ROBATEL GROUP

RT-100 Cask
Certificate of Compliance
Pre-Application Meeting

June 26-27, 2012

Open Session

Structural and Thermal

Robatel Technologies, LLC

Roanoke, VA

Agenda

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- ***Introductions***
- ***RT-100 Design Summary***
  - Overview
  - Design Features
  - Summary of Recent Changes
- ***Structural Analysis***
  - Drop Analysis – Impact Limiter & Cask Body
  - Confirmatory Drop Testing
  - Pin Puncture Evaluation
  - Lifting and Tie-Down Analysis

Agenda (continued)

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- ***Thermal Analysis***
  - Summary of Thermal Design Features
  - NCT Evaluations
  - HAC Evaluations
- ***Schedule for Application Submittal***
- ***Proprietary Session***

Introductions

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- ***Robatel RT-100 Team***
  - Robatel Technologies
  - Robatel Industries
  - ENERCON Federal Services
- ***NRC***

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Cask Design

- Multi-layer wall construction
  - ✓Stainless steel inner / outer shells and lids
  - ✓Lead gamma shielding in cask wall and lids
  - ✓Ceramic fiber-based thermal shielding in cask wall
- Cylindrical Foam Impact Limiters
  - ✓General Plastics FR 3700 series foam
  - ✓Stainless steel shells
  - ✓Fabricated foam blocks assembled into shells

RT-100 Overview – Design Features

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- ***Lid Attachment***
  - Primary Lid – 32 M48 Bolts
  - Secondary Lid – 18 M36 Bolts
- ***Impact Limiter Attachment***
  - Top and Bottom Limiter - 12 M36 Bolts
  - Upper and Lower Flanges

RT-100 Overview

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- ***Tie-down System***
  - Four tie-down arms
  - Connected to trailer deck via shear pins
- ***Lifting Devices***
  - Lifting Pocket / Lock Pin design
  - Simple to engage lift yoke arms

RT-100 Design

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Design - Dimensions

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Dimensions	Value
Overall Height with Impact Limiters	130.6 in (3316 mm)
Overall Height w/o Impact Limiters	91.5 in (2324 mm)
Outside Diameter with Impact Limiters	101.9 in (2587 mm)
Outside Diameter w/o Impact Limiters	81.1 in (2060 mm)
Cavity Length	77 in (1956 mm)
Cavity Diameter	68.1 in (1730 mm)
Weights	**Value**
Empty Weight w/Impact Limiters	75,023 lbs (34,024 kg)
Loaded Weight w/Impact Limiters	90,023 lbs (40,827 kg)

Design - Dimensions

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Dimensions	Nominal Value
Inner Shell Thickness	1.18 in (30 mm)
Lead Thickness	3.54 in (90 mm)
Outer Shell Thickness	1.38 in (35 mm)
Bottom Inner Plate Thickness	1.97 in (50 mm)
Bottom Lead Thickness	2.95 in (75 mm)
Bottom Outer Plate Thickness	1.18 in (30 mm)
Primary Lid Thickness	8.27 in (210 mm)
Secondary Lid Plate Thickness	3.94 in (100 mm)
Secondary Lid Lead Thickness	2.36 in (60 mm)

Design

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Materials

- Structural: ASME/ASTM-A240 304 L Stainless Steel
- Shielding: 5” Pb equivalent on all sides – Stainless Steel / Lead
- Thermal: Ceramic Paper
- Impact Limiters
  - ✓General Plastics Foam FR3700 series

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Impact Limiter Analysis

- Purpose:
  - ✓ Calculate maximum g-loads on the cask body due to the 10 CFR 71.73(c)(1) 30-foot drop accident
  - ✓ Calculate maximum crush depth of the impact limiter material
- Drop Orientations
  - ✓ End
  - ✓ Side
  - ✓ CG over Corner

Impact Limiter Analysis

- Temperatures
  - ✓-20 °F (-29 °C) (cold condition)
  - ✓150 °F (66 °C) (hot condition)

Polyurethane Foam Material

- Polyurethane foams are used for impact limiters as energy absorbing materials
- Each Impact limiter is composed of two types of polyurethane foam materials

Polyurethane Foam Material

- General Plastics provides the crush strength-strain curves based on testing. The following design parameters are considered for the curves.
  - ✓ Density
  - ✓ Temperature (-20°F, 75°F, 100°F, 180°F, 220°F, 260°F)
  - ✓ Strain Rate (Static and Dynamic)
  - ✓ Direction (Parallel & Perpendicular to rise)

- ***Polyurethane Foam Material***
  - General Plastics provides limited test data (strains of 10, 20, 30, 40, 50, 60, 65, and 70% only).
  - For full numerical analysis, full stress-strain curves are required – Curve fitted equations using simple power law are used.

Impact Limiter Evaluation

- Maximum forces and accelerations are evaluated using a numerical iteration of the drop accident time history
- These evaluations are performed based on the **Energy Conservation Principle** and **Newton's second law**
- Additional details of this method will be provided in the proprietary meeting session

Impact Limiter Evaluation

- Impact limiters are evaluated using stress-strain data from General Plastics for static and dynamic conditions
- The worst-case results for each drop orientation are selected for use in the ANSYS cask analysis

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End Drop Accelerations

Temperature	Speed Condition	Acceleration (g)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	84	135
	Dynamic	118	208
100ºF (38 ºC)	Static	72	93
	Dynamic	81	134
150ºF (66 ºC)	Static	75	82
	Dynamic	73	113

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End Drop Crush Depth

- Limit: 350 mm

Temperature	Speed Condition	Crush depth (mm)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	126	77
	Dynamic	87	53
100ºF (38 ºC)	Static	176	110
	Dynamic	128	75
150ºF (66 ºC)	Static	197	123
	Dynamic	149	87

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Side Drop Accelerations

Temperature	Speed Condition	Acceleration (g)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	117	151
	Dynamic	139	199
100ºF (38 ºC)	Static	114	129
	Dynamic	115	151
150ºF (66 ºC)	Static	123	125
	Dynamic	110	138

Structural – Impact Limiter Analysis

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Side Drop Crush Depth

- Limit: 270 mm

Temperature	Speed Condition	Crush depth (mm)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	133	93
	Dynamic	104	72
100ºF (38 ºC)	Static	166	123
	Dynamic	135	94
150ºF (66 ºC)	Static	180	136
	Dynamic	150	105

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CG Over Corner Drop Accelerations

Temperature	Speed Condition	Acceleration (g)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	77	81
	Dynamic	72	82
100ºF (38 ºC)	Static	121	84
	Dynamic	73	78
150ºF (66 ºC)	Static	132	97
	Dynamic	108	74

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CG Over Corner Drop Crush Depth

- Limit: 540 mm

Temperature	Speed Condition	Crush depth (mm)	
		(-15% density)	(+15% density)
-20ºF (-29 ºC)	Static	441	372
	Dynamic	402	333
100ºF (38 ºC)	Static	474	417
	Dynamic	453	378
150ºF (66 ºC)	Static	486	435
	Dynamic	471	399

Impact Limiter Analysis Conclusions

- Highest acceleration selected for each drop orientation for use in ANSYS cask body analyses
- Largest crush depth ensures that the cask body does not impact the ground during the drop event
- Selection conservatively considers worst case combination of ambient temperature, foam material density, and static/dynamic crush properties

Structural – Drop Analysis

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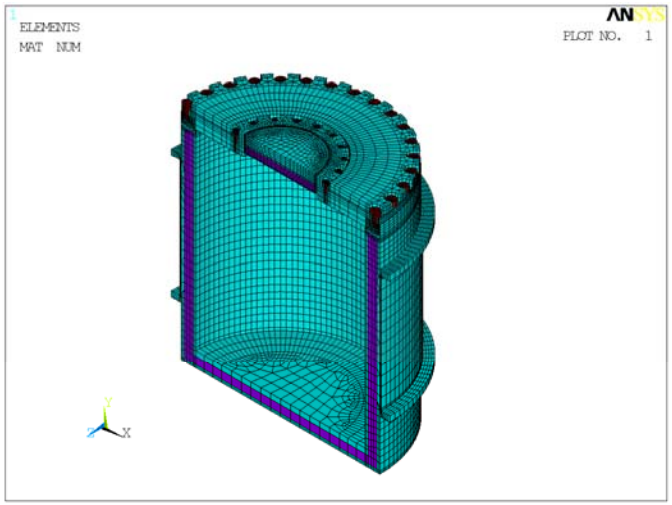
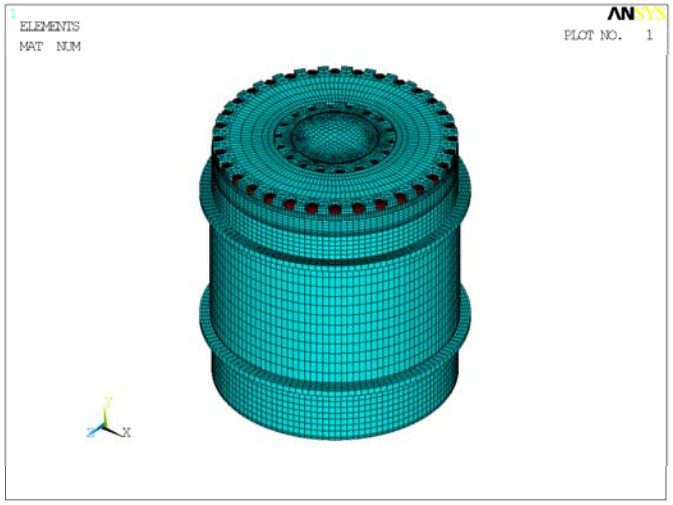
Cask Body Analysis

- Finite element model being developed with ANSYS
  - ✓ Half model shown but structural model is a full 360° model with SOLID95 elements
- Linear-elastic materials
- Contact elements used to simulate lid/sealing surfaces





Structural – Drop Analysis

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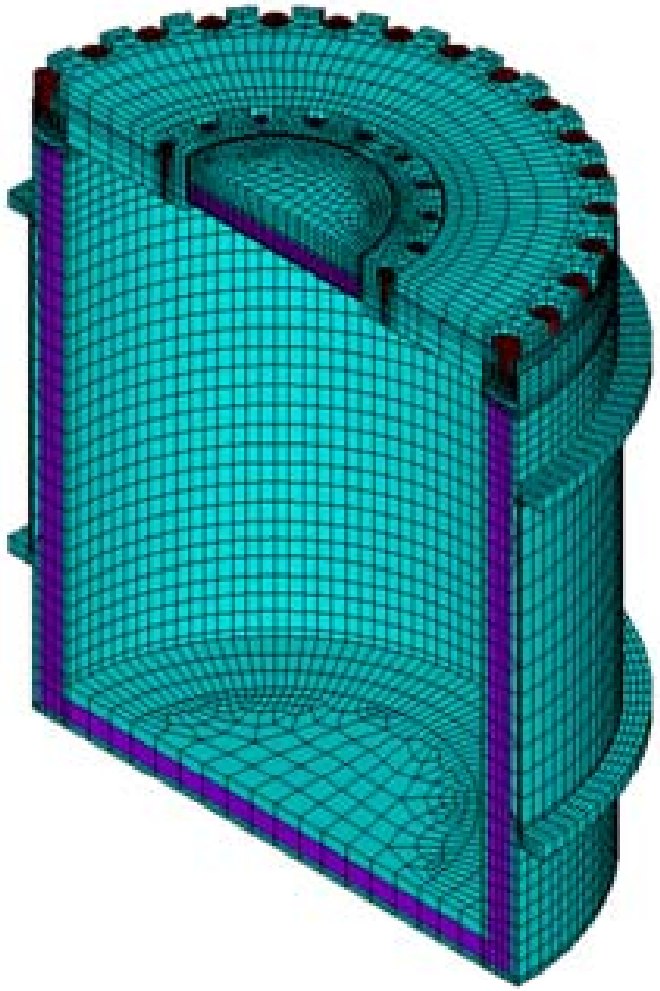
Cask Body Analysis

- Preliminary results obtained for two drop orientations
  - ✓ End drop onto bottom impact limiter
  - ✓ Side drop
- CG Over Corner to be analyzed later, but expected to be bounded by End and Side drop



Structural – Drop Analysis

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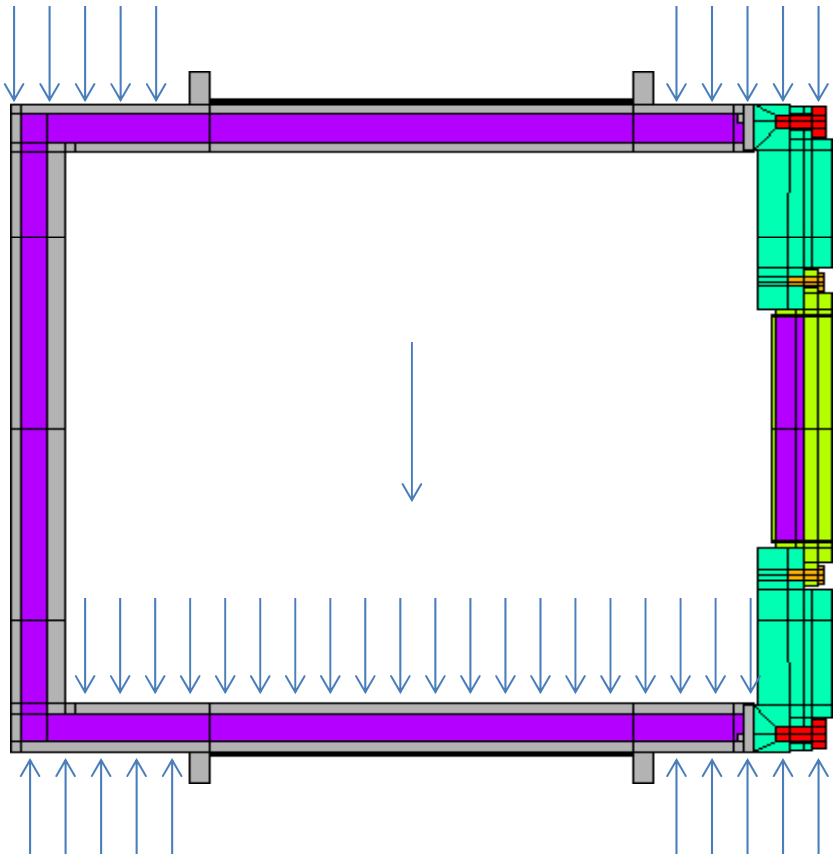
Side Drop Loading:

- Inertia load of 200 g
- Pressures to simulate
  - ✓Top and Bottom Impact Limiter Contact forces
  - ✓Max. payload weight
  - ✓Top and Bottom Impact limiter weights



Structural – Drop Analysis

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Side Drop Loading

- Inertia load of 200 g
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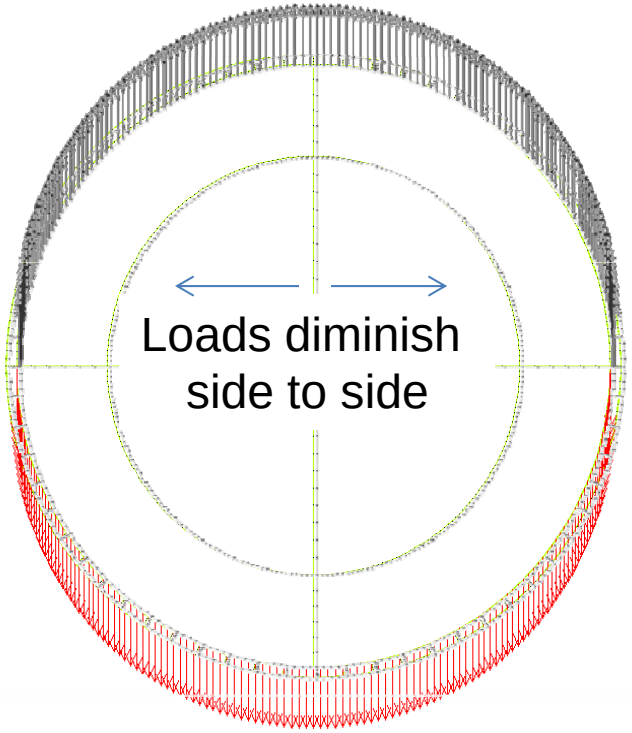
  - ✓Max. payload weight
  - ✓Top and Bottom Impact limiter weights



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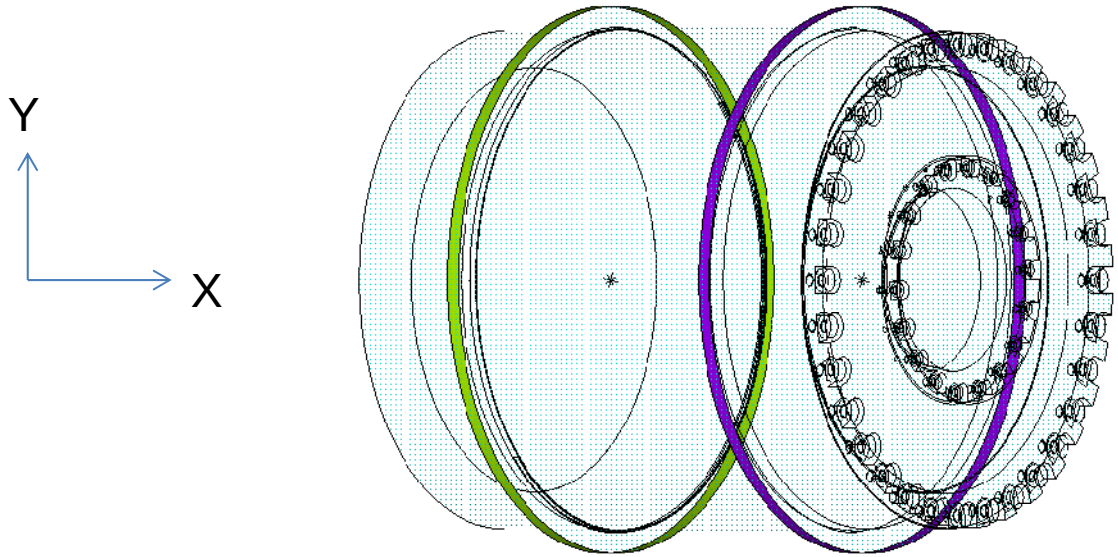
Side Drop Loading

- Numerical stability ensured by constraining UZ on the Z=0 plane; and with multipoint constraints on the impact limiter attachment rings outer surface



Structural – Drop Analysis

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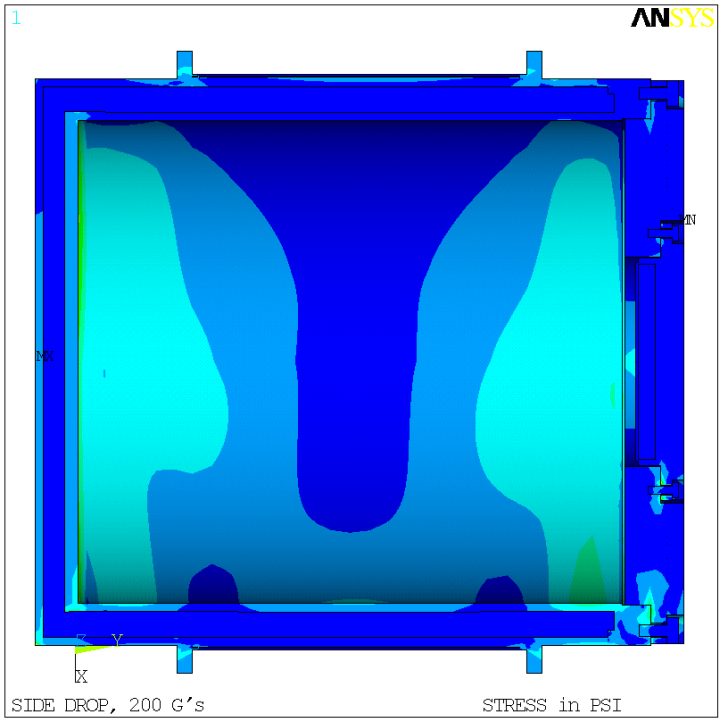
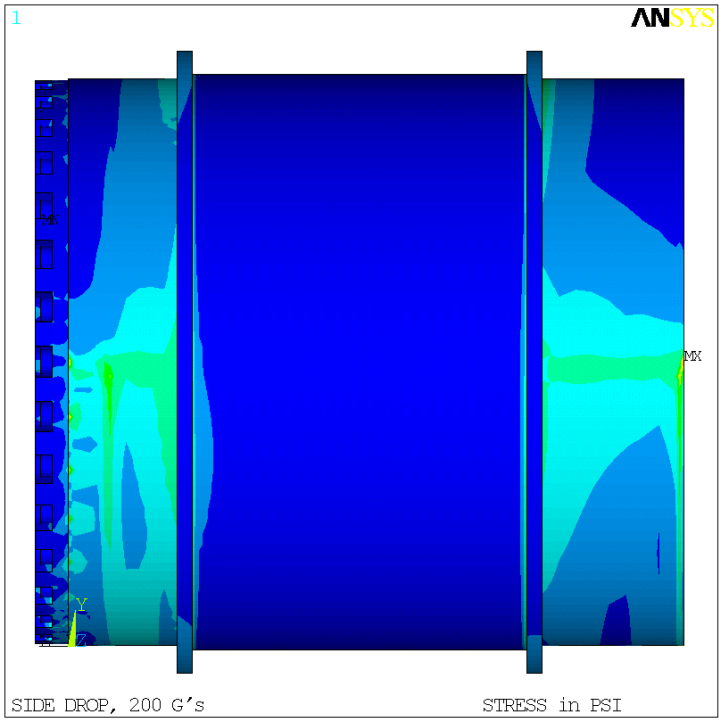
Side Drop Stress Intensity





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304 L Stainless Steel ASME Code Allowables

- ASME B&PVC Section III, Subsection ND
- U.S. Regulatory Guide 7.6

Criteria		ASTM A240 Type 304L	
		ksi	MPa
Yield Stress, S_y		25.0	172.4
Ultimate Stress, S_u		70.0	482.6
Design Intensity Stress (Membrane), S_m		16.7	115.1
Normal Conditions	Membrane Stress	16.7	115.1
	Membrane + Bending Stress	25.1	172.7
	Peak Stress	50.1	345.3
Hypothetical Accident Conditions	Membrane Stress	40.1	276.2
	Membrane + Bending Stress	60.1	414.4
	Peak Stress	140.0	965.2

Structural – Drop Analysis

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Preliminary Side Drop Results

- All stresses are within peak stress limits
- Post-processing of stresses currently underway
- No issues are foreseen

Structural – Drop Analysis

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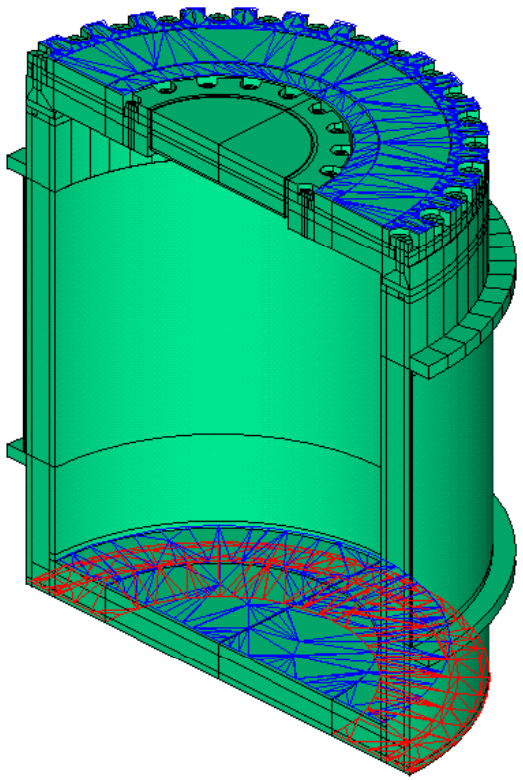
- ***Cask Body End Drop Analysis Loading***
  - Inertia load of 200 g
  - Pressures to simulate
    - ✓ Impact Limiter Contact forces
    - ✓ Max. payload weight
    - ✓ Impact limiter weights



Structural – Drop Analysis

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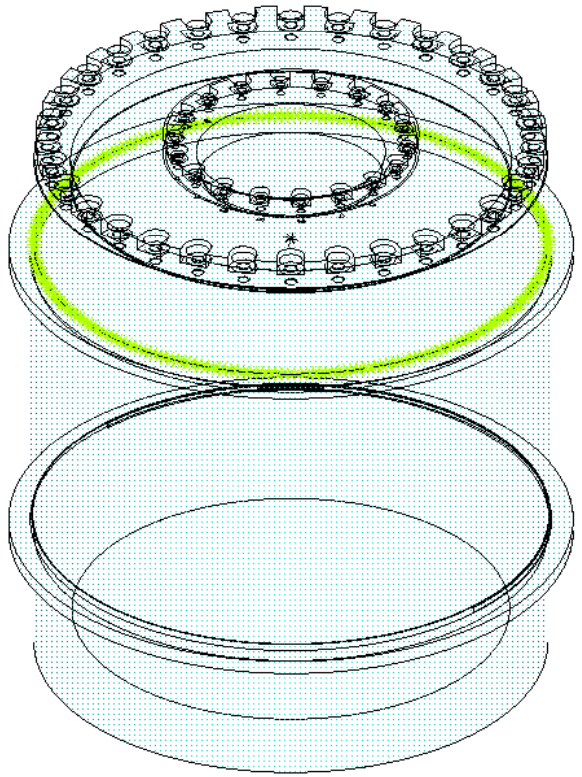
- ***Cask Body End Drop Analysis Loading***
  - Numerical stability ensured with multipoint constraints around the inner circumference of the upper impact limiter attachment ring



Structural – Drop Analysis

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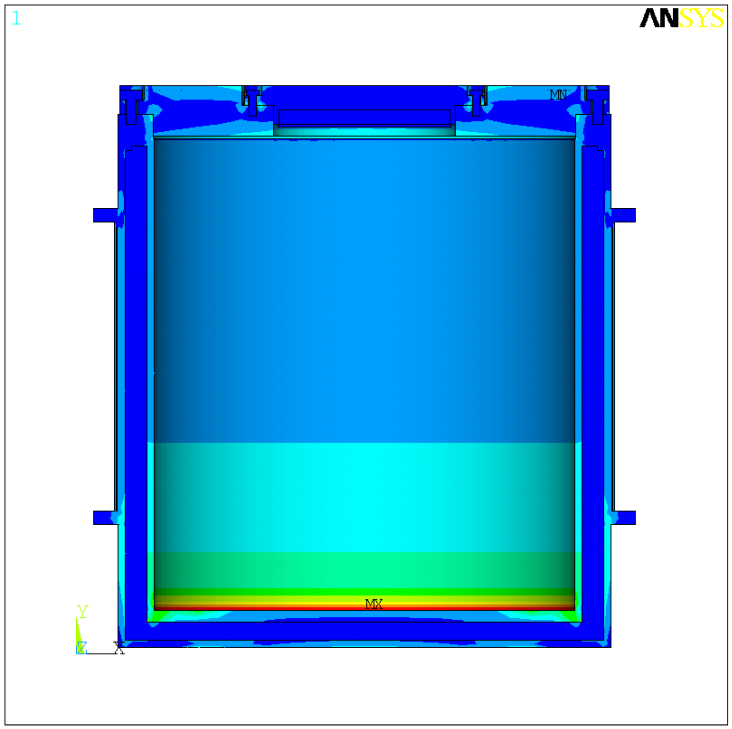
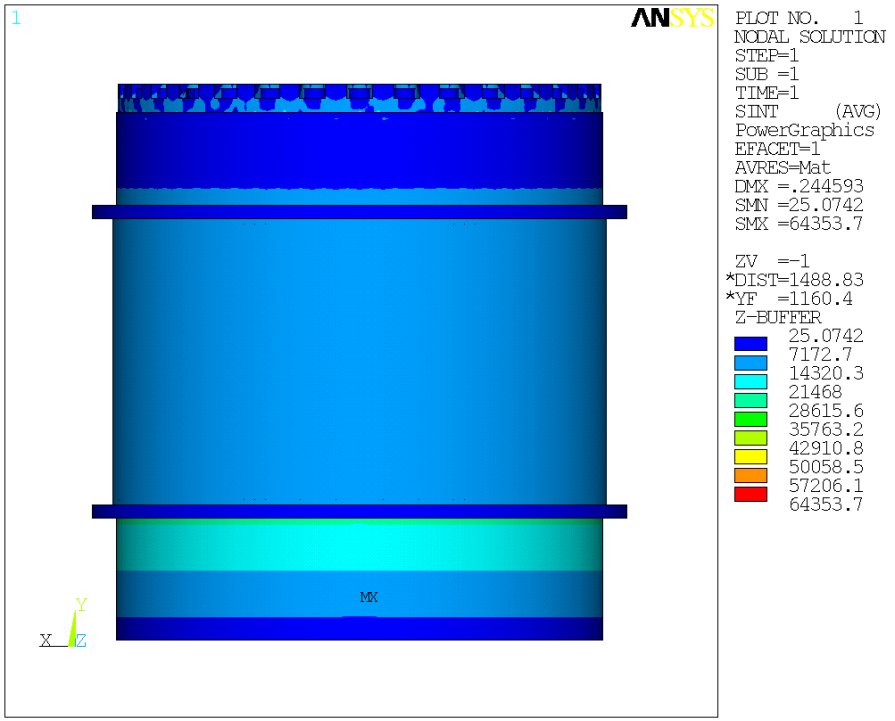
End Drop Stress Intensity





Structural – Drop Analysis

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Preliminary End Drop Results

- All stresses are within peak stress limits
- Post-processing of stresses currently underway
- No issues are foreseen

- ***Scale-Model Testing Program***
  - Purpose: Confirm impact limiter performance assumed in cask body analysis

Structural – Scale Model Testing

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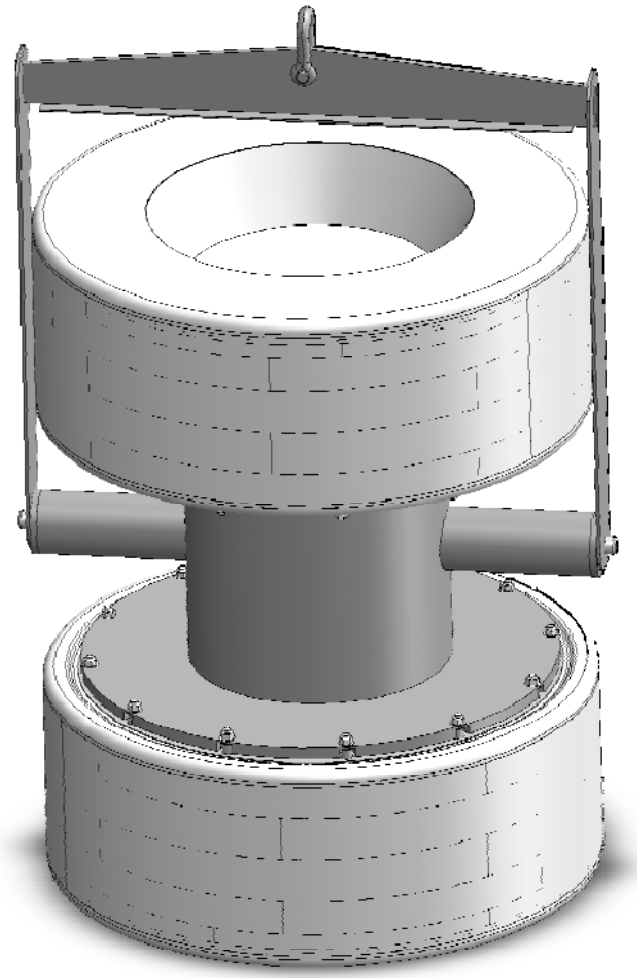
Scale-Model Description

- Scale: 3/10
- Impact limiter design fully representative of RT-100 design:
  - ✓ Shell thicknesses, attachments, bolts
  - ✓ Same machined block configuration.
- Cask body design is simplified:
  - ✓ Interface with impact limiters fully representative of the full scale model
  - ✓ Body weight and center of gravity are representative



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Anticipated Drop Configurations

- Height: 9m, Temperature: ambient
- Accelerometers placed on the model body
- Anticipated drop orientations:
  - ✓One side drop
  - ✓One end drop
  - ✓One CG over corner drop (38° from vertical)

- ***Impact Limiter Performance Benchmarking***
  - Impact limiter analysis technique will be benchmarked by comparing predicted accelerations of the scale model drops against actual test results

Structural – Puncture Analysis

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- ***Pin puncture evaluation performed using Nelm's equation for:***
  - Cask sidewall (steel / lead / steel)
- ***Analysis performed for 10 CFR 71.73(c)(3)***
  - 1-meter (40-in) drop onto a vertical, 15-cm (6-in) diameter mild steel bar

Structural – Puncture Analysis

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- ***Conservative pin puncture analysis of cask sidewall shows positive safety margin.***
  - Minimum outer shell thickness is 30 mm

- ***Lifting Device Evaluation***
  - Lifting Pockets receive lift yoke arms
  - Lift yoke arms are secured in pockets with locking pins
  - Locking pins are retained in the yoke arms by a retaining pin

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Lifting Configuration

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Lifting Configuration

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Lifting Device Evaluation

Lifting Attachment	Lifted Elements	Lifted Weight (kg)	Maximum Stress (MPa)	Minimum Factor of Safety	Comments
M20 Removable Lifting Rings	Primary Lid	4,500	N/A	1.92	The removable lifting rings are not a structural part of the package. The lifting load is compared to the lifting ring allowable working loads.
M20 Removable Lifting Rings	Secondary Lid	900	N/A	1.92	The removable lifting rings are not a structural part of the package. The lifting load is compared to the lifting ring allowable working loads.
M20 Removable Lifting Rings	Upper Impact Limiter	2,700	N/A	1.92	The removable lifting rings are not a structural part of the package. The lifting load is compared to the lifting ring allowable working loads.
M36 Hex Head Bolts	Lower Impact Limiter	2,600	11.6	1.41	The M36 hex head bolts are not a structural part of the package for the purposes of lifting. The lifting load is compared to the bolt allowable stresses.
Lifting Pockets	Assembled Cask with Full Payload	38,500	201.4	1.44	The upper impact limiter will be removed from the cask for the lifts.
Lifting Pocket Weld	Assembled Cask with Full Payload	38,500	1416.3	1.461	The upper impact limiter will be removed from the cask for the lifts.

Structural – Tie-Down Analysis

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Tie-Down System

- Tie-down arms and load plate
  - ✓318 SS material
- Shear key and tie-down lugs mounted to trailer
- Turnbuckle / rod system between tie-down arms and trailer deck

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Tie-Down Configuration

Structural – Tie-Down Analysis

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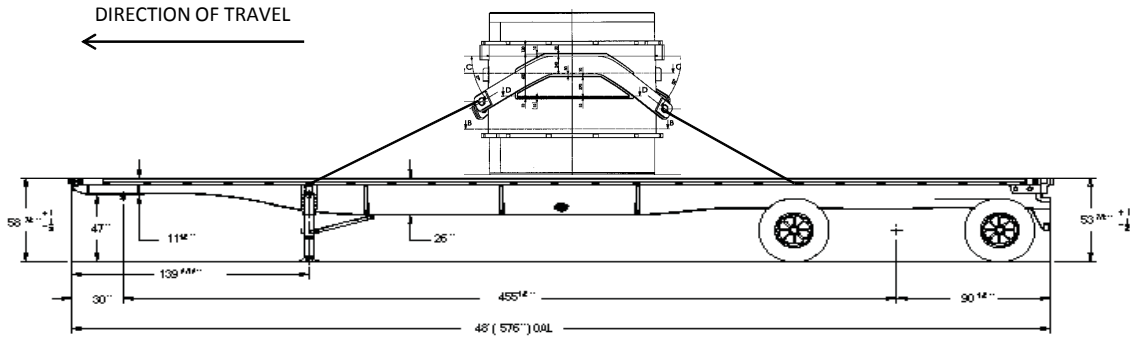
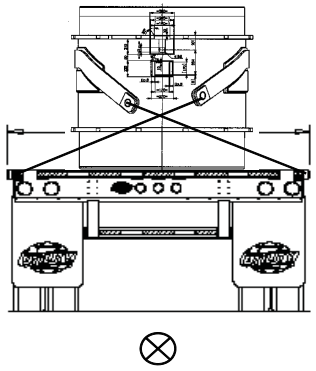
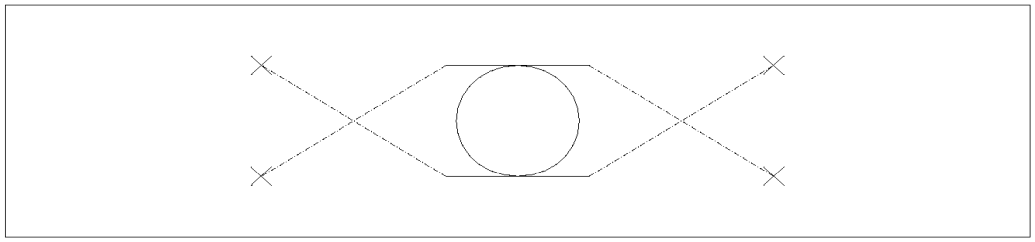
Tie-Down Configuration







(not to scale)

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Tie-Down Evaluation Results

Tie-Down Attachment	Restrained Elements	Restrained Load	Maximum Stress (MPa)	Minimum Factor of Safety	Comments
Tie-Down Arm Attachment Eyes	Assembled Cask	2g Vertical 10g Axial 5g Lateral	240.3	1.21	Shear stops will be provided to take the 5g transverse load on the cask.
Tie-Down Arms	Assembled Cask	2g Vertical 10g Axial 5g Lateral	197	1.73	Shear stops will be provided to take the 5g transverse load on the cask.
Tie-Down Arm Attachment Eyes	Assembled Cask with Full Payload	2g Vertical 10g Axial 5g Lateral	1440.92	1.196	-
Tie-Down Arms (Configuration A)	Assembled Cask with Full Payload	2g Vertical 10g Axial 5g Lateral	976.73	1.765	-

Thermal – Finite Element Model

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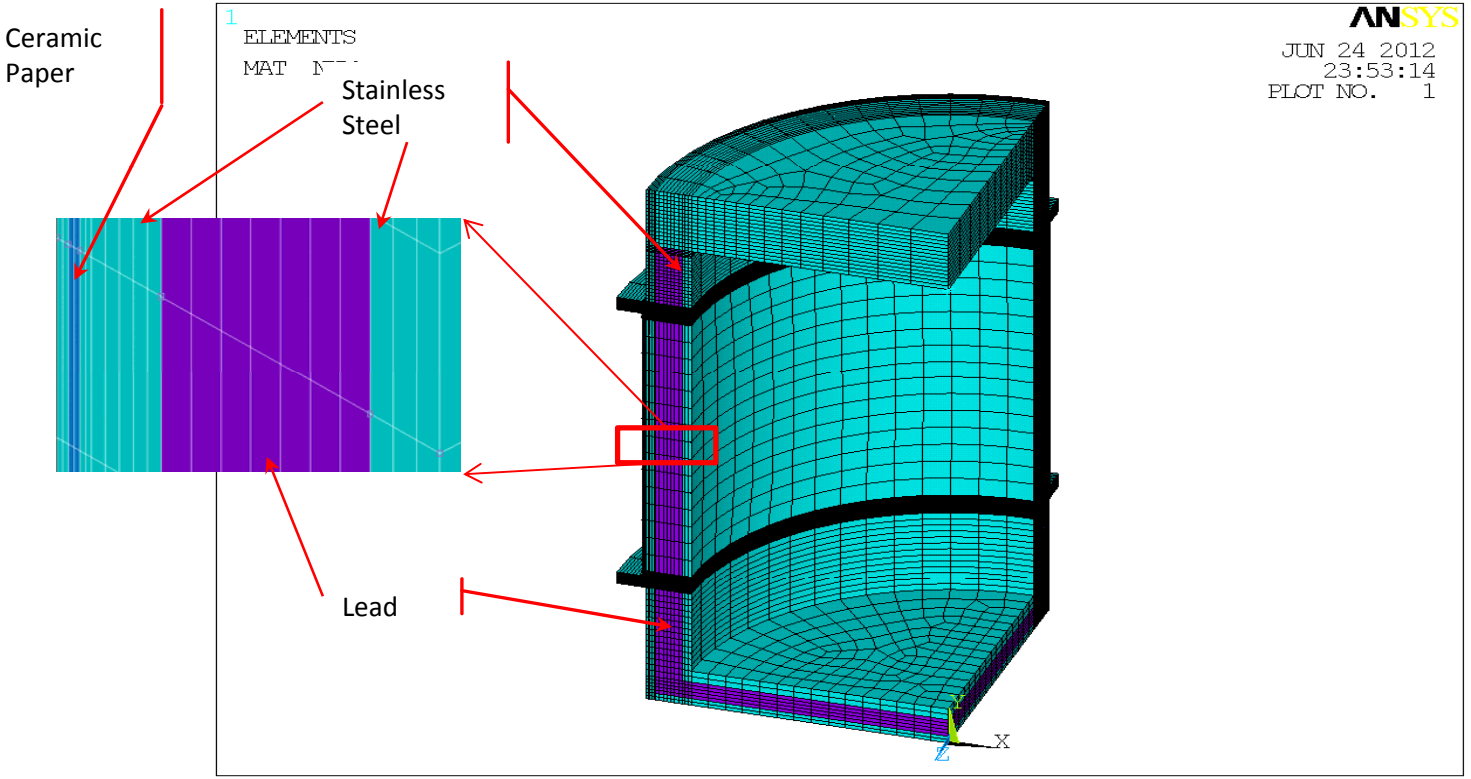
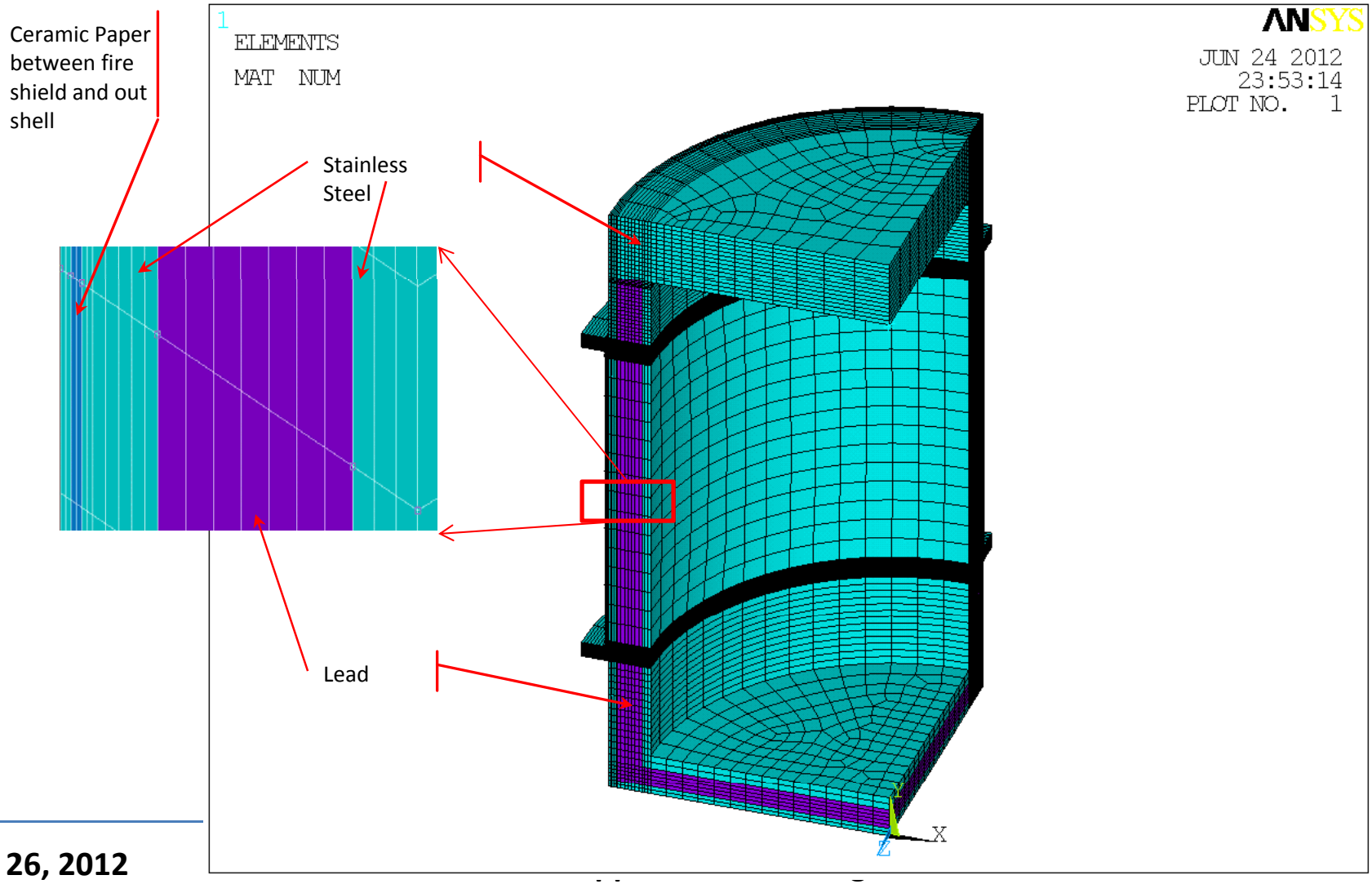
Thermal Finite Element Model



Thermal - Finite Element Model



June 26, 2012

Thermal – Accident Evaluation

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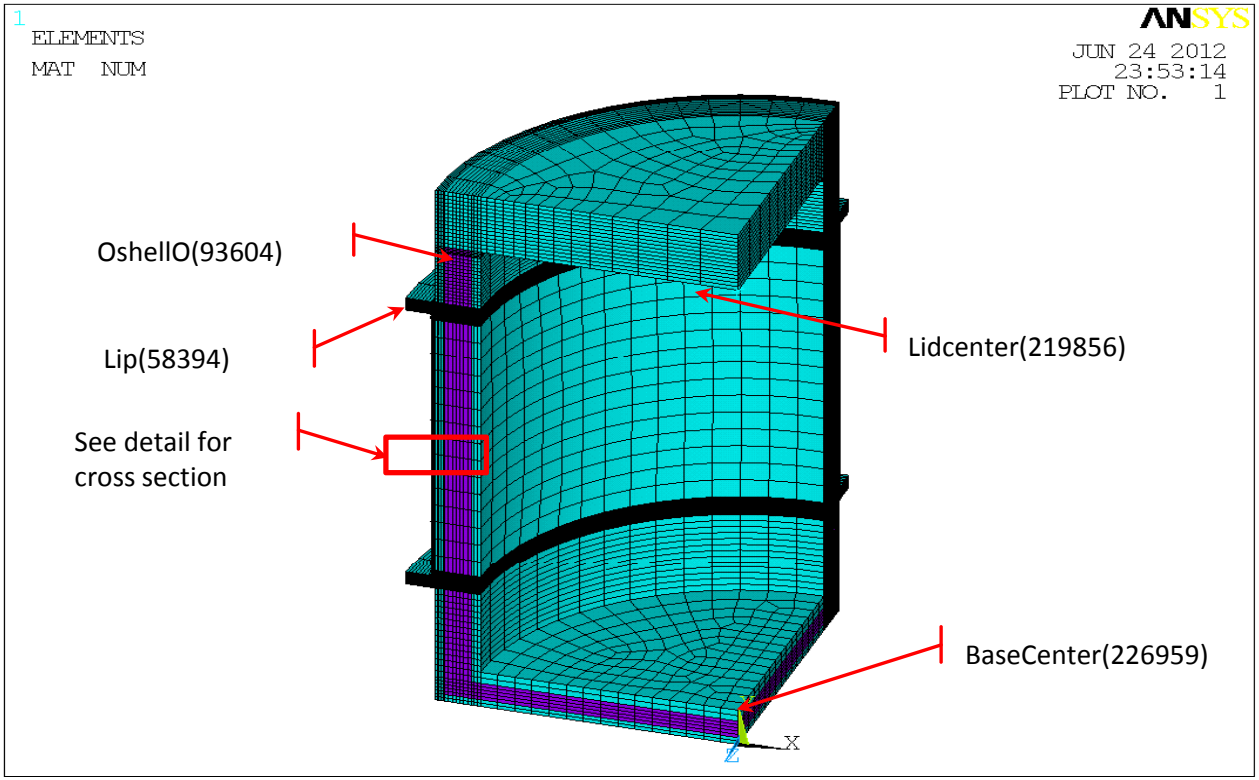
- ***Identification of the nodes where temperatures are monitored***



Thermal – Accident Evaluation

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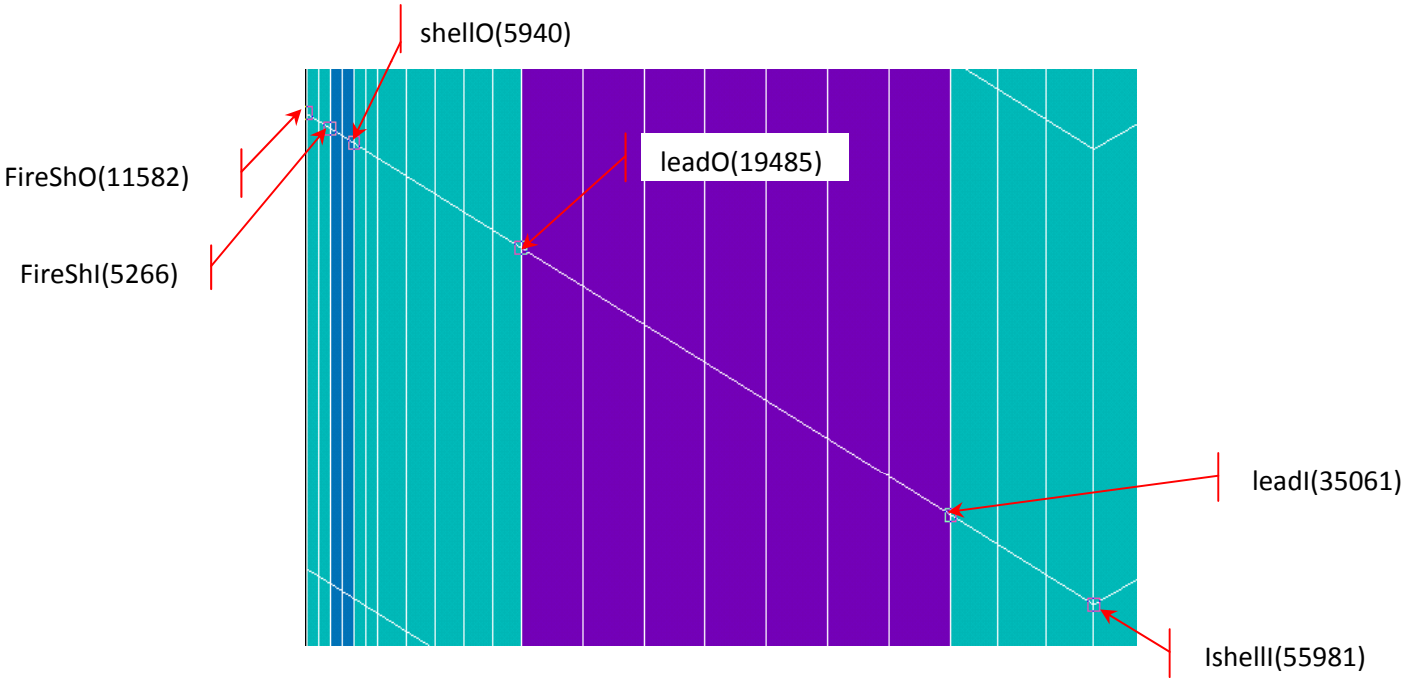
Closeup view of the cross section



Thermal – Accident Evaluation

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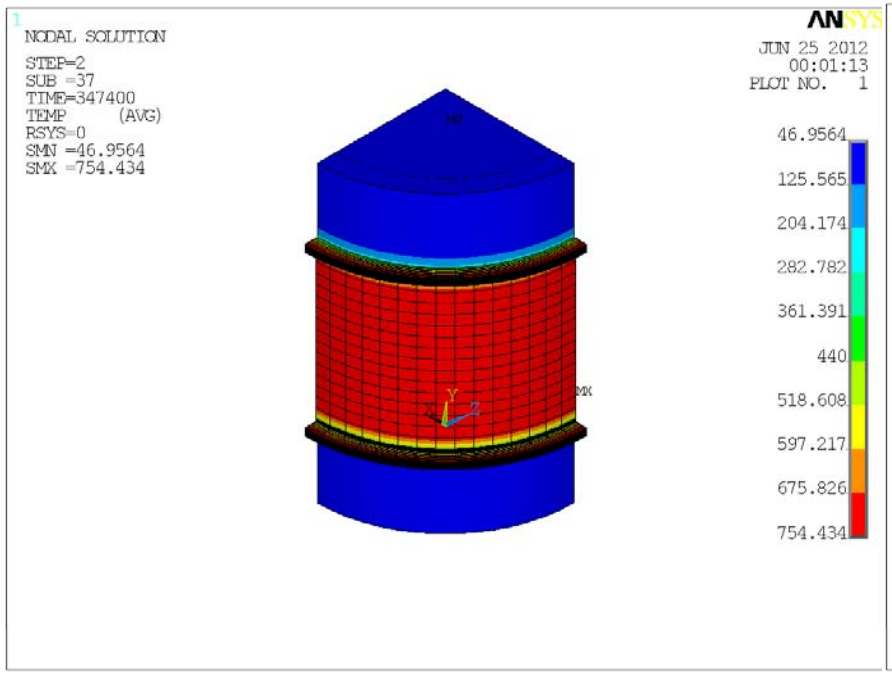
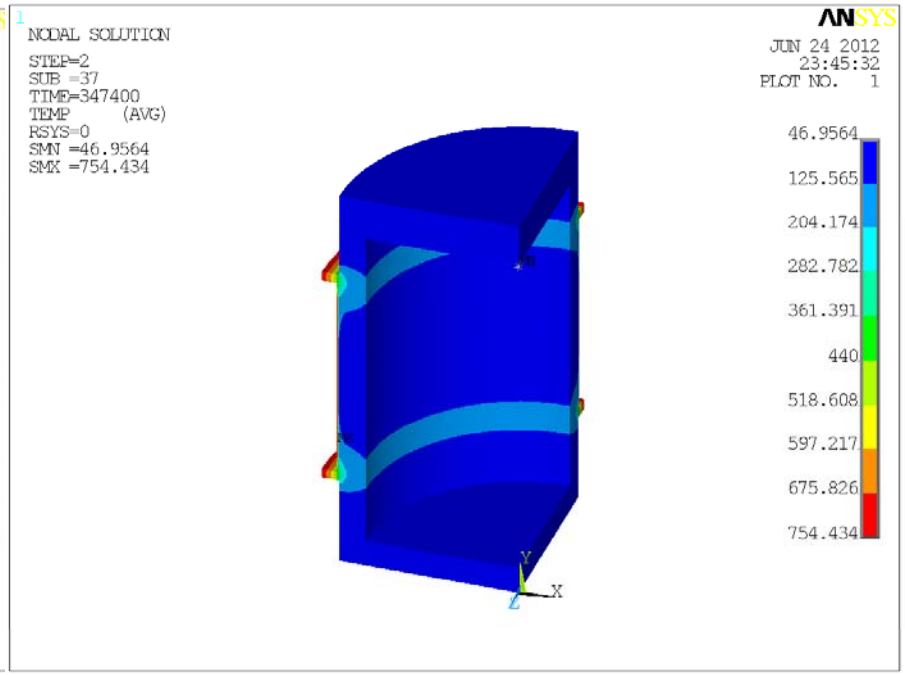
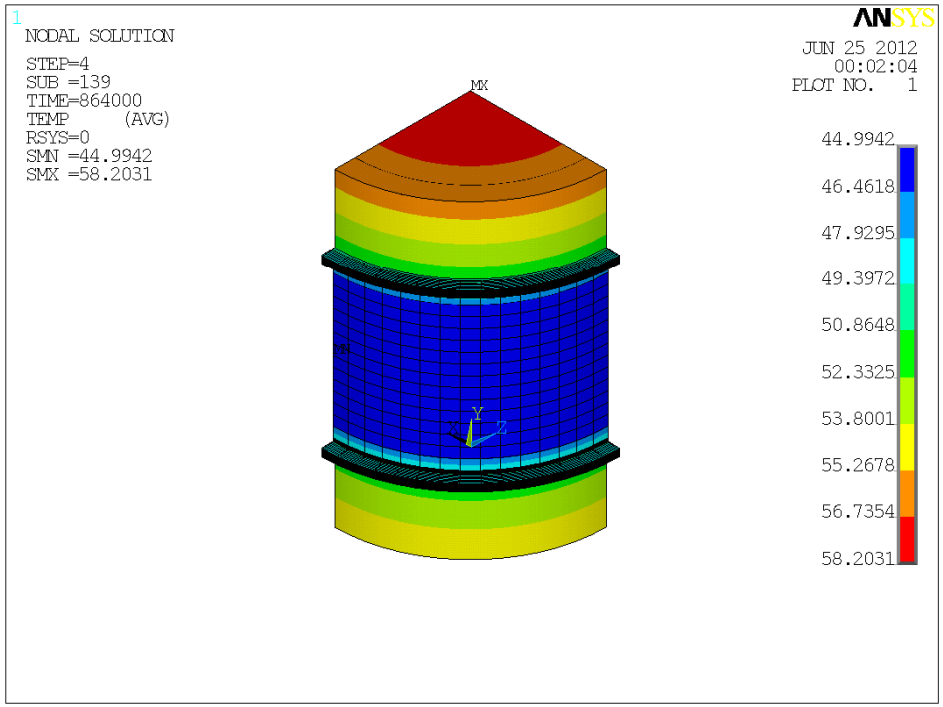
- Initial condition is normal hot with insolation
- Insolation is turned off during fire
- Temperatures shown below are after 1800 seconds of fire

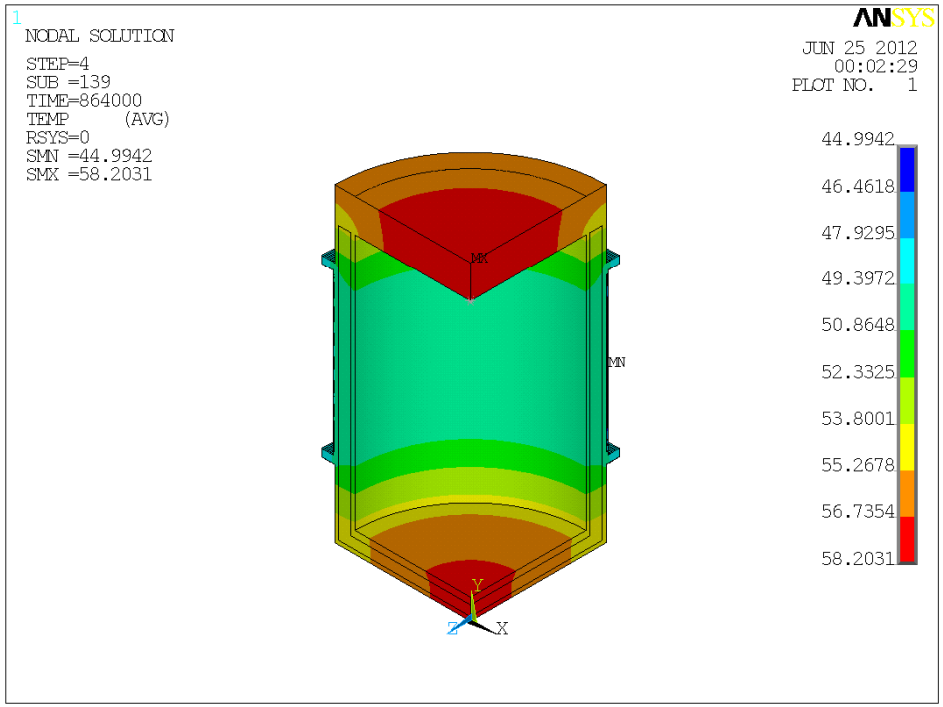




Thermal – Accident Evaluation

- *Cool down for 26100 seconds*
- *Ambient is at 38 C*
- *Insolation applied as a semi sinusoidal heat flux during cool down*





Thermal – Accident Evaluation

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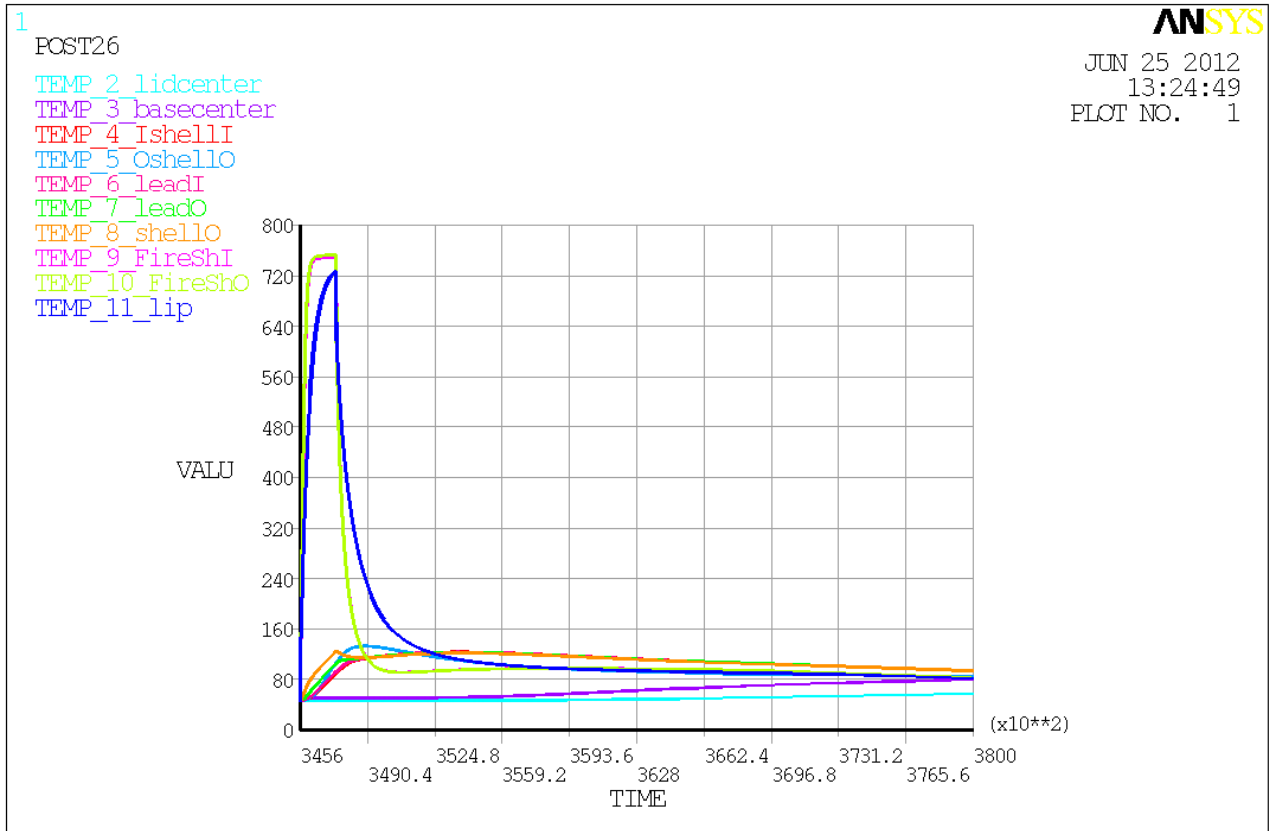
➢ Fire Transient and Cool Down



Thermal – Accident Evaluation

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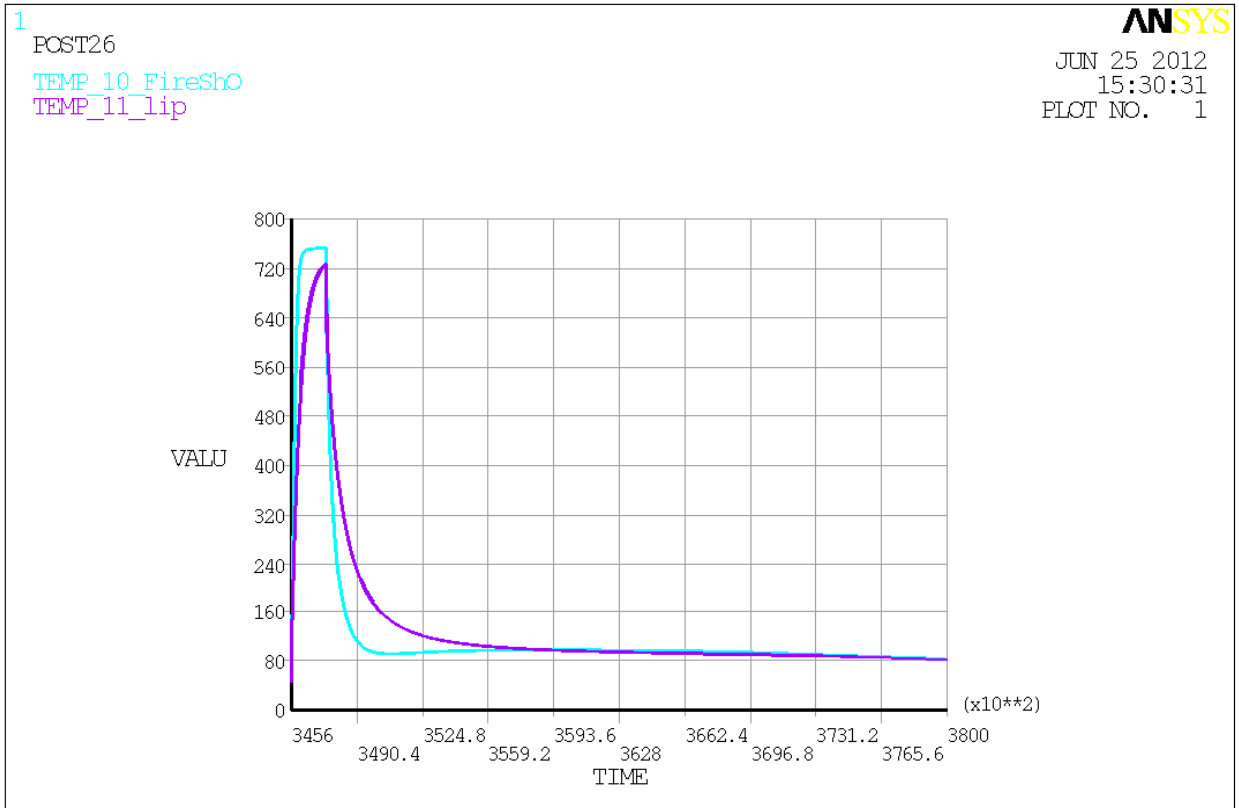
- ***Close Look of the Nodes Directly Exposed to Fire***



Thermal – Accident Evaluation

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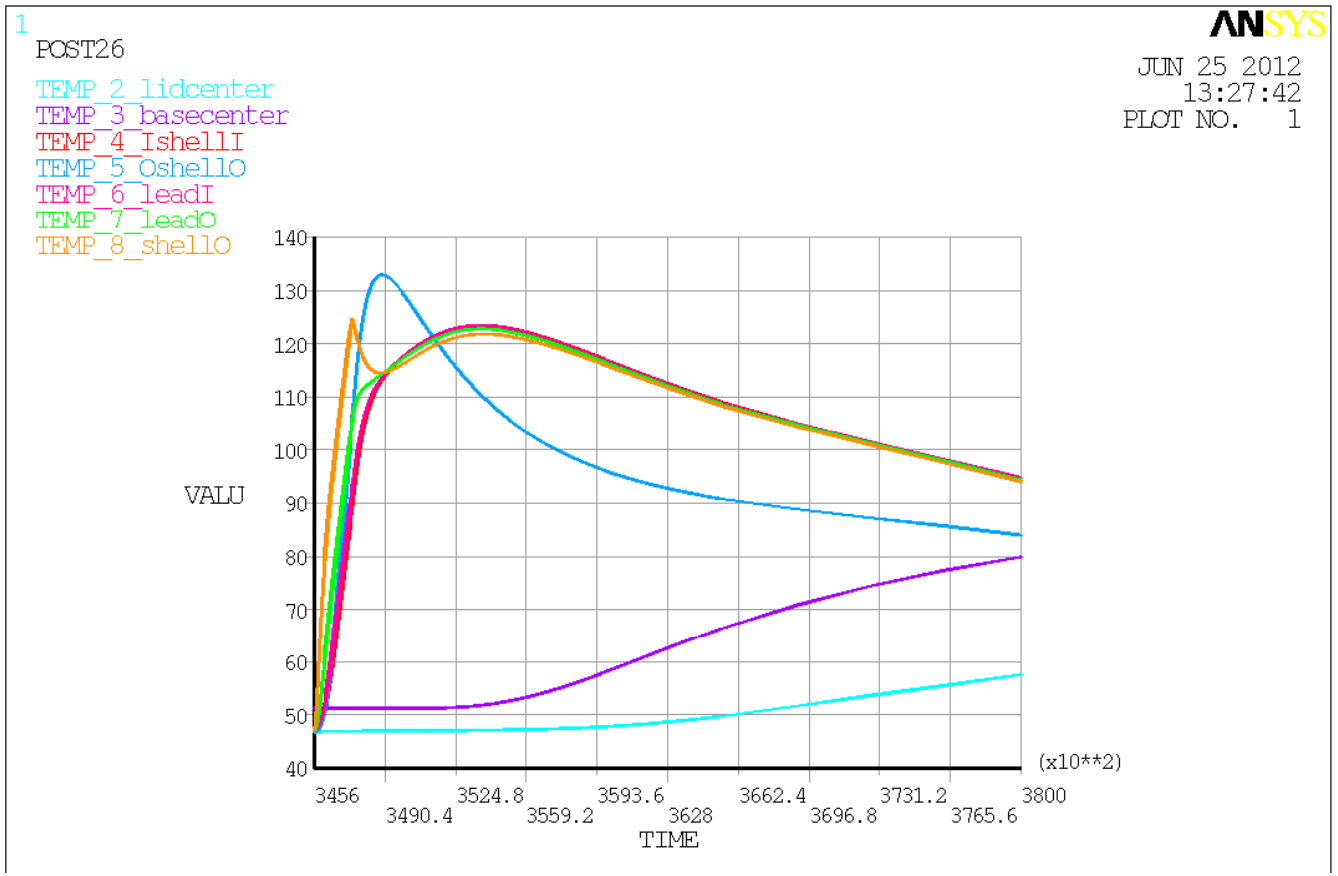
- ***Close Look of the Nodes not Directly Exposed to Fire***



Thermal – Accident Evaluation

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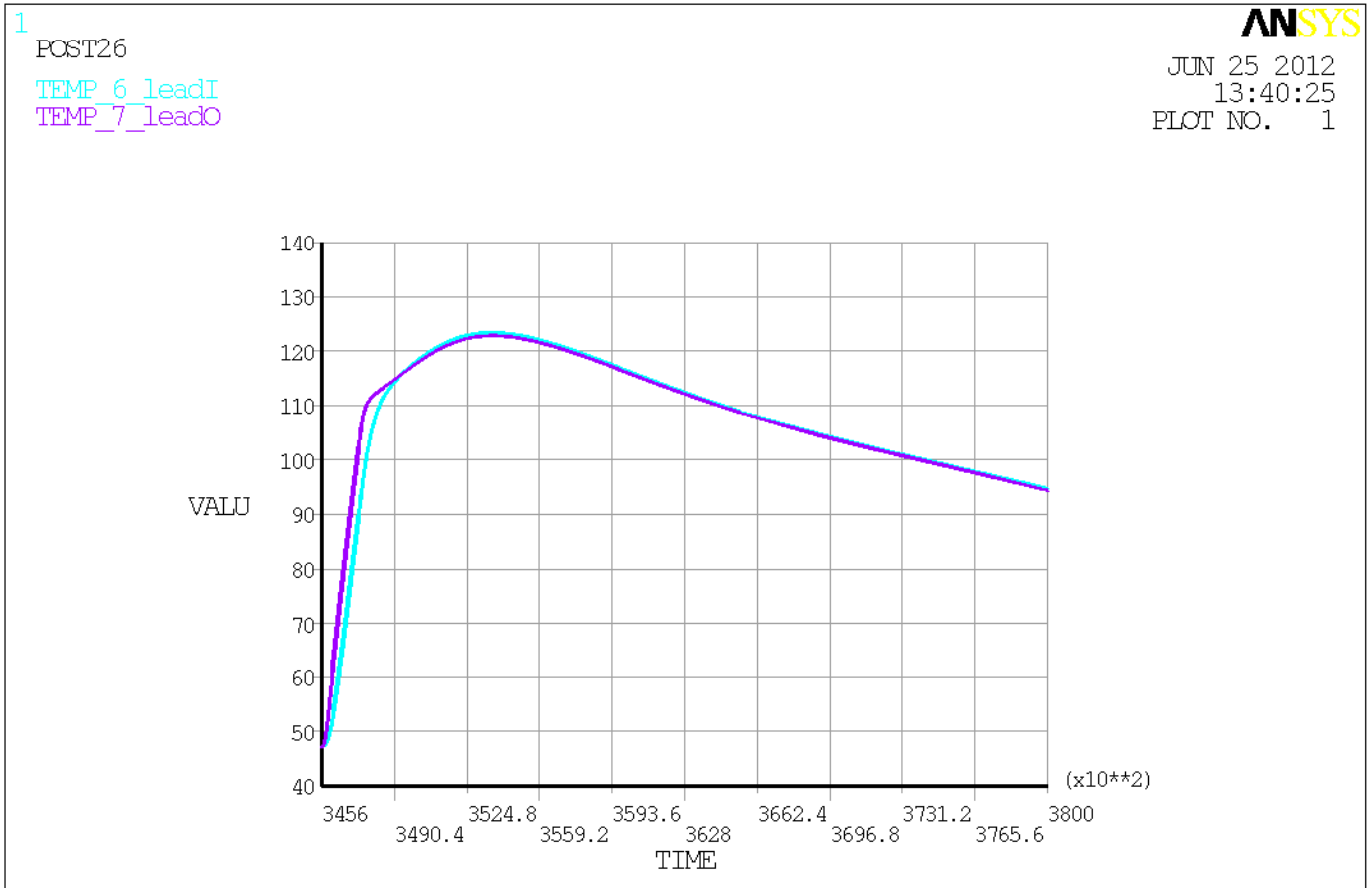
Lead Temperature



Thermal – Cask Body Evaluation

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Results Summary

- Temperatures of cask materials within allowable limits
- Structural evaluation performed for temperatures that bound the thermal results

SAR Submittal Schedule

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Action	Date
Final Pre-Application Meeting	June 2012
SAR Completion and Submittal	August 2012
Issuance of Certificate of Compliance	???