TN Calculation 1121-0401, Revision 1,

OS197L 75 Ton Transfer Cask Thermal Analysis to be used with OPPD Exemption Request (18.4 kW/DSC & 11.0 kW/DSC

TRANSNUCLEAR AN AREVA COMPANY	Form 3.2-1 Calculation Cover Sheet	Calculation No.: 1121-0401
		Revision No.: 1

CALCULATION TITLE:

OS197L 75 Ton Transfer Cask Thermal Analysis to be Used with OPPD Exemption Request (18.4 kW/DSC & *11.0 kW/DSC*)

Project No.: 1121

DCR No.: 1121-010

PROJECT NAME:

Fort Calhoun Station Spent Fuel Storage Project

Number of CDs attached:

2 CD*s*

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

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

This calculation determines maximum fuel cladding temperature within the OS197L TC in support of an exemption request by OPPD to be submitted to the NRC. OPPD is planning to load the NUHOMS® 32PT DSC using the OS197L Transfer Cask. These calculations are NOT the design basis for the NUHOMS® 32PT System Configurations. Therefore, a 72.48 licensing review per TIP 3.5 is not required.

Software Utilized:	Version:
ANSYS	8.1

Calculation is complete: Originator Signature: **Davy Qi**	Date: 06/05/06
Calculation has been checked for consistency, completeness and correctness: Checker Signature: **Slava Guzeyev**	Date: 6/05/06
Calculation is approved for use: Project Engineer Signature: **James Axline**	Date: 6/06/06

REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISCS
0	6/1/06	Initial issue – *Calculation of maximum fuel clad temperatures for 18.4 kW heat load per DSC*	All	All
1	6/6/06	To incorporate Appendix A, which calculates maximum fuel cladding temperature within the OS197L TC based on OPPD candidate fuel assemblies with maximum 11 kW heat load per DSC. This revision also uses the fuel properties of the OPPD fuel assembly (CE 14x14 FC). Minor editorial corrections are incorporated.	1-6, 9, 13, 16-25	2

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 PURPOSE

The purpose of the calculation is determine 32PT DSC basket components and fuel cladding temperatures within the OS197L (75 ton) cask with 18.4 kW/DSC *and 11.0 kW/DSC* total heat load for off-normal transfer condition. This is the controlling case (lowest margin to fuel cladding temperature limit) during fuel load and transfer operation. *The body of the calculation addresses the 18.4 kW heat load case and Appendix A addresses the 11.0 kW condition.*

2.0 ASSUMPTIONS/*CONSERVATISMS*

The assumptions and conservatism described in NUHOMS® 32PT DSC thermal evaluation [1] are applied in this calculation.

3.0 DESIGN INPUT – *18.4 KW*

The material properties listed in [1] are used in the analysis.

1) The fuel assembly used in [1] is used as the limiting assembly type in this calculation based on the determination of limiting fuel effective conductivity among the fuel assemblies that are considered to be stored in 32PT DSC. Total heat load is 18.4 kW/DSC. The heat zone configuration is shown in Figure 3-1.

	0.50	0.50	0.50	0.50	
0.50	0.70*	0.70	0.70	0.70*	0.50
0.50	0.70	0.70	0.70	0.70	0.50
0.50	0.70	0.70	0.70	0.70	0.50
0.50	0.70*	0.70	0.70	0.70*	0.50
	0.50	0.50	0.50	0.50	

Figure 3-1 Fuel Loading Configuration (18.4 kW/DSC)

* This is a very conservative assumption for the fuel assemblies (CE 14x14) to be loaded at OPPD in the 32PT DSC. Based on Reference [1], CE 14x14 fuel assembly has higher effective fuel conductivities compared to design basis fuel assembly used in [1]. Moreover, the use of 0.7 kW/FA for fuel assemblies in all basket center locations is also very conservative for OPPD fuel loading. It is expected that fuel assemblies to be loaded at OPPD site will have significantly lower decay heat than 0.7 kW.

2) Summary of ambient conditions considered in the analysis is shown in Table 3-1 below.

Table 3-1 Ambient Conditions Considered in OS197L Thermal Analyses

Operating Conditions	Ambient Temperature, °F	Average Insolation Rate during 12 (24) Hour Period, $Btu/hr\text{-}ft^2$
Off-Normal Transfer	117*	0
Normal Transfer	100	123

* 107°F shall be used as the average ambient air temperature for the steady state maximum off-normal condition [1].

4.0 METHODOLOGY

The methodology used for thermal analysis is the same as described in [3]. The DSC shell temperature profile is calculated *using a* two dimensional thermal model of the OS197L cask *and* DSC shell, *and uses the* ANSYS [2] *computer program*. These DSC shell temperatures are than used as a constant temperature boundary condition in *an* ANSYS model *of* the 32PT DSC *and basket* to calculate the fuel cladding temperature [1]. These fuel cladding temperatures are then used to calculate the effect of *the* transfer cask skid shielding as described in Section 5.3.

5.0 FINITE ELEMENT MODELS

5.1 2D OS197L Cask Thermal Model

The DSC shell within the OS197L cask is analyzed for the operating conditions listed in Table 3-1 for 18.4 kW/DSC heat load.

The ANSYS models of the OS197L (75 ton) transfer cask including the DSC shell represent a two-dimensional slice of the OS197L cask at the axial centerline as shown in Figure 5-1 through Figure 5-2.

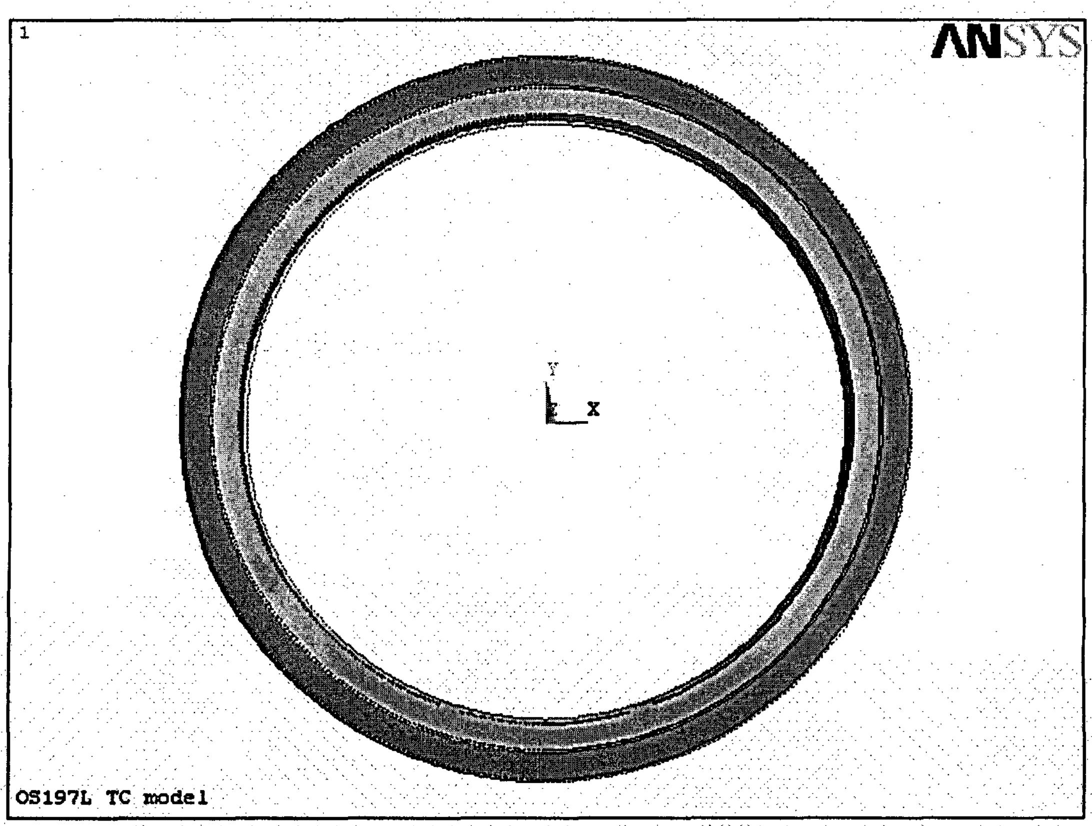


Figure 5-1 OS197L (75 ton) Transfer Cask ANSYS Model

Figure 5-2 below shows details of the OS197L transfer cask ANSYS model.

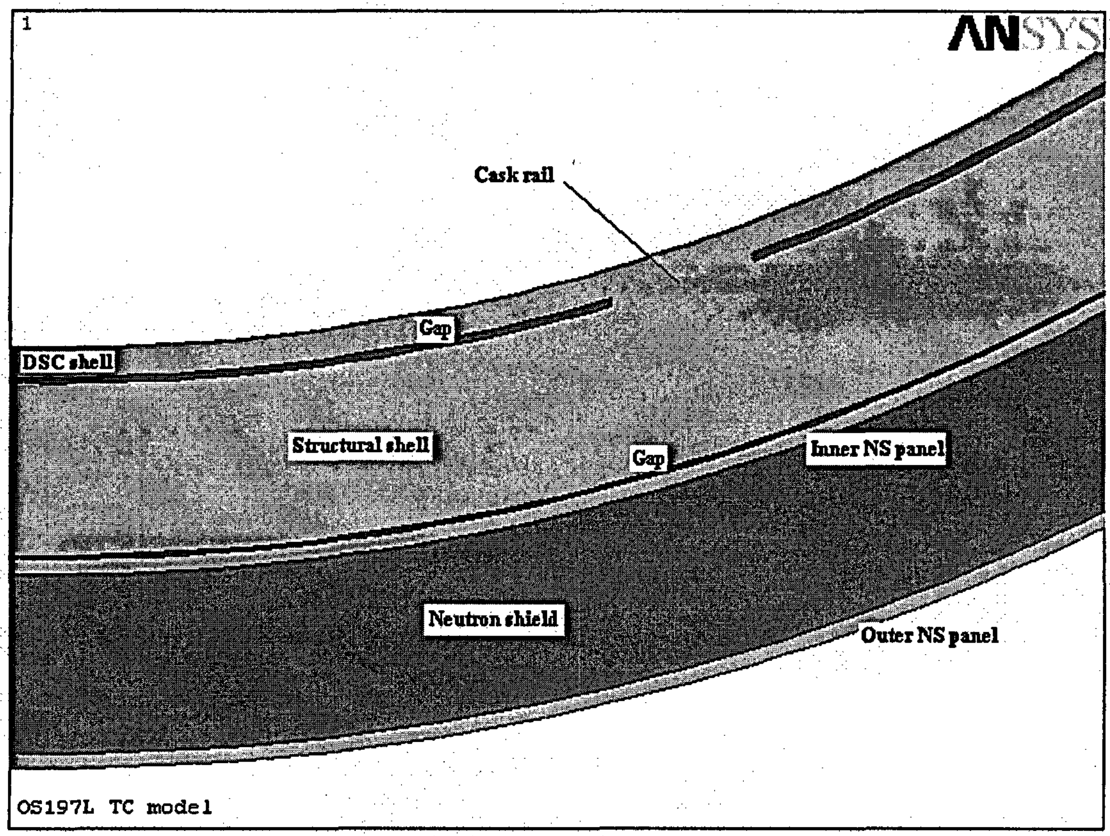


Figure 5-2 Details of OS197L (75 ton) Transfer Cask ANSYS Model

The material properties and cask dimensions are taken from [3]. Only the total heat load per DSC is changed to 18.4 kW from 24 kW.

The method of the heat flux calculation is consistent with the OS197L analysis methodology [3]. Note that any heat removed by the ends of DSC is conservatively neglected in calculation of heat flux. The heat flux is calculated based on the 32PT DSC shell length [1] as:

$$\ddot{q} = \frac{18.4\text{kW} \cdot 3412.3 \frac{\text{Btu}/\text{hr}}{\text{kW}}}{60 \frac{\text{min}}{\text{hr}} \cdot (\pi \cdot 66\text{in} \cdot 182\text{in})} = 0.0277 \frac{\text{Btu}}{\text{min} \cdot \text{in}^2}.$$

The radiation is modeled by overlaying surface elements and using the /AUX12 processor to compute view factors. Radiation to the environment is modeled with SURF151 elements in ANSYS. Radiation between the DSC shell and cask structural shell, between the cask structural shell and the cask inner neutron shield panel (or steel shielding) is also modeled using the /AUX12 processor in ANSYS [3].

The convection to the ambient is conservatively based on average film temperature for convection coefficient evaluation in the ANSYS model. The convection coefficients are calculated based on correlation of turbulent natural convection for horizontal cylinder [4]:

$$h = 0.18(\Delta T)^{1/3} \frac{\text{Btu}}{\text{hr - ft}^2\,°\text{F}} = 2.083\text{e - }5(\Delta T)^{1/3} \frac{\text{Btu}}{\text{min - inch}^2\,°\text{F}} \quad \text{for } 10^9 < Gr_L < 10^{12}.$$

The heat is applied to the model as a heat flux on the inner surface of the DSC using SURF151 elements in ANSYS.

5.2 3D 32PT DSC Thermal Model

The DSC outer shell temperatures are based on a 2D DSC/cask model, which assumes no heat transfer in the axial direction. This 2D OS197L model produces conservative (higher) DSC shell temperatures, which are used as input to the 3D DSC thermal model, which calculated the fuel clad temperatures. Both the normal (with insolation) and off-normal OS197L transfer conditions with 18.4 kW/DSC are calculated.

The same basket component and fuel properties from [1] are used. Heat generations are calculated based on the dimensions of the fuel and basket. The heat is assumed to be distributed evenly through the 8.7" square nominal fuel cell opening. Axial variations are accounted for in ANSYS by using the peaking factors similar to [1]. The base heat generations with the corresponding peaking factors are applied according to the loading patterns given in Figure 3-1:

For 0.7 kW heat load:

$$\ddot{q} = \frac{0.7\text{kW} \cdot 3414 \frac{\text{Btu}/\text{hr}}{\text{kW}} \cdot \frac{1\text{hr}}{60\text{ min}}}{(8.7\text{in})^2 \cdot 141.8\text{in}} = 3.711\text{e} - 3 \frac{\text{Btu}}{\text{min} \cdot \text{in}^3}.$$

For 0.5 kW heat load:

$$\ddot{q} = \frac{0.5kW \cdot 3414 \frac{Btu/hr}{kW} \cdot \frac{1hr}{60\text{ min}}}{(8.7in)^2 \cdot 141.8in} = 2.65e - 3 \frac{Btu}{\text{min} \cdot in^3}.$$

5.3 Methodology to Determine Maximum Fuel Cladding Temperatures in OS197L Transfer Cask with Skid Shielding

An additional skid shielding prevents insolation on the cask surface but effects the convective flow at the outer cask surface. The 3D OS197L cask/DSC shell CFD model was developed to analyze this effect on the cask component temperatures [5].

The effect of the skid shielding on the maximum fuel cladding temperature was evaluated by the following steps:

1) The average temperature of the outer surface of neutron shield outer panel $T_{out\ NS\ p\ aver}$ was calculated by CFD run [5] and used to obtain the average DSC shell temperature $T_{sh\ av}$ by extrapolation of the results $T_{sh\ av} = f(T_{out\ NS\ p\ aver})$ available from the 2D ANSYS runs for hot off-normal (117°F ambient, no insolation) and hot normal (100°F ambient, insolation) cases calculated in Section 5.1.

2) The average DSC shell temperature $T_{sh\ av}$, calculated above, was then used to obtain the maximum fuel cladding temperature T_{fuel} max by extrapolation of the results $T_{fuel\ max} = f(T_{sh\ av})$ available from the DSC within OS197L-1 runs in Section 5.2 for hot off-normal (117°F ambient, no insolation) and hot normal (100°F ambient, insolation) for the OS197L cask with skid shielding (See Section 5.2 above for $T_{fuel\ max}$ calculation).

6.0 REFERENCES

1. Calculation, *NUHOMS® 32PT DSC Thermal Evaluation for 10CFR, Part 72 Storage Conditions*, Transnuclear, Inc. Calculation No. NUH 32PT.0403, Rev 3.

2. On-Line User's Manual for ANSYS, Revision 8.1.

3. Calculation, *Thermal Analysis of OS197L and OS197L100 Transfer Cask*, Transnuclear, Inc. Calculation No. NUH06L-0400, Rev 2.

4. Ozisik, N. M., *Basic Heat Transfer*, McGraw Hill Book Company, 1977.

5. Calculation, *Calculation of OS197L Cask Shell Temperature with 18.4 kW and 11.0 kW Heat Load,* Transnuclear, Inc. Calculation No. 1121.0400. Rev. 1.

6. Calculation, *Minimum Fuel Effective Conductivity for 32PT Design,* Transnuclear, Inc. Calculation No. 60220-14, Rev 0.

7.0 COMPUTATIONS

The ANSYS 8.1 [2] model was runs on Xeon 3.2 GHz platform. The runs are summarized in Table 7-1 below. The input, output ANSYS database, and result files are located on the CD, which accompany this calculation.

Table 7-1 Summary of ANSYS runs – 11.0 kW and 18.4 kW

Operating Conditions	T_{amb}, °F	Insolation	Run ID	Date /Time
2D OS197L Cask ANSYS Thermal Models, 18.4 kW				
Off-normal, transfer OS197L cask/32 PT DSC, w/o skid shielding	117	no	Lc_axc	05/31/06 16:08:42
Normal, transfer OS197L cask/32PT DSC, w/o skid shielding	100	yes		
3D DSC ANSYS Thermal Model, 18.4 kW				
Off-normal, transfer OS197L cask/32 PT DSC, w/o skid shielding	117	no	T32s_OS197L _18kw	05/31/06 18:21:23
Normal, transfer OS197L cask/32PT DSC, w/o skid shielding	117	yes	T32s_OS197L _18kwn	05/31/06 19:32:02
2D OS197L Cask ANSYS Thermal Models, 11.0 kW				
Off-normal, transfer OS197L cask/32 PT DSC, w/o skid shielding	117	no	Lc_ax_11kw	06/02/06 20:52:37
Normal, transfer OS197L cask/32PT DSC, w/o skid shielding	100	yes		
3D DSC ANSYS Thermal Model, 11.0 kW				
Off-normal, transfer OS197L cask/32 PT DSC, w/o skid shielding	117	no	T32s_OPPD_ 11kw	06/02/06 22:33:01
Normal, transfer OS197L cask/32PT DSC, w/o skid shielding	117	yes	T32s_OPPD_ 11kwn	06/02/06 23:22:38

8.0 RESULTS AND SUMMARY

8.1 Temperature of OS197L Components, and 18.4 kW DSC Shell

The temperature plots for *the* DSC shell *and the* OS197L transfer cask for normal operating conditions (with insolation) and off-normal *(*without insolation*)* are shown in Figure 8-1 and Figure 8-2, respectively.

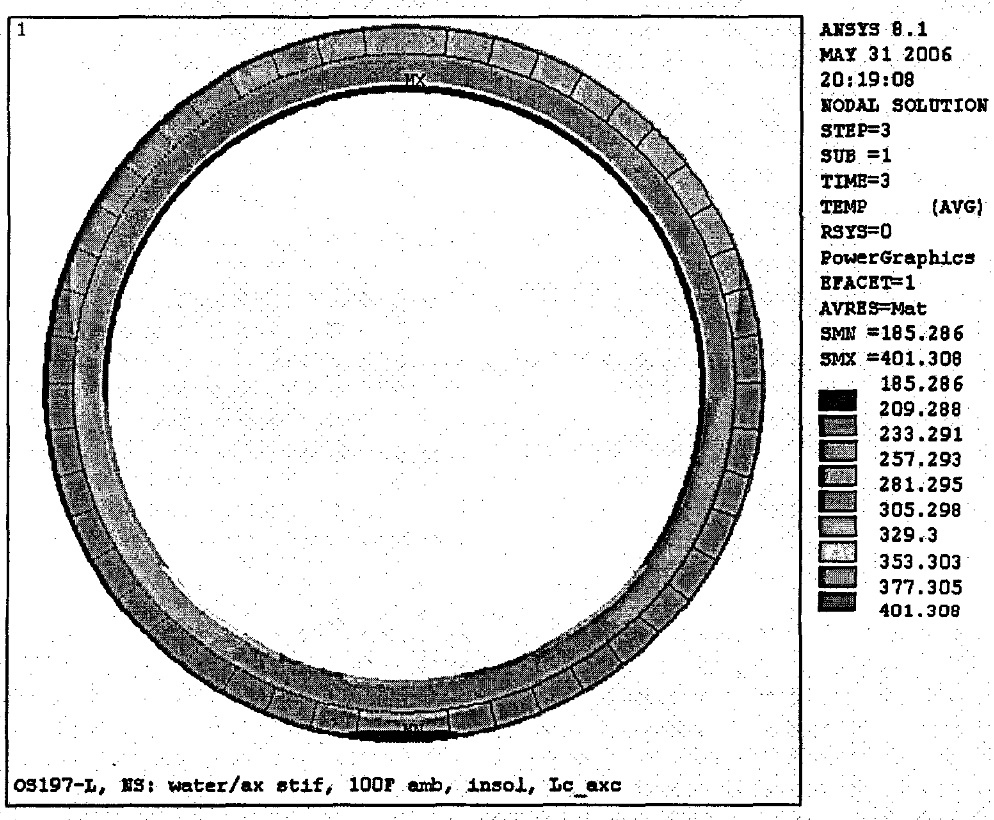


Figure 8-1 Temperature Plot for 18.4 kW DSC in OS197L, T_{amb}=100°F, insolation

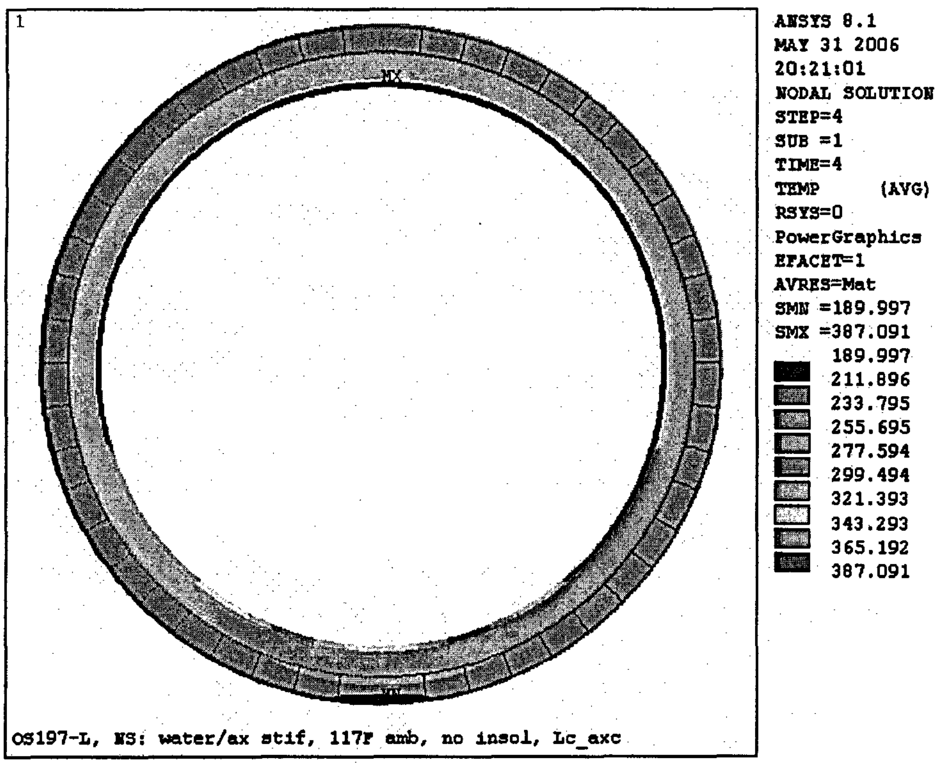


Figure 8-2 Temperature Plot for 18.4 kW DSC in OS197L, T_{amb}=117°F, No Solar

Summary of the 18.4 kW DSC shell, and maximum OS197L transfer cask component temperatures are shown in Table 8-1 below.

Table 8-1 DSC Shell and OS197L Cask Component Maximum Temperatures, ANSYS Results (18.4 kW/DSC)

Operating Conditions	T_{amb}, °F	T_{top}, °F	T_{side}, °F	T_{bot}, °F	$T_{out\ NS\ p}$, °F	$T_{sh\ av}$, °F
Off-normal, transfer OS197L w/o skid *shielding*	117	387	375(1)	329	215	362
Normal, transfer OS197L w/o skid *shielding*	100, insolation	401	388(1)	325	225	368
Off-normal, transfer OS197L with skid shielding [5]	117	-	-	-	259	388(2)

(1) Conservative value is applied in DSC thermal model.

(2) Extrapolated value based on 2D cask ANSYS runs for off-normal and normal transfer OS197L cases

where

T_{top}, T_{side}, T_{bot} – DSC shell top, side and bottom maximum temperature, respectively,

$T_{sh\ av}$ – DSC shell inner surface average temperature,

$T_{out\ NS\ p}$ – cask outer NS panel average temperature.

8.2 Evaluation of Maximum Fuel Cladding Temperature during Transfer in OS197L

The DSC shell top, side, and bottom temperatures are used in this calculation. An average DSC shell temperature $T_{sh\ av}$ was calculated as the average nodal temperature at the inner DSC shell diameter. This average temperature is then used to calculate maximum fuel cladding temperature for 18.4 kW/DSC transferred within the OS197L. The results are shown in Table 8-2 below.

Table 8-2 DSC Shell and Fuel Cladding Maximum Temperatures for OS197L Cask ANSYS Results (18.4 kW/DSC)

Operating Conditions	T_{amb}, °F	T_{top}, °F	T_{side}, °F	T_{bot}, °F	$T_{out\ NS\ p}$, °F	$T_{sh\ av}$, °F	$T_{fuel,\ max}$ °F	$T_{fuel,\ limit}$ °F
Off-normal, transfer OS197L w/o skid shielding	117	387	375 (1)	329	215	362	678	752
Normal, transfer OS197L, w/o skid shielding	100, insolation	401	388(1)	325	225	368	686	752
Off-normal, transfer OS197L with skid shielding [5]	117	-	-	-	259	388(1)	713(2)	752

(1) See Table 8-1.
(2) Extrapolated value.

8.3 Effect of Skid Shielding on Thermal Analysis Results

As seen from Table 8-2 , the maximum fuel cladding temperature for 18.4 kW /32PT DSC within OS197L are below allowable limits for normal and off-normal transfer conditions *without skid shielding and for off-normal transfer conditions with skid shielding. The normal condition with skid shielding is bounded by the off-normal as the skid shielding eliminates the insolation and the ambient temperature is higher.*

APPENDIX A

EVALUATION OF MAXIMUM FUEL CLADDING TEMPERATURE FOR 11 KW/DSC TOTAL HEAT LOAD WITHIN OS197L

A.1 Purpose

The purpose of this Appendix A is to determine 32PT DSC basket components and fuel cladding temperatures within the OS197L (75 ton) cask with 11.0 kW/DSC total heat load for off-normal transfer condition.

A.2 Assumptions/Conservatisms

There is no change to the assumptions or conservatisms, and those of [1] are applied in this calculation.

A.3 Design Input – 11.0 kW

This Appendix A provides *a* thermal evaluation of *the* maximum fuel cladding temperature for *an* 11.*0* kW/DSC within OS197L.

The thermal evaluation is similar to *the* evaluation described *previously* in Sections 2.0 through 5.0 for *the* 18.4 kW/DSC total heat load.

Three different design inputs are used in this Appendix A:

A.3.1 The heat flux applied on DSC shell inner surface for 11 kW/DSC is:

$$\ddot{q} = \frac{11kW \cdot 3412.3 \frac{\text{Btu}/\text{hr}}{\text{kW}}}{60\frac{\text{min}}{\text{hr}} \cdot (\pi \cdot 66\,\text{in} \cdot 182\,\text{in})} = 0.0166 \frac{\text{Btu}}{\text{min} \cdot \text{in}^2}.$$

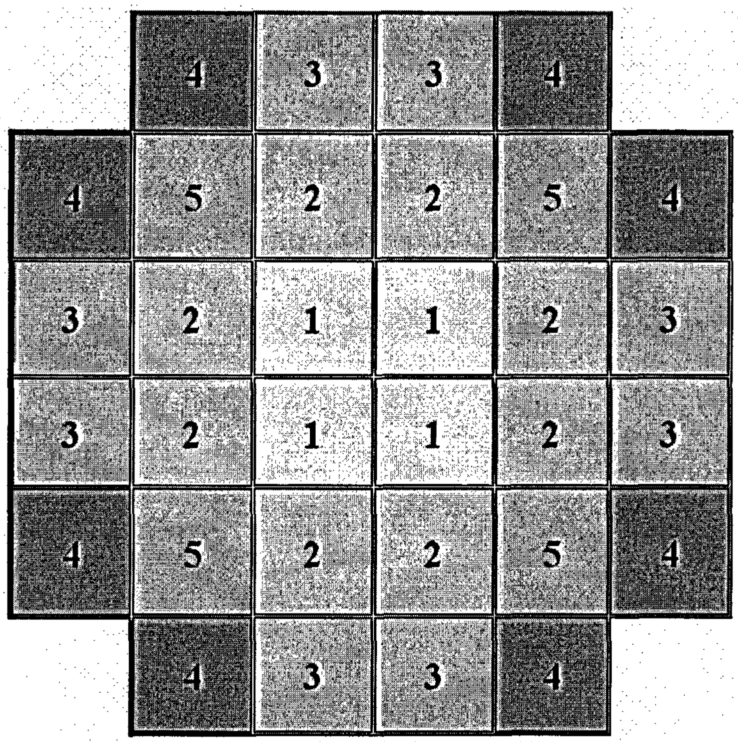
A.3.2 The effective fuel *thermal* conductivity of *the* fuel assembly CE 14x14-FC is listed in Appendix Table A-1 [6], *and was used in the model.*

Appendix Table A-1 Effective Fuel Thermal Conductivities (CE 14x14-FC) in Helium

T (°F)	Transverse Effective Conductivity (Btu/min-in-°F)	T (°F)	Axial Effective Conductivity (Btu/min-in-°F)
136	3.452E-04	200	1.016E-03
231	3.927E-04	300	1.072E-03
326	4.675E-04	400	1.128E-03
422	5.579E-04	500	1.174E-03
519	6.634E-04	600	1.221E-03
616	7.842E-04	800	1.323E-03
713	9.193E-04		
811	1.072E-03		

A.3.3 *The fuel zoning configuration was redefined to reduce peak fuel clad temperatures and to incorporate the lower* 11.0 kW/DSC *heat loading. The configuration* is shown in Appendix Figure A-1.

A.3.4 *The base heat generation with the corresponding axial peaking factor is applied according to the loading pattern given in the fuel loading configuration for 11 kW/DSC, as shown in* Appendix Figure A-1.



Heat Zone	1	2	3	4	5
# of Fuel Assemblies	4	8	8	8	4
Max Heat Load / Assembly (kW)	0.16	0.35	0.40	0.50	0.50
Max Heat Load / Zone (kW)	0.64	2.80	3.20	4.00	2.00
Max Heat Load / DSC (kW)	11.0				

Appendix Figure A-1 Fuel Loading Configuration (11 kW/DSC)

* This is a bounding fuel load for the fuel assemblies (CE 14x14) to be loaded at OPPD in the 32PT DSC. *Conservatively, the* total heat *generation* used in *the* 3D DSC thermal model based on the above fuel loading configuration is 12.64 kW/ DSC. The total heat load to be loaded at OPPD site at the Phase I campaign will be less than 11 kW per DSC.

A.4 <u>Methodology</u>

There is no change to the methodology used to calculate the peak fuel clad temperatures, described previously in Section 4.0.

A.5 Finite Element Models

The same models, as were used previously for the 18.4 kW/DSC calculation, were used in this 11.0 kW/DSC calculation. The differences were the reduction in heat flux detailed above and the reduction in base fuel assembly heat generations within the basket, which correspond to the reduced 0.40, 0.35, and 0.16 kW/Assembly Zones (Zones 1 through 3).

A.6 References

There is no change to the references.

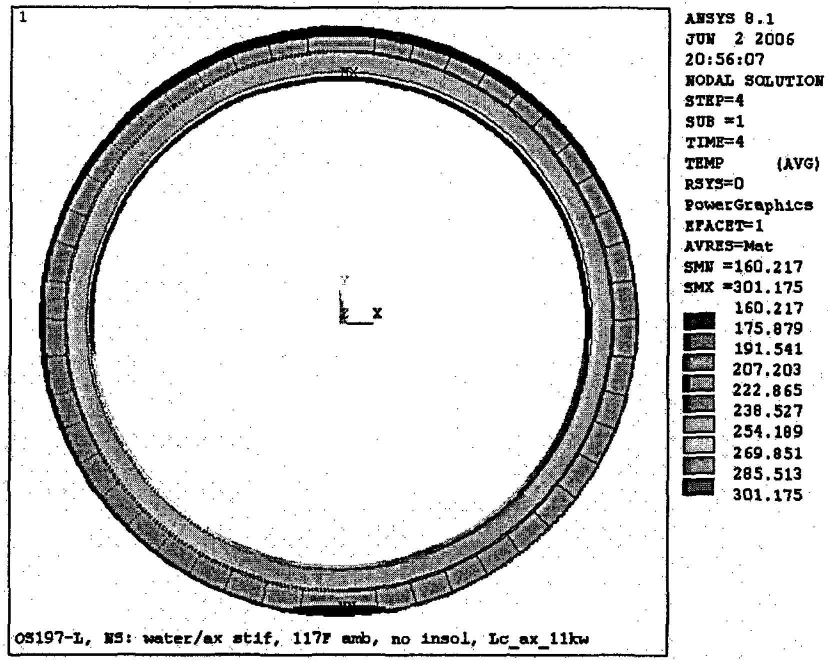
A.7 Computations

All computer runs for the 11.0 kW conditions are listed in Section 7.0.

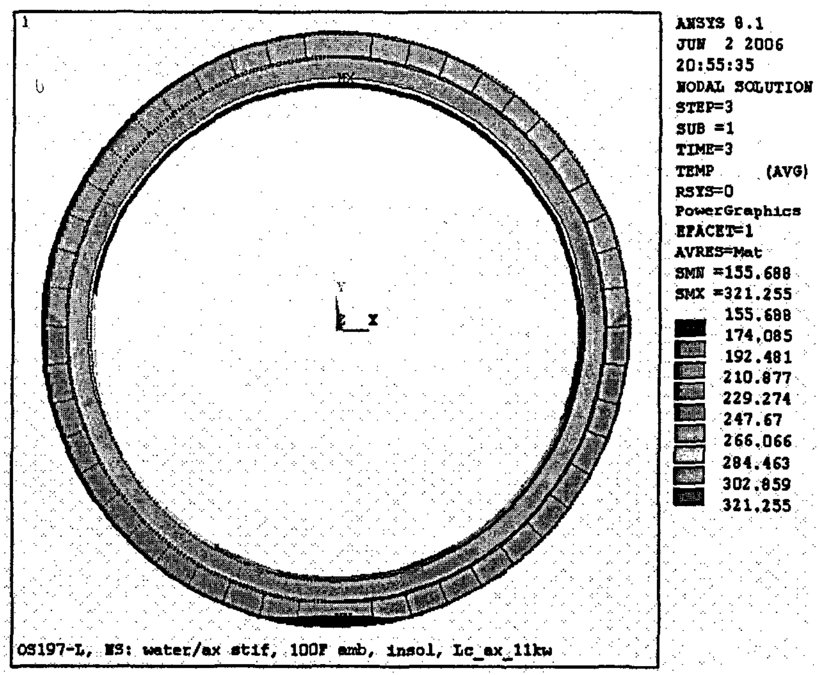
A.8 Results and Summary

The ANSYS runs for 11 kW/DSC heat load are listed in Table 7-1.

The temperature plots for *the* DSC shell and OS197L transfer cask for normal operating conditions (with insolation) and off-normal (without insolation) for 11 kW/DSC heat load are shown in Appendix Figure A-2 and Appendix Figure A-3, respectively.



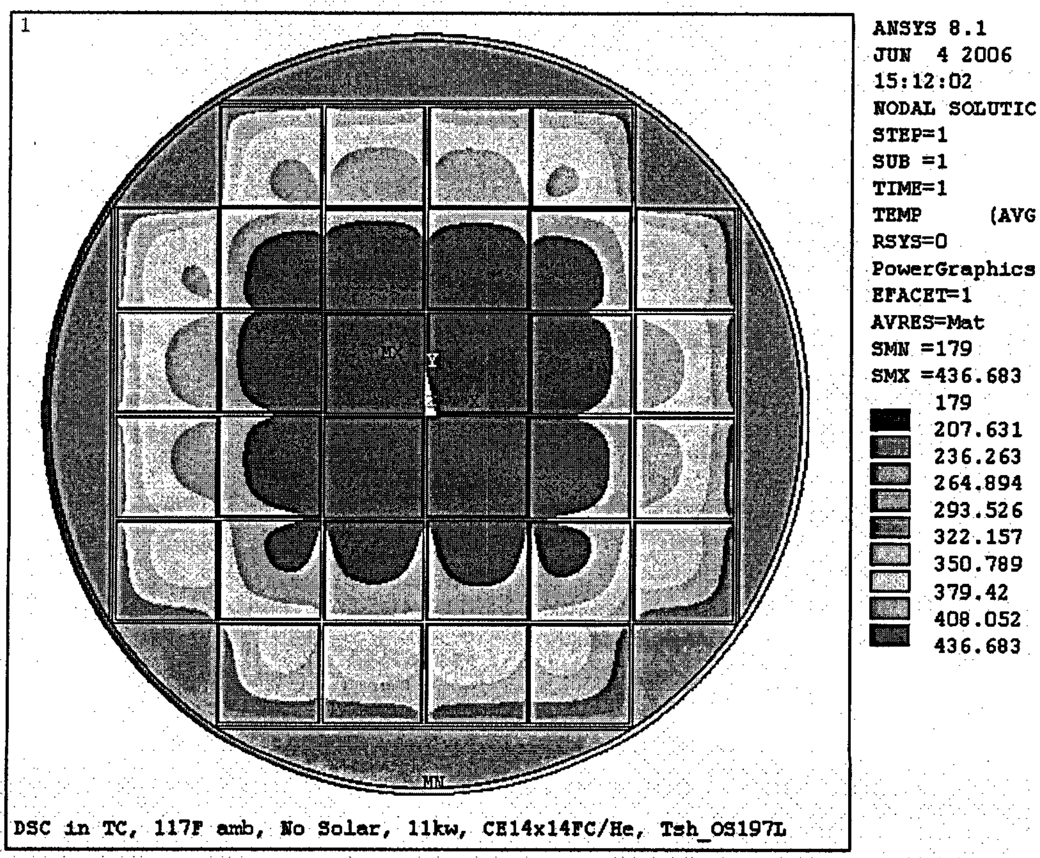
Appendix Figure A-2 Temperature Plot for 11 kW/DSC in OS197L, Tamb=117°F, *No Solar*



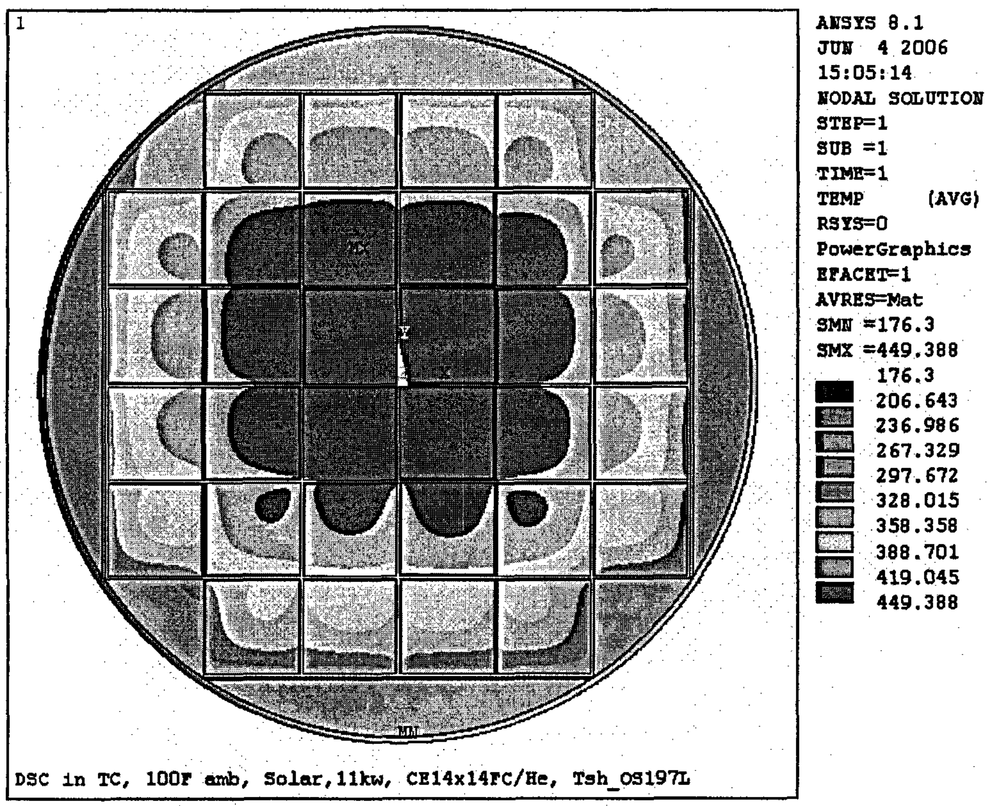
Appendix Figure A-3 Temperature Plot for 11 kW/DSC in OS197L, T_{amb}=100°F, with insolation

The summary of the DSC shell and OS197L transfer cask component temperatures is shown in Appendix Table A-2 below.

Appendix Figure A-4 and Appendix Figure A-5 show DSC component and fuel temperature plots for off-normal and normal transfer conditions for *the* 11 kW/DSC heat load.



Appendix Figure A-4 Temperature Plot for Transfer of 11 kW/DSC within OS197L for Off-Normal Conditions (117°F, *No Solar*), No Skid Shielding



Appendix Figure A-5 Temperature Plot for Transfer of 11 kW/DSC within OS197L for Normal Conditions (100°F, Insolation), No Skid Shielding

<u>Effect of Skid Shielding on Thermal Analysis Results</u>

Appendix Table A-2 shows *the* DSC shell temperatures, average temperatures of *the* OS197L outer neutron shield panel, and *the* maximum fuel cladding temperatures for normal and off-normal transfer conditions *with the* 11.*0* kW/DSC heat load.

Appendix Table A-2 also includes *the* average DSC shell and maximum fuel cladding temperatures for off-normal transfer within *the* OS197L with skid shielding.

Appendix Table A-2 DSC Shell Temperatures, Average Outer Neutron Shield Panel Temperatures and Maximum Fuel Cladding Temperatures (11 kW/DSC)

Operating Conditions	T_{amb}, °F	T_{top}, °F	T_{side}, °F	T_{bot}, °F	$T_{out\ NS\ p}$, °F	$T_{sh\ av}$, °F	$T_{fuel,\ max}$ °F	$T_{fuel,\ limit}$ °F
Off-normal, transfer OS197L w/o skid shielding	117	301	291(1)	250	176	279	437	752
Normal, transfer OS197L, w/o skid shielding	100, insolation	321	306(1)	247	189	289	449	752
Off-Normal, transfer OS197L with skid shielding	117	-	-	-	214(4)	308(2)	472(3)	752

(1) Conservative value is applied in DSC thermal model.
(2) Extrapolated value based on 2D cask ANSYS runs for off-normal and normal transfer OS197L cases
(3) Extrapolated value based on 3D DSC ANSYS runs for off-normal and normal transfer OS197L cases
(4) Calculated using CFD model [5]

As seen from Appendix Table A-2, the maximum fuel cladding temperature for 11 kW /32PT DSC within OS197L are below allowable limits for normal and off-normal transfer conditions without skid shielding, *and for off-normal conditions with skid shielding. The normal condition with skid shielding is bounded by the off-normal as the skid shielding eliminates the insolation and the ambient temperature is higher.*