AREVA TRANSNUCLEAR INC.	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 4)	Calculation No.: NUH32PHB-0403	Revision No.: 0
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DCR NO (if applicable) : N/A	PROJECT NAME: NUHOMS® 32PHB System
PROJECT NO: 10955	CLIENT: CENG-Calvert Cliff Nuclear Power Plant Inc. (CCNPP)

CALCULATION TITLE:

Thermal Evaluation of NUHOMS® 32PHB DSC for Storage and Transfer Conditions

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation determines the maximum fuel cladding temperature and the maximum basket component temperatures for 32PHB DSC storage in NUHOMS® HSM-HB and transfer in the CCNPP-FC transfer cask during normal, off-normal, and accident operating conditions. This calculation evaluates these conditions for the bounding maximum heat load of 29.6 kW per DSC.

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 performed 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: Davy Qi [signature]	Date: 4/8/2010
Calculation has been checked for consistency, completeness and correctness: Checker Name and Signature: Slava Guzeyev [signature]	Date: 4/8/2010
Calculation is approved for use: Project Engineer Name and Signature: [signature]	Date: 04/09/10

REVISION SUMMARY

REV.	DESCRIPTION	AFFECTED PAGES	AFFECTED Computational I/O
0	Initial Issue	All	All

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1.0 PURPOSE

The purpose of this calculation is to determine the maximum fuel cladding and component temperatures of 32PHB DSC in the HSM-HB storage module and in the CCNPP-FC transfer cask (TC) for normal, off-normal and accident conditions. A maximum heat load of 29.6 kW per DSC is considered for the evaluations in this calculation.

Effective properties of 32PHB baskets are determined in Section 5.2 for the use in transient analysis.

2.0 REFERENCES

1 Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, NUH-003, Rev. 11.

2 CCNPP Demo DE10269, "Axial Burnup Distribution of VAP Assemblies with and without Axial Blankets", Constellation Energy Nuclear Group, January 23, 2009.

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

4 Design Criteria Document, "Design Criteria Document (DCD) for the NUHOMS® 32PHB System for Storage", Transnuclear, Inc., Document No. NUH32PHB.0101, Rev. 0.

5 Calculation, "Finite Element Model, Thermal Analysis", Transnuclear, Inc., Calculation No. 1095-5, Rev. 0.

6 Calculation, "Sensitivity Analysis of Homogenized Fuel Region", Transnuclear, Inc., Calculation No. 1095-84, Rev. 1.

7 Calculation, "NUHOMS® 32PHB Weight Calculation of DSC/TC System", Transnuclear, Inc., Calculation No. NUH32PHB-0201, Rev. 0.

8 Calculation, "Fuel Effective Thermal Properties for 32PHB DSC Design", Transnuclear, Inc., Calculation No. NUH32PHB-0407, Rev. 0.

9 ASME Boiler and Pressure Vessel Code, Section II, Part D, "Material Properties", 1998.

10 Specification, "Procurement Specification for Borated Aluminum Sheets for the NUHOMS -32P Dry Shielded Canister", Transnuclear, Inc., Specification No. E-20112, Rev. 3.

11 Calculation, "Thermal Analysis of NUH61BTH DSC in HSM-H Storage Module", Transnuclear, Inc., Calculation No. NUH61BTH-0421, Rev. 0.

12 Rohsenow, Hartnett, Cho, "Handbook of Heat Transfer", 3rd Edition, 1998.

13 Report, "Topical Report on Actinide-Only Burnup Credit for PWR Spent Fuel Nuclear Fuel Packages", Office of Civilian Radioactive Waste Management, DOE/RW-0472, Revision 2, September 1998.

14 Kreith, Frank, "Principles of Heat Transfer", 3rd Edition, 1973.

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

16 Calculation, "Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions", Transnuclear, Inc., Calculation No. NUH32PHB-0402, Rev. 0.

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

3.0 ASSUMPTIONS AND CONSERVATISM

The assumptions and conservatism considered for 32PHB DSC model are the same as those assumed in the 32P DSC model [5, 6] except additional assumptions as below:

- Axial decay heat profile is based on axial burnup distribution of VAP fuel assemblies with maximum peaking factor of 1.101 [2].
- Active fuel length for fuel assemblies (FA) is 136.7"and located at 6" from the bottom of the fuel assembly [2]. The position of active fuel in the 32PHB DSC model is assumed 7.0" from the bottom of the basket, which maximizes radial heat dissipation through the DSC shell to bound the maximum component temperatures conservatively.
- 0.30" diametrical hot gap between the shield plugs and the DSC inner surface. This gap is larger than the fabrication tolerances and therefore conservative.
- 0.20" axial gap between the bottom of the basket and the DSC bottom inner cover plate. This gap is larger than the fabrication tolerances to bound the maximum basket component temperatures conservatively by minimizing axial heat transfer through the DSC bottom plates.
- 1.50" axial distance between the top of the basket and the DSC top inner cover plate. The conservative assumption is that the heat transfer between the top basket and the inner cover plate only occurs by condition through cavity gas.
- 0.01" axial air gap between shield plugs and DSC cover plates. This gap is larger than the contact gap tolerances and therefore conservative.
- 0.27" diametrical hot gap between the basket outer surface and the DSC inner surface. This assumption is justified in APPENDIX A. A 0.30" helium gap is modeled in the 32PHB DSC model and an effective conductivity is used for the elements that represent the 0.27" helium gaps (see Section 5.1.3).
- 0.01" contact gap on either side of the paired aluminum/poison basket plates. This gap is larger than the contact gap tolerances and therefore conservative. This contact gap is modeled by 0.02" and an effective conductivity is used for the elements that represent the 0.01" helium gaps (see Section 5.1.3).
- DSC cavity length is modeled as 159.5" which is slightly longer than nominal cavity length from [7]. This assumption conservatively increases thermal resistance between the top of the basket and the DSC top inner cover plate.

The major component dimensions are based on nominal sizes of 32PHB basket from [7]. Due to the above conservative assumptions, small dimension differences between the modeling and nominal sizes have an insignificant effect on thermal analysis results in Section 6.0.

Radial and axial effective conductivities for homogenized 32PHB basket are calculated based on slice models of the baskets described in Section 5.2.

4.0 DESIGN INPUT

A thickness of 0.125" and a conductivity of 130 W/m-K (=6.26 Btu/hr-in-°F) is considered for the poison basket plates in this calculation. This poison basket plate is considered to be paired with 0.12" thick aluminum 1100 basket plate. The thermal conductivities for the paired aluminum/poison basket plates are calculated in Section 5.1.3.

4.1 Thermal Properties of Materials

Material properties used in 32PHB DSC ANSYS model are listed in Table 4-1.

The effective thermal conductivities for basket components in 32PHB DSC model are calculated in Section 5.1.3.

The peaking factors used in the finite element model to create axial heat profile for the fuel assemblies are discussed in Section 5.1.4.

The effective properties of the 32PHB basket are calculated in Section 5.2. These properties are used in transient analysis.

Table 4-1 Material Numbers in ANSYS Model for the 32PHB DSC

Component	Material	Material
Homogenized Fuel Assembly (137.6" Active Fuel Length)	1	Effective conductivity
Solid Rails	3	Al 6061
Top/Bottom Shielding	5	Lead
Cavity Gas (Excluding 0.01" NA contact gaps)	7	Cavity Gas (Helium/Nitrogen)
Rail Edge Space	70	Cavity Gas (Helium/Nitrogen)
DSC Shell and End Cover Plates	12	SA-240, Type 304
Axial gap gas between end cover plates (0.01" gap)	17	Air
DSC-Rail Gap (0.27")	72	Effective conductivity
Al/Poison Contact Gaps, 90°-270° orientation (0.01"")	19	Effective conductivity
Al/Poison Contact Gaps, 0°-180° orientation (0.01")	29	Effective conductivity
Guide Sleeve, 90°-270° orientation (0.1874")	31	Effective conductivity
Guide Sleeve, 0°-180° orientation (0.1874")	32	Effective conductivity
Steel Bar Plates, 90°-270° orientation (0.25")	41	Effective conductivity
Steel Bar Plates, 0°-180° orientation (0.25")	42	Effective conductivity
Al/Poison Plates, 90°-270° orientation (0.125" Poison/0.12" Al1100)	53	Effective conductivity
Al/Poison Plates, 0°-180° orientation (0.125" Poison/0.12" Al1100)	54	Effective conductivity
Al Basket Plates, 90°-270° orientation (0.25")	55	Effective conductivity
Al Basket Plates, 0°-180° orientation(0.25")	56	Effective conductivity

Thermal property values used in this calculation are listed in Table 4-2 through Table 4-8.

Table 4-2 Thermal Properties of Homogenized Fuel Assembly in Helium [8]

Temperature (°F)	Transverse Conductivity (Btu/hr-in-°F)	Axial Conductivity (Btu/hr-in-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)
136.40	0.0202	0.0601	0.1308	0.0576
231.08	0.0237			
326.54	0.0277			
422.72	0.0324			
519.44	0.0378			
616.70	0.0440			
714.48	0.0508			
812.62	0.0583			
911.07	0.0665			
1009.76	0.0754			

Table 4-3 SA 240/SA-479 Type 304 Stainless Steel Thermal Properties [4, 9]

Temperature (°F)	Thermal conductivity (Btu/hr-ft-°F)	Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)
70	8.6	0.29	0.114
100	8.7		0.114
200	9.3		0.119
300	9.8		0.122
400	10.4		0.126
500	10.9		0.128
600	11.3		0.130
700	11.8		0.132
800	12.2		0.132
900	12.7		0.134
1000	13.2		0.136

Table 4-4 Aluminum Alloys Thermal Properties [4, 9]

Temperature	Al 1100	Al 6061	Al1100	Al6061	Al1100/Al6061
	Thermal Conductivity		Specific Specific Heat		Density
(°F)	(Btu/hr-ft-°F)	(Btu/hr-ft-°F)	(Btu/ lbm-°F)		(lbm/in^3)
70	133.1	96.1	0.214	0.213	0.098
100	131.8	96.9	0.216	0.215	
150	130.0	98.0	0.219	0.218	
200	128.5	99.0	0.222	0.221	
250	127.3	99.8	0.224	0.223	
300	126.2	100.6	0.227	0.226	
350	125.3	101.3	0.229	0.228	
400	124.5	101.9	0.232	0.230	

Table 4-5 Helium Thermal Conductivity

Temperature (K)	Thermal conductivity (W/m-K) [12]	Temperature (°F)	Thermal conductivity (Btu/hr-in-°F) [4]
300	0.1499	80	0.0072
400	0.1795	260	0.0086
500	0.2115	440	0.0102
600	0.2466	620	0.0119
800	0.3073	980	0.0148
1000	0.3622	1340	0.0174
1050	0.3757	1430	0.0181

The above data are calculated base on the following polynomial function from [12].

$k = \sum C_i \, T_i$ for conductivity in (W/m-K) and T in (K)

For 300 < T < 500 K		for 500< T < 1050 K	
C0	-7.761491E-03	C0	-9.0656E-02
C1	8.66192033E-04	C1	9.37593087E-04
C2	-1.5559338E-06	C2	-9.13347535E-07
C3	1.40150565E-09	C3	5.55037072E-10
C4	0.0E+00	C4	-1.26457196E-13

Table 4-6 Air Thermal Conductivity

Temperature (K)	Thermal conductivity (W/m-K) [12]	Temperature (°F)	Thermal conductivity (Btu/hr-in-°F) [4]
250	0.02228	-10	0.0011
300	0.02607	80	0.0013
400	0.03304	260	0.0016
500	0.03948	440	0.0019
600	0.04557	620	0.0022
800	0.05698	980	0.0027
1000	0.06721	1340	0.0032

The above data are calculated base on the following polynomial function from [12].

$k = \sum C_i \, T_i$ for conductivity in (W/m-K) and T in (K)

For 250 < T < 1050 K	
C0	-2.2765010E-03
C1	1.2598485E-04
C2	-1.4815235E-07
C3	1.7355064E-10
C4	-1.0666570E-13
C5	2.4766304E-17

Table 4-7 Nitrogen Thermal Conductivity [4, 12]

Temp (°F)	Thermal conductivity (Btu/hr-in-°F)
200	1.47E-03
300	1.64E-03
400	1.80E-03
500	1.95E-03
600	2.10E-03
700	2.24E-03
800	2.37E-03
900	2.50E-03
1000	2.63E-03
1100	2.75E-03

Table 4-8 Thermal Properties of Lead (ASTM B29) [4]

Temp (K)	Temp (°F)	ρ (lb/in^3)	K (Btu/hr-in-°F)	C_p (Btu/lb-°F)
200	-100	0.413	1.767	0.0299
250	-10	0.411	1.733	0.0303
300	80	0.409	1.700	0.0308
400	260	0.406	1.637	0.0315
500	440	0.402	1.579	0.0327
600	620	0.398	1.512	0.0339

4.2 Design Criteria

Maximum fuel cladding temperatures are in accordance with the guidance in ISG-11, Rev.3 [3], which are specified in [4] and shown in Table 4-9.

Table 4-9 Maximum Fuel Cladding Temperature Limits for 32PHB DSC Thermal Analyses

Operating Condition		Ambient Temperature (°F) [4]		Fuel Cladding Limit (°F) [3]
		Cold [(3)]	Hot [(3)]	
Storage	Normal	-8	104	752
	Off-Normal	-8	104	1058
	Accident (Blocked Vent)	-8	104	1058
Transfer	Normal/Off-Normal	-8	104	752
	Accident (Fire)	n/a	104	1058
Within Fuel Building [(1)]	DSC in Vertical TC (w/o water in DSC/TC annulus)	100 [(2)]		752

Notes:

(1) Operations within fuel building when DSC is located in the TC in vertical orientation are considered normal conditions.

(2) An average ambient temperature within fuel building [4].

(3) Ambient air temperatures ranging from -8 to 104°F are conservative compared to the ambient air temperature range from -3 to 103°F in [17], Section 12.3.6.

Materials of the 32PHB basket can be subjected to a minimum environment temperature of -8°F (-22.2°C) without any adverse effects.

5.0 METHODOLOGY

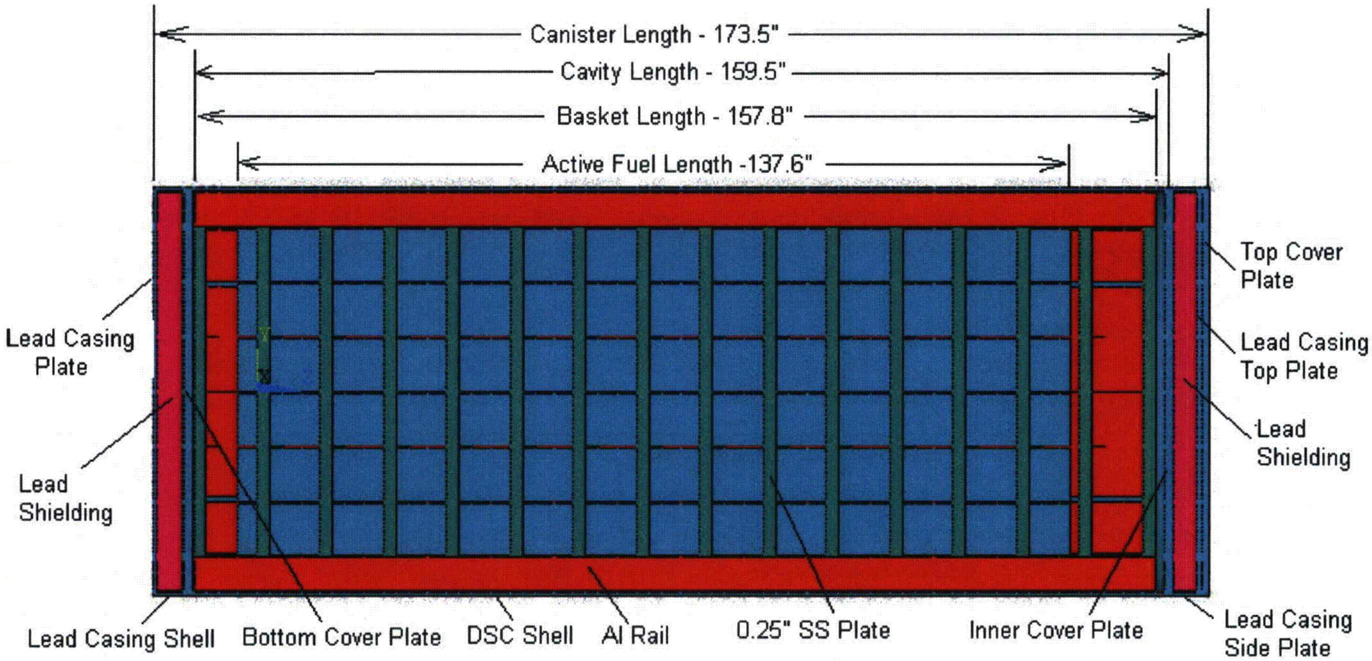
Thermal evaluations for 32PHB DSC in the HSM-HB are performed based on a finite element model using ANSYS computer code [15]. This model is described in the following sections.

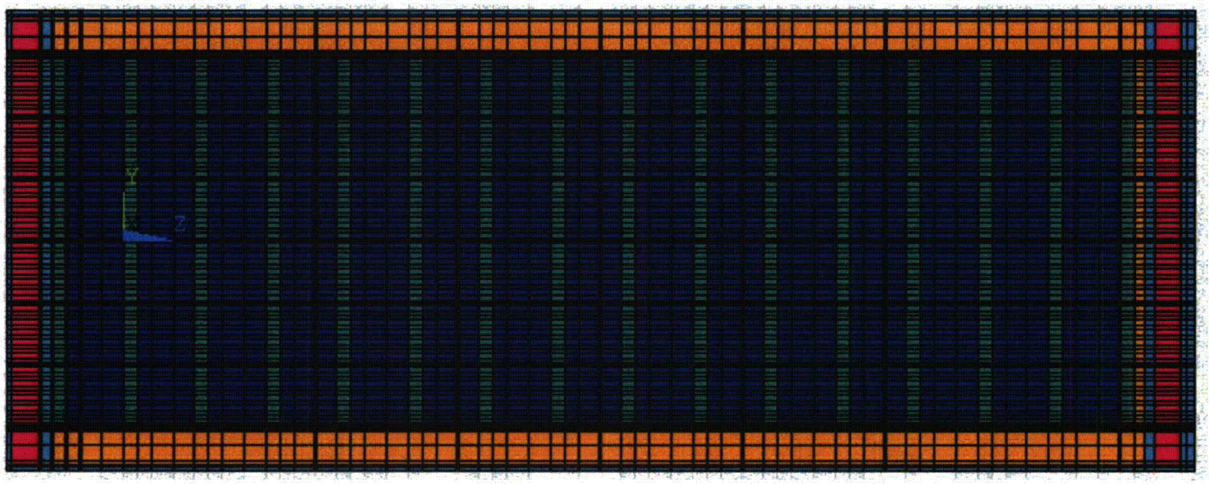
5.1 32PHB DSC Model

A half-symmetric, three-dimensional finite element model of 32PHB DSC (DSC shell and basket) is developed using ANSYS [15]. The model contains the DSC shell, the cover plates, shield plugs, aluminum rails, basket plates, and homogenized fuel assemblies. Only SOLID70 elements are used in the 32PHB DSC model.

The geometry of the 32PHB DSC model and its mesh density are shown in Figure 5-1 through Figure 5-4.

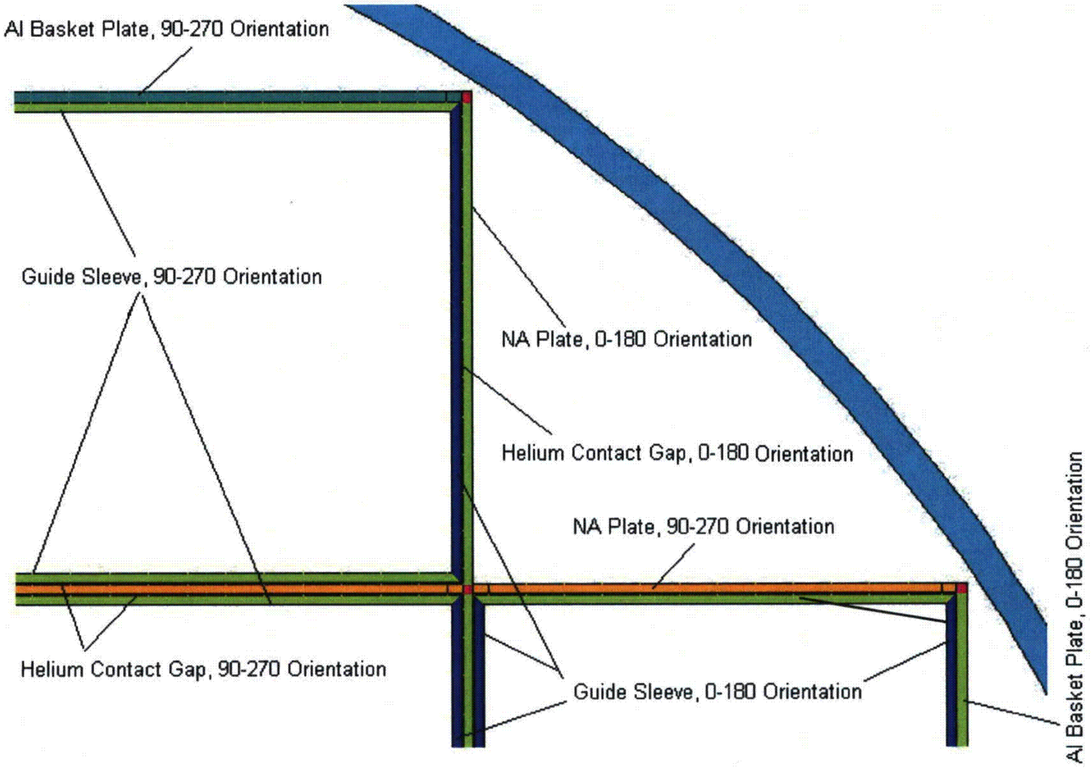
The sensitivity of mesh density on temperature distribution of the NUHOMS-32P DSC components is investigated in [6]. The results shows that the maximum fuel cladding temperature change is within 1°F for 14x14 fine mesh density compared to the coarse mesh densities between 5x5 and 6x6. Hence, a mesh density of 14x14 in the 32PHB DSC model is reasonable and acceptable.



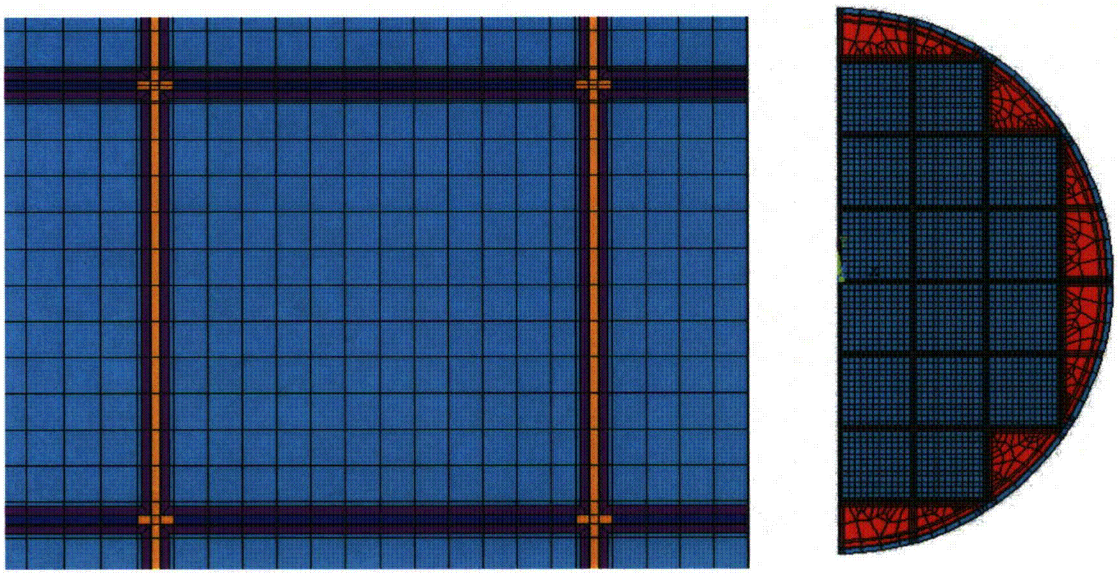


Mesh Density

Figure 5-1 Finite Element Model of 32PHB DSC



Basket Plate Locations



Mesh Density

Figure 5-2 32PHB DSC Model – Cross Section

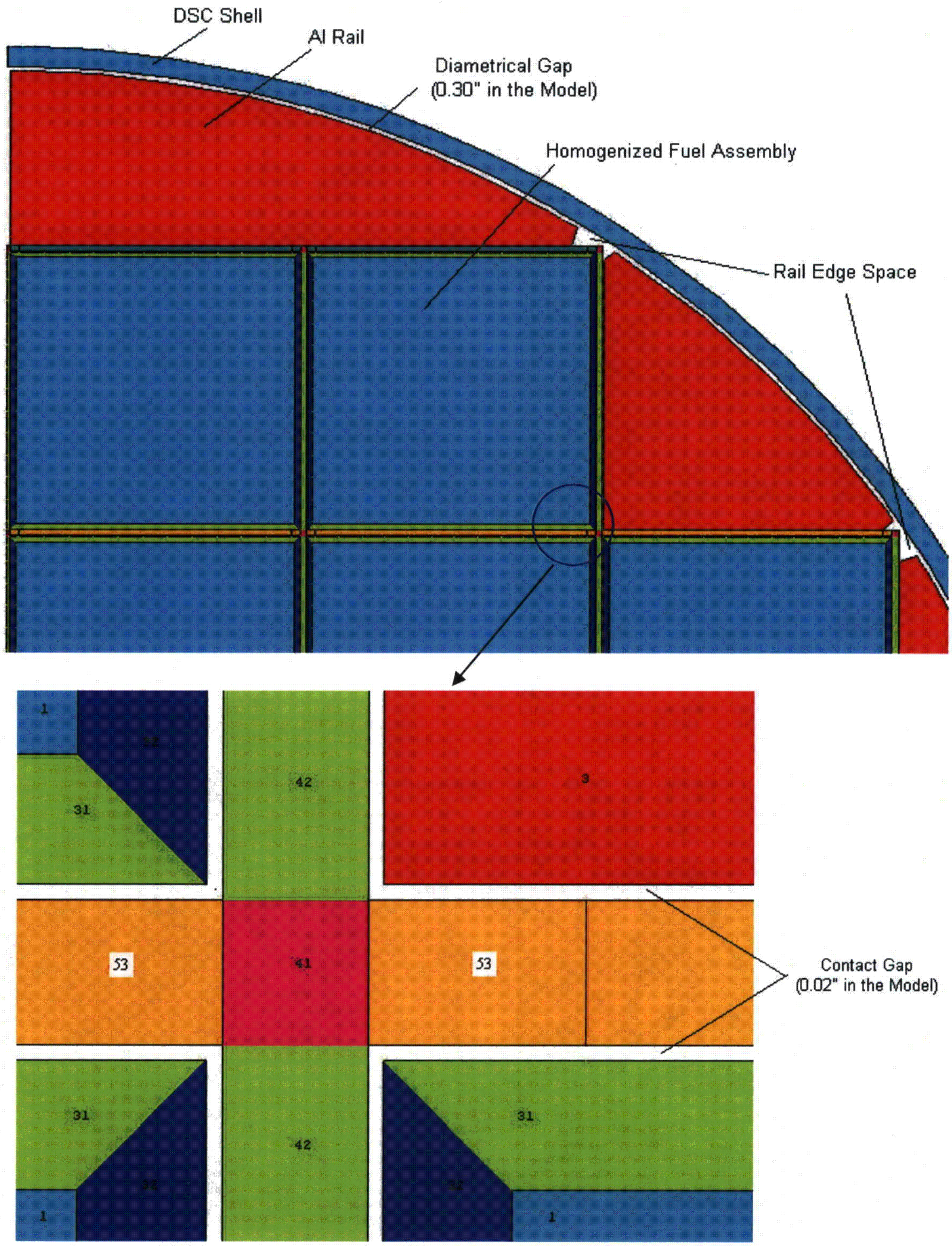
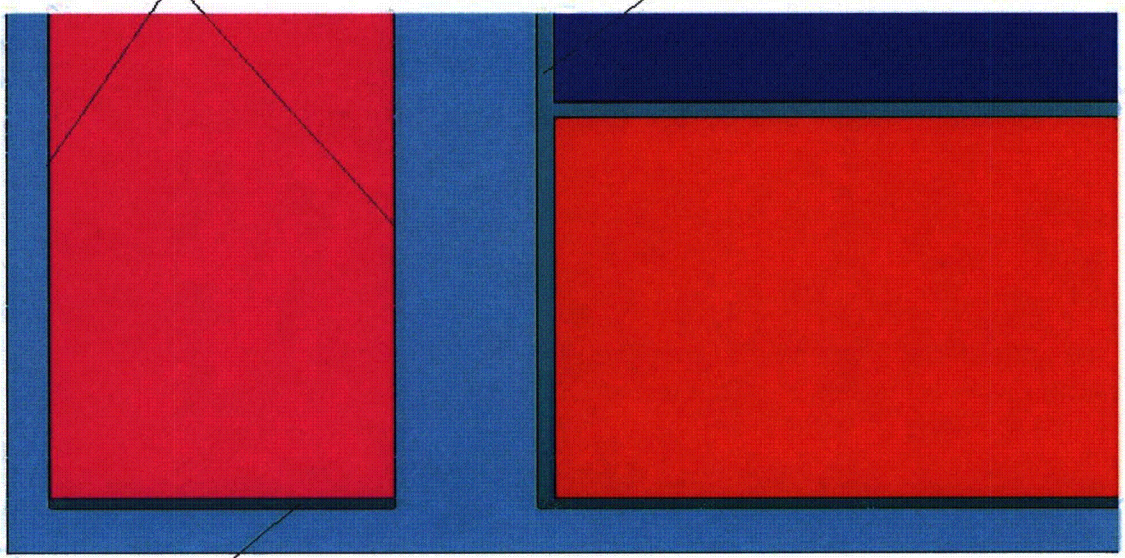
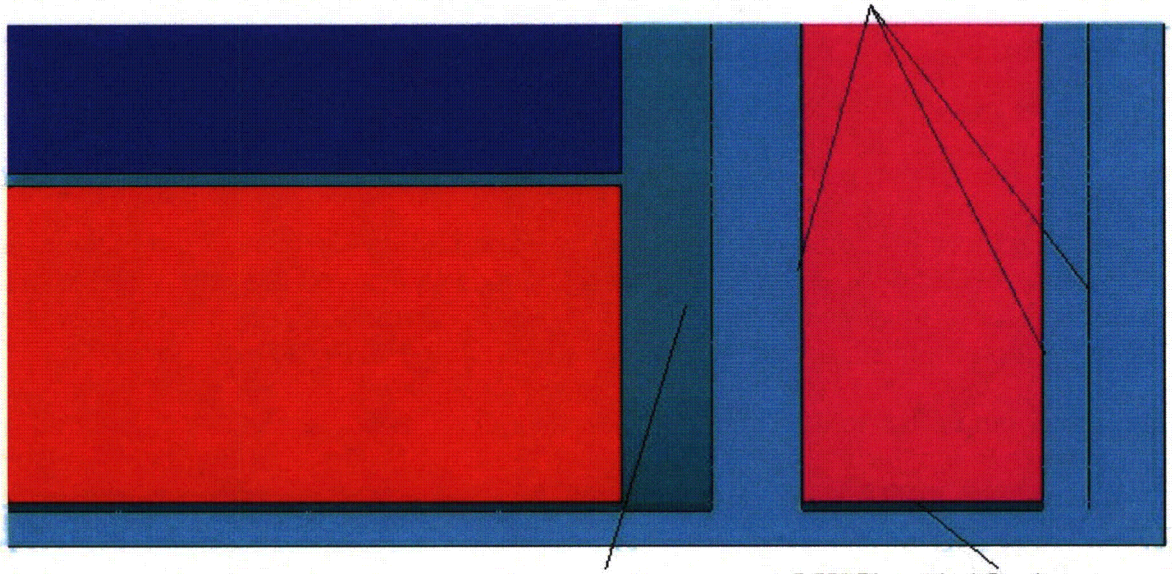


Figure 5-3 32PHB DSC Model – Gaps in the Basket



(a) DSC Bottom End Plates



(b) DSC Top End Plates

Figure 5-4 32PHB DSC Model– Axial Gaps at DSC Ends

5.1.1 Heat Generation

Decay heat load is applied as heat generation load over the elements representing homogenized fuel assemblies.

The heat generation rates used in this analysis is calculated as follows.

$$\dot{q}''' = \left(\frac{q}{a^2 L_a} \times PF \right) \times CF \qquad (5.1)$$

Where
q = Decay heat load per assembly defined for each loading zone,
a = Width of the homogenized fuel assembly = 8.5",
L_a =Active fuel length = 136.7" [4],
PF = Peaking factor, see Section 5.1.4 for distribution of peaking factor,
CF = correction factor = 1.0 assumed for 32PHB basket (see Section 5.1.4).

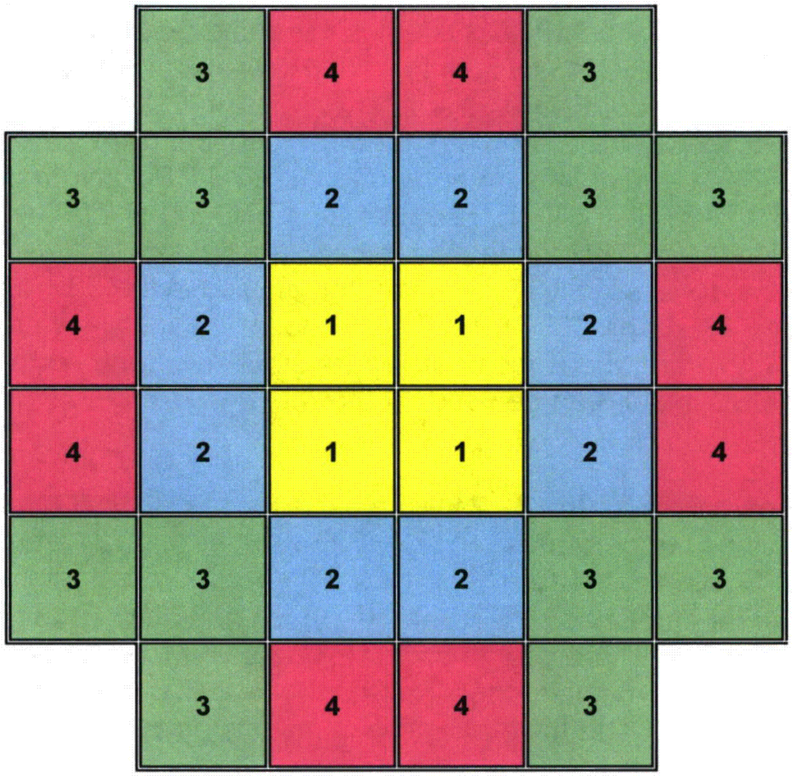
The heat generation rates used in 32PHB DSC model are listed in Table 5-1.

Table 5-1 Heat Generation Rates for 32PHB Basket

Heat Load in the Model (kW)	Heat Generation Rate ($Btu/hr-in^3$)	
	PF=1.0 (Base)	PF=1.101 (Maximum)
1.0	0.345	0.380
0.8	0.276	0.304

The base heat generation rate is multiplied by peaking factors along the axial fuel length to represent the axial decay heat profile. The peaking factors from [2] are converted to match the regions defined for the fuel assembly in the finite element model. Section 5.1.4 describes the conversion method and lists the peaking factors used in the 32PHB DSC model.

The heat generating rates for the elements representing the active fuel are calculated based on the heat load zone configuration (HLZC) for the 32PHB DSC. Figure 5-5 shows the HLZC with maximum heat load of 29.6 kW.



Heat Zone Level	No of FA	kW/FA	Total
1	4	0.8	3.2
2	8	1.0	8.0
3	12	1.0	12.0
4	8	0.8	6.4
Total Heat Load, kW			**29.6**

Figure 5-5 Heat Load Zoning Configuration (HLZC) for 32PHB DSC with 29.6 kW Heat Load

5.1.2 Boundary Conditions for 32PHB DSC in the HSM-HB and CCNPP-FC TC

The HSM-HB to be used for the 32PHB system is the same as the HSM-H described in the UFSAR for standardized NUHOMS system [1]. The HSM-H is used to store a 61BTH DSC (with a maximum DSC length of 195.8", DSC diameter of 67.25") [11], which has the similar design feature as the 32PHB DSC. The outer diameter of 32PHB DSC is 67.25" and the maximum DSC length is 176.5" that is slightly shorter than the 61BTH DSC length of 195.8" considered in the HSM-H model for 61BTH DSC [11]. Because the heat load of 31.2 kW and basket length of 164"are considered in the HSM-H model, the decay heat flux applied in the 61BTH DSC inner shell in the HSM-H model is slightly higher than that applied in the 32PHB DSC with a maximum heat load of 29.6 kW. The short 32PHB DSC also causes a slightly lower hydraulic resistance within the HSM-H. Therefore, the values derived for DSC shell temperatures from the HSM-H model with 61BTH DSC in [11] can be used for thermal analysis of 32PHB DSC under storage conditions.

The DSC shell temperatures for the 31.2 kW heat load in the HSM-H Model provided in [11] are used to map the surface temperatures for 32PHB DSC shell surface temperature via the related macro files listed in Section 8.0, Table 8-2. The DSC shell temperatures based on normal ambient 0°F, off-normal ambient 117°F (average 105°F) and accident blocked vent (40 hours) from the HSM-H model in [11] are design basis DSC shell temperatures for 32PHB DSC storage conditions. The differences in ambient temperatures between 61BTH and 32PHB DSCs under storage conditions are minor and have insignificant effects on thermal evaluation of 32PHB DSC.

The 32PHB DSC shell temperatures for normal, off-normal, and accident transfer operations are retrieved from the CCNPP-FC TC model described in [16].

Typical boundary conditions for 32PHB DSC model are shown in Figure 5-6.

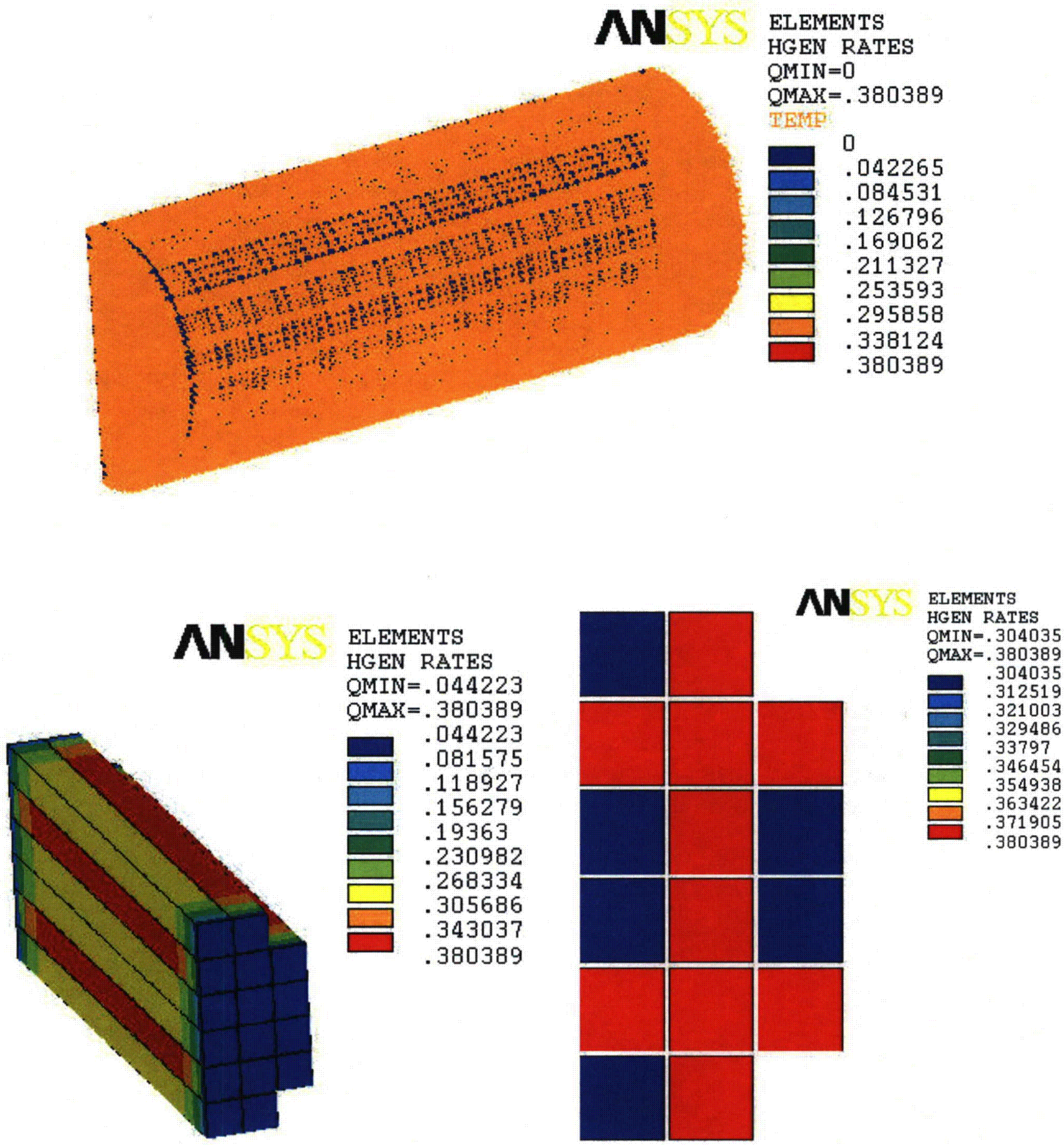


Figure 5-6 Typical Boundary Conditions for 32PHB DSC

5.1.3 Effective Conductivity for Basket Components with Modified Thickness

The effective conductivities of basket components used in the analysis are determined based on modified thicknesses as summarized in Table 5-2.

Table 5-2 32PHB Basket Component Thicknesses

Components	Thickness, inch		ANSYS Material No
	Model (t_{Model})	Nominal (t_{Design})	
Al/Poison Contact Gap	0.02	0.01	19, 29
Guide Sleeve	0.1674	0.1874	31, 32
Basket SS Plate	0.1874	0.25	41, 42
Al/Poison Plate	0.1874	0.245	53, 54
Basket Al1100 Plate	0.1874	0.25	55, 56
DSC-Rail Diametrical Gap	0.30	0.27	72

The effective thermal conductivities for the basket components in 32PHB DSC model are calculated as follows:

$$k_{eff,parallel} = \frac{k_{parallel} \times t_{Design}}{t_{Model}} \quad (5.2)$$ along the plane (parallel resistance),

$$k_{eff,across} = \frac{k_{across} \times t_{Model}}{t_{Design}} \quad (5.3)$$ across the thickness (serial resistance)

Where

$k_{parallel}$ = thermal conductivity along the plane for basket component (Btu/hr-in-°F),
k_{across} = thermal conductivity across the thickness for basket component (Btu/hr-in-°F),
t_{Design} = nominal thickness of basket component (in),
t_{Model} = modeled thickness of basket component (in).

The conductivities for paired Al/poison basket plates are calculated below:

$$k_{Al/Poison,\ parallel} = \frac{k_{Al} \times t_{Al} + k_{PP} \times t_{PP}}{t_{Al} + t_{PP}} = 8.28 \text{ Btu/hr-in-°F}$$ Along the plane (parallel resistance),

$$k_{Al/Poison,\ across} = \frac{t_{Al} + t_{PP}}{t_{Al}/k_{Al} + t_{PP}/k_{PP}} = 7.77 \text{ Btu/hr-in-°F}$$ Across the thickness (serial resistance)

Where

k_{Al} = thermal conductivity for Al1100 plate at 400°F = 10.375 Btu/hr-in-°F,
k_{pp} = thermal conductivity of 130 W/m-K for poison plate = 6.26 Btu/hr-in-°F,
t_{Al} = nominal thickness of Al plate =0.12",
t_{pp} = nominal thickness of poison plate = 0.125".

The effective thermal properties for the basket components in 32PHB DSC model are listed in Table 5-3 through Table 5-8.

Table 5-3 Effective Thermal Conductivities for 0.02" Al/Poison Contact Gap (Mat 19/29)

Cavity Gas -Helium			Cavity Gas - Nitrogen		
Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)	Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)
80	3.600E-03	1.440E-02	200	7.326E-04	2.930E-03
260	4.300E-03	1.720E-02	300	8.177E-04	3.271E-03
440	5.100E-03	2.040E-02	400	8.981E-04	3.592E-03
620	5.950E-03	2.380E-02	500	9.745E-04	3.898E-03
980	7.400E-03	2.960E-02	600	1.048E-03	4.191E-03
1340	8.700E-03	3.480E-02	700	1.118E-03	4.472E-03
1430	9.050E-03	3.620E-02	800	1.186E-03	4.743E-03
			900	1.251E-03	5.005E-03
			1000	1.315E-03	5.259E-03
			1100	1.376E-03	5.506E-03

Table 5-4 Effective Thermal Properties for Guide Sleeve (Mat 31/32)

Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)	ρ (lbm/in³)	C_p (Btu/lb-°F)
70	0.802	0.640	0.290	0.114
100	0.812	0.648		0.114
200	0.868	0.692		0.119
300	0.914	0.730		0.122
400	0.970	0.774		0.126
500	1.017	0.811		0.128
600	1.054	0.841		0.130
700	1.101	0.878		0.132
800	1.138	0.908		0.132
900	1.185	0.945		0.134
1000	1.231	0.983		0.136

Table 5-5 Effective Thermal Properties for Basket Stainless Steel Plate (Mat 41/42)

Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)	ρ (lbm/in^3)	C_p (Btu/lb-°F)
70	0.956	0.537	0.290	0.114
100	0.967	0.543		0.114
200	1.034	0.581		0.119
300	1.090	0.612		0.122
400	1.156	0.650		0.126
500	1.212	0.681		0.128
600	1.256	0.706		0.130
700	1.312	0.737		0.132
800	1.356	0.762		0.132
900	1.412	0.793		0.134
1000	1.467	0.825		0.136

Table 5-6 Effective Thermal Properties for Al/Poison Plate (Mat 53/54)

Conductivity (1) (Btu/hr-in-°F)		Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)
$K_{eff,parallel}$	$K_{eff,across}$	0.98 (2)	0.222 (2)
10.82	5.94		

Notes: (1) Minimum thermal conductivities assumed in the model.
(2) Based on the values of Al1100 at 200°F from Table 4-4.

Table 5-7 Effective Thermal Properties for Basket Al1100 Plate (Mat 55/56)

Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)	ρ (lbm/in^3)	C_p (Btu/lbm-°F)
70	14.797	8.314	0.098	0.214
100	14.652	8.233		0.216
150	14.452	8.121		0.219
200	14.285	8.027		0.222
250	14.152	7.952		0.224
300	14.030	7.883		0.227
350	13.930	7.827		0.229
400	13.841	7.777		0.232

Table 5-8 Effective Thermal Properties for DSC-Rail Gap (Mat 72)

Cavity Gas -Helium			Cavity Gas - Nitrogen		
Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)	Temp (°F)	$K_{eff,parallel}$ (Btu/hr-in-°F)	$K_{eff,across}$ (Btu/hr-in-°F)
80	6.480E-03	8.000E-03	200	1.319E-03	1.628E-03
260	7.740E-03	9.556E-03	300	1.472E-03	1.817E-03
440	9.180E-03	1.133E-02	400	1.617E-03	1.996E-03
620	1.071E-02	1.322E-02	500	1.754E-03	2.166E-03
980	1.332E-02	1.644E-02	600	1.886E-03	2.328E-03
1340	1.566E-02	1.933E-02	700	2.012E-03	2.484E-03
1430	1.629E-02	2.011E-02	800	2.134E-03	2.635E-03
			900	2.252E-03	2.781E-03
			1000	2.367E-03	2.922E-03
			1100	2.478E-03	3.059E-03

5.1.4 Axial Decay Heat Profile for PWR Fuel Assemblies

The axial decay heat profile for fuel assemblies considered in the 32PHB DSC is based on axial burnup distribution of VAP fuel assemblies described in [2], which can accommodate spent fuel with a maximum average burnup of 53 GWd/MTU. For conservatism, the bounding peaking factor profile is determined according to the maximum axial peaking factor value at each axial location from all Unit 1/2 fuel assemblies in [2] and is shown in Table 5-9. The discussion in [13] shows that at a higher burnup, the heat flux shape tends to flatten with a reduction in the maximum axial peaking factor in the middle region, and the flux shape becomes more pronounced in the fuel end regions. Therefore, the application of a heat flux shape for a lower burnup spent fuel (≤53 GWd/MTU) on a higher burnup spent fuel (up to 62 GWd/MTU for 32PHB fuel assemblies [4]) is conservative.

The active fuel length for 32PHB basket is divided into 21 sections. The peaking factors from [2] are converted as follows to match the 21 regions defined for the active fuel length.

- An average height is calculated for each peaking factor section of defined in [2].
- An average height is calculated for each section of active fuel length defined in the finite element model (FEM) of 32PHB DSC.
- The peaking factor for each section in FEM is calculated by interpolation between the peaking factors in [2] using the average heights.

The peaking factors for fuel assemblies in the 32PHB DSC model are listed in Table 5-10 and illustrated in Figure 5-7.

Table 5-9 Bounding Peaking Factors for 32PHB Fuel Assemblies [2]

% of Core length	Length	Peaking Factors	Area under Curve
0.00	0	0.000	0.00
2.19	3.0	0.641	0.96
5.85	8.0	0.853	3.74
7.50	10.3	0.920	1.99
8.23	11.3	0.941	0.93
9.51	13.0	0.967	1.67
12.45	17.0	1.027	4.01
16.87	23.1	1.074	6.35
21.29	29.1	1.091	6.54
25.71	35.1	1.094	6.60
30.12	41.2	1.093	6.60
34.54	47.2	1.090	6.59
38.96	53.3	1.087	6.57
43.38	59.3	1.085	6.56
47.80	65.3	1.086	6.56
52.30	71.5	1.098	6.72
56.88	77.8	1.101	6.88
61.46	84.0	1.101	6.89
66.04	90.3	1.100	6.89
70.61	96.5	1.097	6.88
75.19	102.8	1.092	6.85
79.77	109.1	1.080	6.80
84.35	115.3	1.049	6.66
88.93	121.6	0.979	6.35
91.77	125.5	0.915	3.67
92.50	126.5	0.883	0.90
94.15	128.7	0.821	1.92
97.81	133.7	0.616	3.59
100.00	136.7	0.000	0.92

Table 5-10 Peaking Factors for Fuel Assemblies in the 32PHB DSC Model

Region #	Fuel Model Z-Coord (in) from	to	Average Height from Bottom (in)	Peaking Factor	Area under Curve
1	-3.140	-0.060	1.540	0.329	1.013
2	-0.060	4.120	5.170	0.733	3.064
3	4.120	12.460	11.430	0.933	7.779
4	12.460	20.740	19.740	1.047	8.671
5	20.740	28.060	27.540	1.086	7.948
6	28.060	35.320	34.830	1.093	7.937
7	35.320	41.600	41.600	1.092	6.859
8	41.600	48.860	48.370	1.089	7.906
9	48.860	56.120	55.630	1.086	7.885
10	56.120	64.460	63.430	1.087	9.061
11	64.460	72.800	71.770	1.097	9.150
12	72.800	80.060	79.570	1.101	7.991
13	80.060	87.320	86.830	1.100	7.988
14	87.320	95.660	94.630	1.098	9.158
15	95.660	100.860	101.400	1.093	5.686
16	100.860	111.260	109.200	1.076	11.187
17	111.260	118.520	118.030	1.019	7.395
18	118.520	124.800	124.800	0.919	5.770
19	124.800	128.920	130.000	0.767	3.159
20	128.920	132.000	133.600	0.565	1.740
21	132.000	133.560	135.920	0.160	0.250
				Sum	137.60
				Normalized	1.007
				Corr. Factor	0.993

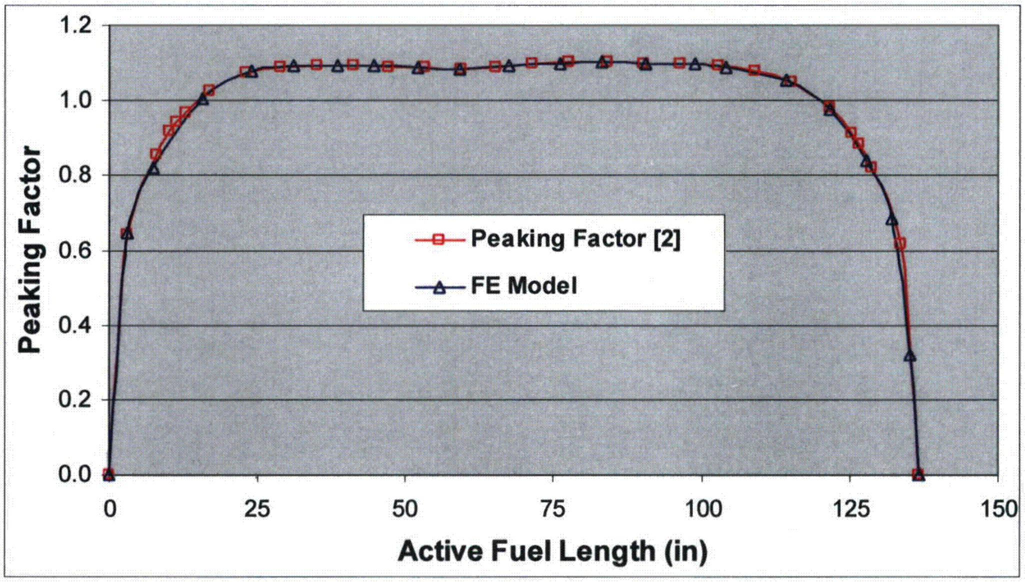


Figure 5-7 Peaking Factor Curve for PWR Fuels

As seen in Table 5-10, the normalized area under peaking factor curve is greater than 1.0. Normalization of the area under the peaking factor curve results in a correction factor of 0.993 as calculated below.

$$Nomalized\ Area\ under\ Curve = \frac{\text{Area under Axial Heat Profile}}{\text{Active Fuel Length}} = 1.007.$$

$$Correction\ Factor = \frac{1}{Normalized\ Area\ under\ Curve} = 0.993.$$

For conservatism, the correction factor of 1.0 is assumed in the 32PHB DSC model.

5.2 Effective Thermal Properties of 32PHB Basket

The 32PHB basket effective density, thermal conductivity and specific heat are calculated for use in the transient analyses. The calculation of effective density and specific heat are based on the DSC component weight data provided in [7].

The effective properties are valid only when the homogenized basket are modeled with the dimensions listed in Table 5-11 :

Table 5-11 Dimensions of Homogenized Baskets

DSC Type	32PHB
Basket OD (in)	66.0
Basket length (in)	158.0

5.2.1 Effective Density and Specific Heat

The basket effective density $\rho_{eff\ basket}$, and specific heat $c_{p\ eff\ basket}$ are calculated respectively using equations (5.4), (5.5) below.

$$\rho_{eff\ basket} = \frac{\sum W_i}{V_{basket}} = \frac{W_{steel} + W_{Al} + W_{poison} + W_{fuel}}{L_{basket} \cdot \pi \cdot D_{basket}^{\ 2} / 4} \quad (5.4)$$

$$c_{p\,eff\ basket} = \frac{\sum W_i \cdot c_{pi}}{\sum W_i} = \frac{W_{steel} \cdot c_{p\,steel} + W_{Al} \cdot c_{p\,Al} + W_{poison} \cdot c_{p\,poison} + W_{fuel} \cdot c_{p\ fuel}}{W_{steel} + W_{Al} + W_{poison} + W_{fuel}} \quad (5.5)$$

Where: W_i = weight of basket components,
L_{basket} = basket length (see Table 5-11),
D_{basket} = basket OD (see Table 5-11),
$c_{p\,i}$ = specific heat of basket materials.

The following assumptions are used in the calculation of the basket effective density (ρ) and specific heat (C_p):

- For aluminum at T > 400°F, C_p value is conservatively assumed equal to value at 400°F.
- For poison material, ρ *and* C_p value is conservatively based on Al 6061.
- Conservatively, helium is not included in density and specific heat calculation.

The calculation of 32PHB basket effective density is summarized in Table 5-12. The calculation of effective specific heat for 32PHB basket is shown in Table 5-13.

Table 5-12 Effective Density for 32PHB Basket

Components	Material	Total Weight [7] (lbm)
Fuel Assembly		46400
Guide Sleeve	SS304	9548
Al/Poison Plate	Aluminum	2092
Steel Plate	SS304	1616
Rail 90	Aluminum	8122
Rail 45	Aluminum	2952
Total		70730
	Dimension	
D_{basket}	66.00	in
L_{basket}	158.0	in
V_{basket}	540549	in^3
$\rho_{eff\ basket}$	0.1308	lbm/in^3

Table 5-13 Effective Specific Heat for 32PHB Basket

Components	Fuel Assembly	Guide Sleeve	Stainless Steel Plates of Basket	Aluminum/Poison Plates	Rail 90	Rail 45	Total	
Material (1)	---	Stainless Steel	Stainless Steel	Al	Al	Al	---	
Weight (lbm) [7]	46400	9548	1616	2092	8122	2952	70730	
Temp	$m.C_p$	$m.C_p$	$m.C_p$	$m.C_p$	$m.C_p$	$m.C_p$	$\Sigma\, m.C_p$	$C_{p\ \mathrm{eff\ basket}}$
(F)	(Btu/°F)	(Btu/°F)	(Btu/°F)	(Btu/°F)	(Btu/°F)	(Btu/°F)	(Btu/°F)	(Btu/lbm-°F)
70	2,673	1,085	184	446	1,730	629	6,746	0.095
100	2,673	1,091	185	450	1,747	635	6,780	0.096
200	2,673	1,136	192	462	1,792	651	6,906	0.098
300	2,673	1,167	198	473	1,835	667	7,012	0.099
400	2,673	1,201	203	480	1,865	678	7,101	0.100
500	2,673	1,222	207	480	1,865	678	7,125	0.101
600	2,673	1,237	209	480	1,865	678	7,143	0.101
700	2,673	1,256	213	480	1,865	678	7,165	0.101
800	2,673	1,263	214	480	1,865	678	7,174	0.101
900	2,673	1,280	217	480	1,865	678	7,193	0.102
1000	2,673	1,296	219	480	1,865	678	7,212	0.102

Note: (1) Specific heat values are listed in Section 4.1.

5.2.2 Effective Thermal Conductivity

A 22.86" long slice of 32PHB basket is created by selecting the nodes and elements of the basket from the finite element model described in Section 5.1 to calculate the effective thermal conductivities. The slice model is shown in Figure 5-8.

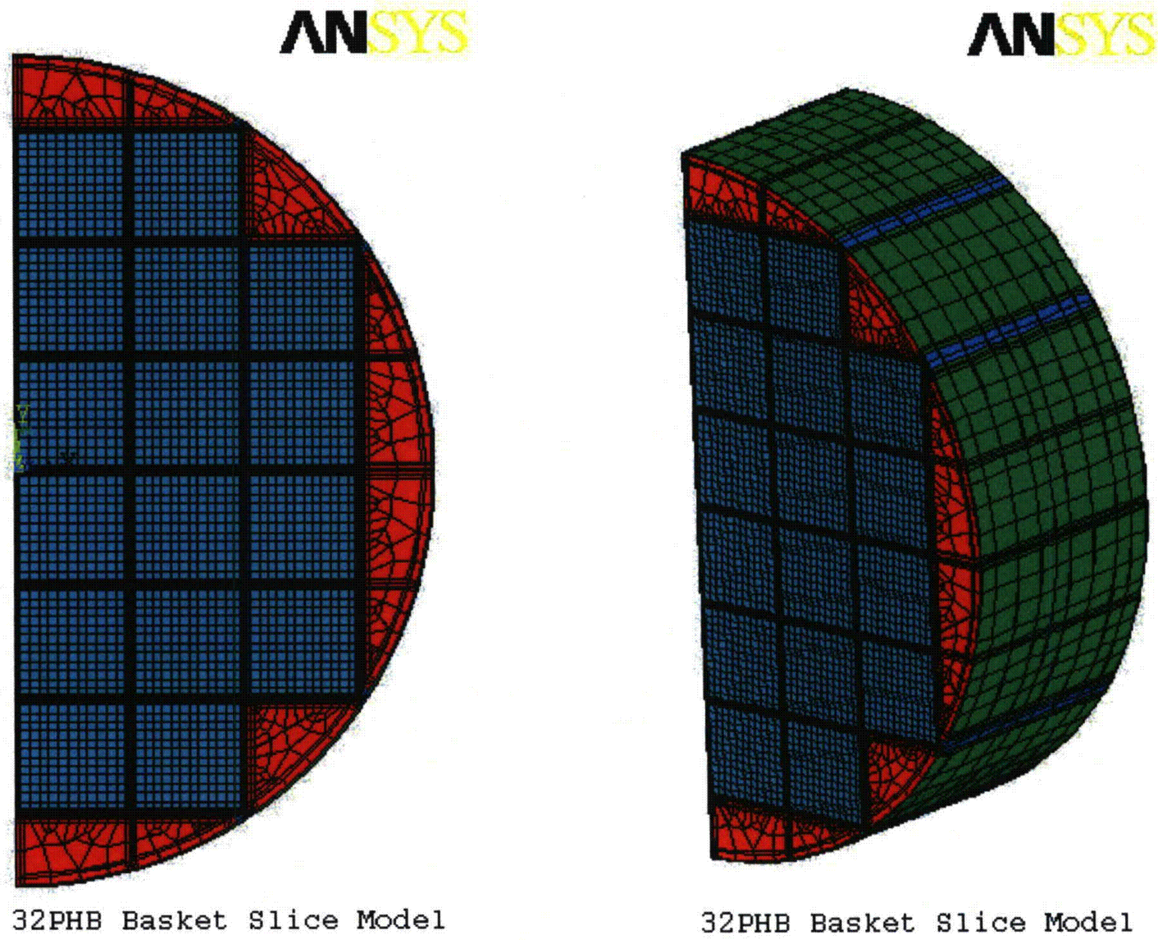


Figure 5-8 32PHB Basket Slice Models

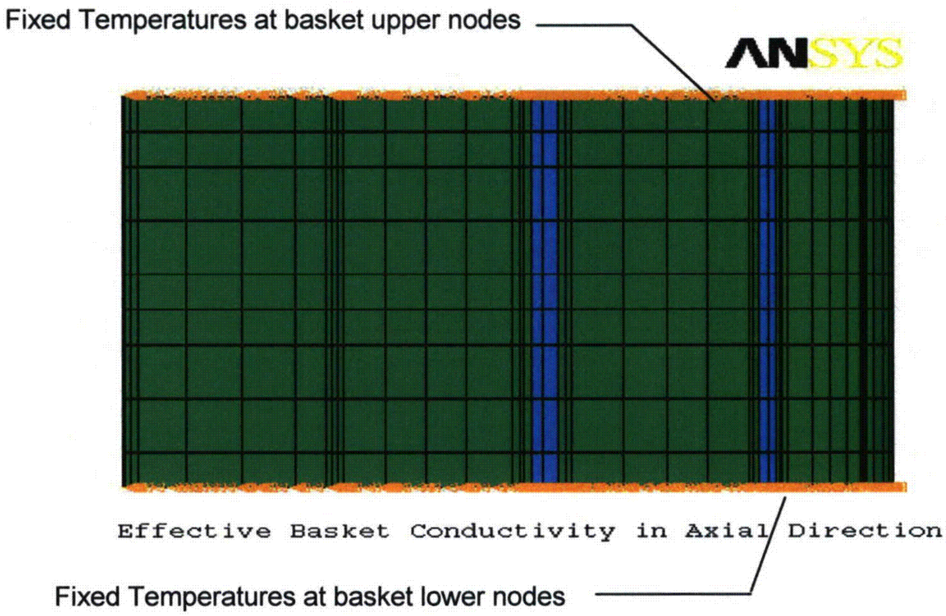
5.2.2.1 Axial Effective Thermal Conductivity

To calculate the axial effective conductivity of the basket, constant temperature boundary conditions are applied at the top and bottom of the slice model. No heat generation is considered for the fuel elements in this case. The axial effective conductivity is calculated using equation (5.6) below.

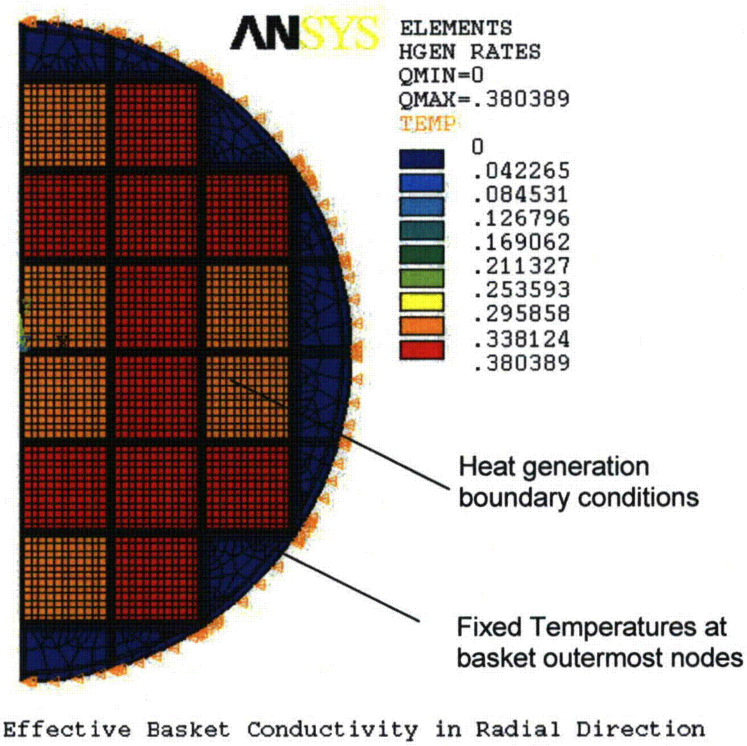
$$k_{basket,axl} = \frac{Q_{axl} \times L}{A_{slice} \times \Delta T} \qquad (5.6)$$

Where:
- Q_{axl} = Amount of heat leaving the upper face of the slice model – reaction solution of the uppermost nodes (Btu/hr),
- L = Length of the model = 22.86",
- A_{slice} = Surface area of the upper (or bottom) face of the basket slice model $\approx$ 1709.73 in^2 ($=\pi/8 \times D_{basket}^2$),
- ΔT = $(T_2 - T_1)$ =Temperature difference between upper and lower faces of the model (°F),
- T_2 = Constant temperature applied on the upper face of the model (°F),
- T_1 = Constant temperature applied on the lower face of the model (°F).

Typical applied boundary conditions are shown in Figure 5-9 (a).



(a) Boundary Condition - Axial Effective Thermal Conductivity



(b) Boundary Condition - Radial Effective Thermal Conductivity

Figure 5-9 Typical Boundary Conditions for Basket Slice Model

In determining the temperature dependent axial effective conductivities an average temperature, equal to $T_{avg} = (T_1 + T_2)/2$, is used for the basket temperature. The axial effective conductivities for 32PHB basket are listed in Table 5-14.

Table 5-14 Effective Axial Conductivity for 32PHB Basket

T_1 (T_{top}) (°F)	T_2 (T_{bottom}) (°F)	T_{avg} (°F)	$Q_{reaction}$ (Btu/hr)	$k_{basket, axl}$ (Btu/hr-in-°F)
50	150	100	14918	1.9946
150	250	200	15252	2.0393
250	350	300	15527	2.0760
350	450	400	15747	2.1055
450	550	500	15826	2.1160
550	650	600	15877	2.1228
650	750	700	15928	2.1297
750	850	800	15972	2.1355
850	950	900	16019	2.1418
950	1050	1000	16061	2.1474

5.2.2.2 Radial Effective Thermal Conductivity

The basket slice model is also used to calculate the transverse effective thermal conductivity of the basket. For this purpose, constant temperature boundary conditions are applied on the outermost nodes of the slice model and heat generating conditions are applied over the fuel elements.

The heat generation rates for the slice model of 32PHB basket are calculated based on the HLZC shown in Figure 5-5 with a total heat load of 29.6 kW and a peaking factor of 1.1 for 32PHB fuel assemblies.

The following equation to calculate maximum temperature is given in [14] for long solid cylinders with uniformly distributed heat sources.

$$T = T_o + \frac{\dot{q}\, r_o^2}{4k}\left[1 - \left(\frac{r}{r_o}\right)^2\right] \qquad (5.7)$$

With T_o = Temperature at the outer surface of the cylinder (°F),
T = Maximum temperature of the cylinder (°F),
$\dot{q}$ = Heat generation rate (Btu/hr-in^3),
r_o = Outer radius = $D_{basket}/2$ = 33.0" for 32PHB basket,
r = Inner radius,
k = Conductivity (Btu/hr-in-°F).

Equation (5.7) is rearranged to calculate the transverse effective conductivity of the basket as follows.

$$\dot{q} = \frac{Q_{rad}}{V} \qquad (5.8)$$

$$k_{basket,rad} = \frac{Q_{rad} \cdot r_0^2}{4 \cdot V \cdot \Delta T} = \frac{Q_{rad}}{2\pi \cdot L \cdot \Delta T} \qquad (5.9)$$

With Q_{rad} = Amount of heat leaving the periphery of the slice model – reaction solution of the outermost nodes (Btu/hr),
L = Length of the slice model = 22.86",
V = Volume of the slice model = $(\pi r_0^2 L)/2$,
ΔT = $(T_{max} - T_o)$ = Difference between maximum and the outer surface temperatures in (°F).

Since the surface area of the fuel assemblies at the basket cross section is much larger than the other components, assuming a uniform heat generation is a reasonable approximation to calculate the radial effective conductivity.

Typical applied boundary conditions are shown in Figure 5-9 (b).

In determining the temperature dependent transverse effective conductivities an average temperature, equal to $(T_{max} + T_o)/2$, is used for the basket temperature.

The transverse effective conductivities of 32PHB basket are listed in Table 5-15.

Table 5-15 Effective Radial Conductivity for 32PHB Basket

T_O (°F)	T_{MAX} (°F)	T_{avg} [°F]	$Q_{reaction}$ (Btu/hr)	$k_{basket, rad}$ (Btu/hr-in-°F)
100	530	315	9298	0.151
200	605	403	9298	0.160
300	683	492	9298	0.169
400	762	581	9298	0.179
500	843	672	9298	0.189
600	926	763	9298	0.199
700	1010	855	9298	0.209
800	1097	949	9298	0.218
900	1189	1045	9298	0.224
1000	1285	1143	9298	0.227

6.0 RESULTS

For cold normal and cold off-normal storage conditions with -8°F ambient temperature, the 32PHB DSC shell temperatures are derived from 61BTH DSC shell temperatures for normal storage with 0°F ambient temperature and 31.2 kW heat load in the HSM-H model [11]. This approach is conservative and acceptable for thermal evaluation of 32PHB DSC for both cold normal and cold off-normal storage conditions.

As discussed in [16], thermal analysis results of 32PHB DSC for hot off-normal transfer condition bounds all normal and off-normal transfer conditions.

The maximum 32PHB DSC component temperatures are listed in Table 6-1 for normal, off-normal, and accident storage and transfer conditions.

Table 6-1 Maximum 32PHB DSC Component Temperatures

Operating Condition			Fuel Cladding	Basket (Guide Sleeve)	DSC (Shell)	Al/Poison Plate	Basket Rails	Top Shield Plug	Bottom Shield Plug
			T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)
Storage	Normal	Cold (1)	648	626	362	626	372	63	170
		Hot (4)	<724	<706	<436	<705	<461	<185	<273
	Off-Normal	Cold (1)	648	626	362	626	372	63	170
		Hot (2)	724	706	436	705	461	185	273
	Accident	Blocked Vent (3)	867	853	595	853	626	344	496
Transfer	Normal	Cold (6)	<728	<709	<408	<708	<472	<346	<358
		Hot 104°F @ 20 hrs (6)	<728	<709	<408	<708	<472	<346	<358
	Off-Normal	Cold (6)	<728	<709	<408	<708	<472	<346	<358
		Hot 104°F@ 20 hrs	728	709	408	708	472	346	358
	Accident	Fire (7)	932	919	656	919	705	560	570
Within Fuel Building		DSC in Vertical TC @ 20 hrs (5)	733	715	397	715	466	348	365

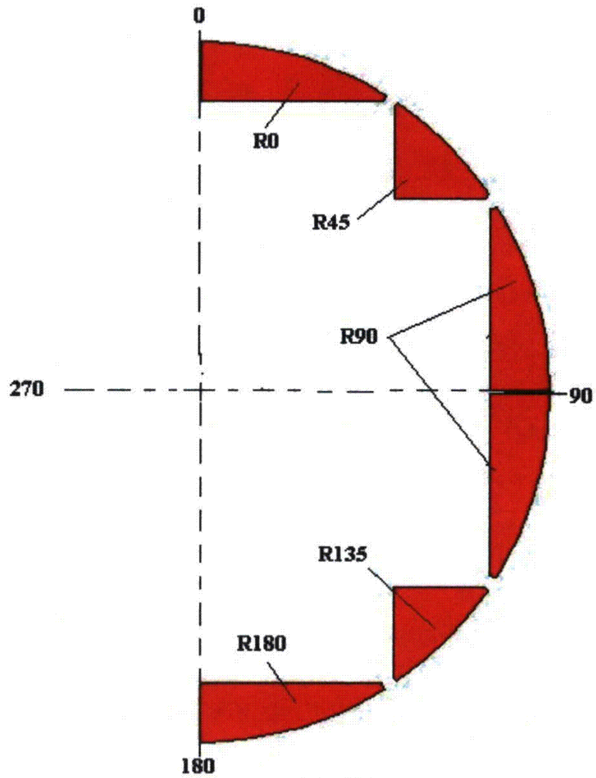
Notes:
(1) Based on normal storage with 0°F ambient temperature.
(2) Based on off-normal storage with 105°F average ambient temperature.
(3) Based on accident storage with 40 hours' blocked vent.
(4) Bounded by hot off-normal storage case.
(5) An average ambient temperature of 100°F considered within fuel building and no water in DSC/TC annulus [4].
(6) Bounded by hot off-normal transfer case @ 20 hrs [16].
(7) Based on steady-state fire accident transfer result [16].

Table 6-2 shows the average temperatures for the 32PHB DSC shell and basket components (including the hottest cross section) for normal, off-normal, and accident storage and transfer conditions.

Table 6-2 Average 32PHB DSC Component Temperatures

Operating Condition	Description	Hottest Section (°F) R0 (5)	R45 (5)	R90 (5)	R135 (5)	R180 (5)	Bask. Comp.	Shell	Whole DSC (°F) Bask. Comp	Rail (6)	Shell	Helium (7)	Fuel
Storage Condition													
Normal	Cold (1)	345	364	341	348	354	491	298	431	332	256	415	474
	Hot (4)	<440	<453	<431	<437	<438	<574	<390	<518	<423	<353	<501	<557
Off-Normal	Cold (1)	345	364	341	348	354	491	298	431	332	256	415	474
	Hot (2)	440	453	431	437	438	574	390	518	423	353	501	557
Accident	Block Vent (3)	614	619	601	607	589	730	567	674	586	523	657	708
Transfer Condition													
Normal	Cold (8)	<449	<464	<439	<439	<398	<575	<387	<532	<446	<373	<516	<566
	Hot (8)	<449	<464	<439	<439	<398	<575	<387	<532	<446	<373	<516	<566
Off-Normal	Cold (8)	<449	<464	<439	<439	<398	<575	<387	<532	<446	<373	<516	<566
	Hot 104°F @ 20 hrs	449	464	439	439	398	575	387	532	446	373	516	566
Accident	Fire (9)	685	698	678	680	650	799	642	748	670	607	732	778
Within Fuel Building	DSC in Vertical TC @ 20 hrs (10)	440	458	440	458	440	583	395	541	442	385	526	575

Notes:
(1) Based on normal storage with 0°F ambient temperature.
(2) Based on off-normal storage with 105°F average ambient temperature.
(3) Based on accident storage with 40 hours' blocked vent.
(4) Bounded by hot off-normal storage case.
(5) The locations of the rails are shown in Figure 6-1.
(6) Based on maximum average rail temperatures.
(7) Based on all components in the DSC cavity.
(8) Bounded by hot off-normal transfer case @ 20 hrs [16].
(9) Based on steady-state fire accident transfer result [16].
(10) An average ambient temperature of 100°F considered within fuel building and no water in DSC/TC annulus [4].



32PHB Rails

Figure 6-1 Location of 32PHB Basket Rails

Typical temperature plots for 32PHB DSC components with 29.6 kW heat load are shown in Figure 6-2 to Figure 6-7.

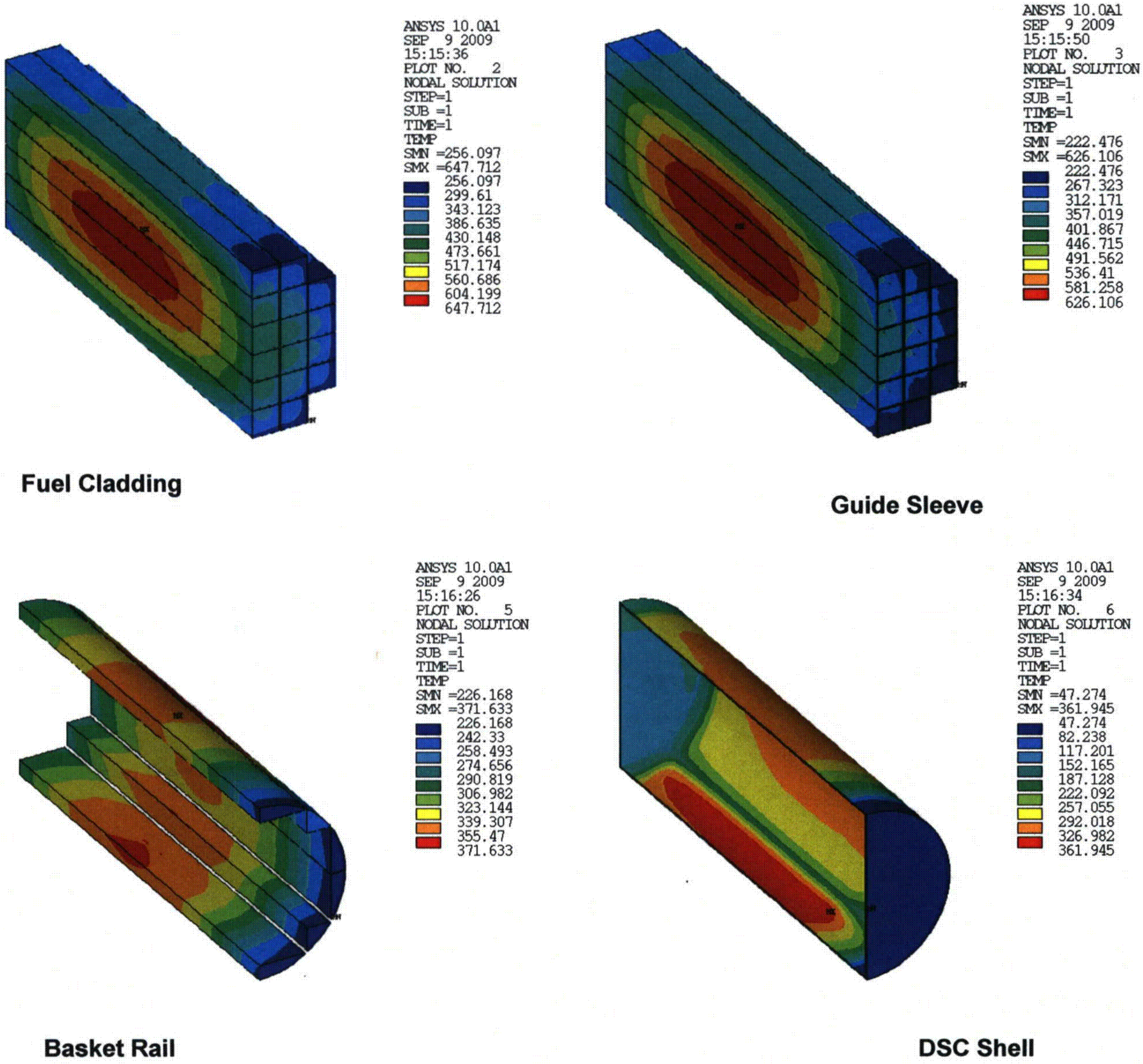


Figure 6-2 Temperature Plots for 32PHB DSC (Normal Storage @ 0°F, 29.6 kW)

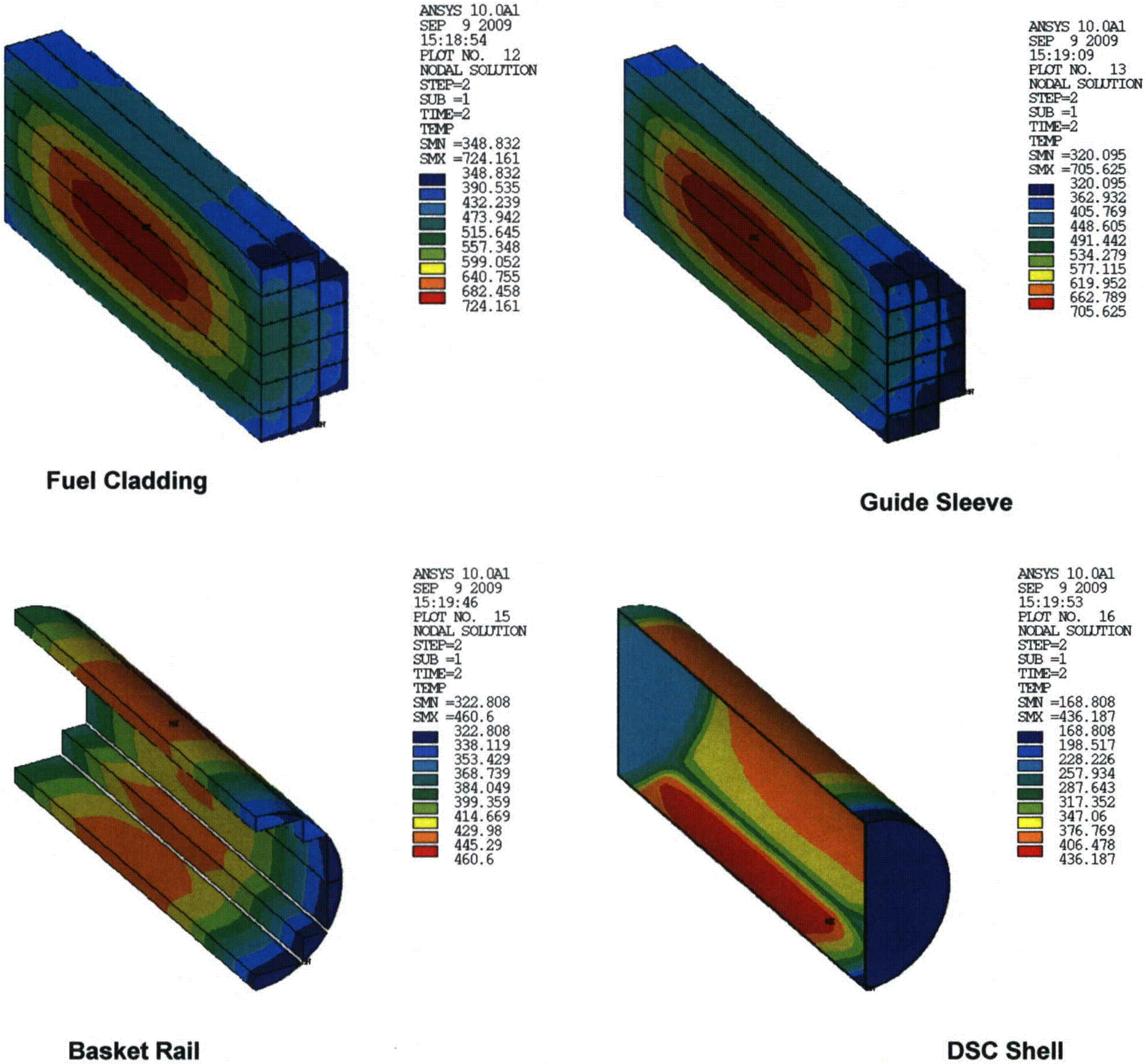


Figure 6-3 Temperature Plots for 32PHB DSC (Off-Normal Storage @ 104°F, 29.6 kW)

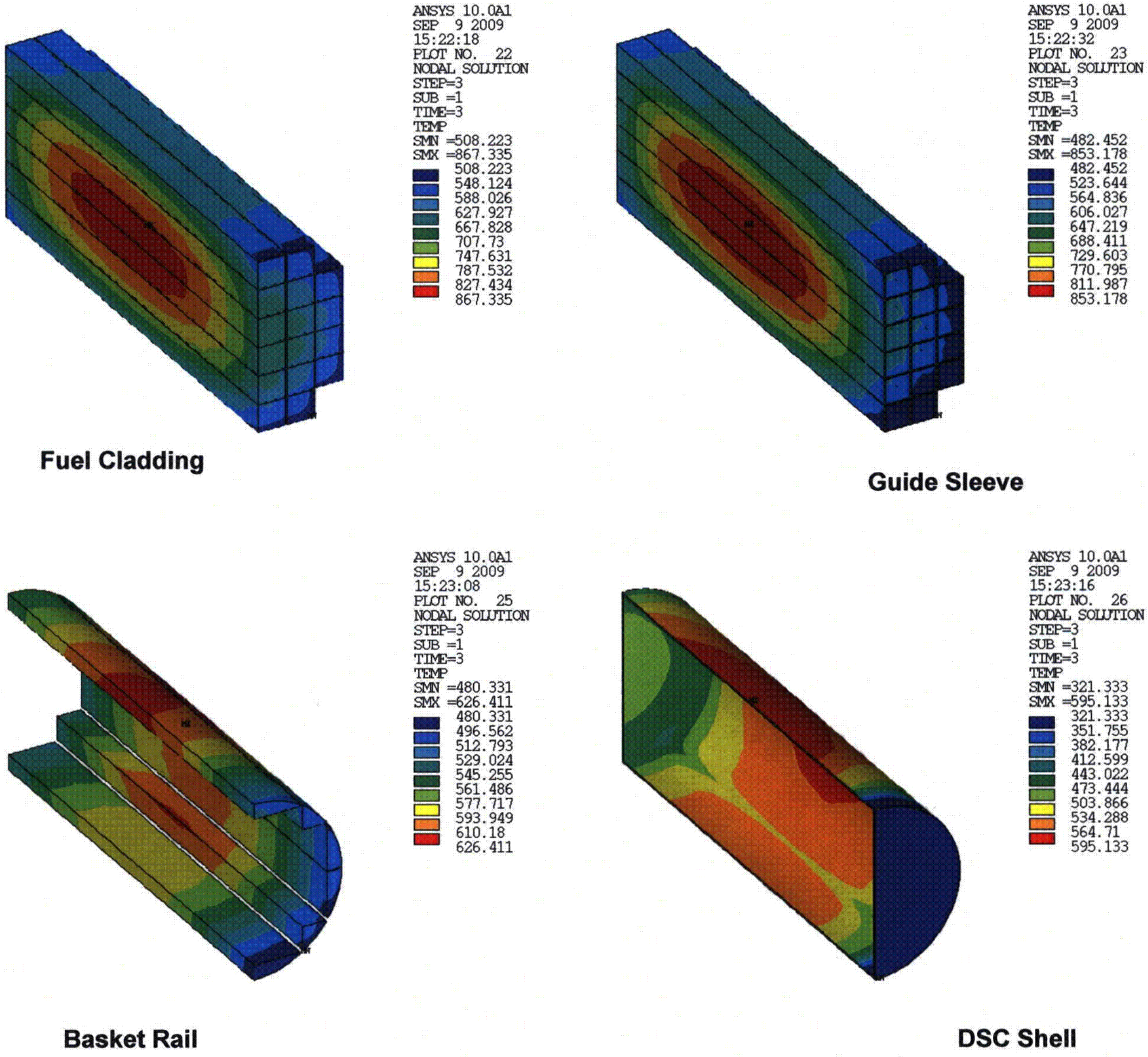


Figure 6-4 Temperature Plots for 32PHB DSC (Block Vent @ 40 Hour, 29.6 kW)

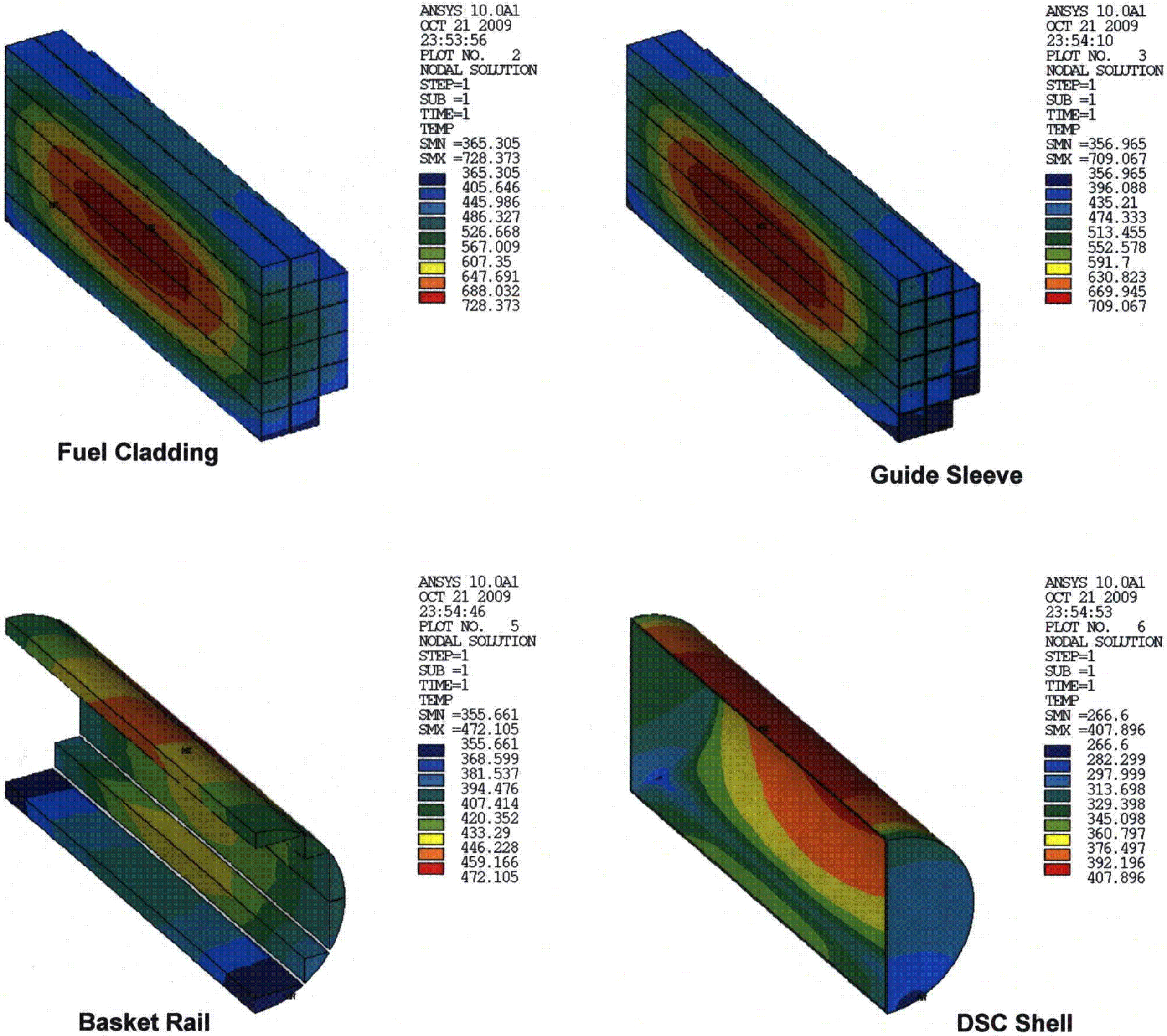


Figure 6-5 Temperature Plots for 32PHB DSC (Off-Normal Transfer, 104°F @ 20 Hour, 29.6 kW)

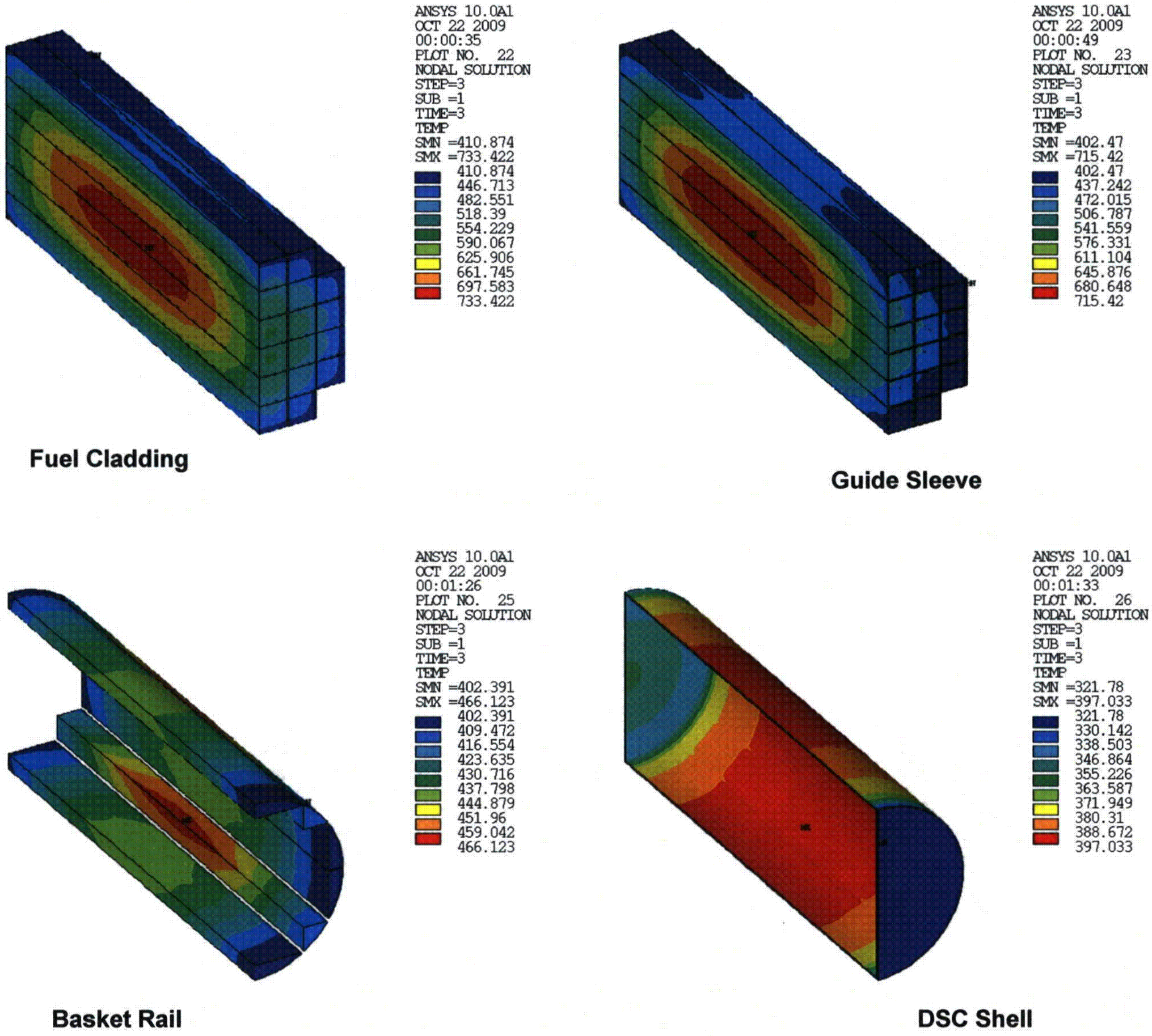
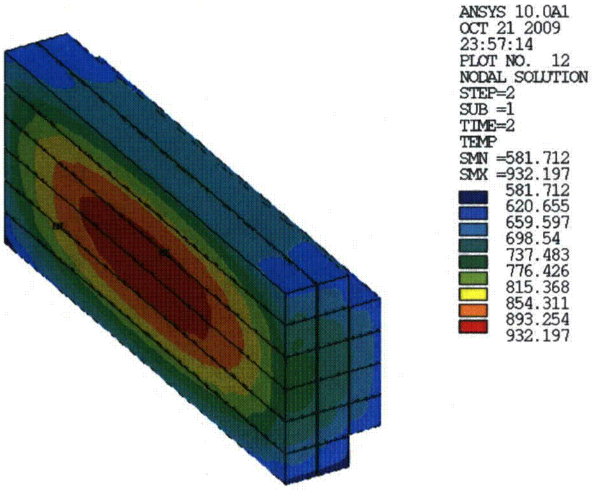
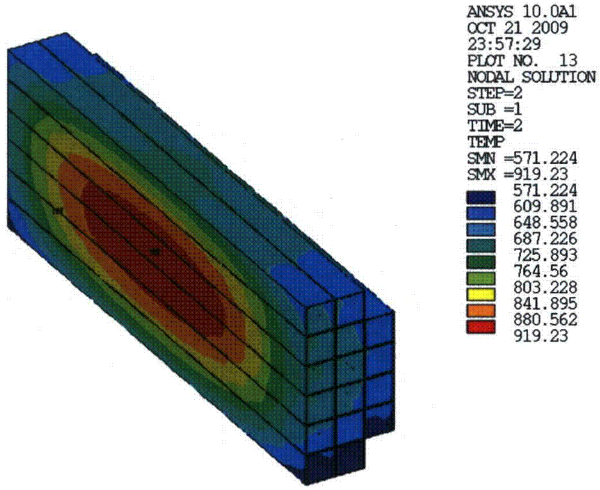


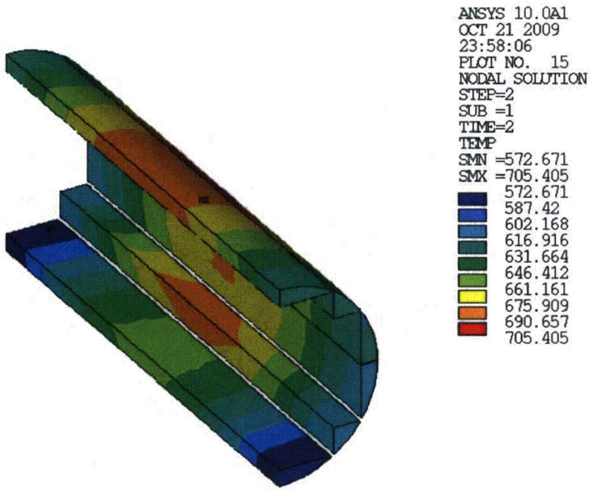
Figure 6-6 Temperature Plots for 32PHB DSC (Vertical Transfer, 100°F @ 20 Hour, 29.6 kW)



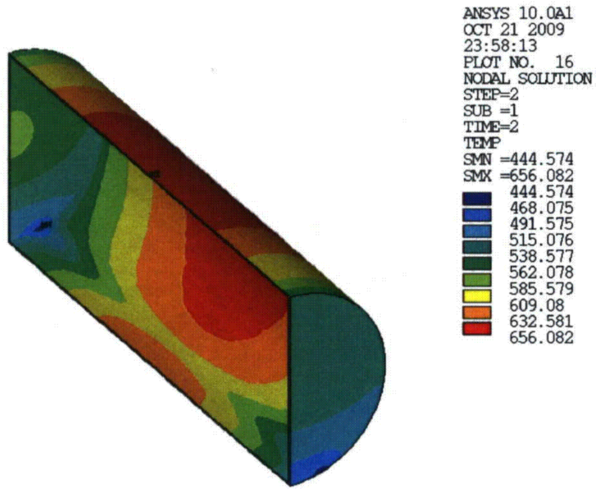
Fuel Cladding



Guide Sleeve



Basket Rail



DSC Shell

Figure 6-7 Temperature Plots for 32PHB DSC (Fire Accident Transfer, 29.6 kW)

7.0 CONCLUSION

The maximum fuel cladding temperatures for 32PHB DSC storage in HSM-HB and transfer in the CCNPP-FC TC are shown in Table 7-1.

Table 7-1 Maximum Fuel Cladding Temperatures for Storage and Transfer Conditions

Operating Condition		Description	Fuel Cladding T_{max} (°F)	Limit T_{limit} (°F)
Storage	Normal	Cold (1)	648	752 [3, 4]
		Hot (4)	<724	
	Off-Normal	Cold (1)	648	1058 [3, 4]
		Hot (2)	724	
	Accident	Block Vent (3)	867	
Transfer	Normal	Cold (6)	<728	752 [3, 4]
		Hot (6)	<728	
	Off-Normal	Cold (6)	<728	1058 [3, 4]
		Hot 104°F @ 20 hrs	728	
	Accident	Fire (7)	932	
Within Fuel Building		DSC in Vertical TC @ 20 hrs (5)	733	752 [3, 4]

Notes: (1) Based on normal storage with 0°F ambient temperature.
(2) Based on off-normal storage with 105°F average ambient temperature.
(3) Based on accident storage with 40 hours' blocked vent.
(4) Bounded by hot off-normal storage case.
(5) An average ambient temperature of 100°F considered within fuel building and no water in DSC/TC annulus [4].
(6) Bounded by hot off-normal transfer case @ 20 hrs [16].
(7) Based on steady-state fire accident transfer result [16].

As seen from Table 7-1, the maximum fuel cladding temperatures calculated for storage and transfer conditions are lower than the allowable limits.

The maximum component temperatures of 32PHB DSC for normal, off-normal, and accident storage conditions are summarized in Table 7-2. All materials can be subjected to a minimum environment temperature of -8°F (-22°C) without any adverse effects.

Table 7-2 Maximum Basket Component Temperatures

Operating Condition		Description	Basket (Compartment)	DSC (Shell)	Al/Poison Plate	Basket Rails	Top Shield Plug	Bottom Shield Plug
			T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)	T_{max} (°F)
Storage	Normal	Cold (1)	626	362	626	372	63	170
		Hot (4)	<706	<436	<705	<461	<185	<273
	Off-Normal	Cold (1)	626	362	626	372	63	170
		Hot (2)	706	436	705	461	185	273
	Accident	Block Vent (3)	853	595	853	626	344	496
Transfer	Normal	Cold (6)	<709	<408	<708	<472	<346	<358
		Hot (6)	<709	<408	<708	<472	<346	<358
	Off-Normal	Cold (6)	<709	<408	<708	<472	<346	<358
		Hot 104°F@ 20 hrs	709	408	708	472	346	358
	Accident	Fire (7)	919	656	919	705	560	570
Within Fuel Building		DSC in Vertical TC @ 20 hrs (5)	715	397	715	466	348	365

Notes: (1) Based on normal storage with 0°F ambient temperature.
(2) Based on off-normal storage with 105°F average ambient temperature.
(3) Based on accident storage with 40 hours' blocked vent.
(4) Bounded by hot off-normal storage case.
(5) An average ambient temperature of 100°F considered within fuel building and no water in DSC/TC annulus [4].
(6) Bounded by hot off-normal transfer case @ 20 hrs [16].
(7) Based on steady-state fire accident transfer result [16].

The maximum temperatures for top and bottom shield plugs are below lead melting temperature limit of 662°F [4]. All design criteria specified in Section 4.2 are herein satisfied.

The effective thermal properties for 32PHB basket are summarized in Table 7-3.

Table 7-3 Effective Thermal Properties for 32PHB Basket

Basket OD = 66.0"
Basket length = 158.0"

Temperature (°F)	$k_{basket, rad}$ (Btu/hr-in-°F)	Temperature (°F)	$k_{basket, axl}$ (Btu/hr-in-°F)	Temperature (°F)	$C_{p\ eff\ basket}$ (Btu/lbm-°F)
315	0.151	100	1.9946	70	0.095
403	0.160	200	2.0393	100	0.096
492	0.169	300	2.0760	200	0.098
581	0.179	400	2.1055	300	0.099
672	0.189	500	2.1160	400	0.100
763	0.199	600	2.1228	500	0.101
855	0.209	700	2.1297	600	0.101
949	0.218	800	2.1355	700	0.101
1045	0.224	900	2.1418	800	0.101
1143	0.227	1000	2.1474	900	0.102
$\rho_{eff\ basket}$ =	0.1308	lbm/in^3		1000	0.102

8.0 LISTING OF COMPUTER FILES

A summary of ANSYS runs is listed in Table 8-1. All the runs are performed using ANSYS version 10.0 [15] with operating system "Linux RedHat ES 5.1", and CPU "Opteron 275 DC 2.2 GHz" / "Xeon 5160 DC 3.0 GHz".

Table 8-1 Summary of ANSYS Runs

Run Name		Description	Date / Time
32PHB_STB1M	Load 1	Normal Storage Conditions, 0°F ambient, 29.6 kW	09/09/09 03:24 PM
	Load 2	Off-Normal Storage Conditions, 104°F ambient, 29.6 kW	
	Load 3	Accident Storage Conditions, Block Vent @ 40 hrs, 29.6 kW	
32PHB_TC2M	Load 1	Off-Normal Transfer Conditions @ 20 hrs, 104°F ambient, 29.6 kW	10/22/09 00:02 AM
	Load 2	Fire Accident Transfer Conditions @ Steady-State, 29.6 kW	
	Load 3	Vertical Transfer Conditions @ 20 hrs, 29.6 kW	
32PHB_Radial_Keff		Effective conductivity for 32PHB basket in radial direction	09/16/09 06:00 PM
32PHB_Axial_Keff		Effective conductivity for 32PHB basket in axial direction	09/14/09 10:50 AM

A list of the macro files to map the DSC shell temperature from 61BTH DSC with 31.2 kW [11] is shown in Table 8-2.

Table 8-2 List of Macro Files to Map DSC Shell Temperatures from 61BTH DSC [11]

File Name (Input and Output)	Description	Date / Time for Output File
TempMap_ST31	Normal storage shell temp – 32PHB DSC model, 29.6 kW @ 0°F	07/13/09 08:52 AM
	Off-Normal storage shell temp – 32PHB DSC model, 29.6 kW @ 105°F	
	Accident storage shell temp – 32PHB DSC model, 29.6 kW, Block Vent @ 40 hrs	

A list of the files to create geometries for 32PHB DSC is shown in Table 8-3.

Table 8-3 List of 32PHB DSC Geometry Generation Files

File Name (Input and Output)	Description	Date / Time for Output File
32PHB_Model	Creates geometry for 32PHB DSC (14×14 for FA mesh)	07/10/09 07:49 PM

ANSYS macros, and associated files used in this calculation are shown in Table 8-4.

Table 8-4 Associated Files and Macros

File Name	Description	Date / Time
32PHB_TC_OFN_TRANS_20hr_Map.cbdo [16]	Off-normal transfer shell temperature profile @ 20 hrs from Transfer Cask model [16].	10/21/09 05:44 PM
32PHB_TC_VERT_TRANS_20hr_Map.cbdo [16]	Vertical transfer shell temperature profile @ 20 hrs from Transfer Cask model [16].	10/21/09 05:49 PM
32PHB_TC_ACC_NS_Map.cbdo [16]	Fire accident transfer shell temperature profile @ steady state from Transfer Cask model [16].	10/21/09 06:00 PM
32PHB_Mat1.inp	Material properties for 32PHB DSC with Helium	09/09/09 09:54 AM
32PHB_HLZC2.MAC	Heat generation for 32PHB DSC, 29.6 kW	09/03/09 08:56 AM
Macro	Macro to get Maximum/Minimum temperatures	05/20/05 12:03 PM
Results.mac	Macro to list maximum and average 32PHB DSC component temperatures	07/22/09 11:52 AM

The spreadsheets used in this calculation are listed in Table 8-5.

Table 8-5 List of Spreadsheets

File Name	Description	Date / Time	
32PHB_Input.xls	Peaking factors and material properties for 32PHB DSC	11/10/09	03:13 PM
32PHB_Basket_Prop.xls	32PHB basket effective properties	11/10/09	03:29 PM
hot_gap_32PHB.xls	Hot gap between 32PHB basket rail/DSC shell	11/03/09	11:04 AM

APPENDIX A JUSTIFICATION OF HOT GAP BETWEEN BASKET AND DSC SHELL

A.1 Hot Gap for 32PHB DSC

Based on sketch NUH32PHB-30-7, Note 8 [7], a nominal diametrical cold gap of 0.375" is considered between the basket and the 32PHB DSC shell. The nominal DSC inner diameter (ID) is 66.0". The nominal basket outer diameter (OD) is then 65.625".

The average temperatures for the basket, aluminum rails, and shell at the hottest cross section for hot off-normal transfer condition are considered to calculate the nominal hot gap size at thermal equilibrium. The average temperatures are listed in Table A–1.

Table A–1 Average Temperatures at Hottest Cross Section for 32PHB DSC

Component	Hot Off-Normal Transfer @ 20 hrs T_{avg} (°F)
Basket (compartments & wrap plates only)	575
Al Rail @ 0 degree	449
Al Rail @ 180 degree	398
DSC Shell	387

The hot dimensions of the basket OD and DSC ID are calculated as follows.

The outer diameter of the hot basket is:

$$OD_{B,hot} = OD_B + [L_{SS,B} \times \alpha_{SS,B} (T_{avg,B} - T_{ref})] + L_{Rail} \times [\alpha_{Al,0} (T_{avg,R0} - T_{ref}) + \alpha_{Al,180} (T_{avg,R180} - T_{ref})]$$

Where:

$OD_{B,hot}$ = hot OD of the basket,

OD_B = nominal cold OD of the basket
= 66.0" – 0.375" = 65.625",

$L_{SS,B}$ = width of basket at 0-180 direction
= 12 × guide sleeve width (0.1874") +
6 × compartment width (8.5") +
7 × basket plate thickness (0.25")
= 12*0.1874+6*8.5+7*0.25 ≈ 54.999",

L_{Rail} = width of aluminum rail = $(OD_B - L_{SS,B})/2 \approx 5.313$",

$\alpha_{SS,B}$ = Average stainless steel axial coefficient of thermal expansion (in/in-°F, interpolated using data in [9] Table TE-1),

α_{Al} = Average aluminum coefficient of thermal expansion (in/in-°F, interpolated using data in [9] Table TE-2),

$T_{avg,B}$ = Average basket temperature at the hottest cross section, see Table A–1 (°F),

$T_{avg,R0}$ = Average Al rail temperature at the hottest cross section at 0 degree orientation, see Table A–1 (°F),
$T_{avg,R180}$ = Average Al rail temperature at the hottest cross section at 180 degree orientation, see Table A–1 (°F),
T_{ref} = reference temperature for stainless steel and aluminum alloys = 70°F [9].

The inner diameter of the hot DSC shell is:

$$ID_{CAN,\ hot} = ID_{CAN}\ [1 + \alpha_{SS,\ CAN}\ (T_{avg,\ CAN} - T_{ref})]$$

Where:
$ID_{CAN,\ hot}$ = Hot ID of DSC shell,
ID_{CAN} = Cold ID of DSC shell = 66.0",
$\alpha_{SS,\ CAN}$ = Average stainless steel axial coefficient of thermal expansion (in/in-°F, interpolated using data in [9] Table TE-1),
$T_{avg,\ CAN}$ = Average DSC shell temperature at hottest cross section, see Table A–1 (°F),
T_{ref} = Reference temperature for low alloy steel = 70°F [9].

The diametrical hot gap between the basket and DSC inner shell is:

$$G_{hot} = ID_{CAN,\ hot} - OD_{B,hot}\ .$$

The diametrical hot gap at the hottest cross section is calculated for 29.6 kW maximum heat loads in 32PHB basket to bound the problem. The calculated hot gap is listed in Table A–2.

Table A–2 Diametrical Hot Gap in 32PHB DSC

29.6 kW Heat Load,	**Off-Normal Transfer**	**@ 104°F**	**Ambient**		
	Cold dimension	Temp	$\alpha x10^{-6}$ (1)	ΔL	Hot dimension
	(in)	(°F)	(in/in/°F)	(in)	(in)
Basket width	54.999	575	9.775	0.271	55.270
Large rail @ 0°	5.313	449	13.796	0.028	5.341
Large rail @ 180°	5.313	398	13.592	0.024	5.337
Basket OD	65.625				65.948
DSC shell ID	66.00	387	9.461	0. 198	66.198
Gap	0.375				**0.25**

Note: (1) The average thermal expansion coefficient is calculated by interpolation using data in [9] Table TE-1 Group 3 for stainless steel and Table TE-2 for aluminum.

A uniform diametrical hot gap of 0.27" is considered in the model between the basket and the DSC shell. This assumption is conservative since the hot gap calculated in Table A–2 is smaller than the assumed gap of 0.27".