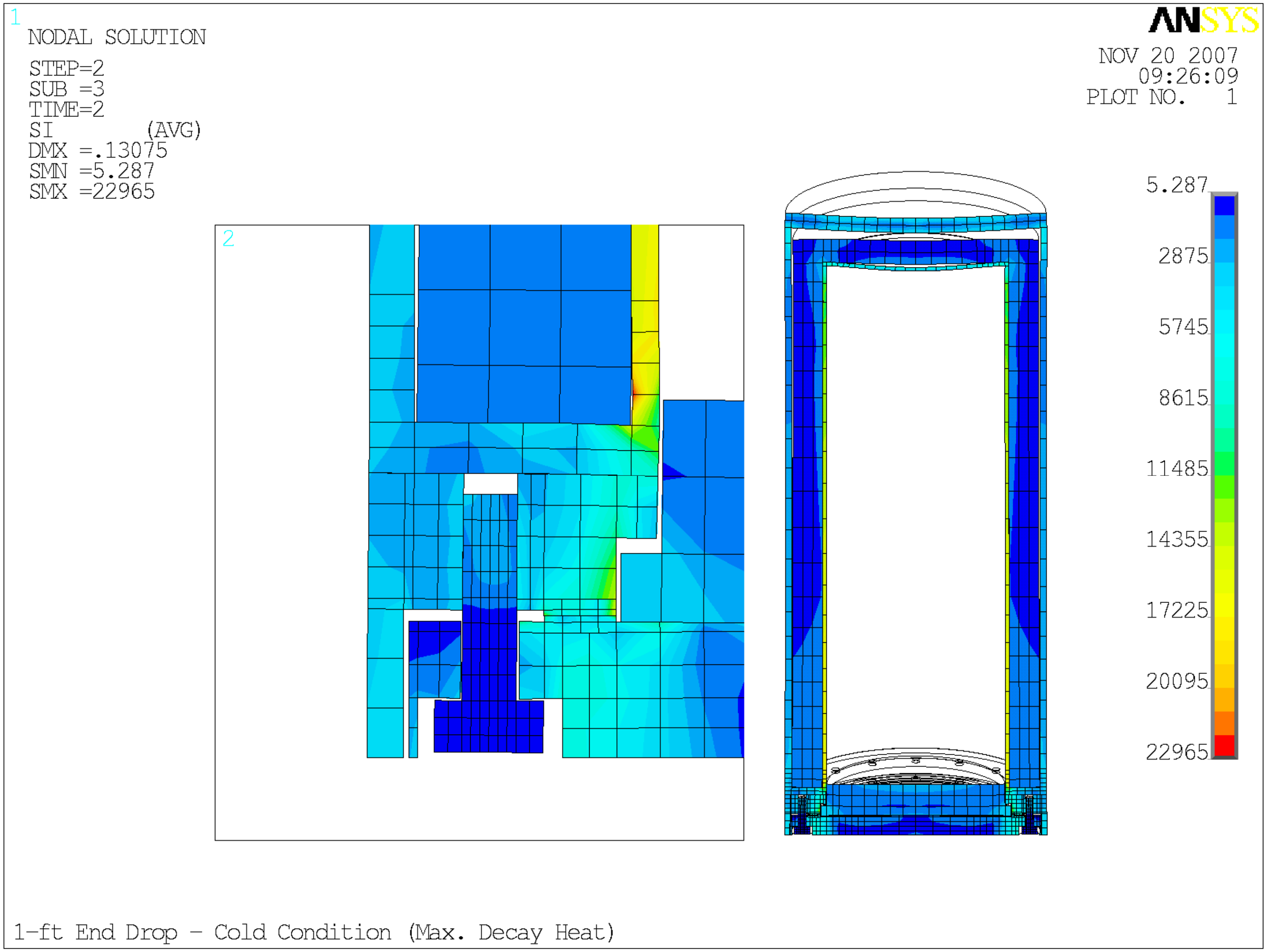

Figure 35

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

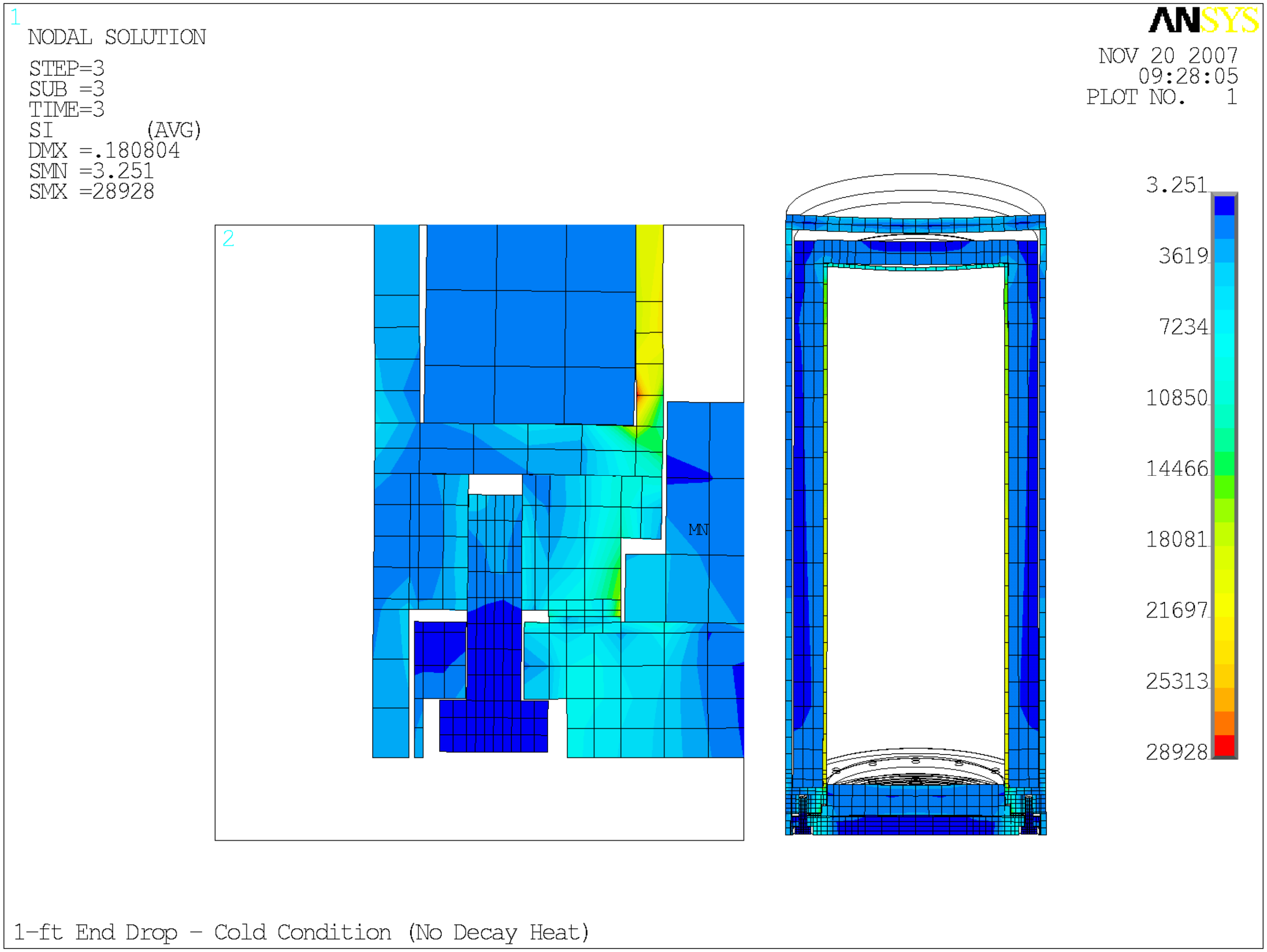

Figure 36

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

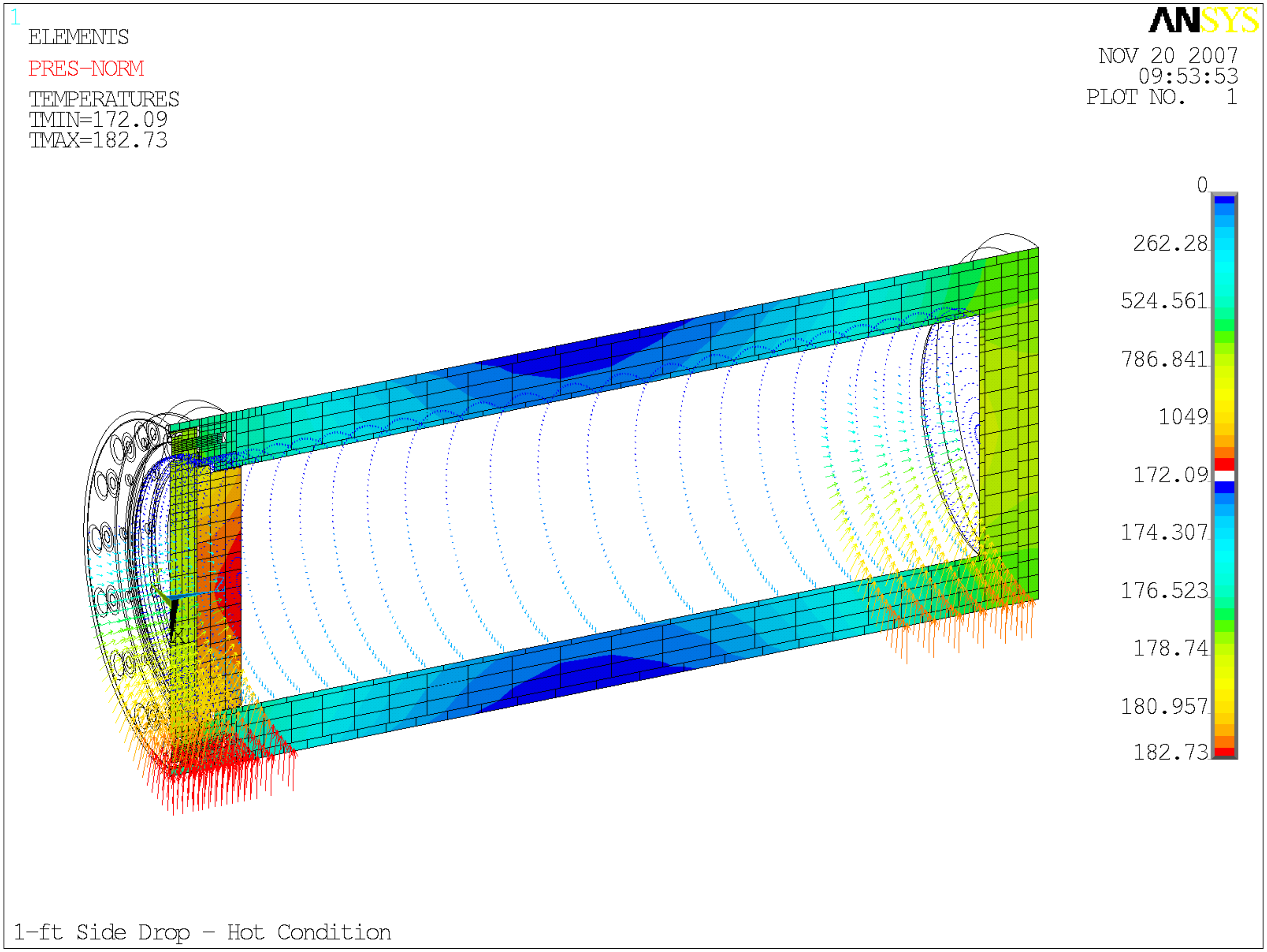

Figure 37

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

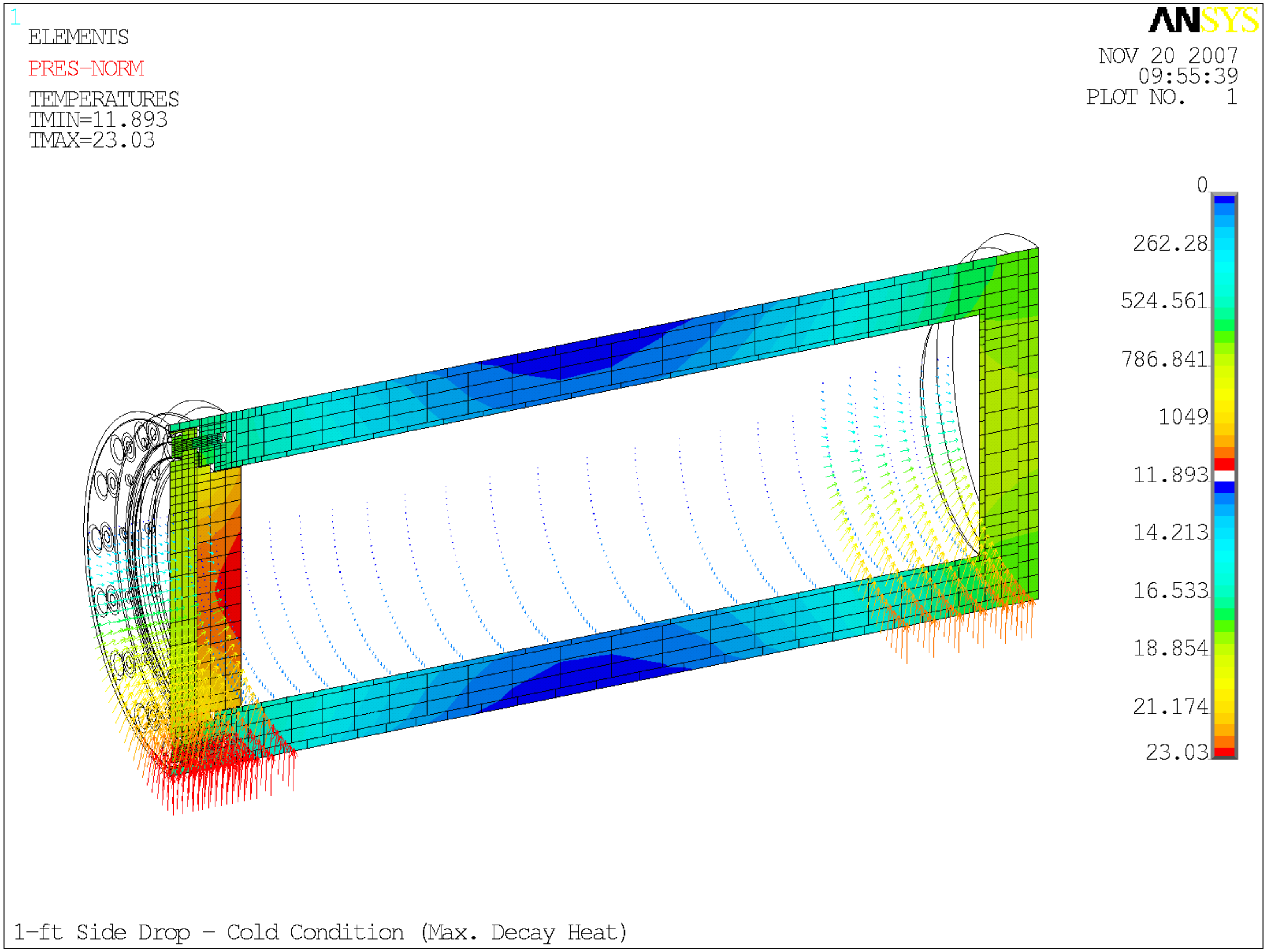

Figure 38

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

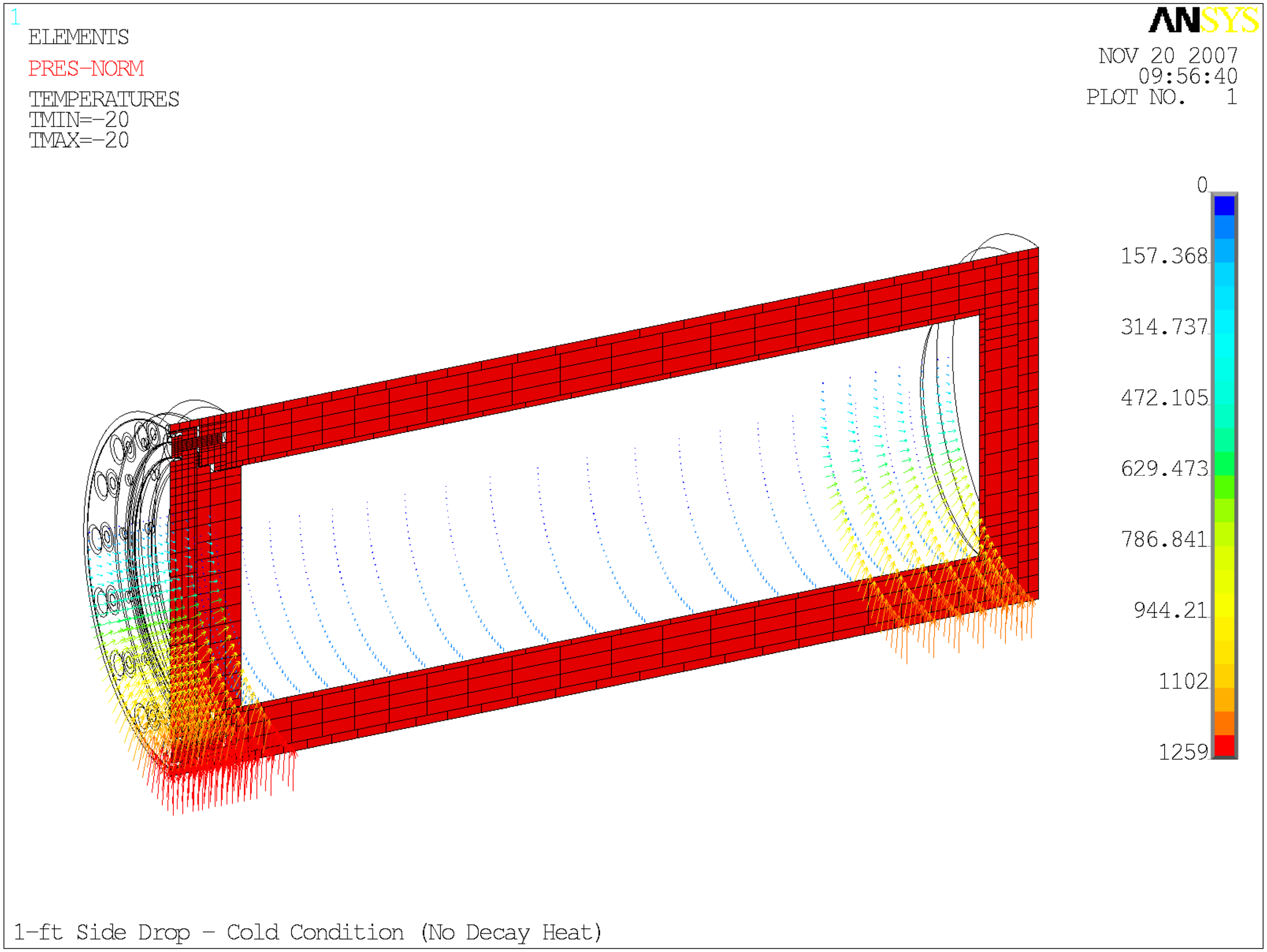

Figure 39

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

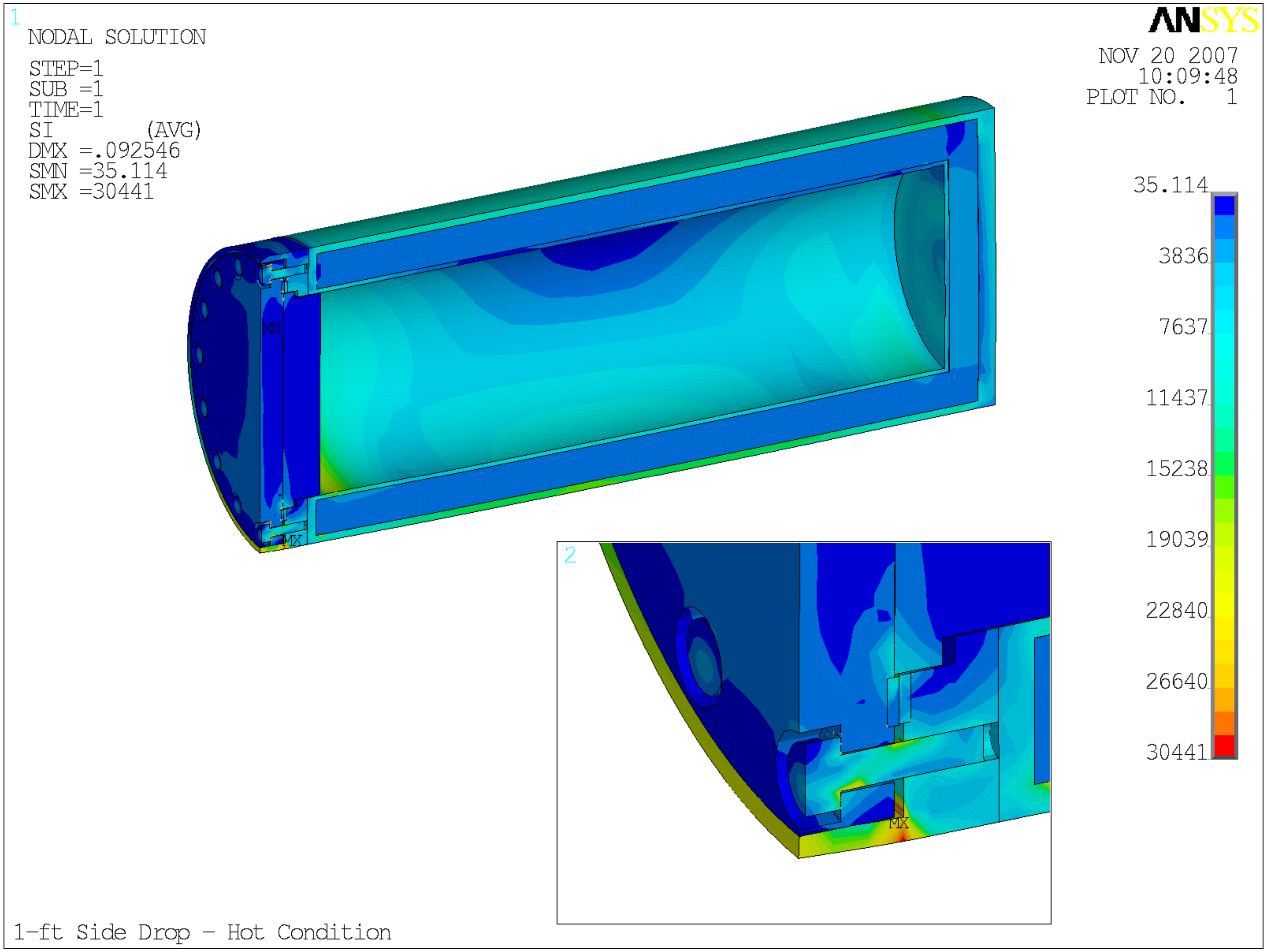

Figure 40

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

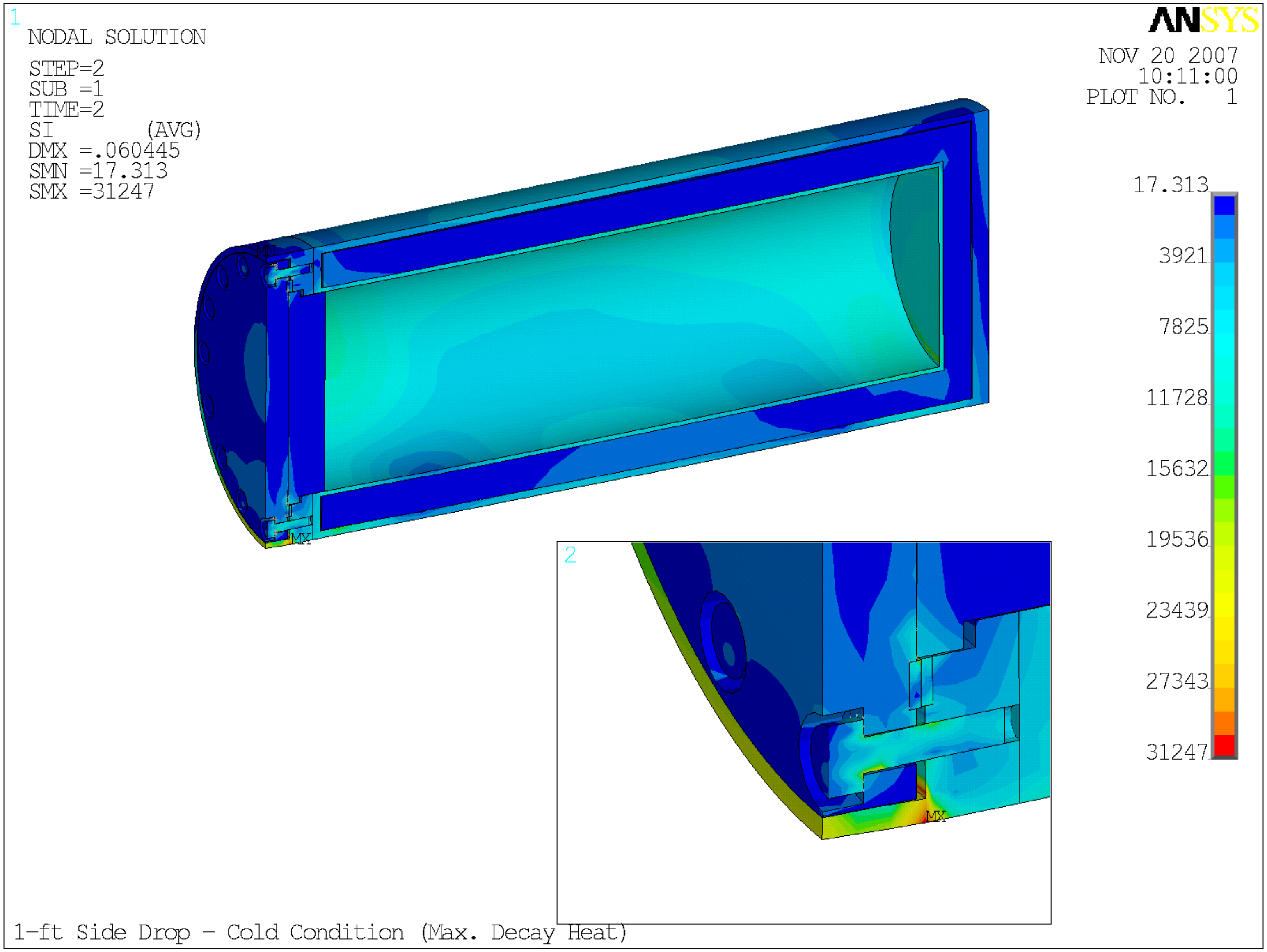

Figure 41

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

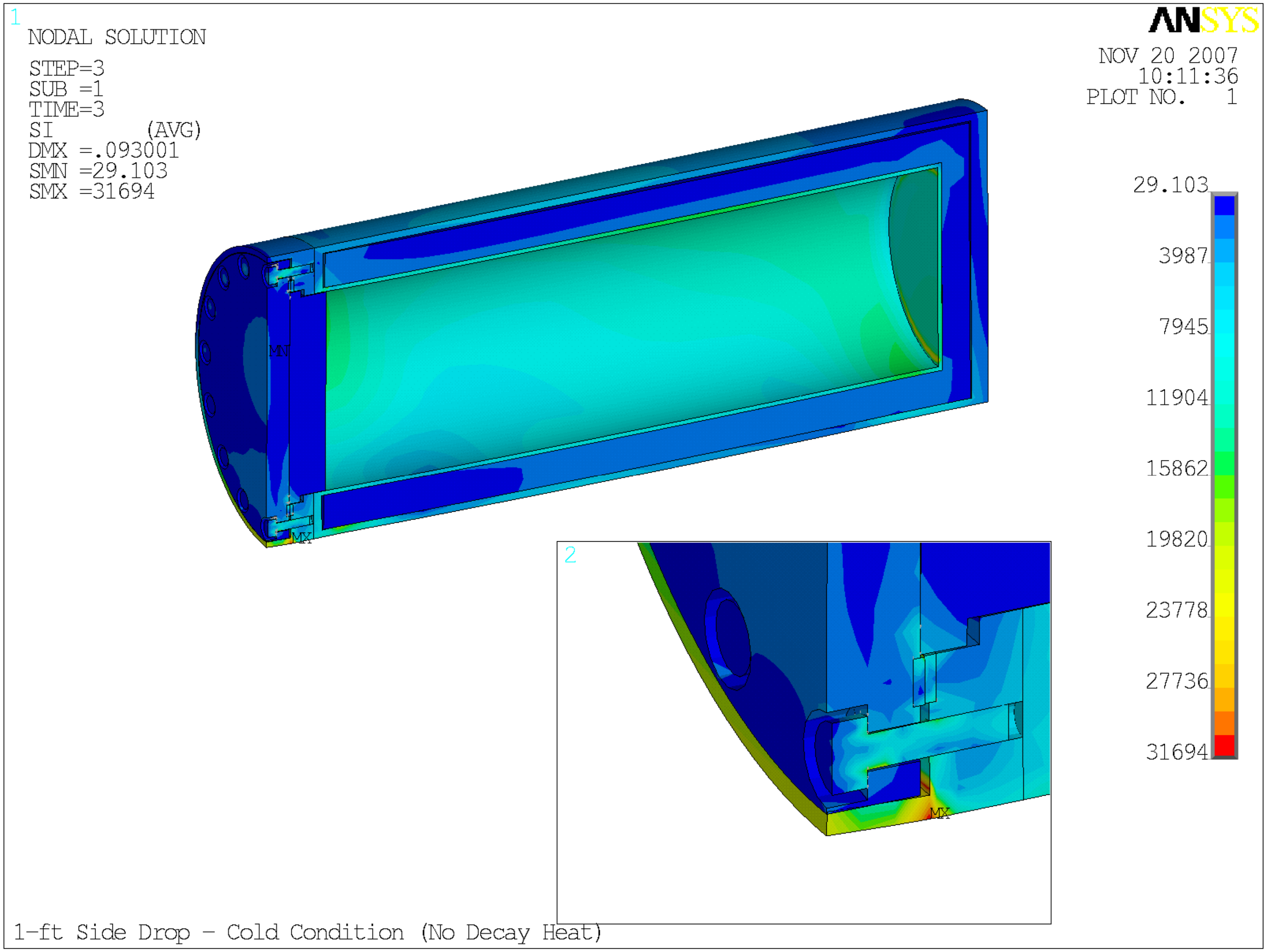

Figure 42

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

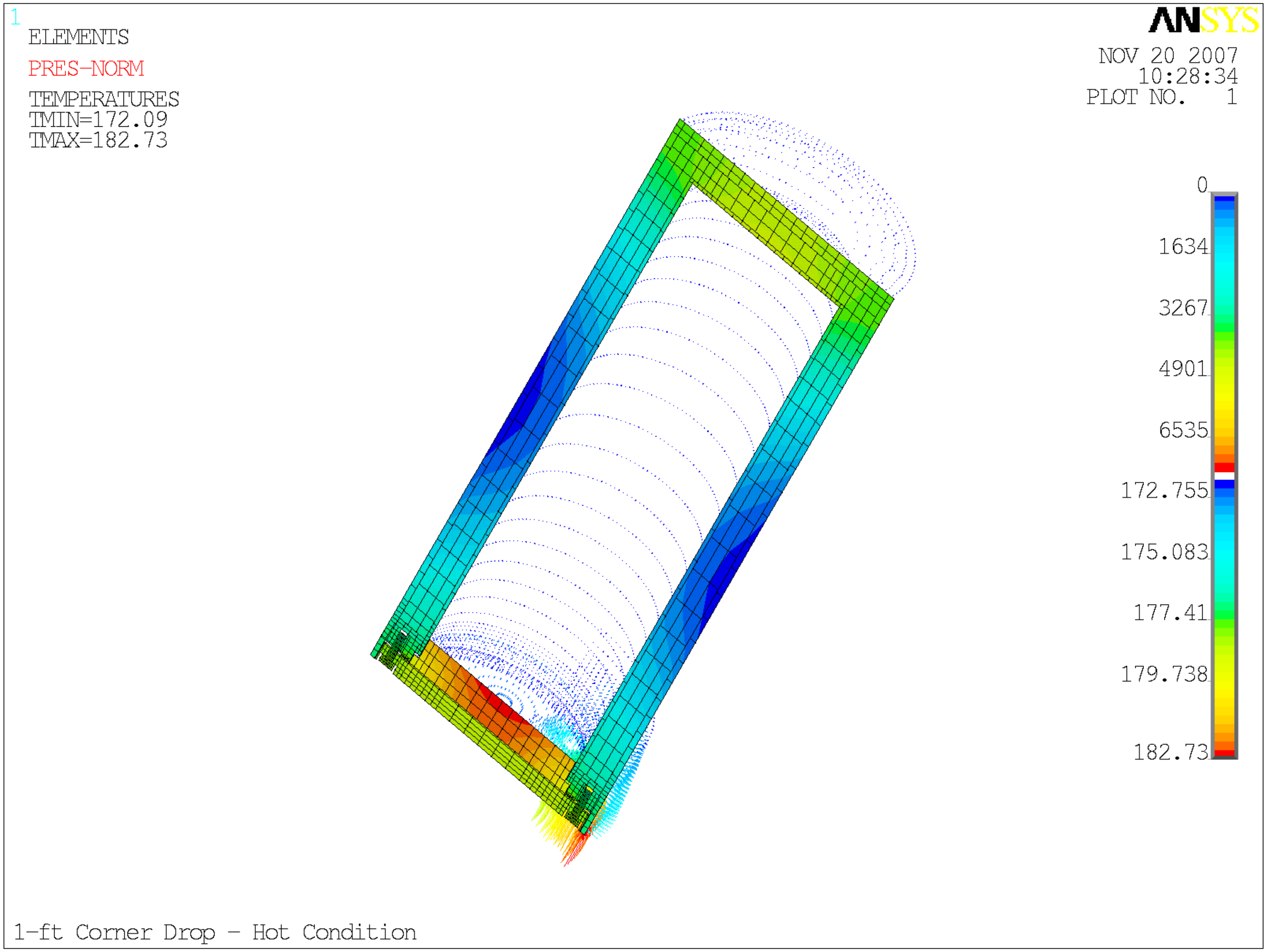

Figure 43

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

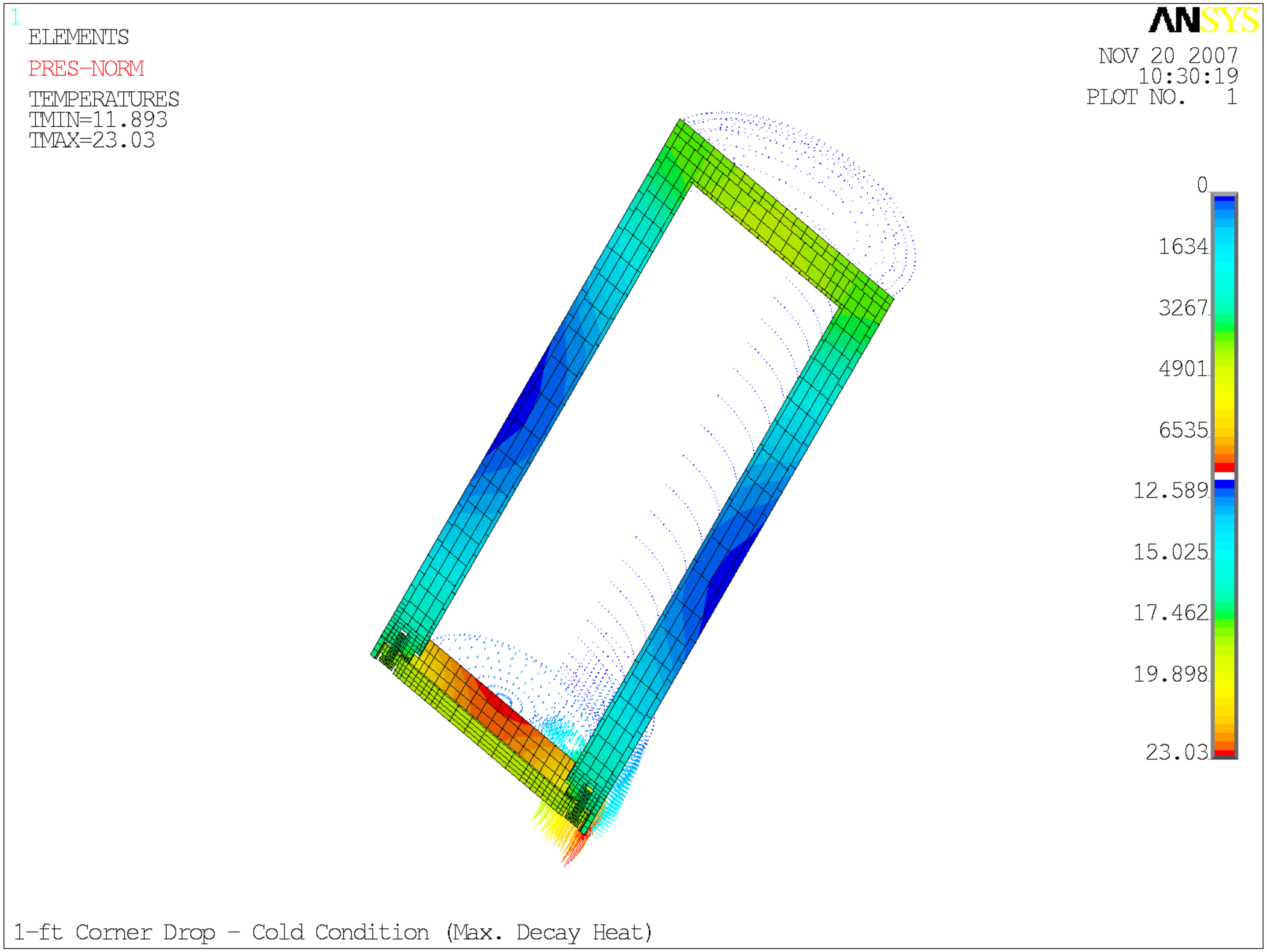

Figure 44

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

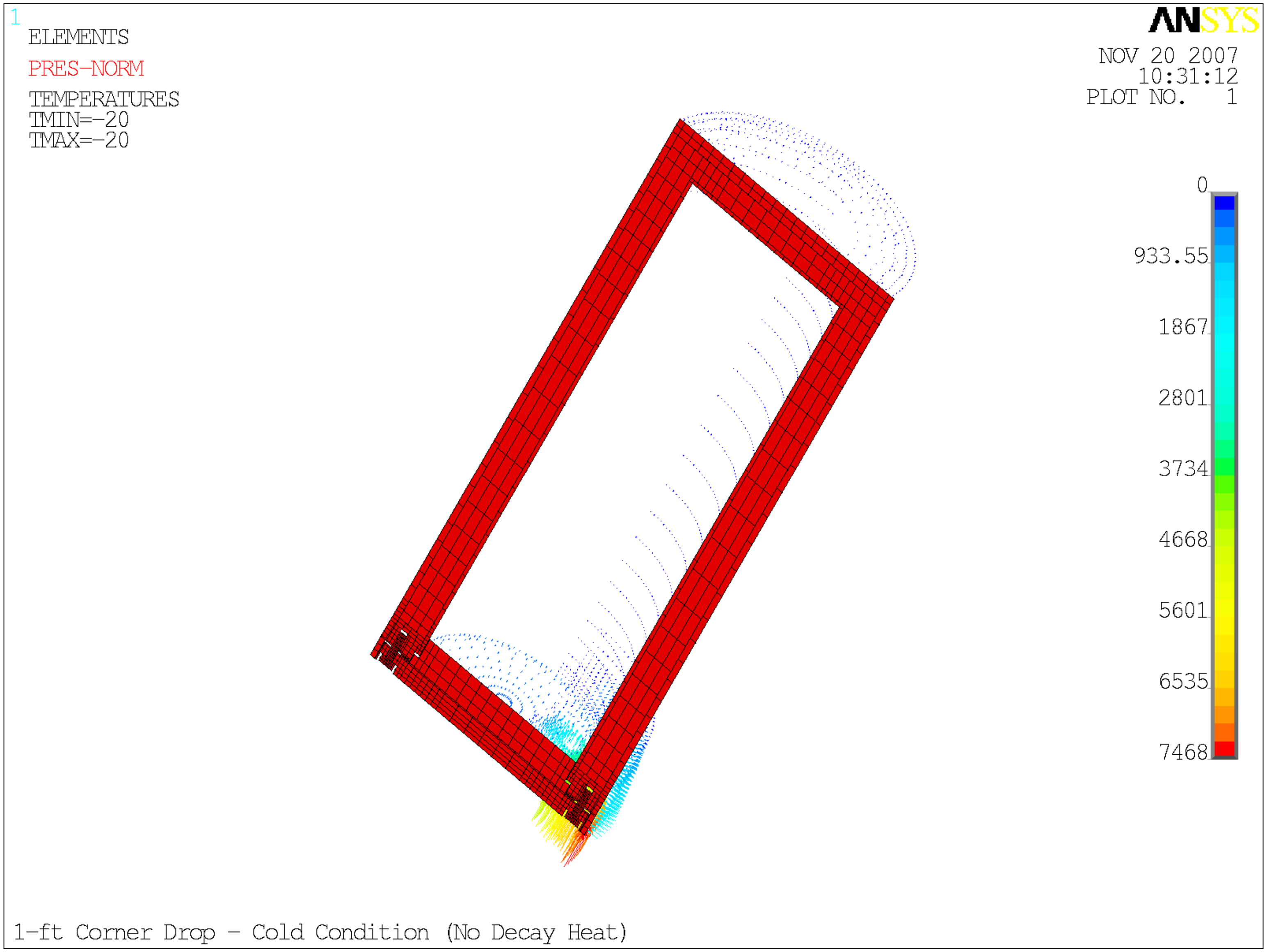

Figure 45

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

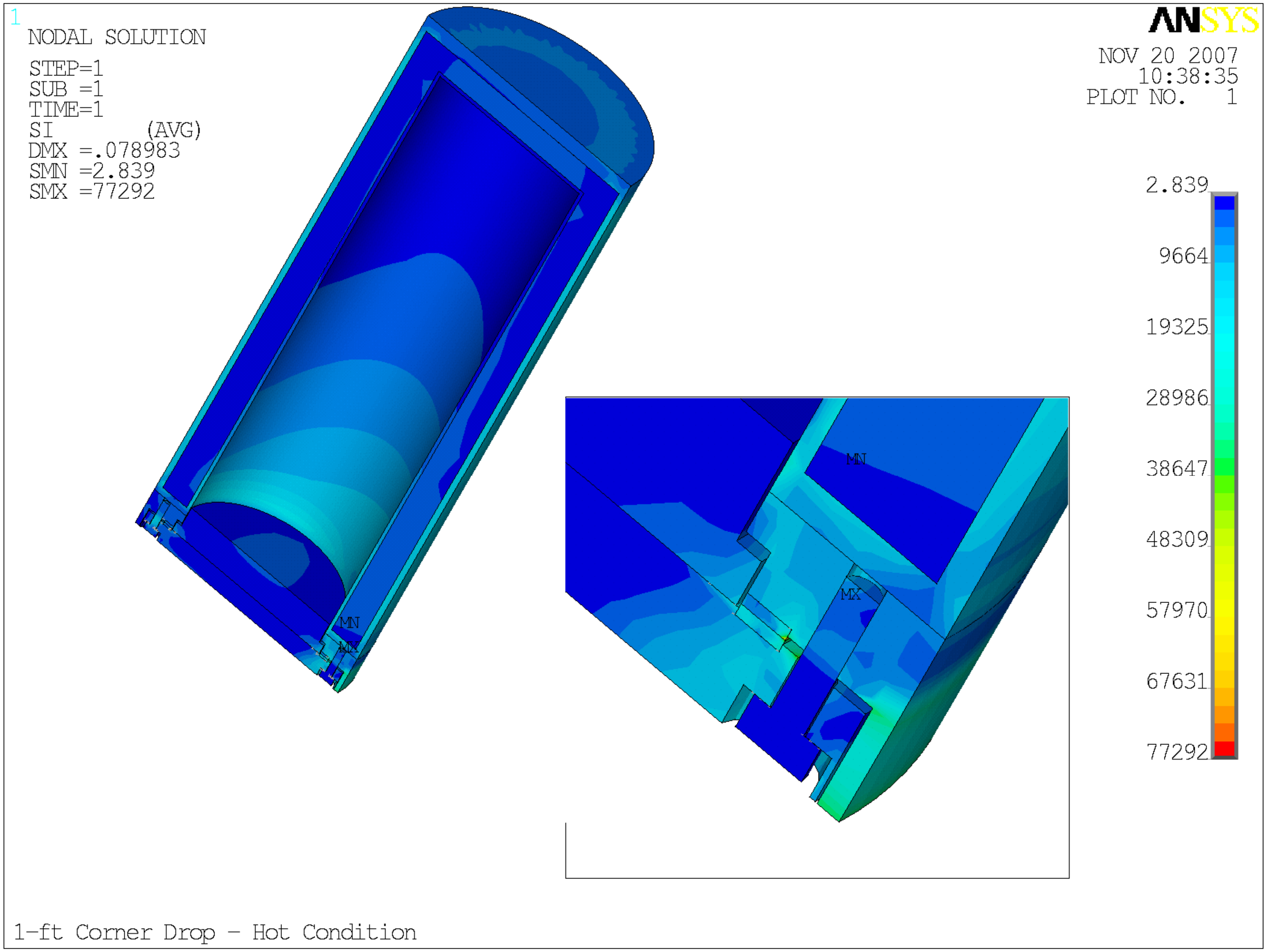

Figure 46

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

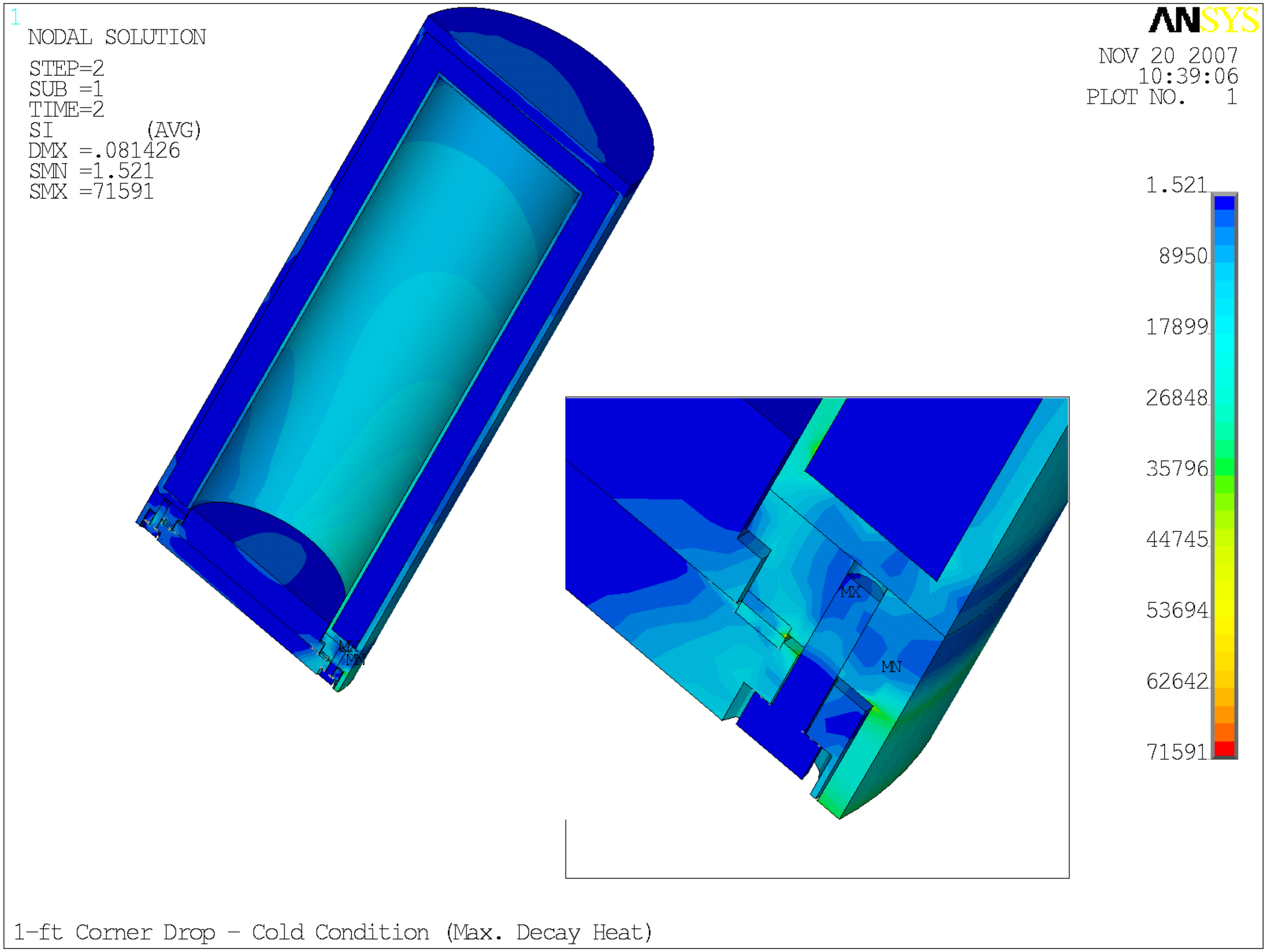

Figure 47

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

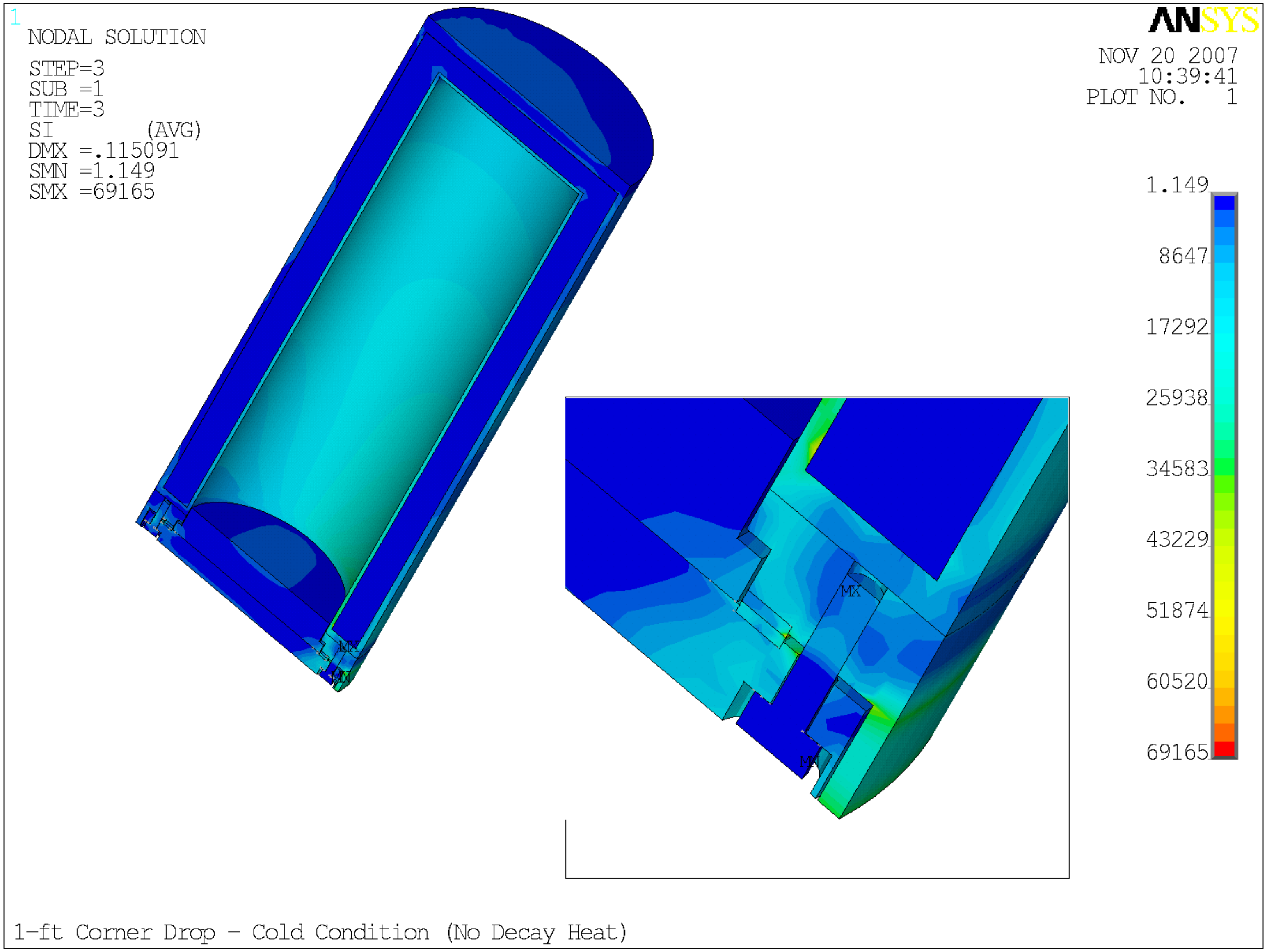

Figure 48

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

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

Summary Print-Out of the ANSYS Results and Stress Linearization

(52 Pages)

ANSYS FEM Drop Analyses Result Summary

30-ft End Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	32803.	34141.	35803.
Shell Extension	32727.	52643.	61463.(1)
Bolting Ring Skirt	30895.	21036.	19504.
Inner Shell	17652.	38207.	43700.
Outer Shell	31224.	24782.	24687.
Lid	30311.	33945.	35126.
Baseplates	14924.	24661.	27593.
Seal Plates	51854.(2)	56497.(2)	57706.(2)
Bolts	9023.	7592.	7442.

30-ft Side Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	89102.(3)	90474.(3)	90936.(3)
Shell Extension	45723.	48347.	52021.
Bolting Ring Skirt	138864.(3)	141086.(3)	141946.(3)
Inner Shell	44216.(1)	42230.(1)	43486.
Outer Shell	44151.(1)	47487.(1)	49364.(1)
Lid	40684.(1)	42435.(1)	41878.(1)
Baseplates	31876.	52020.(1)	57405.(1)
Seal Plates	104463.(2)	106333.(2)	103855.(2)
Bolts	57103.	55860.	54432.

30-ft Corner Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	139619.(3)	130466.(3)	126485.(3)
Shell Extension	47453.	71881.(1)	80758.(1)
Bolting Ring Skirt	99406.(3)	103380.(3)	104484.(3)
Inner Shell	35571.	50708.	55586.
Outer Shell	31297.	25953.	26917.
Lid	100032.(1)	96158.(1)	95863.(1)
Baseplates	10203.	16204.	21989.
Seal Plates	185156.(2)	173418.(2)	169949.(2)
Bolts	27642.	25437.	26079.

1-ft End Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	14825.	13602.	16002.
Shell Extension	18459.(1)	24129.(1)	30436.(1)
Bolting Ring Skirt	7951.	5097.	4370.
Inner Shell	4244.	17043.	21183.
Outer Shell	15035.(1)	7562.	7467.
Lid	10138.	10320.	11125.
Baseplates	10182.	12590.	18208.(1)
Seal Plates	16808.	17356.	19186.
Bolts	6725.	3646.	5301.

1-ft Side Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	21532.	22153.	22443.
Shell Extension	23587.(1)	18408.	23567.(1)
Bolting Ring Skirt	33725.(1)	34603.(1)	35103.(1)
Inner Shell	16467.	13051.	16167.
Outer Shell	20069.(1)	14816.	16807.(1)
Lid	7439.	10147.	11179.
Baseplates	12645.	18373.(1)	24154.(1)
Seal Plates	22040.(2)	26446.(2)	24543.(2)
Bolts	24328.	21543.	19916.

1-ft Corner Drop

	Hot Conditions	Cold (Max Heat)	Cold (No Heat)
Bolting Ring	55516.(3)	52478.(3)	49660.(3)
Shell Extension	26202.	41032.(1)	49505.(1)
Bolting Ring Skirt	43340.(3)	45737.(3)	46708.(3)
Inner Shell	14534.	27569.	32217.
Outer Shell	16269.(1)	12611.	14387.(1)
Lid	41359.(1)	39236.(1)	39298.(1)
Baseplates	10896.	11656.	18310.(1)
Seal Plates	77292.(2)	71591.(2)	69165.(2)
Bolts	18243.	14026.	13725.

NOTES:

(1) Stresses linearized over the cross-section for component qualification. See the following pages for stress linearization print-out.

(2) The maximum stress intensities in the seal plates are caused by compressive loadings. These stress intensities are classified as bearing stresses. The maximum principal stresses (tensile) are used for component qualification. See the corresponding ls1post.out file for hot conditions, ls2post.out file for Cold (Max. Heat) conditions and ls3post.out file for Cold (No Heat) conditions.

(3) Component qualified by alternate analyses. See Reference 12.

Stress Linearization Print-Out Index

Serial No.	Description
1	30-ft End Drop - Cold (No Heat) Conditions - Shell Extension
2	30-ft Side Drop - Hot Conditions - Inner Shell
3	30-ft Side Drop - Hot Conditions - Outer Shell
4	30-ft Side Drop - Hot Conditions - Lid
5	30-ft Side Drop - Cold (Max Heat) Conditions - Inner Shell
6	30-ft Side Drop - Cold (Max Heat) Conditions - Outer Shell
7	30-ft Side Drop - Cold (Max Heat) Conditions - Lid
8	30-ft Side Drop - Cold (Max Heat) Conditions - Baseplates
9	30-ft Side Drop - Cold (No Heat) Conditions - Outer Shell
10	30-ft Side Drop - Cold (No Heat) Conditions - Lid
11	30-ft Side Drop - Cold (No Heat) Conditions - Baseplates
12	30-ft Corner Drop - Hot Conditions - Lid
13	30-ft Corner Drop - Cold (Max Heat) Conditions - Shell Extension
14	30-ft Corner Drop - Cold (Max Heat) Conditions - Lid
15	30-ft Corner Drop - Cold (No Heat) Conditions - Shell Extension
16	30-ft Corner Drop - Cold (No Heat) Conditions - Lid
17	1-ft End Drop - Hot Conditions - Shell Extension
18	1-ft End Drop - Hot Conditions - Outer Shell
19	1-ft End Drop - Cold (Max Heat) Conditions - Shell Extension
20	1-ft End Drop - Cold (No Heat) Conditions - Shell Extension
21	1-ft End Drop - Cold (No Heat) Conditions - Baseplates
22	1-ft Side Drop - Hot Conditions - Shell Extension

23	1-ft Side Drop - Hot Conditions - Bolting Ring Skirt
24	1-ft Side Drop - Hot Conditions - Outer Shell
25	1-ft Side Drop - Cold (Max Heat) Conditions - Bolting Ring Skirt
26	1-ft Side Drop - Cold (Max Heat) Conditions - Baseplates
27	1-ft Side Drop - Cold (No Heat) Conditions - Shell Extension
28	1-ft Side Drop - Cold (No Heat) Conditions - Bolting Ring Skirt
29	1-ft Side Drop - Cold (No Heat) Conditions - Outer Shell
30	1-ft Side Drop - Cold (No Heat) Conditions - Baseplates
31	1-ft Corner Drop - Hot Conditions - Outer Shell
32	1-ft Corner Drop - Hot Conditions - Lid
33	1-ft Corner Drop - Cold (Max Heat) Conditions - Shell Extension
34	1-ft Corner Drop - Cold (Max Heat) Conditions - Lid
35	1-ft Corner Drop - Cold (No Heat) Conditions - Shell Extension
36	1-ft Corner Drop - Cold (No Heat) Conditions - Outer Shell
37	1-ft Corner Drop - Cold (No Heat) Conditions - Lid
38	1-ft Corner Drop - Cold (No Heat) Conditions - Baseplates

30-ft End Drop - Cold (No Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    1609     OUTSIDE NODE =    1504

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

            ** MEMBRANE **
    SX          SY          SZ          SXY         SYZ         SXZ
 -3246.     -0.1344E+05 -0.4212E+05   250.4       59.28       2134.
    S1          S2          S3          SINT        SEQV
 -3123.     -0.1345E+05 -0.4224E+05 0.3912E+05  0.3511E+05

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I   41.90       6438.      0.2236E+05  -157.1      -5.327      -206.1
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -41.90      -6438.     -0.2236E+05   157.1       5.327       206.1
    S1          S2          S3          SINT        SEQV
I  0.2237E+05   6442.       36.14      0.2233E+05  0.1992E+05
C   0.000       0.000       0.000       0.000       0.000
O  -36.14      -6442.     -0.2237E+05  0.2233E+05  0.1992E+05

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I  -3204.      -7007.     -0.1976E+05   93.24       53.95       1928.
C  -3246.    -0.1344E+05 -0.4212E+05   250.4       59.28       2134.
O  -3288.    -0.1988E+05 -0.6449E+05   407.5       64.61       2341.
    S1          S2          S3          SINT        SEQV
I  -2980.      -7009.     -0.1998E+05  0.1700E+05  0.1539E+05
C  -3123.    -0.1345E+05 -0.4224E+05  0.3912E+05  0.3511E+05
O  -3188.    -0.1989E+05 -0.6458E+05  0.6139E+05  0.5498E+05

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I  0.1819E-01   2.795       9.711     -0.6822E-01 -0.2313E-02 -0.8948E-01
C -0.1364E-11 -0.3820E-10 -0.1310E-09  0.9095E-12  0.4974E-13  0.1819E-11
O -0.1819E-01  -2.795      -9.711      0.6822E-01  0.2313E-02  0.8948E-01
    S1          S2          S3          SINT        SEQV
I   9.712       2.797      0.1569E-01   9.696       8.648
C -0.1316E-11 -0.3822E-10 -0.1310E-09  0.1297E-09  0.1157E-09
O -0.1569E-01  -2.797      -9.712       9.696       8.648

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
    SX          SY          SZ          SXY         SYZ         SXZ
I  -3204.      -7004.     -0.1975E+05   93.18       53.95       1928.
C  -3246.    -0.1344E+05 -0.4212E+05   250.4       59.28       2134.
O  -3288.    -0.1989E+05 -0.6450E+05   407.5       64.61       2341.
    S1          S2          S3          SINT        SEQV        TEMP
I  -2980.      -7006.     -0.1997E+05  0.1699E+05  0.1538E+05  -20.00
C  -3123.    -0.1345E+05 -0.4224E+05  0.3912E+05  0.3511E+05
O  -3188.    -0.1990E+05 -0.6459E+05  0.6140E+05  0.5498E+05  -20.00
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1658      OUTSIDE NODE =    1679

 LOAD STEP      3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
    SX           SY           SZ          SXY          SYZ          SXZ
  901.7      -0.1298E+05 -0.4216E+05   340.9        49.37        1794.
    S1           S2           S3          SINT         SEQV
  984.8      -0.1299E+05 -0.4223E+05  0.4322E+05  0.3820E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY           SZ          SXY          SYZ          SXZ
I  -23.89       4274.      0.1555E+05  -105.6        1.310        61.60
C   0.000       0.000       0.000       0.000        0.000        0.000
O   23.89      -4274.     -0.1555E+05   105.6       -1.310       -61.60
    S1           S2           S3          SINT         SEQV
I  0.1555E+05   4277.      -26.73      0.1558E+05  0.1394E+05
C   0.000       0.000       0.000       0.000        0.000
O   26.73      -4277.     -0.1555E+05  0.1558E+05  0.1394E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY           SZ          SXY          SYZ          SXZ
I   877.8      -8702.     -0.2660E+05   235.3        50.68        1856.
C   901.7     -0.1298E+05 -0.4216E+05   340.9        49.37        1794.
O   925.6     -0.1725E+05 -0.5771E+05   446.4        48.06        1732.
    S1           S2           S3          SINT         SEQV
I   1008.      -8708.     -0.2673E+05  0.2774E+05  0.2438E+05
C   984.8     -0.1299E+05 -0.4223E+05  0.4322E+05  0.3820E+05
O   987.8     -0.1726E+05 -0.5776E+05  0.5875E+05  0.5208E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY           SZ          SXY          SYZ          SXZ
I -0.1037E-01   1.856       6.753     -0.4585E-01  0.5689E-03  0.2675E-01
C -0.6821E-12 -0.9095E-11 -0.5821E-10  0.3979E-12   0.000        0.000
O  0.1037E-01  -1.856      -6.753      0.4585E-01 -0.5689E-03 -0.2675E-01
    S1           S2           S3          SINT         SEQV
I   6.754       1.857     -0.1161E-01   6.765        6.051
C -0.6633E-12 -0.9114E-11 -0.5821E-10  0.5754E-10  0.5382E-10
O  0.1161E-01  -1.857      -6.754       6.765        6.051

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY           SZ          SXY          SYZ          SXZ
I   877.8      -8700.     -0.2660E+05   235.2        50.68        1856.
C   901.7     -0.1298E+05 -0.4216E+05   340.9        49.37        1794.
O   925.6     -0.1725E+05 -0.5772E+05   446.5        48.06        1732.
    S1           S2           S3          SINT         SEQV         TEMP
I   1008.      -8706.     -0.2672E+05  0.2773E+05  0.2437E+05   -20.00
C   984.8     -0.1299E+05 -0.4223E+05  0.4322E+05  0.3820E+05
O   987.8     -0.1726E+05 -0.5777E+05  0.5875E+05  0.5209E+05   -20.00
```

30-ft Side Drop - Hot Conditions - Inner Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =    1781      OUTSIDE NODE =    1861

 LOAD STEP     1  SUBSTEP=     1
 TIME=    1.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY          SYZ          SXZ
 -64.42     -0.3324E+05   3156.        810.4        10.47        40.54
     S1          S2          S3          SINT         SEQV
  3156.       -45.16     -0.3326E+05  0.3642E+05   0.3493E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I   6.656       3959.      0.1176E+05  -97.17       -39.32       -33.00
C   0.000       0.000      0.000       0.000        0.000        0.000
O  -6.656      -3959.     -0.1176E+05  97.17        39.32        33.00
     S1          S2          S3          SINT         SEQV
I  0.1176E+05   3961.      4.170       0.1175E+05   0.1036E+05
C   0.000       0.000      0.000       0.000        0.000
O  -4.170      -3961.     -0.1176E+05  0.1175E+05   0.1036E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  -57.77     -0.2928E+05  0.1491E+05   713.2        -28.85       7.539
C  -64.42     -0.3324E+05   3156.       810.4         10.47       40.54
O  -71.08     -0.3720E+05  -8600.       907.6         49.80       73.55
     S1          S2          S3          SINT         SEQV
I  0.1491E+05  -40.37     -0.2930E+05  0.4421E+05   0.3895E+05
C   3156.      -45.16     -0.3326E+05  0.3642E+05   0.3493E+05
O  -48.25      -8601.     -0.3722E+05  0.3717E+05   0.3372E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  0.2890E-02   1.719       5.105     -0.4219E-01 -0.1708E-01 -0.1433E-01
C  0.1323E-10 -0.4366E-10  0.7276E-11  0.9095E-12  0.8704E-13 -0.1599E-11
O -0.2890E-02  -1.719      -5.105      0.4219E-01  0.1708E-01  0.1433E-01
     S1          S2          S3          SINT         SEQV
I   5.105       1.720      0.1811E-02   5.103        4.497
C  0.1365E-10  0.6876E-11 -0.4367E-10  0.5732E-10   0.5425E-10
O -0.1811E-02  -1.720      -5.105       5.103        4.497

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  -57.76     -0.2928E+05  0.1492E+05   713.2        -28.87       7.525
C  -64.42     -0.3324E+05   3156.       810.4         10.47       40.54
O  -71.08     -0.3720E+05  -8605.       907.6         49.81       73.56
     S1          S2          S3          SINT         SEQV         TEMP
I  0.1492E+05  -40.37     -0.2930E+05  0.4422E+05   0.3895E+05   177.4
C   3156.      -45.16     -0.3326E+05  0.3642E+05   0.3493E+05
O  -48.26      -8606.     -0.3722E+05  0.3718E+05   0.3372E+05   177.3
```

30-ft Side Drop - Hot Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1626      OUTSIDE NODE =   1645

 LOAD STEP      1  SUBSTEP=       1
 TIME=    1.0000            LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
 -4074.     -0.2318E+05  0.1061E+05   427.9      -304.6      -69.47
      S1          S2          S3          SINT        SEQV
 0.1061E+05  -4065.     -0.2319E+05  0.3380E+05  0.2936E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
I  -27.82       5619.     0.1597E+05  -139.6       8.877      0.1253E-03
C   0.000       0.000      0.000       0.000       0.000       0.000
O   27.82      -5619.    -0.1597E+05   139.6      -8.877     -0.1253E-03
      S1          S2          S3          SINT        SEQV
I  0.1597E+05   5623.      -31.27     0.1600E+05  0.1405E+05
C   0.000       0.000       0.000      0.000       0.000
O   31.27      -5623.    -0.1597E+05  0.1600E+05  0.1405E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
I  -4102.     -0.1756E+05  0.2658E+05   288.3      -295.7      -69.47
C  -4074.     -0.2318E+05  0.1061E+05   427.9      -304.6      -69.47
O  -4046.     -0.2880E+05  -5362.       567.6      -313.5      -69.47
      S1          S2          S3          SINT        SEQV
I  0.2658E+05  -4096.     -0.1757E+05  0.4415E+05  0.3919E+05
C  0.1061E+05  -4065.     -0.2319E+05  0.3380E+05  0.2936E+05
O  -4029.      -5363.     -0.2882E+05  0.2479E+05  0.2415E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
I -0.1208E-01   2.440       6.934     -0.6063E-01  0.3854E-02  0.5439E-07
C -0.9095E-12 -0.2910E-10 -0.8913E-10  0.7390E-12 -0.2842E-12 -0.1421E-13
O  0.1208E-01  -2.440      -6.934      0.6063E-01 -0.3854E-02 -0.5439E-07
      S1          S2          S3          SINT        SEQV
I   6.934       2.441     -0.1358E-01   6.948       6.102
C -0.8901E-12 -0.2912E-10 -0.8913E-10  0.8824E-10  0.7805E-10
O  0.1358E-01  -2.441      -6.934       6.948       6.102

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
I  -4102.     -0.1756E+05  0.2658E+05   288.2      -295.7      -69.47
C  -4074.     -0.2318E+05  0.1061E+05   427.9      -304.6      -69.47
O  -4046.     -0.2880E+05  -5369.       567.6      -313.5      -69.47
      S1          S2          S3          SINT        SEQV        TEMP
I  0.2658E+05  -4096.     -0.1757E+05  0.4415E+05  0.3919E+05   176.0
C  0.1061E+05  -4065.     -0.2319E+05  0.3380E+05  0.2936E+05
O  -4029.      -5370.     -0.2882E+05  0.2479E+05  0.2415E+05   176.0
```

30-ft Side Drop - Hot Conditions - Lid

```
 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT       DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     266     OUTSIDE NODE =     87

  LOAD STEP      1  SUBSTEP=      1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
   6020.      -2521.       8895.       199.4       1110.      -0.1293E+05
      S1          S2          S3          SINT        SEQV
  0.2049E+05  -2299.      -5793.      0.2628E+05  0.2472E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   8859.      -1592.       1756.       245.7      -10.97      -7126.
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O  -8859.       1592.      -1756.      -245.7       10.97       7126.
      S1          S2          S3          SINT        SEQV
 I  0.1327E+05  -1582.      -2668.      0.1594E+05  0.1543E+05
 C   0.000       0.000       0.000       0.000       0.000
 O   2668.       1582.     -0.1327E+05  0.1594E+05  0.1543E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  0.1488E+05  -4113.      0.1065E+05  445.1       1099.      -0.2005E+05
 C   6020.      -2521.       8895.       199.4       1110.      -0.1293E+05
 O  -2838.      -928.8       7139.      -46.35       1121.      -5802.
      S1          S2          S3          SINT        SEQV
 I  0.3293E+05  -3774.      -7743.      0.4068E+05  0.3885E+05
 C  0.2049E+05  -2299.      -5793.      0.2628E+05  0.2472E+05
 O   9902.      -988.6      -5541.      0.1544E+05  0.1374E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   3.847      -0.6912      0.7623      0.1067     -0.4765E-02  -3.094
 C  0.7003E-10 -0.2865E-10  0.1037E-09  0.3809E-11  0.4547E-11 -0.1837E-09
 O  -3.847       0.6912     -0.7623     -0.1067      0.4765E-02   3.094
      S1          S2          S3          SINT        SEQV
 I   5.763      -0.6868     -1.159       6.922       6.698
 C  0.2713E-09 -0.2815E-10 -0.9813E-10  0.3695E-09  0.3399E-09
 O   1.159       0.6868     -5.763       6.922       6.698

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  0.1488E+05  -4113.      0.1065E+05  445.2       1099.      -0.2006E+05
 C   6020.      -2521.       8895.       199.4       1110.      -0.1293E+05
 O  -2842.      -928.1       7139.      -46.46       1121.      -5799.
      S1          S2          S3          SINT        SEQV        TEMP
 I  0.3294E+05  -3775.      -7744.      0.4068E+05  0.3885E+05   177.9
 C  0.2049E+05  -2299.      -5793.      0.2628E+05  0.2472E+05
 O   9899.      -988.0      -5542.      0.1544E+05  0.1374E+05   178.0
```

30-ft Side Drop - Cold (Max Heat) Conditions - Inner Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    1781      OUTSIDE NODE =    1861

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

            ** MEMBRANE **
     SX          SY          SZ          SXY          SYZ          SXZ
  819.3     -0.3670E+05  -1274.       911.7        30.38        107.9
     S1          S2          S3          SINT         SEQV
  847.0      -1280.      -0.3672E+05  0.3756E+05  0.3655E+05

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  -6.578       3397.      0.1018E+05  -83.81       -35.76       51.98
C   0.000       0.000       0.000       0.000        0.000        0.000
O   6.578      -3397.     -0.1018E+05   83.81        35.76       -51.98
     S1          S2          S3          SINT         SEQV
I  0.1018E+05   3399.      -8.897      0.1019E+05   8984.
C   0.000       0.000       0.000       0.000        0.000
O   8.897      -3399.     -0.1018E+05  0.1019E+05   8984.

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I   812.7     -0.3330E+05   8905.       827.9       -5.378        159.9
C   819.3     -0.3670E+05  -1274.       911.7        30.38        107.9
O   825.9     -0.4009E+05 -0.1145E+05   995.5        66.13        55.94
     S1          S2          S3          SINT         SEQV
I   8908.       829.6     -0.3332E+05  0.4223E+05  0.3882E+05
C   847.0      -1280.     -0.3672E+05  0.3756E+05  0.3655E+05
O   850.4     -0.1145E+05 -0.4012E+05  0.4097E+05  0.3641E+05

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I -0.2856E-02   1.475       4.420     -0.3639E-01 -0.1553E-01  0.2257E-01
C  0.2512E-10 -0.2183E-10  0.6821E-11  0.1137E-11  0.1030E-12 -0.2203E-11
O  0.2856E-02  -1.475      -4.420      0.3639E-01  0.1553E-01 -0.2257E-01
     S1          S2          S3          SINT         SEQV
I   4.420       1.476     -0.3863E-02   4.424        3.901
C  0.2541E-10  0.6562E-11 -0.2186E-10  0.4727E-10  0.4121E-10
O  0.3863E-02  -1.476      -4.420       4.424        3.901

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I   812.7     -0.3330E+05   8910.       827.9       -5.393        159.9
C   819.3     -0.3670E+05  -1274.       911.7        30.38        107.9
O   825.9     -0.4009E+05 -0.1146E+05   995.5        66.15        55.91
     S1          S2          S3          SINT         SEQV        TEMP
I   8913.       829.6     -0.3332E+05  0.4223E+05  0.3882E+05    17.34
C   847.0      -1280.     -0.3672E+05  0.3756E+05  0.3655E+05
O   850.4     -0.1146E+05 -0.4012E+05  0.4097E+05  0.3641E+05    17.22
```

30-ft Side Drop - Cold (Max Heat) Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    1626      OUTSIDE NODE =    1645

 LOAD STEP      2   SUBSTEP=      1
 TIME=    2.0000             LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY           SZ          SXY         SYZ          SXZ
 -3729.     -0.3274E+05   2445.       687.1       -291.0       424.6
     S1          S2           S3          SINT        SEQV
  2476.      -3741.      -0.3276E+05  0.3523E+05  0.3257E+05

             ** BENDING **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY         SYZ          SXZ
I  -17.46       5841.       0.1812E+05  -144.5       1.628       -0.7591E-09
C   0.000       0.000        0.000       0.000       0.000        0.000
O   17.46      -5841.      -0.1812E+05   144.5      -1.628        0.7591E-09
     S1          S2           S3          SINT        SEQV
I  0.1812E+05   5844.       -21.02      0.1814E+05  0.1603E+05
C   0.000       0.000        0.000       0.000       0.000
O   21.02      -5844.      -0.1812E+05  0.1814E+05  0.1603E+05

             ** MEMBRANE PLUS BENDING **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY         SYZ          SXZ
I  -3747.     -0.2690E+05  0.2056E+05   542.6       -289.4       424.6
C  -3729.     -0.3274E+05   2445.       687.1       -291.0       424.6
O  -3712.     -0.3858E+05 -0.1567E+05   831.6       -292.6       424.6
     S1          S2           S3          SINT        SEQV
I  0.2057E+05  -3741.      -0.2691E+05  0.4748E+05  0.4112E+05
C   2476.      -3741.      -0.3276E+05  0.3523E+05  0.3257E+05
O  -3678.     -0.1568E+05 -0.3860E+05  0.3492E+05  0.3073E+05

             ** PEAK **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY         SYZ          SXZ
I -0.7580E-02   2.536       7.867      -0.6274E-01  0.7068E-03 -0.5116E-12
C -0.9095E-12 -0.2183E-10 -0.9413E-10  0.5684E-12 -0.1705E-12 -0.1137E-12
O  0.7580E-02  -2.536      -7.867       0.6274E-01 -0.7068E-03  0.1705E-12
     S1          S2           S3          SINT        SEQV
I   7.867       2.538      -0.9126E-02   7.876       6.961
C -0.8939E-12 -0.2184E-10 -0.9413E-10  0.9324E-10  0.8473E-10
O  0.9126E-02  -2.538      -7.867        7.876       6.961

             ** TOTAL **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY           SZ          SXY         SYZ          SXZ
I  -3747.     -0.2689E+05  0.2057E+05   542.5       -289.4       424.6
C  -3729.     -0.3274E+05   2445.       687.1       -291.0       424.6
O  -3712.     -0.3858E+05 -0.1568E+05   831.6       -292.6       424.6
     S1          S2           S3          SINT        SEQV         TEMP
I  0.2058E+05  -3741.      -0.2691E+05  0.4749E+05  0.4113E+05   15.94
C   2476.      -3741.      -0.3276E+05  0.3523E+05  0.3257E+05
O  -3678.     -0.1569E+05 -0.3860E+05  0.3493E+05  0.3073E+05   15.92
```

30-ft Side Drop - Cold (Max Heat) Conditions - Lid

PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT DSYS= 0

***** POST1 LINEARIZED STRESS LISTING *****
INSIDE NODE = 266 OUTSIDE NODE = 87

LOAD STEP 2 SUBSTEP= 1
TIME= 2.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

** MEMBRANE **

SX	SY	SZ	SXY	SYZ	SXZ
5900.	-2437.	0.1215E+05	27.67	1204.	-0.1332E+05
S1	**S2**	**S3**	**SINT**	**SEQV**	
0.2274E+05	-2227.	-4897.	$\boxed{0.2764E+05}$	0.2640E+05	

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	8655.	-1605.	2932.	132.4	-87.71	-7727.
C	0.000	0.000	0.000	0.000	0.000	0.000
O	-8655.	1605.	-2932.	-132.4	87.71	7727.
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	0.1403E+05	-1606.	-2447.	0.1648E+05	0.1608E+05	
C	0.000	0.000	0.000	0.000	0.000	
O	2447.	1606.	-0.1403E+05	0.1648E+05	0.1608E+05	

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	0.1455E+05	-4041.	0.1509E+05	160.1	1116.	-0.2104E+05
C	5900.	-2437.	0.1215E+05	27.67	1204.	-0.1332E+05
O	-2755.	-831.9	9222.	-104.7	1292.	-5591.
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	0.3588E+05	-3730.	-6550.	$\boxed{0.4243E+05}$	0.4109E+05	
C	0.2274E+05	-2227.	-4897.	0.2764E+05	0.2640E+05	
O	0.1155E+05	-921.4	-4994.	0.1654E+05	0.1493E+05	

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	3.758	-0.6968	1.273	0.5748E-01	-0.3809E-01	-3.355
C	0.5639E-10	-0.3774E-10	0.1510E-09	0.3443E-11	0.4547E-11	-0.1874E-09
O	-3.758	0.6968	-1.273	-0.5748E-01	0.3809E-01	3.355
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	6.094	-0.6975	-1.062	7.157	6.981	
C	0.2969E-09	-0.3717E-10	-0.9013E-10	0.3871E-09	0.3635E-09	
O	1.062	0.6975	-6.094	7.157	6.981	

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	0.1456E+05	-4042.	0.1509E+05	160.1	1116.	-0.2105E+05
C	5900.	-2437.	0.1215E+05	27.67	1204.	-0.1332E+05
O	-2759.	-831.2	9221.	-104.8	1292.	-5587.
	S1	**S2**	**S3**	**SINT**	**SEQV**	**TEMP**
I	0.3588E+05	-3731.	-6551.	0.4243E+05	0.4110E+05	17.86
C	0.2274E+05	-2227.	-4897.	0.2764E+05	0.2640E+05	
O	0.1155E+05	-920.8	-4995.	0.1654E+05	0.1493E+05	17.95

30-ft Side Drop - Cold (Max Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    2140      OUTSIDE NODE =    2167

 LOAD STEP      2  SUBSTEP=      1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
-0.2492E+05 -0.2197E+05   1065.        62.63      -37.96       1677.
     S1          S2          S3          SINT        SEQV
  1172.      -0.2197E+05 -0.2503E+05  0.2621E+05  0.2482E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2439E+05  -8815.     -0.4930     -227.4     -0.2166E-10  0.3036E-09
C   0.000       0.000       0.000       0.000       0.000       0.000
O  0.2439E+05   8815.      0.4930      227.4      0.2166E-10 -0.3036E-09
     S1          S2          S3          SINT        SEQV
I -0.4930      -8811.     -0.2440E+05  0.2440E+05  0.2140E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.2440E+05   8811.      0.4930      0.2440E+05  0.2140E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.4932E+05 -0.3078E+05   1064.      -164.7      -37.96       1677.
C -0.2492E+05 -0.2197E+05   1065.       62.63      -37.96       1677.
O  -530.0     -0.1315E+05   1065.       290.0      -37.96       1677.
     S1          S2          S3          SINT        SEQV
I   1120.     -0.3078E+05 -0.4938E+05  0.5050E+05  0.4423E+05
C   1172.     -0.2197E+05 -0.2503E+05  0.2621E+05  0.2482E+05
O   2125.      -1583.     -0.1316E+05  0.1529E+05  0.1381E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -10.59      -3.827     -0.2141E-03 -0.9872E-01  0.1613E-11 -0.1137E-11
C  0.3638E-11 -0.3638E-11 -0.1364E-11   0.000      0.2629E-12 -0.4547E-12
O   10.59       3.827      0.2141E-03  0.9872E-01  0.4121E-12 -0.9095E-12
     S1          S2          S3          SINT        SEQV
I -0.2141E-03  -3.826      -10.59       10.59       9.292
C  0.3679E-11 -0.1375E-11 -0.3668E-11  0.7347E-11  0.6511E-11
O   10.59       3.826      0.2141E-03   10.59       9.292

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.4933E+05 -0.3079E+05   1064.      -164.8      -37.96       1677.
C -0.2492E+05 -0.2197E+05   1065.       62.63      -37.96       1677.
O  -519.4     -0.1315E+05   1065.       290.1      -37.96       1677.
     S1          S2          S3          SINT        SEQV        TEMP
I   1120.     -0.3079E+05 -0.4939E+05  0.5051E+05  0.4424E+05   18.08
C   1172.     -0.2197E+05 -0.2503E+05  0.2621E+05  0.2482E+05
O   2128.      -1575.     -0.1316E+05  0.1529E+05  0.1381E+05   17.96
```

30-ft Side Drop - Cold (No Heat) Conditions - Outer Shell

```
 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1626      OUTSIDE NODE =    1645

  LOAD STEP     3  SUBSTEP=      1
  TIME=    3.0000           LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
      SX           SY           SZ          SXY          SYZ          SXZ
  -3758.     -0.3429E+05   2366.        725.3       -285.3        499.7
      S1           S2           S3          SINT         SEQV
   2408.      -3780.      -0.3430E+05  0.3671E+05  0.3404E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX           SY           SZ          SXY          SYZ          SXZ
 I  -19.70        5894.       0.1857E+05  -145.9       0.5191      -0.6071E-09
 C   0.000        0.000        0.000        0.000       0.000        0.000
 O   19.70       -5894.      -0.1857E+05   145.9      -0.5191       0.6071E-09
      S1           S2           S3          SINT         SEQV
 I  0.1857E+05    5897.       -23.30      0.1860E+05  0.1646E+05
 C   0.000        0.000        0.000        0.000       0.000
 O   23.30       -5897.      -0.1857E+05  0.1860E+05  0.1646E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX           SY           SZ          SXY          SYZ          SXZ
 I  -3778.      -0.2839E+05  0.2094E+05   579.4       -284.8        499.7
 C  -3758.      -0.3429E+05   2366.       725.3       -285.3        499.7
 O  -3738.      -0.4018E+05 -0.1621E+05   871.2       -285.8        499.7
      S1           S2           S3          SINT         SEQV
 I  0.2095E+05   -3774.      -0.2841E+05  0.4936E+05  0.4275E+05
 C   2408.       -3780.      -0.3430E+05  0.3671E+05  0.3404E+05
 O  -3698.      -0.1622E+05 -0.4020E+05  0.3651E+05  0.3213E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX           SY           SZ          SXY          SYZ          SXZ
 I -0.8556E-02    2.559        8.065      -0.6335E-01  0.2254E-03 -0.1705E-12
 C   0.000      -0.3638E-10 -0.9550E-10  0.9095E-12  0.5684E-13  0.1137E-12
 O  0.8556E-02   -2.559       -8.065      0.6335E-01 -0.2254E-03  0.2842E-12
      S1           S2           S3          SINT         SEQV
 I   8.065        2.561      -0.1012E-01   8.075        7.145
 C  0.2286E-13 -0.3640E-10 -0.9550E-10  0.9552E-10  0.8350E-10
 O  0.1012E-01   -2.561       -8.065       8.075        7.145

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX           SY           SZ          SXY          SYZ          SXZ
 I  -3778.      -0.2839E+05  0.2095E+05   579.3       -284.8        499.7
 C  -3758.      -0.3429E+05   2366.       725.3       -285.3        499.7
 O  -3738.      -0.4018E+05 -0.1622E+05   871.2       -285.8        499.7
      S1           S2           S3          SINT         SEQV         TEMP
 I  0.2096E+05   -3774.      -0.2840E+05  0.4936E+05  0.4275E+05   -20.00
 C   2408.       -3780.      -0.3430E+05  0.3671E+05  0.3404E+05
 O  -3698.      -0.1623E+05 -0.4021E+05  0.3651E+05  0.3213E+05   -20.00
```

30-ft Side Drop - Cold (No Heat) Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT       DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     266     OUTSIDE NODE =     87

 LOAD STEP     3   SUBSTEP=     1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  5590.      -2605.      0.1282E+05  -18.11       1297.      -0.1302E+05
     S1          S2          S3          SINT        SEQV
 0.2276E+05  -2345.      -4605.      0.2736E+05  0.2630E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   8293.      -1595.       3221.       54.68      -73.26      -7689.
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -8293.       1595.      -3221.      -54.68       73.26       7689.
     S1          S2          S3          SINT        SEQV
I  0.1385E+05  -1595.      -2340.      0.1619E+05  0.1583E+05
C   0.000       0.000       0.000       0.000       0.000
O   2340.       1595.     -0.1385E+05  0.1619E+05  0.1583E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1388E+05  -4200.      0.1604E+05   36.57       1223.      -0.2070E+05
C   5590.      -2605.      0.1282E+05  -18.11       1297.      -0.1302E+05
O  -2703.      -1010.       9599.      -72.80       1370.      -5326.
     S1          S2          S3          SINT        SEQV
I  0.3571E+05  -3830.      -6159.      0.4187E+05  0.4076E+05
C  0.2276E+05  -2345.      -4605.      0.2736E+05  0.2630E+05
O  0.1172E+05  -1098.      -4735.      0.1645E+05  0.1497E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   3.601      -0.6927      1.399      0.2374E-01 -0.3181E-01  -3.339
C  0.5275E-10 -0.4138E-10  0.1601E-09  0.2629E-11  0.4547E-11 -0.1874E-09
O  -3.601       0.6927     -1.399     -0.2374E-01  0.3181E-01   3.339
     S1          S2          S3          SINT        SEQV
I   6.015      -0.6924     -1.016       7.032       6.875
C  0.3013E-09 -0.4090E-10 -0.8897E-10  0.3903E-09  0.3686E-09
O   1.016       0.6924     -6.015       7.032       6.875

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1389E+05  -4201.      0.1604E+05   36.60       1223.      -0.2071E+05
C   5590.      -2605.      0.1282E+05  -18.11       1297.      -0.1302E+05
O  -2706.      -1009.       9598.      -72.82       1370.      -5323.
     S1          S2          S3          SINT        SEQV        TEMP
I  0.3572E+05  -3831.      -6160.      0.4188E+05  0.4076E+05  -20.00
C  0.2276E+05  -2345.      -4605.      0.2736E+05  0.2630E+05
O  0.1172E+05  -1098.      -4736.      0.1645E+05  0.1497E+05  -20.00
```

30-ft Side Drop - Cold (No Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    2140     OUTSIDE NODE =    2167

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
-0.2849E+05 -0.2543E+05   754.0       78.18       69.35       2567.
     S1          S2          S3          SINT        SEQV
  977.8     -0.2543E+05 -0.2872E+05  0.2969E+05  0.2819E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2446E+05  -8377.     -0.1272E-09  -160.0    -0.7091E-11 -0.7782E-10
C   0.000       0.000       0.000       0.000       0.000       0.000
O  0.2446E+05   8377.      0.1272E-09   160.0     0.7091E-11  0.7782E-10
     S1          S2          S3          SINT        SEQV
I   0.000      -8376.     -0.2447E+05  0.2447E+05  0.2154E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.2447E+05   8376.       0.000      0.2447E+05  0.2154E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.5295E+05 -0.3380E+05   754.0      -81.84       69.35       2567.
C -0.2849E+05 -0.2543E+05   754.0       78.18       69.35       2567.
O  -4027.     -0.1705E+05   754.0       238.2       69.35       2567.
     S1          S2          S3          SINT        SEQV
I   876.5     -0.3380E+05 -0.5308E+05  0.5395E+05  0.4736E+05
C   977.8     -0.2543E+05 -0.2872E+05  0.2969E+05  0.2819E+05
O   1872.      -5140.     -0.1705E+05  0.1893E+05  0.1657E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -10.62      -3.638     -0.7390E-11 -0.6948E-01  0.5116E-12 -0.5457E-11
C  0.1819E-10   0.000     -0.1251E-11  0.2842E-13  0.7105E-13 -0.9095E-12
O   10.62       3.638     -0.1705E-11  0.6948E-01  0.1279E-12 -0.9095E-12
     S1          S2          S3          SINT        SEQV
I   0.000      -3.637      -10.62       10.62       9.351
C  0.1823E-10  0.3996E-14 -0.1297E-11  0.1953E-10  0.1891E-10
O   10.62       3.637       0.000       10.62       9.351

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.5297E+05 -0.3381E+05   754.0      -81.91       69.35       2567.
C -0.2849E+05 -0.2543E+05   754.0       78.18       69.35       2567.
O  -4016.     -0.1705E+05   754.0       238.3       69.35       2567.
     S1          S2          S3          SINT        SEQV        TEMP
I   876.5     -0.3381E+05 -0.5309E+05  0.5396E+05  0.4736E+05  -20.00
C   977.8     -0.2543E+05 -0.2872E+05  0.2969E+05  0.2819E+05
O   1874.      -5132.     -0.1705E+05  0.1892E+05  0.1657E+05  -20.00
```

30-ft Corner Drop - Hot Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     150      OUTSIDE NODE =    191

 LOAD STEP     1  SUBSTEP=      1
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
-0.1184E+05 -0.2275E+05  2354.       -872.1       5379.       1612.
     S1          S2          S3          SINT        SEQV
  3587.      -0.1185E+05 -0.2397E+05  0.2755E+05  0.2392E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.2726E+05  0.3556E+05 -0.1622E+05  4020.       4095.      -1989.
C   0.000       0.000       0.000       0.000       0.000       0.000
O -0.2726E+05 -0.3556E+05  0.1622E+05 -4020.      -4095.       1989.
     S1          S2          S3          SINT        SEQV
I  0.3737E+05  0.2590E+05 -0.1667E+05  0.5404E+05  0.4931E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.1667E+05 -0.2590E+05 -0.3737E+05  0.5404E+05  0.4931E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1542E+05  0.1282E+05 -0.1387E+05  3148.       9474.      -377.1
C -0.1184E+05 -0.2275E+05  2354.      -872.1       5379.       1612.
O -0.3910E+05 -0.5831E+05  0.1858E+05 -4892.       1283.       3601.
     S1          S2          S3          SINT        SEQV
I  0.1855E+05  0.1277E+05 -0.1694E+05  0.3549E+05  0.3298E+05
C   3587.     -0.1185E+05 -0.2397E+05  0.2755E+05  0.2392E+05
O  0.1881E+05 -0.3811E+05 -0.5954E+05  0.7836E+05  0.7014E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -7688.      -3181.       4103.       910.9      -2239.       312.8
C   4868.       2152.      -2554.      -516.6       1366.      -78.90
O -0.2220E+05  -590.3      0.1479E+05  6453.      -9814.       8771.
     S1          S2          S3          SINT        SEQV
I   4736.      -3589.      -7914.      0.1265E+05  0.1114E+05
C   4978.       2410.      -2922.       7900.       6980.
O  0.2023E+05  -1190.     -0.2704E+05  0.4727E+05  0.4100E+05

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   7735.       9637.      -9766.       4059.       7234.      -64.23
C  -6971.     -0.2059E+05  -199.5      -1389.       6745.       1533.
O -0.6131E+05 -0.5890E+05  0.3337E+05  1561.      -8531.      0.1237E+05
     S1          S2          S3          SINT        SEQV        TEMP
I  0.1430E+05   5566.     -0.1226E+05  0.2656E+05  0.2344E+05   177.9
C   1959.      -6902.     -0.2282E+05  0.2478E+05  0.2175E+05
O  0.3568E+05 -0.5817E+05 -0.6435E+05  0.1000E+06  0.9709E+05   178.0
```

30-ft Corner Drop - Cold (Max Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1609      OUTSIDE NODE =    1504

 LOAD STEP      2  SUBSTEP=      1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -2518.     -0.1443E+05 -0.5391E+05   386.2       -290.3       2155.
     S1          S2          S3          SINT        SEQV
 -2416.     -0.1443E+05 -0.5400E+05  0.5158E+05  0.4675E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -52.10       5791.      0.2026E+05  -141.6       41.77       -191.5
C   0.000       0.000       0.000       0.000       0.000        0.000
O   52.10      -5791.     -0.2026E+05   141.6      -41.77        191.5
     S1          S2          S3          SINT        SEQV
I  0.2026E+05   5794.      -57.31      0.2032E+05  0.1812E+05
C   0.000       0.000       0.000       0.000       0.000
O   57.31      -5794.     -0.2026E+05  0.2032E+05  0.1812E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -2570.      -8634.     -0.3364E+05   244.6      -248.5        1963.
C  -2518.     -0.1443E+05 -0.5391E+05   386.2      -290.3        2155.
O  -2466.     -0.2022E+05 -0.7417E+05   527.7      -332.1        2346.
     S1          S2          S3          SINT        SEQV
I  -2438.      -8640.     -0.3377E+05  0.3133E+05  0.2874E+05
C  -2416.     -0.1443E+05 -0.5400E+05  0.5158E+05  0.4675E+05
O  -2374.     -0.2023E+05 -0.7425E+05  0.7187E+05  0.6482E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2262E-01   2.515       8.798     -0.6147E-01  0.1814E-01 -0.8315E-01
C -0.1364E-11  0.3638E-11 -0.7276E-11  0.5684E-13   0.000      0.9095E-12
O  0.2262E-01  -2.515      -8.798      0.6147E-01 -0.1814E-01  0.8315E-01
     S1          S2          S3          SINT        SEQV
I   8.799       2.516     -0.2489E-01   8.824       7.867
C  0.3639E-11 -0.1228E-11 -0.7413E-11  0.1105E-10  0.9593E-11
O  0.2489E-01  -2.516      -8.799       8.824       7.867

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -2570.      -8632.     -0.3364E+05   244.5      -248.5        1963.
C  -2518.     -0.1443E+05 -0.5391E+05   386.2      -290.3        2155.
O  -2466.     -0.2022E+05 -0.7418E+05   527.8      -332.1        2346.
     S1          S2          S3          SINT        SEQV        TEMP
I  -2438.      -8638.     -0.3376E+05  0.3132E+05  0.2873E+05   16.61
C  -2416.     -0.1443E+05 -0.5400E+05  0.5158E+05  0.4675E+05
O  -2374.     -0.2023E+05 -0.7426E+05  0.7188E+05  0.6482E+05   16.49
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    1658      OUTSIDE NODE =    1679

 LOAD STEP      2  SUBSTEP=      1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

            ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  729.7     -0.1331E+05 -0.5357E+05  336.0       -301.9       1754.
     S1          S2          S3          SINT        SEQV
  793.8     -0.1331E+05 -0.5363E+05  0.5442E+05  0.4892E+05

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   37.54       4073.      0.1375E+05  -99.31       20.43       58.63
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -37.54      -4073.     -0.1375E+05   99.31      -20.43      -58.63
     S1          S2          S3          SINT        SEQV
I  0.1375E+05   4076.       34.84      0.1371E+05  0.1220E+05
C   0.000       0.000       0.000       0.000       0.000
O  -34.84      -4076.     -0.1375E+05  0.1371E+05  0.1220E+05

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   767.2      -9236.     -0.3982E+05   236.6      -281.5       1812.
C   729.7     -0.1331E+05 -0.5357E+05   336.0      -301.9       1754.
O   692.2     -0.1738E+05 -0.6731E+05   435.3      -322.4       1695.
     S1          S2          S3          SINT        SEQV
I   853.0      -9238.     -0.3991E+05  0.4076E+05  0.3677E+05
C   793.8     -0.1331E+05 -0.5363E+05  0.5442E+05  0.4892E+05
O   744.4     -0.1739E+05 -0.6736E+05  0.6810E+05  0.6109E+05

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1630E-01   1.769       5.969     -0.4312E-01  0.8873E-02  0.2546E-01
C -0.3411E-12   0.000      0.2183E-10 -0.1705E-12 -0.1137E-12  0.4547E-12
O -0.1630E-01  -1.769      -5.969      0.4312E-01 -0.8873E-02 -0.2546E-01
     S1          S2          S3          SINT        SEQV
I   5.969       1.770      0.1513E-01   5.954       5.299
C  0.2184E-10  0.6711E-13 -0.4181E-12  0.2226E-10  0.2202E-10
O -0.1513E-01  -1.770      -5.969       5.954       5.299

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   767.3      -9234.     -0.3982E+05   236.6      -281.5       1812.
C   729.7     -0.1331E+05 -0.5357E+05   336.0      -301.9       1754.
O   692.1     -0.1738E+05 -0.6732E+05   435.3      -322.4       1695.
     S1          S2          S3          SINT        SEQV        TEMP
I   853.0      -9236.     -0.3990E+05  0.4075E+05  0.3676E+05   16.61
C   793.8     -0.1331E+05 -0.5363E+05  0.5442E+05  0.4892E+05
O   744.4     -0.1739E+05 -0.6736E+05  0.6811E+05  0.6109E+05   16.57
```

30-ft Corner Drop - Cold (Max Heat) Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =     150     OUTSIDE NODE =    191

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
-0.1146E+05 -0.2140E+05  2199.       -904.7       5397.       1704.
     S1          S2          S3          SINT        SEQV
  3520.      -0.1147E+05 -0.2272E+05  0.2624E+05  0.2280E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.2659E+05  0.3531E+05 -0.1561E+05  3997.       3839.      -1793.
C   0.000       0.000       0.000       0.000       0.000       0.000
O -0.2659E+05 -0.3531E+05  0.1561E+05 -3997.      -3839.       1793.
     S1          S2          S3          SINT        SEQV
I  0.3703E+05  0.2526E+05 -0.1600E+05  0.5303E+05  0.4824E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.1600E+05 -0.2526E+05 -0.3703E+05  0.5303E+05  0.4824E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1513E+05  0.1391E+05 -0.1341E+05  3092.       9237.      -89.37
C -0.1146E+05 -0.2140E+05  2199.      -904.7       5397.       1704.
O -0.3805E+05 -0.5671E+05  0.1781E+05 -4901.       1558.       3497.
     S1          S2          S3          SINT        SEQV
I  0.1898E+05  0.1291E+05 -0.1628E+05  0.3525E+05  0.3265E+05
C   3520.     -0.1147E+05 -0.2272E+05  0.2624E+05  0.2280E+05
O  0.1805E+05 -0.3701E+05 -0.5799E+05  0.7604E+05  0.6802E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -7428.      -3123.       3815.       864.2      -2123.       185.0
C   4705.       2110.      -2368.      -490.3       1295.      -1.462
O -0.2136E+05 -811.5       0.1419E+05  6108.      -9337.       8176.
     S1          S2          S3          SINT        SEQV
I   4413.      -3522.      -7627.       0.1204E+05  0.1060E+05
C   4803.       2361.      -2718.       7520.       6645.
O  0.1926E+05 -1408.      -0.2584E+05  0.4510E+05  0.3911E+05

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   7699.      0.1078E+05 -9599.       3956.       7114.       95.64
C  -6758.     -0.1929E+05 -169.5      -1395.       6692.       1702.
O -0.5941E+05 -0.5752E+05  0.3200E+05  1206.      -7779.       0.1167E+05
     S1          S2          S3          SINT        SEQV        TEMP
I  0.1501E+05  5772.      -0.1190E+05  0.2691E+05  0.2368E+05  17.88
C   2106.     -6695.      -0.2163E+05  0.2374E+05  0.2078E+05
O  0.3409E+05 -0.5696E+05 -0.6207E+05  0.9616E+05  0.9371E+05  17.97
```

30-ft Corner Drop - Cold (No Heat) Conditions - Shell Extension

```
 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =    1609      OUTSIDE NODE =    1504

  LOAD STEP     3  SUBSTEP=      1
  TIME=    3.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

              ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
  -3559.     -0.1782E+05 -0.5807E+05   446.7       -289.9       2727.
      S1          S2          S3          SINT        SEQV
  -3410.     -0.1783E+05 -0.5821E+05  0.5480E+05  0.4920E+05

              ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -31.72       7442.      0.2596E+05  -181.6       41.60       -243.6
 C   0.000       0.000       0.000       0.000       0.000        0.000
 O   31.72      -7442.     -0.2596E+05   181.6      -41.60        243.6
      S1          S2          S3          SINT        SEQV
 I  0.2597E+05   7447.      -38.39      0.2600E+05  0.2319E+05
 C   0.000       0.000       0.000       0.000       0.000
 O   38.39      -7447.     -0.2597E+05  0.2600E+05  0.2319E+05

              ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -3591.     -0.1037E+05 -0.3211E+05   265.2      -248.3        2483.
 C  -3559.     -0.1782E+05 -0.5807E+05   446.7      -289.9        2727.
 O  -3527.     -0.2526E+05 -0.8404E+05   628.3      -331.5        2970.
      S1          S2          S3          SINT        SEQV
 I  -3368.     -0.1038E+05 -0.3233E+05  0.2896E+05  0.2617E+05
 C  -3410.     -0.1783E+05 -0.5821E+05  0.5480E+05  0.4920E+05
 O  -3401.     -0.2527E+05 -0.8415E+05  0.8075E+05  0.7233E+05

              ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1377E-01   3.232       11.27      -0.7884E-01  0.1807E-01 -0.1058
 C -0.9095E-12 -0.3638E-11  0.2910E-10 -0.5684E-13   0.000       0.000
 O  0.1377E-01  -3.232      -11.27       0.7884E-01 -0.1807E-01  0.1058
      S1          S2          S3          SINT        SEQV
 I   11.27       3.233     -0.1667E-01   11.29       10.07
 C  0.2910E-10 -0.9083E-12 -0.3639E-11  0.3274E-10  0.3147E-10
 O  0.1667E-01  -3.233      -11.27       11.29       10.07

              ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -3591.     -0.1037E+05 -0.3210E+05   265.1      -248.2        2483.
 C  -3559.     -0.1782E+05 -0.5807E+05   446.7      -289.9        2727.
 O  -3527.     -0.2526E+05 -0.8405E+05   628.4      -331.5        2970.
      S1          S2          S3          SINT        SEQV        TEMP
 I  -3368.     -0.1038E+05 -0.3232E+05  0.2895E+05  0.2616E+05  -20.00
 C  -3410.     -0.1783E+05 -0.5821E+05  0.5480E+05  0.4920E+05
 O  -3401.     -0.2528E+05 -0.8416E+05  0.8076E+05  0.7234E+05  -20.00
```

PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2 DSYS= 0

***** POST1 LINEARIZED STRESS LISTING *****
INSIDE NODE = 1658 OUTSIDE NODE = 1679

LOAD STEP 3 SUBSTEP= 1
TIME= 3.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

** MEMBRANE **

SX	SY	SZ	SXY	SYZ	SXZ
1019.	-0.1627E+05	-0.5773E+05	415.2	-303.7	2247.
S1	**S2**	**S3**	**SINT**	**SEQV**	
1114.	-0.1628E+05	-0.5782E+05	0.5893E+05	0.5245E+05	

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	16.51	5117.	0.1755E+05	-125.5	21.37	75.68
C	0.000	0.000	0.000	0.000	0.000	0.000
O	-16.51	-5117.	-0.1755E+05	125.5	-21.37	-75.68
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	0.1755E+05	5120.	13.09	0.1754E+05	0.1562E+05	
C	0.000	0.000	0.000	0.000	0.000	
O	-13.09	-5120.	-0.1755E+05	0.1754E+05	0.1562E+05	

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	1035.	-0.1115E+05	-0.4018E+05	289.8	-282.3	2323.
C	1019.	-0.1627E+05	-0.5773E+05	415.2	-303.7	2247.
O	1002.	-0.2139E+05	-0.7528E+05	540.7	-325.1	2172.
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	1172.	-0.1116E+05	-0.4032E+05	0.4149E+05	0.3690E+05	
C	1114.	-0.1628E+05	-0.5782E+05	0.5893E+05	0.5245E+05	
O	1077.	-0.2140E+05	-0.7534E+05	0.7642E+05	0.6803E+05	

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	0.7168E-02	2.222	7.620	-0.5448E-01	0.9280E-02	0.3286E-01
C	-0.7958E-12	-0.1819E-11	0.1455E-10	-0.1705E-12	0.1137E-12	0.1364E-11
O	-0.7168E-02	-2.222	-7.620	0.5448E-01	-0.9280E-02	-0.3286E-01
	S1	**S2**	**S3**	**SINT**	**SEQV**	
I	7.620	2.223	0.5685E-02	7.614	6.783	
C	0.1467E-10	-0.8816E-12	-0.1854E-11	0.1653E-10	0.1606E-10	
O	-0.5685E-02	-2.223	-7.620	7.614	6.783	

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	1035.	-0.1115E+05	-0.4018E+05	289.7	-282.3	2323.
C	1019.	-0.1627E+05	-0.5773E+05	415.2	-303.7	2247.
O	1002.	-0.2139E+05	-0.7529E+05	540.8	-325.1	2172.
	S1	**S2**	**S3**	**SINT**	**SEQV**	**TEMP**
I	1172.	-0.1115E+05	-0.4031E+05	0.4148E+05	0.3690E+05	-20.00
C	1114.	-0.1628E+05	-0.5782E+05	0.5893E+05	0.5245E+05	
O	1077.	-0.2140E+05	-0.7535E+05	0.7643E+05	0.6803E+05	-20.00

30-ft Corner Drop - Cold (No Heat) Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     150      OUTSIDE NODE =     191

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000         LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY          SYZ          SXZ
-0.1141E+05 -0.2129E+05   2087.       -904.6        5424.        1702.
     S1          S2          S3          SINT         SEQV
  3430.      -0.1142E+05 -0.2262E+05  0.2605E+05  0.2264E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  0.2654E+05  0.3538E+05 -0.1554E+05  4013.        3780.       -1734.
C   0.000       0.000       0.000       0.000        0.000        0.000
O -0.2654E+05 -0.3538E+05  0.1554E+05  -4013.      -3780.        1734.
     S1          S2          S3          SINT         SEQV
I  0.3709E+05  0.2520E+05 -0.1592E+05  0.5301E+05  0.4818E+05
C   0.000       0.000       0.000       0.000        0.000
O  0.1592E+05 -0.2520E+05 -0.3709E+05  0.5301E+05  0.4818E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  0.1512E+05  0.1409E+05 -0.1346E+05  3108.        9205.       -31.76
C -0.1141E+05 -0.2129E+05   2087.      -904.6       5424.        1702.
O -0.3795E+05 -0.5666E+05  0.1763E+05  -4918.       1644.        3436.
     S1          S2          S3          SINT         SEQV
I  0.1910E+05  0.1293E+05 -0.1628E+05  0.3538E+05  0.3273E+05
C   3430.     -0.1142E+05 -0.2262E+05  0.2605E+05  0.2264E+05
O  0.1787E+05 -0.3689E+05 -0.5796E+05  0.7582E+05  0.6779E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I  -7507.      -3131.       3778.       853.9       -2101.        139.2
C   4756.       2115.      -2342.      -483.7        1281.        27.29
O -0.2151E+05  -812.9      0.1422E+05  6080.       -9266.        8028.
     S1          S2          S3          SINT         SEQV
I   4367.      -3533.      -7694.      0.1206E+05  0.1061E+05
C   4848.       2368.      -2687.       7535.       6651.
O  0.1921E+05  -1444.     -0.2587E+05  0.4508E+05  0.3908E+05

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY          SYZ          SXZ
I   7617.      0.1096E+05  -9680.       3962.        7103.        107.4
C  -6657.     -0.1917E+05  -255.6      -1388.        6705.        1729.
O -0.5946E+05 -0.5748E+05  0.3185E+05  1163.       -7622.      0.1146E+05
     S1          S2          S3          SINT         SEQV         TEMP
I  0.1512E+05   5726.     -0.1195E+05  0.2707E+05  0.2380E+05  -20.00
C   2056.      -6602.     -0.2154E+05  0.2359E+05  0.2067E+05
O  0.3388E+05 -0.5697E+05 -0.6199E+05  0.9586E+05  0.9346E+05  -20.00
```

1-ft End Drop - Hot Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =    1609      OUTSIDE NODE =    1504

 LOAD STEP     1  SUBSTEP=     3
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

            ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  4433.       2397.      -2133.       46.47      -79.87      -3415.
     S1          S2          S3          SINT        SEQV
  5889.       2396.      -3588.       9477.       8301.

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -55.44     -2716.      -8764.       65.29       1.688       79.83
C   0.000      0.000       0.000       0.000       0.000       0.000
O   55.44      2716.       8764.      -65.29      -1.688      -79.83
     S1          S2          S3          SINT        SEQV
I  -53.11     -2718.      -8765.       8711.       7731.
C   0.000      0.000       0.000       0.000       0.000
O   8765.      2718.       53.11       8711.       7731.

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   4377.     -319.7     -0.1090E+05   111.8      -78.18      -3336.
C   4433.      2397.      -2133.       46.47      -79.87      -3415.
O   4488.      5113.       6631.      -18.82      -81.56      -3495.
     S1          S2          S3          SINT        SEQV
I   5077.     -322.3     -0.1159E+05  0.1667E+05  0.1473E+05
C   5889.      2396.      -3588.       9477.       8301.
O   9216.      5114.       1903.       7313.       6349.

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2407E-01  -1.180      -3.805      0.2835E-01  0.7332E-03  0.3466E-01
C  0.3638E-11  0.1774E-10  0.5093E-10 -0.3553E-12 -0.2842E-13 -0.1364E-11
O  0.2407E-01   1.180       3.805     -0.2835E-01 -0.7332E-03 -0.3466E-01
     S1          S2          S3          SINT        SEQV
I -0.2306E-01  -1.180      -3.806      3.783       3.357
C  0.5097E-10  0.1774E-10  0.3590E-11  0.4738E-10  0.4213E-10
O   3.806       1.180      0.2306E-01  3.783       3.357

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   4377.     -320.8     -0.1090E+05   111.8      -78.18      -3336.
C   4433.      2397.      -2133.       46.47      -79.87      -3415.
O   4488.      5114.       6635.      -18.85      -81.56      -3495.
     S1          S2          S3          SINT        SEQV        TEMP
I   5077.     -323.5     -0.1160E+05  0.1667E+05  0.1474E+05   176.7
C   5889.      2396.      -3588.       9477.       8301.
O   9219.      5115.       1904.       7315.       6350.        176.6
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1519      OUTSIDE NODE =    1612

 LOAD STEP      1  SUBSTEP=      3
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX           SY           SZ          SXY          SYZ          SXZ
  5623.        5109.        1242.        9.964        86.25        3641.
     S1           S2           S3          SINT         SEQV
  7682.        5109.       -817.1        8499.        7549.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -89.64       3697.      0.1238E+05   -93.08       -12.38       -81.66
C   0.000       0.000       0.000        0.000        0.000        0.000
O   89.64      -3697.     -0.1238E+05    93.08        12.38        81.66
     S1           S2           S3          SINT         SEQV
I  0.1238E+05   3699.      -92.46      0.1247E+05   0.1107E+05
C   0.000       0.000       0.000        0.000        0.000
O   92.46      -3699.     -0.1238E+05  0.1247E+05   0.1107E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I   5533.       8806.      0.1362E+05   -83.11        73.87        3559.
C   5623.       5109.       1242.        9.964        86.25        3641.
O   5712.       1412.     -0.1113E+05    103.0        98.63        3722.
     S1           S2           S3          SINT         SEQV
I  0.1496E+05   8808.       4187.      0.1077E+05    9363.
C   7682.       5109.      -817.1        8499.        7549.
O   6501.       1410.     -0.1192E+05  0.1842E+05   0.1648E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I -0.3892E-01   1.605       5.374      -0.4042E-01 -0.5375E-02 -0.3546E-01
C  0.9095E-12  0.3638E-11  0.1592E-11  0.4086E-13   0.000      -0.4547E-12
O  0.3892E-01  -1.605      -5.374       0.4042E-01  0.5375E-02  0.3546E-01
     S1           S2           S3          SINT         SEQV
I   5.374       1.606     -0.4015E-01    5.414        4.807
C  0.3639E-11  0.1819E-11  0.6817E-12  0.2957E-11  0.2583E-11
O  0.4015E-01  -1.606      -5.374        5.414        4.807

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I   5533.       8808.      0.1362E+05   -83.16        73.87        3559.
C   5623.       5109.       1242.        9.964        86.25        3641.
O   5712.       1411.     -0.1114E+05    103.1        98.63        3722.
     S1           S2           S3          SINT         SEQV         TEMP
I  0.1497E+05   8810.       4188.      0.1078E+05    9366.        176.4
C   7682.       5109.      -817.1        8499.        7549.
O   6501.       1408.     -0.1192E+05  0.1843E+05   0.1648E+05    176.4
```

1-ft End Drop - Hot Conditions - Outer Shell

```
 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =  25886     OUTSIDE NODE =  25910

  LOAD STEP     1  SUBSTEP=     3
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
   246.9     0.1397E+05   7385.       330.8       13.33       -444.8
      S1          S2          S3          SINT        SEQV
  0.1397E+05   7413.       211.3      0.1376E+05  0.1192E+05

             ** BENDING **   I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I  -3.417       1278.       5777.       35.14      -0.5406     -0.4010E-03
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O   3.417      -1278.      -5777.      -35.14       0.5406      0.4010E-03
      S1          S2          S3          SINT        SEQV
 I   5777.       1279.      -4.380       5781.       5258.
 C   0.000       0.000       0.000       0.000       0.000
 O   4.380      -1279.      -5777.       5781.       5258.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   243.5     0.1524E+05  0.1316E+05   365.9       12.79       -444.8
 C   246.9     0.1397E+05   7385.       330.8       13.33       -444.8
 O   250.3     0.1269E+05   1608.       295.6       13.87       -444.8
      S1          S2          S3          SINT        SEQV
 I  0.1525E+05  0.1318E+05   219.2      0.1503E+05  0.1411E+05
 C  0.1397E+05   7413.       211.3      0.1376E+05  0.1192E+05
 O  0.1270E+05   1740.       111.0      0.1258E+05  0.1185E+05

             ** PEAK **   I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1484E-02  0.5549       2.508      0.1526E-01 -0.2347E-03 -0.1741E-06
 C -0.5684E-13  0.5457E-11  0.3274E-10  0.2842E-12 -0.5329E-14  0.5684E-13
 O  0.1484E-02 -0.5549      -2.508     -0.1526E-01  0.2347E-03  0.1741E-06
      S1          S2          S3          SINT        SEQV
 I   2.508      0.5553     -0.1902E-02   2.510       2.283
 C  0.3274E-10  0.5472E-11 -0.7155E-13  0.3281E-10  0.3042E-10
 O  0.1902E-02 -0.5553      -2.508       2.510       2.283

             ** TOTAL **   I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I   243.5     0.1525E+05  0.1316E+05   365.9       12.79       -444.8
 C   246.9     0.1397E+05   7385.       330.8       13.33       -444.8
 O   250.3     0.1269E+05   1606.       295.6       13.87       -444.8
      S1          S2          S3          SINT        SEQV        TEMP
 I  0.1525E+05  0.1318E+05   219.2      0.1503E+05  0.1411E+05   177.3
 C  0.1397E+05   7413.       211.3      0.1376E+05  0.1192E+05
 O  0.1270E+05   1738.       110.8      0.1258E+05  0.1185E+05   177.3
```

1-ft End Drop - Cold (Max Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1609      OUTSIDE NODE =    1504

 LOAD STEP     2  SUBSTEP=     3
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -1380.      -5726.     -0.1638E+05   107.6       24.60       914.8
     S1          S2          S3          SINT        SEQV
 -1322.      -5728.     -0.1644E+05  0.1512E+05  0.1346E+05

             ** BENDING **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   6.369       2572.       9017.      -63.00      -1.787      -83.59
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -6.369      -2572.      -9017.       63.00       1.787       83.59
     S1          S2          S3          SINT        SEQV
I   9018.       2574.       4.047       9014.       8043.
C   0.000       0.000       0.000       0.000       0.000
O  -4.047      -2574.      -9018.       9014.       8043.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -1374.      -3154.      -7365.       44.62       22.81       831.2
C  -1380.      -5726.     -0.1638E+05   107.6       24.60       914.8
O  -1387.      -8298.     -0.2540E+05   170.6       26.38       998.4
     S1          S2          S3          SINT        SEQV
I  -1260.      -3155.      -7478.       6218.       5520.
C  -1322.      -5728.     -0.1644E+05  0.1512E+05  0.1346E+05
O  -1341.      -8302.     -0.2544E+05  0.2410E+05  0.2148E+05

             ** PEAK **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.2765E-02   1.117       3.915     -0.2736E-01 -0.7760E-03 -0.3630E-01
C -0.1137E-11 -0.1455E-10 -0.5457E-10  0.3553E-12  0.1776E-13   0.000
O -0.2765E-02  -1.117      -3.915      0.2736E-01  0.7760E-03  0.3630E-01
     S1          S2          S3          SINT        SEQV
I   3.916       1.117      0.1757E-02   3.914       3.492
C -0.1127E-11 -0.1456E-10 -0.5457E-10  0.5344E-10  0.4815E-10
O -0.1757E-02  -1.117      -3.916       3.914       3.492

             ** TOTAL **   I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -1374.      -3153.      -7361.       44.59       22.81       831.1
C  -1380.      -5726.     -0.1638E+05   107.6       24.60       914.8
O  -1387.      -8299.     -0.2540E+05   170.7       26.38       998.4
     S1          S2          S3          SINT        SEQV        TEMP
I  -1259.      -3154.      -7474.       6215.       5517.       16.61
C  -1322.      -5728.     -0.1644E+05  0.1512E+05  0.1346E+05
O  -1341.      -8303.     -0.2544E+05  0.2410E+05  0.2149E+05   16.49
```

PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2 DSYS= 0

***** POST1 LINEARIZED STRESS LISTING *****
INSIDE NODE = 1658 OUTSIDE NODE = 1667

LOAD STEP 2 SUBSTEP= 3
TIME= 2.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM 1

** MEMBRANE **

SX	SY	SZ	SXY	SYZ	SXZ
-492.4	-3537.	-8814.	43.12	12.63	811.9
S1	S2	S3	SINT	SEQV	
-413.3	-3538.	-8892.	8479.	7427.	

** BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	878.0	-385.9	-1448.	52.43	8.629	-18.48
C	0.000	0.000	0.000	0.000	0.000	0.000
O	-878.0	385.9	1448.	-52.43	-8.629	18.48
	S1	S2	S3	SINT	SEQV	
I	880.3	-388.0	-1449.	2329.	2019.	
C	0.000	0.000	0.000	0.000	0.000	
O	1449.	388.0	-880.3	2329.	2019.	

** MEMBRANE PLUS BENDING ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	385.6	-3923.	-0.1026E+05	95.54	21.26	793.5
C	-492.4	-3537.	-8814.	43.12	12.63	811.9
O	-1370.	-3152.	-7365.	-9.306	4.002	830.4
	S1	S2	S3	SINT	SEQV	
I	446.6	-3925.	-0.1032E+05	0.1077E+05	9379.	
C	-413.3	-3538.	-8892.	8479.	7427.	
O	-1257.	-3152.	-7478.	6221.	5523.	

** PEAK ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	1.310	0.1338	-0.7474	10.41	-0.9449E-01	-0.1809
C	-0.4649	-0.1509	0.5934E-01	-5.198	0.4918E-01	0.8657E-01
O	0.5474	0.4689	0.5104	10.36	-0.1020	-0.1649
	S1	S2	S3	SINT	SEQV	
I	11.15	-0.7503	-9.701	20.85	18.11	
C	4.893	0.6088E-01	-5.510	10.40	9.017	
O	10.87	0.5071	-9.852	20.72	17.95	

** TOTAL ** I=INSIDE C=CENTER O=OUTSIDE

	SX	SY	SZ	SXY	SYZ	SXZ
I	386.9	-3923.	-0.1026E+05	105.9	21.17	793.3
C	-492.8	-3538.	-8814.	37.92	12.68	812.0
O	-1370.	-3151.	-7365.	1.054	3.900	830.3
	S1	S2	S3	SINT	SEQV	TEMP
I	448.3	-3926.	-0.1032E+05	0.1077E+05	9381.	16.61
C	-413.8	-3538.	-8892.	8478.	7426.	
O	-1257.	-3151.	-7478.	6221.	5523.	16.61

1-ft End Drop - Cold (No Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1609      OUTSIDE NODE =   1504

 LOAD STEP     3  SUBSTEP=      3
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -2048.      -8319.     -0.2027E+05   155.8       33.78       1291.
     S1          S2          S3          SINT        SEQV
 -1953.      -8323.     -0.2036E+05  0.1841E+05  0.1619E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   25.20       3455.      0.1207E+05  -84.21      -2.303      -111.7
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -25.20      -3455.     -0.1207E+05   84.21       2.303       111.7
     S1          S2          S3          SINT        SEQV
I  0.1207E+05   3457.       22.10      0.1205E+05  0.1075E+05
C   0.000       0.000       0.000       0.000       0.000
O  -22.10      -3457.     -0.1207E+05  0.1205E+05  0.1075E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -2023.      -4864.      -8198.       71.56       31.48       1179.
C  -2048.      -8319.     -0.2027E+05   155.8       33.78       1291.
O  -2073.     -0.1177E+05 -0.3234E+05   240.0       36.09       1403.
     S1          S2          S3          SINT        SEQV
I  -1803.      -4866.      -8416.       6613.       5732.
C  -1953.      -8323.     -0.2036E+05  0.1841E+05  0.1619E+05
O  -2002.     -0.1178E+05 -0.3240E+05  0.3040E+05  0.2688E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.1094E-01   1.500       5.241     -0.3656E-01 -0.9999E-03 -0.4850E-01
C -0.1137E-11 -0.2001E-10 -0.6912E-10  0.4547E-12  0.1421E-13  0.2274E-12
O -0.1094E-01  -1.500      -5.241      0.3656E-01  0.9999E-03  0.4850E-01
     S1          S2          S3          SINT        SEQV
I   5.241       1.501      0.9595E-02   5.232       4.668
C -0.1125E-11 -0.2002E-10 -0.6912E-10  0.6800E-10  0.6079E-10
O -0.9595E-02  -1.501      -5.241       5.232       4.668

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -2023.      -4862.      -8193.       71.52       31.48       1179.
C  -2048.      -8319.     -0.2027E+05   155.8       33.78       1291.
O  -2073.     -0.1178E+05 -0.3234E+05   240.0       36.09       1403.
     S1          S2          S3          SINT        SEQV        TEMP
I  -1803.      -4864.      -8411.       6608.       5727.      -20.00
C  -1953.      -8323.     -0.2036E+05  0.1841E+05  0.1619E+05
O  -2002.     -0.1178E+05 -0.3241E+05  0.3041E+05  0.2688E+05  -20.00
```

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PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

          ***** POST1 LINEARIZED STRESS LISTING *****
         INSIDE NODE =    1658      OUTSIDE NODE =    1667

 LOAD STEP     3  SUBSTEP=      3
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -734.8      -5342.     -0.1026E+05   64.97       16.74       1147.
     S1          S2          S3          SINT        SEQV
 -597.6      -5343.     -0.1039E+05   9796.       8485.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  1282.      -480.3      -2058.       77.14       12.54      -30.86
C  0.000       0.000       0.000       0.000       0.000       0.000
O -1282.       480.3       2058.      -77.14      -12.54       30.86
     S1          S2          S3          SINT        SEQV
I  1286.      -483.5      -2059.       3344.       2898.
C  0.000       0.000       0.000       0.000       0.000
O  2059.       483.5      -1286.       3344.       2898.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  547.4      -5823.     -0.1232E+05   142.1       29.28       1116.
C -734.8      -5342.     -0.1026E+05   64.97       16.74       1147.
O -2017.      -4862.      -8199.      -12.17       4.201       1178.
     S1          S2          S3          SINT        SEQV
I  646.8      -5826.     -0.1241E+05  0.1306E+05  0.1131E+05
C -597.6      -5343.     -0.1039E+05   9796.       8485.
O -1800.      -4862.      -8416.       6616.       5735.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  2.040       0.1571     -1.008       14.57      -0.1965     -0.2654
C -0.7426     -0.1830      0.5736E-01 -7.279       0.1011      0.1262
O  0.9265      0.5741      0.7791      14.51      -0.2074     -0.2386
     S1          S2          S3          SINT        SEQV
I  15.71      -1.015      -13.50       29.21       25.39
C  6.822       0.6065E-01 -7.751       14.57       12.63
O  15.26       0.7723     -13.76       29.02       25.13

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  549.4      -5823.     -0.1232E+05   156.7       29.08       1116.
C -735.6      -5343.     -0.1026E+05   57.69       16.84       1147.
O -2016.      -4862.      -8198.       2.338       3.994       1178.
     S1          S2          S3          SINT        SEQV        TEMP
I  649.4      -5826.     -0.1241E+05  0.1306E+05  0.1131E+05   -20.00
C -598.5      -5343.     -0.1039E+05   9795.       8484.
O -1799.      -4862.      -8415.       6616.       5735.       -20.00
```

1-ft End Drop - Cold (No Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    2140      OUTSIDE NODE =    2167

 LOAD STEP     3  SUBSTEP=      3
 TIME=    3.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -7883.      -7441.       2131.       16.58      -178.0       978.5
     S1          S2          S3          SINT        SEQV
  2229.      -7442.      -7979.      0.1021E+05   9951.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -6914.      -1359.     -0.3297E-10   50.60      -0.1845E-09  0.1931E-09
C   0.000       0.000       0.000       0.000       0.000       0.000
O   6914.       1359.      0.3297E-10  -50.60       0.1845E-09 -0.1931E-09
     S1          S2          S3          SINT        SEQV
I   0.000      -1359.      -6915.       6915.       6346.
C   0.000       0.000       0.000       0.000       0.000
O   6915.       1359.       0.000       6915.       6346.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1480E+05  -8800.       2131.       67.18      -178.0       978.5
C  -7883.      -7441.       2131.       16.58      -178.0       978.5
O  -968.2      -6082.       2131.      -34.02      -178.0       978.5
     S1          S2          S3          SINT        SEQV
I   2190.      -8802.     -0.1485E+05  0.1704E+05  0.1497E+05
C   2229.      -7442.      -7979.      0.1021E+05   9951.
O   2418.      -1251.      -6085.       8504.       7387.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -3.002      -0.5902     -0.1091E-10  0.2197E-01  0.6253E-12 -0.2615E-11
C -0.9095E-12  0.1819E-11 -0.1819E-11 -0.6750E-13  0.1421E-12 -0.3411E-12
O   3.002       0.5902     -0.3183E-11 -0.2197E-01  0.2842E-12 -0.4547E-12
     S1          S2          S3          SINT        SEQV
I   0.000      -0.5900     -3.003       3.003       2.755
C  0.1827E-11 -0.8003E-12 -0.1936E-11  0.3763E-11  0.3343E-11
O   3.003       0.5900      0.000       3.003       2.755

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1480E+05  -8801.       2131.       67.21      -178.0       978.5
C  -7883.      -7441.       2131.       16.58      -178.0       978.5
O  -965.2      -6081.       2131.      -34.04      -178.0       978.5
     S1          S2          S3          SINT        SEQV        TEMP
I   2190.      -8802.     -0.1486E+05  0.1705E+05  0.1497E+05  -20.00
C   2229.      -7442.      -7979.      0.1021E+05   9951.
O   2418.      -1248.      -6085.       8503.       7387.       -20.00
```

1-ft Side Drop - Hot Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1519      OUTSIDE NODE =    1612

 LOAD STEP      1  SUBSTEP=      1
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  3400.       -1017.       8582.       97.16       33.38       2680.
     S1          S2          S3          SINT        SEQV
  9719.        2264.       -1019.      0.1074E+05  9531.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -75.81       4206.       0.1329E+05  -105.5      1.766       -89.30
C   0.000       0.000       0.000       0.000       0.000       0.000
O   75.81      -4206.      -0.1329E+05  105.5      -1.766       89.30
     S1          S2          S3          SINT        SEQV
I  0.1329E+05   4208.      -79.00       0.1337E+05  0.1183E+05
C   0.000       0.000       0.000       0.000       0.000
O   79.00      -4208.      -0.1329E+05  0.1337E+05  0.1183E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   3324.       3189.       0.2188E+05  -8.294      35.14       2591.
C   3400.      -1017.       8582.       97.16       33.38       2680.
O   3475.      -5223.      -4712.       202.6       31.61       2770.
     S1          S2          S3          SINT        SEQV
I  0.2223E+05   3190.       2968.       0.1926E+05  0.1915E+05
C   9719.       2264.      -1019.       0.1074E+05  9531.
O   4329.      -5225.      -5564.       9892.       9727.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.3292E-01   1.826       5.772      -0.4579E-01  0.7670E-03 -0.3877E-01
C -0.4547E-12  0.1080E-10  0.4002E-10 -0.2984E-12  0.2132E-13 -0.4547E-12
O  0.3292E-01  -1.826      -5.772       0.4579E-01 -0.7670E-03  0.3877E-01
     S1          S2          S3          SINT        SEQV
I   5.773       1.827      -0.3430E-01  5.807       5.136
C  0.4002E-10  0.1081E-10 -0.4677E-12  0.4049E-10  0.3619E-10
O  0.3430E-01  -1.827      -5.773       5.807       5.136

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   3324.       3191.       0.2188E+05  -8.340      35.14       2591.
C   3400.      -1017.       8582.       97.16       33.38       2680.
O   3476.      -5225.      -4718.       202.7       31.61       2770.
     S1          S2          S3          SINT        SEQV        TEMP
I  0.2224E+05   3191.       2968.       0.1927E+05  0.1916E+05  176.4
C   9719.       2264.      -1019.       0.1074E+05  9531.
O   4328.      -5226.      -5569.       9897.       9730.       176.4
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1623      OUTSIDE NODE =   1644

 LOAD STEP     1  SUBSTEP=     1
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

            ** MEMBRANE **
     SX           SY           SZ           SXY          SYZ          SXZ
 -3737.       -2645.        8591.       -30.68        14.36        1992.
     S1           S2           S3           SINT         SEQV
  8905.       -2645.       -4052.       0.1296E+05   0.1231E+05

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I   41.27        3148.        9020.       -76.41        9.030        29.10
C   0.000        0.000        0.000        0.000        0.000        0.000
O  -41.27       -3148.       -9020.        76.41       -9.030       -29.10
     S1           S2           S3           SINT         SEQV
I   9021.        3150.        39.29        8981.        7899.
C   0.000        0.000        0.000        0.000        0.000
O  -39.29       -3150.       -9021.        8981.        7899.

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I  -3696.        502.7       0.1761E+05  -107.1        23.39        2021.
C  -3737.       -2645.        8591.       -30.68        14.36        1992.
O  -3778.       -5794.       -429.2        45.74        5.328        1962.
     S1           S2           S3           SINT         SEQV
I  0.1780E+05   505.4       -3888.       0.2169E+05   0.1986E+05
C   8905.       -2645.       -4052.       0.1296E+05   0.1231E+05
O   476.1       -4682.       -5795.        6271.        5795.

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I  0.1792E-01   1.367        3.917       -0.3318E-01   0.3921E-02   0.1263E-01
C  0.2728E-11   0.9550E-11   0.2728E-10  -0.2309E-12   0.3375E-13  -0.4547E-12
O -0.1792E-01  -1.367       -3.917        0.3318E-01  -0.3921E-02  -0.1263E-01
     S1           S2           S3           SINT         SEQV
I   3.917        1.368       0.1706E-01    3.900        3.430
C  0.2729E-10   0.9557E-11   0.2712E-11   0.2458E-10   0.2197E-10
O -0.1706E-01  -1.368       -3.917         3.900        3.430

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I  -3696.        504.0       0.1762E+05  -107.1        23.39        2021.
C  -3737.       -2645.        8591.       -30.68        14.36        1992.
O  -3778.       -5795.       -433.1        45.77        5.324        1962.
     S1           S2           S3           SINT         SEQV         TEMP
I  0.1781E+05   506.7       -3888.       0.2169E+05   0.1986E+05    176.3
C   8905.       -2645.       -4052.       0.1296E+05   0.1231E+05
O   472.9       -4683.       -5796.        6269.        5793.        176.3
```

1-ft Side Drop - Hot Conditions - Bolting Ring Skirt

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PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1194      OUTSIDE NODE =    1188

 LOAD STEP      1  SUBSTEP=      1
 TIME=    1.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY           SZ           SXY          SYZ          SXZ
 -5435.       -3962.       746.2        134.7        -419.7       0.1407E+05
     S1           S2           S3           SINT         SEQV
 0.1207E+05   -3955.      -0.1676E+05   0.2883E+05   0.2502E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I   5101.        5319.     -0.1043E+05   9.792        -14.13        1207.
C   0.000        0.000      0.000        0.000         0.000        0.000
O  -5101.       -5319.      0.1043E+05  -9.792         14.13       -1207.
     S1           S2           S3           SINT         SEQV
I   5319.        5194.     -0.1052E+05   0.1584E+05   0.1578E+05
C   0.000        0.000      0.000        0.000         0.000
O  0.1052E+05   -5194.     -5319.        0.1584E+05   0.1578E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I  -334.1        1357.      -9683.        144.5        -433.9       0.1528E+05
C  -5435.       -3962.       746.2        134.7        -419.7       0.1407E+05
O -0.1054E+05   -9281.      0.1118E+05   124.9        -405.6       0.1287E+05
     S1           S2           S3           SINT         SEQV
I  0.1097E+05    1363.     -0.2100E+05   0.3197E+05   0.2841E+05
C  0.1207E+05   -3955.     -0.1676E+05   0.2883E+05   0.2502E+05
O  0.1716E+05   -9273.     -0.1653E+05   0.3368E+05   0.3071E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I   2.215        2.309      -4.529       0.4252E-02 -0.6136E-02  0.5243
C -0.1637E-10 -0.1546E-10  0.3013E-10   0.000        0.000      -0.3638E-11
O  -2.215       -2.309       4.529      -0.4252E-02  0.6136E-02 -0.5243
     S1           S2           S3           SINT         SEQV
I   2.310        2.255      -4.569        6.879        6.852
C  0.3041E-10 -0.1546E-10 -0.1665E-10   0.4706E-10   0.4648E-10
O   4.569       -2.255      -2.310        6.879        6.852

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ           SXY          SYZ          SXZ
I  -331.9        1359.      -9688.        144.5        -433.9       0.1528E+05
C  -5435.       -3962.       746.2        134.7        -419.7       0.1407E+05
O -0.1054E+05   -9283.      0.1118E+05   124.9        -405.6       0.1287E+05
     S1           S2           S3           SINT         SEQV         TEMP
I  0.1097E+05    1365.     -0.2100E+05   0.3197E+05   0.2842E+05    176.9
C  0.1207E+05   -3955.     -0.1676E+05   0.2883E+05   0.2502E+05
O  0.1716E+05   -9276.     -0.1653E+05   0.3369E+05   0.3071E+05    176.9
```

1-ft Side Drop - Hot Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =  38028      OUTSIDE NODE =  37932

 LOAD STEP     1  SUBSTEP=      1
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  5114.       4058.       9580.       583.2       -3998.      -990.2
     S1          S2          S3          SINT        SEQV
 0.1187E+05   4920.       1959.       9915.       8815.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   3764.       153.7      0.1262E+05   752.9       -39.49      -198.6
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -3764.      -153.7     -0.1262E+05  -752.9       39.49       198.6
     S1          S2          S3          SINT        SEQV
I  0.1263E+05   3910.       2.979      0.1262E+05  0.1119E+05
C   0.000       0.000       0.000       0.000       0.000
O  -2.979      -3910.     -0.1263E+05  0.1262E+05  0.1119E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   8879.       4211.      0.2220E+05   1336.       -4038.      -1189.
C   5114.       4058.       9580.       583.2       -3998.      -990.2
O   1350.       3904.      -3041.      -169.6       -3959.      -791.6
     S1          S2          S3          SINT        SEQV
I  0.2321E+05   8932.       3148.      0.2006E+05  0.1789E+05
C  0.1187E+05   4920.       1959.       9915.       8815.
O   5704.       1442.      -4934.      0.1064E+05   9274.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   1.635      0.6673E-01   5.480       0.3269     -0.1715E-01 -0.8621E-01
C  0.2547E-10   0.000      0.8185E-10  0.5230E-11 -0.9095E-12 -0.1478E-11
O  -1.635     -0.6673E-01  -5.480      -0.3269      0.1715E-01  0.8621E-01
     S1          S2          S3          SINT        SEQV
I   5.482       1.698      0.1293E-02   5.481       4.860
C  0.8191E-10  0.2645E-10 -0.1037E-11  0.8294E-10  0.7318E-10
O -0.1293E-02  -1.698      -5.482       5.481       4.860

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   8880.       4211.      0.2221E+05   1336.       -4038.      -1189.
C   5114.       4058.       9580.       583.2       -3998.      -990.2
O   1348.       3904.      -3046.      -170.0       -3959.      -791.5
     S1          S2          S3          SINT        SEQV        TEMP
I  0.2322E+05   8933.       3148.      0.2007E+05  0.1789E+05   177.6
C  0.1187E+05   4920.       1959.       9915.       8815.
O   5703.       1441.      -4938.      0.1064E+05   9277.        177.6
```

1-ft Side Drop - Cold (Max Heat) Conditions - Bolting Ring Skirt

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1194      OUTSIDE NODE =   1188

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX            SY            SZ            SXY           SYZ           SXZ
 -5569.        -3815.         801.9         13.77        -381.6        0.1446E+05
     S1            S2            S3            SINT          SEQV
 0.1242E+05    -3816.       -0.1719E+05    0.2962E+05    0.2569E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX            SY            SZ            SXY           SYZ           SXZ
I  5265.         5405.       -0.1068E+05    -5.551        -24.76         1242.
C  0.000         0.000         0.000         0.000         0.000         0.000
O -5265.        -5405.        0.1068E+05     5.551         24.76        -1242.
     S1            S2            S3            SINT          SEQV
I  5406.         5360.       -0.1078E+05    0.1619E+05    0.1616E+05
C  0.000         0.000         0.000         0.000         0.000
O  0.1078E+05   -5360.        -5406.        0.1619E+05    0.1616E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX            SY            SZ            SXY           SYZ           SXZ
I -303.7         1590.        -9883.         8.222        -406.4        0.1570E+05
C -5569.        -3815.         801.9         13.77        -381.6        0.1446E+05
O -0.1083E+05   -9220.        0.1149E+05     19.32        -356.9        0.1321E+05
     S1            S2            S3            SINT          SEQV
I  0.1132E+05    1589.       -0.2151E+05    0.3284E+05    0.2921E+05
C  0.1242E+05   -3816.       -0.1719E+05    0.2962E+05    0.2569E+05
O  0.1763E+05   -9220.       -0.1697E+05    0.3460E+05    0.3145E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX            SY            SZ            SXY           SYZ           SXZ
I  2.286         2.347        -4.639       -0.2410E-02   -0.1075E-01    0.5393
C -0.1637E-10   -0.1728E-10    0.3183E-10    0.1599E-13    0.1137E-12    0.000
O -2.286        -2.347         4.639         0.2410E-02    0.1075E-01   -0.5393
     S1            S2            S3            SINT          SEQV
I  2.347         2.327        -4.681         7.029         7.019
C  0.3183E-10   -0.1637E-10   -0.1728E-10    0.4911E-10    0.4866E-10
O  4.681        -2.327        -2.347         7.029         7.019

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX            SY            SZ            SXY           SYZ           SXZ
I -301.4         1592.        -9888.         8.220        -406.4        0.1570E+05
C -5569.        -3815.         801.9         13.77        -381.6        0.1446E+05
O -0.1084E+05   -9222.        0.1149E+05     19.33        -356.9        0.1321E+05
     S1            S2            S3            SINT          SEQV          TEMP
I  0.1133E+05    1591.       -0.2151E+05    0.3284E+05    0.2921E+05    16.83
C  0.1242E+05   -3816.       -0.1719E+05    0.2962E+05    0.2569E+05
O  0.1763E+05   -9222.       -0.1697E+05    0.3460E+05    0.3145E+05    16.81
```

1-ft Side Drop - Cold (Max Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    2140      OUTSIDE NODE =    2167

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -9893.      -8657.       156.1       18.36       18.02       1071.
     S1          S2          S3          SINT        SEQV
  269.1      -8657.     -0.1001E+05  0.1028E+05   9672.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -6777.      -2096.     -0.4930      -20.56      0.2862E-10  0.2076E-10
C   0.000       0.000       0.000       0.000       0.000       0.000
O   6777.       2096.      0.4930       20.56     -0.2862E-10 -0.2076E-10
     S1          S2          S3          SINT        SEQV
I -0.4930      -2096.      -6777.       6777.       6009.
C   0.000       0.000       0.000       0.000       0.000
O   6777.       2096.      0.4930       6777.       6009.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1667E+05 -0.1075E+05   155.6      -2.193       18.02       1071.
C  -9893.      -8657.       156.1       18.36       18.02       1071.
O  -3116.      -6561.       156.6       38.92       18.02       1071.
     S1          S2          S3          SINT        SEQV
I   223.6     -0.1075E+05 -0.1674E+05  0.1696E+05  0.1490E+05
C   269.1      -8657.     -0.1001E+05  0.1028E+05   9672.
O   476.3      -3435.      -6561.       7037.       6107.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -2.943     -0.9102     -0.2141E-03 -0.8926E-02  0.3553E-14 -0.2728E-11
C  0.7276E-11  0.1819E-11 -0.2842E-12  0.1066E-13  0.3553E-14 -0.4547E-12
O   2.943      0.9102      0.2141E-03  0.8926E-02 -0.1421E-13 -0.9095E-12
     S1          S2          S3          SINT        SEQV
I -0.2141E-03 -0.9102      -2.943       2.943       2.609
C  0.7303E-11  0.1819E-11 -0.3115E-12  0.7615E-11  0.6804E-11
O   2.943      0.9102      0.2141E-03   2.943       2.609

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1667E+05 -0.1075E+05   155.6      -2.202       18.02       1071.
C  -9893.      -8657.       156.1       18.36       18.02       1071.
O  -3113.      -6560.       156.6       38.93       18.02       1071.
     S1          S2          S3          SINT        SEQV        TEMP
I   223.6     -0.1075E+05 -0.1674E+05  0.1696E+05  0.1490E+05   18.08
C   269.1      -8657.     -0.1001E+05  0.1028E+05   9672.
O   476.5      -3433.      -6560.       7037.       6106.       17.96
```

1-ft Side Drop - Cold (No Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =   1626      OUTSIDE NODE =   1645

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

            ** MEMBRANE **
     SX           SY           SZ          SXY         SYZ         SXZ
 -777.1     -0.1112E+05   1319.        255.8       -45.94       11.16
     S1           S2           S3          SINT        SEQV
  1319.       -770.8       -0.1113E+05  0.1245E+05  0.1155E+05

            ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I   3.365        2990.        9674.       -73.31       1.755       63.59
C   0.000        0.000        0.000        0.000       0.000       0.000
O  -3.365       -2990.       -9674.        73.31      -1.755      -63.59
     S1           S2           S3          SINT        SEQV
I   9674.        2992.        1.148        9673.       8578.
C   0.000        0.000        0.000        0.000       0.000
O  -1.148       -2992.       -9674.        9673.       8578.

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  -773.7       -8132.       0.1099E+05   182.5       -44.18       74.75
C  -777.1      -0.1112E+05   1319.        255.8       -45.94       11.16
O  -780.4      -0.1411E+05  -8355.        329.1       -47.69      -52.43
     S1           S2           S3          SINT        SEQV
I  0.1099E+05  -769.6       -8136.       0.1913E+05  0.1671E+05
C   1319.      -770.8       -0.1113E+05  0.1245E+05  0.1155E+05
O  -771.9      -8355.       -0.1412E+05  0.1335E+05  0.1160E+05

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  0.1461E-02   1.298        4.201      -0.3183E-01  0.7619E-03  0.2761E-01
C  0.1137E-12   0.3638E-11   0.3365E-10 -0.2558E-12  0.000       0.1048E-12
O -0.1461E-02  -1.298       -4.201       0.3183E-01 -0.7619E-03 -0.2761E-01
     S1           S2           S3          SINT        SEQV
I   4.201       1.299        0.4984E-03   4.200       3.725
C  0.3365E-10   0.3656E-11   0.9489E-13   0.3356E-10  0.3193E-10
O -0.4984E-03  -1.299       -4.201        4.200       3.725

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  -773.7       -8130.       0.1100E+05   182.4       -44.18       74.77
C  -777.1      -0.1112E+05   1319.        255.8       -45.94       11.16
O  -780.4      -0.1411E+05  -8359.        329.1       -47.69      -52.46
     S1           S2           S3          SINT        SEQV        TEMP
I  0.1100E+05  -769.6       -8135.       0.1913E+05  0.1671E+05  -20.00
C   1319.      -770.8       -0.1113E+05  0.1245E+05  0.1155E+05
O  -771.9      -8359.       -0.1412E+05  0.1335E+05  0.1160E+05  -20.00
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1625      OUTSIDE NODE =   1642

 LOAD STEP     3  SUBSTEP=     1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY          SZ          SXY         SYZ          SXZ
 -555.3      -0.1065E+05   1284.        249.5       -48.06       -259.5
     S1           S2          S3          SINT        SEQV
  1320.        -585.5      -0.1066E+05  0.1198E+05  0.1115E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ          SXZ
I   1.487        2821.       9093.       -69.21       3.443       -3.837
C   0.000        0.000       0.000        0.000       0.000        0.000
O  -1.487       -2821.      -9093.        69.21      -3.443        3.837
     S1           S2          S3          SINT        SEQV
I   9093.        2822.      -0.2130       9093.       8061.
C   0.000        0.000       0.000        0.000       0.000
O  0.2130       -2822.      -9093.        9093.       8061.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ          SXZ
I  -553.9       -7833.      0.1038E+05   180.3       -44.62       -263.3
C  -555.3      -0.1065E+05   1284.       249.5       -48.06       -259.5
O  -556.8      -0.1347E+05  -7809.       318.8       -51.51       -255.6
     S1           S2          S3          SINT        SEQV
I  0.1038E+05   -555.8      -7838.      0.1822E+05  0.1589E+05
C   1320.       -585.5      -0.1066E+05 0.1198E+05  0.1115E+05
O  -539.9       -7818.      -0.1348E+05 0.1294E+05  0.1124E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ          SXZ
I  0.6456E-03   1.225       3.948      -0.3005E-01  0.1495E-02 -0.1666E-02
C   0.000       0.7276E-11  0.2819E-10 -0.1705E-12  0.2132E-13 -0.5684E-13
O -0.6456E-03  -1.225      -3.948       0.3005E-01 -0.1495E-02  0.1666E-02
     S1           S2          S3          SINT        SEQV
I   3.948       1.226      -0.9249E-04   3.948       3.500
C  0.2819E-10   0.7280E-11 -0.4107E-14  0.2820E-10  0.2535E-10
O  0.9249E-04  -1.226      -3.948        3.948       3.500

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ          SXZ
I  -553.9       -7832.      0.1038E+05   180.3       -44.62       -263.3
C  -555.3      -0.1065E+05   1284.       249.5       -48.06       -259.5
O  -556.8      -0.1348E+05  -7813.       318.8       -51.51       -255.6
     S1           S2          S3          SINT        SEQV         TEMP
I  0.1039E+05   -555.8      -7837.      0.1822E+05  0.1589E+05   -20.00
C   1320.       -585.5      -0.1066E+05 0.1198E+05  0.1115E+05
O  -539.9       -7822.      -0.1348E+05 0.1294E+05  0.1124E+05   -20.00
```

1-ft Side Drop - Cold (No Heat) Conditions - Bolting Ring Skirt

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=   0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1194      OUTSIDE NODE =    1188

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY           SZ          SXY          SYZ          SXZ
 -5623.       -3561.        829.9       -3.754       -372.9      0.1467E+05
     S1           S2           S3          SINT         SEQV
 0.1263E+05   -3563.      -0.1742E+05  0.3004E+05   0.2604E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I   5350.       5486.      -0.1084E+05  -7.561       -26.02        1259.
C   0.000       0.000        0.000       0.000        0.000        0.000
O  -5350.      -5486.       0.1084E+05   7.561        26.02       -1259.
     S1           S2           S3          SINT         SEQV
I   5488.       5445.      -0.1093E+05  0.1642E+05   0.1640E+05
C   0.000       0.000        0.000       0.000        0.000
O  0.1093E+05  -5445.       -5488.      0.1642E+05   0.1640E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -273.9       1925.      -0.1001E+05  -11.32       -399.0      0.1592E+05
C  -5623.      -3561.        829.9      -3.754       -372.9      0.1467E+05
O -0.1097E+05  -9047.       0.1167E+05   3.807       -346.9      0.1341E+05
     S1           S2           S3          SINT         SEQV
I  0.1152E+05   1922.      -0.2180E+05  0.3331E+05   0.2970E+05
C  0.1263E+05  -3563.      -0.1742E+05  0.3004E+05   0.2604E+05
O  0.1790E+05  -9048.      -0.1720E+05  0.3510E+05   0.3182E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I   2.323       2.382       -4.705     -0.3283E-02 -0.1130E-01   0.5466
C -0.1910E-10 -0.1683E-10  0.3058E-10  0.2043E-13  0.5684E-13 -0.1819E-11
O  -2.323      -2.382        4.705      0.3283E-02  0.1130E-01  -0.5466
     S1           S2           S3          SINT         SEQV
I   2.383       2.364       -4.747       7.130        7.121
C  0.3065E-10 -0.1683E-10 -0.1917E-10  0.4981E-10   0.4869E-10
O   4.747      -2.364       -2.383       7.130        7.121

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -271.5       1927.      -0.1001E+05  -11.32       -399.0      0.1593E+05
C  -5623.      -3561.        829.9      -3.754       -372.9      0.1467E+05
O -0.1098E+05  -9050.       0.1167E+05   3.810       -346.9      0.1341E+05
     S1           S2           S3          SINT         SEQV         TEMP
I  0.1152E+05   1925.      -0.2180E+05  0.3332E+05   0.2970E+05   -20.00
C  0.1263E+05  -3563.      -0.1742E+05  0.3004E+05   0.2604E+05
O  0.1790E+05  -9051.      -0.1720E+05  0.3510E+05   0.3182E+05   -20.00
```

1-ft Side Drop - Cold (No Heat) Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1626      OUTSIDE NODE =    1645

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY          SZ          SXY         SYZ         SXZ
 -804.8      -0.1116E+05   1228.        256.4       -56.59       316.5
     S1           S2          S3          SINT        SEQV
  1277.       -846.3      -0.1117E+05  0.1244E+05  0.1153E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ         SXZ
I   3.442        2015.       6415.       -49.36      -9.142      -0.1382E-08
C   0.000        0.000       0.000        0.000       0.000       0.000
O  -3.442       -2015.      -6415.        49.36       9.142       0.1382E-08
     S1           S2          S3          SINT        SEQV
I   6415.        2016.       2.231        6413.       5681.
C   0.000        0.000       0.000        0.000       0.000
O  -2.231       -2016.      -6415.        6413.       5681.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ         SXZ
I  -801.3       -9143.       7644.        207.0      -65.74       316.5
C  -804.8      -0.1116E+05   1228.        256.4      -56.59       316.5
O  -808.2      -0.1317E+05  -5187.        305.7      -47.45       316.5
     S1           S2          S3          SINT        SEQV
I   7656.       -807.9      -9149.       0.1680E+05  0.1455E+05
C   1277.       -846.3     -0.1117E+05   0.1244E+05  0.1153E+05
O  -778.1       -5209.     -0.1318E+05   0.1240E+05  0.1089E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ         SXZ
I  0.1495E-02   0.8750       2.786      -0.2143E-01 -0.3970E-02 -0.8527E-12
C   0.000      -0.9095E-11 -0.3229E-10  0.2274E-12  0.4974E-13 -0.5684E-13
O -0.1495E-02  -0.8750      -2.786       0.2143E-01  0.3970E-02  0.5116E-12
     S1           S2          S3          SINT        SEQV
I   2.786       0.8755      0.9689E-03   2.785       2.467
C  0.5776E-14  -0.9101E-11 -0.3229E-10  0.3229E-10  0.2884E-10
O -0.9689E-03  -0.8755      -2.786       2.785       2.467

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY         SYZ         SXZ
I  -801.3       -9143.       7647.        207.0      -65.74       316.5
C  -804.8      -0.1116E+05   1228.        256.4      -56.59       316.5
O  -808.2      -0.1317E+05  -5190.        305.8      -47.45       316.5
     S1           S2          S3          SINT        SEQV        TEMP
I   7659.       -807.9      -9148.       0.1681E+05  0.1456E+05  -20.00
C   1277.       -846.3     -0.1117E+05   0.1244E+05  0.1153E+05
O  -778.1       -5212.     -0.1318E+05   0.1240E+05  0.1089E+05  -20.00
```

1-ft Side Drop - Cold (No Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    2140      OUTSIDE NODE =    2167

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
-0.1342E+05 -0.1207E+05   599.1       30.88       -7.324       1378.
     S1          S2          S3          SINT        SEQV
  733.2      -0.1207E+05 -0.1356E+05 0.1429E+05  0.1361E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -8139.      -2333.     -0.5765E-10  -9.037      0.1292E-09 -0.2302E-09
C   0.000       0.000       0.000       0.000       0.000       0.000
O   8139.       2333.      0.5765E-10   9.037     -0.1292E-09  0.2302E-09
     S1          S2          S3          SINT        SEQV
I   0.000      -2333.     -8139.       8139.       7259.
C   0.000       0.000       0.000       0.000       0.000
O   8139.       2333.       0.000       8139.       7259.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2156E+05 -0.1441E+05   599.1       21.85       -7.324       1378.
C -0.1342E+05 -0.1207E+05   599.1       30.88       -7.324       1378.
O  -5282.      -9741.       599.1       39.92       -7.324       1378.
     S1          S2          S3          SINT        SEQV
I   684.4     -0.1441E+05 -0.2165E+05  0.2233E+05  0.1973E+05
C   733.2     -0.1207E+05 -0.1356E+05  0.1429E+05  0.1361E+05
O   905.8      -5588.      -9741.      0.1065E+05   9294.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -3.534      -1.013     -0.4320E-11 -0.3924E-02 -0.3553E-14 -0.4093E-11
C  0.5457E-11   0.000     -0.7958E-12 -0.3553E-14 -0.1243E-13 -0.4547E-12
O   3.534       1.013     -0.1251E-11  0.3924E-02 -0.8527E-13 -0.4547E-12
     S1          S2          S3          SINT        SEQV
I   0.000      -1.013      -3.534       3.534       3.152
C  0.5490E-11  0.1920E-15 -0.8289E-12  0.6319E-11  0.5948E-11
O   3.534       1.013       0.000       3.534       3.152

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2156E+05 -0.1441E+05   599.1       21.84       -7.324       1378.
C -0.1342E+05 -0.1207E+05   599.1       30.88       -7.324       1378.
O  -5278.      -9740.       599.1       39.92       -7.324       1378.
     S1          S2          S3          SINT        SEQV        TEMP
I   684.4     -0.1441E+05 -0.2165E+05  0.2233E+05  0.1974E+05   -20.00
C   733.2     -0.1207E+05 -0.1356E+05  0.1429E+05  0.1361E+05
O   905.9      -5585.      -9740.      0.1065E+05   9293.       -20.00
```

1-ft Corner Drop - Hot Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =  14028     OUTSIDE NODE =  13932

 LOAD STEP     1  SUBSTEP=     1
 TIME=    1.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  5591.       3448.       8195.       -558.0      -3322.      -108.7
     S1          S2          S3          SINT        SEQV
  9910.       5661.       1663.       8248.       7144.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   3050.       93.04       9941.       -615.2      -1.792      9.023
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -3050.      -93.04      -9941.       615.2       1.792      -9.023
     S1          S2          S3          SINT        SEQV
I   9941.       3173.      -29.84       9971.       8817.
C   0.000       0.000       0.000       0.000       0.000
O   29.84      -3173.      -9941.       9971.       8817.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   8641.       3541.      0.1814E+05  -1173.      -3324.      -99.69
C   5591.       3448.       8195.      -558.0      -3322.      -108.7
O   2541.       3355.      -1746.       57.26      -3320.      -117.7
     S1          S2          S3          SINT        SEQV
I  0.1886E+05   8865.       2594.      0.1627E+05  0.1421E+05
C   9910.       5661.       1663.       8248.       7144.
O   4996.       2537.      -3384.       8379.       7461.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   1.325      0.4040E-01   4.317      -0.2671     -0.7780E-03  0.3918E-02
C  0.1455E-10  0.1364E-11  0.4366E-10 -0.3411E-11 -0.9095E-12 -0.5684E-13
O  -1.325     -0.4040E-01  -4.317       0.2671      0.7780E-03 -0.3918E-02
     S1          S2          S3          SINT        SEQV
I   4.317       1.378     -0.1296E-01   4.330       3.829
C  0.4368E-10  0.1538E-10  0.5157E-12  0.4316E-10  0.3798E-10
O  0.1296E-01  -1.378      -4.317       4.330       3.829

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   8643.       3541.      0.1814E+05  -1173.      -3324.      -99.68
C   5591.       3448.       8195.      -558.0      -3322.      -108.7
O   2539.       3355.      -1751.       57.53      -3320.      -117.7
     S1          S2          S3          SINT        SEQV        TEMP
I  0.1886E+05   8866.       2594.      0.1627E+05  0.1421E+05   177.6
C   9910.       5661.       1663.       8248.       7144.
O   4995.       2536.      -3387.       8382.       7463.        177.6
```

1-ft Corner Drop - Hot Conditions - Lid

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 PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     191      OUTSIDE NODE =     12

  LOAD STEP     1  SUBSTEP=     1
  TIME=    1.0000          LOAD CASE=  0

 THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
      SX          SY          SZ          SXY         SYZ         SXZ
   1974.      -3890.      -4651.       386.1       2018.       2809.
      S1          S2          S3          SINT        SEQV
   3171.      -2944.      -6794.       9966.       8705.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1385E+05  -9545.       5597.      -3455.      -159.0       568.9
 C   0.000       0.000       0.000       0.000       0.000       0.000
 O  0.1385E+05   9545.      -5597.       3455.       159.0      -568.9
      S1          S2          S3          SINT        SEQV
 I   5618.      -7640.     -0.1578E+05  0.2140E+05  0.1871E+05
 C   0.000       0.000       0.000       0.000       0.000
 O  0.1578E+05   7640.      -5618.      0.2140E+05  0.1871E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1188E+05 -0.1343E+05   945.3      -3069.       1859.       3378.
 C   1974.      -3890.      -4651.       386.1       2018.       2809.
 O  0.1583E+05   5655.     -0.1025E+05   3841.       2177.       2240.
      S1          S2          S3          SINT        SEQV
 I   1859.      -9674.     -0.1655E+05  0.1841E+05  0.1611E+05
 C   3171.      -2944.      -6794.       9966.       8705.
 O  0.1740E+05   4487.     -0.1066E+05  0.2806E+05  0.2432E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.1327E+05 -0.1081E+05  0.1297E+05   3569.      -5383.       2062.
 C   3189.       1866.      -2388.      -244.5       1105.       177.3
 O  -2221.      -5155.       3198.      -678.9      -1573.      -913.7
      S1          S2          S3          SINT        SEQV
 I  0.1419E+05  -8674.     -0.1663E+05  0.3082E+05  0.2772E+05
 C   3233.       2101.      -2667.       5900.       5423.
 O   3589.      -2121.      -5647.       9236.       8073.

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
      SX          SY          SZ          SXY         SYZ         SXZ
 I -0.2515E+05 -0.2425E+05  0.1392E+05   500.7      -3524.       5440.
 C   5163.      -2024.      -7040.       141.6       3123.       2986.
 O  0.1360E+05   500.3      -7051.       3162.       604.4       1327.
      S1          S2          S3          SINT        SEQV        TEMP
 I  0.1496E+05 -0.2404E+05 -0.2640E+05  0.4136E+05  0.4023E+05   178.0
 C   5952.      -818.9      -9033.      0.1499E+05  0.1300E+05
 O  0.1442E+05  -210.3      -7158.      0.2158E+05  0.1908E+05   178.2
```

1-ft Corner Drop - Cold (Max Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =   1609     OUTSIDE NODE =   1504

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX           SY          SZ          SXY          SYZ          SXZ
 -2195.       -9661.     -0.2823E+05   229.0       -129.5       1519.
     S1           S2          S3          SINT         SEQV
 -2101.       -9666.     -0.2832E+05  0.2622E+05  0.2337E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY          SYZ          SXZ
I  -21.31        4236.      0.1483E+05  -103.6        19.68       -138.8
C   0.000        0.000       0.000       0.000        0.000        0.000
O   21.31       -4236.     -0.1483E+05   103.6       -19.68        138.8
     S1           S2          S3          SINT         SEQV
I  0.1483E+05   4239.       -25.12      0.1485E+05  0.1324E+05
C   0.000        0.000       0.000       0.000        0.000
O   25.12       -4239.     -0.1483E+05  0.1485E+05  0.1324E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY          SYZ          SXZ
I  -2217.       -5425.     -0.1341E+05   125.4       -109.8        1380.
C  -2195.       -9661.     -0.2823E+05   229.0       -129.5        1519.
O  -2174.     -0.1390E+05 -0.4306E+05   332.6       -149.1        1657.
     S1           S2          S3          SINT         SEQV
I  -2045.       -5426.     -0.1357E+05  0.1153E+05  0.1027E+05
C  -2101.       -9666.     -0.2832E+05  0.2622E+05  0.2337E+05
O  -2098.     -0.1390E+05 -0.4312E+05  0.4103E+05  0.3658E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY          SYZ          SXZ
I -0.9254E-02   1.839       6.437     -0.4499E-01  0.8544E-02 -0.6026E-01
C -0.1819E-11  0.3638E-11  0.7276E-11   0.000     -0.2842E-13 -0.4547E-12
O  0.9254E-02  -1.839      -6.437      0.4499E-01 -0.8544E-02  0.6026E-01
     S1           S2          S3          SINT         SEQV
I   6.438       1.840     -0.1091E-01   6.449        5.751
C  0.7299E-11  0.3638E-11 -0.1842E-11  0.9141E-11  0.7968E-11
O  0.1091E-01  -1.840      -6.438       6.449        5.751

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY          SZ          SXY          SYZ          SXZ
I  -2217.       -5423.     -0.1340E+05   125.4       -109.8        1380.
C  -2195.       -9661.     -0.2823E+05   229.0       -129.5        1519.
O  -2174.     -0.1390E+05 -0.4306E+05   332.7       -149.1        1657.
     S1           S2          S3          SINT         SEQV         TEMP
I  -2045.       -5425.     -0.1357E+05  0.1152E+05  0.1026E+05    16.61
C  -2101.       -9666.     -0.2832E+05  0.2622E+05  0.2337E+05
O  -2098.     -0.1391E+05 -0.4313E+05  0.4103E+05  0.3659E+05    16.49
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1659      OUTSIDE NODE =    1678

 LOAD STEP      2  SUBSTEP=      1
 TIME=     2.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM    1

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -198.9      -7930.      -0.2776E+05   191.0       -151.8       787.6
     S1          S2          S3          SINT        SEQV
 -171.9      -7934.      -0.2779E+05  0.2761E+05  0.2467E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -10.46       624.5       2391.       -15.57      0.1733      27.22
C   0.000       0.000       0.000       0.000       0.000       0.000
O   10.46      -624.5      -2391.       15.57      -0.1733     -27.22
     S1          S2          S3          SINT        SEQV
I   2391.       624.8      -11.15       2403.       2156.
C   0.000       0.000       0.000       0.000       0.000
O   11.15      -624.8      -2391.       2403.       2156.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -209.3      -7306.      -0.2537E+05  175.4       -151.7      814.8
C  -198.9      -7930.      -0.2776E+05  191.0       -151.8      787.6
O  -188.4      -8555.      -0.3015E+05  206.6       -152.0      760.4
     S1          S2          S3          SINT        SEQV
I  -178.9      -7309.      -0.2540E+05 0.2522E+05  0.2252E+05
C  -171.9      -7934.      -0.2779E+05 0.2761E+05  0.2467E+05
O  -164.2      -8559.      -0.3017E+05 0.3001E+05  0.2682E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.4543E-02  0.2712       1.038      -0.6762E-02  0.7523E-04  0.1182E-01
C  0.8527E-13   0.000     -0.3638E-11 -0.5684E-13   0.000       0.000
O  0.4543E-02 -0.2712      -1.038      0.6762E-02 -0.7523E-04 -0.1182E-01
     S1          S2          S3          SINT        SEQV
I   1.038       0.2713    -0.4843E-02   1.043       0.9362
C  0.1137E-12 -0.2842E-13 -0.3638E-11  0.3752E-11  0.3683E-11
O  0.4843E-02 -0.2713      -1.038       1.043       0.9362

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -209.3      -7306.      -0.2537E+05  175.4       -151.7      814.8
C  -198.9      -7930.      -0.2776E+05  191.0       -151.8      787.6
O  -188.4      -8555.      -0.3015E+05  206.6       -152.0      760.4
     S1          S2          S3          SINT        SEQV        TEMP
I  -178.9      -7308.      -0.2540E+05 0.2522E+05  0.2252E+05   16.51
C  -171.9      -7934.      -0.2779E+05 0.2761E+05  0.2467E+05
O  -164.2      -8559.      -0.3017E+05 0.3001E+05  0.2682E+05   16.35
```

1-ft Corner Drop - Cold (Max Heat) Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     191     OUTSIDE NODE =     12

 LOAD STEP     2  SUBSTEP=     1
 TIME=    2.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  2028.      -3604.      -4534.       405.2       2023.       2866.
     S1          S2          S3          SINT        SEQV
  3285.      -2739.      -6657.       9943.       8675.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1368E+05  -9453.       5559.      -3472.      -135.2       477.7
C   0.000       0.000       0.000       0.000       0.000       0.000
O  0.1368E+05   9453.      -5559.       3472.       135.2      -477.7
     S1          S2          S3          SINT        SEQV
I   5574.      -7510.     -0.1563E+05  0.2121E+05  0.1853E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.1563E+05   7510.      -5574.      0.2121E+05  0.1853E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1165E+05 -0.1306E+05   1024.      -3067.       1888.       3344.
C   2028.      -3604.      -4534.       405.2       2023.       2866.
O  0.1570E+05   5848.     -0.1009E+05   3877.       2159.       2388.
     S1          S2          S3          SINT        SEQV
I   1937.      -9372.     -0.1625E+05  0.1818E+05  0.1590E+05
C   3285.      -2739.      -6657.       9943.       8675.
O  0.1737E+05   4609.     -0.1052E+05  0.2789E+05  0.2418E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1237E+05 -0.1070E+05  0.1214E+05   3408.      -4997.       1675.
C   3081.       1852.      -2226.      -282.1       1075.       253.0
O  -2103.      -5080.       3050.      -671.9      -1551.      -1018.
     S1          S2          S3          SINT        SEQV
I  0.1322E+05  -8386.     -0.1577E+05  0.2899E+05  0.2609E+05
C   3143.       2074.      -2510.       5653.       5201.
O   3476.      -2033.      -5577.       9053.       7902.

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2402E+05 -0.2376E+05  0.1316E+05   341.0      -3109.       5018.
C   5109.      -1752.      -6761.       123.1       3098.       3119.
O  0.1360E+05   768.2      -7043.       3205.       607.9       1370.
     S1          S2          S3          SINT        SEQV        TEMP
I  0.1407E+05 -0.2353E+05 -0.2516E+05  0.3924E+05  0.3844E+05   17.97
C   5984.      -589.0      -8799.      0.1478E+05  0.1283E+05
O  0.1446E+05   22.77      -7155.      0.2161E+05  0.1907E+05   18.19
```

1-ft Corner Drop - Cold (No Heat) Conditions - Shell Extension

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-1     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1609      OUTSIDE NODE =    1504

 LOAD STEP      3  SUBSTEP=      1
 TIME=     3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
    SX           SY          SZ          SXY         SYZ          SXZ
 -3335.      -0.1296E+05 -0.3218E+05   285.8       -141.4        2058.
    S1           S2          S3          SINT        SEQV
 -3181.      -0.1297E+05 -0.3233E+05 0.2914E+05  0.2569E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY          SZ          SXY         SYZ          SXZ
I -0.8878       5834.      0.2044E+05  -142.3       19.55       -190.3
C   0.000       0.000       0.000       0.000       0.000        0.000
O  0.8878      -5834.     -0.2044E+05   142.3      -19.55        190.3
    S1           S2          S3          SINT        SEQV
I  0.2044E+05   5837.      -6.117      0.2044E+05  0.1824E+05
C   0.000       0.000       0.000       0.000       0.000
O   6.117      -5837.     -0.2044E+05  0.2044E+05  0.1824E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY          SZ          SXY         SYZ          SXZ
I  -3336.      -7127.     -0.1174E+05   143.5      -121.8        1868.
C  -3335.    -0.1296E+05 -0.3218E+05   285.8      -141.4        2058.
O  -3334.    -0.1879E+05 -0.5261E+05   428.1      -160.9        2248.
    S1           S2          S3          SINT        SEQV
I  -2936.      -7126.     -0.1214E+05   9207.       7984.
C  -3181.    -0.1297E+05 -0.3233E+05  0.2914E+05  0.2569E+05
O  -3220.    -0.1881E+05 -0.5272E+05  0.4950E+05  0.4383E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY          SZ          SXY         SYZ          SXZ
I -0.3855E-03   2.533       8.873     -0.6178E-01  0.8490E-02 -0.8263E-01
C -0.1819E-11 0.3638E-11 -0.1091E-10   0.000      -0.2842E-13  0.9095E-12
O  0.3855E-03  -2.533      -8.873      0.6178E-01 -0.8490E-02  0.8263E-01
    S1           S2          S3          SINT        SEQV
I   8.874       2.535     -0.2656E-02   8.877       7.919
C  0.3638E-11 -0.1729E-11 -0.1100E-10  0.1464E-10  0.1283E-10
O  0.2656E-02  -2.535      -8.874       8.877       7.919

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
    SX           SY          SZ          SXY         SYZ          SXZ
I  -3336.      -7124.     -0.1173E+05   143.4      -121.8        1868.
C  -3335.    -0.1296E+05 -0.3218E+05   285.8      -141.4        2058.
O  -3334.    -0.1880E+05 -0.5262E+05   428.1      -160.9        2249.
    S1           S2          S3          SINT        SEQV         TEMP
I  -2936.      -7123.     -0.1213E+05   9199.       7977.       -20.00
C  -3181.    -0.1297E+05 -0.3233E+05  0.2914E+05  0.2569E+05
O  -3220.    -0.1881E+05 -0.5273E+05  0.4951E+05  0.4384E+05   -20.00
```

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECT-2     DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =    1659      OUTSIDE NODE =    1678

 LOAD STEP      3  SUBSTEP=      1
 TIME=    3.0000           LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN COORDINATE SYSTEM   1

             ** MEMBRANE **
     SX           SY           SZ          SXY         SYZ         SXZ
 -282.2      -0.1041E+05 -0.3165E+05   249.8       -174.2       1115.
     S1           S2           S3          SINT        SEQV
 -236.8      -0.1041E+05 -0.3169E+05  0.3146E+05  0.2780E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I   1.988        813.0        3272.       -19.90       1.679       38.56
C   0.000        0.000        0.000        0.000       0.000       0.000
O  -1.988       -813.0       -3272.        19.90      -1.679      -38.56
     S1           S2           S3          SINT        SEQV
I   3272.        813.5        1.044        3271.       2950.
C   0.000        0.000        0.000        0.000       0.000
O  -1.044       -813.5       -3272.        3271.       2950.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  -280.2       -9597.     -0.2838E+05   229.9       -172.5       1154.
C  -282.2     -0.1041E+05 -0.3165E+05   249.8       -174.2       1115.
O  -284.2     -0.1122E+05 -0.3492E+05   269.7       -175.9       1076.
     S1           S2           S3          SINT        SEQV
I  -227.6       -9601.     -0.2843E+05  0.2820E+05  0.2488E+05
C  -236.8     -0.1041E+05 -0.3169E+05  0.3146E+05  0.2780E+05
O  -244.4     -0.1123E+05 -0.3496E+05  0.3472E+05  0.3073E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  0.8630E-03  0.3530       1.421      -0.8642E-02  0.7290E-03  0.1674E-01
C   0.000     -0.5457E-11  0.3638E-11  0.2842E-13  0.2842E-13  0.2274E-12
O -0.8630E-03 -0.3530      -1.421       0.8642E-02 -0.7290E-03 -0.1674E-01
     S1           S2           S3          SINT        SEQV
I   1.421      0.3532      0.4534E-03   1.420       1.281
C  0.3652E-11 -0.1403E-13 -0.5457E-11  0.9109E-11  0.7939E-11
O -0.4534E-03 -0.3532      -1.421       1.420       1.281

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY         SYZ         SXZ
I  -280.2       -9597.     -0.2838E+05   229.9       -172.5       1154.
C  -282.2     -0.1041E+05 -0.3165E+05   249.8       -174.2       1115.
O  -284.2     -0.1122E+05 -0.3493E+05   269.7       -175.9       1076.
     S1           S2           S3          SINT        SEQV        TEMP
I  -227.6       -9601.     -0.2843E+05  0.2820E+05  0.2488E+05  -20.00
C  -236.8     -0.1041E+05 -0.3169E+05  0.3146E+05  0.2780E+05
O  -244.4     -0.1123E+05 -0.3496E+05  0.3472E+05  0.3073E+05  -20.00
```

1-ft Corner Drop - Cold (No Heat) Conditions - Outer Shell

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   1626     OUTSIDE NODE =   1645

 LOAD STEP     3  SUBSTEP=     1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
 -228.3      -5882.     -0.1022E+05   139.0      -91.02       93.02
     S1          S2          S3          SINT        SEQV
 -224.1      -5884.     -0.1022E+05   9999.       8685.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   1.099       1253.       4388.      -30.83      -3.299      -0.7403E-09
C   0.000       0.000       0.000       0.000       0.000       0.000
O  -1.099      -1253.      -4388.       30.83       3.299       0.7403E-09
     S1          S2          S3          SINT        SEQV
I   4388.       1253.       0.3406      4387.       3914.
C   0.000       0.000       0.000       0.000       0.000
O -0.3406      -1253.      -4388.       4387.       3914.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -227.2      -4630.      -5833.       108.2      -94.32       93.02
C  -228.3      -5882.     -0.1022E+05   139.0      -91.02       93.02
O  -229.4      -7135.     -0.1461E+05   169.8      -87.72       93.02
     S1          S2          S3          SINT        SEQV
I  -223.1      -4625.      -5842.       5619.       5120.
C  -224.1      -5884.     -0.1022E+05   9999.       8685.
O  -224.7      -7138.     -0.1461E+05  0.1439E+05  0.1246E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  0.4774E-03  0.5439      1.905      -0.1339E-01 -0.1432E-02 -0.3553E-12
C  0.2842E-13 -0.5457E-11 -0.2365E-10  0.2274E-12  0.1421E-13 -0.1421E-13
O -0.4774E-03 -0.5439     -1.905       0.1339E-01  0.1432E-02  0.2984E-12
     S1          S2          S3          SINT        SEQV
I   1.905      0.5443      0.1479E-03   1.905       1.700
C  0.3784E-13 -0.5466E-11 -0.2365E-10  0.2368E-10  0.2147E-10
O -0.1479E-03 -0.5443     -1.905       1.905       1.700

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I  -227.2      -4629.      -5831.       108.2      -94.32       93.02
C  -228.3      -5882.     -0.1022E+05   139.0      -91.02       93.02
O  -229.4      -7136.     -0.1461E+05   169.8      -87.72       93.02
     S1          S2          S3          SINT        SEQV        TEMP
I  -223.1      -4624.      -5840.       5617.       5118.      -20.00
C  -224.1      -5884.     -0.1022E+05   9999.       8685.
O  -224.7      -7139.     -0.1461E+05  0.1439E+05  0.1246E+05  -20.00
```

1-ft Corner Drop - Cold (No Heat) Conditions - Lid

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =     191      OUTSIDE NODE =     12

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  2026.       -3576.      -4554.       412.3       2028.       2858.
     S1          S2          S3          SINT        SEQV
  3278.       -2721.      -6662.       9940.       8669.

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1364E+05  -9594.       5524.      -3497.      -102.5       494.1
C   0.000       0.000       0.000       0.000       0.000       0.000
O  0.1364E+05   9594.      -5524.       3497.       102.5      -494.1
     S1          S2          S3          SINT        SEQV
I   5539.      -7585.     -0.1566E+05  0.2120E+05  0.1853E+05
C   0.000       0.000       0.000       0.000       0.000
O  0.1566E+05   7585.      -5539.      0.2120E+05  0.1853E+05

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1161E+05 -0.1317E+05   970.1      -3084.       1925.       3352.
C   2026.      -3576.      -4554.       412.3       2028.       2858.
O  0.1566E+05   6018.     -0.1008E+05   3909.       2130.       2364.
     S1          S2          S3          SINT        SEQV
I   1895.      -9382.     -0.1633E+05  0.1822E+05  0.1593E+05
C   3278.      -2721.      -6662.       9940.       8669.
O  0.1737E+05   4728.     -0.1049E+05  0.2785E+05  0.2416E+05

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.1261E+05 -0.1077E+05  0.1218E+05   3414.      -4939.       1514.
C   3103.       1881.      -2227.      -262.4       1068.       247.2
O  -2168.      -5104.       3042.      -693.9      -1527.      -1011.
     S1          S2          S3          SINT        SEQV
I  0.1322E+05  -8541.     -0.1589E+05  0.2911E+05  0.2622E+05
C   3157.       2104.      -2505.       5661.       5215.
O   3456.      -2082.      -5603.       9059.       7910.

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.2423E+05 -0.2394E+05  0.1315E+05   329.4      -3014.       4866.
C   5128.      -1696.      -6781.       149.9       3095.       3105.
O  0.1350E+05   913.3      -7036.       3215.       603.3       1353.
     S1          S2          S3          SINT        SEQV        TEMP
I  0.1400E+05 -0.2372E+05 -0.2529E+05  0.3930E+05  0.3854E+05  -20.00
C   6000.      -553.6      -8795.      0.1479E+05  0.1284E+05
O  0.1437E+05   149.2      -7145.      0.2151E+05  0.1895E+05  -20.00
```

1-ft Corner Drop - Cold (No Heat) Conditions - Baseplates

```
PRINT LINEARIZED STRESS THROUGH A SECTION DEFINED BY PATH= SECTION    DSYS=  0

         ***** POST1 LINEARIZED STRESS LISTING *****
        INSIDE NODE =   2148      OUTSIDE NODE =   2179

 LOAD STEP     3  SUBSTEP=      1
 TIME=    3.0000          LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

             ** MEMBRANE **
     SX           SY           SZ          SXY          SYZ          SXZ
 -8965.       -8173.        1649.       -71.82        249.0        1156.
     S1           S2           S3          SINT         SEQV
  1779.       -8168.       -9100.      0.1088E+05   0.1044E+05

             ** BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -7399.       -1531.      0.4727E-10   -905.9      0.6085E-10  -0.2462E-09
C   0.000        0.000       0.000        0.000       0.000        0.000
O   7399.        1531.      -0.4727E-10   905.9     -0.6085E-10   0.2462E-09
     S1           S2           S3          SINT         SEQV
I   0.000       -1394.      -7536.        7536.       6944.
C   0.000        0.000       0.000        0.000       0.000
O   7536.        1394.       0.000        7536.       6944.

             ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I -0.1636E+05   -9704.       1649.       -977.7       249.0        1156.
C  -8965.       -8173.       1649.       -71.82       249.0        1156.
O  -1566.       -6642.       1649.        834.1       249.0        1156.
     S1           S2           S3          SINT         SEQV
I   1726.       -9564.     -0.1658E+05  0.1831E+05   0.1600E+05
C   1779.       -8168.      -9100.      0.1088E+05   0.1044E+05
O   2050.       -1833.      -6776.       8826.        7662.

             ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I  -3.213       -0.6647    -0.1023E-10  -0.3933     -0.2842E-12  -0.3411E-11
C -0.1819E-11  -0.1819E-11 -0.6594E-11   0.3268E-12 -0.2274E-12  -0.2046E-11
O   3.213        0.6647     0.4775E-11   0.3933      0.1137E-12   0.1137E-11
     S1           S2           S3          SINT         SEQV
I   0.000       -0.6053     -3.272        3.272       3.015
C -0.9001E-12  -0.1979E-11 -0.7353E-11   0.6453E-11   0.5986E-11
O   3.272        0.6053      0.000        3.272       3.015

             ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX           SY           SZ          SXY          SYZ          SXZ
I -0.1637E+05   -9704.       1649.       -978.1       249.0        1156.
C  -8965.       -8173.       1649.       -71.82       249.0        1156.
O  -1563.       -6641.       1649.        834.4       249.0        1156.
     S1           S2           S3          SINT         SEQV         TEMP
I   1726.       -9564.     -0.1658E+05  0.1831E+05   0.1600E+05   -20.00
C   1779.       -8168.      -9100.      0.1088E+05   0.1044E+05
O   2050.       -1830.      -6775.       8826.        7662.       -20.00
```

Appendix 3

Electronic Data on DVD

(1 DVD)

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1.0 OBJECTIVE

To demonstrate that the techniques employed in constructing the ANSYS finite element model of the 3-60B Cask represents the structure accurately and the element sizes used in the models converge to within a small tolerance of the theoretical values.

2.0 INTRODUCTION

The evaluations performed in the SAR of the 3-60B Cask (Reference 1 through 3) employ 3-dimensional finite element models for ANSYS software code (Reference 4). These models use 8-node solid elements (SOLID-185) for representing the cask components that do not undergo significant amount of bending deformation. The cask components that undergo significant amount of bending deformation have been represented by solid shell (SOLSH-190) elements in the models. Figure 1 shows a typical model of the 3-60B cask, identifying the element types employed in its modeling.

The modeling techniques employed in the 3-60B Cask model also utilize ANSYS contact elements to combine parts of the model with different grid densities. In order to model the bolting ring, which includes bolts holes, with octahedral elements, the bolting ring is modeled in two parts. These parts are combined together with the help of contact elements. Verification that this simplification does not compromise the stresses in the bolting ring is also included in this study.

The study is performed in two parts. In the first part, two finite element models of the bolting ring region- one identical to the SAR model and another model employing fine elements - are subjected to an internal pressure of 1,000 psi on the inner shell. The stresses in the two models are computed and compared with each other. It is shown that the stresses predicted by the SAR model are within 94% of the fine model.

In the second part of the study the effect of element size on stress prediction is studied. A simplified model of the inner shell is used for this study. The model represents a fixed-end inner shell that is subjected to 1,000 psi internal pressure. The number of elements through the thickness and along the longitudinal direction is varied and its effect on the end-moment and longitudinal stresses are plotted parametrically. The parameters corresponding to the inner shell are superimposed on these plots. It is shown that the element size corresponding to the SAR model can predict the end moment within 95% of the theoretical value. Models with these parameters will also predict the longitudinal stresses in the shell within 90% of a model with fine elements.

Additional comparison with the theoretical stress values has been performed with models representing the unit width of the inner shell element as a beam. The number of elements through the thickness and along the length is varied. The maximum longitudinal stresses are plotted parametrically. The parameters corresponding to the inner and outer shell model of the SAR have been superimposed. It is shown that these models are capable of predicting the stresses within 95% of the theoretical values.

3.0 REFERENCES

(1) Energy*Soutions* Document ST-501, Structural Analyses of the 3-60B Cask under Normal Conditions of Transport.

(2) Energy*Solutions* Document ST-502, Structural Analyses of the 3-60B Cask under Hypothetical Fire Accident Conditions.

(3) Energy*Solutions* Document ST-504, Structural Analyses of the 3-60B Cask under Drop Conditions.

(4) ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

(5) Formulas for Stress and Strain, Roark and Young, Fifth Edition, McGraw Hill Publications.

4.0 ANLYSIS DESCRIPTION

The studies performed in this document are divided into two parts. The first part includes a study to show that the simplifications employed in modeling techniques for representing the bolting ring-inner shell region in the 3-60B Cask ANSYS finite element model is appropriate. The second includes a study to show that finite element grid size employed in the inner-shell model of the 3-60B Cask accurately predicts the stresses.

The pertinent data of the finite element models used in this study is provided in Appendix 1 in printed form. The electronic data for all the analyses are provided in Appendix 2 on a DVD.

4.1 Modeling Technique Study

The 3-60B Cask finite element model representing the bolting ring-inner shell region has the following major characteristics.

- Uses ANSYS SOLIDSH-190 elements to represent the shells.
- Uses SOLID-185 elements to represent parts of the structure that do not undergo large bending deformation.
- Uses 1-element through the thickness to represent the shells.
- The shell elements at the interface are connected with single elements in the plate.
- The bolting ring is modeled in two parts that are tied together using bonded contact interface.

The objective of this study is to show that the model of the bolting ring-inner shell region constructed with the above characteristics appropriately represents the true nature of the region. To accomplish this two simplified finite element models of this region are constructed and analyzed for an internal pressure loading of 1,000 psi. The first model is similar to the model used in the 3-60B Cask SAR. This model is subsequently referred to as the "SAR Model" in the rest of the document. The second model is made with very fine elements and without the use of contact elements. This model is subsequently referred to as the "fine model" in the rest of the document. The simplified models have the following characteristics.

- They use an 11.25^{o} (1/32nd symmetry) model.
- They use the bolting ring and a sufficient length (> $4\sqrt{Rt}$) of the inner shell in the model.
- They disregard the bolt-holes.
- They disregard the outer shell and the skirt part of the bolting ring.
- They are analyzed for 1,000 psi internal pressure loading on the inner shell.
- The maximum stress intensity, maximum axial stress, and linearized axial stress are computed for both the models.

The geometry of the bolting ring-inner shell region of the 3-60B Cask is shown in Figure 2. The region shown in solid colors in this figure is represented in the simplified finite element models.

4.1.1 The SAR Model

The SAR model finite element grid and the boundary conditions are shown in Figure 3. This model has the following additional characteristics (in addition to those described under the simplified model characteristics).

- It uses SOLSH-190 elements to represent the inner shell and keep the element size identical to the SAR model.
- It uses SOLID-185 elements to represent the plate part of the bolting ring, keeping the element size identical to the SAR model everywhere except in the bolt-hole area.
- It models the bolting ring in two parts and joins the two parts by bonded contact interface, identical to the SAR model.

The stress intensity contour plot of the SAR model is shown in Figure 4. The stress intensity contour plot in the inner shell is shown in Figure 5 and the contour of the longitudinal stresses in the inner shell is shown in Figure 6. The linearized membrane and membrane plus bending plots over the inner shell cross-section are shown in Figure 7.

4.1.2 The Fine Model

The fine model finite element grid geometry is shown in Figure 8. This model has the following additional characteristics (in addition to those described under the simplified model characteristics).

- It uses SOLID-185 elements to represent the entire model.
- It uses 5-elements through the thickness of the shell.
- It uses very fine elements to represent the plate near the interface region.
- It models the plate in one piece. No bonded contact is used.

The stress intensity contour plot of the fine model is shown in Figure 9. The stress intensity contour plot in the inner shell is shown in Figure 10 and the contour of the longitudinal stresses in the inner shell is shown in Figure 11. The linearized membrane and membrane plus bending plots over the inner shell cross-section are shown in Figure 12.

4.1.2 Results and Comparison

The results of the SAR model and the fine model analyses are presented in Table 1. The comparison of the results and percentage difference of the results between the two models are also shown in this table. The following conclusions are made from the comparison of the results of the two models.

- The SAR Model computes the maximum stress intensity within 94% of the Fine Model.
- The SAR Model computes higher axial stresses than the Fine Model. It is +9% for the maximum value and +5% for the linearized membrane + bending value.
- Inclusion of bonded contact interface at the location chosen by EnergySolutions in the SAR model does not have any significant effect. The stress values and pattern are very similar to each other (see Figures 4 & 9). Also the interface is located at a relatively lightly loaded location of the bolting ring.

4.2 Grid Sensitivity Study

In order to demonstrate that the finite element grid used in the ANSYS model of the 3-60B Cask adequately represents the bending behavior of the shell, a grid sensitivity study is performed. For this purpose a sufficiently large length ($>4\sqrt{Rt}$) of the inner shell, fixed at one of its edges and free on the other, is analyzed for an internal pressure loading of 1,000 psi. The models are constructed from solid shell (SOLSH-190) elements - the same elements used in the 3-60B Cask ANSYS model to represent the inner shell. Each model has a length of 25" and extends 10^{o} in the circumferential direction. Figure 13 shows the geometry of the model.

Various grid densities are obtained by varying the number of elements through the thickness and through the length. Permutations of 1, 2, 3, and 4 elements through the thickness and 10, 15, 20, 25, 30, and 40 elements through the length is used to encompass grid densities that range between "coarse" and "fine". All the 24 (4×6) models resulting from the aforementioned permutations are analyzed for end moments and maximum longitudinal stresses. The longitudinal stress data is linearized over the shell thickness at the fixed-edge for each model. An input file written in ANSYS programming language (APL) is used to automate the computation process. This file is included in Appendix 2 of this document.

The contour plot of the longitudinal stress for a typical model (4 elements through the thickness; 40 elements through the length) is shown in Figure 14. The end-moments from each model analysis are plotted in Figure 15 in a parametric form. This plot also shows the length-to-thickness ratio of the finite element size used in the 3-60B Cask ANSYS model. It is observed that the end-moment is not sensitive to the number of elements through the thickness or the length direction. The plot also shows a "theoretical value" calculated from the formulas obtained from Reference 5. It should be noted that this "theoretical value" is not precise and is given here for reference purpose only.

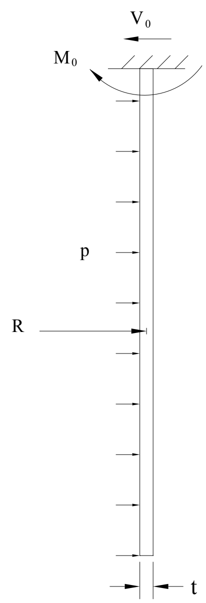
Using the formulas from Reference 5 the theoretical end moment is obtained as follows:

R = Mean radius of the shell = 17.875 in

t = Shell thickness = 0.75 in

E = Young's modulus of the material = 30×10^6 psi

ν = Poisson's ratio of the material = 0.3



$$D = \frac{Et^3}{12(1-\nu^2)} = \frac{30\times10^6\times0.75^3}{12\times(1-0.3^2)} = 1.159\times10^6 \text{ in-lb}$$

$$\lambda = \left[\frac{3\times(1-\nu^2)}{R^2t^2}\right]^{0.25} = \left[\frac{3\times(1-0.3^2)}{17.875^2\times0.75^2}\right]^{0.25} = 0.3511\ /\text{in}$$

Radial displacement due to p, V_0, and M_0 are:

$$\Delta R_p = \frac{pR^2}{Et}$$

$$\Delta R_{V_0} = \frac{-V_0}{2D\lambda^3}$$

$$\Delta R_{M_0} = \frac{M_0}{2D\lambda^2}$$

Rotation due to V_0 and M_0 are:

$$\psi_{V_0} = \frac{V_0}{2D\lambda^2}$$

$$\psi_{M_0} = \frac{-M_0}{D\lambda}$$

For the fixed boundary conditions:

$$\Delta R_p + \Delta R_{V_0} + \Delta R_{M_0} = 0 \quad \text{...(1)}$$

$$\psi_{V_0} + \psi_{M_0} = 0 \quad \text{...(2)}$$

Solving equations (1) and (2) simultaneously, one gets:

$$M_0 = \frac{p}{2\lambda^2} = \frac{1{,}000}{2\times0.3511^2} = 4{,}056 \text{ in-lb/in}$$

The longitudinal membrane + bending stresses, linearized over the thickness, obtained from various models are plotted in Figure 16 in a parametric form. Taking the value corresponding to the fine model (4 elements through the thickness; 40 elements through the length) as the datum, 90 and 95 percentile lines are shown in this figure. It is observed that the membrane + bending stress corresponding to the size of elements used in the 3-

60B Cask ANSYS model yields a result that is within approximately 90% of the fine model result.

4.2.1 Comparison with the Theoretical Stresses

In order to compare the stresses calculated by the finite element models of various grid densities that use solid shell (SOLSH-190) elements with the theoretical value, cantilever beam model, as shown in Figure 17, was analyzed for various grid densities. The choice of this model was influenced by the fact that the theoretical stress for this case is precise and is not strongly dependent on the thickness of the cross-section. A 1"×1" cross-section and 10" length of the beam was used for modeling. The top surface of the beam was subjected to a uniform pressure of 100 psi. Under this loading the bending moment at the support is:

$$M = 1\times10\times100\times10/2 = 5{,}000 \text{ in-lb}$$

The maximum bending stress is:

$$\sigma = 6\times5{,}000/1 = 30{,}000 \text{ psi}$$

The finite element model is constructed using SOLSH-190 elements and the following material properties.

$$E = 30\times10^6 \text{ psi, and } \nu = 0.3$$

Various grid densities are obtained by varying the number of elements through the thickness and through the length. Permutations of 1, 2, 3, 4, 6 and 8 elements through the thickness and 5, 10, 15, 20, 30, and 40 elements through the length is used to encompass grid densities that range between "coarse" and "fine". All the 36 (6×6) models resulting from the aforementioned permutations are analyzed. An input file written in ANSYS programming language (APL) is used to automate the computation process. This file is included in Appendix 2 of this document.

Contour plot of longitudinal stresses in a typical model is shown in Figure 18. The maximum longitudinal stresses obtained from each model analysis are plotted in Figure 19 in a parametric form. To prevent over-crowding this plot, results from 6 and 8 elements through the thickness are not included in this plot since they are very close to the corresponding results from the 4 element through the thickness solution.

Figure 20 shows a plot of 1-element through the thickness plot for various element sizes. The theoretical result is also superimposed in this plot along with the 95 and 90 percentile of the theoretical result band. The element size of the shell elements at the bolting ring-shell interface region is 0.9375" (from Reference 1 through 3). The inner shell is 0.75" thick and the outer shell is 1.25" thick. Thus the length-to-thickness ratios of the two shells are:

Inner shell element length = 0.9375/0.75 = 1.25t

Outer shell element length = 0.9375/1.25 = 0.75t

Figure 20 also indicates these element length-to-thickness ratios. It is seen that for the pure bending problem the element size chosen for the inner and outer shells near the bolting ring interface region is expected to produce results within 95% of the theoretical value.

As an additional check a finite element model of a unit width of the inner shell, having the same element sizes as used in the 3-60B Cask ANSYS model is analyzed as a cantilever beam. The beam has the following geometric properties.

Width = 1", Thickness = 0.75", Length = 10"

It is subjected to a uniform pressure of 56.25 psi over the top surface. Under this loading,

$M = 1\times10\times56.25\times10/2 = 2{,}812.5$ in-lb

The maximum bending stress is:

$\sigma = 6\times2{,}812.5/0.75^2 = 30{,}000$ psi

The finite element model is constructed using SOLSH-190 elements and the following material properties.

$E = 30\times10^6$ psi, and $\nu = 0.3$

The longitudinal stress contour plot of this model is shown in Figure 21. The maximum stress obtained from this model is 29,971 psi, which is within 99.9% of the theoretical value.

5.0 CONCLUSIONS

From the analyses provided in this document it has been demonstrated that the modeling techniques employed in constructing the ANSYS finite element models, used for the analyses of the 3-60B Cask, adequately represent the cask structure in the most vulnerable area (the bolting ring- inner/outer shell region). It has been further demonstrated that the selection of the element sizes in this region will predict the results that are within small tolerances of the corresponding theoretical values.

Table 1 - Comparison of Results of the SAR & the Fine Models

Comparison of Results			
Quantity	SAR Model	Fine Model	% Difference(1)
Maximum Deflection (in)	0.0149(2)	0.014682(3)	+1.48%
Maximum S.I. in the joint (psi)	28,093(2)	29,741(3)	-5.54%
Maximum S.I. in the shell (psi)	28,093(4)	29,741(5)	-5.54%
Maximum Sigz in the shell (psi)	21,118(6)	19,356(7)	+9.10%
Linearized Mem+Bend Sigz (psi)	21,118(8)	20,124(9)	+4.94%

NOTES:

(1) Percentage difference is calculated with respect to the fine model value.

(2) See Figure 4.

(2) See Figure 9.

(3) See Figure 5.

(4) See Figure 10.

(5) See Figure 6.

(6) See Figure 11.

(7) See Figure 7.

(8) See Figure 12.

Figures

(21 Pages)

Figure-1

3-60B Cask FEM - Element Types Used to Model Structural Components

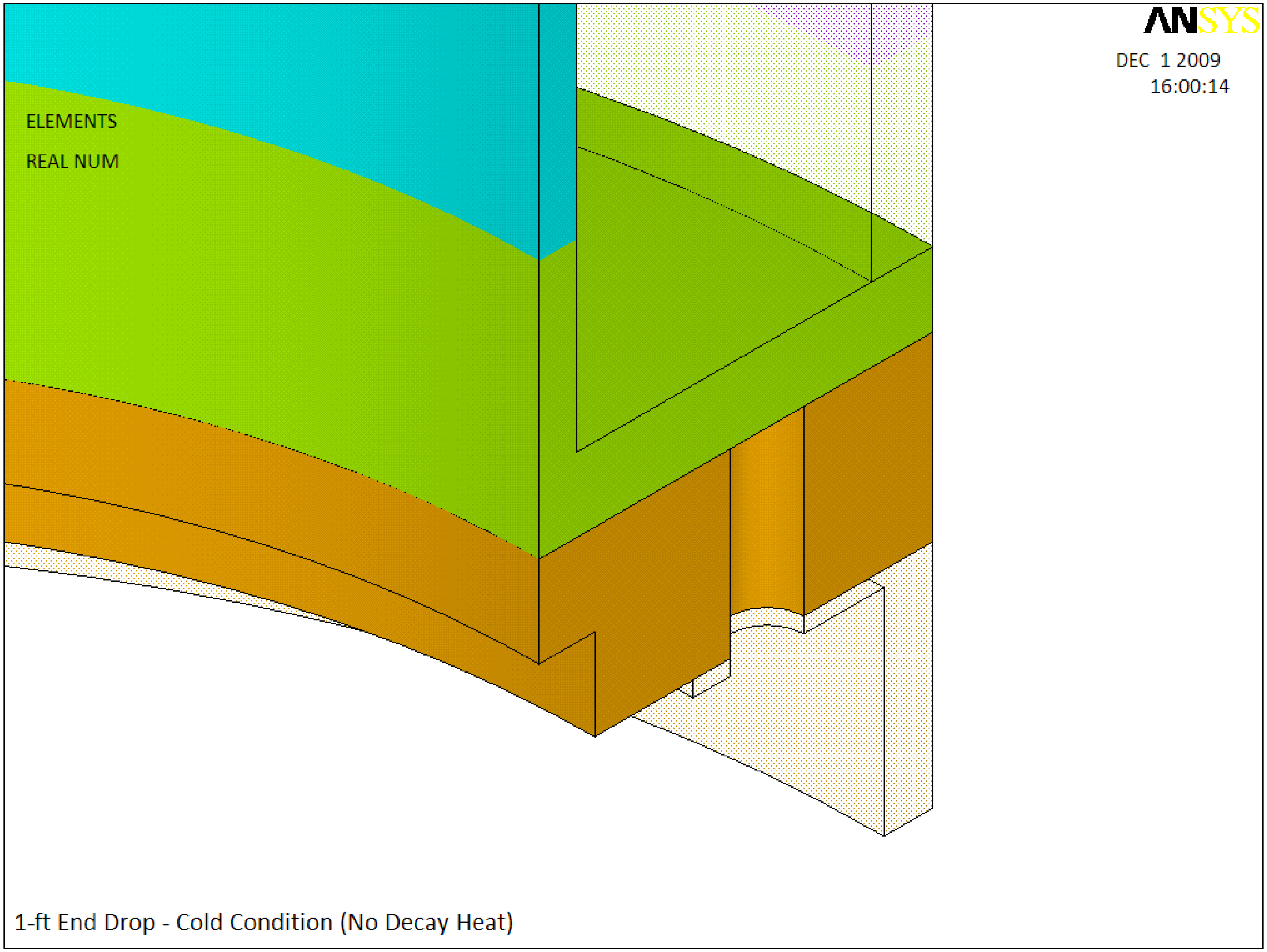


Figure-2

3-60B Cask FEM - Bolting Ring Area Modeling Details

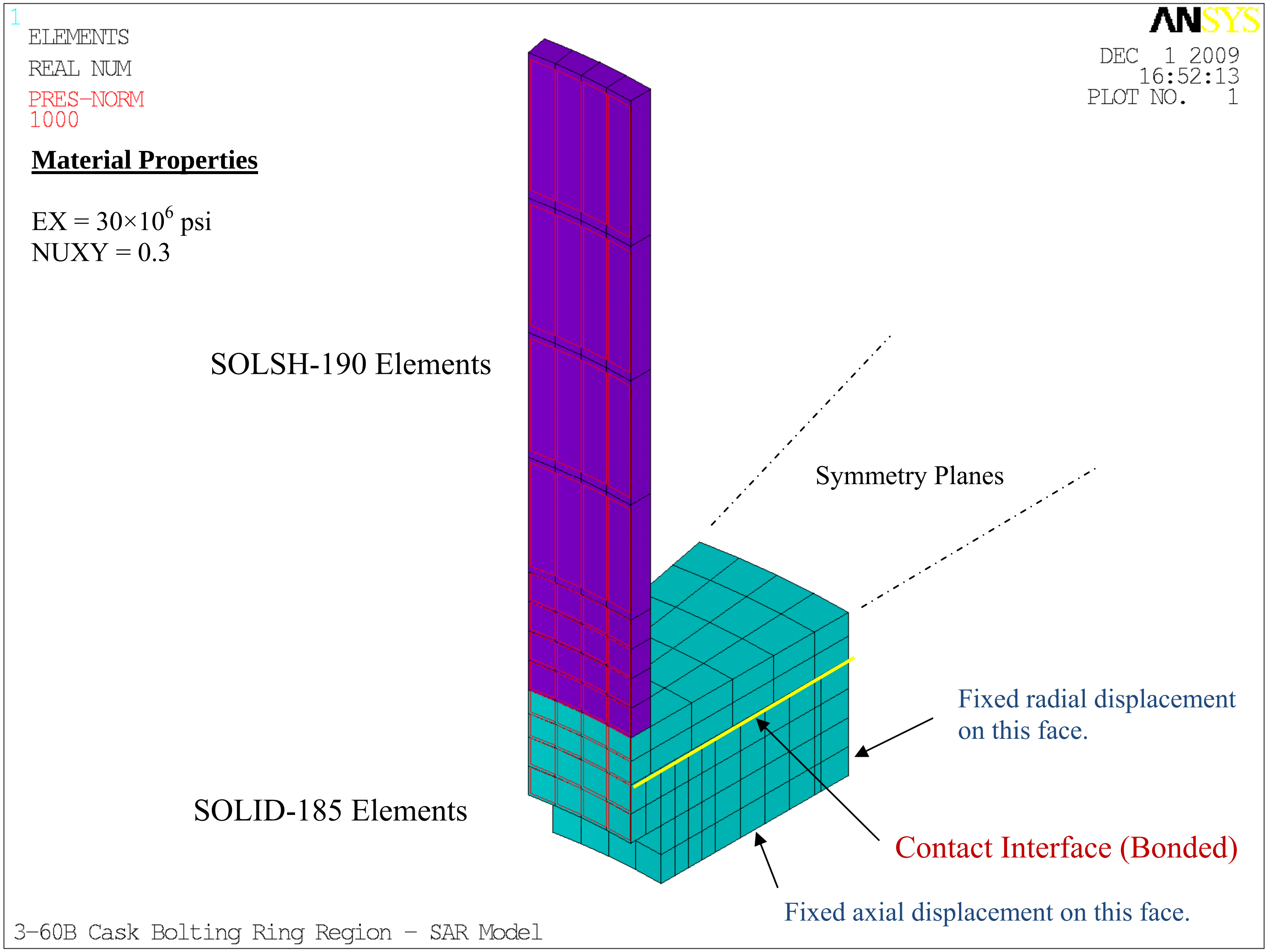


Figure-3

Simplified Bolting Ring Area - SAR Model

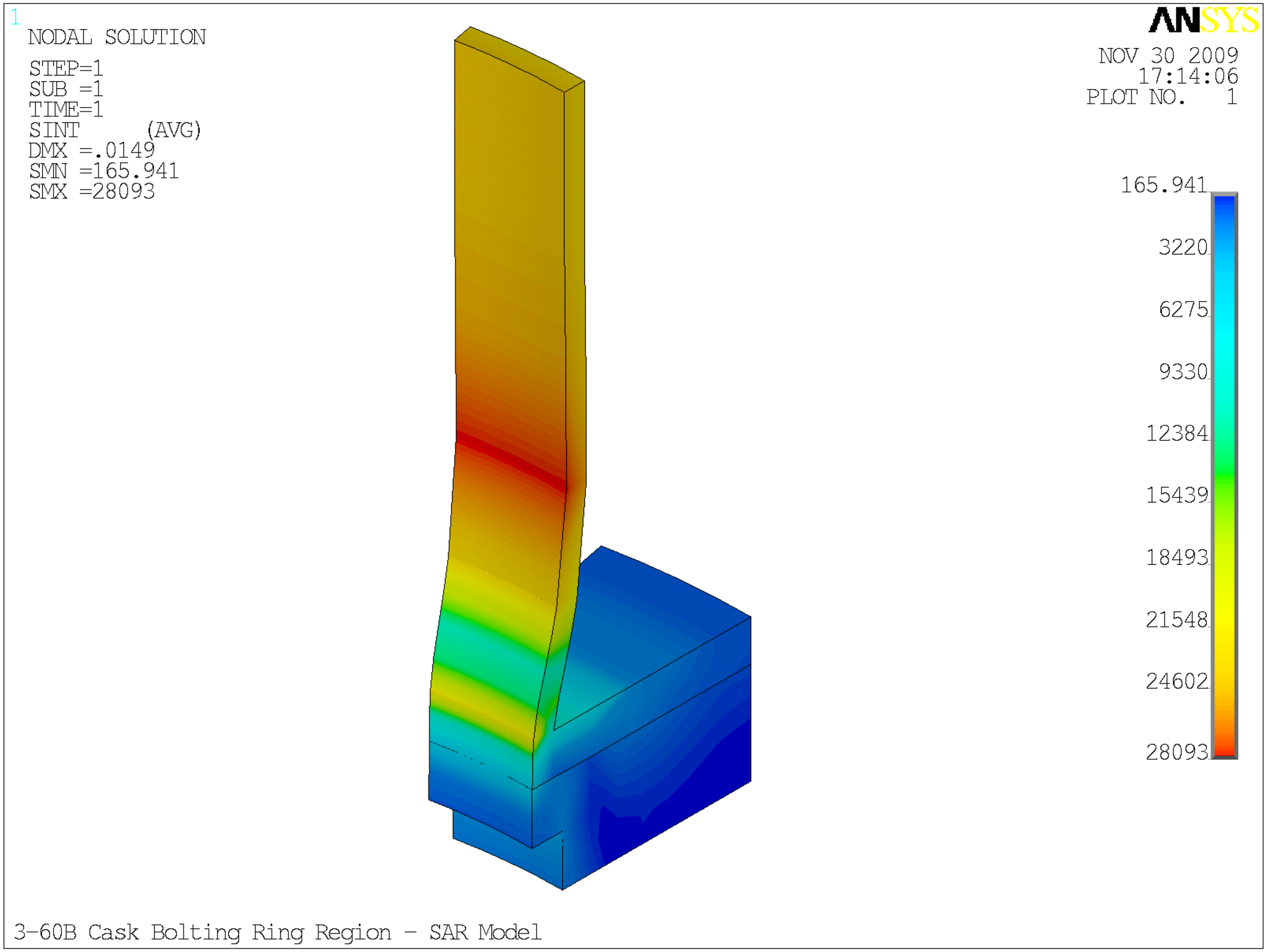


Figure-4

SAR Model - Stress Intensity Contour Plot

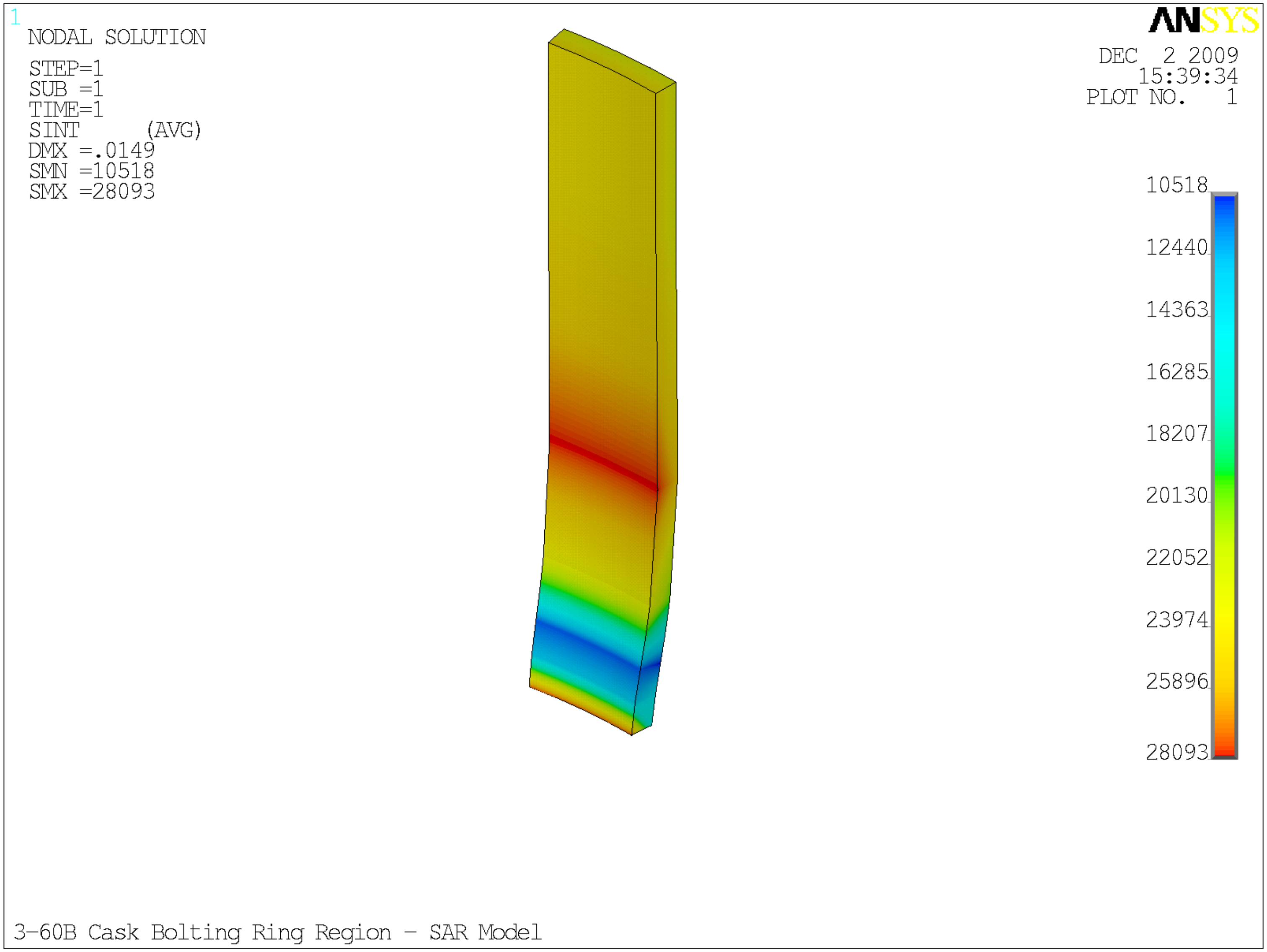


Figure-5

SAR Model - Shell Stress Intensity Contour Plot

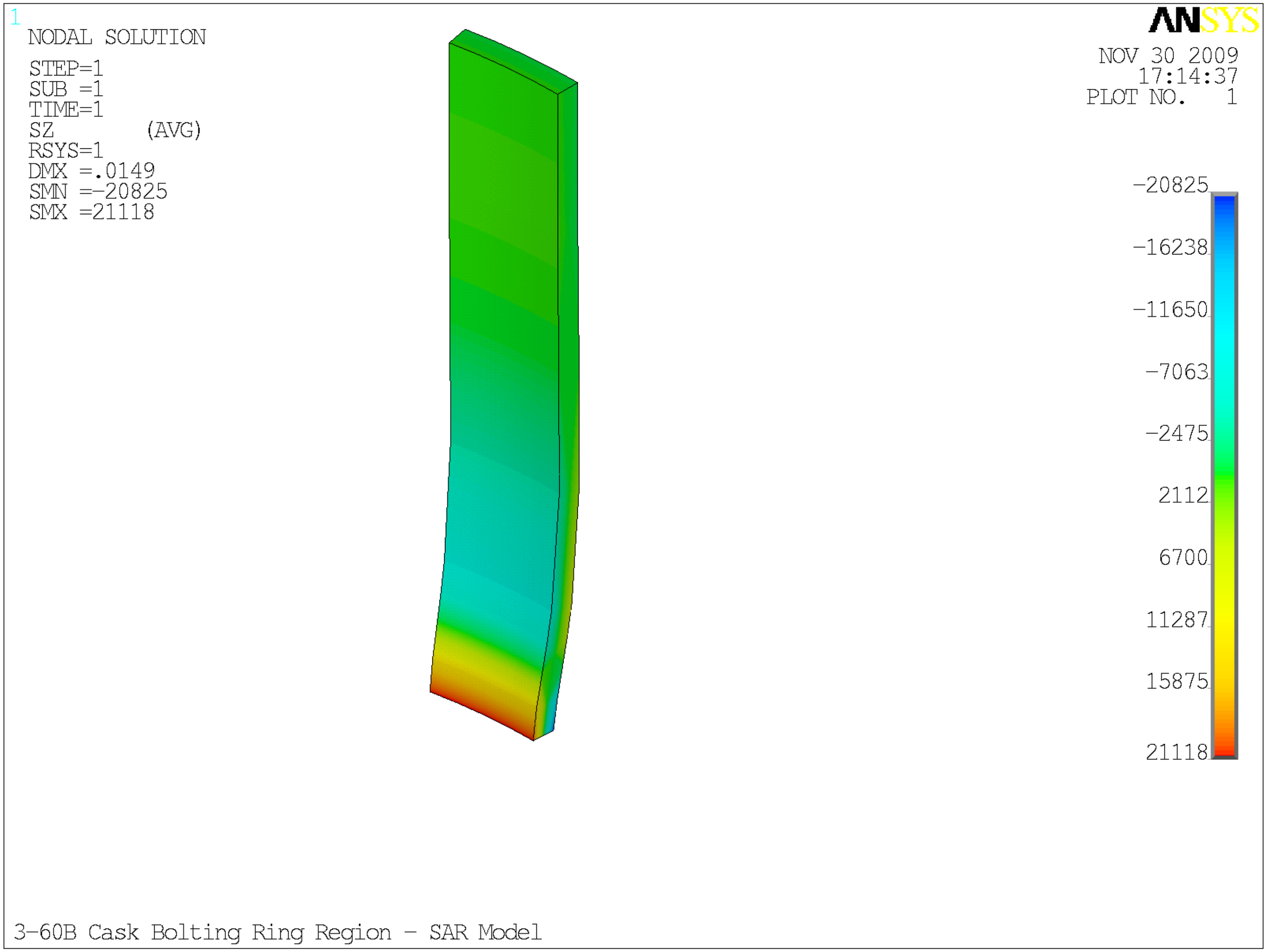


Figure-6

SAR Model - Shell Longitudinal Stress Contour Plot

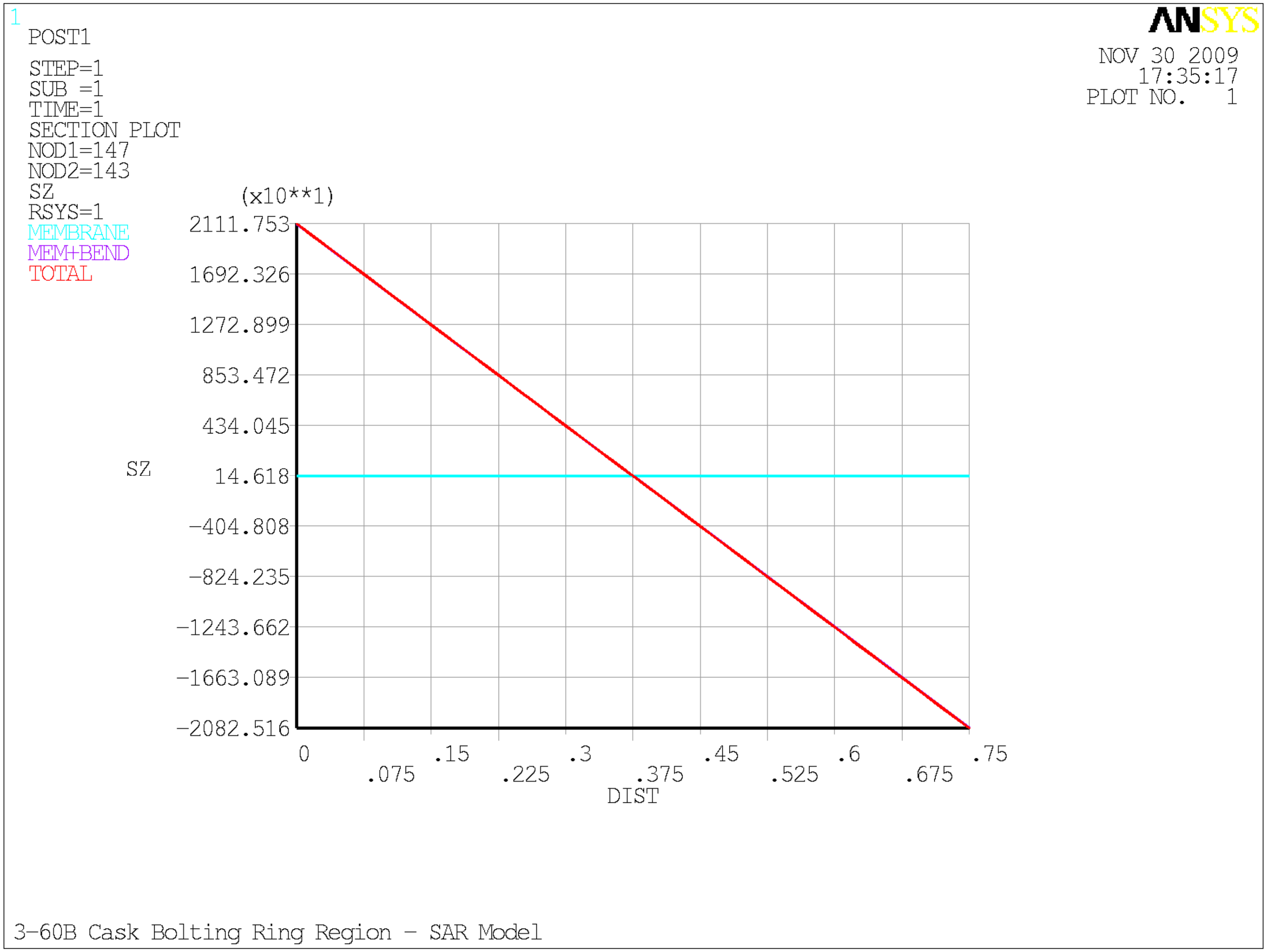


Figure-7

SAR Model - Linearized Longitudinal Stress in the Shell

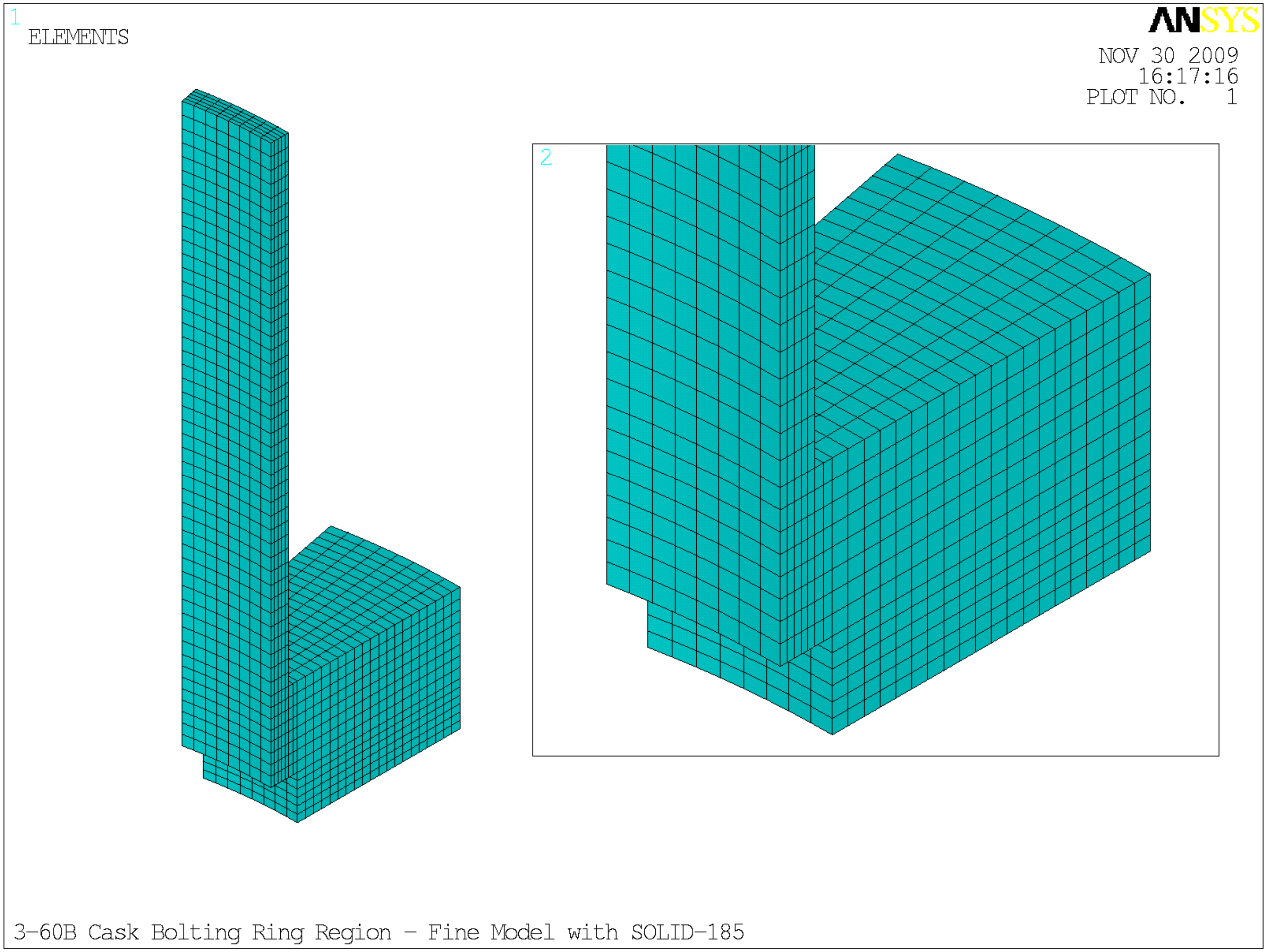


Figure-8

Simplified Bolting Ring Area - Fine Model

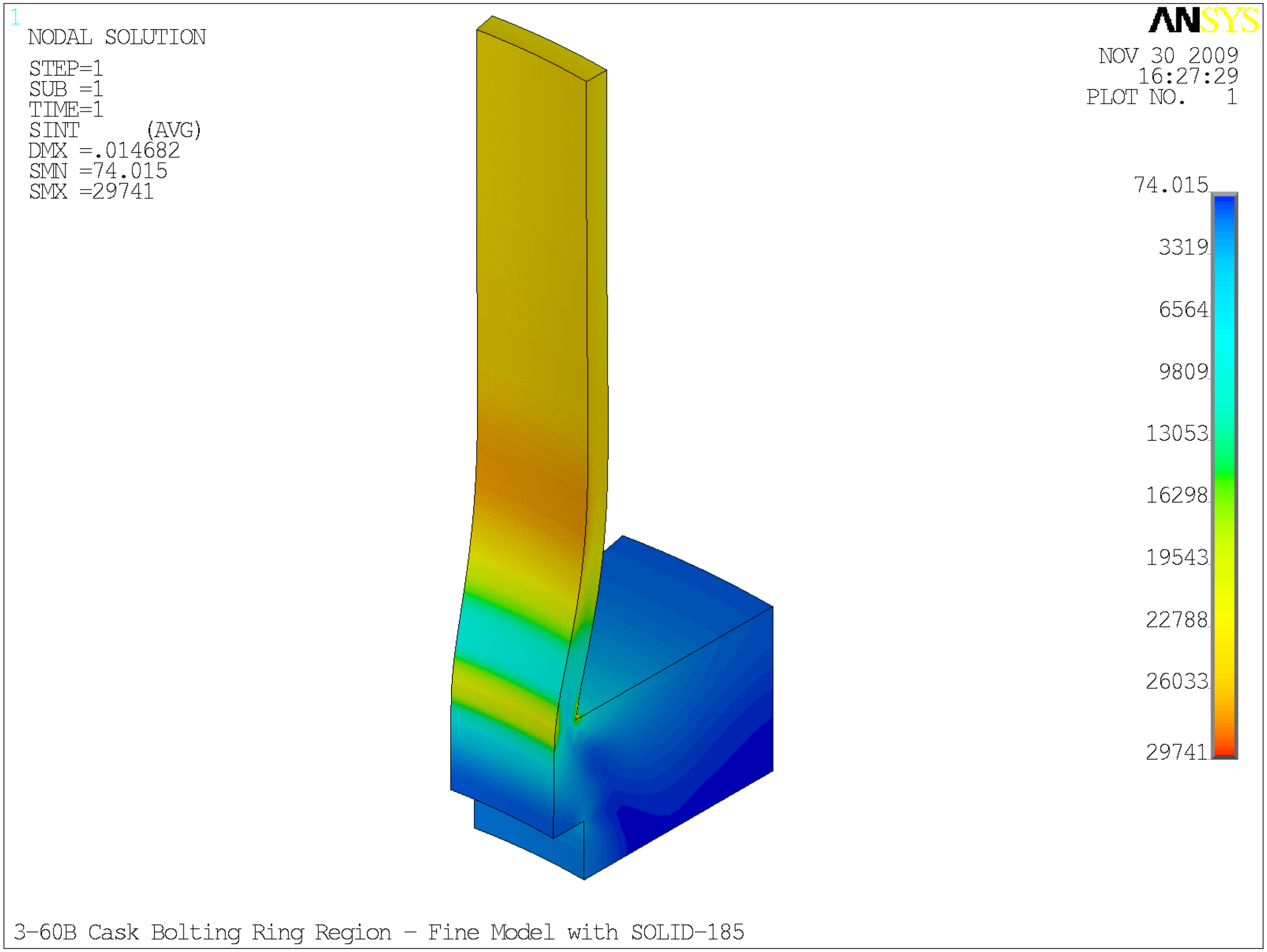


Figure-9

Fine Model - Stress Intensity Contour Plot

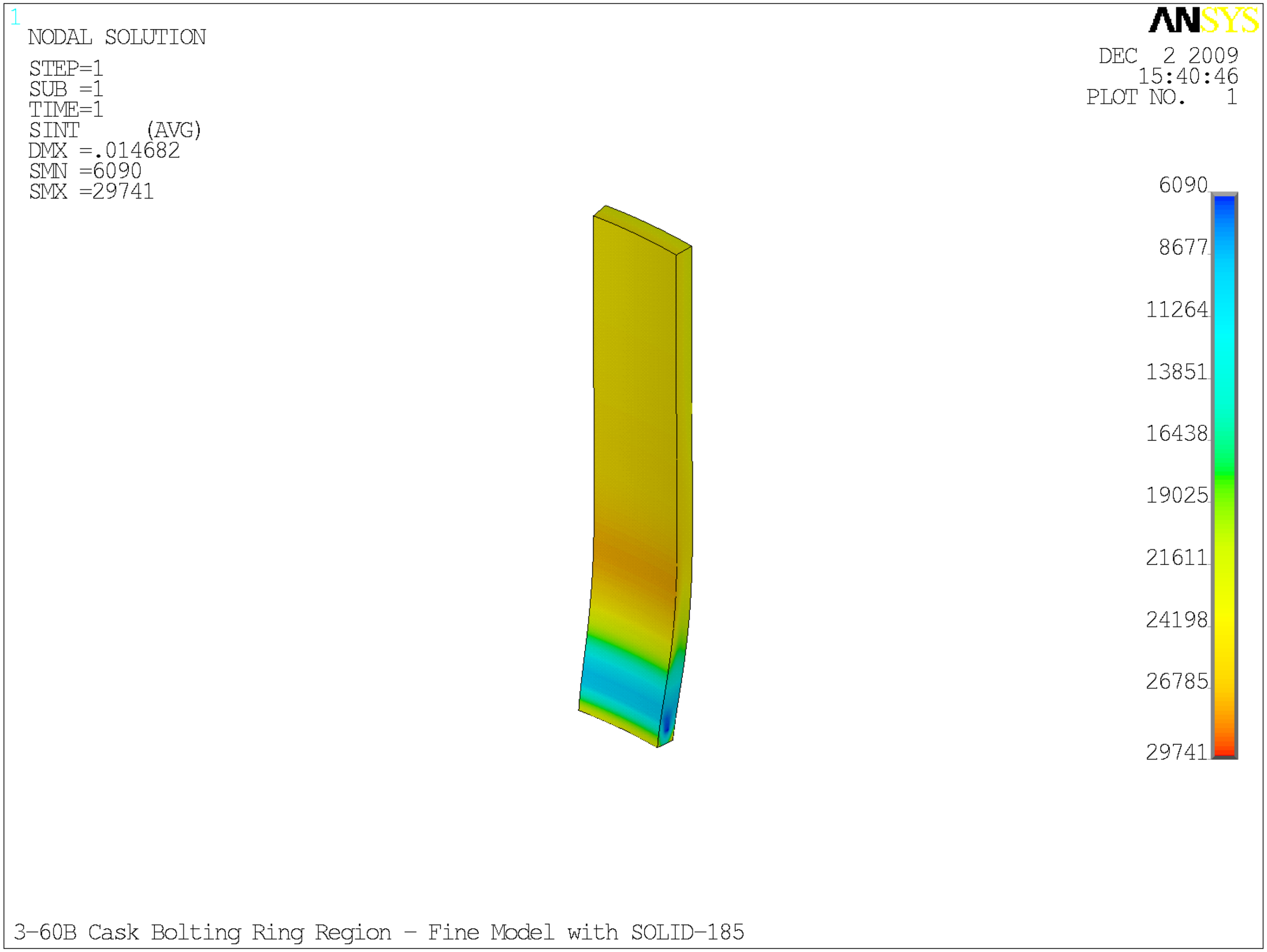


Figure-10

Fine Model - Shell Stress Intensity Contour Plot

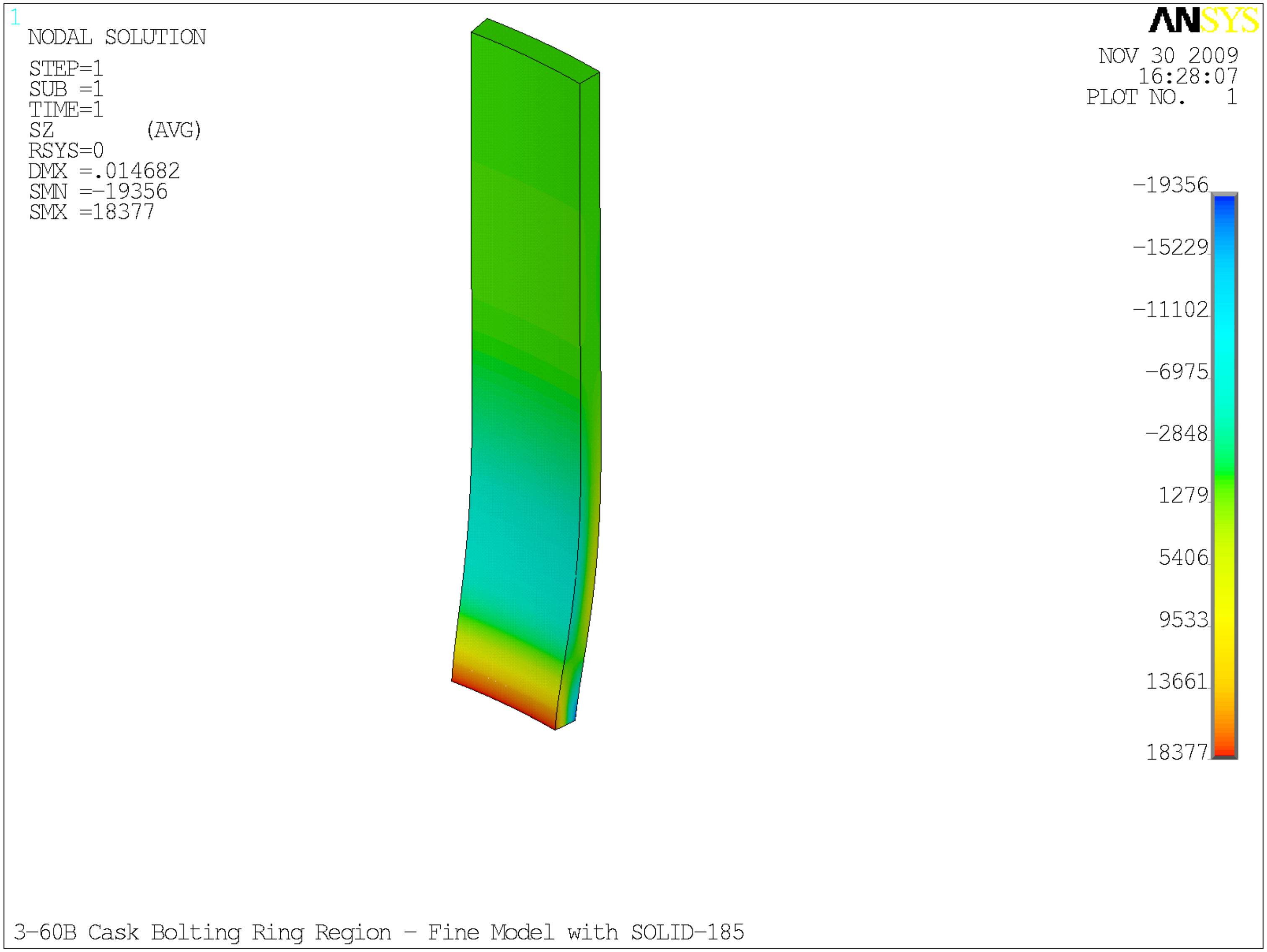


Figure-11

Fine Model - Shell Longitudinal Stress Contour Plot

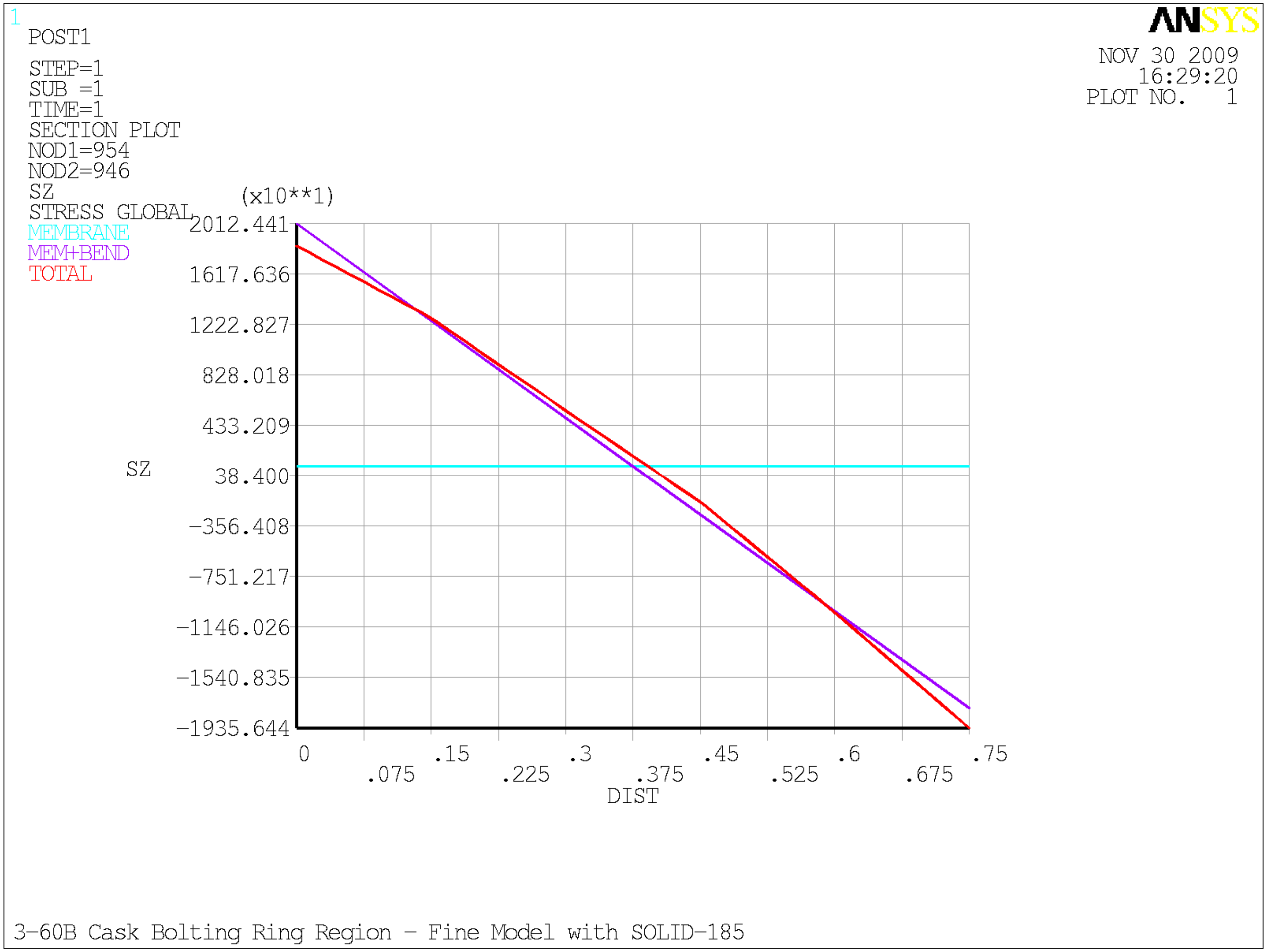


Figure-12

Fine Model - Linearized Longitudinal Stress in the Shell

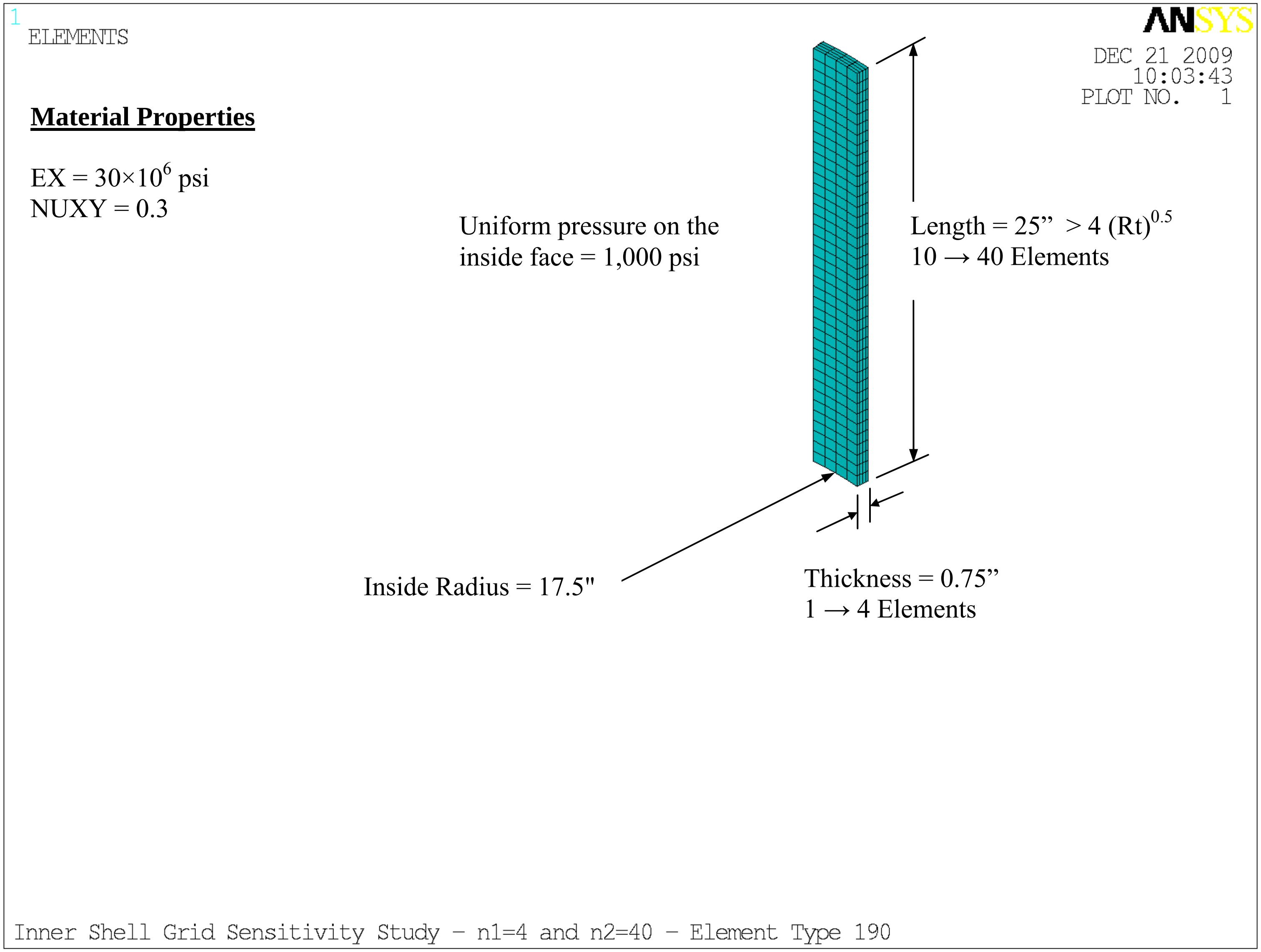


Figure-13

Shell Modeling Grid Sensitivity Study - FEM Dimensions

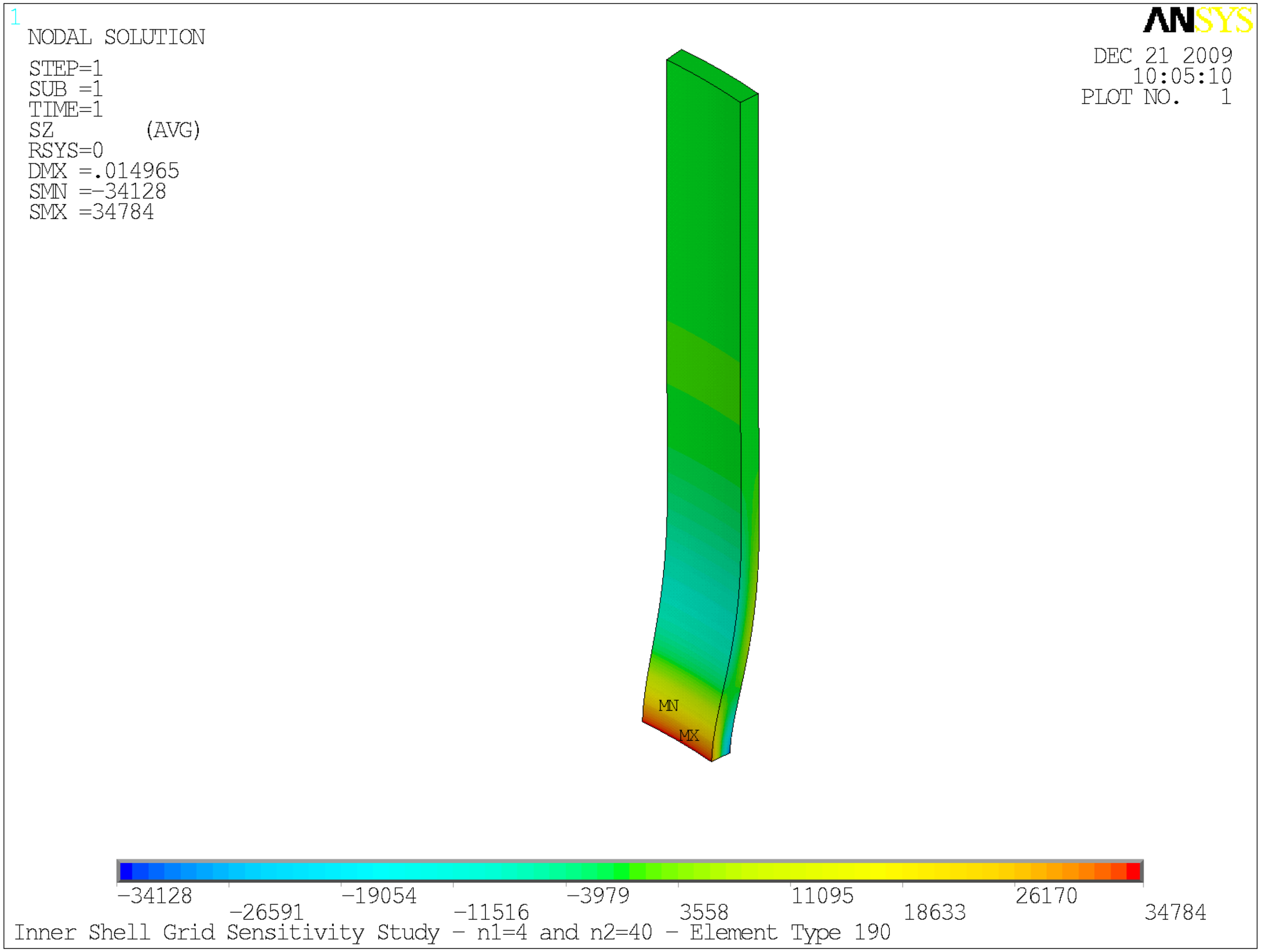


Figure-14

Grid Sensitivity Study - A Typical Longitudinal Stress Contour Plot

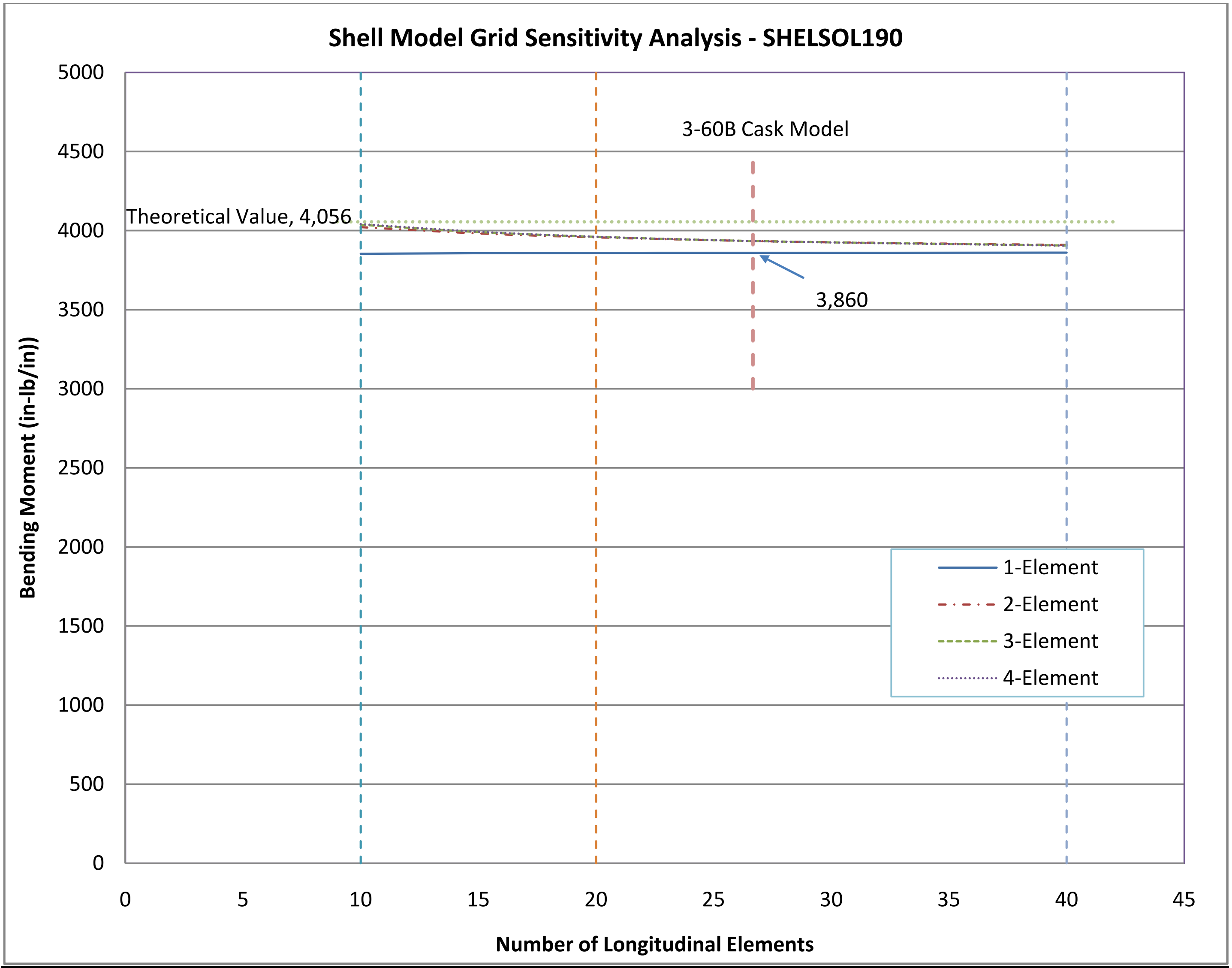


Figure-15

Grid Sensitivity Study - End Moment Plot for Models with Various Grid Densities

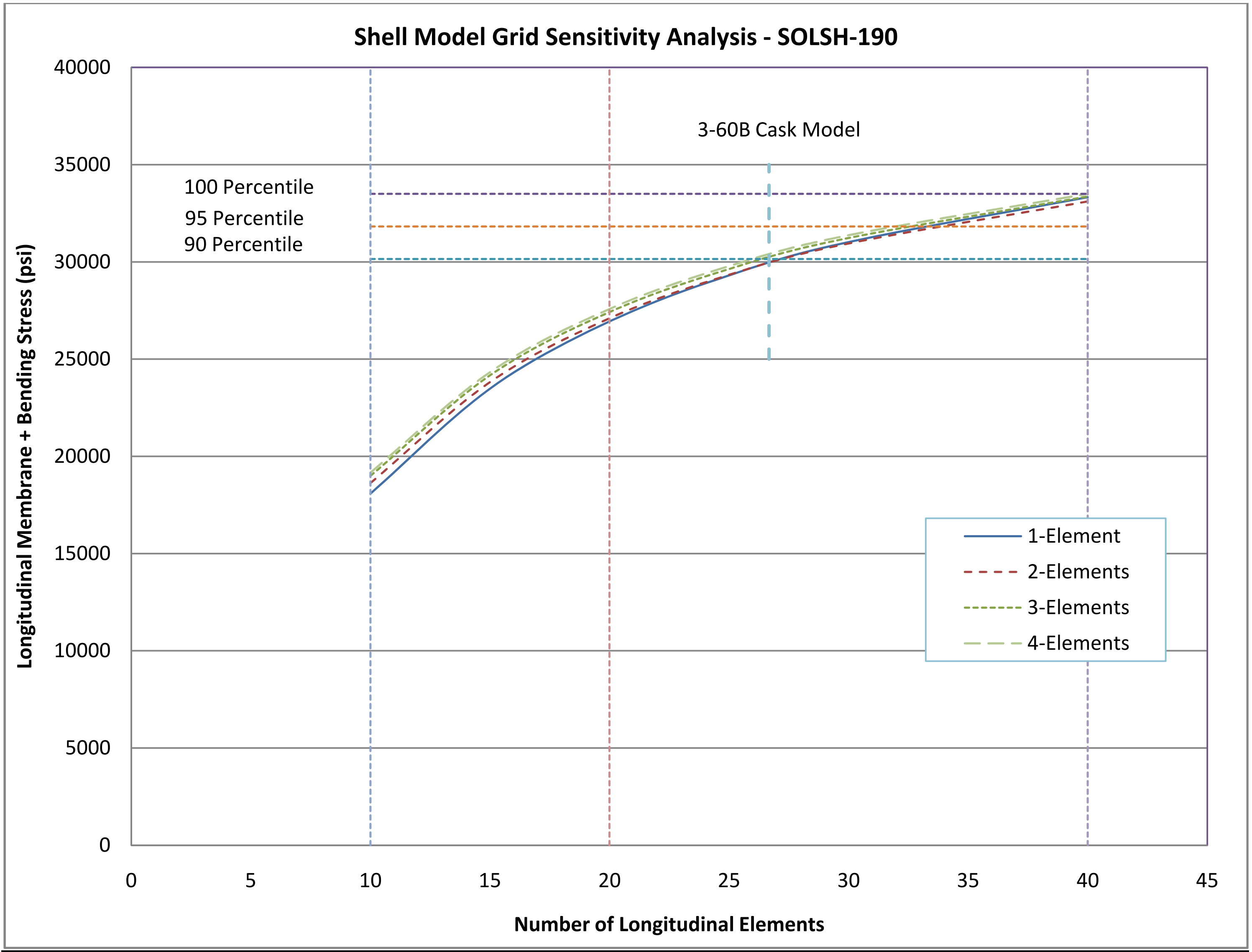


Figure-16

Grid Sensitivity Study - Linearized Longitudinal Bending Stress Plot for Models with Various Grid Densities

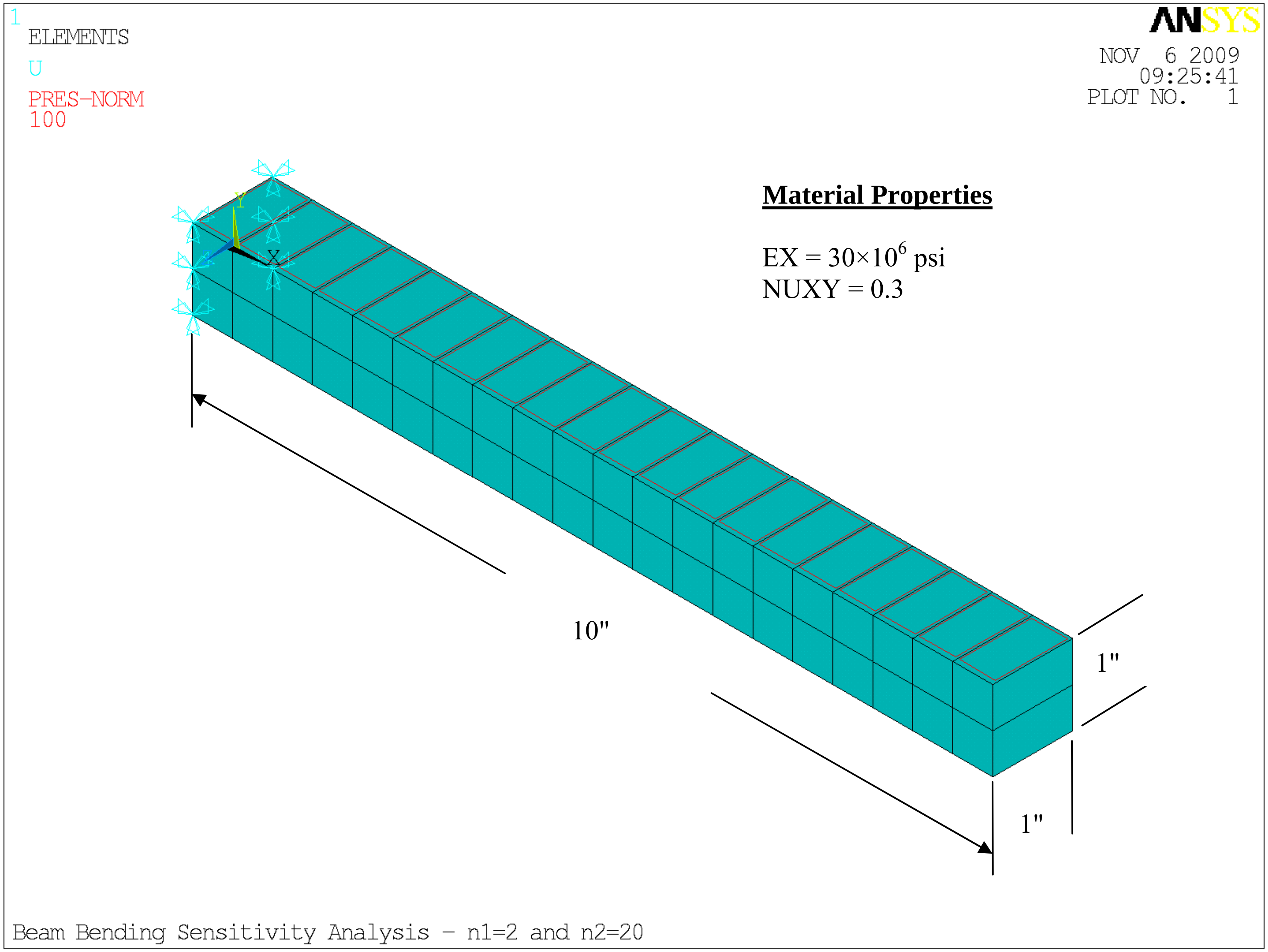


Figure-17

Beam Model Grid Sensitivity Study - FEM Dimensions

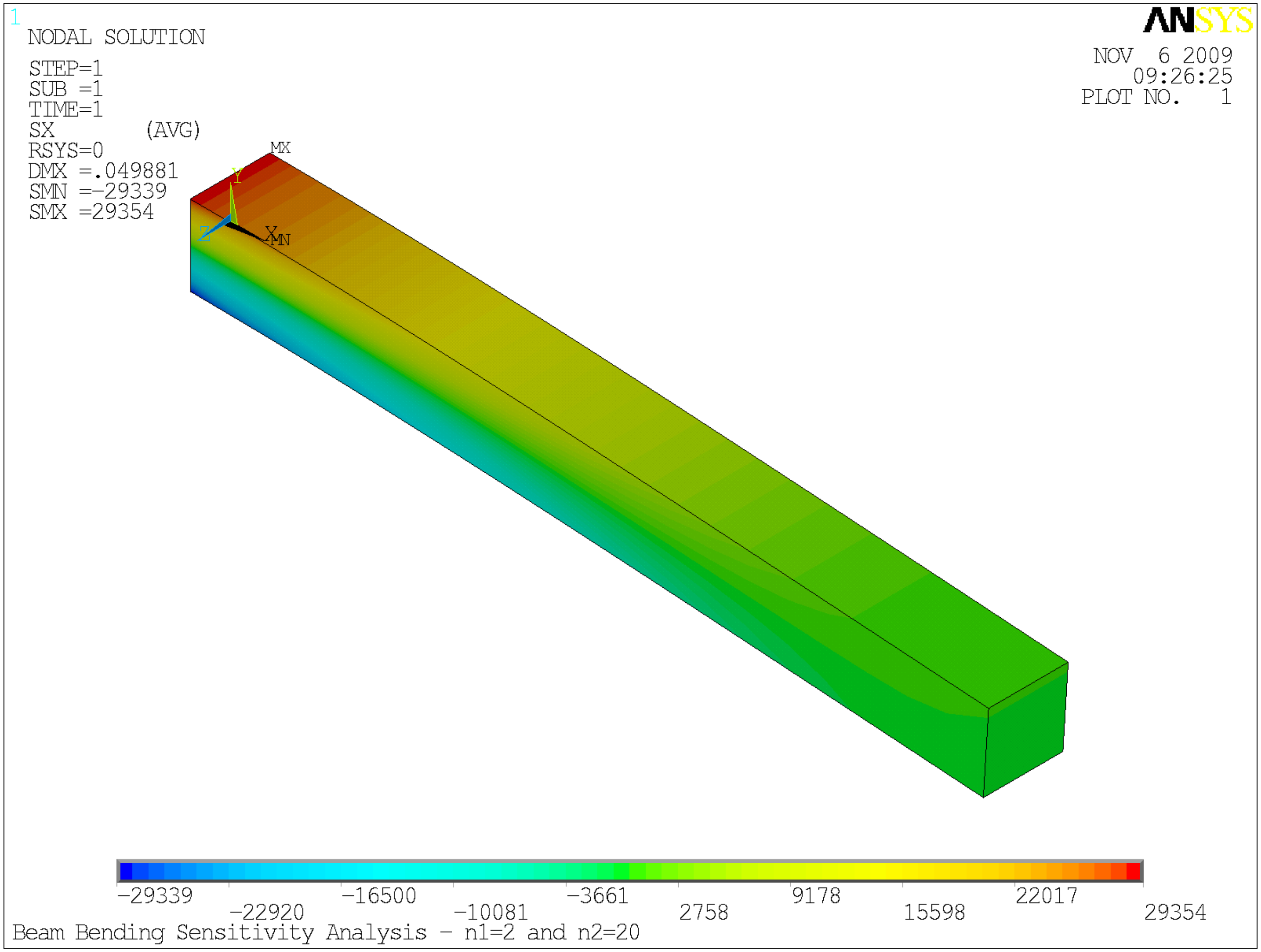


Figure-18

Beam Model Grid Sensitivity Study - A Typical Bending Stress Contour Plot

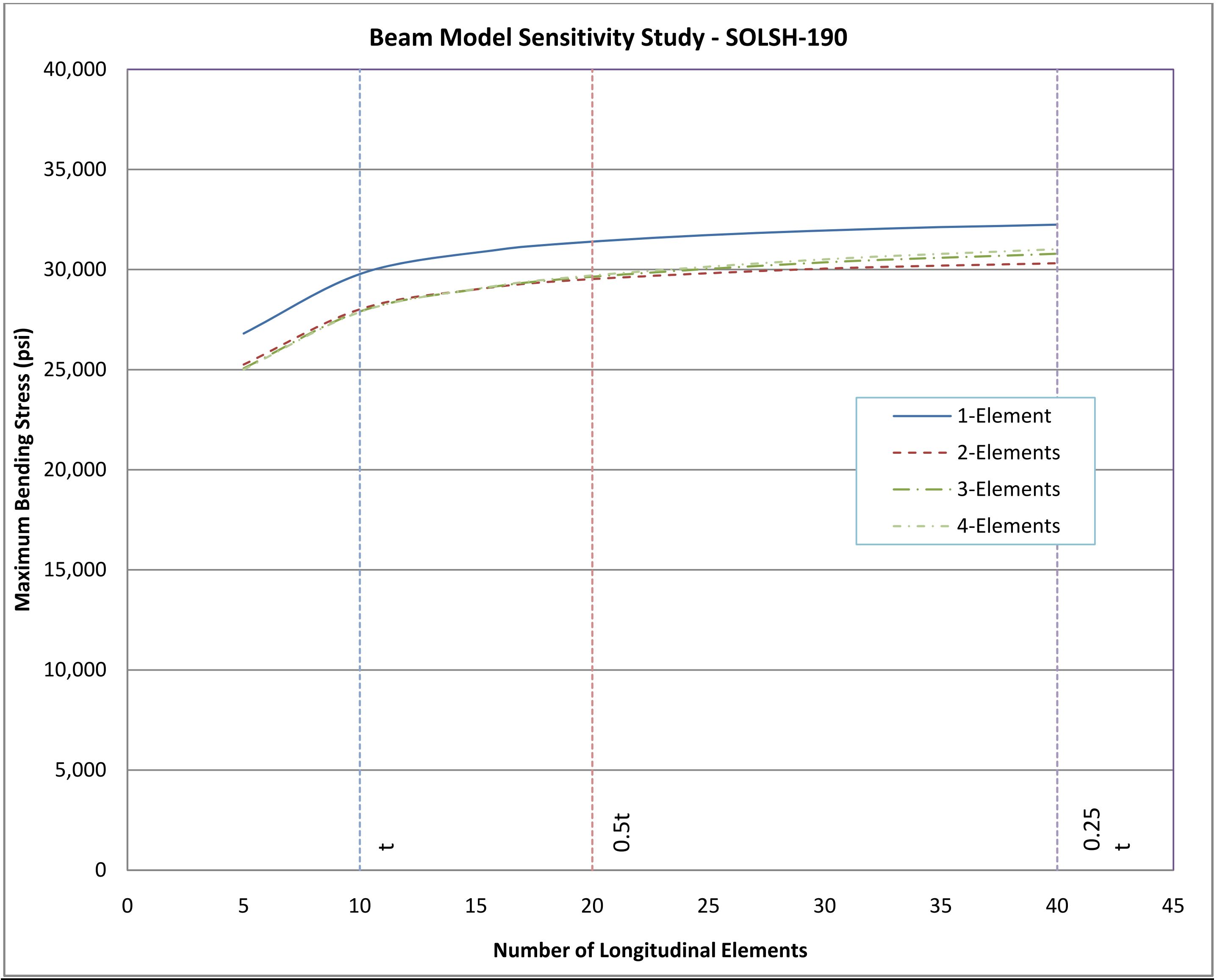


Figure-19

Beam Model Grid Sensitivity Study - Bending Stress Plot for Models with Various Grid Densities

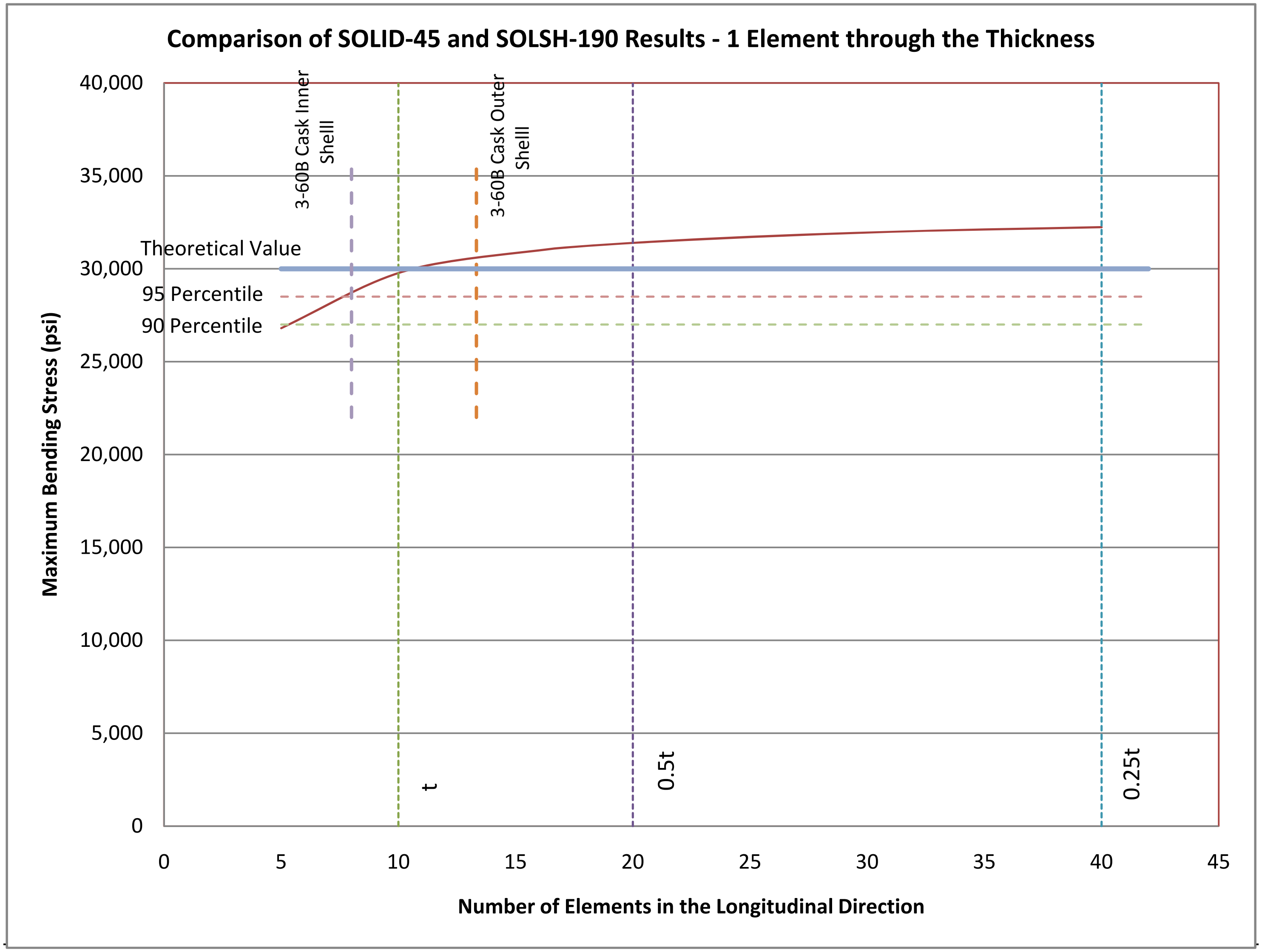


Figure-20

Beam Model Grid Sensitivity Study - Bending Stress Plot for Models with 1-Element through the Thickness

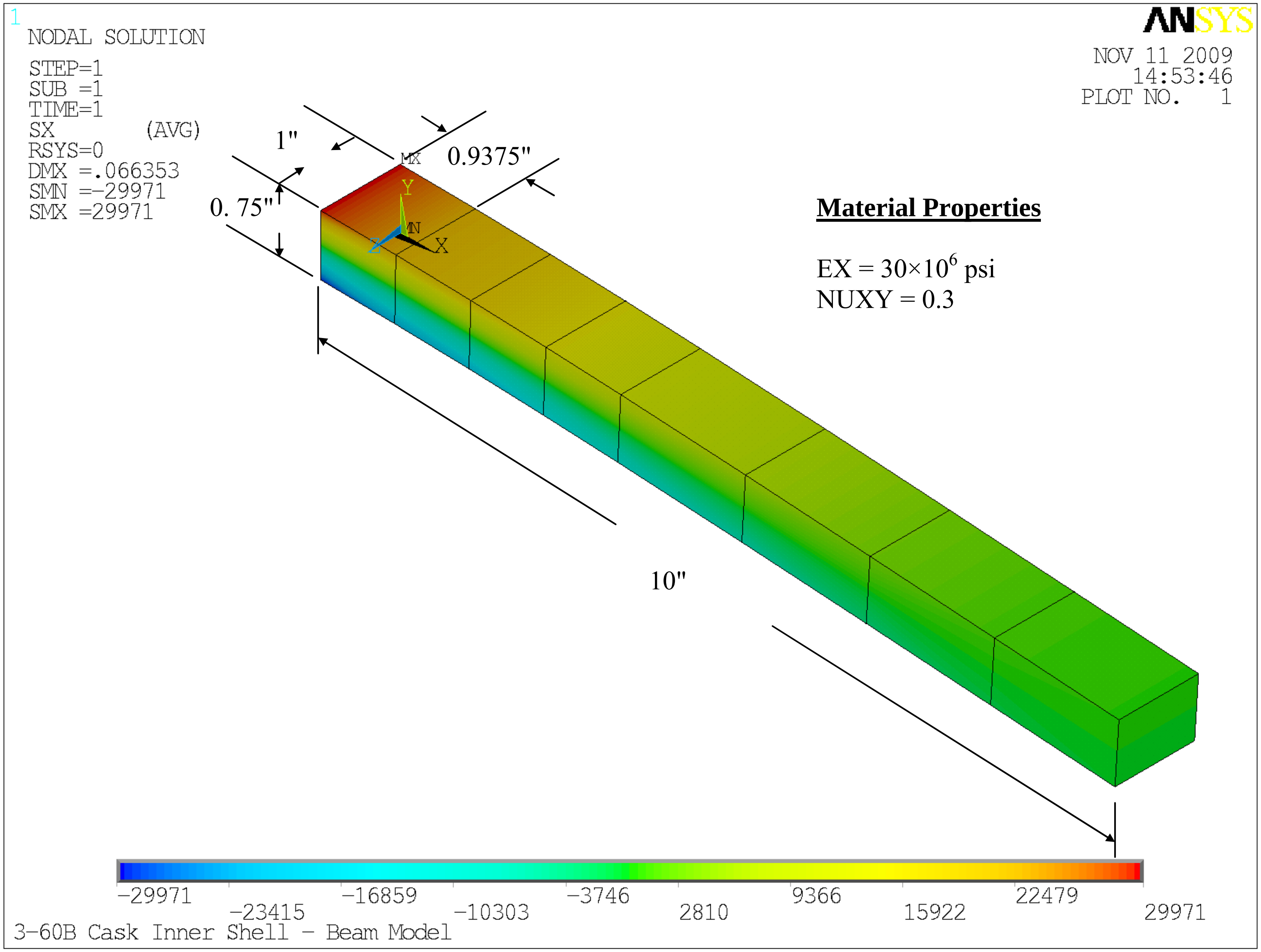


Figure-21

Beam Model Corresponding the SAR Inner Shell Modeling - Dimensions & Stress Contours

Appendix 1

FEM Data Print-Out

(8 Pages)

1. **Partial Print-out of the SAR Model Database (Reference Section 4.1.1)**

```
/COM,ANSYS RELEASE 11.0SP1 UP20070830       11:37:49    12/30/2009
/PREP7
/NOPR
/TITLE,3-60B Cask Bolting Ring Region - SAR Model
ANTYPE, 0
*IF,_CDRDOFF,EQ,1,THEN     !if solid model was read in
_CDRDOFF=             !reset flag, numoffs already performed
*ELSE               !offset database for the following FE model
NUMOFF,NODE,     490
NUMOFF,ELEM,     395
NUMOFF,MAT ,       1
NUMOFF,REAL,       4
NUMOFF,TYPE,       7
*ENDIF
*SET,I       ,  1.000000000000
*SET,MAXLAYER,  0.000000000000
*SET,_BUTTON ,  1.000000000000
*SET,_CMAP   ,  1.000000000000
*SET,_RETURN ,  0.000000000000
*SET,_RL1    ,  1.000000000000
*SET,_STATUS ,  1.000000000000
*SET,_UIQR   ,  1.000000000000
DOF,DELETE
ET,       2,185
ET,       3,190
ET,       4,170
ET,       5,175
KEYOP,       5, 9,        1
KEYOP,       5,10,        2
KEYOP,       5,12,        5
ET,       6,170
ET,       7,174
KEYOP,       7, 2,        2
KEYOP,       7, 4,        2
KEYOP,       7, 9,        1
KEYOP,       7,10,        2
KEYOP,       7,12,        5
```

The complete database is included in Appendix 2.

2. <u>Partial Print-out of the Fine Model Database</u> (Reference Section 4.1.2)

```
/COM,ANSYS RELEASE 11.0SP1 UP20070830       11:37:09    12/30/2009
/PREP7
/NOPR
/TITLE,3-60B Cask Bolting Ring Region - Fine Model with SOLID-185
ANTYPE, 0
*IF,_CDRDOFF,EQ,1,THEN     !if solid model was read in
_CDRDOFF=             !reset flag, numoffs already performed
*ELSE               !offset database for the following FE model
NUMOFF,NODE,    5562
NUMOFF,ELEM,    4288
NUMOFF,MAT ,       1
NUMOFF,TYPE,       1
NUMOFF,CSYS,       9
*ENDIF
*SET,I       ,  1.000000000000
*SET,MAXLAYER,  0.000000000000
*SET,R1      ,  17.50000000000
*SET,R2      ,  18.25000000000
*SET,R3      ,  18.62500000000
*SET,R4      ,  25.50000000000
*SET,Z1      ,  30.14700000000
*SET,Z2      ,  9.875000000000
*SET,Z3      ,  6.531200000000
*SET,Z4      ,  4.687500000000
*SET,_BUTTON ,  1.000000000000
*SET,_CHKMSH ,  0.000000000000
*SET,_CMAP   ,  1.000000000000
*SET,_RETURN ,  0.000000000000
*SET,_RL1    ,  1.000000000000
*SET,_STATUS ,  0.000000000000
*SET,_UIQR   ,  1.000000000000
DOF,DELETE
ET,       1,185
CSYS,   0
REAL,        2
```

The complete database is included in Appendix 2.

3. Input Data File for the Analyses of Section 4.2

3.1 Shell Model

```
C***   3-60B Cask Outer Shell - Inner Shell Grid Sensitivity Study
!
*dim,m,array,4,1
*dim,n,array,6,1
*dim,smbi,array,6,4
*dim,smbo,array,6,4
*dim,sii,array,6,4
*dim,sio,array,6,4
*dim,mom,array,6,4
m(1,1)=1
m(2,1)=2
m(3,1)=3
m(4,1)=4
n(1,1)=10
n(2,1)=15
n(3,1)=20
n(4,1)=25
n(5,1)=30
n(6,1)=40
*do,j,1,4,1
*do,i,1,6,1
/prep7
et,1,190
*get,stiff,etype,1,attr,enam
*use,steel,1
vclear,all
vdel,all,,,1
numcmp,all
csys,1
r1=17.5            ! Inside radius of the shell
r2=18.25           ! Outside radius of the shell
l=25               ! Shell length - arbitrary
t=10               ! 10-degee segment
n1=m(j,1)          ! segements along radial direction
n2=n(i,1)          ! segments along axial direction
n3=4               ! segments along tangential direction
/title,Inner Shell Grid Sensitivity Study - n1=%n1% and n2=%n2% - Element Type %stiff%
r=1                ! element size ratio
ir=1/r
t1=-t/2
k,1,r1,t1
k,2,r2,t1
k,3,r1,t1,l
k,4,r2,t1,l
l,1,2
l,2,4
l,4,3
l,3,1
al,1,2,3,4
```

```
lesize,1,,,n1
lesize,3,,,n1
lesize,2,,,n2,r
lesize,4,,,n2,ir
lgen,2,all,,,0,t
l,1,5
l,2,6
l,3,8
l,4,7
v,1,5,6,2,3,8,7,4
lesize,9,,,n3
lesize,10,,,n3
lesize,11,,,n3
lesize,12,,,n3
vsweep,1
/view,,1,1,1
/vup,,z
eplot
nsel,x,r1
sf,all,press,1000
nsel,z,0
d,all,uz
d,all,ux
nsel,y,t1
nasel,y,t1+t
nrot,all
d,all,uy
/solu
nall
eall
solve
/post1
set,last
/EDGE,1,1,45
/GLINE,1,0
/cont,1,64,auto
plnstr,sz
/show,term
PATH,sect,2,30,20,
n1=node(r1,0,0)
n2=node(r2,0,0)
PPATH,1,n1
PPATH,2,n2
prsect,,0
*get,smbi(i,j),section,sum,inside,s,z
*get,smbo(i,j),section,sum,outside,s,z
*get,sii(i,j),section,sum,inside,s,int
*get,sio(i,j),section,sum,outside,s,int
spoint,,17.875,0,0
nsel,z,0
fsum
*get,a,fsum,0,item,my
mom(i,j)=a/3.1198
```

```
*enddo          ! end of do loop i
*enddo          ! end of do loop j
*cfopen,et%stiff%.out
*vwrite,stiff
('Element Type',f10.0,' Results'/)
*vwrite
(//'Longitudinal Stress on the Inside Face'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1)
(5x,6f10.0)
*vwrite,n(1,1),smbi(1,1),smbi(1,2),smbi(1,3),smbi(1,4)
(f5.0,4f10.0)
*vwrite
(//'Longitudinal Stress on the Onside Face'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1)
(5x,4f10.0)
*vwrite,n(1,1),smbo(1,1),smbo(1,2),smbo(1,3),smbo(1,4)
(f5.0,4f10.0)
*vwrite
(//'Stress Intensity on the Inside Face'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1)
(5x,4f10.0)
*vwrite,n(1,1),sii(1,1),sii(1,2),sii(1,3),sii(1,4)
(f5.0,4f10.0)
*vwrite
(//'Stress Intensity on the Outside Face'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1)
(5x,4f10.0)
*vwrite,n(1,1),sio(1,1),sio(1,2),sio(1,3),sio(1,4)
(f5.0,4f10.0)
*vwrite
(//'End Moment per Inch'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1)
(5x,4f10.0)
*vwrite,n(1,1),mom(1,1),mom(1,2),mom(1,3),mom(1,4)
(f5.0,4f10.0)
*cfclose,et%stiff%.out
```

The electronic file of this data is included in Appendix 2.

3.2 Beam Model

```
C***   Beam Stress - Sensitivity Analysis
!
*dim,m,array,6,1
*dim,n,array,6,1
*dim,sigx,array,6,6
m(1,1)=1
m(2,1)=2
m(3,1)=3
m(4,1)=4
m(5,1)=6
m(6,1)=8
n(1,1)=5
n(2,1)=10
n(3,1)=15
n(4,1)=20
n(5,1)=30
n(6,1)=40
*do,j,2,2,1
*do,i,4,4,1
/prep7
et,1,185
*use,steel,1
vclear,all
vdel,all,,,1
numcmp,all
n1=m(j,1)          ! segements along depth direction
n2=n(i,1)          ! segments along length direction
n3=1               ! segments along width direction
/title,Beam Bending Sensitivity Analysis - n1=%n1% and n2=%n2%
r=1                ! element size ratio
ir=1/r
k,1,0,-0.5,-0.5
k,2,0,-0.5,0.5
k,3,0,0.5,-0.5
k,4,0,0.5,0.5
l,1,2
l,2,4
l,4,3
l,3,1
al,1,2,3,4
lesize,1,,,n3
lesize,3,,,n3
lesize,2,,,n1,r
lesize,4,,,n1,ir
lgen,2,all,,,10,0,0
l,1,5
l,2,6
l,3,8
l,4,7
v,1,5,6,2,3,8,7,4
lesize,9,,,n2
```

```
lesize,10,,,n2
lesize,11,,,n2
lesize,12,,,n2
vsweep,1
/view,,1,1,1
eplot
nsel,y,0.5
sf,all,press,100
nsel,x,0
d,all,ux,,,,,uy,uz
/solu
nall
eall
solve
/post1
set,last
/cont,1,64,auto
plnstr,sx
*get,a,plnsol,0,max
sigx(i,j)=a
/show,term
*enddo          ! end of do loop i
*enddo          ! end of do loop j
*get,stiff,etype,1,attr,enam
*cfopen,et%stiff%.out
*vwrite,stiff
('Element Type',f10.0,' Results'/)
*vwrite
(//'Maximum Bending Stress'/)
*vwrite,m(1,1),m(2,1),m(3,1),m(4,1),m(5,1),m(6,1)
(5x,6f10.0)
*vwrite,n(1,1),sigx(1,1),sigx(1,2),sigx(1,3),sigx(1,4),sigx(1,5),sigx(1,6)
(f5.0,6f10.0)
*cfclose,et%stiff%.out
```

The electronic file of this data is included in Appendix 2.

3.1 Partial Print-out of the Unit Width of the Inner Shell Model Database (Ref. Section 4.2.1)

```
/COM,ANSYS RELEASE 11.0SP1 UP20070830       13:22:24    12/30/2009
/PREP7
/NOPR
/TITLE,3-60B Cask Inner Shell - Beam Model
ANTYPE, 0
*IF,_CDRDOFF,EQ,1,THEN     !if solid model was read in
_CDRDOFF=             !reset flag, numoffs already performed
*ELSE              !offset database for the following FE model
NUMOFF,NODE,      39
NUMOFF,ELEM,       8
NUMOFF,MAT ,       1
NUMOFF,TYPE,       1
*ENDIF
*SET,_BUTTON ,  1.000000000000
*SET,_CMAP   ,  1.000000000000
*SET,_GUI_CLR_BG,' systemButtonFace             '
*SET,_GUI_CLR_FG,' systemButtonText             '
*SET,_GUI_CLR_INFOBG,' systemInfoBackground            '
*SET,_GUI_CLR_SEL,' systemHighlight              '
*SET,_GUI_CLR_SELBG,' systemHighlight              '
*SET,_GUI_CLR_SELFG,' systemHighlightText          '
*SET,_GUI_CLR_WIN,' systemWindow                 '
*SET,_GUI_FNT_FMLY,'Arial                         '
*SET,_GUI_FNT_PXLS,  16.00000000000
*SET,_GUI_FNT_SLNT,'r                             '
*SET,_GUI_FNT_WEGT,'medium                        '
*SET,_RETURN ,  0.000000000000
*SET,_RL1    ,  1.000000000000
*SET,_STATUS ,  1.000000000000
*SET,_UIQR   ,  0.000000000000
DOF,DELETE
ET,       1,190
```

The complete database is included in Appendix 2.

Appendix 2

FEM Electronic Data

(2 Pages + 1 CD)

Directory of Files on the CD

```
 Volume in drive F is ST-608 Rev.0 App
 Volume Serial Number is EA86-CE64

 Directory of F:\

12/18/2009  11:53 AM    <DIR>          Joint Evaluation
12/30/2009  03:11 PM    <DIR>          Shell Evaluation
               0 File(s)              0 bytes

 Directory of F:\Joint Evaluation

12/18/2009  11:53 AM    <DIR>          .
12/30/2009  03:35 PM    <DIR>          ..
12/30/2009  03:10 PM    <DIR>          Fine Model
12/30/2009  03:11 PM    <DIR>          SAR Model
               0 File(s)              0 bytes

 Directory of F:\Joint Evaluation\Fine Model

12/30/2009  03:10 PM    <DIR>          .
12/18/2009  11:53 AM    <DIR>          ..
12/30/2009  11:37 AM         1,305,837 file.cdb
12/23/2009  03:45 PM        17,170,432 file.db
12/01/2009  01:52 PM         8,257,536 file.rst
11/30/2009  04:17 PM           133,291 file000.png
11/30/2009  04:27 PM           107,324 file001.png
11/30/2009  04:28 PM            71,515 file002.png
11/30/2009  04:29 PM            28,878 file003.png
11/30/2009  04:29 PM            30,203 file004.png
12/02/2009  03:40 PM            59,765 file006.png
12/30/2009  11:25 AM           958,598 model.out
              10 File(s)     28,123,379 bytes

 Directory of F:\Joint Evaluation\SAR Model

12/30/2009  03:11 PM    <DIR>          .
12/18/2009  11:53 AM    <DIR>          ..
12/30/2009  11:37 AM           116,229 file.cdb
12/03/2009  11:05 AM         2,621,440 file.db
12/01/2009  04:49 PM           917,504 file.rst
11/30/2009  05:35 PM            26,677 file000.png
11/30/2009  05:35 PM            27,049 file001.png
12/01/2009  04:52 PM            62,182 file002.png
12/02/2009  03:39 PM            85,865 file004.png
11/30/2009  05:12 PM            58,391 file005.png
11/30/2009  05:14 PM           109,167 file007.png
11/30/2009  05:14 PM            71,049 file008.png
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              11 File(s)      4,147,538 bytes
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 Directory of F:\Shell Evaluation

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12/30/2009  03:35 PM    <DIR>          ..
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12/23/2009  08:33 AM         1,835,008 file.rst
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12/21/2009  10:05 AM            57,223 file002.png
12/23/2009  08:32 AM             2,740 Input.txt
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               5 File(s)      1,813,808 bytes

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              18 Dir(s)               0 bytes free
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OBJECTIVE

To evaluate the following components of 3-60B cask:

1. Cask tie-down lugs/brackets for installation of the impact limiters.
2. Impact limiter tie-down attachment.
3. Cask drain port assembly.

INTRODUCTION

3-60 Cask is detailed per Reference 1. To evaluate the cask tie-down lug/bracket and the impact limiter tie-down attachment, the maximum applied loading per Table 4 of Reference 2 is utilized. The maximum attachment force is 56,890 lbs and it occurs under regulatory hypothetical accident drop condition in corner drop orientation for cold thermal environment. To evaluate the cask drain port assembly, the maximum applicable loading per Table 3 of Reference 2 is used. The loading that the drain port assembly is examined for is the tributary load caused by the maximum impact limiter reaction under regulatory hypothetical accident drop condition in slap-down (7.5º) orientation for cold thermal environment.

REFERENCES

(1) Energy*Solutions* Drawing No. C-002-165024-001, Revision 0, "3-60 Cask General Arrangement and Details."

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

(3) Roark's Formulas for Stress & Strain, 6th Edition.

MATERIAL PROPERTIES

Cask Shell and Attachments

Specification: ASTM A-240 Type 304L

Minimum Yield Strength, S_y = 25,000 psi

Minimum Ultimate Strength, S_u = 70,000 psi

Bolts

Specification: ASTM A-193, Grade B5

Minimum Yield Strength, S_y = 80,000 psi

Minimum Ultimate Strength, S_u = 100,000 psi

ALLOWABLE STRESSES

The following allowable values are utilized for the evaluations performed in this document:

Material Type	Normal Stress Allowable, psi	Shear Stress Allowable, psi
ASTM A-240 Type 304L	70,000	42,000
ASTM A-193, Grade B5	100,000	60,000

The allowable stresses in the weld are conservatively taken to be the same as the base metal.

STRUCTURAL EVALUATION

A. Cask Tie-Down Lugs/Brackets for the Installation of the Impact Limiters

Each impact limiter is attached to the cask at eight locations, as detailed per Reference 1, using 7/8" diameter bolts. Figure – 1 of this document shows the location and detail of a typical cask tie-down lug/bracket. Each bracket consists of a 1" × 5" × 4" top plate and two ½"×5" ×6" gusset plates. To install the 7/8" diameter bolt, the top plate is equipped with a 1 1/8" diameter hole centered in one direction and 1 ½" from the edge of the plate.

As stated earlier the maximum attachment force is 56,890 lbs. Conservatively an attachment force of 60,000 lbs is used for the evaluation herein. Evaluating the top plate using an expression from Roark (Reference 3) for a rectangular plate simply supported along three sides and free on the other side with the uniform pressure (q) applied over entire plate, Table 26, case 2a,

a/b = 4/5 = 0.8

ß = 0.538

q = 0,000/(4×5) = 3,000 psi

The maximum bending stress is:

$$\sigma_{\max} = \frac{\beta q b^2}{t^2} = \frac{0.538 \times 3{,}000 \times 5^2}{1^2} = 40{,}350 \text{ psi} < 70{,}000 \text{ psi} \qquad \text{O.K.}$$

Calculating the bearing stress on the top plate using the washer projection on the plate. The bearing stress is:

$f_{bearing} = 60{,}000/[(\pi/4) \times (1.75^2 - 1.25^2)] = 50{,}930$ psi < 70,000 psi O.K.

Assuming each gusset plate to react to ½ of the 60,000 psi load, the gusset plate bending stress is:

$$\sigma_{max} = \frac{(60{,}000 \times 0.5) \times 2.5 \times 6}{0.5 \times 6^2} = 25{,}000 \text{ psi} < 70{,}000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1" top plate to the cask outer shell, assuming simply supported edge and using the tributary shear load (F),

F = 3,000×(0.5×2.5×5) = 18,750 lbs

Using 5/16" continuous fillet weld all around connecting the 1" top plate to the 1 ¼" cask outer shell, assuming credit only for 4" of weld on top and bottom of the plate and conservatively ignoring the end welds, the weld shear stress is:

$$\tau = \frac{18{,}750}{0.707 \times 0.3125 \times 2 \times 4} = 10{,}608 \text{ psi} < 42{,}000 \text{ psi} \qquad \text{O.K.}$$

Using 5/16" continuous fillet weld all around connecting the ½" gusset plates to the 1 ¼" cask outer shell, considering a 45º bevel at corner of the gusset plate to allow for the 5/16" weld connecting the 1" top plate to 1 ¼" cask outer shell and assuming credit for a 5 ½" long line weld on each side of the gusset plate and conservatively ignoring the end welds, the weld shear stress is calculated using the following tributary loads:

The tributary shear load reacted by the gusset plate (V) is:

$$V = 3{,}000 \times [(4 \times 5 - 0.5 \times 2.5 \times 5) \times 0.5] = 20{,}625 \text{ lbs.}$$

Consider the load V centered on the 4" wide gusset plate, the bending moment is:

M = 20,625 ×2 = 41,250 in-lbs.

$$\tau = [(\frac{20{,}625}{2 \times 5.5 \times 0.707 \times 0.3125})^2 + (\frac{41{,}250}{\frac{5.5^2}{3} \times 0.707 \times 0.3125})^2]^{0.5} = 20{,}368 \text{ psi} < 42{,}000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1" top plate to the ½" gusset plates, assuming simply supported edges and using the tributary shear load (V), same as above,

$$V = 3{,}000 \times [(4 \times 5 - 0.5 \times 2.5 \times 5) \times 0.5] = 20{,}625 \text{ lbs.}$$

Using full penetration groove weld connecting the 1" top plate to the ½" gusset plates, allow for corner bevel and assuming 3" weld length, the weld shear stress is:

$$\tau = \frac{20{,}625}{0.5 \times 3} = 13{,}750 \text{ psi} < 42{,}000 \text{ psi} \qquad \text{O.K.}$$

Using the area of the 7/8" diameter tie-down bolt, the maximum bolt tensile stress is:

$$f_t = \frac{60{,}000}{\frac{\pi}{4} \times 0.875^2} = 99{,}780 \text{ psi} < 100{,}000 \text{ psi}$$ O.K.

B. Impact Limiter Tie-Down Attachment

As stated earlier, each impact limiter is bolted to the cask at eight locations as per Reference 1. Figure – 2 of this document shows the arrangement and detail of the impact limiter tie-down attachment. The tie-down attachment consists of a 1 ¾” ×53” I.D. ×59” O.D ring plate and sixteen ½” × 3” × 10” gusset plates. A pair of gusset plates connects the 1 ¾” ring to the ½” thick impact limiter inner plate at each bolt location as per Reference 1.

Examining the 1 ¾” ring using an expression from Roark (Reference 3) for a rectangular plate with three edges simply supported and one edge free with uniform load applied over entire plate, Table 26, case 2a,

a = 3, b = 2 ½”, a/b = 1.2

By interpolation ß = 0.71

q = 60,000/(3×2.5) = 8,000 psi

$$\sigma_{\max} = \frac{0.71 \times 8{,}000 \times 2.5^2}{1.75^2} = 11{,}592 < 70{,}000 \text{ psi}$$ O.K.

Assuming each gusset plate reacts to one-half of the 60,000 lb load, the gusset plate bending stress is:

$$\sigma_{\max} = \frac{(60{,}000 \times 0.5) \times 1.5 \times 6}{0.5 \times 10^2} = 5{,}400 \text{ psi} < 70{,}000 \text{ psi}$$ O.K.

Using 5/16” continuous fillet weld all around connecting the 1” gusset plate to the ½” thick impact limiter inner plate, considering a 45º bevel at corner of the gusset plates to allow for the 5/16” weld connecting the 1 ¾” ring plate to ½” impact limiter inner ring and assuming credit for a 9 ½” long line weld on each side of the gusset plate and conservatively ignoring the end welds, the weld shear stress is:

The shear load reacted by the gusset plate (V) is:

V = 60,000×0.5 = 30,000 lbs

The bending moment is:

M = 30,000 ×1.5 = 45,000 in-lbs.

$$\tau = [(\frac{30,000}{2 \times 9.5 \times 0.707 \times 0.3125})^2 + (\frac{45,000}{\frac{9.5^2}{3} \times 0.707 \times 0.3125})^2]^{0.5} = 9,844 \text{ psi} < 42,000 \text{ psi} \qquad \text{O.K.}$$

Considering 5/16" continuous fillet weld all around and on both sides to connect the 1 ¾" thick ring plate to ½" thick impact limiter inner plate, conservatively ignoring the gusset plate contribution and assuming only 6" of this weld to react to the shear load of 60,000 lbs, the weld shear stress is:

$$\tau = \frac{60,000}{0.707 \times 0.3125 \times 2 \times 6} = 22,631 \text{ psi} < 42,000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1 ¾" ring plate to each ½" gusset plate,

V = 60,000×0.5 = 30,000 lbs

Using full penetration groove weld connecting the 1 ¾" ring plate to each ½" gusset plate, allow for corner bevel and assuming 2" weld length, the weld shear stress is:

$$\tau = \frac{30,000}{0.5 \times 2} = 30,000 \text{ psi} < 42,000 \text{ psi} \qquad \text{O.K.}$$

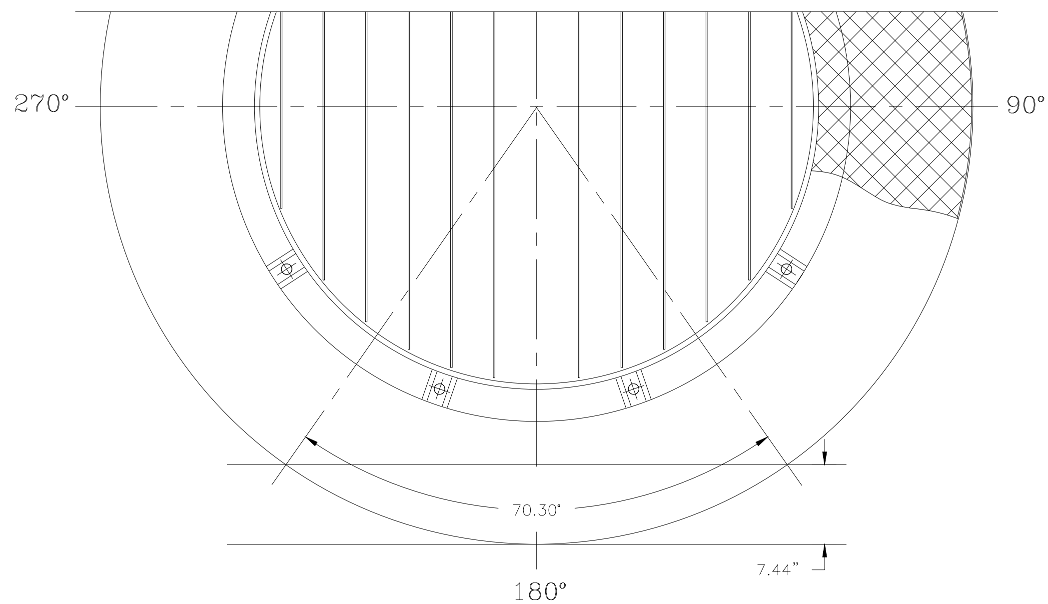
C. Cask Drain Port Assembly

The 3-60B cask is equipped with a drain line that is detailed per Reference 1. Figure – 3 of this document shows the drain line connecting to the ¾" thick cask inner bottom cover. The drain line has a 2 ½" outside diameter and 1" inside diameter.

Examining this line for the maximum load that the drain port assembly is subjected to under regulatory hypothetical accident drop condition in slap-down (7.5º) orientation for cold thermal environment. Per Table 3 of Reference 2, the maximum impact limiter reaction for this loading condition is 2.009×10^6 lbs.

Using 22" impact limiter coverage of the cask bottom end, for a maximum impact limiter crush of 7.44" in for the above slap-down drop (per Table 3, of Reference 2) a nominal 70º impact zone could be assumed as shown in the following sketch, conservatively calculating the estimated pressure on the cask body using a smaller 30º impact zone:

$$q = \frac{2.009 \times 10^6}{22 \times (\frac{51 \times \pi}{360}) \times 30} = 6,840 \text{ psi}$$



Using a 4 ½" diameter nozzle diameter on the side wall, the tributary shear load on the drain port assembly is:

$$F = 6{,}840 \times \frac{\pi}{4} \times 4.5^2 = 108{,}786 \text{ lbs.}$$

The weld connecting the drain port to the cask outer shell is as shown in Figure 3. Using an allowable base material and weld shear stress equal to $0.6 \times S_u = 0.6 \times 70{,}000 = 42{,}000$ psi and conservatively assuming credit only for the ¼" partial penetration groove weld, the maximum shear load that this weld can withstand is,

$$V = 42{,}000 \times [\pi \times 4.5 \times (0.25 - 0.125)] = 74{,}220 \ lbs.$$

Therefore the ratio of the maximum shear load that this weld can withstand to the tributary shear load applied to the drain port ($\frac{V}{F}$) is:

$$\frac{V}{F} = \frac{74{,}220}{108{,}786} = 0.68 > 0.50$$

Since the above ratio of V/F is larger than 0.5 and also the above weld strength calculation is based on conservative weld effective throat, it is conservative to assume that the shear load of 108,786 lbs. is reacted equally by the welds connecting the drain port to the cask outer shell and inner bottom cover. The drain line shear stress is:

$$\tau = \frac{108{,}786 \times 0.5}{(\pi/4) \times (2.5^2 - 1^2)} = 13{,}192 \text{ psi} < 42{,}000 \text{ psi}$$ O.K.

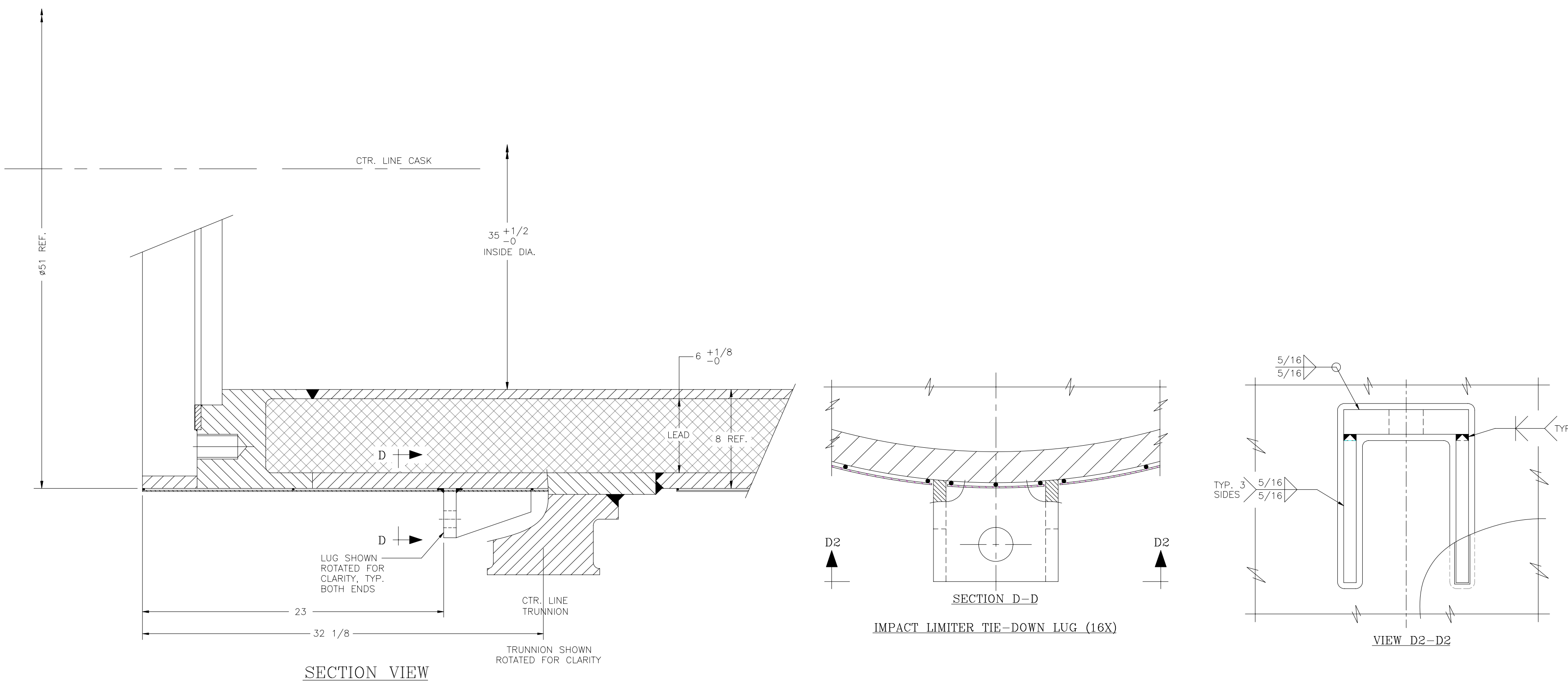


Figure – 1: 3-60B Cask Tie-Down/Bracket Details for the Installation of the Impact Limiter

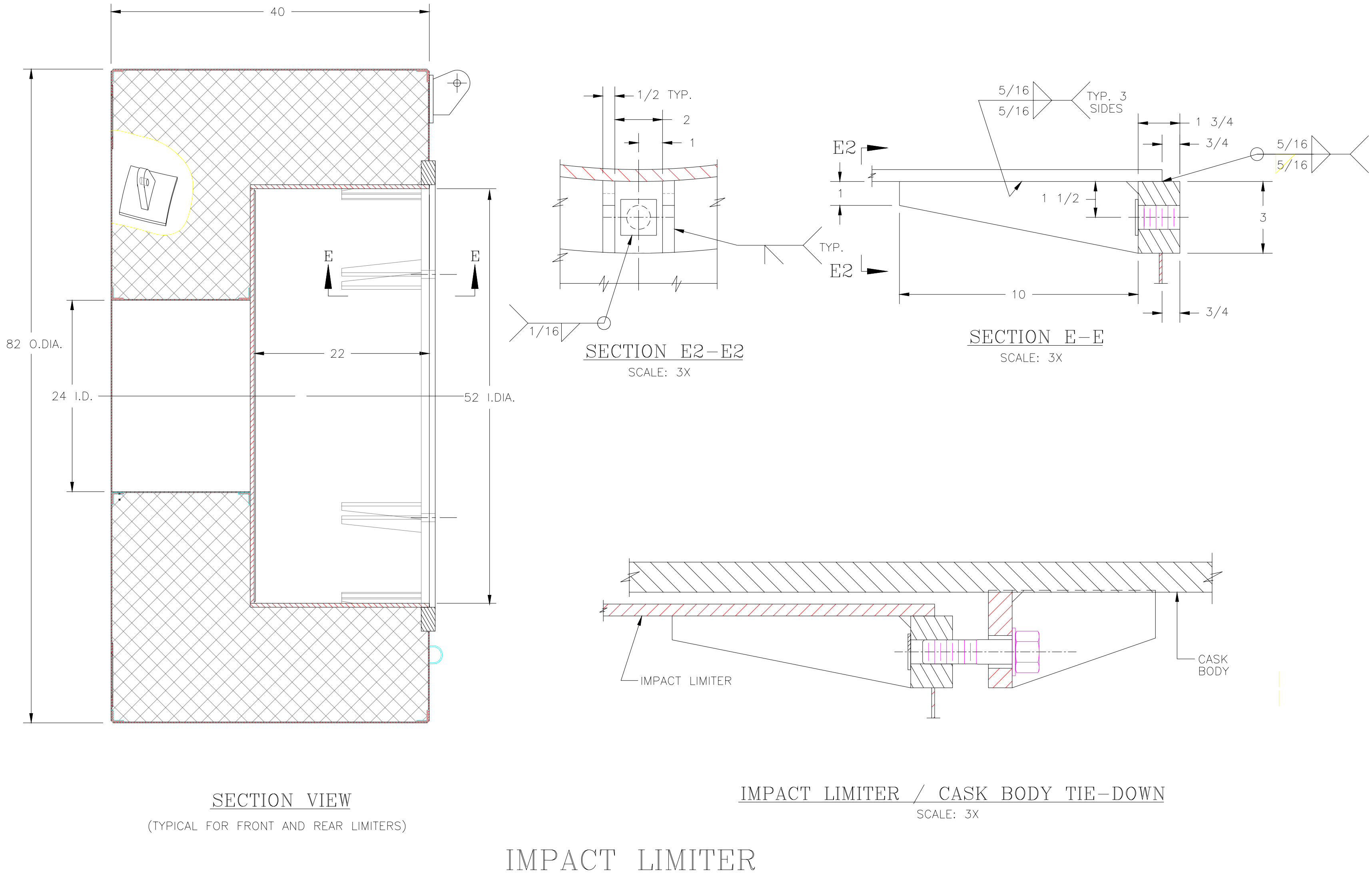


Figure – 2: 3-60B Cask - Impact Limiter Tie-Down Attachment Details

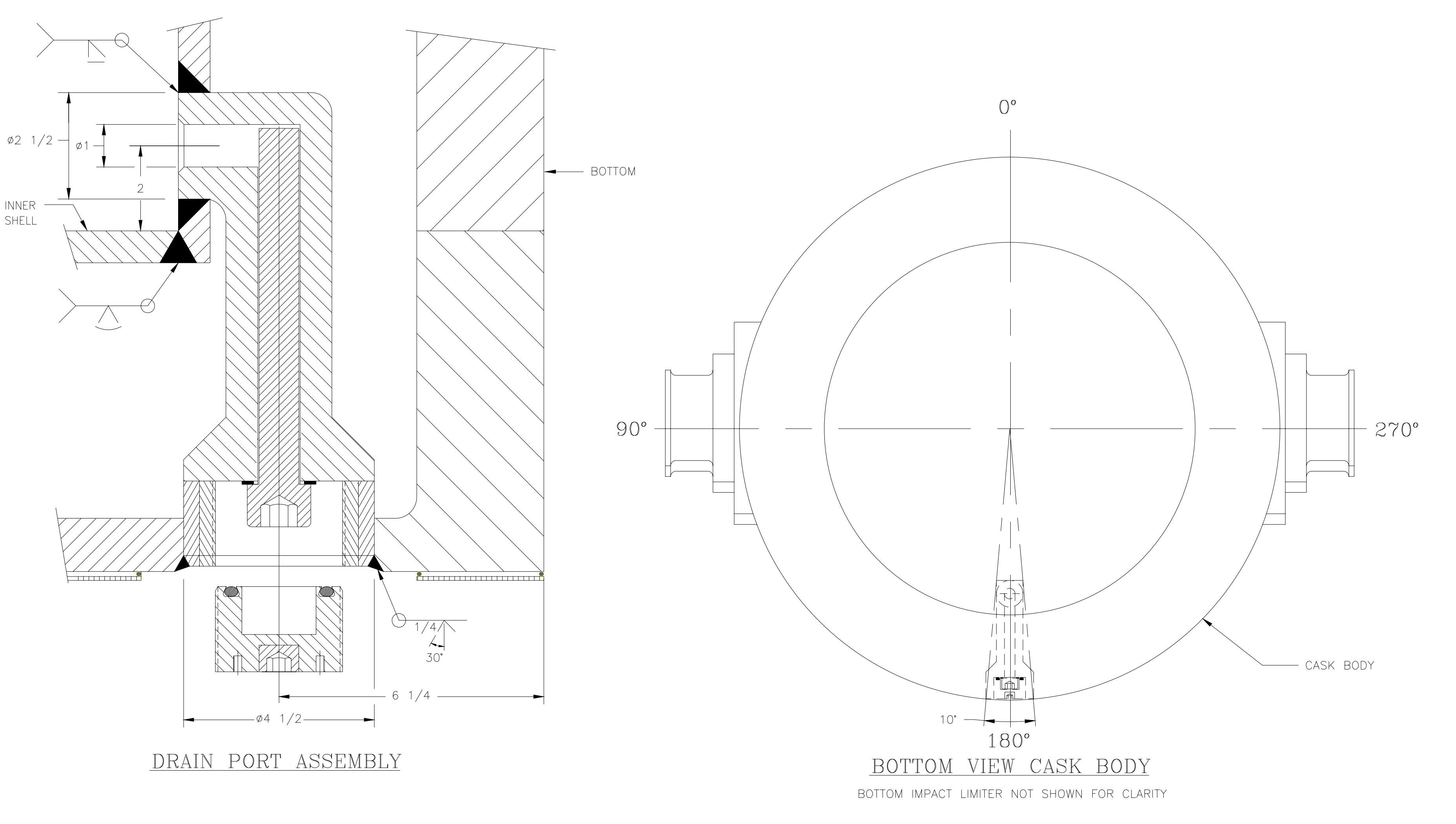


Figure – 3: 3-60B Cask – Drain Port Assembly Details

1.0 OBJECTIVE

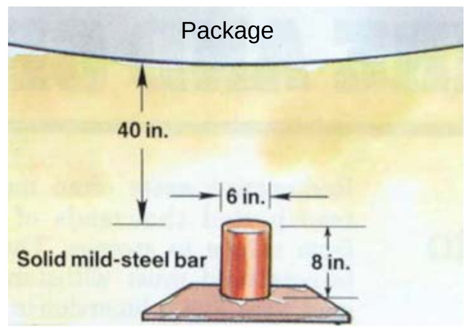
Evaluation of the 3-60B Cask (Reference 1) under:

- Regulatory puncture drop-test
- Hypothetical drop test when the trunnions are orientated in the vertical plane.

2.0 INTRODUCTION

In order to get the 3-60B Cask certified as a Type-B package, it must demonstrate the requirements of the 10 CFR Part 71 (Reference 2) code. One of the requirements listed in the code is for the cask to meet a puncture drop test of § 71.73(c)(3), which states:

"A free drop test of the specimen through a distance of 1 m (40 in) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in) and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical."



This test is required to be conducted after the hypothetical drop tests.

In order to assess the package performance an analytical evaluation is accepted means. This document presents the analyses performed for the 3-60B Cask to meet the requirement of the puncture test.

Two scenarios are identified that could cause the maximum damage to a particular component of the cask. In one, the cask is assumed to be dropped on the puncture bar in a horizontal orientation such that the puncture bar impacts the sidewall of the cask. In this case the outer shell is evaluated against the puncture bar piercing through it. In the other, the cask is assumed to be dropped in a vertical orientation such that its lid impacts the puncture bar. In this case the cask lid is evaluated. The closure bolts are separately evaluated for this condition using NUREG-6007 methodology in the SAR.

For the puncture drop on the sidewall a nonlinear inelastic analysis of the cask wall has been performed using ANSYS (Reference 3) finite element model to show that the entire amount of the potential energy may be converted into mechanical work done, without exceeding the allowable stresses in the cask outer shell.

For the evaluation of the puncture drop on the cask lid, analysis is performed using the linear elastic finite element model that has been used in other evaluations, e.g. NCT conditions (Reference 4). The effect of cold and hot conditions is included in the analyses.

The results of the analyses show that the 3-60B Cask can withstand the drop on the puncture bar, without rupture. Therefore, the requirements of § 71.73(c)(3) are satisfied.

The analyses performed here are also utilized to evaluate the 3-60B Cask under the hypothetical drop tests scenario in which the trunnions are located in the vertical plane. Under such drop scenarios the impact limiters may deform enough so that the trunnions could impact the rigid plane before the cask comes to rest. It has been shown that under all the drop orientations, except the slapdown, the impact limiters provide enough protection that the trunnions will not impact the rigid target plane. Under the slapdown conditions the impact limiters absorb enough energy such that the remaining energy can be safely absorbed by the cask, without damage to the outer shell. Hence the package will meet the requirements of § 71.73(c)(3) for the hypothetical drop test in this orientation.

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

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

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. Energy*Solutions* Proprietary Document ST-557, Drop Analyses of the 3-60B Cask Package Using LS-DYNA Program.

4.0 MATERIAL PROPERTIES

Material	Temp. (°F)	Strength (ksi) Yield (S_y)	Strength (ksi) Ultimate (S_u)	Strength (ksi) Membrane Allowable (S_m)	Young's Modulus (10^6 psi)	Coefficient of Thermal Expansion (10^{-6} in/in)
		(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 puncture drop conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code

(Reference 3) has been employed to perform the analyses. Two different models have been employed to address two puncture drop scenarios.

6.1 Scenario 1: Puncture Drop on the Sidewall

The puncture drop on the sidewall causes high local stresses at the point of contact. The magnitude of these stresses attenuates quickly with distance. Thus for the evaluation of the stresses in the cask under this loading a finite element model representing the sidewall in the vicinity of the impact has been employed. Since the cylindrical cask-to-the cylindrical pin impact provides two planes of symmetry, the model uses two vertical symmetry planes. In the horizontal plane there is no plane of symmetry. However, since the stresses resulting from the impact are highly local, based on St. Venant's principle, approximate boundary conditions on the horizontal plane will have little effects on the stresses at the point of impact. Symmetry boundary conditions on this plane, in fact will result in a conservative stress prediction. Thus the FEM used in the analysis has three planes of symmetry. This model is shown in Figure 1.

6.2 Scenario 2: Puncture Drop on the Lid

For the puncture drop on the lid, the cyclic symmetry of the cask has been utilized. 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 of the cask 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 a pair of contact (CONTA174) and target (TARGE170) elements. These elements allow the lead to slide over the steel at the same time prevent it from penetrating the steel surface.

Figure 2 shows the finite element model of the cask used for the puncture drop analysis of 3-60B on its lid.

7.0 RESULTS & CONCLUSIONS

7.1 Scenario 1: Puncture Drop on the Sidewall

Analyses using the FEM described in Section 6.1 are performed for obtaining the force-deflection plot. A known amount of load is applied in form of surface pressure at the end of the puncture bar. The deflection of the bar is obtained from the analysis of the FEM. Figure 3 shows the force-deflection plot at the end of the rod. The area under this plot gives the work done versus deflection relation. Using Microsoft Excel spreadsheet program the force-deflection curve is integrated to obtain the work done versus deflection plot shown in Figure 4. Energy versus deflection diagram also created as follows:

Mass of the package = 80,000 lb

Height of the package = 40 in

Assuming that the package travels an additional distance δ before it comes to stop, the total potential energy is:

$$PE(\delta) = 80{,}000\times(40+\delta)$$

This curve is also plotted in Figure 4. The intersection of the potential energy curve and the work done curve represent the energy balance point. Any loading larger than that at the intersection point, applied to the FEM can be used to conservatively calculate the stresses in the structure. A loading much larger than the balance point loading is used to compute the stresses. This loading point is shown in Figure 4. Its selection is based on the fact that it envelopes the puncture drop loading and the cask drop on the trunnion loading covered in Section 7.3 of this document.

Figure 5 shows the maximum stress intensity in the inner and outer shells of the cask under this loading. Figure 6 shows the maximum stress intensity in the lead and Figure 7 shows the stress intensity in the outer shell of the cask under this loading.

From Figures 5 to 7, the maximum stress intensity in the lead is small (6,507 psi) and the maximum stress intensity in the outer shell is 63,084 psi. This stress intensity is compared to the ultimate tensile strength of the shell material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory puncture drop on its sidewall.

7.2 Scenario 2: Puncture Drop on the Lid

The puncture bar has 6" diameter and it is made of mild steel. Conservatively assuming a flow stress of 45,000 psi for the mild steel, the corresponding load is:

$$F = \pi/4\times6^2\times45{,}000 = 1.272\times10^6 \text{ lb}$$

This load is applied over a circle of 3.333 in. The equivalent pressure is therefore,

$$p = 1.272\times10^6/(\pi\times3.333^2) = 36{,}447 \text{ psi}$$

This load is applied as a surface pressure on the model described in Section 6.2. Both cold and hot environments have been analyzed for this loading.

The stresses in the cask under this loading are shown in Figures 8 through 10. From these figures it is observed that the maximum stress intensity occurs in the lid at the point of impact and its value is 41,568 psi. This stress intensity is compared to the ultimate tensile strength of the lid material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory puncture drop on its sidewall.

7.3 Impact on Trunnion during HAC Testing

Analyses of the 3-60B Cask have been performed in Reference 8 for the HAC drop test loading conditions. These analyses were performed using finite element models of the package with its major components. Since the objective of these analyses was to obtain the impact limiter reactions, detailed modeling of the cask was not necessary. However, from these analyses the complete deformation of the package can be obtained. These deformations could be used to establish whether the trunnions of the cask will contact the rigid target surface if the cask were to be dropped in an orientation such that the trunnions were located in the vertical plane as shown in Figure 11.

From the geometry of the package shown in Figure 11, the vertical distance between the lowest point of the impact limiter to the lowest point of the trunnions is 8 in. From the results of the Reference 8 analyses the maximum crush of the impact limiters during various drop scenarios is as follows:

Drop Orientation	Environment	Max. Crush
Side	Cold	6.50
	Hot	8.02
Slapdown-1	Cold	7.44
	Hot	9.04
Slapdown-2	Cold	7.23
	Hot	8.86

It can be seen that for most drop orientations the impact limiter crush is less than the minimum foam thickness available, i.e. 8 in. The largest crush of the impact limiter occurs during the slapdown-1 orientation (7½º form the horizontal) in the hot environment. Figure 12 shows a pictorial depiction of the deformation of the package at the instant of maximum tail impact limiter crush. Figure 13 shows the time-history of this crush. The internal energy time-history of the package is shown in Figure 14.

Figures 13 and 14 are used to establish the amount of energy that has been absorbed by the impact limiters before the tail-end trunnion could impact the rigid surface. The foam of the tail-end impact limiter crushes by 8" at time instant 0.057 second (see Figure 13). Figure 14 shows that at this time instant 12.2×10^6 in-lb energy has been absorbed by the impact limiters. Since the result is for ½ model. The energy absorbed is $2\times12.2\times10^6 = 24.4\times10^6$ in-lb.

The maximum potential energy of the package is obtained from its initial to final (resting) positions. Figure 15 shows these orientations. The distances of the C.G. for the two positions are also marked in this figure. The potential energy of the system is:

$$PE = 80{,}000 \times (360 + 51.418 - 35.025) = 30.1\times10^6 \text{ in-lb}$$

Since 24.4×10^6 in-lb energy has already been absorbed in the impact limiters, the rest of the energy, i.e. $(30.1 - 24.4)\times10^6 = 5.7\times10^6$ in-lb must be accounted for between the crush of the trunnion and that of the tail-end impact limiter. Let us conservatively assume that this energy is totally absorbed by the cask body by the trunnion crush. The minimum diameter of the trunnion body is 8". Therefore, during the trunnion crush the load on the cask sidewall will be distributed over 8" circular area. Let us further conservatively assume that the bearing area on the cask is a circle of 6" diameter which is equal to the diameter of the puncture bar. Therefore, the evaluation performed for the puncture bar drop can be conservatively used to envelope the stresses in the package sidewall for direct impact on the trunnion during the HAC drop tests. Figure 4 annotates 5.7×10^6 in-lb location on the energy-deflection plot curve.

In Section 7.2 stresses are evaluated in the cask sidewall for a loading level that envelopes both the puncture drop loading and the cask drop on the trunnion loading. It is shown that the maximum stress intensity of 63,084 psi will result in the cask sidewall under these loading conditions (see Figure 7). This stress intensity is compared to the ultimate tensile strength of the shell material, i.e. 70,000 psi. It is, therefore, concluded that the 3-60B Cask can safely withstand the regulatory HAC drop tests, with its trunnions oriented in the vertical plane, without exceeding the allowable stress value.

8.0 ANSYS PRINTOUT AND DATA FILES

The printout of the pertinent model quantities is included in Appendix 1. The printout of the important data from the program is included in electronic form as Appendix 2.

APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on CDROM

Figures

(15 Pages)

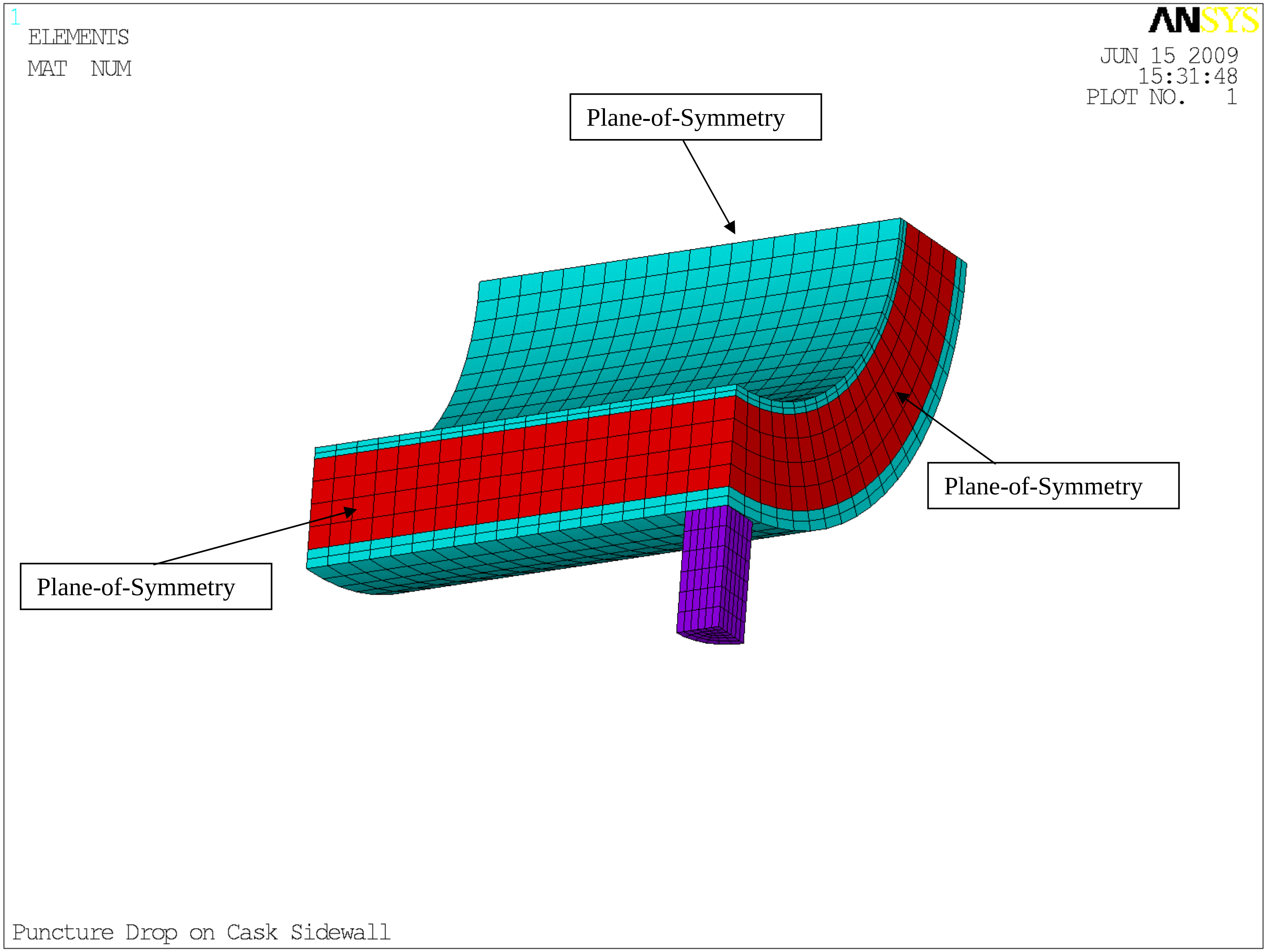


Figure 1

Finite Element Model of the 3-60B Cask for Puncture Drop on the Sidewall Analysis

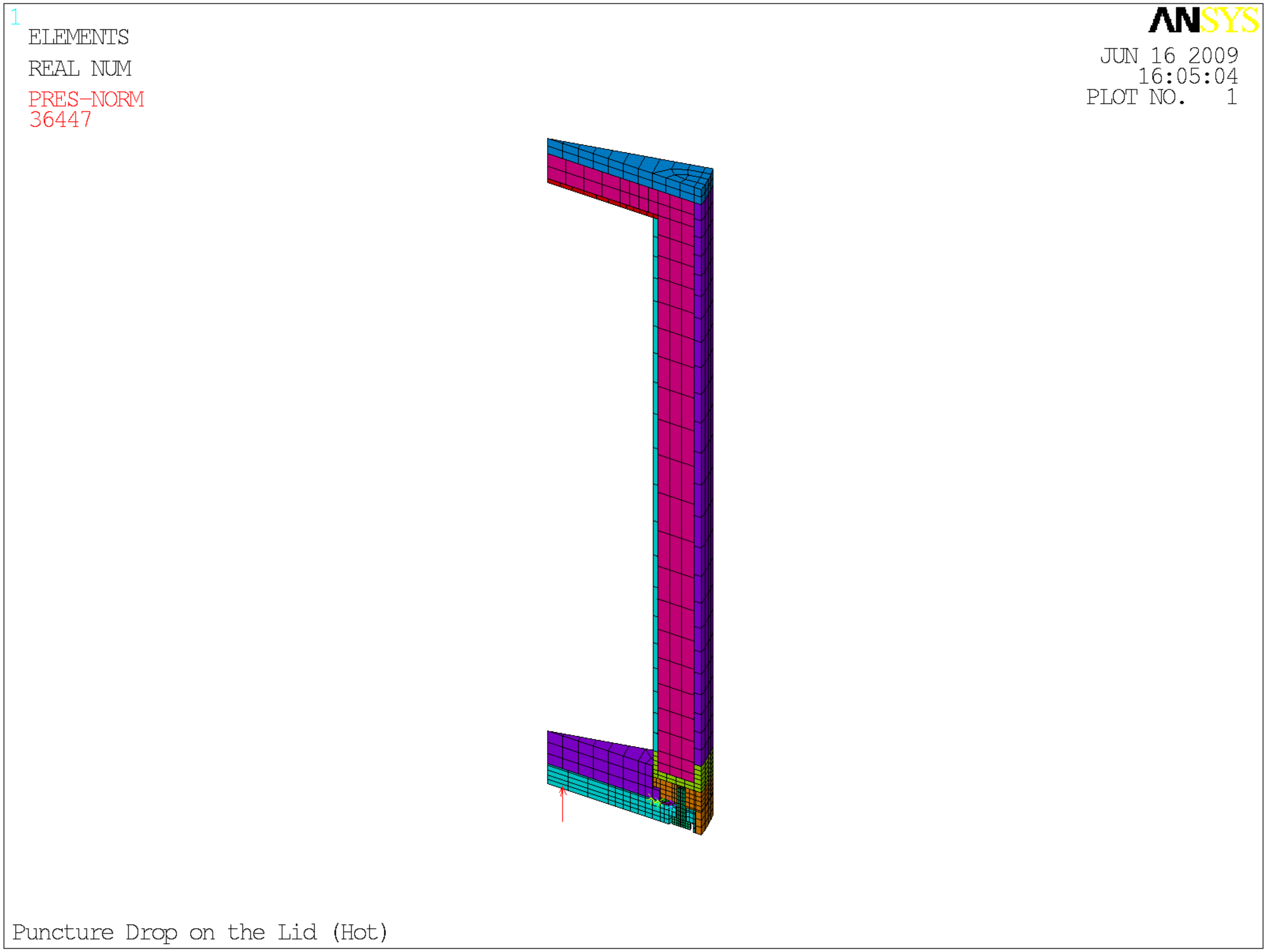


Figure 2

Finite Element Model of the 3-60B Cask for Puncture Drop on the Lid Analysis

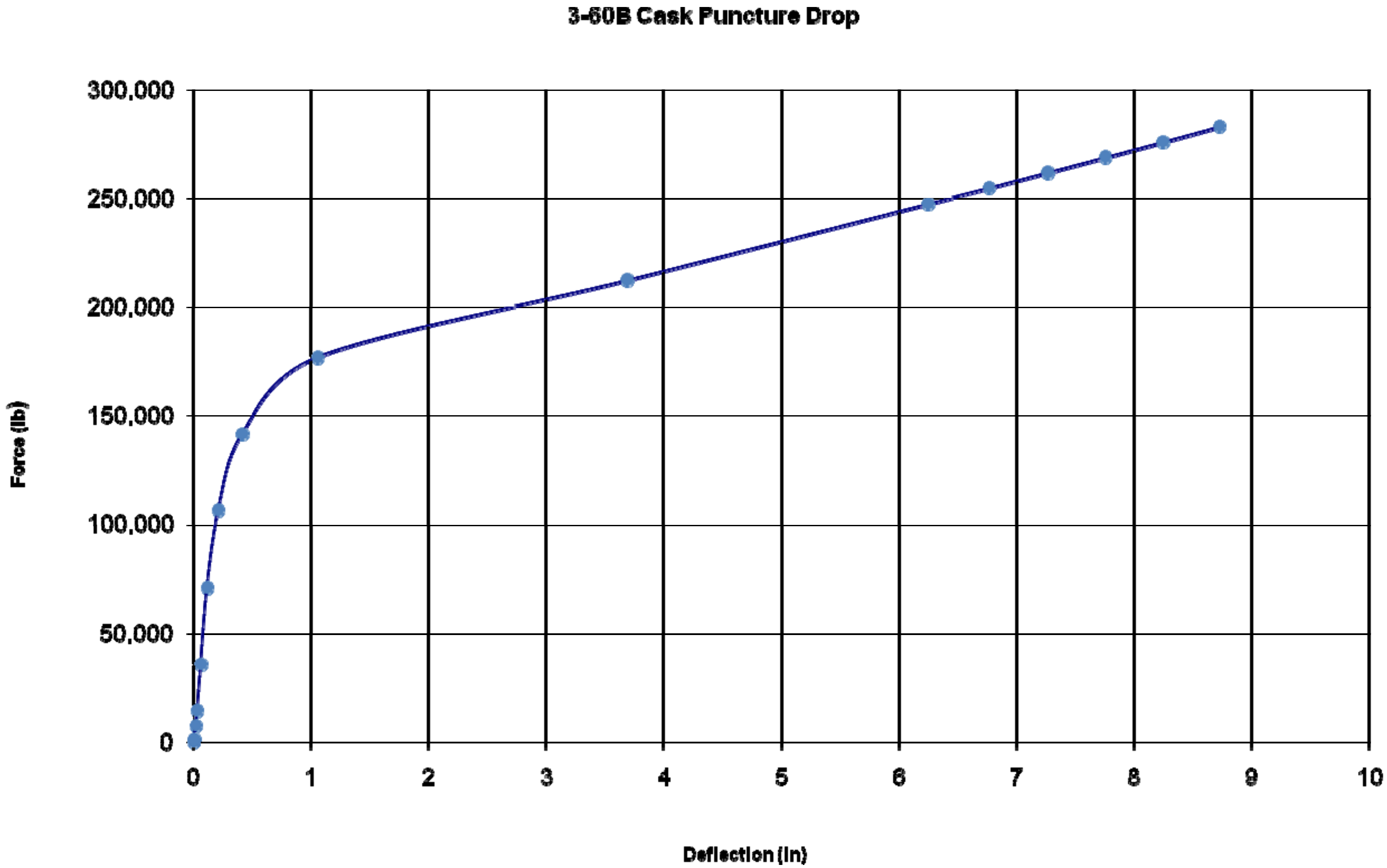


Figure 3
Force-Deflection Plot at the Point of Impact

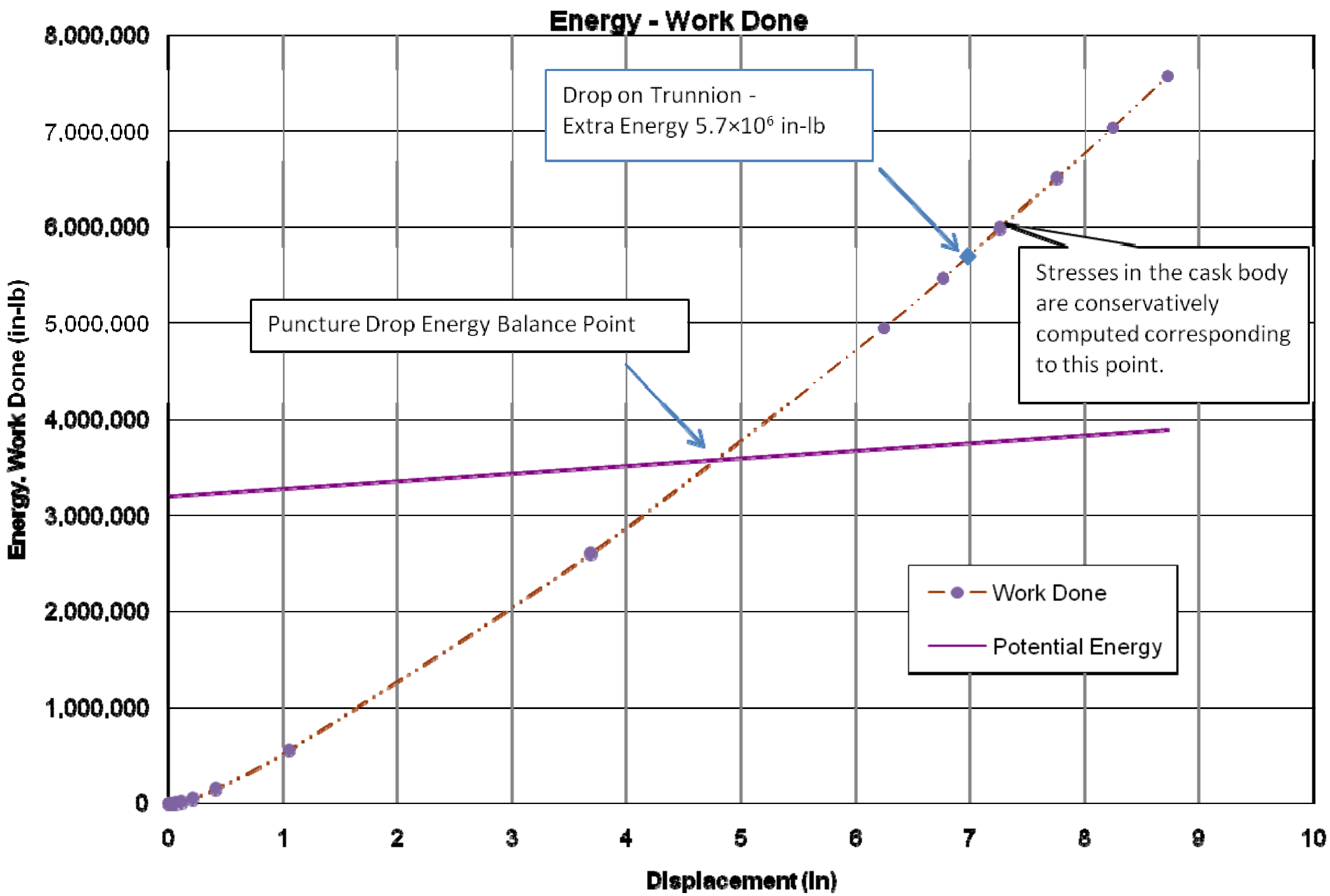


Figure 4
Energy versus Deflection Plot

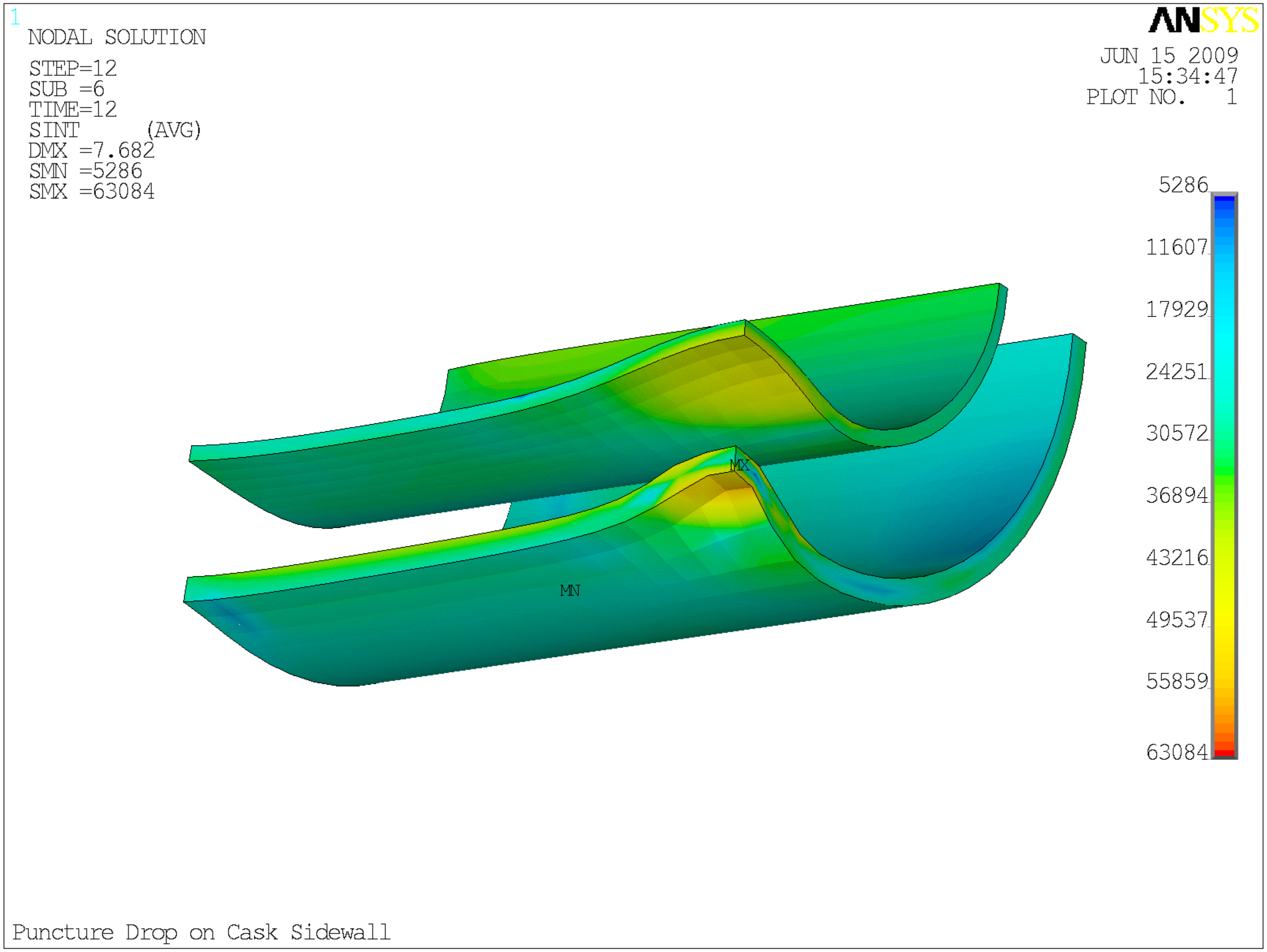


Figure 5
Maximum Stress Intensity in the Inner & Outer Shells of the Cask under Puncture Drop

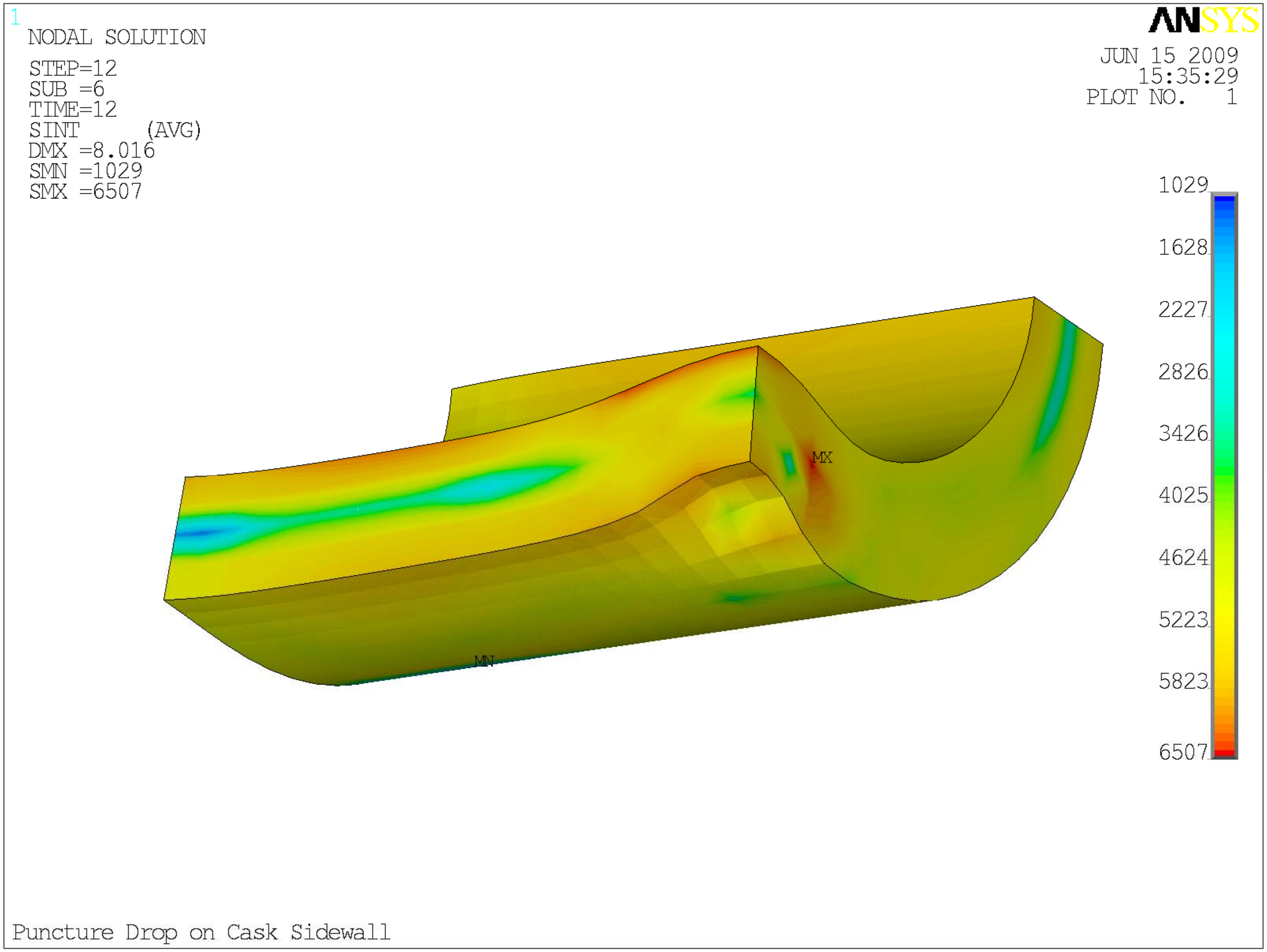


Figure 6

Maximum Stress Intensity in the Lead under Puncture Drop

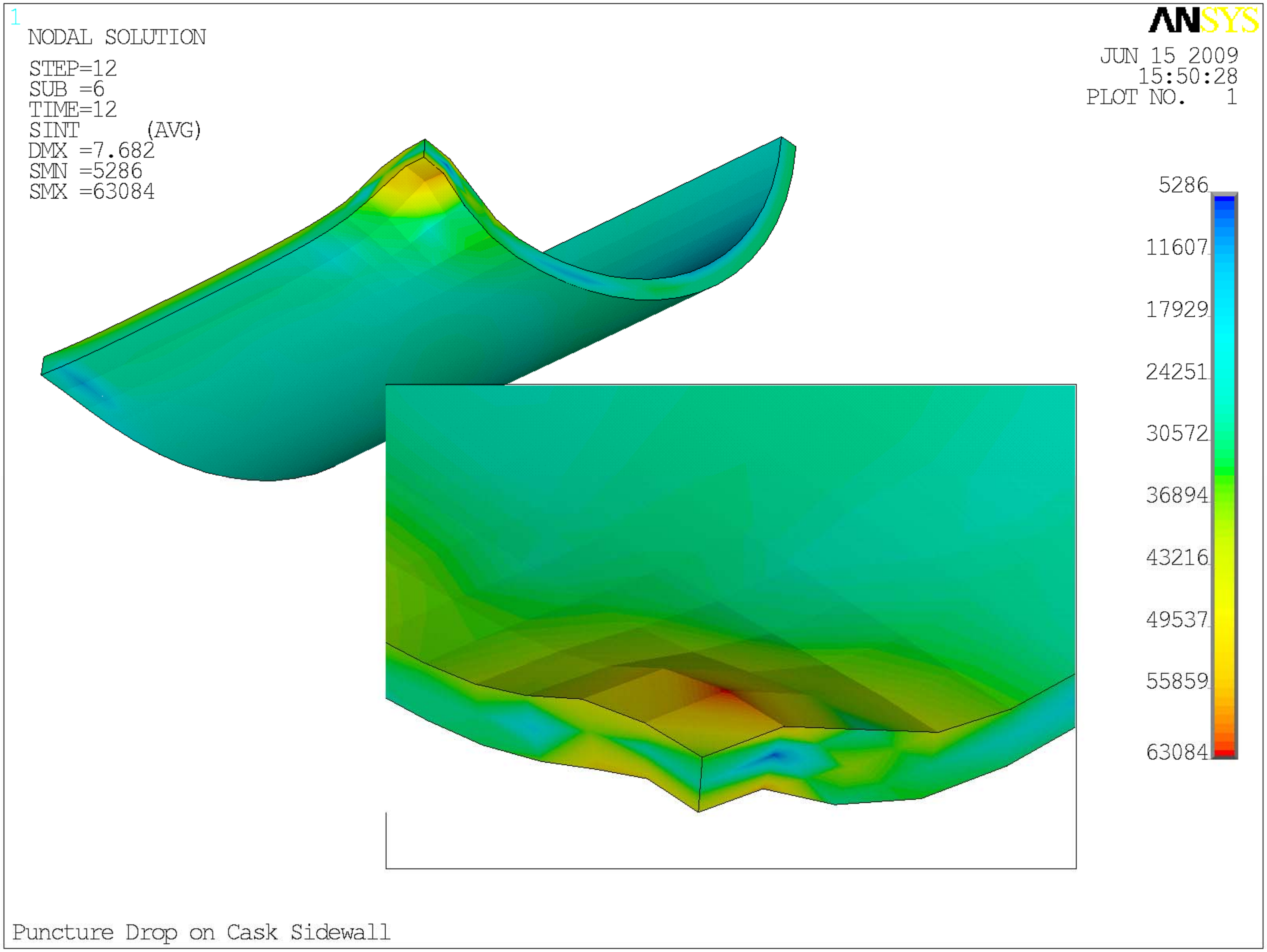


Figure 7

Maximum Stress Intensity in the Outer Shells of the Cask under Puncture Drop

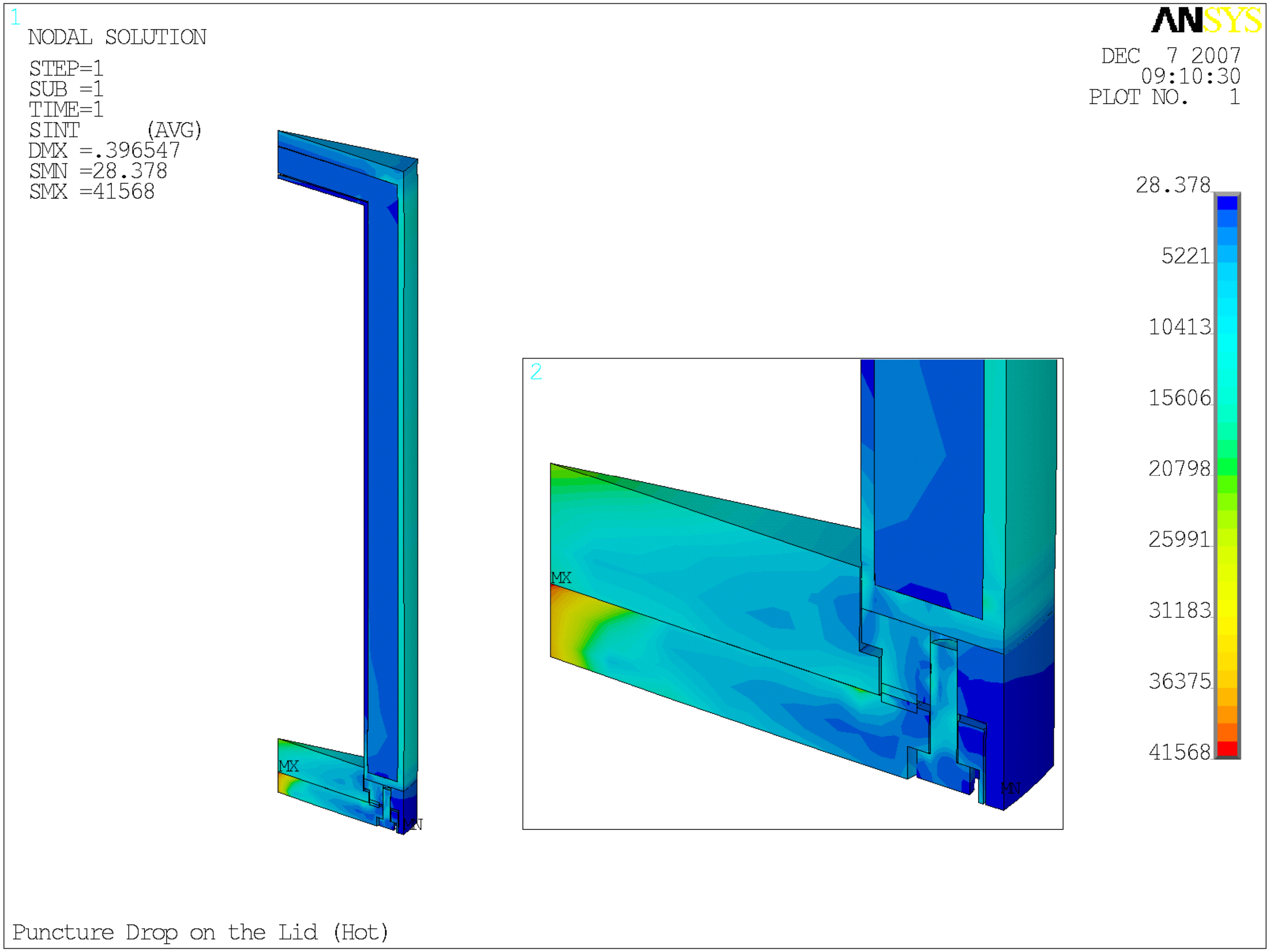


Figure 8

Maximum Stress Intensity in the Cask under Puncture Drop on the Lid

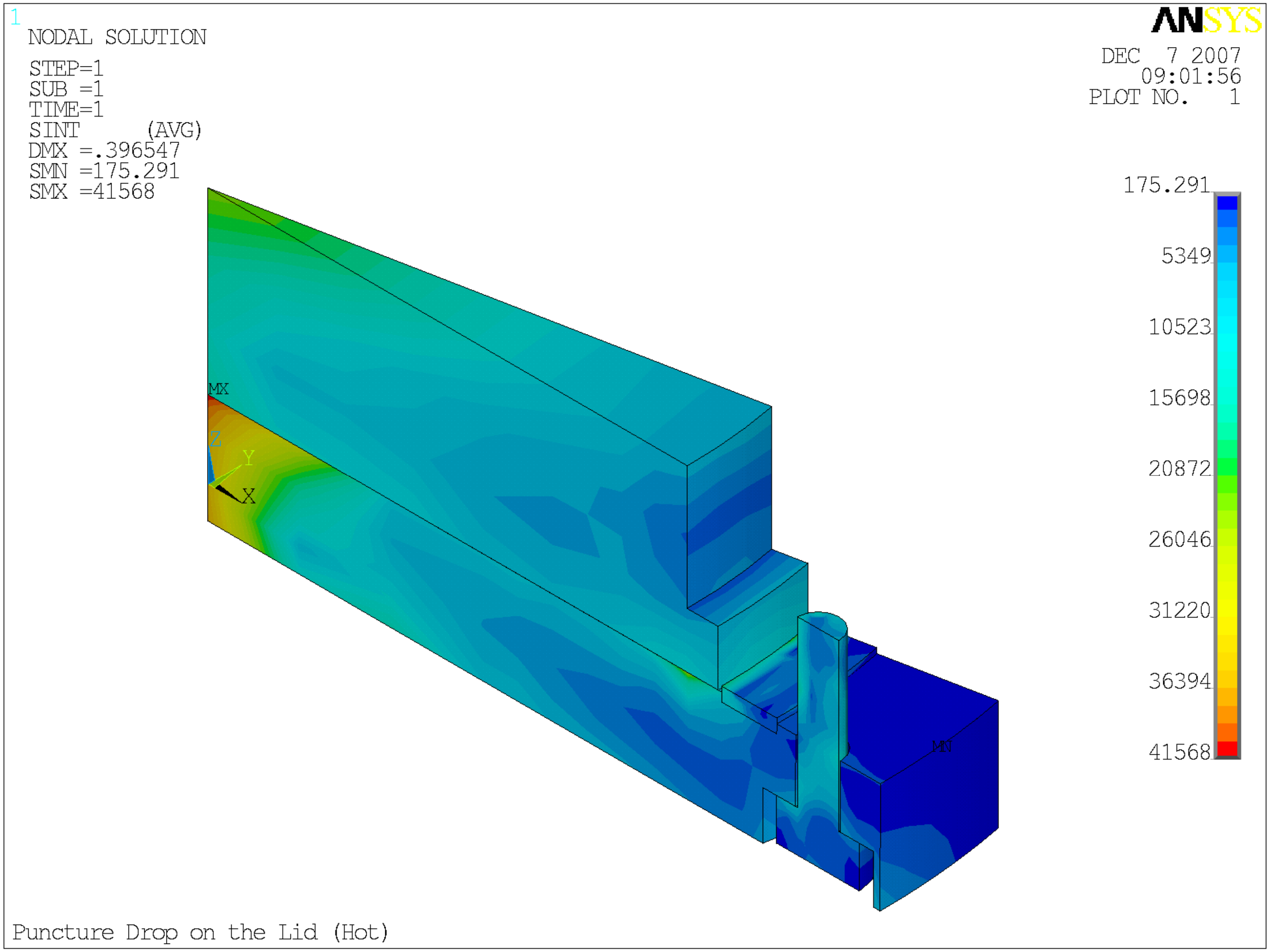


Figure 9

Maximum Stress Intensity in the Lid under Puncture Drop (Hot Conditions)

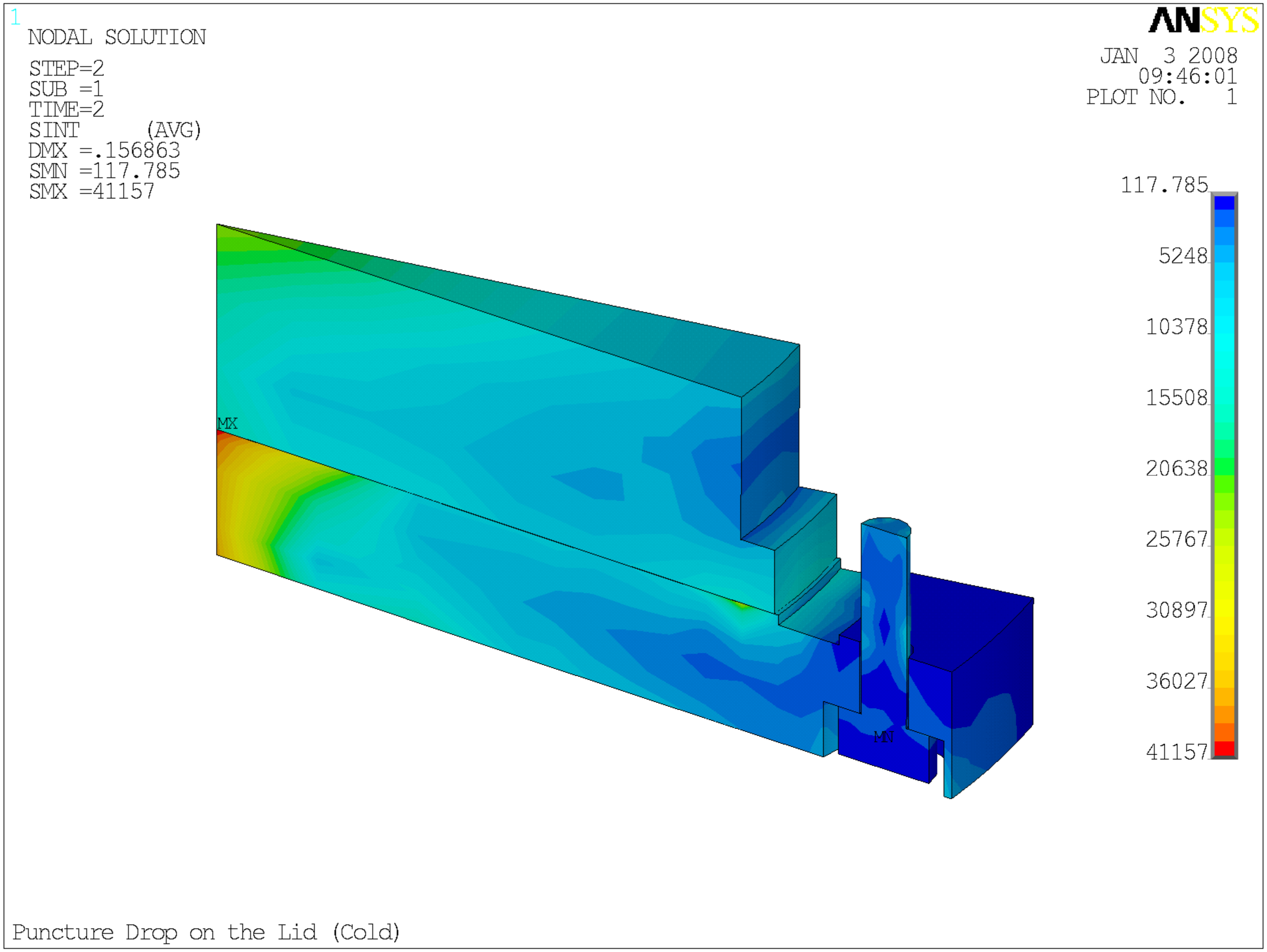


Figure 10

Maximum Stress Intensity in the Lid under Puncture Drop (Cold Conditions)

Title 3-60B Cask Analyses under Puncture Drop & Impact on Trunnions during HAC Testing

Calc. No. ST-505 (Figures) **Rev.** 1 **Sheet** 10 of 15

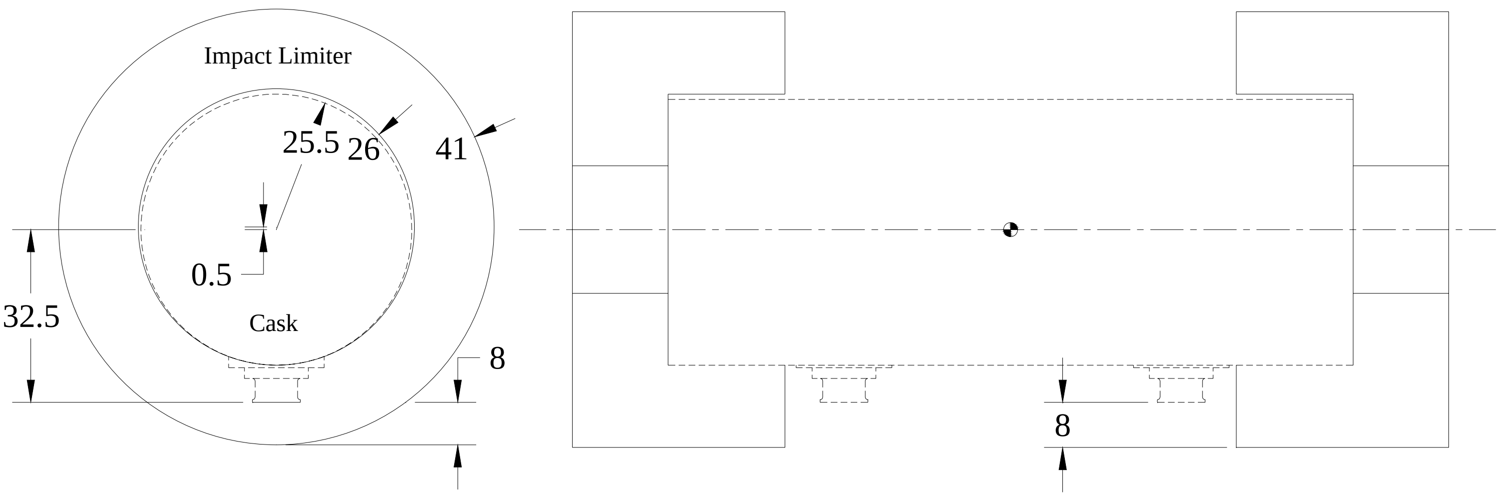


Figure 11
Package Geometry with Trunnions in the Vertical Plane

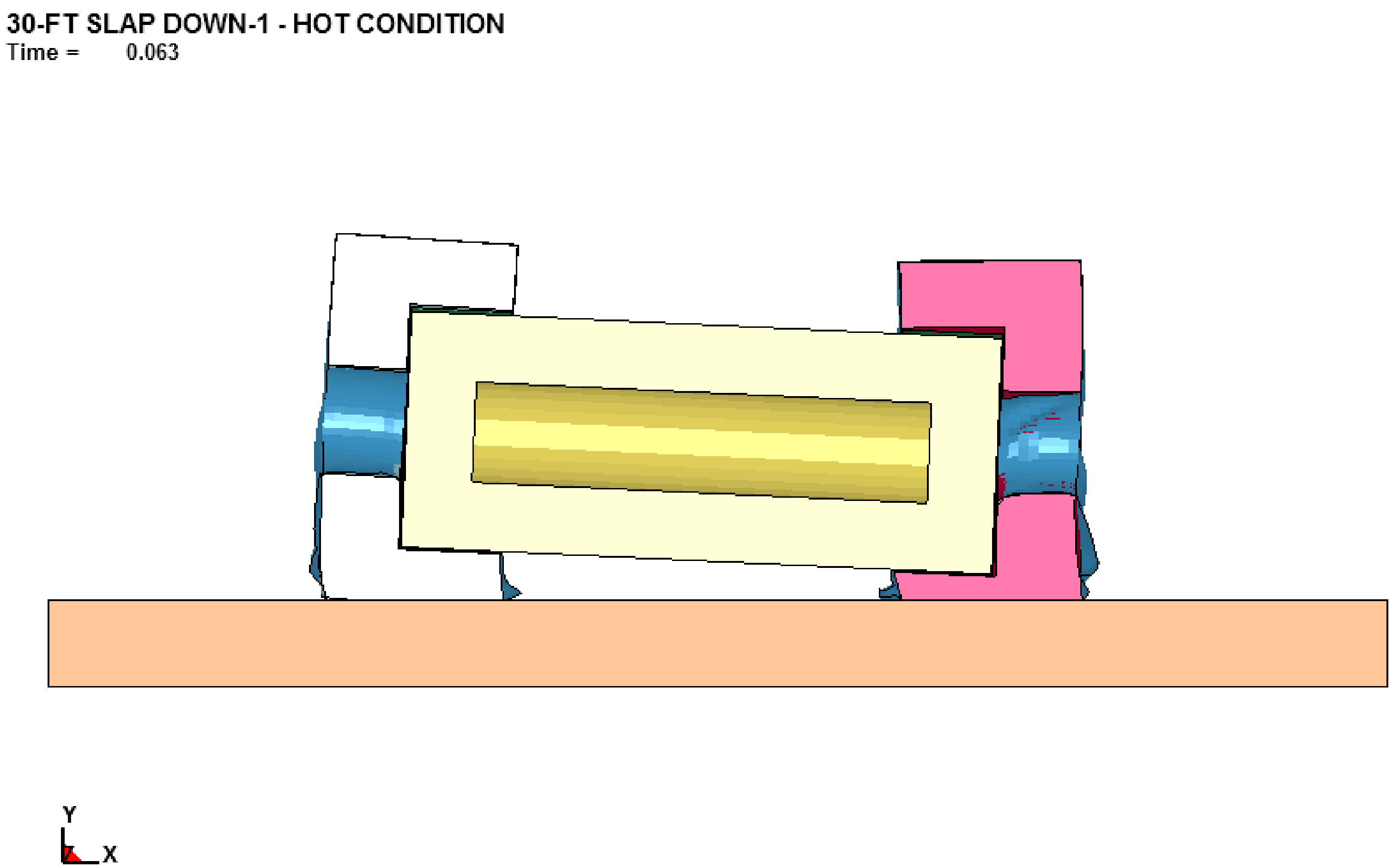


Figure 12
Deformation of the Impact Limiters with 8" Foam Crush at the Tail End
(Reference 8 Analysis)

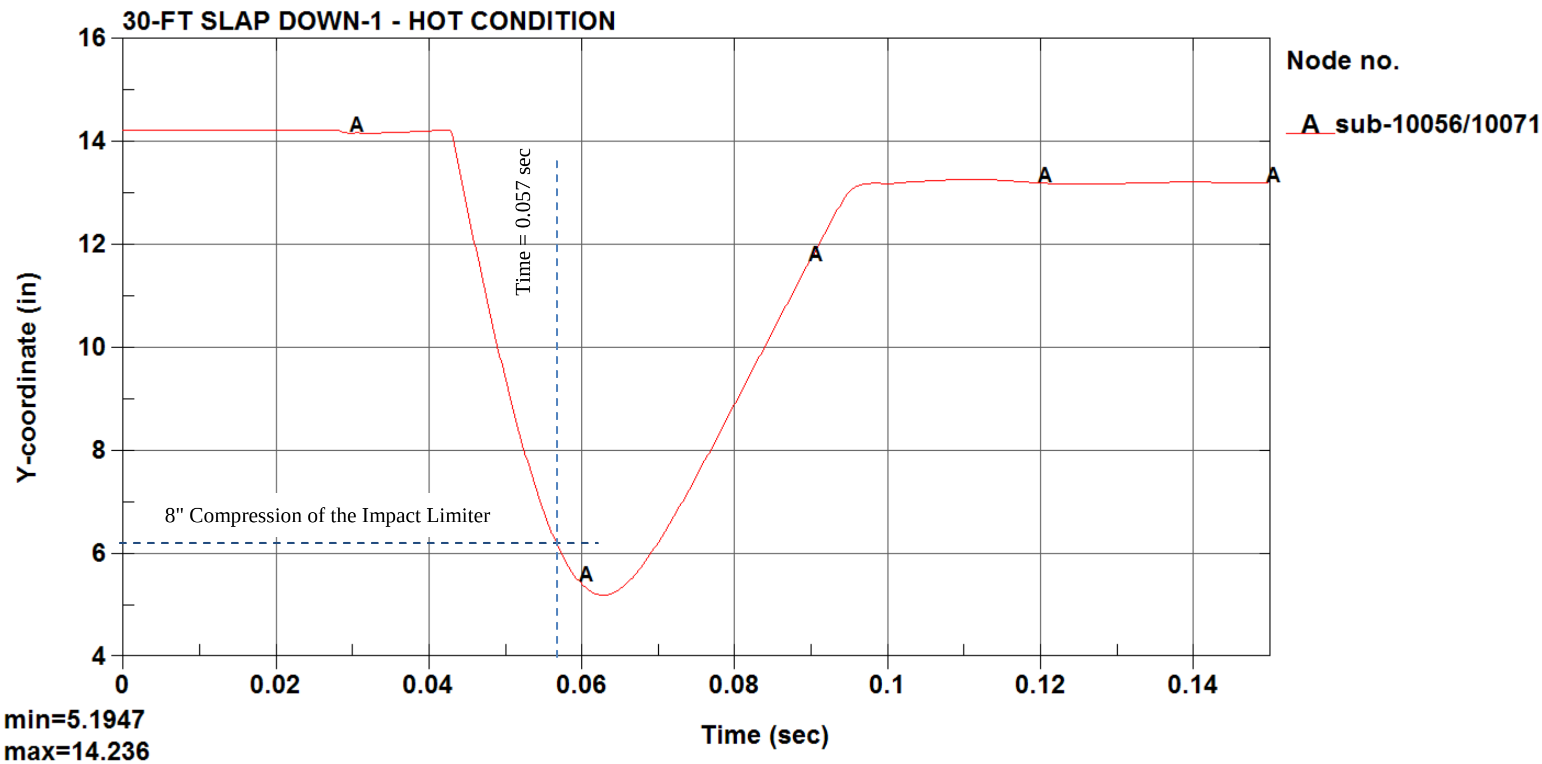


Figure 13
Impact Limiter Deformation Time-History for Slapdown-1 in Hot Environment
(ST-557 Reference 8, Figure 95)

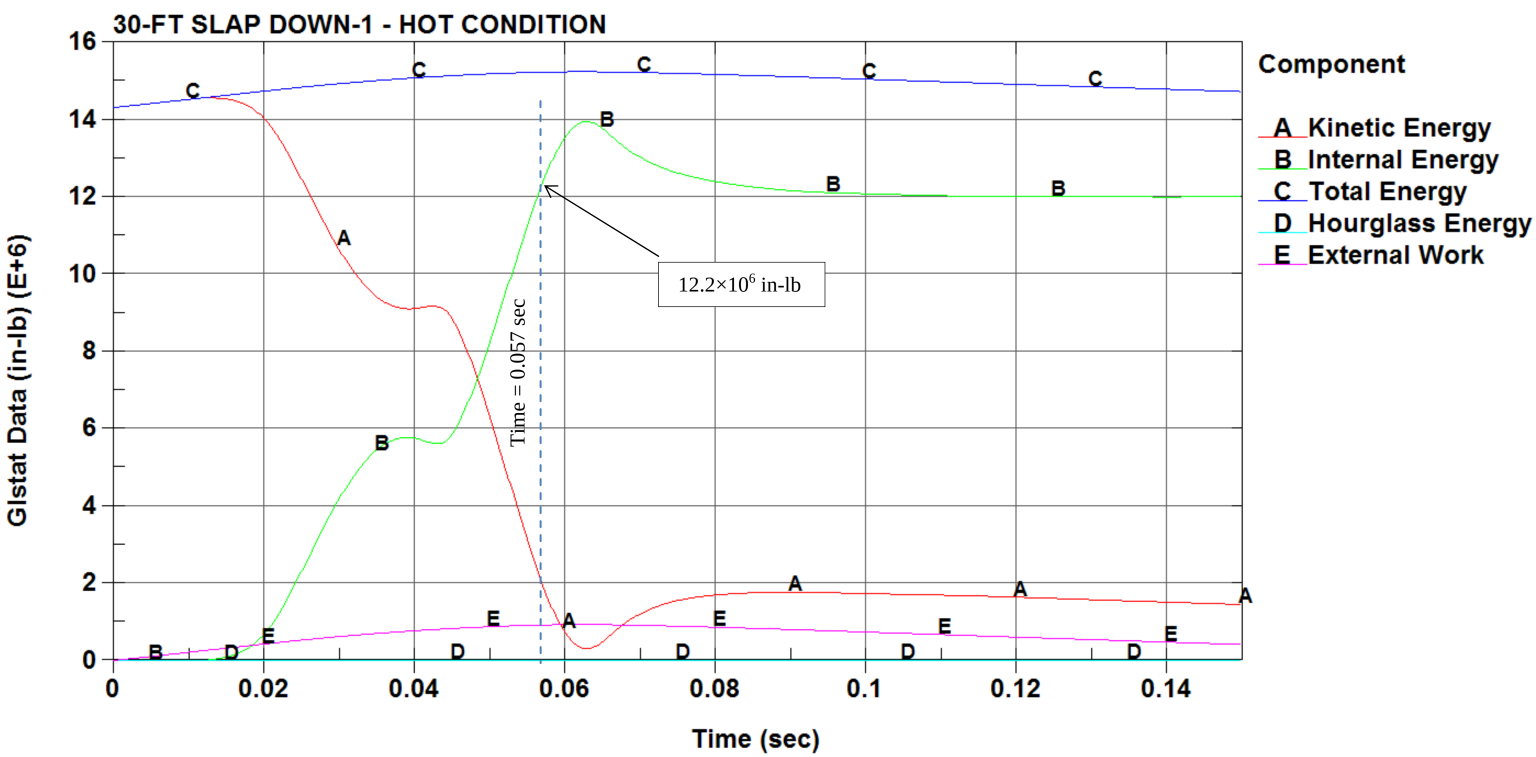


Figure 14
Impact Limiter Internal Energy Time-History for Slapdown-1 in Hot Environment
(ST-557 Reference 8, Figure 92)

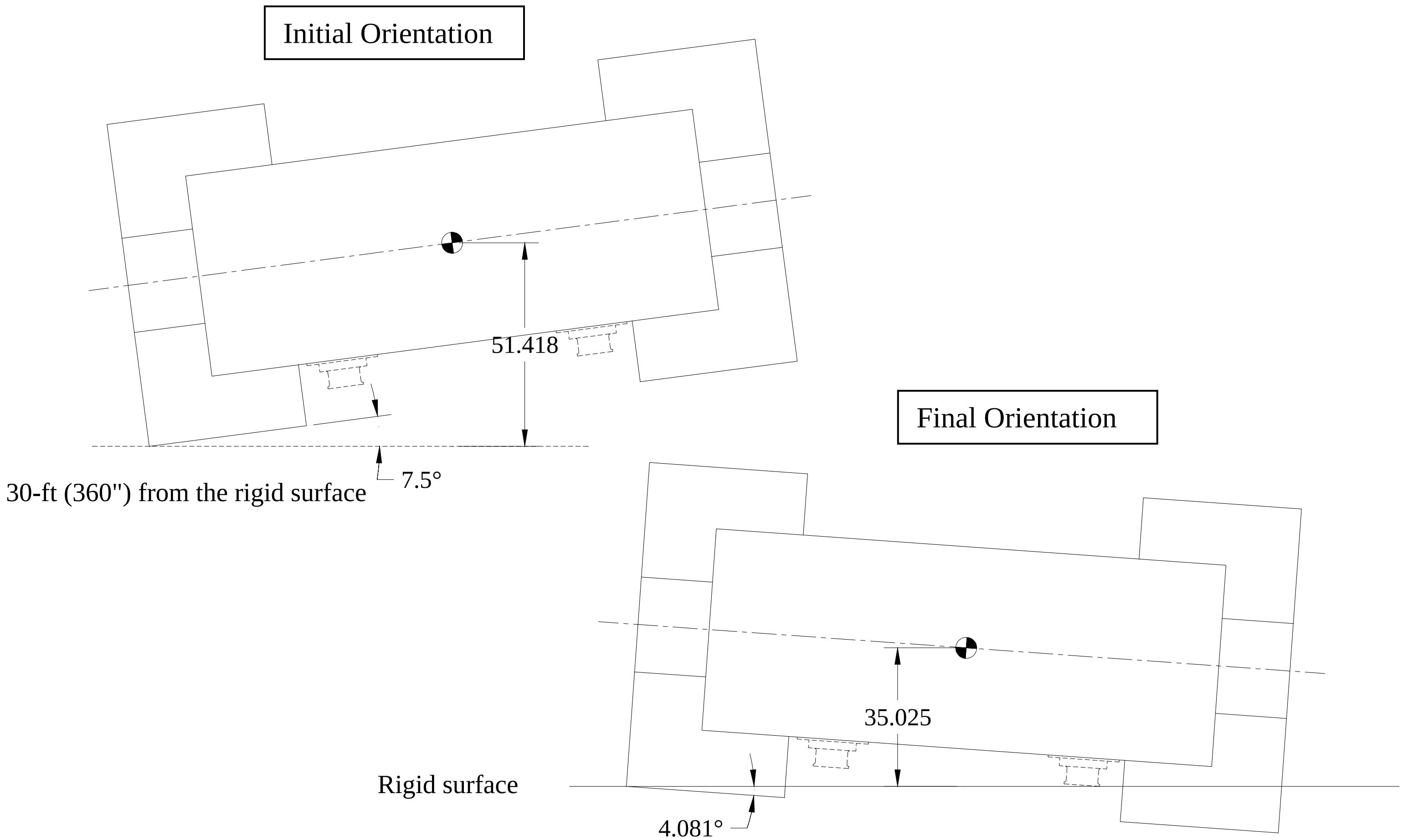


Figure 15
C.G. Location of the Package Before and After the Slapdown-1 Drop Test

Appendix 1

Printout of the ANSYS Model Data

(18 Pages)

ANSYS Model Sample Print-Out

Scenario 1: Puncture Drop on the Sidewall

```
    ***** 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\Puncture Drop on Wall

 TITLE= Puncture Drop on Cask Sidewall

 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          08:48
 Release 11.0SP1              00222442                 WINDOWS x64  Version

 Current working directory: D:\Ansys Analyses\3-60B\Puncture Drop on Wall


 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 -----------------------------------------------

Puncture Drop on Cask Sidewall

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

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

                                Available             Used
 Scratch Memory Space. . . .    4796.000 mb          6.538 mb (  0.1%)
 Database space  . . . . . . 1048572.000 mb         29.115 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 . . . . . . . . .      33             33            15
```

```
Lines . . . . . . . . . . . .      47             47             22
Areas . . . . . . . . . . . .      23             23             11
Volumes . . . . . . . . . . .       4              4              2

Finite element model summary:

                              Largest        Number        Number
                               Number        Defined       Selected
Nodes . . . . . . . . . . . .  25932          18541          4725
Elements. . . . . . . . . . .   5250           5019           800

Element types . . . . . . .        9              9          n.a.
Real constant sets. . . . .       14             10          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. . . . . . . . . . .    2123
Constraints on keypoints. . . . . . . . .       0
Constraints on lines. . . . . . . . . . .       0
Constraints on areas. . . . . . . . . . .       0

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

Surface loads on elements . . . . . . . .      27
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. . . . . . . . . .     0.000
   Reference temperature. . . . . . . . .     0.000
   Offset from absolute scale . . . . . .     0.000

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

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

Current routine. . . . . . . . . . . .None (BEGIN level)

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. . . . . . . . . . . . .Included
   Creep . . . . . . . . . . . . . . .Not included
   Equation solver to use. . . . . . .Sparse

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

Load step number . . . . . . . . . .    13

Number of substeps:
   Starting number of substeps . . . .     10
   Maximum number of substeps. . . . .    100
   Minimum number of substeps. . . . .      1
   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
  ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
  EQUATION SOLVER OPTION. . . . . . . . . . . . .SPARSE
  PLASTIC MATERIAL PROPERTIES INCLUDED. . . . . .YES
  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. . . . . . . . . . . . . . . .    13
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  16.000
  AUTOMATIC TIME STEPPING . . . . . . . . . . . .    ON
     INITIAL NUMBER OF SUBSTEPS . . . . . . . . .    10
     MAXIMUM NUMBER OF SUBSTEPS . . . . . . . . .   100
     MINIMUM 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
  COPY INTEGRATION POINT VALUES TO NODE . . . . .YES, FOR ELEMENTS WITH
                                                 ACTIVE MAT. NONLINEARITIES
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
      ALL        ALL


LIST ELEMENT TYPES FROM      1 TO      9 BY      1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   08:48:42  JUN 17, 2009 CP=      2.406

Puncture Drop on Cask Sidewall


ELEMENT TYPE      1 IS SOLID186     3-D 20-NODE STRUCTURAL SOLID   INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      2 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      3 IS CONTA174     3D 8-NODE SURF-SURF CONTACT    INOPR
```

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 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

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

ELEMENT TYPE      9 IS CONTA174     3D 8-NODE SURF-SURF CONTACT    INOPR
 KEYOPT(1-12)=    0  0  0    0  1  0    0  0  1    1  0  0       0

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

LIST REAL SETS       1 TO      14 BY       1

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REAL CONSTANT SET       3  ITEMS  19 TO  24
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REAL CONSTANT SET       4  ITEMS  13 TO  18
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REAL CONSTANT SET       5  ITEMS  13 TO  18
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```

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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
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REAL CONSTANT SET        7  ITEMS   1 TO   6
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REAL CONSTANT SET        7  ITEMS   7 TO  12
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REAL CONSTANT SET        7  ITEMS  13 TO  18
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REAL CONSTANT SET        7  ITEMS  19 TO  24
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REAL CONSTANT SET        8  ITEMS   7 TO  12
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REAL CONSTANT SET        8  ITEMS  13 TO  18
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REAL CONSTANT SET       11  ITEMS   7 TO  12
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REAL CONSTANT SET       11  ITEMS  19 TO  24
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REAL CONSTANT SET       12  ITEMS  19 TO  24
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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

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. =   0.00
  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      0.0000

PROPERTY TABLE EMIS  MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.78886E-30

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. =   0.00
  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. =   0.00
  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

LIST DATA TABLE  ALL   FOR ALL MATERIALS

              BiKin Pl (BKIN) Table For Material     1

              1
  Temps   0.0000
Yld Strs  25000.
Tang Mod 0.13406E+06

              BiKin Pl (BKIN) Table For Material     3

              1
  Temps   0.0000
Yld Strs  4300.0
Tang Mod  4200.0

LIST NODAL SURFACE LOAD PRES FOR ALL SELECTED NODES
```

Scenario 2: Puncture Drop on the Lid

```
    ***** 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: G:\3-60B Rev 2\Puncture

 TITLE= Puncture Drop on the Lid (Hot)

 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            Dec 07, 2007           10:10
 Release 11.0SP1              00222442                  INTEL NT     Version

 Current working directory: G:\3-60B Rev 2\Puncture


 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  2.3 seconds

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

Puncture Drop on the Lid (Hot)

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

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

                                Available             Used
 Scratch Memory Space. . . .     256.000 mb          4.598 mb (  1.8%)
 Database space  . . . . . .   65535.750 mb          8.777 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 . . . . . . . . . . .     3001           2879          2878
Elements. . . . . . . . . .     3946           2369          1522

Element types . . . . . . .       71             36          n.a.
Real constant sets. . . . .       71             29          n.a.
Material property sets. . .        3              3          n.a.

Coupling. . . . . . . . . .       82             30          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. . . . . . . . . . .   1196
Constraints on keypoints. . . . . . . . .      0
Constraints on lines. . . . . . . . . . .      0
Constraints on areas. . . . . . . . . . .      0

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

Surface loads on elements . . . . . . . .      1
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 . . . . . . . . . . .   2878
Body loads on keypoints . . . . . . . . .      0

Temperatures
   Uniform temperature. . . . . . . . . .  -20.000
   Reference temperature. . . . . . . . .   70.000
   Offset from absolute scale . . . . . .  460.000

                                               X           Y           Z
Linear acceleration . . . . . . . . . . . 0.0000      0.0000      22.390
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 . . . . . . . . . . . .    71  (COMBIN14)
   Real number . . . . . . . . . . . .    71
   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 . . . . . . . . .     1
   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. . . . . . . . . .  3.0000
  NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS
     LABEL   REFERENCE    TOLERANCE  NORM     MINREF
      F      0.1000       0.1000E-02   2     -1.000
  INERTIA LOADS                         X           Y           Z
     ACEL . . . . . . . . . . . . .  0.0000      0.0000      22.390
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     BASI        ALL


LIST ELEMENT TYPES FROM      1 TO     71 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  1       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  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    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  1       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

ELEMENT TYPE     71 IS COMBIN14     SPRING-DAMPER                  INOPR
 KEYOPT(1-12)=    0  3  0    0  0  0    0  0  0    0  0  0       0

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

LIST REAL SETS       1 TO      71 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      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  13
  0.33300

REAL CONSTANT SET      27  ITEMS   1 TO   6
   1.0000      0.33056E-14   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  13
  0.33300

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
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Appendix 2

Electronic Data on CDROM

(1 Page & 1 CDROM)

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) Yield (S_y)	Ultimate (S_u)	Membrane Allowable (S_m)	Young's Modulus (10^6 psi)	Coefficient of Thermal Expansion (10^{-6} in/in)
		(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[(3)]
	Mem. + Bending Stress	60,120[(2)]	87,000[(2)]	150,000[(3)]

Notes:

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

(2) Established from Regulatory Guide 7.6 (Reference 6), Position 6.

(3) 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.

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 shell components of the cask - the inner and outer shells, and the baseplates have been represented in the finite element model by SOLSH190 elements.

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,

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

Payload Mass = 9,500 lb

Lid Radius = 17.5 in

Pressure on the lid surface due to payload weight,

$p_{lid} = 9{,}500/(\pi\times 17.5^2) = 9.874$ 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	4,892	17.78
Bolting Ring Shell Extension	$P_m + P_b$	87,000	11,070	7.86
Bolting Ring Skirt	$P_m + P_b$	87,000	3,422	25.42
Inner Shell	$P_m + P_b$	87,000	4,637	18.76
Outer Shell	$P_m + P_b$	60,120	6,860	8.76
Lid	$P_m + P_b$	60,120	5,437	11.06
Base Plates	$P_m + P_b$	87,000	5,190	16.76
Seal Plates	$P_m + P_b$	60,120	3,560	16.89
Bolts	$P_m + P_b$	150,000	10,593	14.16

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 maximum stress intensity values, obtained from the finite element model, 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	53,681	1.62
Bolting Ring Shell Extension	$P_m + P_b$	87,000	46,277	1.88
Bolting Ring Skirt	$P_m + P_b$	87,000	- [3]	- [3]
Inner Shell	$P_m + P_b$	87,000	14,035	6.20
Outer Shell	$P_m + P_b$	60,120	39,916	1.51
Lid	$P_m + P_b$	60,120	49,043	1.23
Base Plates	$P_m + P_b$	87,000	80,106	1.09
Seal Plates	$P_m + P_b$	60,120	49,134	1.22
Bolts	$P_m + P_b$	150,000	85,618	1.75

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 maximum stress intensity values, obtained from the finite element model, 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	65,848	1.32
Bolting Ring Shell Extension	$P_m + P_b$	87,000	65,241	1.33
Bolting Ring Skirt	$P_m + P_b$	87,000	- [3]	- [3]
Inner Shell	$P_m + P_b$	87,000	19,313	4.50
Outer Shell	$P_m + P_b$	60,120	46,666	1.29
Lid	$P_m + P_b$	60,120	59,543 [4]	1.01
Base Plates	$P_m + P_b$	87,000	80,086	1.09
Seal Plates	$P_m + P_b$	60,120	58,328 [5]	1.03
Bolts	$P_m + P_b$	150,000	131,900	1.14

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 maximum stress intensity 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	63,726	1.37
Bolting Ring Shell Extension	$P_m + P_b$	87,000	63,705	1.37
Bolting Ring Skirt	$P_m + P_b$	87,000	- [3]	- [3]
Inner Shell	$P_m + P_b$	87,000	19,511	4.46
Outer Shell	$P_m + P_b$	60,120	46,084	1.30
Lid	$P_m + P_b$	60,120	59,242 [4]	1.01
Base Plates	$P_m + P_b$	87,000	69,170	1.26
Seal Plates	$P_m + P_b$	60,120	57,300 [5]	1.05
Bolts	$P_m + P_b$	150,000	132,370	1.13

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 maximum stress intensity 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	21,957	3.96
Bolting Ring Shell Extension	$P_m + P_b$	87,000	48,562	1.79
Bolting Ring Skirt	$P_m + P_b$	87,000	14,632	5.95
Inner Shell	$P_m + P_b$	87,000	20,863	4.17
Outer Shell	$P_m + P_b$	60,120	36,829	1.63
Lid	$P_m + P_b$	60,120	52,277[3]	1.15
Base Plates	$P_m + P_b$	87,000	27,088	3.21
Seal Plates	$P_m + P_b$	60,120	16,635	3.61
Bolts	$P_m + P_b$	150,000	76,154	1.97

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 maximum stress intensity 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	22,032	3.95
Bolting Ring Shell Extension	$P_m + P_b$	87,000	47,484	1.83
Bolting Ring Skirt	$P_m + P_b$	87,000	6,057	14.36
Inner Shell	$P_m + P_b$	87,000	21,080	4.13
Outer Shell	$P_m + P_b$	60,120	37,135	1.62
Lid	$P_m + P_b$	60,120	57,409	1.05
Base Plates	$P_m + P_b$	87,000	26,526	3.28
Seal Plates	$P_m + P_b$	60,120	15,413	3.90
Bolts	$P_m + P_b$	150,000	68,448	2.19

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 maximum stress intensity 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 (w/o Skirt)	$P_m + P_b$	87,000	19,860	4.38
Bolting Ring Shell Extension	$P_m + P_b$	87,000	43,574	2.00
Bolting Ring Skirt	$P_m + P_b$	87,000	14,279	6.09
Inner Shell	$P_m + P_b$	87,000	19,547	4.45
Outer Shell	$P_m + P_b$	60,120	34,102	1.76
Lid	$P_m + P_b$	60,120	25,297	2.38
Base Plates	$P_m + P_b$	87,000	23,033	3.78
Seal Plates	$P_m + P_b$	60,120	9,585	6.27
Bolts	$P_m + P_b$	150,000	44,073	3.40

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 maximum stress intensity 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)

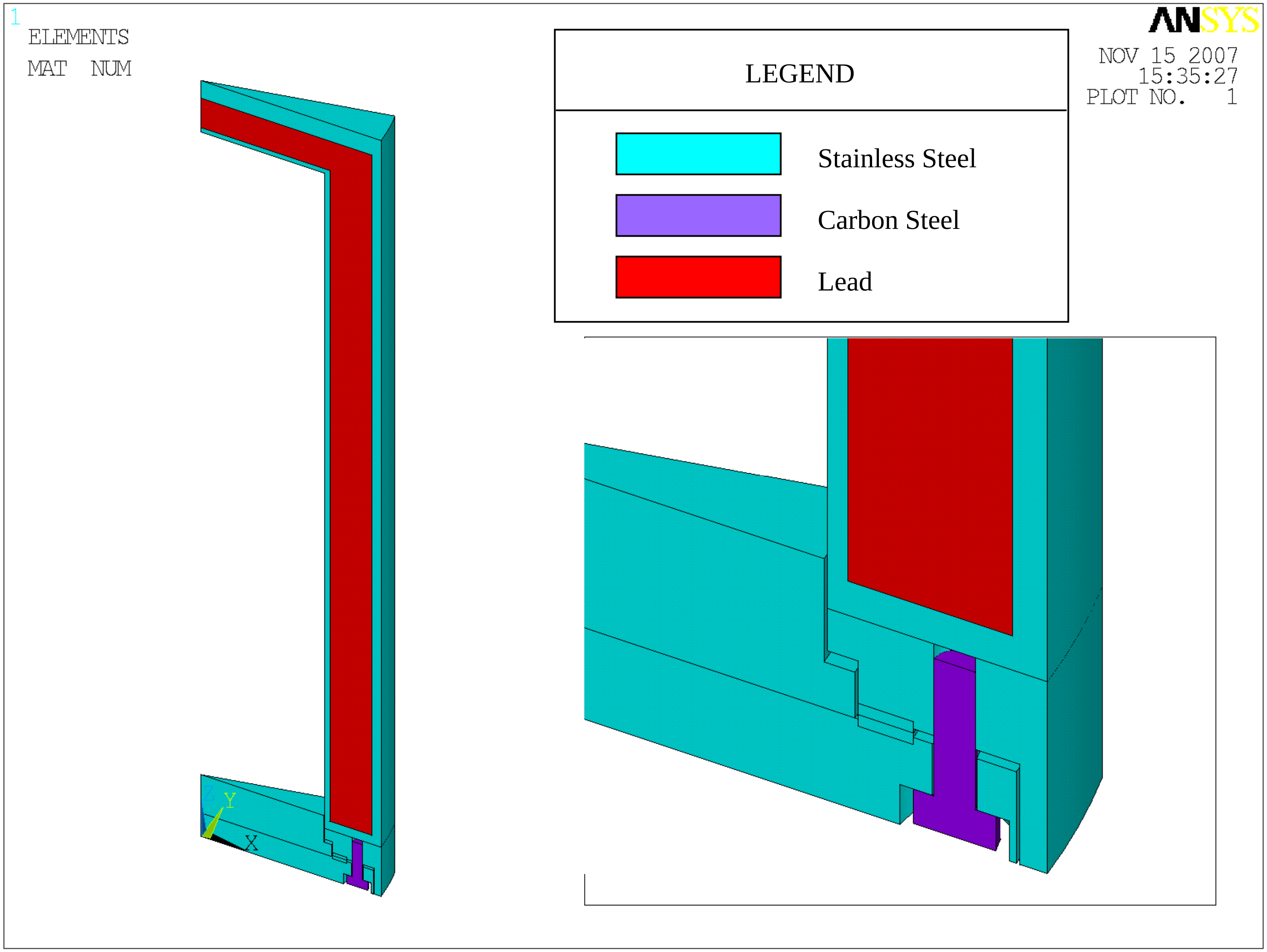

Figure 1

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

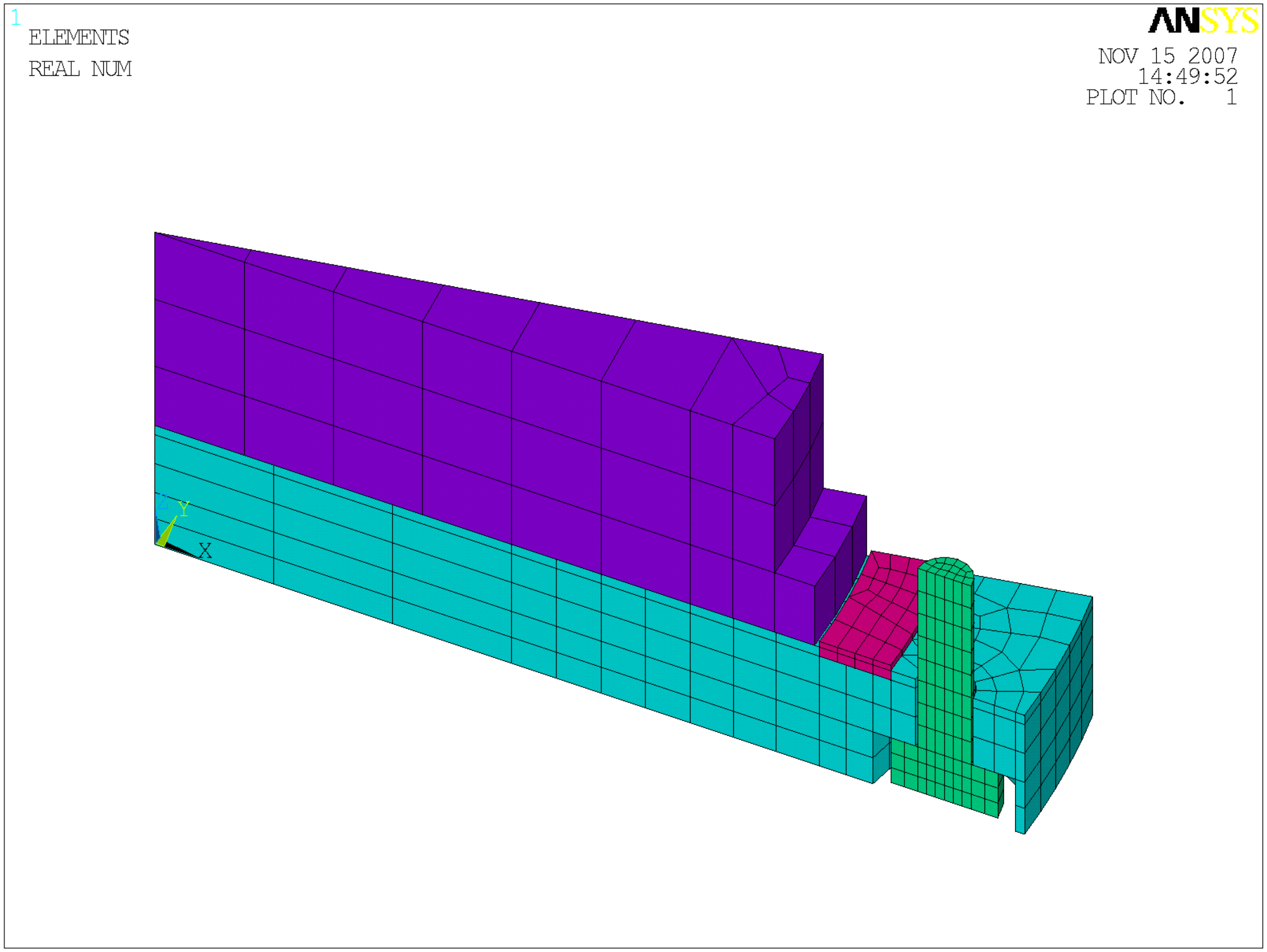

Figure 2
Finite Element Model of the Lid, Seal-Plate and Bolts

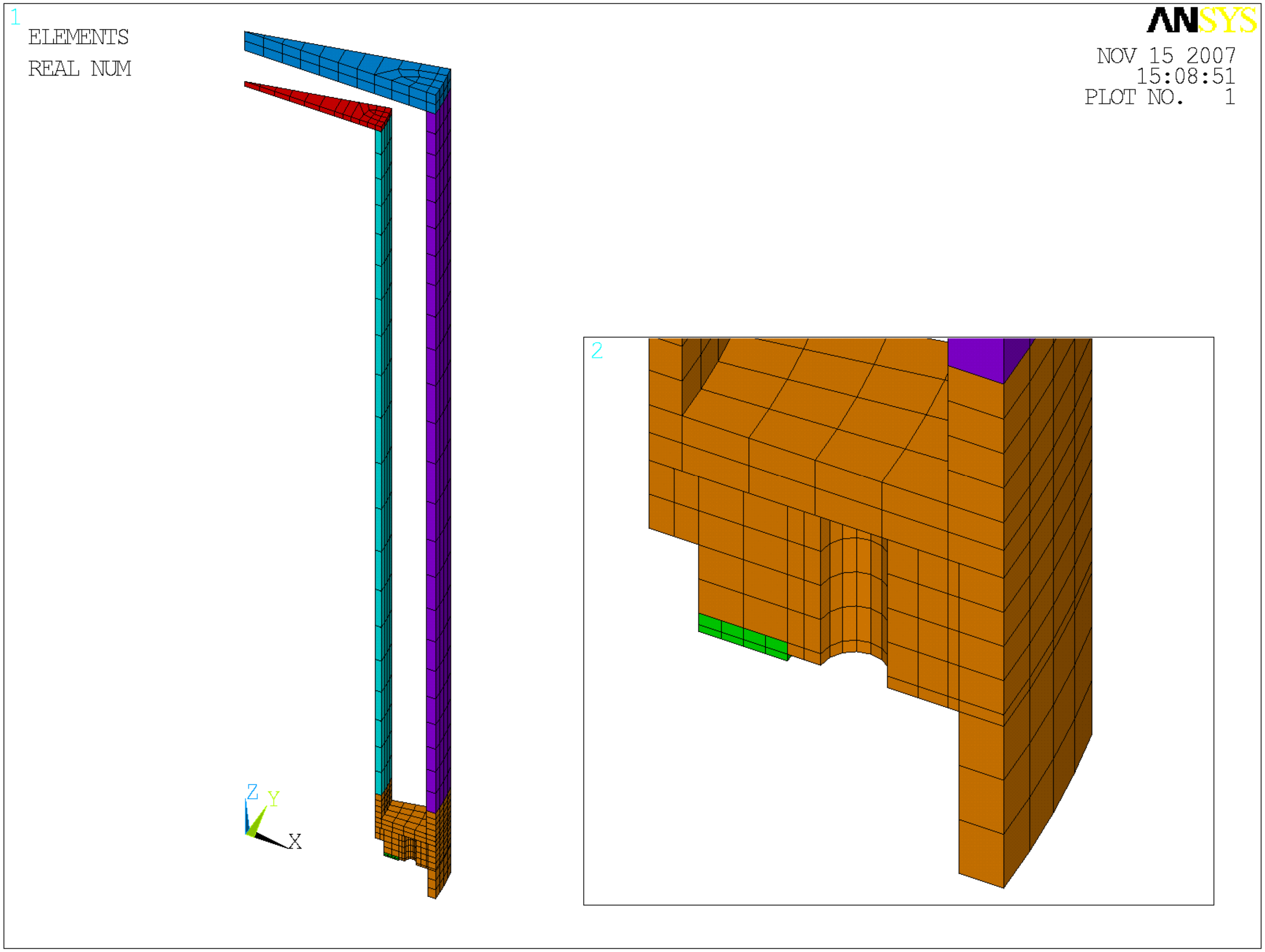

Figure 3
Finite Element Model of the Cask Body without Lead

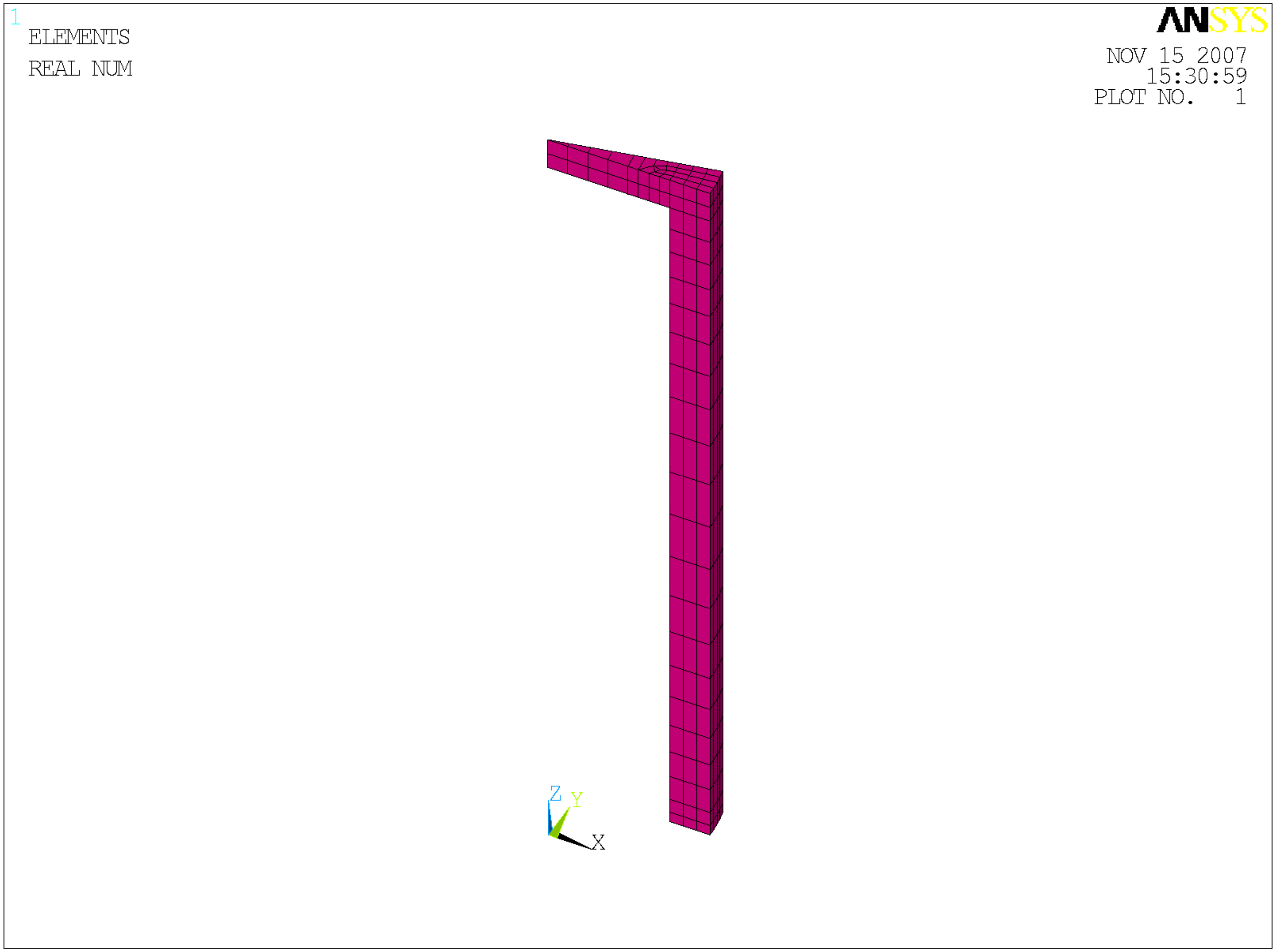

Figure 4
Finite Element Model of the Lead

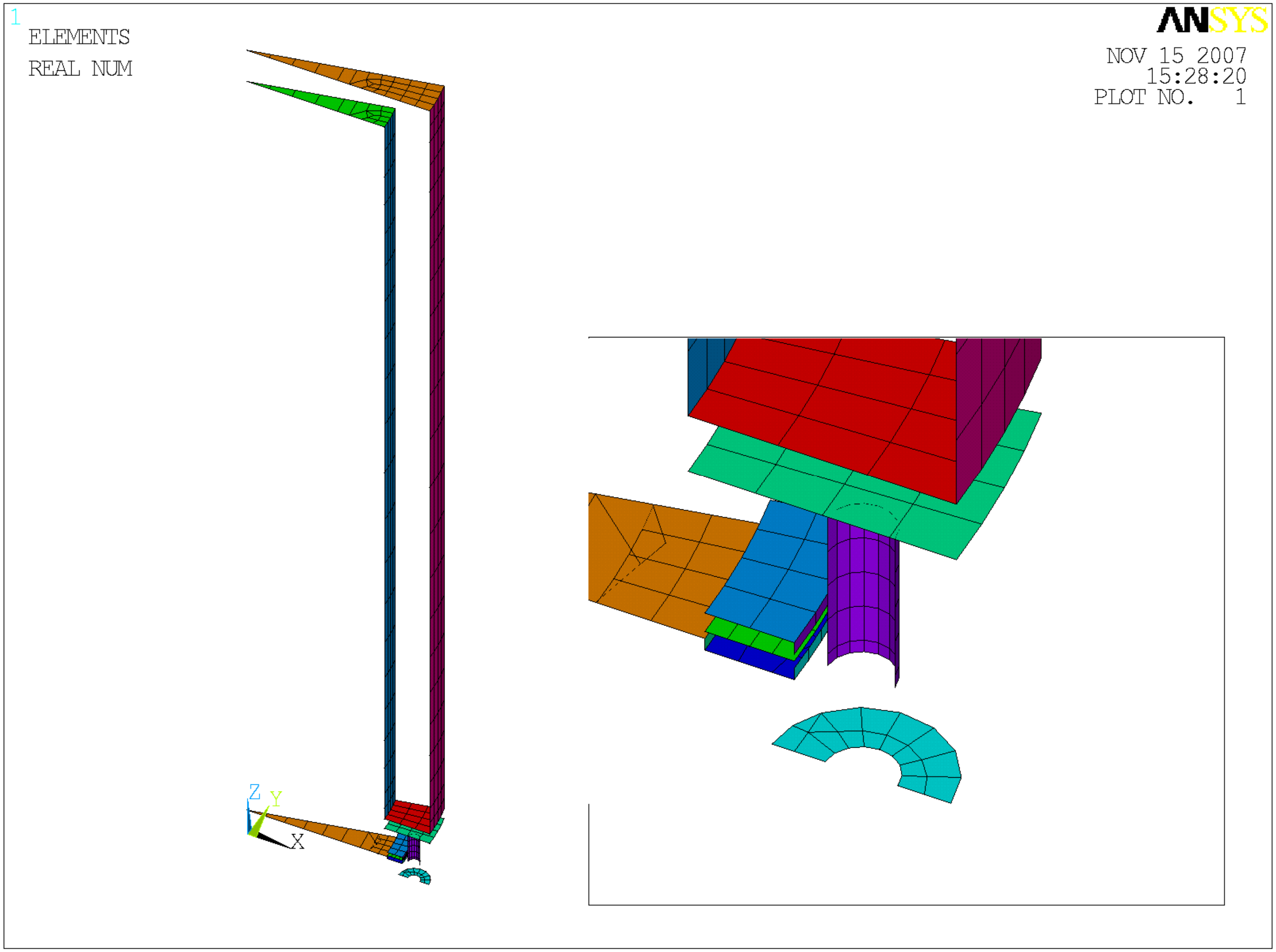

Figure 5

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

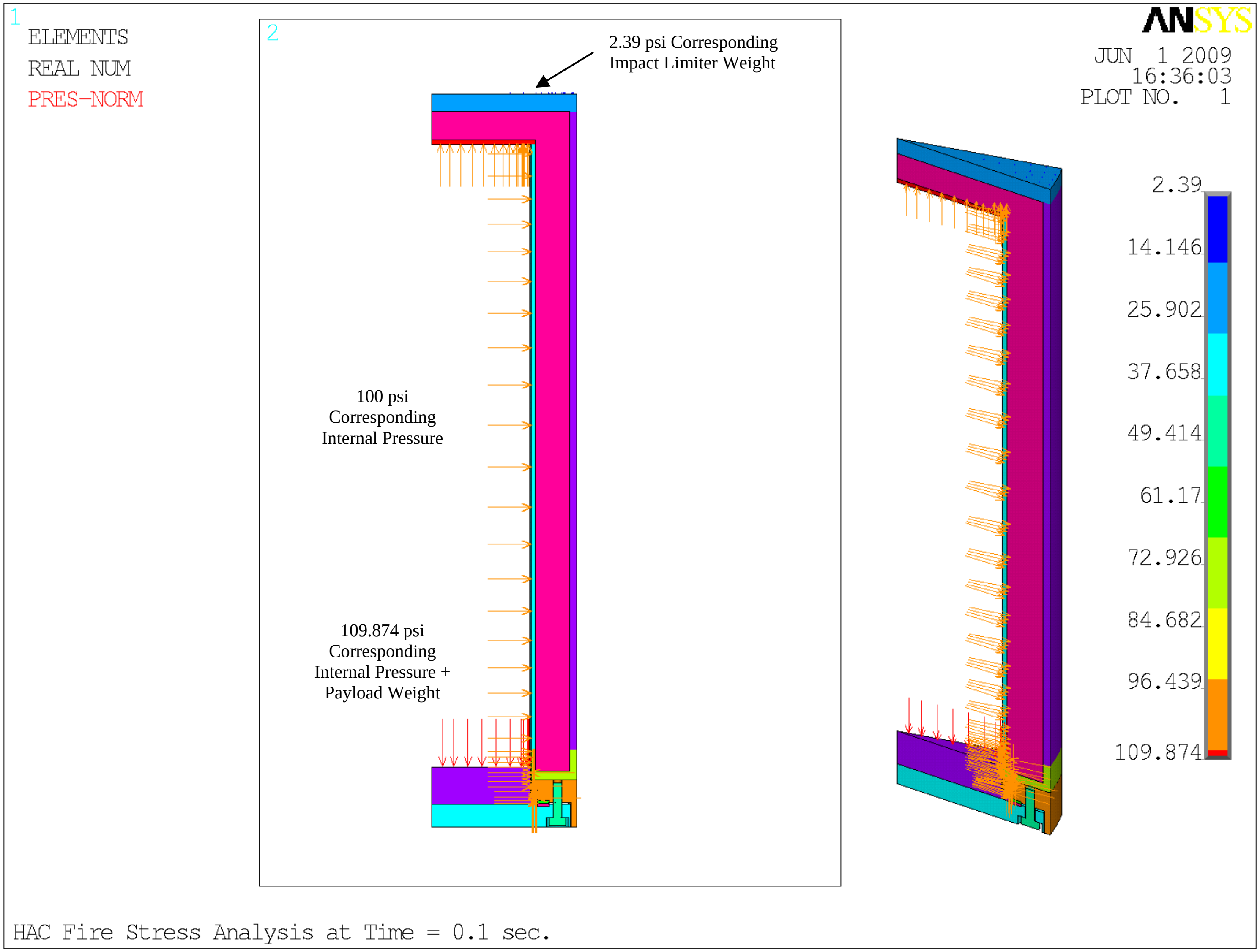

Figure 6
Pressure Distribution Used for All Load Steps

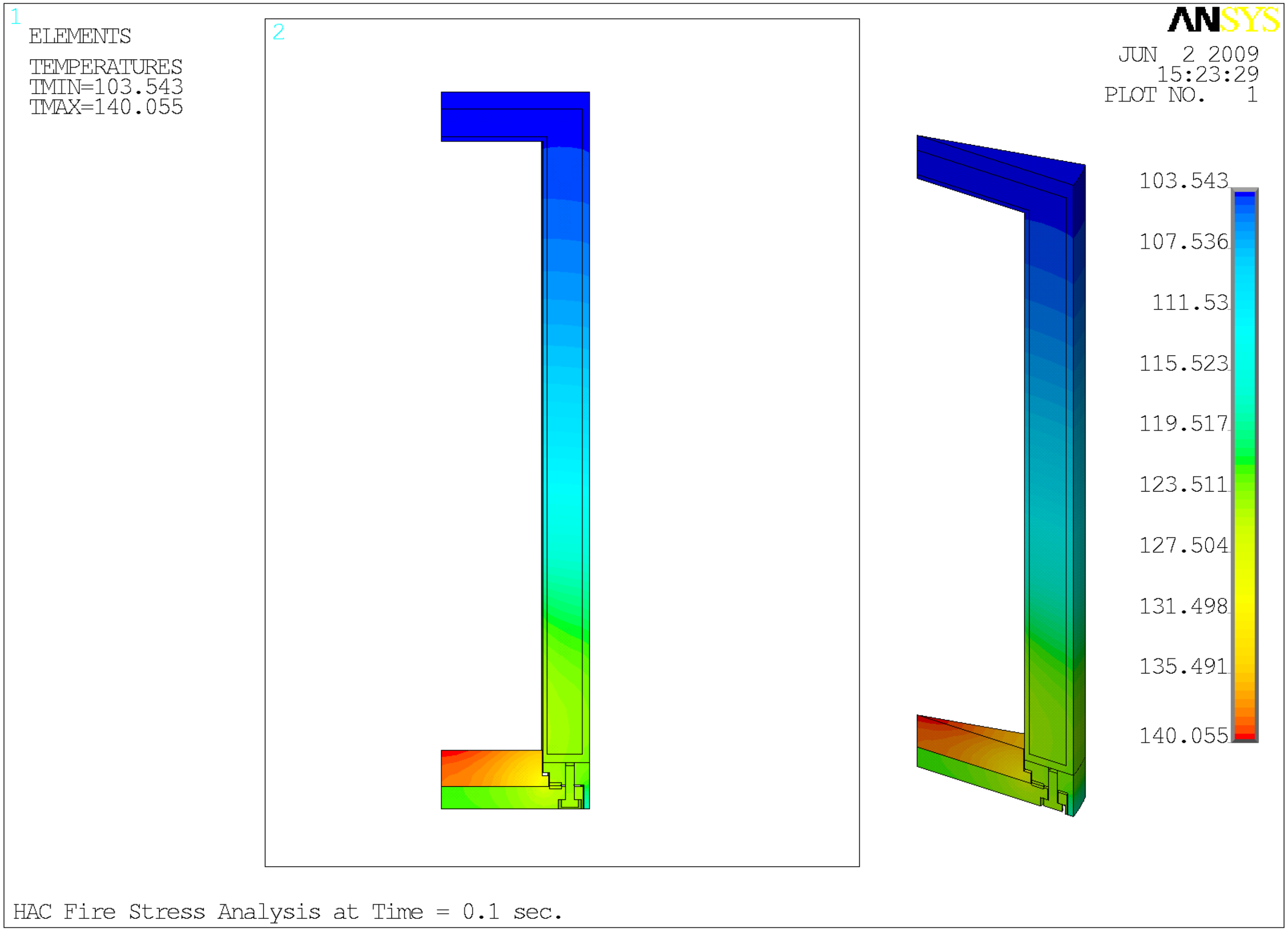

Figure 7
Temperature Profile Used for Load Step No.1 - HAC Thermal Analysis (Time = 0.1 sec)

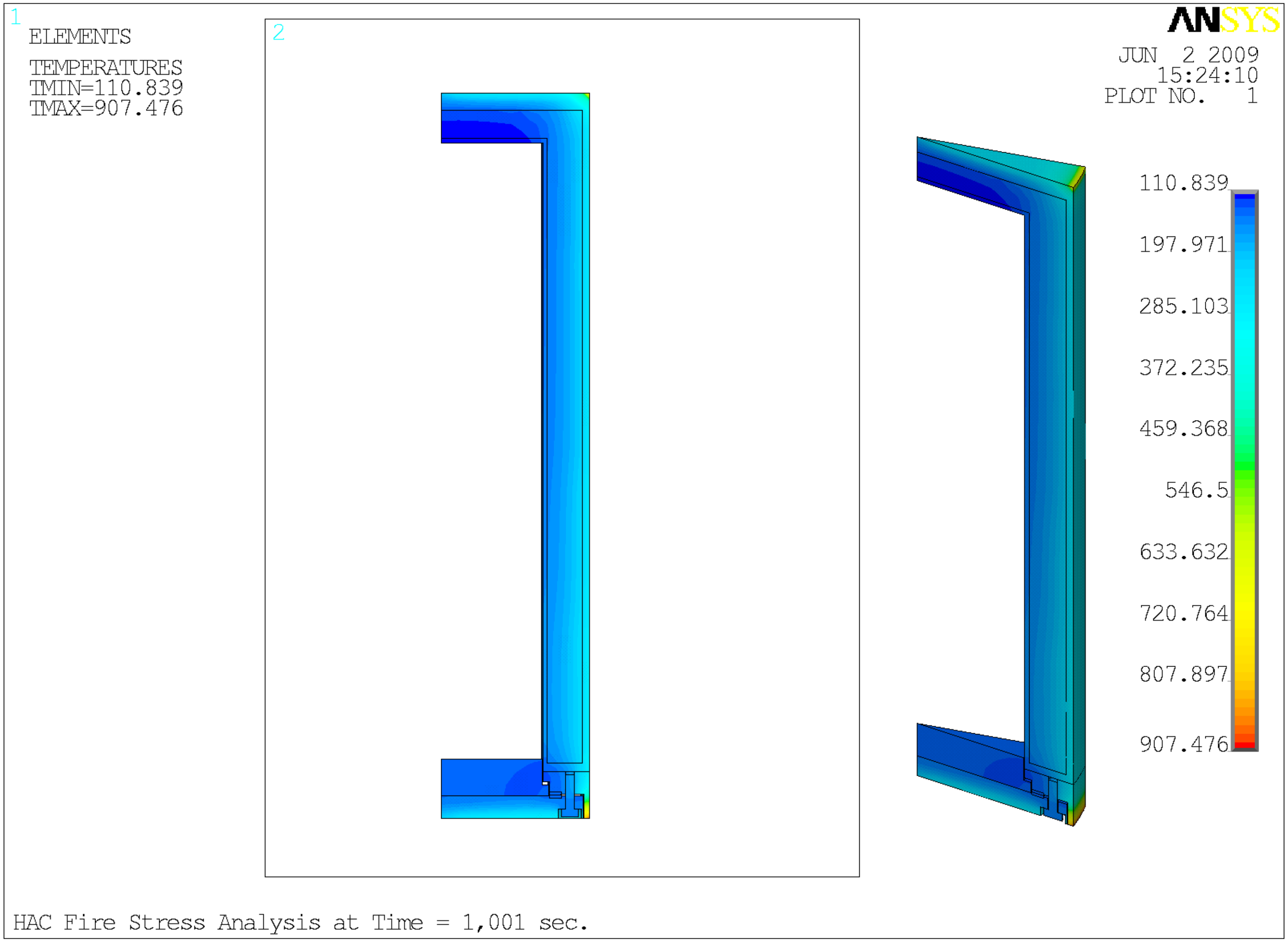

Figure 8

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

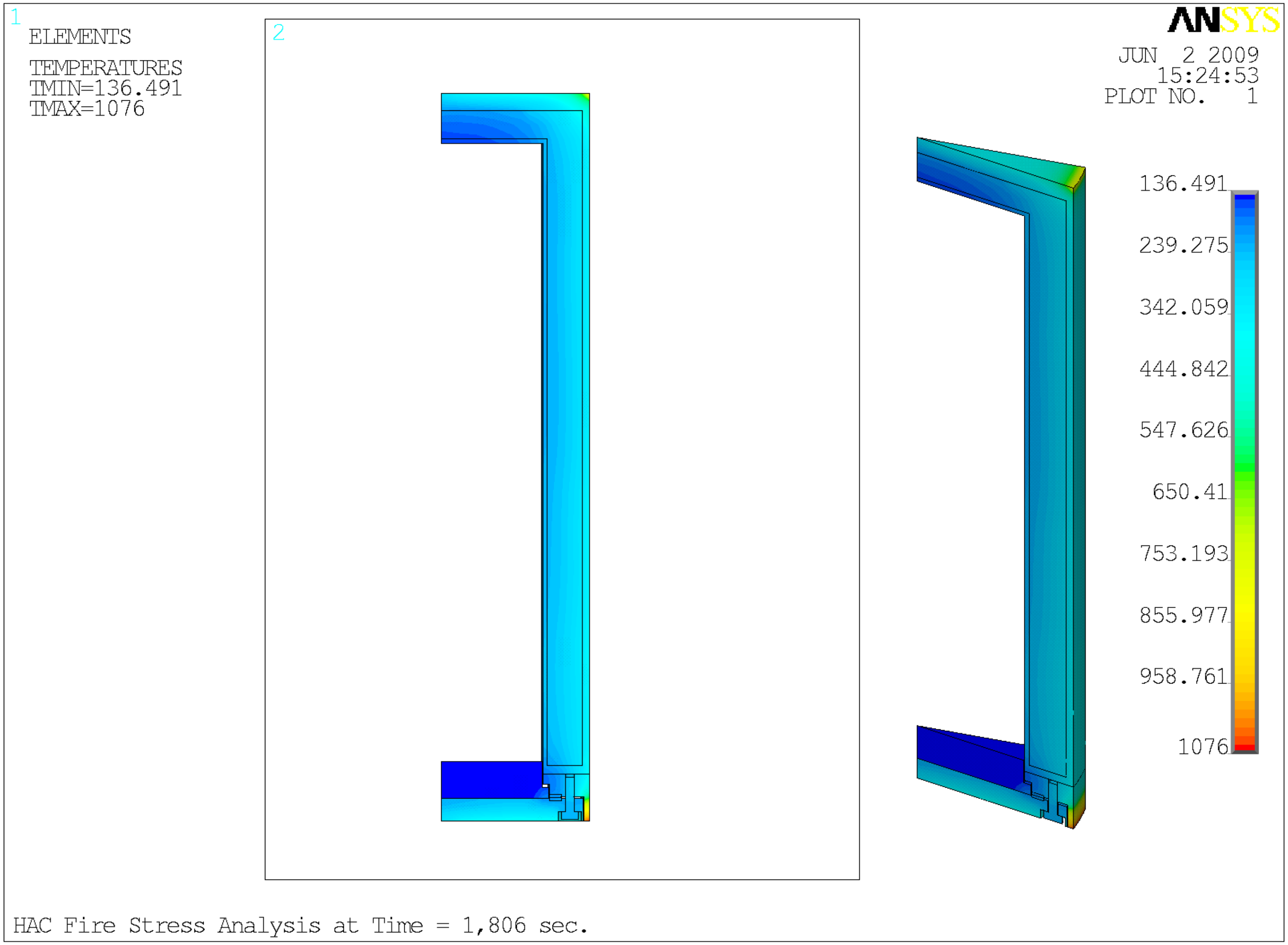

Figure 9

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

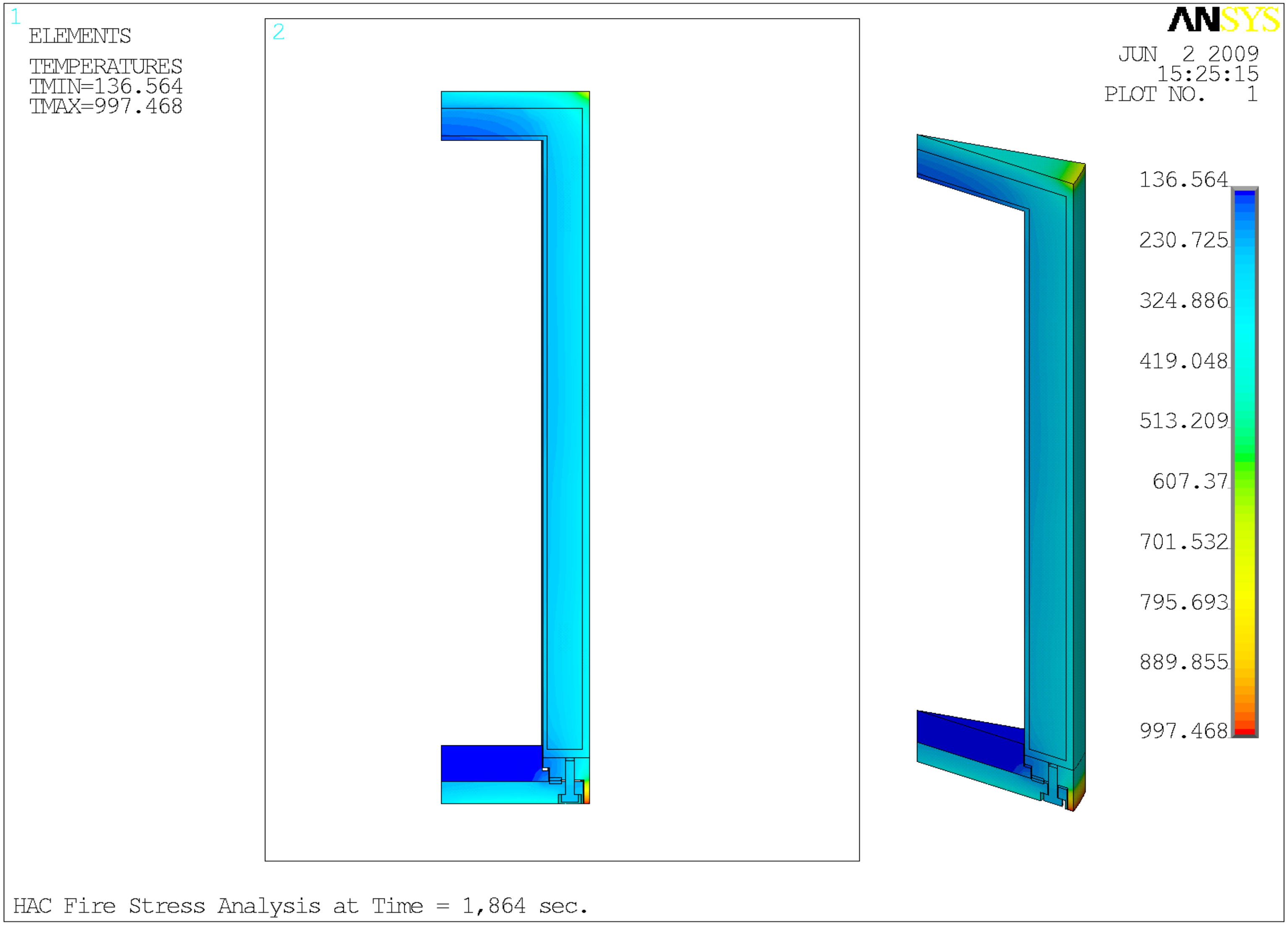

Figure 10

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

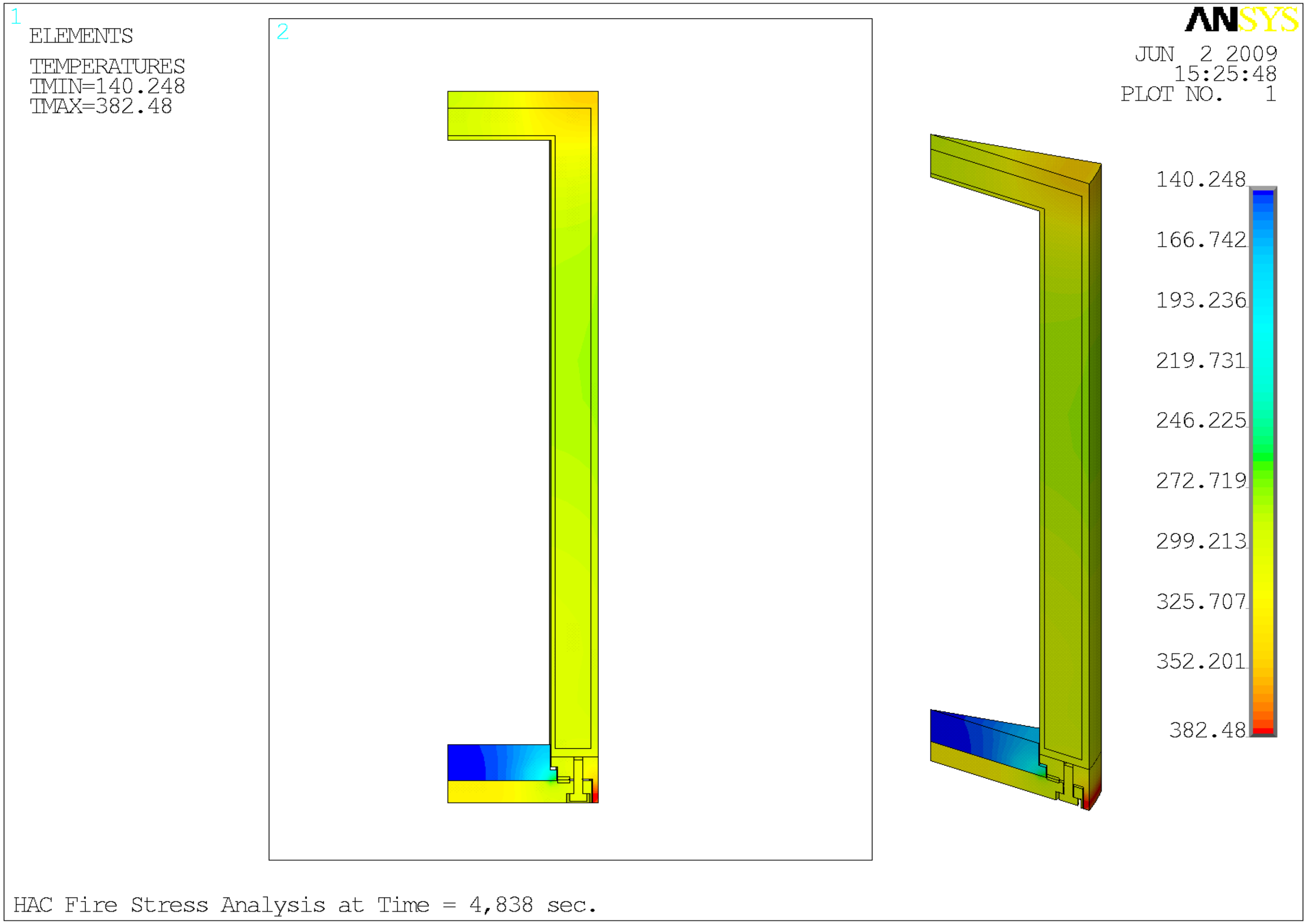

Figure 11
Temperature Profile Used for Load Step No.5 - HAC Thermal Analysis (Time = 4,838 sec)

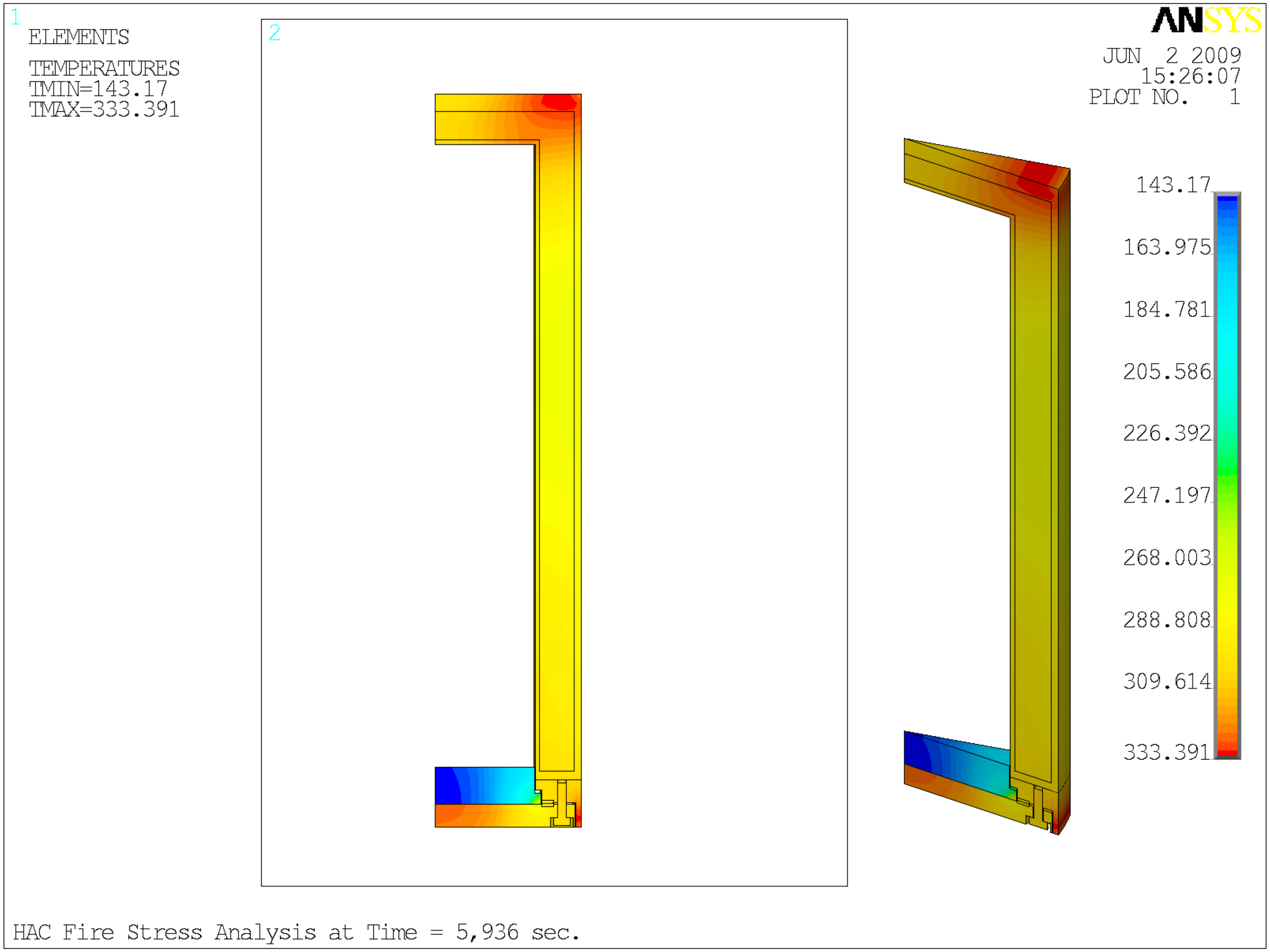

Figure 12

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

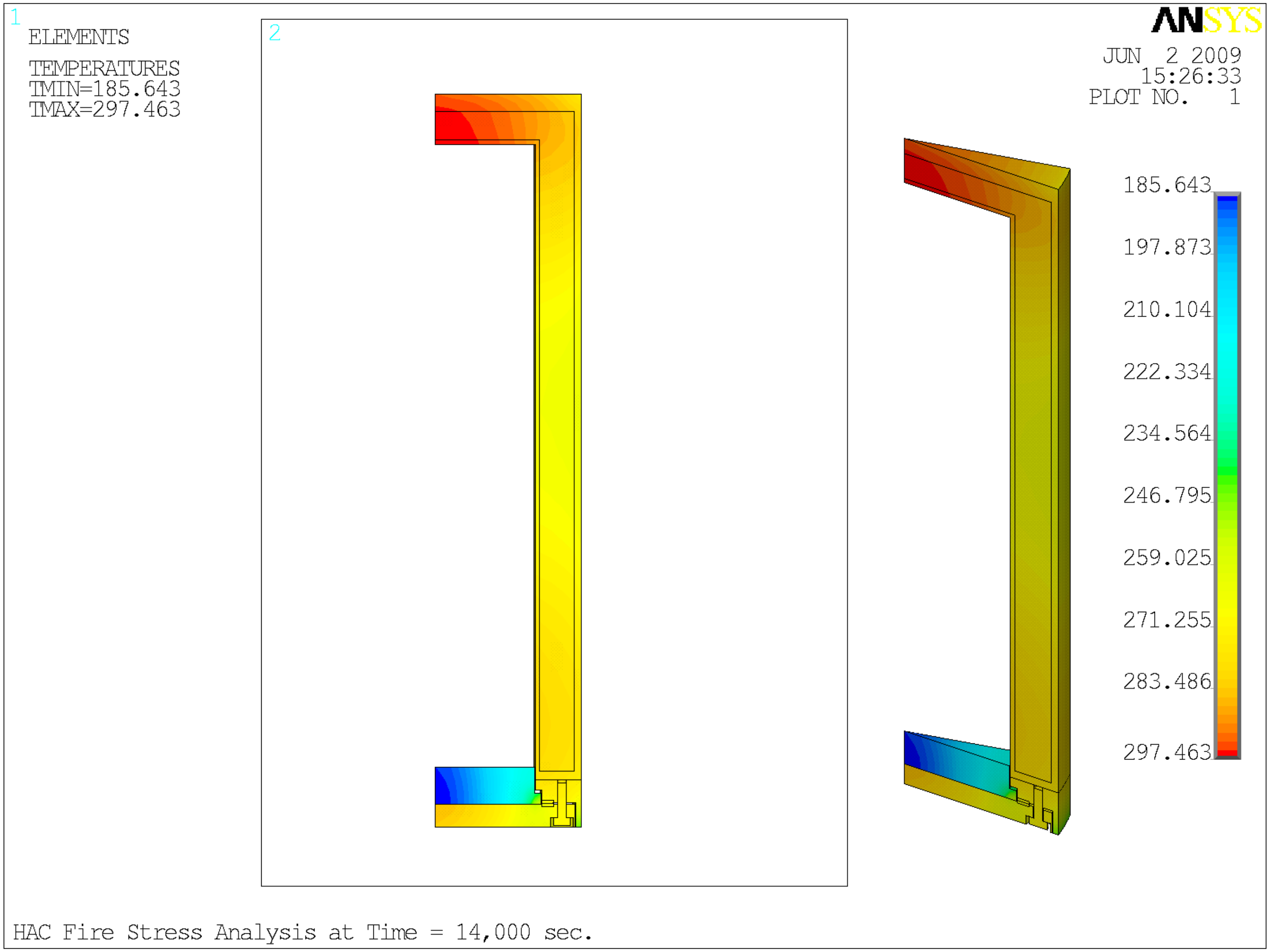

Figure 13

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

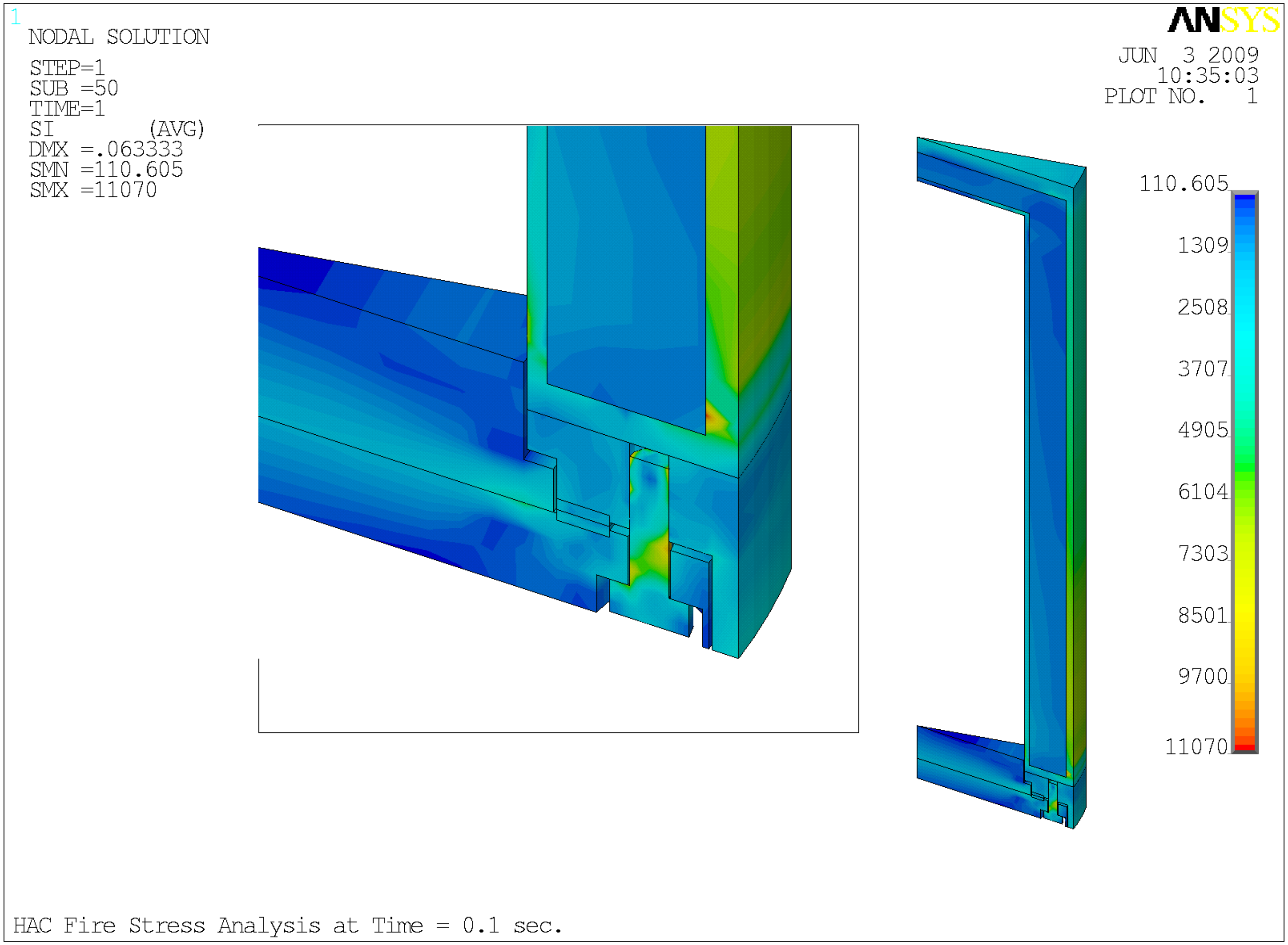

Figure 14
Stress Intensity Contour Plot Cask Body – Load Step No.1

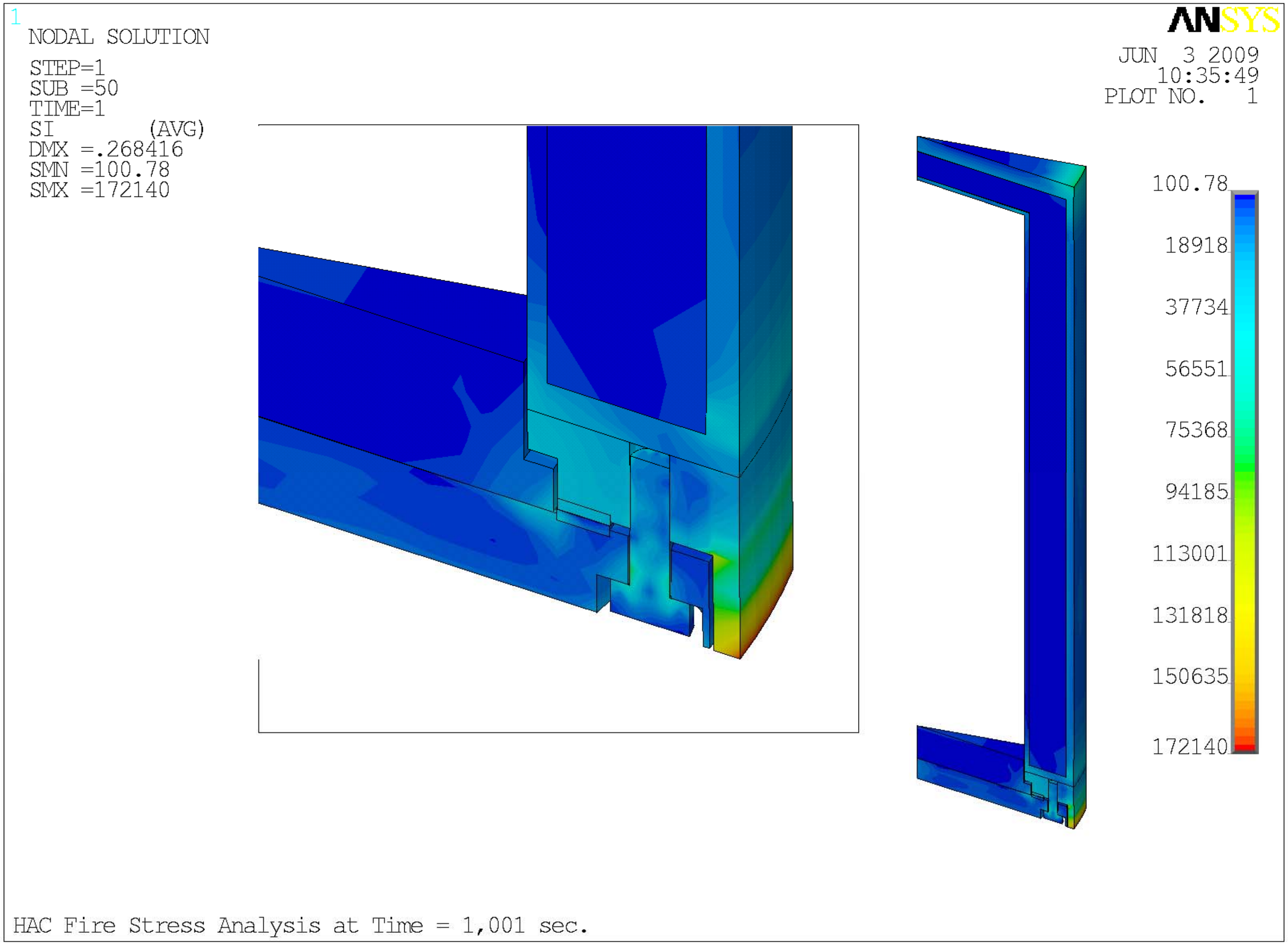

Figure 15
Stress Intensity Contour Plot Cask Body – Load Step No.2

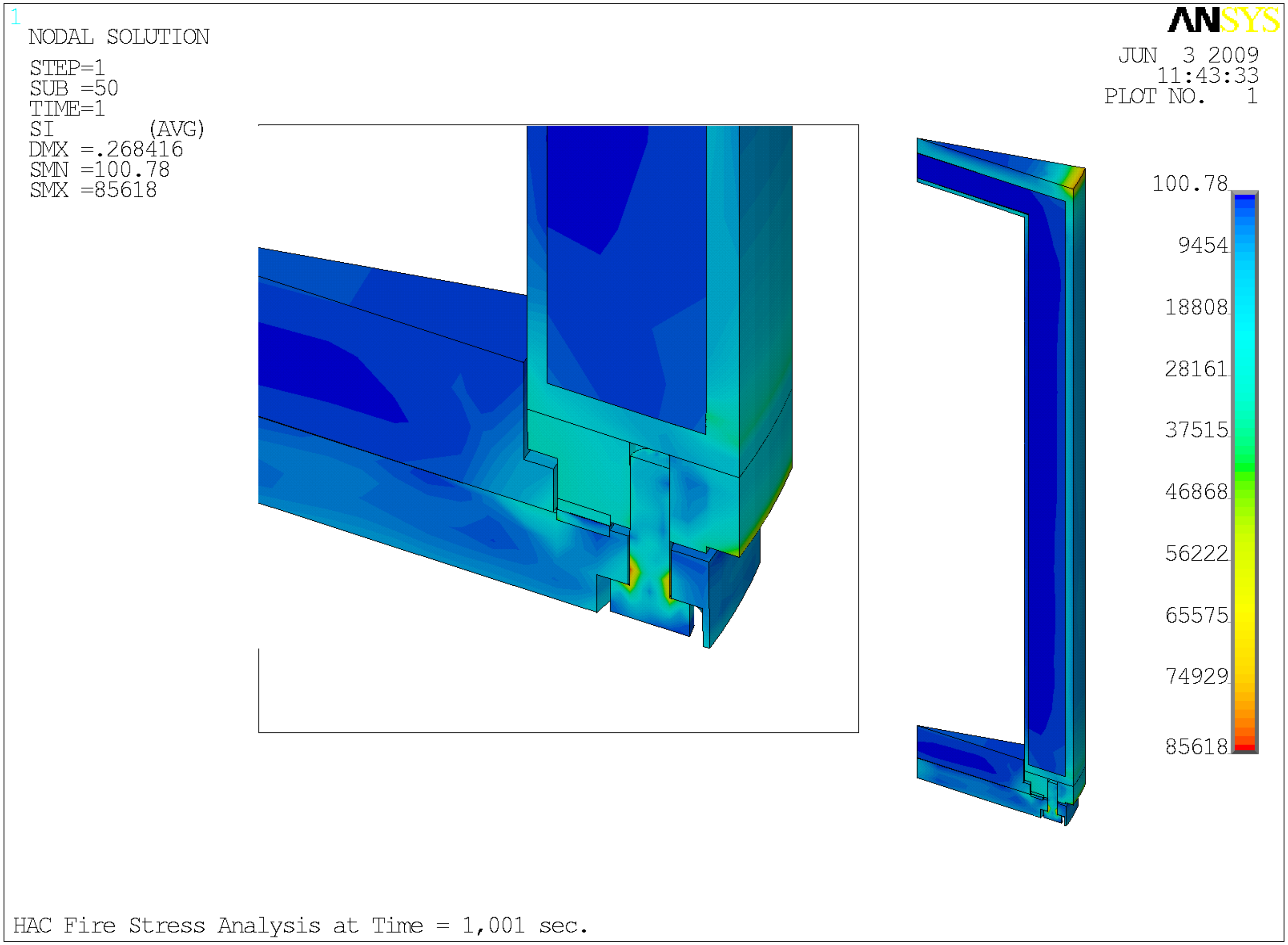

Figure 16

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

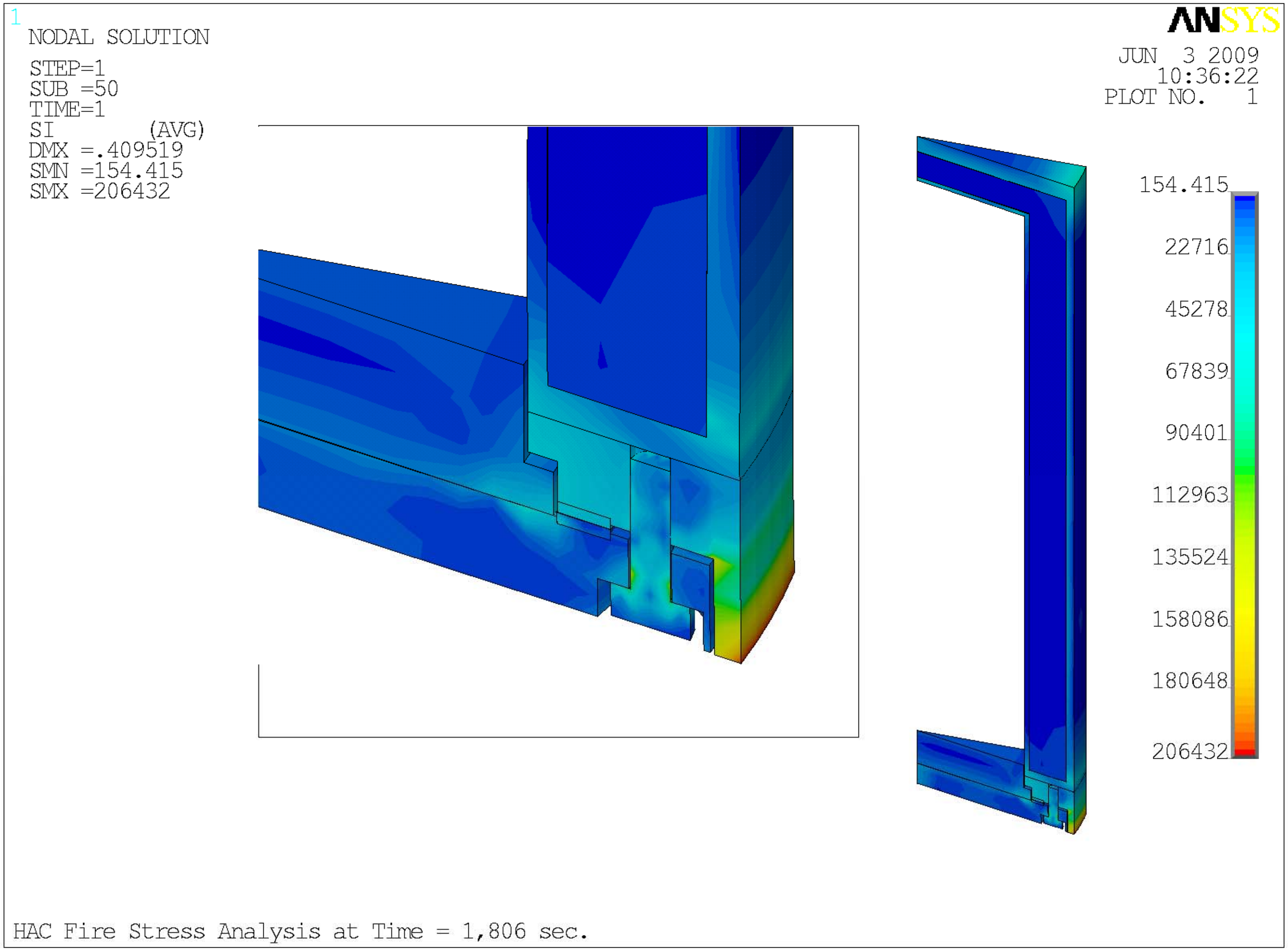

Figure 17
Stress Intensity Contour Plot Cask Body – Load Step No.3

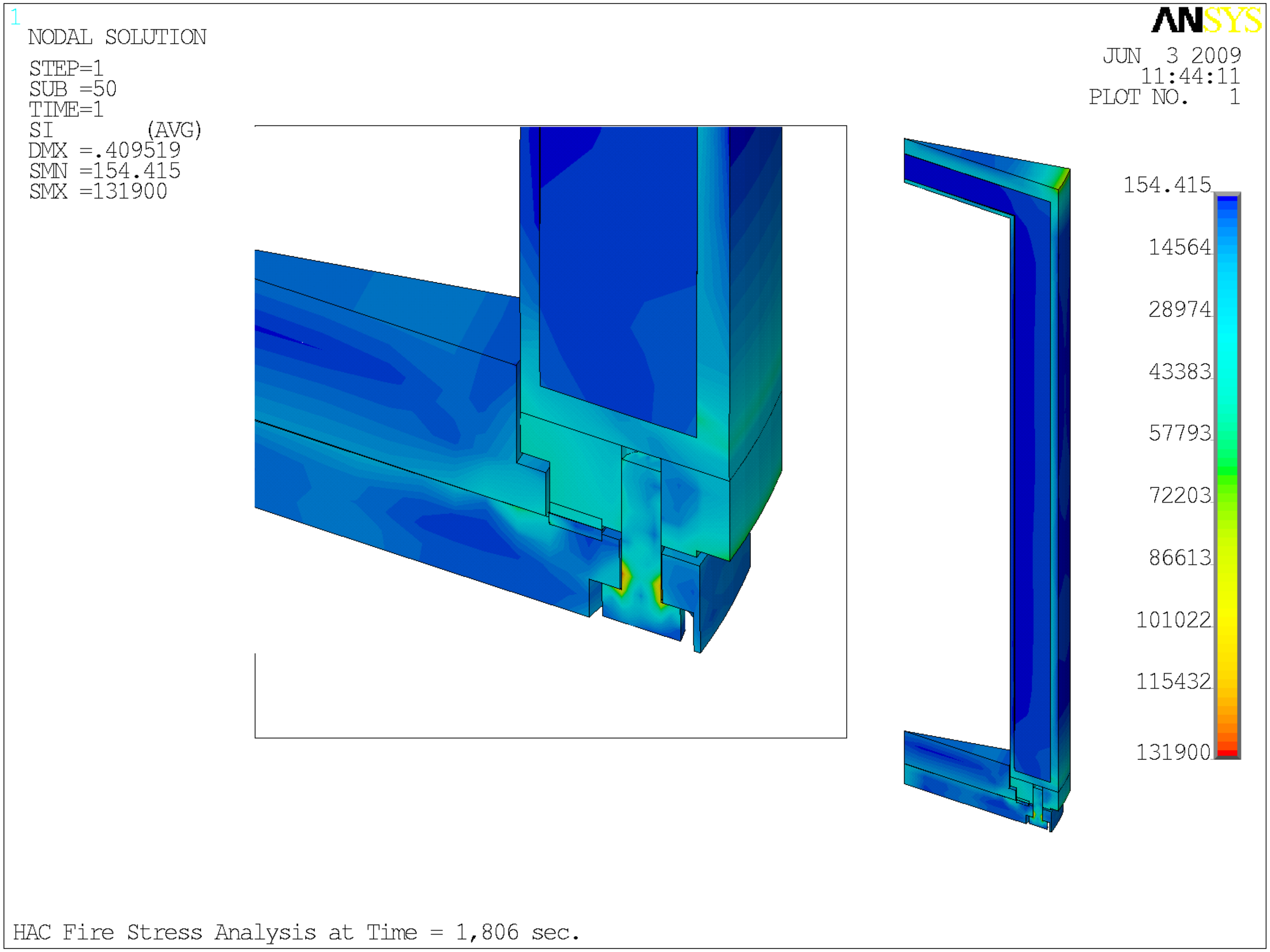

Figure 18

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

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

Calc. No. ST-502 (Figures) **Rev.** 2 **Sheet** 18 of 28

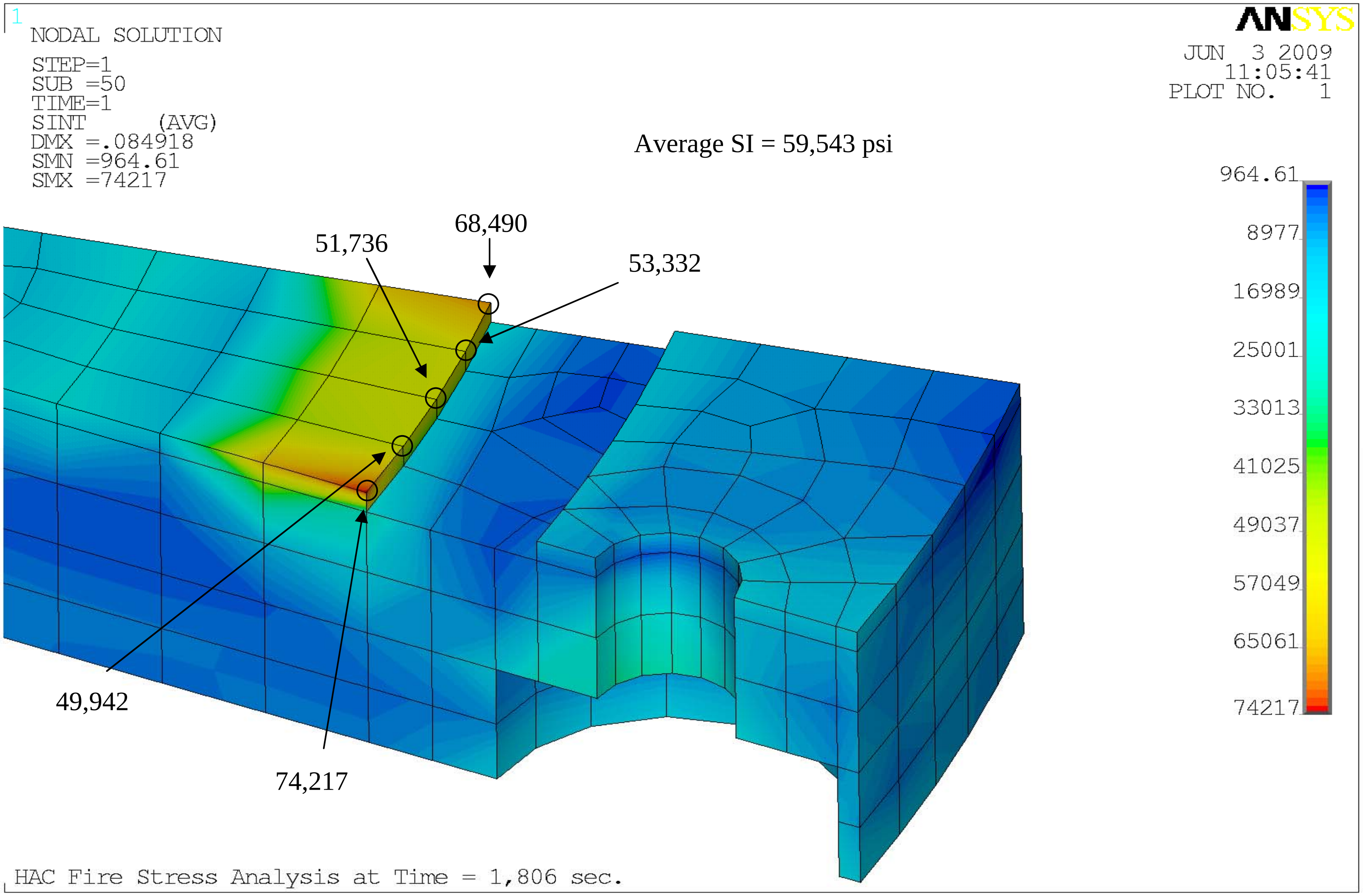

Figure 19

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

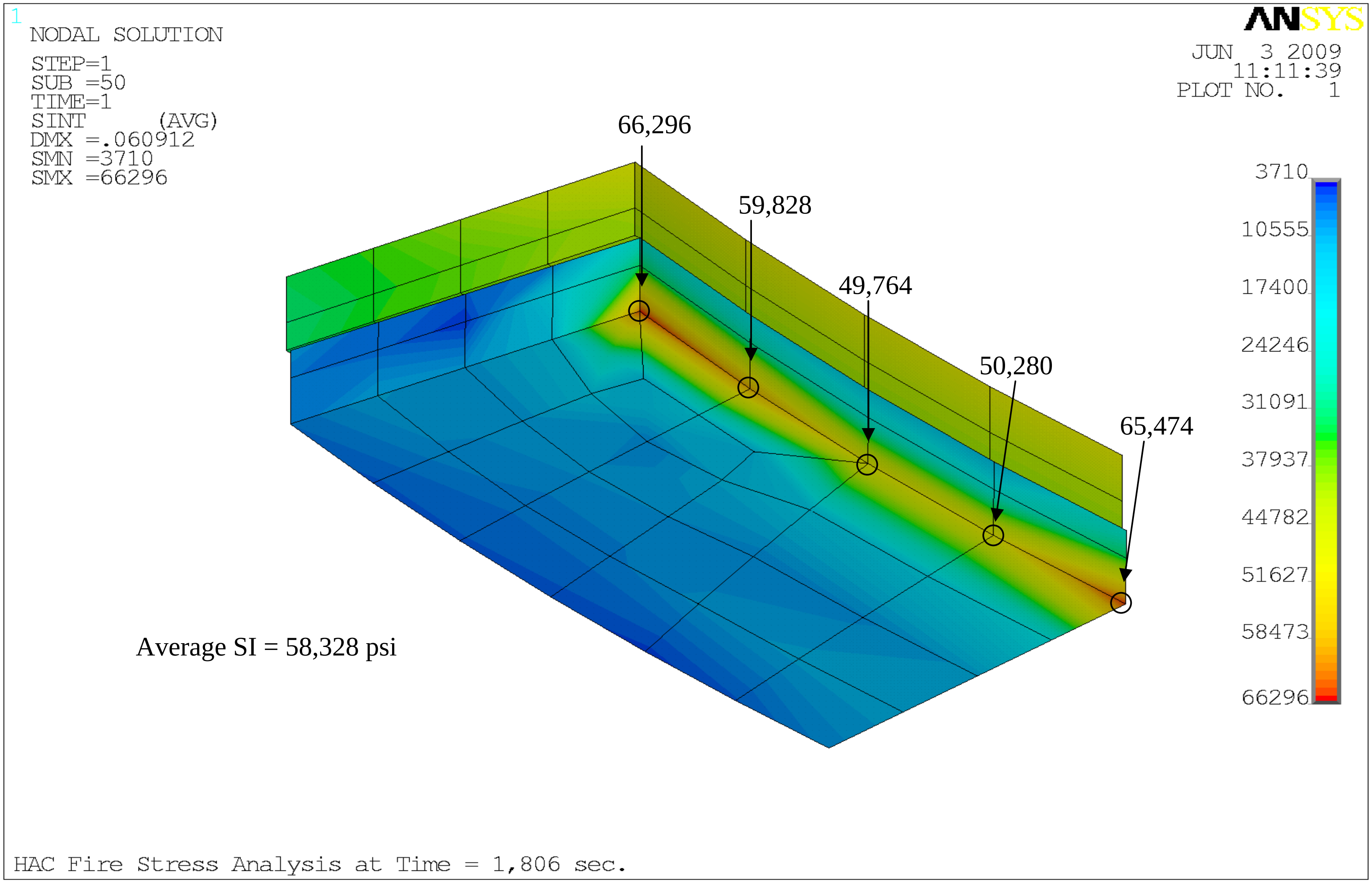

Figure 20

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

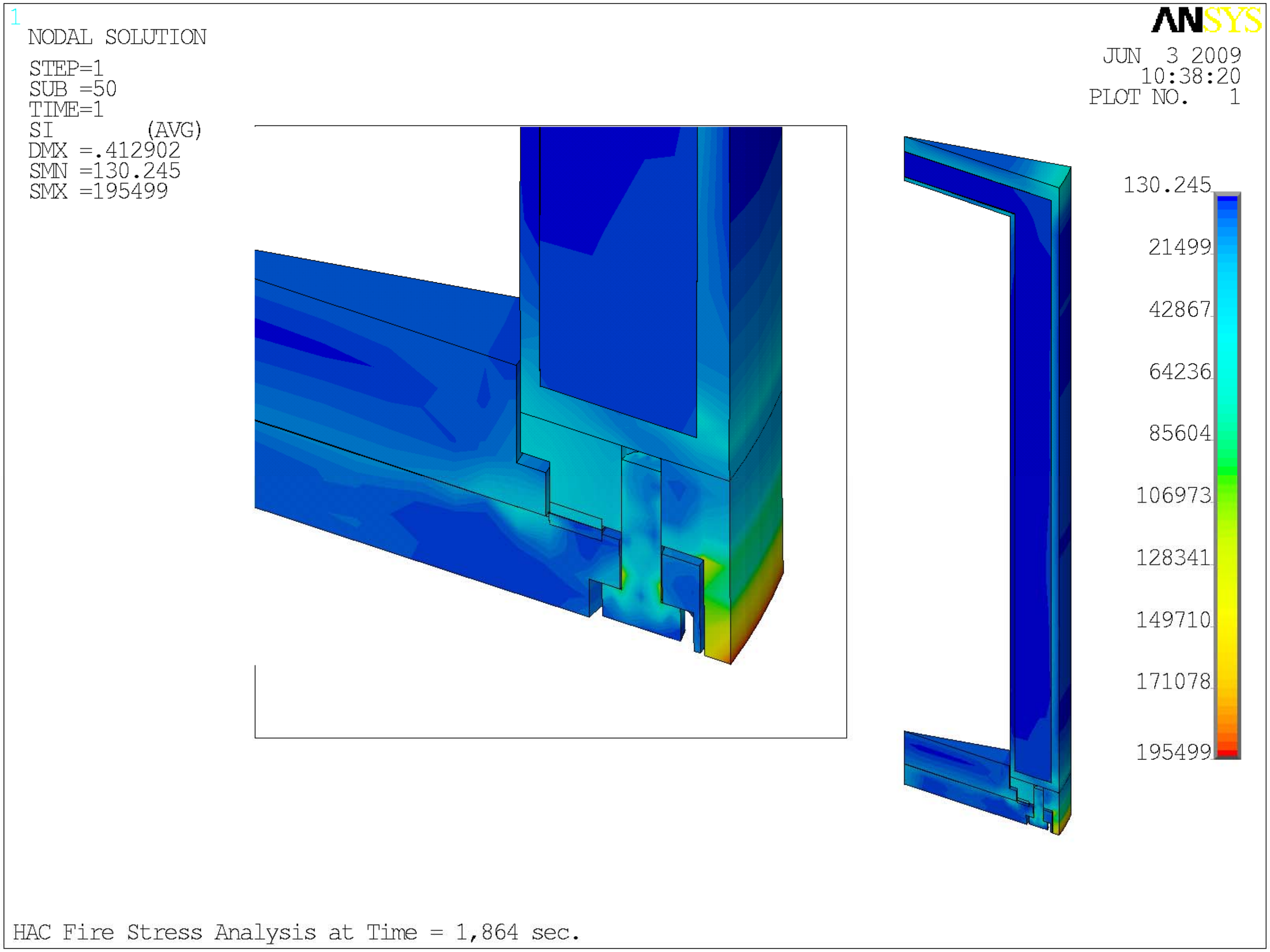

Figure 21
Stress Intensity Contour Plot – Load Step No.4

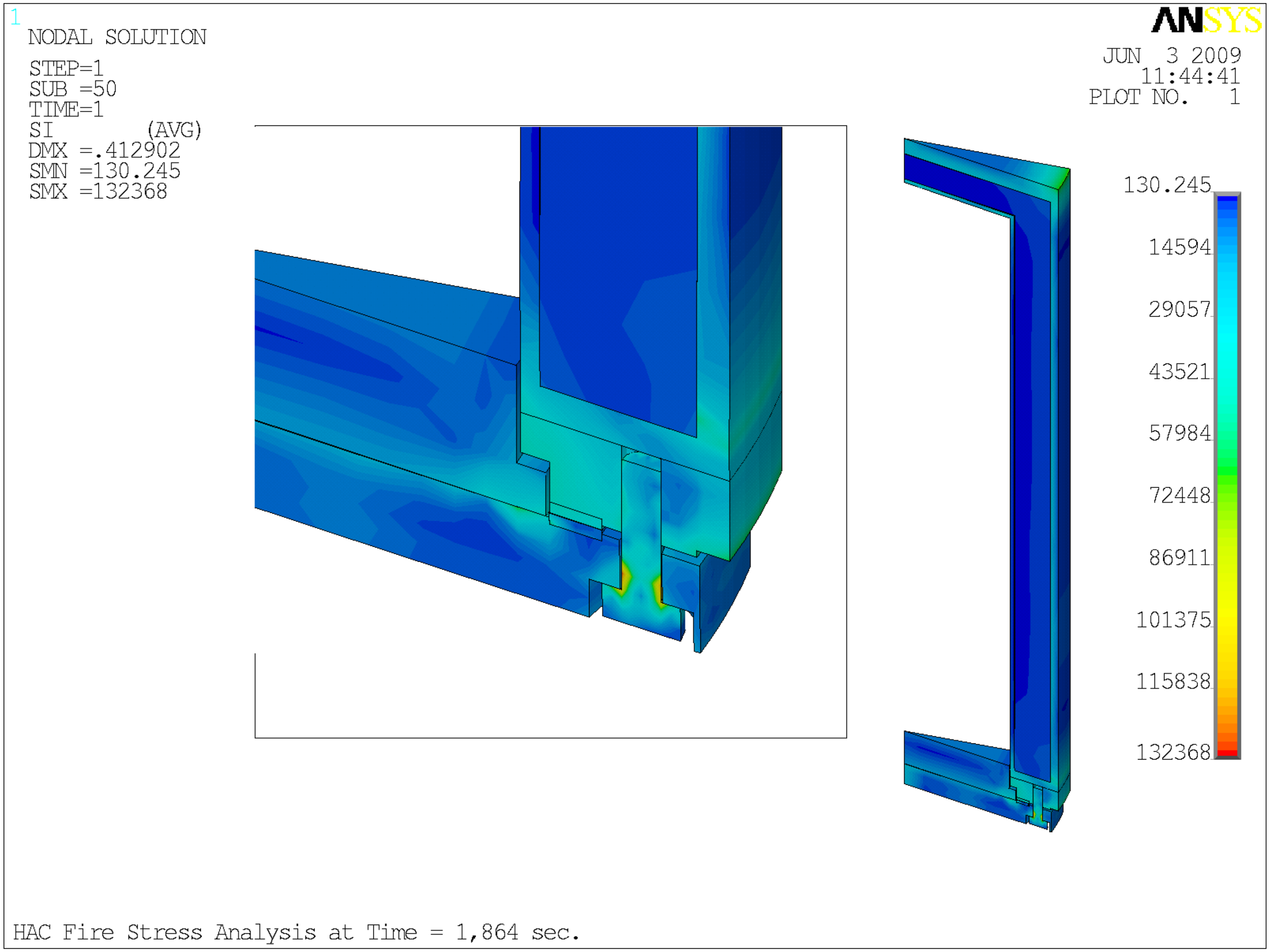

Figure 22

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

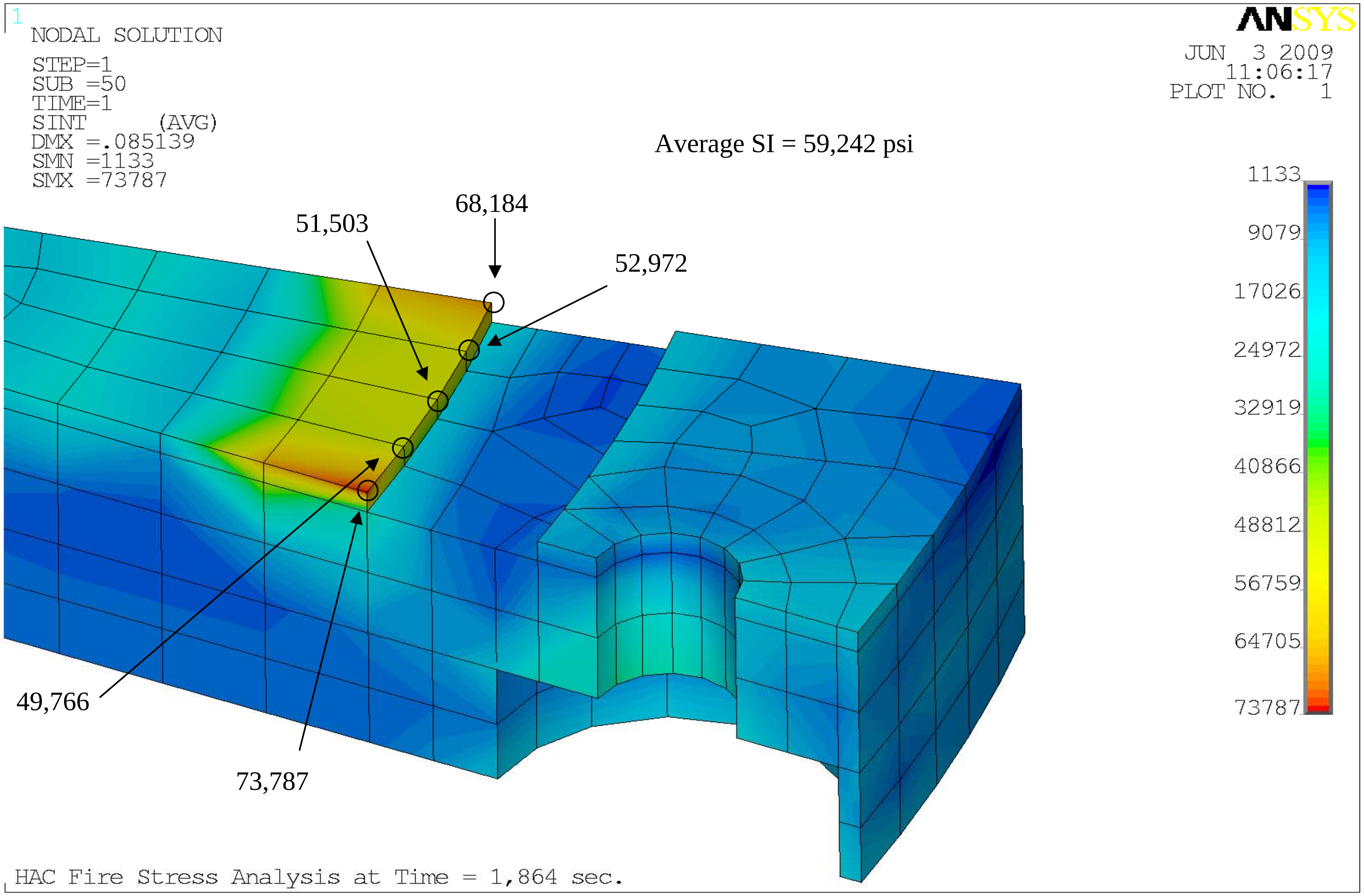

Figure 23
Stress Intensity Averaging in the Lid-Load Step No.4

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

Calc. No. ST-502 (Figures) **Rev.** 2 **Sheet** 23 of 28

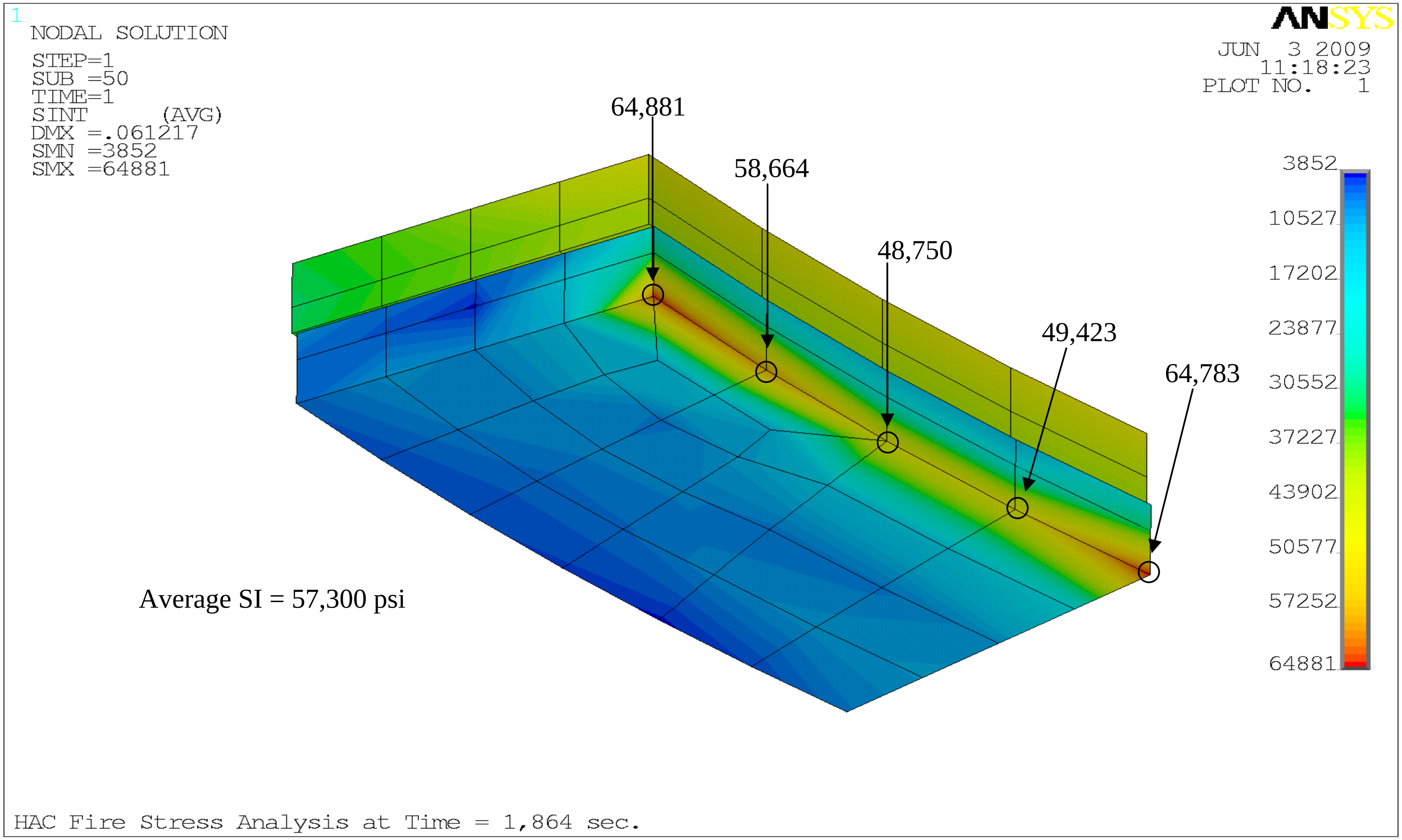

Figure 24

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

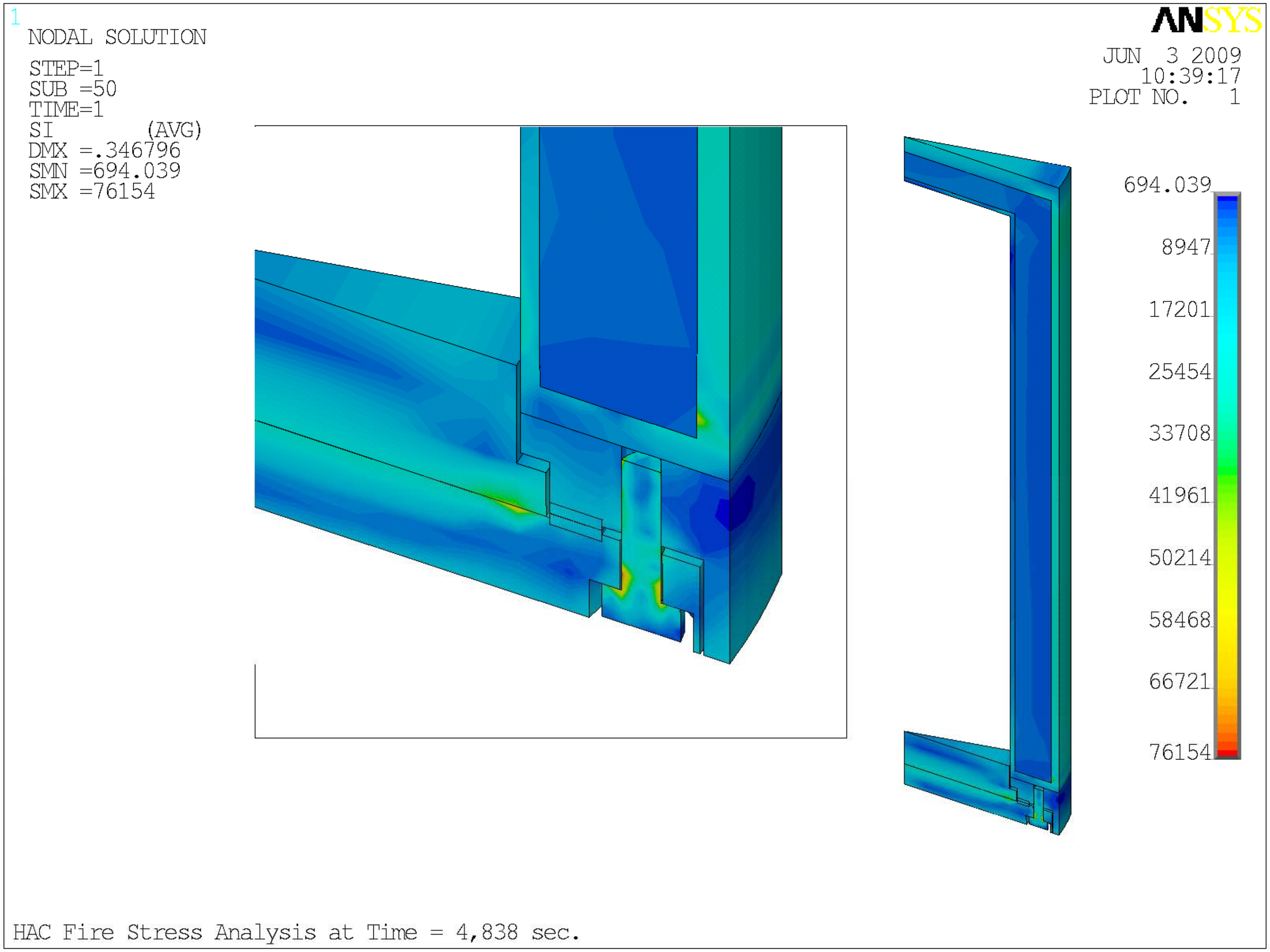

Figure 25
Stress Intensity Contour Plot – Load Step No.5

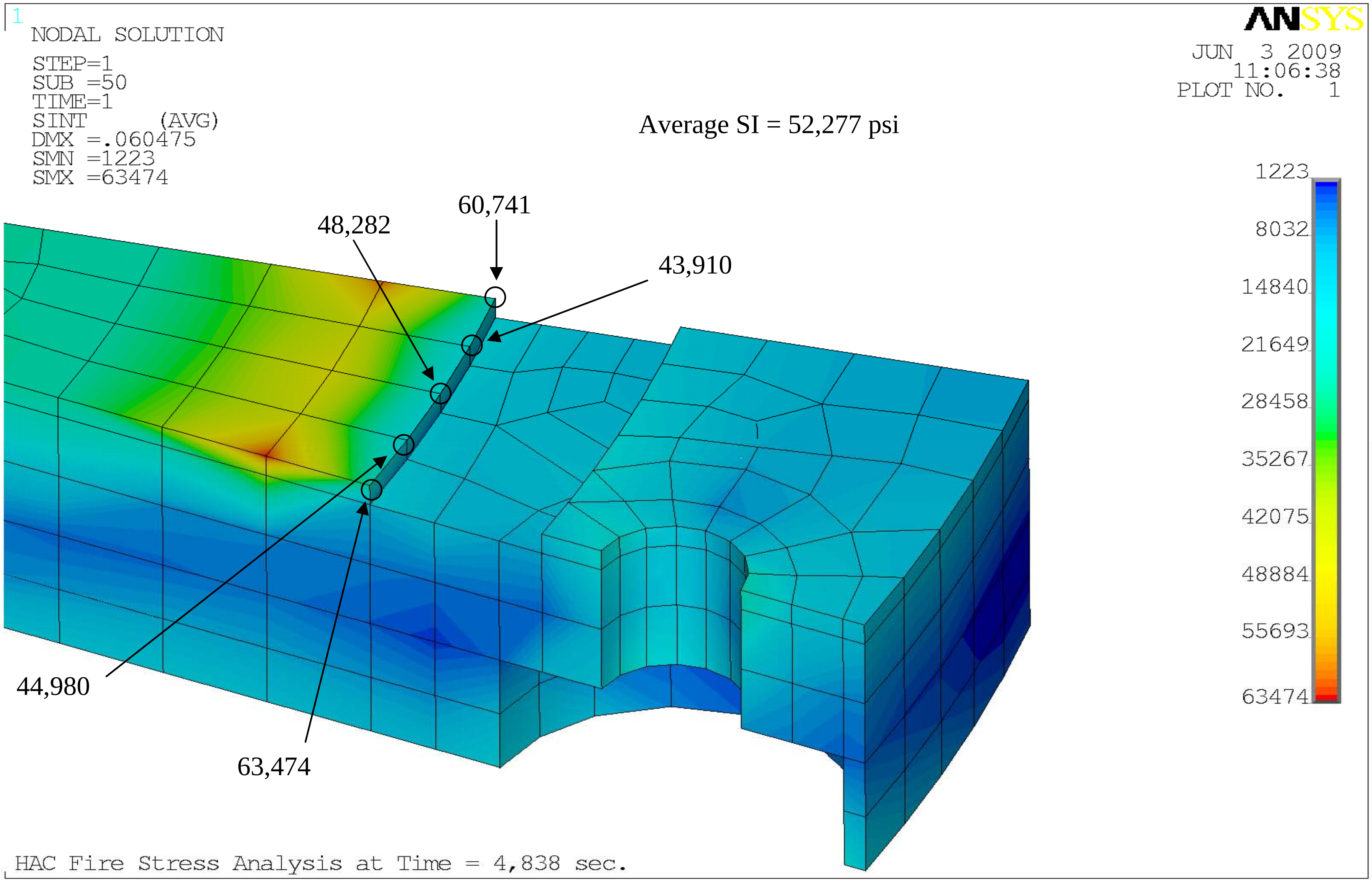

Figure 26
Stress Intensity Averaging in the Lid-Load Step No.5

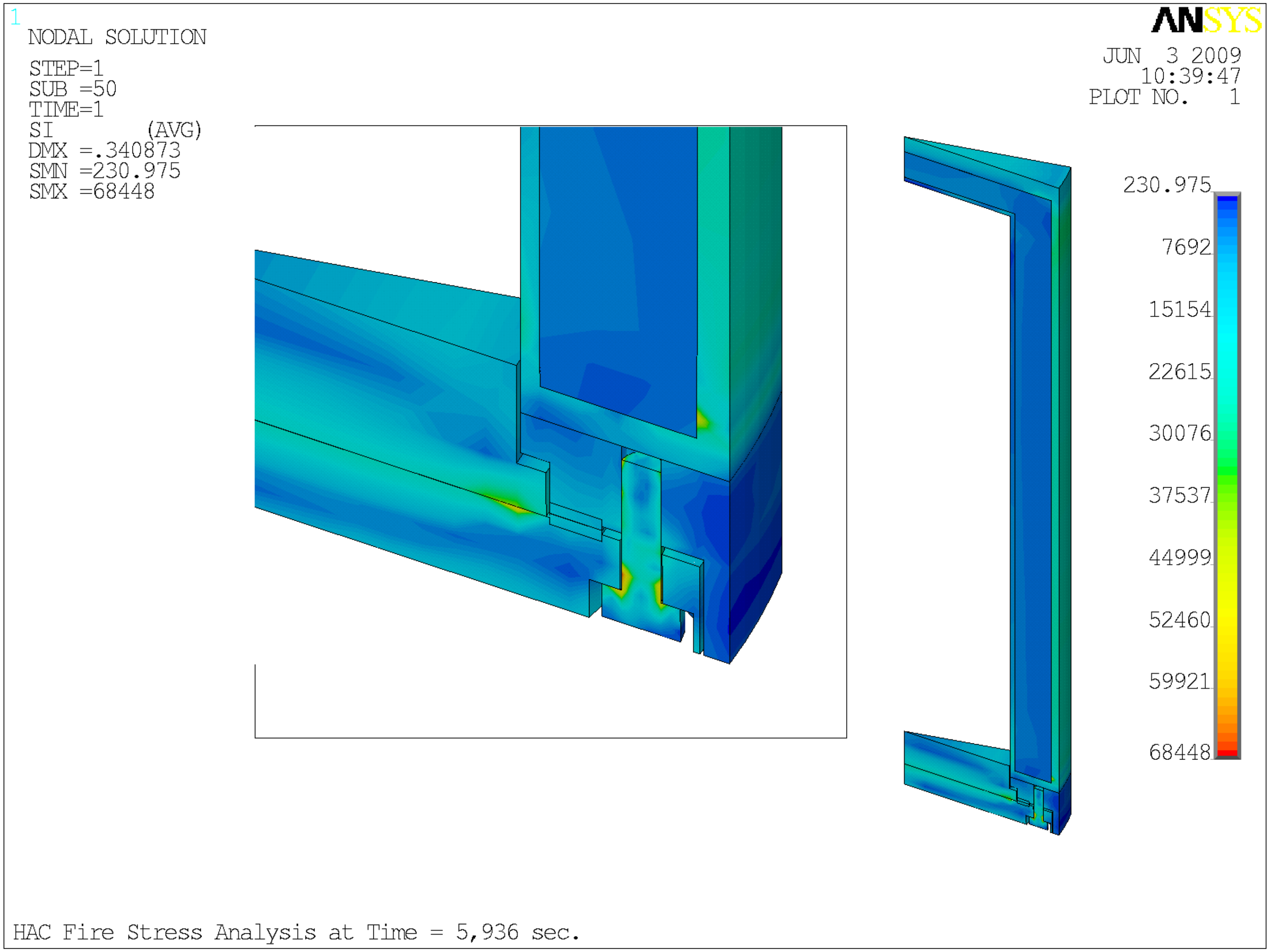

Figure 27

Stress Intensity Contour Plot – Load Step No.6

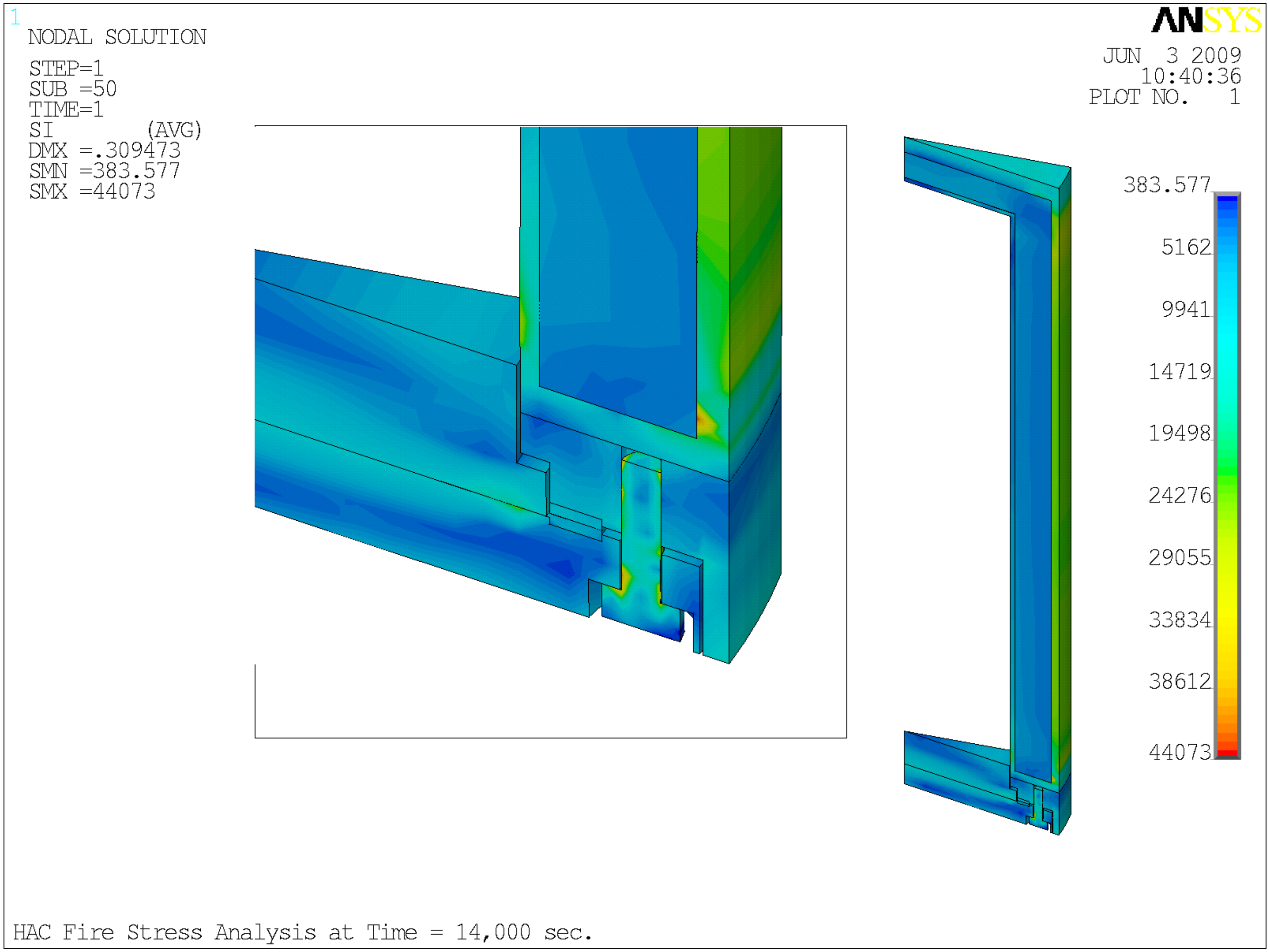

Figure 28
Stress Intensity Contour Plot – Load Step No.7

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
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```
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)

```
 Volume in drive F is ST-502 Rev.2 App2
 Volume Serial Number is A745-A81C

 Directory of F:\

06/18/2009  09:25 AM           855,975 file.cdb
01/15/2010  04:52 PM        12,386,304 file.db
06/02/2009  01:43 PM           239,097 file.s01
06/02/2009  01:43 PM           239,097 file.s02
06/02/2009  01:43 PM           239,097 file.s03
06/02/2009  01:43 PM           239,097 file.s04
06/02/2009  01:43 PM           239,097 file.s05
06/02/2009  01:43 PM           239,097 file.s06
06/02/2009  01:43 PM           239,097 file.s07
06/02/2009  02:22 PM            52,074 file000.png
06/02/2009  02:23 PM            57,572 file001.png
06/02/2009  02:24 PM            60,662 file002.png
06/02/2009  02:24 PM            64,150 file003.png
06/02/2009  02:25 PM            65,786 file004.png
06/02/2009  02:25 PM            58,240 file005.png
06/02/2009  02:26 PM            59,590 file006.png
06/02/2009  02:26 PM            62,057 file007.png
06/03/2009  09:35 AM           157,354 file008.png
06/03/2009  09:35 AM           125,648 file009.png
06/03/2009  09:36 AM           135,501 file010.png
06/03/2009  09:38 AM           137,430 file011.png
06/03/2009  09:39 AM           159,949 file012.png
06/03/2009  09:39 AM           161,291 file013.png
06/03/2009  09:40 AM           172,836 file014.png
06/03/2009  10:05 AM           184,387 file015.png
06/03/2009  10:06 AM           180,663 file016.png
06/03/2009  10:06 AM           181,159 file017.png
06/03/2009  10:11 AM           150,091 file018.png
06/03/2009  10:18 AM           150,870 file019.png
06/03/2009  10:43 AM           140,190 file020.png
06/03/2009  10:44 AM           144,929 file021.png
06/03/2009  10:44 AM           143,369 file022.png
06/02/2009  01:47 PM       134,152,192 ls1.rst
06/02/2009  02:04 PM           283,759 ls1post.out
06/02/2009  01:49 PM       130,088,960 ls2.rst
06/02/2009  02:04 PM           283,531 ls2post.out
06/02/2009  01:52 PM       130,547,712 ls3.rst
06/02/2009  02:04 PM           283,531 ls3post.out
06/02/2009  01:55 PM       130,547,712 ls4.rst
06/02/2009  02:04 PM           283,531 ls4post.out
06/02/2009  01:58 PM       133,365,760 ls5.rst
06/02/2009  02:04 PM           283,531 ls5post.out
06/02/2009  02:00 PM       133,431,296 ls6.rst
06/02/2009  02:04 PM           283,531 ls6post.out
06/02/2009  02:03 PM       133,627,904 ls7.rst
06/02/2009  02:13 PM           292,416 ls7post.out
06/17/2009  10:50 AM           144,570 model.out
01/15/2010  04:51 PM            19,680 summary-fire.in
01/15/2010  04:51 PM             5,558 summary.out
              49 File(s)    945,646,930 bytes

     Total Files Listed:
              49 File(s)    945,646,930 bytes
               0 Dir(s)               0 bytes free
```

1.0 OBJECTIVE

Perform the buckling evaluation of the 3-60B Cask under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) loading using the ASME Boiler and Pressure Vessel Code Case N-284.

2.0 INTRODUCTION

The buckling evaluation of the 3-60B Cask is performed on the ASME Boiler & Pressure Vessel Code Case N-284 (Reference 1) criteria. The buckling requirement of Paragraph C.5 of Regulatory Guide 7.6 (Reference 2) ("buckling should not occur as the result of any normal or accident condition loading") are satisfied by demonstrating that the 3-60B Cask meets the requirements of this Code Case. Consistent with Regulatory Guide 7.6 philosophy, the NCT is considered to be the ASME Service Level A condition; and HAC is considered to be Service Level D condition.

The most vulnerable component of the 3-60B Cask for buckling is its inner shell since it is the thinnest component and is subjected to both axial and hoop compressions. The axial compressive stress in this shell arises from the end and corner drops and the hoop compression occurs due to shrinkage of the lead over the inner shell in the cold environment. In order to obtain the maximum components of these stresses, all the loading combinations are examined. The NCT and HAC drop analyses performed under various environmental conditions in Reference 3 have been used to obtain the stress components needed for the evaluation of the shell buckling. The maximum components of axial compression, hoop compression, and the in-plane shear stress for various loading obtained from Reference 3 analyses are summarized in Table 1. Conservatively, the largest value of each component is assumed to occur concurrently and they have been used for the NCT and HAC condition's evaluation.

3.0 REFERENCES

(1) American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section III, Division 1, Class MC, Code Case N-284, Metal Containment Shell Buckling Design Method, August 25, 1980.

(2) U.S.N.R.C. Regulatory Guide 7.6, Design Criteria for the Structural Analysis of Shipping Package Containment Vessel, Revision 1, March 1978.

(3) Energy*Solutions* Document No. ST-504, Rev.1, Structural Analyses of the 3-60B Cask under Drop Conditions.

4.0 CODE CASE EVALUATION PROCESS

ASME Code Case N-284 addresses both elastic and inelastic buckling and employs a factor of safety of 2.0 for service Level A (NCT) and 1.34 for service Level D (HAC). Interaction equations are employed which account for the effect of combined axial compressive, hoop compressive, and in-plane shear loadings. The basic analytical approach is summarized as follows:

1. Theoretical elastic buckling stresses are determined using classical theory.

2. Capacity reduction factors are applied which account for the difference between classical theory and predicted instability stresses for fabricated shells.
3. Plasticity reduction factors are applied for those cases where elastically determined buckling stresses are above the proportional limit.
4. Elastic and inelastic buckling checks which employ appropriate factors of safety and appropriate interaction equations are made using worst case applied compressive and in-plane shear stresses.

All terminology used herein is consistent with that in ASME Code Case N-284.

4.1 Theoretical Elastic Buckling Stresses

a) Axial compression

The theoretical axial buckling stress ($\sigma_{\phi eL}$) is:

$$\sigma_{\phi eL} = C_{\phi} \frac{Et}{R}$$

where,

$$C_{\phi} = \frac{0.904}{M_{\phi}^{2}} + (0.1013)M_{\phi}^{2} \quad \text{if } 1.5 \le M_{\phi} \le 1.73$$

$$C_{\phi} = 0.605 \quad \text{if } M_{\phi} \ge 1.73$$

b) Hoop Compression

i) No End Pressure

The theoretical hoop buckling stress ($\sigma_{\theta eL}$) is:

$$\sigma_{\theta eL} = \sigma_{reL} = C_{\theta r} \frac{Et}{R}$$

where,

$$C_{\theta r} = \frac{2.41}{M_{\phi}^{1.49} - 0.338} \quad \text{if } 1.5 \le M_{\phi} < 3.0$$

$$C_{\theta r} = \frac{0.92}{M_{\phi} - 1.17} \quad \text{if } 3.0 \le M_{\phi} < (1.65)(R/t)$$

$$C_{\theta r} = (0.275)\left(\frac{t}{R}\right) + \left(\frac{2.1}{M_{\phi}^{4}}\right)\left(\frac{R}{t}\right)^{3} \quad \text{if } M_{\phi} \ge (1.65)(R/t)$$

ii) End Pressure Included

The theoretical hoop buckling stress ($\sigma_{\theta eL}$) is:

$$\sigma_{\theta eL} = \sigma_{heL} = C_{\theta h} \frac{Et}{R}$$

where,

$$C_{\theta h} = \frac{1.08}{M_{\phi}^{1.07} - 0.45} \qquad \text{if } 1.5 \le M_{\phi} < 3.0$$

$$C_{\theta h} = \frac{0.92}{M_{\phi} - 0.636} \qquad \text{if } 3.0 \le M_{\phi} < (1.65)(R/t)$$

$$C_{\theta h} = (0.275)\left(\frac{t}{R}\right) + \left(\frac{2.1}{M_{\phi}^{4}}\right)\left(\frac{R}{t}\right)^{3} \qquad \text{if } M_{\phi} \ge (1.65)(R/t)$$

c) <u>In-Plane Shear</u>

The theoretical in-plane shear buckling stress, $\sigma_{\phi\theta eL}$, is:

$$\sigma_{\phi\theta eL} = C_{\phi\theta} \frac{Et}{R}$$

where,

$$C_{\phi\theta} = \left(\frac{4.82}{M_{\phi}^{2}}\right)\sqrt{1 + (0.0239)M_{\phi}^{3}} \qquad \text{if } 1.5 \le M_{\phi} < 26$$

$$C_{\phi\theta} = \frac{0.746}{\sqrt{M_{\phi}}} \qquad \text{if } 26 \le M_{\phi} < (8.69)(R/t)$$

$$C_{\phi\theta} = 0.253\sqrt{\frac{t}{R}} \qquad \text{if } M_{\phi} \ge (8.69)(R/t)$$

4.2 <u>Capacity Reduction Factors</u>

a) <u>For Axial Compression</u>, the larger of (i) or (ii) is used:

i) <u>Effect of R/t</u>:

$$\alpha_{\phi L} = 0.207 \qquad \text{if } R/t \ge 600$$

$$\left.\begin{aligned} \alpha_{\phi L} &= 1.52 - (0.473)\log_{10}(R/t) \\ \alpha_{\phi L} &= (10^{-5})\sigma_{y} - 0.033 \end{aligned}\right\} \quad \text{if } R/t < 600 \text{ (use smaller value)}$$

ii) <u>Effect of Length</u>

$$\alpha_{\phi L} = 0.837 - (0.14)M \qquad \text{if } 1.5 \le M < 1.73$$

$$\alpha_{\phi L} = \frac{0.837}{M^{0.6}} \quad \text{if } 1.73 \le M < 10$$

$$\alpha_{\phi L} = 0.207 \quad \text{if } M \ge 10$$

b) For Hoop Compression

$$\alpha_{\theta L} = 0.8$$

c) For Shear:

$$\alpha_{\phi\theta L} = 0.8 \quad \text{if } R/t \le 250$$

$$\alpha_{\phi\theta L} = 1.323 - (0.218)\log_{10}(R/t) \quad \text{if } 250 < R/t < 1000$$

4.3 Plasticity Reduction Factors

a) For Axial Compression

$$\eta_\theta = 1.0 \quad \text{if } \sigma_\phi (FS)/\sigma_y \le 0.55$$

$$\eta_\phi = \frac{0.18}{1 - \dfrac{(0.45)\sigma_y}{(FS)\sigma_\phi}} \quad \text{if } 0.55 < \sigma_\phi (FS)/\sigma_y \le 0.738$$

$$\eta_\phi = 1.31 - \frac{(1.15)\sigma_\phi (FS)}{\sigma_y} \quad \text{if } 0.738 < \sigma_\phi (FS)/\sigma_y \le 1.0$$

b) For Hoop Compression

$$\eta_\theta = 1.0 \quad \text{if } \sigma_\theta (FS)/\sigma_y \le 0.67$$

$$\eta_\theta = 2.53 - \frac{(2.29)\sigma_\theta (FS)}{\sigma_y} \quad \text{if } 0.67 < \sigma_\theta (FS)/\sigma_y \le 1.0$$

c) For Shear

$$\eta_{\phi\theta} = 1.0 \quad \text{if } \sigma_{\phi\theta} (FS)/\sigma_y \le 0.48$$

$$\eta_{\phi\theta} = \frac{0.1}{1 - \dfrac{(0.43)\sigma_y}{(FS)\sigma_{\phi\theta}}} \quad \text{if } 0.48 < \sigma_{\phi\theta} (FS)/\sigma_y \le 0.6$$

4.4 Interaction Equations

Elastic and inelastic equations must be satisfied for all states of compressive and in-plane shear stresses. The interaction equations for cylindrical shells obtained from Code Case N-284 are as follows:

Elastic Buckling (Paragraph--1713.1.1 of the Code Case)

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \frac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \geq \frac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \frac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \frac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \leq 1.0$$

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

Inelastic Buckling (Paragraph—1713.2.1 of the Code Case)

a) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \leq 1.0$$

b) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \leq 1.0$$

c) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

d) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

5.0 EVALUATION OF THE 3-60B CASK INNER SHELL

The inner shell of the 3-60B cask is made of A-240 Gr. 45 (UNS S30815) material for which the mechanical properties versus temperature are listed in Reference xx, Table xx). Since the largest compressive loading on the shell occurs in the cold environment, its mechanical properties at the lowest shell temperature (i.e. -20ºF) are used for the buckling evaluation. Also, since the largest stress occur under the dynamic loading conditions; the yield stress of the material has been increased by a factor of 1.33.

R = Mean radius of the shell = 17.875 in

t = Thickness of the shell = 0.75 in

l_φ = Length of the shell = 110 in

E = Modulus of elasticity = 28×10^6 psi (see Material Properties Table of Reference 3)

σ_y = Yield stress = 1.333×45,000 = 60,000 psi

$$M_\phi = \frac{l_\phi}{\sqrt{Rt}} = \frac{110}{\sqrt{17.875\times0.75}} = 30 > 1.73$$

5.1 Theoretical Elastic Buckling Stresses (Independent of Loading)

Axial Compression

Since $M_\varphi > 1.73$

$$C_\phi = 0.605$$

$$\sigma_{\phi eL} = C_\phi \frac{Et}{R} = 0.605\times\frac{28\times10^6\times0.75}{17.875} = 710{,}769 \text{ psi}$$

Hoop Compression

$1.65\times R/t$ = 1.65×17.875/0.75 = 39.3

Since, $3 < M_\varphi < 1.65\times R/t$

$$C_{\theta h} = \frac{0.92}{M_\phi - 0.636} = \frac{0.92}{30-0.636} = 0.0313$$

$$\sigma_{\theta eL} = \sigma_{heL} = C_{\theta h}\frac{Et}{R} = 0.0313\times\frac{28\times10^6\times0.75}{17.875} = 36{,}772 \text{ psi}$$

In-Plane Shear

$8.69\times R/t$ = 8.69×17.875/0.75 = 207

Since, $26 \le M_\phi < (8.69)(R/t)$

$$C_{\phi\theta} = \frac{0.746}{\sqrt{M_\phi}} = \frac{0.746}{\sqrt{30}} = 0.1362$$

$$\sigma_{\phi\theta eL} = C_{\phi\theta}\frac{Et}{R} = 0.1362\times\frac{28\times10^{6}\times0.75}{17.875} = 160{,}011 \text{ psi}$$

5.2 <u>Capacity Reduction Factors</u> (Independent of Loading)

R/t = 17.875/0.75 = 23.83

<u>Effect of R/t</u>

R/t is < 600

$\alpha_{\varphi L}$ = smaller of [{1.52 – 0.473×log$_{10}$ (R/t)} and {$10^{-5}\times\sigma_y$ -0.033}]

1.52 – 0.473×log$_{10}$ (R/t) = 1.52 – 0.473×log$_{10}$ (*23.83*) = 0.869

The material is specified as A-240 Gr. 45 which has a static yield stress of 45,000 psi. Since the loadings considered here are dynamic, the dynamic yield stress is used for σ_y.

σ_y = 1.333 × 45,000 = 60,000 psi

$10^{-5}\times\sigma_y$ -0.033 = $10^{-5}\times$60,000 -0.033 = 0.567

$\alpha_{\varphi L}$ = smaller of (0.8213 & 0.567) = 0.567

<u>Effect of Length</u>

$M = M_\varphi$ = 30 > 10

$\alpha_{\varphi L}$ = 0.207

For the combination the larger of the two $\alpha_{\varphi L}$ are used. Thus,

$\alpha_{\varphi L}$ = 0.567

<u>For Hoop Compression</u>

$\alpha_{\theta L}$ = 0.8

<u>For Shear</u>

Since, R/t = 23.83 < 250

$\alpha_{\varphi\theta L}$ = 0.8

5.3 <u>Plasticity Reduction Factors for NCT</u>

Plasticity reduction factors are function of applied stresses. For NCT conditions the maximum values of each loading components are used for the calculation of plasticity reduction factors. From Table 1 these values are:

σ_φ = maximum longitudinal stress = 18,494 psi

σ_θ = maximum hoop stress = 10,718 psi

$\sigma_{\varphi\theta}$ = maximum in-plane shear stress = 1,590 psi

The factor of safety for the NCT loading is 2.0. Therefore,

$$\sigma_{\phi}(FS) = 18{,}494 \times 2.0 = 36{,}988 \text{ psi}$$

$$\sigma_{\theta}(FS) = 10{,}718 \times 2.0 = 21{,}436 \text{ psi}$$

$$\sigma_{\theta\phi}(FS) = 1{,}590 \times 2.0 = 3{,}180 \text{ psi}$$

Plasticity reduction factors are calculated using the equations presented in Section 4.3,

$$\sigma_{\phi}(FS)/\sigma_y = 18{,}494 \times 2.0/60{,}000 = 0.616$$

$$\sigma_{\theta}(FS)/\sigma_y = 10{,}718 \times 2.0/60{,}000 = 0.357$$

$$\sigma_{\phi\theta}(FS)/\sigma_y = 1{,}590 \times 2.0/60{,}000 = 0.053$$

Since, $0.55 < \sigma_{\phi}(FS)/\sigma_y \leq 0.738$

$$\eta_{\phi} = \frac{0.18}{1 - \dfrac{(0.45)\sigma_y}{(FS)\sigma_{\phi}}} = \frac{0.18}{1 - \dfrac{(0.45) \times 60{,}000}{36{,}988}} = 0.667$$

Since, $\sigma_{\theta}(FS)/\sigma_y \leq 0.67$

$$\eta_{\theta} = 1.0$$

Since, $\sigma_{\phi\theta}(FS)/\sigma_y \leq 0.48$

$$\eta_{\phi\theta} = 1.0$$

Compute the elastic stress components:

$$\sigma_{\phi s} = \frac{(FS)\sigma_{\phi}}{\alpha_{\phi L}} = \frac{36{,}988}{0.567} = 65{,}235 \text{ psi}$$

$$\sigma_{\theta s} = \frac{(FS)\sigma_{\theta}}{\alpha_{\theta L}} = \frac{21{,}436}{0.8} = 26{,}795 \text{ psi}$$

$$\sigma_{\phi\theta s} = \frac{(FS)\sigma_{\phi\theta}}{\alpha_{\phi\theta L}} = \frac{3{,}180}{0.8} = 3{,}975 \text{ psi}$$

Compute the inelastic stress components:

$$\sigma_{\phi p} = \frac{\sigma_{\phi s}}{\eta_{\phi}} = \frac{65{,}235}{0.667} = 97{,}804 \text{ psi}$$

$$\sigma_{\theta p} = \frac{\sigma_{\theta s}}{\eta_{\theta}} = \frac{26{,}795}{1.0} = 26{,}795 \text{ psi}$$

$$\sigma_{\phi\theta p} = \frac{\sigma_{\phi\theta s}}{\eta_{\phi\theta}} = \frac{3{,}975}{1.0} = 3{,}975 \text{ psi}$$

5.4 Interaction Equations for NCT

Elastic Buckling

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \tfrac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \geq \tfrac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \tfrac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \tfrac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \leq 1.0$$

$$\frac{65{,}235 - \tfrac{1}{2}\times 36{,}772}{710{,}769 - \tfrac{1}{2}\times 36{,}772} + \left(\frac{26{,}795}{36{,}772}\right)^2 = 0.599 < 1.0$$ O.K.

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{65{,}235}{710{,}769} + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.0924 < 1.0$$ O.K.

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{26{,}795}{36{,}772} + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.729 < 1.0$$ O.K.

Inelastic Buckling

e) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \leq 1.0$$

$$\frac{97{,}804}{710{,}769} = 0.138 \leq 1.0$$ O.K.

f) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \leq 1.0$$

$$\frac{26{,}795}{36{,}772} = 0.729 < 1.0$$ O.K.

g) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{97{,}804}{710{,}769}\right)^2 + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.0196 < 1.0$$ O.K.

h) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{26{,}795}{36{,}772}\right)^2 + \left(\frac{3{,}975}{160{,}011}\right)^2 = 0.532 < 1.0$$ O.K.

5.5 Plasticity Reduction Factors for HAC

Plasticity reduction factors are function of applied stresses. For HAC conditions the maximum values of each loading components are used for the calculation of plasticity reduction factors. From Table 1 these values are:

σ_φ = maximum longitudinal stress = 35,285 psi

σ_θ = maximum hoop stress = 16,363 psi

$\sigma_{\varphi\theta}$ = maximum in-plane shear stress = 3,731 psi

The factor of safety for the HAC loading is 1.34. Therefore,

$$\sigma_\phi(FS) = 35{,}285 \times 1.34 = 47{,}282 \text{ psi}$$

$$\sigma_\theta(FS) = 16{,}363 \times 1.34 = 21{,}926 \text{ psi}$$

$$\sigma_{\theta\phi}(FS) = 3{,}731 \times 1.34 = 5{,}000 \text{ psi}$$

Plasticity reduction factors are calculated using the equations presented in Section 4.3,

$$\sigma_\phi(FS)/\sigma_y = 35{,}285 \times 1.34 / 60{,}000 = 0.788$$

$$\sigma_\theta(FS)/\sigma_y = 16{,}363 \times 1.34 / 60{,}000 = 0.365$$

$$\sigma_{\phi\theta}(FS)/\sigma_y = 3{,}731 \times 1.34 / 60{,}000 = 0.083$$

Since, $0.738 < \sigma_\phi(FS)/\sigma_y \leq 1.0$

$$\eta_\phi = 1.31 - \frac{(1.15)\sigma_\phi(FS)}{\sigma_y} = 1.31 - \frac{1.15 \times 47{,}282}{60{,}000} = 0.404$$

Since, $\sigma_\theta(FS)/\sigma_y \leq 0.67$

$$\eta_\theta = 1.0$$

Since, $\sigma_{\phi\theta}(FS)/\sigma_y \leq 0.48$

$$\eta_{\phi\theta} = 1.0$$

Compute the elastic stress components:

$$\sigma_{\phi s} = \frac{(FS)\sigma_\phi}{\alpha_{\phi L}} = \frac{47{,}282}{0.567} = 83{,}390 \text{ psi}$$

$$\sigma_{\theta s} = \frac{(FS)\sigma_\theta}{\alpha_{\theta L}} = \frac{21{,}926}{0.8} = 27{,}408 \text{ psi}$$

$$\sigma_{\phi\theta s} = \frac{(FS)\sigma_{\phi\theta}}{\alpha_{\phi\theta L}} = \frac{5{,}000}{0.8} = 6{,}250 \text{ psi}$$

Compute the inelastic stress components:

$$\sigma_{\phi p} = \frac{\sigma_{\phi s}}{\eta_\phi} = \frac{83{,}390}{0.404} = 206{,}410 \text{ psi}$$

$$\sigma_{\theta p} = \frac{\sigma_{\theta s}}{\eta_\theta} = \frac{27{,}408}{1} = 27{,}408 \text{ psi}$$

$$\sigma_{\phi\theta p} = \frac{\sigma_{\phi\theta s}}{\eta_{\phi\theta}} = \frac{6{,}250}{1.0} = 6{,}250 \text{ psi}$$

5.6 Interaction Equations for HAC

Elastic Buckling

a) Axial compression-plus-hoop compression $(\sigma_{\phi s} < \tfrac{1}{2}\sigma_{\theta s})$

Not Applicable (n/a)

b) Axial compression-plus-hoop compression $(\sigma_{\phi s} \geq \tfrac{1}{2}\sigma_{\theta s})$:

$$\frac{\sigma_{\phi s} - \frac{1}{2}\sigma_{heL}}{\sigma_{\phi eL} - \frac{1}{2}\sigma_{heL}} + \left(\frac{\sigma_{\theta s}}{\sigma_{heL}}\right)^2 \leq 1.0$$

$$\frac{83{,}390 - \frac{1}{2}\times 36{,}772}{710{,}769 - \frac{1}{2}\times 36{,}772} + \left(\frac{27{,}408}{36{,}772}\right)^2 = 0.649 < 1.0$$ O.K.

c) Axial compression-plus-shear:

$$\frac{\sigma_{\phi s}}{\sigma_{\phi eL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{83{,}390}{710{,}769} + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.119 < 1.0$$ O.K.

d) Hoop compression-plus-shear

$$\frac{\sigma_{\theta s}}{\sigma_{reL}} + \left(\frac{\sigma_{\phi\theta s}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\frac{27{,}408}{36{,}772} + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.747 < 1.0$$ O.K.

<u>Inelastic Buckling</u>

i) Axial compression:

$$\frac{\sigma_{\phi p}}{\sigma_{\phi eL}} \leq 1.0$$

$$\frac{206{,}410}{710{,}769} = 0.290 \leq 1.0$$ O.K.

j) Hoop compression:

$$\frac{\sigma_{\theta p}}{\sigma_{\theta eL}} \leq 1.0$$

$$\frac{27{,}408}{36{,}772} = 0.745 < 1.0$$ O.K.

k) Axial compression-plus-shear:

$$\left(\frac{\sigma_{\phi p}}{\sigma_{\phi eL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{206{,}410}{710{,}769}\right)^2 + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.086 < 1.0 \qquad \text{O.K.}$$

l) Hoop compression-plus-shear

$$\left(\frac{\sigma_{\theta p}}{\sigma_{reL}}\right)^2 + \left(\frac{\sigma_{\phi\theta p}}{\sigma_{\phi\theta eL}}\right)^2 \leq 1.0$$

$$\left(\frac{27{,}408}{36{,}772}\right)^2 + \left(\frac{6{,}250}{160{,}011}\right)^2 = 0.557 < 1.0 \qquad \text{O.K.}$$

6.0 SUMMARY & CONCLUSIONS

The results of the buckling evaluation of the 3-60B Cask are summarized in Table 2. It is observed from the table that all the stress combination requirements of the ASME Code Case N-284 are satisfied by the cask inner shell for the NCT and HAC loading conditions for the combination of maximum stress components arising under all the operating environments. Therefore, it is concluded that buckling will not occur as the result of any normal or accident condition loading and the buckling requirement of Paragraph C.5 of Regulatory Guide 7.6 is satisfied.

Table 1

Maximum Compressive Stress Components in the Inner Shell
Under Various NCT & HAC Drop Orientation & Environments

Condition	Orientation	Environment	S_y (psi)	S_z (psi)	S_{yz} (psi)
NCT	End	Hot	112.5	-1,035	-0.1098
		Cold-1	-5,800	-14,437	-0.3013
		Cold-2	-9,195	-18,494	-0.2798
	Side	Hot	-847.39	-2,724	-60.848
		Cold-1	-7,733	-12,520	-3.864
		Cold-2	-10,718	-15,416	-9.063
	Corner	Hot	-460.1	-1,527	-1,590
		Cold-1	-6,780	-12,845	-1,519
		Cold-2	-10,094	-16,487	-1,441
HAC	End	Hot	-183.6	-12,577	-1.587
		Cold-1	-5,039	-31,241	-0.7761
		Cold-2	-8,435	-35,285	-0.8368
	Side	Hot	-3,555	-17,725	2.068
		Cold-1	-13,327	-29,549	1.245
		Cold-2	-16,363	-33,136	0.3436
	Corner	Hot	-1,308	-7,292	-3,731
		Cold-1	-7,901	-20,975	-3,691
		Cold-2	-11,113	-24,709	-3,557

Reference: Analyses of ST-504 (Reference 3).

Table 2

3-60B Cask Inner Shell Summary of the Interaction Ratios

	Interaction	NCT	HAC
Elastic	Axial Compression + Hoop Compression [Code Case N-284, 1713.1.1 (b)]	0.599	0.649
	Axial Compression + Shear [Code Case N-284, 1713.1.1 (c)]	0.0924	0.119
	Hoop Compression + Shear [Code Case N-284, 1713.1.1 (d)]	0.729	0.747
Inelastic	Axial Compression [Code Case N-284, 1600]	0.138	0.290
	Hoop Compression [Code Case N-284, 1600]	0.729	0.745
	Axial Compression + Shear [Code Case N-284, 1713.2.1 (a)]	0.0196	0.086
	Hoop Compression + Shear [Code Case N-284, 1713.2.1 (b)]	0.532	0.557

Acceptable Values are ≤ 1.0

Appendix 1

Print-Out of the Stress Data for Various Loading Conditions

(Reference 3)

(11 Pages)

```
***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:26:56  JUN 18, 2009 CP=      3.266

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


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.266   TIME= 16:26:56
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.266   TIME= 16:26:56
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     3  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft End Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     3
  TIME=    1.0000      LOAD CASE=   0

MINIMUM VALUES
NODE      43831       31790       46753        1870        1870       25832
VALUE   -31.790      112.47     -1034.9     -4.3964    -0.10977     -4.4316

MAXIMUM VALUES
NODE      43713        7870        1870       25870       25870       19713
VALUE   -31.679      147.28     -991.08      4.3968     0.10775     -4.1974


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     3  CUMULATIVE ITERATION=    36
  TIME/FREQUENCY=  2.0000
```

```
TITLE= 1-ft End Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     3
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE      19751       22752       10752       25790        1790       22832
VALUE   -123.63     -5799.8     -14437.     -139.44    -0.30127     -12.389

MAXIMUM VALUES
NODE      43832       46832       34831        1790       25790       25790
VALUE   -123.10     -5428.9     -14301.      139.44     0.30086     -11.939


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     3  CUMULATIVE ITERATION=    41
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft End Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     3
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       7751       22751       22752       25790        1790       22832
VALUE   -196.57     -9195.3     -18494.     -221.06    -0.27977     -11.693

MAXIMUM VALUES
NODE      31832       46832       34831        1790       25790       13790
VALUE   -196.33     -8667.9     -18326.      221.06     0.27974     -10.963


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442         VERSION=WINDOWS x64   16:28:12  JUN 18, 2009 CP=      3.219

1-ft Side Drop - Cold Condition (No Decay Heat)


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.234   TIME= 16:28:12
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
```

```
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.234   TIME= 16:28:12
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    12
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft Side Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25832       25870        1790       31790       13833
VALUE   -115.22     -847.39     -2723.6     -36.230     -60.848      4.1833

MAXIMUM VALUES
NODE      37751        1790        1870        7752        4751        1870
VALUE   -27.129      1367.1      8777.0      3.0805      1.7409      10.968


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    22
  TIME/FREQUENCY=  2.0000
TITLE= 1-ft Side Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       43751       25870       25870       28752       13833
VALUE   -224.71     -7733.3     -12520.     -182.91     -3.8640      11.430

MAXIMUM VALUES
NODE      25870        1870        1870        1790       19751        1693
VALUE   -118.81     -5237.3      2059.1      134.81      117.11      18.357
```

```
USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    26
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft Side Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       46751       25870       25870       28753       25752
VALUE   -282.32     -10718.     -15416.     -252.19     -9.0627      37.473

MAXIMUM VALUES
NODE      25832        1870        1870        1790       19753       19832
VALUE   -174.75     -8093.0      256.72      204.73      68.238      47.432


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:25:55  JUN 18, 2009 CP=      2.656

1-ft Corner Drop - Hot Condition


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       2.656   TIME= 16:25:55
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 1-ft Corner Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE
```

```
 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25870        1870        1790       13753       25833
VALUE   -67.553     -460.14     -1527.4     -23.755     -1590.0     -9.1219

MAXIMUM VALUES
NODE      46833        1790       25870        7752       25790        1870
VALUE   -33.019      907.87      2192.0      4.4971     -35.234      10.558


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    23
  TIME/FREQUENCY=  2.0000
TITLE= 1-ft Corner Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1870       40753        1870       25870       37753        1752
VALUE   -160.60     -6780.3     -12845.     -161.12     -1518.9     -26.782

MAXIMUM VALUES
NODE      25832        1790       25790        1870        1870       13752
VALUE   -128.93     -5299.0     -10238.      130.14     -33.689     -14.732


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    28
  TIME/FREQUENCY=  3.0000
TITLE= 1-ft Corner Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

MINIMUM VALUES
NODE       1870       40753        1870       25870       37752        1752
VALUE   -232.19     -10094.     -16487.     -238.18     -1440.8     -25.036

MAXIMUM VALUES
NODE      25832       10832       25790        1790        1870       25870
VALUE   -197.84     -8616.2     -14410.      206.65     -30.338     -9.0511
```

```
***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:23:51  JUN 18, 2009 CP=      3.172

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


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.172   TIME= 16:23:51
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.172   TIME= 16:23:51
An active coordinate system is not zero.
 RSYS= 1 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     6
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft End Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       7790       40751       31753       25790       16753        1833
VALUE   -40.194     -183.58     -12577.     -3.6271     -1.5866     -8.3154

MAXIMUM VALUES
NODE       1790        7870        7870        1790       46753        4751
VALUE   -34.414     -123.52     -12517.      3.6580      2.7845     -3.3607


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0
```

```
SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    19
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft End Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1870       19752        1752       25790        1790       25752
VALUE   -104.64     -5039.0     -31241.     -121.25    -0.77611     -31.252

MAXIMUM VALUES
NODE       1790       28832       31832        1790       25790       28870
VALUE   -103.73     -4693.5     -31056.      121.25     0.77515     -30.321


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    22
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft End Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE      25870       31752       25752       25790        1790       28752
VALUE   -182.43     -8434.6     -35285.     -202.73    -0.83680     -33.666

MAXIMUM VALUES
NODE      40832       16832       13832        1790       25790        4870
VALUE   -182.27     -7950.6     -35129.      202.73     0.84711     -32.545


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:24:48  JUN 18, 2009 CP=      3.109

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


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                           CP =       3.109   TIME= 16:24:48
Reading results into the database (SET command) will update the current
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```
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.109   TIME= 16:24:48
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=    11
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft Side Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25831       25870        1790       25790       13870
VALUE   -358.91     -3555.4     -17725.     -178.51      2.0680     0.63220

MAXIMUM VALUES
NODE      37753        1790        1870        7713       22753       25713
VALUE    8.4213      6941.6      27427.      13.240      807.50      27.800


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    18
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft Side Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25870       25870       25870       25790       13833
VALUE   -550.64     -13327.     -29549.     -325.25      1.2447     -5.6047

MAXIMUM VALUES
NODE      37753        1870        1870        1790       22752        1870
```

```
VALUE   -158.06     -3300.6      21007.      77.588      851.09      20.412


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    21
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft Side Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1790       25870       25870       25870       25790       13833
VALUE   -622.39     -16363.     -33136.     -398.34     0.34364      3.7155

MAXIMUM VALUES
NODE      37753        1870        1870        1790       22752        1870
VALUE   -223.08     -6468.0      19042.      161.15      821.27      27.999


***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 11.0SP1  *****
ANSYS Mechanical/Emag
00222442          VERSION=WINDOWS x64   16:22:13  JUN 18, 2009 CP=      3.000

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


         ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ENTER  /SHOW,DEVICE-NAME  TO ENABLE GRAPHIC DISPLAY
ENTER  FINISH             TO LEAVE POST1

*** NOTE ***                            CP =       3.000   TIME= 16:22:13
Reading results into the database (SET command) will update the current
displacement and force boundary conditions in the database with the
values from the results file for that load set.  Note that any
subsequent solutions will use these values unless action is taken to
either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

*** NOTE ***                            CP =       3.000   TIME= 16:22:13
An active coordinate system is not zero.
 RSYS= 0 CSYS= 12 DSYS= 0.

ACTIVE COORDINATE SYSTEM SET TO      1  (CYLINDRICAL) Z- CYL. AXIS

RSYS KEY SET TO   1

USE COORDINATE SYSTEM   1 FOR SOLUTION RESULTS


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0
```

```
SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     6
  TIME/FREQUENCY=  1.0000
TITLE= 30-ft Corner Drop - Hot Condition

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       4752       25870        1870        1790       13751        7751
VALUE   -160.15     -1307.6     -7292.4     -55.077     -3731.4     -24.102

MAXIMUM VALUES
NODE      37752        1790       25790        4752       25790        4832
VALUE   -26.915      2246.0      631.81      15.764     -80.850      31.292


USE LOAD STEP     2  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     2  SUBSTEP=     1  CUMULATIVE ITERATION=    19
  TIME/FREQUENCY=  2.0000
TITLE= 30-ft Corner Drop - Cold Condition (Max. Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     2  SUBSTEP=     1
  TIME=    2.0000      LOAD CASE=   0

 MINIMUM VALUES
NODE       1870       25870        1870       25870       13753        7713
VALUE   -201.26     -7901.4     -20975.     -191.34     -3690.5     -47.008

MAXIMUM VALUES
NODE      37833        1790       25790        1870       25790       25870
VALUE   -128.08     -4204.4     -13185.      116.85     -88.245     -20.825


USE LOAD STEP     3  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     3  SUBSTEP=     1  CUMULATIVE ITERATION=    24
  TIME/FREQUENCY=  3.0000
TITLE= 30-ft Corner Drop - Cold Condition (No Decay Heat)

PRINT S    NODAL SOLUTION PER NODE

 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=     3  SUBSTEP=     1
  TIME=    3.0000      LOAD CASE=   0

 MINIMUM VALUES
```

NODE	1870	25870	1870	25870	13753	7713
VALUE	-271.34	-11113.	-24709.	-268.53	-3557.1	-45.552

MAXIMUM VALUES

NODE	13870	1790	25790	1870	25790	25870
VALUE	-200.65	-7466.4	-17489.	192.38	-86.722	-17.783

1.0 OBJECTIVE

To demonstrate that the inelastic deformation of the 3-60B Cask bolting ring skirt under HAC drop tests will not compromise the lid effectiveness due to bolt failure.

2.0 INTRODUCTION

The finite element analyses of the 3-60B Cask performed in Reference 1 for the HAC drop test conditions show that the bolting ring skirt will be subjected to high stresses during the side and corner drop scenarios. Figures 1 and 2 show the plot of the stress intensities in the cask body under side and corner drop conditions, respectively. It is observed from these plots that the high stresses are confined to a small region near the skirt-bolting ring junction. The stresses are mostly compressive in nature and occur on the non-containment part of the cask. Due to the ductility of the material a redistribution of the stresses will occur after they reach the elastic limit. This will result in a permanent deformation of the region. The large deformation will bring the skirt into contact with the lid, and a part of the impact limiter reaction will be transferred to the lid bolts.

The analyses provided in this document conservatively determine the extent of skirt deformation and calculate the amount of impact limiter reaction that will be transferred to the lid bolts. The analyses have been performed for the HAC side and corner drop scenarios.

A simplified ANSYS (Reference 2) inelastic finite element model has been employed to perform the evaluations. It has been demonstrated that the skirt will undergo less than 2% plastic strains and the load transferred to the lid due to this deformation can be reacted by the bolts without failure.

3.0 REFERENCES

(1) Energy*Solutions* Document ST-504, Structural Analyses of the 3-60B Cask under Drop Conditions.

(2) ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

4.0 FINITE ELEMENT MODEL DESCRIPTION

The inelastic analyses of the bolting ring skirt region are performed using a simplified 3-dimensional model of a portion of the region. Figure 3 shows the region in consideration. The skirt and a portion of the bolting ring shown in solid color in the figure have been explicitly modeled. The lid has been represented in the finite element model by a rigid cylindrical target that has an annular clearance of 1/8" (same as the nominal clearance provided in the design). The portion of the bolting ring not included in the finite element model has been represented by fixed boundary conditions. It should be noted that the fixed boundary conditions on the cut face prevent bolting ring rotation, thereby concentrating larger loads near the impact area. This will result in larger stresses at the point of contact and a larger load transfer to the lid. This assertion has been confirmed with the analysis of the FEM with linear material properties and compared with the resulting stresses of Reference 1 for both side drop and corner drop load cases.

4.1 Modeling Details

The FEM used in the analyses of this document is made from 3-dimensional solid finite elements (ANSYS SOLID-45). The choice of this element was based on the fact these 8-node isoparametric elements are very robust for representing an inelastic solid that undergoes a significant amount of bending. The lid is modeled with a rigid cylindrical target surface (ANSYS TARGE-170) and the interface between the skirt surface and the lid is modeled with 3-dimensional 8-node surface-to-surface contact elements (ANSYS CONTA-174). The combination of contact and target elements prevents penetration of one surface into another.

The finite element model geometry is shown in Figures 4 and 5. The portion of the structure near the impact zone is modeled by finer elements than that which is away from the impact zone. Further, the portion of the skirt near the junction with the bolting ring is modeled with finer element than that which is away from the juncture. Thus the stresses and strains in the highly stressed area of the structure are captured by the fine finite elements.

It should be noted that the bolt-holes in the bolting ring have not been modeled as their presence does not have an appreciable effect on the stresses in the skirt.

4.2 Material Properties

The mechanical properties of the material of the finite element model have been represented by the bi-linear kinematic hardening rule. The material is assumed to be isotropic. The tangent modulus of the material has been obtained by using the specified minimum mechanical properties of the material of construction. The bolting ring and the skirt have been specified to have the following mechanical properties.

Yield Stress, S_y = 45,000 psi

Ultimate Strength, S_u = 87,000 psi

Elongation at the break, e = 40%

Modulus of Elasticity, $E = 28\times10^6$ psi

True strain at break,

$$\varepsilon = \ln(1 + e) = 0.3365$$

To get a lower bound on the tangent modulus, use engineering strain rather than the true strain. Thus,

$$E_t = \frac{87{,}000 - 45{,}000}{0.4 - \dfrac{45{,}000}{28 \times 10^6}} = 105{,}424 \text{ psi}$$

Conservatively use 100,000 psi for the tangent modulus of the material.

4.3 Boundary Conditions

The cut-face of the bolting ring is specified to have fixed boundary conditions. The rigid target surface automatically is fixed in space by the program. The applied loadings are the same as those used in Reference 1.

5.0 ANALYSES DETAILS AND RESULTS

5.1 Side Drop

The impact limiter reaction for the side drop loading described in Reference 1 is applied as a sinusoidally varying pressure along the circumferential direction and uniform along the longitudinal direction. The magnitude of this pressure is obtained from Reference 1. The applied pressure is shown in Figure 6.

The model is analyzed with the boundary conditions mentioned above. The deformation of the structure is shown in Figure 7 and the stress intensity contour plot is shown in Figure 8. Figure 9 shows the contour plot of the equivalent plastic strain in the structure. A maximum value of 1.32% equivalent plastic strain is obtained from the analysis.

The radial deflection of the tip of the skirt is listed in Appendix 1 and is plotted in Figure 10. Superimposing the radial gap of 1/8" over this graph shows that approximately $2\times20 = 40^{o}$ of the skirt-tip around the 6 O'clock location will make contact with the lid.

The reaction of the skirt on the lid is obtained from the contact surface load summation. The print-out of this load summation is given in Appendix 1. It shows that 2×45,417 = 90,834 lb load will be transferred to the lid. Assuming that this load is transferred to the bolts in shear and further assuming that only 2 bolts near 6 O'clock location carry the entire load, the shear stress in the bolts is calculated. Please note that the lid has 16 bolts, uniformly located around the circumference. Therefore, the angle between the 2 bolts is $360/16 = 22.5^{o} < 40^{o}$, the angle over which the skirt-tip contacts the lid.

Bolts are specified to be 1½-6UNC A354 Gr. BD. The mechanical properties of these bolts are:

Yield stress, S_y = 130,000 psi

Ultimate strength, S_u = 150,000 psi

The stress area of these bolts is 1.4041 in^2. Therefore, the shear stress,

$$\tau = 45{,}417/1.4041 = 32{,}346 \text{ psi}$$

Under accident conditions, the allowable bolt shear stress is the smaller of $0.42S_u$ and $0.6S_y$.

Therefore, the allowable shear stress is:

$$\tau_{allow} = \text{Smaller of } (0.42\times150{,}000 \text{ and } 0.6\times130{,}000) = 63{,}000 \text{ psi}$$

Thus, the bolts will be subjected to shear stresses that are much below the allowable value.

As a confirmation that the applied loading in this simplified model conservatively depicts the behavior of the side drop loading analyzed in Reference 1, the inelastic properties of the model were suppressed and the model was run for the same loading. The elastic stress intensity contour plot under this loading is shown in Figure 11. Comparing the plot of Figure 1 and Figure 11, it can be seen that this model predicts the stress intensity in the structure more conservatively than the analysis of Reference 1.

5.2 Corner Drop

The impact limiter reaction for the corner drop is applied as pressure loading as shown in Figure 12. The distribution of the pressure loading is obtained from Reference 2.

The model is analyzed with the boundary conditions mentioned above. The deformation of the structure is shown in Figure 13 and the stress intensity contour plot is shown in Figure 14. Figure 15 shows the contour plot of the equivalent plastic strain in the structure. A maximum value of 1.61% equivalent plastic strain is obtained from the analysis.

The radial deflection of the tip of the skirt is listed in Appendix 1 and is plotted in Figure 16. Superimposing the radial gap of 1/8" over this graph shows that approximately $2 \times 20 = 40^{o}$ of the skirt-tip around the 6 O'clock location will make contact with the lid.

The reaction of the skirt on the lid is obtained from the contact surface load summation. The print-out of this load summation is given in Appendix 1. It shows that $2 \times 13{,}315 = 26{,}630$ lb load will be transferred to the lid. Assuming that this load is transferred to the bolts in shear and further assuming that only 2 bolts near 6 O'clock location carry the entire load, the shear stress in the bolts is calculated. Please note that the lid has 16 bolts, uniformly located around the circumference. Therefore, the angle between the 2 bolts is $360/16 = 22.5^{o} < 40^{o}$, the angle over which the skirt-tip contacts the lid.

The bolt shear stress,

$$\tau = 13{,}315/1.4041 = 9{,}483 \text{ psi} \ll \tau_{allow} = 63{,}000 \text{ psi}$$

Thus, the bolts will be subjected to shear stresses that are much below the allowable value.

As a confirmation that the applied loading in this simplified model conservatively depicts the behavior of the corner drop loading analyzed in Reference 1, the inelastic properties of the model were suppressed and the model was run for the same loading. The elastic stress intensity contour plot under this loading is shown in Figure 17. Comparing the plots of Figure 2 and Figure 17, it can be seen that this model predicts the stress intensity in the structure more conservatively than the analysis of Reference 1.

5.0 CONCLUSIONS

The analyses performed in this document demonstrate that under HAC side and corner drop conditions the bolting ring skirt will undergo less than 2% plastic deformation, and the load transferred to the lid due to this deformation will subject the lid bolts to shear stresses that are well below the allowable value for the HAC loading. Therefore, it is concluded that the bolts will not fail under these test conditions.

Figures

(17 Pages)

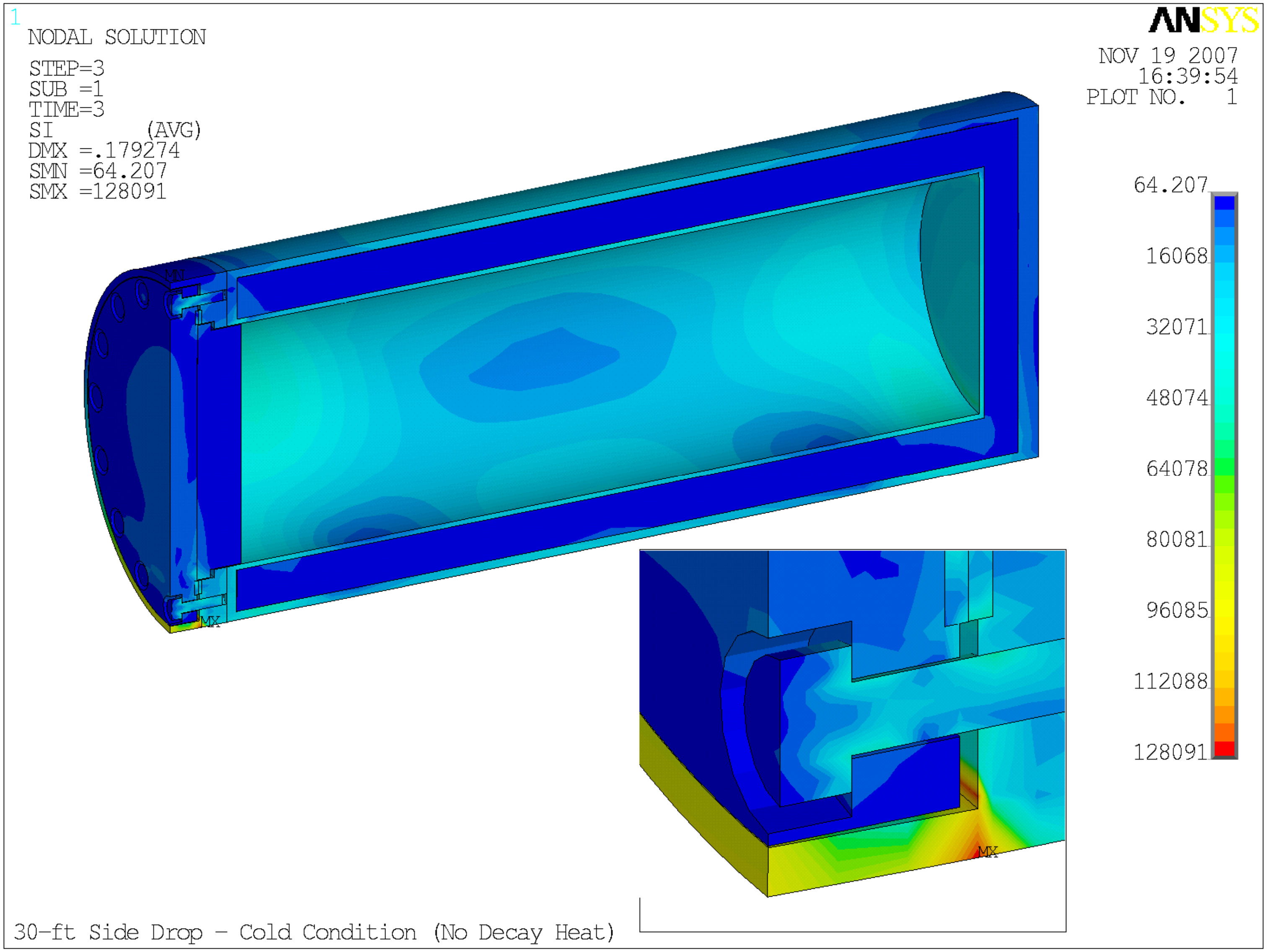

Figure-1

3-60B Cask Stress Intensity Contour Plot - HAC Side Drop

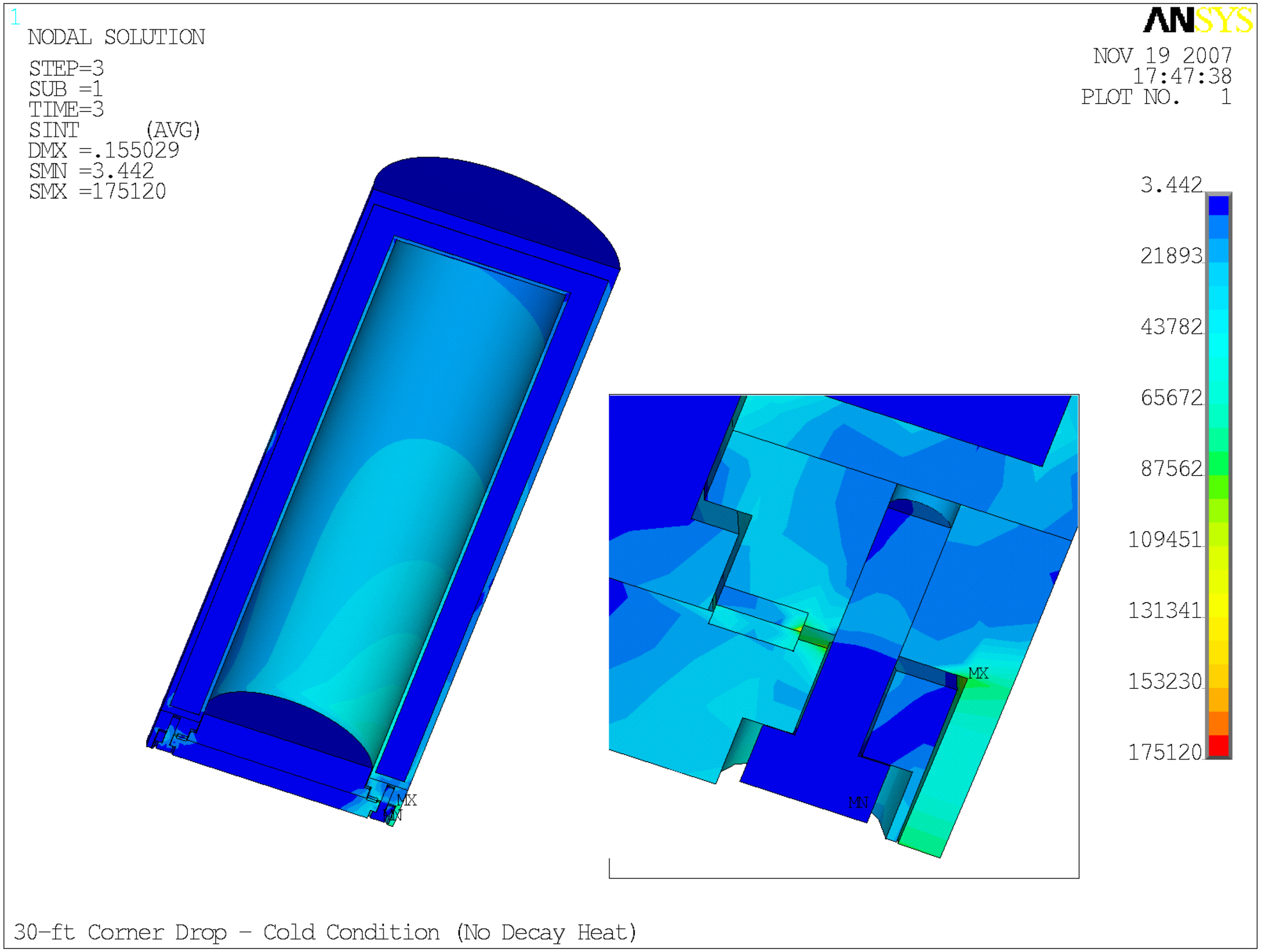

Figure-2

3-60B Cask Stress Intensity Contour Plot - HAC Corner Drop

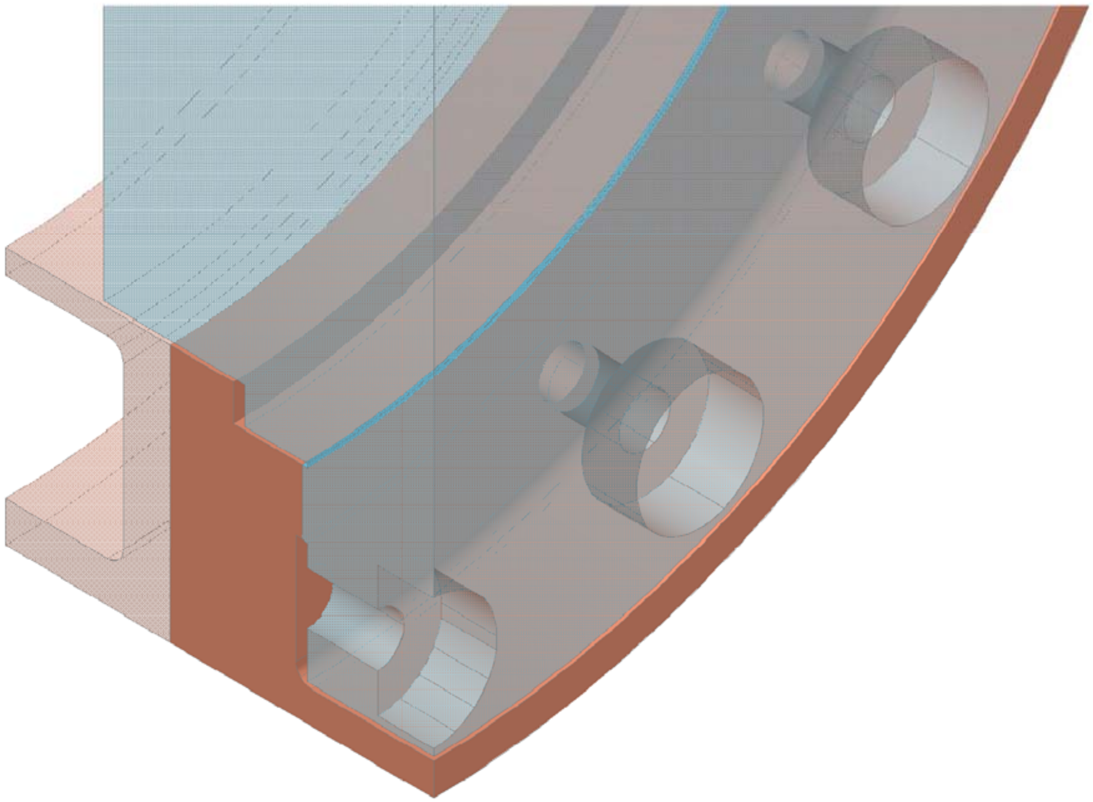

Figure-3
3-60B Cask - Bolting Ring Skirt Components Included in the Inelastic Model

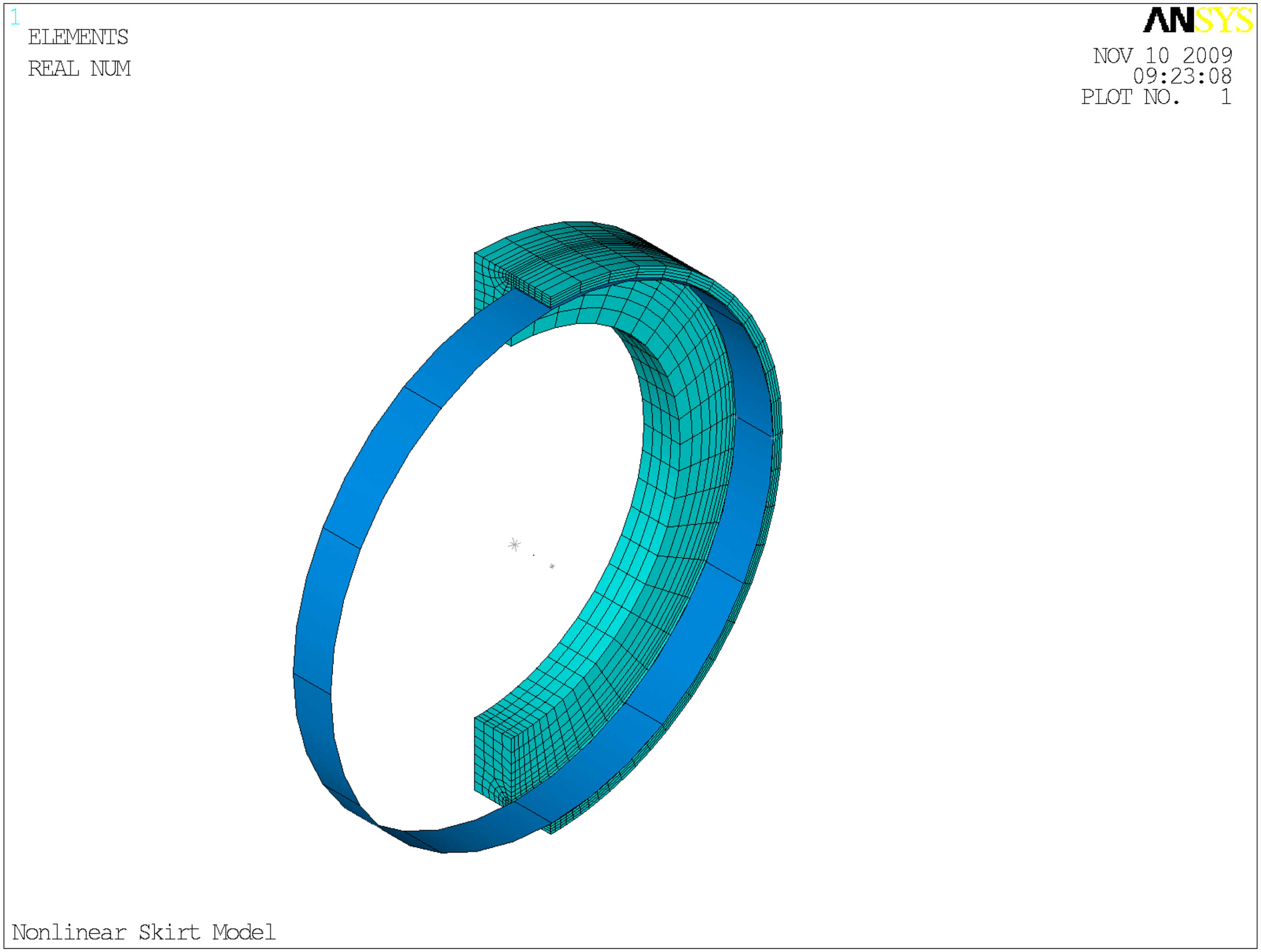

Figure-4

3-60B Cask - Skirt Region Inelastic Model

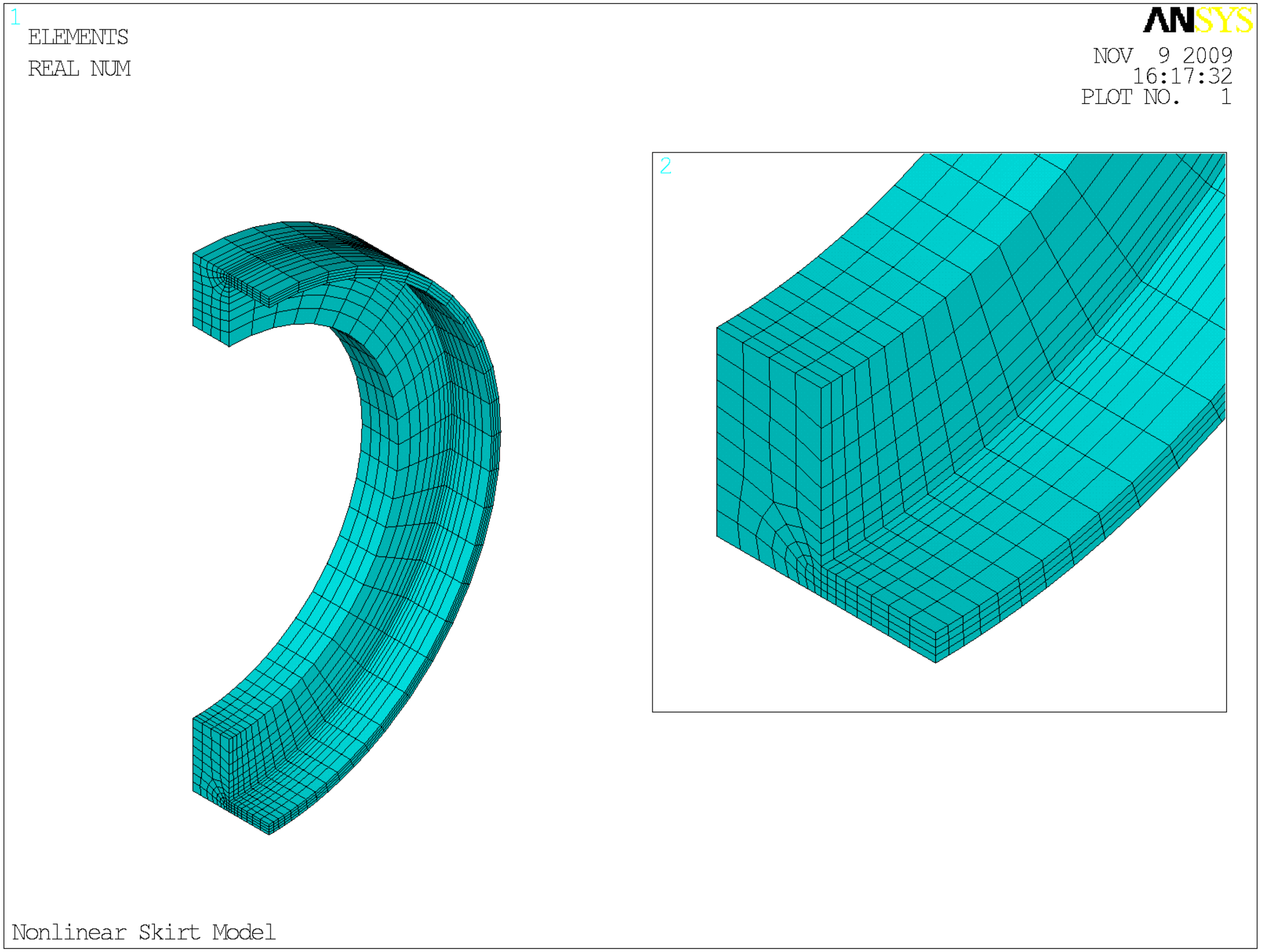

Figure-5

Close-Up of the Skirt Bolting-Ring Intersection

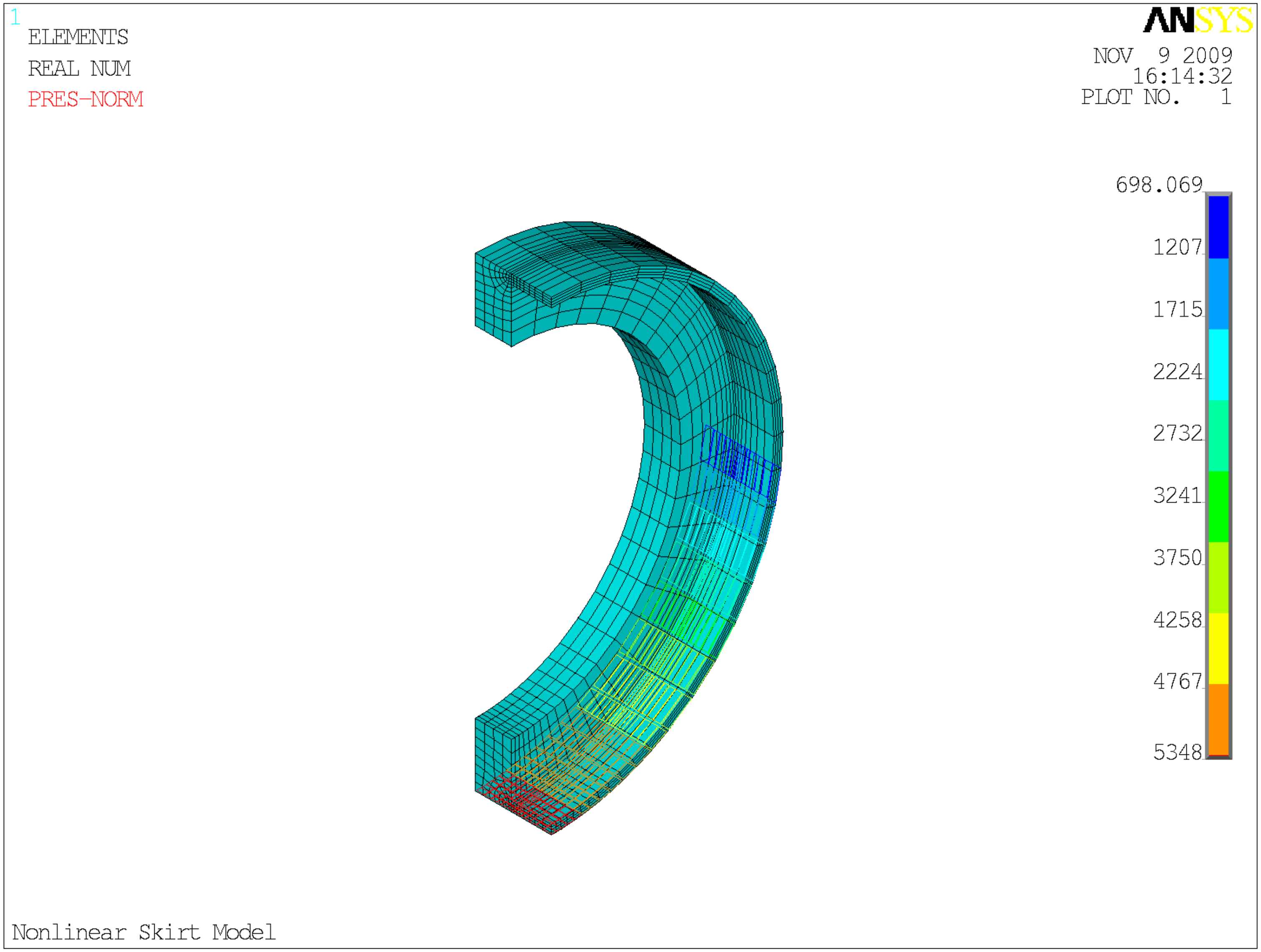

Figure-6

HAC Side Drop Model Applied Impact Limiter Reaction Loading

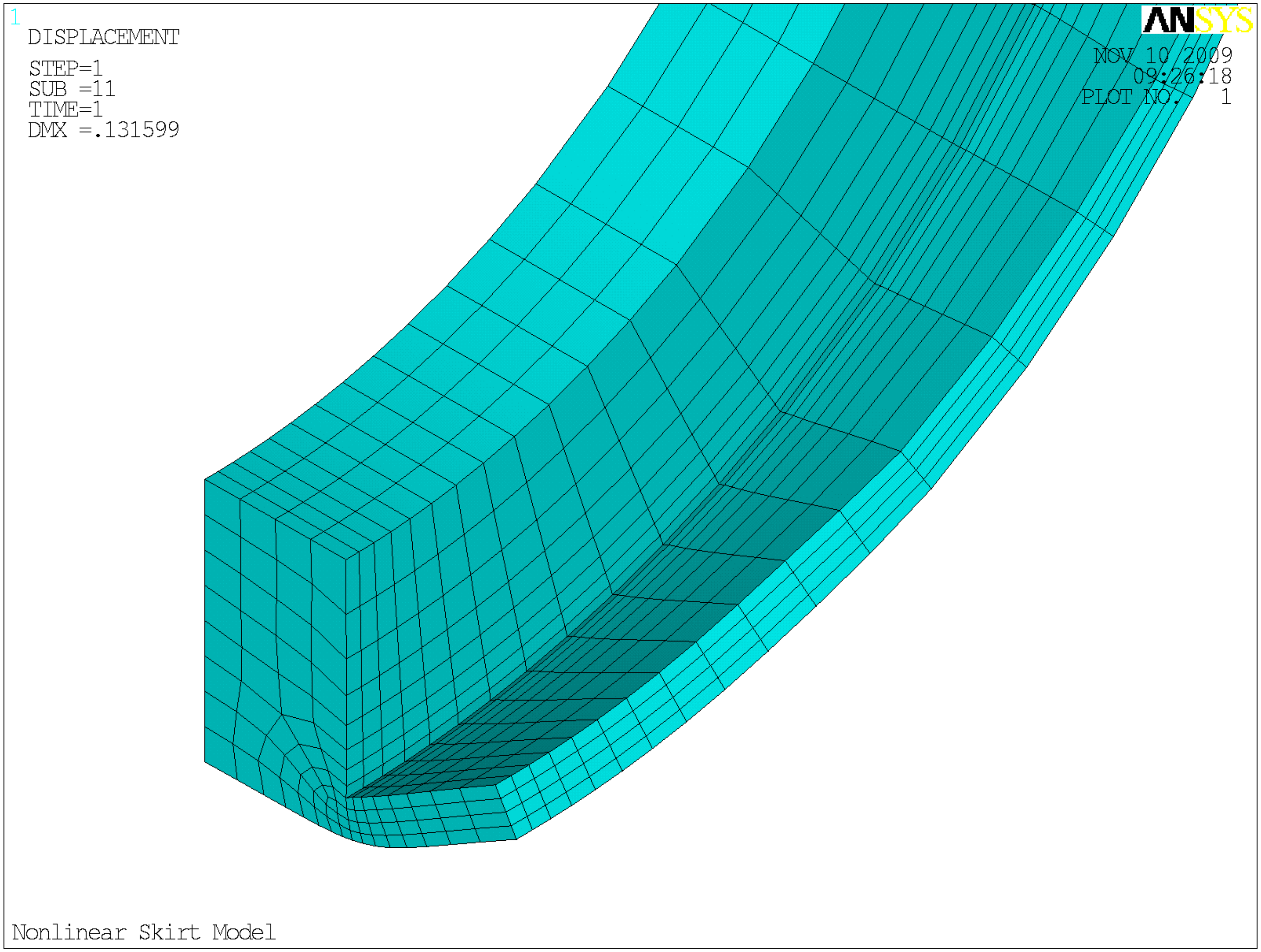

Figure-7

Displacement of the Skirt under HAC Side Drop Loading

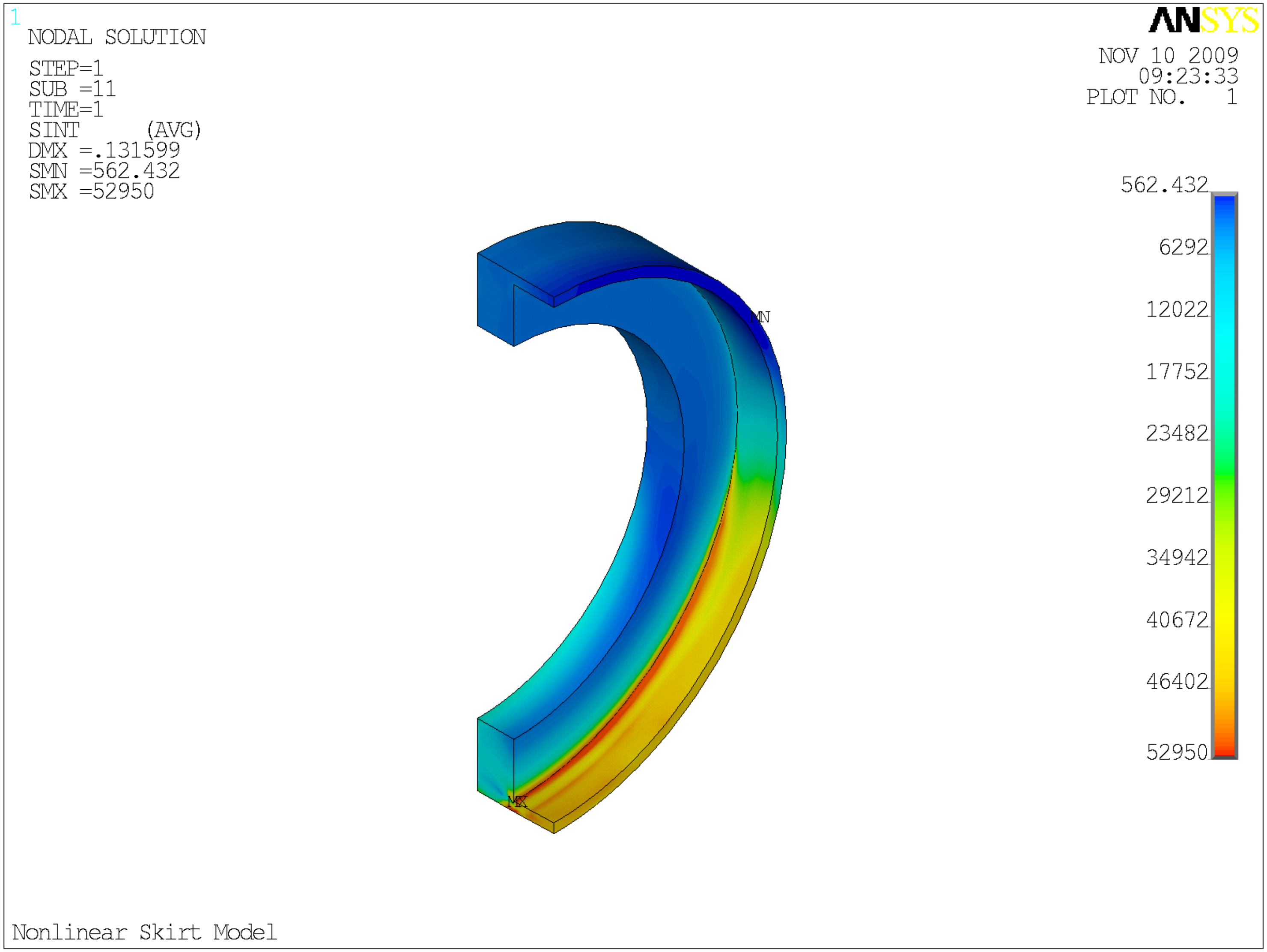

Figure-8

Stress Intensity Contour Plot - HAC Side Drop Loading

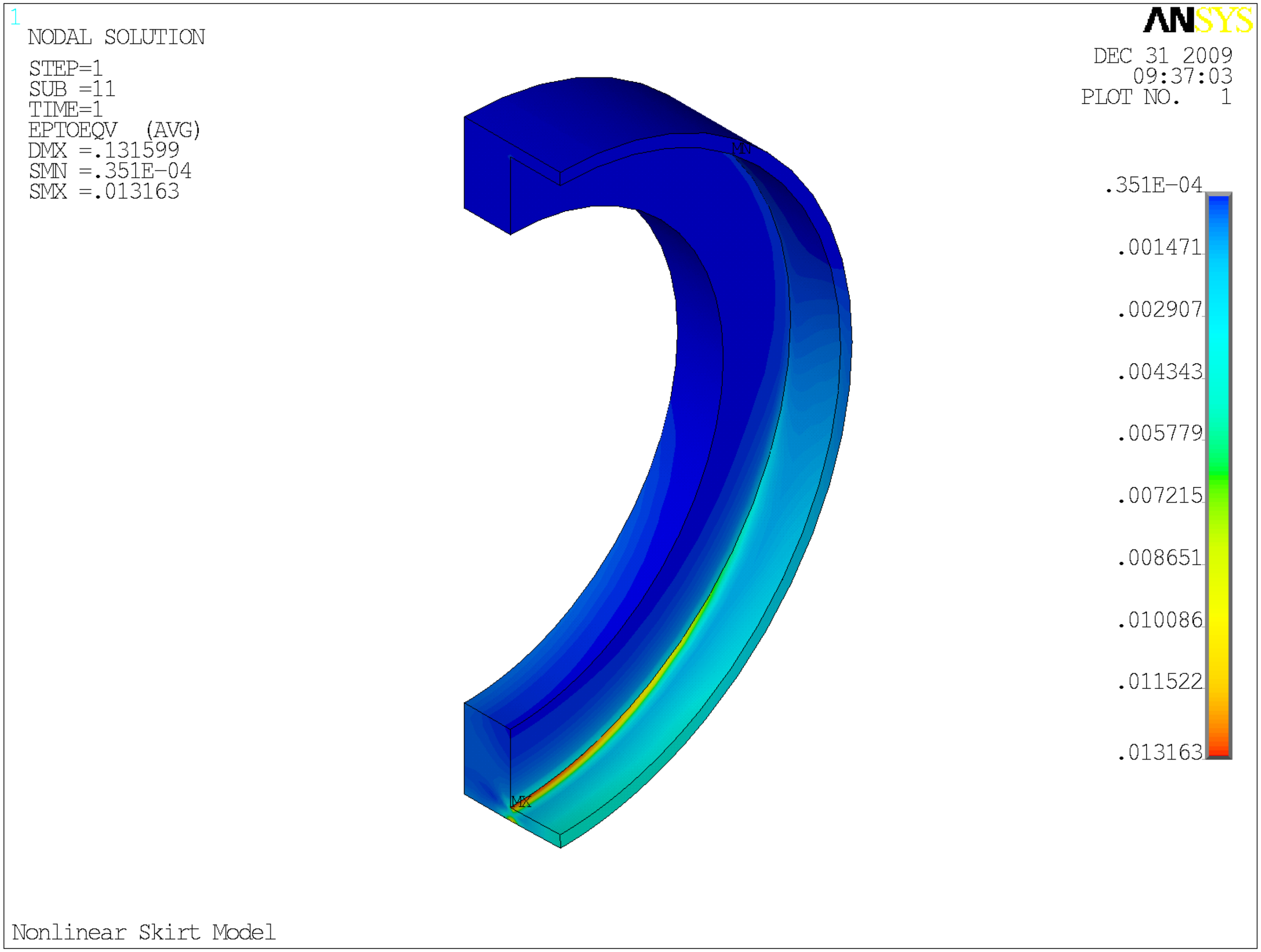

Figure-9

Equivalent Plastic Strain Plot under HAC Side Drop Loading

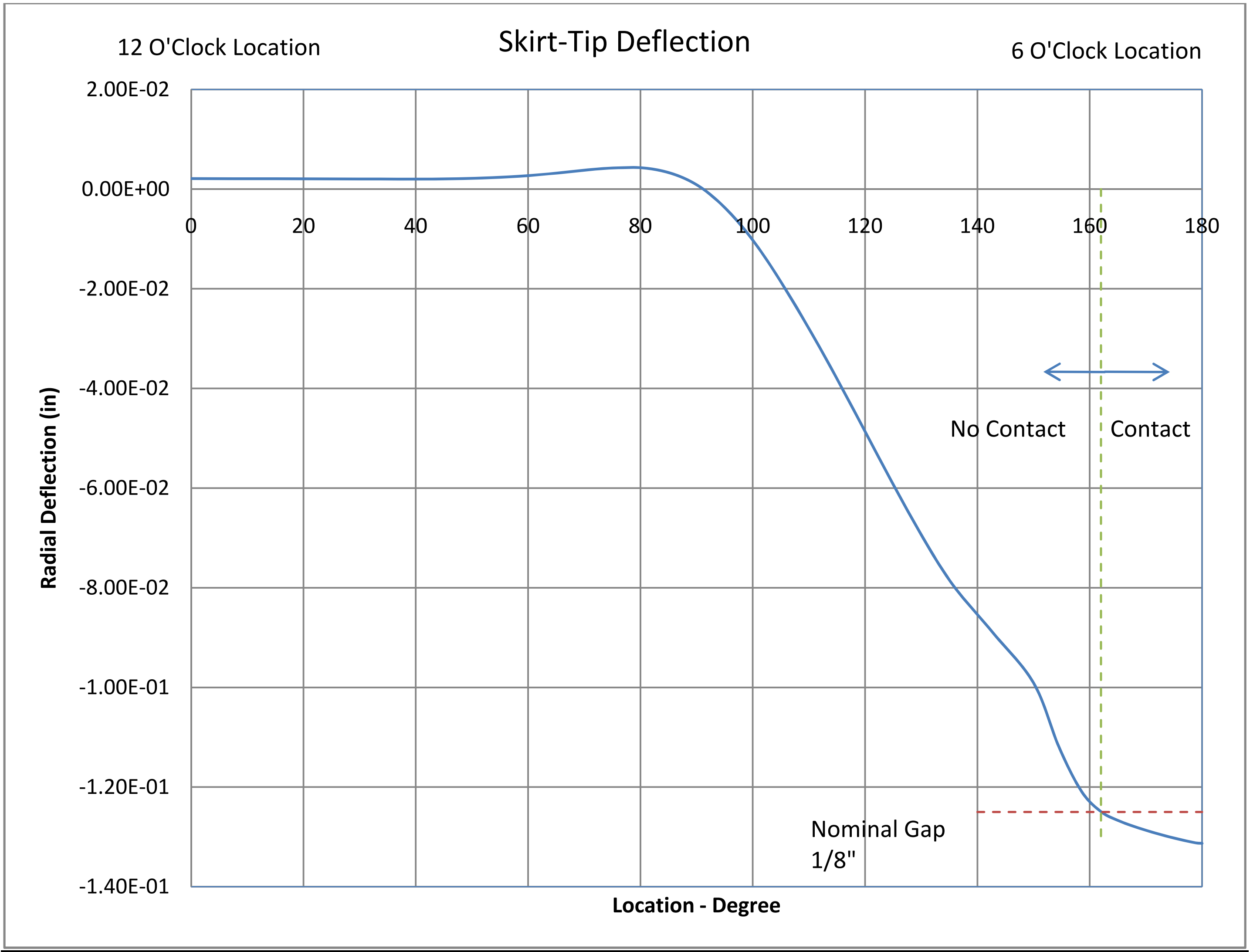

Figure-10

Displacement of the Skirt Tip under HAC Side Drop Loading

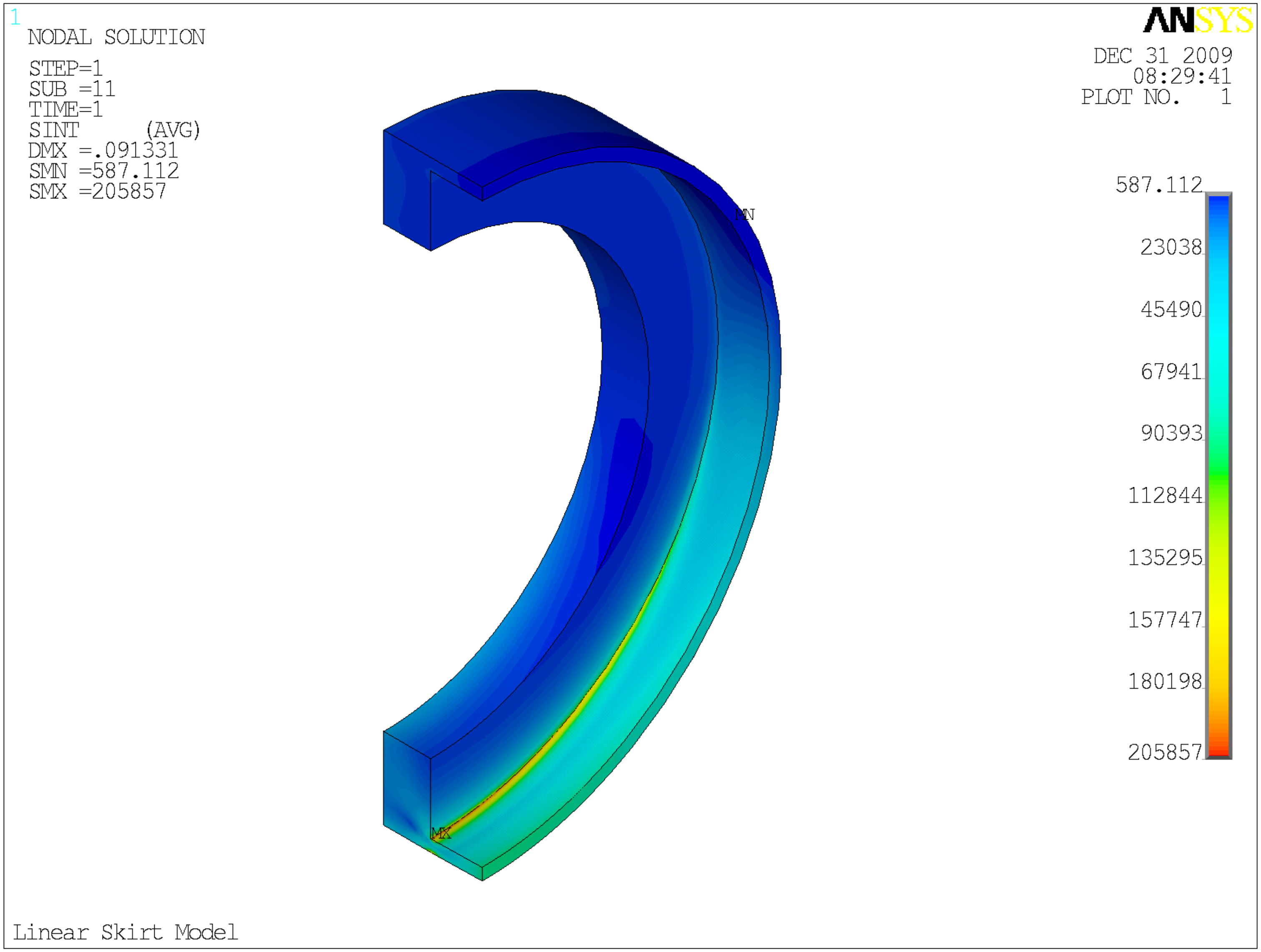

Figure-11

Stress Intensity Plot under HAC Side Drop Loading Computed by Elastic Model

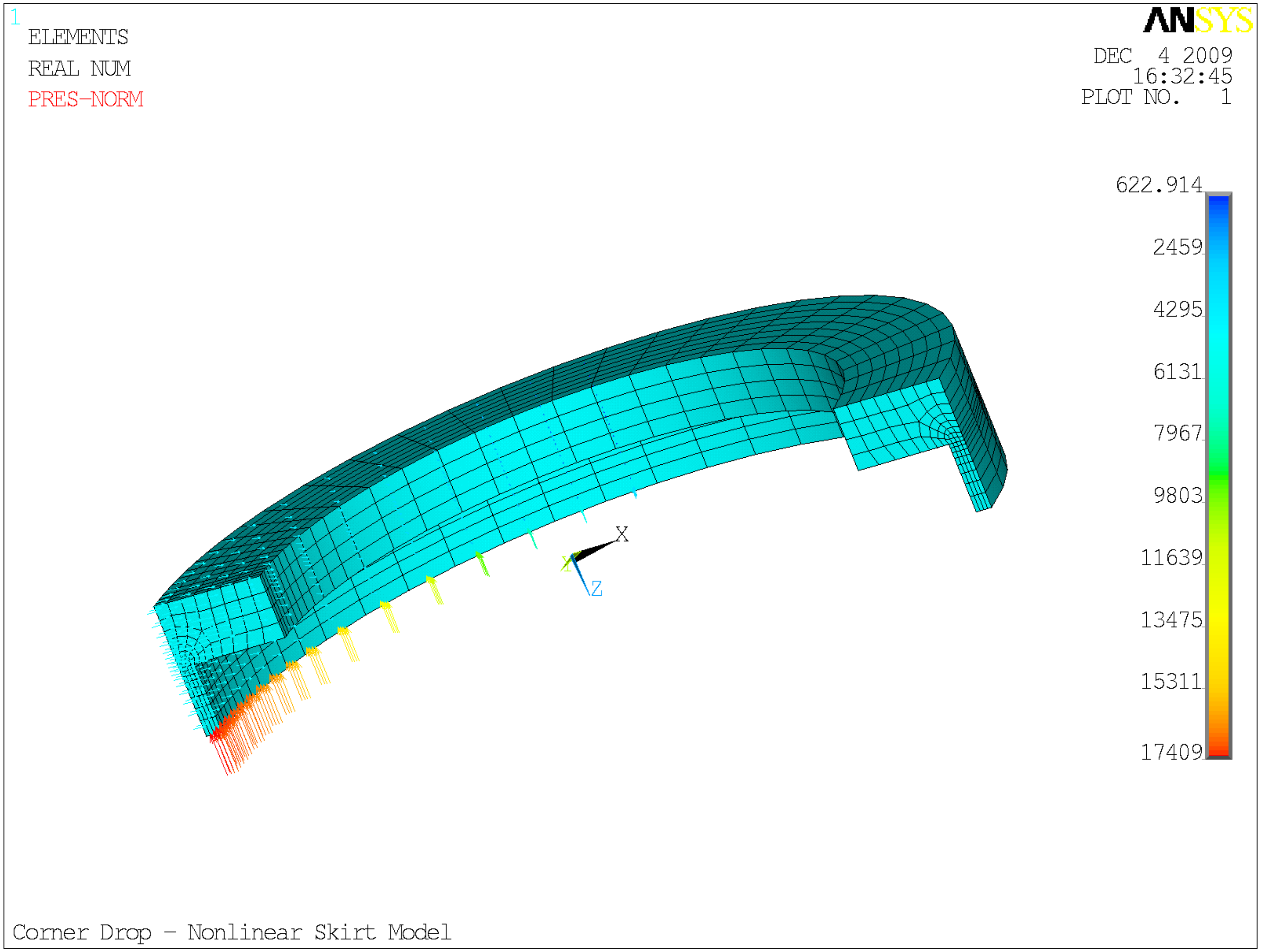

Figure-12

HAC Corner Drop Model Applied Impact Limiter Reaction Loading

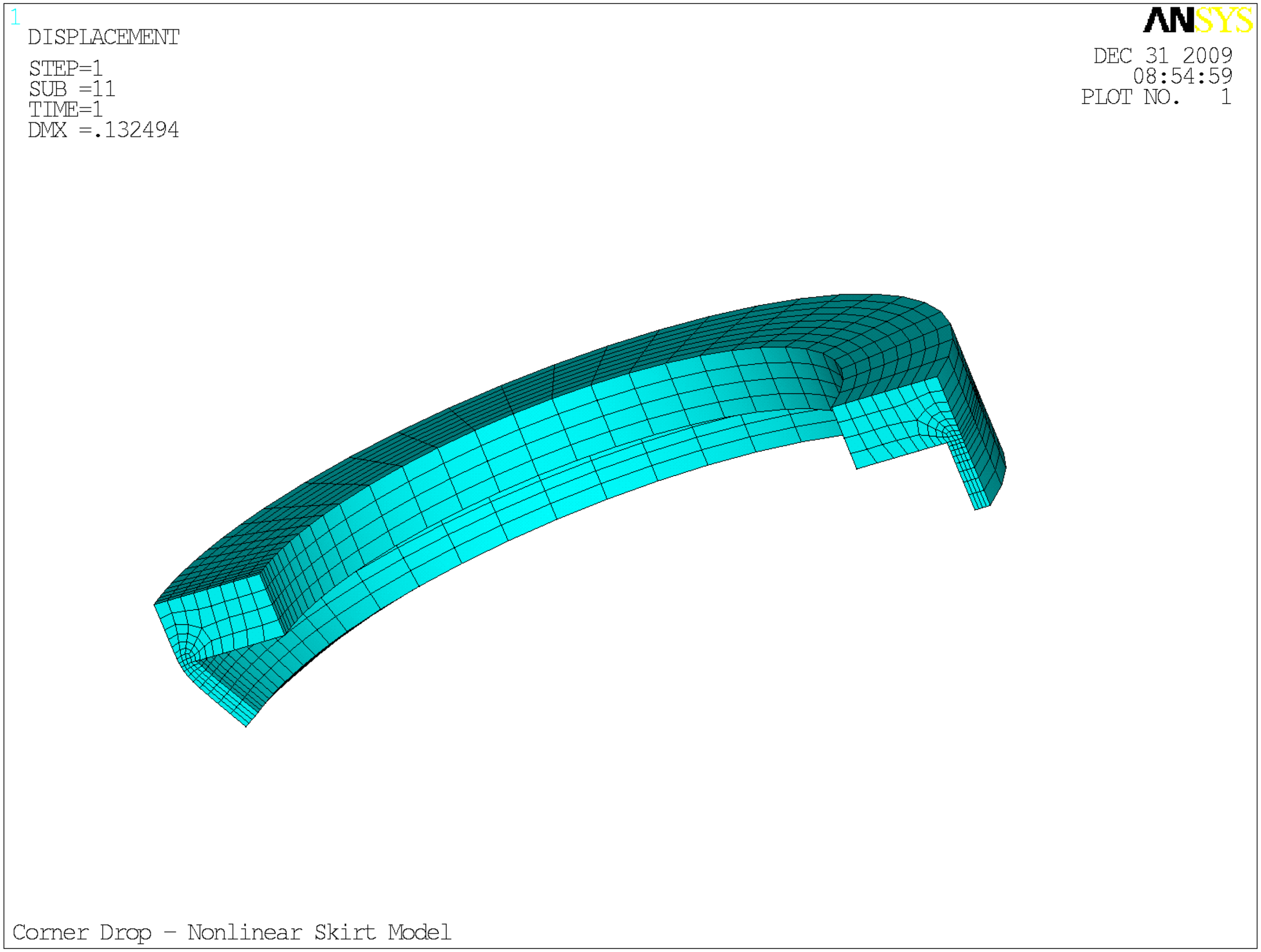

Figure-13

Displacement of the Skirt under HAC Corner Drop Loading

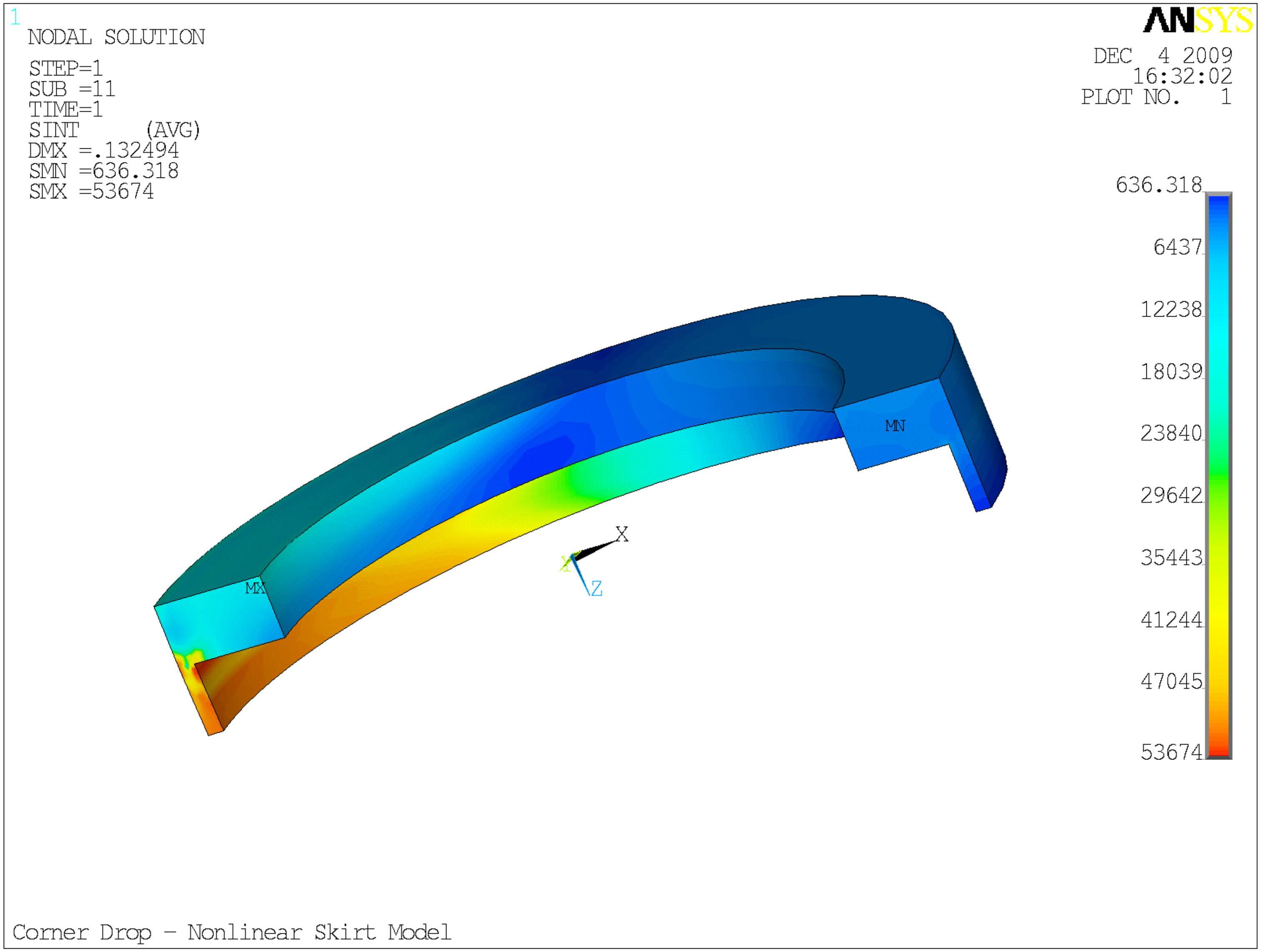

Figure-14

Stress Intensity Contour Plot - HAC Corner Drop Loading

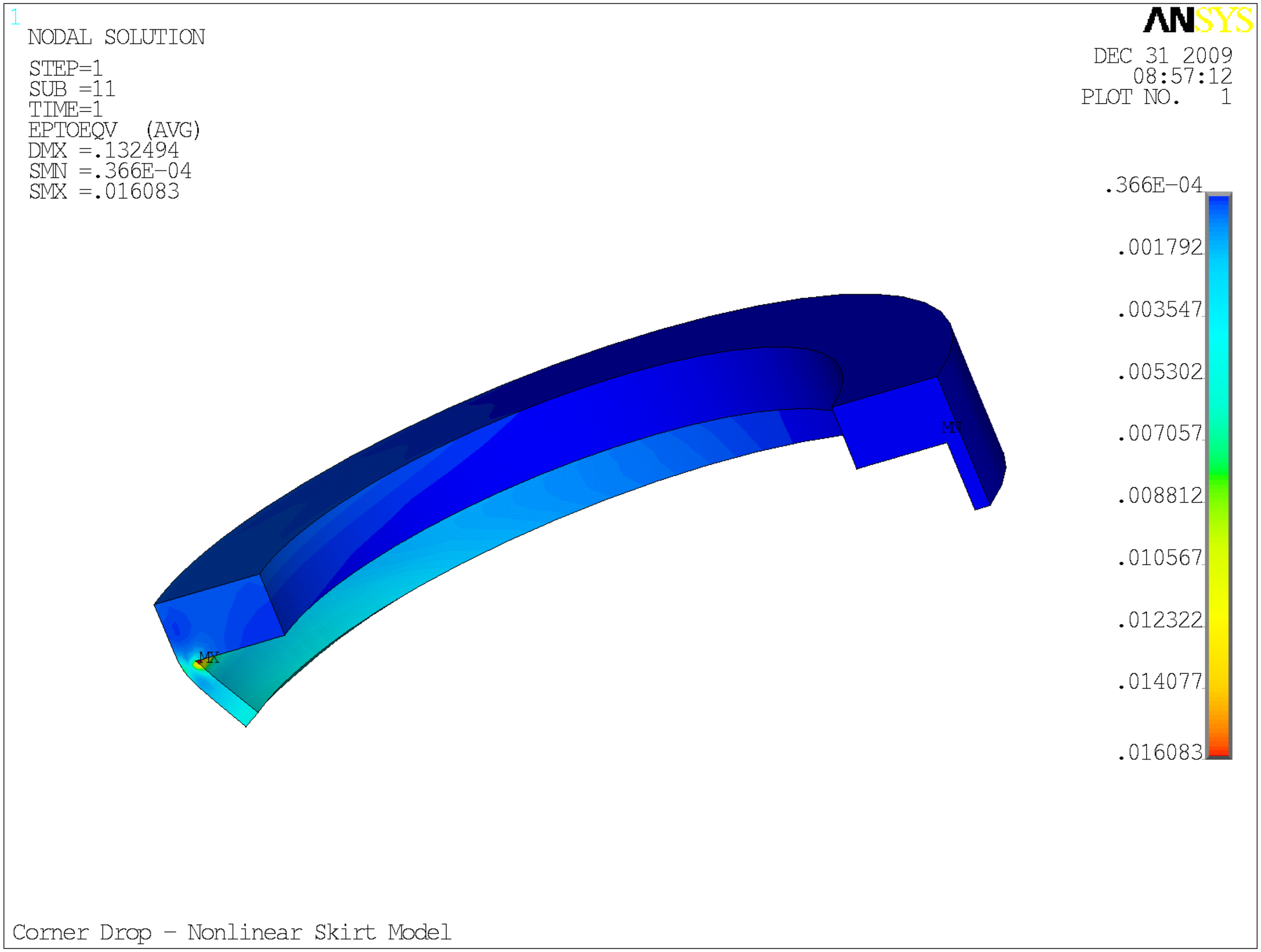

Figure-15

Equivalent Plastic Strain Plot under HAC Corner Drop Loading

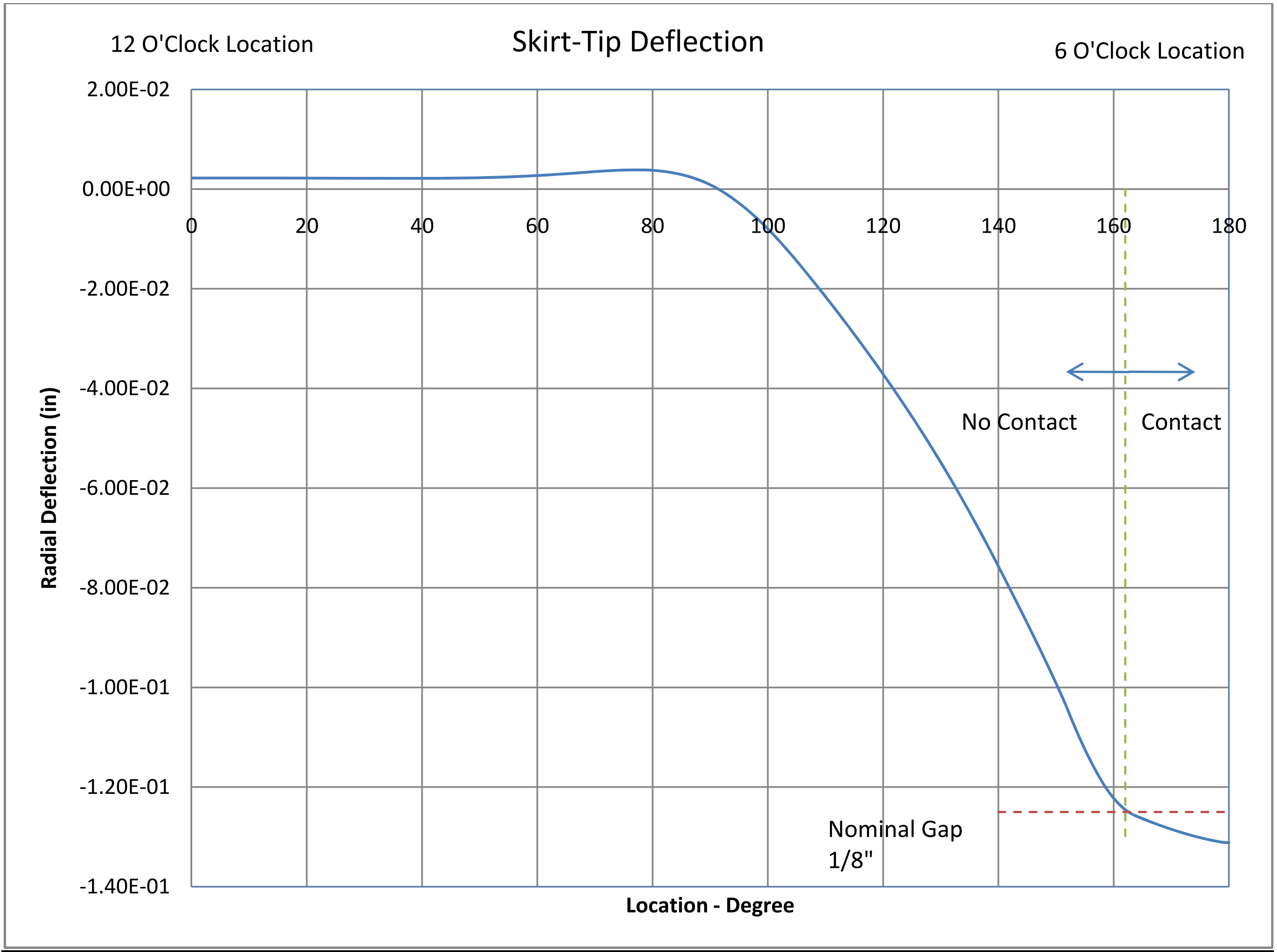

Figure-16
Displacement of the Skirt Tip under HAC Corner Drop Loading

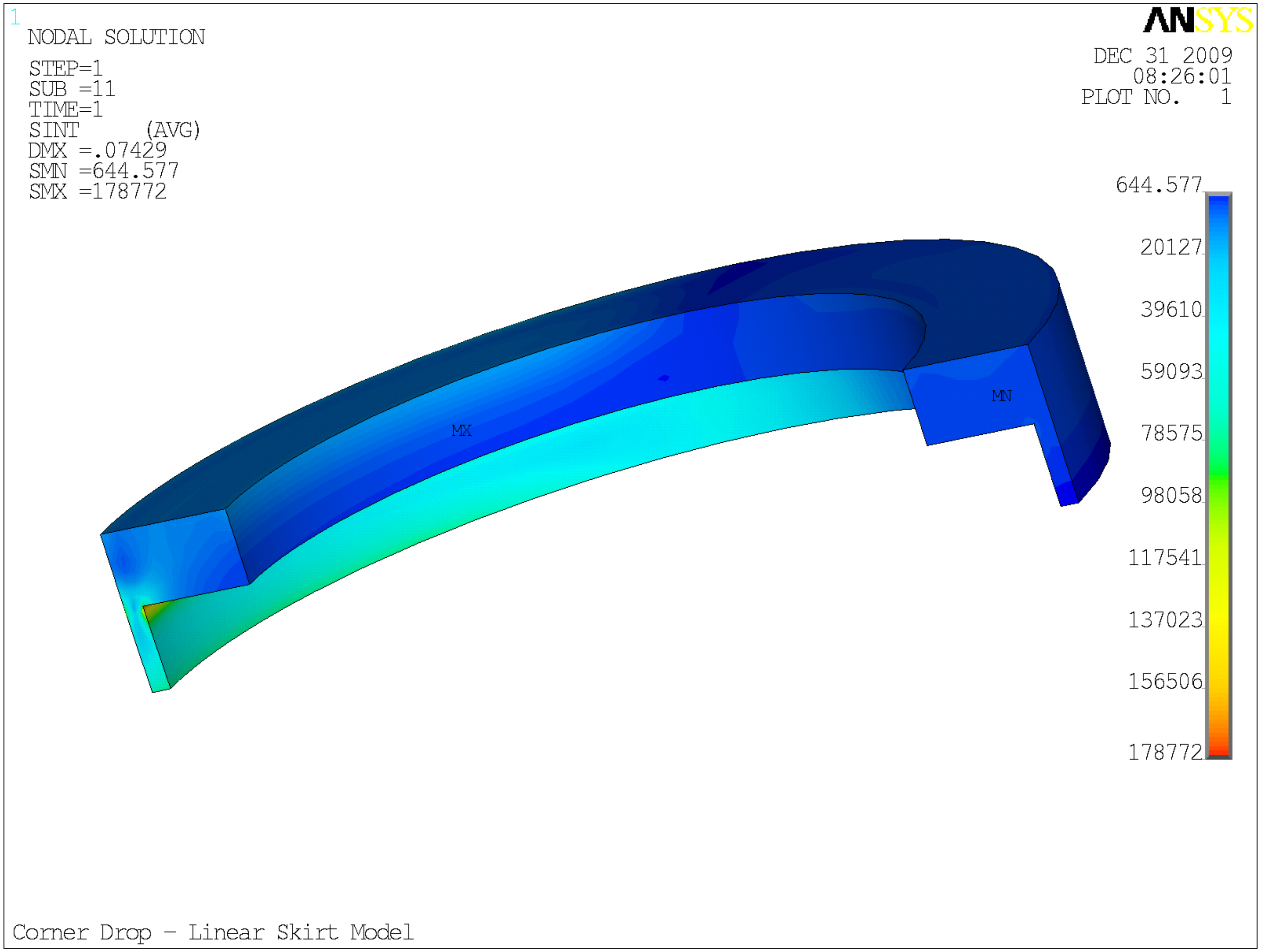

Figure-17

Stress Intensity Plot under HAC Corner Drop Loading Computed by Elastic Model

Title 3-60B Cask Inelastic Analyses of the Bolting Ring Skirt under HAC Drop Loading

Calc. No. ST-609 **Rev.** 0 **Sheet** 17 of 17

Appendix 1

FEM Data Print-Out

(6 Pages)

1.0 SIDE DROP EVALUATION

1.1 Inelastic FEM Database Print-Out

```
/COM,ANSYS RELEASE 11.0SP1 UP20070830       11:11:38    12/31/2009
/PREP7
/NOPR
/TITLE,Nonlinear Skirt Model
ANTYPE, 0
NLGEOM, 1
*IF,_CDRDOFF,EQ,1,THEN     !if solid model was read in
_CDRDOFF=             !reset flag, numoffs already performed
*ELSE              !offset database for the following FE model
NUMOFF,NODE,   10002
NUMOFF,ELEM,    3029
NUMOFF,MAT ,       1
NUMOFF,REAL,       4
NUMOFF,TYPE,       5
NUMOFF,CSYS,       9
*ENDIF
*SET,R1      ,  18.62500000000
*SET,R2      ,  24.50000000000
*SET,R3      ,  25.50000000000
*SET,R4      ,  24.37500000000
*SET,TH1     ,  180.0000000000
*SET,Z1      , -4.000000000000
*SET,Z2      ,  0.000000000000
*SET,Z3      ,  4.375000000000
*SET,_BUTTON ,  1.000000000000
*SET,_CHKMSH ,  0.000000000000
*SET,_CMAP   ,  1.000000000000
*SET,_CONTYP ,  174.0000000000
*SET,_ET_TYPE,  2.000000000000
*SET,_GUI_CLR_BG,' systemButtonFace               '
*SET,_GUI_CLR_FG,' systemButtonText               '
*SET,_GUI_CLR_INFOBG,' systemInfoBackground           '
*SET,_GUI_CLR_SEL,' systemHighlight                 '
*SET,_GUI_CLR_SELBG,' systemHighlight                 '
*SET,_GUI_CLR_SELFG,' systemHighlightText             '
*SET,_GUI_CLR_WIN,' systemWindow                    '
*SET,_GUI_FNT_FMLY,'Arial                           '
*SET,_GUI_FNT_PXLS,  16.00000000000
*SET,_GUI_FNT_SLNT,'r                               '
*SET,_GUI_FNT_WEGT,'medium                          '
*DIM,_L3     ,ARRAY,      44,       1,       1,
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*DIM,_L5     ,ARRAY,      44,       1,       1,
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*SET,_L5     (       4,       1,       1), -1.000000000000
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*SET,_RETURN ,  0.000000000000
*SET,_RL1    ,  1.000000000000
*SET,_STATUS ,  1.000000000000
*SET,_UIQR   ,  1.000000000000
DOF,DELETE
ET,        1, 63
ET,        2, 45
KEYOP,        2, 1,        1
ET,        3, 45
ET,        4,170
ET,        5,174
KEYOP,        5, 9,        1
```

The complete database is included in Appendix 2.

1.2 Skirt Tip Deflection Print-Out

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN COORDINATE SYSTEM 1

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
10	-0.13129	0.16078E-16	-0.90087E-02	0.0000	0.0000	0.0000
264	-0.99094E-01	0.53473E-02	-0.57774E-02	0.0000	0.0000	0.0000
265	-0.13119	0.23049E-03	-0.89793E-02	0.0000	0.0000	0.0000
266	-0.13092	0.47528E-03	-0.89083E-02	0.0000	0.0000	0.0000
267	-0.13054	0.72912E-03	-0.88223E-02	0.0000	0.0000	0.0000
268	-0.13005	0.98318E-03	-0.87390E-02	0.0000	0.0000	0.0000
269	-0.12947	0.12365E-02	-0.86672E-02	0.0000	0.0000	0.0000
270	-0.12883	0.15059E-02	-0.86355E-02	0.0000	0.0000	0.0000
271	-0.12795	0.18344E-02	-0.86178E-02	0.0000	0.0000	0.0000
272	-0.12678	0.23372E-02	-0.87028E-02	0.0000	0.0000	0.0000
273	-0.12501	0.32472E-02	-0.89012E-02	0.0000	0.0000	0.0000
274	-0.12090	0.46511E-02	-0.88141E-02	0.0000	0.0000	0.0000
275	-0.11206	0.57669E-02	-0.78369E-02	0.0000	0.0000	0.0000
1427	0.21057E-02	0.0000	0.36147E-03			
1501	-0.88666E-01	0.57232E-02	-0.57390E-02	0.0000	0.0000	0.0000
1502	-0.78421E-01	0.69272E-02	-0.54697E-02	0.0000	0.0000	0.0000
1503	-0.64409E-01	0.82935E-02	-0.44544E-02	0.0000	0.0000	0.0000
1504	-0.48575E-01	0.93263E-02	-0.32258E-02	0.0000	0.0000	0.0000
1505	-0.32981E-01	0.96823E-02	-0.21217E-02	0.0000	0.0000	0.0000
1506	-0.18564E-01	0.92227E-02	-0.11426E-02	0.0000	0.0000	0.0000
1507	-0.66853E-02	0.80467E-02	-0.36986E-03	0.0000	0.0000	0.0000
1508	0.88128E-03	0.64254E-02	0.13534E-03	0.0000	0.0000	0.0000
1509	0.39639E-02	0.49321E-02	0.38420E-03	0.0000	0.0000	0.0000
1510	0.42408E-02	0.38956E-02	0.45388E-03	0.0000	0.0000	0.0000
1511	0.34889E-02	0.32591E-02	0.43948E-03	0.0000	0.0000	0.0000
1512	0.27154E-02	0.28454E-02	0.40500E-03	0.0000	0.0000	0.0000
1513	0.22435E-02	0.25123E-02	0.37821E-03	0.0000	0.0000	0.0000
1514	0.20499E-02	0.21861E-02	0.36414E-03	0.0000	0.0000	0.0000
1515	0.20155E-02	0.18432E-02	0.35921E-03	0.0000	0.0000	0.0000
1516	0.20409E-02	0.14838E-02	0.35879E-03	0.0000	0.0000	0.0000
1517	0.20728E-02	0.11152E-02	0.35977E-03	0.0000	0.0000	0.0000
1518	0.20937E-02	0.74347E-03	0.36074E-03	0.0000	0.0000	0.0000
1519	0.21032E-02	0.37150E-03	0.36130E-03	0.0000	0.0000	0.0000

MAXIMUM ABSOLUTE VALUES

	UX	UY	UZ	ROTX	ROTY	ROTZ
NODE	10	1505	10	0	0	0
VALUE	-0.13129	0.96823E-02	-0.90087E-02	0.0000	0.0000	0.0000

1.3 Contact Surface Reaction Print-Out

```
**** SUMMATION OF TOTAL FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****
  FX  =  -45416.58
  FY  =  -15488.74
  FZ  =   1318.375
  MX  =   55567.04
  MY  =  -158553.7
  MZ  =   18741.39

 SUMMATION POINT=  0.0000      0.0000      0.0000
```

2.0 CORNER DROP EVALUATION

2.1 Inelastic FEM Database Print-Out

```
/COM,ANSYS RELEASE 11.0SP1 UP20070830       11:10:36    12/31/2009
/PREP7
/NOPR
/TITLE,Corner Drop - Nonlinear Skirt Model
ANTYPE, 0
NLGEOM, 1
*IF,_CDRDOFF,EQ,1,THEN     !if solid model was read in
_CDRDOFF=             !reset flag, numoffs already performed
*ELSE              !offset database for the following FE model
NUMOFF,NODE,   10002
NUMOFF,ELEM,    3029
NUMOFF,MAT ,       1
NUMOFF,REAL,       4
NUMOFF,TYPE,       5
NUMOFF,CSYS,       9
*ENDIF
*SET,R1      ,  18.62500000000
*SET,R2      ,  24.50000000000
*SET,R3      ,  25.50000000000
*SET,R4      ,  24.37500000000
*SET,TH1     ,  180.0000000000
*SET,Z1      , -4.000000000000
*SET,Z2      ,  0.000000000000
*SET,Z3      ,  4.375000000000
*SET,_BUTTON ,  1.000000000000
*SET,_CHKMSH ,  0.000000000000
*SET,_CMAP   ,  1.000000000000
*SET,_CONTYP ,  174.0000000000
*SET,_ET_TYPE,  2.000000000000
*SET,_GUI_CLR_BG,' systemButtonFace               '
*SET,_GUI_CLR_FG,' systemButtonText               '
*SET,_GUI_CLR_INFOBG,' systemInfoBackground           '
*SET,_GUI_CLR_SEL,' systemHighlight                 '
*SET,_GUI_CLR_SELBG,' systemHighlight                 '
*SET,_GUI_CLR_SELFG,' systemHighlightText             '
*SET,_GUI_CLR_WIN,' systemWindow                    '
*SET,_GUI_FNT_FMLY,'Arial                           '
*SET,_GUI_FNT_PXLS,  16.00000000000
*SET,_GUI_FNT_SLNT,'r                               '
*SET,_GUI_FNT_WEGT,'medium                          '
*DIM,_L3     ,ARRAY,      44,       1,       1,
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*SET,_L3     (      40,       1,       1),  1.000000000000
*SET,_L3     (      41,       1,       1),  1.000000000000
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*SET,_L3     (      43,       1,       1),  1.000000000000
*SET,_L3     (      44,       1,       1),  1.000000000000
*DIM,_L4     ,ARRAY,      44,       1,       1,
*DIM,_L5     ,ARRAY,      44,       1,       1,
*SET,_L5     (       1,       1,       1), -1.000000000000
*SET,_L5     (       2,       1,       1), -1.000000000000
*SET,_L5     (       3,       1,       1), -1.000000000000
*SET,_L5     (       4,       1,       1), -1.000000000000
```

```
*SET,_L5     (       5,       1,       1), -1.000000000000
*SET,_L5     (       6,       1,       1), -1.000000000000
*SET,_L5     (       7,       1,       1), -1.000000000000
*SET,_L5     (       8,       1,       1), -1.000000000000
*SET,_L5     (       9,       1,       1), -1.000000000000
*SET,_L5     (      10,       1,       1), -1.000000000000
*SET,_L5     (      11,       1,       1), -1.000000000000
*SET,_L5     (      12,       1,       1), -1.000000000000
*SET,_L5     (      13,       1,       1), -1.000000000000
*SET,_L5     (      14,       1,       1), -1.000000000000
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*SET,_L5     (      21,       1,       1), -1.000000000000
*SET,_L5     (      22,       1,       1), -1.000000000000
*SET,_L5     (      23,       1,       1), -1.000000000000
*SET,_L5     (      24,       1,       1), -1.000000000000
*SET,_L5     (      25,       1,       1), -1.000000000000
*SET,_L5     (      26,       1,       1), -1.000000000000
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*SET,_L5     (      29,       1,       1), -1.000000000000
*SET,_L5     (      30,       1,       1), -1.000000000000
*SET,_L5     (      31,       1,       1), -1.000000000000
*SET,_L5     (      32,       1,       1), -1.000000000000
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*SET,_L5     (      34,       1,       1), -1.000000000000
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*SET,_RC_SET ,  4.000000000000
*SET,_RETURN ,  0.000000000000
*SET,_RL1    ,  1.000000000000
*SET,_STATUS ,  1.000000000000
*SET,_UIQR   ,  1.000000000000
DOF,DELETE
ET,       1, 63
ET,       2, 45
KEYOP,       2, 1,       1
ET,       3, 45
ET,       4,170
ET,       5,174
KEYOP,       5, 9,       1
```

The complete database is included in Appendix 2.

2.2 Skirt Tip Deflection Print-Out

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN COORDINATE SYSTEM 1

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
10	-0.13116	0.16063E-16	-0.18728E-01	0.0000	0.0000	0.0000
264	-0.99116E-01	0.58145E-02	-0.13217E-01	0.0000	0.0000	0.0000
265	-0.13107	0.19258E-03	-0.18697E-01	0.0000	0.0000	0.0000
266	-0.13082	0.40429E-03	-0.18623E-01	0.0000	0.0000	0.0000
267	-0.13046	0.63170E-03	-0.18534E-01	0.0000	0.0000	0.0000
268	-0.12999	0.87884E-03	-0.18430E-01	0.0000	0.0000	0.0000
269	-0.12939	0.11602E-02	-0.18303E-01	0.0000	0.0000	0.0000
270	-0.12863	0.14940E-02	-0.18144E-01	0.0000	0.0000	0.0000
271	-0.12766	0.19109E-02	-0.17952E-01	0.0000	0.0000	0.0000
272	-0.12642	0.24980E-02	-0.17764E-01	0.0000	0.0000	0.0000
273	-0.12464	0.34003E-02	-0.17683E-01	0.0000	0.0000	0.0000
274	-0.12000	0.45346E-02	-0.17017E-01	0.0000	0.0000	0.0000
275	-0.11135	0.53960E-02	-0.15533E-01	0.0000	0.0000	0.0000
1427	0.22331E-02	0.0000	0.38371E-03			
1501	-0.81332E-01	0.70582E-02	-0.10463E-01	0.0000	0.0000	0.0000
1502	-0.64853E-01	0.78651E-02	-0.81243E-02	0.0000	0.0000	0.0000
1503	-0.50122E-01	0.84995E-02	-0.61531E-02	0.0000	0.0000	0.0000
1504	-0.37133E-01	0.88507E-02	-0.45505E-02	0.0000	0.0000	0.0000
1505	-0.25299E-01	0.87792E-02	-0.31283E-02	0.0000	0.0000	0.0000
1506	-0.14425E-01	0.83364E-02	-0.18358E-02	0.0000	0.0000	0.0000
1507	-0.52001E-02	0.74396E-02	-0.61064E-03	0.0000	0.0000	0.0000
1508	0.87911E-03	0.62078E-02	0.13964E-03	0.0000	0.0000	0.0000
1509	0.34741E-02	0.50077E-02	0.39399E-03	0.0000	0.0000	0.0000
1510	0.38196E-02	0.41038E-02	0.45971E-03	0.0000	0.0000	0.0000
1511	0.33007E-02	0.34963E-02	0.44811E-03	0.0000	0.0000	0.0000
1512	0.27232E-02	0.30610E-02	0.41989E-03	0.0000	0.0000	0.0000
1513	0.23583E-02	0.26913E-02	0.39806E-03	0.0000	0.0000	0.0000
1514	0.22019E-02	0.23301E-02	0.38650E-03	0.0000	0.0000	0.0000
1515	0.21690E-02	0.19578E-02	0.38229E-03	0.0000	0.0000	0.0000
1516	0.21847E-02	0.15735E-02	0.38175E-03	0.0000	0.0000	0.0000
1517	0.22078E-02	0.11821E-02	0.38243E-03	0.0000	0.0000	0.0000
1518	0.22236E-02	0.78818E-03	0.38315E-03	0.0000	0.0000	0.0000
1519	0.22311E-02	0.39394E-03	0.38358E-03	0.0000	0.0000	0.0000

MAXIMUM ABSOLUTE VALUES

NODE	10	1504	10	0	0	0
VALUE	-0.13116	0.88507E-02	-0.18728E-01	0.0000	0.0000	0.0000

2.3 Contact Surface Reaction Print-Out

**** SUMMATION OF TOTAL FORCES AND MOMENTS IN THE GLOBAL COORDINATE SYSTEM *****

FX = -13314.88
FY = -3473.623
FZ = 414.9515
MX = 12230.61
MY = -45516.20
MZ = 4697.977

SUMMATION POINT= 0.0000 0.0000 0.0000

Appendix 2

FEM Electronic Data

(2 Pages + 1 CD)

Directory of Files on the CD

```
 Volume in drive F is ST-609 Rev0 App2
 Volume Serial Number is 2F60-7758

 Directory of F:\

12/31/2009  11:12 AM    <DIR>          Corner Drop
12/31/2009  11:12 AM    <DIR>          Side Drop
               0 File(s)              0 bytes

 Directory of F:\Corner Drop

12/31/2009  11:12 AM    <DIR>          .
12/31/2009  11:17 AM    <DIR>          ..
12/31/2009  10:11 AM            15,594 Disp.xlsx
12/31/2009  11:10 AM           888,677 file.cdb
12/31/2009  09:53 AM        17,629,184 file.db
12/04/2009  04:21 PM        88,014,848 file.rst
12/31/2009  08:54 AM            74,184 file000.png
12/04/2009  04:32 PM           111,020 file001.png
12/04/2009  04:32 PM            94,217 file002.png
12/31/2009  08:57 AM            73,815 file003.png
12/31/2009  09:42 AM               519 FSUM.lis
12/31/2009  10:42 AM    <DIR>          Linear
12/31/2009  11:10 AM           673,864 model.out
12/31/2009  09:53 AM             3,349 PRDISP.lis
              11 File(s)    107,579,271 bytes

 Directory of F:\Corner Drop\Linear

12/31/2009  10:42 AM    <DIR>          .
12/31/2009  11:12 AM    <DIR>          ..
12/31/2009  08:26 AM        15,532,032 file.db
12/04/2009  03:20 PM        82,313,216 file.rst
12/31/2009  08:26 AM           109,685 file001.png
               3 File(s)     97,954,933 bytes

 Directory of F:\Side Drop

12/31/2009  11:12 AM    <DIR>          .
12/31/2009  11:17 AM    <DIR>          ..
11/10/2009  10:09 AM            15,658 Disp.xlsx
12/31/2009  11:11 AM           873,933 file.cdb
12/31/2009  09:39 AM        17,563,648 file.db
11/10/2009  09:18 AM        88,211,456 file.rst
11/09/2009  04:14 PM            87,359 file000.png
11/09/2009  04:17 PM           123,524 file001.png
11/10/2009  09:23 AM            71,168 file002.png
11/10/2009  09:23 AM           116,313 file003.png
11/10/2009  09:26 AM           137,338 file004.png
11/10/2009  01:34 PM           103,710 file005.png
```

```
12/31/2009  09:37 AM           106,517 file008.png
11/10/2009  09:19 AM               519 FSUM.lis
12/31/2009  10:44 AM    <DIR>          Linear
10/28/2009  09:34 AM               472 Model.in
12/31/2009  11:11 AM           655,015 model.out
11/10/2009  09:21 AM             2,567 NLIST.lis
11/10/2009  09:21 AM             3,349 PRDISP.lis
              16 File(s)    108,072,546 bytes

 Directory of F:\Side Drop\Linear

12/31/2009  10:44 AM    <DIR>          .
12/31/2009  11:12 AM    <DIR>          ..
12/31/2009  08:29 AM        15,466,496 file.db
12/04/2009  11:08 AM        82,182,144 file.rst
12/31/2009  08:29 AM           126,101 file001.png
               3 File(s)     97,774,741 bytes

     Total Files Listed:
              33 File(s)    411,381,491 bytes
              12 Dir(s)               0 bytes free
```

1.0 OBJECTIVE

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

2.0 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. Heat Transfer, J.P. Holman, McGraw Hill Book Company, New York, Fifth Edition, 1981.
5. Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.
6. CRC Handbook of Chemistry and Physics, Robert C. Weast and Melvin J. Astel, eds., CRC Press, Inc., Boca Raton, Florida, 62nd ed., 1981.
7. ASME Boiler & Pressure Vessel Code, 2005, Section II, Part D, Materials, American Society of Mechanical Engineers, New York, NY, 2005.
8. Rohsenow and Hartnett, Handbook of Heat Transfer, McGraw Hill Publication, 1973.
9. ANSYS, Version 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.

3.0 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 thermal load analysis of the 3-60B Cask for the normal conditions of transportation (NCT). These conditions include the hot and cold environments - the initial loading for the free and hypothetical drop conditions. The hypothetical fire accident test condition analysis has been performed in a separate document. 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 load cases are presented pictorially in temperature contour plots as well as digital data format, suitable for use with a structural finite element model to obtain the thermal stresses.

4.0 MATERIAL PROPERTIES

Temperature-Independent Metal Thermal Properties

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

Temperature-Dependent Metal Thermal Properties

Temp. (°F)	**Stainless Steel** (Ref. 7)		**Carbon Steel** (Ref.7)		**Lead** (Ref.8)
	Sp. Heat Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Sp. Heat** Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F
70	0.117	0.199	0.104	0.813	0.465
100	0.117	0.201	0.106	0.803	0.461
150	0.120	0.208	0.109	0.789	0.455
200	0.122	0.215	0.113	0.778	0.448
250	0.125	0.222	0.115	0.762	0.441
300	0.126	0.227	0.118	0.748	0.435
350	0.128	0.234	0.122	0.731	0.428
400	0.129	0.241	0.124	0.715	0.422
450	0.130	0.245	0.126	0.701	0.415
500	0.131	0.252	0.128	0.683	0.409
550	0.132	0.257	0.131	0.667	0.402
600	0.133	0.262	0.133	0.648	0.395
650	0.134	0.269	0.135	0.632	0.389
700	0.135	0.273	0.139	0.616	0.389
750	0.136	0.278	0.142	0.600	0.389
800	0.136	0.282	0.146	0.583	0.389
900	0.138	0.294	0.154	0.551	0.389
1,000	0.139	0.306	0.163	0.519	0.389
1,100	0.141	0.315	0.172	0.484	0.389
1,200	0.141	0.324	0.184	0.451	0.389
1,300	0.143	0.336	0.205	0.417	0.389
1,400	0.144	0.345	0.411	0.380	0.389
1,500	0.145	0.354	0.199	0.363	0.389

Temperature-Dependent Air Thermal Properties

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

5.0 MODEL DESCRIPTION

The thermal analyses of the 3-60B Cask under various loading conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Ref. 9) 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 employed. Figure 1 shows the finite element model used in various thermal load analyses. Figures 2 and 3 show the exploded views of various regions of the finite element model. Figure 4 shows the material property model numbers of various components of the cask.

The finite element model is made of 3-dimensional thermal solid elements (ANSYS SOLID70)that represent the major components of the cask, the cask body, the lid, the bolts, and the fire shield. The 3-60B Cask package is designed to maintain an air gap between the cask ends and the impact limiters. These impact limiters remain attached to the cask body during the normal as well as hypothetical drop test conditions. Heat transfer between the cask ends and the impact limiter plate takes place by means of radiation and conduction through the air gap. Therefore, the impact limiter end plates are also included in the finite element model (see Figure 3). These plates are modeled by 3-dimensional thermal solid elements. The interstitial air gaps between the impact limiter plates and the cask end as well as that between the fire-shield and the cask body are modeled by these elements also.

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

The heat transfer by radiation between the fire-shield and the ambient air is modeled by 3-d thermal surface (ANSYS SURF152). The radiation between the outer shell and the fire-shield, and between the impact limiter plates and the cask body, is modeled by superelements (ANSYS MATRIX50). These elements are formed by modeling the radiating surfaces with thermal shells (ANSYS SHELL57) and specifying the appropriate emissivity of the surfaces and the Stefan-Boltzmann constant. The heat transfer by natural convection between the fire-shield and the ambient air is simulated by 3-d thermal surface (ANSYS SURF152). The outer surfaces of the impact limiter plates, which are covered by foam, are considered to be totally insulated. The real constants used in the ANSYS finite element model, to define the characteristic of various finite elements to simulate the heat transfer by convection and radiation, are based on the derivation in the following section. The heat flux representing the internal heat load and the solar insolation is also presented in the following section. A print-out of the model data input is included in Appendix 1.

5.1 Convection Modeling

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

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

where:

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

A = Area (sq ft)

T_s = cask surface temperature (°F)

T_a = ambient temperature (°F)

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

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

where, for horizontal casks,

$$C = 0.18 \text{ (Btu/hr-ft}^2\text{-F}^{4/3}) = 3.4722\times10^{-7} \text{ (Btu/sec-in}^2\text{-F)}$$

5.2 Radiation Modeling

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

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

where:

q = heat flow rate (Btu/hr)

σ = Stefan-Boltzmann Constant
= 1.7136×10^{-9} (Btu/hr-ft^2-R^4)
= 3.3056×10^{-15} (Btu/sec-in^2-R^4)

ε = emissivity

F = geometric form factor

A = area (sq ft)

T = temperature (°R)

I = first node number

J = second node number

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

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

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

where: ε = overall emissivity

ε_1 = surface 1 emissivity

ε_2 = surface 2 emissivity

An environment emissivity coefficient of 0.9 was assumed for the normal conditions of transport. The emissivity of the outside of the fire-shield and the environment are 0.8 and 0.9, respectively. Thus, the overall emissivity is calculated by the above equation to be 0.7347.

Form factor value of 1.0 is used and the area of the surface is automatically calculated by the computer program.

It should be noted that the use of 0.7347 for emissivity instead of the code specified value of 0.9 is conservative for the NCT environment as a lesser amount of heat is rejected from the cask, which results in higher cask temperatures.

The radiation between the outer shell and the fire-shield, and between the impact limiter plates and the cask body, is modeled by superelements (ANSYS MATRIX50). These elements are formed by modeling the radiating surfaces with thermal shells (ANSYS SHELL57). The emissivity value is set equal to minimum emissivity of stainless steel, i.e. 0.15. Stefan-Boltzmann constant as defined above is used. The form-factor of unity is used and the appropriate radiating surface area is automatically calculated by the computer program.

5.3 Solar Insolation Modeling

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

5.4 Internal Heat Load Modeling

The internal heat load content of the 3-60B Cask has been represented in the finite element models by two different ways. In the first, the heat load is implicitly represented by a uniform heat flux over the cask cavity. In the second, it is explicitly represented by the finite element model of the waste container and the cavity air. The heat load in this case is applied as a constant heat flux over the waste container wall.

5.4.1 Implicit Internal Heat Load Modeling

The 500-Watt decay heat load is modeled as a constant heat flux over the exposed sidewall inner surface of the cask. The heat flow rate across the inner surface of the cask inner shell is set equal to the decay heat load. This is a conservative approximation during the fire transient, since, in reality, some of the heat from the fire would be transferred to the waste. Thus, the waste would act as a heat sink lowering the wall temperature.

$$\text{Internal heat load, } q = 500 \text{ W} = 500\times9.4804\times10^{-4} = 0.4740 \text{ Btu/sec}$$

The cask inside diameter is 35" and the cavity height is 109.375". Thus, the heat flux on the inside surface of the cask is:

$$q_s = 0.4740/\left(\pi\times35\times109.375 + 2\times\pi/4\times35^2\right)$$
$$= 3.398\times10^{-5} \text{ Btu/sec-in}^2$$

5.4.2 Explicit Internal Heat Load Modeling

In order to obtain the temperature of the waste container and the cavity air during the NCT, they are explicitly represented in the finite element model by 3-dimensional solid elements with appropriate material properties. The waste container is conservatively assumed to be a cylindrical shell having the diameter and length to be approximately ½ of the corresponding cavity dimensions.

Waste Container Outside Diameter = 17", Length = 50", Wall Thickness = 1.0"

Container Inside Surface Area = $\pi\times(17\text{-}2)\times(50\text{-}2) + 2\times[\pi\times(17\text{-}2)^2/4] = 2{,}615\ in^2$

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

$$q_w = 0.474/2{,}615 = 1.813\times10^{-4}\ \text{Btu/sec-in}^2$$

The cavity air is conservatively assumed to be stagnant - no convective heat transfer is assumed to take place between the waste container and the cask cavity. Thus, the heat transfer between these components takes place by means of conduction through the air and radiation between the two bodies. The air conduction is accounted for by the appropriate material properties of the finite elements representing it. The heat transfer by radiation is achieved by the ANSYS radiosity process. The coefficient of emissivity for both the surfaces is assumed to be 0.8 and the form-factor is automatically calculated by the computer program from the geometry of the two bodies. The finite element model of the cask with explicit internal heat load modeling is shown in Figure 6.

6.0 ANALYSES

The finite element model, with the implicit internal heat load modeling, described in Section 5.0 is analyzed for the following loading conditions:

1. Hot Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (1). The loading includes a 100° F ambient temperature, solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation.
2. Cold Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (2). The loading includes a -40° F ambient temperature, no solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation.
3. Normal Hot - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a 100° F ambient temperature, no solar insolation, and maximum internal heat load.
4. Normal Cold - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a -20° F ambient temperature, no solar insolation, and maximum internal heat load.

The finite element model, with explicit heat load modeling, has been used to analyze the NCT hot environment loading case.

7.0 RESULTS

The results of the analyses of the finite element model, with the implicit heat load modeling, are presented in Figures 7 through 10 in form of temperatures contour plots. Table 1 summarizes the maximum calculated temperature of various components of the cask.

The finite element model of the cask, with the explicit internal heat load modeling, results are shown in Figures 11 through 14. Figure 11 shows the temperature profile in the entire cask-waste container system. Figure 12 shows the temperature profile of the cask cavity air. Figure 13 shows the temperature profile in the waste container. The cask body temperature profile is shown in Figure 14.

The calculated temperatures are summarized below:

Maximum cavity temperature	= 227.3 ºF
Average cavity temperature	= 186 ºF (see Figure 13)
Maximum waste container temperature	= 227.5 ºF

From the results of the analyses it is clear that the model with the implicit heat load representation gives higher temperatures in the cask body whereas the one with the explicit heat load representation gives higher cavity temperature. For comparison purposes, the temperature profile of the cask body obtained from the two models for the NCT hot environment loading conditions is shown in Figure 15.

Since the model with implicit heat load representation predicts a more conservative cask body temperature results, they are used in the thermal stress evaluation of the cask.

Table 1

Summary of Maximum NCT Temperatures

Component	**Maximum Calculated Temp.**		**Maximum Allowable Temperature (°F)**
	Location (Node Nos.)	**Value (°F)**	
Fire Shield	2268	177.7	185(1)
Outer Shell	2028	177.6	(2)
Inner Shell	1800	177.8	(2)
Lead	2718	178.9	622
Seals	249	178.6	450

NOTES:

(1) Based on the requirements of 10CFR71.45(g)

(2) Set by stress conditions.

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

9.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on CDROM

Figures

(15 Pages)

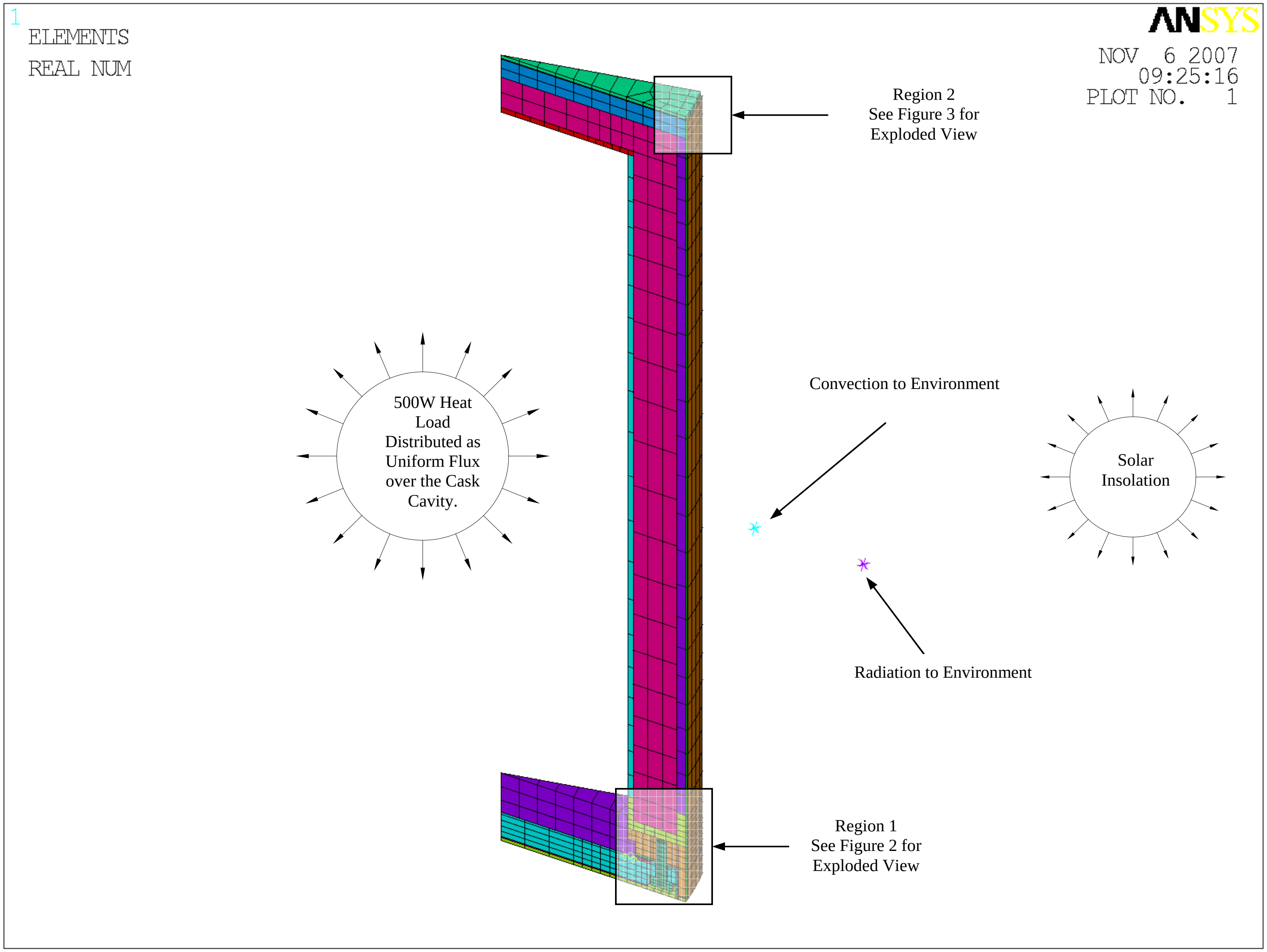


Figure 1 – Finite Element Model of the 3-60B Cask Used for the Thermal Analyses

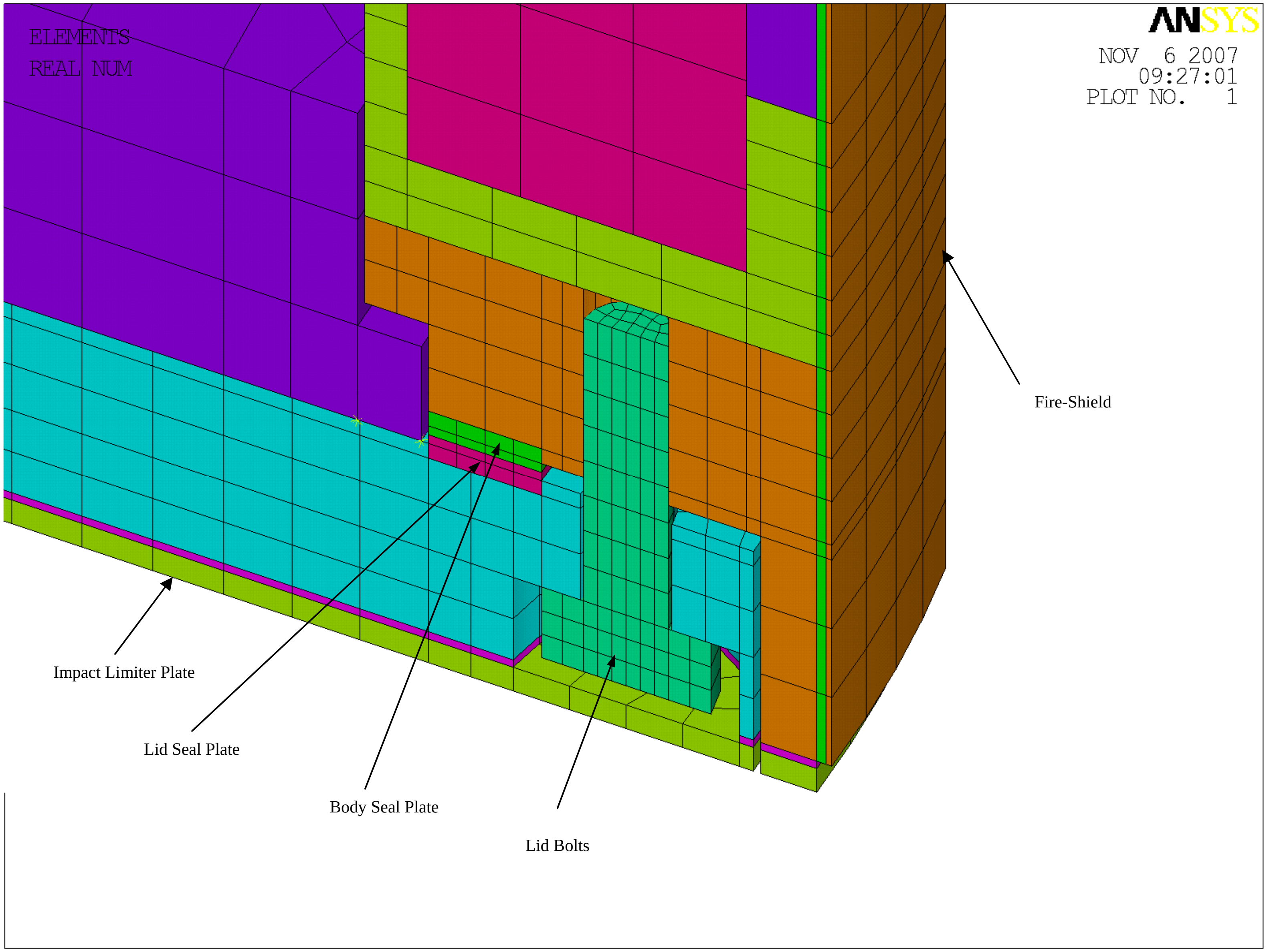


Figure 2 – Exploded View of Region 1 of Figure 1

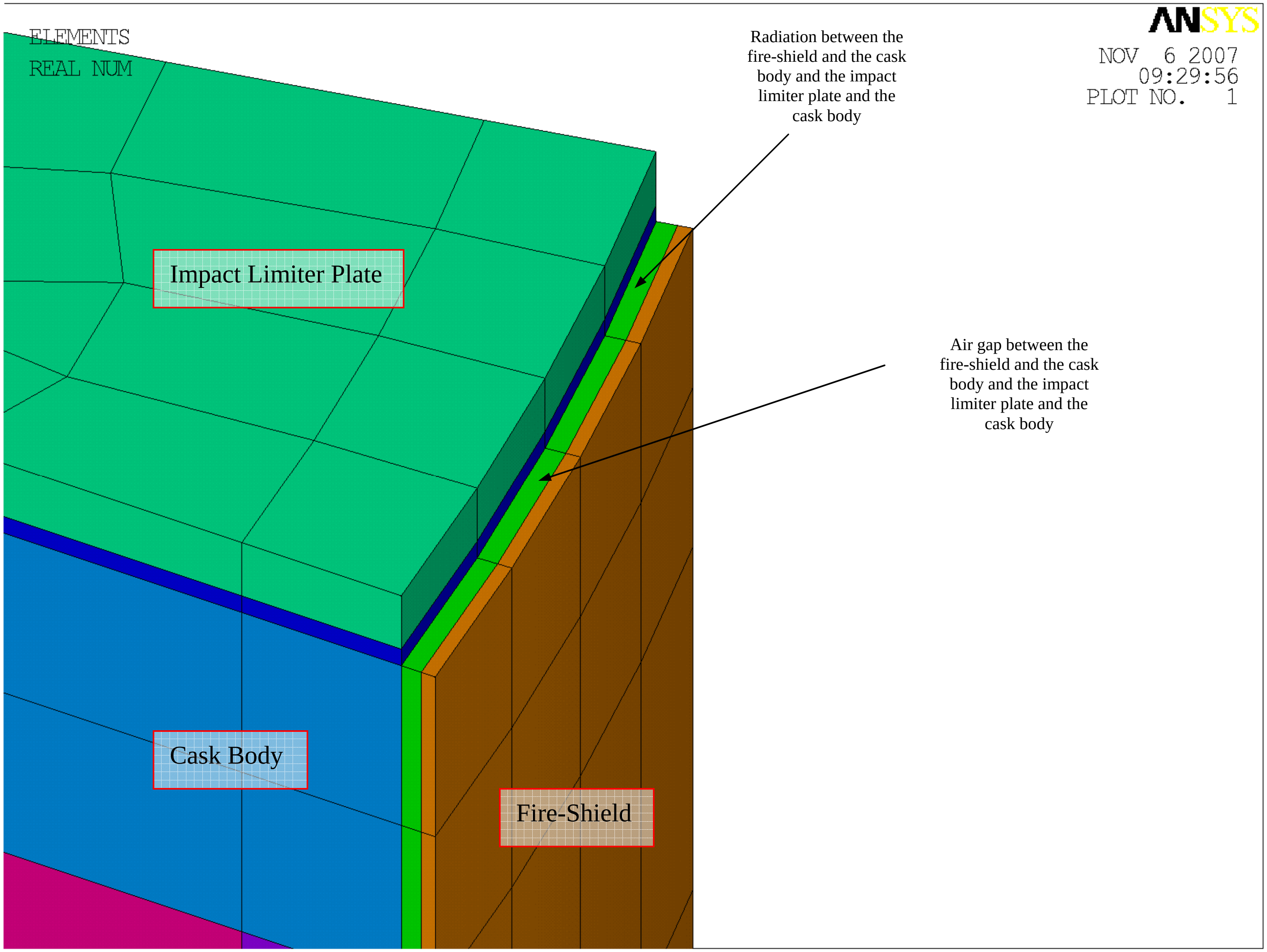


Figure 3 – Exploded View of Region 2 of Figure 1

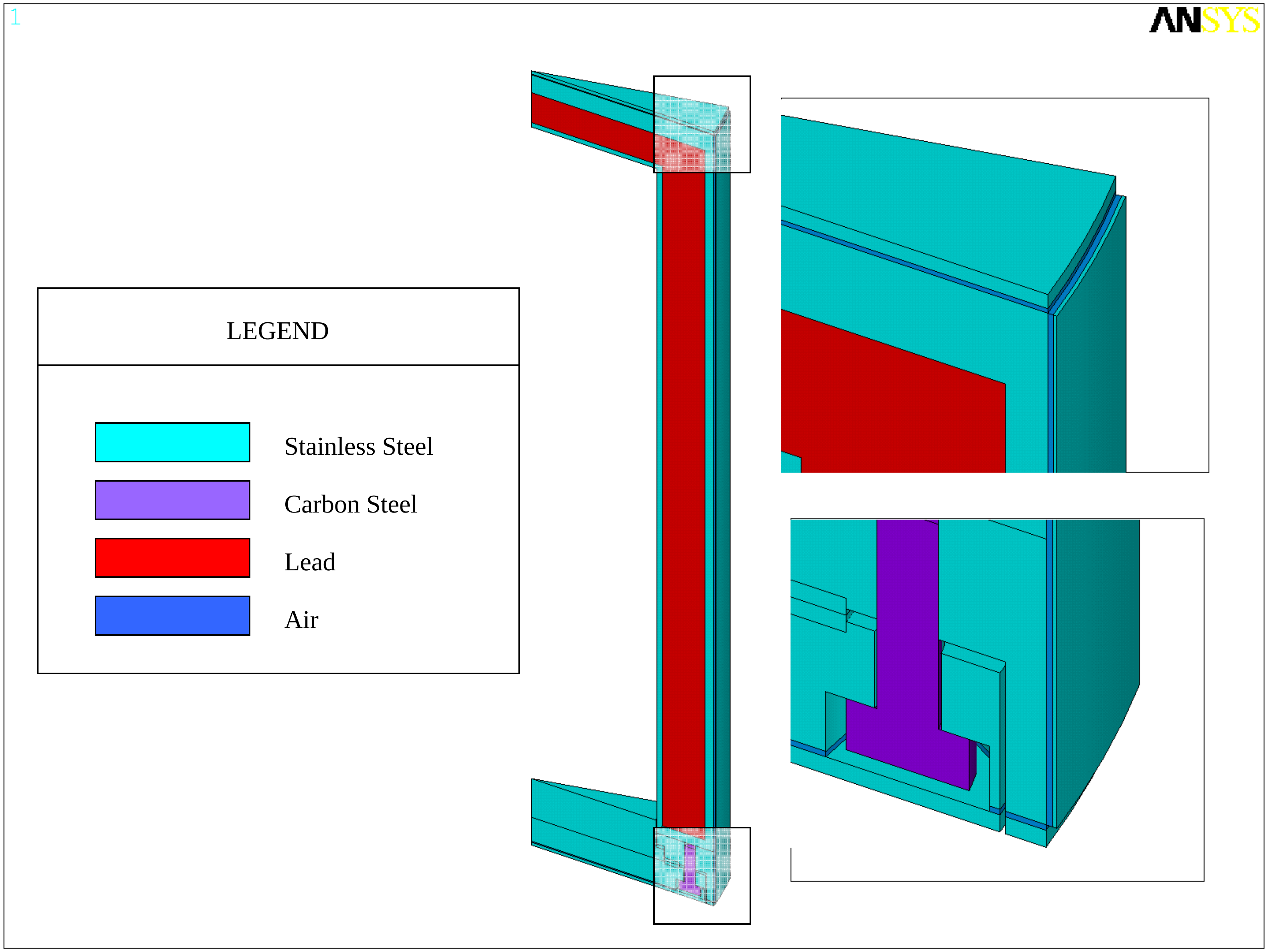


Figure 4 – Materials Used in the Finite Element Model

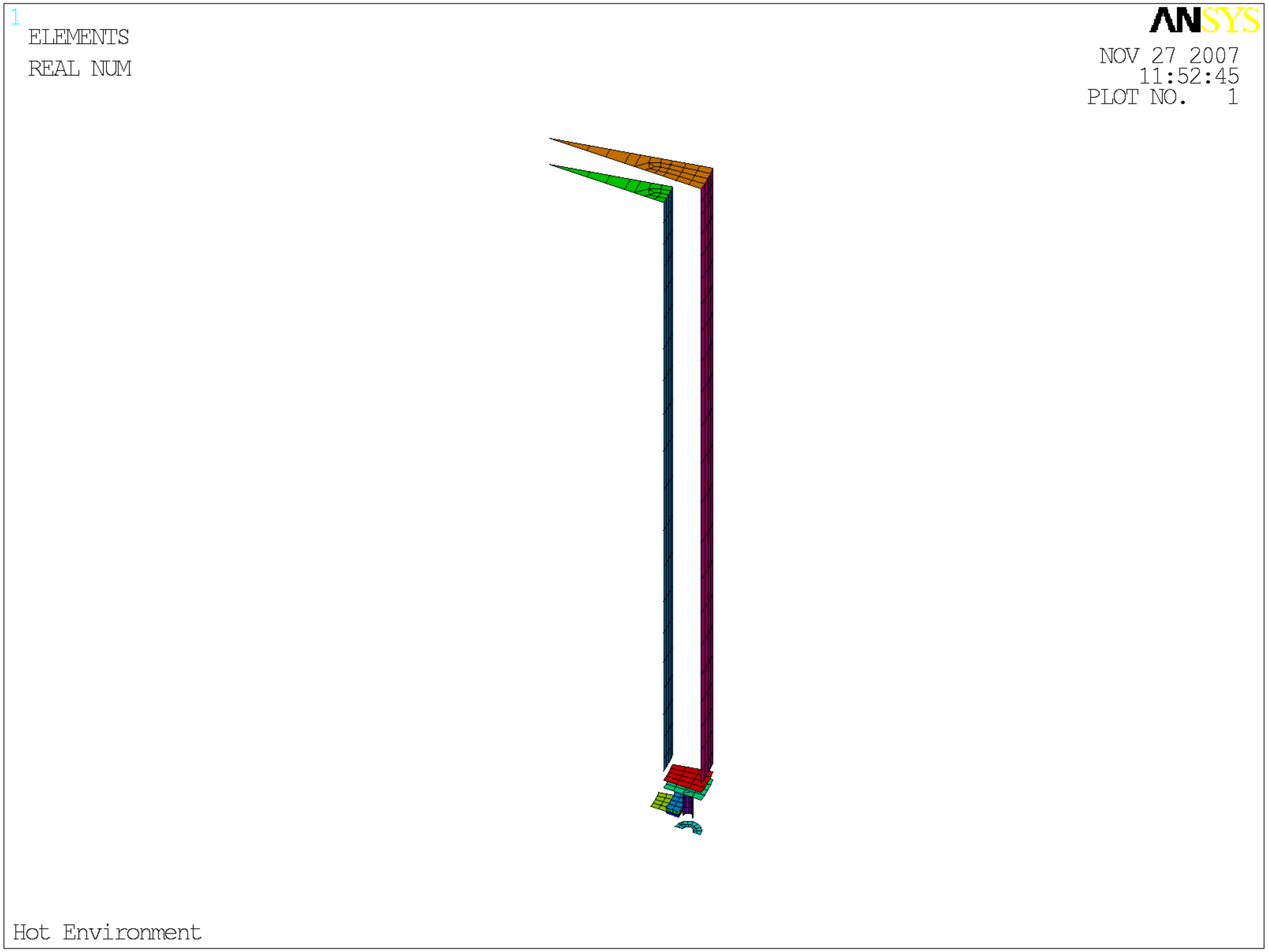


Figure 5 – Contact-Target Pair Elements (Only Target Elements Shown for Clarity)

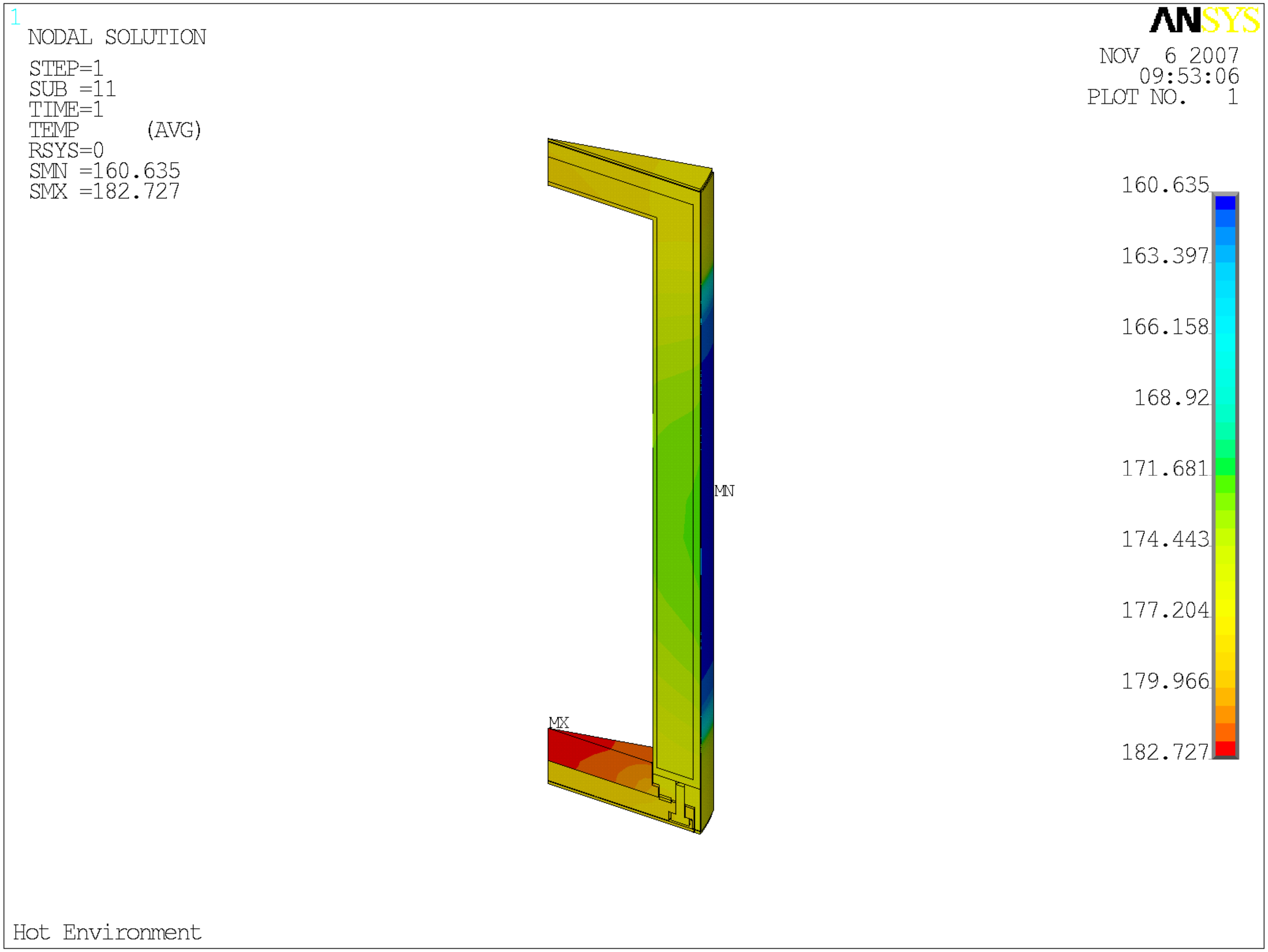


Figure 6 – Temperature Distribution – Hot Environment

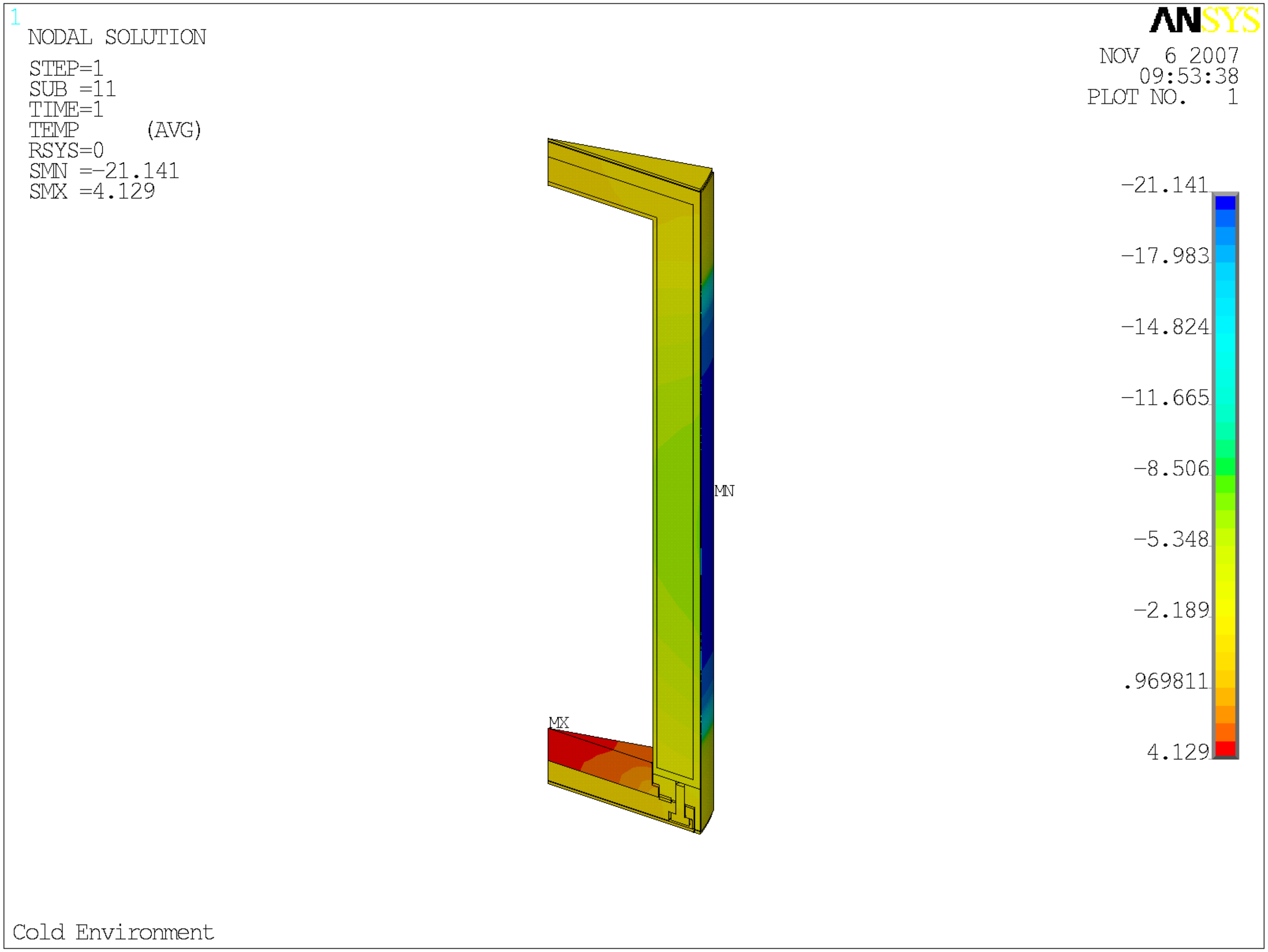


Figure 7 – Temperature Distribution – Cold Environment

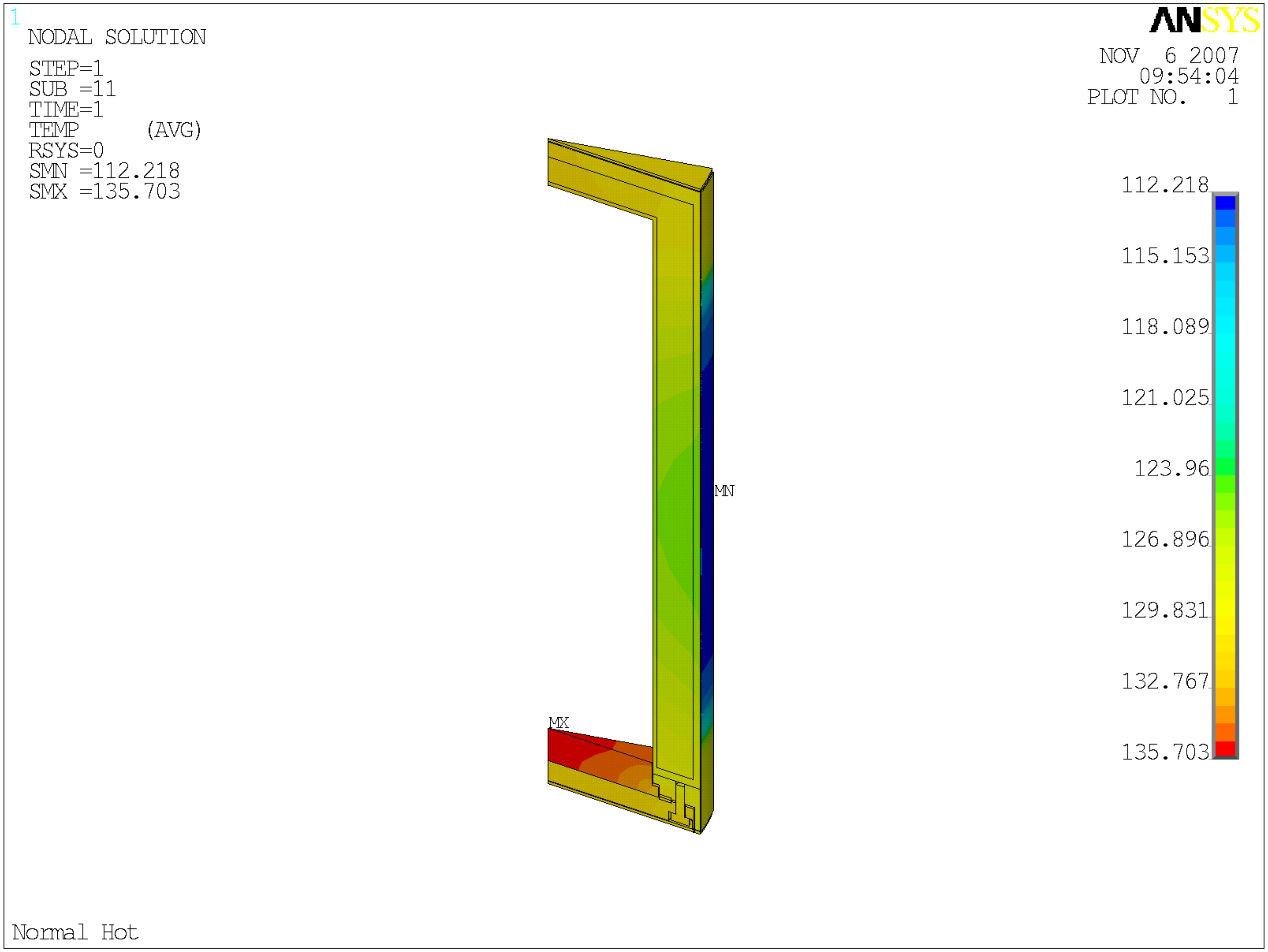


Figure 8 – Temperature Distribution – Normal Hot

Figure 9 – Temperature Distribution – Normal Cold

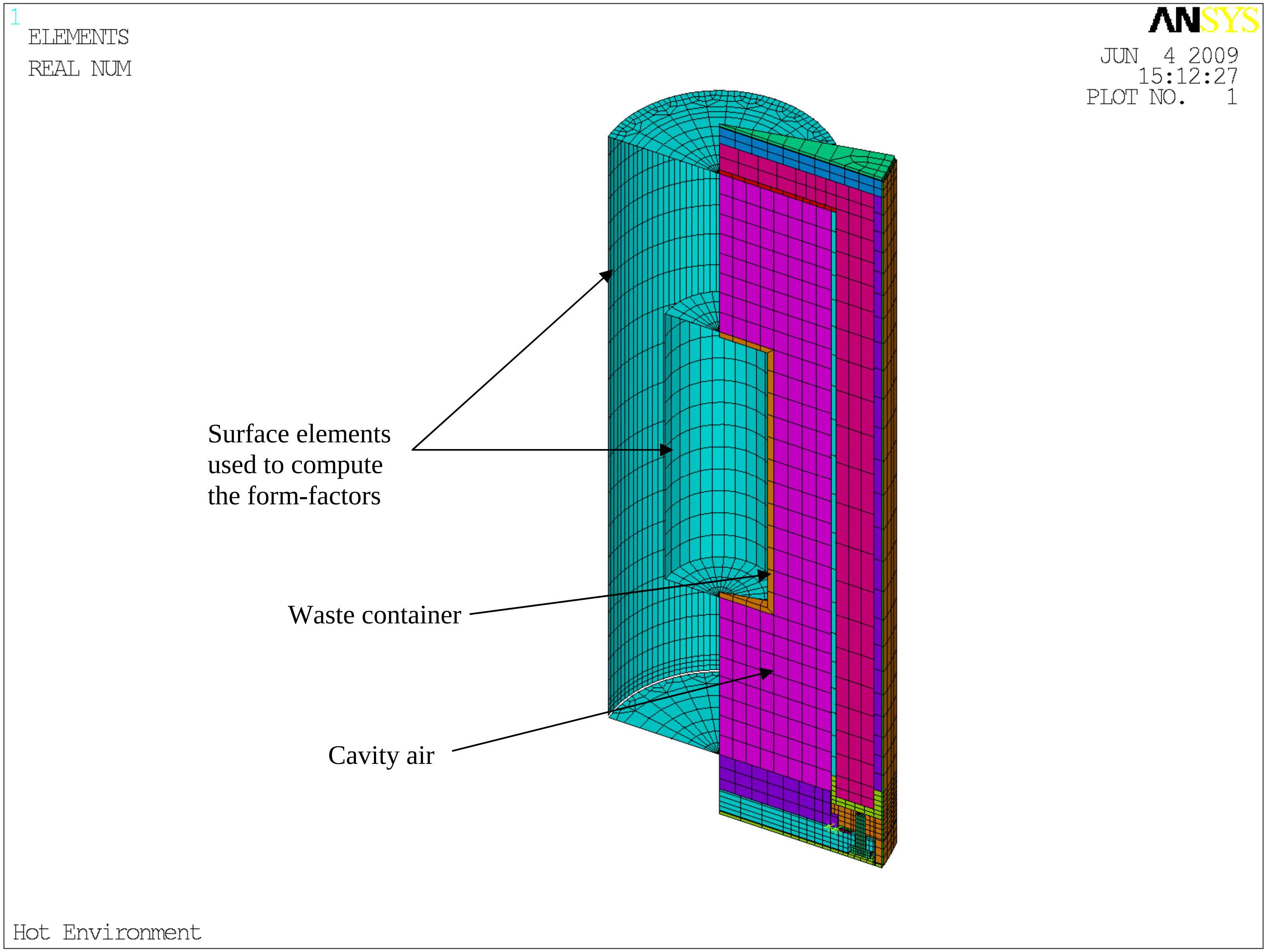


Figure 10 - Finite Element Model with Internal Heat Load Explicitly Modeled

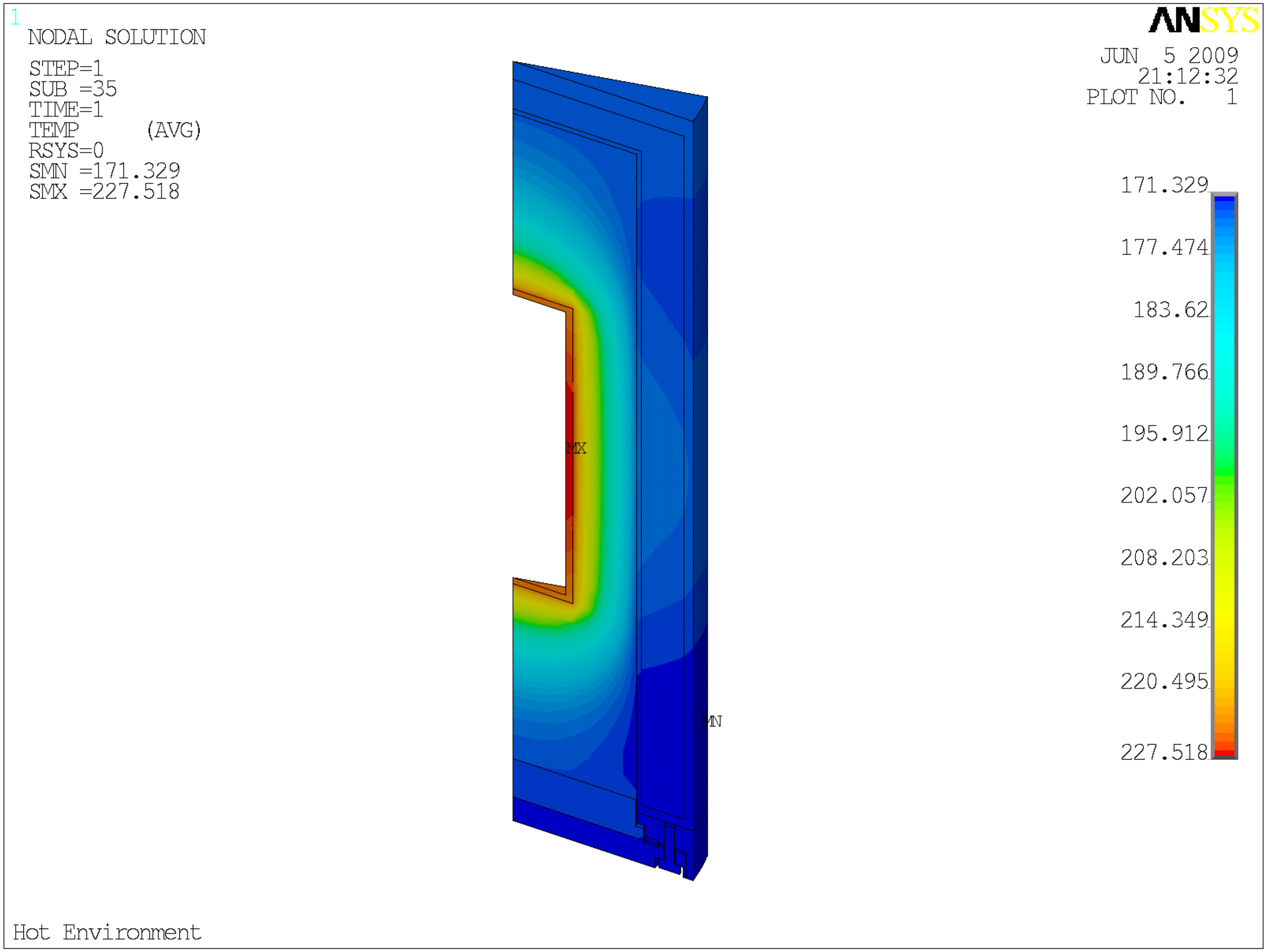


Figure 11 - Temperature Profile of the Entire Cask Including the Contents

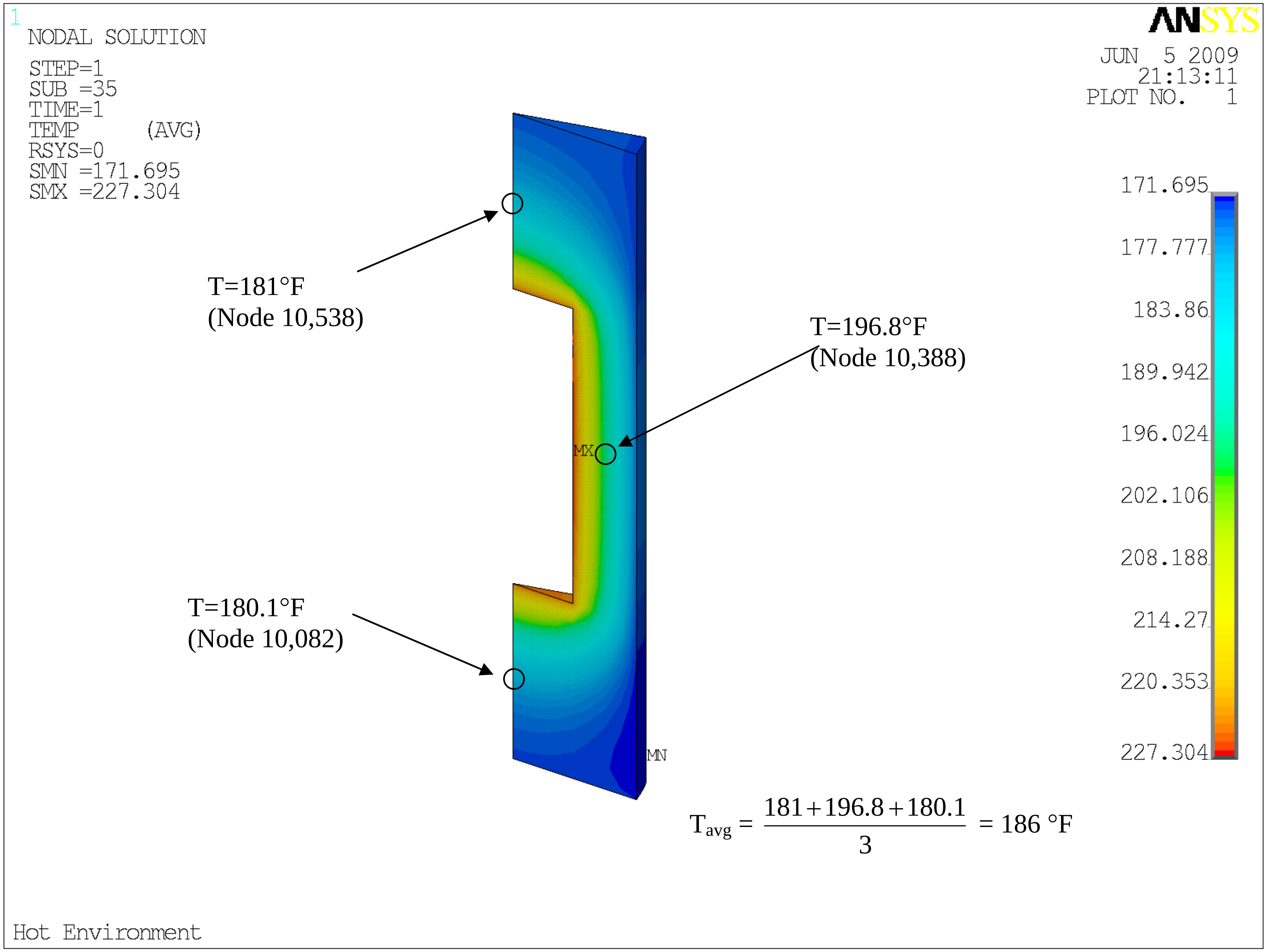


Figure 12 - Temperature Profile of the Cask Cavity Air

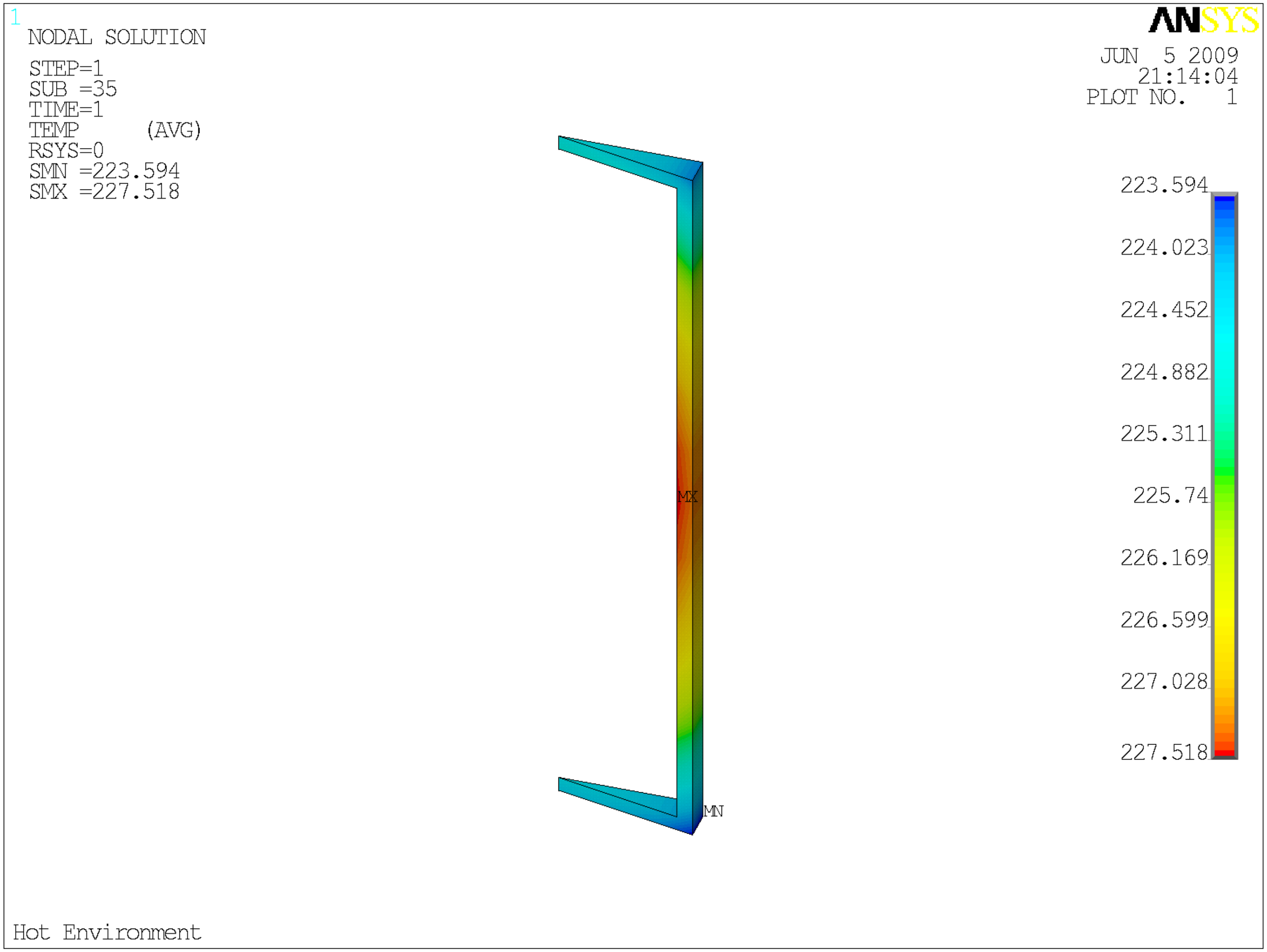


Figure 13 - Temperature Profile of the Waste Container

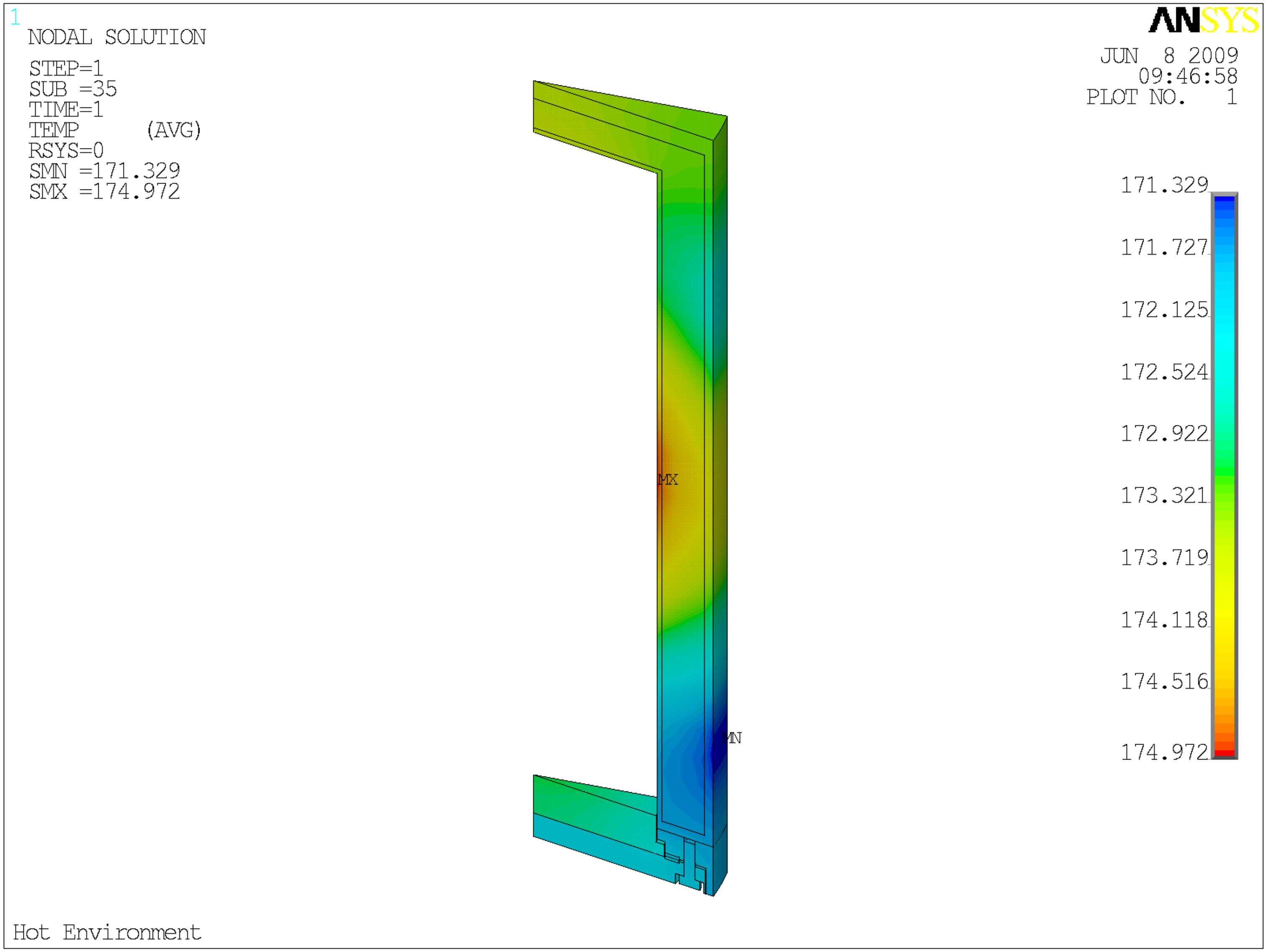
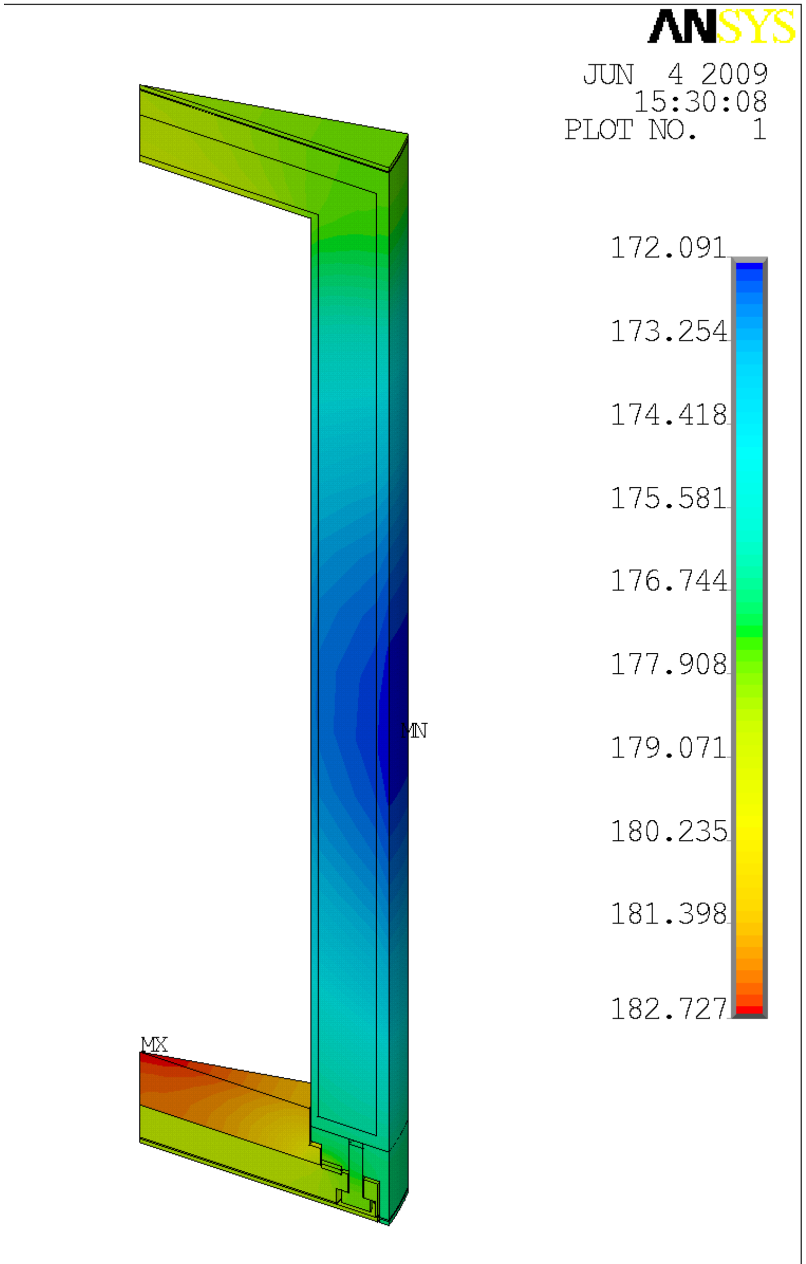


Figure 14 - Cask Temperature Profile with Explicit Content Modeling



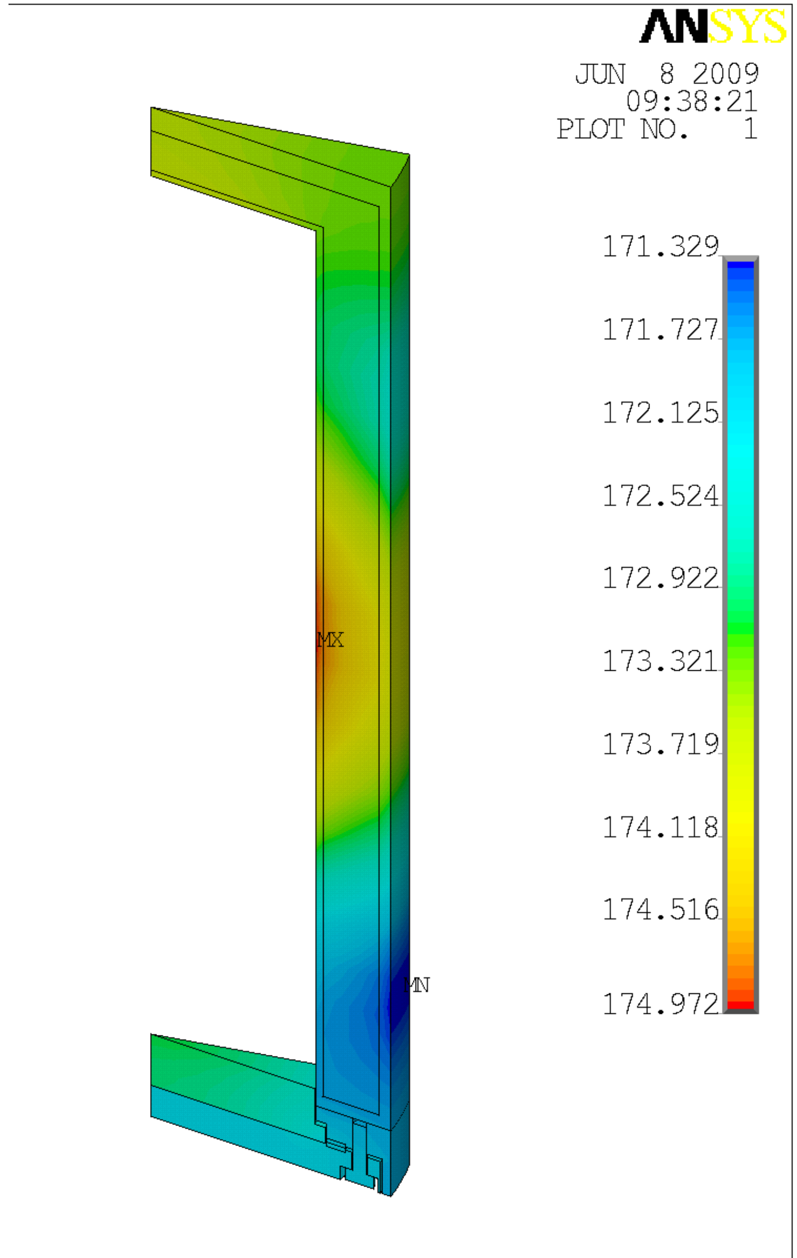


Figure 15 - Comparison of Implicit & Explicit Cask Content Modeling Results

Appendix 1

Printout of the ANSYS model data input

(13 Pages)

3-60B Cask NCT Analyses - ANSYS Model Data

```
    ***** 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\NCT with Conc Heat Load -1

TITLE= Hot Environment

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 09, 2009          11:49
Release 11.0SP1              00222442                 WINDOWS x64  Version

Current working directory: D:\Ansys Analyses\3-60B\Thermal\NCT with Conc Heat Load -1


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  2.5 seconds

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

Hot Environment

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

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

                                Available             Used
Scratch Memory Space. . . .    4796.000 mb          10.632 mb (  0.2%)
Database space  . . . . . . 1048572.000 mb          15.685 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 . . . . . . . . . . .   33290          10933         10933
Elements. . . . . . . . . .   13560           8232          8232

Element types . . . . . . .      69             41          n.a.
Real constant sets. . . . .      53             25          n.a.
Material property sets. . .      27              7          n.a.

Coupling. . . . . . . . . .      52             20          n.a.
Constraint equations. . . .       0              0          n.a.
Master DOFs . . . . . . . .       0              0          n.a.
Dynamic gap conditions. . .       0              0          n.a.

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

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

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

Surface loads on elements . . . . . . . .    156
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. . . . . . . . . .   100.000
   Offset from absolute scale . . . . . .   460.000

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

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

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

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

Current element attributes:
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   Type number . . . . . . . . . . . . .    68  (CONTA174)
   Real number . . . . . . . . . . . . .    53
   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 . . . . . . .   0 (Cartesian)

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

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

Active options for this analysis type:
   Equation solver to use. . . . . . .Program Chosen

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

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

Number of substeps . . . . . . . . . .   100
   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. . . . . . 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. . . . . . . . . .  2.0000
  NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .   100
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
  CONVERGENCE CONTROLS. . . . . . . . . . . . . .USE DEFAULTS
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     BASI        ALL


LIST ELEMENT TYPES FROM      1 TO     69 BY      1

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 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

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 KEYOPT(1-12)=    0  0  0    1  1  0    0  0  1    0  0  0       0

ELEMENT TYPE      5 IS SURF152      3-D THERMAL SURFACE           INOPR
 KEYOPT(1-12)=    0  0  0    1  1  0    1  4  0    0  0  0       0

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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 THERMAL CONTACT     INOPR
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ELEMENT TYPE     17 IS CONTA174     3D 8-NODE THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     50 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)     INOPR
 KEYOPT(1-12)=    1  0  0    0  0  0    0  0  0    0  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-SURF PURE THERM CONTACT    INOPR
 KEYOPT(1-12)=    2  2  0    0  0  0    0  0  0    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 THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     59 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     60 IS CONTA174     3D 8-NODE THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 CONTA174     3D 8-NODE THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 CONTA174     3D 8-NODE THERMAL CONTACT       INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     69 IS SURF252      3-D THERMAL SURFACE             INOPR
 KEYOPT(1-12)=    0  0  0    1  0  0    0  0  0    0  0  0       0

CURRENT NODAL DOF SET IS  TEMP
 THREE-DIMENSIONAL MODEL

LIST REAL SETS       1 TO      53 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

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
   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      49  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      49  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      49  ITEMS  13 TO  18
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      49  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

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

LIST MATERIALS       1 TO      27 BY       1
 PROPERTY= ALL

PROPERTY TABLE DENS  MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.28240      100.00     0.28240      150.00     0.28240
    200.00     0.28240      250.00     0.28240      300.00     0.28240
    350.00     0.28240      400.00     0.28240      450.00     0.28240
    500.00     0.28240      550.00     0.28240      600.00     0.28240
    650.00     0.28240      700.00     0.28240      750.00     0.28240
    800.00     0.28240      900.00     0.28240      1000.0     0.28240
    1100.0     0.28240      1200.0     0.28240      1300.0     0.28240
    1400.0     0.28240      1500.0     0.28240

PROPERTY TABLE MU    MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000      0.0000

PROPERTY TABLE KXX   MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.19900E-03  100.00     0.20100E-03  150.00     0.20800E-03
    200.00     0.21500E-03  250.00     0.22200E-03  300.00     0.22700E-03
    350.00     0.23400E-03  400.00     0.24100E-03  450.00     0.24500E-03
    500.00     0.25200E-03  550.00     0.25700E-03  600.00     0.26200E-03
    650.00     0.26900E-03  700.00     0.27300E-03  750.00     0.27800E-03
    800.00     0.28200E-03  900.00     0.29400E-03  1000.0     0.30600E-03
    1100.0     0.31500E-03  1200.0     0.32400E-03  1300.0     0.33600E-03
    1400.0     0.34500E-03  1500.0     0.35400E-03

PROPERTY TABLE C     MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
```

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

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

PROPERTY TABLE DENS  MAT=       2  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
   0.0000     0.28300

PROPERTY TABLE KXX   MAT=       2  NUM. POINTS= 16
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
   70.000     0.81300E-03  100.00     0.80300E-03  200.00     0.77800E-03
   300.00     0.74800E-03  400.00     0.71500E-03  500.00     0.67700E-03
   600.00     0.64800E-03  700.00     0.61600E-03  800.00     0.58300E-03
   900.00     0.55100E-03  1000.0     0.51900E-03  1100.0     0.48400E-03
   1200.0     0.45100E-03  1300.0     0.41700E-03  1400.0     0.38000E-03
   1500.0     0.36300E-03

PROPERTY TABLE C     MAT=       2  NUM. POINTS= 16
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
   70.000     0.10330      100.00     0.10530      200.00     0.11210
   300.00     0.11770      400.00     0.12340      500.00     0.12780
   600.00     0.13220      700.00     0.13810      800.00     0.14520
   900.00     0.15350      1000.0     0.16240      1100.0     0.17100
   1200.0     0.18290      1300.0     0.20450      1400.0     0.40900
   1500.0     0.19820

PROPERTY TABLE DENS  MAT=       3  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
   70.000     0.41090      100.00     0.41090      150.00     0.41090
   200.00     0.41090      250.00     0.41090      300.00     0.41090
   350.00     0.41090      400.00     0.41090      450.00     0.41090
   500.00     0.41090      550.00     0.41090      600.00     0.41090
   650.00     0.41090      700.00     0.41090      750.00     0.41090
   800.00     0.41090      900.00     0.41090      1000.0     0.41090
   1100.0     0.41090      1200.0     0.41090      1300.0     0.41090
   1400.0     0.41090      1500.0     0.41090

PROPERTY TABLE KXX   MAT=       3  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
   70.000     0.46500E-03  100.00     0.46100E-03  150.00     0.45500E-03
   200.00     0.44800E-03  250.00     0.44100E-03  300.00     0.43500E-03
   350.00     0.42800E-03  400.00     0.42200E-03  450.00     0.41500E-03
   500.00     0.40900E-03  550.00     0.40200E-03  600.00     0.39500E-03
   650.00     0.38900E-03  700.00     0.38900E-03  750.00     0.38900E-03
   800.00     0.38900E-03  900.00     0.38900E-03  1000.0     0.38900E-03
   1100.0     0.38900E-03  1200.0     0.38900E-03  1300.0     0.38900E-03
   1400.0     0.38900E-03  1500.0     0.38900E-03

PROPERTY TABLE C     MAT=       3  NUM. POINTS= 23
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   350.00     0.31050E-01  400.00     0.31050E-01  450.00     0.31050E-01
   500.00     0.31050E-01  550.00     0.31050E-01  600.00     0.31050E-01
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350.00	0.28310E-04	400.00	0.26730E-04	450.00	0.25220E-04
500.00	0.23960E-04	550.00	0.22780E-04	600.00	0.21680E-04
650.00	0.20710E-04	700.00	0.19800E-04	750.00	0.18980E-04
800.00	0.18180E-04	900.00	0.16900E-04	1000.0	0.15710E-04
1100.0	0.14720E-04	1200.0	0.13850E-04	1300.0	0.13040E-04
1400.0	0.12350E-04	1500.0	0.11710E-04		

PROPERTY TABLE KXX MAT= 4 NUM. POINTS= 23

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350.00	0.49570E-06	400.00	0.52040E-06	450.00	0.54480E-06
500.00	0.56880E-06	550.00	0.59210E-06	600.00	0.61430E-06
650.00	0.63630E-06	700.00	0.65810E-06	750.00	0.67900E-06
800.00	0.69960E-06	900.00	0.74090E-06	1000.0	0.78040E-06
1100.0	0.81750E-06	1200.0	0.85450E-06	1300.0	0.88970E-06
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350.00	0.24380	400.00	0.24500	450.00	0.24610
500.00	0.24740	550.00	0.24900	600.00	0.25110
650.00	0.25270	700.00	0.25380	750.00	0.25520
800.00	0.25680	900.00	0.25960	1000.0	0.26280
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600.00	0.64800E-03	700.00	0.61600E-03	800.00	0.58300E-03
900.00	0.55100E-03	1000.0	0.51900E-03	1100.0	0.48400E-03
1200.0	0.45100E-03	1300.0	0.41700E-03	1400.0	0.38000E-03
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PROPERTY TABLE C MAT= 5 NUM. POINTS= 16

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600.00	0.13220	700.00	0.13810	800.00	0.14520
900.00	0.15350	1000.0	0.16240	1100.0	0.17100
1200.0	0.18290	1300.0	0.20450	1400.0	0.40900
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Appendix 2

Electronic Data on CDROM

(2 Pages & 1 CDROM)

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1.0 OBJECTIVE

Perform the thermal analyses of the Energy*Solutions* 3-60B Cask under hypothetical fire accident conditions, using a 3-dimensional finite element model.

2.0 REFERENCES

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2. Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material, January 2003.
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5. Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.
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7. ASME Boiler & Pressure Vessel Code, 2001, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2005.
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9. ANSYS, Rev. 11.0, Computer Software, ANSYS Inc., Canonsburg, PA, 2007.
10. IAEA Safety Series No.37, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material - 1985 Edition, International Atomic Energy Agency, Vienna, 1990.
11. Kreith, Frank, *Principles of Heat Transfer*, 3rd Edition, Harper & Row, 1973.

3.0 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 thermal load analysis of the 3-60B Cask for the hypothetical accident conditions (HAC) fire test. The normal conditions of transport (NCT) analyses have been performed in a separate document. The analyses in this document are performed using the finite element modeling techniques. 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 load cases are presented pictorially in temperature contour plots as well as digital data format, suitable for use with a structural finite element model to obtain the thermal stresses.

4.0 MATERIAL PROPERTIES

Temperature-Independent Metal Thermal Properties

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

Temperature-Dependent Metal Thermal Properties

Temp. (°F)	**Stainless Steel** (Ref. 7)		**Carbon Steel** (Ref.7)		**Lead** (Ref.8)
	Sp. Heat Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Sp. Heat** Btu/lb-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F	**Conductivity** $\times 10^{-3}$ Btu/sec-in-°F
70	0.117	0.199	0.104	0.813	0.465
100	0.117	0.201	0.106	0.803	0.461
150	0.120	0.208	0.109	0.789	0.455
200	0.122	0.215	0.113	0.778	0.448
250	0.125	0.222	0.115	0.762	0.441
300	0.126	0.227	0.118	0.748	0.435
350	0.128	0.234	0.122	0.731	0.428
400	0.129	0.241	0.124	0.715	0.422
450	0.130	0.245	0.126	0.701	0.415
500	0.131	0.252	0.128	0.683	0.409
550	0.132	0.257	0.131	0.667	0.402
600	0.133	0.262	0.133	0.648	0.395
650	0.134	0.269	0.135	0.632	0.389
700	0.135	0.273	0.139	0.616	0.389
750	0.136	0.278	0.142	0.600	0.389
800	0.136	0.282	0.146	0.583	0.389
900	0.138	0.294	0.154	0.551	0.389
1,000	0.139	0.306	0.163	0.519	0.389
1,100	0.141	0.315	0.172	0.484	0.389
1,200	0.141	0.324	0.184	0.451	0.389
1,300	0.143	0.336	0.205	0.417	0.389
1,400	0.144	0.345	0.411	0.380	0.389
1,500	0.145	0.354	0.199	0.363	0.389

Temperature-Dependent Air Thermal Properties

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

5.0 MODEL DESCRIPTION

The thermal analyses of the 3-60B Cask under hypothetical fire accident test conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Ref. 9) has been employed to perform the analyses. 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 employed. Figure 1 shows the finite element model used in various thermal load analyses. Figures 2 and 3 show the exploded views of various regions of the finite element model. Figure 4 shows the material property model numbers of various components of the cask.

The finite element model is made of 3-dimensional thermal solid elements (ANSYS SOLID70) that represent the major components of the cask, the cask body, the lid, the bolts, and the fire shield. The 3-60B Cask package is designed to maintain an air gap between the cask ends and the impact limiters. These impact limiters remain attached to the cask body during the normal as well as hypothetical drop test conditions. Heat transfer between the cask ends and the impact limiter plate takes place by means of radiation and conduction through the air gap. Therefore, the impact limiter end plates are also included in the finite element model (see Figure 3). These plates are modeled by 3-dimensional thermal solid elements. The interstitial air gaps between the impact limiter plates and the cask end as well as that between the fire-shield and the cask body are modeled by these elements also.

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

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

For the HAC fire the foam of the impact limiters is conservatively assumed not to provide any thermal insulation. In the structural analyses of the HAC drop and puncture drop conditions, it has been shown that after these tests, the casing of the impact limiter will be intact and remain attached to the cask body. Therefore, it is assumed that the fire directly hits the two ends of the cask through the 1/2" plate that form the casing of the impact limiters, in addition to the entire length of the fire-shield.

The real constants used in the ANSYS finite element model, to define the characteristic of various finite elements to simulate the heat transfer by convection and radiation, are based on the derivation in the following section. The heat flux representing the internal heat load and the solar insolation is also presented in the following section. A print-out of the model data input is included in Appendix 1.

5.1 Natural Convection Modeling

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

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

where:

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

A = Area (sq ft)

T_s = cask surface temperature (°F)

T_a = ambient temperature (°F)

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

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

where, for horizontal cask,

$$C = 0.18 \text{ (Btu/hr-ft}^2\text{-F}^{4/3}\text{)}$$

$$= 3.4722\times10^{-7} \text{ (Btu/sec-in}^2\text{-F)}$$

5.2 Forced Convection Modeling

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

$$h = 10 \frac{W}{m^2 \, ^\circ C}$$

For conversion, using,

$$1 \text{ W} = 9.4804\times10^{-4} \text{ Btu/sec}$$

$$1 \text{ m} = 39.37 \text{ inch}$$

$$1^\circ C = 1.8^\circ F$$

Therefore,

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

The heat transfer coefficients for forced convection are also obtained from additional sources and compared with the IAEA recommended value. It is shown that the value calculated above is larger than the values calculated from other sources. Therefore, the IAEA recommended value will result in a conservative prediction of the cask temperatures during the HAC fire test.

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

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

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

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

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

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

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

d = diameter of the cylinder = 51 in

μ_f = Air viscosity at film temperature

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

= 246.2×10^{-8} lb/(in-sec)

Therefore,

$$\mathrm{Re} = \frac{\left(1.1707\times10^{-5}\,\dfrac{lb}{in^3}\right)\times\left(394\,\dfrac{in}{\sec}\right)\times(51in)}{246.2\times10^{-8}\,\dfrac{lb}{in\cdot\sec}} = 95{,}549$$

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

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

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

k_f = Conductivity of air at film temperature

= 9.706×10^{-7} Btu/sec-in-ºF

Therefore,

$$\mathrm{Pr} = \frac{\left(246.2*10^{-8}\,\dfrac{lb}{in\cdot\sec}\right)\times\left(0.2766\,\dfrac{Btu}{lb\cdot\deg F}\right)}{9.706\times10^{-7}\,\dfrac{Btu}{\sec\cdot in\cdot\deg F}} = 0.7$$

Substitution of these values in Equation 1 results in:

$$Nu_d = 0.3 + \frac{0.62\times(95{,}549)^{1/2}\times(0.7)^{1/3}}{\left[1+\left(\dfrac{0.4}{0.7}\right)^{2/3}\right]^{3/4}}\left[1+\left(\frac{95{,}549}{282{,}000}\right)^{5/8}\right]^{4/5} = 0.3+\left(\frac{170.18}{1.481}\times[1+0.5084]^{4/5}\right)$$

$$= 0.3 + [(114.91) \times (1.389)] = 159.9 \approx 160$$

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

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{(160) \times (9.706 \times 10^{-7})}{51} = 3.045 \times 10^{-6} \frac{\text{Btu}}{\text{sec} \cdot \text{in}^2 \cdot \text{degF}}$$

......Equation 2

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

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

......Equation 3

The limits of applicability of this equation is:

$\text{Re}_L < 5 \times 10^5$ and $\text{Pr} > 0.1$

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

L = 128.625 in

$$\text{Re}_L = \frac{(1.1707 \times 10^{-5}) \times (394) \times (128.625)}{246.2 \times 10^{-8}} = 240{,}979 \approx 2.41 \times 10^5$$

Substitution of values in Equation 3 gives,

$$Nu = (0.664) \times (\text{Re}_L)^{0.5} \times (\text{Pr})^{1/3} = (0.664) \times (240{,}979)^{0.5} \times (0.7)^{1/3} = 289.45$$

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{(289.45) \times (9.706 \times 10^{-7})}{128.625} = 2.184 \times 10^{-6} \frac{\text{Btu}}{\text{sec} \cdot \text{in}^2 \cdot \text{degF}}$$

The forced convection heat transfer coefficient for both horizontal and vertical cylinders calculated above are both smaller than IAEA recommended value for the 3-60B cask geometry. Therefore, in order to predict the cask temperature conservatively during the HAC fire test, the IAEA recommended value has been used in all the analyses.

5.3 Radiation Modeling

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

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

where:

q = heat flow rate (Btu/hr)

σ = Stefan-Boltzmann Constant

= 1.7136×10^{-9} (Btu/hr-ft^2-R^4)

= 3.3056×10^{-15} (Btu/sec-in^2-R^4)

ε = emissivity

F = geometric form factor

A = area (sq ft)

T = temperature (°R)

I = first node number

J = second node number

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

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

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

where:

ε = overall emissivity

ε_1 = surface 1 emissivity

ε_2 = surface 2 emissivity

The regulations (Article 71.73 of Reference 2) require that an average environment emissivity coefficient of 0.9 must be used for HAC fire test. It also requires that for purpose of calculation, the surface absorptivity coefficient must be either that which the package may be expected to possess if exposed to fire specified or 0.8, whichever is greater. It is conservatively assumed in the analyses that the package has an absorptivity of 1.0. Therefore, an emissivity coefficient of 0.9 has been conservatively specified for all the elements that radiate heat to the environment. Form factor value of 1.0 is used and the area of the surface is automatically calculated by the computer program.

The radiation between the outer shell and the fire-shield, and between the impact limiter plates and the cask body, is modeled by superelements (ANSYS MATRIX50). These elements are formed by modeling the radiating surfaces with thermal shells (ANSYS SHELL57). The thermal shield forms an air annulus between itself and the cask body. This annulus is formed by separating the two components with the help of helically wound stainless steel wires. The ends of the fire-shield are seal welded to the cask body. Thus, the two surfaces forming the annulus will remain in polished condition throughout the operating life of the cask. The emissivity coefficient of as-received stainless steel is 0.15. However, since a higher value of emissivity coefficient will result in a higher cask body temperature, the value of 0.15 is conservatively increased by a factor of 3 and a value of 0.45 is used for the emissivity coefficient for the heat transfer due to radiation between the fire-shield and the cask body.

It has been shown in structural analyses section that the foam impact limiters may suffer some damage during the HAC drop tests. However, the stainless steel shells forming the cup remain attached to the cask body after these tests. Conservatively, it is assumed in the HAC fire analyses that the foam in the impact limiters are totally ineffective during the fire test. And the stainless steel cup that remains attached to the cask is directly exposed to the fire. Since the surface of the cask and that of that of the impact limiter cup are made of stainless steel that has been aged, the emissivity coefficient of 0.8 is used for the heat transfer due to radiation between the cask and impact limiter cups.

5.4 Solar Insolation Modeling

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

5.5 Internal Heat Loading

The internal heat load content of the 3-60B Cask has been represented in the finite element models by two different ways. In the first, the heat load is implicitly represented by a uniform heat flux over the cask cavity. In the second, it is explicitly represented by the finite element model of the waste container and the cavity air. The heat load in this case is applied as a constant heat flux over the waste container wall.

5.5.1 Implicit Internal Heat Load Modeling

The 500-Watt decay heat load is modeled as a uniform heat flux over the inside surface of the lid and the lower 30” of the inside surface of the cask inner shell (see Figure 5). This loading conservatively represents the compaction of the payload during the hypothetical drop tests and positioning of it near the most vulnerable part of the cask, i.e. the seal surface. The representation of the decay heat load as surface flux is a conservative approximation during the fire transient, since, in reality, some of the heat from the fire would be transferred to the waste. Thus, the waste would act as a heat sink lowering the wall temperature.

$$\text{Internal heat load, } q = 500 \text{ W} = 500\times9.4804\times10^{-4} = 0.4740 \text{ Btu/sec}$$

The cask inside diameter is 35” and the cavity height is 30”. Thus, the heat flux on the inside surface of the cask is:

$$q_s = 0.4740/\,(\pi\times35\times30 + \pi/4\times35^2)$$

$$= 1.112\times10^{-4} \text{ Btu/(sec-in}^2\text{)}$$

5.5.2 Explicit Internal Heat Load Modeling

In order to obtain the temperature of the waste container and the cavity air during the NCT, they are explicitly represented in the finite element model by 3-dimensional solid elements with appropriate material properties. The waste container is conservatively assumed to be a cylindrical shell having the diameter and length to be approximately ½ of the corresponding cavity dimensions.

Waste Container Outside Diameter = 17", Length = 50", Wall Thickness = 1.0"

Container Inside Surface Area = $\pi\times(17-2)\times(50-2) + 2\times[\pi\times(17-2)^2/4] = 2{,}615$ in^2

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

$$q_w = 0.474/2{,}615 = 1.813\times10^{-4} \text{ Btu/sec-in}^2$$

The cavity air is conservatively assumed to be stagnant - no convective heat transfer is assumed to take place between the waste container and the cask cavity. Thus, the heat transfer between these components takes place by means of conduction through the air and radiation between the two bodies. The air conduction is accounted for by the appropriate material properties of the finite elements representing it. The heat transfer by radiation is achieved by the ANSYS radiosity process. The coefficient of emissivity for both the surfaces is assumed to be 0.8 and the form-factor is automatically calculated by the computer program from the geometry of the two bodies. The finite element model of the cask with explicit internal heat load modeling is shown in Figure 6.

5.6 Puncture Drop Damage Modeling

During the regulatory puncture drop test specified in Article 71.73(c)(3) of Reference 2, the structural analyses have shown that no damage to the cask body will occur. However, the fire-shield which is separated from the cask body with the help of helically-wound stainless steel wires, may jam into the cask body at the puncture bar contact location. An analysis of the 3-60B cask has been performed assuming that such a contact occurred at the exposed location closest to the lid seals. The 1/32nd symmetric model is used for this analysis, which conservatively makes the contact area in shape of a circular ring having a width equal to the contact diameter instead of a circle. Full thermal contact is assumed between the fire-shield and the outer shell of the cask at the assumed location of the puncture drop. In other words, the outer shell is assumed to be directly exposed to the fire at this location.

6.0 ANALYSES

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

1. The initial temperature condition is obtained by running the finite element model with the following boundary conditions:
   - Internal heat load – 500 W
   - Solar insolation - no
   - Heat Transfer to the ambient by radiation – yes
   - Heat transfer to the ambient by natural convection – yes

- Ambient air temperature - 100°F

2. The fire transient is run with the body temperature resulting from the above initial conditions. The fire transient is run for 30 minutes (1,800 sec) with the following boundary conditions:
    - Internal heat load – 500 W
    - Solar insolation - no
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by forced convection – yes
    - Ambient air temperature - 1475°F
3. The end of fire analysis of the model is performed with the body temperature resulting from the above fire transient to 1801 sec with the following boundary conditions:
    - Internal heat load – 500 W
    - Solar insolation - no
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by natural convection – yes
    - Ambient air temperature - 100°F
4. The cool-down analysis of the model is performed with the body temperature resulting from the above fire transient to 14,000 sec with the following boundary conditions:
    - Internal heat load – 500 W
    - Solar insolation - yes
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by natural convection – yes
    - Ambient air temperature - 100°F

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

The finite element models are analyzed for three configuration to obtain the limiting thermal loading on the 3-60B cask. The first model that represents the internal heat load implicitly has been used for the cask body temperature evaluation. It has been demonstrated in the NCT thermal analysis that this model predicts the cask temperature conservatively. The second model that explicitly represents the internal heat load is used for predicting the internal cavity temperature. The third model assumes that the fire-shield has been damaged at the puncture drop contact location and the portion of the outer shell of the cask is directly exposed to the fire. For this analysis, the internal heat load is implicitly represented since it results in a more conservative temperature prediction than the explicit representation.

7.0 RESULTS

7.1 Cask Temperature Results

As described earlier the model representing the internal heat load implicitly is used for obtaining the cask body temperature. From the transient analyses of the finite element model, using the loading described in Section 6.0, a time-history data of the temperature in various components of the cask is obtained. The fire shield, outer shell, inner shell, lead, and seal were considered as the critical components of the cask. The temperatures at representative locations in these locations are monitored during the entire fire and cool down transient analysis. The nodes that are monitored at these critical components are shown in Figure 8.

Figure 9 gives the plot of the time-history data at the representative nodes of the cask components. Figure 10 gives the same data in cask components that are not directly exposed to the fire. The ANSYS printout of the data is included in Appendix 1.

Table 7.1 summarizes the maximum temperature of various components of the cask during the entire analysis period.

Table 7.1

Summary of Maximum Hypothetical Fire Temperatures

Component	**Maximum Calculated Temp.**			**Maximum Allowable Temperature (°F)**
	Location (Node Nos.)	**Time (Sec.)**	**Value (°F)**	
Fire Shield	3600	1,800	1331	N.A
Outer Shell	1897	1,806	353.5	800
Inner Shell	1790	3,984	284.1	800
Lead	2366	2,051	301.6	622
Seals	288	4,838	295.7	450

To capture the maximum stresses in the cask components during the fire accident test conditions, the structural finite element model, with identical node numbers, needs to be run at some critical time instances. From the time-history plot several critical time instants were identified. The criterion used for determining these time instants was that one of the components achieved the highest temperature during the fire transient. Figure 10 identifies these time instants. The temperature distribution in the cask at these time instances is shown in Figures 11 through 17.

7.2 Cavity Air Temperature Results

Transient thermal analysis of the model with explicit internal heat load representation (Figure 6) is performed for the loading described in Section 6.0 to obtain the time-history of the cavity and waste container temperature.

The time-history plots of the temperature of the air at various locations in the cask cavity, and the waste container, are shown in Figure 18. The average temperature in the cavity is also plotted in this figure. Figure 19 shows the temperature profile in the cask cavity at the time instant when the cavity air reaches the maximum value. Figure 20 shows the temperature profile in the cask cavity at the time instant when the average temperature reaches the maximum value. Figure 21 shows the maximum waste container temperature profile.

The calculated temperatures are summarized below:

Maximum cavity temperature	= 329.3ºF	(see Figure 19)
Maximum average cavity temperature	= 273.2ºF	(see Figure 19)
Maximum waste container temperature	= 294ºF	(see Figure 21)

7.3 Puncture Drop Damage Results

The temperature profile of the cask obtained from the finite element model with damaged fire shield at the location of puncture drop is shown in Figure 22. From this figure it is observed that due to the assumed damage to the fire shield the temperature increase in the cask body under HAC fire is highly localized. The temperature plot in the cask wall near the assumed damage location is shown in Figure 23. The cask wall temperature is shown in Figure 24 and that in the lead shielding is shown in Figure 25.

The calculated temperatures are summarized below:

Maximum outer shell temperature	= 827.4ºF	(see Figure 23)
Maximum lead temperature	= 695.3ºF	(see Figure 25)
Average outer shell temperature	= 726.5ºF	(see Figure 24)
Average lead temperature	= 561.5ºF	(see Figure 25)

It should be noted that the maximum temperatures listed above occur over a very small region and they have also been obtained from very conservative assumptions. Therefore, the average values are more representative of the component behavior than the absolute maximum values. Thus both the outer shell and the lead shielding meet their allowable maximum values of 800ºF and 622ºF, respectively.

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

9.0 APPENDICES

Appendix 1 Print-out of the ANSYS model data input

Appendix 2 Electronic data on CDROM

Figures

(25 Pages)

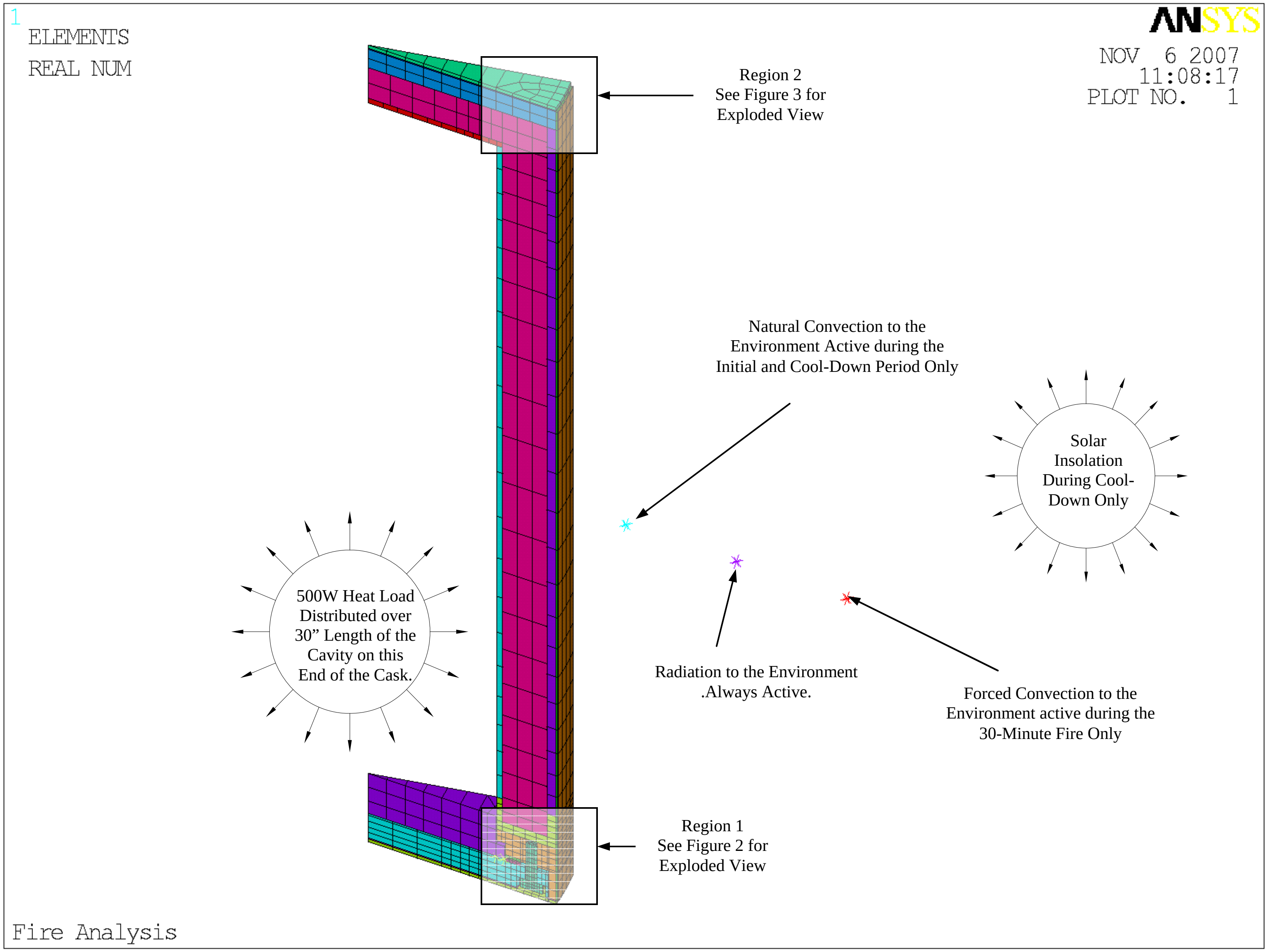


Figure 1 – Finite Element Model of the 3-60B Cask Used for the Thermal Analyses

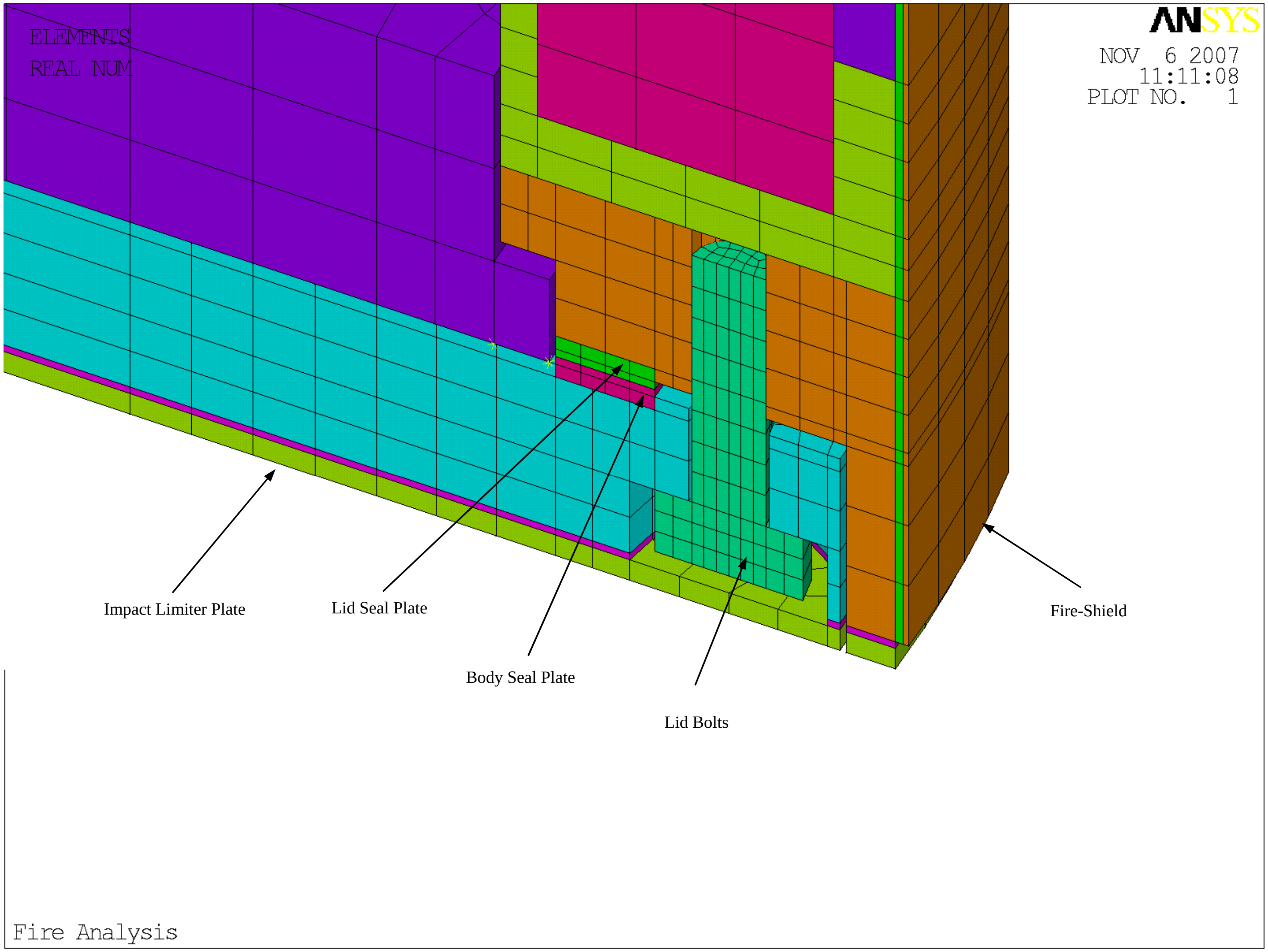


Figure 2 – Exploded View of Region 1 of Figure 1

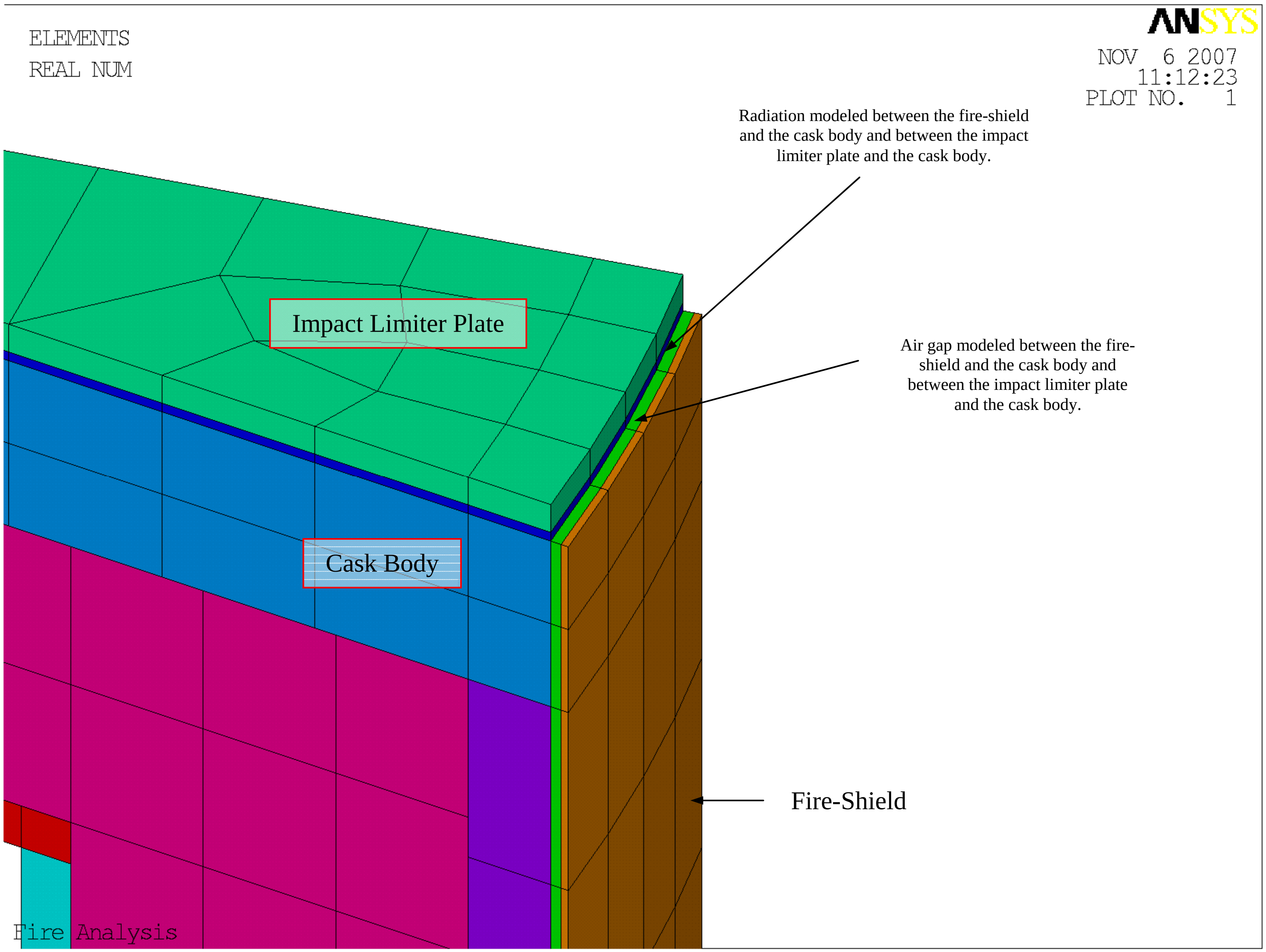


Figure 3 – Exploded View of Region 2 of Figure 1

Title Fire Transient Analyses of the 3-60B Cask Using a 3-D Finite Element Model

Calc. No. TH-023 (Figures) **Rev.** 3 **Sheet** 3 of 25

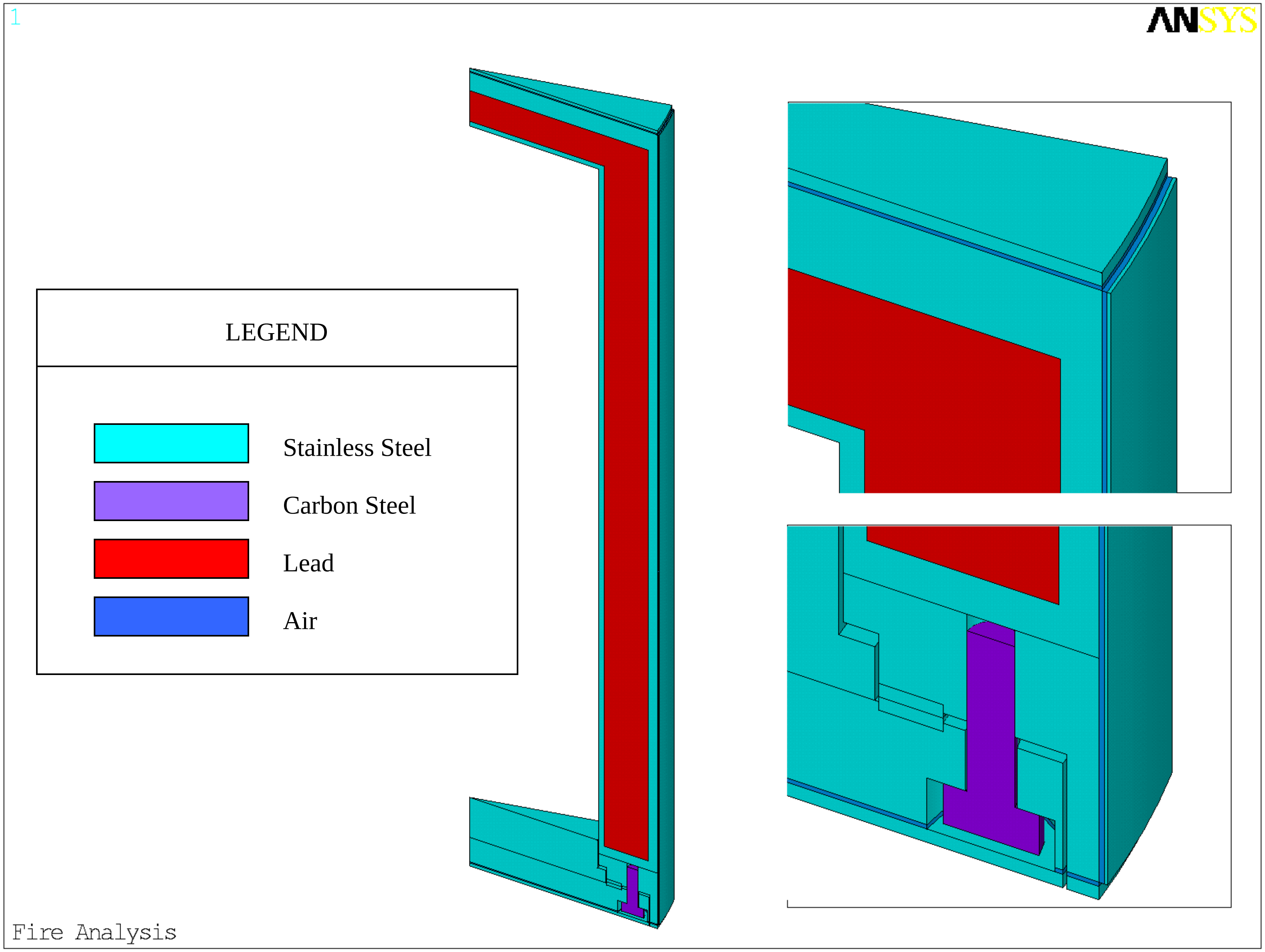


Figure 4 – Materials Used in the Finite Element Model

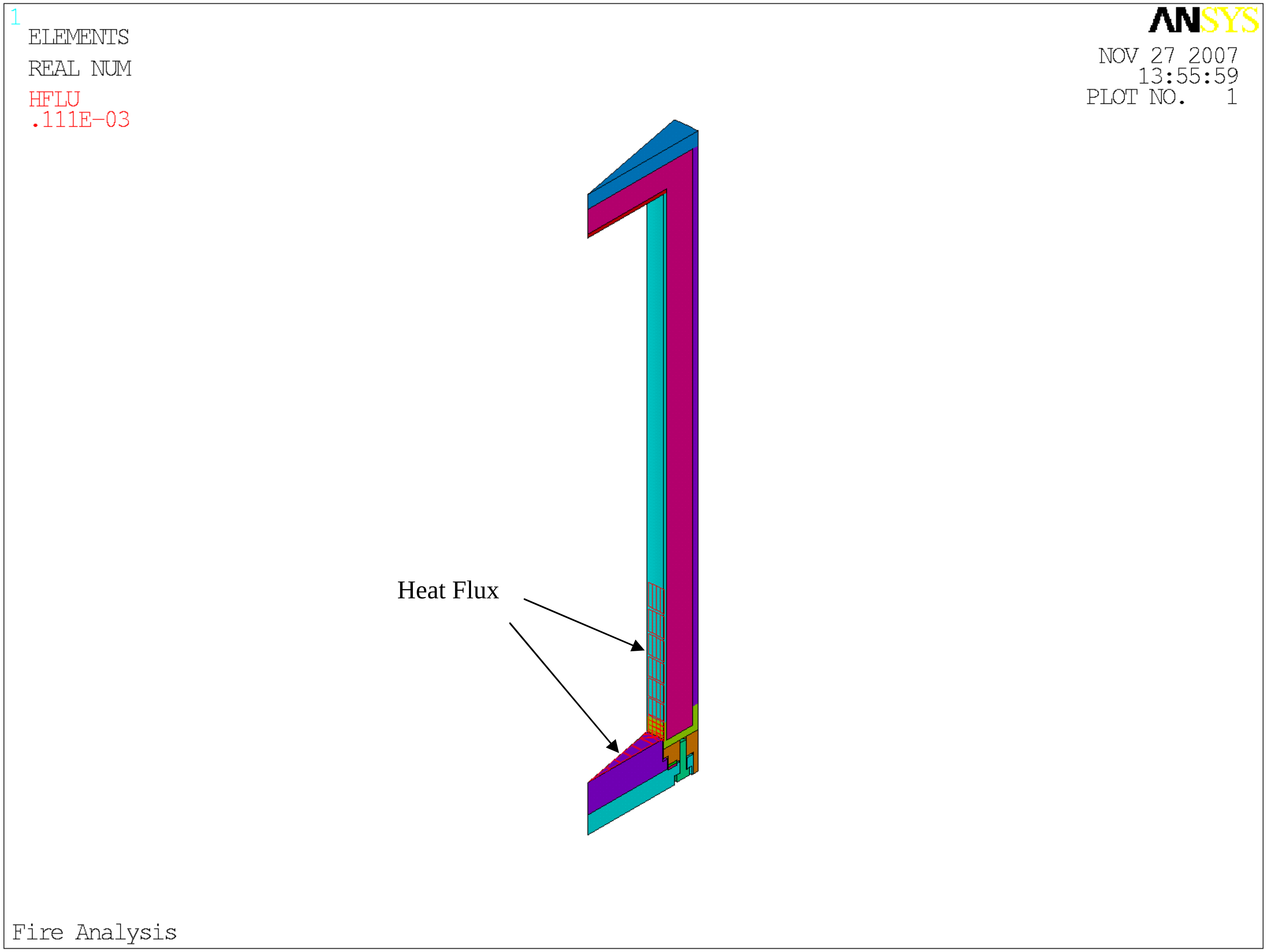


Figure 5 – Finite Element Model with Implicit Internal Heat Load Modeling

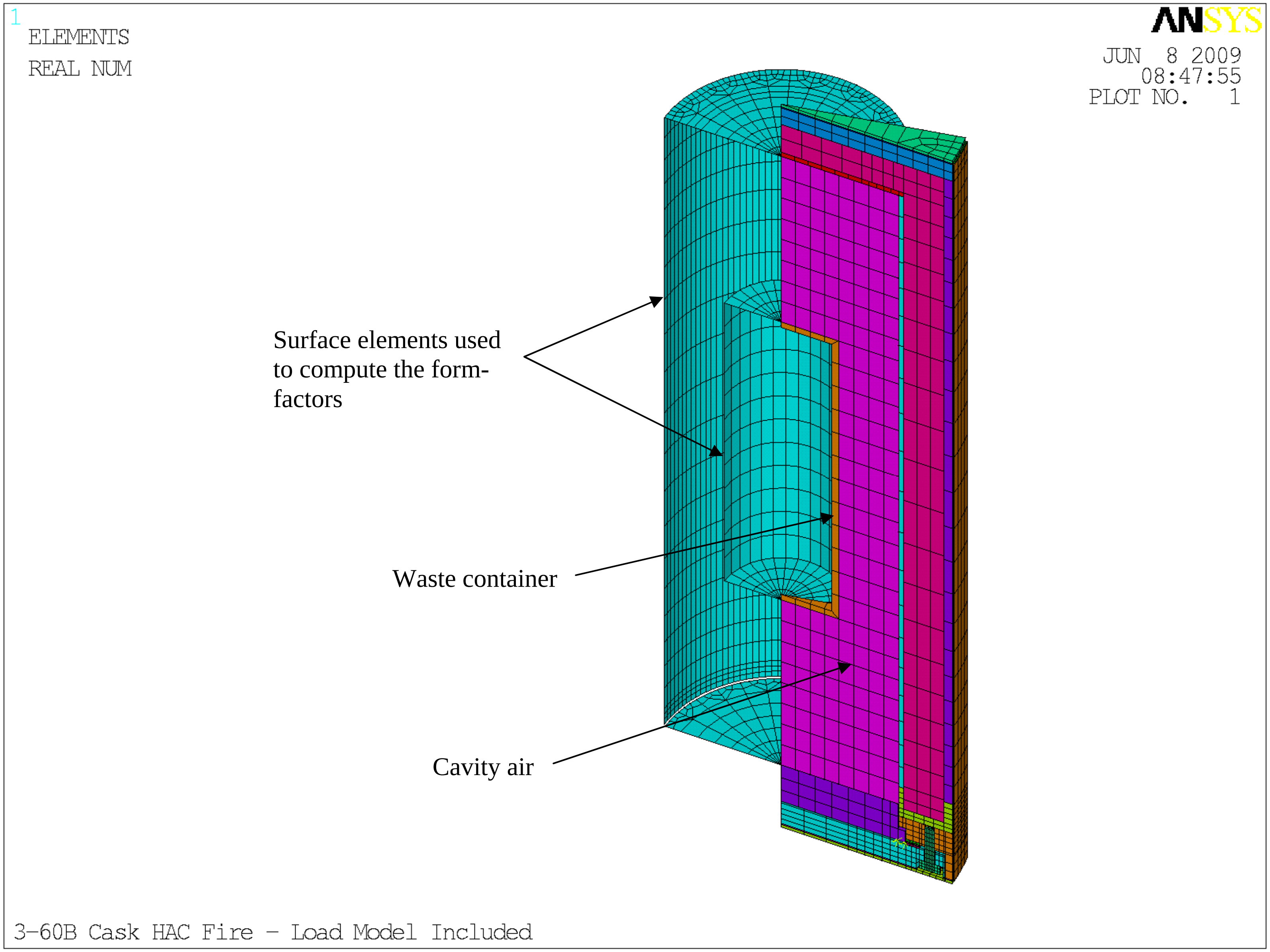


Figure 6 – Finite Element Model with Explicit Internal Heat Load Modeling

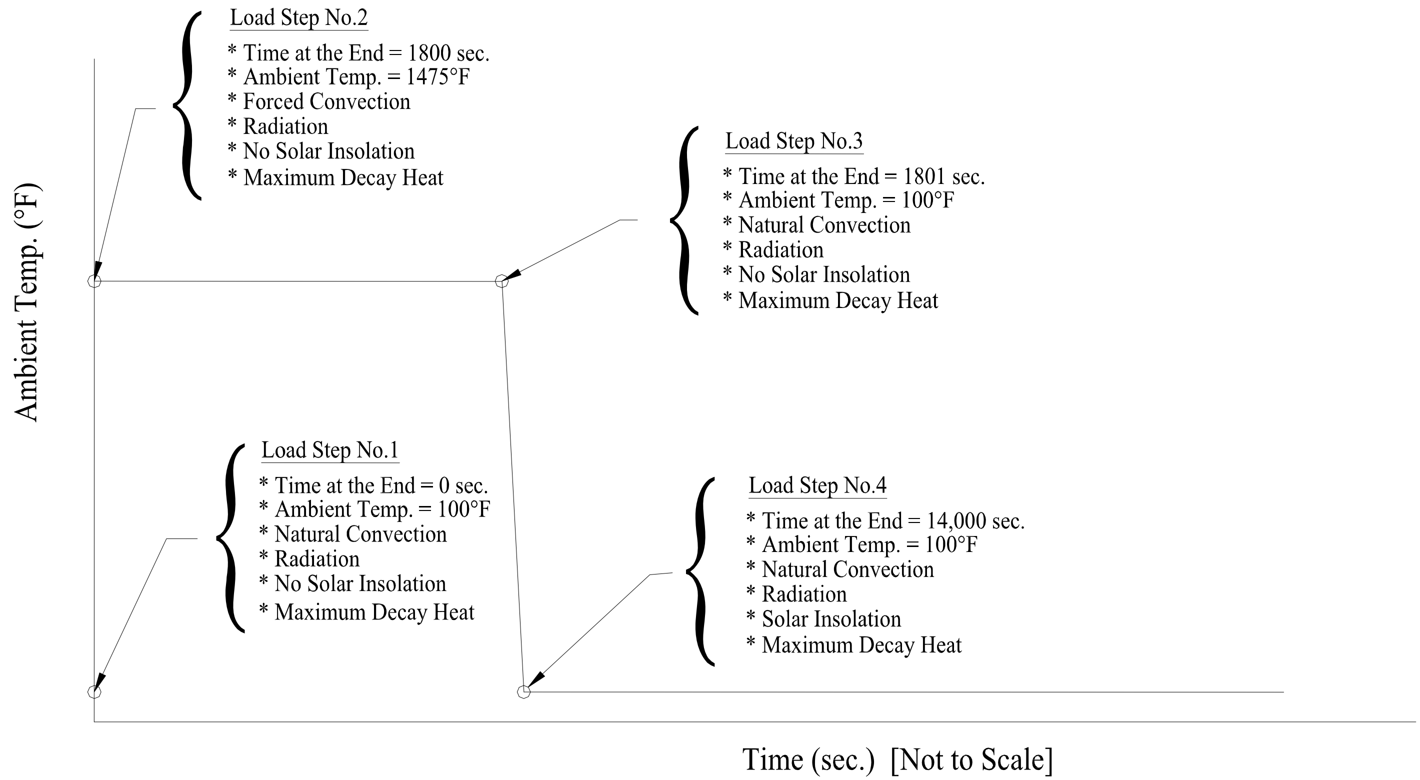


Figure 7 – HAC Fire Analysis Load Steps and Boundary Conditions

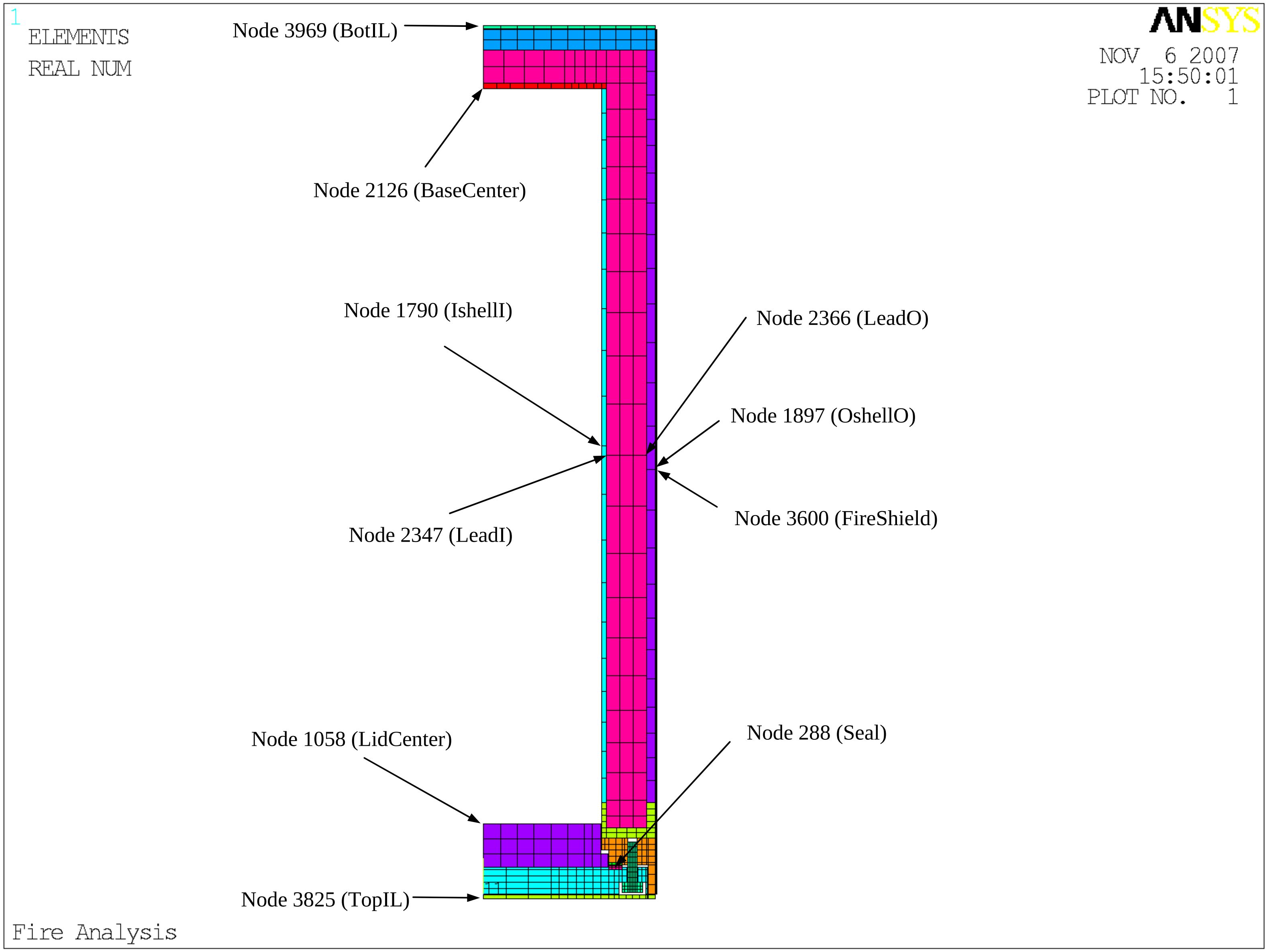


Figure 8 – Identification of the Nodes where Time-History is Monitored

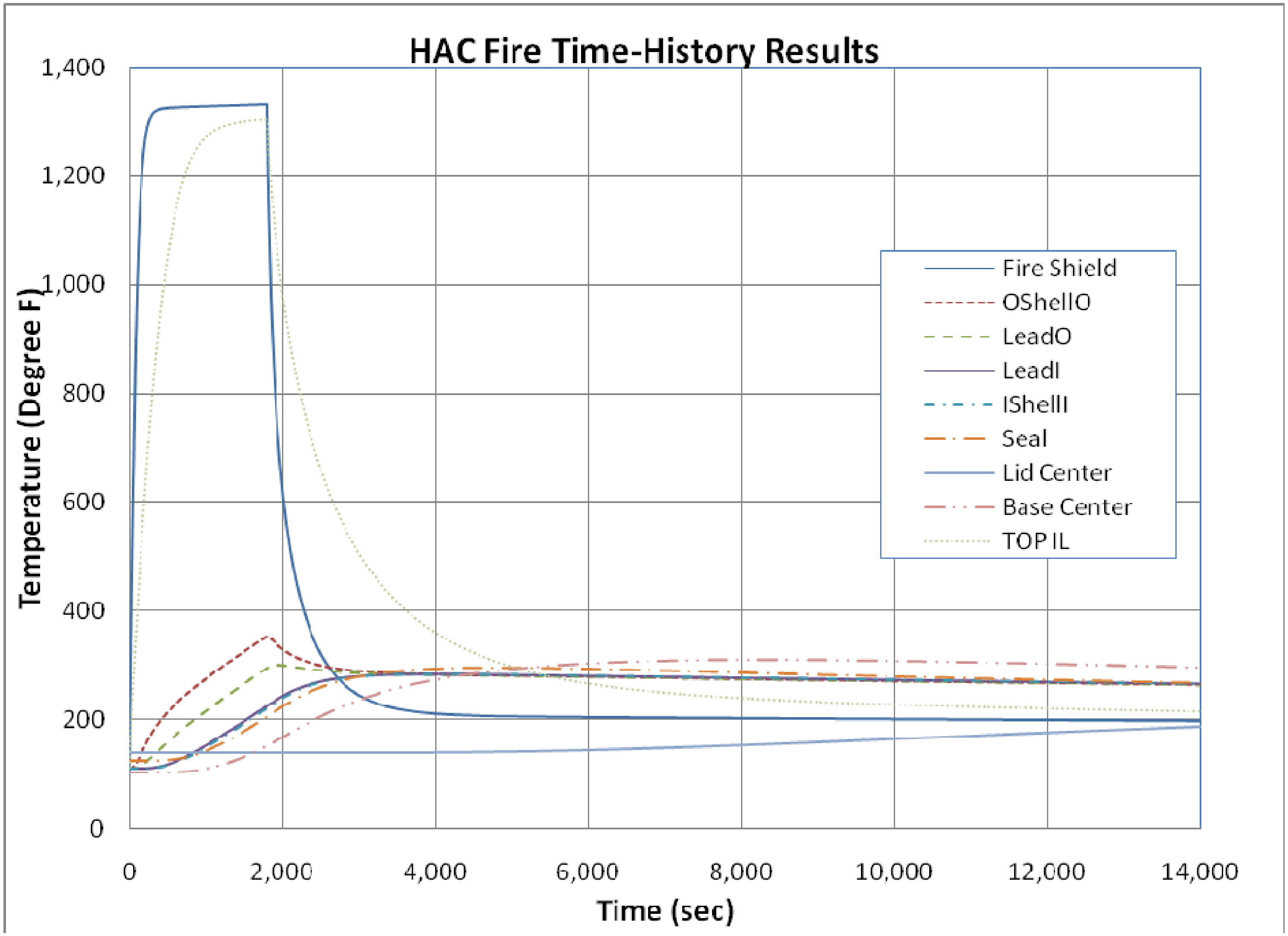


Figure 9 – Temperature Time-History Plot in Various Components of the Cask

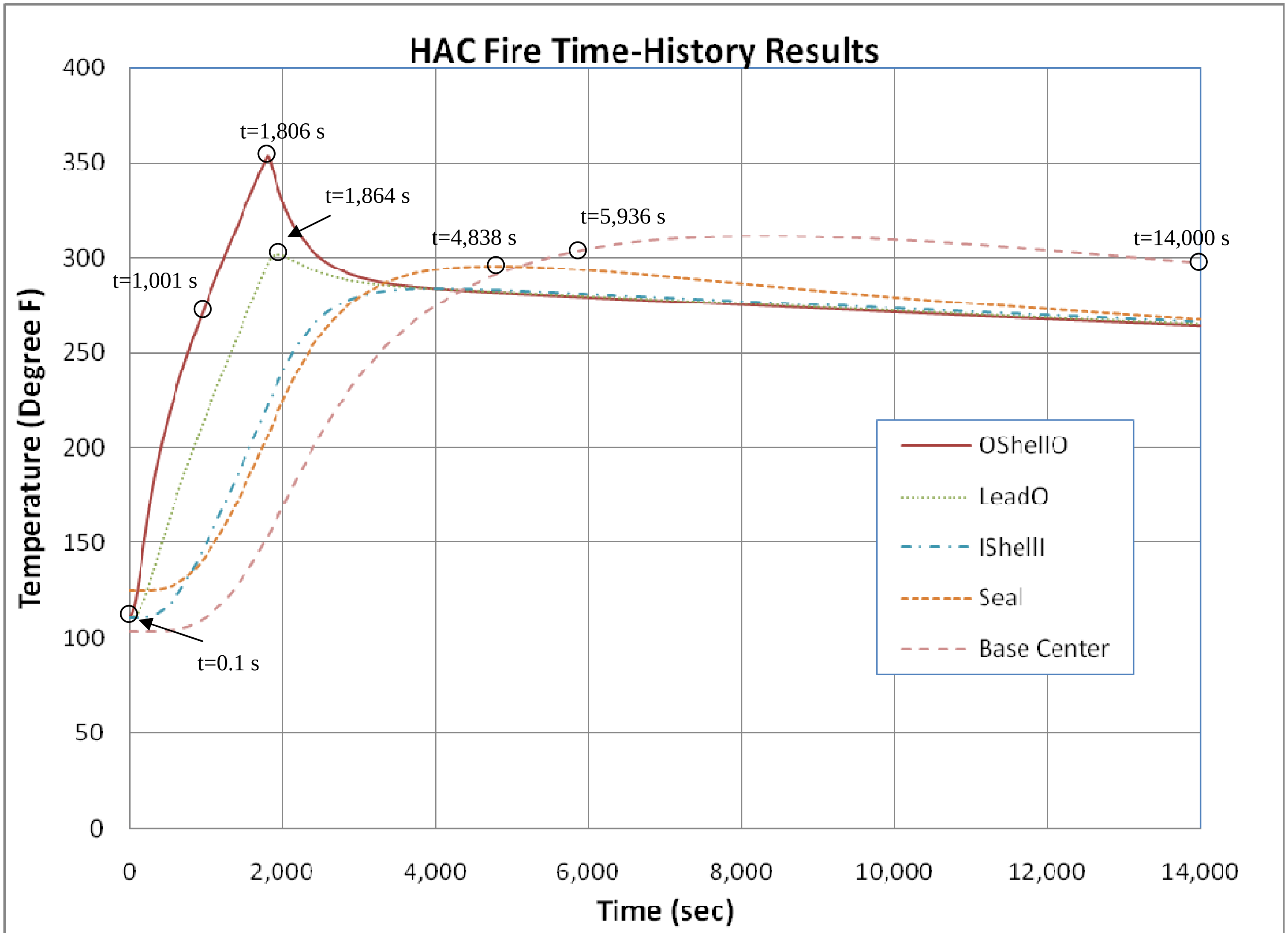


Figure 10 – Temperature Time-History Plot in Various Components of the Cask (Not Under Direct Contact with the Fire)

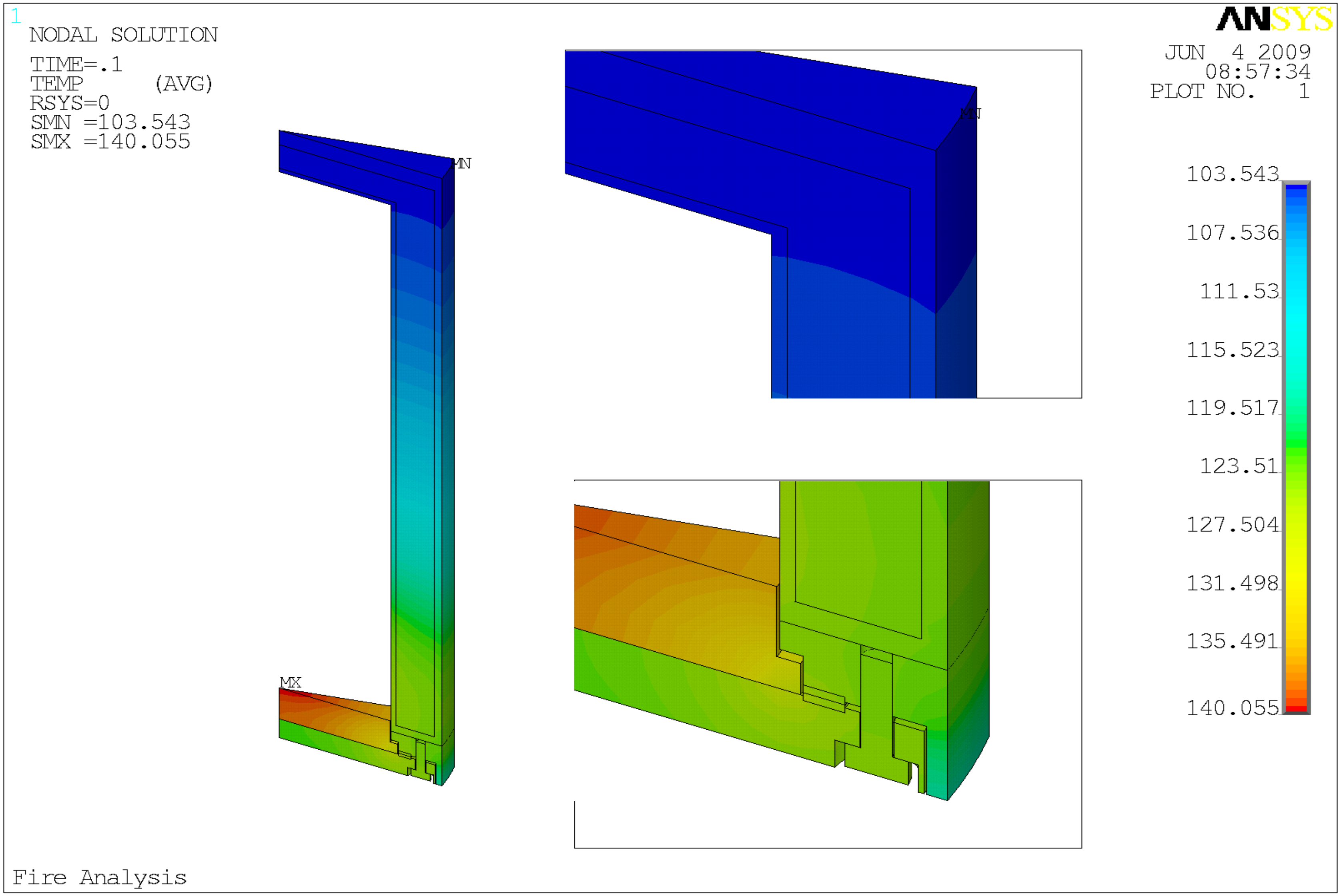


Figure 11 – Temperature Distribution – 0.1 Sec. After the Start of the Fire

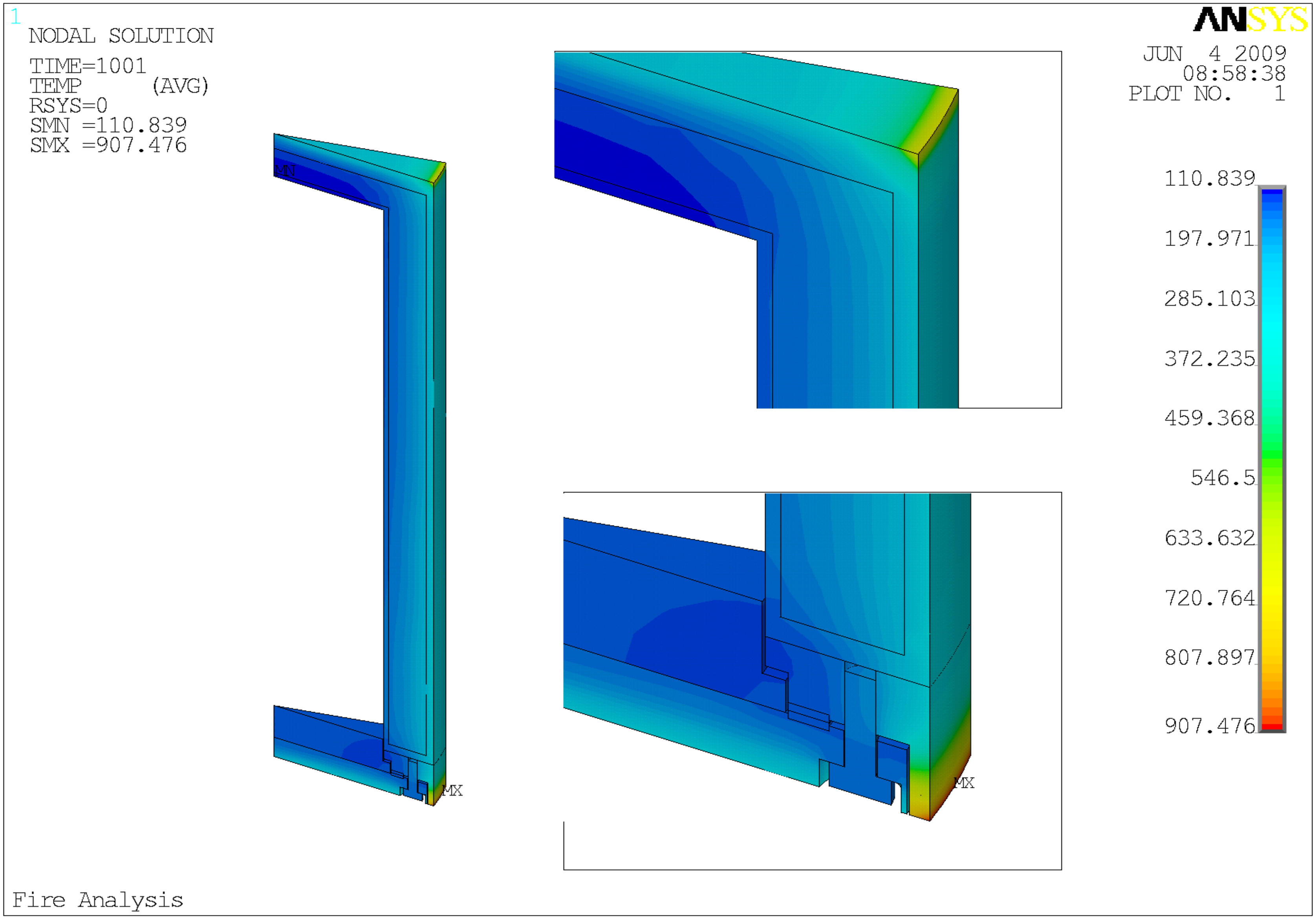


Figure 12 – Temperature Distribution – 1,001 Sec. After the Start of the Fire

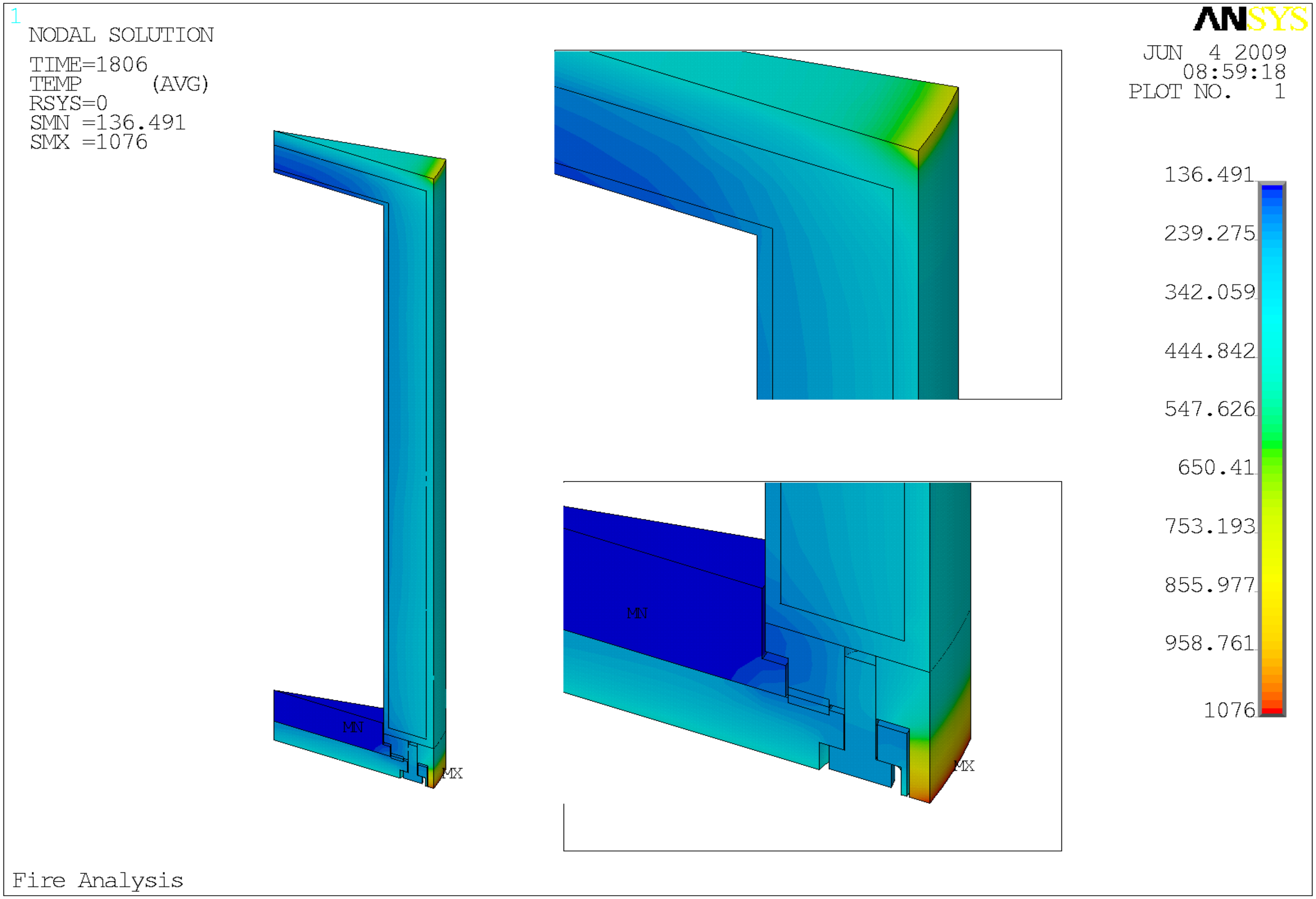


Figure 13 – Temperature Distribution – 1,806 Sec. After the Start of the Fire

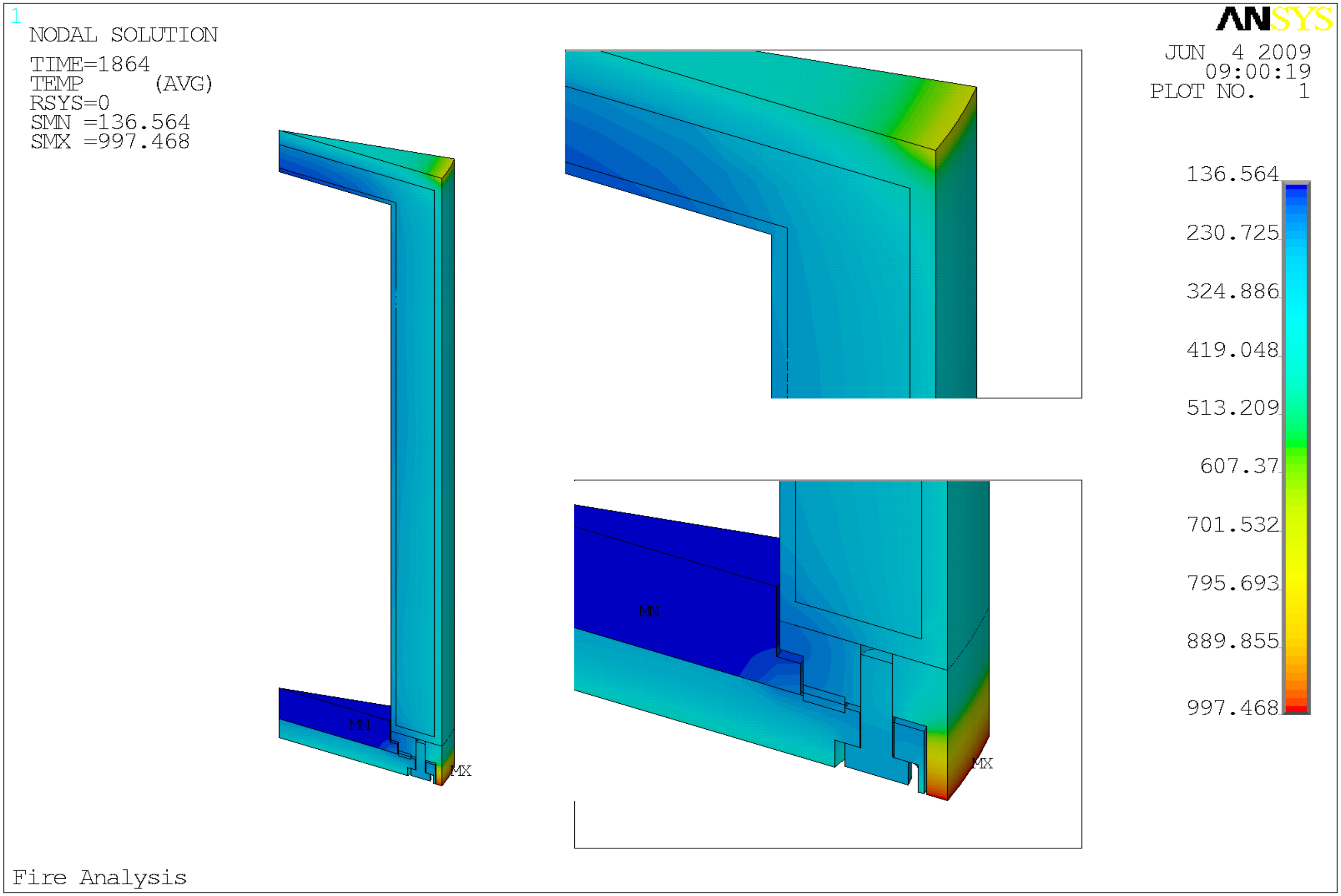


Figure 14 – Temperature Distribution – 1,864 Sec. After the Start of the Fire

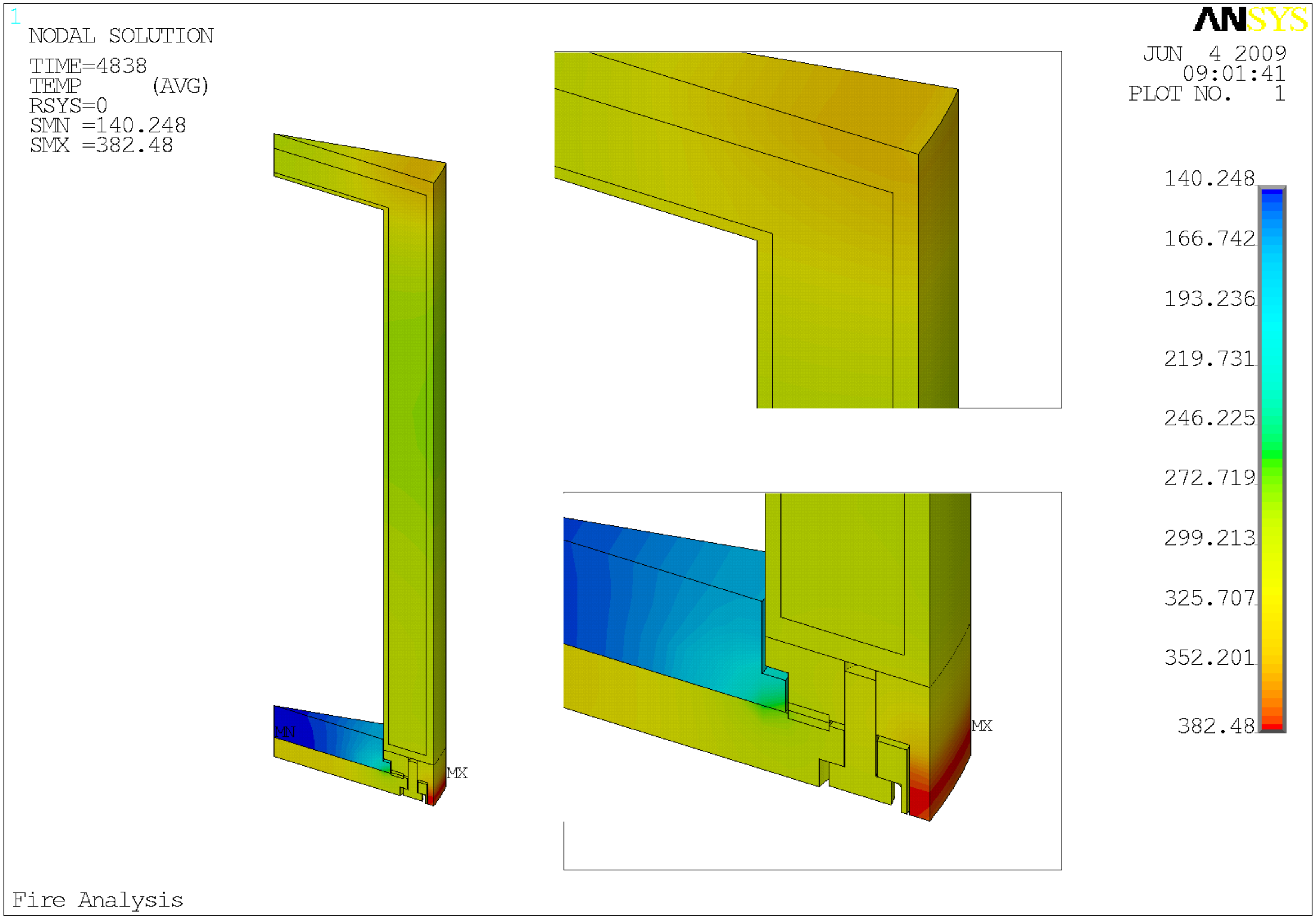


Figure 15 – Temperature Distribution – 4,838 Sec. After the Start of the Fire

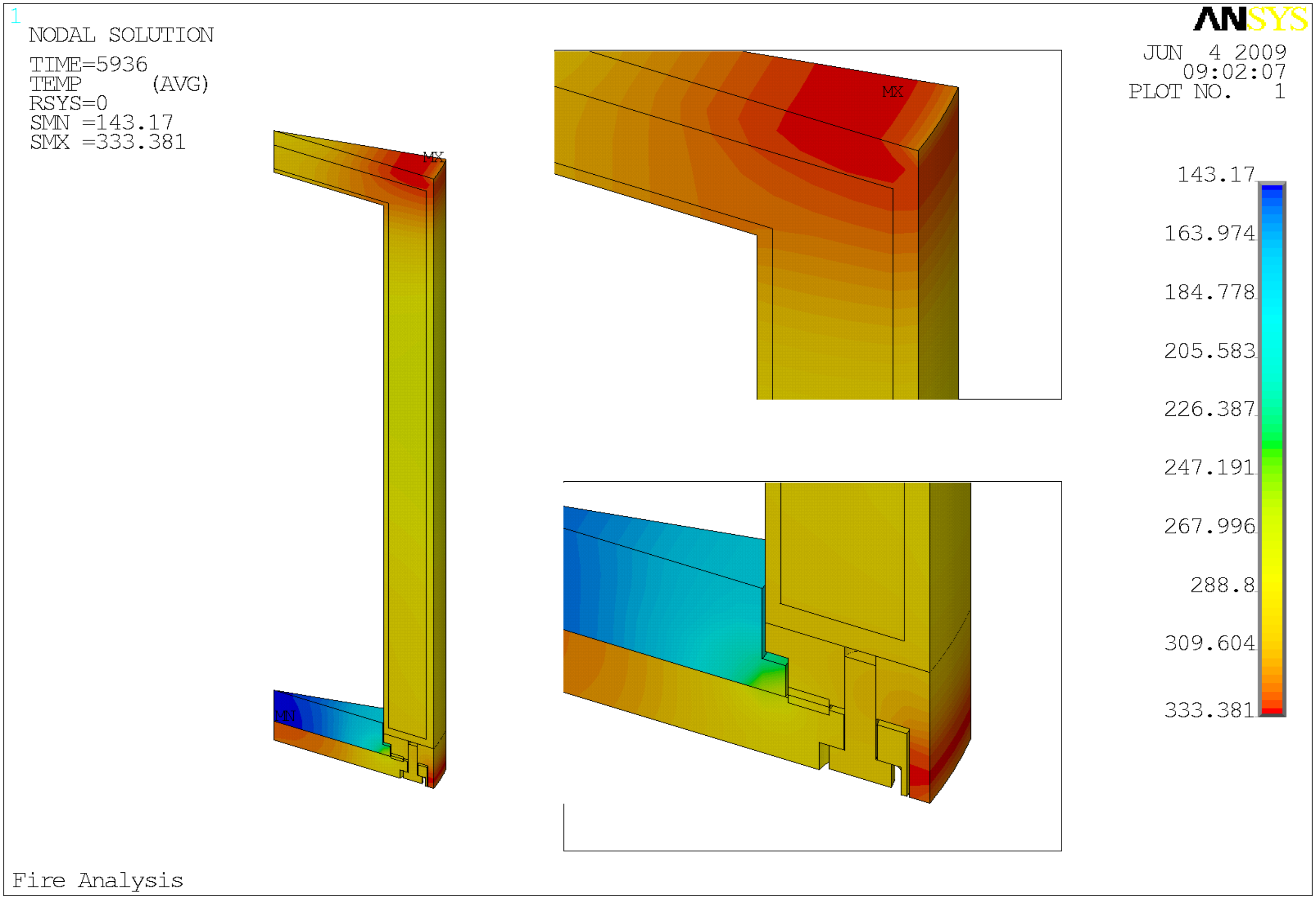


Figure 16 – Temperature Distribution – 5,936 Sec. After the Start of the Fire

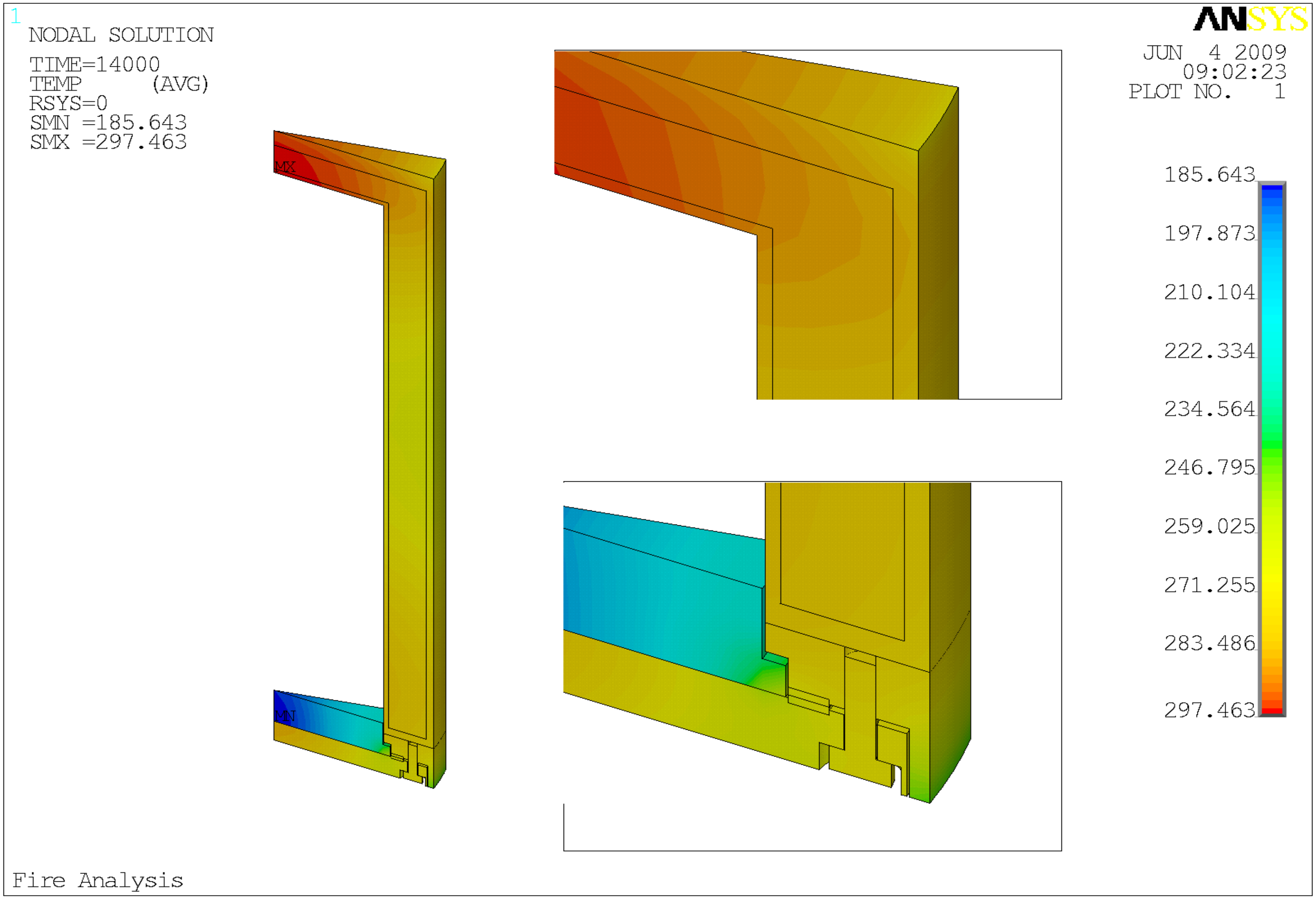


Figure 17 – Temperature Distribution – 14,000 Sec. After the Start of the Fire

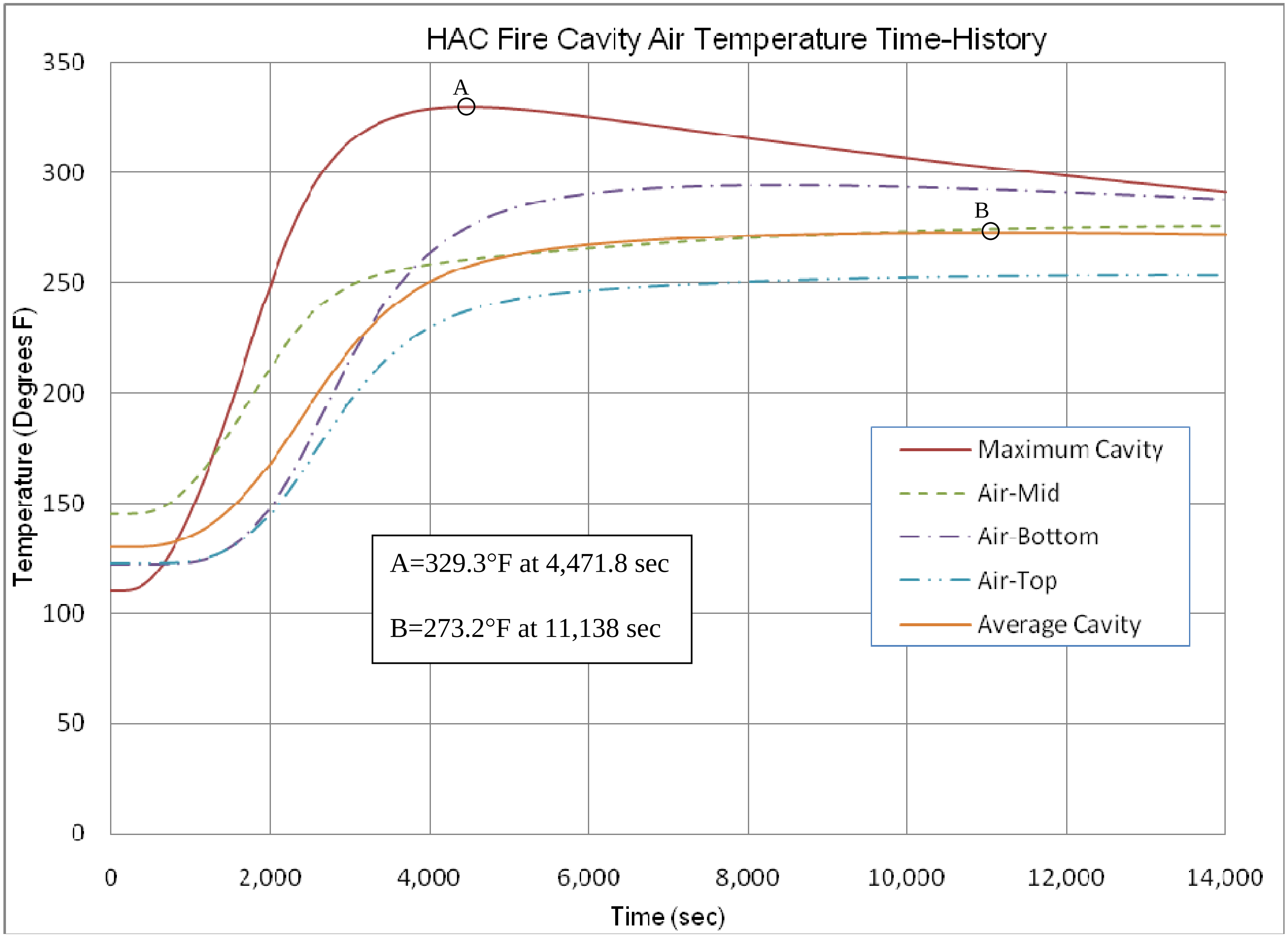


Figure 18 – Time-History Plot of the Cavity Air at Various Locations
(See Figure 19 for the Monitored Locations)

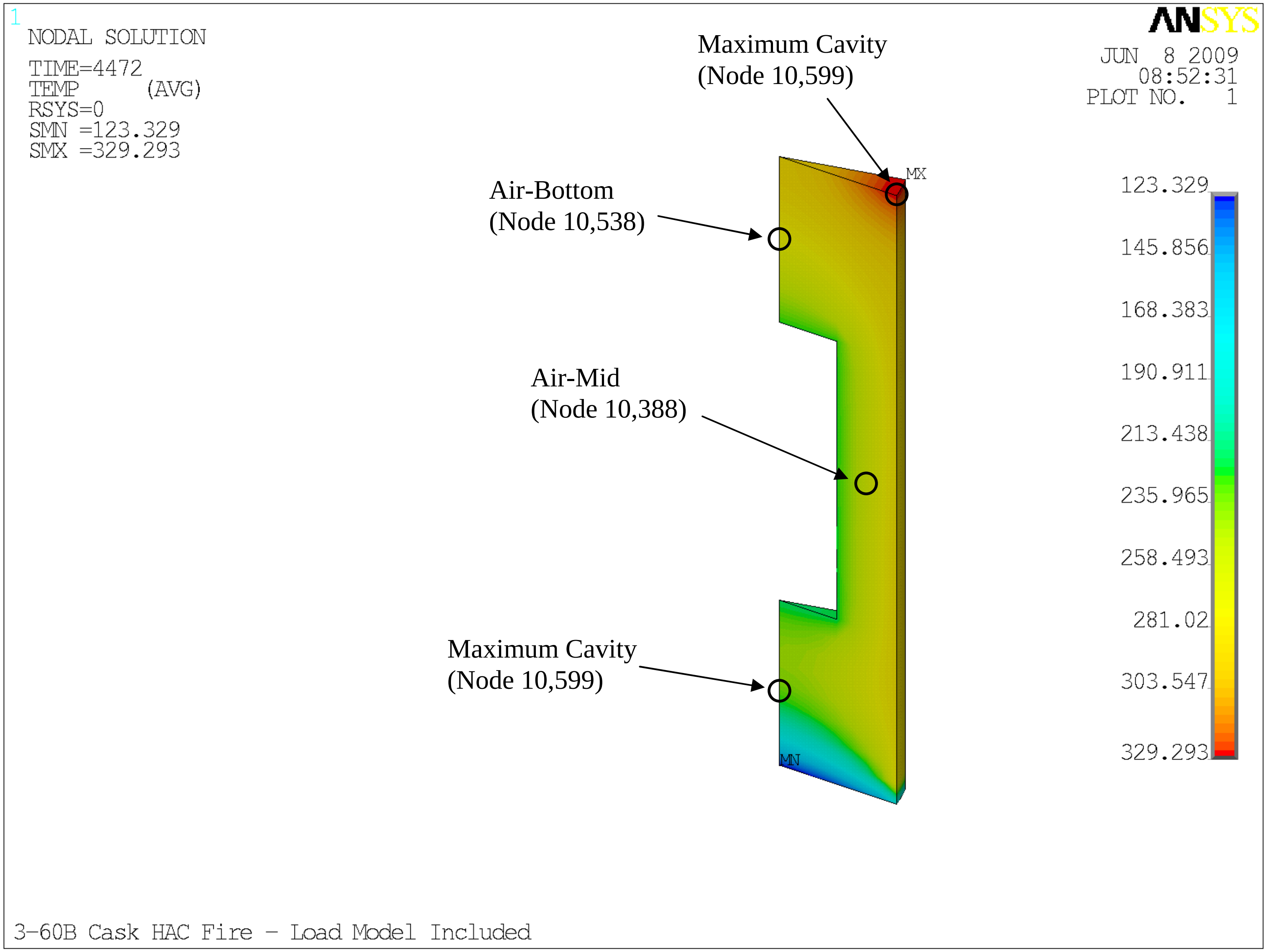


Figure 19 – Temperature Profile of the Cavity Air at Time Corresponding Maximum Air Temperature

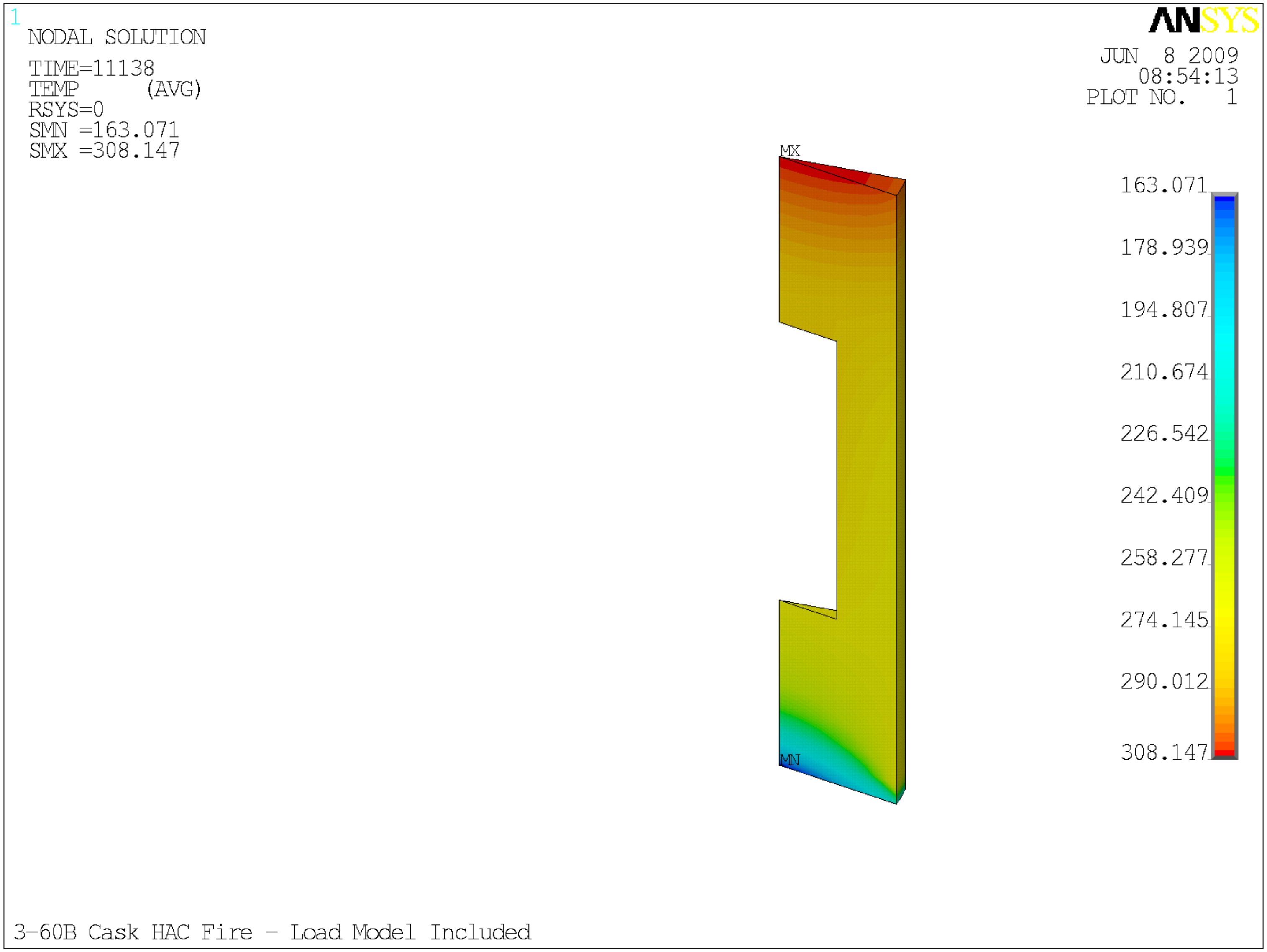


Figure 20 – Temperature Profile of the Cavity Air at Time Corresponding Maximum Average Air Temperature

Figure 21 – Temperature Profile of the Waste Container at Time Corresponding Maximum Temperature

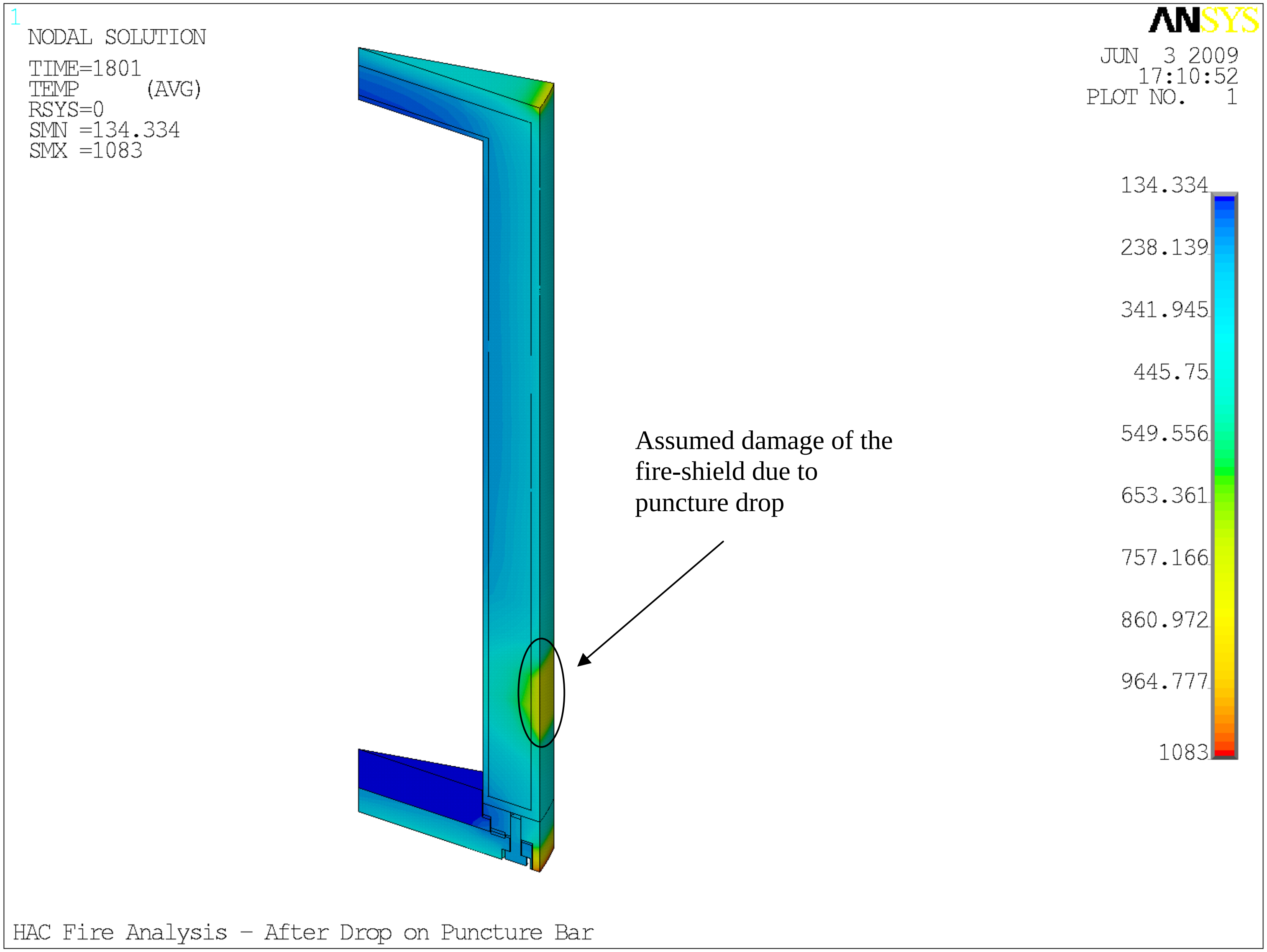


Figure 22 – Temperature Profile in the Cask at Time Corresponding Maximum Temperature at the Puncture Drop Damage Location

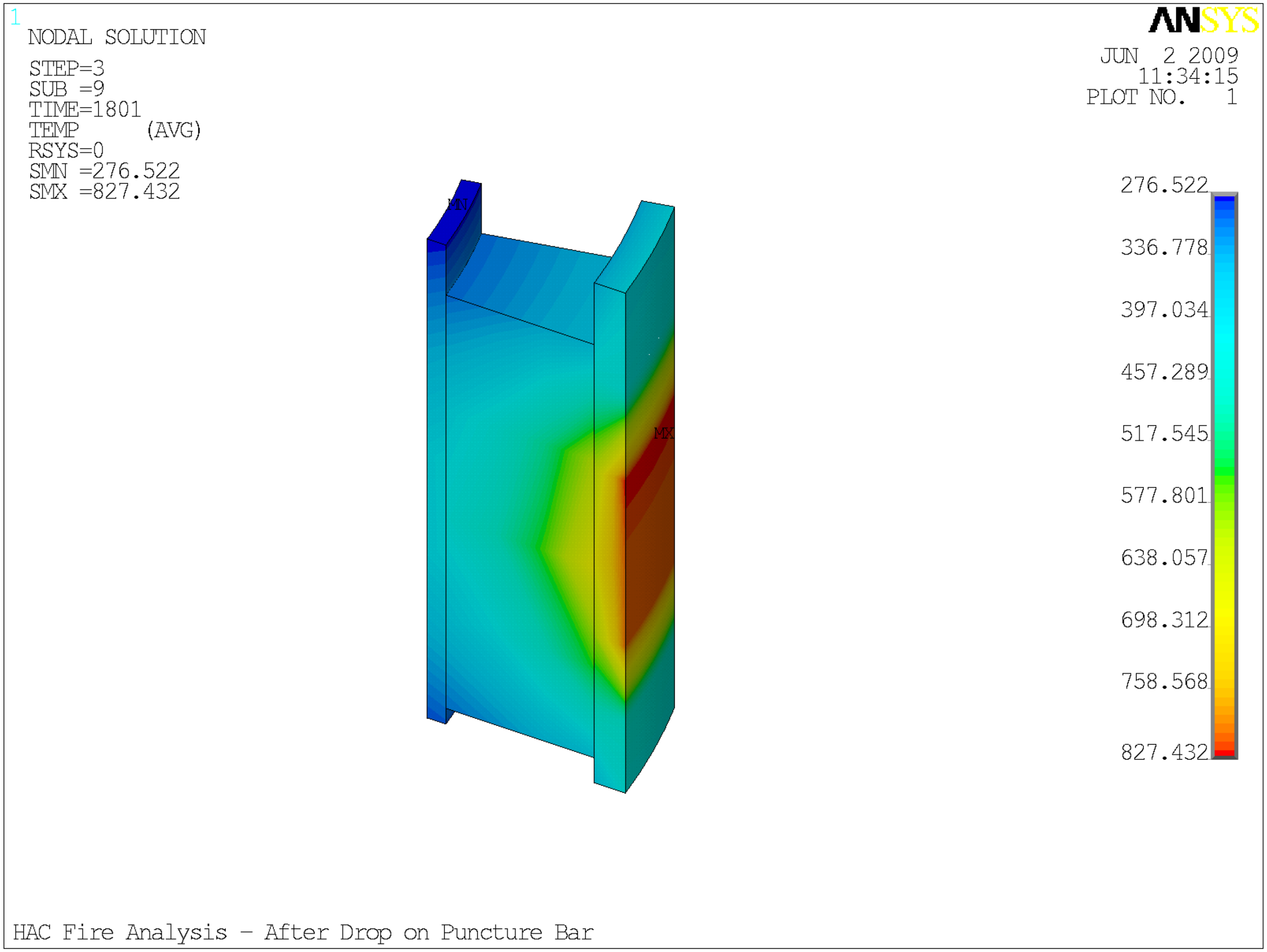
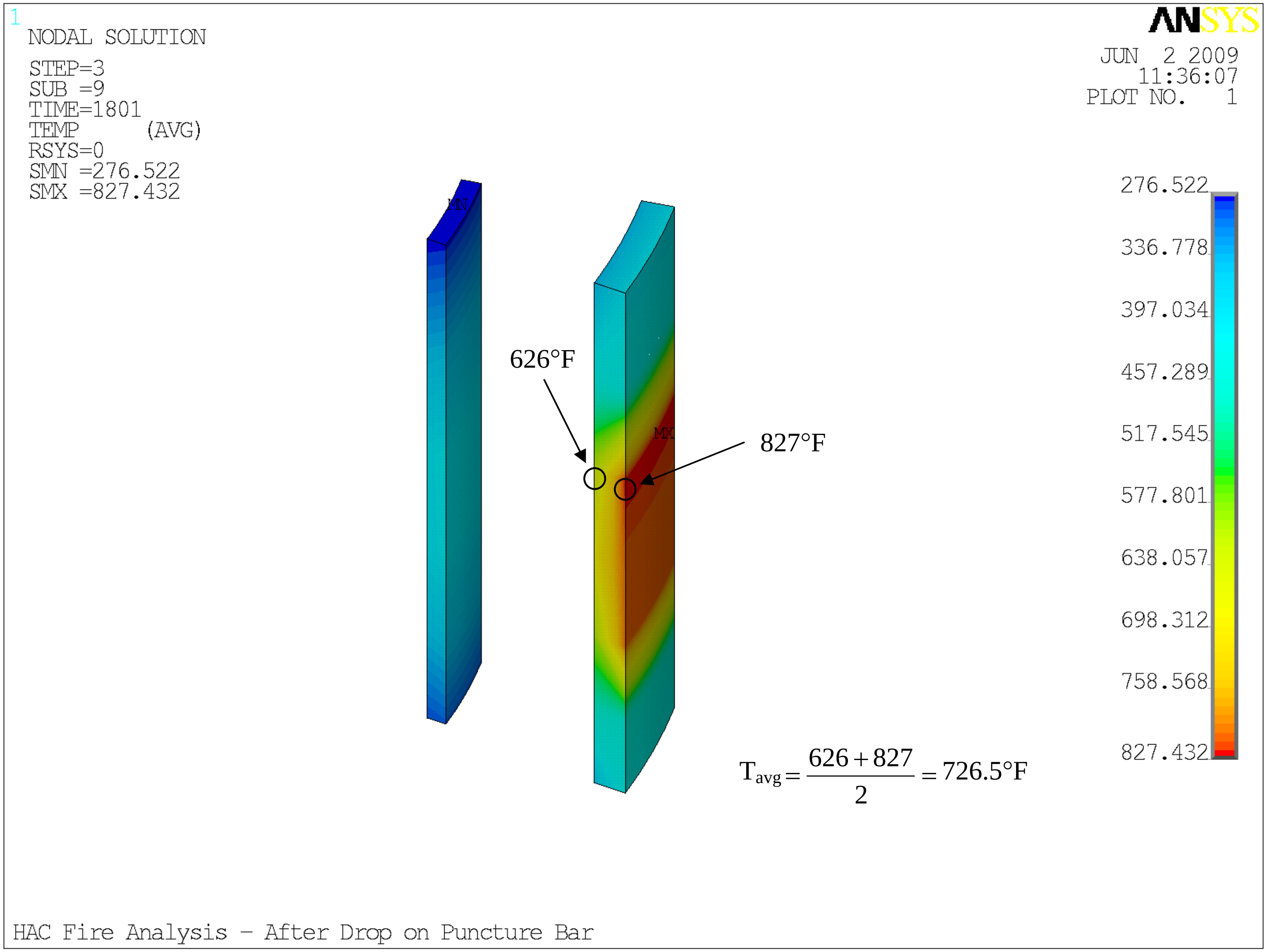


Figure 23 – Temperature Profile in the Cask Wall at Time Corresponding Maximum Temperature at the Puncture Damage Location



<u>Figure 24 – Temperature Profile in the Cask Outer & Inner Shells at Time Corresponding Maximum Temperature at the Puncture Damage Location</u>

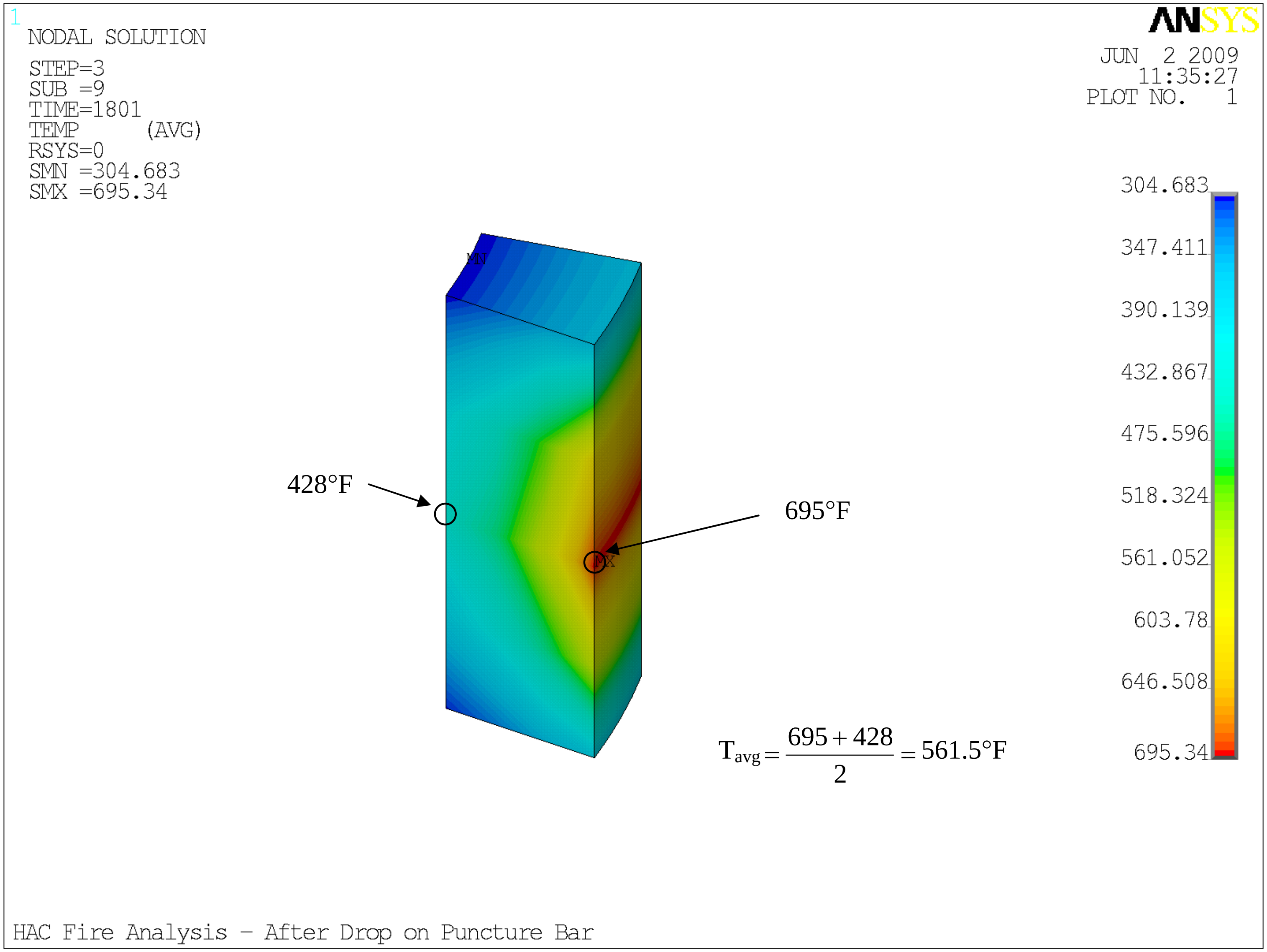


Figure 25 – Temperature Profile in the Lead Shielding at Time Corresponding Maximum Temperature at the Puncture Damage Location

Appendix 1

Print-out of the ANSYS model data input

(13 Pages)

3-60B Cask HAC Fire Analysis - ANSYS Model Data

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

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 ANSYS Mechanical/Emag
 RELEASE  11.0SP1   UPDATE 20070830   CUSTOMER  00222442

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 CURRENT JOBNAME = file

 Current Working Directory: D:\Ansys Analyses\3-60B\Thermal\Fire with Conc Heat Load-1

 TITLE= 3-60B Cask HAC Fire - Load Model Included

 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 09, 2009          11:27
 Release 11.0SP1              00222442                 WINDOWS x64  Version

 Current working directory: D:\Ansys Analyses\3-60B\Thermal\Fire with Conc Heat Load-1


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 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 -----------------------------------------------

3-60B Cask HAC Fire - Load Model Included

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 Initial jobname . . . . . .file

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

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 Database space  . . . . . . 1048572.000 mb         16.778 mb (  0.0%)

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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 . . . . . . . . . . . .  30003          10934          10934
Elements. . . . . . . . . . .  10557           9048           9048

Element types . . . . . . . .     69             43           n.a.
Real constant sets. . . . . .     53             25           n.a.
Material property sets. . . .     27              7           n.a.

Coupling. . . . . . . . . . .     52             20           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. . . . . . . . . . .    3
Constraints on keypoints. . . . . . . . .    0
Constraints on lines. . . . . . . . . . .    0
Constraints on areas. . . . . . . . . . .    0

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

Surface loads on elements . . . . . . . .  785
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. . . . . . . . . .  100.000
   Offset from absolute scale . . . . . .  460.000

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

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

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

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

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

Current element attributes:
   Type number . . . . . . . . . . . . .     7  (SURF152)
```

```
   Real number . . . . . . . . . . . . .    26
   Material number . . . . . . . . . . .    26
   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 . . . . . . .   0 (Cartesian)

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

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

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

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

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

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

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

  PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
  DEGREES OF FREEDOM. . . . . . TEMP
  ANALYSIS TYPE . . . . . . . . . . . . . . . . .TRANSIENT
     SOLUTION METHOD. . . . . . . . . . . . . . .FULL
  OFFSET TEMPERATURE FROM ABSOLUTE ZERO . . . . .  460.00
  EQUATION SOLVER OPTION. . . . . . . . . . . . .SPARSE
  NEWTON-RAPHSON OPTION . . . . . . . . . . . . .PROGRAM CHOSEN
  GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . .SYMMETRIC

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

  LOAD STEP NUMBER. . . . . . . . . . . . . . . .     1
  TIME AT END OF THE LOAD STEP. . . . . . . . . .  14001.
  AUTOMATIC TIME STEPPING . . . . . . . . . . . .    ON
     INITIAL NUMBER OF SUBSTEPS . . . . . . . . .  5000
     MAXIMUM NUMBER OF SUBSTEPS . . . . . . . . .  5000
     MINIMUM NUMBER OF SUBSTEPS . . . . . . . . .   100
  MAXIMUM NUMBER OF EQUILIBRIUM ITERATIONS. . . .    15
  STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .   YES
  TRANSIENT (INERTIA) EFFECTS
     THERMAL DOFS . . . . . . . . . . . . . . . .    ON
  TRANSIENT INTEGRATION PARAMETERS
     THETA. . . . . . . . . . . . . . . . . . . .  1.0000
     OSCILLATION LIMIT CRITERION. . . . . . . . . 0.50000
     TOLERANCE. . . . . . . . . . . . . . . . . .  0.0000
  PRESSURE LOAD STIFFNESS . . . . . . . . . . . .NEVER USED
  TERMINATE ANALYSIS IF NOT CONVERGED . . . . . .YES (EXIT)
```

```
  CONVERGENCE CONTROLS. . . . . . . . . . . . . . .USE DEFAULTS
  PRINT OUTPUT CONTROLS . . . . . . . . . . . . . .NO PRINTOUT
  DATABASE OUTPUT CONTROLS
     ITEM     FREQUENCY   COMPONENT
     BASI        ALL


LIST ELEMENT TYPES FROM      1 TO     69 BY      1

ELEMENT TYPE      1 IS SOLID70      3-D THERMAL SOLID             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      2 IS SHELL57      THERMAL SHELL                 INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      3 IS SOLID70      3-D THERMAL SOLID             INOPR
 KEYOPT(1-12)=    0  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE      4 IS SURF152      3-D THERMAL SURFACE           INOPR
 KEYOPT(1-12)=    0  0  0    1  1  0    0  0  1    0  0  0       0

ELEMENT TYPE      5 IS SURF152      3-D THERMAL SURFACE           INOPR
 KEYOPT(1-12)=    0  0  0    1  1  0    1  4  0    0  0  0       0

ELEMENT TYPE      6 IS SURF152      3-D THERMAL SURFACE           INOPR
 KEYOPT(1-12)=    0  0  0    1  1  0    0  4  0    0  0  0       0

ELEMENT TYPE      7 IS SURF152      3-D THERMAL SURFACE           INOPR
 KEYOPT(1-12)=    0  0  0    1  0  0    0  1  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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    0  0  5       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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT     INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     50 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)    INOPR
 KEYOPT(1-12)=    1  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE     51 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)    INOPR
 KEYOPT(1-12)=    1  0  0    0  0  0    0  0  0    0  0  0       0

ELEMENT TYPE     52 IS MATRIX50     SUPERELEMENT (SUBSTRUCTURE)    INOPR
 KEYOPT(1-12)=    1  0  0    0  0  0    0  0  0    0  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-SURF PURE THERM CONTACT   INOPR
 KEYOPT(1-12)=    2  2  0    0  0  0    0  0  0    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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     59 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     60 IS CONTA174     3D 8-NODE THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 CONTA174     3D 8-NODE THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       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 CONTA174     3D 8-NODE THERMAL CONTACT      INOPR
 KEYOPT(1-12)=    2  2  0    2  0  0    0  0  0    2  0  5       0

ELEMENT TYPE     69 IS SURF252      3-D THERMAL SURFACE            INOPR
 KEYOPT(1-12)=    0  0  0    1  0  0    0  0  0    0  0  0       0

CURRENT NODAL DOF SET IS  TEMP
 THREE-DIMENSIONAL MODEL

LIST REAL SETS       1 TO      53 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

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
   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      49  ITEMS   1 TO   6
   0.0000       0.0000       1.0000      0.10000       0.0000       0.0000

REAL CONSTANT SET      49  ITEMS   7 TO  12
   0.0000       0.0000      0.10000E+21   0.0000       1.0000       0.0000

REAL CONSTANT SET      49  ITEMS  13 TO  18
```

```
   0.0000       0.0000       1.0000       0.0000       1.0000      0.50000

REAL CONSTANT SET      49  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

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

LIST MATERIALS       1 TO      27 BY       1
 PROPERTY= ALL

PROPERTY TABLE DENS  MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.28240      100.00     0.28240      150.00     0.28240
    200.00     0.28240      250.00     0.28240      300.00     0.28240
    350.00     0.28240      400.00     0.28240      450.00     0.28240
    500.00     0.28240      550.00     0.28240      600.00     0.28240
    650.00     0.28240      700.00     0.28240      750.00     0.28240
```

```
    800.00     0.28240      900.00     0.28240      1000.0     0.28240
    1100.0     0.28240      1200.0     0.28240      1300.0     0.28240
    1400.0     0.28240      1500.0     0.28240

PROPERTY TABLE MU    MAT=       1  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000      0.0000

PROPERTY TABLE KXX   MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.19900E-03  100.00     0.20100E-03  150.00     0.20800E-03
    200.00     0.21500E-03  250.00     0.22200E-03  300.00     0.22700E-03
    350.00     0.23400E-03  400.00     0.24100E-03  450.00     0.24500E-03
    500.00     0.25200E-03  550.00     0.25700E-03  600.00     0.26200E-03
    650.00     0.26900E-03  700.00     0.27300E-03  750.00     0.27800E-03
    800.00     0.28200E-03  900.00     0.29400E-03  1000.0     0.30600E-03
    1100.0     0.31500E-03  1200.0     0.32400E-03  1300.0     0.33600E-03
    1400.0     0.34500E-03  1500.0     0.35400E-03

PROPERTY TABLE C     MAT=       1  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.11700      100.00     0.11700      150.00     0.12000
    200.00     0.12200      250.00     0.12500      300.00     0.12600
    350.00     0.12800      400.00     0.12900      450.00     0.13000
    500.00     0.13100      550.00     0.13200      600.00     0.13300
    650.00     0.13400      700.00     0.13500      750.00     0.13600
    800.00     0.13600      900.00     0.13800      1000.0     0.13900
    1100.0     0.14100      1200.0     0.14100      1300.0     0.14300
    1400.0     0.14400      1500.0     0.14500

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

PROPERTY TABLE DENS  MAT=       2  NUM. POINTS=  1
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    0.0000     0.28300

PROPERTY TABLE KXX   MAT=       2  NUM. POINTS= 16
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.81300E-03  100.00     0.80300E-03  200.00     0.77800E-03
    300.00     0.74800E-03  400.00     0.71500E-03  500.00     0.67700E-03
    600.00     0.64800E-03  700.00     0.61600E-03  800.00     0.58300E-03
    900.00     0.55100E-03  1000.0     0.51900E-03  1100.0     0.48400E-03
    1200.0     0.45100E-03  1300.0     0.41700E-03  1400.0     0.38000E-03
    1500.0     0.36300E-03

PROPERTY TABLE C     MAT=       2  NUM. POINTS= 16
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.10330      100.00     0.10530      200.00     0.11210
    300.00     0.11770      400.00     0.12340      500.00     0.12780
    600.00     0.13220      700.00     0.13810      800.00     0.14520
    900.00     0.15350      1000.0     0.16240      1100.0     0.17100
    1200.0     0.18290      1300.0     0.20450      1400.0     0.40900
    1500.0     0.19820

PROPERTY TABLE DENS  MAT=       3  NUM. POINTS= 23
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE     DATA
    70.000     0.41090      100.00     0.41090      150.00     0.41090
    200.00     0.41090      250.00     0.41090      300.00     0.41090
    350.00     0.41090      400.00     0.41090      450.00     0.41090
    500.00     0.41090      550.00     0.41090      600.00     0.41090
    650.00     0.41090      700.00     0.41090      750.00     0.41090
```

800.00	0.41090	900.00	0.41090	1000.0	0.41090
1100.0	0.41090	1200.0	0.41090	1300.0	0.41090
1400.0	0.41090	1500.0	0.41090		

PROPERTY TABLE KXX MAT= 3 NUM. POINTS= 23

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.46500E-03	100.00	0.46100E-03	150.00	0.45500E-03
200.00	0.44800E-03	250.00	0.44100E-03	300.00	0.43500E-03
350.00	0.42800E-03	400.00	0.42200E-03	450.00	0.41500E-03
500.00	0.40900E-03	550.00	0.40200E-03	600.00	0.39500E-03
650.00	0.38900E-03	700.00	0.38900E-03	750.00	0.38900E-03
800.00	0.38900E-03	900.00	0.38900E-03	1000.0	0.38900E-03
1100.0	0.38900E-03	1200.0	0.38900E-03	1300.0	0.38900E-03
1400.0	0.38900E-03	1500.0	0.38900E-03		

PROPERTY TABLE C MAT= 3 NUM. POINTS= 23

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

PROPERTY TABLE DENS MAT= 4 NUM. POINTS= 23

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.43510E-04	100.00	0.41120E-04	150.00	0.37520E-04
200.00	0.34680E-04	250.00	0.32360E-04	300.00	0.30310E-04
350.00	0.28310E-04	400.00	0.26730E-04	450.00	0.25220E-04
500.00	0.23960E-04	550.00	0.22780E-04	600.00	0.21680E-04
650.00	0.20710E-04	700.00	0.19800E-04	750.00	0.18980E-04
800.00	0.18180E-04	900.00	0.16900E-04	1000.0	0.15710E-04
1100.0	0.14720E-04	1200.0	0.13850E-04	1300.0	0.13040E-04
1400.0	0.12350E-04	1500.0	0.11710E-04		

PROPERTY TABLE KXX MAT= 4 NUM. POINTS= 23

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

PROPERTY TABLE C MAT= 4 NUM. POINTS= 23

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

PROPERTY TABLE DENS MAT= 5 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.28300				

PROPERTY TABLE KXX MAT= 5 NUM. POINTS= 16

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

PROPERTY TABLE C MAT= 5 NUM. POINTS= 16

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
70.000	0.10330	100.00	0.10530	200.00	0.11210
300.00	0.11770	400.00	0.12340	500.00	0.12780
600.00	0.13220	700.00	0.13810	800.00	0.14520
900.00	0.15350	1000.0	0.16240	1100.0	0.17100
1200.0	0.18290	1300.0	0.20450	1400.0	0.40900
1500.0	0.19820				

PROPERTY TABLE EMIS MAT= 23 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.90000				

PROPERTY TABLE EMIS MAT= 27 NUM. POINTS= 1

TEMPERATURE	DATA	TEMPERATURE	DATA	TEMPERATURE	DATA
0.0000	0.90000				

Appendix 2

Electronic Data on CDROM

(3 Pages & 1 DVD)

```
 Volume in drive F is TH-023r3a2
 Volume Serial Number is E21F-6848

 Directory of F:\

02/23/2010  10:03 AM    <DIR>          Explicit Heat Load Modeling
02/23/2010  10:01 AM    <DIR>          Implicit Heat Load Modeling
02/23/2010  10:02 AM    <DIR>          Puncture Drop Damage Modeling
               0 File(s)              0 bytes

 Directory of F:\Explicit Heat Load Modeling

02/23/2010  10:03 AM    <DIR>          .
02/23/2010  10:07 AM    <DIR>          ..
05/12/2009  09:33 AM            65,536 bot.sub
06/08/2009  07:52 AM            63,845 fig19.png
06/08/2009  07:54 AM            48,817 fig20.png
06/08/2009  07:55 AM            37,978 fig21.png
06/08/2009  07:47 AM           114,877 fig6.png
06/02/2009  08:32 AM        11,553,792 file.avi
06/05/2009  07:06 PM             2,234 file.BCS
06/08/2009  07:57 AM        17,432,576 file.db
06/05/2009  07:40 PM         2,621,440 file.dsub
06/09/2009  10:27 AM           301,174 file.err
06/05/2009  07:40 PM         5,898,240 file.esav
06/05/2009  07:40 PM         1,114,112 file.full
06/05/2009  06:46 PM         1,064,980 file.ldhi
06/09/2009  10:47 AM            22,004 file.log
06/05/2009  07:06 PM            21,708 file.mntr
06/05/2009  07:06 PM         5,898,240 file.osav
06/05/2009  06:23 PM         6,160,384 file.r001
06/05/2009  07:06 PM         6,160,384 file.r002
06/05/2009  06:22 PM         9,961,472 file.rdb
06/08/2009  07:57 AM           393,216 file.rsm
06/05/2009  07:40 PM       845,152,256 file.rth
06/05/2009  04:34 PM                 0 file.sda
06/05/2009  06:22 PM               151 file.stat
06/05/2009  06:21 PM       148,887,064 file.vf
05/12/2009  07:18 AM             1,645 generate superelements.txt
05/12/2009  10:26 AM               965 loading.txt
06/08/2009  07:32 AM            23,680 PRVAR.lis
06/08/2009  08:34 AM            43,453 PRVAR.xlsx
06/09/2009  10:27 AM           486,892 report.out
05/12/2009  09:33 AM         1,441,792 side.sub
06/03/2009  01:13 PM               153 TimeHisInput.txt
05/12/2009  09:33 AM           327,680 top.sub
              32 File(s)  1,065,302,740 bytes

 Directory of F:\Implicit Heat Load Modeling

02/23/2010  10:01 AM    <DIR>          .
02/23/2010  10:07 AM    <DIR>          ..
05/12/2009  07:25 AM            65,536 bot.sub
06/04/2009  07:57 AM            91,611 fig11.png
```

```
06/04/2009  07:58 AM           126,308 fig12.png
06/04/2009  07:59 AM           130,779 fig13.png
06/04/2009  08:00 AM           132,237 fig14.png
06/04/2009  08:01 AM           111,963 fig15.png
06/04/2009  08:02 AM           114,196 fig16.png
06/04/2009  08:02 AM           110,070 fig17.png
05/31/2009  10:28 AM        11,293,696 file.avi
05/31/2009  10:23 AM             2,234 file.BCS
06/04/2009  08:04 AM        10,354,688 file.db
05/31/2009  10:23 AM         2,621,440 file.dsub
06/04/2009  07:25 AM             5,943 file.err
05/31/2009  10:23 AM         4,390,912 file.esav
05/31/2009  10:23 AM           917,504 file.full
05/31/2009  10:21 AM         1,875,176 file.ldhi
06/04/2009  08:04 AM            14,140 file.log
05/31/2009  10:23 AM            21,708 file.mntr
05/31/2009  10:23 AM         4,390,912 file.osav
05/31/2009  10:20 AM         4,521,984 file.r001
05/31/2009  10:23 AM         4,521,984 file.r002
05/31/2009  10:20 AM         8,716,288 file.rdb
05/31/2009  10:23 AM       501,743,616 file.rth
05/31/2009  10:20 AM               151 file.stat
05/12/2009  07:18 AM             1,645 generate superelements.txt
05/11/2009  02:24 PM               909 loading.txt
06/01/2009  07:35 AM            19,130 PRVAR.lis
06/03/2009  09:19 AM            35,361 PRVAR.xlsx
06/03/2009  07:43 AM            26,214 PRVAR1.lis
06/09/2009  09:23 AM            78,613 PRVAR1.xlsx
06/03/2009  07:44 AM            19,970 PRVAR2.lis
05/12/2009  07:25 AM         1,441,792 side.sub
05/20/2009  08:40 AM               266 TimeHisInput-1.txt
10/10/2007  02:01 PM               266 TimeHisInput.txt
05/12/2009  07:25 AM           327,680 top.sub
              35 File(s)    558,226,922 bytes

 Directory of F:\Puncture Drop Damage Modeling

02/23/2010  10:02 AM    <DIR>          .
02/23/2010  10:07 AM    <DIR>          ..
05/12/2009  07:25 AM            65,536 bot.sub
05/12/2009  03:02 PM               402 coupling.txt
06/03/2009  04:10 PM            69,853 fig22.png
06/02/2009  10:34 AM           107,785 fig23.png
06/02/2009  10:36 AM            80,958 fig24.png
06/02/2009  10:35 AM            98,433 fig25.png
06/02/2009  10:29 AM        16,999,424 file.avi
06/02/2009  10:24 AM             2,234 file.BCS
06/03/2009  04:11 PM        10,289,152 file.db
06/02/2009  10:25 AM         2,621,440 file.dsub
06/09/2009  08:43 AM            11,091 file.err
06/02/2009  10:25 AM         4,390,912 file.esav
06/02/2009  10:25 AM           917,504 file.full
06/02/2009  10:22 AM         1,877,996 file.ldhi
06/09/2009  08:43 AM            18,750 file.log
```

```
06/02/2009  10:24 AM            21,616 file.mntr
06/02/2009  10:24 AM         4,390,912 file.osav
06/02/2009  10:20 AM         4,521,984 file.r001
06/02/2009  10:24 AM         4,521,984 file.r002
06/02/2009  10:20 AM         8,716,288 file.rdb
06/02/2009  10:25 AM       499,777,536 file.rth
06/02/2009  10:20 AM               151 file.stat
05/12/2009  07:18 AM             1,645 generate superelements.txt
05/11/2009  02:24 PM               909 loading.txt
05/12/2009  07:25 AM         1,441,792 side.sub
10/10/2007  02:01 PM               266 TimeHisInput.txt
05/12/2009  07:25 AM           327,680 top.sub
              27 File(s)    561,274,233 bytes

     Total Files Listed:
              94 File(s)  2,184,803,895 bytes
               9 Dir(s)               0 bytes free
```