ENCLOSURE 5

TN Calculation NUH32PHB-0406, Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions

(Heat Loads <29.6kW)

AREVA TRANSNUCLEAR INC.	**Form 3.2-1 Calculation Cover Sheet** TIP 3.2 (Revision 4)	Calculation No.: NUH32PHB-0406 Revision No.: 2 Page: 1 of 33

DCR NO (if applicable): NUH32PHB-011	**PROJECT NAME:** NUHOMS® 32PHB System
PROJECT NO: 10955	**CLIENT:** CENG - Calvert Cliff Nuclear Power Plant (CCNPP)

CALCULATION TITLE:

Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions (Heat Loads of <29.6 kW)

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation determines the following aspects for the Calvert Cliff Nuclear Power Plant Onsite Transfer Cask (CCNPP-FC TC) loaded with 32PHB DSC:

The maximum heat loads and component temperatures for transfer time limits of 48 hours and 72 hours and also for transfer operations without any time limits.

The peak fuel cladding temperatures in the 32PHB DSC corresponding to the above transfer conditions.

The steady-state temperatures after the initiation of the forced cooling and the time limit to restore forced cooling or complete the transfer of 32PHB DSC to HSM-HB in case of forced cooling failure.

2) Storage Media Description

Secure network server initially, then redundant tape backup

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

Yes ☐ No ☒ (explain below) Licensing Review No.:____________

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

Software Utilized (subject to test requirements of TIP 3.3):	**Version:**
ANSYS	10.0

Calculation is complete: Originator Name and Signature: Venkata Venigalla *Venkat*	Date: 4/14/11
Calculation has been checked for consistency, completeness and correctness: Checker Name and Signature: Davy Qi [signature]	Date: 11/14/2011
Calculation is approved for use: Project Engineer Name and Signature: Kamran Tavassoli [signature]	Date: 11/29/11

REVISION SUMMARY

REV.	DESCRIPTION	AFFECTED PAGES	AFFECTED Computational I/O
0	Initial Issue	All	All
1	To update and clarify the loss of forced cooling condition based on the maximum fuel cladding temperature limit used for this condition.	1,2,6,8,16 and 17	None
2	To add thermal evaluation for steady-state transfer operations of 32PHB DSC in CCNPP-FC TC.	1-5, 7-13, 15-23 and 28-30	See Table 8-1

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1.0 PURPOSE

This calculation establishes the maximum heat loads for 32PHB DSC in the Calvert Cliff Nuclear Power Plant Onsite Transfer Cask (CCNPP-FC TC) for transfer time limits of 48 hours and 72 hours before initiation of forced convection (FC) as noted in Section 5.0 of [2]. An additional heat load is also determined that will permit steady-state transfer operations of 32PHB DSC in CCNPP-FC-TC without any time limits and without FC.

The maximum heat loads per 32PHB DSC for the transfer time limits of 48 hours, 72 hours and steady-state transfer operations are determined such that the maximum CCNPP-FC TC component temperatures remain below the temperatures evaluated for the CCNPP TC with 32P DSC in [10] or either below the temperatures considered in the structural evaluation of the CCNPP TC [11].

Based on the maximum heat loads described above, this calculation determines the maximum component temperatures during transfer operations of a 32PHB DSC in CCNPP-FC TC for transfer time limits of 48 hours, 72 hours before initiation of a corrective action such as FC or refilling the TC/DSC annulus with clean demineralized water. It also determines the maximum component temperatures during steady-state transfer operations without any time limits.

To determine the maximum component temperatures of the CCNPP-FC TC loaded with 32PHB DSC for heat loads < 29.6 kW without FC under transient conditions, this calculation utilizes the methodology and the ANSYS thermal model of CCNPP-FC TC described in [4]. The peak fuel cladding and the basket component temperatures for 32PHB DSC are determined using the ANSYS thermal model and methodology described in [3].

The CCNPP-FC TC loaded with 32PHB DSC utilizes FC as a possible recovery mode to improve the thermal performance of the system if the transfer operations exceed the 48 hours and 72 hours transfer time limits. The heat load specified for steady-state transfer operations without time limits does not require any recovery action.

This calculation determines the maximum component temperatures of the CCNPP-FC TC loaded with 32PHB DSC for heat loads < 29.6 kW with FC under steady-state conditions and also determines the peak fuel cladding temperature within the 32PHB DSC with the FC. There are no time limits associated for transfer operations once the forced air circulation is initiated.

It also establishes a time limit to restore the FC in case of system failure or complete the transfer of the 32PHB DSC for heat loads < 29.6 kW in CCNPP-FC TC to the HSM-HB to ensure that the peak fuel cladding temperature remains below the temperature limit of 752°F [5].

2.0 REFERENCES

1 ANSYS computer code and On-Line User's Manuals, Version 10.0.

2 Design Criteria Document, "Design Criteria Document (DCD) for the NUHOMS® 32PHB System for Storage", Transnuclear, Inc., NUH32PHB.0101 Rev. 2.

3 Calculation, "Thermal Evaluation of NUHOMS 32PHB Canister for Storage and Transfer Conditions", Transnuclear, Inc., NUH32PHB-0403, Rev. 0.

4 Calculation, "Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions", Transnuclear, Inc., NUH32PHB-0402, Rev. 0.

5 NRC Spent Fuel Project Office, Interim Staff Guidance, ISG-11, Rev 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel".

6 GESC, NAC International, Atlanta Corporate Headquarters, 655 Engineering Drive, Norcross, Georgia (Engineering Report # NS3-020, Effects of 1300°F on Unfilled NS-3, while Bisco Products, Inc., 11/84).

7 Calvert Cliffs Independent Spent Fuel Storage Installation Updated Safety Analysis Report, Rev.17.

8 Calculation, "Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions with Forced Cooling (Steady State)", Transnuclear, Inc., NUH32PHB-0401, Rev. 1.

9 Perry & Chilton, Chemical Engineers Handbook, 5th Edition, 1973.

10 Calculation, "NUHOMS-32P, Transfer Thermal Analysis 103°F Ambient", Transnuclear, Inc., 1095-6 Rev. 1.

11 Calculation, "NUHOMS-32P, Transfer Cask Structural Analysis", Transnuclear, Inc., 1095-35 Rev. 2.

3.0 ASSUMPTIONS AND CONSERVATISM

The following assumptions and conservatism are considered in the calculation.

3.1 CCNPP-FC TC Model

All the assumptions and conservatisms described in Section 3.1 and Section 3.2 of [4] are applicable for this calculation except as note below.

The following modifications are considered for the CCNPP-FC TC model for steady-state transfer operations without any time limits:

For the bottom surface of the CCNPP-FC TC in contact with the fuel building floor, the heat is dissipated via conduction to the floor. To bound the heat loss due to conduction a maximum temperature of 250°F is considered for the bottom surface of the cask.

Based on the results presented in Section 6.1.1, a fixed 250°F temperature on the CCNPP-FC TC bottom results in approximately 2.86% of the heat to be dissipated via the bottom of the CCNPP-FC TC with the remaining 97.14% dissipated from the cask radial surface via free convection and radiation to ambient. This shows that heat loss considered from the bottom of CCNPP-FC TC is insignificant and therefore acceptable.

Further, the maximum temperatures of the fuel cladding and basket components remain unaffected by the assumed temperature of 250°F at the bottom of the CCNPP-FC TC. The only component potentially affected by this assumption is the bottom neutron shield. Since the contribution of the neutron sources to the dose rate at the cask bottom is not significant, any localized increase of temperatures does not affect the shielding performance of the CCNPP-FC TC.

3.2 32PHB DSC Model

The assumptions and conservatism considered for 32PHB DSC model are the same as those described in [3], Section 3.0.

4.0 DESIGN INPUT

4.1 Design Load Cases

The following design cases in Table 4-1 are analyzed in this calculation to determine the thermal performance of CCNPP-FC TC with 32PHB DSC for transfer time limits of 48 hours and 72 hours as noted in Section 5.0 of [2] with and without FC.

Table 4-1 Design Load Cases for 32PHB DSC in CCNPP-FC TC

Case	Operation Condition	Description	Notes	Ambient Temperature	Insolation	Airflow
				[°F]	[Btu/hr-ft²]	[cfm]
1	Normal	Normal Hot	(1)	104	82	0
2	Normal	Normal Cold	(1)	-8	0	0
3	Off-Normal	Off-Normal Hot	(1)	104	127	0
4	Off-Normal	Off-Normal Cold	(1)	-8	0	0
5	Normal	Vertical Operations, Transient	(3) (6)	100	0	0
6	Off-Normal	Off-Normal Hot, Transient	(1) (6)	104	127	0
7	Normal	Normal Hot, FC	(2)	104	82	450
8	Normal	Normal Cold, FC	(2)	-8	0	450
9	Off-Normal	Off-Normal Hot, FC	(2)	104	127	450
10	Off-Normal	Off-Normal Cold, FC	(2)	-8	0	450
11	Off-Normal(7)	Loss of Forced Airflow, Transient	(4)	104	127	0
12	Accident	Fire Accident	(5)	104/1475/104	127	0

Notes:

1) Load cases # 1, 2, 3 and 4 are bounded by the Load Case # 6 (See Section 6.0 for justification).
2) Load cases # 7, 8, 9 and 10 are bounded by the Load Case # 3 of Reference [8] (See Section 6.0 for justification).
3) Load case # 5 is bounded by the Load Case # 5 of Reference [4] (See Section 6.0 for justification).
4) Load case # 11 is bounded by the Load Case # 5 of Reference [8] (See Section 6.0 for justification).
5) See Section 6.3 for the fire accident analysis.
6) Initial steady-state conditions with 212°F water assumed in the DSC/TC annulus. At time t=0, the water is drained, no forced air circulation is available, and the system begins to heat up. See Appendix C of Reference [4] for justification of the DSC/TC annulus temperature.
7) The temperature limits of off-normal transfer conditions are considered to evaluate this load case.

The following design cases in Table 4-2 are analyzed in this calculation to determine the thermal performance of CCNPP-FC TC with 32PHB DSC for steady-state transfer operations without time limits and without FC.

Table 4-2 Design Load Cases for 32PHB DSC in CCNPP-FC TC for Steady-State Transfer Operations

Case	Operation Condition	Description	Notes	Ambient Temperature	Insolation	Airflow
				[°F]	[Btu/hr-ft²]	[cfm]
SS1	Normal	Normal Hot	(1)	104	82	0
SS2	Normal	Normal Cold	(1)	-8	0	0
SS3	Off-Normal	Off-Normal Hot	(1)	104	127	0
SS4	Off-Normal	Off-Normal Cold	(1)	-8	0	0
SS5	Normal	Vertical Operations	--	100	0	0
SS6	Accident	Fire Accident	(2)	104/1475/104	127	0

Notes:

1) The maximum temperatures for Load cases # SS1, SS2 and SS4 are bounded by the Load Case # SS3 (See Section 6.1 for justification).
2) See Section 6.3 for the fire accident analysis.

4.2 Thermal Properties of Materials

Materials used in CCNPP-FC TC ANSYS thermal model are listed in Table 4-3, Section 4.3 of [4]. Materials and Thermal properties used in the 32PHB DSC models are listed in Section 4.1 of [3].

4.3 Surface Properties of Materials

Surface properties of materials used in this calculation are the same as those described in Section 4.4 of [4].

4.4 Design Criteria

The design criteria and evaluation of 32PHB DSC basket are presented in Reference [3] and design criteria for the CCNPP-FC TC are presented in Reference [4] and are listed below.

- Maximum fuel cladding temperature limits of 752°F (400°C) for normal/off-normal load cases listed in Table 4-1 and 1,058°F (570°C) for accident conditions listed in Table 4-1 are considered for the FAs with an inert cover gas as concluded in ISG-11 [5].
- The ASTM B29 lead used in the gamma shield has a melting point of approximately 620°F [9].

For design purposes of this application, the long-term, bulk average temperature of the NS-3 material is set to 280 °F [7] or less, and short-term limits for accident conditions should be 1,300 °F or less [6].

5.0 METHODOLOGY

This calculation establishes the maximum heat loads for 32PHB DSC in the CCNPP-FC TC for transfer time limits of 48 hours and 72 hours before initiation of FC as noted in Section 5.0 of [2]. It also specifies the maximum heat load for steady-state transfer operations without time limit.

The maximum heat loads of 25.6 kW and 23.04 kW per 32PHB DSC are determined for the transfer time limits of 48 hours and 72 hours, respectively as specified in Section 5.0 of [2] such that the maximum TC component temperatures remain below the temperatures evaluated for the 32P DSC in [10].

Based on the maximum heat loads described above, transient thermal analyses are performed to determine the maximum component temperatures of the CCNPP-FC TC loaded with 32PHB DSC for 25.6 kW and 23.04 kW heat loads at 48 hours and 72 hours, respectively, before initiation of a corrective action such as FC or refilling the TC/DSC annulus with clean demineralized water. A description of the thermal model used for the CCNPP-FC TC thermal analysis is presented in Section 5.1.

An additional heat load of 21.12 kW per 32PHB DSC is determined for steady-state transfer operations without time limits such that the maximum TC component temperatures remain below the temperatures considered for the structural evaluation of the CCNPP TC with 32P DSC in [11]. To determine the maximum temperatures with this heat load, steady-state thermal evaluations are performed for both horizontal and vertical transfer operations as noted in Section 5.1

The 32PHB DSC shell temperature profiles from 48 hours, 72 hours and steady-state transfer conditions with the 32PHB DSC in the CCNPP-FC TC for 25.6kW, 23.04 kW and 21.12 kW heat loads, respectively are used to determine the peak fuel cladding and basket component temperatures based on the 32PHB DSC/Basket thermal model steady state analysis. A description of the thermal model used for the 32PHB DSC/Basket thermal analysis is presented in Section 5.2.

The CCNPP-FC TC loaded with 32PHB DSC utilizes FC as a possible recovery mode to improve the thermal performance of the system if the transfer operations exceed the 48 hours and 72 hours transfer time limits noted in Section 5.0 of [2] for heat loads of 25.6 kW and 23.04 kW, respectively. A recovery mode such as the FC system is not required for steady-state transfer operations of CCNPP-FC TC with 21.12 kW heat load.

This calculation determines the maximum component temperatures of the CCNPP-FC TC loaded with 32PHB DSC for 25.6 kW and 23.04 kW heat loads with FC under steady-state conditions and also determines the peak fuel cladding temperature within the 32PHB DSC with the FC. There are no time limits associated for horizontal transfer operations once the forced air circulation is initiated. Section 6.2 of this calculation discussed the thermal analysis of the CCNPP-FC TC with FC.

This calculation also establishes a time limit to restore the FC in case of system failure or complete the transfer of the 32PHB DSC for 25.6 kW and 23.04 kW heat loads in CCNPP-FC TC to the HSM-HB to ensure that the peak fuel cladding temperature remains below the temperature limit of 752°F [5].

5.1 CCNPP-FC TC Model

Transient and steady-state simulations are performed using the ANSYS model and the thermal analysis methodology for the CCNPP-FC TC as described in Section 5.0 of reference [4]. No changes are considered to the thermal model of the CCNPP-FC TC model and the methodology presented in Reference [4] except for the decay heat load values and the assumptions noted in Section 3.0 applicable to load case # SS5 in Table 4-2. Decay heat load is applied as a uniform volumetric heat generated throughout the homogenized region of the basket. The volumetric heat generation rate is calculated as

$$q''' = \frac{Q}{\pi\,(D_i/2)^2\,L_b}$$

where
q''' = Volumetric Heat Generation Rate (Btu/hr-in^3),
Q = decay heat load (Btu/hr) (to convert from kW multiply by 3412.3),
D_i = DSC inner Diameter (in),
L_b = Basket length (in).

The applied decay heat value in the model for the 32PHB DSC with 25.6 kW and 23.04 kW is listed in Table 5-1.

Table 5-1 Decay Heat Load

Heat Load (kW)	Heat Load (Btu/hr)	D_i (in)	L_b (in)	Decay heat Load (Btu/hr-in^3)
25.6	87355	66	158	0.1616
23.04	78619	66	158	0.1454
21.12	72068	66	158	0.1333

For load cases with insolance, the insolance is applied as a heat flux over the TC outer surfaces using average insolence values listed in Table 4-1. The insolance values are multiplied by the surface absorptivity factor to calculate the solar heat flux. The solar heat flux values used in CCNPP-FC TC model are summarized in Table 5-2 of Reference [4].

5.2 32PHB DSC/Basket Analysis

The DSC shell temperature profiles from the transient analysis in Section 5.1 for load case # 6 are used to determine the maximum basket component temperatures including the maximum fuel cladding temperature for 25.6 kW and 23.04 kW heat loads based on the 32PHB DSC/basket model described in Reference [3].

Similarly the DSC shell temperature profiles from steady-state thermal analysis using the CCNPP-FC TC model in Section 5.1 for load cases # SS3, SS5 listed in Table 4-2 are used to determine the maximum basket component temperatures including the maximum fuel cladding temperature for 21.12 kW heat load based on the 32PHB DSC/basket model described in Reference [3].

No changes are considered to the thermal model of the 32PHB DSC and the methodology presented in Reference [3] except for the heat generation values. Decay heat load is applied as heat generation load over the elements representing homogenized fuel assemblies. For the maximum decay heat loads of 25.6 kW, 23.04 kW and 21.12 kW per 32PHB DSC, a uniform heat load of 0.8 kW, 0.72 kW and 0.66 kW per fuel assembly is considered, respectively.

The heat generation rates used in this analysis for the 32PHB DSC/basket model are calculated as follows.

$$\dot{q}''' = \left(\frac{q}{a^2 L_a} \times PF \right) \times CF$$

where
q = Decay heat load per assembly defined for each loading zone,
a = Width of the homogenized fuel assembly = 8.5", see Section 5.1.1 of [3],
L_a =Active fuel length = 136.7", see Section 5.1.1 of [3],
PF = Peaking factor, see Section 5.1.4 of [3],
CF = correction factor = 1.0 assumed for 32PHB basket (see Section 5.1.4 of [3]).

The heat generation rates used in 32PHB DSC model are listed in Table 5-2.

Table 5-2 Heat Generation Rates for 32PHB Basket

Heat Load in the Model (kW)	Heat Generation Rate ($Btu/hr\text{-}in^3$)	
	PF=1.0 (Base)	PF=1.101 (Maximum)
0.8	0.276	0.304
0.72	0.249	0.274
0.66	0.228	0.251

6.0 RESULTS AND DISCUSSION

6.1 Transfer Operations without Forced Convection

6.1.1 Steady-State Transfer Operations without Forced Convection

For steady-state transfer operations listed in Table 4-2, this calculation establishes a maximum heat load of 21.12 kW. Steady-state thermal analyses are performed for off-normal hot transfer conditions (load case # SS3, Table 4-2) and for normal hot vertical operations within the fuel building (load case # SS5, Table 4-2). Since the load cases # SS1, SS2 and SS4 compared to load case # SS3 have lower ambient temperatures and lower solar insolation, the peak temperatures determined for load case # SS3 bound the other load cases.

Table 6-1 summarizes the maximum temperatures for the CCNPP-FC TC components and shows that the maximum component temperatures are below the allowable limits for steady-state transfer operations without time limits.

Figure 6–1and Figure 6–2 present the temperature profiles for the off-normal hot transfer under steady-state conditions for the CCNPP-FC TC and 32PHB DSC at 21.12 kW heat load.

Figure 6–3 and Figure 6–4 present the temperature profiles for the normal hot vertical operations under steady-state conditions for the CCNPP-FC TC and 32PHB DSC at 21.12 kW heat load.

Further, to determine the amount of heat dissipated from the bottom of the cask for steady-state vertical operations (Load Case # SS5), the "PRRSOL, HEAT" command is applied over the nodes with the fixed temperature of 250°F assumed in Section 3.1. The heat dissipated from the bottom of the TC is 1029.5 Btu/hr for half-symmetric 3D model (See Run ID: PP_32PHB_TC_VERT_SS listed in Table 8-1). This amounts to approximately 2.86% (1029.5 Btu/hr*2 / (21.12 kW/3412.3 Btu/hr)) of the total heat load dissipated via the bottom surface with the remaining 97.14% heat load being dissipated from remaining surfaces.

6.1.2 Transient Transfer Operations without Forced Convection

Due to the high decay heat loads considered for the NUHOMS® 32PHB system the transfer operations under normal and off-normal steady state conditions without forced airflow listed in Table 4-1 (load case # 1 to 4) are not permitted and transfer time limits of 48 hours and 72 hours without FC are established in Section 5.0 of [2] for heat loads ≥ 21.12 kW and ≤ 29.6 kW.

This calculation establishes a maximum heat load of 25.6 kW and 23.04 kW per 32 PHB DSC for the transfer time limits of 48 hours and 72 hours, respectively. Transient thermal analyses are performed for off-normal hot transfer conditions (load case # 6, Table 4-1) based on the time limits specified in Section 5.0 of [2] and the heat loads established above. The peak temperatures determined for the time limits established for off-normal hot transient conditions bounds the peak temperatures for normal hot/cold and off-normal hot/cold conditions listed in Table 4-1.

For the off-normal hot transient condition (load case # 6), at time = 0, the cask is assumed to be drained, and the cask closure is completed, TC is assumed to be rotated and moved outdoors. However, for practical purposes, the time limits for transfer operations should be considered after sealing the DSC when the water in the TC/DSC annulus starts to be drained completely.

Transient thermal analyses with the 32PHB DSC in the CCNPP-FC TC are performed for a maximum duration of 48 hours and 72 hours specified in Section 5.0 of [2] with the applicable heat loads described above for the off-normal hot transfer operations (load case # 6) to determine the peak component temperatures.

Table 6-1 summarizes the maximum temperatures for the CCNPP-FC TC components and shows that the maximum component temperatures are below the allowable limits for transfer duration of 48 hours and 72 hours for the off-normal hot transfer operations (load case # 6) with the 32PHB DSC in the CCNPP-FC TC at 25.6 kW and 23.04 kW heat loads, respectively.

Figure 6–5 and Figure 6–6 present the temperature profiles for the off-normal transfer condition at 48 hours for the CCNPP-FC TC and 32PHB DSC at 25.6 kW heat load.

Figure 6–7 and Figure 6–8 present the temperature profiles for the off-normal transfer condition at 72 hours for the CCNPP-FC TC and 32PHB DSC at 23.04 kW heat load.

For the vertical loading transient condition (load cases # 5), the transient begins at steady-state with 212°F water in the TC-DSC annulus and the cask is in vertical orientation. At time t= 0, the water in the cask is assumed to be drained, and the cask closure is completed. The TC is assumed to be left inside the fuel building in the vertical position.

An operational time limit of 20 hours is established for the vertical operations with the 32PHB DSC in CCNPP-FC TC at 29.6 kW heat load based on the thermal analyses results presented in Section 6.0 of [4] for the CCNPP-FC TC and Section 6.0 of [3] for the 32PHB DSC/basket.

Since the only change in this calculation for the vertical operations (load case # 5) is reduction of heat load in the 32PHB DSC to 25.6 kW and 23.04 kW from 29.6 kW analyzed in [3] and [4], the maximum temperatures calculated for the vertical operations with the 32PHB DSC in CCNPP-FC TC at 29.6 kW heat load in Section 6.0 of [4] for the CCNPP-FC TC and Section 6.0 of [3] for the 32PHB DSC/basket, bound the maximum temperatures with the 32PHB DSC in CCNPP-FC TC at 25.6 kW and 23.04 kW heat loads. Therefore this calculation conservatively specifies an operational time limit of 20 hours for the transient vertical operations (load case # 5) with the 32PHB DSC in CCNPP-FC TC at 25.6 kW and 23.04 kW heat loads.

Table 6-1 Maximum Temperatures of CCNPP-FC TC, Without Forced Convection

Heat Load	25.6 kW	23.04 kW	21.12 kW	21.12 kW	21.12 kW 32P DSC	
Time	48 hours	72 hours	∞	∞	∞	
	Off-Normal Hot (Load Case # 6)	Off-Normal Hot (Load Case # 6)	Off-Normal Hot (Load Case # SS3)	Vertical Operations (Load Case # SS5)	Off-Normal Hot [10]	Max. Allowable
Component	[°F]	[°F]	[°F]	[°F]	[°F]	[°F]
Fuel Cladding	728	705	704	705	--	752 [5]
Basket (Guide Sleeve)	709	686	688	690	--	---
Al/Poison Plate	708	686	687	689	--	---
Basket Rails	501	500	519	508	--	---
Top Shield Plug	391	400	426	413	--	---
Bottom Shield Plug	400	407	431	439	--	---
Max. DSC Shell (1)	451	456	480	464	460	---
Inner Shell	356(2)	365(3)	392(4)	362(4)	355	---
Gamma Shield	351	360(3)	387(4)	360(4)	352	620 [9]
Structural Shell	304	313	338	319	349	---
Bulk Avg. Temp of Radial Neutron Shield	242	249	265	247	277	280 [7]
Bulk Avg. Temp of Top Neutron Shield	199	203	214	178	253	280 [7]
Bulk Avg. Temp of Bottom Neutron Shield	219	225	237	262	263	280 [7]
Cask Lid	240	246	263	226	318	---
Cask Outer Shell	262	269	288	263	271	---

(1) The maximum DSC shell temperature is the temperature along the "DSC Shell" as shown in Figure 5-3 of [4] and does not include the top and bottom end plates.

(2) The maximum temperature for the inner shell of the CCNPP-FC TC with 32PHB for 25.6 kW at 48 hours is 1°F greater than the temperature obtained for the TC with 32P DSC. However, the structural analysis is based on a design temperature of 400°F [Appendix 1, Section 3.4.1 of Ref. 11]. Therefore, temperatures used in the structural evaluation are bounding.

(3) The maximum temperatures for the inner shell and gamma shield of the CCNPP-FC TC with 32PHB for 23.04 kW at 72 hours are increased by 10°F and 8°F, respectively compared to the temperatures obtained for the TC with 32P DSC. However, the structural analysis is based on a design temperature of 400°F [Appendix 1, Section 3.4.1 of Ref. 11]. Therefore, temperatures used in the structural evaluation are bounding.

(4) The maximum temperatures for the inner shell and gamma shield of the CCNPP-FC TC with 32PHB for 21.12 kW under steady-state conditions exceed the maximum temperatures determined for the TC with 32P DSC. However, the structural analysis is based on a design temperature of 400°F [Appendix 1, Section 3.4.1 of Ref. 11]. Therefore, temperatures used in the structural evaluation remain bounding.

Table 6-2 shows the average temperatures for the 32PHB DSC shell and basket components (including the hottest cross section).

Table 6-2 Average 32PHB DSC Component Temperatures

	Hottest Section (°F)							Whole DSC (°F)				
Operating Condition	**R0** (1)	**R45** (1)	**R90** (1)	**R135** (1)	**R180** (1)	**Basket Comp.**	**Shell**	**Basket Comp.**	**Rail**	**Shell**	**Helium**	**Fuel**
Off-Normal Hot (Load Case # 6) 25.6 kW at 48 hrs	484	495	472	466	430	588	428	549	478	413	535	578
Off-Normal Hot (Load Case # 6) 23.04 kW at 72 hrs	485	494	473	467	433	577	434	541	478	419	529	568
Off-Normal Hot (Load Case # SS3) 21.12 kW Steady-State	505	513	494	487	455	588	459	554	498	443	482	579
Vertical Operations (Load Case # SS5) 21.12 kW Steady-State	491	502	491	503	492	592	463	559	488	448	487	583

Note 1: See Figure 6-1 of Reference [3] for a location of the rail components.

6.2 Transfer Operations with Forced Convection

The CCNPP-FC TC loaded with 32PHB DSC at 25.6 kW and 23.04 kW heat loads utilizes FC as a possible recovery mode to improve the thermal performance of the system if the transfer operations exceed the operational time limits of 48 hrs at 25.6 kW and 72 hrs at 23.04 kW, specified in Section 5.0 of [2]. There are no time limits associated with the transfer operations (load cases # 7 to 10) once the FC is initialized and steady-state operations are allowed.

The CCNPP-FC TC with 32PHB DSC at 29.6 kW heat load with FC is analyzed in [8] for steady-state off-normal conditions. It shows that the maximum component temperatures for the TC and the 32PHB DSC/basket including the fuel cladding remain below the allowable temperature limits specified in Section 4.4 with FC.

The only change in this calculation for the transfer operations (load cases # 7 to 10) with FC is the reduction of heat load in the 32PHB DSC to 25.6 kW and 23.04 kW from 29.6 kW analyzed in [8]. Due to the reduction in heat load, the peak component temperatures of the TC and 32PHB DSC at 25.6 kW or 23.04 kW heat loads with FC under steady state conditions will be lower than those calculated for the TC and 32PHB DSC at 29.6 kW heat load under steady state conditions.

Therefore, no further analysis is required for the CCNPP-FC TC and 32PHB DSC at 25.6 kW and 23.04 kW heat loads with FC.

An operational time limit of 8 hours is also established in [8] for the loss of forced air circulation condition to complete the transfer to the HSM-HB or re-establish the FC with the 32PHB DSC in CCNPP-FC TC at 296 kW heat load based on the transient thermal analyses results presented in Section 6.0 of [8].

As discussed above, the maximum temperatures calculated for with the 32PHB DSC in CCNPP-FC TC at 29.6 kW heat load with FC under steady-state conditions (Section 6.0 of [8]) bound the maximum temperatures with the 32PHB DSC in CCNPP-FC TC at 25.6 kW or 23.04 kW heat loads. This results in lower initial temperatures at the start of the transient analysis for the loss of forced airflow condition with 32PHB DSC at < 29.6 kW heat load. Further, lower total decay heat load decreases the heatup rate of the system, which results in a longer time limit to re-establish the FC.

However, for the loss of forced air circulation condition (load case # 11) this calculation conservatively specifies an operational time limit of 8 hours to complete the transfer to the HSM-HB or re-establish the FC with the 32PHB DSC in CCNPP-FC TC at 25.6 kW or 23.04 kW heat load.

6.3 Fire Accident Condition

The fire accident condition for the CCNPP-FC TC with 32PHB at 29.6 kW heat load is analyzed based on the methodology presented in Section 5.2 of [4]. Table 7-2 of [4] summarizes the maximum temperatures for the TC components and the DSC shell when subjected to the fire accident conditions along with the time at which they occur.

Based on the results presented in Table 7-2 of [4], the maximum temperatures for the DSC shell, Inner Liner, Gamma Shield and Structural Shell occur during the post-fire steady state conditions with damaged neutron shield. Since the temperatures under steady-state conditions are directly dependent on the heat load under the same external conditions, for the CCNPP-FC TC with 32PHB DSC at 25.6 kW or 23.04 kW or 21.12 kW heat load, the maximum temperatures under steady-state conditions will be lower than those listed in Table 7-2 of [4] for 29.6 kW heat load.

Therefore for the fire accident condition, the DSC shell, Inner Liner, Gamma Shield and Structural Shell the maximum temperatures listed in Table 7-2 of [4] bound the temperatures for the CCNPP-FC TC with 32PHB DSC at 25.6 kW or 23.04 kW heat load.

The temperatures of the 32PHB DSC/Basket components including the fuel cladding are dependent on the maximum decay heat load and the DSC shell temperature profile. Since, the maximum decay heat load is less than 29.6 kW and the lower DSC shell temperature, the maximum fuel cladding and basket component temperatures determined in [3] for the fire accident conditions remain bounding for the 32PHB DSC with 25.6 kW or 23.04 kW or 21.12 kW heat load.

For the cask outer shell, cask lid, and NS-3 in the cask (top neutron shield, bottom neutron shield and radial neutron shield), the maximum temperatures (maximum bulk average for NS-3 materials) are obtained at the end of 15 minute fire.

The maximum temperature at the end of the 15 minute fire is based on the initial conditions and the heat up rate of the system. The fire accident condition in [4] assumes the initial conditions from the off-normal hot transient condition at 20 hours (See load case # 6 of [4]), whereas the fire accident analysis for CCNPP-FC TC with 32PHB at 25.6 kW, 23.04 kW and 21.12 kW heat loads assumes the initial conditions from the off-normal hot transient condition at 48 hours, 72 hours and steady-state conditions, respectively.

Table 6-3 presents a comparison of the initial conditions used for fire accident analysis of the CCNPP-FC TC with 32PHB DSC at various heat loads for the cask outer shell, cask lid, and NS-3 components in the cask. As seen from the table, the maximum difference between the initial conditions is a 55°F increase in initial temperature for the TC cask outer shell with the 32PHB DSC at 21.12 kW heat load under steady-state conditions.

Table 6-3 Initial Conditions for Fire Accident

Heat Load	25.6 kW @ t = 48 hrs	23.04 kW @ t = 72 hrs	21.12 kW @ t = ∞ hrs	29.6 kW @ t = 20 hrs	$\Delta T_{max} = T_{max}(T_{25.6}, T_{23.04}, T_{21.12}) - T_{29.6}$
Component	[°F]	[°F]	[°F]	[°F]	[°F]
Bulk Avg. Temp of Radial Neutron Shield	242	249	265	214 [4]	51
Bulk Avg. Temp of Top Neutron Shield	199	203	214	186 [4]	28
Bulk Avg. Temp of Bottom Neutron Shield	219	225	237	201 [4]	36
Cask Lid	240	246	263	216 [4]	47
Cask Outer Shell	262	269	288	233 [4]	55

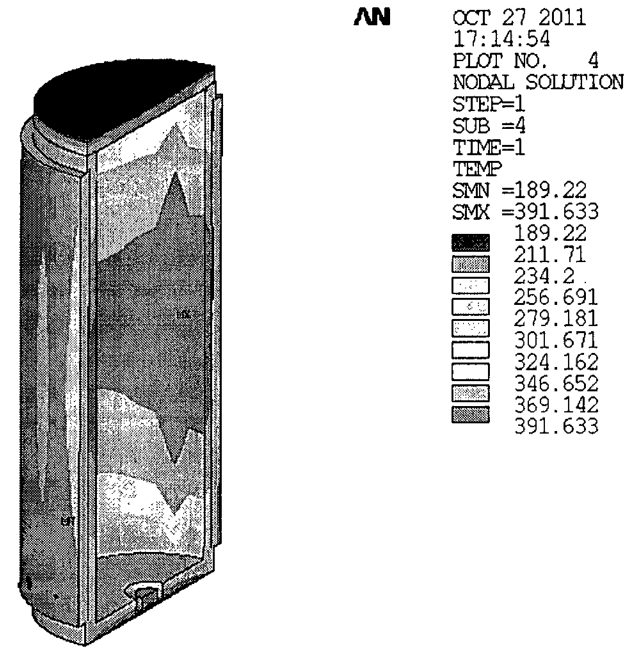
The heatup rate of a system is directly proportional to the total decay heat load. Since the heat capacity of the system ($m.C_p$) is same for the CCNPP-FC TC with 32PHB DSC for all heat loads, the heatup rate of the system decreases with lower heat loads.

However, to bound the maximum temperatures of the cask outer shell, cask lid, and NS-3 in the cask at the end of the fire accident condition for the CCNPP-FC TC with 32PHB at 25.6 kW or 23.04 kW or 21.12 kW heat load, the maximum initial temperature difference of 55°F is conservatively added to the maximum temperature at the end of fire determined in [4] conservatively assuming that the heatup rate for system with lower heat loads of 25.6 kW, 23.04 kW and 21.12 kW is the same as that for 29.6 kW. Table 6-4 summarizes the maximum temperatures for the TC components and the DSC shell when subjected to the fire accident conditions along with the time at which they occur.

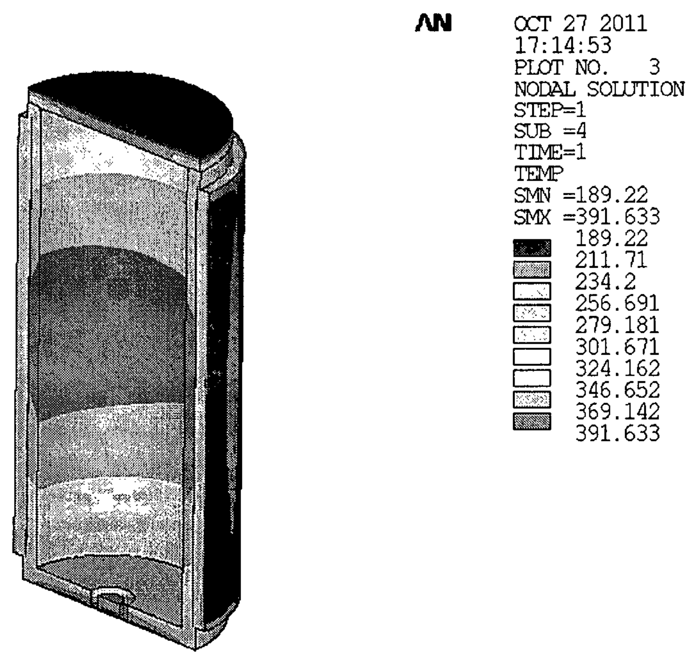
Table 6-4 Maximum Temperatures of CCNPP-FC TC for Fire Accident Conditions

Components	Time	Maximum Temperature [°F]	Max. Allowable [°F]
Fuel Cladding	∞	< 932 [3]	1058 [5]
Basket (Guide Sleeve)	∞	< 919 [3]	---
Al/Poison Plate	∞	< 919 [3]	---
Basket Rails	∞	< 705 [3]	---
Top Shield Plug	∞	< 560 [3]	---
Bottom Shield Plug	∞	< 570 [3]	---
Max. DSC Shell	∞	< 656 [4]	---
Inner Shell	∞	< 590 [4]	---
Gamma Shield	∞	< 585 [4]	620 [9]
Structural Shell	∞	< 568 [4]	---
Bulk Avg. Temp of Radial Neutron Shield	End of Fire	597(1)	1300 [6]
Bulk Avg. Temp of Top Neutron Shield	End of Fire	695(1)	1300 [6]
Bulk Avg. Temp of Bottom Neutron Shield	End of Fire	496(1)	1300 [6]
Cask Lid	End of Fire	965(1)	---
Cask Outer Shell	End of Fire	1376(1)	---

(1) The maximum temperature = Temperature from Table 7-2 of [4] + ΔT_{max} (= 55°F, See Table 6-3)

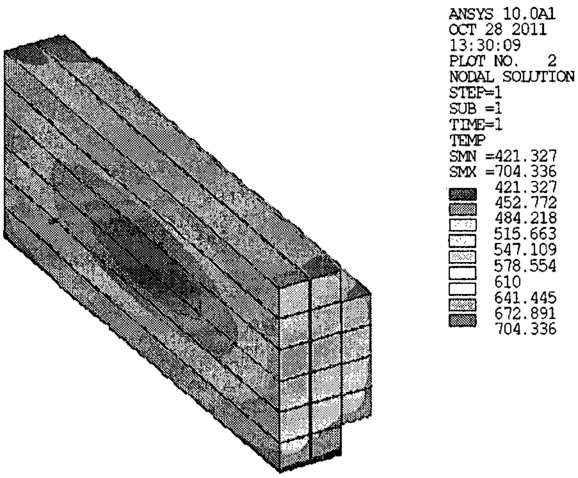


CCNPP-FC-TC with 32PHB, 21.12 kW - Off-Normal Transfer Steady-State Runs

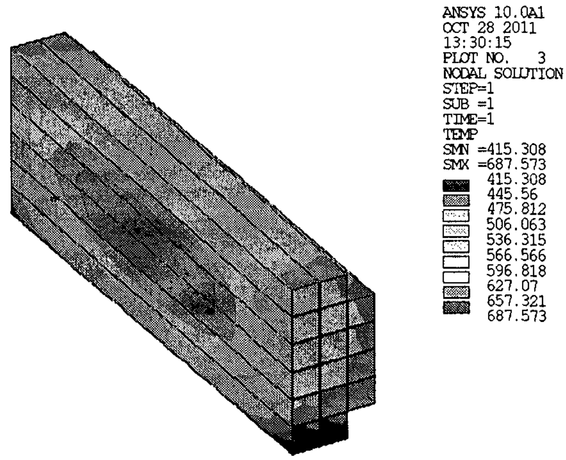


CCNPP-FC-TC with 32PHB, 21.12 kW - Off-Normal Transfer Steady-State Runs

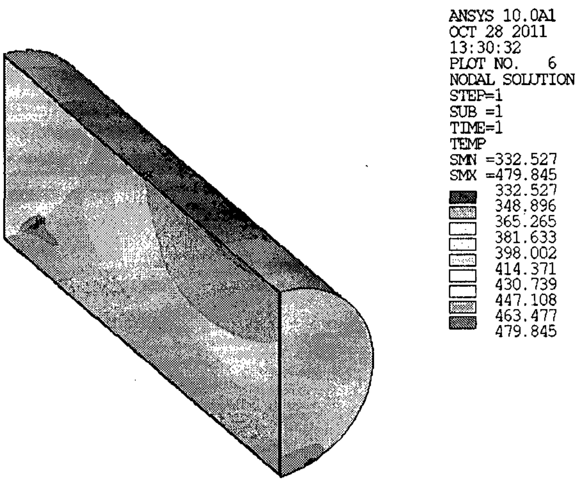
Figure 6–1 TC Temperature Distribution – Off-Normal Hot Steady-State, @ 21.12 kW, 127 Btu/hr-ft² Insolation, 104°F Ambient (Load Case # SS3)



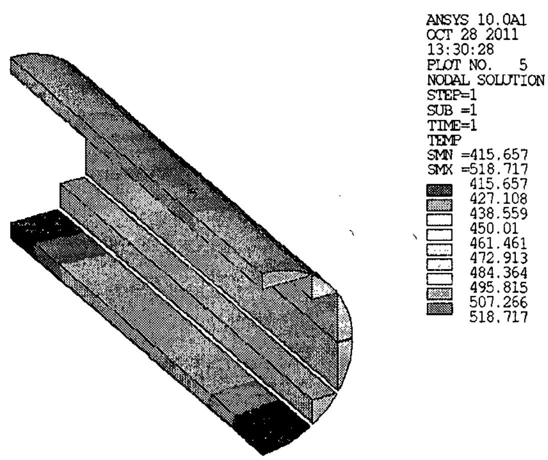
Fuel Cladding



Guide Sleeve

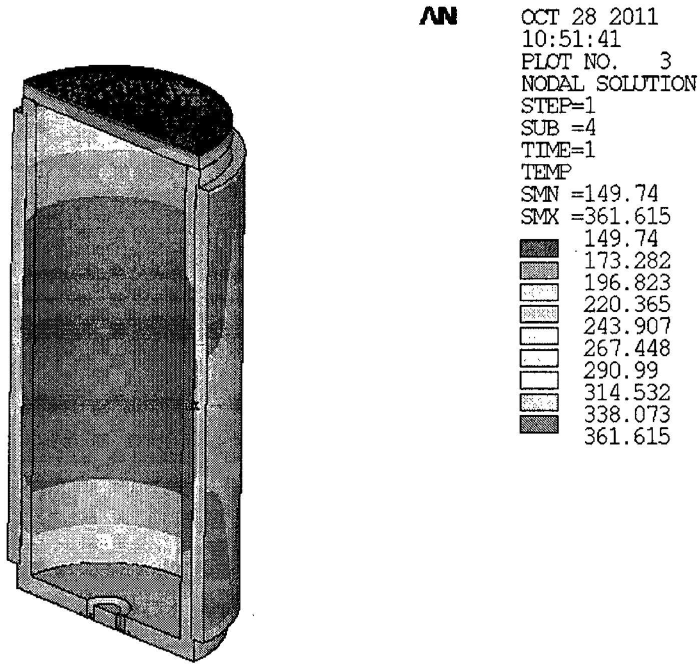


DSC Shell

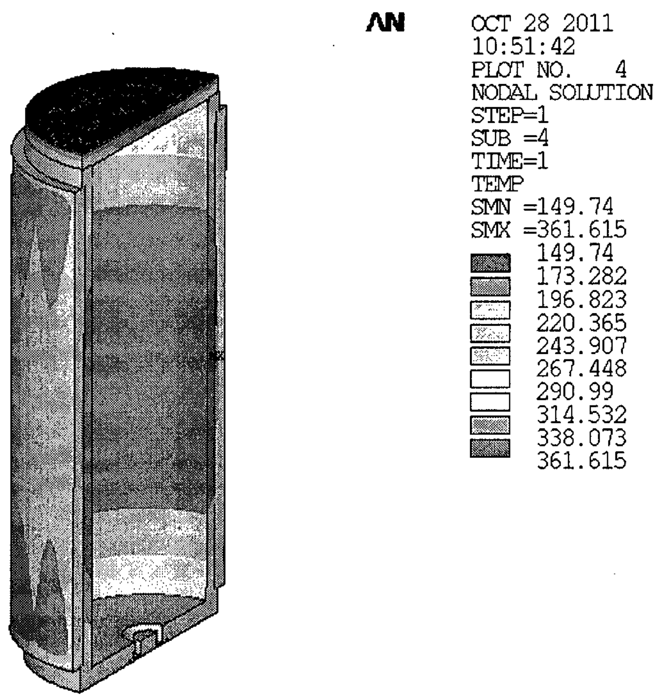


Basket Rail

Figure 6–2 32PHB DSC Temperature Distribution – Off-Normal Hot Steady-State, @ 21.12 kW, 127 Btu/hr-ft^2 Insolation, 104°F Ambient (Load Case # SS3)

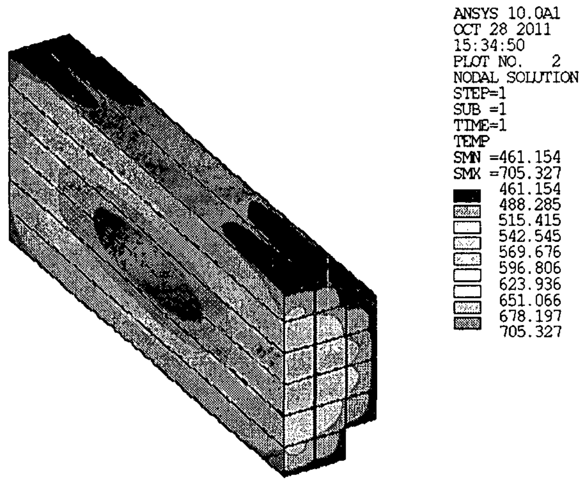


CCNPP-FC-TC with 32PHB, 21.12kW - Vertical in Fuel Bldg SS

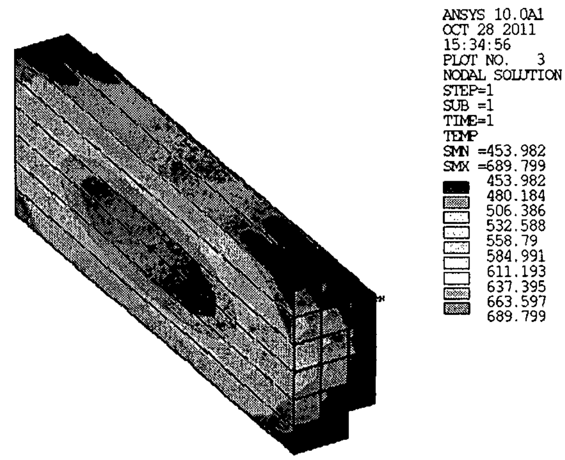


CCNPP-FC-TC with 32PHB, 21.12kW - Vertical in Fuel Bldg SS

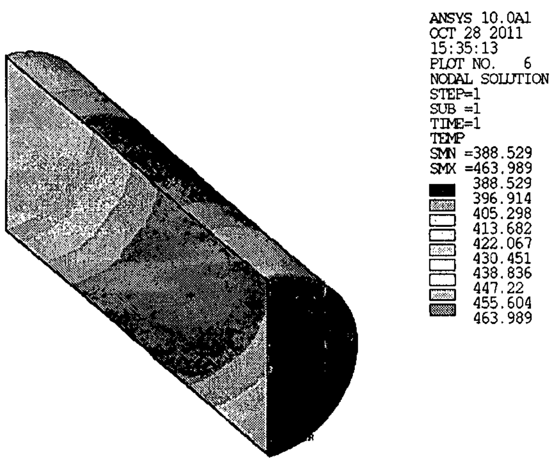
Figure 6–3 TC Temperature Distribution – Vertical Operations Steady-State, @ 21.12 kW, 100°F Ambient (Load Case # SS5)



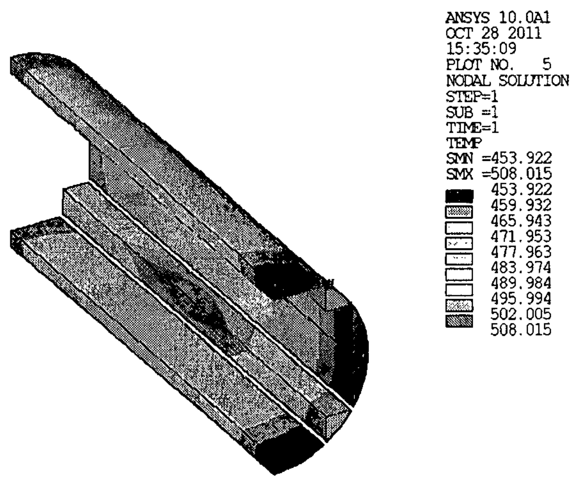
Fuel Cladding



Guide Sleeve

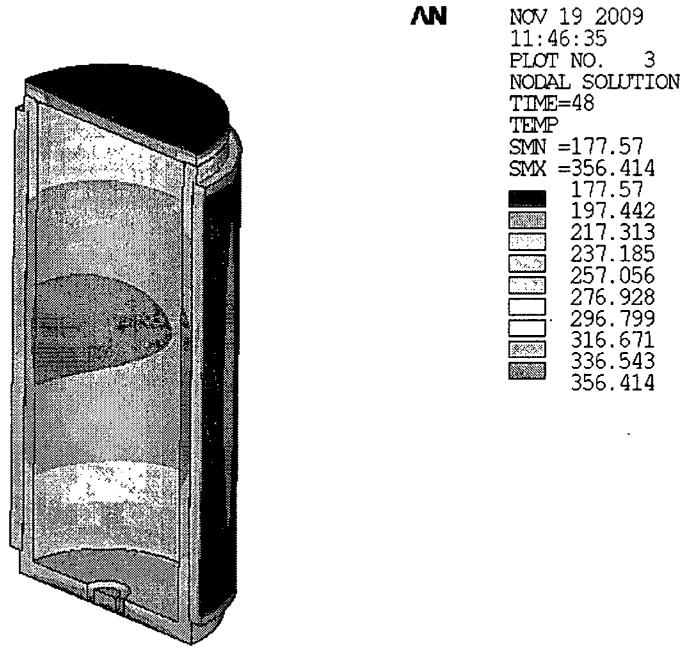


DSC Shell

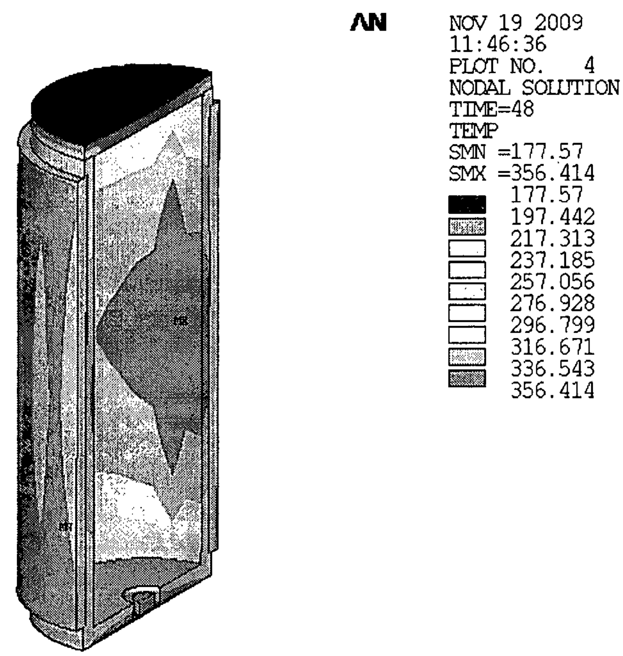


Basket Rail

Figure 6–4 32PHB DSC Temperature Distribution – Vertical Operations Steady-State, @ 21.12 kW, 100°F Ambient (Load Case # SS5)

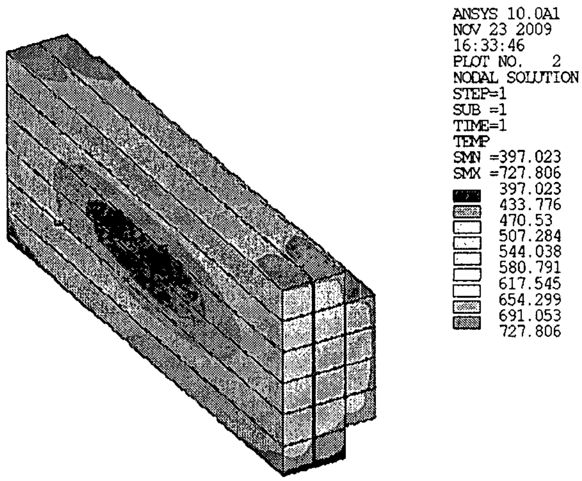


CCNPP-FC-TC with 32PHB, 25.6 kW - Off-Normal Transfer Transient Runs

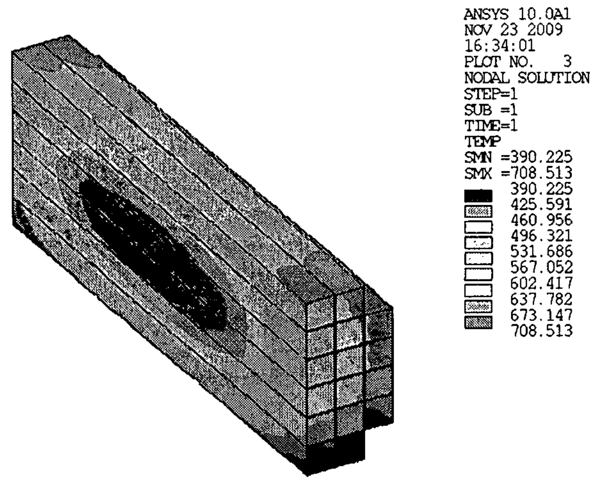


CCNPP-FC-TC with 32PHB, 25.6 kW - Off-Normal Transfer Transient Runs

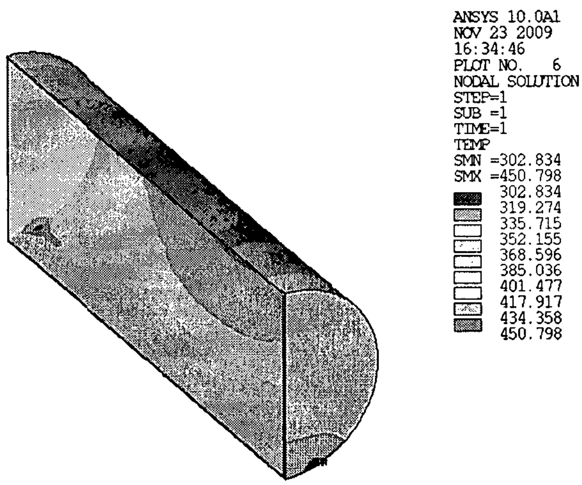
Figure 6–5 TC Temperature Distribution – Off-Normal Hot Transient, t=48 hr, @ 25.6 kW, 127 Btu/hr-ft^2 Insolation, 104°F Ambient (Load Case # 6)



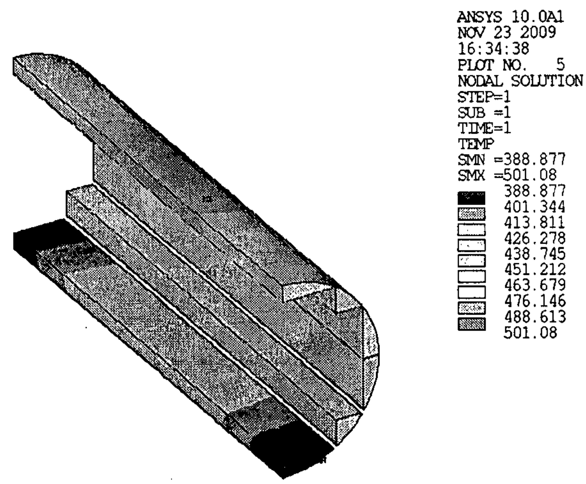
Fuel Cladding



Guide Sleeve

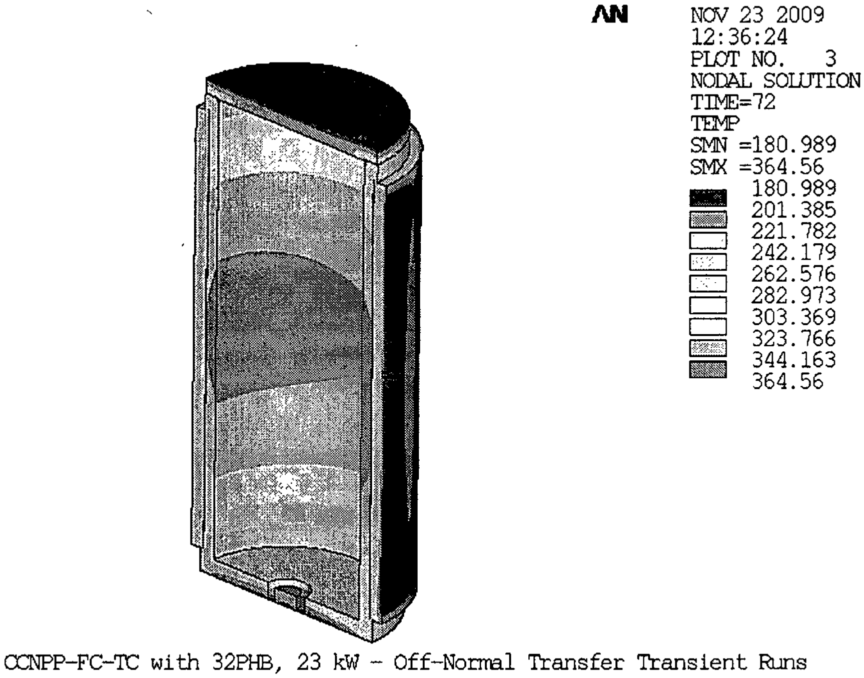


DSC Shell



Basket Rail

Figure 6–6 32PHB DSC Temperature Distribution – Off-Normal Hot Transient, t=48 hr, @ 25.6 kW, 127 Btu/hr-ft^2 Insolation, 104°F Ambient (Load Case # 6)



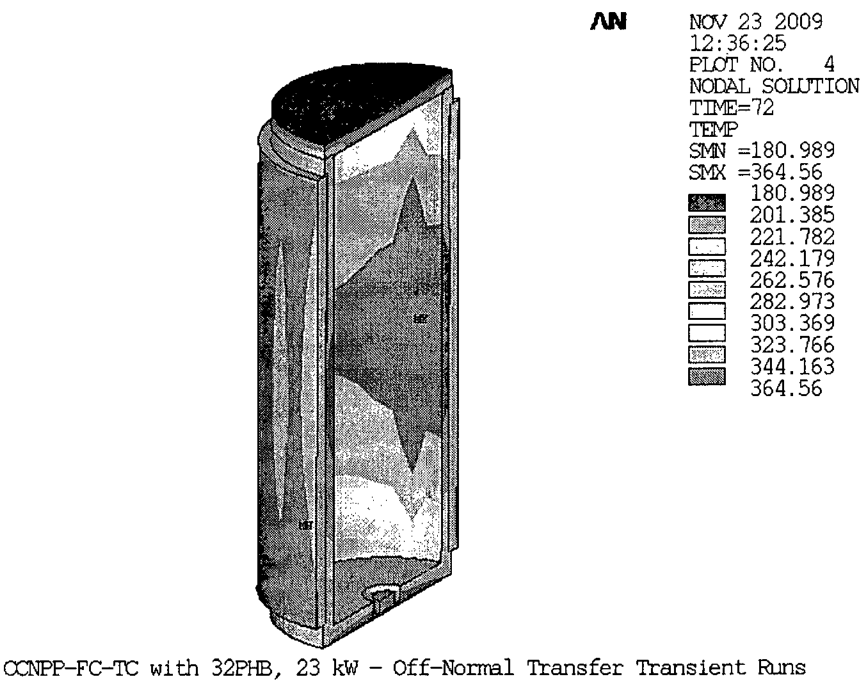
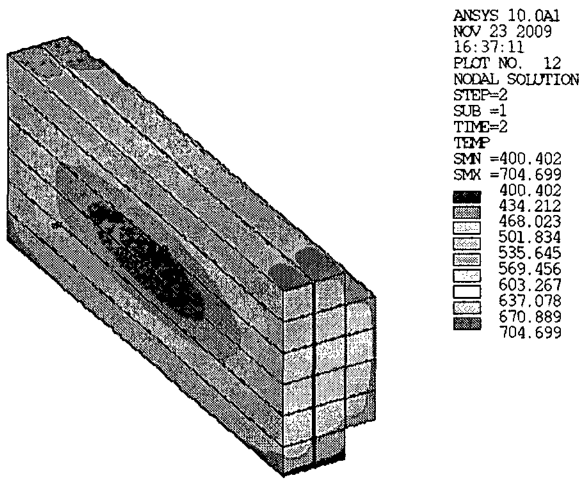
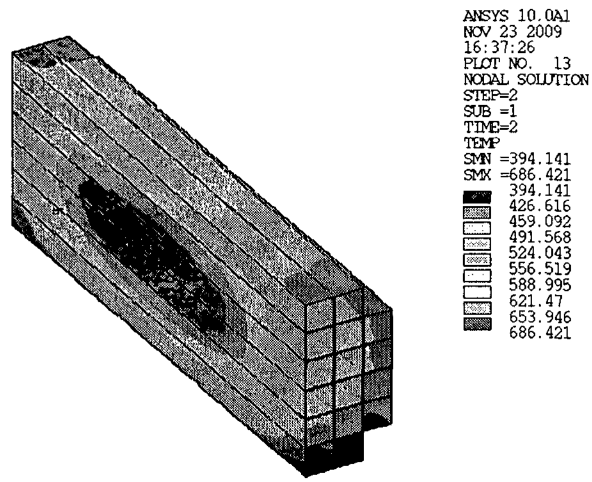


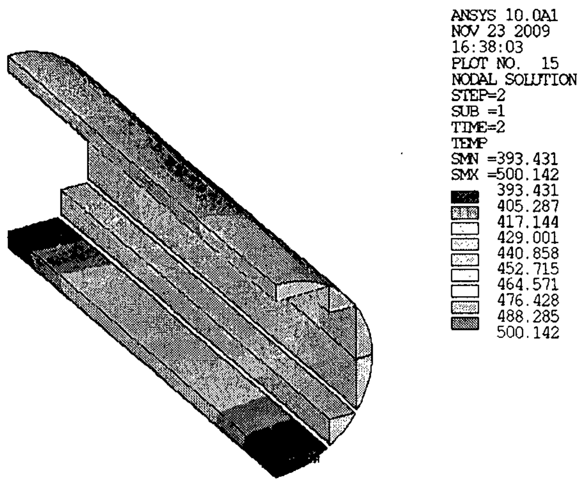
Figure 6–7 32PHB DSC Temperature Distribution – Off-Normal Hot Transient, t=72 hr, @ 23.04 kW, 127 Btu/hr-ft^2 Insolation, 104°F Ambient (Load Case # 6)



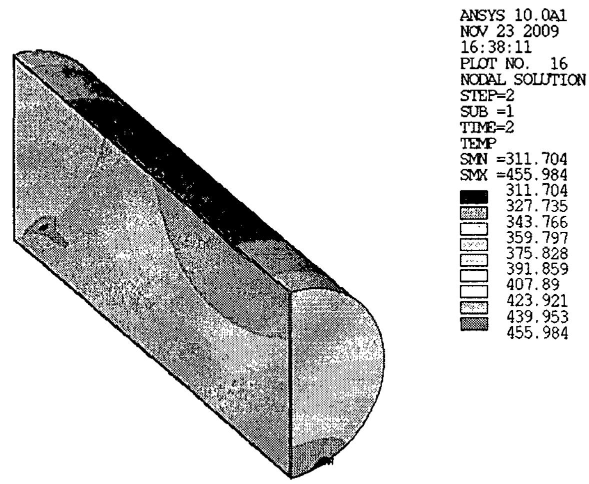
Fuel Cladding



Guide Sleeve



DSC Shell



Basket Rail

Figure 6–8 32PHB DSC Temperature Distribution – Off-Normal Hot Transient, t=72 hr, @ 23.04 kW, 127 Btu/hr-ft^2 Insolation, 104°F Ambient (Load Case # 6)

7.0 CONCLUSION

Based on the analyses presented in Section 5.0 and 6.1, steady-state transfer operations are permitted for CCNPP-FC TC with 32PHB DSC at 21.12 kW heat load.

Similarly, based on the analyses presented in Section 5.0 and 6.1 the maximum duration for the on-site transfer operations of the CCNPP-FC TC with 32PHB DSC at 25.6 kW is 48 hours and for 23.04 kW is 72 hours. Further a time limit of 20 hours is also established as the maximum duration that the TC can be left in the fuel building in a vertical orientation once the water in the DSC/TC annulus is drained. If the transfer operations exceeds or are expected to exceed the above time limits, corrective actions such as forced air circulation or refilling of the TC/DSC annulus with clean demineralized water should be initiated.

Table 7-1 summarizes the maximum temperatures of the TC components and the 32PHB DSC for the off-normal hot transfer condition and steady-state vertical operations without forced convection.

Table 7-1 Maximum Temperatures of CCNPP-FC TC, Without Forced Convection

Heat Load	25.6 kW	23.04 kW	21.12 kW	21.12 kW	
Time	48 hours	72 hours	∞	∞	
	Off-Normal Hot (Load Case # 6)	Off-Normal Hot (Load Case # 6)	Off-Normal Hot (Load Case # SS3)	Vertical Operations (Load Case # SS5)	Max. Allowable
Component	[°F]	[°F]	[°F]	[°F]	[°F]
Fuel Cladding	728	705	704	705	752 [5]
Basket (Guide Sleeve)	709	686	688	690	---
Al/Poison Plate	708	686	687	689	---
Basket Rails	501	500	519	508	---
Top Shield Plug	391	400	426	413	---
Bottom Shield Plug	400	407	431	439	---
Max. DSC Shell (1)	451	456	480	464	---
Inner Shell	356	365	392	362	---
Gamma Shield	351	360	387	360	620 [9]
Structural Shell	304	313	338	319	---
Bulk Avg. Temp of Radial Neutron Shield	242	249	265	247	280 [7]
Bulk Avg. Temp of Top Neutron Shield	199	203	214	178	280 [7]
Bulk Avg. Temp of Bottom Neutron Shield	219	225	237	262	280 [7]
Cask Lid	240	246	263	226	---
Cask Outer Shell	262	269	288	263	---

(1) The maximum DSC shell temperature is the temperature along the "DSC Shell" as shown in Figure 5-3 of [4] and does not include the top and bottom end plates.

Also based on the discussion presented in Section 6.2, the maximum temperatures for the CCNPP-FC TC with 32PHB at 25.6 kW or 23.04 kW heat loads with FC are bounded by the temperatures listed in Table 7-1 of [8]. Also in the event of loss of forced air flow a maximum duration of 8 hours is available to complete the transfer to the HSM-HB or re-establish the fan airflow.

Table 7-2 summarizes the maximum temperatures for the TC components and the 32PHB DSC components when subjected to the fire accident conditions along with the time at which they occur.

Table 7-2 Maximum Temperatures of CCNPP-FC TC for Fire Accident Conditions

Components	Time	Maximum Temperature [°F]	Max. Allowable [°F]
Fuel Cladding	∞	< 932 [3]	1058 [5]
Basket (Guide Sleeve)	∞	< 919 [3]	---
Al/Poison Plate	∞	< 919 [3]	---
Basket Rails	∞	< 705 [3]	---
Top Shield Plug	∞	< 560 [3]	---
Bottom Shield Plug	∞	< 570 [3]	---
Max. DSC Shell	∞	< 656 [4]	---
Inner Shell	∞	< 590 [4]	---
Gamma Shield	∞	< 585 [4]	620 [9]
Structural Shell	∞	< 568 [4]	
Bulk Avg. Temp of Radial Neutron Shield	End of Fire	597(1)	1300 [6]
Bulk Avg. Temp of Top Neutron Shield	End of Fire	695(1)	1300 [6]
Bulk Avg. Temp of Bottom Neutron Shield	End of Fire	496(1)	1300 [6]
Cask Lid	End of Fire	965(1)	---
Cask Outer Shell	End of Fire	1376(1)	---

(1) The maximum temperature = Temperature from Table 7-2 of [4] + ΔT_{max} (= 55°F, See Table 6-3)

As seen in the above table, all design criteria specified in Section 4.4 are herein satisfied.

8.0 LISTING OF COMPUTER FILES

All the runs are performed using ANSYS version 10.0 [1] with operating system "Linux RedHat ES 5.1", and CPU "Opteron 275 DC 2.2 GHz" / "Xeon 5160 DC 3.0 GHz".

A summary of ANSYS runs is shown in Table 8-1.

Table 8-1 Summary of ANSYS Runs

Run Name	Description	Date / Time for Output File
32PHB_TC_Initial_26kW	Initial Conditions for 25.6 kW Load Case	11/19/2009 11:27 AM
32PHB_TC_OFN_TRANS_26kW	Off-Normal Hot Transient for 25.6 kW Load Case	11/19/2009 11:46 AM
32PHB_TC_OFN_TRANS_48hr_26kW_Map	Off-Normal Hot Transient for 25.6 kW Load Case Map for DSC shell Temperature Profile	11/19/2009 12:08 PM
32PHB_TC_Initial_23kW	Initial Conditions for 23.04 kW Load Case	11/23/2009 12:03 PM
32PHB_TC_OFN_TRANS_23kW	Off-Normal Hot Transient for 23.04 kW Load Case	11/23/2009 12:36 PM
32PHB_TC_OFN_TRANS_72hr_23kW_Map	Off-Normal Hot Transient for 23.04 kW Load Case Map for DSC shell Temperature Profile	11/23/2009 01:45 PM
32PHB_TC5M	Load 1: 32PHB DSC Basket for Off-Normal Hot Transfer without Forced Convection @ 25.6 kW Load 2: 32PHB DSC Basket for Off-Normal Hot Transfer without Forced Convection @ 23.04 kW	11/23/2009 4:39 PM
CCNPP-FC-TC-Fine	Run for creating a Fine mesh model of CCNPP-FC TC	12/02/2009 02:52 PM
Run_Coarse	Coarse Mesh Run for Sensitivity Analysis of CCNPP-FC TC Slice Model	12/02/2009 03:44 PM
Run_Fine	Fine Mesh Run for Sensitivity Analysis of CCNPP-FC TC Slice Model	12/02/2009 03:38 PM
32PHB_TC_VERT_SS	Vertical Operations, Steady-State for 21.12 kW	10/28/2011 10:51 AM
32PHB_TC_VERT_SS_Map	Vertical Operations, Steady-State for 21.12 kW, Map for DSC Shell Temperature Profile	10/28/2011 12:22 PM
32PHB_DSC_VERT_SS	32PHB DSC Basket for Vertical Operations Steady-State@ 21.12 kW	10/28/2011 03:35 PM
32PHB_TC_OFN_SS_21kW	Off-Normal Hot Steady-State for 21.12 kW	10/27/2011 05:14 PM
32PHB_TC_OFN_SS_21kW_Map	Off-Normal Hot Steady-State for 21.12 kW, Map for DSC Shell Temperature Profile	10/28/2011 12:16 PM
32PHB_DSC_OFN_SS_21kW	32PHB DSC Basket for Off-Normal Hot Transfer, Steady-State@ 21.12 kW	10/28/2011 01:30 PM
PP_32PHB_TC_VERT_SS	Post-processing to determine the heat loss from the bottom of TC for Load Case # SS5	11/14/11 11:55 PM

ANSYS macros, and associated files used in this calculation are shown in Table 8-2.

Table 8-2 Associated Files and Macros

File Name	Description	Date / Time
HTOT_HCL.MAC [4]	Total heat transfer coefficients for horizontal cylindrical surface	2/19/2009 12:37 PM
HTOT_VPL.MAC [4]	Total heat transfer coefficients for vertical flat surface	2/19/2009 12:37 PM
32PHBTC_Mat.inp [4]	Material properties for CCNPP-FC Cask	10/21/2009 6:07 PM
32PHB_TC_RAD_Horizontal.inp [4]	Macro for Creating Radiation Exchange between the DSC/TC when the TC is in Horizontal Orientation	10/21/2009 4:46 PM
32PHB_TC_RAD_Horizontal1.inp	Macro for Creating Radiation Exchange between the DSC/TC when the TC is in Horizontal Orientation for Mesh Sensitivity Runs	12/02/2009 3:33 PM
32PHB_Mat1.inp [3]	Material properties for 32PHB DSC with Helium	09/09/09 09:54 AM
32PHB_HLZC3.MAC	Heat generation for 32PHB DSC, 25.6 kW	11/19/09 01:48 PM
32PHB_HLZC4.MAC	Heat generation for 32PHB DSC, 23.04 kW	11/23/09 12:09 PM
Macro [3]	Macro to get Maximum/Minimum temperatures	05/20/05 12:03 PM
Results.mac [3]	Macro to list maximum and average 32PHB DSC component temperatures	07/22/09 11:52 AM
CCNPP-FC-TC.db [4]	ANSYS thermal model for CCNPP-FC TC	08/28/09 2:41 PM
32PHB_Model.db [3]	ANSYS thermal model for 32PHB DSC	07/10/09 7:49 PM
32PHB_TC_PP_23kW.inp	Macros for Post-Processing Transient Runs	11/19/2009 12:17 PM
32PHB_TC_PP_26kW.inp		11/19/2009 11:22 AM

APPENDIX A MESH SENSITIVITY

A slice of the CCNPP-FC TC model containing the 32PHB DSC homogenized basket and shell is recreated for mesh sensitivity analysis ("Run_Coarse" run listed in Table 8-1). The length of the CCNPP-FC TC slice model is 24.185" and includes the DSC shell and TC shells. The mesh density of this model is the same as the mesh density of the geometry model "CCNPP-FC-TC.db" listed in from z=44.885" to z=69.070". The slice model contains 8904 solid elements and 10,640 nodes. The number of nodes and elements in the slice model are identical to the model "CCNPP-FC-TC.db" from z=44.885" to z=69.070".

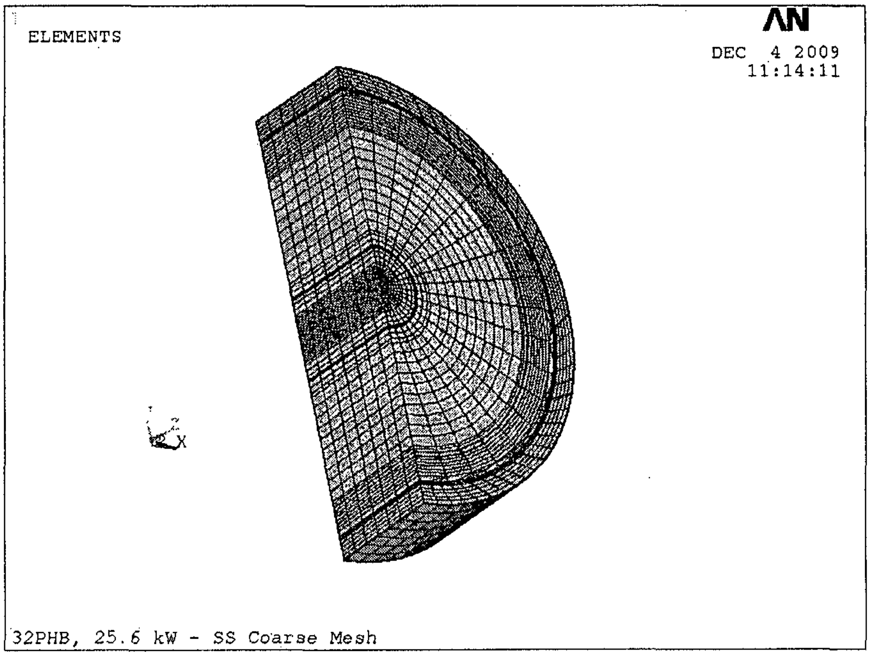
For the purpose of mesh sensitivity analysis, the mesh density of the slice model is increased to approximately four times of its original value so that the number of elements and nodes are increased to 36092 solid elements and 39075 nodes, respectively ("Run_Fine" run listed in Table 8-1). Figure A–1 shows the coarse and fine meshes used for the mesh sensitivity analysis.

Steady-state analysis is performed with ambient temperature of 104°F, off-normal insolation and a decay heat load of 25.6 kW are considered as boundary conditions for both the CCNPP-FC TC slice models with coarse and fine meshes. Steady-state operations are not permitted for the CCNPP-FC TC with 32PHB DSC; however this analysis is performed only to illustrate the mesh independency of the thermal model. The boundary conditions are applied using the same methodology as described in Section 5.1. The maximum temperatures are retrieved from these models and listed in Table A-1 for comparison.

As seen in Table A-1, the DSC shell temperature increases by 2°F with the fine mesh model. For the TC, the inner shell increases by 3.2°F with the fine mesh model. These temperature differences between the fine and coarse mesh model for the DSC shell and inner shell are less than 1%. Therefore, the thermal analysis results based on the coarse mesh of the CCNPP-FC TC model are adequate to evaluate the thermal performance.

Table A-1 Maximum Temperatures for Coarse and Fine Model of CCNPP-FC TC

Mesh Density	Coarse	Fine	
Component	T_{max} (°F)	T_{max} (°F)	Difference ($T_{Fine} - T_{Coarse}$) (°F)
32PHB DSC shell	616.6	618.6	+2.0
Inner shell	525.5	528.7	+3.2
Gamma shield	519.3	519.5	+0.2
Structural Shell	452.2	452.5	+0.3
Bulk Avg. Temp of Radial Neutron Shield	354.0	354.8	+0.8
Cask Outer Shell	306.3	305.3	-1.0



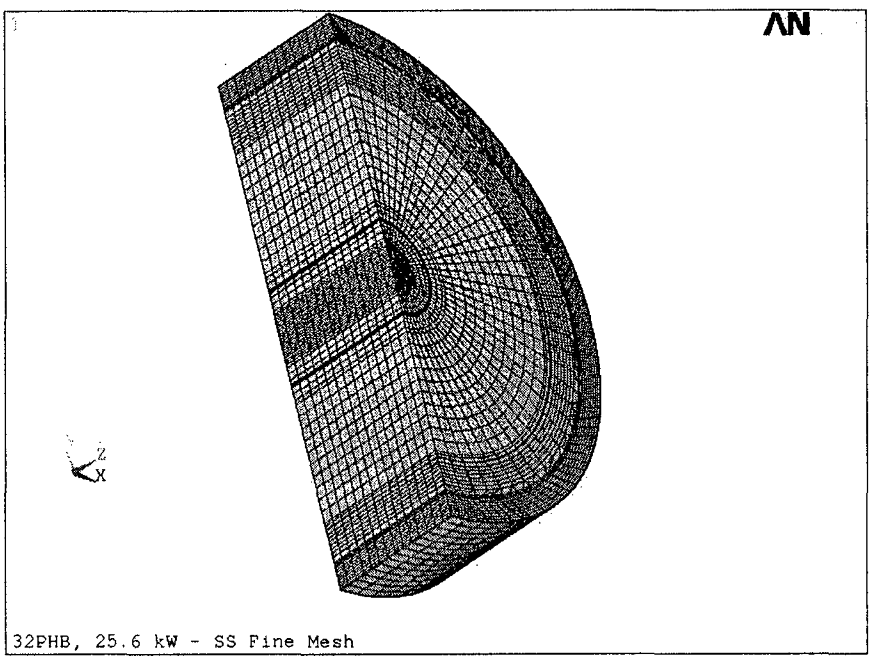


Figure A–1 Coarse Mesh and Fine Mesh