CNS Type B Casks
Structural Evaluation of the Thermal Shields of the 8-120B & 10-160B Casks under Puncture Drop Conditions

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0		Initial Issue	JD Sparks	BA Crea	JD Sohl

History Sheet

Rev	Reason for revision	Originator
0	Initial Issue	JD Sparks

Calculation Summary and Control Sheet

<table>
<tr><td colspan="2">Quality Level / Category: ☒QL-1 ☐QL-2 ☐QL-3 ☐QL-4</td></tr>
<tr><td>Calculation results rely on a COMPUTER PROGRAM:
☒ Yes ☐ No
If "Yes," complete Verification and Validation Information section</td><td>Verification and Validation Information
Program Used: ANSYS
Revision: 13
Desktop Computer tag #: 27929-D
V&V report (number and date): VV-ETD-ST-0004 (Ref. 8.1.2)
August 26, 2011</td></tr>
<tr><td>Results generated using a SOFTWARE TOOL are reported and checked by hand for applications that are not validated and verified:
☒ Yes ☐ No
("No" to be checked only if a software tool is not used)</td><td>Note: All calculations, including those generated using a software tool, shall be hand checked unless a computer program was used to perform the calculation AND proper documentation exists confirming that the computer program has been verified and validated in accordance with ES-QA-PR-019, Computer Software Management, and that modeling conditions are within the scope of the verification and validation of the program.</td></tr>
<tr><td>Calculation contains Unverified Assumptions:
☐ Yes ☒ No</td><td>Note: If calculation contains unverified assumptions identify them in the box below.</td></tr>
<tr><td colspan="2">Identify and Number Unverified Assumptions:
None.</td></tr>
<tr><td colspan="2">Identify Design Inputs (may reference appropriate calculation section):
See section 3.</td></tr>
<tr><td colspan="2">Results and Conclusions:

The evaluations performed in this document show the 8-120B and 10-160B cask thermal shields have sufficient flexibility such that they can deflect to the lid with only local deformation. Thus, under the puncture drop test of the packages, the plates of the thermal shields will come in contact with the lid near the location of the puncture bar contact with only localized failure.</td></tr>
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1. Introduction and Scope

This calculation documents puncture analyses on the thermal shield of the 8-120B and 10-160B casks as part of the precursor accidents prior to the fire accident required in the Hypothetical Accident Condition (HAC) of 10 CFR 71.73 (Ref. 8.2.1). The puncture test involves dropping the loaded cask onto a six inch diameter puncture bar. The loaded cask must fall forty inches before impacting the puncture bar The thermal shield for the cask lid has been designed to protect the cask from the effects of the subsequent fire event that is the culmination of the HAC scenario, and is, therefore, required to retain its functionality after the puncture test.

In order to analyze the puncture test, models of the thermal shield for each cask were generated and analyzed using ANSYS finite element models.

2. Assumptions

None.

3. Inputs

3.1. Design Inputs

3.1.1. Geometry Inputs

The design inputs are based on the drawings of the cask radiation shields (Ref. 8.1.4 – 8.1.5). The current design of the thermal shield is based on 6 inch schedule 40 pipe standoffs. There is one central pipe and six equally spaced pipes in an annular pattern approximately half way between the center and the outside.

3.1.2. Load Cask Energy Input

Cask 8-120B has a gross weight of 74,000 lb, while cask 10-160B has a gross weight of 72,000 lb. This calculation will conservatively use a gross weight of 74,000 lb (Ref. 8.1.4 – 8.1.5). The total energy of the loaded cask drop is 2,960,000 inch pounds (gross weight multiplied by 40 inches).

3.1.3. Puncture Inputs

The puncture loadings and specifications are called out in 10 CFR 71.73 (Ref.8.2.1).

Puncture bar is 40 inches away from the thermal shield.
Puncture bar is six inches in diameter.
Puncture bar top horizontal end is rounded to a radius of 0.25 inches or less.

Puncture bar length is variable, but must be the length required to cause maximum damage and be at least eight inches.

See Figure 3-1 for an illustration of the cask puncture test arrangement.

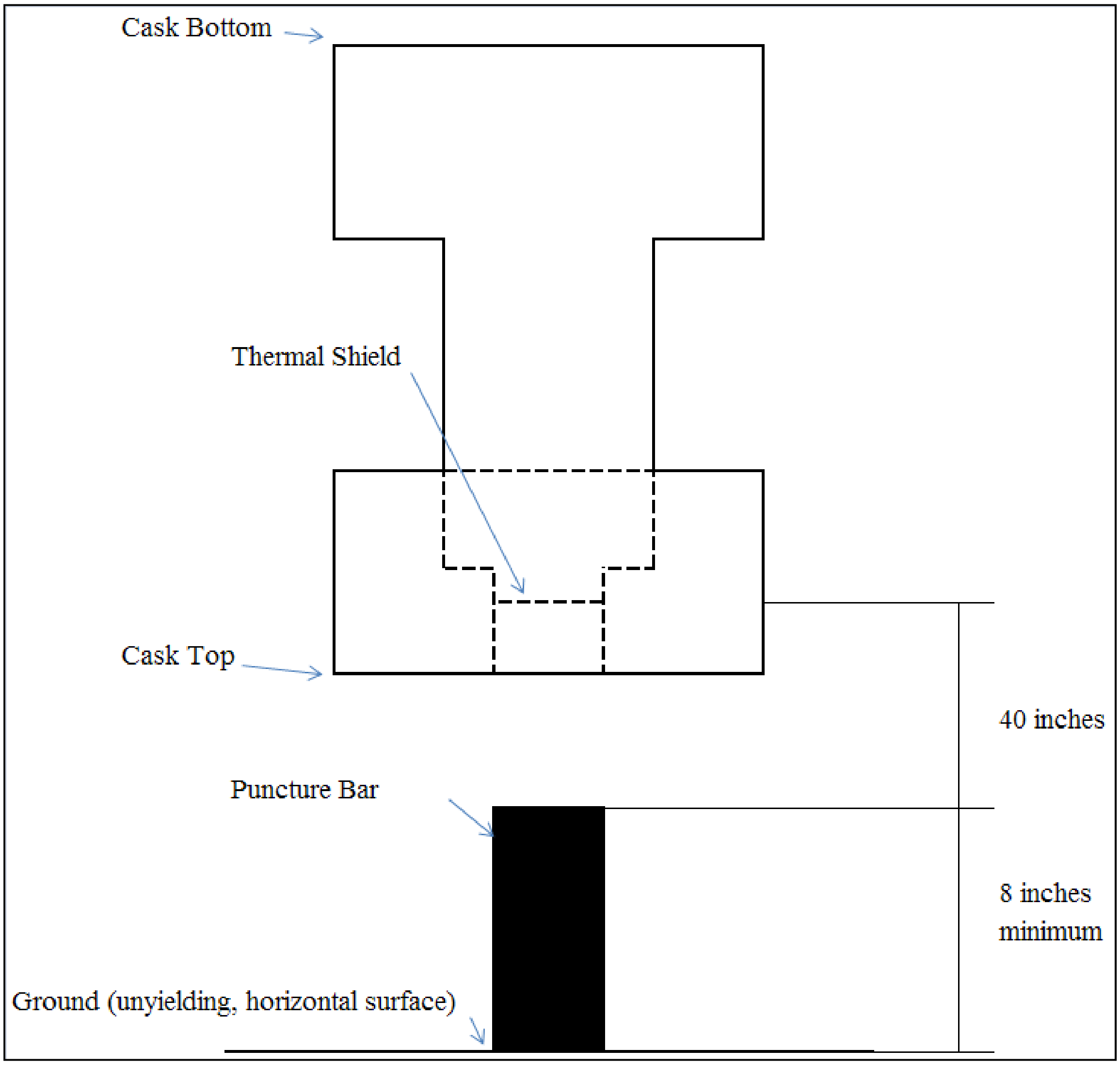

Figure 3-1 Cask Puncture Test Arrangement (not to scale)

4. Calculation Methodology

4.1. ANSYS Finite Element Models

Models of the thermal shields were generated using the finite element modeling program ANSYS. The thermal shields were subjected to the puncture inputs defined in section 3.1.2.

The ANSYS models are made up of shells and use X and Y as the lateral directions with Z as the vertical direction.

ANSYS has been verified and validated in accordance with Energy*Solutions*' NQA-1 compliant quality assurance program and as documented in the Software Plan and Test Report, Ref. 8.1.1 and 8.1.2, respectively.

4.2. Analysis Method

4.2.1. Puncture Test Initial Condition & Procedure

As shown in Figure 3-1, the cask is suspended, top down, with the thermal shield forty inches above a six inch diameter mild steel bar (puncture bar). The steel bar is attached to the ground, which is an unyielding and horizontal surface. The cask is released and allowed to fall directly onto the steel bar at the worst location the cask could be punctured. It is unknown where on the thermal shield is the worst location. Multiple analyses are performed to ensure the worst location is analyzed (see section 4.4).

4.2.2. Puncture Test in ANSYS

The puncture tests were simulated in ANSYS by applying a uniform displacement across the thermal shield's top ¼" plate and bottom 1/8" plate (see Figure 5-1).

The energy that the thermal shield is subjected to (see section 3.1.2) will lead to plastic deformation. Therefore, elastic plastic analyses were performed. The analyses follow an iterative process where the displacement deforms the thermal shield plates. This iterative process allows the model to accurately track the amount of energy absorbed by the thermal shield and the corresponding plastic deformation for each displacement iteration.

4.3. Allowable Puncture Criteria

The strain experienced by the thermal shield is compared to the allowable strain of the thermal shield's top plate material (A240 304/316, Ref. 8.1.4 & 8.1.5). Per ASTM A240 (Ref. 8.3.3), the minimum strain percentage for fracture of a 304 test sample is 40%. However, typical values in practice have fracture at 60%-90% strain (Ref. 8.3.4, Pages 11-12). For this calculation, the thermal shield will be allowed to plastically deform to 40% strain. If the strain placed on the thermal shield by the puncture bar is less than 40%, and it is shown the thermal shield has absorbed all of the loaded cask energy, it can be concluded the thermal shield is not punctured and left intact for the subsequent thermal test (Test Four, Ref. 8.2.1). If the strain placed on the thermal shield is larger than 40%, it can be concluded the thermal shield has started to rupture.

4.3.1.1. Energy Absorbed by the Thermal Shield Calculation

The energy absorbed by the thermal shield for each load step is calculated using a right-handed Riemann Sum method. The energy absorbed is calculated by extracting the total load (lb) placed on the footprint nodes (see section 5.1.1) at the end of each load step and multiplying it by the

difference of the deflection of the thermal shield at that point and the deflection of the thermal shield at the previous point. The total energy absorbed is the sum of the energies for each load step.

4.4. Number of Analyses Performed

Three analyses are performed, two on the 8-120B cask and one on the 10-160B cask.

The first analysis on the 8-120B cask has the puncture bar striking the thermal shield between the center standoff and two of the six outer standoffs. The second analysis on the 8-120B cask has the puncture bar striking between two outer standoffs and the edge of the thermal shield.

The analysis performed on the 10-160B has the puncture bar striking between two outer standoffs and the edge of the thermal shield. The puncture analysis for the 10-160B for the puncture location between the center standoff and the two outer standoffs was considered bounded by the 8-120B due to its larger mass. The second analysis on the 8-120B cask, however, does not cover the 10-160B cask because the 10-160B cask thermal shield is supported at the edges due to proximity with the secondary lid bolts. See section 5.1.3, which shows the boundary conditions for each of the three analyses.

5. Calculations

5.1. ANSYS Models

ANSYS models of the thermal shield for both the 8-120B cask and the 10-160B cask were generated, loaded, and evaluated.

5.1.1. Load Application

The application of the puncture load is accomplished by applying a displacement to a select group of nodes on the thermal shield's top plate and bottom plate, the puncture bar footprint nodes. The puncture bar footprint represents the end of the six inch diameter bar impacting the top plate and is placed in areas expected to generate the maximum strain in the thermal shield. The displacements chosen are shown in Table 5-1, which correspond to the displacements required to produce 40% strain.

Table 5-1 Analysis Displacements

Cask	Analysis	Displacement (in)
8-120B	1	1.0
8-120B	2	2.0
10-160B	1	0.4

See Figure 5-1 for a plot of the puncture bar footprint nodes on the thermal shield top plate of the 8-120B cask Analysis 1. See Figure 5-2 for a plot of the puncture bar footprint nodes on the

thermal shield top plate of the 8-120B cask Analysis 2. See Figure 5-3 for a plot of the puncture bar footprint nodes on the thermal shield top plate of the 10-160B cask Analysis 1.

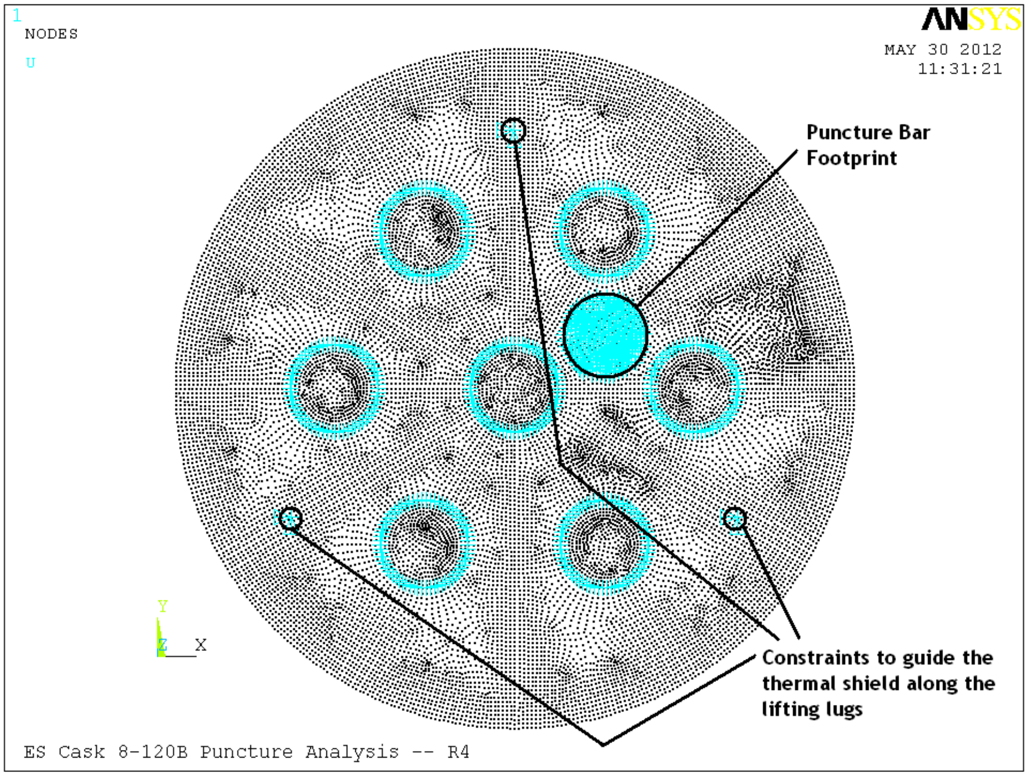

Figure 5-1 Cask 8-120B Analysis 1 Puncture Bar Footprint

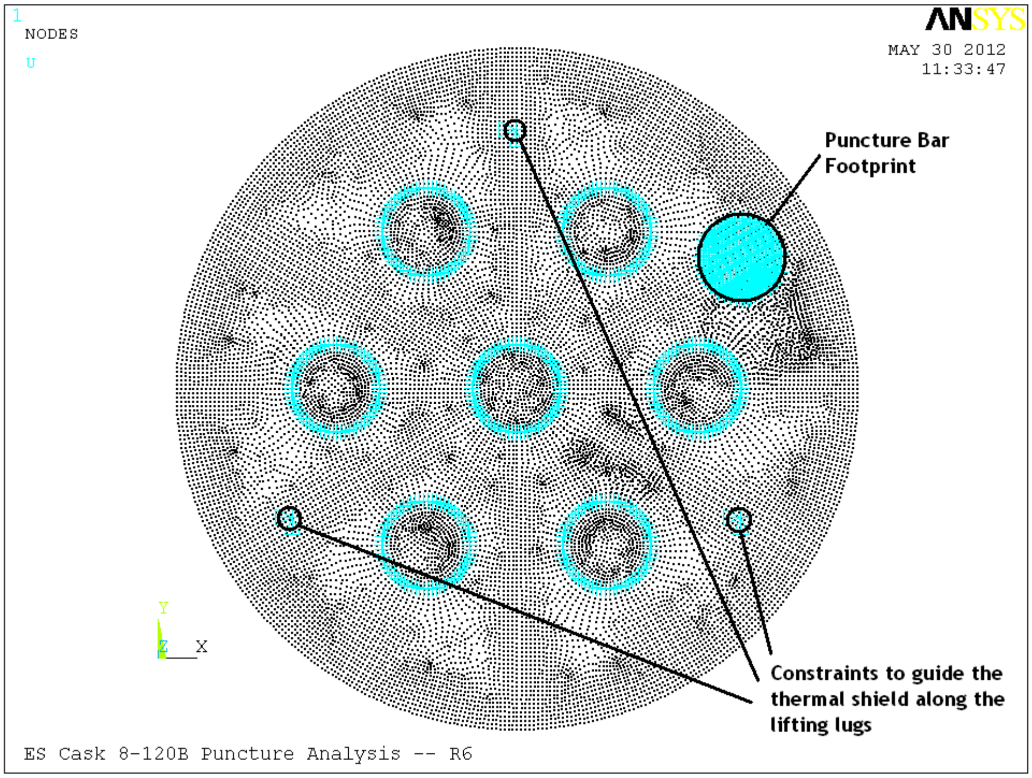

Figure 5-2 Cask 8-120B Analysis 2 Analysis 1 Puncture Bar Footprint

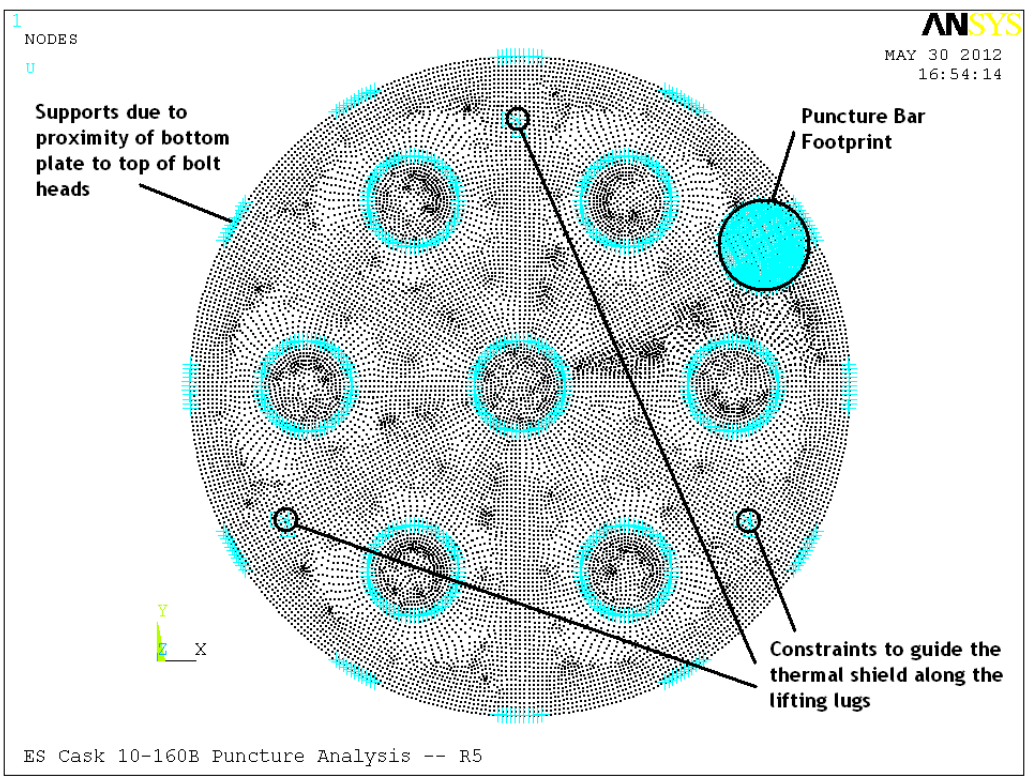

Figure 5-3 Cask 10-160B Analysis 1 Puncture Bar Footprint

5.1.2. Model Development

5.1.2.1. Material Properties

Material properties for stainless steel were extracted from ASME B&PV Section II 2004 (Ref. 8.2.2).

5.1.2.1.1. Material 20, Stainless Steel – Cask Thermal Shields

Material 20, Figure 5-4, is used to model the thermal shields. Figure 5-4 is representative of both the 8-120B and 10-160B stainless steel thermal shield elements.

Material:	ASTM A240 304/316
$E = 28.3 \times 10^6$ lbs/in^2	(Ref. 8.2.2)
$\nu = 0.3$	(Ref. 8.2.2)
ρ= 490/1728 lbs/in^3	(Ref. 8.2.2)
Yield Stress = 30 ksi	(Ref. 8.2.2)
Rupture Strain = 40%	(Ref. 8.3.3)
Rupture Stress = 56.25 ksi	(Ref. 8.3.3 & 8.3.5)

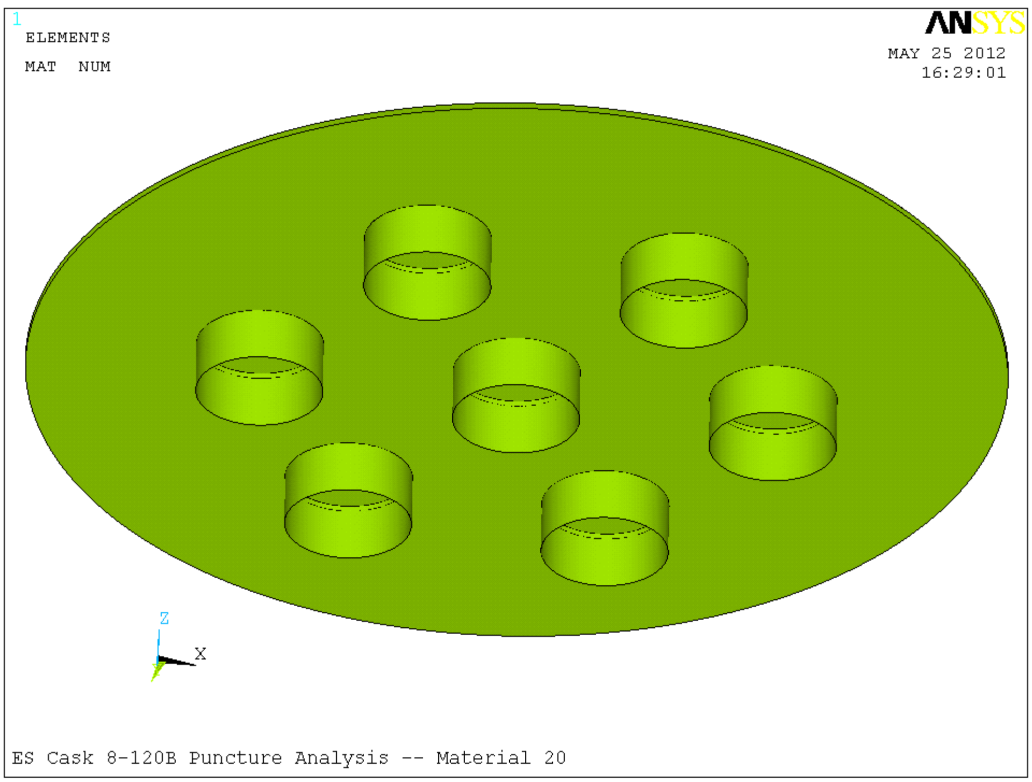

Figure 5-4 Cask 8-120B Material 20 Elements

5.1.3. Boundary Conditions

5.1.3.1. Cask 8-120B Analyses 1 & 2

The bottom of the six inch schedule 40 pipe pieces are constrained vertically using the translational UZ constraint (representing the thermal shield sitting on top of the cask secondary lid). The three nodes on the top plate where the secondary lid lifting lugs protrude through the thermal shield are constrained in all three translational directions (UX, UY, and UZ), which represent the pins placed through the secondary lid lifting lugs securing the radiation shield to the cask. See Figure 5-5 and Figure 5-6.

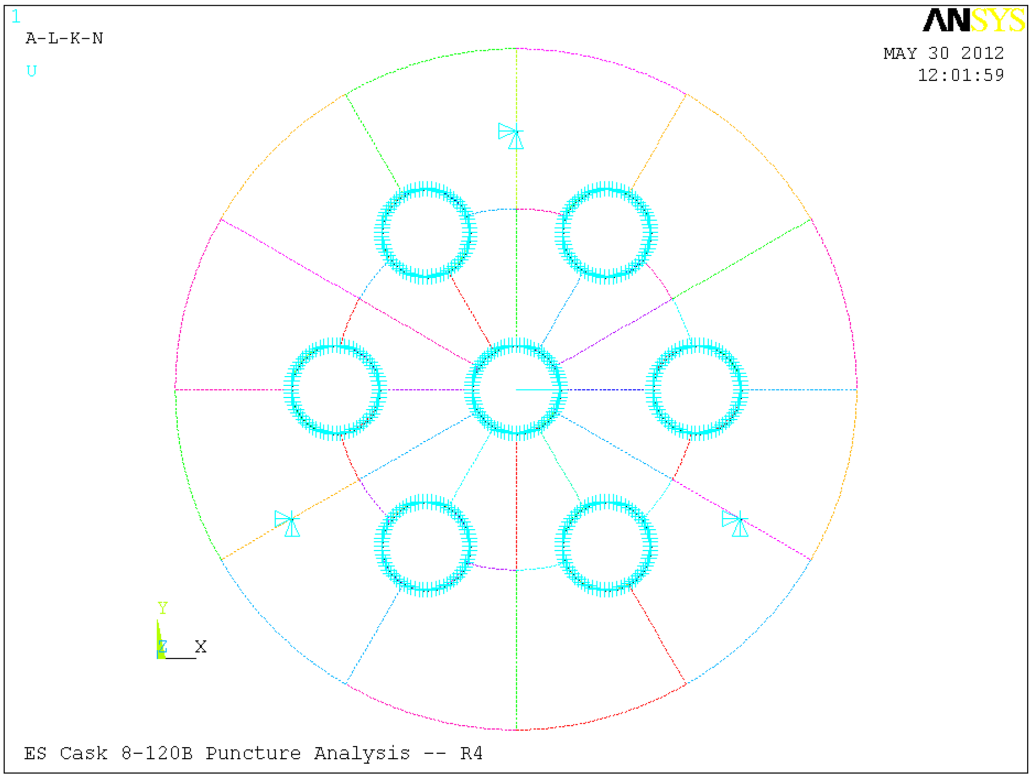

Figure 5-5 Cask 8-120B Analyses 1 & 2 Thermal Shield BCs – Plot 1 of 2

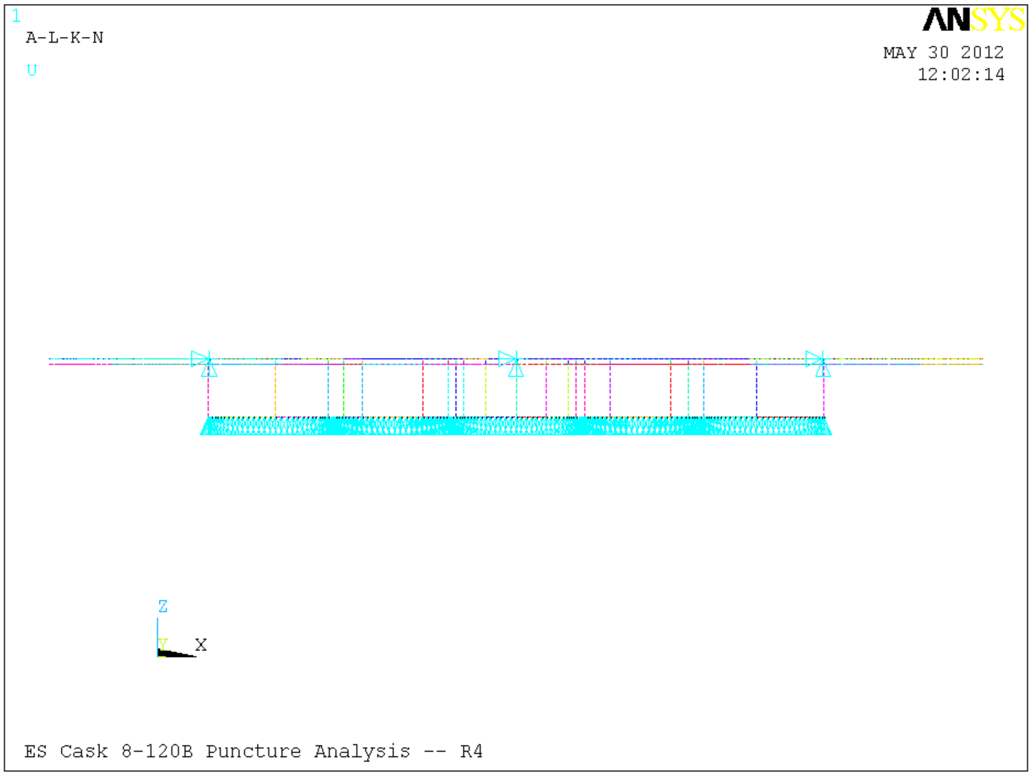

Figure 5-6 Cask 8-120B Analyses 1 & 2 Thermal Shield BCs – Plot 2 of 2

5.1.3.2. Cask 10-160B Analysis 1

The bottom of the six inch schedule 40 pipe pieces are constrained vertically using the translational UZ constraint (representing the thermal shield sitting on top of the cask secondary lid). The three nodes on the top plate where the secondary lid lifting lugs protrude through the thermal shield are constrained in all three translational directions (UX, UY, and UZ), which represent the pins placed through the secondary lid lifting lugs securing the radiation shield to the cask. Nodes representing the top surface of each secondary lid bolt are constrained vertically using the translational UZ constraint. See Figure 5-7 and Figure 5-8.

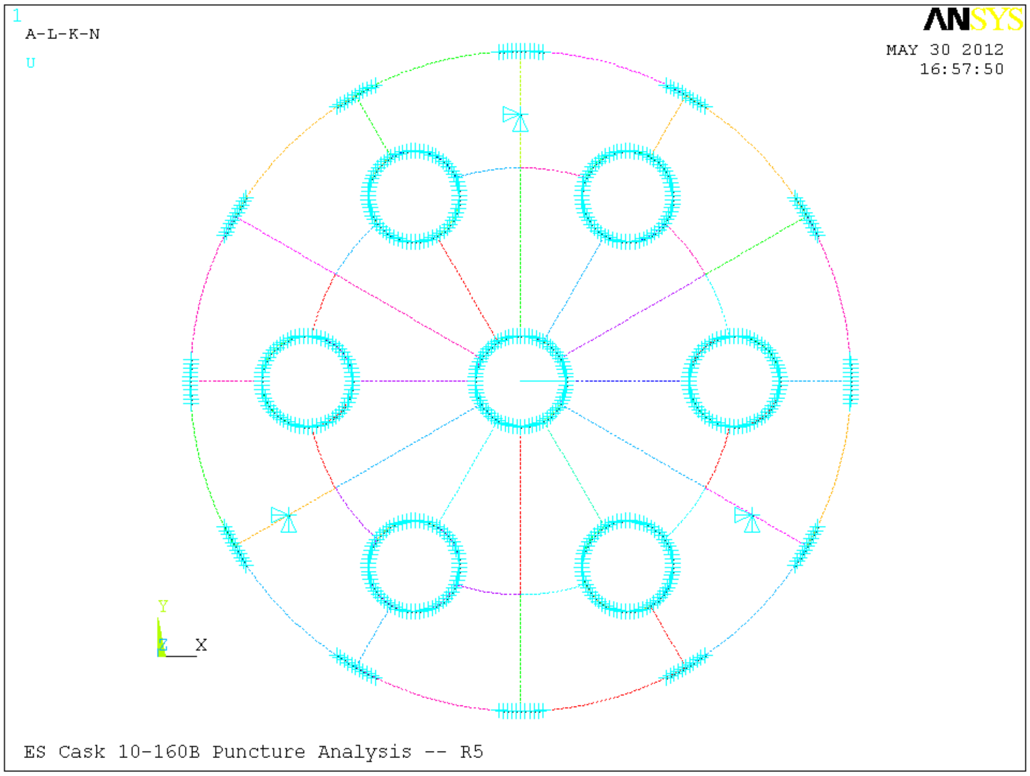

Figure 5-7 Cask 10-160B Analysis 1 Thermal Shield BCs – Plot 1 of 2

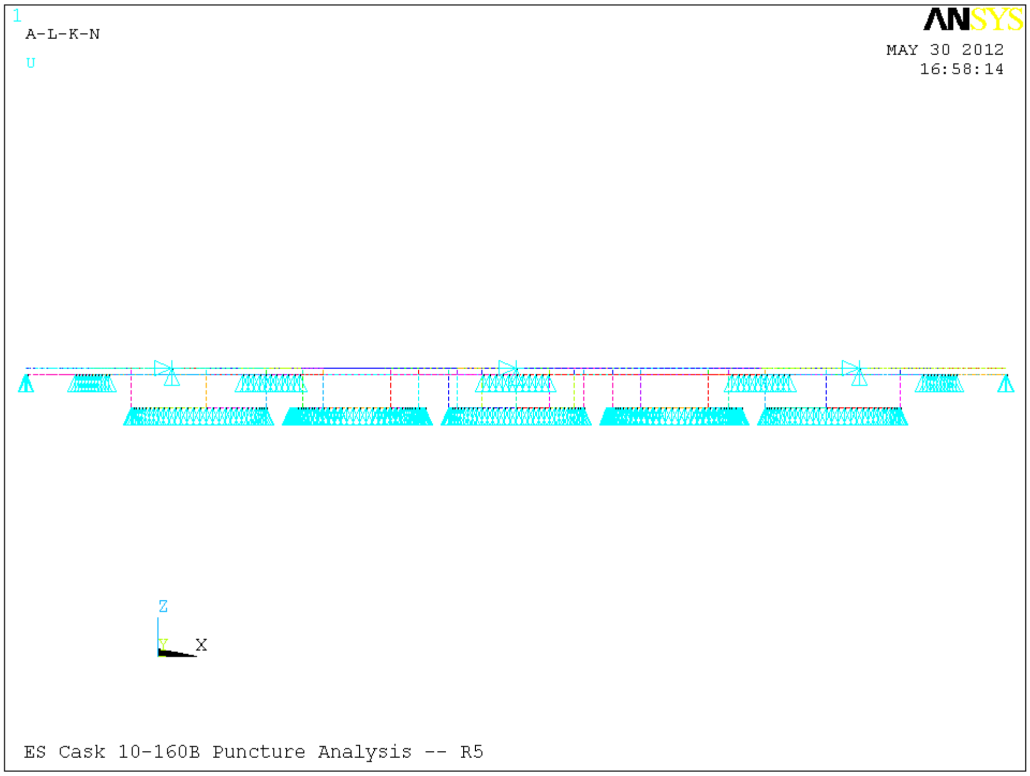

Figure 5-8 Cask 10-160B Analysis 1 Thermal Shield BCs – Plot 2 of 2

5.1.4. Connections

5.1.4.1. Bottom Plate to Top Plate

The bottom plate is connected to the top plate by the six inch schedule 40 pipe pieces and 1/8" diameter wire spaced at even intervals. For this analysis, however, the bottom plate is connected to the top plate by the six inch schedule 40 pipe pieces only.

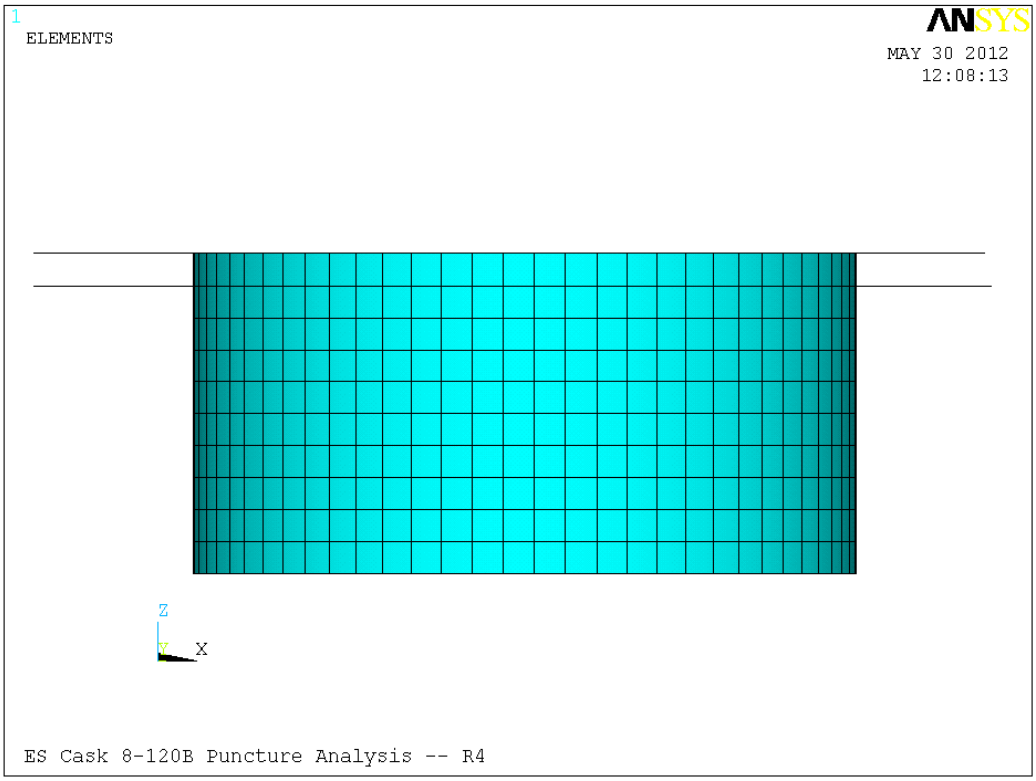

Figure 5-9 Cask 8-120B Thermal Shield Connection – Bottom Plate to Top Plate

6. Results and Conclusions

6.1. Plate Shearing Force and Energy of a ¼" Plate

In order to fully interpret the results of the analyses, it is helpful to know the force and energy required to shear a ¼" plate using a standard six inch diameter die. The top plate of the thermal shield is made from ¼" plate. A calculation showing the required force and energy to shear a ¼" plate using a standard six inch diameter die and is properly supported is shown below.

The formula for determining the force and energy required to shear a ¼" plate is:

$$F = A_{Shear} * \sigma_{Ultimate\_Shear\_Stress}$$

The shear area used by a six inch diameter die to shear a ¼ inch plate is 4.712 in^2 (Area equals circumference of die times thickness of plate.) The ultimate shear stress is commonly taken as 0.75 of the ultimate tensile stress (UTS) (Ref. 8.3.5, Table 13). The UTS for 304 is 75 ksi (Ref. 8.3.3). The ultimate shear stress is 0.75*75 ksi = 56.25 ksi.

Performing the force calculation gives a force of 266,250 lb. Multiplying this by the thickness of the part being sheared gives the energy required, which is 66,563 in-lb. This is the maximum amount of energy that could be dissipated during the shearing process. From section 3.1.2, the energy available from the drop load case is 2,960,000 in-lb. This equates to over 44 times more energy than can be absorbed during this event. As a result, large deformations will occur and the thermal shield will be crushed against the cask secondary lid.

6.2. Cask Analysis Results

For each cask analysis, a table is given showing the required displacement of the thermal shield to produce 40% strain, the associated force absorbed by the thermal shield due to the puncture bar at the given strain, and the strain energy absorbed by the thermal shield. The maximum strain energy absorbed is compared to the energy inputted into the analysis by the cask dropping onto the puncture bar.

All plots shown are strain intensity plots.

6.2.1. Cask 8-120B Results

6.2.1.1. Cask 8-120B Analysis 1

Analysis 1 for Cask 8-120B has the puncture bar striking the thermal shield between the center standoff and two of the six outer standoffs. See the table below for a summary of the results.

Table 6-1 Cask 8-120B Analysis 1 Strain Summary Table

	Maximum Displacement (in)	Maximum Force (lb)	Maximum Strain (%)	Strain Energy Absorbed (in·lb)
Cask 8-120B A1	0.46	67,250.64	39.22%	17,980.49

As seen in Table 6-1, 17,980.49 in-lb of strain energy was absorbed by the thermal shield at a strain of 39.22%. This value is less than 1% of the energy produced by the falling cask.

Since the strain energy absorption amount is so small compared to the energy of the falling cask, and the strain energy absorption amount is smaller than the energy required to completely shear a properly supported ¼" plate, it is concluded the ¼" top plate and the 1/8" bottom plate of the thermal shield will be crushed at the puncture bar footprint location against the cask secondary lid. If the ¼" top plate does rupture, it will be localized (see Figure 6-1 through Figure 6-4), and the 1/8" bottom plate will not rupture as it is extremely flexible. However, due to the flexibility of the thermal shield assembly, and the conservatively low 40% strain percentage for rupture, the top plate is not expected to rupture. Therefore, the thermal shield will remain in place and protect the cask secondary lid for the thermal test.

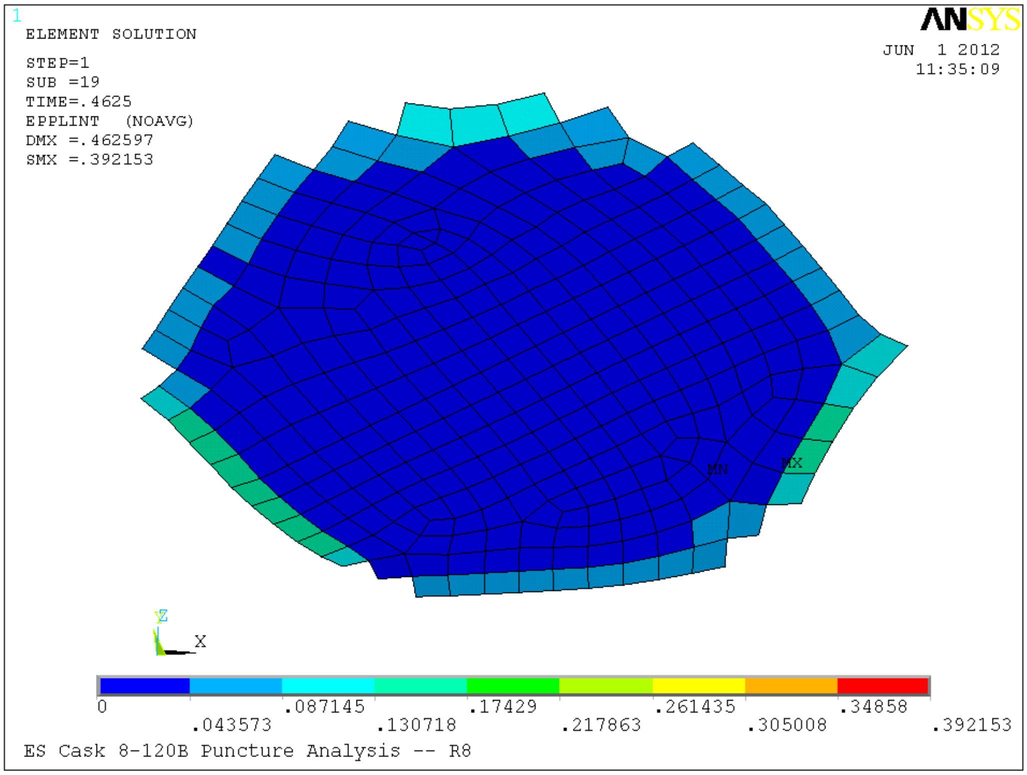

Figure 6-1 Cask 8-120B A1 – Top Plate at ~40% Strain – Top View

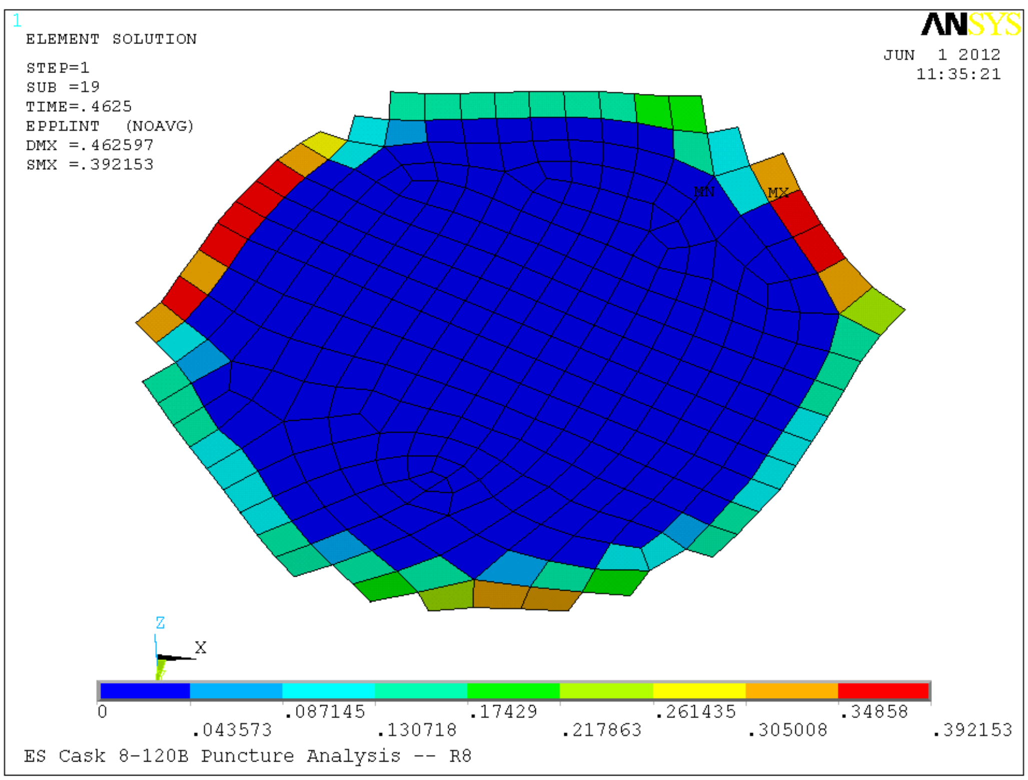

Figure 6-2 Cask 8-120B A1 – Top Plate at ~40% Strain – Bottom View

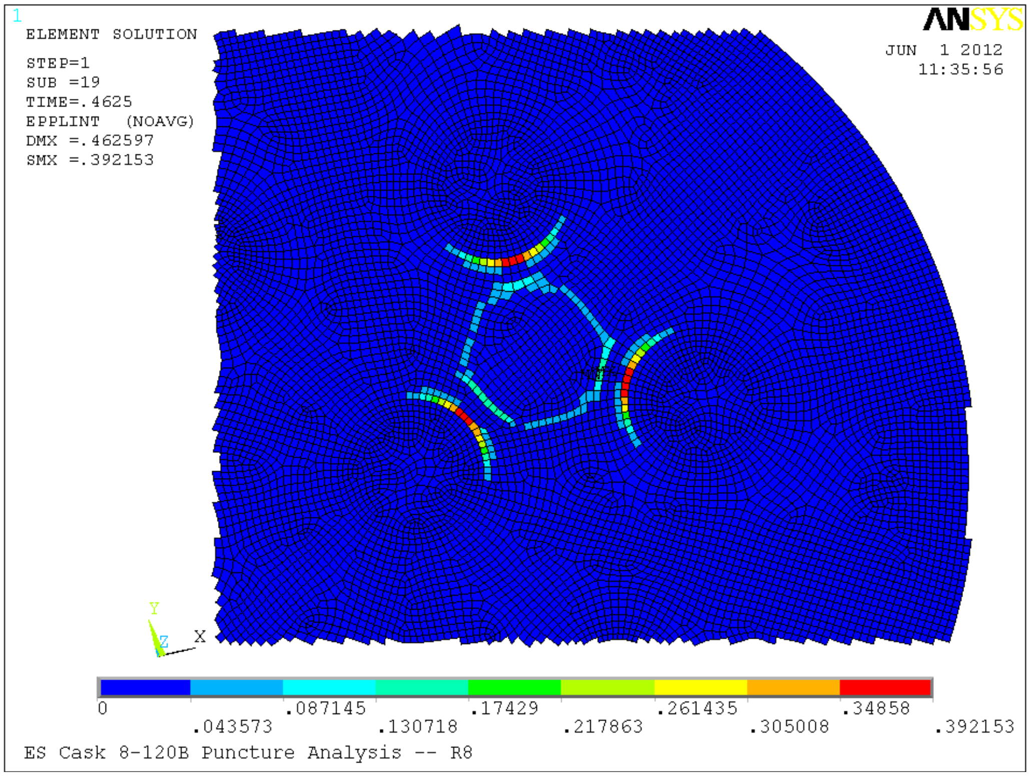

Figure 6-3 Cask 8-120B A1 – Top Plate at ~40% Strain – Expanded Top View

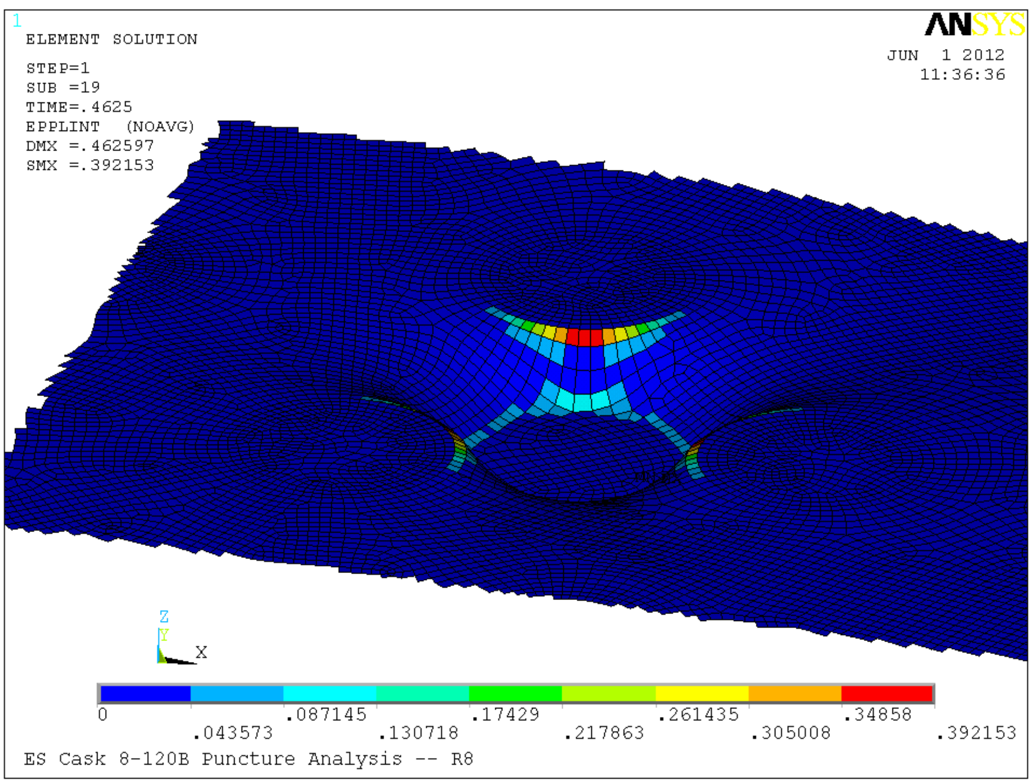

Figure 6-4 Cask 8-120B A1 – Top Plate at ~40% Strain – Side View w/ Imprint

6.2.1.2. Cask 8-120B Analysis 2

Analysis 2 for Cask 8-120B has the puncture bar striking between two outer standoffs and the edge of the thermal shield. See the table below for a summary of the results.

Table 6-2 Cask 8-120B Analysis 2 Strain Summary Table

	Maximum Displacement (in)	Maximum Force (lb)	Maximum Strain (%)	Strain Energy Absorbed (in·lb)
Cask 8-120B A2	1.36	26,015.18	40.69%	21,381.45

As seen in Table 6-2, 21,381.45 in-lb of strain energy was absorbed by the thermal shield at a strain of 40.69%. This value is less than 1% of the energy produced by the falling cask.

Since the strain energy absorption amount is so small compared to the energy of the falling cask, and the strain energy absorption amount is smaller than the energy required to completely shear a properly supported ¼" plate, it is concluded the ¼" top plate and the 1/8" bottom plate of the thermal shield will be crushed at the puncture bar footprint location against the cask secondary lid. If the ¼" top plate does rupture, it will be localized (see Figure 6-5 through Figure 6-8), and the 1/8" bottom plate will not rupture as it is extremely flexible. However, due to the flexibility of the thermal shield assembly, and the conservatively low 40% strain percentage for rupture, the top plate is not expected to rupture. Therefore, the thermal shield will remain in place and protect the cask secondary lid for the thermal test.

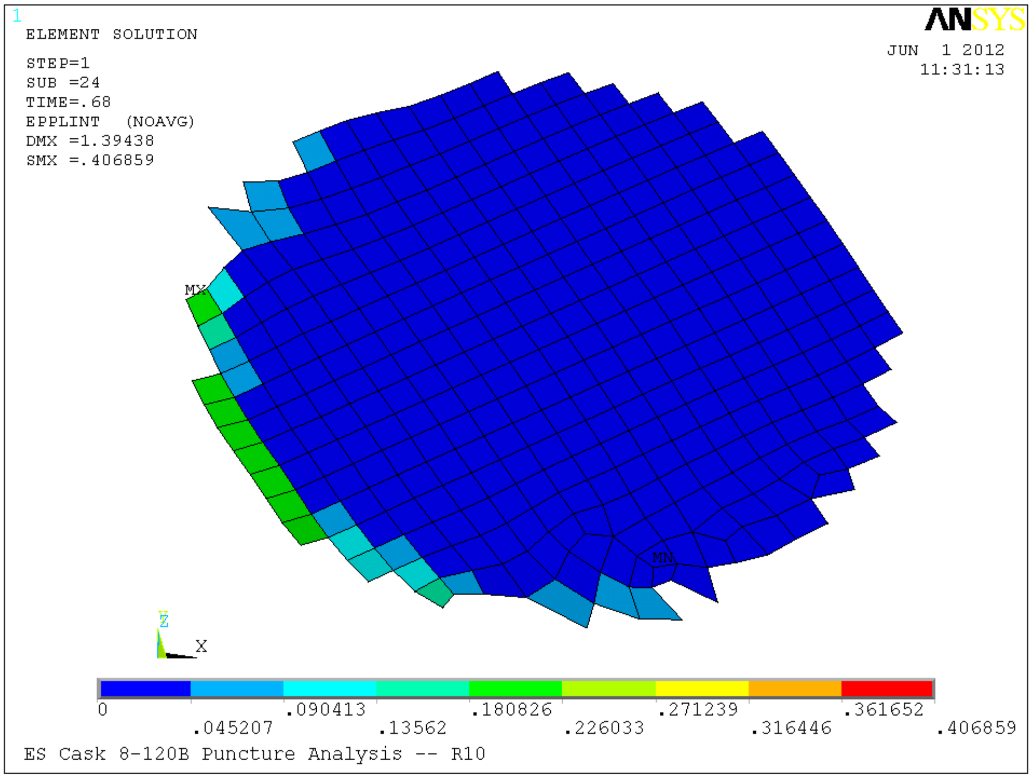

Figure 6-5 Cask 8-120B A2 – Top Plate at ~40% Strain – Top View

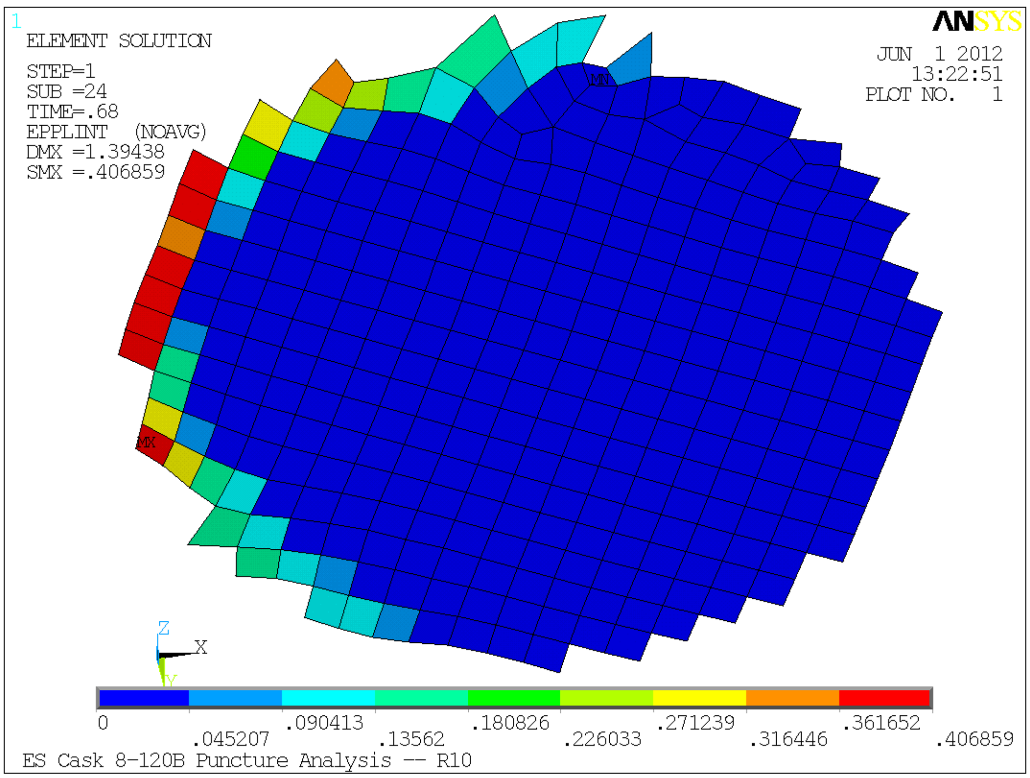

Figure 6-6 Cask 8-120B A2 – Top Plate at ~40% Strain – Bottom View

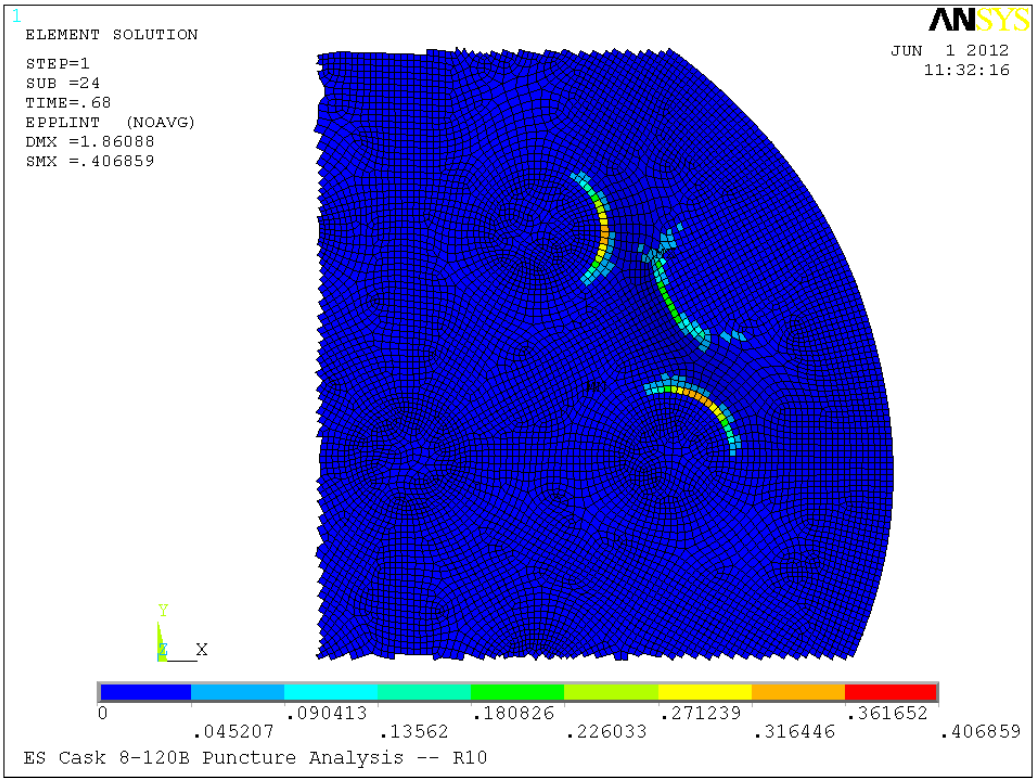

Figure 6-7 Cask 8-120B A2 – Top Plate at ~40% Strain – Expanded Top View

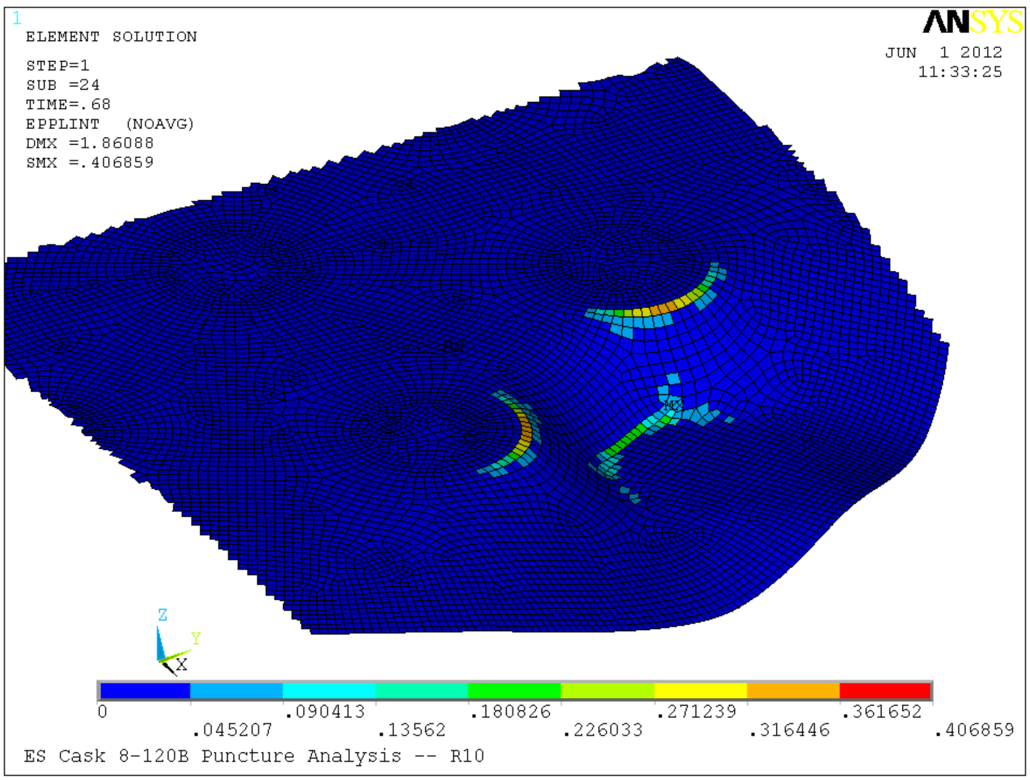

Figure 6-8 Cask 8-120B A2 – Top Plate at ~40% Strain – Side View w/ Imprint

6.2.2. Cask 10-160B Results

6.2.2.1. Cask 10-160B Analysis 1

Analysis 1 for Cask 10-160B has the puncture bar striking between two outer standoffs and the edge of the thermal shield.

Table 6-3 Cask 10-160B Analysis 1 Strain Summary Table

	Maximum Displacement (in)	Maximum Force (lb)	Maximum Strain (%)	Strain Energy Absorbed (in·lb)
Cask 10-160B A1	0.40	13,589.58	7.35%	3,497.11

As seen in Table 6-3, 3,497.11 in-lb of strain energy was absorbed by the thermal shield at a strain of 7.35%.

ANSYS was unable to solve the analysis using a larger initial displacement due to excessive element distortion. Therefore, the displacement, force, and strain data from each load substep were used to generate three charts and three equations so that the maximum force, maximum displacement, and strain energy absorbed at 40% strain can be obtained (see Figure 6-9, Figure 6-10, and Figure 6-11).

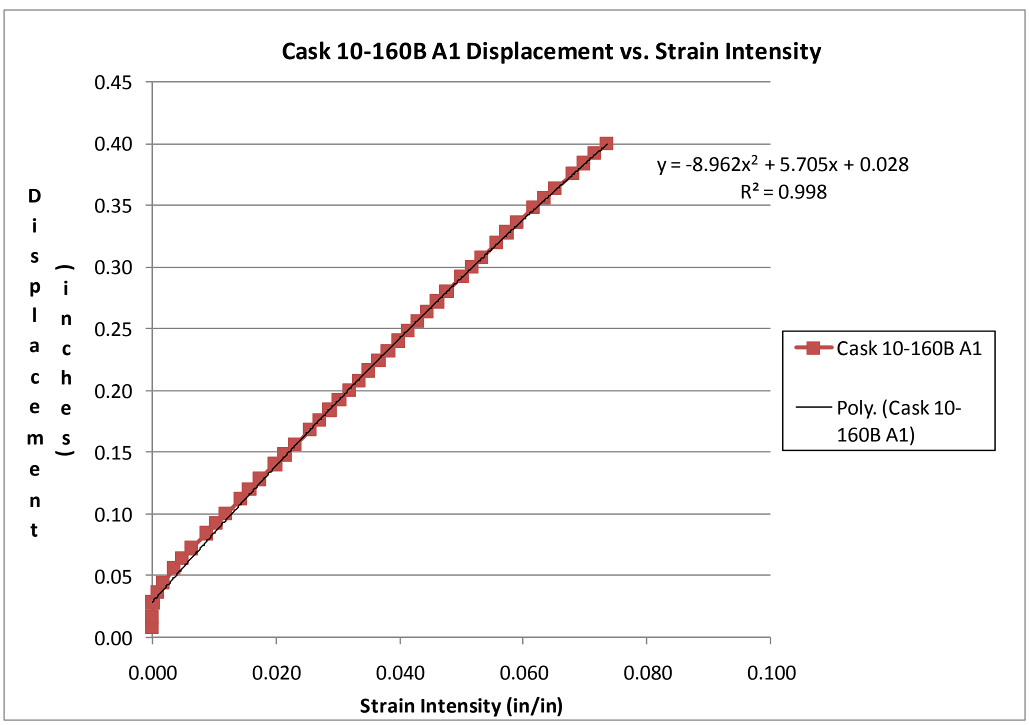

Figure 6-9 Cask 10-160B Analysis 1 – Displacement vs. Strain Intensity

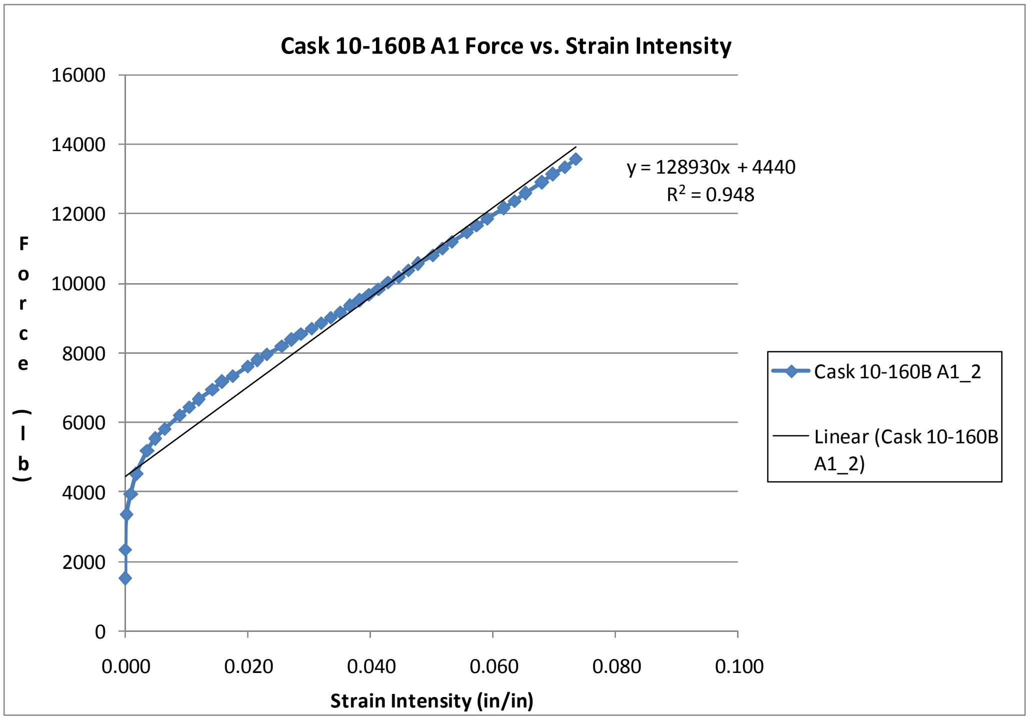

Figure 6-10 Cask 10-160B Analysis 1 – Force vs. Strain Intensity

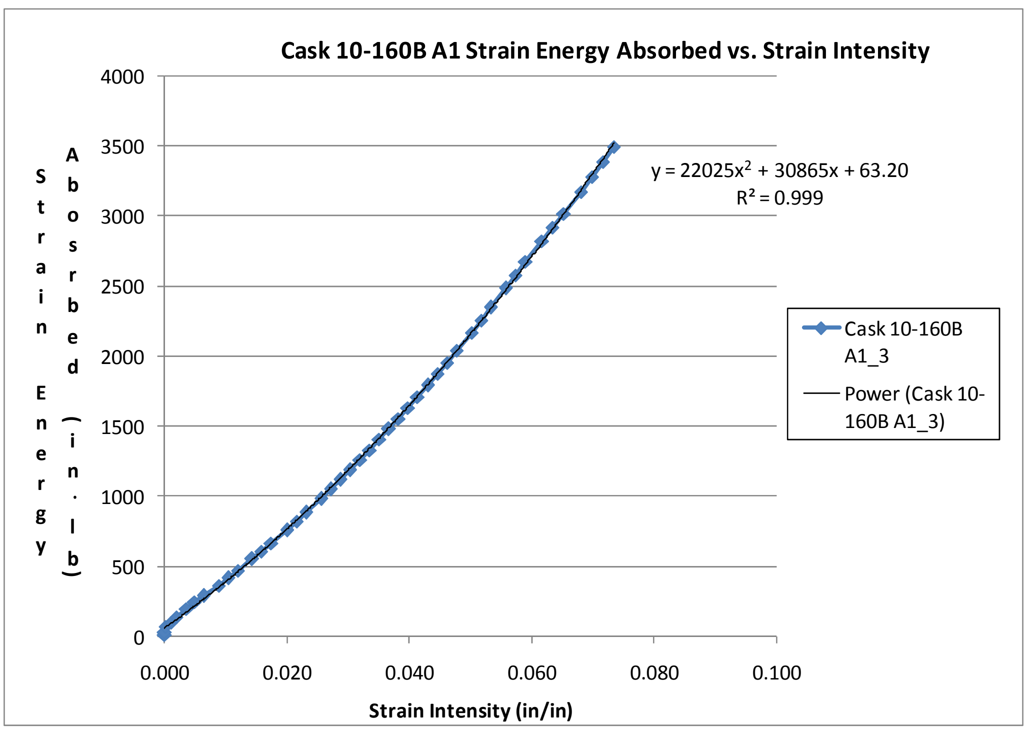

Figure 6-11 Cask 10-160B Analysis 1 – Strain Energy Absorbed vs. Strain Intensity

Using the equations shown in Figure 6-9, Figure 6-10, and Figure 6-11, the approximate displacement, force, and strain energy absorbed at 40% (x = 0.4 in/in) strain are 0.9 inches, 56,012 lb, and 15,933 in-lb, respectively. This strain energy absorption value is less than 1% of the energy produced by the falling cask.

Since the strain energy absorption amount is so small compared to the energy of the falling cask, and the strain energy absorption amount is smaller than the energy required to completely shear a properly supported ¼" plate, it is concluded the ¼" top plate and the 1/8" bottom plate of the thermal shield will be crushed at the puncture bar footprint location against the cask secondary lid. If the ¼" top plate does rupture, it will be localized (see Figure 6-5 through Figure 6-8), and the 1/8" bottom plate will not rupture as it is extremely flexible. However, due to the flexibility of the thermal shield assembly, and the conservatively low 40% strain percentage for rupture, the top plate is not expected to rupture. Therefore, the thermal shield will remain in place and protect the cask secondary lid for the thermal test.

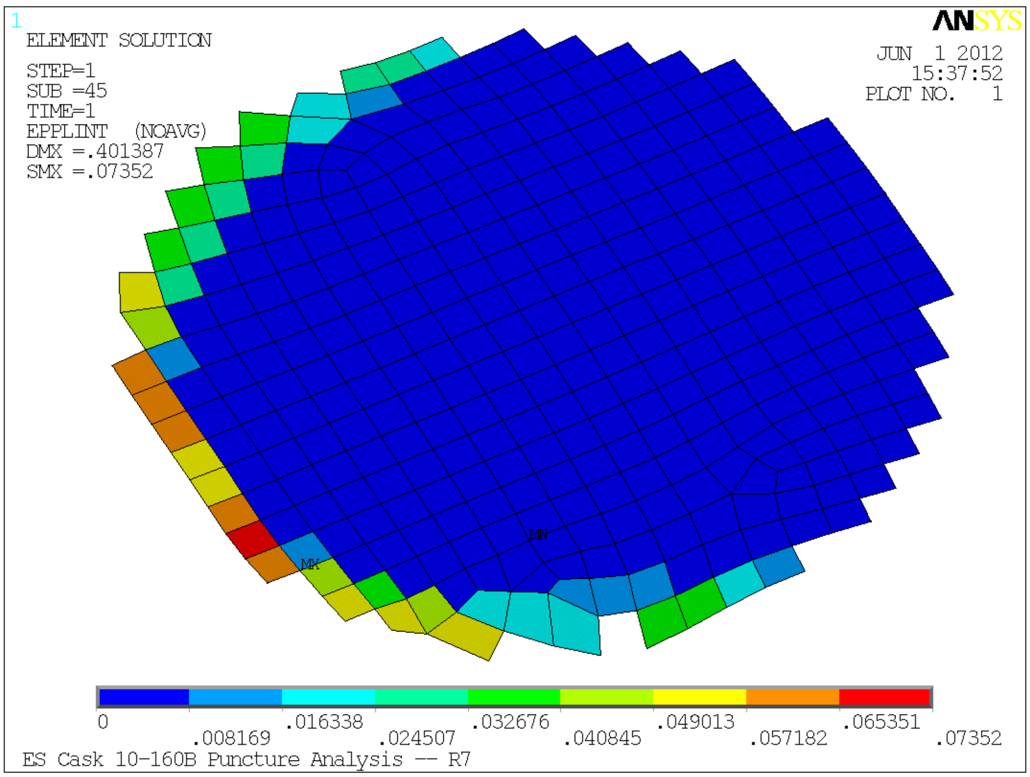

Figure 6-12 Cask 10-160B A1 – Top Plate at ~7.35% Strain – Top View

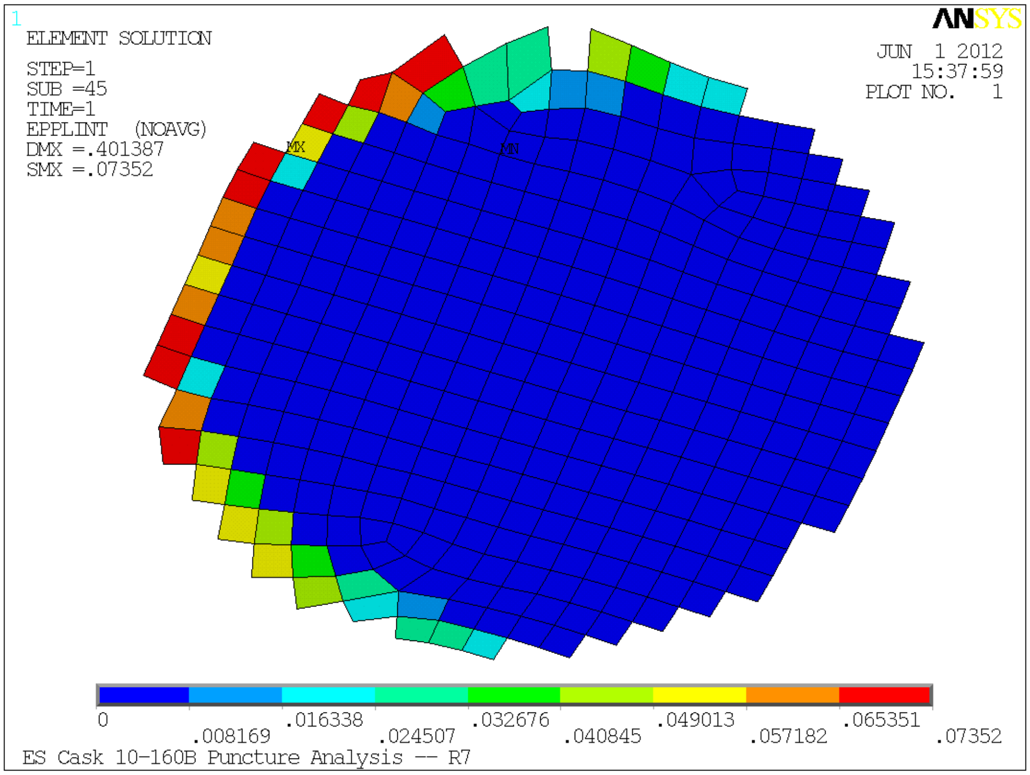

Figure 6-13 Cask 10-160B A1 – Top Plate at ~7.35% Strain – Bottom View

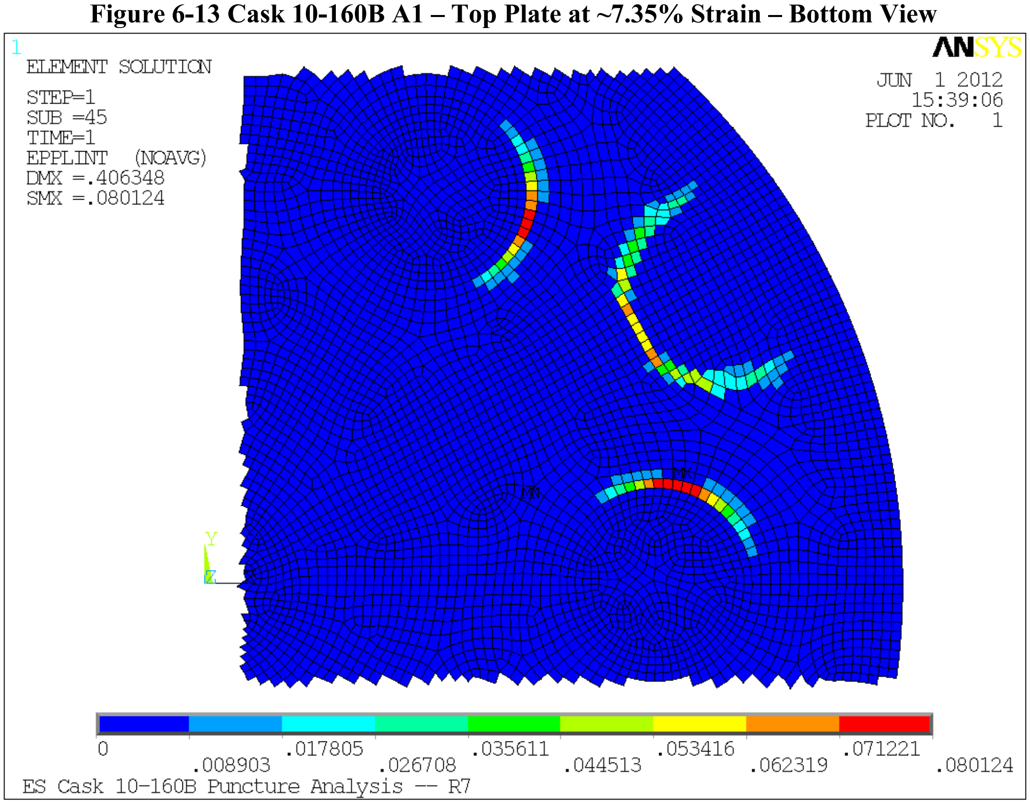

Figure 6-14 Cask 10-160B A1 – Top Plate at ~7.35% Strain – Expanded Top View

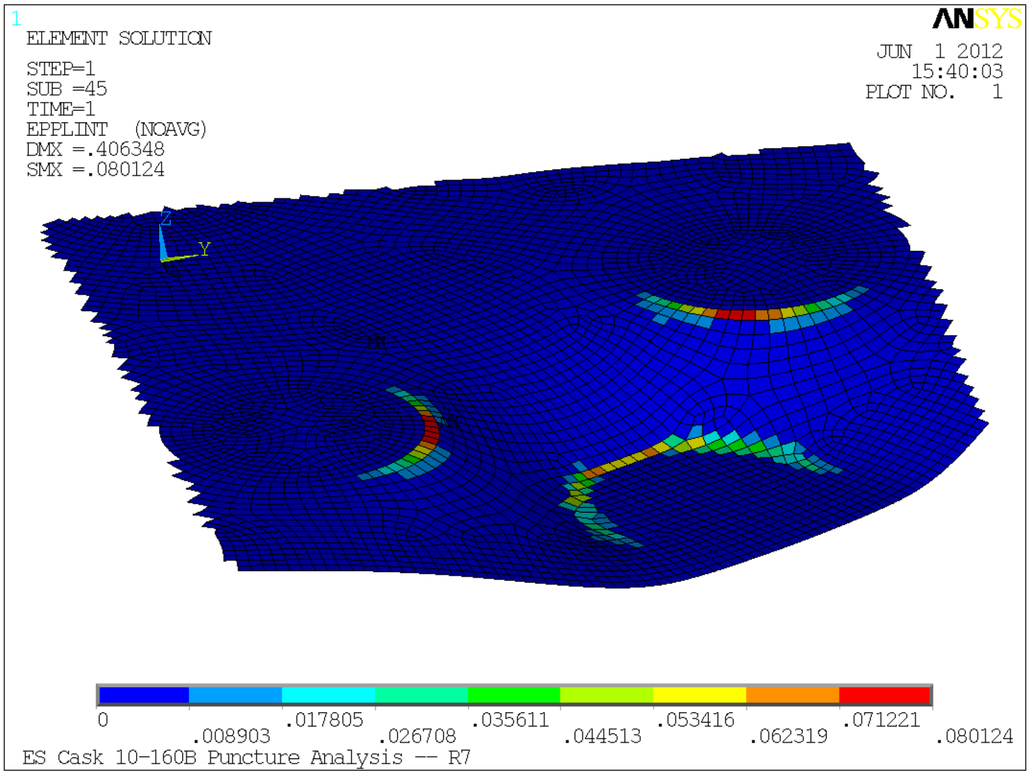

Figure 6-15 Cask 10-160B A1 – Top Plt at ~7.35% Strain – Side View w/Imprint

6.3. Conclusion

The evaluations performed in this document show the 8-120B and 10-160B cask thermal shields have sufficient flexibility such that they can deflect to the lid with only local deformation. Thus, under the puncture drop test of the packages, the plates of the thermal shields will come in contact with the lid near the location of the puncture bar contact with only localized failure.

7. Electronic Files

The following summarizes the computer the ANSYS model was run on.

OS Name	Microsoft(R) Windows(R) XP Professional x64 Edition
Version	5.2.3790 Service Pack 2 Build 3790
System Name	27929-D
System Manufacturer	Dell Inc.
System Model	Precision WorkStation T5400
System Type	x64-based PC
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz

Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Processor	EM64T Family 6 Model 23 Stepping 6 GenuineIntel ~2494 Mhz
Total Physical Memory	8,189.33 MB

8. References

8.1. Energy Solutions Documents & Drawings

8.1.1. PL-ETD-ST-0004, Rev. 0, Software Plan for ANSYS, Version 13

8.1.2. VV-ETD-ST-0004, Rev. 0, Software Validation Test Report for ANSYS Version 13

8.1.3. C50-ETD-ST-0004, Computer Software In-Use Test Log

8.1.4. DWG-CSK-12CV01-EG-0001-01, Rev. 0, 8-120B Cask Secondary Lid Thermal-Shield Details, Sheet 1 of 1

8.1.5. DWG-CSK-12CV01-EG-0002-01, Rev. 0, 10-160B Cask Secondary Lid Thermal-Shield Details, Sheet 1 of 1

8.2. Codes and Standards

8.2.1. Hypothetical Accident Conditions Section 71.73, Title 10 Code of Federal Regulations

8.2.2. ASME B&PV Code, Section II, 2004

8.3. Other References

8.3.1. Bird, RB Stewart, WE and Lightfoot, EN; Transport Phenomena; John Wiley and Sons; 1960

8.3.2. Safety Analysis Report for Model 8-120B Type B Shipping Packaging, Revision 7, January 2010

8.3.3. ASTM A 240/A 240M – 05a, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

8.3.4. Miller, G.K., Failure Criteria for Evaluating Accidental Drops of Fuel Containers at INTEC, Idaho National Engineering and Environmental Laboratory, 1998

8.3.5. Oberg, Erik, et al., Machinery's Handbook, 28th Edition, Industrial Press, 2008