Enclosure 5 to TN E-25513

Transnuclear, Inc. Calculation 10421-37,
Revision 1 (Non-proprietary version)

TRANSNUCLEAR AN AREVA COMPANY	**Calculation Cover Sheet**	**Calculation No.:** 10421-37 **Revision No.:** 1 **Page:** 1 of 20

DCR NO:	10421-2	**PROJECT NAME:**	TN-40 Transport Package
PROJECT NO:	10421	**CLIENT:**	Transnuclear, Inc.

CALCULATION TITLE:

Thermal Analysis for Fire Accident Conditions with damaged/deformed impact limiters

SUMMARY DESCRIPTION:

This Calculation determines the maximum component temperatures and temperature profiles of TN-40 Transport Cask for thermal and structural evaluation for accident transport conditions considering damaged/deformed impact limiters.

If original issue, is licensing review per TIP 3.5 required? N/A

Yes ☐ **No** ☐ **(explain below)** **Licensing Review No.:** N/A

Software Utilized:	**Version:**	**Number of DVDs:**
ANSYS	8.1	3

Calculation is complete: Originator Signature:	Date: 06/20/06
Calculation has been checked for consistency, completeness and correctness: Checker Signature:	Date: 06/21/06
Calculation is approved for use: Project Engineer Signature:	08/07/2006 Date:

Form 3.2-1 Rev. 1, Equivalent

REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	03/24/06	Initial Issue	All	All
1	~~06/13/06~~ 08/07/06	Editorial corrections and considering drop on steel pole before fire accident	All	All

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1.0 PURPOSE

Determine the temperature distribution and the maximum component temperatures for hypothetical drop and sub-sequential fire accident conditions based on 10CFR71 regulations [2.1].

2.0 REFERENCES

2.1 U.S. Code of Federal Regulations 10CFR 71, "Packaging and Transportation of Radioactive Material"

2.2 Calculation 10421-15, rev. 0, "TN-40 Transport Cask Crush Area for ANSYS Run"

2.3 Calculation 10421-10, rev.1, "Thermal Analysis for Normal / Off-Normal Conditions"

2.4 Calculation 10421-11, rev.1, "Thermal Analysis for Fire Accident Conditions"

2.5 U.S. NRC Interim Staff Guidelines, ISG11, rev. 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel"

2.6 ANSYS Computer Code and User's Manuals, Rev. 8.1.

2.7 Safety Analysis Report for TN-68 Transport Package, Rev 4, CoC 71-9293.

2.8 Mitchell S. Sweet, "*Fire Performance of Wood: Test Methods and Fire Retardant Treatments*", Fire Safety of Wood Products, USDA Forest Service http://www.fpl.fs.fed.us/documnts/pdf1993/sweet93a.pdf

2.9 TN-40 Transport Packaging Configuration, Drawings 10421-71-40 to 10421-71-44, Rev. 0

2.10 U.S. Department of Agriculture, Forest Service, "Wood Handbook: Wood as an Engineering Material"

3.0 METHODOLOGY

The thermal performance of the TN-40 transport cask for fire accident conditions with undamaged impact limiters was evaluated in [2.4]. The fire accident might occur after a drop accident. The impact limiters are deformed after a drop accident. The impact limiters are locally deformed from the free drop and puncture conditions, but they remain firmly attached to the cask. The steel encased wooden impact limiters provide protection to the lid of the cask from the external heat load applied during the hypothetical accident events. A hypothetical fire accident subsequent to the drop accident might cause higher temperatures since the fire temperature is closer to the cask surface areas after deformation of the impact limiters.

Reference [2.2] calculates the crush area of the impact limiters for side, corner, and slap down drops. The geometries of the crush areas are taken from [2.2] and depicted in Figure 4-1. The maximum deformation is re-calculated based on the crush area and illustrated in Figure 4-1. The maximum deformation gives the minimum distance between the cask and the surface of the damaged impact limiter. As shown in Figure 4-1, the maximum horizontal deformations for top and bottom impact limiters are 13.42" and 13.58" respectively which is resulted from side drop. The maximum diameters are:

Top impact limiter: 144 - 2x13.42 = 117.2"
Bottom impact limiter: 144 - 2x13.58 = 116.8"

The maximum vertical deformation is 17.6" for the corner drop. The closest vertical distance between the deformed impact limiter and the cask is then:

38-17.6=20.4"

For conservatism, the deformation of impact limiters is considered uniformly in all directions. Therefore, the radius and the height of deformed impact limiters in the model are changed to reflect the above dimensions.

Considering the maximum deformation of impact limiters results in the shortest distance between the fire and the cask surface area and is therefore conservative.

The worst-case damage due to a hypothetical puncture conditions based on 10CFR71.73 [2.1] may result in the tearing of the outer steel skin of the front impact limiter, exposing the outer surface of a section of wood to the ambient conditions such as fire.

A study of fire performance of wood at elevated temperatures and heat fluxes [2.8] shows that the surface temperature for the rapid spontaneous ignition of wood is between 330 °C and 600 °C (626 °F and 1,112 °F). Reference [2.8] shows further if a thick piece of wood is exposed to fire temperatures between 815 °C and 1,038 °C (1,500 °F and 1,900 °F) based on standard fire test (ASTM E119, 1988), the outermost layer of wood is charred. At a depth of 13mm (~0.5") from the active char zone, the wood is only 105 °C (220 °F). This behavior is due to the low conductivity of wood and fire retardant characteristics of char. It is also shown that the char forming rate under high temperature fire conditions is between 37 mm/hr for soft woods and 55 mm/hr for hard woods. Redwood has a char rate of 46 mm/hr [2.8].

It is more likely that wood remains completely contained in the impact limiter. In this case, the fire effect on the cask thermal performance is limited because of fire retardant characteristics of wood and char.

The worst accident case occurs when wood chips off from the damaged area and is only partially contained in the upper impact limiter. The partially contained wood continues charring after the fire.

The thickness of Redwood at the center of the TN-40 cask impact limiter is 34.75 inches (883 mm) [2.9]. Considering the char rate for Redwood, it takes about 19 hours until the char reaches 13 mm above the inner surface of the center cover plate. At that moment the maximum char temperature would be imposed at the impact limiter inner surface.

(Redwood thickness -13) / char rate $= \frac{(883-13)}{46} = 18.9$ hr

It takes another 17 minutes until the last 13mm of Redwood is charred.

(thickness of last portion of hot Redwood) / char rate $= \frac{13}{46} = 0.28$ hr = 17.0 min

During the last 17 minutes the inner surface of the impact limiter is exposed to the high temperature of charring wood. The impact of charring wood on the cask is maximized if charring occurs immediately after fire for 17 minutes.

To bound the problem and remain conservative, it will be considered in the model that the inner surface of the impact limiter inner cover is exposed to 1,112 °F maximum char wood temperature for 30 minutes immediately after the end of fire. No heat dissipation will be considered for the open surface of the torn segment after this period, assuming conservatively that this surface is entirely covered with a thin layer of low conductivity wood char.

Considering the size of wood segments and location of seals, the worst case occurs when a middle segment of wood (ID 44" to OD 88", 90 degree) is torn. Nevertheless, the effects of a torn side segment (ID 88" OD 144", 30 degree) are also evaluated in this calculation.

A three dimensional finite element model of the TN-40 transport cask developed in reference [2.3] is used in this analysis to determine the maximum component temperatures for the hypothetical drop and fire accident conditions. The material properties of the model are identical to those described in reference [2.3] except for wood. A conservative value for wood conductivity is used in the model during fire period. The wood conductivity value is discussed in Section 4.0. All dimensions of the model are also identical to those described in reference [2.3] except for the impact limiters. The nodes and elements of impact limiters are moved and scaled to represent the deformed dimensions as discussed above.

The pre fire nodal temperatures are retrieved from the result file of model for normal conditions at 100 °F from reference [2.3] and transferred to the model with deformed impact limiters via “CBDOF” commands in ANSYS [2.6]. These nodal temperatures represent the conditions before drop accident. No temperature change is considered for the drop accident case. It is assumed that hypothetical fire occurs after the drop. The boundary conditions during the fire are identical to those described in [2.4].

A constant temperature of 1,112 °F is imposed on the nodes of the impact limiter inner disc surface belonging to the torn segment for a period of 30 minutes to consider the worst case wood smoldering after the end of fire. During this period, cool-down boundary conditions are applied over the other elements of the model. The cool-down boundary conditions are identical to those described in [2.4].

The model simulates 40.5 hours of accident from start of fire.

4.0 ASSUMPTIONS AND CONSERVATISM

All the assumptions and conservatism, including gap size are identical to those described in [2.4].

Wood conductivity parallel to the grain is 2.0 to 2.8 times higher than the conductivity across the grain [2.10]. The maximum wood conductivity, used during the fire accident condition, is taken to be 2.8 times that of the bounding maximum conductivity across the grain to maximize heat conductance from fire toward the cask during fire period. The maximum wood conductivity across the grain is 0.0135 Btu/hr-in-F as discussed in [2.3].

$$k = (2.8)(0.0135 \text{ Btu/hr-in-°F}) = 0.0378 \text{ Btu/hr-in-°F}$$

Proprietary Information Withheld in accordance with 10 CFR 2.390.

5.0 COMPUTATIONS

To split the output file into smaller, manageable files the solution of the model is performed in two consecutive runs as described in Table 5-1.

The nodal temperatures for the pre accident conditions (normal conditions at 100°F) are transferred from the result file in reference [2.3] using "NWRITE" and "CBDOF" commands in ANSYS [2.6]. These nodal temperatures (NC100.cbdo) are considered as load step one. Load step two is for fire accident. The resultant nodal temperatures at the end of fire are saved in an input file (fire.cbdo). This file is used as initial boundary conditions for the models considering either torn middle segment or torn side segment of front impact limiter. The other load steps consider smoldering and cool down period boundary conditions up to 40 hours.

Proprietary Information Withheld in accordance with 10 CFR 2.390.

6.0 DESIGN CRITERIA

To establish the heat removal capability, several thermal design criteria are established for the TN-40 transport packaging. These are:

- Seal temperatures must be maintained within specified limits to satisfy the leak tight functio of transfer cask back filled with helium. A maximum long-term seal temperature limit of 536°F is considered for the Helicoflex seals (double metallic O-rings) in the containment vessel closure lid [2.7].
- A maximum fuel cladding temperature limit of 570 °C (1058 °F) is set for the fuel assemblies with an inert cover gas as concluded in Reference [2.5].

7.0 RESULTS

The maximum component temperatures are listed in Table 8-1, Table 8-2, and Table 8-3 for accident 1 (deformed impact limiters), accident 2 (torn middle segment), and accident 3 (torn side segment), respectively. As seen, the accident case in which one middle segment of front impact limiter is torn (accident 2) represents the bounding maximum temperatures.

The temperature distributions are shown in Figure 8-2 at the end of fire and in Figure 8-3 at the end of wood smoldering. The temperature distributions of the bounding accident condition (accident 2) for the cool-down period is shown in Figure 8-5. This Figure illustrates temperature distributions at 26 hours after the end of fire. The temperature distribution for the accident 3 (torn side segment) is shown in for comparison. The time-temperature history of the maximum component temperatures are shown in Figure 8-5.

8.0 CONCLUSIONS

The thermal analysis for the hypothetical drop and subsequent fire accident conditions concludes that the TN-40 cask design meets all applicable requirements. The maximum component temperatures calculated using conservative assumptions are below the allowable limits. The maximum seal temperature (325 °F, 163 °C) is well below the 536 °F long-term limit specified for continued seal function. The predicted maximum fuel cladding temperature (529 °F, 276 °C) is well within allowable fuel temperature limit of 1058 °F (570 °C).

Table 8-1 Maximum Component Temperature for 22kW Heat Load
Crushed Impact Limiters

Component	Node #	Temperature (°F)	Time * (hr)	Result File	Allowable Limit (°F)
Fuel Cladding	243926	528	27.1	TN40crash	1058 [2.5]
Fuel Compartment	250401	479	19.5	TN40crash	†
Basket Al-Plate	242844	479	19.5	TN40crash	†
Cask Rail	178379	316	1.7	TN40crash	†
Cask Shim	222932	326	1.7	TN40crash	†
Cask Inner Shell	739865	403	end of fire	TN40crash	†
Inner Bottom Plate	651435	333	1.7	TN40crash	†
Cask Shield Shell	664129	694	end of fire	TN40crash	†
Bottom Shield Plate	715933	710	end of fire	TN40crash	†
Cask Lid	738086	250	1.7	TN40crash	†
Top Shield Plate	739361	247	7.3	TN40crash	†
Lid Seal	739753	306	0.3	TN40crash	536 [2.7]
Vent & Port Seal	728434	247	7.3	TN40crash	536 [2.7]
Cask Outer Shell	50984	1084	end of fire	TN40crash	†
Impact Limiter Surface	725861	1431	end of fire	TN40crash	†

* Time starts at the end of 30 minute Fire
† The components perform their intended safety function within the operating range

Table 8-2 Maximum Component Temperature for 22kW Heat Load
One Middle Segment of the Front Impact Limiter is Torn

Component	Node #	Temperature (°F)	Time* (hr)	Result File	Allowable Limit (°F)
Fuel Cladding	250321	529	26	TN40Acc_1PF	1058 [2.5]
Fuel Compartment	250401	480	20	TN40Acc_1PF	†
Basket Al-Plate	249239	479	20	TN40Acc_1PF	†
Cask Rail	619609	323	1	TN40Acc_1PF	†
Cask Shim	619417	330	1	TN40Acc_1PF	†
Cask Inner Shell	739865	403	end of fire	TN40Acc_F	†
Inner Bottom Plate	739878	380	0.04	TN40Acc_1PF	†
Cask Shield Shell	664129	694	end of fire	TN40Acc_F	†
Bottom Shield Plate	715933	709	end of fire	TN40Acc_F	†
Cask Lid	738086	289	4.2	TN40Acc_1PF	†
Top Shield Plate	739359	279	4.2	TN40Acc_1PF	†
Lid Seal	739070	325	1	TN40Acc_1PF	536 [2.7]
Vent & Port Seal	741799	284	4.2	TN40Acc_1PF	536 [2.7]
Cask Outer Shell	50984	1084	end of fire	TN40Acc_F	†
Impact Limiter Surface	725861	1431	end of fire	TN40Acc_F	†

Table 8-3 Maximum Component Temperature for 22kW Heat Load
One Side Segment of the Front Impact Limiter is Torn

Component	Node #	Temperature (°F)	Time* (hr)	Result File	Allowable Limit (°F)
Fuel Cladding	250321	529	26	TN40Acc_2PF	1058 [2.5]
Fuel Compartment	250401	480	20	TN40Acc_2PF	†
Basket Al-Plate	249239	479	20	TN40Acc_2PF	†
Cask Rail	619609	322	0.9	TN40Acc_2PF	†
Cask Shim	619417	329	0.9	TN40Acc_2PF	†
Cask Inner Shell	739865	403	end of fire	TN40Acc_F	†
Inner Bottom Plate	739878	380	0.04	TN40Acc_2PF	†
Cask Shield Shell	664129	694	end of fire	TN40Acc_F	†
Bottom Shield Plate	715933	709	end of fire	TN40Acc_F	†
Cask Lid	738085	263	3.7	TN40Acc_2PF	†
Top Shield Plate	739248	253	3.7	TN40Acc_2PF	†
Lid Seal	739757	312	0.5	TN40Acc_2PF	536 [2.7]
Vent & Port Seal	741683	256	3.7	TN40Acc_2PF	536 [2.7]
Cask Outer Shell	50984	1084	end of fire	TN40Acc_F	†
Impact Limiter Surface	725861	1431	end of fire	TN40Acc_F	†

* Time starts at the end of 30 minute Fire
† The components perform their intended safety function within the operating range

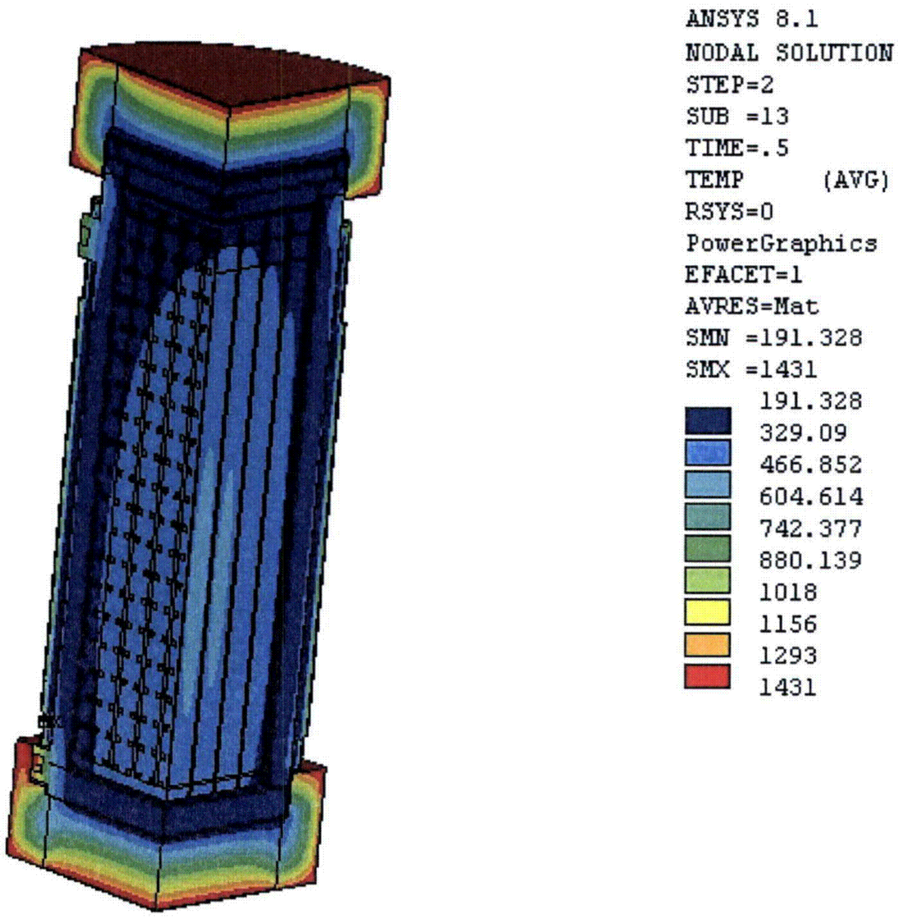


Figure 8-1 Temperature Distribution at the End of Fire Subsequent to Drop Accident

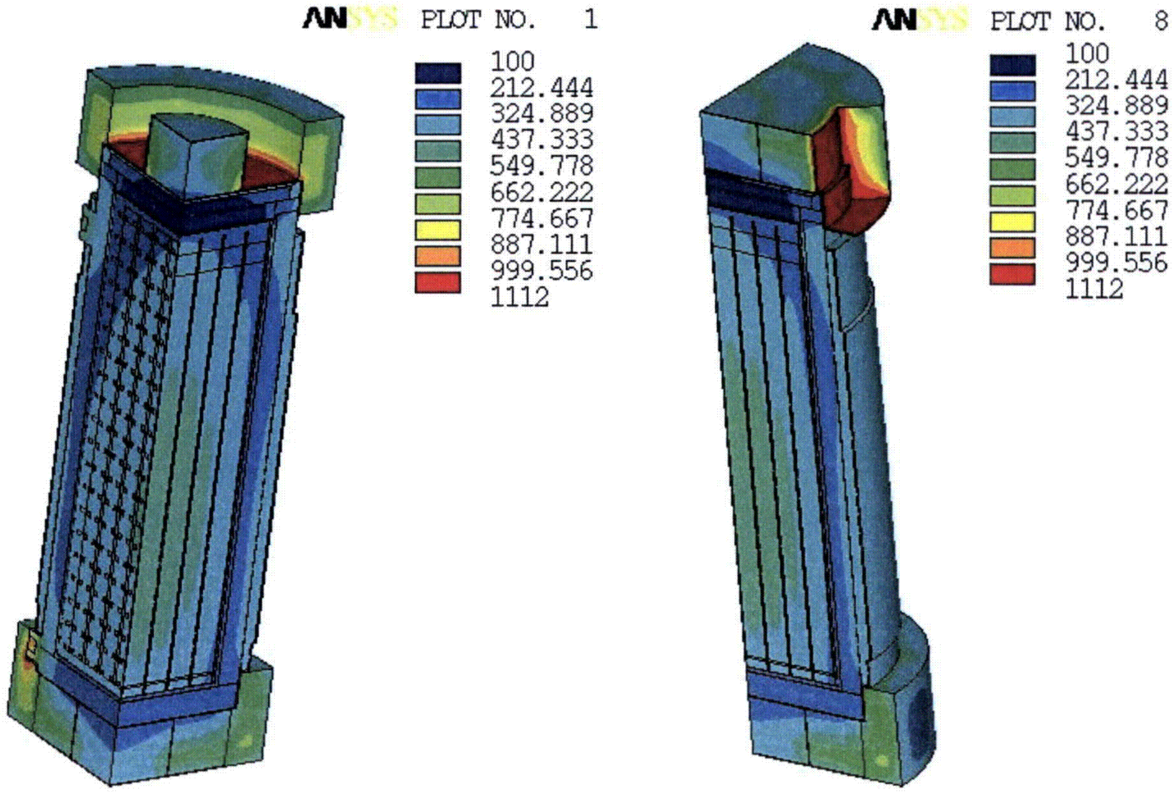
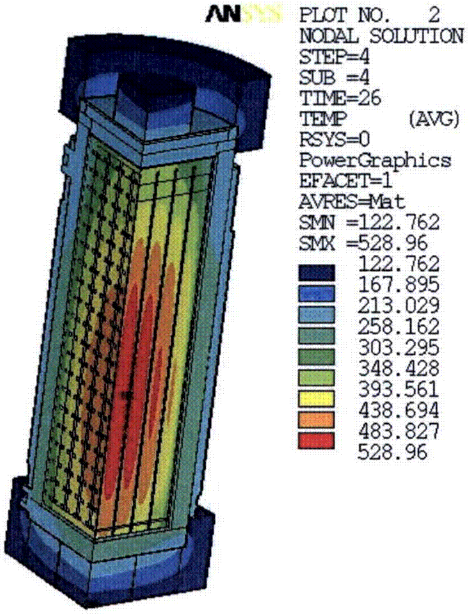
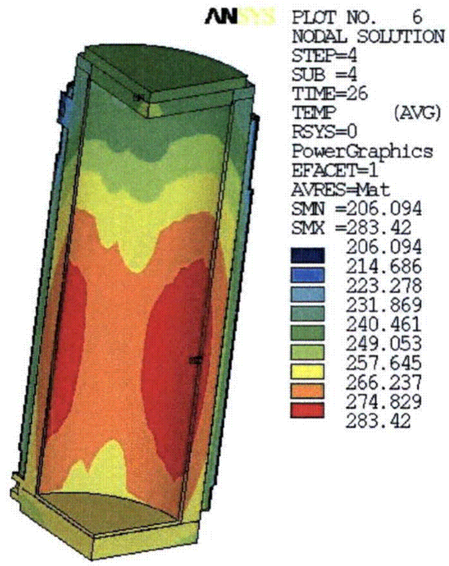


Figure 8-2 Temperature Distribution at the End of Smoldering
(0.5 hour after the end of fire)

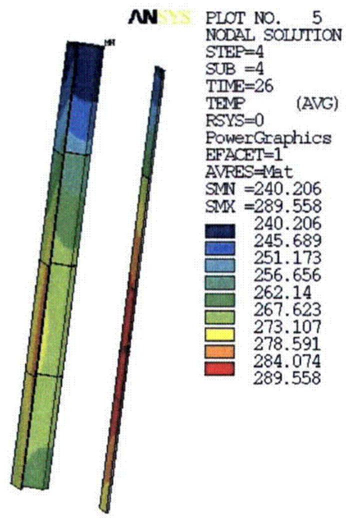
Cask Body – Bounding Case, Acc2



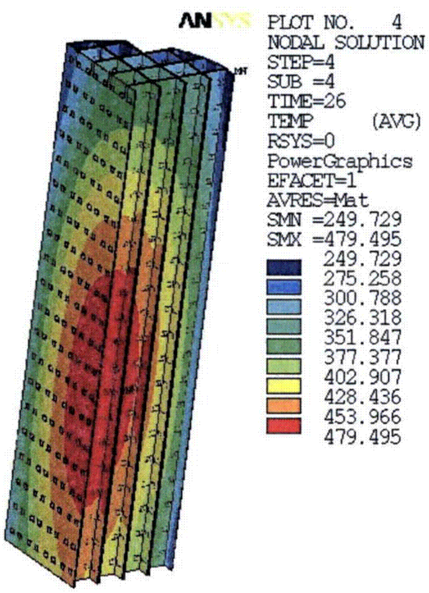
Cask Body– Bounding Case, Acc 2



Cask Rails– Bounding Case, Acc 2



Basket – Bounding Case, Acc 2



Fuel Assemblies – Bounding Case, Acc 2

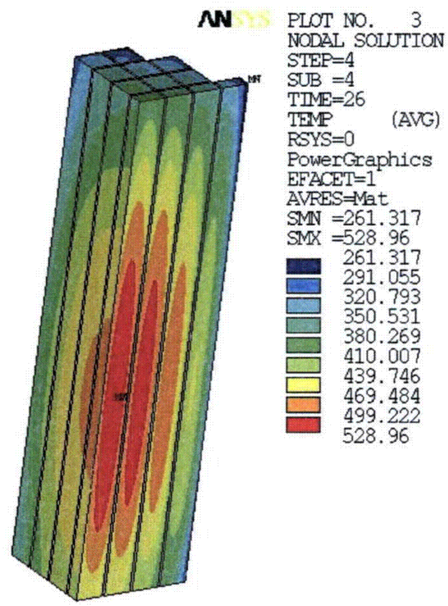
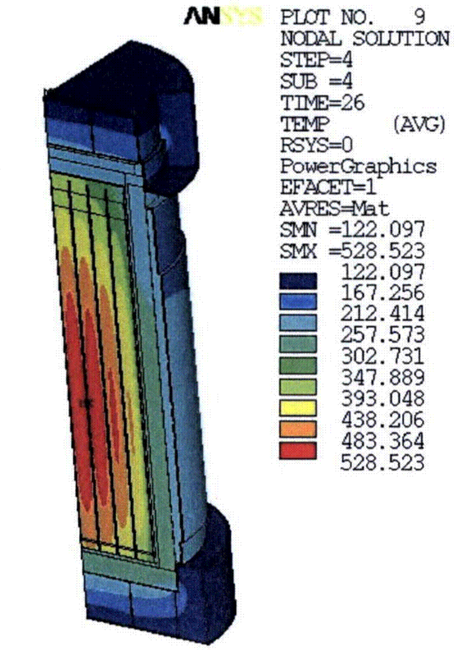


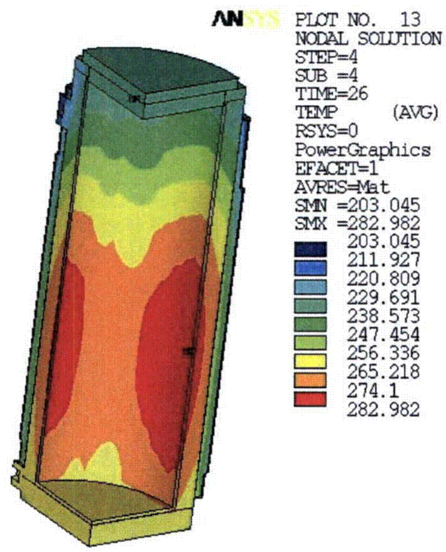
Figure 8-3 Temperature Distribution during Cool-Down Period

(26 hours after the End of Fire – Bounding Case Accident 2)

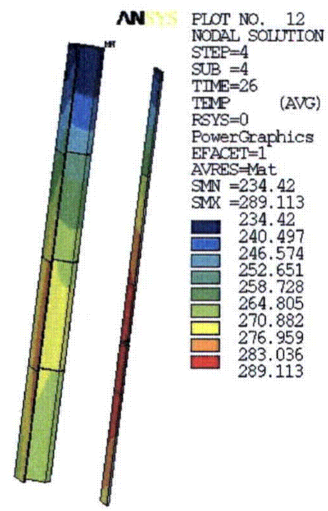
Cask Body – Acc3



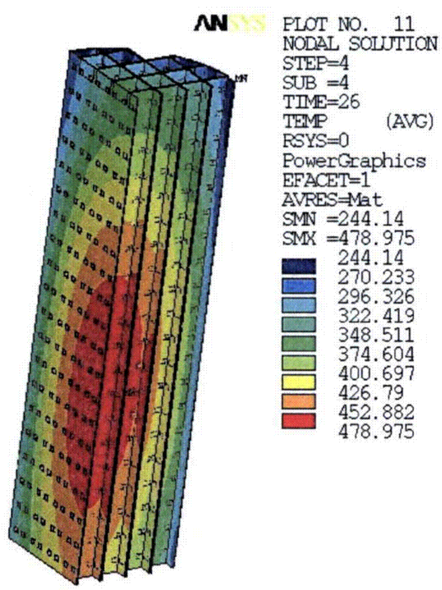
Cask Body– Acc 3



Cask Rails– Acc 3



Basket – Acc 3



Fuel Assemblies – Acc 3

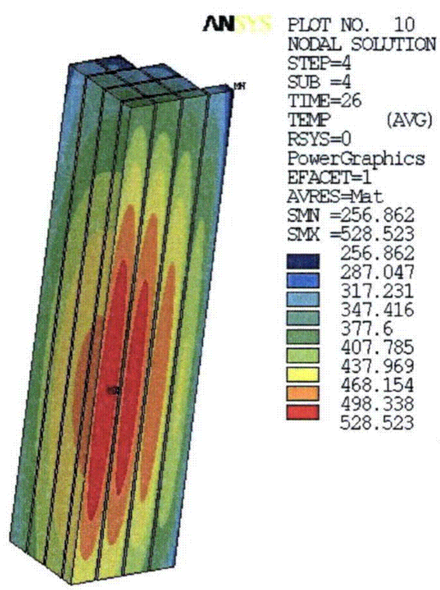
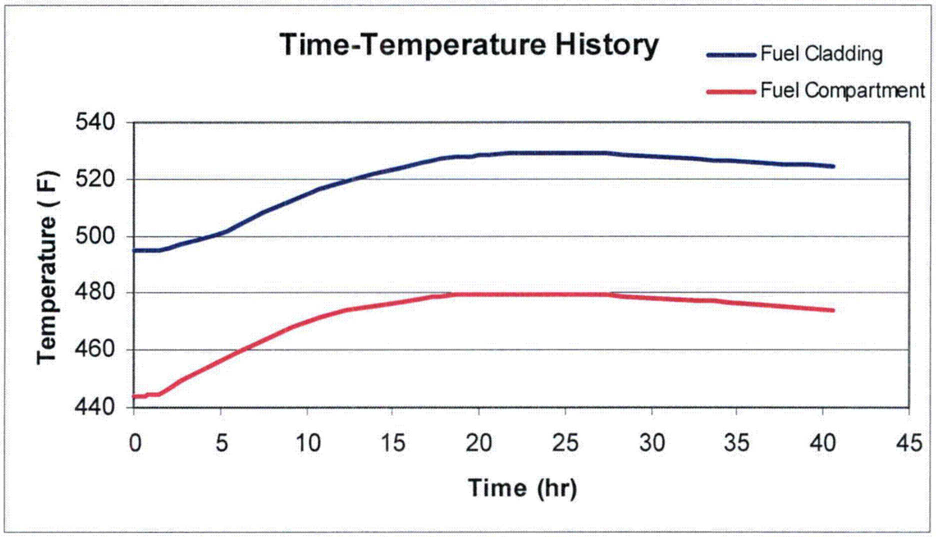


Figure 8-4 Temperature Distribution during Cool-Down Period

(26 hours after the End of Fire – Accident 3 for Comparison)



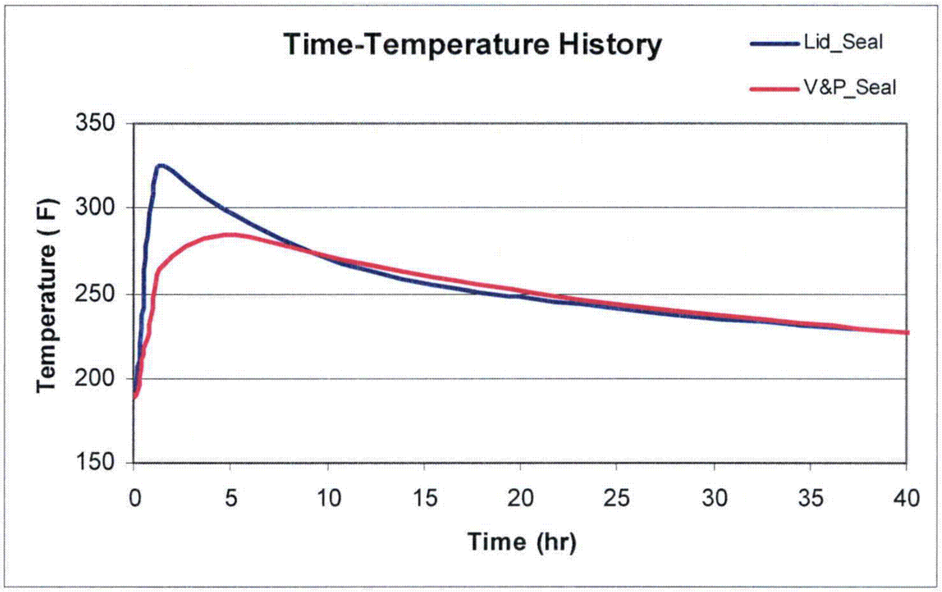
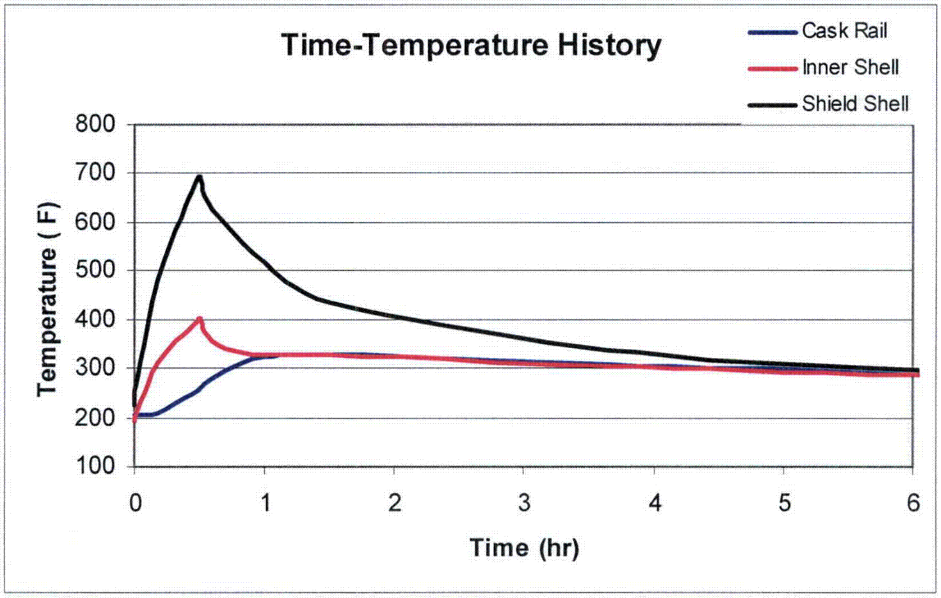


Figure 8-5 Time-Temperature History of Components



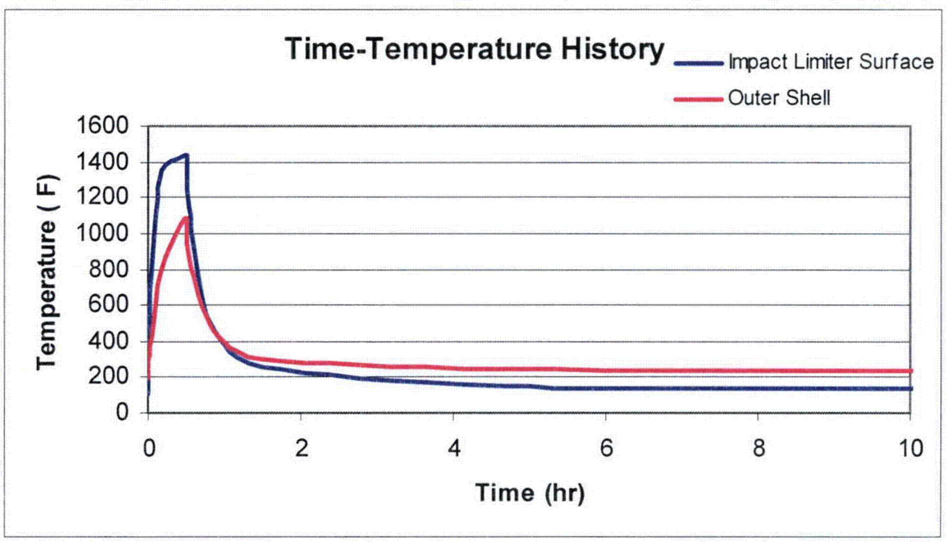


Figure 8-5 Time-Temperature History of Components (continued)

Enclosure 6 to TN E-25513
List of files contained in Enclosure 7 to TN-25513
Listing of Disk Numbering and Contents
(All files are Proprietary)

Disk ID No (type, size)	Discipline	Handling	File Series (topics)	Number of Files
1 (CD, 332 MB)	Thermal	Proprietary	A001-ReadMe_Normal.txt (Instruction file for ANSYS run for normal transport case)	A001 to A001 for a total of 1
	Thermal	Proprietary	A002-tn40_tr.cdb (Database file for TN40 geometry)	A002 to A002 for a total of 1
	Thermal	Proprietary	A003-TN40tr_100.inp to A007-HTOT_HCL.mac (Normal transport conditions at 100°F – input and macro files)	A003 to A007 for a total of 5
	Thermal	Proprietary	A008-TN40tr_100.out to A011-TN40_100.rth (Normal transport conditions at 100°F - ANSYS database and output files)	A008 to A011 for a total of 4
2 (DVD, 1.76 GB)	Thermal	Proprietary	B001-ReadMe_Accident.txt (Instruction file for ANSYS run for accident fire case)	B001 to B001 for a total of 1
	Thermal	Proprietary	B002-MatTN40tr.mac to B006-HTOT_VPL.mac (Macro files for material properties, heat generating and total heat transfer coefficients)	B002 to B006 for a total of 5
	Thermal	Proprietary	B007-TN40Acc.cdb (ANSYS Database file for geometry with deformed/damaged impact limiter)	B007 to B007 for a total of 1
	Thermal	Proprietary	B008-LSAccF.inp to B013-runAcc1PostFire.inp (30 minute fire and post fire accident conditions – load steps and input files)	B008 to B013 for a total of 6
	Thermal	Proprietary	B014-TN40.node to B016-fire.cbdo (Nodal temperature files retrieved from 100°F ambient normal and the end of 30 minute fire conditions)	B014 to B016 for a total of 3

Enclosure 6 to TN E-25513
List of files contained in Enclosure 7 to TN-25513
Listing of Disk Numbering and Contents
(All files are Proprietary)

Disk ID No (type, size)	Discipline	Handling	File Series (topics)	Number of Files
2 (continued)	Thermal	Proprietary	B017-PeakAccF.inp to B025-PtmpTN40_PF1.mac (30 minute fire and post fire accident conditions - post processing files for peak component temperatures and temperature plots)	B017 to B025 for a total of 9
	Thermal	Proprietary	B026-TN40Acc_F.db to B031-TN40Acc_F.out (30 minute fire conditions – ANSYS database and output files)	B026 to B031 for a total of 6
3 (DVD, 3.31 GB)	Thermal	Proprietary	C001-TN40Acc_1PF.db to C008-TN40Acc_1PF.out (Post fire accident conditions – ANSYS database and output files)	C001 to C008 for a total of 8