CHAPTER 4
THERMAL EVALUATION

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4. THERMAL EVALUATION

NOTE: Since the basket types directly correlate to the Heat Load Zone Configurations (HLZCs), throughout this chapter, basket types are directly referred to by the HLZC.

The thermal evaluation described in this chapter is applicable to the NUHOMS® EOS System that includes an EOS-37PTH or EOS-89BTH dry shielded canisters (DSCs) loaded inside the EOS-TC108, EOS-TC125 or EOS-TC135 transfer cask (TC) and the EOS horizontal storage module (HSM) or EOS-HSMS. With respect to thermal evaluations, the EOS-HSM and EOS-HSMS are identical; therefore, when the EOS-HSM is referred to in this chapter, the analysis is applicable to both the EOS-HSM and EOS-HSMS.

A summary of the EOS-37PTH and EOS-89BTH DSC configurations analyzed in this chapter is shown below:

DSC Type	Heat Load Zone Configuration (HLZC)	Max. Heat Load (kW)	Transfer Cask	Storage Module
EOS-37PTH	1	50.00	EOS-TC125/ EOS-TC135	EOS-HSM/ EOS-HSMS
	2	41.80	EOS-TC125/ EOS-TC135/ EOS-TC108	
	3	36.35		
EOS-89BTH	1	43.60	EOS-TC125	
	2	41.60	EOS-TC125/ EOS-TC108	
	3	34.44		

Descriptions of the detailed analyses performed for normal, off-normal, and hypothetical accident conditions are provided in Section 4.4 for storage operations, Section 4.5 for transfer operations in EOS-TC125/EOS-TC135, and Section 4.6 for transfer operations in EOS-TC108. The thermal analyses performed for the loading and unloading conditions are described in Section 4.5.11. DSC internal pressures are discussed in Section 4.7.

4.1 Discussion of Decay Heat Removal System

The EOS-37PTH and EOS-89BTH DSCs are designed to passively reject decay heat during storage and transfer for normal, off-normal, and hypothetical accident conditions while maintaining temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to material limits to ensure components perform their intended safety functions,
- Determination of temperature distributions to support the calculation of thermal stresses,
- Determination of maximum DSC internal pressures for normal, off-normal, and hypothetical accident conditions, and
- Determination of the maximum fuel cladding temperature, and to confirm that this temperature will remain sufficiently low to prevent unacceptable degradation of the fuel during storage.

The EOS-37PTH DSC is analyzed based on a maximum heat load of 50.0 kW from 37 pressurized water reactor (PWR) fuel assemblies (FAs) with a maximum heat load of 2.0 kW per assembly. The EOS-89BTH DSC is analyzed based on a maximum heat load of 43.6 kW from 89 boiling water reactor (BWR) fuel assemblies (FAs) with a maximum heat load of 0.6 kW per assembly. The authorized heat load zoning configurations (HLZC) for each DSC type are provided in Figures 1 and 2 of the Technical Specification [4-24].

Fuel assemblies are considered as homogenized materials in the fuel compartments. The effective thermal conductivity of the FAs used in the thermal analysis is based on the conservative assumption that heat transfer within the fuel region occurs only by conduction and radiation where any convection heat transfer is neglected. The lowest effective properties among the applicable FAs are selected to perform the thermal analysis. Evaluations of heat transfer from the FAs to the basket assembly credits conduction through the basket assembly materials (steel/metal matrix composite/aluminum) and helium fill gas within the DSC. Convection and radiation heat transfer within the basket assembly are conservatively ignored.

During loading and transfer operations, evaluations of the heat transfer from the DSC shell assembly through the TC credit conduction and radiation through the TC/DSC annulus gap, conduction through the various shells of the TC, and convection through the liquid neutron shield along with the impact of the TC being vertical or horizontal. For heat loads above 36.35 kW in the EOS-37PTH DSC and 34.44 kW in the EOS-89BTH DSC, there is a time limit to transfer. If this time limit cannot be met, then either the TC/DSC annulus gap must be refilled with water or forced cooling (convection) must be implemented.

During DSC storage in the EOS-HSM, the evaluation of the heat transfer from the DSC shells through the EOS-HSM credits conduction, convection, and radiation in the following manners:

- Conduction through the DSC shell assembly and into the DSC support structure in the EOS HSM,
- Convection through the air flowing from the front vents around the DSC and out of the roof vents, and
- Radiation from the DSC outer surface to the concrete and heat shields in the EOS-HSM.

There is no instrumentation required to monitor TC thermal performance. For the EOS-HSM, no instrumentation is required to monitor the thermal performance if daily visual inspections of the air inlet and outlet vents are performed. However, in lieu of the daily visual inspections, a direct measurement of the EOS-HSM temperature or any other means that would provide an indication of the thermal performance may be used for monitoring in accordance with requirements in Technical Specifications.

4.2 Material and Design Limits

To establish the heat removal capability, several thermal design criteria are established for the NUHOMS® EOS System. These are:

- Maximum temperatures of the containment structural components must not adversely affect the containment function.
- A maximum fuel cladding temperature limit of 400 °C (752 °F) has been established for normal conditions of storage and for short-term storage operations such as transfer and vacuum drying [4-1]. During off-normal storage and accident conditions, the fuel cladding temperature limit is 570 °C (1058 °F) [4-1].
- A maximum temperature limit of 327 °C (620 °F) is considered for the lead in the TC, corresponding to the melting point [4-2].
- A maximum temperature limit of 128 °C (262 °F) is considered for the bottom neutron shield (Borotron® HD050) in the TC, corresponding to the melting point [4-3].
- The temperature of the water in the neutron shield is limited by the rating of the pressure relief valves (20 psig) on the neutron shield. The temperature of the water cannot rise above the equivalent steam saturation temperature at this pressure (i.e., approximately 259 ºF) without risk of activating the relief valves and losing some of the water in the neutron shield.
- The ambient temperature ranges are -20 to 100 °F (-28.9 to 37.8 °C) for normal storage, and -40 to 117 °F (-40 to 47.2 °C) for off-normal storage operations. The ambient temperature ranges are 0 to 100 °F (-17.8 to 37.8 °C) for normal transfer and 0 to 117 °F (-17.8 to 47.2 °C) for off-normal transfer operations. In general, all the thermal criteria are associated with maximum temperature limits and not minimum temperatures. All materials can be subjected to a minimum environment temperature of -40 °F (-40 °C) without adverse effects.
- The maximum DSC internal pressure during normal and off-normal conditions must be below the pressure of 20 psig used for structural evaluations. For hypothetical accident cases, the maximum DSC internal pressure must be lower than 130 psig. The evaluations of the maximum DSC internal pressure during normal, off-normal, and hypothetical accident conditions assume the rupture of 1%, 10 %, and 100% of the fuel rods, respectively.
- For normal and off-normal conditions, the maximum concrete temperature limit is 300 °F, as noted in Section 3.5.1.2 of [4-1]. For the accident conditions, if the concrete temperature exceeds the short-term limit of 350 °F noted in Appendix E.4 of ACI 349-06[4-4], concrete testing will be performed, as described in Section 8.2.1.3.

4.2.1 Summary of Thermal Properties of Materials

Thermal properties for the various components identified in the drawings in Chapter 1 and, also, for materials such as helium and air are provided in Chapter 8. The thermal properties listed in Chapter 8 are converted to SI units for the evaluations presented in Section 4.4 for storage operations, Sections 4.5 and 4.6 for transfer operations in EOS-TC125/EOS-TC135/EOS-TC108. The effective thermal properties used in the thermal evaluations based on the various methodologies described in this chapter are listed in this section. The following nomenclature is used in the tables of material properties.

T = temperature,
k = thermal conductivity,
C_p = specific heat,
ρ = density.

1. Bounding Transverse and Axial Effective Thermal Conductivities of FAs in EOS-37PTH DSC

	T (K)	**k_{eff} W/(m-K)**
Transverse	344.15	3.047E-01
	394.15	3.589E-01
	446.15	4.266E-01
	497.15	5.107E-01
	550.15	6.043E-01
	603.15	7.110E-01
	656.15	8.241E-01
	710.15	9.800E-01
	764.15	1.133E+00
	819.15	1.295E+00
	873.15	1.450E+00
Axial	**T (K)**	**k_{eff} W/(m-K)**
	366.15	0.957
	422.15	1.008
	477.15	1.056
	533.15	1.104
	589.15	1.149
	700.15	1.243

The above data are inputted into ANSYS FLUENT CFD model based on the following polynomial functions from the curve fitting.

$k = \Sigma C_i T^i$ for conductivity in (W/m-K) and T in (K)

	Transverse	**Axial**
C0	4.3074E-01	4.8590E-01
C1	-1.6875E-03	1.7489E-03
C2	4.2472E-06	-1.6031E-06
C3	-1.1101E-09	9.2774E-10

2. Bounding Effective Specific Heat and Density of Fuel Assemblies in EOS-37PTH DSC

T (K)	**$C_{p\ eff}$ J/(kg-K)**	**ρ_{eff} (kg/m^3)**
300.15	241.1	2679
400.15	270.6	
640.15	300.8	
1090.15	326.3	

The above data are inputted into ANSYS FLUENT CFD model based on the following polynomial functions from the curve fitting.

$c_p = \sum A_i T^i$ for specific heat in (J/kg-K) and T in (K)

A0	1.6262E+02
A1	3.1873E-01
A2	-1.5495E-04

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8. Bounding Transverse and Axial Effective Thermal Conductivities of Fuel Assemblies in EOS-89BTH DSC

	T (K)	**k_{eff} W/(m-K)**
Transverse	324	2.92E-01
	378	3.42E-01
	432	4.02E-01
	486	4.74E-01
	540	5.55E-01
	595	6.48E-01
	649	7.49E-01
	704	8.60E-01
	759	9.88E-01
	814	1.12E+00
	869	1.27E+00
Axial	**T (K)**	**k_{eff} W/(m-K)**
	366	8.88E-01
	422	9.35E-01
	477	9.80E-01
	533	1.02E+00
	589	1.07E+00
	700	1.15E+00

The above data is inputted into ANSYS FLUENT CFD model based on the following polynomial functions from the curve fitting.

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

	Transverse	**Axial**
C0	2.021E-01	4.539E-01
C1	-2.858E-04	1.605E-03
C2	1.732E-06	-1.453E-06
C3	7.401E-12	8.390E-10

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13. Surface Properties

Material	Emissivity (ε)	Solar Absorptivity (α)	References
Zircaloy based Fuel Cladding	0.8	--	Figure 3.4-1 from [4-16]
Aluminum	0.09	--	[4-17]
Stainless steel	0.46 (1)	--	[4-19], Appendix U, Section U.4.2
	0.587 (2)	--	[4-18]
Carbon steel	0.55	--	[4-19], Appendix U, Section U.4.2
Concrete	0.9 (3)	1.0	[4-17]

Notes:
1. For machined or flat stainless steel surfaces
2. For rolled surfaces of the DSC cylindrical shell
3. Emissivity of 0.8 is conservatively used in the analyses

Emissivity of rolled stainless steel plates is 0.587 as considered in [4-18]. The emissivity for rolled steel sheets is 0.657 as reported in Table 10-17 of [4-2]. An emissivity of 0.587 is assumed for the exterior surfaces of the DSC.

All exposed internal and external surfaces of the transfer cask are painted. Based on the emissivities listed in Table B-1 of [4-17], it is observed that all paints have an emissivity between 0.92-0.96. Therefore, an emissivity of 0.9 is used for all painted surfaces of the TC.

Based on Table B-2 of [4-17], the solar absorptivity for white paints is between 0.09 and 0.23. To account for dust and dirt and to bound the problem, the thermal analysis uses a solar absorptivity of 0.3 for all the painted external surfaces.

The solar absorptivity of the concrete surface is 0.73 - 0.91 at 300 K [4-17]. For conservatism, a solar absorptivity of 1 is considered for the concrete surface.

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4.3 Thermal Loads and Environmental Conditions

Ambient temperatures in the range of -20 °F to 100 °F are considered as normal storage conditions. Off-normal ambient temperature is considered in the range of - 40°F to 117°F. A daily average ambient temperature of 90 °F is used in the evaluations, corresponding to a daily maximum temperature of 100 °F for the normal hot storage conditions, and a daily average ambient temperature of 103 °F is used in the evaluations, corresponding to a daily maximum temperature of 117 °F for the off-normal hot storage conditions, based on the methodology presented in Appendix M, Section M.4.5 of [4-19]. Ambient temperatures of -20 °F and -40 °F are considered for the normal and off-normal cold storage conditions, respectively.

EOS-HSM is located outdoors and is exposed to the environment. Wind is a normal environment variable that varies frequently both in direction and magnitude. If the inlet and outlet are close to each other, the wind has a potential to increase the inlet temperature due to intermixing of air entering the inlet and air exiting the outlet. However, in the EOS-HSM the inlet and outlet vents are separated by about 16 ft (192 inches). Due to the large separation in the EOS-HSM between the inlet and outlet vents, there is no impact of wind on the mixing the airflow of the inlet and outlet of the EOS-HSM. Appendix 4.9.4 presents the thermal evaluation of the wind impact on the thermal performance of the EOS-HSM.

4.4 Thermal Evaluation for Storage

This section provides an evaluation of the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC with a maximum heat load of 50 kW and the EOS-89BTH DSC with a maximum heat load of 43.6 kW for normal, off-normal, and hypothetical accident conditions. ANSYS FLUENT CFD models are used to demonstrate that the maximum temperatures of key components such as fuel cladding, concrete, heat shields, etc. are below maximum temperature limits. This section also provides the average temperature of cavity gas for pressure calculation, and the average temperatures of basket plates and DSC shells for thermal expansion calculations.

To evaluate the thermal performance of the EOS-HSM loaded with the EOS-37PTH and EOS-89BTH DSCs, a three-dimensional (3D), half-symmetrical, CFD and thermal model in ANSYS FLUENT [4-5] is developed for each DSC. Due to the complexity of the geometries, it is impractical to generate a single conformal mesh for the whole model. Instead, the EOS-37PTH, EOS-89BTH basket assemblies and the EOS-HSM are separately meshed and combined in ANSYS FLUENT.

Section 4.4.1 and Section 4.4.2 present a description of the loading cases and the CFD model used for the thermal evaluation of the EOS-37PTH during storage in EOS-HSM, respectively. Sections 4.4.3, 4.4.4 and 4.4.5 present the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of storage for the EOS-37PTH DSC.

Section 4.4.6 Section 4.4.7 present a description of the loading cases and the CFD model used for the thermal evaluation of the EOS-89BTH during storage in EOS-HSM, respectively. Sections 4.4.9, 4.4.10 and 4.4.11 present the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of storage for the EOS-89BTH DSC.

4.4.1 EOS-37PTH DSC - Description of Loading Cases for Storage

To determine the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC, the load combinations (load cases) listed in Table 4-1 are evaluated for normal, off-normal, and accident conditions using the CFD model described in Section 4.4.2.3.

The HLZCs are described in Figure 1 of the Technical Specification [4-24] for the EOS-37PTH DSC. As shown in Figure 1 of the Technical Specification [4-24], HLZCs #1, #2 and #3 have identical zoning with different allowable heat loads. Since HLZC #1 has the maximum total heat load and the maximum heat load per FA in each zone, it is the bounding HLZC among all HLZCs. Therefore, load cases for normal, off-normal, and accident conditions will be evaluated with HLZC #1. No thermal evaluation is performed for HLZCs #2 and #3 for all storage conditions.

Among the various load cases shown in Table 4-1, Load Case #1a with HLZC #1 for the EOS-37PTH DSC is the bounding case for normal hot storage conditions among all EOS-37PTH HLZCs (Load Cases #1a-1c). Load Case #2 is the normal cold storage condition with -20 ºF ambient temperature. Its maximum temperatures are bounded by Load Case #1a and temperature gradients are bounded by Load Case #4. Load Case #3 evaluates the off-normal hot storage condition with 117 °F ambient temperature. Load Case #4 analyzes the off-normal cold storage condition with -40°F ambient temperature, and provides the bounding thermal gradients for structural analysis. Insolation is conservatively neglected for load cases with cold ambient temperatures of -20 °F and -40 °F.

Since the EOS-HSM is located outdoors, there is a remote probability that the air inlet or outlet openings will be blocked by debris from events such as flooding, high wind, and tornados. The perimeter security fence around independent spent fuel storage installation (ISFSI) and the location of the air inlet and outlet openings reduce the probability of such an accident. A complete blockage of all air inlets and outlets simultaneously is not a credible event. However, to bound this scenario, Load Case #5 performs a transient analysis assuming complete blockage of the inlet and outlet vents with 117 °F ambient temperature. Initial temperatures are taken from steady-state results of off-normal hot storage condition (Load Case #3). Blocked vents accident transient conditions are considered for up to 40 hours. The test requirements for concrete at elevated temperatures are described in Section 8.2.1.3.

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4.4.3 EOS-37PTH DSC - Normal Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-37PTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-5.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-37PTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-6. The average temperatures of key components of the EOS-HSM loaded with the EOS-37PTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-7.

As shown for Load Cases #1a, 1b, 1c and 2 in Table 4-5 through Table 4-7, the EOS-37PTH DSC with HLZC #1 of 50 kW heat load represents the bounding HLZC among all HLZCs for the EOS-37PTH DSC during normal conditions of storage in the EOS-HSM.

Typical temperature plots for the key components in the EOS-HSM loaded with the EOS-37PTH DSC are shown in Figure 4-12 for normal hot conditions.

Airflow Calculations

The streamlines for the airflow inside the EOS-HSM loaded with the EOS-37PTH DSC under normal hot storage condition is shown in Figure 4-17. Cool air enters into the EOS-HSM from the inlet, absorbs the heat from the EOS-37PTH DSC, and leaves the EOS-HSM through the outlet with higher temperatures.

Table 4-9 summarizes the air temperatures and mass flow rates at the inlet and outlet for Load Case # 1a for normal conditions of storage. The air temperature is increased by 97 °F for normal hot conditions. The mass flow rate imbalances between the inlet and outlet are five to six orders of magnitude lower than the mass flow rates through the inlet and outlet for normal conditions. Therefore, the airflow calculations are convergent.

Hot Gap between Basket Assembly and DSC Shell

A nominal diametrical cold gap of 0.4” is considered between the basket assembly and the DSC shell for EOS-37PTH DSC. The nominal EOS-37PTH DSC inner diameter (ID) is 74.5 inches. The nominal basket outer diameter (OD) is 74.1 inches.

To calculate the minimum gap, the average temperatures for the basket plates, transition rails, and DSC shell at the hottest cross section for normal hot condition are used to calculate the thermal expansion at thermal equilibrium. These temperatures are listed in Table 4-7.

The normal hot storage condition (Load Case #1a) is considered as the bounding case for hot gap calculation, since it has the least margin of maximum fuel cladding temperature from the temperature limit. The hottest cross section is defined as the 2-inch thick section centered at the location where maximum fuel cladding temperature occurs. In the thermal model, a uniform diametrical hot gap of 0.30 inch is considered between the EOS-37PTH DSC shell and basket assembly. The computed hot gap of 0.307 inches, as shown in Table 4-10, is higher than the 0.30-inch gap considered in the CFD model and results in a 1.5 °F higher temperature difference across the gap. Considering a margin of 28 °F between the calculated maximum fuel cladding temperature and the temperature limit for the normal hot storage condition as shown in Table 4-5, using the uniform diametrical hot gap of 0.3 inch is justified.

4.4.4 EOS-37PTH DSC - Off-Normal Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-37PTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-5.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-37PTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-6. The average temperatures of key components of the EOS-HSM loaded with the EOS-37PTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-7.

The basket assembly temperature gradient for storage conditions is calculated as the average temperature difference between the center basket and the DSC shell at the hottest section. The off-normal cold storage condition with 50 kW (Load Case #4) is the bounding case providing the maximum basket assembly temperature gradient.

Typical temperature plots for the key components in the EOS-HSM loaded with the EOS-37PTH DSC are shown in Figure 4-13 and Figure 4-14 for off-normal hot and off-normal cold conditions, respectively.

The minimum temperatures for fuel cladding and basket assembly components are based on assuming no credit for decay heat for off-normal cold storage condition (-40 °F ambient and no insolation) and are summarized in Table 4-8. All materials can be subjected to a minimum environment temperature of -40 °F without any adverse effects.

Airflow Calculations

Table 4-9 summarizes the air temperatures and mass flow rates at the inlet and outlet for Load Cases #3 and 4 for off-normal conditions of storage. The air temperatures are increased by 99 °F and 75 °F for off-normal hot and cold conditions, respectively. The mass flow rate imbalances between the inlet and outlet are five to six orders of magnitude lower than the mass flow rates through the inlet and outlet for off-normal conditions. Therefore, the airflow calculations are convergent.

4.4.5 EOS-37PTH DSC - Hypothetical Accident Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-37PTH DSC for hypothetical accident condition of storage (Load Case # 5) are summarized in Table 4-5.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-37PTH DSC for hypothetical accident condition of storage (Load Case # 5) are summarized in Table 4-6. The average temperatures of key components of the EOS-HSM loaded with the EOS-37PTH DSC for hypothetical accident condition of storage (Load Case # 5) are summarized in Table 4-7. The values listed in Table 4-6 and Table 4-7 for Load Case #5 are based on transient simulation results at 40 hours.

Typical temperature plots for the key components in the EOS-HSM loaded with the EOS-37PTH DSC are shown in Figure 4-15 for hypothetical accident conditions.

For the accident blocked vent condition, the time histories of the maximum and average temperatures for the key components are shown in Figure 4-16. All the temperatures increase steadily during the 40 hours of blocked vent event.

4.4.6 EOS-89BTH DSC - Description of Loading Cases for Storage

To determine the thermal performance of the EOS-HSM loaded with the EOS-89BTH DSC, the load cases listed in Table 4-14 are evaluated for normal, off-normal and accident conditions using the CFD model described in Section 4.4.7.3.

The HLZCs are described in Figure 2 of the Technical Specifications [4-24] for the EOS-89BTH DSC. As shown in Figure 2 of the Technical Specifications [4-24], HLZCs #1, #2 and #3 have identical zoning with different allowable heat loads. Since HLZC #1 has the maximum total heat load and the maximum heat load per fuel assembly in each zone, it is the bounding HLZC among all HLZCs. Therefore, load cases for normal, off-normal, and accident conditions will be evaluated with HLZC #1. No thermal evaluation is performed for HLZCs #2 and #3 for all storage conditions.

Among the various load cases shown in Table 4-14, Load Case #1a with HLZC #1 with 43.6 kW is the bounding case for normal hot storage conditions among all three HLZCs (Load Cases #1a-1c). Load Case #2 and Load Case # 4 evaluate the normal and off-normal cold storage conditions with -20 ºF and -40 ºF ambient temperatures, respectively. These load cases are not explicitly analyzed in this calculation. Instead, the evaluation performed for Load Case #1a is considered to bound these load cases due to the higher ambient temperature for Load Case # 1a.

Load Case #3 evaluates the off-normal hot storage condition with a maximum ambient temperature of 117 °F. Load Case #5 evaluates the complete blockage of the inlet and outlet vents with a maximum ambient temperature of 117 °F for 40 hours. These two load cases are not explicitly analyzed for EOS-89BTH DSC. However, Section 4.4.8 presents an analytical evaluation based on the comparison with the evaluations performed for EOS-37PTH in EOS-HSM with 50 kW heat load.

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4.4.9 EOS-89BTH DSC - Normal Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-89BTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-17.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-89BTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-18. The average temperatures of key components of the EOS-HSM loaded with the EOS-89BTH DSC for normal storage conditions (Load Cases #1a, 1b, 1c and 2) are summarized in Table 4-19.

Typical temperature plots for the key components in the EOS-HSM loaded with the EOS-89BTH DSC are shown in Figure 4-27 for normal hot conditions.

Airflow Calculations

Table 4-21 summarizes the air temperatures and mass flow rates at the inlet and outlet for Load Case # 1a for normal conditions of storage. The air temperature is increased by 89 °F for normal hot conditions. The mass flow rate imbalances between the inlet and outlet are four orders of magnitude lower than the mass flow rates through the inlet and outlet for normal conditions. Therefore, the airflow calculations are convergent.

Hot Gap between Basket Assembly and DSC Shell

A nominal diametrical cold gap of 0.4 inch is considered between the basket assembly and the EOS-89BTH DSC shell. The nominal EOS-89BTH DSC inner diameter (ID) is 74.5 inches. The nominal basket outer diameter (OD) is 74.1 inches.

To calculate the minimum gap, the average temperatures for the basket plates, transition rails, and DSC shell at the hottest cross section for normal hot condition are used to calculate the thermal expansion at thermal equilibrium. These temperatures are listed in Table 4-19.

The normal hot storage condition (Load Case #1a) is considered as the bounding case for hot gap calculation, since it has the least margin of maximum fuel cladding temperature from the temperature limit. The calculated diametrical hot gap at the hottest cross section is 0.304 inch, as listed in Table 4-22. In the thermal model, a uniform diametrical hot gap of 0.30 inch is considered between the EOS-89BTH DSC shell and basket assembly. The computed hot gap of 0.304 inch, as shown in Table 4-22 is higher than the 0.30-inch gap considered in the CFD model and results in a 0.67 °F higher temperature difference across the gap. Considering a margin of 57 °F between the calculated maximum fuel cladding temperature and the temperature limit for the normal hot storage condition, as shown in Table 4-17, using the uniform diametrical hot gap of 0.3 inch is justified.

4.4.10 EOS-89BTH DSC - Off-Normal Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-89BTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-17.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-89BTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-18. The average temperatures of key components of the EOS-HSM loaded with the EOS-37PTH DSC for off-normal storage conditions (Load Cases #3 and 4) are summarized in Table 4-19.

The minimum temperatures for fuel cladding and basket assembly components are based on assuming no credit for decay heat for off-normal cold storage condition (-40 °F ambient and no insolation) and are summarized in Table 4-20. All materials can be subjected to a minimum environment temperature of -40 °F without any adverse effects.

4.4.11 EOS-89BTH DSC - Hypothetical Accident Conditions of Storage

Temperature Calculations

The maximum temperatures of fuel cladding and concrete of EOS-HSM loaded with EOS-89BTH DSC for hypothetical accident storage condition (Load Case # 5) are summarized in Table 4-17.

The maximum temperatures of various components of the EOS-HSM loaded with the EOS-89BTH DSC for hypothetical accident storage condition (Load Case # 5) are summarized in Table 4-18. The average temperatures of key components of the EOS-HSM loaded with the EOS-89BTH DSC hypothetical accident storage condition (Load Case # 5) are summarized in Table 4-19.

4.5 Thermal Evaluation for Transfer in EOS-TC125 or EOS-TC135

The transfer of the EOS-37PTH and the EOS-89BTH DSCs from the fuel building to the EOS-HSM can be performed using an EOS-TC125, EOS-TC135 or EOS-TC108. This section presents the thermal evaluation of the EOS-37PTH and EOS-89BTH DSCs during normal, off-normal and hypothetical accident transfer operations in the EOS-TC125 and EOS-TC135. Section 4.6 presents the thermal evaluation for transfer in the EOS-TC108.

As described in Chapter 1, Section 1.3.4, the EOS-TC135 is a longer variant of the EOS-TC125 with identical limits on the maximum heat loads. Since the heat load is the same but the heat dissipation area and the thermal mass are larger for the EOS-TC135, its temperatures remain bounded by EOS-TC125. Therefore, the evaluations presented in this section for EOS-37PTH and EOS-89BTH DSCs during transfer in EOS-TC125 remain bounding for EOS-TC135.

This section also establishes the maximum time limits for transfer operations during normal and off-normal conditions, and recommends the applicable corrective actions if the transfer operations cannot be completed within the time limits. The time limits are necessary to satisfy the criteria described in Section 4.2 for the fuel cladding and for the various components of the TCs. There are no time limits for any postulated accident conditions considered during transfer operations.

The EOS-TC125 contains design provisions for the use of air circulation system to improve its thermal performance for heat loads greater than 36.35 kW and 34.44 kW for EOS-37PTH DSC and EOS-89BTH DSCs, respectively. The air circulation system consists of redundant, industrial grade pressure blowers and power systems, ducting, etc. When operating, the fan system is expected to generate a flow rate of 850 cfm or greater, which will be ducted to the location of the ram access cover at the bottom of the TC. The air circulation system is not needed for heat loads ≤36.35 kW in EOS-37PTH DSC and ≤ 34.44 kW in EOS-89BTH DSC.

Section 4.5.1 presents a discussion on the various load cases considered in the thermal evaluation of the EOS-37PTH DSC during transfer operations in EOS-TC125. Section 4.5.2 presents a description of the model used for the thermal evaluation of the EOS-37PTH during the transfer in EOS-TC125. Sections 4.5.3, 4.5.4 and 4.5.5 present the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of transfer for the EOS-37PTH DSC in EOS-TC125.

Section 4.5.6 presents a discussion on the various load cases considered in the thermal evaluation of the EOS-89BTH DSC during transfer operations in EOS-TC125. Section 4.5.7 presents a description of the model used for the thermal evaluation of the EOS-89BTH DSC during transfer in EOS-TC125. Sections 4.5.8, 4.5.9, and 4.5.10 present the results of the thermal evaluation for normal, off-normal, and hypothetical accident conditions of transfer for the EOS-89BTH DSC in EOS-TC125.

4.5.1 EOS-37PTH DSC - Description of Load Cases for Transfer

The loading cases considered for transfer of the EOS-37PTH DSC include the vertical loading condition inside of the fuel handling facility, normal and off-normal horizontal transfer conditions with and without air circulation, and two hypothetical accident scenarios. The first accident scenario involves the potential loss of both the air circulation system and the water in the neutron shield. This case includes a transient heat up trend, which achieves the ultimate temperatures under steady-state conditions. The second accident scenario involves a 15-minute hypothetical fire. The maximum duration of the fire event will be controlled under actual operations by administratively limiting the available fuel sources within the vicinity of the EOS-TC125. An additional condition considered in this section involves the potential interruption of the air circulation system, if used, and determines the time available to re-establish the air circulation, complete the transfer operation, or initiate some other recovery mode.

The operating conditions listed in Table 4-23 are analyzed in this section to determine the thermal performance of the EOS-TC125 with the EOS-37PTH DSC. The following naming convention is used in the descriptions of the loading cases listed in Table 4-23:

- Hot refers to the highest ambient temperature with insolation.
- Cold refers to lowest ambient temperature without insolation.
- Horizontal/outdoor refers to transfer operations outside of the fuel building.
- Vertical/indoor refers to operations within the fuel building.
- Steady-state refers to modeling mode for conditions without a time limit.
- Transient refers to modeling mode for conditions with a time limit.

Among the three HLZCs allowed for the EOS-37PTH DSCs as shown in Figure 1 of the Technical Specifications [4-24], steady-state transfer operations are permitted only for HLZC #3. For EOS-37PTH DSC loaded with HLZC #1 and HLZC #2, time limits are established to complete the normal and off-normal transfer operations to ensure that the temperature limits for the various components are not exceeded. There are no time limits associated with accident conditions that are evaluated at steady-state.

A review of the HLZCs #1 and 2 from Figure 1 of the Technical Specifications [4-24] shows that they have identical zones with different allowable heat loads. Since HLZC #1 has the maximum total heat load and the maximum heat load per FA in each zone, it bounds HLZC #2. Therefore, the time limits and the maximum temperatures computed for HLZC #1 are applicable for HLZC #2.

Load Case # 8 (normal hot, vertical steady-state) is used to determine the bounding maximum temperatures for normal loading operations inside the fuel building with the EOS-TC125 loaded with the EOS-37PTH DSC and with the TC/DSC annulus drained. This load case demonstrates that no time limit is required for operations within fuel building for EOS-37PTH DSC with HLZC # 3 (36.35 kW heat load), shown in Figure 1 of the Technical Specifications [4-24].

Load Case # 10 (off-normal hot, horizontal, steady-state) is used to determine the bounding maximum temperatures for normal (Load Case # 9) and off-normal (Load Case # 10) conditions with heat loads less than or equal to 36.35 kW (HLZC # 3). This approach is acceptable since the ambient temperature for Load Case # 10 represents the highest ambient temperature for both Load Cases #9 and 10.

Load Cases # 1, 2, 3 and 4 are used to determine the time limits for the loading operations inside the fuel building or transfer operations outside the fuel building for HLZCs # 1 and 2 (heat loads > 36.35 kW and ≤ 50 kW). In this evaluation, the maximum component temperatures and time limits for the EOS-TC125 loaded with EOS-37PTH DSC and HLZC # 1 (50 kW heat load) are considered to bound the corresponding values for EOS-37PTH DSC with HLZC # 2 (41.8 kW heat load). The transient analyses for both the horizontal transfer operations and vertical loading operations in these load cases begin with the initial conditions established from the steady-state thermal analyses with the EOS-37PTH DSC with water in the TC/DSC annulus at 223 ºF and a 120 °F ambient temperature within the fuel building. In vertical operation, the bottom surface of EOS-TC125 is fixed at 220 ºF to account for the heat dissipation to the floor. For the initial conditions with water in the annulus, a maximum temperature of 223 ºF is considered based on the boiling temperature of water. Since the bottom of the TC is located further away from the heat generating region, assuming a temperature of 220 ºF is reasonable. A review of the Load Cases #2, 3 and 4 shows that Load Case #3 bounds Load Cases #2 and 4 due to higher ambient temperature. Therefore, the time limits determined for Load Case #3 are applicable to Load Cases #2 and 4.

Load Case # 6a (Off-Normal Hot, Horizontal, Transient, Air Circulation) is used to determine the minimum duration required to operate the air circulation. If the air circulation is initiated as a recovery operation during transfer, the air circulation needs to be turned off before transferring the DSC into the storage module. However, due to the large thermal mass of the system, the air circulation needs to be operated for a minimum duration before it can be turned off to allow sufficient cooling time. This load case determines the minimum duration required to operate the air circulation before it can be turned off.

Load Case #6b (Off-Normal Hot, Horizontal, Steady-State, Air Circulation) is performed to demonstrate that the maximum component temperatures for the EOS-TC125 TC and EOS-37PTH DSC remain below the allowable limits if the air circulation as the recovery operation is initiated. This load case bounds the maximum temperatures for heat loads less than or equal to 50 kW when the air circulation is activated.

Load Case #5 considers the accident case of the loss of neutron shield, wherein the liquid neutron absorber is replaced with air, combined with the loss of air circulation in a steady-state analysis. Off-normal ambient temperature of 117 °F is considered for this load case.

Due to large thermal inertia of the EOS-TC125 TC and the relative short period of 15-minute fire, the effect of heat input from the fire on the EOS-37PTH DSC shell and basket assembly is minimal. The maximum DSC shell temperature is achieved at the post-fire steady-state conditions. The conditions and material properties during the post-fire period are the same as those for the accident case of loss of neutron shield and loss of air circulation, except for the TC outer surface emissivity. As discussed in the Updated Final Safety Analysis Report (UFSAR) for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, Revision 14 [4-19], Appendix U, Section U.4.5.4.2, the sooting and oxidation of the exterior TC surfaces for the fire event raise the surface emissivity, thus improving the heat transfer between the TC and the ambient. As shown in the UFSAR, Appendix U, Table U.4-10 and Section U.4.5.5 [4-19], other than certain components at the top and bottom ends of the transfer cask, which are exposed to fire, there are no adverse effects on the performance of the TC due to fire accident. Therefore, maximum temperatures for fire accident transfer case are bounded by the loss of neutron shield, loss of air circulation accident case and no further analysis is required for fire accident transfer case.

Load Case #7 begins at the end of Load Case # 6a, in which the air circulation was in operation, and it applies for an EOS-TC125 with EOS-37PTH DSC with a heat load greater than 36.35 kW. If the air circulation is activated as a recovery operation during transfer, the air circulation needs to be turned off before transferring the EOS-37PTH DSC into the EOS-HSM storage module. This condition presents a routine transfer operation.

A condition is also postulated where the air circulation is lost during transfer operation. To minimize the occurrence of this condition, the EOS-TC125 skid is equipped with redundant industrial grade blowers and each one of these blowers is capable of supplying the required minimum airflow rate. These blowers are also powered with a redundant power supply.

Both of the above scenarios, i.e., turning off air circulation to offload the EOS-37PTH DSC to the storage module or failure of the air circulation, will decrease the heat dissipation and result in a gradual increase of the maximum temperatures of the EOS-TC125 and EOS-37PTH DSC components. Therefore, for these conditions, an additional time limit is calculated to complete the transfer of the EOS-37PTH DSC from the EOS-TC125 to the storage module or to restart the air circulation or initiate other recovery operations to ensure that the peak fuel cladding temperature remains below the temperature limit of 752 °F established in [4-1].

For all the normal, off-normal hot conditions, and accident design load cases considered in Table 4-23, insolation is considered per 10 CFR 71.71 [4-15].

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4.5.3 EOS-37PTH DSC - Normal and Off-Normal Conditions of Transfer

Due to the high decay heat loads considered for the EOS-37PTH DSC, certain time limits are applicable to the transfer operations under normal and off-normal conditions. The time limits are established to maintain the fuel cladding and the EOS-TC125 components temperatures below the allowable limits based on various load cases discussed in Section 4.5.1. An overview of these time limits is provided in Section 4.5.4 and Table 4-31.

4.5.3.1 Normal/Off-Normal Transfer Conditions without Air Circulation for Heat Loads >36.35 and ≤ 50 kW (HLZCs # 1 and 2)

Temperature Calculations

For both the normal hot, vertical transient condition (Load Case # 1) and off-normal hot, horizontal transient condition (Load Case # 3), the initial conditions are determined from a steady-state analysis of the EOS-TC125 with EOS-37PTH DSC with 223 ºF (379 K) water in the TC/DSC annulus.

For both cases, when the clock starts (t= 0), the water in the TC/DSC annulus is assumed to be drained, and the TC closure is completed. For Load Case # 1, the TC is assumed to be left inside the fuel building in a vertical position. For Load Case # 3, the transfer cask is moved outdoor in a horizontal orientation.

For practical purposes, the time limits for vertical or horizontal transfer operations should be considered after sealing the EOS-37PTH DSC when the water in the TC/DSC annulus starts to drain.

Based on the transient thermal analyses, a maximum duration of 14 hours is allowed for both the vertical loading operations (Load Case # 1) and also for the off-normal hot horizontal transfer operations (Load Case # 3) for heat loads >36.35 and ≤ 50 kW.

Table 4-24 summarizes the maximum temperatures for the EOS-TC125 components for Load Cases # 1 and 3. Table 4-29 and Table 4-30 summarize the maximum and average temperatures for the key components of the EOS-37PTH DSC for all load cases listed in Table 4-23.

Figure 4-32 and Figure 4-33 show the temperature distribution of the key components in the EOS-TC125 with EOS-37PTH DSC for, respectively, Load Case # 1 (50 kW, normal hot, vertical transient transfer operations) and Load Case # 3 (50 kW, off-normal hot, horizontal transient transfer operations) at 14 hours after drainage of water in the TC/DSC annulus. Figure 4-38 shows the temperature history of the fuel cladding during the transfer operation for Load Cases #1 and 3.

4.5.3.2 Normal/Off-Normal Transfer Conditions without Air Circulation for Heat Loads ≤ 36.35 kW (HLZC # 3)

Temperature Calculations

Table 4-25 summarizes the maximum temperatures for EOS-37PTH DSC in EOS-TC125 TC loaded with heat loads ≤36.35 kW for both the normal hot vertical steady-state transfer operations (Load Case # 8) and the off-normal hot horizontal steady-state transfer operations (Load Case # 10).

Figure 4-34 and Figure 4-35 show the temperatures distribution of the key components in the EOS-TC125 with EOS-37PTH DSC for, respectively, Load Case # 8 (36.35 kW, normal hot, vertical, steady-state transfer operations) and Load Case # 10 (36.35 kW, off-normal hot, horizontal, steady-state transfer operations).

Based on the analysis results shown in Table 4-25 for Load Cases # 8 and 10, no time limit is required for the transfer operation for heat loads ≤ 36.35 kW (HLZC #3).

4.5.3.3 Normal/Off-Normal Transfer Conditions with Air Circulation for 50 kW Heat Load (HLZC # 1)

Temperature Calculations

Transient (Load Case #6a) and steady-state (Load Case #6b) thermal analyses are performed for the EOS-TC125 with EOS-37PTH DSC and 50.0 kW heat load with air circulation for off-normal, hot, horizontal transfer conditions. They demonstrate that the maximum fuel cladding and TC component temperatures remain below the allowable limits once the air circulation is activated. Table 4-26 summarizes the maximum temperatures for these load cases. The temperature profiles for Load Case #6a are presented in Figure 4-36. The streamlines for the airflow within the TC/DSC annulus gap is shown in Figure 4-37. Based on the transient analysis for Load Case #6a, if air circulation is initiated as a recovery option, it must be operated for a minimum duration of 8 hours to allow sufficient time for the TC/DSC components to cool down.

Transient thermal analysis is performed for the EOS-TC125 with EOS-37PTH DSC and 50.0 kW heat load without air circulation when the air circulation is turned off or lost (Load Case #7). This analysis is assumed to begin with TC and DSC temperatures at the end of Load Case #6a. At time = 0, the fan airflow is turned off or lost and the system starts to heat up.

Based on the transient thermal analysis, a maximum duration of 6 hours is available to complete the transfer of the EOS-37PTH DSC to the EOS-HSM or to re-establish the air circulation. Table 4-27 summarizes the maximum temperatures for this load case. Figure 4-38 shows the temperature history of the fuel cladding during the transfer operation for Load Cases # 6a and 7.

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Based on the above discussion, the flow in the TC/DSC annulus can be characterized as turbulent and that forced convection dominates the heat transfer within the TC/DSC annulus while the blower is in operation. Therefore, the use of the Realizable $k - \varepsilon$ model is acceptable for simulating the air circulation within the TC/DSC annulus.

4.5.4 EOS-37PTH DSC - Time Limits for Normal/Off-Normal Transfer Operations

Based on the results for Load Cases # 8 and 10 in Section 4.5.3.2, steady-state transfer operations are permitted for the EOS-TC125 loaded with the EOS-37PTH DSC with heat loads ≤ 36.35 kW (HLZC # 3).For heat loads > 36.35 kW and ≤ 50 kW (HLZCs # 1 and 2), based on the results for Load Cases # 1 and 3 in Section 4.5.3.1, steady-state transfer operations are not permitted, and a time limit of 14 hours is determined to complete both vertical and horizontal transfer operations.

At the end of the 14 hours transient transfer operation, the maximum fuel cladding temperature reaches 736 °F with sufficient margin to the fuel cladding temperature limit of 752 °F. However, to provide an additional margin and to ensure sufficient time for the initiation of recovery actions, a time limit of 10 hours is chosen for all transfer operations for heat loads > 36.35 kW and ≤ 50 kW (HLZCs # 1 and 2). The maximum fuel cladding temperature at 10 hours after start of the transfer operations is 711 °F.

If transfer operations cannot be completed within the time limit of 10 hours and the TC/DSC is in a horizontal orientation, one of the recovery actions is to initiate air circulation within 1 hour as noted in Technical Specifications [4-24].

If air circulation is initiated as a recovery option, it must be operated for a minimum duration of 8 hours to allow sufficient time for the TC/DSC components to cool down. After 8 hours has elapsed with the blowers in operation, they can be turned off to complete the DSC transfer. The maximum fuel cladding temperature 6 hours after the air circulation is turned off is 737 °F, which has sufficient margin to the temperature limit of 752 °F as shown in Table 4-27. However, to provide additional margin, a time limit of 4 hours is chosen to complete the DSC transfer operations. The maximum fuel cladding temperature 4 hours after the air circulation is turned off is 733 °F, as shown in Table 4-27.

If air circulation cannot be initiated within 1 hour of exceeding the 10-hour time limit specified in Table 4-31, the TC/DSC has to be returned to the cask handling area to be positioned in vertical orientation and then the TC/DSC annulus will be filled with clean water. As specified in the Actions for LCO 3.1.3 of the Technical Specifications [4-24], a total of 5 hours is available to complete Action A.2 and Action A.3 of the LCO 3.1.3 with a maximum duration of 1 hour for Action A.2. The following evaluation considers the maximum duration allowed for Action A.2 (1 hour) and the remaining duration of 4 hours allowed for Action A.3. However, in this instance, the total time from the beginning of transfer operations is 15 hours as shown below.

Total Time for Transfer = T1 + T2 + T3 = 10 hours + 1 hour + 4 hours = 15 hours

where:

T1 = Transfer Time Limit after draining the water from the TC/DSC annulus
= 10 hours (See Table 4-31)
T2 = Time to Initiate Air Circulation = 1 hour (See Technical Specification)

T3 = Time to move the TC/DSC into the cask handling area to be positioned in Vertical orientation and to fill the TC/DSC annulus with clean water = 4 hours (See Technical Specification)

It is very unlikely that air circulation cannot be initiated because of the redundant nature of the air circulation system, which includes redundant blower and power systems. Further, the entire air circulation system is installed on the transfer skid and verified to operate prior to transfer operation as indicated in the Technical Specifications [4-24] and in Chapter 9, Section 9.1.5.

In the extremely unlikely event that air circulation cannot be initiated, the 15 hours duration to complete the refilling of the TC/DSC annulus with water exceeds the 14 hours considered for Load Case #1 and 3 (See Table 4-24). The result of transient analysis presented in Table 4-24 for Load Case # 1 shows that the fuel cladding temperature is 724 °F at 12 hour into the transfer operation and increases to 736 °F after an additional 2 hours. This shows that the fuel cladding temperature increases at most by 6 °F per hour during the transfer operation. Based on this information, the maximum fuel cladding temperature at the end of 15 hours is:

$$T_{max,Fuel,15\ hrs} = T_{max,Fuel,14\ hrs} + \Delta T/hour = 736\ °F + 1\ hour * 6\ °F/hour = 742\ °F$$

where:

$T_{max,Fuel,14\ hrs}$	=	Maximum temperature at the end of 14 hours into transfer operation
	=	736 °F from Table 4-24 @ 14 hours for Load Case #1
$T_{max,Fuel,12\ hrs}$	=	Maximum temperature at the end of 12 hours into transfer operation
	=	724 °F from Table 4-24 @ 12 hours for Load Case #1
$\Delta T/hour$	=	Temperature Increase per hour
	=	6 °F ($T_{max,Fuel,14\ hrs}$ - $T_{max,Fuel,12\ hrs}$ / 2 hours = 6 °F/ hour)

Even for this worst-case condition, the maximum fuel cladding temperature remains below the allowable limit of 752 °F. In addition to the fuel cladding temperature, a review of the maximum temperatures in Table 4-24 shows large margins for other TC components. Therefore, the temperature limits specified for the TC/DSC in Section 4.2 will be satisfied for this condition.

Table 4-31 presents an overview of time limits of the transfer operations based on the discussions presented in Section 4.5.3.

The time limits for transfer operations presented in Table 4-31 are based on the maximum heat load of 50.0 kW and the bounding ambient conditions noted in Section 4.3. However, if the maximum heat load for a loaded DSC is between 36.35 kW and 50 kW, the time limits for transfer operations can be recalculated based on the maximum heat load and ambient conditions for that DSC using the methodology/models presented in Sections 4.5.1 and 4.5.2 to provide more accurate time limits for transfer operations.

4.5.5 EOS-37PTH DSC - Hypothetical Accident Conditions of Transfer

Temperature Calculations

As noted in Section 4.5.1, the accident condition with loss of neutron shield and loss of air circulation (Load Case # 5) is bounding for the fire accident case. The maximum temperatures for the bounding Load Case # 5 are presented in Table 4-28. As shown in Table 4-28, maximum component temperatures are below the allowable limits. Figure 4-39 presents the temperature profiles for the loss of neutron shield and loss of air circulation accident condition for the EOS- TC125 TC loaded with the EOS-37PTH DSC and 50.0 kW heat load.

4.5.6 EOS-89BTH DSC - Description of Load Cases for Transfer

The loading cases considered for transfer of the EOS-89BTH DSC are identical to those described for the EOS-37PTH DSC in Section 4.5.1 and listed in Table 4-23. However, the maximum heat loads and HLZCs for the EOS-89BTH DSC are different from those considered for the EOS-37PTH DSC. The load cases listed in Table 4-23 are applicable to the EOS-89BTH DSC based on the maximum heat loads and the HLZCs shown in Figure 2 of the Technical Specifications [4-24]. As shown in Figure 2 of the Technical Specifications [4-24], HLZCs #1, 2 and 3 are subject to maximum heat loads of 43.6, 41.60 and 34.44 kW, respectively.

Since the same load cases are considered for both the EOS-37PTH and the EOS-89BTH DSCs, and also because the maximum heat load for the EOS-89BTH DSC (43.6 kW) is lower compared to that of the EOS-37PTH DSC (50.0 kW), the thermal evaluation of the EOS-89BTH DSC in EOS-TC125 is not repeated for all the load cases discussed in Section 4.5.1. Instead, the thermal evaluation of the EOS-89BTH DSC in EOS-TC125 is only limited to verify that the maximum temperatures and time limits computed for the EOS-37PTH DSC in EOS-TC125 remain bounding for the EOS-89BTH DSC in EOS-TC125.

4.5.6.1 Load Cases # 1, 2, 3, 4, 6a, and 7

Based on the discussion in Section 4.5.1, Load Cases # 2 and 4 are bounded by Load Case # 3 due to the higher ambient temperature. Since the same load cases as described in Section 4.5.1 are considered for the EOS-89BTH DSC during transfer in EOS-TC125, a similar behavior is expected and no evaluations are needed for Load Cases # 2 and 4.

Due to the lower heat load of 43.6 kW considered for EOS-89BTH DSC compared to the 50 kW considered for the EOS-37PTH DSC, Load Cases # 1, 3, 6a, and 7 are not explicitly analyzed for the EOS-89BTH DSC during transfer in EOS-TC125. However, an analytical evaluation is presented in Section 4.5.6.2 and shows that the maximum temperatures and time limits determined for the EOS-37PTH DSC in EOS-TC125 remain bounding.

4.5.6.3 Load Cases # 5, 6b

Table 4-32 presents a comparison of the maximum component temperatures for the steady-state initial conditions of Load Case #1 between the two systems, i.e., EOS-89BTH DSC loaded in EOS-TC125 at 43.6 kW and EOS-37PTH DSC loaded in EOS-TC125 at 50 kW. It shows that the maximum fuel cladding temperature determined for the EOS-37PTH DSC loaded in EOS-TC125 is bounding. Since the same load cases are considered between the two systems, a similar behavior is expected for these systems for other steady state load cases.

For Load Cases #5 and #6b, since the same heat loads are maintained, i.e., 50 kW for EOS-37PTH DSC loaded in EOS-TC125 and 43.6 kW for EOS-89BTH DSC loaded in EOS-TC125, the maximum temperatures determined for EOS-37PTH DSC loaded in EOS-TC125 will bound those for EOS-89BTH DSC loaded in EOS-TC125. Therefore, no further evaluation is performed for Load Cases #5 and #6b for EOS-89BTH DSC loaded in EOS-TC125.

4.5.6.4 Load Cases # 8, 9 and 10

For load cases that allow steady-state transfer operations (Load Cases # 8, 9 and 10) of the EOS-37PTH DSC in EOS-TC125, as described Section 4.5.1, a review of the maximum fuel cladding temperatures presented in Table 4-29 shows that Load Case # 8 has the least margin to the fuel cladding temperature limit. Since the same load cases are considered for the EOS-89BTH DSC in EOS-TC125, a similar behavior is expected wherein Load Case # 8 will result in the least margin to the fuel cladding temperature limit. Therefore, Load Case # 8 is repeated for the EOS-89BTH DSC in EOS-TC125 to ensure that the maximum fuel cladding temperature remains below that of the EOS-37PTH DSC in EOS-TC125.

In addition, a review of Table 4-29 shows that the maximum fuel cladding temperature determined for Load Case # 8 bounds the temperatures for Load Cases # 9 and 10. Since Load Case # 8 is explicitly analyzed for the EOS-89BTH DSC in EOS-TC125, the temperatures from this evaluation are used to bound the temperature for Load Cases # 9 and 10.

4.5.7 EOS-89TBH DSC - Thermal Model for Transfer in EOS-TC125

4.5.8 EOS-89BTH DSC - Normal and Off-Normal Conditions of Transfer

Due to the high decay heat loads considered for the EOS-89BTH DSC, certain time limits are applicable to the transfer operations under normal and off-normal conditions. The time limits are established to maintain the fuel cladding and the EOS-TC125 components temperatures below the allowable limits based on various load cases discussed in Section 4.5.6. An overview of these time limits is provided in Section 4.5.9 and Table 4-35.

4.5.8.1 Normal/Off-Normal Transfer Conditions without Air Circulation for Heat Loads >34.44 and ≤ 43.6 kW (HLZCs # 1 and 2)

As described in Section 4.5.6.2, the maximum temperatures and time limits determined for the EOS-37PTH DSC with 50 kW heat load during transfer in EOS-TC125 bound the maximum temperatures and time limits determined for the EOS-89BTH DSC with 43.6 kW heat load during transfer in EOS-TC125.

Based on the results of the transient thermal analyses presented in Section 4.5.3.1 for the EOS-37PTH DSC in EOS-TC125 , a maximum duration of 14 hours is allowed for both the vertical loading operations (Load Case # 1) and the off-normal hot horizontal transfer operations (Load Case # 3). The same time limits are applicable for the transfer operations of EOS-89BTH DSC in EOS-TC125 for heat loads >34.44 and ≤ 43.6 kW.

For practical purposes, the time limits for vertical or horizontal transfer operations should be considered after sealing the EOS-89BTH DSC when the water in the TC/DSC annulus starts to drain.

Table 4-34 summarizes the maximum temperatures of the EOS-89BTH DSC in EOS-TC125 for Load Cases # 1, 2, 3 and 4.

4.5.8.2 Normal/Off-Normal Transfer Conditions without Air Circulation for Heat Loads ≤ 34.44 kW (HLZC # 3)

Table 4-33 summarizes the maximum temperatures for EOS-89BTH DSC in EOS-TC125 TC with heat loads ≤34.44 kW for the normal hot vertical steady-state transfer operations (Load Case # 8). Figure 4-41 shows the temperatures distribution of the key components in the EOS-TC125 with EOS-89BTH DSC for Load Case # 8.

Furthermore, as discussed in Section 4.5.6.4, the maximum temperature determined for Load Case # 8 bound the maximum temperatures for Load Case # 9 and 10. Table 4-34 summarizes the maximum temperatures of the EOS-89BTH DSC in EOS-TC125 for Load Cases # 8, 9 and 10.

Based on the analysis results shown in Table 4-34 for Load Cases # 8, 9 and 10, no time limit is required for the transfer operation for heat loads ≤ 34.44 kW (HLZC # 3).

4.5.8.3 Normal/Off-Normal Transfer Conditions with Air Circulation for 43.6 kW Heat Load (HLZC # 1)

As discussed in Section 4.5.3.3, transient (Load Case #6a) and steady-state (Load Case #6b) thermal analyses are performed for the EOS-TC125 loaded with EOS-37PTH DSC and a 50.0 kW heat load with air circulation for off-normal, hot, horizontal transfer conditions to demonstrate that the maximum fuel cladding and TC component temperatures remain below the allowable limits once the air circulation is activated. The maximum temperatures determined for the EOS-37PTH DSC bound the temperatures for the EOS-89BTH DSC in EOS-TC125 as noted in Sections 4.5.6.2 and 4.5.6.3 for Load Cases # 6a and 6b, respectively.

A transient thermal analysis is performed for the EOS-TC125 loaded with EOS-37PTH DSC with 50.0 kW heat load without air circulation to analyze the thermal performance of the system if the air circulation is turned off or lost (Load Case # 7) to determine the maximum fuel cladding and cask component temperatures. This transient analysis begins with TC and DSC at steady-state conditions from Load Case # 6a. At time = 0, the fan airflow is turned off or lost and the system starts to heat up. Based on the transient thermal analysis presented in Section 4.5.3.3 for the EOS-37PTH DSC in EOS-TC125, a maximum duration of 6 hours is available to complete the transfer of the DSC to the EOS-HSM or to re-establish the air circulation.

As described in Section 4.5.6.2, the maximum temperatures and time limits determined for the EOS-37PTH DSC with 50 kW heat load during transfer in EOS-TC125 bound those for the EOS-89BTH DSC with 43.6 kW heat load during transfer in EOS-TC125. The same time limits are applicable for the transfer operations of EOS-89BTH DSC in EOS-TC125.

Table 4-34 summarizes the maximum temperatures of the EOS-89BTH DSC in EOS-TC125 for Load Cases # 6a, 6b, and 7.

4.5.9 EOS-89BTH DSC - Time Limits for Normal/Off-Normal Transfer Operations

Based on the discussion presented in Section 4.5.8.2 for Load Cases # 8 and 10, steady-state transfer operations are permitted for the EOS-TC125 loaded with the EOS-89BTH DSC with heat loads ≤ 34.44 kW (HLZC # 3).

For heat loads >34.44 and ≤ 43.6 kW (HLZC # 1 and 2), based on the discussion presented in Section 4.5.8.1 for Load Cases # 1 and 3, steady-state transfer operations are not permitted, and a time limit of 14 hours is determined to complete both vertical and horizontal transfer operations. However, to provide an additional margin and to ensure sufficient time for the initiation of recovery actions, a time limit of 10 hours is chosen for all transfer operations for heat loads >34.44 and ≤ 43.6 kW (HLZCs # 1 and 2) similar to the approach presented in Section 4.5.4.

Table 4-35 presents an overview of the time limits for all transfer operations based on the discussions presented in Section 4.5.8. The time limits for transfer operations presented in Table 4-35 are based on the maximum heat load of 43.6 kW and the bounding ambient conditions noted in Section 4.3.

However, if the maximum heat load for a loaded DSC is between 34.44 kW and 43.6 kW, the time limits for transfer operation can be recalculated based on the maximum heat load and ambient conditions for that DSC, using the methodology presented in Sections 4.5.1, 4.5.2, and 4.5.3, and the thermal model described in Section 4.5.7 for EOS-89BTH DSC in EOS-TC125 to provide a more accurate time limits for transfer operations.

4.5.10 EOS-89BTH DSC - Hypothetical Accident Conditions of Transfer

As noted in Section 4.5.1, the loss of neutron shield and loss of air circulation is bounding for the fire accident case. The maximum temperatures for the bounding loss of neutron shield and loss of air circulation steady-state accident condition (Load Case # 5) are presented in Table 4-28 for the EOS-37PTH DSC in EOS-TC125. The maximum temperatures determined for the EOS-37PTH DSC bound the temperatures for the EOS-89BTH DSC in EOS-TC125 as noted in Section 4.5.6.3. Table 4-34 summarizes the maximum temperatures of the EOS-89BTH DSC in EOS-TC125 for Load Case # 5. As shown in Table 4-28, maximum component temperatures are below the allowable limits.

4.5.11 Thermal Evaluation for Loading/Unloading Conditions

All fuel loading operations occur when the EOS-37PTH/EOS-89BTH DSCs and EOS-TC125/TC135/TC108 are in the spent fuel pool. The fuel is always submerged in free-flowing pool water permitting heat dissipation. After completion of the fuel loading, the TC and DSC are removed from the pool and the DSC is drained, dried, sealed, and backfilled with helium. These operations occur when the annulus between the TC and DSC remains filled with water.

The water in the annulus is monitored and replenished with fresh water to prevent boiling, and to maintain the water level if excessive evaporation occurs, as noted for the fuel loading operation procedures in Section 9.1. Presence of water within the annulus maintains the maximum DSC shell temperature below the boiling temperature of water in open atmosphere (223 °F).

Water in the DSC cavity is forced out of the cavity (blowdown operation) before the start of vacuum drying. Helium is used as the medium to remove water and subsequent vacuum drying occurs with a helium environment in the DSC cavity. Since the DSC is filled with helium after drainage of water and water is maintained in the annulus between the DSC and TC, there is no time limit for completion of the vacuum drying process.

With helium being present during vacuum drying operations and a DSC shell temperature equal to water boiling temperature of 223 °F, the EOS-37PTH and EOS-89BTH DSC models described in Sections 4.5.2 and 4.5.7, respectively, are used in a steady-state analysis to determine the maximum fuel cladding temperatures for vacuum drying operations in the EOS-37PTH and EOS-89BTH DSCs. The maximum fuel cladding temperatures for vacuum drying operations in the EOS-37PTH and EOS-89BTH DSCs are, respectively, 648 °F at 50 kW decay heat load and 637 °F at 43.6 kW decay heat load, as noted in Table 4-32.

The presence of helium during blowdown and vacuum drying operations and the cooling provided by water in the annulus between the DSC and TC eliminate the thermal cycling of fuel cladding during helium backfilling of the DSCs subsequent to vacuum drying. Therefore, the thermal cycling limit of 65 °C (117 °F) for short-term operations set by NUREG-1536 [4-1] is satisfied for vacuum drying operation.

The bounding unloading operation considered is the reflood of the EOS-37PTH/EOS-89BTH DSCs with water. For unloading operations, the DSC is filled with the spent fuel pool water through its siphon port. During this filling operation, the EOS-37PTH/EOS-89BTH DSC vent port remains open with effluents routed to the plant's off-gas monitoring system.

The maximum fuel cladding temperature during the reflood event is significantly less than the vacuum drying condition, owing to the presence of water/steam in the DSC cavity. Based on the above rationale, the maximum cladding temperature during unloading operation is bounded by the maximum fuel cladding temperature for vacuum drying operation.

Initially, when spent fuel pool water is added to the EOS-37PTH/EOS-89BTH DSC cavity containing hot fuel and basket components, some water will flash to steam causing the internal DSC pressure to rise. This steam pressure is released through the vent port. The procedures in Chapter 9, Section 9.2 specify that the flow rate of the reflood water will be controlled so that the internal pressure in the DSC cavity does not exceed the maximum pressure of 15 psig considered for reflood operations. This is ensured by monitoring the maximum internal pressure in the EOS-37PTH/EOS-89BTH DSC cavity during the reflood event. The reflood for the EOS-37PTH/EOS-89BTH DSCs is evaluated as a Service Level D event with a pressure of 130 psig. The evaluated pressure for the EOS-37PTH/EOS-89BTH DSCs for this condition is well above the pressure limit of 15 psig. Therefore, there is sufficient margin in the DSC internal pressure during the reflood event to ensure that the DSC will not be over pressurized.

The effects of the thermal loads on the fuel cladding during reflood operations are evaluated in Appendix U, Section U.4.7.3 and Appendix T, Section T.4.7.2 of [4-19] for PWR and BWR FAs, respectively. Since the FAs that are allowed in the EOS-37PTH and EOS-89BTH DSCs are the same as those allowed within 32PTH1 and 61BTH DSCs, these evaluations remain valid for EOS-37PTH and EOS-89BTH DSCs.

These loading/unloading evaluation presented in this are also applicable for the EOS-TC108 since the maximum allowable heat loads are lower for both the EOS-37PTH and EOS-89BTH DSCs.

4.6 Thermal Evaluation for Transfer in EOS-TC108

This section presents a summary of the thermal evaluation of the EOS-TC108 with the EOS-37PTH DSC or the EOS-89BTH DSC. As shown in Table 1-1, the EOS-TC108 has a lower weight compared to the EOS-TC125/EOS-TC135, which in turn, contributes to a lower thermal mass. Due to this lower thermal mass, the maximum heat loads allowed are limited to 41.8 kW for EOS-37PTH DSC and 41.6 kW for EOS-89BTH DSC.

Similar to the EOS-TC125, the EOS-TC108 contains design provisions for the use of air circulation system to improve its thermal performance for heat loads greater than 36.35 kW and 34.44 kW for EOS-37PTH and EOS-89BTH DSCs, respectively. The air circulation system consists of redundant, industrial grade pressure blowers and power systems, ducting, etc. When operating, the fan system is expected to generate a flow rate of 850 cfm or greater, which will be ducted to the location of the ram access cover at the bottom of the TC. The air circulation system is not needed for heat loads ≤36.35 kW in EOS-37PTH DSC and ≤ 34.44 kW in EOS-89BTH DSC.

4.6.1 Description of Load Cases for Transfer

The various load cases considered for evaluating the thermal performance of the EOS-TC108 are listed in Table 4-36. The load cases shown in Table 4-36 for EOS-TC108 are similar to the load cases shown in Table 4-23 for EOS-TC125, except for the maximum allowable heat load for Load Cases # 1 through 7. For Load Cases # 1 through 7, the transfer operations in EOS-TC108 are limited to heat loads based on HLZC # 2, shown in Figure 1 of the Technical Specifications [4-24], for EOS-37PTH DSC, and in Figure 2 of the Technical Specifications [4-24]for the EOS-89BTH DSC, unlike the EOS-TC125, where both HLZCs # 1 and 2 are allowed. For Load Cases # 8 through 10, based on HLZC #3, the maximum heat load of the EOS-37PTH DSC and the EOS-89BTH DSC, during transfer in EOS-TC108, remains identical to that considered in EOS-TC125.

Similar to the approach presented in in Section 4.5.6 for the thermal evaluation of EOS-89BTH DSC in EOS-TC125, the thermal evaluation for EOS-37PTH and EOS-89BTH DSCs during transfer in EOS-TC108 does not analyze all the load cases shown in Table 4-36. Instead, the thermal evaluations are only performed to verify that the maximum temperatures and time limits computed for the EOS-37PTH DSC in EOS-TC125 remain bounding for the EOS-TC108 with either the EOS-37PTH DSC or the EOS-89BTH DSC.

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For Load Cases # 5 and 6b, listed in Table 4-36, based on the discussion in Section 4.5.6.3, the maximum temperatures for steady-state conditions will be bounded by the EOS-37PTH DSC in EOS-TC125 with 50 kW heat load, due to the lower heat load of 41.8 kW for EOS-37PTH DSC and 41.6 kW for EOS-89BTH DSC considered during transfer in EOS-TC108.

For Load Cases # 8 through 10, listed in Table 4-36, similar to the approach presented in Section 4.5.6.4, Load Case #8 is evaluated using the thermal models developed for both the EOS-37PTH DSC in EOS-TC108 and EOS-89BTH DSC in EOS-TC108.

4.6.2 Normal and Off-Normal Conditions of Transfer

Due to the high decay heat loads considered for the EOS-37PTH DSC and EOS-89BTH DSC, certain time limits are applicable to the transfer operations under normal and off-normal conditions. The time limits are established to maintain the fuel cladding, and the EOS-TC108 TC components temperatures below the allowable limits based on various load cases discussed in Section 4.6.1. An overview of these time limits is provided in Section 4.6.3 and Table 4-41 for EOS-37PTH DSC in EOS-TC108, and Table 4-44 for EOS-89BTH DSC in EOS-TC108.

4.6.2.1 Normal/Off-Normal Transfer Conditions without Air Circulation (Heat Loads > 36.35 and ≤ 41.8 kW for EOS-37PTH DSC and > 34.44 and ≤ 41.6 kW for EOS-89BTH DSC)

As described in Section 4.6.1, the maximum temperatures and time limits determined for the EOS-37PTH DSC with 50 kW heat load during transfer in EOS-TC125 bound the maximum temperatures and time limits determined for the EOS-37PTH DSC with a maximum heat load of 41.8 kW heat load or EOS-89BTH DSC with a maximum heat load of 41.6 kW.

Based on the results of the transient thermal analyses presented in Section 4.5.3.1 for the EOS-37PTH DSC in EOS-TC125, a maximum duration of 14 hours is allowed for both the vertical loading operations (Load Case # 1) and the off-normal hot horizontal transfer operations (Load Case # 3). The same time limits are applicable for the transfer operations of EOS-37PTH DSC in EOS-TC108 for heat loads >36.35 and ≤ 41.8 kW (HLZC # 2), and also for EOS-89BTH DSC in EOS-TC108 for heat loads >34.44 and ≤ 41.6 kW (HLZC # 2).

For practical purposes, the time limits for vertical or horizontal transfer operations should be considered after sealing the DSC when the water in the TC/DSC annulus starts to drain.

Table 4-40 and Table 4-43 summarize the maximum temperatures of the EOS-37PTH and EOS-89BTH DSCs, respectively, in EOS-TC108 for Load Cases # 1, 2, 3 and 4.

4.6.2.2 Normal/Off-Normal Transfer Conditions without Air Circulation (Heat Loads ≤ 36.35 kW for EOS-37PTH DSC and ≤ 34.44 for EOS-89BTH DSC)

Table 4-39 and Table 4-42 summarize the maximum temperatures for the EOS-37PTH and EOS-89BTH DSCs, respectively, in EOS-TC108 for the normal hot vertical steady-state transfer operations (Load Case # 8). Figure 4-45 and Figure 4-46 show the temperatures distribution of the key components in the EOS-37PTH s and EOS-89BTH DSC, respectively, in EOS-TC108 for Load Case # 8 (normal hot, vertical, steady-state transfer operations).

Furthermore, as discussed in Section 4.6.1, the maximum temperatures determined for Load Case # 8 bound the maximum temperatures for Load Case # 9 and 10. Table 4-40 and Table 4-43 summarize the maximum temperatures of the EOS-37PTH and EOS-89BTH DSCs, respectively, in EOS-TC108 for Load Cases # 8, 9 and 10.

Based on the analysis results shown in Table 4-40 and Table 4-43 for Load Cases # 8, 9 and 10, no time limit is required for the transfer operation of EOS-37PTH with heat loads ≤ 36.35 kW and EOS-89BTH with heat loads ≤ 34.44 kW (HLZC # 3).

4.6.2.3 Normal/Off-Normal Transfer Conditions with Air Circulation (Heat Loads > 36.35 and ≤ 41.8 kW for EOS-37PTH DSC and > 34.44 and ≤ 41.6 kW for EOS-89BTH DSC)

Transient (Load Case #6a) and steady-state (Load Case #6b) thermal analyses are performed for the EOS-TC125 with EOS-37PTH DSC and 50.0 kW heat load with air circulation for off-normal, hot, horizontal transfer conditions to demonstrate that the maximum fuel cladding and TC component temperatures remain below the allowable limits once the air circulation is activated in Section 4.5.3.3. The maximum temperatures determined for the EOS-37PTH DSC in EOS-TC125 with 50 kW heat load bound the temperatures for the EOS-37PTH and EOS-89BTH DSCs in EOS-TC108 as noted in Section 4.6.1.

A transient thermal analysis is performed for the EOS-TC125 loaded with EOS-37PTH DSC and 50.0 kW heat load when the air circulation is turned off or lost (Load Case # 7) to determine the maximum fuel cladding and TC component temperatures. This transient analysis begins with TC and DSC at steady-state conditions from Load Case # 6a. At time = 0, the fan airflow is turned off or lost and the system starts to heat up. Based on the transient thermal analysis presented in Section 4.5.3.3 for the EOS-37PTH DSC in EOS-TC125, a maximum duration of 6 hours is available to complete the transfer of the DSC to the EOS-HSM or to re-establish the air circulation.

As described in Section 4.6.1, the maximum temperatures and time limits determined for the EOS-37PTH DSC with 50 kW heat load during transfer in EOS-TC125 bound the maximum temperatures and time limits determined for the EOS-89BTH DSC with 43.6 kW heat load during transfer in EOS-TC125. The same time limits are applicable for the transfer operations of EOS-89BTH DSC in EOS-TC125.

Table 4-40 and Table 4-43 summarize the maximum temperatures of the EOS-37PTH and EOS-89BTH DSCs, respectively, in EOS-TC108 for Load Cases #6a, 6b, and 7.

4.6.3 Time Limits for Normal/Off-Normal Transfer Operations in EOS-TC108

Based on the discussion presented in Section 4.6.2.2 for Load Cases # 8 and 10, steady-state transfer operations are permitted for the EOS-TC108 loaded with the EOS-37PTH DSC with heat loads ≤ 36.35 kW (HLZC # 3) or EOS-89BTH DSC with heat loads ≤ 34.44 kW (HLZC # 3).

For heat loads >36.35 kW and ≤41.8 kW (HLZC #2) in EOS-37PTH DSC, or heat loads >34.44 and ≤ 41.6 kW (HLZC # 2) for EOS-89BTH DSC during transfer in EOS-TC108, based on the discussion presented in Section 4.6.2.1 for Load Cases # 1 and 3, steady-state transfer operations are not permitted, and a time limit of 14 hours is determined to complete both vertical and horizontal transfer operations. However, to provide an additional margin and to ensure sufficient time for the initiation of recovery actions, a time limit of 10 hours is chosen similar to the approach presented in Section 4.5.4.

Table 4-41 for EOS-37PTH DSC in EOS-TC108 and Table 4-44 for EOS-89BTH DSC in EOS-TC108 present an overview of the time limits of the transfer operations based on the discussions presented in Section 4.6.2.

The time limits for transfer operations presented in Table 4-41 and Table 4-44 are based on the bounding ambient conditions noted in Section 4.3 and the maximum heat loads based on HLZC # 2 for both the EOS-37PTH and EOS-89BTH DSCs. However, if the maximum heat load for a loaded DSC is between maximum heat load for HLZC # 3 and HLZC # 2 for both the EOS-37PTH and EOS-89BTH DSCs, the time limits for transfer operation can be recalculated based on the maximum heat load and ambient conditions for that DSC, using the methodology presented in Sections 4.5.1 and 4.5.2 and the thermal model described in Section 4.6.1 for the EOS-37PTH DSC or EOS-89BTH DSC in EOS-TC108 to provide a more accurate time limit for transfer operation.

4.6.4 Hypothetical Accident Conditions of Transfer

As noted in Section 4.5.1, the loss of neutron shield and loss of air circulation is bounding for the fire accident case. The maximum temperatures for the bounding loss of neutron shield and loss of air circulation steady-state accident condition (Load Case # 5) are presented in Table 4-28 for the EOS-37PTH DSC in EOS-TC125. The maximum temperatures determined for the EOS-37PTH DSC bound the temperatures for the EOS-89BTH DSC in EOS-TC125 as noted in Section 4.6.1. Table 4-40 and Table 4-43 summarize the maximum temperatures of the EOS-37PTH and EOS-89BTH DSCs, respectively, in EOS-TC108 for Load Case # 5. As shown in Table 4-40 and Table 4-43, maximum component temperatures are below the allowable limits.

4.7 Maximum Internal Pressure

This section describes the calculation of the maximum internal pressures for the EOS-37PTH and EOS-89BTH DSCs for normal, off-normal, and accident conditions. The calculations account for the free DSC cavity volume, the quantities of DSC backfill gas, fuel rod fill gas, irradiation gases, and the average gas temperature in the DSC cavity. The internal DSC pressures are then calculated using ideal gas law (*PV=nRT*):

$$P_{DSC} = \frac{\left(1.4504 * 10^{-4} \dfrac{psia}{Pa}\right) * (n_{total}) * R * T_{He\_DSC}}{V_{total} * (1.6387 * 10^{-5} m^3 / in^3)}$$

Where,

n_{total} = Total number of moles of gases within the EOS-37PTH or EOS-89BTH DSC cavity (mol),

R = Universal gas constant (8.314 J/mol-K),

T_{He_DSC} = Average cavity gas temperature in the EOS-37PTH or EOS-89BTH DSC cavity (K),

V_{total} = Total free volume in the EOS-37PTH or EOS-89BTH DSC cavity (in^3),

P_{DSC} = EOS-37PTH or EOS-89BTH DSC internal pressure (psia).

The following conservatisms are considered in calculating the maximum internal pressures within the EOS-37PTH or EOS-89BTH DSCs:

1. The average gas temperatures in the DSC cavity are determined for the bounding fuel assembly with the lowest thermal conductivities, which provides the highest average gas temperatures for FAs in the EOS-37PTH or EOS-89BTH DSC.

2. For conservatism, the average temperatures of FAs are used for the average temperatures of helium within fuel compartments containing FAs. The average temperatures of helium in the EOS-37PTH or EOS-89BTH DSC cavity are used for the average temperature of helium in the DSC cavity outside of fuel compartments.

3. As discussed in Chapter 1, Section 1.1, EOS-37PTH DSCs are variable in lengths with three configurations: short, medium, and long. For each DSC configuration, the bounding amounts of irradiation gases from Section 6.2.7 are used to calculate the maximum pressures. As listed in Table 2-2, CE 15x15 Palisades, BW 15x15 Mark B, and WE 17x17 XL STP FAs are the bounding FAs that provide the smallest DSC cavity free volumes in short, medium, and long EOS-37PTH DSC configurations, respectively. Furthermore, the maximum pressures in the long DSC are bounded by the medium DSC because the long DSC provides a much larger DSC cavity free volume and lower average gas temperatures. For conservatism, CE 15x15 and BW 15x15 FAs are used to evaluate the free volume and average gas temperatures in the EOS-37PTH DSC cavity.

4. For EOS-89BTH DSC, GE 7x7 FA represents the FA with the bounding amount of irradiation gases as discussed in Section 6.2.7. As listed in Table 2-3, the GE 7x7 - 49/0 FA represents the FA with the heaviest fuel payload that fits into the medium EOS-89BTH DSC configuration, which provides the smallest free volume in the DSC cavity. For conservatism, the GE 7x7 – 49/0 FA is used to evaluate the free volume and average gas temperatures in the EOS-89BTH DSC cavity.

5. The highest burnup of 62 GWd/MTU proposed for the EOS-37PTH or EOS-89BTH DSC is assumed for the pressure calculation. Maximum burnup creates a bounding case for the amount of fission gases produced in the fuel rod during reactor operation.

6. For the short and medium EOS-37PTH DSC configurations, the bounding plenum volumes per fuel rod, 0.842 in^3 (CE 15x15 Palisades FA) and 0.989 in^3 (BW 15x15 Mark B10 FA), are conservatively used. For the EOS-89BTH DSC, the bounding plenum volume per fuel rod among all FAs, 2.136 in^3, is conservatively used.

7. For the short and medium EOS-37PTH DSC configurations, the bounding (maximum) initial fuel rod fill pressures, 464.7 psia (CE15x15 Palisades FA) and 429.7 psia (BW 15x15 Mark B10 fuel assembly), are used to maximize the amount of released fill gas from the ruptured rods, respectively. For the EOS-89BTH DSC, the bounding initial fuel rod pressure, P_0 =160 psia (for SVEA FAs), is used to maximize the amount of released fill gas from the ruptured rods.

The following assumptions are considered in calculating the maximum internal pressures within the EOS-37PTH or EOS-89BTH DSC:

1. The DSC internal pressure is calculated for the most limiting normal, off-normal, and accident cases for the EOS-37PTH or EOS-89BTH DSC. For these cases, 1%, 10%, and 100% of the fuel rods are assumed to rupture for normal, off-normal, and accident conditions, respectively. It is considered that 100% of the fuel rod initial fill gas and 30% of the fission gases will be released into the DSC cavity according to Section 4.4.2 of [4-1].

2. The EOS-37PTH or EOS-89BTH DSC is assumed to be backfilled with helium at a pressure of 3.5 psig (2.5 ± 1.0 psig) after vacuum drying.

3. Based on the evaluation presented in Section 4.5.11, the bounding initial thermal condition during and after vacuum during operations is established with helium in the EOS-37PTH or EOS-89BTH DSC cavity and 223 °F water in the TC/DSC annulus. The bounding (lowest) average helium temperatures of 303 °F (424 K) and 299 °F (421 K) are determined and used for the calculation of the initial amount of helium within the EOS-37PTH and EOS-89BTH DSC cavities, respectively.

4. The initial temperature of fill gas in the fuel rod plenum is assumed to be at room temperature (70 °F or 294 K). This is a reasonable assumption since the process takes place in a controlled environment.

4.7.1 Maximum Internal Pressure in EOS-37PTH DSC

4.7.1.1 Free DSC Cavity Volume

The free volume in the EOS-37PTH DSC cavity is calculated as the EOS-37PTH DSC cavity volume minus the volumes of the basket assembly, FAs, and basket assembly hardware. The free volumes in the bounding short and medium EOS-37PTH DSC cavities are summarized in Table 4-45.

4.7.1.2 Average Gas Temperature in DSC Cavity

To calculate the average gas temperatures in the DSC cavity, the free volume in the DSC cavity is divided into two regions. The first region includes the free volume within fuel compartments along the active length of FAs and the second region is the remaining free volume in the DSC cavity outside of the fuel compartments. The average temperature of helium within the cask cavity is then computed as a volume weighted average of the volumetric average temperatures in the two regions.

The average gas temperatures in the EOS-37PTH DSC cavity for normal, off-normal, and accident conditions are summarized in Table 4-45.

4.7.1.3 Quantity of Initial Helium Backfill Gas in the DSC Cavity

The free volume in the EOS-37PTH DSC cavity is assumed to be filled with 3.5 psig (18.2 psia) of helium. Based on the evaluations performed for the loading operations in Section 4.5.11, a bounding (lowest) average temperature of 303 °F (424 K) is determined for the EOS-37PTH DSC cavity gas for the backfilling operation. This temperature is used to determine the quantity of helium backfill gas in the DSC cavity in accordance with ideal gas law ($PV=nRT$). The bounding quantity of helium in the EOS-37PTH DSC cavity due to the initial backfill is summarized in Table 4-45.

4.7.1.4 Quantity of Initial Fill Gas in Fuel Rods

Based on the plenum volume, initial fuel rod fill pressure and initial temperature of fill gas in the fuel rod plenum noted earlier, the quantity of helium fill gas within the fuel rods is computed using the ideal gas law ($PV=nRT$). The bounding quantity of helium within the fuel rods for the bounding FAs in the EOS-37PTH DSC are summarized in Table 4-45 for normal, off-normal, and accident conditions based on 1%, 10%, and 100% rod rupture percentage, respectively.

4.7.1.5 Quantity of Irradiation Gases in Fuel Rods

For the EOS-37PTH DSC, the quantities of irradiation gases in the fuel rods for the bounding FAs for short and medium DSC configurations are 54.8 and 59 moles, respectively, as shown in Section 6.2.7. The irradiation gases are from both the FAs and control components based on a maximum burnup of 62 GWd/MTU. Considering 30% of the irradiation gases are released into the plenum, the total quantities of irradiation gases released per DSC are summarized in Table 4-45 for normal, off-normal, and accident conditions based on 1%, 10%, and 100% rod rupture percentage, respectively.

4.7.1.6 Total Amount of Gases with the EOS-37PTH DSC Cavity

The total amount of gases within the DSC cavity for normal, off-normal, and accident conditions is the sum of the initial helium backfill gas in the DSC cavity noted in Section 4.7.1.3, initial fill gas in the fuel rods released into the DSC cavity from Section 4.7.1.4, and irradiation gases released into the DSC cavity from Section 4.7.1.5.

The total amount of gases within the EOS-37PTH DSC cavity for normal, off-normal, and accident operations are summarized in Table 4-45.

4.7.1.7 Maximum DSC Internal Pressures

The maximum internal pressures for the EOS-37PTH DSC for normal, off-normal and accident operations are calculated using ideal gas law based on the free DSC cavity volume including the plenum volume, average temperatures and the total amount of gases noted in Table 4-45. As shown in Table 4-45, the maximum internal pressures for EOS-37PTH DSC at normal, off-normal, and accident conditions remain below the pressures considered in the structural evaluation.

4.7.2 Maximum Internal Pressure in EOS-89BTH DSC

The maximum internal pressure in the EOS-89BTH DSC in computed using the same approach presented in Sections 4.7.1.1 through 4.7.1.7 for the EOS-37PTH DSC. The maximum internal pressures for the EOS-89BTH DSC for normal, off-normal and accident operations are calculated using ideal gas law based on the free DSC cavity volume including the plenum volume, average temperatures and the total amount of gases noted in Table 4-46. As shown in Table 4-46, the maximum internal pressures for EOS-89BTH DSC at normal, off-normal, and accident conditions remain below the pressures considered in the structural evaluation.

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4-23 Rohsenow, Hartnett, Handbook of Heat Transfer Fundamentals, 2nd Edition, 1985.

4-24 Proposed CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 0.

4-25 W. Rohsenow, J. Hartnett and Y. Cho, "Handbook of Heat Transfer," 3rd Edition, McGraw-Hill, 1998.

4-26 ANSYS FLUENT Theory Guide, Version 14.00, ANSYS Inc.

Table 4-1
EOS-37PTH DSC in EOS-HSM, Design Load Cases for Storage Conditions

Load Case No.	Operation Condition	Description	Ambient Temperature (°F)	Insolation	HLZC
1a	Normal	Normal Hot	100 (1)	Yes	1
1b (2)	Normal	Normal Hot	100 (1)	Yes	2
1c (2)	Normal	Normal Hot	100 (1)	Yes	3
2 (3)	Normal	Normal Cold	-20	No	--
3	Off-Normal	Off-Normal Hot	117 (1)	Yes	1(5)
4 (4)	Off-Normal	Off-Normal Cold	-40	No	1(5)
5 (6)	Accident	Blocked Vents for 40 hours	117 (1)	Yes	1(5)

Notes:

(1) Daily average temperatures are used as noted in Section 4.3.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat loads.

(3) Load Case #2 is bounded by Load Case #4 for largest temperature gradients for structural analyses, and bounded by Load Case #1a for maximum temperatures.

(4) This load case provides the largest temperature gradients for structural analyses.

(5) HLZC #1 is the bounding HLZC among HLZCs #1 to #3.

(6) Initial temperatures are taken from steady-state results of Load Case #3.

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Table 4-3
EOS-37PTH DSC, Applied Peaking Factors for PWR Fuel Assemblies

% of Core Height [4-10]	Length	Peaking Factor [4-10]
0.00	0.00	0
2.78	4.00	0.652
8.33	12.00	0.967
13.89	20.00	1.074
19.44	27.99	1.103
25.00	36.00	1.108
30.56	44.01	1.106
36.11	52.00	1.102
41.69	60.03	1.097
47.22	68.00	1.094
52.78	76.00	1.094
58.33	84.00	1.095
63.89	92.00	1.096
69.44	99.99	1.095
75.00	108.00	1.086
80.56	116.01	1.059
86.11	124.00	0.971
91.67	132.00	0.738
97.22	140.00	0.462
100.00	144.00	0

Table 4-4
EOS-37PTH DSC, Peaking Factors for Fuel Assemblies in the Model

Region #	CFD Model Z-Coord.(1) (in)		% of Active Fuel Length(2)		Average Height from Bottom (in)	Peaking Factor	Area under Curve (in)
	From	To	From	To			
1	0	1.970	0	0.0137	0.985	0.160	0.3160
2	1.970	7.790	0.0137	0.0541	4.880	0.643	3.7406
3	7.790	16.520	0.0541	0.1147	12.155	0.943	8.2302
4	16.520	24.280	0.1147	0.1686	20.400	1.068	8.2865
5	24.280	31.070	0.1686	0.2158	27.675	1.100	7.4673
6	31.070	39.800	0.2158	0.2764	35.435	1.107	9.6634
7	39.800	47.560	0.2764	0.3303	43.680	1.106	8.5816
8	47.560	56.290	0.3303	0.3909	51.925	1.102	9.6197
9	56.290	64.050	0.3909	0.4448	60.170	1.097	8.5140
10	64.050	71.810	0.4448	0.4987	67.930	1.094	8.4924
11	71.810	80.540	0.4987	0.5593	76.175	1.094	9.5519
12	80.540	87.330	0.5593	0.6065	83.935	1.095	7.4350
13	87.330	96.060	0.6065	0.6671	91.695	1.096	9.5657
14	96.060	103.820	0.6671	0.7210	99.940	1.094	8.4899
15	103.820	112.550	0.7210	0.7816	108.185	1.083	9.4557
16	112.550	120.310	0.7816	0.8355	116.430	1.048	8.1360
17	120.310	128.070	0.8355	0.8894	124.190	0.950	7.3686
18	128.070	135.830	0.8894	0.9433	131.950	0.734	5.6995
19	135.830	142.090	0.9433	0.9867	138.960	0.470	2.9391
20	142.090	144.000	0.9867	1.0000	143.045	0.110	0.2105
						Sum	141.76
						Normalized	0.984
						Corr. Factor	1.016

Notes:

(1) Assuming Z=0 is the bottom of the fuel, Z=144" is the top of the fuel.

(2) The percentage is calculated as the Z-coordinate divided by the active fuel length of 144 inches.

Table 4-5
EOS-37PTH DSC in EOS-HSM, Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions

Load Case #(1)	Description	Fuel Cladding Temperature (°F)		Concrete Temperature (°F)	
		Maximum	Limit	Maximum	Limit
1a	Normal hot storage, 50 kW (HLZC#1), Steady-state, 100°F ambient with insolation	724	752(4)	258	300(4)
1b(2)	Normal hot storage, 41.80 kW (HLZC#2), Steady-state, 100°F ambient with insolation	< 724		<258	
1c(2)	Normal hot storage, 36.35 kW (HLZC#3), Steady-state, 100°F ambient with insolation	< 724		<258	
2(3)	Normal cold storage, 50 kW (HLZC#1), Steady-state, -20°F ambient without insolation	< 724		<258	
3	Off-normal hot storage, 50 kW (HLZC#1), Steady-state, 117°F ambient with insolation	734	1058(4)	272	300(4)
4	Off-normal cold storage, 50 kW (HLZC#1), Steady-state, -40°F ambient without insolation	621		116	
5	Blocked vents accident condition at 40 hours, 50 kW (HLZC #1), 117°F ambient with insolation	865		464	500(5)

Notes:

(1) See Table 4-1 for the description of the load cases.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat loads.

(3) Load Case #2 is bounded by Load Case #4 for largest temperature gradients for structural analyses, and bounded by Load Case #1a for maximum temperatures.

(4) The temperature limits are from NUREG-1536 [4-1].

(5) The temperature limit for concrete at accident condition is 500ºF. The maximum concrete temperature for accident conditions is above the 350ºF limit given in ACI-349 [4-4]. Testing will be performed, as described in Section 8.2.1.3.

Table 4-6
EOS-37PTH DSC in EOS-HSM, Maximum Temperatures of Key Components for Storage Conditions

Load Case #(1)	Basket Plate (°F)	Transition Rails (°F)	DSC Shell (°F)	Side Heat Shield (°F)	Top Heat Shield (°F)	Support Structure (°F)
1a	668	516	422	223	234	291
1b(2)	<668	<516	<422	<223	<234	<291
1c(2)	<668	<516	<422	<223	<234	<291
2(3)	<668	<516	<422	<223	<234	<291
3	680	528	435	240	249	305
4	543	388	285	56	69	147
5	830	685	604	483	468	538

Notes:

(1) See Table 4-1 for the description of the load cases.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat loads.

(3) Load Case #2 is bounded by Load Case #4 for largest temperature gradients for structural analyses, and bounded by Load Case #1a for maximum temperatures.

Table 4-7
EOS-37PTH DSC in EOS-HSM, Average Temperatures of Key Components for Storage Conditions

Load Case #[1]	Whole Component					Hottest Section [4]			
	Fuel Assembly (°F)	Cavity Gas (°F)	DSC Shell (°F)	Basket Plates (°F)	R45 Transition Rail (°F)	Center Basket Plate (°F)	R90 Transition Rail @ 180° (°F)	R90 Transition Rail @ 0° (°F)	DSC Shell (°F)
1a	567	382	341	499	429	613	429	469	387
1b[2]	<567	<382	<341	<499	<429	<613	<429	<469	<387
1c[2]	<567	<382	<341	<499	<429	<613	<429	<469	<387
2[3]	<567	<382	<341	<499	<429	<613	<429	<469	<387
3	578	394	354	511	441	625	440	481	400
4	450	251	204	372	301	487	313	338	251
5	727	560	540	671	608	781	625	645	587

Notes:

(1) See Table 4-1 for the description of the load cases.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat loads.

(3) Load Case #2 is bounded by Load Case #4 for largest temperature gradients for structural analyses, and bounded by Load Case #1a for maximum temperatures.

(4) The hottest section is defined as the 2” thick section centered at the location where maximum fuel cladding temperature occurs.

Table 4-8
EOS-37PTH DSC in EOS-HSM, Minimum Temperatures of Components for Storage Conditions

Component	T_{min} (°F)	$T_{min, limit}$ (°F)
Basket Component	-40	-40
Fuel Cladding	-40	-40

Table 4-9
EOS-37PTH DSC in EOS-HSM, Summary of Air Temperatures and Mass Flow Rates at Inlet and Outlet

Load Case #[(1)]	T_{inlet} (°F)	T_{exit} [(2)] (°F)	T_{exit}-T_{inlet} (°F)	Mass Flow Rate at Inlet (kg/s)	Mass Flow Rate at Outlet (kg/s)	Mass Flow Rate Imbalance between Inlet and Outlet (kg/s)
1a	90	188	97	4351.82E-04	-4351.82E-04	2.48E-07
3	103	202	99	4246.60E-04	-4246.58E-04	1.75E-06
4	-40	35	75	5644.78E-04	-5644.76E-04	2.22E-06

Note:

(1) See Table 4-1 for the description of the load cases.

(2) Exit air temperature is computed as the area weighted average over the outlet vent.

Table 4-10
EOS-37PTH DSC, Diametrical Hot Gaps for Basket Assembly

Load Case #1a, 50 kW, HLZC#1					
Component	**Cold Dimension**	**Temp**	**αx10^{-6} (1)**	**ΔL**	**Hot Dimension**
	(in)	**(°F)**	**(in/in-°F)**	**(in)**	**(in)**
Basket width	67.490	613	7.713	0.283	67.773
Transition rail @ 0°	3.305	469	13.838	0.018	3.323
Transition rail @ 180°	3.305	429	13.716	0.016	3.321
Basket OD	74.10				74.417
DSC ID	74.5	387	9.474	0.224	74.724
Gap	0.4				0.307

Note:

1. The average thermal expansion coefficient is calculated by interpolation for steel basket plate (see Table 8-10 in Chapter 8), transition rail (AL Type 6061, see Table 8-16 in Chapter 8), and DSC shell (SA-240 Type 316, see Table 8-6 in Chapter 8).

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Table 4-12
Applied Peaking Factors for BWR Fuel Assemblies

Reference: Table A.5-10a of [4-22]	
Average Burnup	**61.6 GWd/MTU**
% of Core Height	**Peaking Factors**
4	0.6654
8	0.9712
12	1.0730
16	1.1060
20	1.1223
24	1.1141
28	1.1118
32	1.1094
36	1.1044
40	1.1142
44	1.1117
48	1.0957
52	1.0949
56	1.0877
60	1.0675
64	1.0593
68	1.0610
72	1.0654
76	1.0642
80	1.0405
84	0.9930
88	0.9347
92	0.8231
96	0.6562
100	0.2486

Table 4-13
Peaking Factors for Fuel Assemblies in the EOS-89BTH DSC Model

Region #	CFD Model Z-Coordinates(1) (in)		% of Active Fuel Length(2)		Average Height from Bottom (in)	Peaking Factor	Area under Curve (in)
	From	To	From	To			
1	0	2.620	0.000	0.018	1.310	0.151	0.3965
2	2.62	8.620	1.819	5.986	5.620	0.607	3.6400
3	8.62	14.620	5.986	10.153	11.620	0.948	5.6889
4	14.62	21.350	10.153	14.826	17.985	1.071	7.2062
5	21.35	25.890	14.826	17.979	23.620	1.107	5.0246
6	25.89	31.650	17.979	21.979	28.770	1.119	6.4467
7	31.65	37.410	21.979	25.979	34.530	1.115	6.4216
8	37.41	43.290	25.979	30.063	40.350	1.112	6.5372
9	43.29	48.320	30.063	33.556	45.805	1.109	5.5797
10	48.32	54.320	33.556	37.722	51.320	1.106	6.6370
11	54.32	60.320	37.722	41.889	57.320	1.112	6.6744
12	60.32	66.320	41.889	46.056	63.320	1.110	6.6600
13	66.32	72.320	46.056	50.222	69.320	1.097	6.5844
14	72.32	77.590	50.222	53.882	74.955	1.094	5.7660
15	77.59	83.590	53.882	58.049	80.590	1.086	6.5168
16	83.59	89.590	58.049	62.215	86.590	1.069	6.4116
17	89.59	95.590	62.215	66.382	92.590	1.060	6.3622
18	95.59	100.860	66.382	70.042	98.225	1.061	5.5940
19	100.86	106.500	70.042	73.958	103.680	1.065	6.0050
20	106.5	112.320	73.958	78.000	109.410	1.061	6.1775
21	112.32	118.080	78.000	82.000	115.200	1.038	5.9761
22	118.08	123.350	82.000	85.660	120.715	0.994	5.2384
23	123.35	129.350	85.660	89.826	126.350	0.933	5.5987
24	129.35	135.350	89.826	93.993	132.350	0.819	4.9142
25	135.35	141.350	93.993	98.160	138.350	0.619	3.7160
26	141.35	144.000	98.160	100.000	142.675	0.342	0.9073
						Sum	142.68
						Normalized	0.991
						Corr. Factor	1.009

Notes:

(1) Assuming Z=0 is the bottom of the fuel, Z=144" is the top of the fuel

(2) The percentage is calculated as the Z-coordinate divided by the active fuel length of 144 inches

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Table 4-17
EOS-89BTH in EOS-HSM, Maximum Fuel Cladding and Concrete Temperatures for Storage Conditions

Load Case #[1]	Description	Fuel Cladding Temperature (°F)		Concrete Temperature (°F)	
		Maximum	Limit	Maximum	Limit
1a	Normal hot storage, 43.6 kW (HLZC#1), 100°F ambient with insolation	695	752[5]	242	300[5]
1b[2]	Normal hot storage, 41.6 kW (HLZC#2), 100°F ambient with insolation	< 695		<242	
1c[2]	Normal hot storage, 34.44 kW (HLZC#3), 100°F ambient with insolation	< 695		<242	
2[3]	Normal cold storage, 43.6 kW (HLZC#1), -20°F ambient without insolation	< 695		<242	
3[4]	Off-normal hot storage, 43.6 kW (HLZC#1), 117°F ambient with insolation	<734	1058[5]	<272	300[5]
4[3]	Off-normal cold storage, 43.6 kW (HLZC#1), -40°F ambient without insolation	< 695		<242	
5[4]	Blocked vents accident condition at 40 hours, 43.6 kW (HLZC #1), 117°F ambient with insolation	<865		<464	500[6]

Notes:

(1) See Table 4-14 for the description of the load cases.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat load.

(3) Load Cases # 2 and 4 are bounded by Load Case # 1a due to the higher ambient temperatures.

(4) Load Cases # 3 and 5 are not explicitly analyzed. The methodology to evaluate Load Cases # 3 and 5 is presented in Section 4.4.8.

(5) The temperature limits are from NUREG-1536 [4-1].

(6) The temperature limit for concrete at accident condition is 500 ºF. The maximum concrete temperature for accident conditions is above the 350ºF limit given in ACI-349 [4-4]. Testing will be performed, as dwcribed in Section 8.2.1.3.

Table 4-18
EOS-89BTH in EOS-HSM, Maximum Temperatures of Key Components during Storage Conditions

Load Case #[(1)]	Basket Plate (°F)	Transition Rails (°F)	DSC Shell (°F)	Side Heat Shield (°F)	Top Heat Shield (°F)	Support Structure (°F)
1a	676	474	392	209	220	273
1b[(2)]	<676	<474	<392	<209	<220	<273
1c[(2)]	<676	<474	<392	<209	<220	<273
2[(3)]	<676	<474	<392	<209	<220	<273
3[(4)]	<680	<528	<435	<240	<249	<305
4[(3)]	<676	<474	<392	<209	<220	<273
5[(4)]	<830	<685	<604	<483	<468	<538

Notes:

(1) See Table 4-14 for the description of the load cases.

(2) Load Cases #1b and #1c are bounded by Load Case #1a due to lower heat load

(3) Load Cases # 2 and 4 are bounded by Load Case # 1a due to the higher ambient temperatures.

(4) Load Cases # 3 and 5 are not explicitly analyzed. The methodology to evaluate Load Cases # 3 and 5 is presented in Section 4.4.8.

Table 4-19
EOS-89BTH in EOS-HSM, Average Temperatures of Key Components for Storage Conditions

Load Case #[(1)]	Whole Component					Hottest Section [(5)]			
	Fuel Assembly (°F)	Cavity Gas (°F)	DSC Shell (°F)	Basket Plates (°F)	R90 Transition Rail (°F)	Center Basket Plate (°F)	R90 Transition Rail @ 180° (°F)	R90 Transition Rail @ 0° (°F)	DSC Shell (°F)
1a	542	345	310	493	397	596	399	446	363
1b[(2)]	<542	<345	<310	<493	<397	<596	<399	<446	<363
1c[(2)]	<542	<345	<310	<493	<397	<596	<399	<446	<363
2[(3)]	<542	<345	<310	<493	<397	<596	<399	<446	<363
3[(4)]	<578	<394	<354	<511	<441	<625	<440	<481	<400
4[(3)]	<542	<345	<310	<493	<397	<596	<399	<446	<363
5[(4)]	<727	<560	<540	<671	<608	<781	<625	<645	<587

Notes:

(1) See Table 4-14 for the description of the load cases.

(2) Load Cases #1b and 1c are bounded by Load Case #1a due to lower heat load.

(3) Load Cases # 2 and 4 are bounded by Load Case # 1a due to the higher ambient temperatures.

(4) Load Cases # 3 and 5 are not explicitly analyzed. The methodology to evaluate Load Cases # 3 and 5 is presented in Section 4.4.8.

(5) The hottest section is defined as a 1-inch thick section centered at the location where the maximum fuel cladding temperature occurs.

Table 4-20
Minimum Temperatures of EOS-89BTH DSC Components for Storage Conditions

Component	T_{min} (°F)	$T_{min, limit}$ (°F)
Basket Component	-40	-40
Fuel Cladding	-40	-40

Table 4-21
EOS-89BTH in EOS-HSM, Summary of Air Temperatures and Mass Flow Rates at Inlet and Outlet

Load Case #(1)	T_{inlet} (ºF)	T_{exit} (2) (ºF)	T_{exit}-T_{inlet} (ºF)	Mass Flow Rate at Inlet (kg/s)	Mass Flow Rate at Outlet (kg/s)	Mass Flow Rate Imbalance between Inlet and Outlet (kg/s)
1a	90	179	89	4.1576781E-01	-4.1579006E-01	-2.22E-05

Notes:

(1) See Table 4-14 for the description of the load cases.

(2) Exit air temperature is computed as the area weighted average over the outlet vent.

Table 4-22
Diametrical Hot Gaps for EOS-89BTH DSC Basket Assembly

Load Case #1a, 43.6 kW, HLZC#1					
Component	Cold Dimension	Temp	$\alpha x10^{-6}$ (1)	ΔL	Hot Dimension
	(in)	(°F)	(in/in-°F)	(in)	(in)
Basket width	70.197	596	7.694	0.284	70.481
Transition rail @ 0°	1.951	446	13.784	0.010	1.961
Transition rail @ 180°	1.951	399	13.596	0.009	1.960
Basket OD	74.10				74.402
DSC ID	74.5	363	9.426	0.206	74.706
Gap	0.4				0.304

Note:

1. The average thermal expansion coefficient is calculated by interpolation for steel basket plate (see Table 8-10 in Chapter 8), transition rail (AL Type 6061, see Table 8-16 in Chapter 8), and DSC shell (SA-240 Type 316, see Table 8-6 in Chapter 8).

Table 4-23
Design Load Cases for EOS-TC125

Load Case	Operating Condition	EOS-TC125 Orientation	Description	Ambient Temperature (°F)	Solar Insolation	Notes
1	Normal	Vertical	Normal, hot, indoor, Transient, No air circulation HLZC 1	120	No	(1), (2)
2	Normal	Horizontal	Normal, hot, outdoor, Transient, No air circulation, HLZC 1	100	Yes	(1), (2), (3)
3	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, No air circulation, HLZC 1	117	Yes	(1), (2)
4	Off-Normal	Horizontal	Off-normal, cold, outdoor, Transient, No air circulation, HLZC 1	0	No	(3)
5	Accident	Horizontal	Accident, hot, outdoor, loss of liquid in neutron shield, Steady-state, No air circulation, HLZC 1	117	Yes	(1)
6a	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, Air circulation on, HLZC1	117	Yes	(1), (4), (7)
6b	Off-Normal	Horizontal	Off-normal, hot, outdoor, Steady-state, Air circulation on, HLZC 1	117	Yes	(1), (4)
7	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, Air circulation is turned off, HLZC 1	117	Yes	(1), (5)
8	Normal	Vertical	Normal, hot, indoor, Steady State, No air circulation HLZC 3	120	No	(1)
9	Normal	Horizontal	Normal, hot, outdoor, Steady State, No air circulation HLZC 3	100	Yes	(1), (6)
10	Off-Normal	Horizontal	Off-normal, hot outdoor, Steady State, No air circulation HLZC 3	117	Yes	(1)

Notes:

(1) Daily average temperatures as noted in Section 4.3 are used for normal and off-normal transfer conditions outside the fuel building. No averaging is used for the temperature inside the fuel building and the maximum temperature of 120°F is used in the thermal evaluation.

(2) Initial steady-state conditions are calculated assuming water in the TC/DSC annulus is at 223 °F and an ambient temperature of 120 °F.

(3) Load Case # 3 bounds the Load Case # 2 and Load Case # 4 due to higher ambient temperature.

(4) Air circulation with 850 cfm.

(5) Initial temperatures are taken from Load Case # 6a after 8 hours in the transient run. At time=0, the air circulation is assumed to be turned off or lost and the system begins to heat up.

(6) Load Case # 10 bounds Load Case # 9 due to higher ambient temperatures.

(7) Initial temperatures are taken from Load Case #3 after 14 hours in the transient run. At time t=0, the air circulation is assumed to be turned on and the system begins to cool down.

Table 4-24
Maximum Temperatures of EOS-TC125 with EOS-37PTH DSC at 50kW, without Air Circulation

	Normal Hot, Vertical (Load Case # 1)			Off-Normal Hot, Horizontal (Load Case # 3)			Max. Allowable Temperature
	Steady	Transient		Steady	Transient		
Heat Load (kW)	50	50	50	50	50	50	
Time Limit	Initial	12 hours	14 hours	Initial	12 hours	14 hours	
Components Name	Temperature (°F)						
Fuel Cladding	648	724	736	652	723	734	752
DSC Shell	305	474	484	321	474	483	-
Inner Shell	220	307	316	233	339	347	-
Gamma Shield	219	305	315	230	335	344	620
Structural Shell (TC Outer Shell)	206	221	228	194	229	236	-
Neutron Shield (1) Avg.	182	207	212	177	199	203	259
Neutron Shield Outer Skin (Neutron Shield Panel)	193	216	222	181	218	224	-
Solid Neutron Shield Avg.	220	222	223	186	170	172	262
Closure Lid	176	177	179	181	183	185	-
Top Ring	198	197	200	207	213	217	-
Bottom Ring	220	220	220	208	191	194	-

Notes:

1. Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-25
Maximum Temperatures of EOS-TC125 with EOS-37PTH DSC, at 36.35 kW, without Air Circulation

	Normal Hot, Vertical, Steady State (Load Case # 8)	Off-normal, Hot, Horizontal, Steady State (Load Case # 10)	Max. Allowable Temperature
Heat Load	36.35 kW	36.35 kW	
Time Limit	No Time Limit	No Time Limit	
Components Name	Temperature (°F)		
Fuel Cladding	732	714	752
DSC Shell	495	487	-
Inner Shell	344	370	-
Gamma Shield	342	366	620
Structural Shell (TC Outer Shell)	256	262	-
Neutron Shield (1) Avg.	236	227	259
Neutron Shield Outer Skin (Neutron Shield Panel)	250	250	-
Solid Neutron Shield Avg.	228	194	262
Closure Lid (Top Cover Plate)	200	205	-
Top Ring	224	239	-
Bottom Ring	230	219	-

Notes:

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-26
Maximum Temperatures of EOS-TC125 with EOS-37PTH DSC at 50 kW, with Air Circulation

	Off-Normal, Hot, Horizontal, Outdoor, Transient, Air Circulation on (LC # 6a)	Off-Normal, Hot, Horizontal, Steady State, Air Circulation on (Load Case # 6b)	Maximum Allowable Temperature
Heat Load	50 kW		
Time Limit	8 hrs after air circulation is initiated	No Time Limit	
Components Name	Temperature (°F)		
Fuel Cladding	732	698	752
DSC Shell	452	427	-
Inner Shell	368	351	-
Gamma Shield	364	347	620
Structural Shell (TC Outer Shell)	255	248	-
Neutron Shield (1) Avg.	194	170	259
Neutron Shield Outer Skin	243	236	-
Solid Neutron Shield Avg.	121	111	262
Closure Lid	246	223	-
Top Ring	259	252	-
Bottom Ring	147	129	-

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-27
Maximum Temperatures of EOS-TC125 with 37PTH DSC at 50 kW, Air Circulation Turned Off during Transfer Operations

	Off-Normal, Hot, Horizontal, Transient, No Air Circulation (Load Case # 7)		Maximum Allowable Temperature
Heat Load	50 kW		
Time Limit	4 hrs	6 hrs	
Components Name	Temperature (°F)		
Fuel Cladding	733	737	752
DSC Shell	468	474	-
Inner Shell	373	375	-
Gamma Shield	369	371	620
Structural Shell (TC Outer Shell)	259	260	-
Neutron Shield (1) Avg.	197	201	259
Neutron Shield Outer Skin	246	248	-
Solid Neutron Shield Avg.	139	148	262
Closure Lid	214	211	-
Top Ring	249	247	-
Bottom Ring	170	177	-

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-28
Maximum Temperatures of EOS-TC125 with EOS-37PTH DSC at 50 kW, Accident Loss of Neutron Shield with Loss of Air Circulation Accident Conditions

	Accident, Hot, Horizontal, Steady State Air filled Neutron Shield, (Load Case # 5)	Maximum Allowable Temperature
Heat Load	50 kW	
Time Limit	-	
Components Name	Temperature (°F)	
Fuel Cladding	935	1058
DSC Shell	674	-
Inner Shell	583	-
Gamma Shield	579	620
Structural Shell (TC Outer Shell)	478	-
Neutron Shield Outer Skin	296	-
Solid Neutron Shield Avg.	257	262
Closure Lid	255	-
Top Ring	316	-
Bottom Ring	304	-

Table 4-29
Maximum Temperatures of Key Components in EOS-TC125 loaded with EOS-37PTH DSC

Component	Fuel Cladding	Basket Plate	Transition Rail	DSC Shell	Lead	Neutron Shield	Bottom Neutron Shield
	Temperature (°F)						
Temperature Limit	752(3)/1058(3)	--	--	--	620	259	262
Load Case							
1(1)	736	680	553	484	315	212	223
2	<734	<670	<552	<483	<344	<203	<172
3(1)	734	670	552	483	344	203	172
4	<734	<670	<552	<483	<344	<203	<172
5	935	902	750	674	579	N/A(4)	257
6a(5)	732	673	532	452	364	194	121
6b	698	626	501	427	347	170	111
7(2)	737	679	548	474	371	201	148
8	732	687	557	495	342	236	228
9	<714	<669	<549	<487	<366	<227	<194
10	714	669	549	487	366	227	194

Notes:

(1) Temperature reported in transient case at 14 hours.

(2) Temperature reported in transient case at 6 hours.

(3) Temperature limit of 752 °F is applicable for all load cases except load case # 5. For Load Case # 5 a temperature limit of 1058 °F is considered. See Section 4.2 for additional details.

(4) It is assumed that the water in the neutron shield is lost during the accident condition.

(5) Temperature reported in transient case at 8 hours.

Table 4-30
Average Temperatures of Key Components in EOS-TC125 loaded with EOS-37PTH DSC

Load Case #	Fuel Cladding	Basket Plate	Transition Rail	Helium Gap	DSC Shell	TC Inner Shell	TC Lead Gamma Shield
	Temperature (°F)						
1(1)	594	532	468	422	410	279	245
2	<581	<518	<452	<408	<393	<274	<239
3(1)	581	518	452	408	393	274	239
4	<581	<518	<452	<408	<393	<274	<239
5	775	712	635	574	566	473	433
6a(3)	563	496	405	388	320	236	217
6b	513	448	364	351	286	209	191
7(2)	584	523	455	419	395	273	238
8	595	545	485	447	432	306	271
9	<576	<524	<464	<427	<410	<299	<264
10	576	524	464	427	410	299	264

Notes:

(1) Temperature reported in transient case at 14 hours.

(2) Temperature reported in transient case at 6 hours.

(3) Temperature reported in transient case at 8 hours.

Table 4-31
EOS-37PTH DSC in EOS-TC125 - Time Limit for Transfer Operations

Operating Conditions	HLZC	Heat Load (kW)	Time Limit (hours)
Normal/ Off-normal Transfer	HLZC#1 (Load Case # 1)	50	10
	HLZC#1 (Load Case # 2, 3, and 4)	50	10
	HLZC#1 (Load Case # 6b)	50	No Time Limit(1)
	HLZC#3 (Load Case # 8, 9, and 10)	36.35	No Time Limit
Insertion of EOS-37PTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZC#1 (Load Case # 7)	50	4
Loss of Neutron Shield with Loss of Air Circulation, Accident Condition	HLZC#1 (Load Case # 5)	50	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hrs per Load Case #6a, before it is turned off.

Table 4-32
Comparison of Maximum Component Temperatures of EOS-TC125 loaded with EOS-89BTH DSC and EOS-37PTH DSC for Initial Conditions of Load Case #1

	Normal Hot, Vertical (Load Case # 1), Initial Conditions	Normal Hot, Vertical (Load Case # 1) Initial Conditions (See Table 4-24)	Temperature Difference (T_{89BTH}-T_{37PTH})
System	EOS-89BTH DSC	EOS-37PTH DSC	
Heat Load (kW)	43.6	50	
Components Name	Temperature (°F)		
Fuel Cladding	637	648	-11
DSC Shell	294	305	-11
Inner Shell	220	220	0
Gamma Shield	219	219	0
Structural Shell (Outer shell)	208	206	2
Neutron Shield Avg.	183	182	1
Neutron Shield Outer Skin (Neutron Shield Panel)	195	193	2
Solid Neutron Shield Avg.	223	220	3
Closure Lid	169	176	-7
Top Ring	196	198	-2
Bottom Ring	220	220	0

Table 4-33
Maximum Component Temperatures of EOS-TC125 loaded with EOS-89BTH DSC for Load Case #8

	Normal Hot, Vertical (Load Case # 8)	Maximum Allowable Temperature
Heat Load (kW)	34.44	
Components Name	Temperature (°F)	
Fuel Cladding	728	752
DSC Shell	479	-
Inner Shell	334	-
Gamma Shield	332	620
Structural Shell (Outer Shell)	250	-
Neutron Shield (1) Avg.	230	259
Neutron Shield Outer Skin (Neutron Shield Panel)	245	-
Solid Neutron Shield Avg.	238	262
Closure Lid (Top Cover Plate)	173	-
Top Ring	198	-
Bottom Ring	238	-

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-34
Maximum Temperatures of Key Components in EOS-TC125 Loaded with EOS-89BTH DSC

Component	Fuel Cladding	Basket Plate	Transition Rail	DSC Shell	Lead	Neutron Shield	Bottom Neutron Shield
	Temperature (°F)						
Temperature Limit	752[4]/1058[4]	--	--	--	620	259	262
Load Case [3]							
1[1]	<736	<680	<553	<484	<315	<212	<223
2	<734	<670	<552	<483	<344	<203	<172
3[1]	<734	<670	<552	<483	<344	<203	<172
4	<734	<670	<552	<483	<344	<203	<172
5	<935	<902	<750	<674	<579	N/A[5]	<257
6a[6]	<732	<673	<532	<452	<364	<194	<121
6b	<698	<626	<501	<427	<347	<170	<111
7[2]	<737	<679	<548	<474	<371	<201	<148
8	728	710	531	479	332	230	238
9	<728	<710	<531	<479	<332	<230	<238
10	<728	<710	<531	<479	<332	<230	<238

Notes:

(1) Temperature reported in transient case at 14 hours.

(2) Temperature reported in transient case at 6 hours.

(3) See Table 4-23 for the description of the load cases.

(4) Temperature limit of 752 °F is applicable for all load cases except load case # 5. For Load Case # 5 a temperature limit of 1058 °F is considered. See Section 4.2 for additional details.

(5) It is assumed that the water in the neutron shield is lost during the accident condition.

(6) Temperature reported in transient case at 8 hours.

Table 4-35
EOS-89BTH DSC in EOS-TC125, Time Limit for Transfer Operations

Operating Conditions	HLZC	Heat Load (kW)	Time Limit (hours)
Normal/ Off-normal Transfer	HLZC #1 (Load Case # 1)	43.6	10
	HLZC #1 (Load Case # 2, 3, and 4)	43.6	10
	HLZC #1 (Load Case # 6b)	43.6	No Time Limit[(1)]
	HLZC #3 (Load Cases # 8, 9, and 10)	34.44	No Time Limit
Insertion of EOS-89BTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZC #1 (Load Case # 7)	43.6	4
Loss of Neutron Shield with Loss of Air Circulation, Accident Condition	HLZC #1 (Load Case # 5)	43.6	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hrs per Load Case #6a, before it is turned off.

Table 4-36
Design Load Cases for EOS-TC108

Load Case #	Operation Condition	EOS-TC108 Orientation	Description	Ambient Temperature (°F)	Solar Insolation	Notes
1	Normal	Vertical	Normal, hot, indoor, Transient, No air circulation HLZC #2	120	No	(1), (2)
2	Normal	Horizontal	Normal, hot, outdoor, Transient, No air circulation, HLZC #2	100	Yes	(1), (2), (3)
3	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, No air circulation, HLZC #2	117	Yes	(1), (2), (3)
4	Off-Normal	Horizontal	Off-normal, cold, outdoor, Transient, No air circulation, HLZC #2	0	No	(3)
5	Accident	Horizontal	Off-normal, hot, outdoor, loss of liquid in neutron shield, Steady-state, No air circulation, HLZC #2	117	Yes	(1)
6a	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, Air circulation on, HLZC #2	117	Yes	(1), (4), (7)
6b	Off-Normal	Horizontal	Off-normal, hot, outdoor, Steady-state, Air circulation on, HLZC #2	117	Yes	(1), (4)
7	Off-Normal	Horizontal	Off-normal, hot, outdoor, Transient, Air circulation is turned off after initiation, HLZC #2	117	Yes	(1), (5)
8	Normal	Vertical	Normal, hot, indoor, Steady State, No air circulation HLZC #3	120	No	(1)
9	Normal	Horizontal	Normal, hot, outdoor, Steady State, No air circulation HLZC #3	100	Yes	(1), (6)
10	Off-Normal	Horizontal	Off-normal, hot, outdoor, Steady State, No air circulation HLZC #3	117	Yes	(1)

Notes:

(1) Daily average temperatures as noted in Section 4.3 are used for normal and off-normal transfer conditions outside the fuel building. No averaging is used for the temperature inside the fuel building and the maximum temperature of 120 °F is used in the thermal evaluation.

(2) Initial steady-state conditions are calculated assuming water in the TC/DSC annulus is at 223 °F as calculated in Section 4.6.1 and an ambient temperature of 120 °F.

(3) Load Case # 3 bounds the Load Cases # 2 and 4 due to higher ambient temperature.

(4) Air circulation with 850 cfm.

(5) Initial temperatures are taken from Load Case # 6a after 8 hours in the transient run. At time=0, the air circulation is assumed to be turned off or lost and the system begins to heat up.

(6) Load Case # 10 bounds Load Case # 9 due to higher ambient temperatures.

(7) Initial temperatures are taken from Load Case #3 after 14 hours in the transient run. At time t=0, the air circulation is assumed to be turned on and the system begins to cool down.

Table 4-37
Comparison of Maximum Component Temperatures of EOS-TC108 and EOS-TC125 Loaded with EOS-37PTH DSC for Initial Conditions of Load Case #1

	Normal Hot, Vertical (Load Case # 1), Initial Conditions	Normal Hot, Vertical (Load Case # 1) Initial Conditions (See Table 4-24)	Temperature Difference ($T_{37PTH,TC108}$-$T_{37PTH,TC125}$)
	EOS-TC108	EOS-TC125	
Heat Load (kW)	41.8	50	
Components Name	Temperature (°F)		
Fuel Cladding	586	648	-62
DSC Shell	269	305	-36
Inner Shell	219	220	-1
Gamma Shield	218	219	-1
Structural Shell	208	206	2
Neutron Shield Avg.	185	182	3
Neutron Shield Outer Skin	203	193	10
Solid Neutron Shield Avg.	220	220	0
Closure Lid	175	176	-1
Top Ring	199	198	1
Bottom Ring	220	220	0

Table 4-38
Comparison of Maximum Component Temperatures of EOS-TC108 Loaded with EOS-89BTH DSC and EOS-TC125 Loaded with EOS-37PTH DSC for Initial Conditions of Load Case #1

	Normal Hot, Vertical (Load Case # 1), Initial Conditions	Normal Hot, Vertical (Load Case # 1) Initial Conditions (See Table 4-24)	Temperature Difference ($T_{89BTH,TC108}$- $T_{37PTH,TC125}$)
	EOS-TC108 Loaded with EOS-89BTH DSC	EOS-TC125 Loaded with EOS-37PTH DSC	
Heat Load (kW)	41.6	50	
Components Name	Temperature (ºF)		
Fuel Cladding	601	648	-47
DSC Shell	263	305	-42
Inner Shell	219	220	-1
Gamma Shield	218	219	-1
Structural Shell	209	206	3
Neutron Shield Avg.	184	182	2
Neutron Shield Outer Skin	203	193	10
Solid Neutron Shield Avg.	222	220	2
Closure Lid	168	176	-8
Top Ring	195	198	-3
Bottom Ring	220	220	0

Table 4-39
Maximum Component Temperatures of EOS-TC108 loaded with EOS-37PTH DSC for Load Case #8

	Normal Hot, Vertical (Load Case # 8)	Max. Allowable Temperature
Heat Load	36.35 kW	
Time Limit	No Time Limit	
Components Name	Temperature (°F)	
Fuel Cladding	737	752
DSC Shell	498	-
Inner Shell	350	-
Gamma Shield	347	620
Structural Shell	264	-
Neutron Shield (1) Avg.	243	259
Neutron Shield Outer Skin	260	-
Solid Neutron Shield Avg.	228	262
Closure Lid (Top Cover Plate)	201	-
Top Ring	225	-
Bottom Ring	230	-

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-40
Maximum Temperatures of Key Components in EOS-TC108 Loaded with EOS-37PTH DSC

Component	Fuel Cladding	Basket Plate	Transition Rail	DSC Shell	Lead	Neutron Shield	Bottom Neutron Shield
	Temperature (°F)						
Temperature Limit	752[4]/1058[4]	--	--	--	620	259	262
Load Case [3]							
1[1]	<736	<680	<553	<484	<315	<212	<223
2	<734	<670	<552	<483	<344	<203	<172
3[1]	<734	<670	<552	<483	<344	<203	<172
4	<734	<670	<552	<483	<344	<203	<172
5	<935	<902	<750	<674	<579	N/A[5]	<257
6a[6]	<732	<673	<532	<452	<364	<194	<121
6b	<698	<626	<501	<427	<347	<170	<111
7[2]	<737	<679	<548	<474	<371	<201	<148
8	737	692	563	498	347	243	228
9	<737	<692	<563	<498	<347	<243	<228
10	<737	<692	<563	<498	<347	<243	<228

Notes:

(1) Temperature reported in transient case at 14 hours.

(2) Temperature reported in transient case at 6 hours.

(3) See Table 4-36 for the description of the load cases.

(4) Temperature limit of 752 °F is applicable for all load cases except load case # 5. For Load Case # 5 a temperature limit of 1058 °F is considered. See Section 4.2 for additional details.

(5) It is assumed that the water in the neutron shield is lost during the accident condition.

(6) Temperature reported in transient case at 8 hours.

Table 4-41
EOS-37PTH DSC in EOS-TC108, Time Limit for Transfer Operations

Operating Conditions	HLZC	Heat Load (kW)	Time Limit (hours)
Normal/ Off-normal Transfer	HLZC #2 (Load Case # 1)	41.8	10
	HLZC #2 (Load Case # 2, 3, and 4)	41.8	10
	HLZC #2 (Load Case # 6b)	41.8	No Time Limit(1)
	HLZC #3 (Load Case # 8, 9, and 10)	36.35	No Time Limit
Insertion of EOS-37PTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZC #2 (Load Case # 7)	41.8	4
Loss of Neutron Shield with Loss of Air Circulation, Accident Condition	HLZC #2 (Load Case # 5)	41.8	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hrs per Load Case #6a, before it is turned off.

Table 4-42
Maximum Component Temperatures of EOS-TC108 loaded with EOS-89BTH DSC for Load Case #8

	Normal Hot, Vertical (Load Case # 8)	Max. Allowable Temperature
Heat Load	34.44 kW	
Time Limit	No Time Limit	
Components Name	Temperature (°F)	
Fuel Cladding	733	752
DSC Shell	483	-
Inner Shell	342	-
Gamma Shield	339	620
Structural Shell	260	-
Neutron Shield (1) Avg.	237	259
Neutron Shield Outer Skin	255	-
Solid Neutron Shield Avg.	239	262
Closure Lid (Top Cover Plate)	172	-
Top Ring	198	-
Bottom Ring	239	-

(1) Bulk average temperature of water in the neutron shield is limited by the 20 psig pressure relief valves on the shield. The equivalent steam saturation temperature at this pressure is approximately 259 ºF.

Table 4-43
Maximum Temperatures of Key Components in EOS-TC108 Loaded with EOS-89BTH DSC

Component	Fuel Cladding	Basket Plate	Transition Rail	DSC Shell	Lead	Neutron Shield	Bottom Neutron Shield
	Temperature (°F)						
Temperature Limit	752[4]/1058[4]	--	--	--	620	259	262
Load Case [3]							
1[1]	<736	<680	<553	<484	<315	<212	<223
2	<734	<670	<552	<483	<344	<203	<172
3[1]	<734	<670	<552	<483	<344	<203	<172
4	<734	<670	<552	<483	<344	<203	<172
5	<935	<902	<750	<674	<579	N/A[5]	<257
6a[6]	<732	<673	<532	<452	<364	<194	<121
6b	<698	<626	<501	<427	<347	<170	<111
7[2]	<737	<679	<548	<474	<371	<201	<148
8	733	715	538	483	339	237	239
9	<733	<715	<538	<482	<339	<237	<239
10	<733	<715	<538	<482	<339	<237	<239

Notes:

(1) Temperature reported in transient case at 14 hours.

(2) Temperature reported in transient case at 6 hours.

(3) See Table 4-36 for the description of the load cases.

(4) Temperature limit of 752 °F is applicable for all load cases except load case # 5. For Load Case # 5 a temperature limit of 1058 °F is considered. See Section 4.2 for additional details.

(5) It is assumed that the water in the neutron shield is lost during the accident condition.

(6) Temperature reported in transient case at 8 hours.

Table 4-44
EOS-89BTH DSC in EOS-TC108, Time Limit for Transfer Operations

Operating Conditions	HLZC	Heat Load (kW)	Time Limit (hours)
Normal/ Off-normal Transfer	HLZC #2 (Load Case # 1)	41.6	10
	HLZC #2 (Load Case # 2, 3, and 4)	41.6	10
	HLZC #2 (Load Case # 6b)	41.6	No Time Limit(1)
	HLZC #3 (Load Case # 8, 9, and 10)	34.44	No Time Limit
Insertion of EOS-89BTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZC #2 (Load Case # 7)	41.6	4
Loss of Neutron Shield with Loss of Air Circulation, Accident Condition	HLZC #2 (Load Case # 5)	41.6	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hrs per Load Case #6a, before it is turned off.

Table 4-45
Maximum Internal Pressures in the EOS-37PTH DSC

Operating Conditions		Free Volume in DSC Cavity (in^3)	Helium Backfill Amount (mol)	Plenum Volume(1) (in^3)	Fuel Rod Fill Gas Amount(2) (mol)	Fuel Rod Fission Gases Amount(2) (mol)	Total Gas Amount (mol)	Average Temperature of Helium in DSC (K)	Calculated Pressure (psig)	Pressure Used for Structural Evaluation (psig)
Symbols		V_{total}	$n_{He\_backfill}$	$f \times V_{plenum}$	$f \times n_{He\_fuel\_rod}$	$f \times n_{fission\_gas}$	n_{total}	T_{He_DSC}	P_{DSC}	
Short	Normal	329,937	192.42	67	1.44	6.08	200.0	565	10.5	20
	Off-normal	330,543	192.42	673	14.44	60.83	267.7	565	19.0	20
	Accident	336,599	192.42	6,729	144.42	608.28	945.1	653	120.3	130
Medium	Normal	352,613	205.65	76	1.51	6.55	213.7	561	10.3	20
	Off-normal	353,298	205.65	761	15.10	65.49	286.2	561	18.8	20
	Accident	360,147	205.65	7,611	151.04	654.90	1,011.6	649	119.4	130

Notes:

1. Plenum volumes released for normal, off-normal, and accident conditions are calculated based on the assuming rupture of 1%, 10%, and 100% of the fuel rods, respectively.
2. Quantities of initial fill and irradiation gases for normal, off-normal, and accident conditions are calculated based on the assuming rupture of 1%, 10%, and 100% of the fuel rods, respectively.

Table 4-46
Maximum Internal Pressures in the EOS-89BTH DSC

Operating Conditions	Free Volume in DSC Cavity (in³)	Helium Backfill Amount (mol)	Plenum Volume[(1)] (in³)	Fuel Rod Fill Gas Amount[(2)] (mol)	Fuel Rod Fission Gases Amount[(2)] (mol)	Total Gas Amount (mol)	Average Temperature of Helium in DSC (K)	Calculated Pressure (psig)	Used for Structural Evaluation Pressure (psig)
Symbols	V_{total}	$n_{He\_backfill}$	$f \times V_{plenum}$	$f \times n_{He\_fuel\_rod}$	$f \times n_{fission\_gas}$	n_{total}	T_{He_DSC}	P_{DSC}	
Normal	367505	215.6	190.1	1.4	5.5	222.5	572	10.8	20
Off-normal	369216	215.6	1901.0	14.1	55.0	284.6	572	17.8	20
Accident	386326	215.6	19010	140.5	550.0	906.0	671	101.1	130

Notes:

(1) Plenum volumes released for normal, off-normal, and accident conditions are calculated based on the assuming rupture of 1%, 10%, and 100% of the fuel rods, respectively.

(2) Quantities of initial fill and irradiation gases for normal, off-normal, and accident conditions are calculated based on the assuming rupture of 1%, 10%, and 100% of the fuel rods, respectively.

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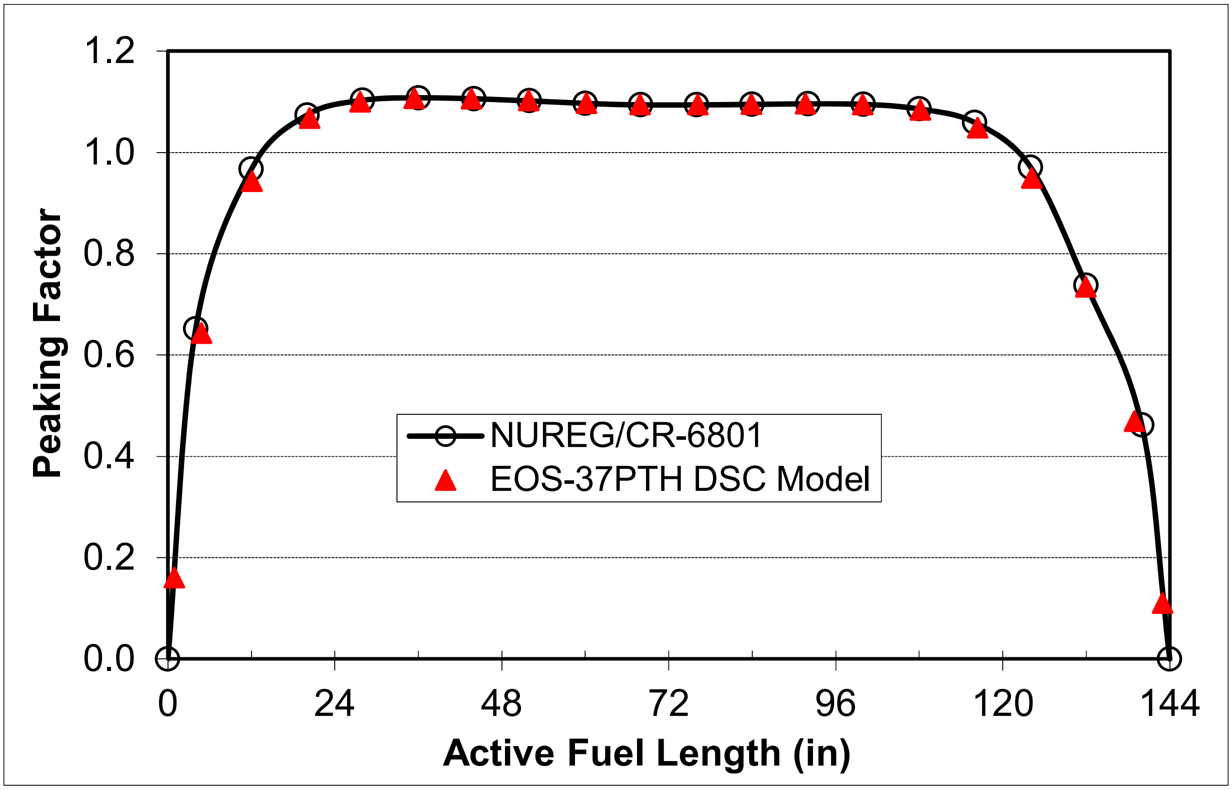

Figure 4-7
Peaking Factor Curve for PWR Fuel Assemblies

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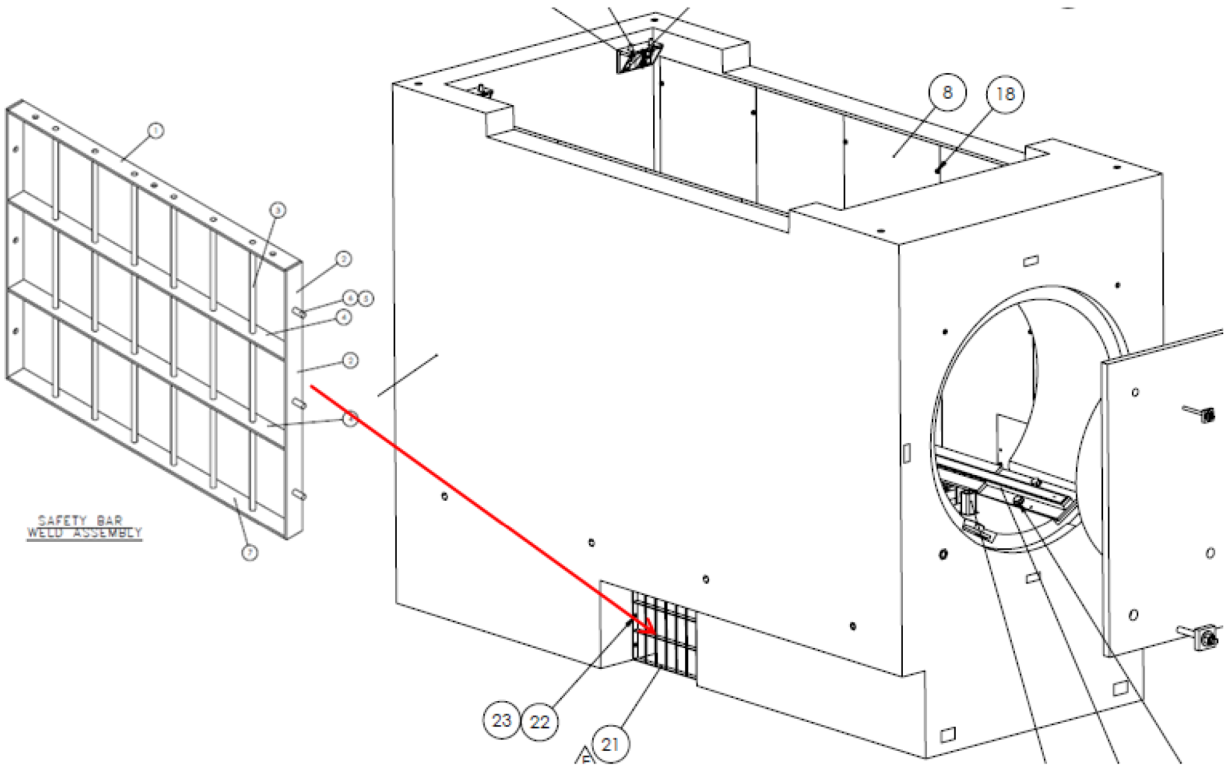
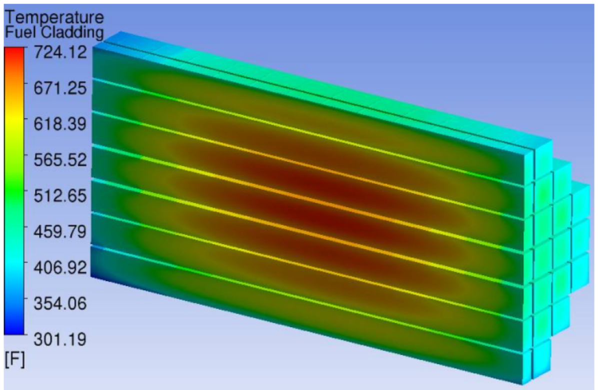
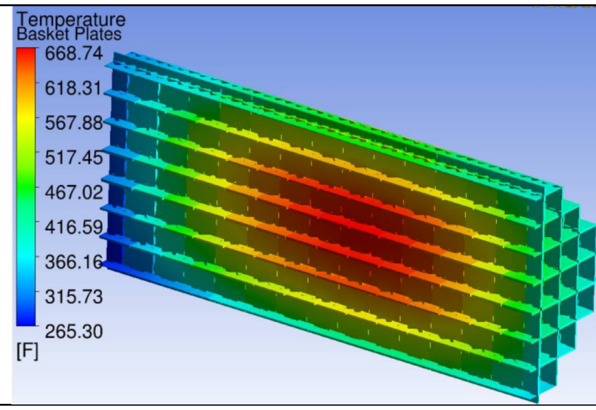


Figure 4-9
Optional Inlet Vent Screen Assembly at the Entrance of EOS-HSM Inlet Channel

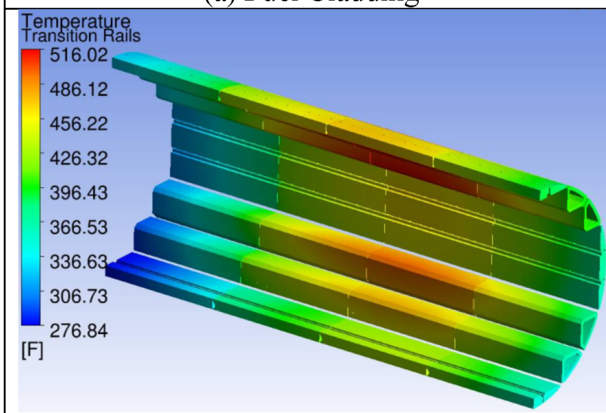
P r o p r i e t a r y I n f o r m a t i o n o n
W i t h h e l d P u r s u a n t t o 1 0



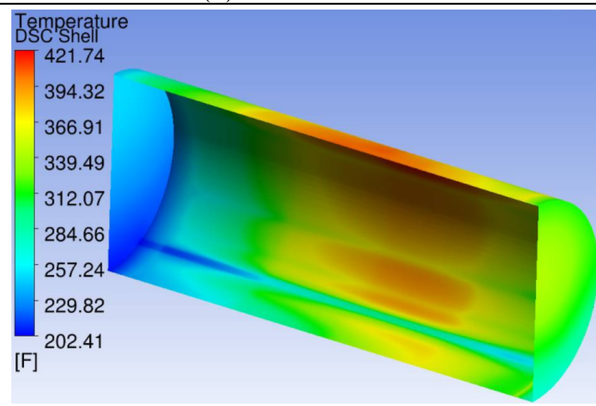
(a) Fuel Cladding



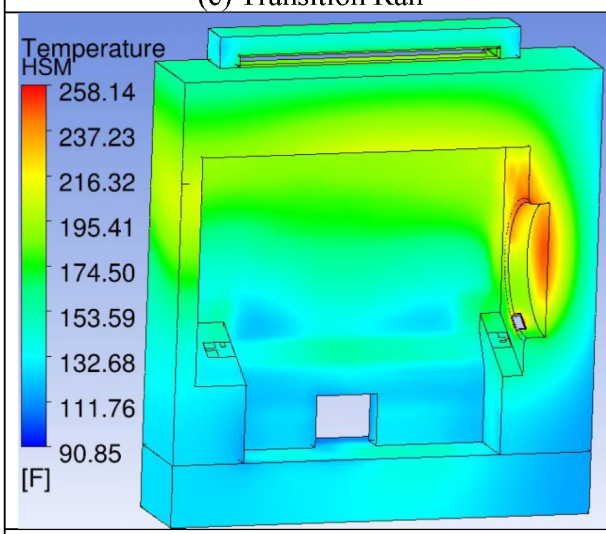
(b) Basket Plates



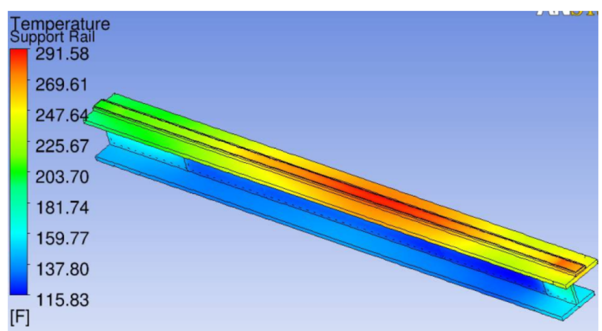
(c) Transition Rail



(d) EOS-37PTH DSC Shell

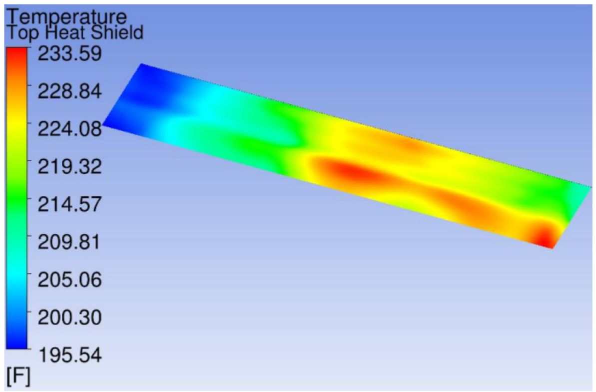


(e) EOS-HSM

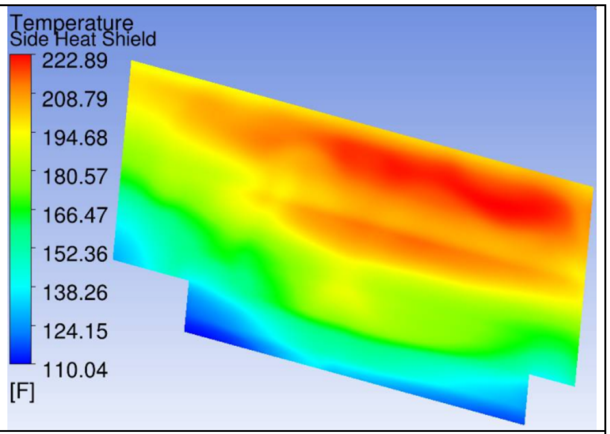


(f) Support Structure

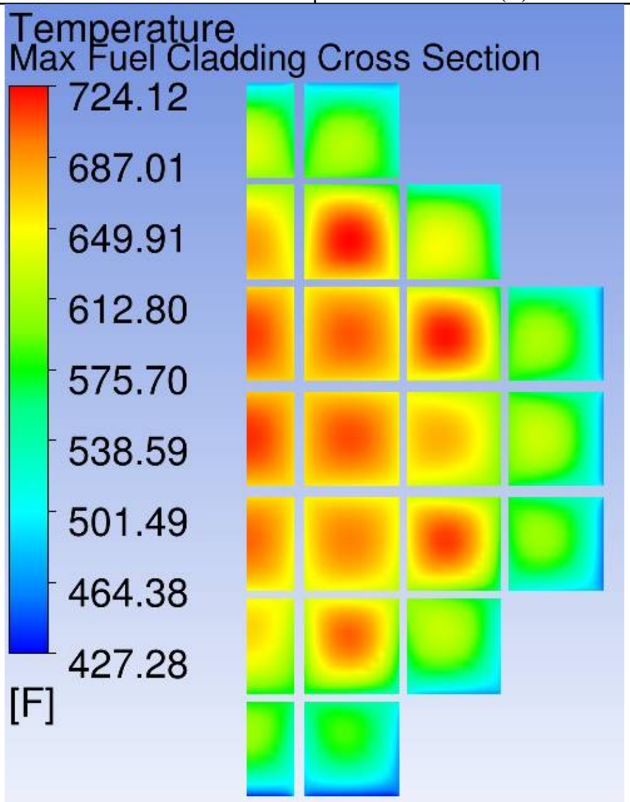
Figure 4-12
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Normal Hot Storage Condition (Load Case #1a)
2 Pages



(g) Top Heat Shield

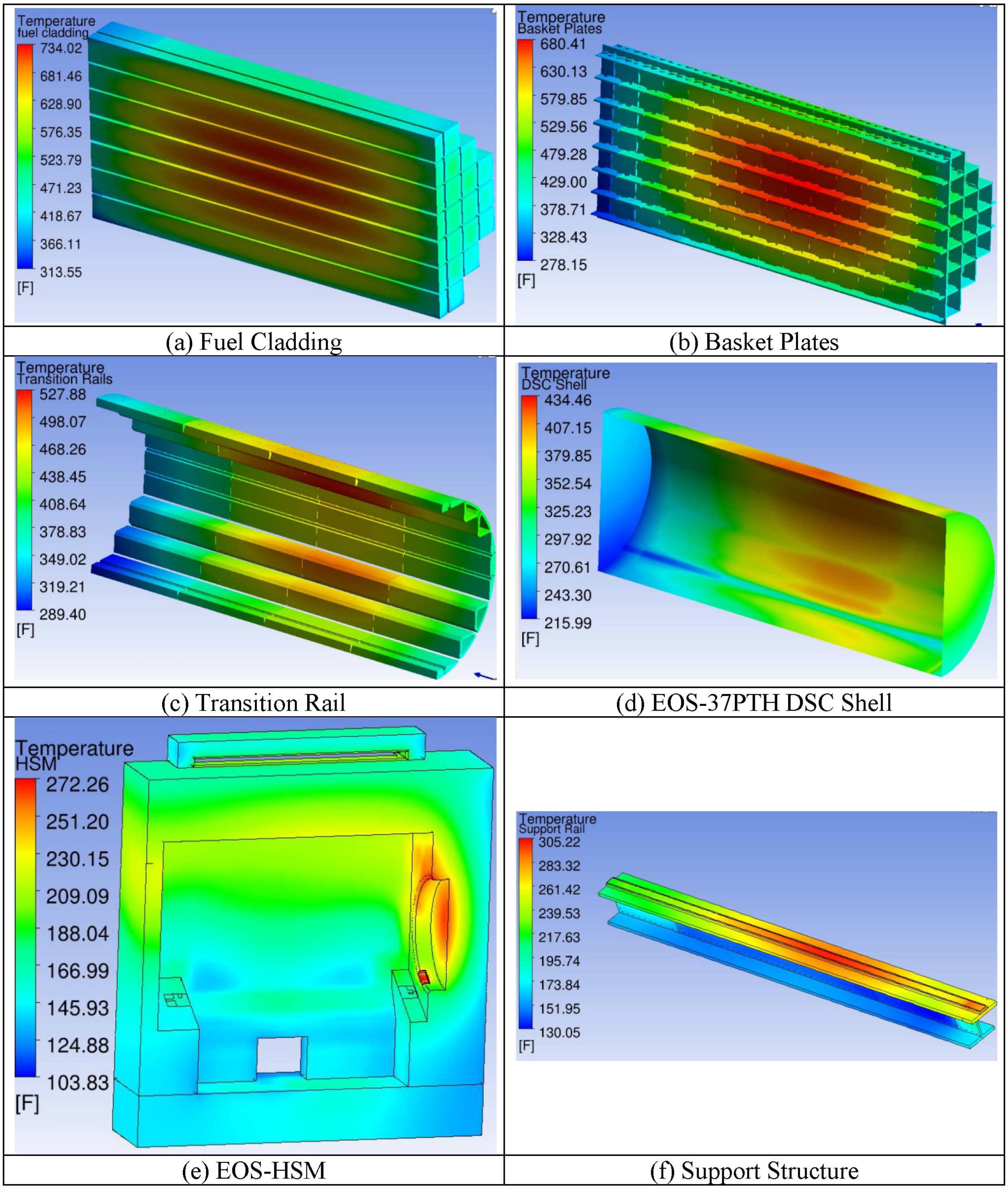


(h) Side Heat Shield



(i) Fuel Cladding at the Hottest Cross Section

Figure 4-12
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Normal Hot Storage Condition (Load Case #1a)
2 Pages



(a) Fuel Cladding

(b) Basket Plates

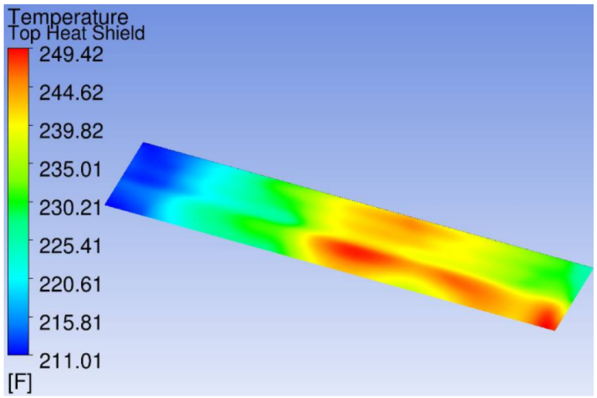
(c) Transition Rail

(d) EOS-37PTH DSC Shell

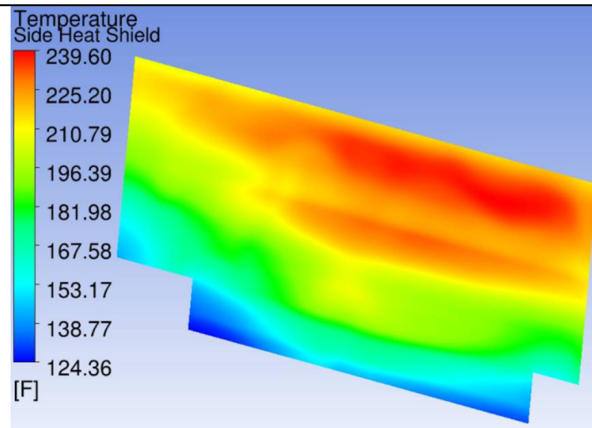
(e) EOS-HSM

(f) Support Structure

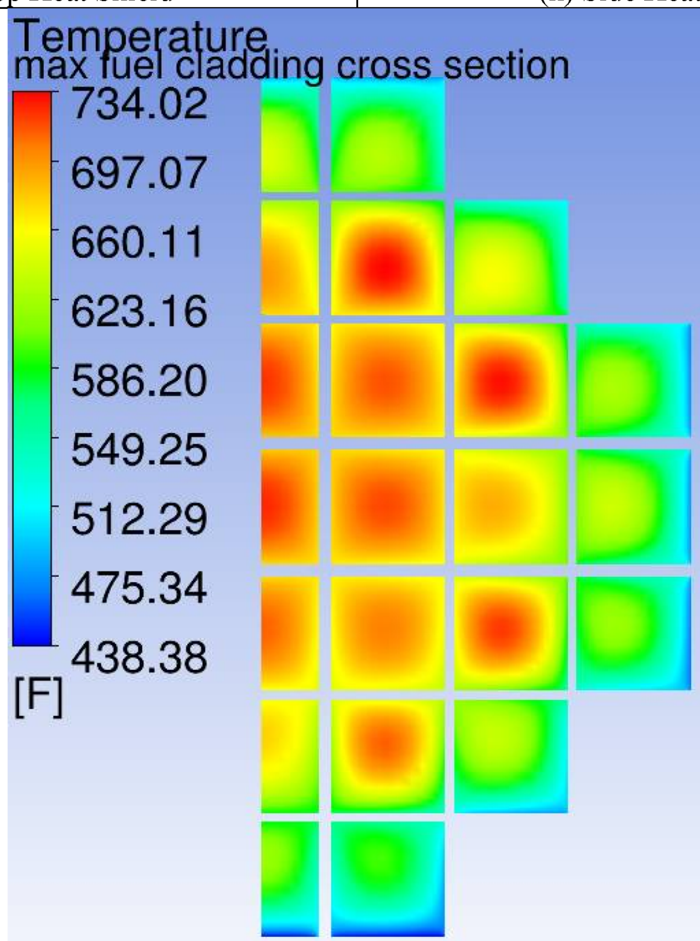
Figure 4-13
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Off-Normal Hot Storage Condition (Load Case #3)
2 Pages



(g) Top Heat Shield



(h) Side Heat Shield



(i) Fuel Cladding at the Hottest Cross Section

Figure 4-13
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Off-Normal Hot Storage Condition (Load Case #3)
2 Pages