CHAPTER 4
THERMAL EVALUATION

Table of Contents

List of Tables

List of Figures

4. THERMAL EVALUATION

NOTE: *For HLZCs 1 through 3,* the basket types directly correlate to the Heat Load Zone Configurations (HLZCs), throughout this chapter, basket types are directly referred to by the HLZC. *For HLZCs 4 through 9, the basket types do not directly correlate to the HLZC. A summary of the loading configuration for HLZCs 4 through 9 is presented below. A description of the various basket assembly types is presented in Chapter 1, Section 1.1.*

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 flat plate support structure (FPS) is an option for the medium length EOS-HSM/HSMS, which allows a DSC support structure to be built up from a flat plate. This option is referred to as the EOS-HSM-FPS or EOS-HSMS-FPS.

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

DSC Type	***Basket Assembly Type or*** **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/ EOS-HSM-FPS/ EOS-HSMS-FPS
	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		

DSC Type	***Basket Assembly Type***	***Heat Load Zone Configuration (HLZC)***	***Max. Heat Load (kW)***	***Transfer Cask***	***Storage Module***
EOS-37PTH	*4L/5*	*4*	*50.00*	*EOS-TC125/ EOS-TC135*	*EOS-HSM/ EOS-HSMS/ EOS-HSM-FPS/EOS-HSMS-FPS*
	4L/5	*5*	*41.00*		
	4L	*6*	*46.00*		
	4H	*7*	*50.00*		*NUHOMS® MATRIX (HSM-MX)*
	4L/5	*8(1)*	*46.40*		
	4L/5	*9*	*37.80*		
EOS-89BTH	*3*	*3*	*34.44*	*EOS-TC125/ EOS-TC108*	

Note 1: Basket Type 5 can only accommodate Intact FAs. Damaged FAs or loaded failed fuel canisters (FFCs) allowed per HLZC 8 shall only be loaded in Basket Type 4L.

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 *the* EOS-TC125/EOS-TC135, and Section 4.6 for transfer operations in *the* 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. The thermal performance of the FPS option of the EOS-HSM is discussed in Appendix 4.9.5. *Appendix 4.9.6 and Chapter A.4 present the thermal evaluation of the EOS-37PTH DSC with HLZCs 4 through 6 and HLZCs 7 through 9, respectively for storage operations. Thermal evaluation of of the EOS-37PTH DSC with HLZCs 4 through 9 is presented in Appendix 4.9.6 for transfer operations. Thermal evaluation of the EOS-89BTH DSC with HLZC 3 during storage operations in the HSM-MX is presented in Chapter A.4.*

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.*4* 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 HLZC for each DSC type are provided in Figures 1 and 2 of the Technical Specification [4-24]. *Figure 1 of the Technical Specification [4-24] is split into nine sub parts, one for each HLZC.*

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 operations with heat load less than or equal to 41.8 kW for the EOS-37PTH DSC and 41.6 kW for the EOS-89BTH DSC. For normal storage operations with heat load greater than 41.8 kW for the EOS-37PTH DSC and 41.6 kW for the EOS-89BTH DSC, the minimum ambient temperature is -20 °F (-28.9 °C) and the maximum yearly average ambient temperature is 70 °F (21.1 °C). For off-normal storage operations, the ambient temperature range is -40 to 117 °F (-40 to 47.2 °C). 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.

$k = \sum C_i T^i$ 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.

for specific heat in (J/kg-K) and T in (K)

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

Proprietary Information on Pages 4-9 through 4-15
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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.

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

For the EOS-37PTH Basket Types 4L and 5, an emissivity of 0.07 is considered based on emissivity of electroless nickel coating [4-28].

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

Maximum ambient temperature for normal storage conditions varies with the heat load during storage operations and is defined as follows:

1. For storage operations with heat load greater than 41.8 kW for the EOS-37PTH DSC and 41.6 kW for the EOS-89BTH DSC, the maximum yearly average temperature of 70 °F for normal storage conditions, and

2. For storage operations with heat load less than or equal to 41.8 kW for the EOS-37PTH DSC and 41.6 kW for the EOS-89BTH DSC, the maximum temperature is 100 °F for normal storage conditions. 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 based on the methodology presented in Appendix M, Section M.4.5 of [4-19].

Off-normal ambient temperature is considered in the range of - 40 °F to 117 °F. 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.

Thermal evaluations presented in this chapter for normal conditions are based on a daily average ambient temperature of 90 °F for all heat loads except for the evaluation presented in Appendix 4.9.4, Section 4.9.4.8.

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 and 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.

The thermal performance of the FPS option of the EOS-HSM is discussed in Appendix 4.9.5.

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.

Proprietary Information on Pages 4-32 through 4-53
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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.

Proprietary Information on Pages 4-58 through 4-68
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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 °F and a 120 °F ambient temperature within the fuel building. In vertical operation, the bottom surface of EOS-TC125 is fixed at 220 °F to account for the heat dissipation to the floor. For the initial conditions with water in the annulus, a maximum temperature of 223 °F 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 °F 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 assembled 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 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 the annulus between the DSC and TC (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 *the TC/DSC annulus* 72.48
water 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.

Proprietary Information on Pages 4-97 and 4-98
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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*):

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

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 *54.3* and *59.4* 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.

4.8 References

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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 (HLZC1), Steady-state, 100 °F ambient with insolation	724	752(4)	258	300(4)
1b(2)	Normal hot storage, 41.80 kW (HLZC2), Steady-state, 100 °F ambient with insolation	< 724		<258	
1c(2)	Normal hot storage, 36.35 kW (HLZC3), Steady-state, 100 °F ambient with insolation	< 724		<258	
2(3)	Normal cold storage, 50 kW (HLZC1), Steady-state, -20 °F ambient without insolation	< 724		<258	
3	Off-normal hot storage, 50 kW (HLZC1), Steady-state, 117 °F ambient with insolation	734	1058(4)	272	300(4)
4	Off-normal cold storage, 50 kW (HLZC1), 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, HLZC1					
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

Proprietary Information on Pages 4-125 through 4-127
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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 (HLZC1), 100 °F ambient with insolation	695	752(5)	242	300(5)
1b(2)	Normal hot storage, 41.6 kW (HLZC2), 100 °F ambient with insolation	< 695		<242	
1c(2)	Normal hot storage, 34.44 kW (HLZC3), 100 °F ambient with insolation	< 695		<242	
2(3)	Normal cold storage, 43.6 kW (HLZC1), -20 °F ambient without insolation	< 695		<242	
3(4)	Off-normal hot storage, 43.6 kW (HLZC1), 117 °F ambient with insolation	<734	1058(5)	<272	300(5)
4(3)	Off-normal cold storage, 43.6 kW (HLZC1), -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 350 ºF limit given in ACI-349 [4-4]. Testing will be performed, as decribed 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} (°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	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, HLZC1					
Component	Cold Dimension (in)	Temp (°F)	$\alpha x10^{-6}$ (1) (in/in-°F)	ΔL (in)	Hot Dimension (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	HLZC1 (Load Case 1)	50	10
	HLZC1 (Load Case 2, 3, and 4)	50	10
	HLZC1 (Load Case 6b)	50	No Time Limit(1)
	HLZC3 (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	HLZC1 (Load Case 7)	50	4
Loss of Neutron Shield with Loss of Air Circulation, Accident Condition	HLZC1 (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	*6.03*	*199.9*	565	10.5	20
	Off-normal	330,543	192.42	673	14.44	*60.27*	*267.1*	565	*18.9*	20
	Accident	336,599	192.42	6,729	144.42	*602.73*	*939.6*	653	*119.5*	130
Medium	Normal	352,613	205.65	76	1.51	*6.59*	*213.8*	561	10.3	20
	Off-normal	353,298	205.65	761	15.10	*65.93*	*286.7*	561	18.8	20
	Accident	360,147	205.65	7,611	151.04	*659.34*	*1,016.0*	649	*119.9*	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 (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)	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	*4.6*	*221.6*	572	*10.7*	20
Off-normal	369216	215.6	1901.0	14.1	*46.5*	*276.1*	572	*16.8*	20
Accident	386326	215.6	19010	140.5	*464.6*	*820.6*	671	*90.2*	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.

Proprietary Information on Pages 4-160 through 4-165
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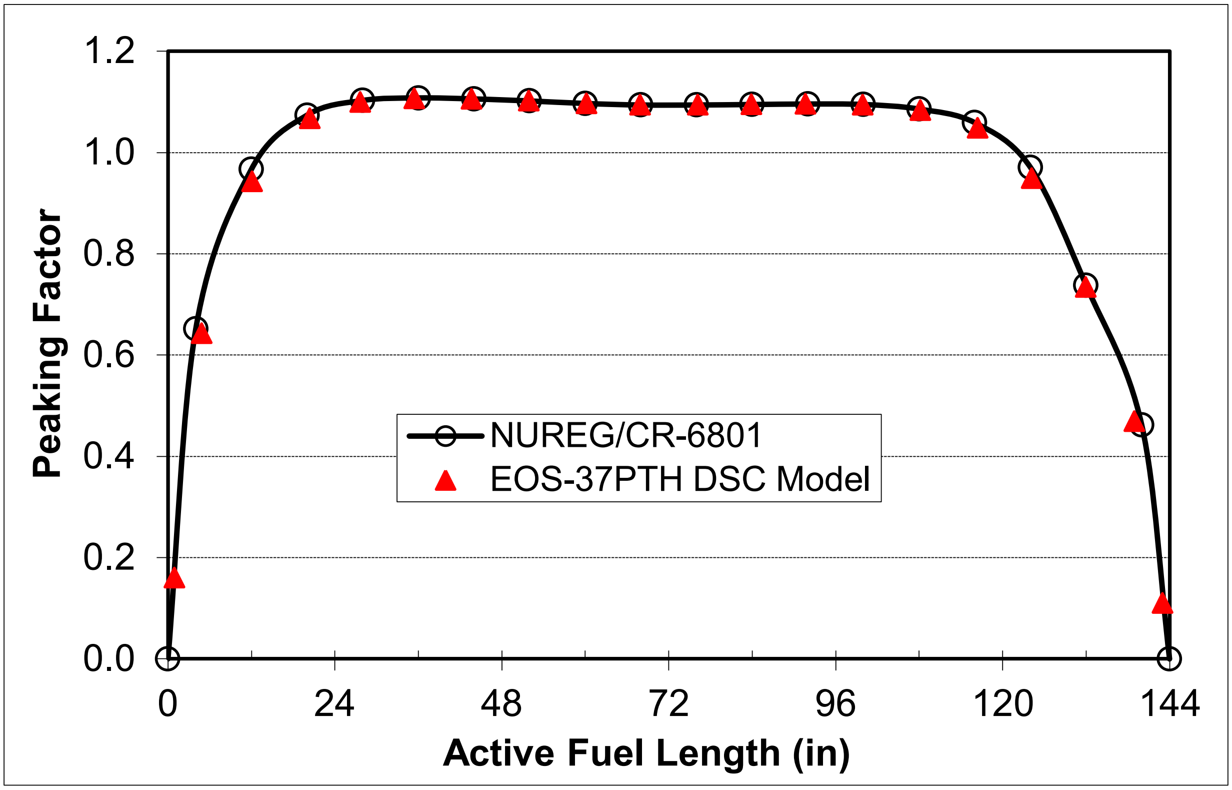

Figure 4-7
Peaking Factor Curve for PWR Fuel Assemblies

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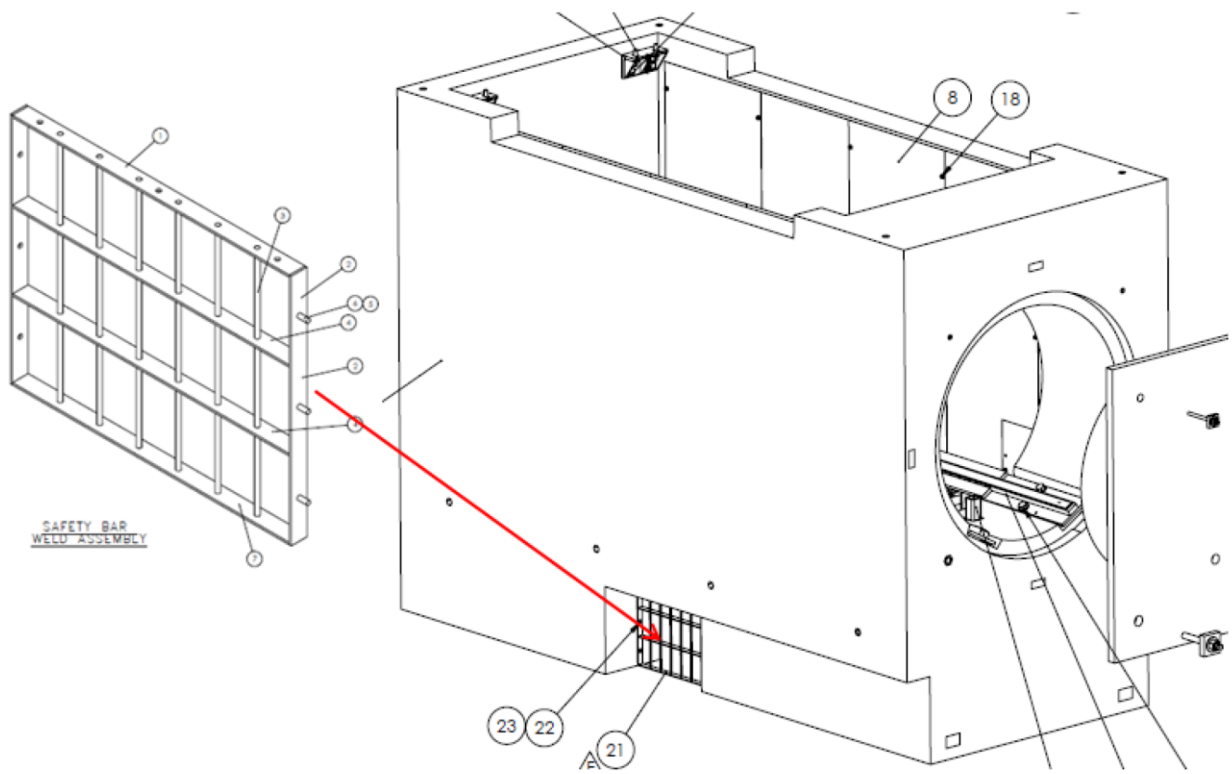


Figure 4-9
Optional Inlet Vent Screen Assembly at the Entrance of EOS-HSM Inlet Channel

Proprietary Information on Pages 4-169 through 4-171
Withheld Pursuant to 10 CFR 2.390

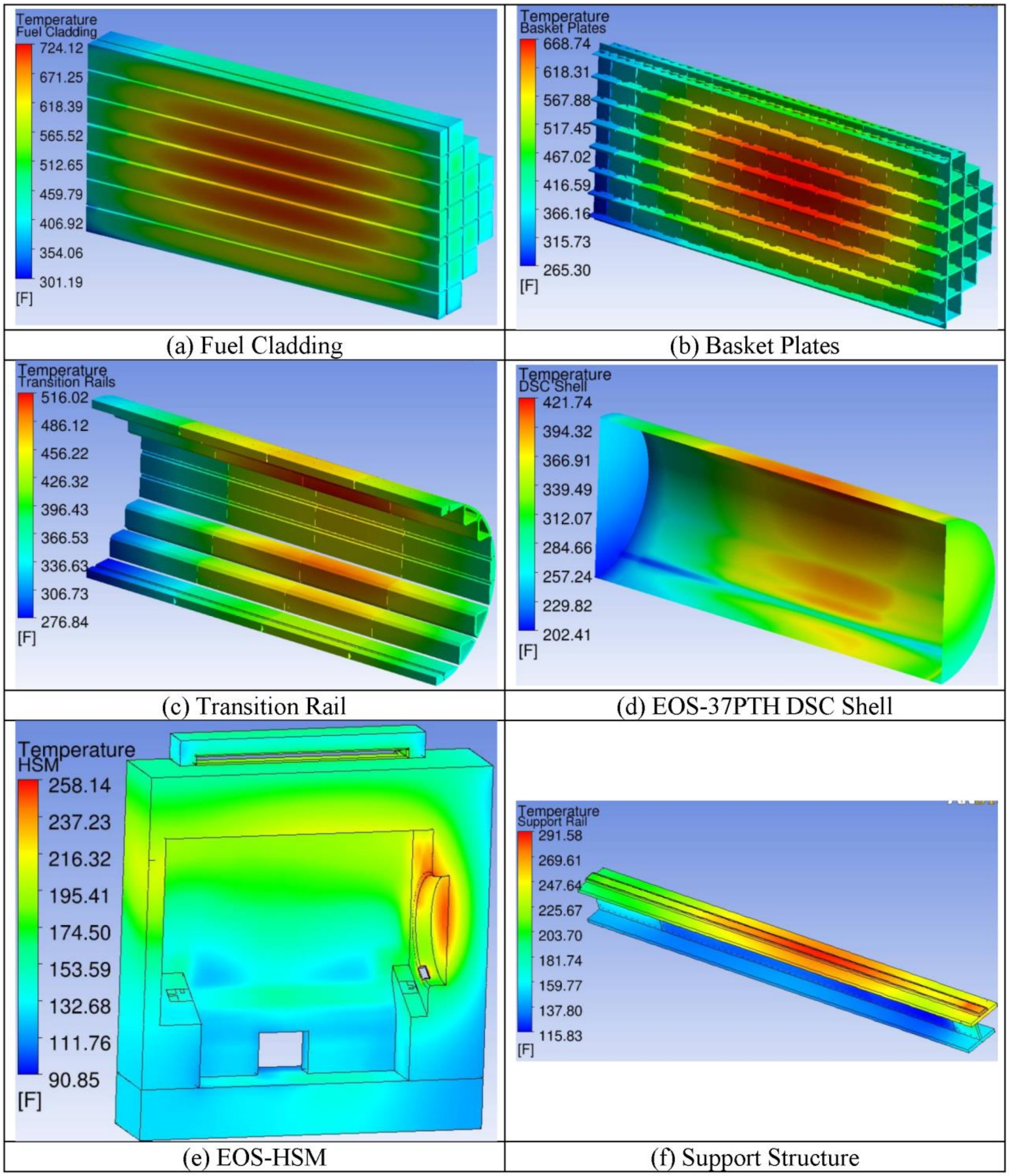
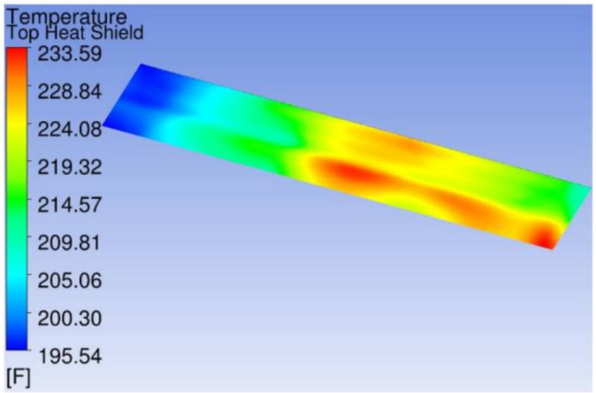
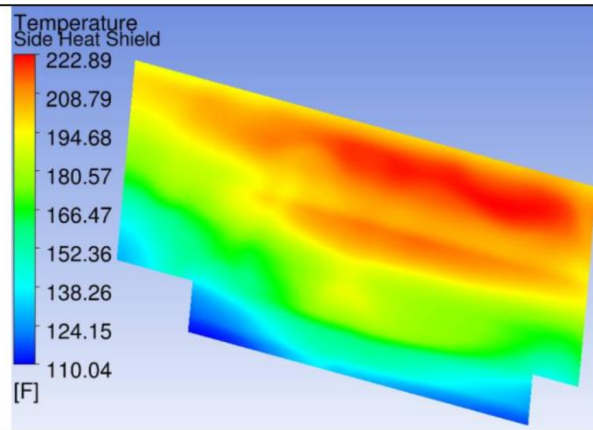


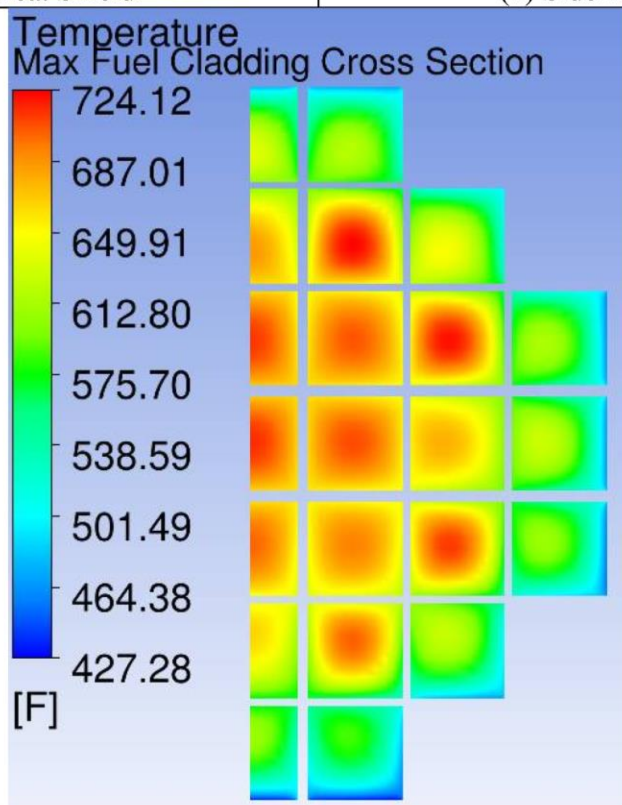
Figure 4-12
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Normal Hot Storage Condition (Load Case 1a)
2 Pages



(g) Top Heat Shield

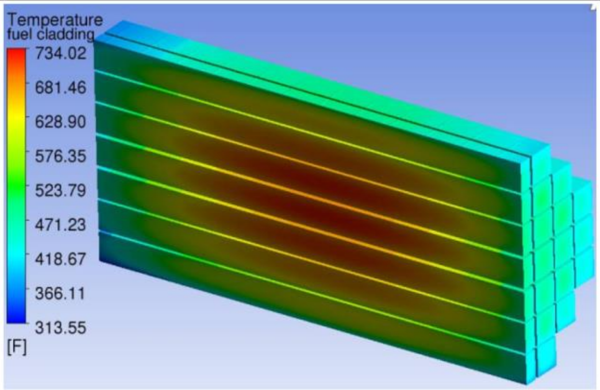


(h) Side Heat Shield

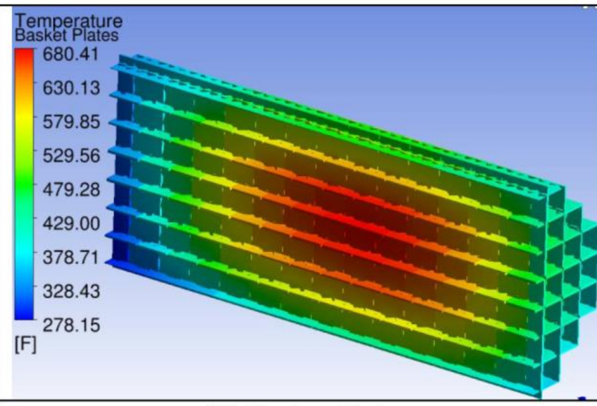


(i) Fuel Cladding at the Hottest Cross Section

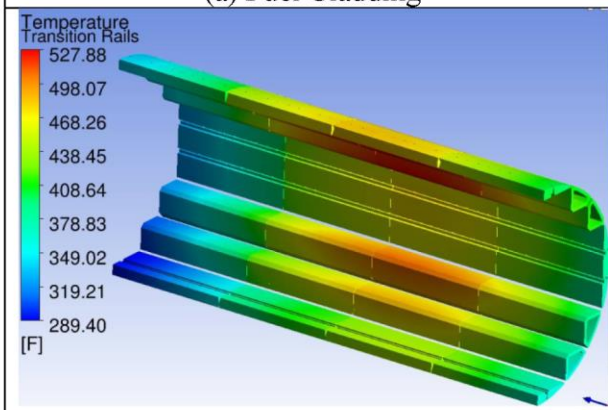
Figure 4-12
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Normal Hot Storage Condition (Load Case 1a)
2 Pages



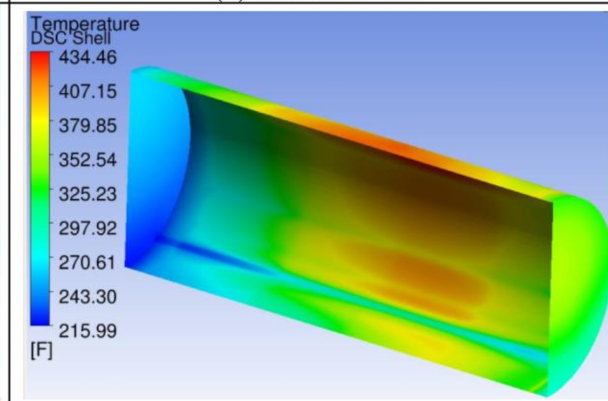
(a) Fuel Cladding



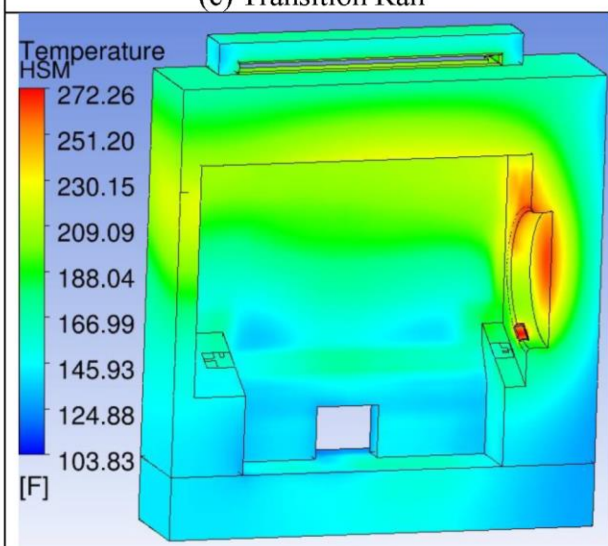
(b) Basket Plates



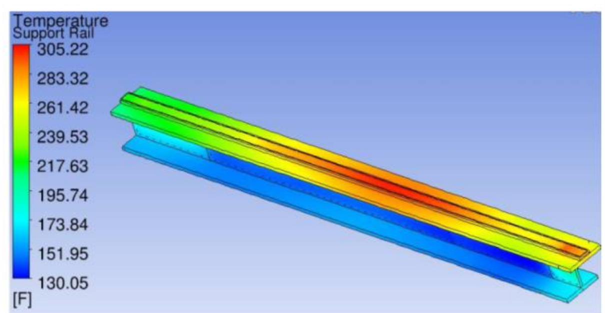
(c) Transition Rail



(d) EOS-37PTH DSC Shell

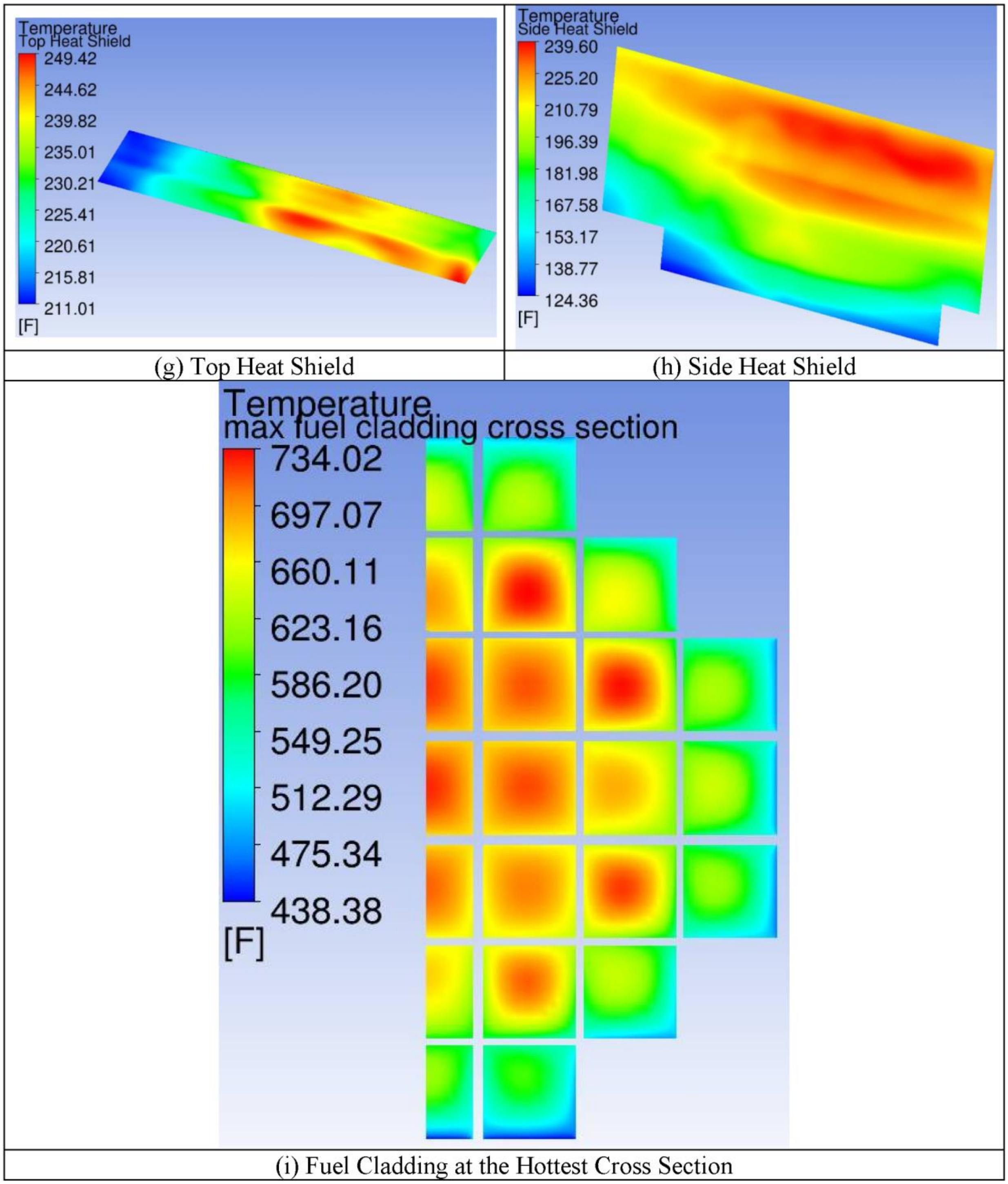


(e) EOS-HSM



(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

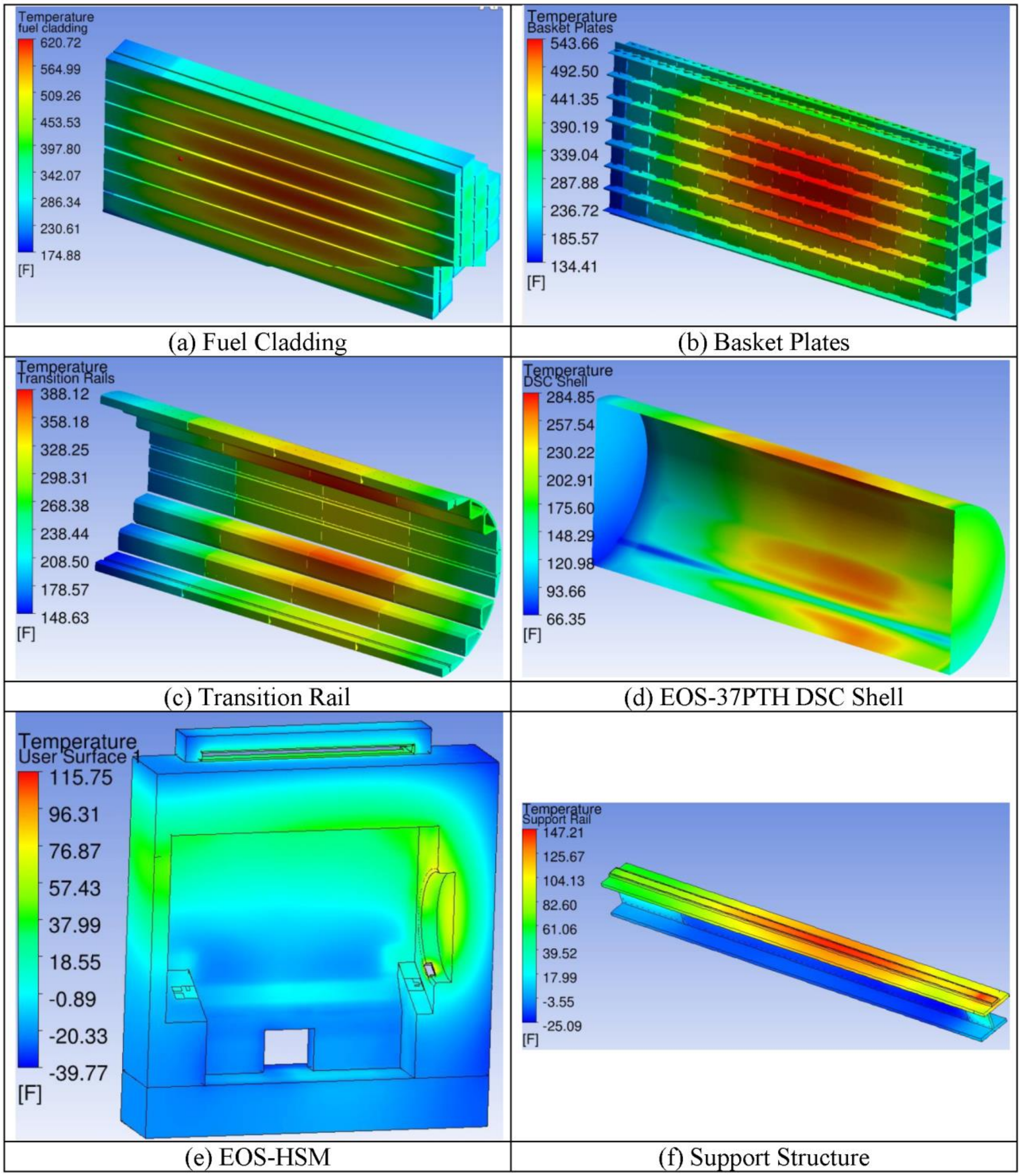


(g) Top Heat Shield

(h) Side Heat Shield

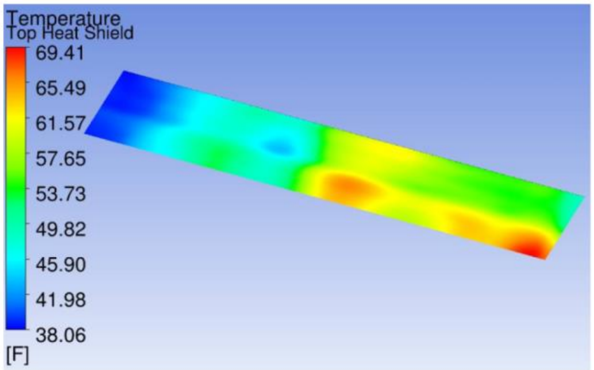
(i) Fuel Cladding at the Hottest Cross Section

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

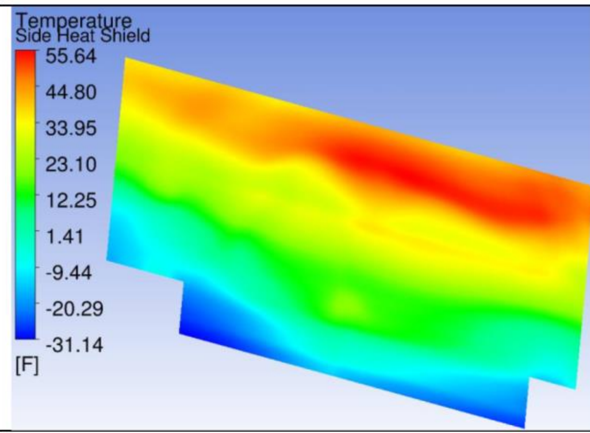


(a) Fuel Cladding | (b) Basket Plates | (c) Transition Rail | (d) EOS-37PTH DSC Shell | (e) EOS-HSM | (f) Support Structure

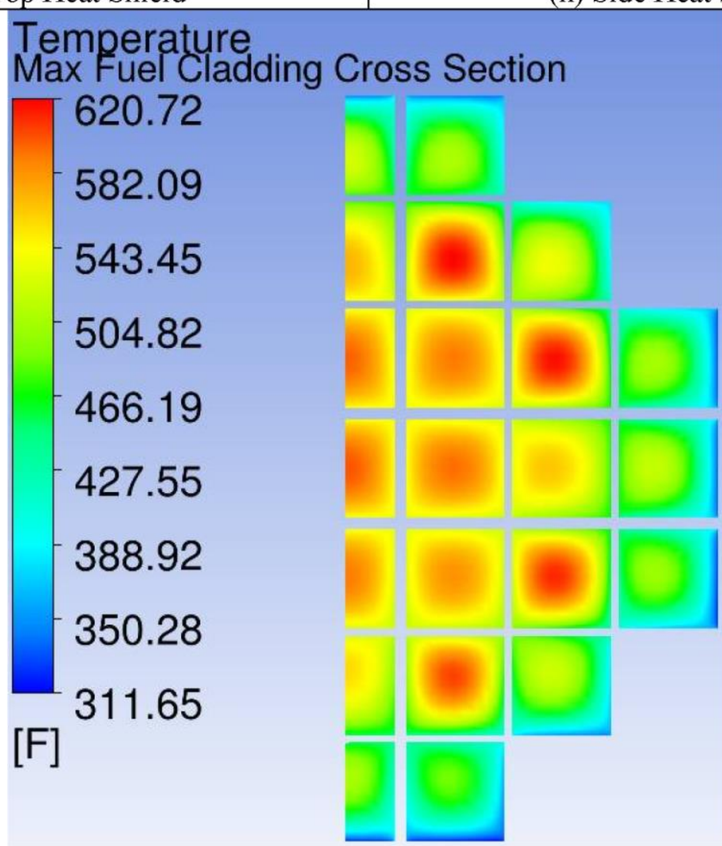
Figure 4-14
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Off-Normal Cold Storage Condition (Load Case 4)
2 Pages



(g) Top Heat Shield

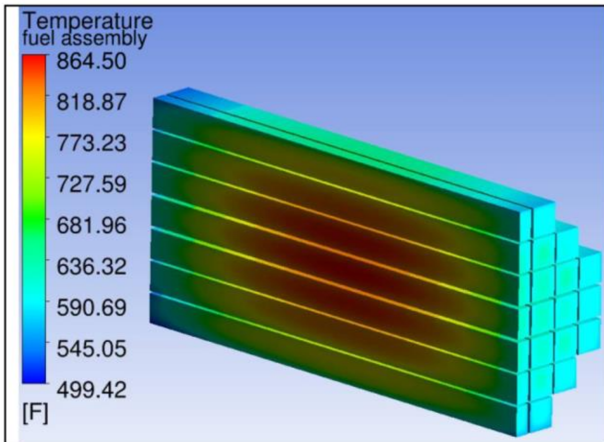


(h) Side Heat Shield

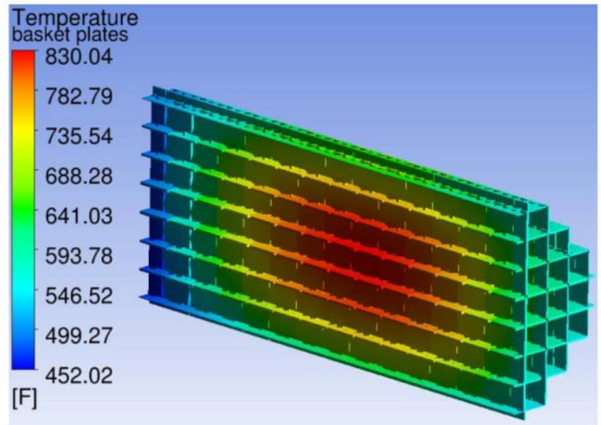


(i) Fuel Cladding at the Hottest Cross Section

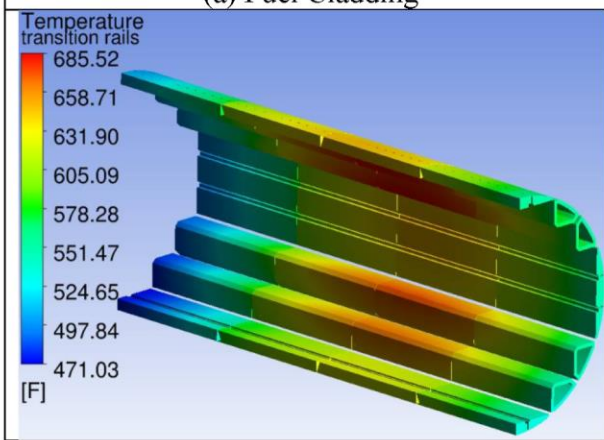
Figure 4-14
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Off-Normal Cold Storage Condition (Load Case 4)
2 Pages



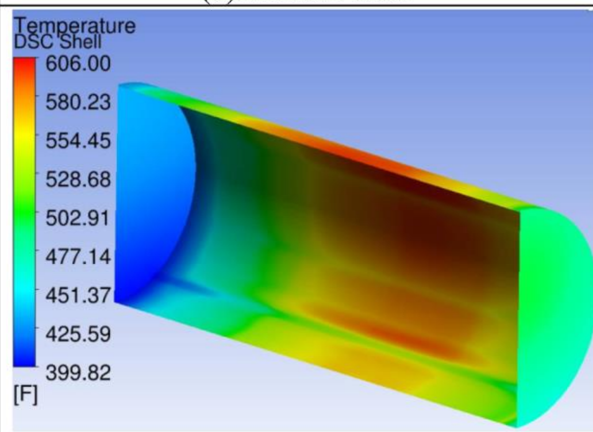
(a) Fuel Cladding



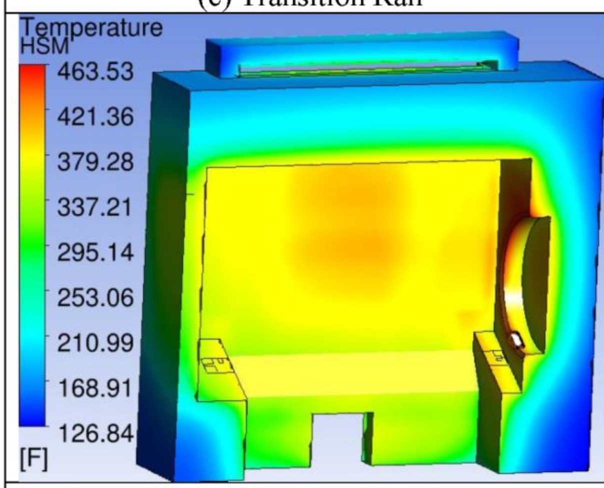
(b) Basket Plates



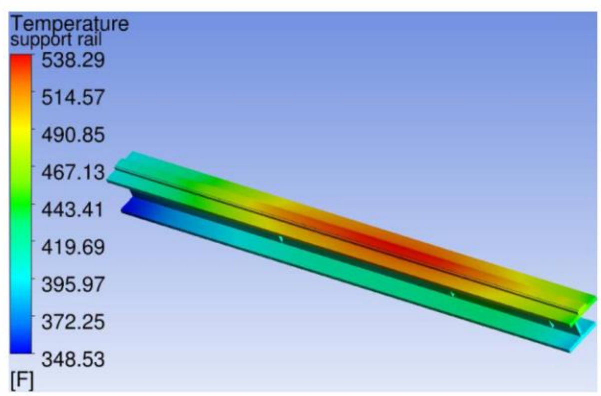
(c) Transition Rail



(d) EOS-37PTH DSC Shell

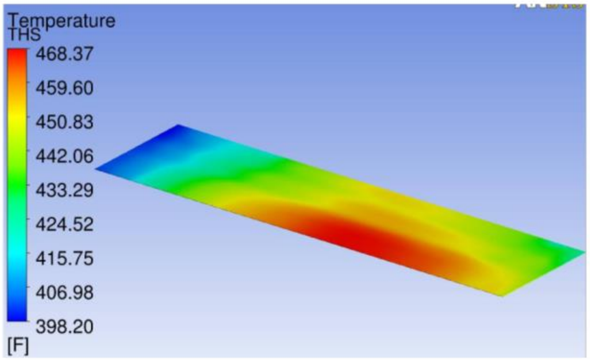


(e) EOS-HSM

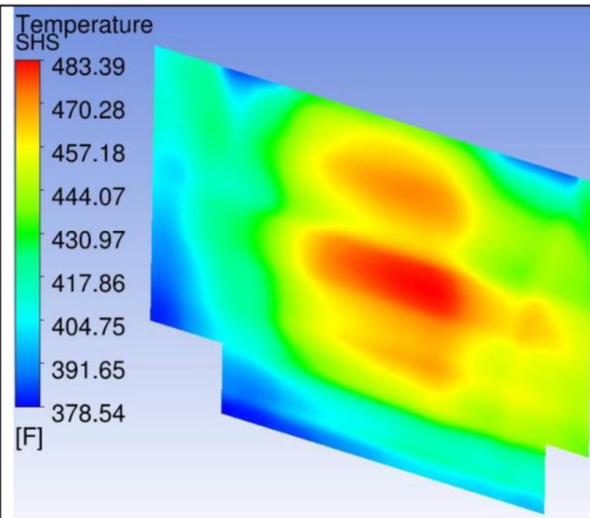


(f) Support Structure

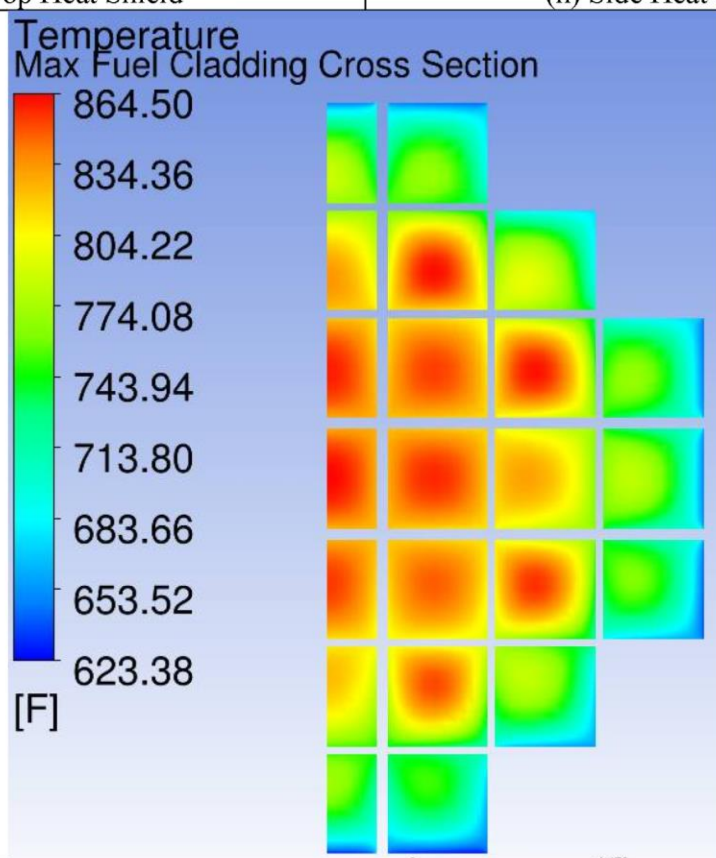
Figure 4-15
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Accident Storage Condition for 40 hours (Load Case 5)
2 Pages



(g) Top Heat Shield



(h) Side Heat Shield



(i) Fuel Cladding at the Hottest Cross Section

Figure 4-15
Temperature Profiles for EOS-HSM loaded with EOS-37PTH DSC at Accident Storage Condition for 40 hours (Load Case 5)
2 Pages

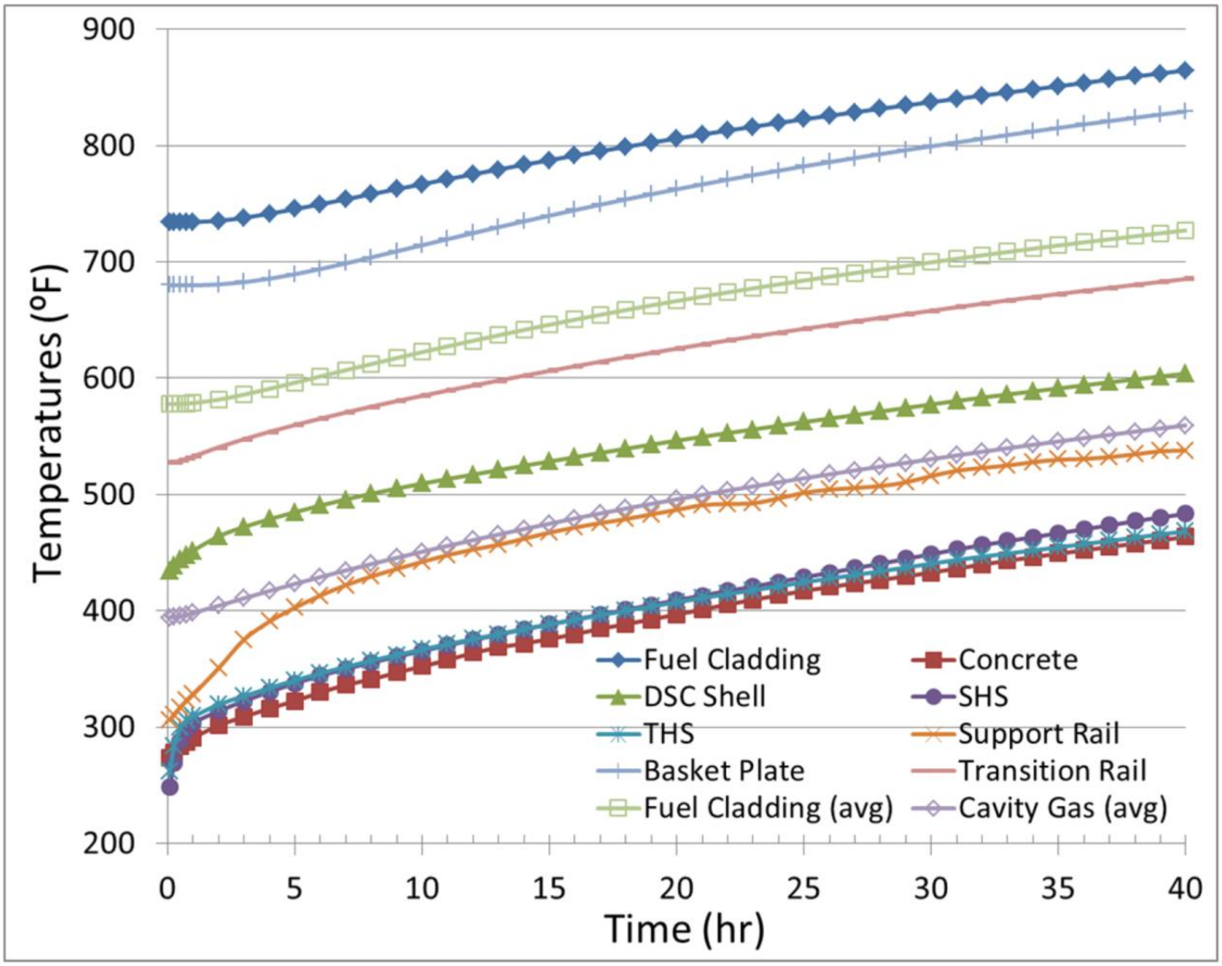


Figure 4-16
Maximum and Average Temperature Histories of Key Components in EOS-HSM loaded with EOS-37PTH DSC at Blocked Vent Accident Condition (Load Case 5)

Proprietary Information on Pages 4-181 through 4-188
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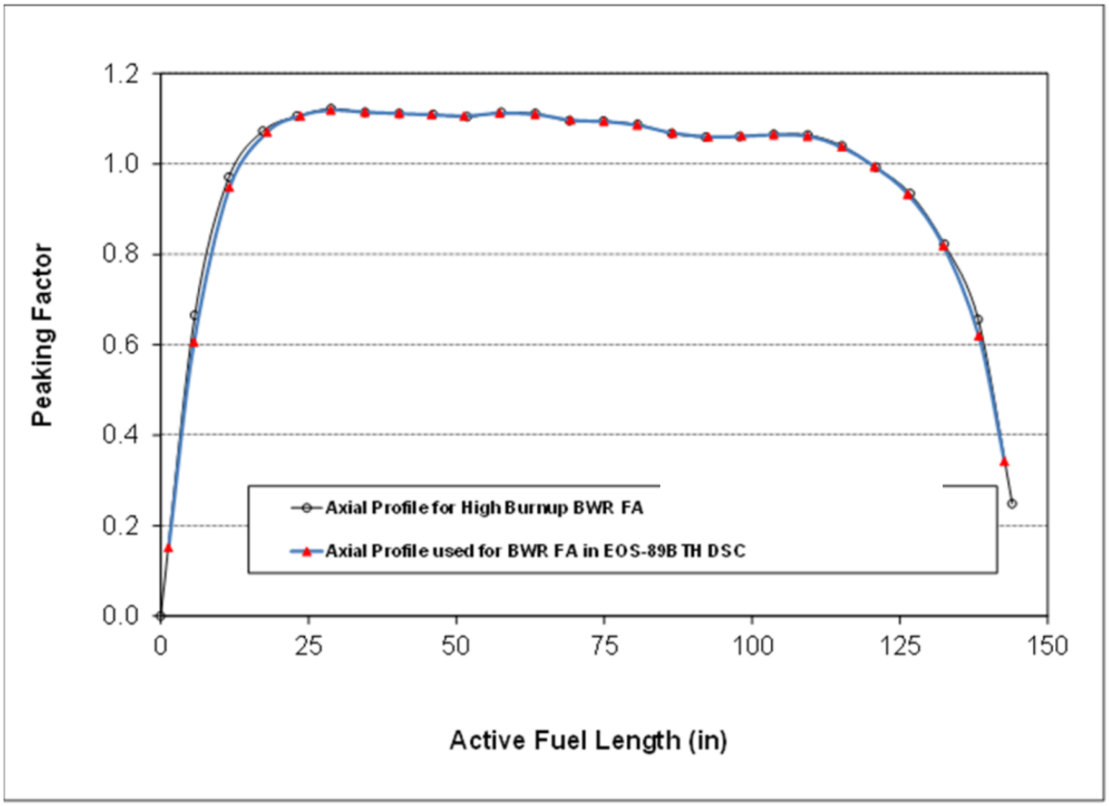

Figure 4-25
Peaking Factor Curve for BWR Fuel Assemblies

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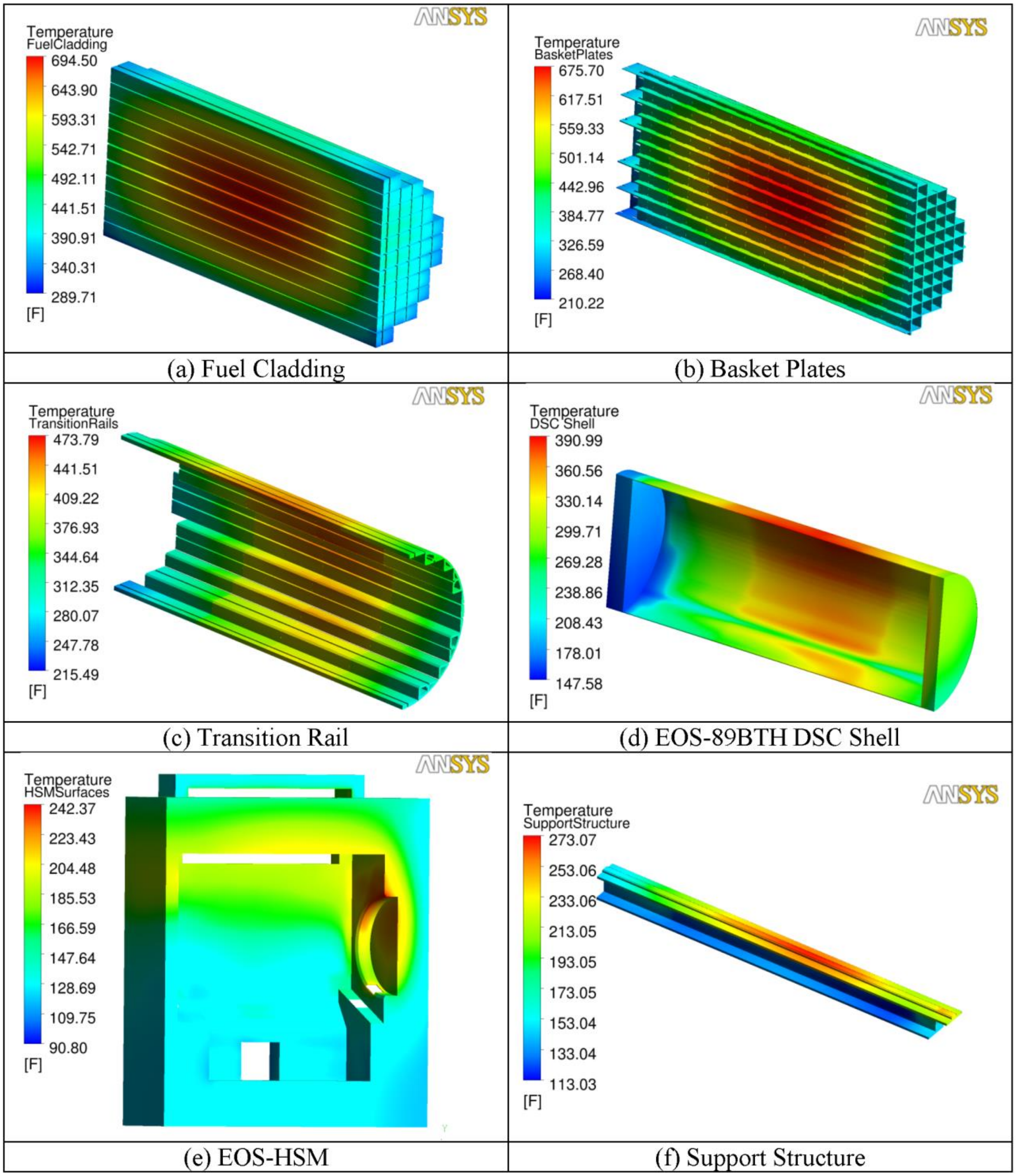
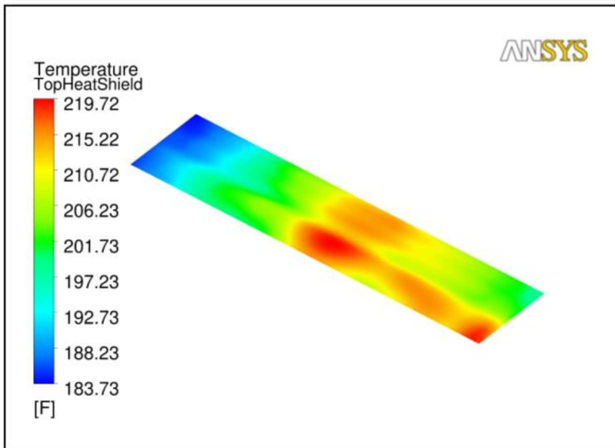
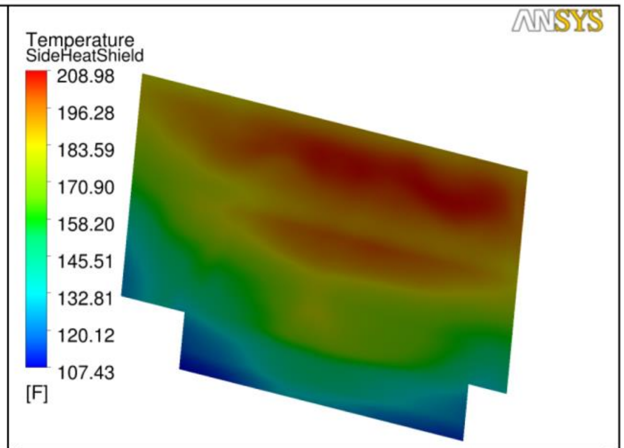


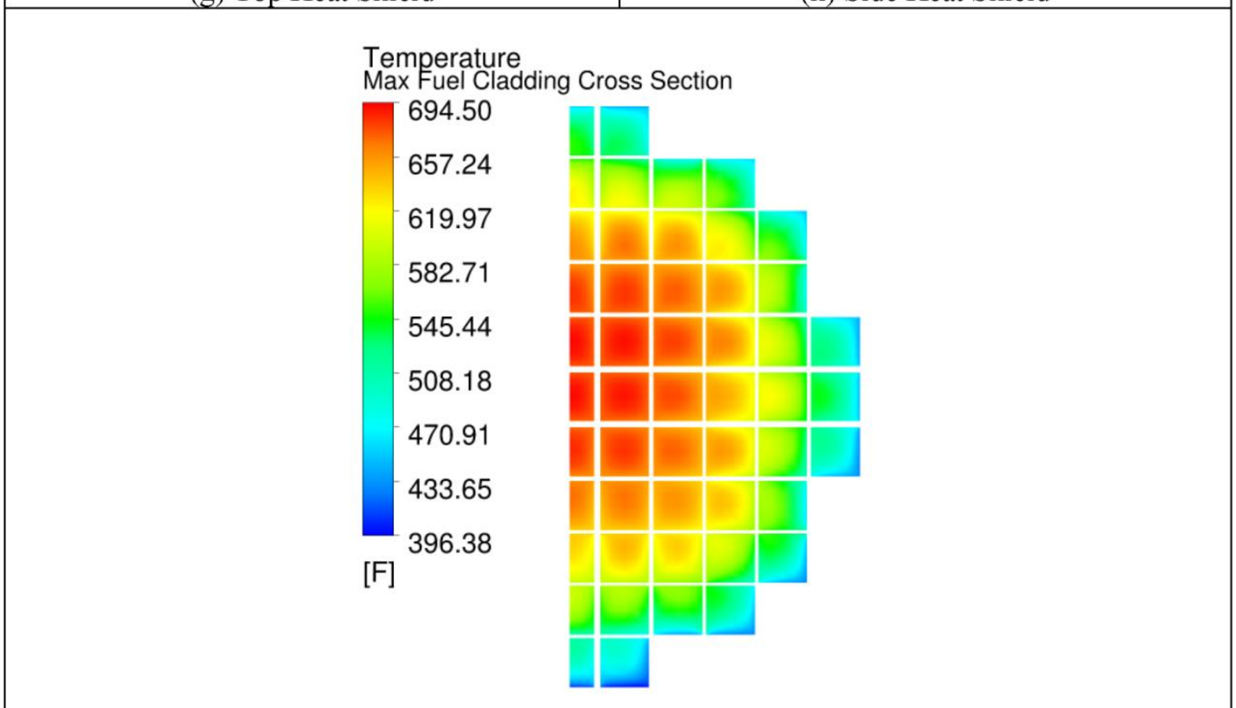
Figure 4-27
Temperature Profiles for EOS-HSM loaded with EOS-89BTH DSC at Normal Hot Storage Condition (Load Case 1a)
2 Pages



(g) Top Heat Shield



(h) Side Heat Shield



(i) Fuel Cladding at the Hottest Cross Section

Figure 4-27
Temperature Profiles for EOS-HSM loaded with EOS-89BTH DSC at Normal Hot Storage Condition (Load Case 1a)
2 Pages

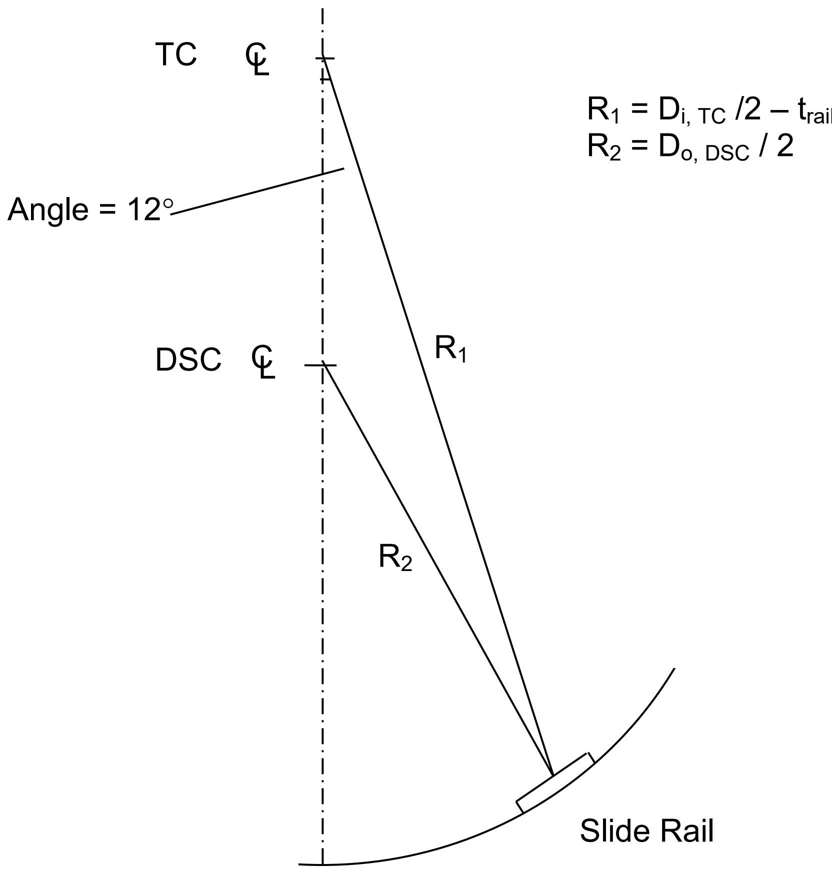


Figure 4-28
Location of DSC within TC during Horizontal Transfer Operations

Proprietary Information on Pages 4-194 through 4-197
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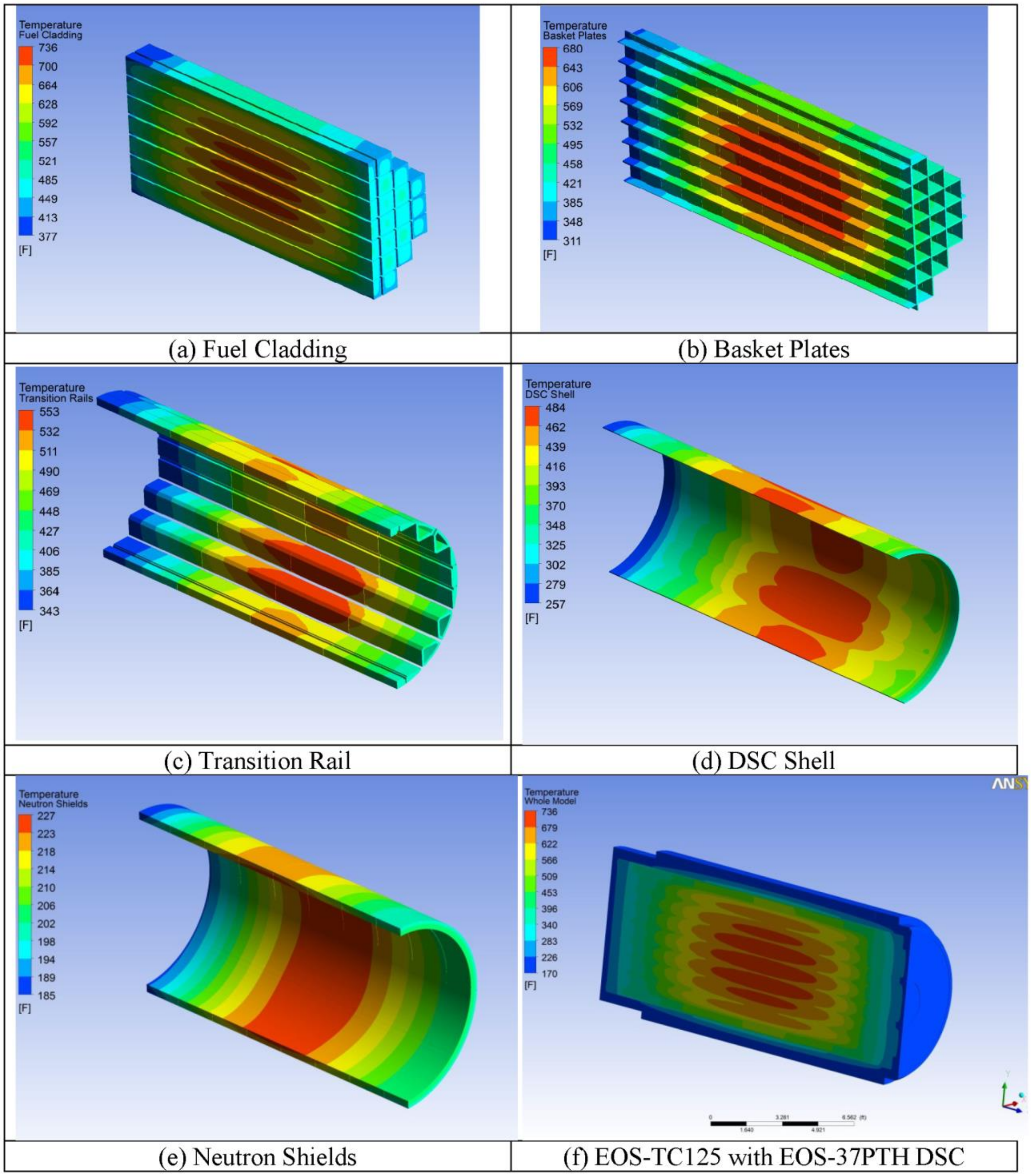
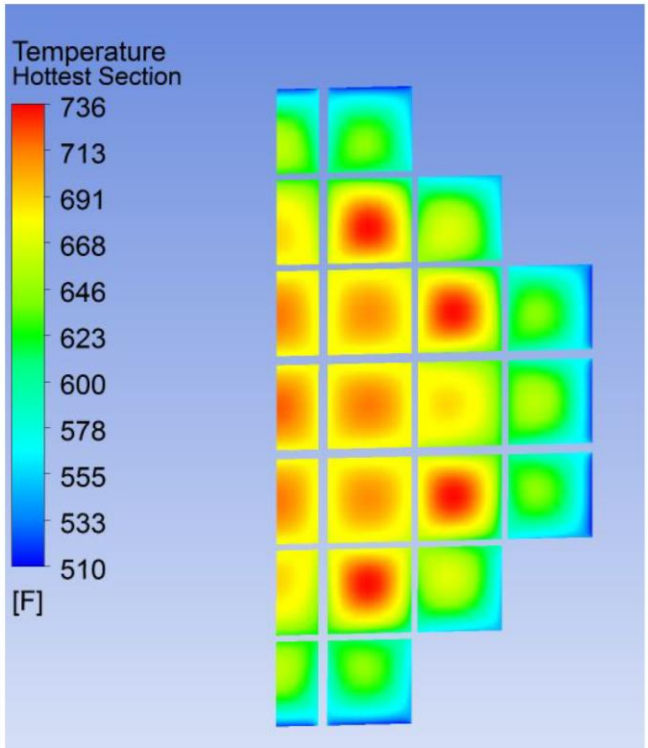


Figure 4-32
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Normal Hot, Vertical Transfer Operations at 14 hours (Load Case 1)
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-32
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Normal Hot, Vertical Transfer Operations at 14 hours (Load Case 1)
2 Pages

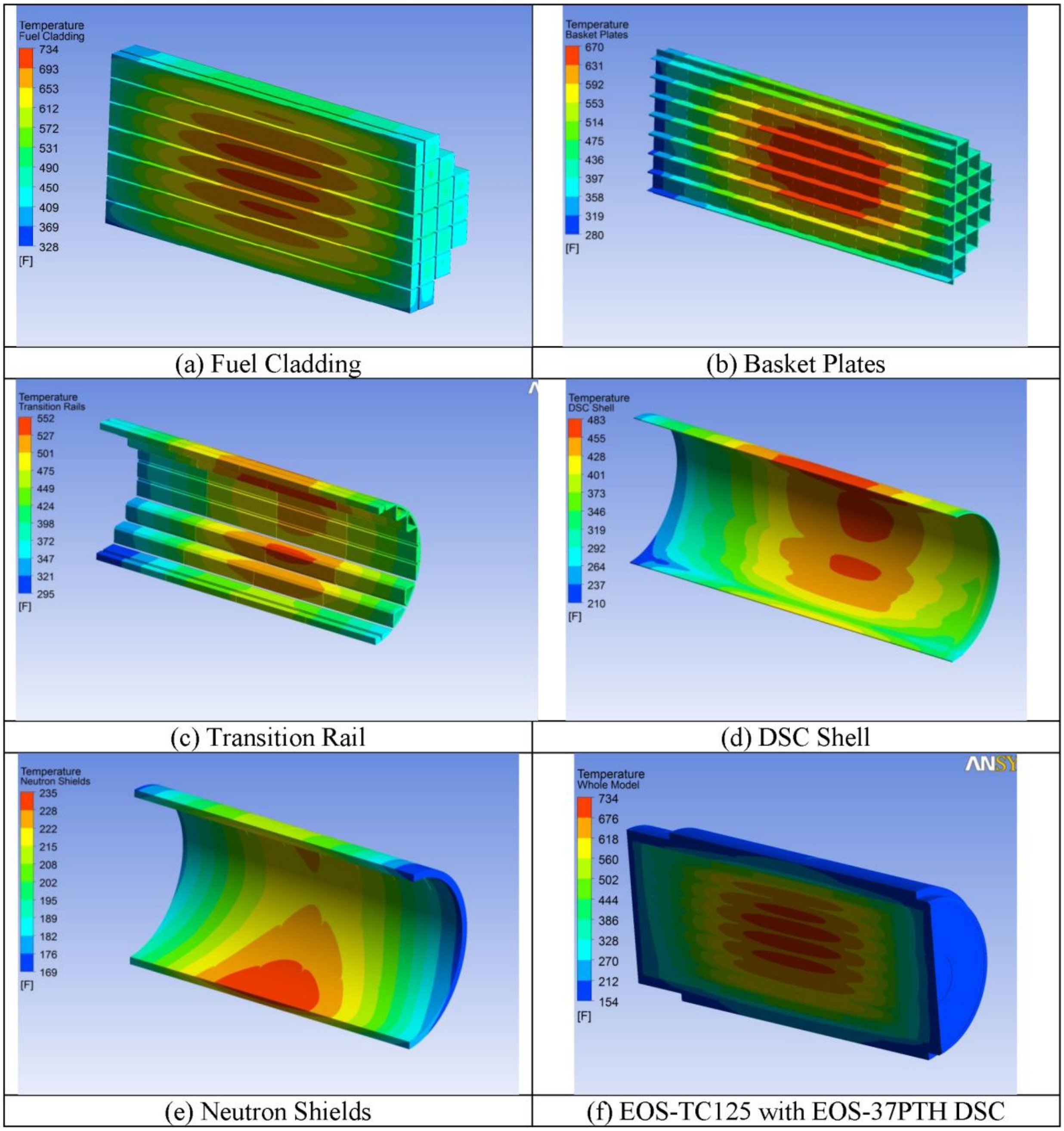
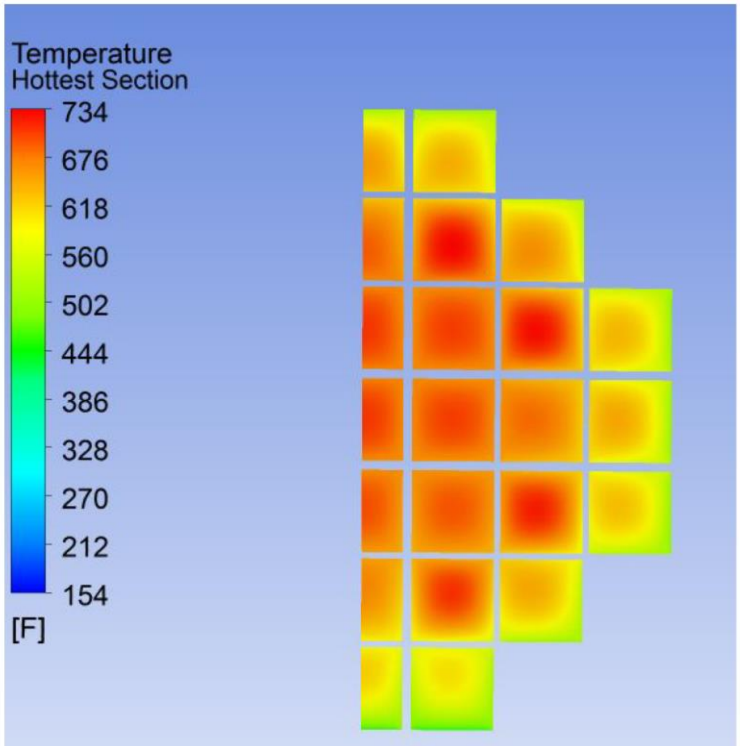


Figure 4-33
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Normal Hot, Horizontal Transfer Operations at 14 hours (Load Case 3)
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-33
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Normal Hot, Horizontal Transfer Operations at 14 hours (Load Case 3)
2 Pages

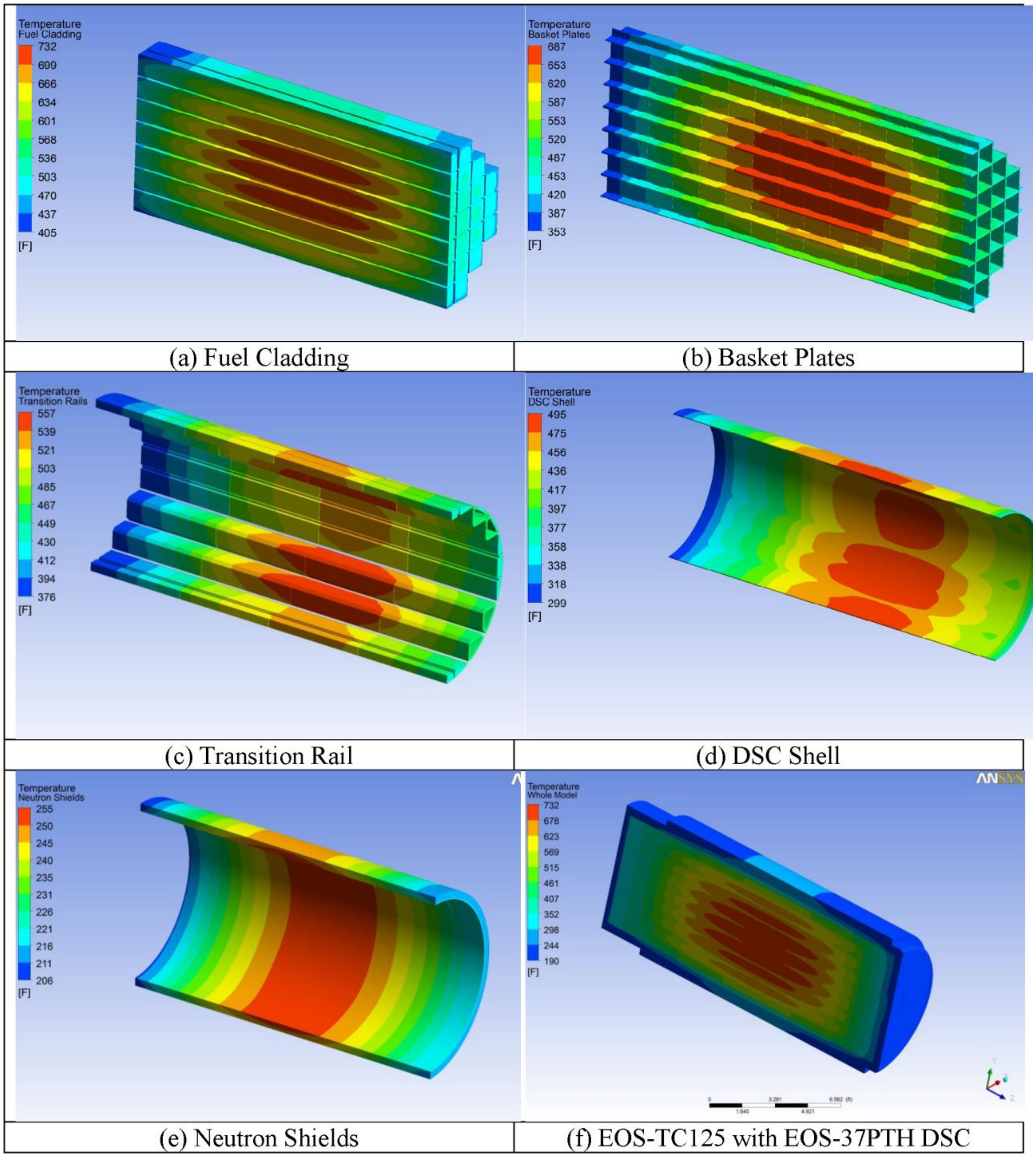
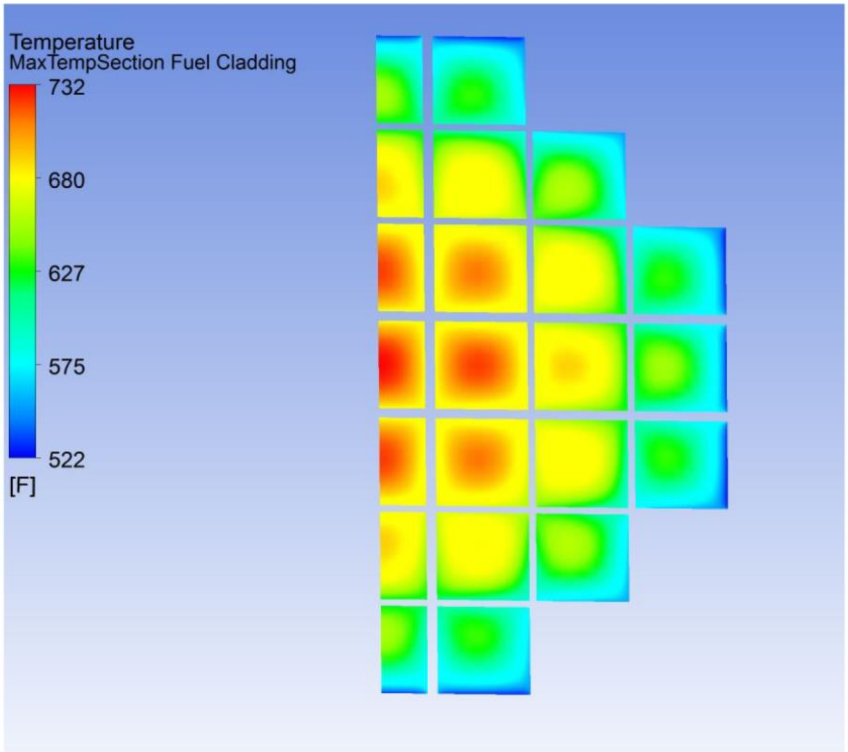


Figure 4-34
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 36.35 kW, Load Case 8
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-34
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 36.35 kW, Load Case 8
2 Pages

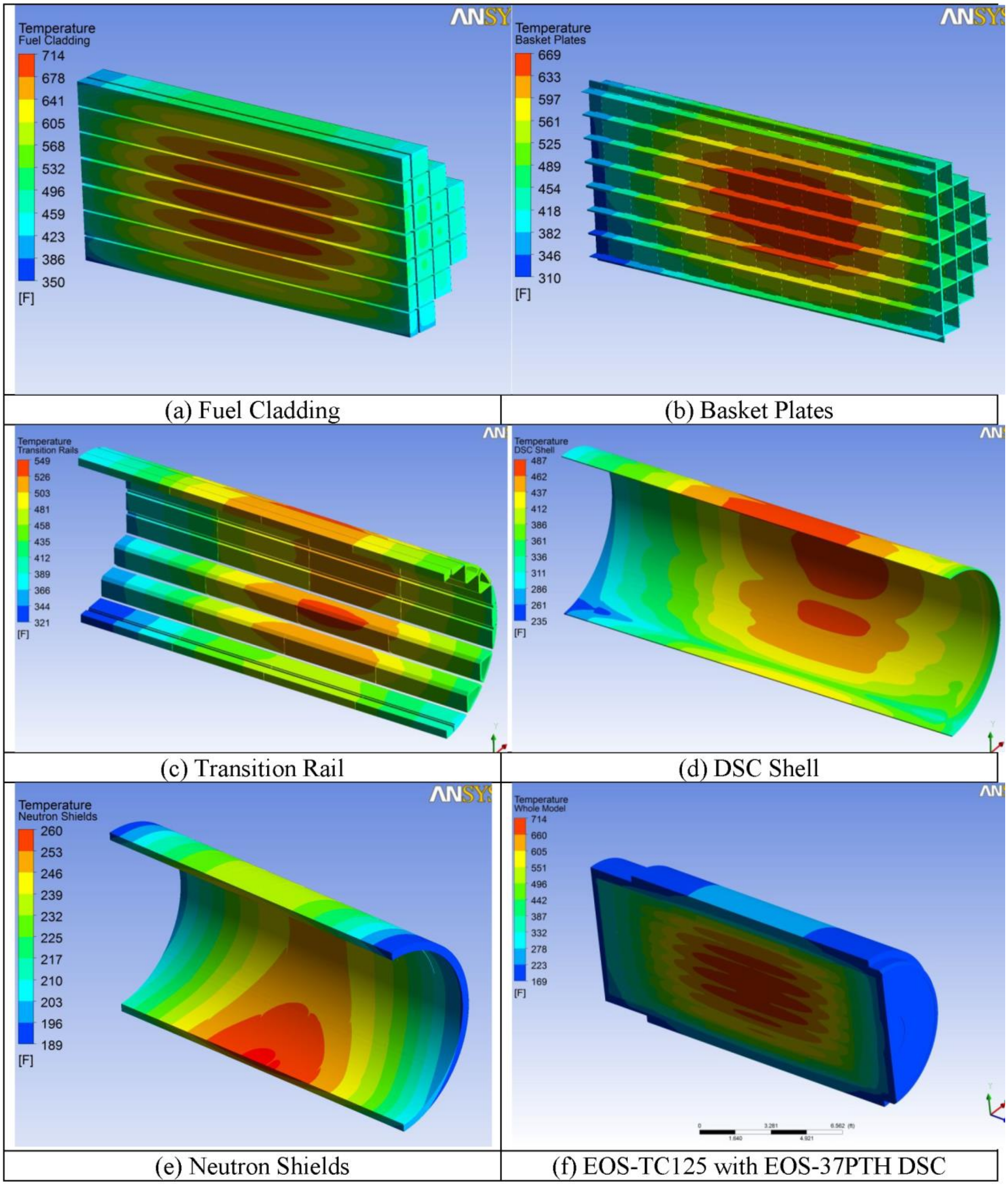
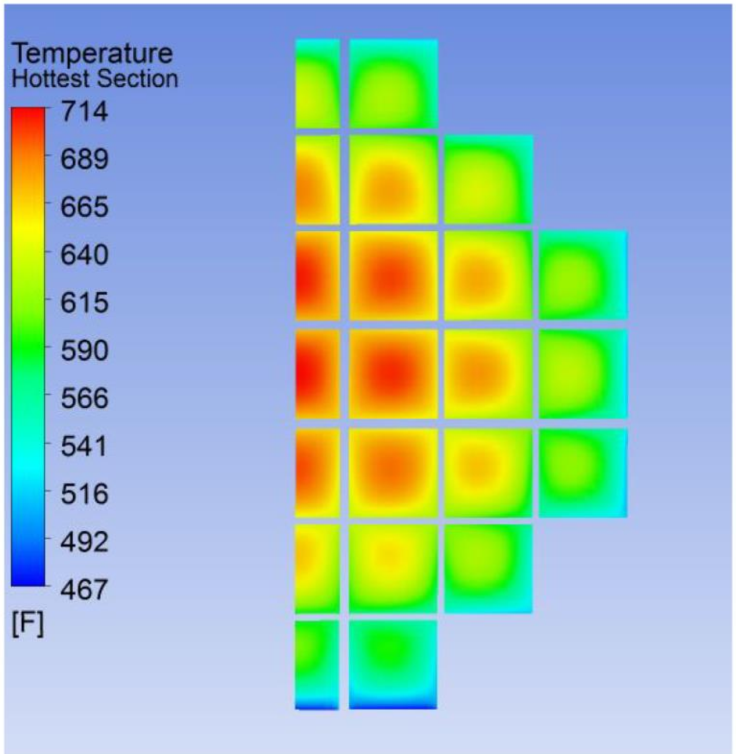
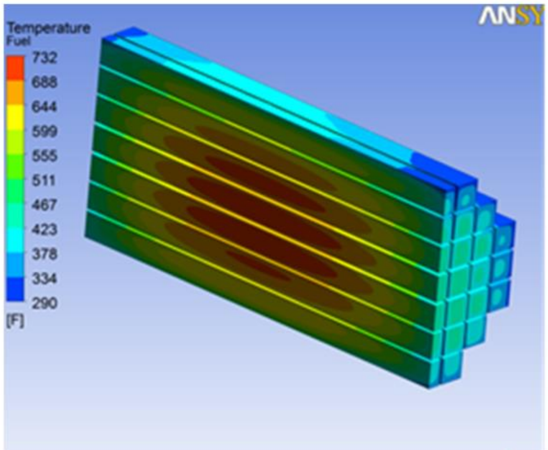


Figure 4-35
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 36.35 kW, Load Case 10
2 Pages

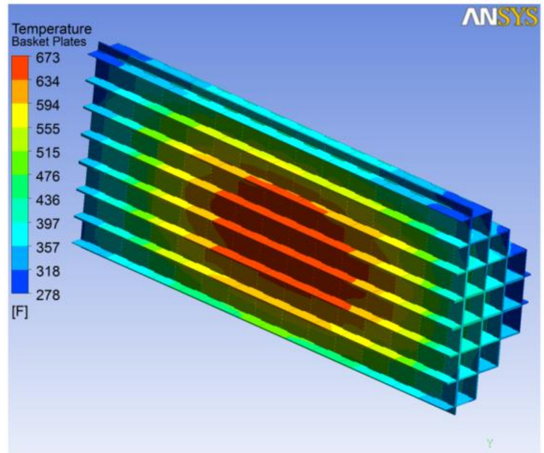


(g) Fuel Cladding at the Hottest Cross Section

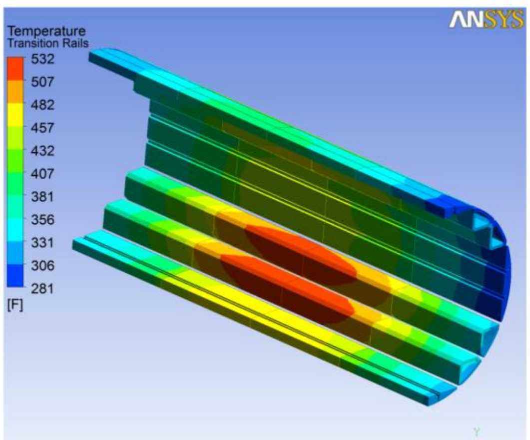
Figure 4-35
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 36.35 kW, Load Case 10
2 Pages



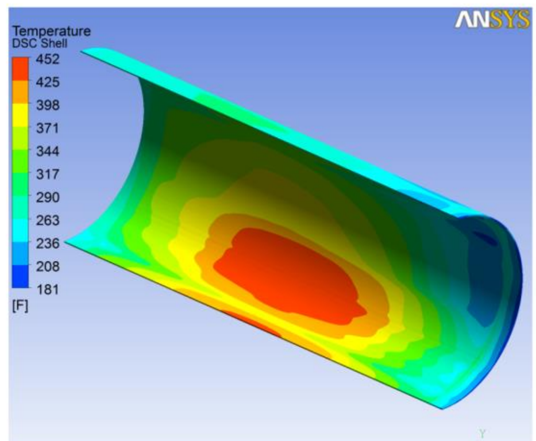
(a) Fuel Cladding



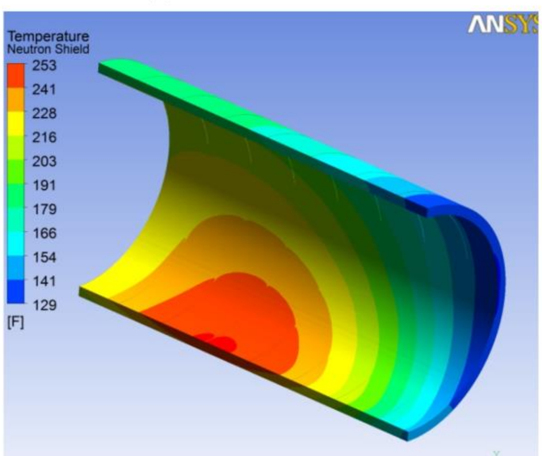
(b) Basket Plates



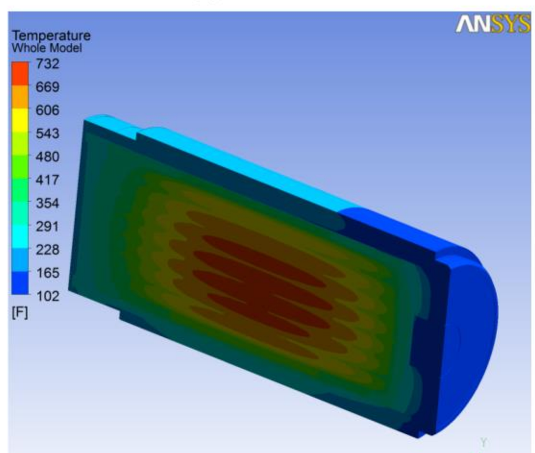
(c) Transition Rails



(d) DSC Shell

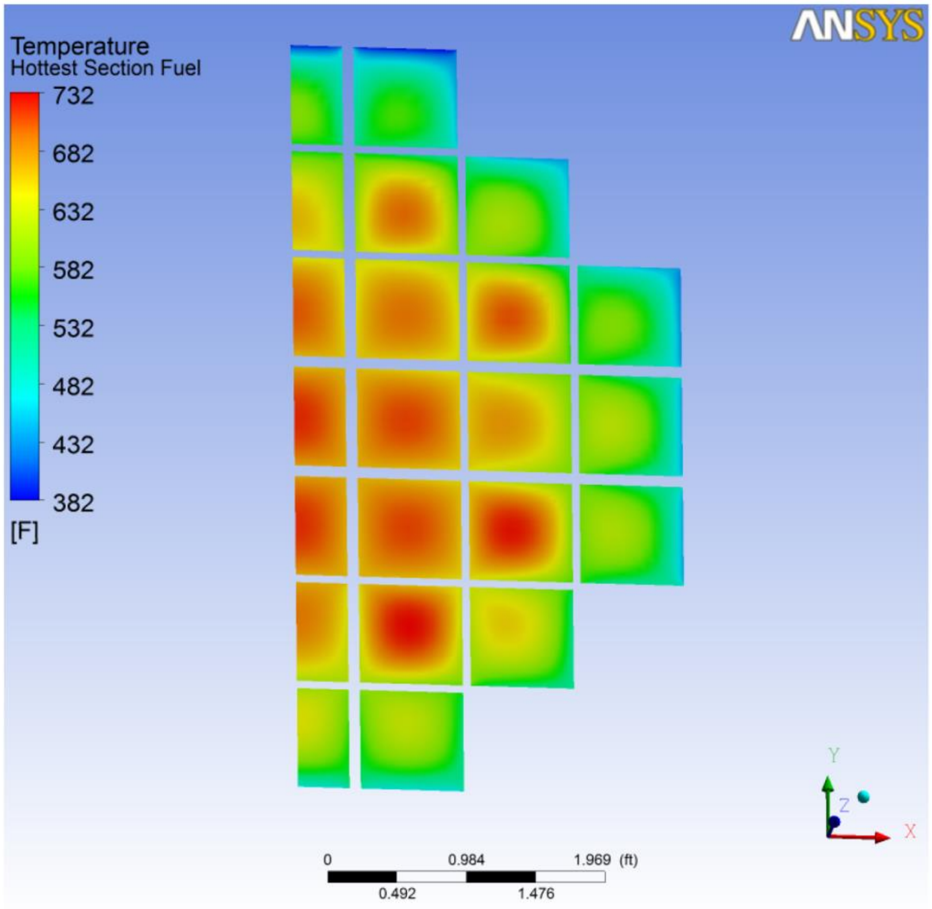


(e) Neutron Shields



(f) EOS-TC125 loaded with EOS-37PTH DSC

Figure 4-36
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Air Circulation and Load Case 6a
2 Pages



(g) Hottest Section in Fuel Cladding

Figure 4-36
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Air Circulation and Load Case 6a
2 Pages

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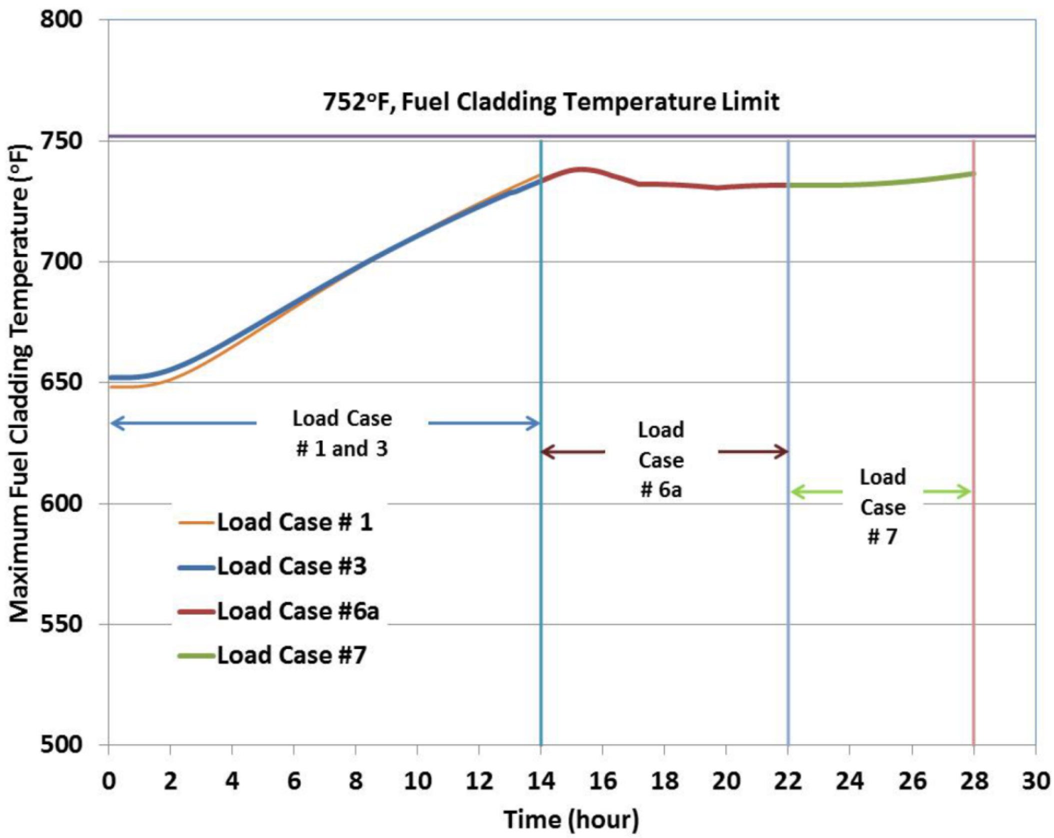


Figure 4-38
Maximum Fuel Cladding Temperature Versus Time in Transient Cases, Load Cases 1, 3, 6a, and 7

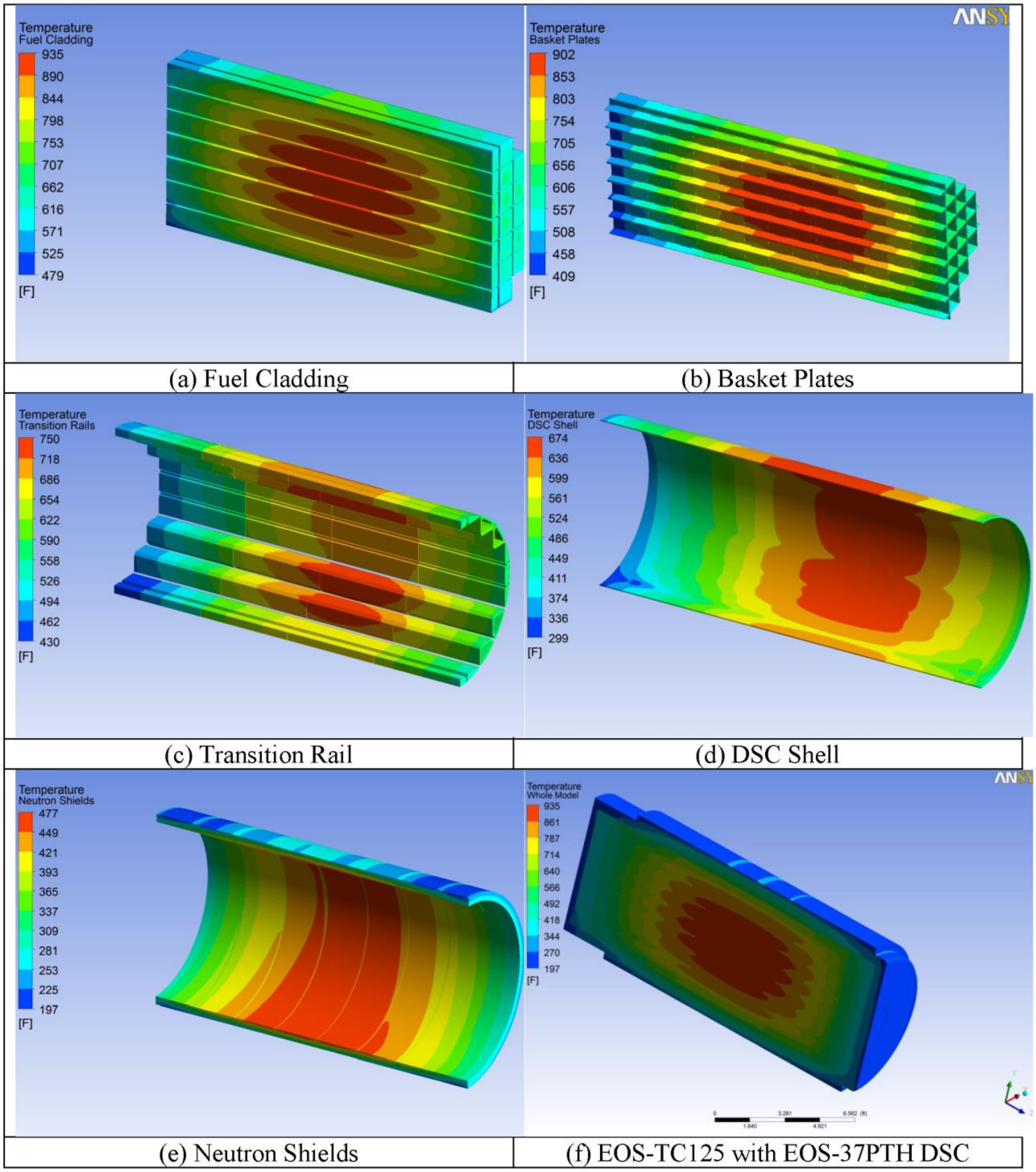
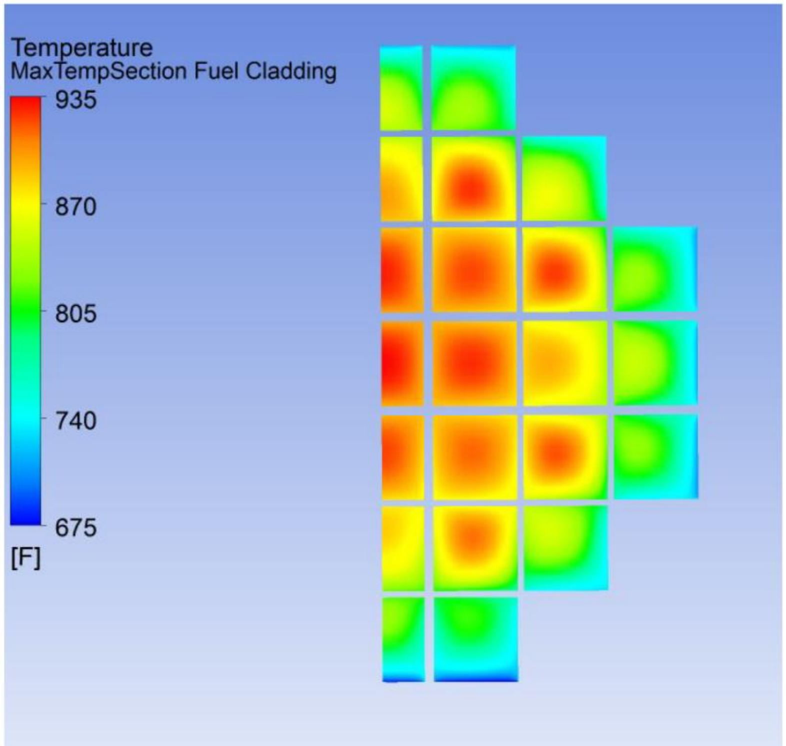


Figure 4-39
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Accident, Loss of Neutron Shield and Load Case 5
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-39
Temperature Distribution of EOS-TC125 Loaded with EOS-37PTH DSC at 50 kW, Accident, Loss of Neutron Shield and Load Case 5
2 Pages

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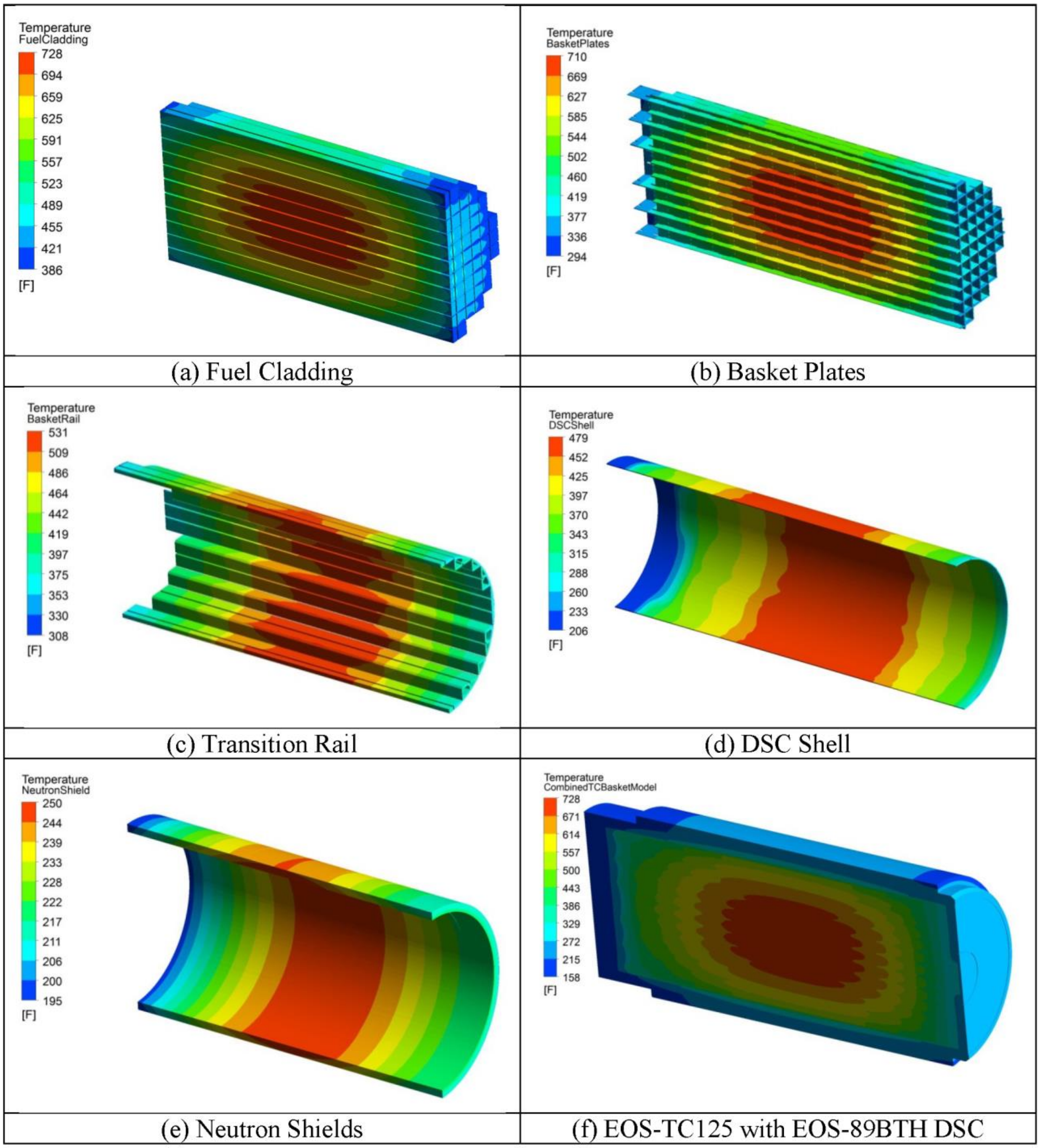
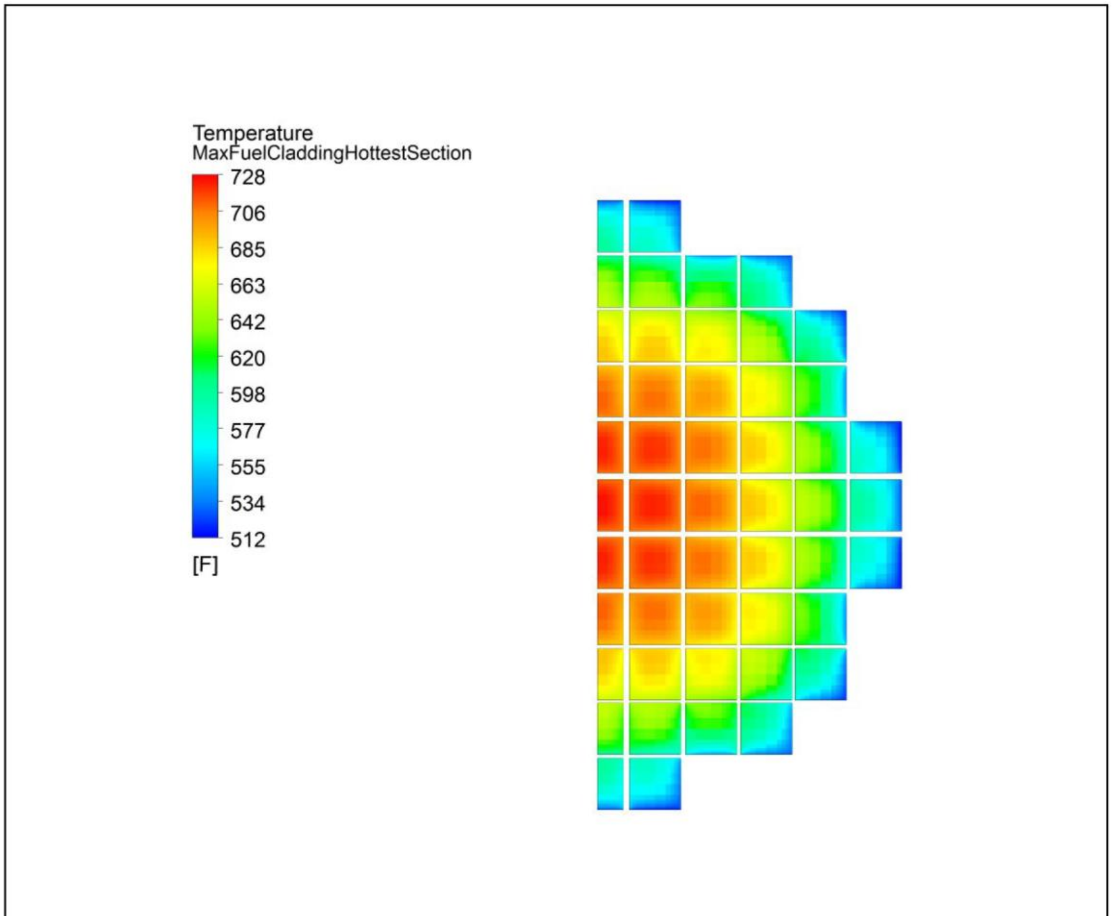


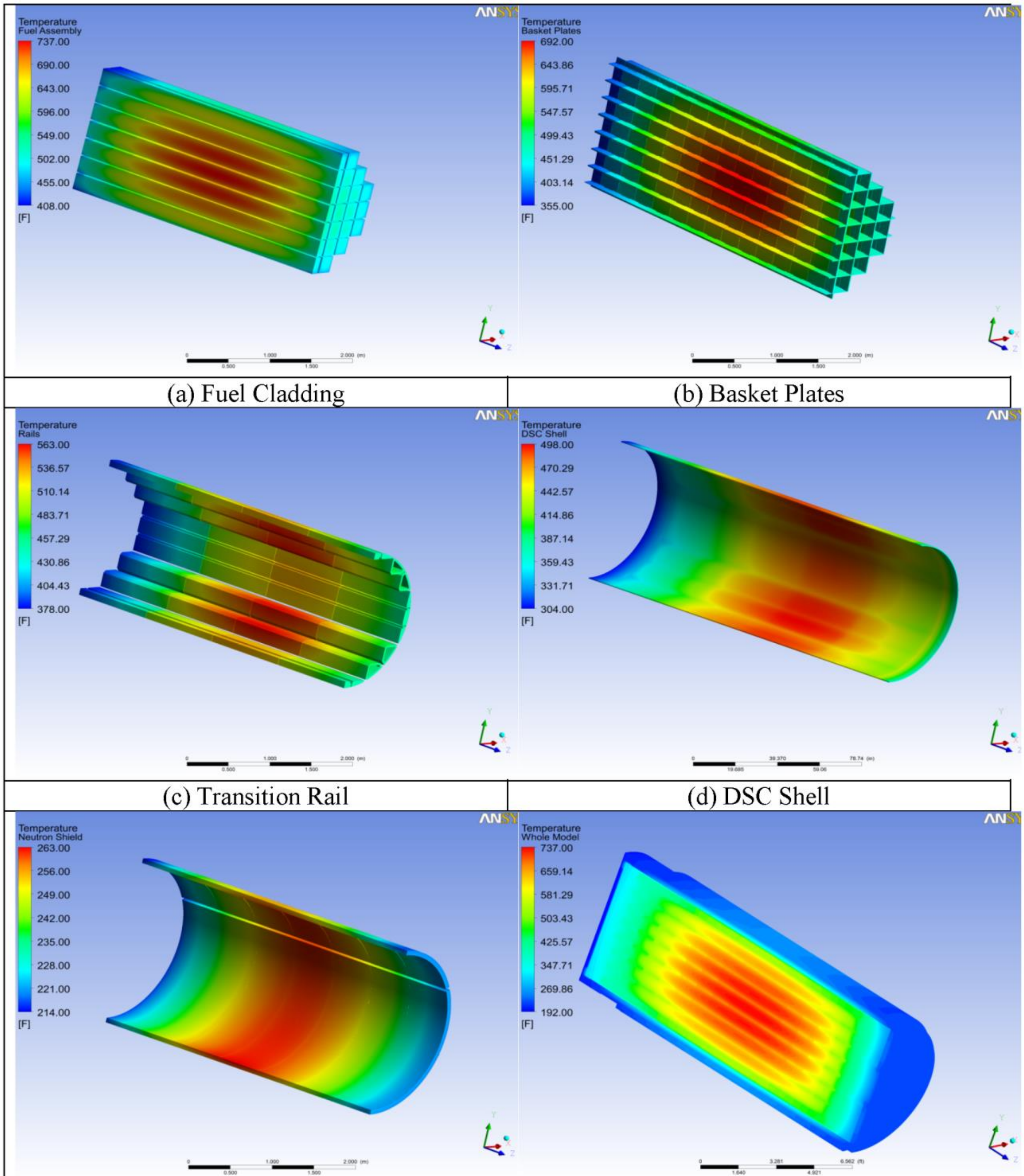
Figure 4-41
Temperature Profiles for EOS-TC125 Loaded with EOS-89BTH DSC at 34.44 kW, Normal Hot Vertical Operations (Load Case 8)
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

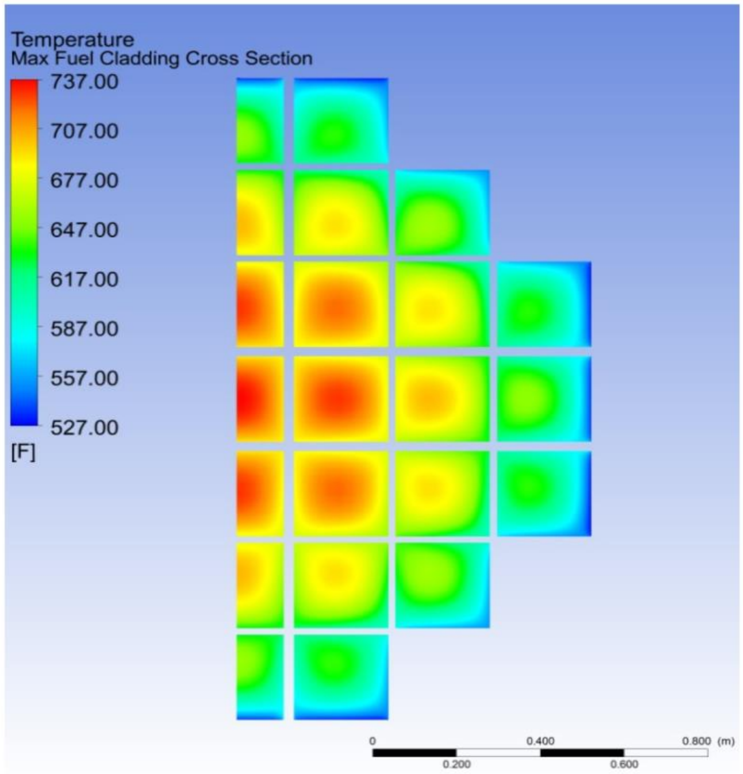
Figure 4-41
Temperature Profiles for EOS-TC125 Loaded with EOS-89BTH DSC at 34.44 kW, Normal Hot Vertical Operations (Load Case 8)
2 Pages

Proprietary Information on Pages 4-215 through 4-218
Withheld Pursuant to 10 CFR 2.390



(a) Fuel Cladding | (b) Basket Plates
(c) Transition Rail | (d) DSC Shell
(e) Neutron Shields | (f) EOS-TC108 with EOS-37PTH DSC

Figure 4-45
Temperature Distributions for EOS-TC108 with EOS-37PTH DSC at 36.35 kW, Load Case 8
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-45
Temperature Distributions for EOS-TC108 with EOS-37PTH DSC at 36.35 kW, Load Case 8
2 Pages

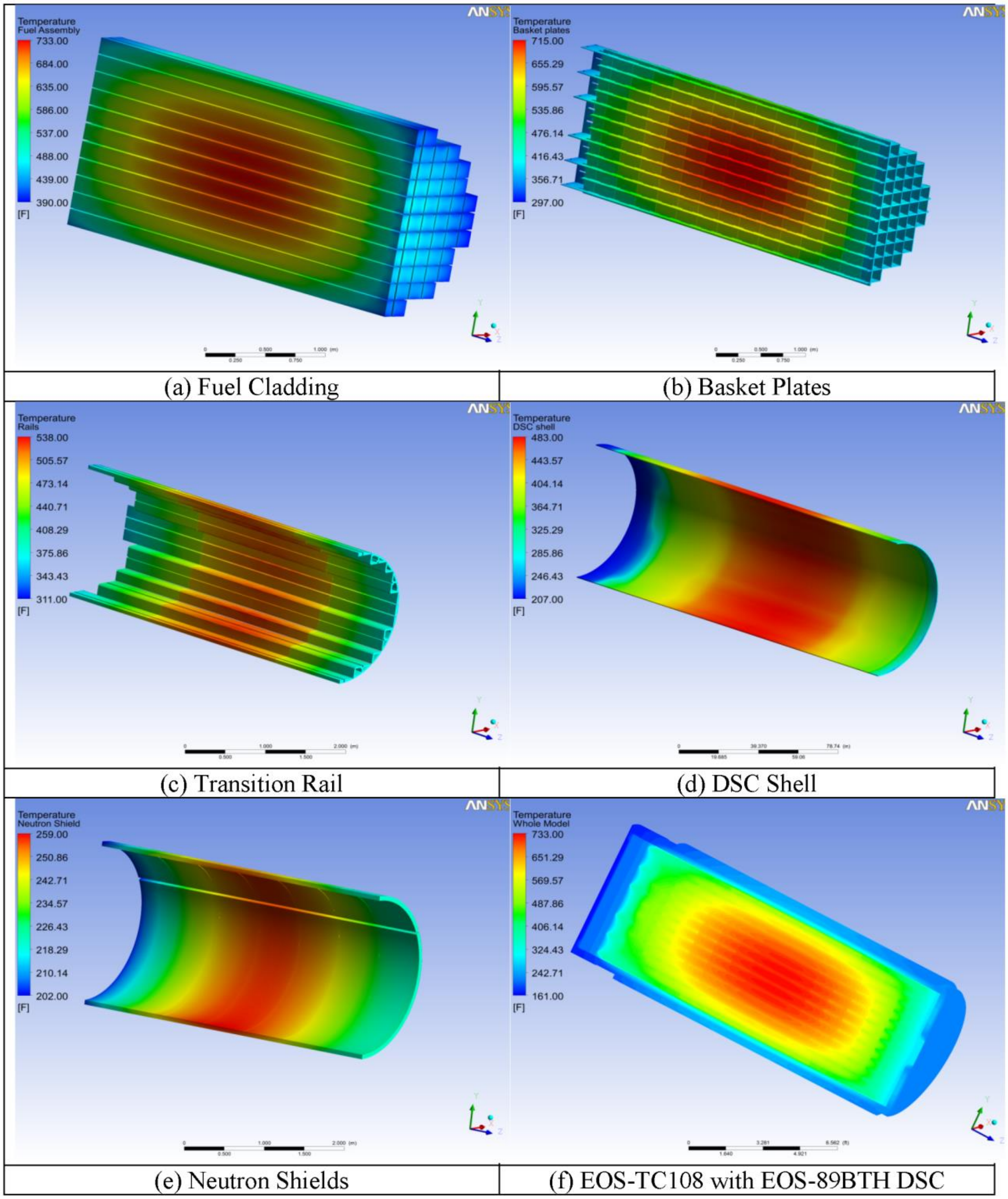
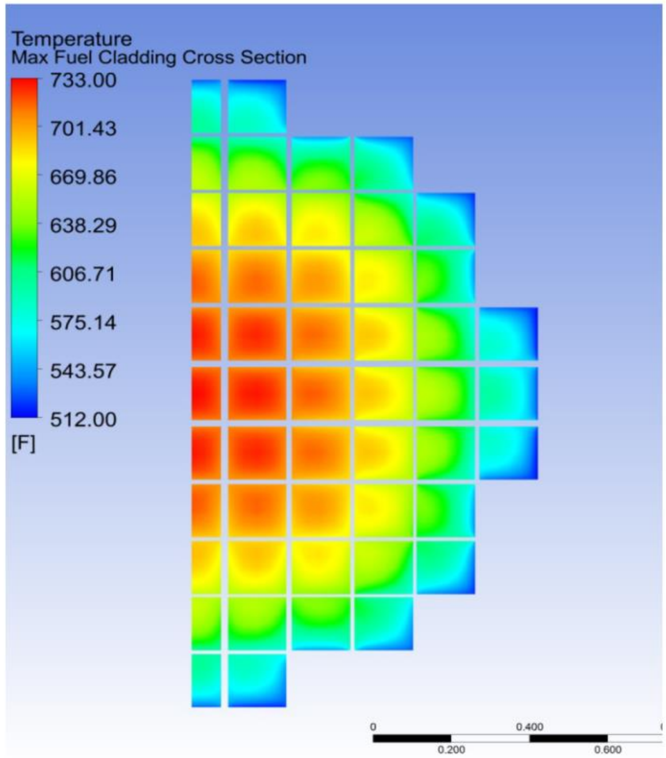


Figure 4-46
Temperature Distributions for EOS-TC108 Loaded with EOS-89BTH DSC
at 34.44 kW, Load Case 8
2 Pages



(g) Fuel Cladding at the Hottest Cross Section

Figure 4-46
Temperature Distributions for EOS-TC108 Loaded with EOS-89BTH DSC at 34.44 kW, Load Case 8
2 Pages

APPENDIX 4.9.1
CALCULATION OF EFFECTIVE PROPERTIES FOR HOMOGENIZED FUEL ASSEMBLIES

Table of Contents

List of Tables

List of Figures

4.9.1 CALCULATION OF EFFECTIVE PROPERTIES FOR HOMOGENIZED FUEL ASSEMBLIES

This section presents the methodology and determines the bounding effective thermal conductivity, specific heat and density for the irradiated spent fuel assemblies (SFAs) for use in the thermal analysis of the EOS-37PTH and EOS-89BTH DSCs. The EOS-37PTH and EOS-89BTH DSC basket assemblies are made up of interlocking slotted plates to form an egg-crate type structure with a grid of 37 and 89 fuel compartments, respectively, that house the fuel assemblies (FAs).

The surface properties of the components that make up the fuel compartment, along with the properties of the FAs, are used to determine the effective thermal properties. Emissivities of 0.8 and 0.09 are used for the Zircaloy fuel cladding and the aluminum sections of the fuel compartment opening as noted in Section 4.2.1. The emissivity of [ ] steel surfaces or alternative surface treatment used in the evaluation is also listed in Section 4.2.1. The thermal properties of irradiated uranium dioxide (UO_2) and the fuel cladding are listed in Table 4.9.1-1 and Table 4.9.1-2, respectively.

The following conservatisms and assumptions are considered in the calculation of effective properties for FAs in EOS-37PTH and EOS-89BTH DSCs:

- Convection heat transfer within fuel assembly is neglected.
- The radiative heat transfer between fuel pellets and fuel cladding is neglected.
- The backfill gas and fuel pellets are not included in the FA axial effective thermal conductivity calculation as required by NUREG-1536 [4.9.1-1].
- The backfill gas is conservatively not included in calculating the FA effective density and specific heat.
- The FA is centered within a fuel compartment which maximizes thermal resistance between the fuel assembly and the compartment wall.
- For the pressurized water reactor (PWR) fuel, the instrument tube is not included in the cross-section of WE14x14 FA model. Change of instrument tube to fuel rod increases the heat generation in the center of the FA and the maximum temperature of the FA, which results in lower effective thermal conductivity of the FA.

4.9.1.1 Effective Thermal Properties for PWR Spent Fuel Assemblies in EOS-37PTH DSC

The FAs considered for storage in the EOS-37PTH DSC, including the design data for each fuel assembly, are listed in Table 2-2 and Table 2-4. The FAs listed in Table 2-2 are previously studied in Section M.4.8 and Section P.4.8 of the Updated Final Safety Analysis Report (UFSAR) for the Standardized NUHOMS® System [4.9.1-2]. In addition to the FAs analyzed in Section M.4.8 and Section P.4.8 of the Standardized NUHOMS® System UFSAR, the EOS-37PTH DSC allows for the storage of certain European and Japanese FAs as shown in Table 2-4.

A comparison of the FA characteristics of the European and Japanese FAs from Table 2-4 to those previously analyzed in Table 2-2 shows that they are either identical or very similar as described below.

- Geometry of Doel 1 and 2 (assembly type 14x14) FA and Kansai (assembly type 14x14 Step I Type A) FA are identical or similar to WE14x14 FA. The active fuel length for Doel 1 and 2 is 96 inches, which is shorter than WE14x14 FA. The heat load for this FA will be adjusted as described in Section 4.9.1.3.
- Geometry of Tihange 1 (assembly type 15x15) FA and Kansai (assembly type 15x15 Step I Type A) FA are identical or similar to WE 15x15 FA.
- Geometry of Doel 3 and 4 (assembly type 17x17) FA, Tihange 2 (assembly type 17x17) FA, Tihange 3 (assembly type 17x17) fuel assembly, Kansai (assembly type 17x17 Step II) FA, ENRESA ASCO (assembly type 17x17) FA, and AM1000 (assembly type 17x17) FA are identical or similar to WE17x17 FA.

Since the European or Japanese FAs are identical or very similar to the assemblies presented in Table 2-2, the thermal properties for these FAs will be bounded by the properties of the corresponding assemblies from Table 2-2. Among the various FAs listed in Table 2-2, based on the study in Section P.4.8 of the Standardized NUHOMS® System UFSAR, the WE 14x14 FA has the bounding transverse effective conductivity, bounding axial effective conductivity, bounding effective density, and bounding effective specific heat.

Since the same FAs or their corresponding versions (European and Japanese fuel assemblies) are considered for storage within the EOS-37PTH DSC, the effective thermal properties for WE 14x14 are recomputed using the methodologies presented in Section M.4.8 and Section P.4.8 of the Standardized NUHOMS® System UFSAR using irradiated UO_2 properties and the EOS-37PTH DSC basket configuration shown in the drawings in Section 1.3.1.

The methodology to determine the axial conductivity is described in Section P.4.8.1.3 of the Standardized NUHOMS® System UFSAR [4.9.1-2] and is used in this evaluation based on the bounding FA and the properties described above. Similarly, the effective density and specific heat are determined based on the methodology presented in Section P.4.8.2 of the Standardized NUHOMS® System UFSAR, using the bounding FA and the properties described above.

Using the methodology presented in Appendix P, Section P.4.8.1.4 of the Standardized NUHOMS® System [4.9.1-2], a two-dimensional (2D) finite element model (FEM) of WE14x14 OFA FA is developed in ANSYS [4.9.1-3] to determine the transverse effective conductivity. The outer surfaces, representing the fuel compartment walls, are held at a constant temperature, and heat generating boundary condition is applied to the fuel pellets within the model. The models were run with a series of isothermal boundary conditions applied to the nodes representing the fuel compartment walls. The FEMs of WE14x14 OFA FA is shown in Figure 4.9.1-1. Figure 4.9.1-2 shows the heat generation rate and temperature boundary conditions.

The computed FA transverse and axial effective conductivities as functions of temperature for irradiated WE14x14 FA are listed in Table 4.9.1-3 and also summarized in Section 4.2.1. The effective specific heat and density for irradiated WE14x14 FA is shown is listed in Table 4.9.1-4 and also summarized in Section 4.2.1. The effective thermal conductivities for the FAs are also applicable for vacuum drying conditions since helium is used for water blowdown from the DSC.

4.9.1.2 Effective Thermal Properties for BWR Spent Fuel Assemblies in EOS-89BTH DSC

The FAs considered for storage in the EOS-89BTH DSC including the design data for each FA, are listed in Table 2-3 and Table 2-4. The FAs listed in Table 2-3 are previously studied in Section T.4.8 and Section Y.4.9 of the Standardized NUHOMS® System UFSAR[4.9.1-2], except for the GNF2 FA. However, the dimensions of GNF2 FA listed in Table 2-3 are very similar to the previously evaluated GE12/GE14 FAs from Section T.4.8 and Section Y.4.9 of the Standardized NUHOMS® System UFSAR. Therefore, the thermal properties for the GE12/GE14 FAs are also applicable to the GNF2 FA.

In addition to the FAs analyzed in Section T.4.8 and Section Y.4.9 of the Standardized NUHOMS® System UFSAR, the EOS-89BTH DSC allows for the storage of certain European and Japanese FAs as shown in Table 2-4. Since transient evaluations are not performed for the EOS-89BTH DSC in Sections 4.4, 4.5, and 4.6,only the effective transverse and axial conductivities are presented for the FAs allowed for storage in the EOS-89BTH DSC.

A comparison of the FA characteristics of the European and Japanese FAs from Table 2-4 to those previously analyzed in Table 2-3 shows that they are either identical or very similar as described below.

- Geometries of Japanese boiling water reactor (BWR) FA (assembly type 8x8 Step II) and Switzerland– KKL BWR 1/4 fuel assembly (assembly type 8x8) from Table 2-4 are similar to GE8 Type II FA (TN ID: 8x8-60/4) from Table 2-3.
- Geometry of Switzerland– KKL BWR 2/5/8 FA (assembly type 9x9) from Table 2-4 is similar to GE 11/13 FA (TN ID: 9x9-74/2) from Table 2-3.
- Geometry of Switzerland– KKL BWR 3/9/12/13 FA (assembly type 10x10) from Table 2-4 is similar to GE 12/14 FA (TN ID: 10x10-92/2) from Table 2-3.
- Geometry of Switzerland– KKL BWR 6 FA (assembly type 4x4x4) from Table 2-4 is identical or similar to SVEA-64 FA from Table 2-3.
- Geometries of Switzerland– KKL BWR 7/14 FA (assembly type 4x(5x5-1)), BWR 10/15 FA (assembly type 4x(5x5-3)/4x(5x5-1)) and BWR 11/16 FA (assembly type 4x(5x5-4)/4x(5x5-2)/4x(5x5-1)) from Table 2-4 are similar to SVEA-96 FA from Table 2-3.

Since the European or Japanese FAs are identical or very similar to the assemblies presented in Table 2-3, the thermal properties for theseFAs will be bounded by the properties of the corresponding assemblies from Table 2-3. Among the various FAs listed in Table 2-3, based on the study in Section T.4.8 and Section Y.4.9 of the Standardized NUHOMS® System UFSAR, the FANP 9x9-81 FA has the bounding transverse effective conductivity. Therefore, the transverse effective conductivities are recomputed using the methodologies presented in Section T.4.8 of the Standardized NUHOMS® System UFSAR using irradiated UO_2 properties and the EOS-89BTH DSC basket configuration shown in the drawings in Section 1.3.2.

Using the methodology presented in Section T.4.8.1.4 of the Standardized NUHOMS® System UFSAR, a 2D FEM of FANP 9x9-81 FA is developed in ANSYS [4.9.1-3] to determine the transverse effective conductivity. The outer surfaces, representing the fuel compartment walls, are held at a constant temperature, and heat generating boundary condition is applied to the fuel pellets within the model. The models were run with a series of isothermal boundary conditions applied to the nodes representing the fuel compartment walls. The FEMs FANP 9x9-81 FA is shown in Figure 4.9.1-3. Figure 4.9.1-4 shows the heat generation rate and temperature boundary conditions.

The methodology to determine the axial conductivity is described in Section T.4.8.1.3 of the Standardized NUHOMS® System [4.9.1-2] and is used in this evaluation for the various FAs listed in Table 2-3 and Table 2-4.

The computed bounding fuel assembly transverse and axial effective conductivities as functions of temperature for the various FAs allowed for storage in EOS-89BTH DSC are listed in Table 4.9.1-5 and also summarized in Section 4.2.1. The effective thermal conductivities determined for the bounding FAs are also applicable for vacuum drying conditions since helium is used for water blowdown from the DSC.

4.9.1.3 Scaling Factors for Short and Long Fuel Assemblies

The various heat load zone configuration (HLZCs) presented in Figure 1 of the Technical Specifications [4.9.1-6] for the EOS-37PTH DSC and Figure 2 of the Technical Specifications [4.9.1-6] for the EOS-89BTH DSC are evaluated in Sections 4.4, 4.5, and 4.6 at the maximum allowable heat loads for each HLZC, assuming that the FA has an active fuel length of 144 inches.

For FAs with active fuel length shorter than 144 inches, there is a possibility that the concentration of the heat generation in a smaller volume might result in a non-conservative temperature distribution. To ensure that the temperature distributions evaluated in Sections 4.4, 4.5, and 4.6 remain bounding, the maximum allowable heat load for FAs with active fuel length shorter than 144 inches should be determined as discussed below.

Since conduction with effective conductivities is the only heat transfer path considered in the EOS-37PTH and EOS-89BTH DSCs, the temperatures are directly proportional to the FA heat load and inversely proportional to the active fuel length and effective fuel conductivity. Therefore, the following equations are used to determine the heat load for FAs with active fuel length shorter than 144 inches in order to maintain the temperatures at the same level as those determined from the bounding FAs.

$$\left(\frac{q}{L_a\ k_{eff}}\right)_{Short\ FA} = \left(\frac{q}{L_a\ k_{eff}}\right)_{Bounding\ FA}$$

$$q_{Short\ FA} = q_{Bounding\ FA} \cdot SF,$$

$$SF = \frac{L_{a,Short\ FA}}{L_{a,Bounding\ FA}} \cdot \frac{k_{eff,Short\ FA}}{k_{eff,Bounding\ FA}}.$$

Where,

k_{eff} = Effective conductivity for FA,
q = Decay heat load per assembly defined for each loading zone,
L_a = Active fuel length,
SF = Scaling factor (SF) for short FAs.

The SF determined from the equation should be used to reduce the maximum heat load per FA in each loading zone of the HLZCs presented Figure 1 of the Technical Specifications [4.9.1-6] for the EOS-37PTH DSC and Figure 2 of the Technical Specifications [4.9.1-6] for the EOS-89BTH DSC.

In the above equation, the effective conductivities for the bounding FA are presented in Table 4.9.1-3 and Table 4.9.1-5 for the EOS-37PTH DSC and EOS-89BTH DSC, respectively. The effective conductivity for the shorter FA should be determined using the same approach presented in Section 4.9.1.1 for the PWR FAs and Section 4.9.1.2 for the BWR FAs.

An alternate option with a low emissivity coating is used for the basket steel plates in the EOS-37PTH DSC. The effective thermal properties for the bounding FA with the low emissivity coating is presented in Section 4.9.1.4.

However, for FAs with active fuel length greater than 144 inches, no scaling is necessary and the maximum heat loads listed for each HLZC in Figure 1 of the Technical Specifications [4.9.1-6] for the EOS-37PTH DSC and Figure 2 of the Technical Specifications [4.9.1-6] for the EOS-89BTH DSC are applicable.

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4.9.1.4 Effective Thermal Properties for PWR Spent Fuel Assemblies in EOS-37PTH DSC with Low Emissivity Basket Coating

Bounding effective properties for the PWR FAs in the EOS-37PTH DSC are presented in Section 4.9.1.1. These evaluations considered that the basket plates in the EOS-37PTH DSC are coated with a high emissivity coating, as noted in Section 4.2.1, Item 13. This section re-evaluates the effective fuel properties with a low emissivity basket coating.

The methodologies used to determine the bounding effective properties for PWR SFAs in the EOS-37PTH DSC are presented in Section 4.9.1.1. A review of these methodologies shows that the emissivity of the basket plates has no impact on the axial thermal conductivity and the effective density/specific heat evaluations. A change in the emissivity of the basket plates only impacts the evaluation of the transverse effective conductivity. Therefore, only the transverse effective conductivity is re-computed with a low emissivity of 0.07 for the basket assembly plates using the same thermal model for the bounding FA (WE 14x14 OFA) presented in Section 4.9.1.1.

Table 4.9.1-6 presents the results of the transverse effective conductivity for the bounding FA with the low emissivity basket coating.

4.9.1.5 References

4.9.1-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

4.9.1-2 *Areva TN Americas*, "Updated Final Safety Analysis Report, Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, NUH-003," Revision 14, September 2014. 72.48

4.9.1-3 ANSYS Mechanical APDL, Version 10.0.

4.9.1-4 NUREG/CR-7024 (PNNL-19417), "Material Property Correlations: Comparisons between FRAPCON-3.4, FRAPTRAN 1.4, and MATPRO," U.S. Nuclear Regulatory Commission, March 2011.

4.9.1-5 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE, A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation," NUREG/CR-0200, Rev. 6, Volume 3, Section M8 (ORNL/NUREG/CSD-2/V3/R6), Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 2000.

4.9.1-6 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *1*.

Table 4.9.1-1
Irradiated UO_2 Thermal Properties

T	Thermal Conductivity (Equation 2.3-9 of [4.9.1-4])	T	Specific Heat (Equation 2.2-1 of [4.9.1-4])	Density (95% of TD of [4.9.1-5])
°F	Btu/(hr-in-°F)	°F	Btu/(lb_m-°F)	lb_m/in^3
100	0.138	32	0.054	0.376
200	0.133	212	0.062	
300	0.128	392	0.067	
400	0.123	752	0.071	
500	0.119	1502	0.076	
600	0.116			
700	0.112			
800	0.109			
900	0.107			
1000	0.105			

Table 4.9.1-2
Fuel Cladding Thermal Properties

T	Thermal Conductivity (Equation 3.2-1 of [4.9.1-4])	T	Specific Heat (Table 3.1-1 of [4.9.1-4])	Density [4.9.1-5]
°F	Btu/(hr-in-°F)	°F	Btu/(lb_m-°F)	lb_m/in^3
100	0.618	80	0.067	0.237
200	0.655	260	0.072	
300	0.690	692	0.079	
400	0.723	1502	0.090	
500	0.756			
600	0.787			
700	0.819			
800	0.851			
900	0.883			
1000	0.916			

Table 4.9.1-3
Bounding Transverse and Axial Effective Thermal Conductivities of Fuel Assemblies in EOS-37PTH DSC

T	k_{eff}	T	k_{axl}
(°F)	Btu/(hr-in-°F)	(°F)	Btu/(hr-in-°F)
160	1.467E-02	200	4.606E-02
251	1.728E-02	300	4.852E-02
343	2.054E-02	400	5.084E-02
436	2.459E-02	500	5.316E-02
530	2.910E-02	600	5.534E-02
626	3.423E-02	800	5.984E-02
722	3.968E-02		
819	4.719E-02		
916	5.456E-02		
1014	6.236E-02		
1113	6.984E-02		
SI UNITS			
T	k_{eff}	T	k_{axl}
(°C)	W/(m-K)	(°C)	W/(m-K)
71	3.047E-01	93	0.957
121	3.589E-01	149	1.008
173	4.266E-01	204	1.056
224	5.107E-01	260	1.104
277	6.043E-01	316	1.149
330	7.110E-01	427	1.243
383	8.241E-01		
437	9.800E-01		
491	1.133E+00		
546	1.295E+00		
600	1.450E+00		

Table 4.9.1-4
Bounding Effective Specific Heat and Density of Fuel Assemblies in EOS-37PTH DSC

T	$C_{p\ eff}$	ρ_{eff}
(°F)	Btu/(lb$_m$-°F)	(lb$_m$/in^3)
80	0.0576	0.0968
260	0.0646	
692	0.0719	
1502	0.0779	
SI units		
T	$C_{p\ eff}$	ρ_{eff}
(°C)	kJ/(kg-K)	(kg/m^3)
27	0.2411	2679
127	0.2706	
367	0.3008	
817	0.3263	

Table 4.9.1-5
Bounding Transverse and Axial Effective Thermal Conductivities of Fuel Assemblies in EOS-89BTH DSC

T	k_{eff}	T	k_{axl}
(°F)	Btu/(hr-in-(°F)	(°F)	Btu/(hr-in-(°F)
124	0.0141	200	0.0427
220	0.0165	300	0.0450
317	0.0194	400	0.0472
415	0.0228	500	0.0493
513	0.0267	600	0.0514
611	0.0312	800	0.0555
709	0.0360		
808	0.0414		
907	0.0476		
1006	0.0541		
1106	0.0610		
SI UNITS			
T	**k_{eff}**	**T**	**k_{axl}**
(°C)	**W/(m-K)**	**(°C)**	**W/(m-K)**
51	2.918E-01	93	0.888
105	3.420E-01	149	0.935
159	4.023E-01	204	204
213	4.735E-01	260	1.024
267	5.547E-01	316	1.066
322	6.476E-01	427	1.153
376	7.486E-01		
431	8.595E-01		
486	9.875E-01		
541	1.123E+00		
596	1.266E+00		

Table 4.9.1-6
Bounding Transverse Effective Thermal Conductivity of Fuel Assemblies in EOS-37PTH DSC with Low Emissivity Basket Coating

T	***K_{eff}***
(°F)	***Btu/(hr-in-°F)***
164	*1.370E-02*
255	*1.579E-02*
348	*1.826E-02*
441	*2.108E-02*
536	*2.432E-02*
631	*2.794E-02*
727	*3.181E-02*
824	*3.607E-02*
921	*4.079E-02*
1019	*4.583E-02*
1117	*5.135E-02*
SI UNITS	
T	***K_{eff}***
(K)	***W/(m-K)***
346	*2.844E-01*
397	*3.278E-01*
449	*3.793E-01*
501	*4.379E-01*
553	*5.050E-01*
606	*5.802E-01*
660	*6.606E-01*
713	*7.492E-01*
767	*8.472E-01*
822	*9.517E-01*
876	*1.066E+00*

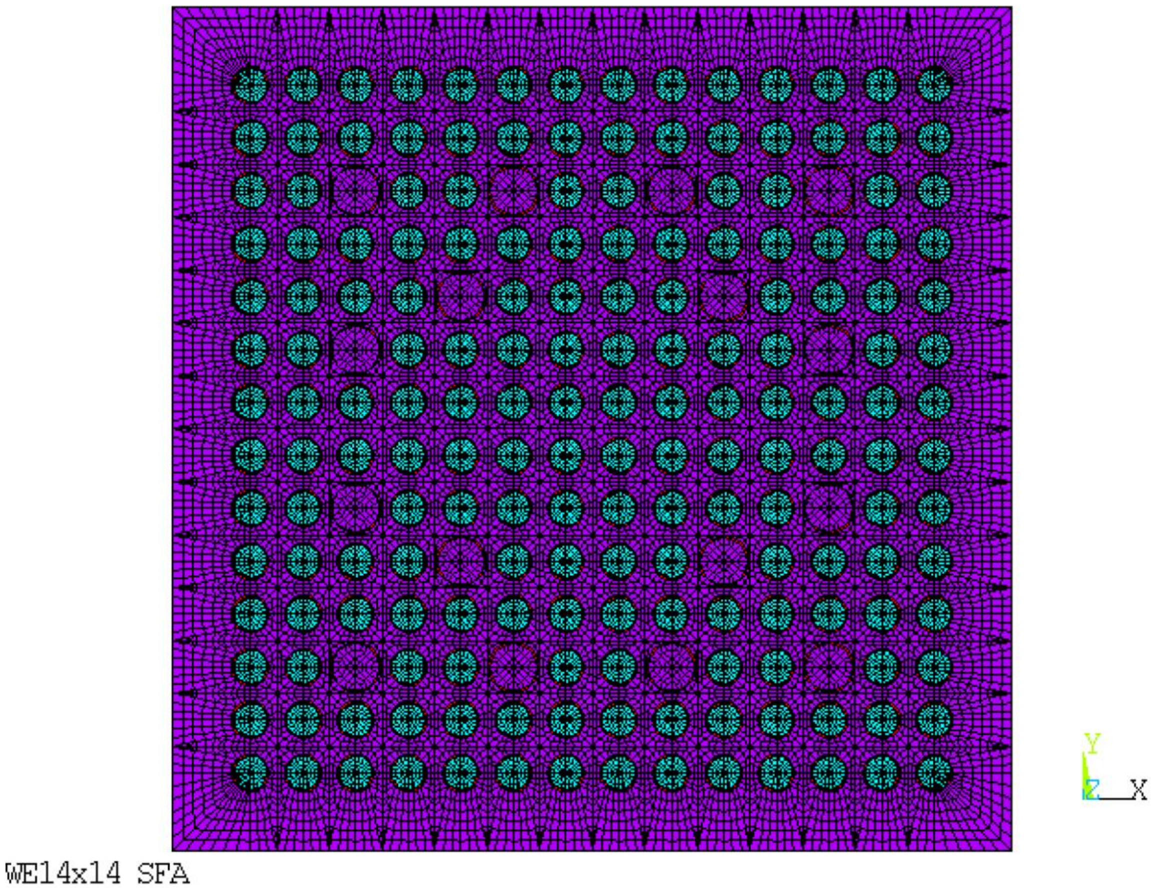

Figure 4.9.1-1
Finite Element Model of WE14x14 Fuel Assembly

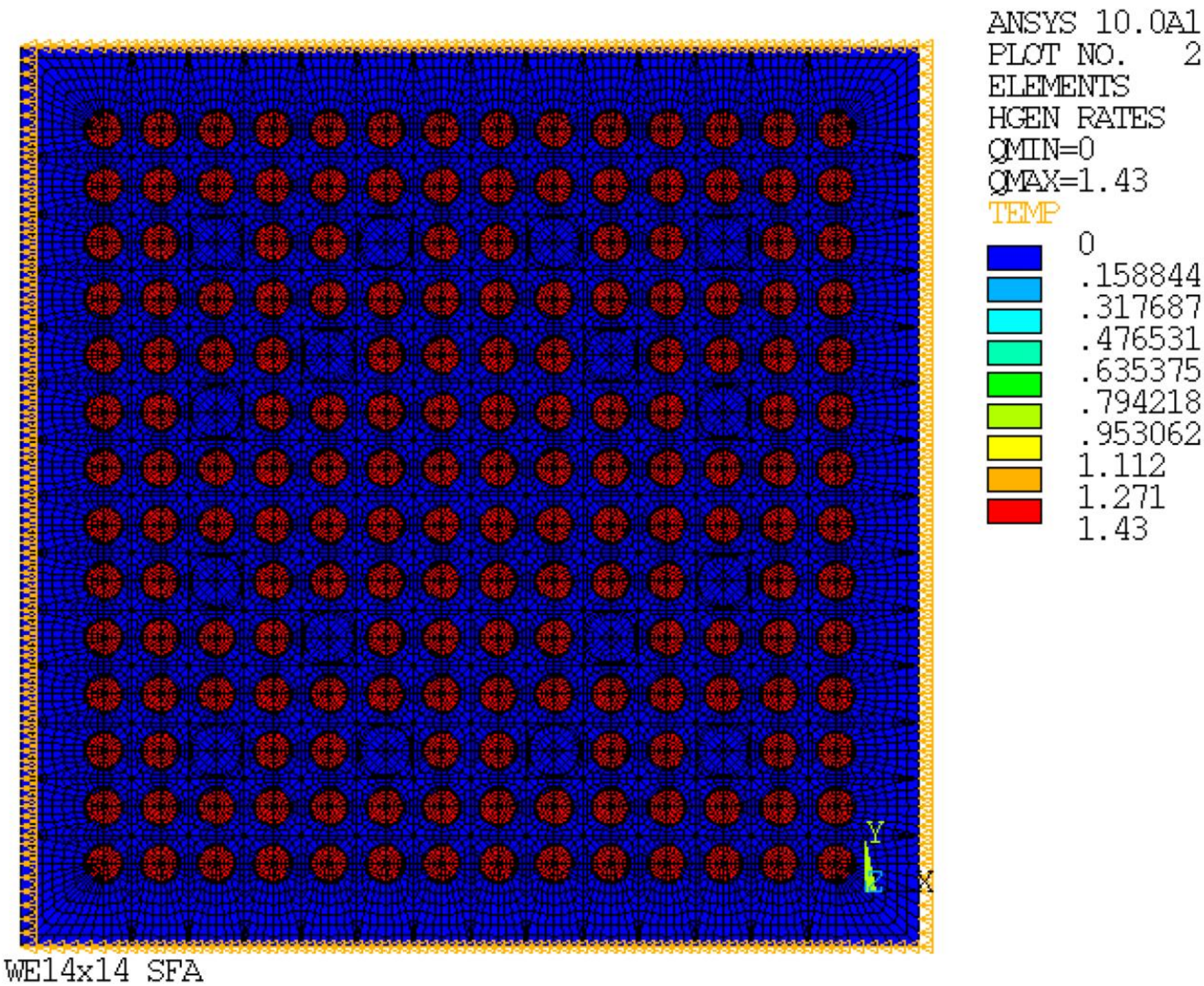

Figure 4.9.1-2
Heat Generation Rate and Temperature Boundary Conditions for WE14x14 Fuel Assembly

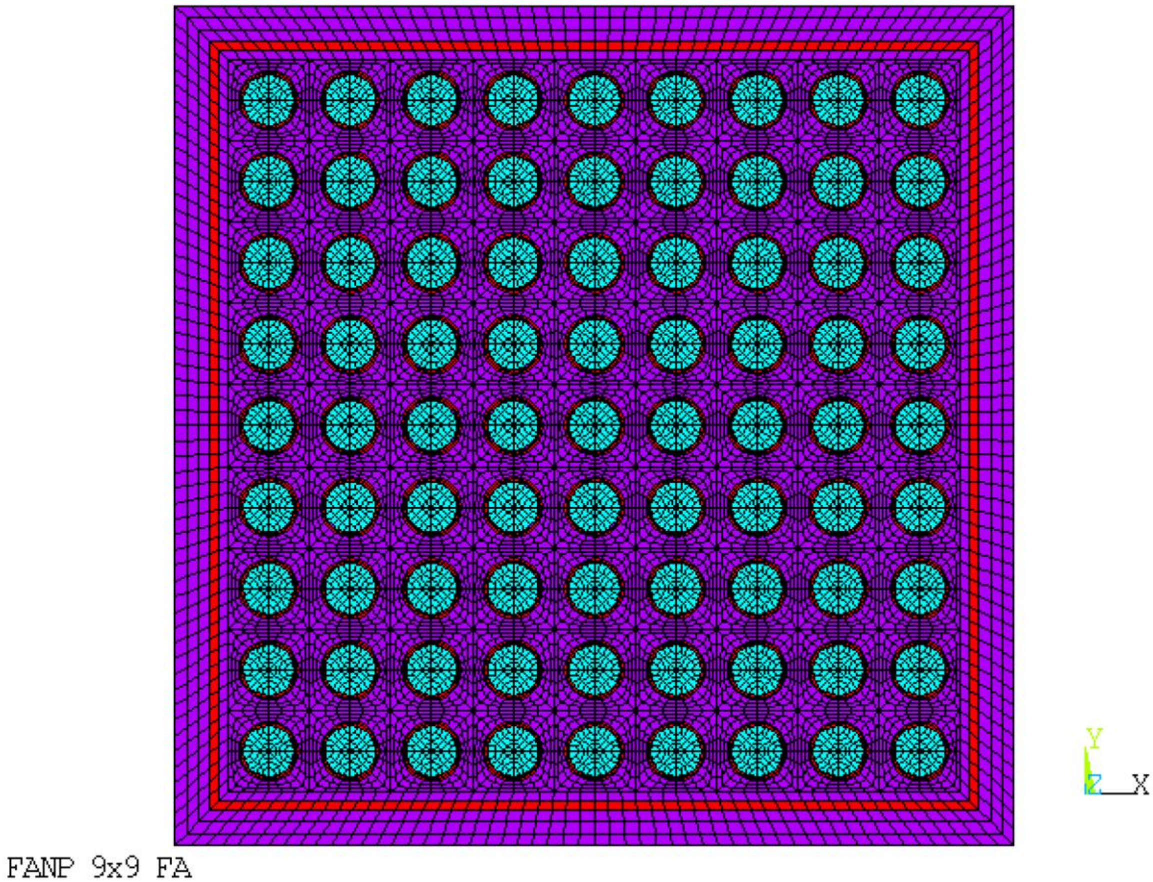

Figure 4.9.1-3
Finite Element Model of the FANP 9x9 Fuel Assembly

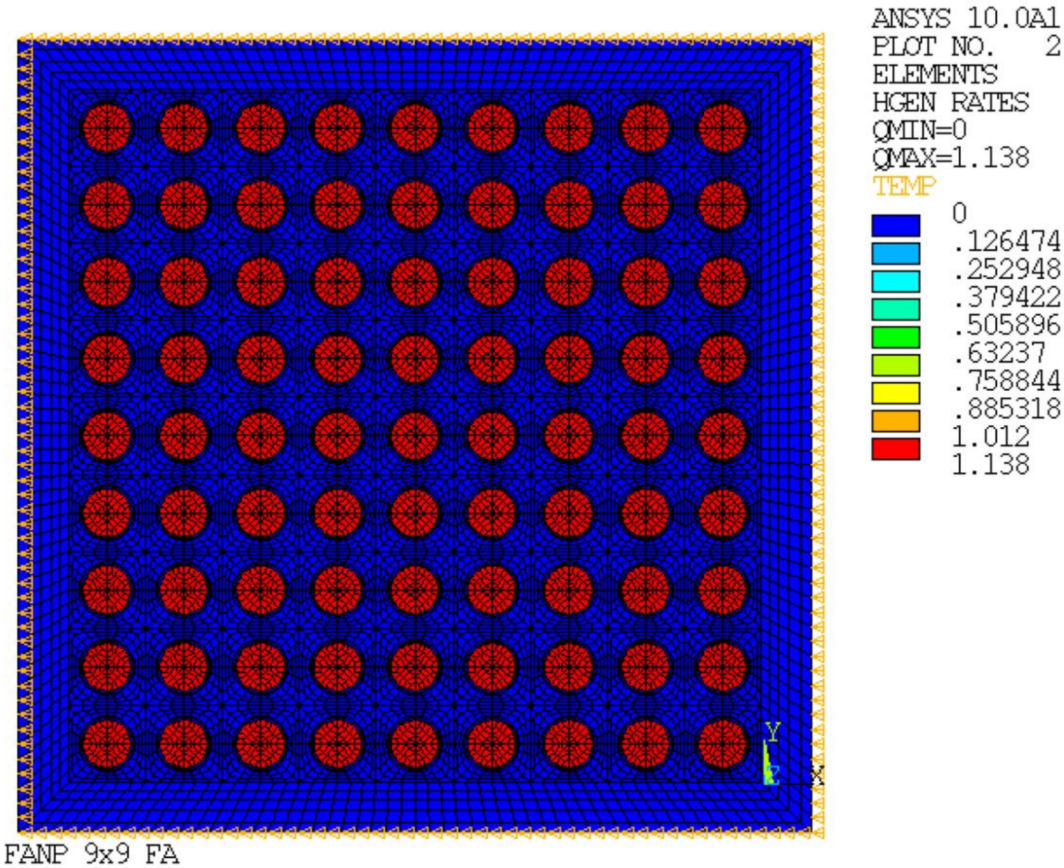

Figure 4.9.1-4
Heat Generation Rate and Temperature Boundary Conditions for FANP 9 x 9 Fuel Assemblies

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APPENDIX 4.9.3
MESH SENSITIVITY

Table of Contents

List of Tables

List of Figures

4.9.3 MESH SENSITIVITY

4.9.3.1 Mesh Sensitivity for Storage Analysis

A grid convergence study of the ANSYS FLUENT computational fluid dynamics (CFD) model for the EOS horizontal storage module (HSM) loaded with the EOS-37PTH dry shielded canister (DSC) is performed to determine the discretization error of the solution. The discretization error is determined by using the five-step procedure for uncertainty estimation specified in Appendix A.4 of NUREG 2152 [4.9.3-8] based on Richardson extrapolation. The Richardson extrapolation method is currently the most robust method available for prediction of numerical uncertainty as noted in [4.9.3-8]. The five-step procedure specified in [4.9.3-8] is identical to the approach presented in Section 2-4.1 of American Society of Mechanical Engineers Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer (ASME V&V) 20-2009 [4.9.3-1]. In addition to the discretization error, this section computes the observed order of accuracy (p) and compares it to the theoretical order of accuracy of the ANSYS FLUENT solution. Four grids are considered for the study of the ANSYS FLUENT model.

Proprietary Information on Pages 4.9.3-2 through 4.9.3-18
Withheld Pursuant to 10 CFR 2.390

4.9.3.3 References

4.9.3-1 American Society of Mechanical Engineers, "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer," ASME V&V 20-2009, November 30th, 2009.

4.9.3-2 ANSYS FLUENT, Version 14.0, ANSYS, Inc.

4.9.3-3 Ismail B. Celik et.al, "Procedure for Estimation and Reporting of Uncertainty Due to Discretization in CFD Applications," Journal of Fluids Engineering, ASME, July 2008, Volume 130.

4.9.3-4 Examining Spatial (Grid) Convergence, NPARC Alliance CFD Verification and Validation Website, http://www.grc.nasa.gov/WWW/wind/valid/tutorial/spatconv.html

4.9.3-5 NUREG-1536, Revision 1, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards.

4.9.3-6 Not used.

4.9.3-7 Not used.

4.9.3-8 U.S. NRC, Office of Nuclear Material Safety and Safeguards, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications-Final Report," NUREG-2152, Rev. 0, March 2013.

Proprietary Information on Pages 4.9.3-20 through 4.9.3-23
Withheld Pursuant to 10 CFR 2.390

APPENDIX 4.9.4
WIND IMPACT ON THE THERMAL PERFORMANCE OF THE EOS-HSM

Table of Contents

List of Tables

List of Figures

Proprietary Information on Pages 4.9.4-1 through 4.9.4-10
Withheld Pursuant to 10 CFR 2.390

[ ]

Among the different load cases evaluated for the EOS-HSM, [ ] results in the maximum air temperature rise of 138°F. The maximum air temperature rise is determined as the difference in the average air temperature between the inlet and outlet.

In summary, if the heat load of a DSC during storage operations is greater than 41.8 kW and less than or equal to 50 kW, wind deflectors will be implemented to ensure the thermal performance of the EOS-HSM remains within its allowable limits. For heat loads less than or equal to 41.8 kW, wind deflectors are not needed for EOS-37PTH DSC.

Further, for each HLZC (1 through 3), the maximum heat loads of the EOS-89BTH DSC are lower compared to the EOS-37PTH DSC. Therefore, the same restriction is also applicable for the EOS-89BTH DSCs. If the heat load of an EOS-89BTH during storage operations is greater than 41.6 kW and less than or equal to 43.6 kW, wind deflectors will be implemented to provide assurance that the thermal performance of the EOS-HSM remains within its allowable limits. For heat loads less than or equal to 41.6 kW, wind deflectors are not needed for the EOS-89BTH DSC.

In addition, wind deflectors are not necessary during accident conditions to maintain the maximum fuel cladding temperature below the allowable limit of 1058 °F. Based on the description presented in Section 4.4.1 for Load Case #5, the blocked vent accident condition considers a complete blockage of the inlet and outlet vents for 40-hour duration. Any loss or damage to the wind deflectors only affects the outlet vents. Therefore, the complete blockage of both the inlet and outlet vents as considered for the blocked vent accident condition bounds the loss of wind deflector accident condition.

Proprietary Information on Pages 4.9.4-12 through 4.9.4-16
Withheld Pursuant to 10 CFR 2.390

4.9.4.9 References

4.9.4-1 NUREG-2174, “Impact of Variation in Environmental Conditions on the Thermal Performance of Dry Storage Casks,” U.S. NRC, Office of Nuclear Material Safety and Safeguards, Feb. 2015.

4.9.4-2 ANSYS ICEM CFD, Version 14.0, ANSYS, Inc.

4.9.4-3 ANSYS FLUENT, ANSYS FLUENT User’s Guide, ANSYS FLUENT Theory Guide, Version 14.0, ANSYS, Inc.

4.9.4-4 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 0.

4.9.4-5 American Society of Mechanical Engineers, “Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer,” ASME V&V 20-2009, November 30th, 2009.

4.9.4-6 U.S. NRC, Office of Nuclear Material Safety and Safeguards, “Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications-Final Report,” NUREG-2152, Rev. 0, March 2013.

4.9.4-7 [
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Table 4.9.4-1
Design Load Cases for Wind Effect Study of the EOS-HSM Loaded with EOS-37PTH DSC with Normal Hot Condition

Table 4.9.4-2
Fuel Cladding and DSC Shell Temperatures

Load Case # (1)	DSC Shell Temperature (°F)		Maximum Fuel Cladding Temperature (°F)
	Maximum	Average	
1	422	352	724 (See Table 4-5)
F-1	406	336	< 724
F-2	397	323	< 724
F-3	388	296	< 724
B-1	417	349	< 724
B-2	416	345	< 724
B-3	406	335	< 724
S-1	434	361	< 735
S-2	436	366	735
	427 (2)	348 (2)	729 (2)
	409 (4)	330 (4)	713 (4)
S-3	430	362	< 735
2(3)	417	350	688

Notes:

(1) See Table 4.9.4-1 for the description of the load cases.

[ ]

(4) These temperatures are determined based on a yearly average ambient temperature of 70 °F based on the discussion in Section 4.9.4.6.1.

Proprietary Information on Pages 4.9.4-20 through 4.9.4-39
Withheld Pursuant to 10 CFR 2.390

Proprietary Information on Pages 4.9.5-i through 4.9.5-iii and 4.9.5-1 through 4.9.5-28
Withheld Pursuant to 10 CFR 2.390

APPENDIX 4.9.6
THERMAL EVALUATION OF EOS-37PTH DSC FOR HLZC 4 THROUGH HLZC 9

Table of Contents

Appendix 4.9.6 is newly added in Revision 3 by Amendment 1.

List of Tables

Appendix 4.9.6 is newly added in Revision 3 by Amendment 1.

List of Figures

4.9.6 THERMAL EVALUATION OF EOS-37PTH DSC FOR HLZC 4 THROUGH HLZC 9

This appendix evaluates the thermal performance of the EOS-37PTH Dry Shielded Canister (DSC) for normal, off-normal, and accident conditions with Heat Load Zone Configurations (HLZCs) 4 through 9. For HLZCs 4 through 6, this appendix presents the thermal evaluation for both storage and transfer operations. For HLZCs 7 through 9, this appendix only presents the thermal evaluation for transfer operations. Storage evaluation for HLZCs 7 through 9 is presented in Chapter A.4.

4.9.6.1 Thermal Evaluation of EOS-37PTH DSC for HLZCs 4, 5 and 6

For HLZCs 4 and 5, only intact fuel assemblies (FAs) are allowed. For HLZC 6, damaged FAs or failed fuel canisters (FFCs) can be loaded along with intact FAs. A summary of the EOS-37PTH DSC configurations analyzed in this section is shown below.

DSC Type	Basket Assembly Type	Heat Load Zone Configuration (HLZC)	Max. Heat Load (kW)	Transfer Cask	Storage Module
EOS-37PTH	4L/5	4	50.00	EOS-TC125/ EOS-TC135	EOS-HSM/ EOS-HSMS/ EOS-HSM-FPS/ EOS-HSMS-FPS
	4L/5	5	41.00		
	4L	6	46.00		

HLZCs 4 and 5 evaluated in this section can be loaded in an EOS-37PTH DSC equipped with either Basket Assembly Type 4L or 5. HLZC 6 shall only be loaded on Basket Assembly Type 4L as discussed in Chapter 1, Section 1.1 since it has the capability to store damaged FAs and FFCs. The various basket assembly types within the EOS-37PTH DSC are described in Chapter 1, Section 1.1 and the various system configurations allowed for these basket assembly types are listed in Table 1-2. Section 4.9.6.1.1 presents a discussion on the differences in the thermal performance between the different basket types. Based on the discussion in Section 4.9.6.1.1, both of these basket assembly variants have identical thermal performance.

Section 4.9.6.1.2 presents descriptions of HLZCs 4, 5 and 6. Section 4.9.6.1.3 presents the evaluation of HLZCs 4, 5 and 6 with intact FAs. Sections 4.9.6.1.5 and 4.9.6.1.6 present the evaluation of HLZC 6 with damaged FAs and FFCs, respectively.

Proprietary Information on Pages 4.9.6-2 through 4.9.6-4
Withheld Pursuant to 10 CFR 2.390

4.9.6.1.2 Description of HLZCs 4, 5, 6

HLZCs 4, 5 and 6 are shown in Figure 1D, Figure 1E and Figure 1F of [4.9.6-1], respectively. HLZC 4 with a maximum heat load of 50 kW, HLZC 5 with a maximum heat load of 41.0 kW, and HLZC 6 with a maximum heat load of 46.0 kW are evaluated. Only intact FAs can be loaded in HLZC 4 and HLZC 5. As shown in Figure 1F of [4.9.6-1], HLZC 6 can accommodate up to eight damaged FAs, or up to four FFCs, along with intact FAs. It should be noted that damaged FAs and FFCs shall not be stored in the same DSC.

As shown in Figure 1D of [4.9.6-1], HLZC 4 maintains the maximum heat load of the DSC at 50 kW similar to HLZC 1 (Figure 1A of [4.9.6-1]) but reduces the maximum heat load per FA to 1.625 kW from 2.0 kW in HLZC 1. To accommodate FAs with decay heat loads greater than 1.625 kW, an additional HLZC is evaluated. As shown in Figure 1E of [4.9.6-1], HLZC 5 can accommodate FAs up to 2.4 kW. The maximum heat load per DSC for HLZC 5 is limited to 41.0 kW.

4.9.6.1.3 Evaluation for Intact FAs in HLZC 4, 5 and 6

Thermal evaluation of HLZCs 4, 5 and 6 with intact FAs in the EOS-37PTH DSC is presented in Section 4.9.6.1.3.1 for storage conditions, and in Section 4.9.6.1.4 for transfer conditions.

The maximum heat load per DSC for HLZC 6 is limited to 46.0 kW, which is lower compared to the maximum heat load of 50 kW for HLZC 4. In addition, while only loading intact FAs, the heat loads in each zone of HLZC 6 are bounded by HLZC 4. Therefore, thermal evaluation for HLZC 6 with intact FAs is bounded by HLZC 4.

4.9.6.1.3.1 Storage Evaluation

This section evaluates the thermal performance of the EOS-HSM loaded with the EOS-37PTH DSC for HLZCs 4, 5 and 6 with intact FAs during normal, off-normal and accident conditions.

4.9.6.1.3.2 Description of Load Cases

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If the maximum temperatures from the above transient analyses and the accident evaluation are less than those previously approved for LC 1 with HLZC 1, the maximum temperatures for all other load cases (Load Cases 3, 6a, 6b and 7) evaluated for transfer operations of HLZC 1 in Table 4-23 will also remain bounded and no further evaluations are necessary for HLZCs 4, 5 and 6.

4.9.6.1.3.3 Ambient Operating Conditions

Ambient temperature for the EOS-37PTH DSC with HLZC 4, 5, and 6 are identical to those in Section 4.3.

In addition to the ambient temperature, normal thermal evaluation for EOS-HSM considers impact of wind on the maximum fuel cladding temperature. Based on the evaluations presented in Section 4.9.4, wind deflectors are implemented on top of the EOS-HSM and next to the outlet as shown in Figure 4.9.4-7.

For the EOS-37PTH DSC with HLZC 4, 5, and 6 during storage operations in an EOS-HSM, wind deflectors are implemented as follows:

- For HLZCs 4 and 6, wind deflectors shall be installed for storage operations with heat load greater than 41.8 kW per DSC similar to HLZC 1.
- For HLZC 5, wind deflectors shall be installed for storage operations if the heat load of a FA is greater than 1.625 kW irrespective of the total heat load per DSC.

4.9.6.1.3.4 CFD Modeling

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4.9.6.1.3.5 Results and Conclusions

Table 4.9.6-3 presents the maximum temperatures and average temperatures for the EOS-37PTH DSC (HLZCs 4 and 5) during storage operations and compares them to the design basis temperatures for HLZCs 1 and 2. Figure 4.9.6-1 through Figure 4.9.6-3 present the temperature and velocity profiles for LC 1 through LC 3, respectively.

As shown in Table 4.9.6-3, the maximum fuel cladding temperature increases by 2 °F and 15 °F for LC 1 and LC 2, respectively, whereas, it decreases by 8 °F for LC 3 compared to the design basis temperatures. Including the GCI of 17.32 °F, described in Section 4.9.4.8.1, the maximum fuel cladding temperatures for the EOS-37PTH DSC (HLZCs 4 and 5) during storage in an EOS-HSM is 732 °F for the bounding LC (LC 1).

Section 4.9.5 presents the thermal evaluation for an additional variant of the EOS-HSM storage module designated as EOS-HSM flat plate support structure (FPS). A review of the results presented in Section 4.9.5 indicates that the thermal performance of the EOS-HSM and the EOS-HSM FPS are very similar with minor differences in the maximum fuel cladding temperatures. The maximum difference observed in the fuel cladding temperature between the EOS-HSM and the EOS-HSM FPS option for normal conditions is an increase of 3 °F for the EOS-HSM FPS option (See Table 4.9.5-3 and Table 4.9.5-6). Therefore, this difference of 3 °F is added to determine the maximum fuel cladding temperature of the EOS-37PTH DSC (HLZCs 4 and 5) during storage in an EOS-HSM FPS option. The maximum fuel cladding temperature for the bounding LC (LC 1) is 735 °F during storage in the EOS-HSM FPS.

For storage operations in both EOS-HSM and the EOS-HSM FPS, the maximum fuel cladding temperatures remains below the allowable temperature limit of 752 °F.

Similar to the normal condition, the maximum fuel cladding temperature during off-normal and accident conditions will also increase by 2 °F for HLZC 4 based on LC 1 and 15 °F based on LC 2 for HLZC 4. However, a review of the maximum fuel cladding temperatures for off-normal and accident conditions in Table 4-5 shows large margins to the temperature limit of 1058 °F. For off-normal and accident conditions, the maximum fuel cladding temperatures are 734 °F and 865 °F with margins of 324 °F and 193 °F, respectively. Based on these large margins, a small increase in the off-normal and accident cladding temperatures will have a negligible impact on fuel cladding integrity.

As shown in Table 4.9.6-3, the maximum concrete temperature is lower for all LCs compared to the design basis temperatures previously evaluated for the EOS-HSM. Therefore, there is no impact on the concrete temperatures.

As shown in Table 4.9.6-3, the average temperatures for the FA and cavity gas are lower for LC 3 compared to the design basis temperatures previously evaluated. For LC 1 and LC 2, the average FA temperature increases by 2°F, whereas, the average helium temperature decreases by 5°F to 6°F . Therefore, these small changes will not impact the internal pressure evaluation.

Based on this discussion, all the temperature criteria along with the internal pressure criteria are satisfied for the storage of the EOS-37PTH DSC with HLZCs 4, 5, or 6 in an EOS-HSM with intact FAs.

4.9.6.1.4 Transfer Evaluation

This section evaluates the thermal performance of the EOS-TC125 loaded with the EOS-37PTH DSC with Basket Type 4L/5 during transfer operations in the EOS-TC125/TC135 with intact FAs for normal, off-normal, and accident conditions, based on HLZCs 4, 5, and 6.

4.9.6.1.4.1 Description of Load Cases

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4.9.6.1.4.2 Ambient Operating Conditions

All ambient operating conditions are identical to those described in Section 4.5.

4.9.6.1.4.3 CFD Modeling

[

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4.9.6.1.4.4 Results and Conclusions

A. Transfer Time Limits

Based on the discussion in Section 4.5.4, the time limit to complete normal and off-normal transfer operations of an EOS-37PTH DSC loaded per HLZC 1 is 10 hours. If transfer operations cannot be completed within the time limit, an additional duration of 5 hours is available to complete one of the recovery actions as described in Section 4.5.4.

For the EOS-37PTH DSC with HLZCs 4, 5, and 6, the time limit for normal and off-normal transfer operations is reduced from 10 hours to 8 hours based on the comparisons of temperatures for HLZCs 4, 5, and 6 to HLZC 1, as shown in Table 4.9.6-5. This ensures that the maximum fuel cladding temperatures for HLZCs 4, 5, and 6 remain below the design basis temperatures determined in Section 4.5.4 for HLZC 1, as shown in Table 4.9.6-5 and discussed in the following section. The duration available to complete the recovery actions if transfer operations cannot be completed within the time limit remains unchanged at 5 hours.

Therefore, the total duration for transfer operations is 13 hours (8-hour transfer time limit + 5-hour recovery time) for the EOS-37PTH DSC with HLZCs 4, 5 and 6, compared to 15 hours for design basis evaluation with HLZC 1 in Section 4.5.4.

B. Component Temperatures

Table 4.9.6-5 presents the maximum temperatures of the fuel cladding and the various components within the EOS-37PTH DSC and the EOS-TC125 for the bounding normal conditions at 13 hours for HLZCs 4 and 5. As shown in Table 4.9.6-5, the maximum fuel cladding temperature at 13 hours is 729 °F and 717 °F for HLZC 4 and HLZC 5, respectively, remaining below the allowable temperature limit of 752 °F. Figure 4.9.6-4 and Figure 4.9.6-5 present the temperature profiles for HLZCs 4 and 5, respectively for normal conditions at 13 hours. The design basis evaluation for HLZC 1 is also included in Table 4.9.6-5 to provide a comparison with the design basis temperatures. As shown in Table 4.9.6-5, the maximum temperatures for normal and off-normal conditions remain bounded by the design basis evaluation with HLZC 1 in Section 4.5 for the EOS-37PTH DSC. Since these temperatures are lower compared to HLZC 1, the remaining time limits listed in Table 4-31 of Section 4.5 for insertion of DSC into the EOS-HSM or restarting of air circulation after its inactivation also remain applicable. The time limits for transfer operations of the EOS-37PTH DSC with HLZCs 4, 5, and 6 are listed in Table 4.9.6-7.

For accident conditions, as shown in Table 4.9.6-6, the maximum fuel cladding temperature is 949 °F with a 14 °F increase compared to the design basis evaluation with HLZC 1 in Section 4.5 for the EOS-37PTH DSC. However, this remains below the allowable temperature limit of 1058 °F for accident conditions. Therefore, there is no impact on the fuel cladding integrity. Figure 4.9.6-6 presents the temperature profiles for HLZC 4 during accident conditions.

For the bounding normal condition with HLZCs 4 and 5, the average helium gas temperature within the DSC cavity is 557 K and 547 K, respectively. Both of these temperatures are lower compared to the design basis value of 565 K (see Table 4-45 of Section 4.7) used to evaluate the internal pressure. Therefore, there is no impact on the internal pressure for normal and off-normal conditions.

For the bounding accident condition, the average helium temperature is 657 K and higher compared to the design basis value of 653 K (see Table 4-45 of Section 4.7) used to evaluate the internal pressure. Based on the methodology in Section 4.7.1, the maximum accident internal pressure is re-computed to be 120.6 psig and remains below the maximum internal pressure limit of 130 psig for accident conditions. Therefore, the design criteria for internal pressure are satisfied.

Based on this discussion, all the temperature criteria along with the internal pressure criteria are satisfied for transfer of the EOS-37PTH DSC with HLZCs 4, 5 or 6 in an EOS-TC125/TC135 with intact FAs.

4.9.6.1.5 Evaluation for Damaged FAs in HLZC 6

HLZC 6 can accommodate a combination of intact FAs along with damaged FAs. It can be loaded with up to eight damaged FAs as noted in Section 4.9.6.1.2. This section presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4L for HLZC 6 with intact and damaged FAs during storage and transfer conditions.

4.9.6.1.5.1 Description of Load Cases

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4.9.6.1.5.2 Ambient Operating Condition

All ambient operating conditions are identical to those described in Section 4.5.1.

4.9.6.1.5.3 CFD Modeling

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4.9.6.1.5.4 Results and Conclusions

Table 4.9.6-9 shows the maximum temperatures of the intact fuel cladding along with the maximum and average temperatures for the various components within the EOS-37PTH DSC and the EOS-TC125 for the bounding transfer accident condition with eight damaged FAs. It also compares them to the design basis evaluation from Section 4.5 with intact FAs. As shown in Table 4.9.6-9, the maximum temperatures for fuel cladding and basket plates increase. However, the maximum fuel cladding temperature remains below the allowable temperature limits of 1058 °F. There are no temperature limits for the basket plates.

To evaluate the impact on internal pressure, the average helium temperature is calculated using the approach presented in Section 4.7.1.2 accounting for the changes due to the damaged FAs turning into rubble at the bottom of the DSC during accident condition. The average helium temperature for the bounding accident condition is 633 K for the short DSC cavity. This is lower than the average helium temperature of 653 K (Table 4-45) used to determine the maximum internal pressure for the bounding hypothetical accident condition with intact FAs. Therefore, the maximum internal pressure during the bounding accident condition with damaged FAs are bounded by the evaluation performed with intact FAs listed in Table 4-45.

Since the temperature criteria along with the internal pressure criteria are satisfied, no further evaluations are required to load damaged FAs in the EOS-37PTH DSC with HLZC 6. Figure 4.9.6-7 shows the temperature contours for the EOS-37PTH DSC with HLZC 6 in the EOS-TC125 with 29 intact/eight damaged FAs during accident transfer condition.

4.9.6.1.6 Evaluation for FFCs in HLZC 6

HLZC 6 can accommodate a combination of intact FAs along with FFCs. It can be loaded with up to four FFCs as noted in Section 4.9.6.1.2. This section presents the thermal evaluation of the EOS-37PTH DSC with Basket Type 4L for HLZC 6 with intact FAs and FFCs during storage and transfer conditions.

4.9.6.1.6.1 Description of Load Cases

[

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4.9.6.1.6.2 Ambient Operating Conditions

All ambient operating conditions are identical to those described in Section 4.5.1 for LC 1.

4.9.6.1.6.3 CFD Modeling

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4.9.6.1.6.4 Results and Conclusions

Table 4.9.6-10 shows the maximum temperatures of fuel cladding and various components for the bounding normal and off-normal transfer conditions based on HLZC 6 with four FFCs. It also compares the maximum temperatures with the results from HLZC 4 evaluated in Section 4.9.6.1.4. As shown in Table 4.9.6-10, the maximum fuel cladding temperature for the intact FAs is 701 °F, and remains below the allowable limit of 752 °F.

In addition, the maximum temperatures determined for HLZC 6 with FFCs are lower compared to that of HLZC 4. This is because a comparison of HLZC 4 in Figure 1D of [4.9.6-1], and HLZC 6 in Figure 1F of [4.9.6-1] shows that both HLZCs have identical zoning and that HLZC 6 is a subset of HLZC 4. Both the total heat load of the DSC and the heat load of each individual FA within HLZC 6 are bounded by HLZC 4. Therefore, the time limits mentioned in Item A of Section 4.9.6.1.4.4 are also applicable for transfer operations of HLZC 6 with FFCs.

Figure 4.9.6-8 shows the temperature contours of the EOS-TC125 loaded with the EOS-37PTH DSC based on HLZC 6 with FFCs.

To evaluate the impact on internal pressure, the average helium temperature is calculated using the approach presented in Section 4.7.1.2 accounting for the changes due to the FFCs. For the bounding normal condition at 13 hours, the average helium temperature within the DSC cavity is 517 °F (543 K) and is lower compared to the design basis value of 557 °F (565 K) (see Table 4-45) used to evaluate the internal pressure. Therefore, it is concluded that there is no impact on the internal pressure for normal and off-normal conditions.

Since the FFCs are conservatively modeled as helium for normal and off-normal conditions, no other changes are expected for accident conditions within the FFCs. Therefore, the maximum accident temperatures determined for HLZC 4 in Section 4.9.6.1.4 will remain bounding for HLZC 6, and no further evaluation is required.

Similar to the transfer conditions, the maximum temperatures for storage operations with HLZC 4 will bound HLZC 6, since the same DSC configuration is considered for storage. Therefore, no further evaluations are required for storage operations.

Based on this discussion, all the temperature criteria along with the internal pressure criteria are satisfied for storage of the EOS-37PTH DSC with HLZC 6 with intact FAs and FFCs.

4.9.6.2 Thermal Evaluation of EOS-37PTH DSC for HLZCs 7, 8, and 9

HLZCs 7, 8, and 9 are shown in Figure 1G, Figure 1H, and Figure 1I of [4.9.6-1], respectively. For HLZCs 7 and 9, only intact FAs are allowed. For HLZC 8, damaged FAs or FFCs can be loaded along with intact FAs. A summary of the EOS-37PTH DSC configurations for HLZCs 7 through 9 is shown below:

DSC Type	Basket Assembly Type	Heat Load Zone Configuration (HLZC)	Max. Heat Load (kW)	Transfer Cask	Storage Module
EOS-37PTH	4H	7	50.00	EOS-TC125/ EOS-TC135	HSM-MX
	4L/5	8(1)	46.40(2)		
	4L/5	9	37.80		

Note:

1. Basket Type 5 can only accommodate intact FAs. Damaged FAs or FFCs allowed per HLZC 8 shall only be loaded in Basket Type 4L.
2. The maximum decay heat per DSC is limited to 41.8 kW when a damaged FA or failed fuel is loaded.

Storage Operations

Thermal evaluation for HLZCs 7 through 9 for storage in the HSM-MX is presented in Chapter A.4.

Transfer Operations

A comparison of HLZC 7 in Figure 1G of [4.9.6-1] with HLZC 4 in Figure 1D of [4.9.6-1] shows that the maximum heat loads in the inner zones (Zones 1 and 2) for HLZC 7 are lower than HLZC 4. Based on the study in [4.9.6-2], maximizing the heat loads of the inner zones is conservative. In addition, HLZC 7 is only permitted in Basket Assembly Type 4H, whereas Basket Assembly Type 4L/5 is considered in Section 4.9.6.1.4 to evaluate transfer operations for HLZC 4. Basket Type 4H has a higher thermal performance compared to Basket Assembly Type 4L/5 based on the discussion in Section 4.9.6.1.1. Based on this discussion, the thermal evaluation of HLZC 4 in Section 4.9.6.1.4 for transfer operations is bounding for HLZC 7, including the transfer time limits.

The maximum heat load per DSC for HLZC 8 is limited to 46.4 kW, which is lower compared to the maximum heat load of 50 kW for HLZC 4. In addition, while only loading intact FAs, the heat loads in each zone of HLZC 8 are bounded by HLZC 4. Based on this discussion, the thermal evaluation of HLZC 4 in Section 4.9.6.1.4 for transfer operations is bounding for HLZC 8, including the transfer time limits while loaded with intact FAs.

In addition, the maximum heat load for HLZC 8 while loaded with damaged or FFCs is limited to 41.8 kW compared to 46.0 kW for HLZC 6. Therefore, the thermal evaluation presented for HLZC 6 in Section 4.9.6.1.5 with damaged FAs, and Section 4.9.6.1.6 with failed fuel remains bounding for HLZC 8.

Similarly, the maximum heat load per DSC for HLZC 9 is limited to 37.80 kW, which is lower compared to the maximum heat load of 41.0 kW for HLZC 5. In addition, the maximum heat load per FA within zone 3 of HLZC 9 is reduced to 2.0 kW compared to 2.4 kW in HLZC 5. Since the total heat load per DSC and the maximum heat load per FA are lower, the thermal evaluation of HLZC 5 in Section 4.9.6.1.4 for transfer operations is bounding for HLZC 9, including the transfer time limits while loaded with intact FAs.

Time limits for transfer operations of the EOS-37PTH DSC with HLZCs 7, 8, and 9 are listed in Table 4.9.6-11.

4.9.6.3 References

4.9.6-1 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 1.

4.9.6-2 J.M. Cuta, U.P. Jenquin, and M.A. McKinnon, "Evaluation of Effect of FA Loading Patterns on Thermal and Shielding Performance of a Spent Fuel Storage/Transportation Cask," PNNL-13583, Pacific Northwest National Laboratory, November 2001.

4.9.6-3 TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel, Revision 16," USNRC Docket No. 72-1004.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table 4.9.6-2
Design Load Cases for EOS-HSM Loaded with EOS-37PTH DSC with HLZCs 4 and 5

Load Case No.	Description	Ambient Temperature (°F)	HLZC
1	Normal Hot, Steady-state, Side wind direction normal to the outlet of the EOS-HSM with wind deflectors, 8 mph	70[(1)]	4 (50 kW)
2	Normal Hot, Steady-state, Side wind direction normal to the outlet of the EOS-HSM without wind deflectors, 8 mph	100[(1)]	4 (41.8 kW)
3	Normal Hot, Steady-state, Side wind direction normal to the outlet of the EOS-HSM with wind deflectors, 8 mph	100[(1)]	5 (41.0 kW)

Notes:

1. See Section 4.9.6.1.3.3, Section 4.9.6.1.3.1 for discussion on ambient temperatures and wind deflectors.

Table 4.9.6-3
Maximum and Average Component Temperatures for EOS-37PTH DSC (HLZCs 4 and 5) during Storage Operations

	Maximum Temperatures (°F)			
	Fuel Cladding	**Concrete**	**Basket Plates**	**Transition Rail**
Design Basis HLZC 1 (50.0 kW)	713[1]	238[2]	657[3]	501[3]
LC1 (HLZC 4, 50.0 kW)	715	232	652	497
ΔT (=$T_{HLZC\ 4\ (50kW)}$ - $T_{HLZC\ 1}$)	+2	-6	-5	-4
LC3 (HLZC 5, 41.0 kW)	705	233	567	460
ΔT (=$T_{HLZC\ 5\ (41.0\ kW)}$ - $T_{HLZC\ 1}$)	-8	-5	-90	-41
Design Basis HLZC 2 (41.8 kW)	688[4]	270[5]	638[6]	500[6]
LC2 (HLZC 4, 41.8 kW)	703	266	640	493
ΔT (=$T_{HLZC\ 4\ (41.8\ kW)}$ - $T_{HLZC\ 2}$)	+15	-4	+2	-7

Notes:

1. Maximum temperature for fuel cladding is from Table 4.9.4-2 for LC S-2 (see Note 4 of Table 4.9.4-2).
2. Maximum temperature for concrete is retrieved from Figure 4.9.4-8.
3. Maximum and average temperatures are retrieved from LC S2, 70 °F ambient, Grid 2 in Section 4.9.4.8.
4. Maximum temperature for fuel cladding is from Table 4.9.4-2 for LC 2.
5. Maximum temperature for concrete is retrieved from Figure 4.9.4-9.
6. Maximum and average temperatures are retrieved from LC 2, 90 °F ambient, in Section 4.9.4.7.

Table 4.9.6-4
Design Load Cases for EOS-TC125 Loaded with EOS-37PTH DSC
(HLZCs 4 and 5)

Load Case No.	Description	Ambient Temperature (°F)	Solar Insolation	HLZC
1	Normal, hot, indoor, transient, no air circulation	120	No	4 (50.0 kW)
1	Normal, hot, indoor, transient, no air circulation	120	No	5 (41.0 kW)
5	Accident, hot, outdoor, loss of liquid in neutron shield, steady-state, no air circulation	117	Yes	4 (50.0 kW)

Table 4.9.6-5
Maximum Component Temperature for EOS-TC125 Loaded with EOS-37PTH DSC (HLZCs 4, 5, and 6) for the Bounding Normal Conditions

Transfer Conditions	Temperature Limit	Normal, Hot, Indoor, Transient, No Air Circulation				
Load Case		LC 1 (HLZC 1) Design Basis, (See Table 4-29)	LC 1 (HLZC 4)	LC 1 (HLZC 5)	ΔT(1) (= $T_{HLZC4} - T_{HLZC1}$)	ΔT(2) (= $T_{HLZC5} - T_{HLZC1}$)
Time Limit (hr)		14	13	13	--	--
Heat Load (kW)		50	50	41	--	--
Component		Temperature (°F)				
Fuel Cladding	752/1058(4)	742(3)	729	717	-13	-25
Basket Plate		680	671	584	-9	-96
Transition Rail		553	547	498	-6	-55
DSC Shell		484	480	440	-4	-44
Gamma Shield	620	315	311	286	-4	-29
Neutron Shield (Average)	259	212	210	200	-2	-12
Bottom Neutron Shield (Average)	262	223	223	221	0	-2

Notes:

1. Temperature difference between LC 1 for HLZC 4 and design basis LC 1 for HLZC 1 for normal and off-normal conditions.
2. Temperature difference between LC 1 for HLZC 5 and design basis LC 1 for HLZC 1 for normal and off-normal conditions.
3. Maximum fuel cladding temperature is reported at 15 hours based on the discussion in Section 4.5.4.
4. Temperature limits for normal and accident conditions are 752 °F and 1058 °F, respectively.

Table 4.9.6-6
Maximum Component Temperature for EOS-TC125 Loaded with EOS-37PTH DSC (HLZCs 4, 5, and 6) for the Bounding Accident Condition

Transfer Conditions	**Accident, Hot, Outdoor, Loss of Liquid in Neutron Shield, No Air Circulation**		
Load Case	**LC 5 (HLZC 1) Design Basis, (See Table 4-29)**	**LC 5 (HLZC 4)**	**ΔT (1) (=$T_{HLZC4} - T_{HLZC1}$)**
Time Limit (hr)	Steady-State	Steady-State	--
Heat Load (kW)	50	50	--
Component	**Temperature (°F)**		
Fuel Cladding	935	949	14
Basket Plate	902	904	2
Transition Rail	750	750	0
DSC Shell	674	674	0
Gamma Shield	579	580	1

Notes:

(1) Temperature difference between LC 5 for HLZC 4 and design basis LC 5 for HLZC 1 for accident condition.

Table 4.9.6-7
Time Limit for Transfer Operations for HLZCs 4, 5, and 6

Operating Conditions(3)	Heat Load Zoning Configuration (HLZC)	Heat Load (kW)	Time Limit (hrs)
Normal/off-normal transfer	HLZCs 4, 5, or 6 (LC 1)	(Note 2)	8
	HLZCs 4, 5 or, 6 (LC 2, 3 and 4)	(Note 2)	8
	HLZCs 4, 5 or, 6 (LC 6b)	(Note 2)	No Time Limit (1)
Insertion of EOS-37PTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZCs 4, 5 or, 6 (LC 7)	(Note 2)	4
Loss of neutron shield with loss of air circulation, accident condition	HLZCs 4, 5 or, 6 (LC 5)	(Note 2)	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hours, per LC 6a, before it is turned off as explained in Section 4.5.4.

(2) Maximum heat load for HLZCs 4, 5, and 6 are 50 kW, 41 kW and 46 kW, respectively.

(3) Description of design LCs is listed in Table 4-23.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table 4.9.6-9
Maximum Component Temperatures of EOS-37PTH DSC with 8 Damaged FAs

Transfer Condition	Accident Loss of Neutron Shield with Loss of Air Circulation Accident Condition		
DSC	EOS-37PTH DSC		
Heat Load, kW	50.0	46.00	
FA Type	37 Intact	29 Intact/ 8 Damaged	
	LC 5, (HLZC 1) Design Basis (See Table 4-28, 4-29 and 4-30)		**ΔT (=$T_{Damaged}$ - T_{Intact})**
Component	**Temperature (°F)**		
Intact FAs	935	941	+6
Fuel Rubble(1)	--	994	--
Basket Plates	902	909	+7
Transition Rail	750	732	-18
DSC Shell	674	651	-23
Gamma Shield	579	554	-25
Basket Plate (Average)	712	667	-45
Transition Rail (Average)	635	607	-28

Note:

(1) The damaged FAs are modeled as rubble during accident conditions as discussed in Section 4.9.6.1.5.

Table 4.9.6-10
Maximum Component Temperatures of EOS-37PTH DSC for HLZC 6 with Four FFCs

Transfer Conditions	**Normal/Off-normal, Hot, Indoor, Transient, No Air Circulation**		
DSC	**EOS-37PTH DSC**		
Heat Load (kW)	50	44.3	**ΔT (=T_{HLZC6}-T_{HLZC4})**
FA Type	**37 Intact**	**33 Intact/ 4 Failed**	
HLZC	**4(1)**	**6**	
Component(2)	**Temperature (°F)**		
Fuel Cladding	729	701	-28
Basket Plate	671	646	-25
Transition Rail	547	522	-25
DSC Shell	480	459	-21
Lead (Gamma Shield)	311	297	-14
Bottom Neutron Shield (Average)	223	222	-1
Neutron Shield (Average)	210	204	-6

Notes:

(1) Temperatures are obtained from Table 4.9.6-5.

(2) All temperatures are reported at 13 hours.

Table 4.9.6-11
Time Limit for Transfer Operations for HLZCs 7, 8 and 9

Operating Conditions(3)	Heat Load Zoning Configuration (HLZC)	Heat Load (kW)	Time Limit (hrs)
Normal/ off-normal transfer	HLZCs 7, 8, or 9 (LC 1)	(Note 2)	8
	HLZCs 7, 8, or 9 (LC 2, 3 and 4)	(Note 2)	8
	HLZCs 7, 8, or 9 (LC 6b)	(Note 2)	No Time Limit (1)
Insertion of EOS-37PTH DSC into the EOS-HSM or restart of air circulation after its inactivation	HLZCs 7, 8, or 9 (LC 7)	(Note 2)	4
Loss of neutron shield with loss of air circulation, accident condition	HLZCs 7, 8, or 9 (LC 5)	(Note 2)	No Time Limit

Notes:

(1) If air circulation is initiated as a recovery option, it must be maintained for a minimum duration of 8 hours as per LC 6a, before it is turned off as explained in Section 4.5.4.

(2) Maximum heat load for HLZCs 7, 8 and 9 are 50 kW, 46.4 kW and 37.80 kW, respectively.

(3) Description of design LCs is listed in Table 4-23.

Proprietary Information on Pages 4.9.6-34 through 4.9.6-49
Withheld Pursuant to 10 CFR 2.390

CHAPTER 5
CONFINEMENT

Table of Contents

List of Figures

5. CONFINEMENT

The confinement evaluation described in this chapter is applicable to the EOS 37PTH dry shielded canister (DSC) and the EOS 89BTH DSC.

5.1 Confinement Boundary

The EOS-37PTH and EOS-89BTH DSCs are high integrity stainless steel or duplex steel welded vessels that provide confinement of radioactive materials, encapsulate the fuel in a helium atmosphere, and provide biological shielding during DSC closure and transfer and storage operations. The DSCs are designed to maintain confinement of radioactive material within the limits of 10 CFR 72.104(a), 10 CFR 72.106(b) and 10 CFR 20 under normal, off-normal, and credible accident conditions. Chapter 3 and associated appendices conclude that the design, including the helium atmosphere within the DSC, will adequately protect the spent fuel cladding against degradation that might otherwise lead to gross ruptures during storage. The design ensures that fuel degradation during storage will not pose operational safety problems with respect to removal of the fuel from storage.

The confinement boundary is shown in Figure 5-1. *Because confinement is provided by the "leaktight" DSC, storage of damaged and failed fuel does not affect radioactive material release from the DSC.* The DSC cylindrical shell, the inner top cover and inner bottom cover form the confinement boundary for the spent fuel. The drain port cover, vent plug and welds are also included in the confinement boundary. The outer top cover plate is an attachment to the confinement boundary that provides bearing to help support the inner top cover plate, and is therefore subject to ASME Code Subsection NB per ASME Figure NB-1132.2-3 note 6. The outer bottom cover plate is not needed to support the inner bottom cover plate under design pressure and is not in the component support path. It is thus outside ASME Code jurisdiction per ASME Figure NB-1132.2-2 note 5 and NB-2190(b). The dimensions and material descriptions for the confinement boundary assemblies and the redundantly welded barriers are discussed in Chapter 1. The components important-to-safety are identified in Chapter 2.

For damaged fuel assemblies, top and bottom end caps are provided to contain any potential fuel debris in the fuel compartment. Failed fuel shall be stored in a failed fuel canister (FFC). The end caps fit snugly into the top and bottom of the fuel compartment. They are held in place by the fuel compartments and the inner bottom cover plate and the top shield plug during transfer and storage. The end caps and FFCs have multiple through holes to permit unrestricted flooding and draining of the fuel compartments.

5.1.1 Boundary Definition/Design Features

The cylindrical shell to bottom cover plate welds are made during fabrication of the DSCs, and are fully compliant with ASME Section III, Subsection NB. The welds between the cylindrical shell and inner top cover (including drain port cover and vent plug welds) are made after fuel loading. These welds are designed, fabricated, inspected, and tested using alternatives to the ASME code specified in Section 4.4.4 of the Technical Specifications [5-3].

Stringent design and fabrication requirements ensure that the confinement function of the DSC is maintained. The cylindrical shell and inner bottom cover are pressure tested in accordance with the ASME Code, Section III, Subarticle NB-6300. This pressure test is performed after installation of the inner bottom cover at the fabricator's facility and may be performed concurrently with the leak test, provided the requirements of NB-6300 are met.

A leak test of the shell assembly, including the inner bottom cover, is performed in accordance with ANSI N14.5 [5-1] and the ASME Code, Section V, Article 10. These tests are typically performed at the fabricator's facility. The acceptance criteria for the test are "leaktight" as defined in ANSI N14.5.

The process for leak testing the DSC involves temporarily sealing the shell from the top end. The gas-filled envelope and evacuated envelope testing methodologies have the required nominal test sensitivity for leaktight construction and are used for leak testing. A helium mass spectrometer is used to detect any leakage as defined in ANSI N14.5. During final drying and sealing operations of the DSC, the top closure confinement welds are applied to confine radioactive materials within the cavity.

The inner top cover weld is welded to the DSC shell using automated welding equipment. Once the DSC has been vacuum dried, a pressure test is performed by backfilling the DSC cavity with helium. Following the satisfactory completion of the pressure test, the drain port cover and vent plug are welded, and a leak test is performed to verify that the weld between the DSC shell and the inner top cover, drain port cover and vent plug meet the leaktight criteria of ANSI N14.5. The outer top cover plate is also welded in place using automated welding equipment.

5.1.2 Confinement Penetrations

All penetrations in the DSC confinement boundary are welded closed. The DSC is designed to have no credible leakage as described above.

5.1.3 Seals and Welds

The welds made during fabrication of the DSC that affect the confinement boundary include the weld applied to the shell bottom, and the circumferential and longitudinal seam welds applied to the cylindrical shell. These welds are inspected (radiographic or ultrasonic inspection, and liquid penetrant inspection (PT)) according to the requirements of Subsection NB of the ASME Code.

The welds applied to the drain port cover, vent plug, and the inner top cover during closure operations define the confinement boundary at the top end of the DSC. These welds are applied using a multiple-layer technique with multi-level PT in accordance with alternatives to the ASME code as specified in Section 4.4.4 of the Technical Specifications [5-3]. This effectively eliminates any pinhole leak that might occur in a single-pass weld, since the chance of pinholes being in alignment on successive weld passes is negligibly small. Figure 5-1 provides a graphic representation of the confinement boundaries and welds.

5.1.4 Closure

Because the DSC is closed entirely by welding, there are no closure devices utilized for confinement.

5.2 Design Criteria

5.2.1 Requirements for Normal Conditions of Storage

The DSC shell is designed to prevent the leakage of radioactive materials. No discernable, undetected leakage is credible and the dose at the controlled area boundary from atmospheric release is negligible.

5.2.1.1 Release of Radioactive Material

Because the DSC is designed to have no credible leakage, Revision 1 of NUREG 1536 [5-2] does not require analyses for determining the annual dose equivalent from releases of radioactive material to an individual located at the site boundary or outside the controlled area. Analyses required for determining the annual dose equivalent based on direct radiation for normal, off-normal, and accident conditions are discussed in Chapters 11 and 12.

5.2.1.2 Pressurization of Confinement Vessel

The design provides for drying and evacuation of the DSC interior as part of the loading operations. As discussed in Chapter 4, the design is acceptable for the pressures that may be experienced during these operations. On completion of fuel loading, the gas fill of the DSC interior is at a pressure level that will maintain a non-reactive environment for at least the 80-year storage life of the DSC interior under normal, off-normal, and accident conditions.

5.2.2 Confinement Requirements for Hypothetical Accident Conditions

5.2.2.1 Fission Gas Products

The DSC confinement boundary is designed to prevent the leakage of radioactive materials. The analyses presented in Chapters 3 and 12 demonstrate that the confinement boundary is not compromised following hypothetical accident conditions. Therefore, estimating the maximum quantity of fission gas products is not necessary in accordance with Revision 1 of NUREG 1536.

5.2.2.2 Release of Contents

The DSC confinement boundary is designed to prevent the leakage of radioactive materials. The analyses presented in Chapters 3 and 12 demonstrate that the confinement boundary is not compromised following hypothetical accident conditions. Therefore, confinement analyses for the release of radioactive materials are not necessary in accordance with Revision 1 of NUREG 1536.

5.2.2.3 Confinement Monitoring Capability

The NUHOMS® EOS System is a self-contained, passive system that does not produce routine, solid, liquid or gaseous effluents. Effluent processing systems, or monitoring for airborne or liquid radioactivity, are not required to protect personnel or the environment during storage conditions. Since the DSC is closed entirely by welding, a closure monitoring system is not utilized in accordance with Revision 1 of NUREG 1536.

5.3 References

5-1 ANSI N14.5, "Leakage Tests on Packages for Shipment of Radioactive Materials," 1997.

5-2 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

5-3 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *1*.

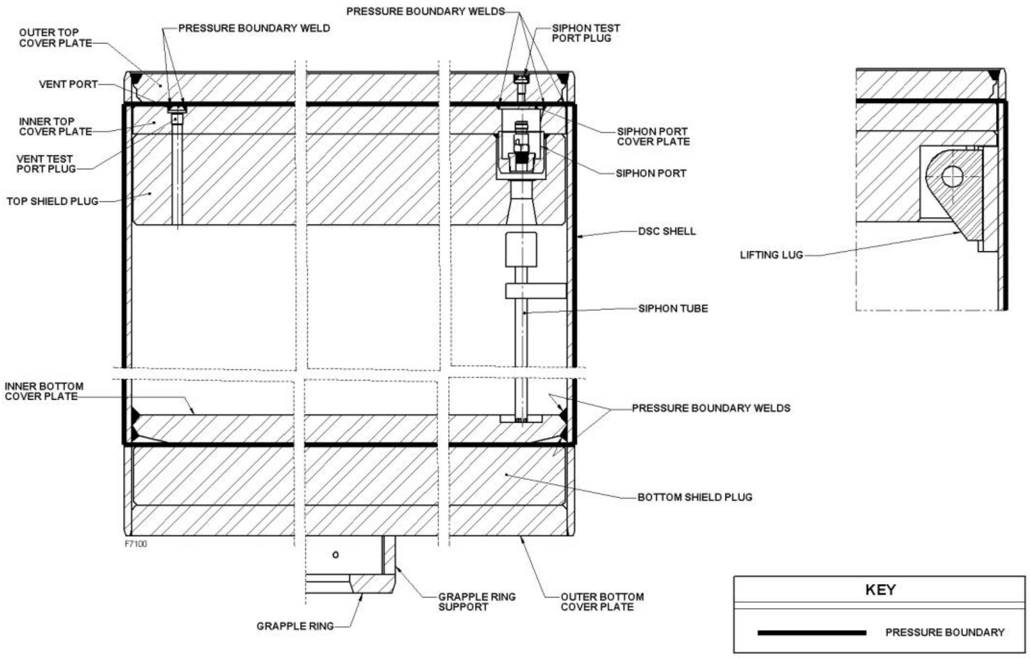

Figure 5-1
DSC Confinement Boundaries and Welds

CHAPTER 6
SHIELDING EVALUATION

Table of Contents

List of Tables

List of Figures

6. SHIELDING EVALUATION

The EOS system is designed to store intact*, damaged, or failed* pressurized water reactor (PWR) and *intact* boiling water reactor (BWR) fuel assemblies (FAs) within the EOS-37PTH dry shielded canister (DSC) and EOS-89BTH DSC, respectively. *Failed PWR fuel shall be stored in a failed fuel canister (FFC).* The transfer casks (TCs) EOS-TC108 and EOS-TC125/135 are used to transfer the EOS-DSC to the EOS horizontal storage module (EOS-HSM). Normal and off-normal condition, near-field dose rates are presented in this chapter for the EOS-TC and EOS-HSM. Detailed three-dimensional dose rate calculations are performed to determine the dose rate fields around the EOS-TCs during loading, decontamination, welding, drying, and transfer operations. Detailed three-dimensional dose rate calculations are also performed to determine the dose rate fields around an EOS-HSM. These near-field dose rates are used as input to the dose assessment documented in Chapter 11, Radiation Protection.

The methodology, source terms, and dose rates presented in this chapter are developed to be reasonably bounding for general licensee implementation of the EOS System. *Justification of the reasonably bounding source term methodology is provided in Section 6.2.8.* These results may be used in lieu of near-field calculations by the general licensee, although the inputs utilized in this chapter should be evaluated for applicability by each site. Site-specific EOS-TC and EOS-HSM near-field calculations may be performed by the general licensee to modify key input parameters.

Compliance with 10 CFR 72.106 is demonstrated in this chapter for a loss of neutron shield accident for a single EOS-TC. Further, site dose calculations for an array of EOS-HSMs under normal, off-normal, and accident conditions are documented in Chapter 11, based on the near-field EOS-HSM results presented in this chapter. Because the number and arrangement of EOS-HSMs and the distance to the site boundary is site-specific, compliance with 10 CFR 72.104 and 10 CFR 72.106 for an array of EOS-HSMs can only be demonstrated using a site-specific calculation. Inputs for the site dose calculations developed in the current chapter may be directly used as input to a site-specific dose calculation by the general licensee.

The shielding evaluation for the NUHOMS® MATRIX is documented in Appendix A.6.

6.1 Discussions and Results

The following is a summary of the methodology and results of the shielding analysis of the EOS system. More detailed information is presented in the body of the chapter.

The EOS-37PTH DSC stores up to 37 PWR FAs, while the EOS-89BTH stores up to 89 BWR FAs. Each EOS-DSC is configured into heat load zones in order to optimize the system performance for both thermal and shielding considerations. *Nine heat load zoning configurations (HLZCs) are available for the EOS-37PTH DSC, and three HLZCs are available for the EOS-89BTH DSC. The HLZCs are defined in the Technical Specifications (TS), Figure 1A through Figure 2 [6-11]*. Fuel to be stored is limited by the decay heat and minimum cooling times *defined in the Technical Specifications.*

The EOS-37PTH DSC is authorized to store up to eight damaged FAs or four FFCs using HLZC 6 or HLZC 8. Damaged and failed fuel shall not be present in the same DSC.

Source Terms

The ORIGEN-ARP module of the Oak Ridge National Laboratory (ORNL) SCALE6.0 code package [6-1] is used to develop reasonably bounding gamma and neutron source terms. [

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Control components (CCs) are allowed to be stored within a PWR FA. Examples of CCs include burnable poison rod assemblies (BPRAs) and thimble plug assemblies. Control components typically have a Co-60 source because of its light element activation, which contributes substantially to the dose rates. The CC source term *used in the analysis* is provided in Table 6-37. *Different CC source terms are used in the inner and peripheral zones. The inner and peripheral zones are defined in Figure 6-1 and are applicable to all PWR HLZCs. Co-60 equivalent activity limits per zone are provided in TS Table 3 [6-11].*

BWR fuel does not include CCs other than the fuel channel, which is conservatively included in the source term. The BWR fuel channel is fabricated from zirconium alloy and does not require a Co-60 limit because the contribution to the source term from the fuel channel is negligible.

Dose Rates

The Monte Carlo transport code, MCNP5 [6-5], is used to compute dose fields around the EOS-TCs and EOS-HSM using detailed three-dimensional models for the following normal configurations:

- EOS-37PTH DSC inside the EOS-TC108
- EOS-37PTH DSC inside the EOS-TC125/135
- EOS-37PTH DSC inside the EOS-HSM-Short
- EOS-89BTH DSC inside the EOS-TC108
- EOS-89BTH DSC inside the EOS-TC125
- EOS-89BTH DSC inside the EOS-HSM-Medium

The EOS-TC125 and EOS-TC135 provide equivalent shielding but accommodate different DSC lengths. The EOS-TC135 is used only with the EOS-37PTH DSC. The EOS-TC125 and EOS-TC135 designs are bounded by the same Monte Carlo N-particle (MCNP) model and are referred to in this chapter as EOS-TC125/135. The EOS-TC108 offers less shielding than the EOS-TC125/135 and features a removable neutron shield. The neutron shield is removed for fuel loading and attached subsequent to fuel loading. The neutron shield for the EOS-TC125/135 is integral to the cask and cannot be removed.

The EOS-37PTH and EOS-89BTH DSCs are custom-built for the fuel to be stored and, therefore, do not have a standard length. BWR fuel is typically longer than PWR fuel, so the EOS-89BTH DSC is longer than the EOS-37PTH DSC in the MCNP models. To accommodate the various DSC lengths, three versions of the EOS-HSM are available: short, medium, and long. In the EOS-HSM models, the EOS-37PTH DSC is paired with the EOS-HSM-Short, while the EOS-89BTH DSC is paired with the EOS-HSM-Medium, as these are the smallest EOS-HSMs that can accommodate the modeled EOS-DSCs.

All EOS-37PTH DSC calculations conservatively include both the FA and CC sources. BWR fuel does not include CC, other than the fuel channel, which is conservatively included in the source term.

Based on the near-field dose rates calculated for the EOS-TCs, a dose assessment is performed for the EOS-TC loading operation. This dose assessment is documented in Chapter 11.

The shielding effectiveness of the EOS-TC and EOS-HSM is not impacted by any off-normal events. Two accident events have been identified:

- Loss of neutron shielding for the EOS-TCs
- Loss of EOS-HSM outlet vent covers due to a tornado or missile event

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MCNP cases are developed for the EOS-HSM in which the vent covers are absent. The EOS-HSM accident increases the average dose rate on the roof of the module to 7400 mrem/hr. The fluxes and dose rates on the surface of the EOS-HSM in an accident condition are used as input to an accident site dose calculation documented in Chapter 11.

6.2 Source Specification

Design basis source terms for PWR and BWR fuels are developed in this section. The source terms are developed to be reasonably bounding consistent with the limits on fuel qualification. A site-specific analysis must evaluate the site-specific used fuel to be stored and determine if the parameters utilized in the UFSAR analysis are bounding and appropriate. Site-specific source terms may be different than the source terms presented herein. However, the source terms presented in this chapter were developed to bound most used fuels and will result in reasonably bounding dose rates.

Fuel types that are authorized for storage are provided in Chapter 2. These fuel types may be divided into PWR and BWR fuel types. The list of authorized fuels is summarized below.

PWR

- Westinghouse (WE) 14x14 class
- WE 15x15 class
- WE 17x17 class
- Babcock & Wilcox (B&W) 15x15 class
- Combustion Engineering (CE) 14x14 class
- CE 15x15 class
- CE 16x16 class

BWR

- 7x7 lattice array type
- 8x8 lattice array type
- 9x9 lattice array type
- 10x10 lattice array type

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6.2.1 Computer Programs

Source terms are generated using the ORIGEN-ARP module of SCALE6.0. ORIGEN-ARP is a control module for the ORIGEN-S computer program. ORIGEN-ARP allows a simplified input description that can rapidly compute source terms and decay heat compared to a full two-dimensional SCALE6.0/TRITON calculation.

Prior to using ORIGEN-ARP, detailed two-dimensional models of the design basis PWR and BWR FAs are developed in TRITON using the FA design data in Chapter 2. *The ENDF/B-VII 238-group cross section library (v7-238) is utilized in the TRITON input files.* TRITON is used to generate ORIGEN-ARP data libraries as a function of burnup and enrichment. These libraries are used by ORIGEN-ARP to compute the source terms.

ORIGEN-ARP uses interpolated cross section libraries to generate source terms that are essentially equivalent to the detailed TRITON runs. TRITON has been benchmarked against experimentally measured isotopes and results in excellent agreement with the measured data in ORNL/TM-2010 SCALE 5.1 [6-2]. As part of the code validation, the TRITON benchmark cases from SCALE 5.1 are rerun using the ENDF/B-VII 238-group cross section library. The isotopes important for shielding for which benchmark data are available include Cs-137/Ba-137m, Cs-134, Eu-154, Ce-144/Pr-144, Ru-106/Rh-106, Sr-90/Y-90, and Cm-244. The average ratio of the measured to calculated concentration for these nuclides is close to unity, indicating that TRITON/ORIGEN-ARP is an acceptable program for source term generation.

6.2.2 PWR and BWR Source Terms

Sources are developed for a variety of different enrichments. For a particular U-235 enrichment, the uranium fuel loading is distributed according to the following relationship from the SCALE 6.0 manual:

- wt. % U-234 = 0.0089 * wt. % U-235
- wt. % U-236 = 0.0046 * wt. % U-235
- wt. % U-238 = 100 – wt. % U-234 – wt. % U-235 – wt. % U-236

The EOS-DSC baskets are zoned by heat load. Heat load zoning allows hotter FAs, which generally have larger neutron and gamma source terms, to be placed in the inner zones and be shielded by FAs in the outer zone. The EOS-TC108 and EOS-TC125/135 have different heat load zone configurations because the EOS-TC125/135 is more heavily shielded than the EOS-TC108 and can therefore be loaded with stronger sources.

Nine HLZCs are available for the EOS-37PTH DSC and three HLZCs are available for the EOS-89BTH DSC. These HLZCs are defined in TS Figure 1A through Figure 2 [6-11]. All HLZCs may be transferred in the EOS-TC125/135, while the EOS-TC108 is limited to PWR HLZCs 2 and 3 and BWR HLZCs 2 and 3. The EOS-HSM may store PWR HLZCs 1 through 6 and all BWR HLZCs.

The bounding HLZCs are used for dose rate analysis. For each zone within a DSC, higher heat loads result in stronger source terms and larger dose rates if the minimum cooling time is the same. When the EOS-89BTH DSC is used with the EOS-TC125, the minimum cooling time is three years in all zones. The EOS-89BTH DSC HLZC 1 and 2 are identical except for Zone 2. The Zone 2 heat load is larger for HLZC 1 compared to HLZC 2. Therefore, HLZC 1 bounds HLZC 2. Also, every zone of HLZC 2 is hotter than the corresponding zone of HLZC 3. Therefore, HLZC 2 bounds HLZC 3. Because HLZC 1 > HLZC 2 > HLZC 3, EOS-89BTH DSC HLZC 1 is bounding for the EOS-TC125 analysis.

The EOS-89BTH DSC HLZC 1 is not allowed in the EOS-TC108. As discussed in the previous paragraph, HLZC 2 has larger heat loads in each zone compared to HLZC 3. When HLZC 2 or 3 is used with the EOS-TC108, the minimum cooling time in zone 3 is 9.7 years and 9.0 years, respectively. While the EOS-89BTH DSC HLZC 2 zone 3 has a slightly longer minimum cooling time than HLZC 3 zone 3, the minimum cooling time difference (0.7 years) is small compared to the large difference in decay heat (0.1 kW/FA). Therefore, EOS-89BTH DSC HLZC 2 is bounding for EOS-TC108 analysis.

Likewise, for the EOS-TC108, the EOS-37PTH DSC HLZC 2 has a larger heat load in each zone compared to HLZC 3. Also, the minimum cooling time is lower in HLZC 2 Zone 3 (five to eight years) compared to HLZC 3 (nine years). Therefore, EOS-37PTH DSC HLZC 2 bounds HLZC 3 for EOS-TC108 analysis.

For PWR fuel in the EOS-TC125/135, the bounding HLZC cannot readily be determined, although the nine HLZCs may be reduced to three candidates based on head load considerations. HLZC 4 has the largest total heat load in the peripheral zone, HLZC 1 has a large heat load in an inner zone, and HLZC 5 has the largest heat load per fuel assembly. Therefore, each of these HLZCs is examined explicitly.

Based on MCNP calculations, HLZC 4 bounds HLZC 1. However, source terms are developed for both HLZC 4 and HLZC 5 because it cannot be determined which HLZC is bounding without performing detailed calculations. Source terms for HLZC 4 are derived for 1.0 kW/FA in Zone 1 and 1.625 kW/FA in Zones 2 and 3 for a total DSC heat load of 52.0 kW. This bounds the maximum DSC heat load of 50.0 kW. HLZC 5 source terms are developed for 0.7 kW/FA in Zone 1, 0.5 kW/FA in Zone 2, 2.4 kW/FA in Zone 3, and 0.85 kW/FA in Zone 4.

Note that up to eight damaged PWR fuel assemblies or up to four FFCs are authorized for HLZC 6 and HLZC 8. Source terms are also developed for a damaged/failed fuel HLZC that bounds both HLZC 6 and 8. These source terms are derived for 1.0 kW/FA in Zone 1, 1.5 kW/FA in Zone 2, 1.5 kW/FA for intact fuel in Zone 3, and 0.85 kW/FA for failed fuel in Zone 3. The ORIGEN-ARP methodology for developing damaged/failed fuel source terms is the same as used for developing intact fuel source terms. Reconfiguration of damaged/failed fuel source terms is addressed in Section 6.3.2.

Because the FAs are zoned by heat load, it is necessary to develop source terms for each zone. Candidate sources are developed for high burnup (62 GWd/MTU), medium burnup (50 GWd/MTU) and lower burnup (40 GWd/MTU) fuel. Cooling time is selected so that the decay heat meets or exceeds the heat load limit for each zone. Because the cooling time required at these burnups is generally much larger than the minimum allowed cooling time for each zone, the burnup that results in a cooling time that matches the minimum cooling time for each zone is also determined. From these four candidate burnup/cooling time combinations, a bounding source for each zone is selected.

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The EOS-TC108 and EOS-TC125/135 feature reduced lead thickness next to the top nozzle region of the fuel assembly. For this reason, the maximum dose rate at the side of the EOS-TC occurs next to the top nozzle rather than the active fuel. The dose rate at this location is due almost entirely to Co-60 in the top nozzle and plenum regions of the FA. Therefore, to be conservative, the burnup/enrichment/cooling time combination that maximizes Co-60 activity is used to develop the top nozzle, plenum, and bottom nozzle sources. The computed Co-60 activity for each burnup/enrichment/cooling time is provided in the last column of Table 6-8 and Table 6-9 and represents the total Co-60 present in the FA. These Co-60 activities are only used for ranking the sources. For the active fuel region, the burnup/enrichment/cooling time combination that maximizes dose rate next to the active fuel is used to develop the active fuel region sources. The final "hybrid" sources are very conservative because the hardware is integral to the FA and the hardware and active fuel cannot be at different burnups/cooling times.

Based on EOS-TC and EOS-HSM dose rates (for the active fuel) and Co-60 activity (for the end hardware), reasonably bounding burnup/enrichment/cooling time combinations are determined. For these burnup/enrichment/cooling time combinations, the sources in the bottom nozzle, active fuel, plenum, and top nozzle are computed using the appropriate light elements from Table 6-5 and Table 6-6.

During an EOS-TC accident, it is postulated that the water in the neutron shield is lost. In this scenario, there is no hydrogenous neutron shield and the neutron dose rate dominates the primary gamma dose rate. Therefore, the *burnup/enrichment/cooling time combination that results in the maximum neutron source* is used in accident calculations with no neutron shield. In many cases, the normal condition and accident condition sources are the same.

PWR source terms are reported in the following tables:

- PWR sources terms for EOS-TC108 *(HLZC 2)*:
  Table 6-10 through Table 6-13
- *PWR source terms for EOS-TC125/135*
  Intact fuel (HLZC 4): Table 6-14 through Table 6-16
  Damaged/failed fuel (HLZC 6/8): Table 6-14, Table 6-16a through Table 6-16c
  Intact fuel (HLZC 5): Table 6-16d through 6-16g
- PWR source terms for EOS-HSM:
  HLZC 4: Table 6-17 through Table 6-19
  HLZC 5: Table 6-19a through Table 6-19d

BWR source terms are reported in the following tables:

- BWR sources terms for EOS-TC108 *(HLZC 2)*:
  Table 6-20 through Table 6-22
- BWR source terms for EOS-TC125 *(HLZC 1)*:
  Table 6-23 through Table 6-26
- BWR source terms for EOS-HSM *(HLZC 1)*:
  Table 6-27 through Table 6-29

In these tables, the "raw" neutron source computed by ORIGEN-ARP is provided, as well as neutron sources that include neutron peaking factors and subcritical neutron multiplication. These factors are derived in Section 6.2.3. The scaled neutron sources are used in the detailed MCNP dose rate calculations. Only the total neutron source magnitude is reported because the Cm-244 spectrum is used in all dose rate calculations for simplicity because the neutron source is almost entirely due to Cm-244 decay. For example, for the 62 GWd/MTU, 10.25 year cooled PWR source, 95% of the neutron source is due to spontaneous fission of Cm-244. Cm-244 is also the dominant neutron source for shorter cooling times. For instance, for a 36.178 GWd/MTU, three-year cooled PWR source, Cm-244 represents 97% of the total neutron source. The effect on the neutron spectrum of neutron source isotopes with shorter half-lives, such as Cm-242 and Cf-252, is negligible.

6.2.3 Axial Source Distributions and Subcritical Neutron Multiplication

ORIGEN-ARP is used to compute source terms for the average assembly burnup. However, an FA will exhibit an axial burnup profile in which the fuel is more highly burned near the axial center of the fuel assembly and less burned near the ends. This axial burnup profile must be taken into account when performing dose rate calculations, as the dose rate will typically peak near the maximum of this distribution.

The PWR axial burnup profile is taken from NUREG/CR-6801 [6-6] for fuel in the burnup range 26-30 GWd/MTU and is provided in Table 6-30. As fuel is more highly peaked for lower burnups, this distribution is more conservative than a flatter high-burnup distribution. The gamma source term varies proportionally to axial burnup, while neutron source terms vary exponentially with burnup by a power of 4.0 to 4.2 [6-7]. Therefore, the burnup profile is used as the gamma axial source distribution, while the neutron axial source distribution is derived as the burnup profile raised to the power of 4.2.

The average value of the neutron source distribution is 1.215, as shown in Table 6-30. This value has a physical meaning, as it is the ratio of the total neutron source from an FA with the given axial burnup profile to an assembly with a flat burnup profile. The neutron source term as computed by ORIGEN-ARP is for a flat burnup profile (average assembly burnup). Therefore, the “raw” PWR neutron source computed by ORIGEN-ARP is scaled by the factor 1.215 to account for the burnup profile.

For clarity, both the gamma and neutron axial source distributions are renormalized to sum to 1.0, as shown in Table 6-30. When normalized in this manner, the source distribution is the fraction of the source in each axial segment. For example, the fraction of the neutron source in axial segment 10 is 0.0781, or 7.81%.

The BWR axial burnup profile is taken from [6-8] for fuel with a burnup of 40.2 GWd/MTU and is provided in Table 6-31. This distribution is highly peaked and is conservative. The BWR gamma and neutron source distributions are derived using the same method used for the PWR source distributions. The average value of the BWR neutron source distribution is 1.232, and the “raw” neutron sources computed by ORIGEN-ARP are increased by this factor to account for the burnup profile.

ORIGEN-ARP does not account for subcritical neutron multiplication. Subcritical neutron multiplication is taken into account by multiplying the neutron source by 1/(1-k), where k is the multiplication factor for the system. When the system is dry, k is low due to the lack of moderation as well as burnup of the fuel. For dry analysis, k is assumed to be 0.40. When the system is wet, such as during decontamination of the EOS-TC, k is larger. For wet analysis, k is assumed to be 0.65. This value of k is reasonable for shielding calculations because the fuel is burned and heavily poisoned. Fresh or lightly burned fuel would have a higher value for k, but fresh or lightly burned FAs have a small neutron source. Because the neutron source increases proportional to the 4.2 power of the burnup, large neutron sources occur only at high burnups, and for such burnups a k of 0.65 is reasonable.

The effect on the neutron source of both the axial source distribution and subcritical neutron multiplication are combined, as shown in the source term tables (Table 6-10 and Table 6-29). For PWR sources, the "raw" ORIGEN-ARP neutron sources are scaled by 1.215/(1-0.40) = 2.025 for dry analysis and 1.215/(1-0.65) = 3.471 for wet analysis. For BWR sources, the "raw" ORIGEN-ARP neutron sources are scaled by 1.232/(1-0.40) = 2.053 for dry analysis and 1.232/(1-0.65) = 3.520 for wet analysis.

The only analysis that uses the wet neutron source term is the loading/decontamination stage of the EOS-TCs. After loading/decontamination the EOS-TCs are modeled as dry. No wet neutron sources are provided in the EOS-HSM source term tables because the DSC is always dry when inside the EOS-HSM.

6.2.4 Control Components

Control components may also be included with the PWR FAs. For BWR fuel, the fuel channel and associated attachment hardware is included in the BWR source presented in Section 6.2.2, so it will not be discussed in this section. While CCs do not contain fuel, these items result in a source term, primarily due to activation of the Co-59 impurity in the metal. Allowed CCs are identified in Section 2.1 of the *TS* [6-11].

Any other CC type is acceptable if it can be demonstrated that the source term is bounded by the source terms presented in this analysis. Also, the total as-loaded decay heat of the system, including CCs, must be less that the heat load zoning configurations defined in *the TS [6-11]*.

Any other CC type is acceptable if it can be demonstrated that the source term is below the CC activity limits provided in TS Table 3 [6-11]. The BPRA is used as a representative CC for category (1) and the TPA is used as a representative CC for category (2). The objective is to use these representative CC types to develop Co-60 activity limits for CCs.

The BPRAs are assumed to be burned in two cycles to a total host FA burnup of 50 GWd/MTU. This represents a limiting burnup because the absorber material is completely depleted for this burnup. TPAs do not contain burnable poisons and may be used in multiple host FAs for very long burnups. A cumulative host FA burnup of 300 GWd/MTU is assumed. However, a TPA is primarily located in the top nozzle and plenum region of the core where the flux is depressed and the "effective" burnup of a TPA is significantly less.

A neutron source may be included in CCs, such as an NSA. Typically, the neutron source from an NSA is negligible compared to the neutron source from spent fuel. However, some neutron sources could have comparable source strength relative to the *FAs*. For this purpose, the loading of neutron sources is limited to the interior locations of the EOS-37PTH basket to maximize self shielding. *The inner locations are defined in Figure 6-1.*

Representative BPRA hardware masses are available for three BPRA types:

- B&W 15x15
- WE 17x17 Pyrex
- WE 17x17 WABA

The BPRA hardware masses are provided in Table 6-32.

Representative TPA hardware masses are available for three TPA hardware types:

- Westinghouse 17x17
- Westinghouse 14x14 Type 1 and 2

The TPA hardware masses are provided in Table 6-33.

Elemental compositions for Zircaloy-4, Inconel-718, Inconel X-750, and 304 stainless steel are provided in Table 6-3. Note that the source term and dose rate are driven by Co-60, which arises primarily from Co-59 activation and to a much lesser extent from Ni-60 activation via an (n,p) reaction. The remaining light elements have little effect on the source term at the decay times of interest.

The poison is assumed to be Pyrex® (borosilicate glass). The choice of poison material has little effect on the source term or decay heat and is included for completeness. The elemental composition is obtained from [6-9] and is reproduced in Table 6-34.

The plenum and top regions are outside the active core and experience a reduced flux. The ratio of the flux in each region to the active fuel flux is provided in Table 6-4.

The source term and decay heat for the decay times of interest are dominated by Co-60. Co-60 primarily arises through activation of the Co-59 impurity present in the metal. Therefore, the BPRA and TPA hardware that has the largest Co-59 mass in each region is used to prepare the light element inputs. For the BPRA, B&W 15x15 is used for the top and WE 17x17 Pyrex is used for the plenum and active fuel regions. For the TPA, the WE 17x17 is used for all regions.

The source terms are computed using ORIGEN-ARP and the B&W 15x15 library. A separate ORIGEN-ARP input file is developed for each hardware type and region.

For the BPRA, the host FA is burned to 50 GWd/MTU in two cycles. The minimum enrichment is 3.1% based on Table 6-7. The FA loading is 0.492 MTU. The assembly power is 19.68 MW, the irradiation time per cycle is 625 days, and the down time between cycles is 30 days. Decay heat, Co-60 activity, and the gamma source term is requested for a decay time of 10 years.

To account for the reduced flux in the plenum and top regions, the BPRA input masses are scaled by the appropriate flux scaling factor. The ORIGEN-ARP inputs for the three BPRA regions are summarized in Table 6-35.

The methodology for TPAs is slightly different than for BPRAs. The reason is that a TPA may reside in several host FAs for a total host fuel assembly burnup of 300 GWd/MTU. ORIGEN-ARP cannot burn a single FA to such a high burnup. Therefore, rather than apply the flux scaling factors to the input masses, the true masses are input and the flux scaling factors are applied to the FA burnup. The TPA input masses are summarized in Table 6-33. These masses do not include flux scaling factors and are therefore larger than the BPRA input masses.

For the TPA plenum, the effective burnup is 300*0.2 = 60 GWd/MTU, while for the TPA top the effective burnup is 300*0.1 = 30 GWd/MTU. This reduces the cumulative burnup in each region to a value within the bounds of a typical ORIGEN-ARP model.

The TPA irradiation time is input to match the true irradiation time to properly credit Co-60 decay during the irradiation. Assuming a reactor assembly power of 19.68 MW and fuel loading of 0.492 MTU, the irradiation time to achieve a cumulative fuel assembly burnup of 300,000 GWd/MTU is 7,500 days. Because the irradiation time is fixed at 7,500 days, the FA power is selected to give the desired effective burnup in the plenum and top regions. For the top, the assembly power is 1.968 MW to achieve an effective burnup of 30 GWd/MTU. For the plenum, the assembly power is 3.936 MW to achieve an effective burnup of 60 GWd/MTU.

For simplicity of input preparation in the TPA calculation, no credit is taken for down time between cycles (typically assumed to be 30 days). Using approximately 12 cycles to achieve a burnup of 300 GWd/MTU, the conservatism of this assumption is 11*30 = 330 days of uncredited decay time.

Results for Co-60 activity and decay heat for both the BPRA and TPA are summarized in Table 6-36 for a cooling time of 10 years. It is observed that the BPRA source may be used in the active fuel region, as the TPA does not extend into this region. However, the TPA has a larger source than the BPRA in the plenum and top regions due to the high TPA burnup. Decay heat for both is small compared to SFA but must be accounted for during loading. The CC source used in the detailed PWR dose rate calculations is a hybrid CC source that combines the active fuel source of the BPRA with the top/plenum source of the TPA in *the inner zones (HLZC 4 Zones 1 and 2)*, but limits *the peripheral zone (HLZC 4 Zone 3)* to the lower BPRA source. This source is provided in Table 6-37. The CC source significantly impacts the peak dose rates on the side of the EOS-TC, due to the reduced lead thickness near the top nozzle.

While the specific CC source term presented in Table 6-37 is computed for a decay time of 10 years, this is not a minimum decay time requirement for licensing purposes. The actual CC to be loaded may have a shorter decay time as long as the as-loaded Co-60 activity is less than the limits provided *in TS Table 3 [6-11]*, and the total EOS-DSC decay heat remains below the applicable limit.

6.2.5 Blended Low Enriched Uranium Fuel

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6.2.6 Reconstituted Fuel

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6.2.7 Irradiation Gases

During irradiation in a reactor, a FA will generate gases due to fission, alpha decay, and light element activation. The moles of gas generated are needed for subsequent pressure calculations documented in Chapter 4, Section 4.7, and are computed using ORIGEN-ARP. The noble gases (He, Ne, Ar, Kr, Xe, and Rn) are of primary interest as these gases do not react with other elements. The elements H, N, F, and Cl *generated during irradiation* are conservatively assumed to be present in a gaseous state, although these elements may have formed solid compounds and may not be present as a gas. Bromine and iodine are also assumed to be present as a gas because the boiling points of these elements are low. Oxygen is not treated as a gas because it is present primarily in the compound UO_2.

The quantities of irradiation gases increase with burnup. Therefore, the quantity of gas is maximized for a burnup of 62 GWd/MTU.

Integral fuel burnable absorber rods (IFBA) are used in some Westinghouse PWR designs. IFBA contains B-10, which results in helium gas generation due to the reaction B-10 + n → Li-7 + He-4. While the design basis B&W 15x15 FA does not contain IFBA, the effect of an IFBA FA is conservatively included by *considering* 450 g boron.

Control components also may result in helium gas generation due to B-10 activation. No actinides or fission products are present in the CCs, so the quantity of gas is smaller than spent fuel. Because the BPRA contains boron while the TPA does not, the BPRA bounds the TPA for gas generation. BPRA data is summarized in Table 6-32. The B&W 15x15 BPRA contains poison in the form B_4C-Al_2O_3, typically up to 5% B_4C, while the WE 17x17 Pyrex design utilizes Pyrex poison. To conservatively bound these designs and potentially other designs, *a boron mass of 450 g is considered for CCs*.

450 g boron is input to ORIGEN-ARP with a burnup of 62 GWd/MTU to estimate the He generation for IFBA or CCs. The resulting helium generation is 8.34 moles. As 450 g boron contains approximately 8.34 moles of B-10, essentially all B-10 is converted to He due to the high burnup.

Irradiation gases are computed for the design basis PWR fuel without IFBA or CCs, and the moles of He due to IFBA and CCs are added. The moles of gas for each isotope of interest are reported in Table 6-40. The design basis PWR fuel assembly without IFBA or CCs contains 42.7 moles of gas. If both IFBA and CCs are included, the total moles of gas for PWR fuel is 42.7 moles + 8.34 moles + 8.34 moles = 59.4 moles.

Moles of gas are also computed for the design basis BWR fuel assembly using the same methodology, although BWR fuel does not contain IFBA or CCs. The design basis BWR fuel contains 17.4 moles of gas, as indicated in Table 6-40.

The quantity of fission gas generated in a FA is proportional to the fuel loading. The moles of gas for the design basis PWR FA are based on a fuel loading of 0.492 MTU. However, there are shorter FAs with smaller fuel loadings and longer FAs with larger fuel loadings. The EOS-DSC may be shorter or longer depending on the length of fuel, and thus the free volume within the DSC changes with fuel length/loading. For the pressure calculation (Section 4.7), FAs are binned into short, medium, and long groups.

The short group has an unirradiated FA length < 157 inches. The medium group has an unirradiated FA length between 157 and 190 inches, while the long group has an unirradiated FA length > 190 inches. The design basis PWR fuel has an unirradiated fuel length of 165.76 inches, which places it in the medium group.

For the pressure calculation the medium length FAs bound the long *FAs*. There are three short PWR FAs, CE 14x14 Fort Calhoun, CE 15x15 Palisades, and Exxon/ANF 15x15 CE. The maximum fuel loading for the three short FAs is 0.450 MTU. Therefore, the irradiation gas result for the design basis assembly *with CCs and IFBA (59.4* moles) may be scaled by 0.450/0.492 = 0.915. The bounding quantity of gas for the short PWR assemblies is then *59.4* moles*0.915 = 54.*3* moles.

Note that the moles of gas presented are only gases generated due to irradiation. Both fuel and CCs will be pre-pressurized with gas (typically helium) when fabricated and the moles of this initial gas is not included.

6.2.8 *Justification for the Reasonably Bounding Source Term Methodology*

Proprietary Information on Pages 6-25 and 6-26
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6.3 Model Specification

MCNP5 is used to perform detailed three-dimensional near-field dose rate calculations for EOS-TCs and EOS-HSMs. All relevant details of the EOS-37PTH DSC, EOS-89BTH DSC, EOS-TC108, EOS-TC125/135, and EOS-HSM are modeled explicitly.

Separate primary gamma and neutron models are developed. The EOS-TC and EOS-HSM neutron models are run in coupled neutron-photon mode so that the secondary gamma dose rate from (n,γ) reactions may be computed. The secondary gamma dose rate from the EOS-TC arises primarily from neutron absorption in the water neutron shield. Secondary gammas from the EOS-HSM are negligible but are computed for completeness.

The treatment of subcritical neutron multiplication is suppressed in MCNP by using the NONU card. This is done because the *FAs* are modeled as fresh fuel and homogenized for simplicity, which would cause inaccurate treatment of subcritical neutron multiplication by MCNP. Subcritical neutron multiplication is accounted for in the neutron source magnitude, as discussed in Section 6.2.3.

6.3.1 Material Properties

Basic materials used in the models, such as 304 stainless steel, carbon steel, and concrete, are obtained from PNNL-15870 [6-9] and are summarized in Table 6-41. Not all materials are used in every model. The density of concrete has been conservatively reduced to 2.243 g/cm^3. Simple materials consisting of one element are not listed in Table 6-41. Such materials include lead, which is modeled with a reduced density of 11.18 g/cm^3. Aluminum is used in the basket plates with a density of 2.7 g/cm^3. The metal matrix composite (MMC) poison is modeled as pure aluminum (no boron) with a reduced density of 2.56 g/cm^3.

Borated polyethylene is used at the bottom of the EOS-TC for neutron shielding. Approximately 16% boric acid by weight (B_2O_3) is added to polyethylene so that the material is 5% boron by weight. The atom density of hydrogen is conservatively reduced by 15% to account for potential hydrogen loss due to aging. The borated polyethylene composition used in the EOS-TC models is provided in Table 6-42.

The FAs are homogenized for simplicity. Fuel assemblies are modeled as fresh with a U-235 enrichment of 3%. The enrichment used is arbitrary because fission has been suppressed with the NONU card. Separate homogenization is performed for the bottom nozzle, active fuel, plenum, and top nozzle regions of the FA for both wet and dry conditions. The masses used for the homogenization are obtained from Table 6-1 and Table 6-2 for PWR and BWR fuel, respectively.

Table 6-1 does not include CC masses. For PWR fuel, the CC mass is also included in the plenum and top nozzle homogenizations because the CC source is always included in the MCNP models (no CC mass is credited in the active fuel region). As discussed in Section 6.2.4, the CC source is based on the BPRA B&W 15x15 in the top region (Zone 3), BPRA WE 17x17 Pyrex in the plenum region (Zone 3), and TPA WE 17x17 in both the top and plenum regions (Zones 1 and 2). The additional CC mass to be homogenized with the fuel is the minimum masses when comparing these CC types. This results in an additional 2.468 kg SS304 and 0.358 kg Inconel-718 in the top nozzle and an additional 2.85 kg SS304 in the plenum.

For BWR fuel, the mass of the channel is conservatively ignored because the channel may not be present. In the wet models, water with a density of 0.958 g/cm^3 fills the void space within the FA. The homogenized PWR fuel compositions are provided in Table 6-43 and Table 6-44 for dry and wet analysis, respectively. The homogenized BWR fuel compositions are provided in Table 6-45 and Table 6-46 for dry and wet analysis, respectively.

Concrete used in the EOS-HSM is modeled without steel rebar at a conservatively low density of 140 pcf (2.243 g/cm^3).

6.3.2 MCNP Model Geometry for the EOS-TC

Intact Fuel, Normal and Off-Normal Conditions

Detailed EOS-TC MCNP models are developed for the following four configurations:

- EOS-TC108 with EOS-37PTH DSC
- EOS-TC108 with EOS-89BTH DSC
- EOS-TC125/135 with EOS-37PTH DSC
- EOS-TC125 with EOS-89BTH DSC

The EOS-37PTH DSC and EOS-89BTH DSC are modeled explicitly, including the steel basket structure, aluminum plates, MMC (conservatively modeled without boron), transition rails, and shield plugs. Key dimensions used to develop the DSC models are summarized in Table 6-47, and figures illustrating the basic MCNP model are provided in Figure 6-3 through Figure 6-6. The figures illustrate the EOS-TC108 with the EOS-89BTH DSC, although the other EOS-TC and EOS-DSC combinations are similar.

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Three model configurations are used to simulate the EOS System during the various stages from loading to transfer. These configurations are loading/decontamination, welding/drying, and downending/transfer, and are described below.

- Loading/Decontamination. The shield plug is in place while the ITCP, OTCP, and top cover plate (lid) are not installed. The neutron shield is off (for the EOS-TC108) or drained (for the EOS-TC125/135), simulating the configuration when the EOS-TC is first removed from the pool. (The actual decontamination operation is performed with the neutron shield full.) Due to crane weight constraints, the EOS-TC108 is modeled with the DSC cavity drained to the top of the active fuel for the EOS-37PTH DSC and drained to the top of the plenum for the EOS-89BTH DSC. The top nozzle of BWR fuel is sufficiently long that draining the plenum region is not anticipated. For the EOS-TC125/135, the DSC cavity is completely filled with water at all times because there is no constraint on crane capacity. The annulus between the EOS-DSC and EOS-TC is filled with water.
- Welding/Drying. The ITCP is installed but the OTCP and top cover plate (lid) are not installed. The neutron shield is filled with water and the DSC is dry. The water height in the annulus is reduced by 12 inches.

- Downending/Transfer. The TC is fully assembled for the transfer operation. The OTCP and top cover plate (lid) are installed. The neutron shield is filled with water and all TC cavities are dry. The EOS-TC108 is modeled with the intermediate aluminum lid rather than the final steel lid.

These three configurations are also summarized in Table 6-49.

The EOS-TC108 has a removable neutron shield. The shield is formed of three panels that are connected with hinges on two joints and latches on the third joint. The interface joint between the three panels features 1.5 inches of aluminum, which allows limited neutron streaming through these three joints along the length of the EOS-TC108. The EOS-TC108 models do not include this streaming path, i.e., the neutron shield is modeled as continuous around the circumference. However, the neutron shield joints are modeled explicitly in a supplementary model, and the dose rates in the vicinity of the joints do not exceed the reported peak dose rates. In addition, the dose rates used in the dose assessment are essentially unchanged when the neutron shield joints are modeled. Therefore, it is acceptable to model the EOS-TC108 neutron shield as continuous around the circumference.

No temporary shielding is modeled, which would be used in practice to shield penetrations or localized areas of high dose rate. Therefore, the computed dose rates are larger than the dose rates that would be observed in actual practice.

The source terms used in the EOS-37PTH DSC models are the combined fuel and CC source terms. The CC source term from Table 6-37 is simply added to the *applicable PWR* fuel source term from *Section 6.2.2*. The CC source is added to every FA in the EOS-37PTH DSC. The EOS-89BTH DSC source terms are provided in Table 6-20 through Table 6-26. Note that the source term tables provide dry and wet neutron sources. Wet neutron sources are used only in the loading/decontamination models, while dry neutron sources are used in all other models. For the active fuel regions, an axial source distribution is applied per Table 6-30 and Table 6-31 for PWR and BWR fuel, respectively. For the top nozzle, plenum, and bottom nozzle regions, the source is evenly distributed throughout the region.

For each TC/DSC combination, dose rates are calculated on the surface, 30 cm, and 100 cm from the surfaces of the EOS-TC. Dose rates are also computed 300 cm from the side surface. All side dose rates are computed in 18 axial bins. The general tally locations are shown in Figure 6-7. In addition, for the final transfer configuration, dose rates are computed on the bottom and top surface in six radial segments (see Figure 6-8 and Figure 6-9) and on the side surface in 18 radial segments and 24 angular segments (see Figure 6-10).

Damaged or Failed Fuel, Normal and Off-Normal Conditions

Damaged or failed fuel may be tranferred in the EOS-37PTH DSC and EOS-TC125/135 using HLZC 6 or 8. Up to eight damaged fuel assemblies may be loaded in Zone 2, or up to four failed fuel canisters (FFCs)in Zone 3. Damaged and failed fuel may not be present in the same DSC. Damaged or failed fuel is not authorized for storage in the EOS-89BTH DSC or transfer in the EOS-TC108.

Proprietary Information on This Page
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Accident Conditions

Accident models are also developed for the four transfer configurations. In the accident models, the water neutron shield, neutron shield panel, and borated polyethylene bottom neutron shield are replaced with void, and the accident source terms are used. The dose rate is calculated at a distance of 100 m from the EOS-TC. Ground is modeled to account for ground scatter at large distances.

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6.3.3 MCNP Model Geometry for the EOS-HSM

Detailed EOS-HSM MCNP models are developed for the following two configurations:

- EOS-HSM-Short with EOS-37PTH DSC
- EOS-HSM-Medium with EOS-89BTH DSC

The EOS-37PTH DSC and EOS-89BTH DSC models developed in Section 6.3.2 are used in the EOS-HSM models. Consistent with the EOS-DSC models, the Z-axis in the EOS-HSM models is along the length of the EOS-DSC. Because the DSC cavity has been reduced in length to match the length of the fuel, the EOS-37PTH DSC model is shorter than the EOS-89BTH DSC model. Short, medium, and long versions of the EOS-HSM may be used, depending on the length of EOS-DSC to be stored. The EOS-HSM modeled is the smallest EOS-HSM that fits the EOS-DSC. Therefore, the EOS-HSM-Short is modeled with the EOS-37PTH DSC and the EOS-HSM-Medium is modeled with the EOS-89BTH DSC.

The EOS-HSM features two DSC support structure designs. The original design utilizes I-beams, while an alternate design utilizes a flat plate system. These options do not affect the bulk shielding provided by the EOS-HSM, and the I-beam supports are represented in the MCNP models.

PWR source terms (without CCs) are provided in Table 6-17 through *Table 6-19d*, and the CC source provided in Table 6-37 is added to these PWR source terms for all FAs. BWR source terms are provided in Table 6-27 through Table 6-29. For the active fuel regions, an axial source distribution is applied per Table 6-30 and Table 6-31 for PWR and BWR fuel, respectively. For the top nozzle, plenum, and bottom nozzle regions, the source is evenly distributed throughout the region.

The EOS-HSMs are modeled explicitly, including the inlet (front) and outlet (roof) vents. Key dimensions used to develop the EOS-HSM models are summarized in Table 6-50, and figures illustrating the basic MCNP model are provided in Figure 6-11 through Figure 6-13. The figures illustrate the EOS-HSM-Medium with the EOS-89BTH DSC, although the geometry of the EOS-HSM-Short with the EOS-37PTH DSC is similar.

The EOS-HSM design consists of a base module that includes the door and 1-foot thick shield walls on the sides and rear. A 3-foot-8-inch thick roof block that matches the length and width of the base rests on the base module. The modules may be positioned either side-by-side in a single row or back-to-back in a double row. When positioned in a single row the rear of the base module is shielded by a 3-foot thick rear shield wall. An end (side) shield wall, which is also 3 feet thick, is placed beside the last module in the row. The end shield wall is comprised of two pieces mated with a Z-joint to prevent direct streaming through the joint. A corner shield wall is placed at the interface of the rear and end shield walls. When the modules are positioned back-to-back, no rear or corner shield walls are used.

Air inlet vents are located on the front and air outlet vents are located on the roof. Because little radiation directly penetrates the thick concrete shielding, essentially all of the dose rate is due to gamma radiation streaming from the vents. Radiation streaming through the outlet vents is mitigated by the use of vent covers. The vent covers feature a 1-inch thick steel plate and approximately 11 inches of concrete. The vent covers are 4 feet wide and are placed between adjacent EOS-HSMs or between an EOS-HSM and the end shield wall. Under normal and off-normal conditions the vent covers are always in place.

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The baseline MCNP model consists of an EOS-HSM with a rear shield wall. On the right side (+x direction) an end shield wall is modeled, while on the left side (-x direction) a mirror boundary is modeled. The mirror boundary simulates an adjacent EOS-HSM so that the model is effectively a 2x1 array of EOS-HSMs. Modeling a 2x1 array significantly increases the vent dose rates compared to simply modeling a single EOS-HSM because a significant source of radiation at a vent is from the EOS-DSC in an adjacent EOS-HSM. The mirror boundary is placed 0.75 inch from the left face of the module to simulate a total gap of 1.5 inches. This model is referred to as the “single reflection model.” Dose rates are computed at the inlet and outlet vents and at the 1.5-inch gaps between the base module and shield walls.

The average fluxes and dose rates on the faces of the EOS-HSM are used as input to a generic site dose calculation that is documented in Chapter 11. These average fluxes and dose rates are computed on the surface of a box that envelops the EOS-HSM model, including the vent covers, door, and fabrication gaps. The average end shield wall dose rates are computed with the 2x1 EOS-HSM “single reflection” model described above. However, to capture the contribution from side-by-side or back-to-back EOS-HSMs, additional “double reflection” and “triple reflection” models are developed.

In the “double reflection” model, the end shield wall and corner shield wall are removed and a reflective boundary is added on the right side. The double reflection model simulates an EOS-HSM with an adjacent EOS-HSM on each side. Gaps are included between the modules. This model is only used to compute the average fluxes and dose rate on the rear shield wall used as input to the site dose calculation.

In the “triple reflection” model, all shield walls are removed and replaced with reflective boundaries. This model is illustrated in Figure 6-14. The triple reflection model simulates an EOS-HSM with an adjacent EOS-HSM on each side and back-to-back. The triple reflection model is used to compute the average dose rates on the front and roof used as input to the site dose calculation. The triple reflection model is also used to compute vent and gap dose rates.

In an accident condition, the vent covers are assumed to be absent. This will cause the average roof dose rate to increase substantially but will have negligible effect on the front, rear, or side dose rates. A triple reflection accident model is developed to compute the average flux and dose rate on the roof when the vent covers are removed.

A simple model of an EOS-89BTH DSC with 44 inches of cylindrical concrete shielding and no vents is used to demonstrate the bulk shielding effectiveness of the EOS-HSM in the absence of penetrations. This model is illustrated in Figure 6-15. The outer three and six inches of this model is also replaced with low-density grout (100 pcf versus the 140 pcf concrete used in the EOS-HSM model) to demonstrate that concrete that has spalled may be patched with grout with a negligible impact on the dose rates.

6.4 Shielding Analysis

6.4.1 Computer Codes

MCNP5 v1.40 is used in the shielding analysis [6-5]. MCNP5 is a Monte Carlo transport program that allows full three-dimensional modeling of the EOS-TC and EOS-HSM. Therefore, no geometrical approximations are necessary when developing the shielding models.

6.4.2 Flux-to-Dose Rate Conversion

MCNP5 is used to compute the neutron or gamma flux at the location of interest and the flux is converted to a dose rate using ANSI/ANS-6.1.1-1977 flux-to-dose rate conversion factors [6-10]. These factors are provided in Table 6-51. Results are computed in the units mrem/hr.

6.4.3 EOS-TC Dose Rates

Intact Fuel, Normal and Off-Normal Conditions

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Proprietary Information on Pages 6-38 through 6-41
Withheld Pursuant to 10 CFR 2.390

The results are presented in Table 6-59. With no grout, the dose rate is 1.4 mrem/hr, while with 6 inches of grout, the dose rate is 2.2 mrem/hr. Therefore, the use of lower density grout to repair concrete is acceptable because the localized dose rate remains small. For example, the average dose rate on the end shield wall of the EOS-HSM is 0.544 mrem/hr (see Table 6-55), and if 6 inches of grout were used, the dose rate would increase to only 0.544*2.2/1.4 = 0.85 mrem/hr. Dose rates are dominated by streaming from the vents because little radiation penetrates the thick concrete shield walls, and repairing the EOS-HSM with grout in localized areas will have no effect on worker exposure or site dose rates.

6.5 Supplemental Information

6.5.1 PWR Fuel Qualification

Chapter 6 presents the shielding analysis for design basis fuel. For the EOS-37PTH DSC, HLZC 4 results in bounding dose rates. HLZC 4 features 1.6 kW fuel in the peripheral region. The peripheral region is illustrated in TS Figure 3. HLZC 5 has a mixture of 2.4 kW and 0.85 kW fuel in the peripheral region, and HLZC 5 dose rates are similar to HLZC 4. HLZC 7 and HLZC 9 have similar peripheral heat loads compared to HLZC 4 and HLZC 5, respectively. HLZC 1, 2, 3, 6, or 8 do not result in bounding dose rates.

To provide additional assurance that TS dose rate limits will be met, a relationship between decay heat, burnup, enrichment, cooling time, and source terms is developed for 2.4 kW and 1.6 kW fuel and provided as fuel qualification tables (FQTs). The methodology to develop these FQTs is the same as used to develop the design basis source terms.

The purpose of the FQTs is solely to provide an additional dose rate constraint. Decay heat for each fuel assembly to be loaded is determined using NRC Regulatory Guide 3.54, ORIGEN-ARP, or other acceptable method.

The FQT developed based on 2.4 kW is a global constraint and is applied to every PWR fuel assembly to be loaded. This FQT is provided as TS Table 7B. The 1.6 kW FQT is applicable only to fuel located in zone 3 of HLZC 4 and HLZC 7 and is provided as TS Table 7C. TS Table 7C does not apply to HLZC 1, 2, 3, 5, 6, 8, or 9, or to the inner basket locations of HLZC 4 or 7.

A range of burnup, enrichment, and cooling time combinations are considered for the inner regions of HLZC 4 and 5, as documented in Table 6-8. The design basis source terms in the inner regions of HLZC 4 and 5 are optimized to maximize dose rates. However, dose rates, both transfer cask and storage, are dominated by thermally hot fuel in the peripheral region because inner locations are heavily self-shielded by peripheral fuel assemblies. For HLZC 4, the peripheral region (zone 3) contributes approximately 80% of the dose rate on the side of the EOS-TC125/135. For the EOS-HSM, the peripheral region (zone 3) contributes approximately 95% of the vent dose rate. Because the inner basket locations do not contribute appreciably to the total dose rate, an FQT constraint on the inner basket locations is not imposed.

The burnup in the FQTs is expressed in units of GWd/FA rather than GWd/MTU. The burnup in GWd/FA is the burnup in GWd/MTU multiplied by the MTU of the fuel assembly. The minimum cooling times are obtained from these tables using linear interpolation.

As documented in Section 6.2.8, a small percentage (<0.5%) of fuel assemblies are low-enrichment outlier fuel (LEOF). LEOF is rare, occurring at a rate of approximately 1 per 200 fuel assemblies. To determine if a fuel assembly is LEOF, the enrichment is compared to the minimum value specified in TS Table 7A. LEOF would not affect storage dose rates, which are gamma dominated, but could have a small effect (generally < 5%) on transfer cask dose rates. Based on these considerations, up to 4 LEOFs are allowed in the peripheral region. A minimum of three non-LEOFs shall circumferentially separate LEOFs within the peripheral region. There are no limitations on the number and location of LEOF stored in the inner region.

Because LEOF, by definition, is below the minimum enrichments provided in the FQTs, minimum cooling times for LEOF are obtained by extrapolating the FQT cooling times using an appropriate method. Because minimum cooling times increase with lower enrichments, this extrapolation provides an additional cooling time penalty.

The overall method for application of these FQTs and qualification of LEOF is provided below.

1. *Determine the decay heat of all fuel to be loaded in an EOS-37PTH DSC using NRC Regulatory Guide 3.54, ORIGEN-ARP, or another acceptable method. Confirm the decay heat limit is met for each basket location.*

2. *Determine if LEOF is present in the fuel to be loaded by application of TS Table 7A.*

   a) *Up to 4 LEOF are allowed in the peripheral region. A minimum of three non-LEOFs shall circumferentially separate LEOFs within the peripheral region.*

   b) *There are no limitations on the number and location of LEOF stored in the inner region.*

3. *Verify all fuel to be loaded meets the minimum cooling time of TS Table 7B. Fuel that does not meet the cooling time limitations of this table cannot be loaded.*

4. *For fuel in zone 3 of HLZC 4 or HLZC 7, verify all fuel to be loaded meets the minimum cooling time of TS Table 7C. This table does not apply to HLZC 1, 2, 3, 5, 6, 8, or 9, or to the inner basket locations of HLZC 4 or HLZC 7.*

These FQTs provide an additional constraint to ensure compliance with the dose rate limitations in TS 5.1.2(c).

Examples

Examples to illustrate application of TS Table 7A, TS Table 7B, and TS Table 7C are provided below.

Example 1 (no LEOF)

This example demonstrates how to determine if a fuel assembly is LEOF and how to determine compliance with TS Table 7B.

A fuel assembly has a burnup (BU) of 50 GWd/MTU, 0.45 MTU, enrichment (E) of 3.5%, and a cooling time (CT) of 4 years. Assume the decay heat has been computed and shown to be acceptable for the basket location of interest.

- *The minimum enrichment for 50 GWd/MTU, per TS Table 7A, is 50/16 = 3.125%, which is rounded down to 3.1%. As E = 3.5% > 3.1%, this fuel assembly is within the minimum enrichment bounds of TS Table 7A and is not LEOF.*
- *Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA*
- *Linearly interpolate on enrichment (first) and burnup (second) to determine the minimum cooling time*
- *Linearly interpolating for E = 3.5% in the 22.14 GWd/FA row of TS Table 7B, CT = 2.95 years*
- *Linearly interpolating for E = 3.5% in the 24.6 GWd/FA row of TS Table 7B, CT = 3.29 years*
- *Linearly interpolating for BU = 22.5 GWd/FA between CT = 2.95 years and CT = 3.29 years, the minimum cooling time is CT = 3.00 years.*

Because 4 years > 3.00 years, the fuel assembly meets the TS Table 7B requirements.

Example 2 (with LEOF)

This example demonstrates how to determine if a fuel assembly is LEOF and how to determine compliance with TS Table 7B.

A fuel assembly has a burnup of 50 GWd/MTU, 0.45 MTU, enrichment of 2.9%, and a cooling time of 4 years. Assume the decay heat has been computed and shown to be acceptable for the basket location of interest.

- *The minimum enrichment for 50 GWd/MTU, per TS Table 7A, is 50/16 = 3.125%, which is rounded down to 3.1%. As E = 2.9% < 3.1%, this fuel assembly is LEOF. It is assumed to be the only LEOF to be loaded in this DSC.*
- *Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA*
- *Linearly interpolate or extrapolate on enrichment (first) and burnup (second) to determine the minimum cooling time. Because the fuel is LEOF, extrapolation on the enrichment value beyond TS Table 7B is acceptable. Extrapolating to a lower enrichment value increases the minimum cooling time, which is a conservative penalty.*
- *Linearly interpolating for E = 2.9% in the 22.14 GWd/FA row of TS Table 7B, CT = 3.05 years*

- *Linearly extrapolating for E = 2.9% in the 24.6 GWd/FA row of TS Table 7B for the two nearest enrichments, CT = 3.41 years. Other extrapolation methods could be employed, although the data in this row is following a linear trend.*
- *Linearly interpolating for BU = 22.5 GWd/FA between CT = 3.05 years and CT = 3.41 years, the minimum cooling time is CT = 3.10 years.*

Because 4 years > 3.10 years, the fuel assembly meets the TS Table 7B requirements. Because it is the only LEOF assembly in the DSC, it may be stored in the basket location of interest.

Example 3 (HLZC 1)

This example demonstrates how to determine if TS Table 7C is applicable.

A 2.0 kW fuel assembly will be loaded in HLZC 1 in zone 2 (inner basket location). Assume the decay heat has been computed and shown to be acceptable for this basket location.

TS Table 7C only applies to zone 3 of HLZC 4 and HLZC 7. Because fuel will be loaded in HLZC 1, TS Table 7C does not apply.

Example 4 (HLZC 4 inner)

This example demonstrates how to determine if TS Table 7C is applicable.

A 1.625 kW fuel assembly will be loaded in HLZC 4 in zone 2 (inner basket location). Assume the decay heat has been computed and shown to be acceptable for this basket location.

TS Table 7C only applies to zone 3 of HLZC 4 and HLZC 7. Because fuel will be loaded in zone 2 of HLZC 4, TS Table 7C does not apply.

Example 5 (HLZC 4 peripheral)

This example demonstrates how to determine compliance with TS Table 7C.

The fuel assembly in Example 1 has a burnup of 50 GWd/MTU, 0.45 MTU, enrichment of 3.5%, and a cooling time of 4 years. It is to be loaded in HLZC 4 zone 3 (peripheral region). Assume the decay heat has been computed and shown to be acceptable for the basket location of interest.

It is known this fuel assembly is not LEOF and meets the TS Table 7B per Example 1. However, TS Table 7C applies because fuel is loaded in the peripheral region of HLZC 4.

- *Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA*
- *Linearly interpolate on enrichment (first) and burnup (second) to determine the minimum cooling time*

- *Linearly interpolating for E = 3.5% for the 22.14 GWd/FA row of TS Table 7C, CT = 4.19 years*
- *Linearly interpolating for E = 3.5% for the 24.6 GWd/FA row of TS Table 7C, CT = 4.80 years*
- *Linearly interpolating for BU = 22.5 GWd/FA between CT = 4.19 years and CT = 4.80 years, the minimum cooling time is CT = 4.28 years.*

Because 4 years < 4.28 years, the fuel assembly cannot be loaded in HLZC 4 zone 3.

6.5.2 References

6-1 Oak Ridge National Laboratory, "A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," ORNL/TM-2005/39, Version 6, SCALE, January 2009.

6-2 Oak Ridge National Laboratory, "Predictions of PWR Spent Nuclear Fuel Isotopic Compositions," ORNL/TM-2010/44, SCALE 5.1, March 2010.

6-3 Oak Ridge National Laboratory, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Code," ORNL/TM-11018, December 1989.

6-4 Pacific Northwest Laboratory, "Spent Fuel Assembly Hardware: Characterization and 10 CFR 61 Classification for Waste Disposal, Volume 1 – Activation Measurements and Comparison with Calculations for Spent Fuel Assembly Hardware," PNL-6906, Vol. 1, June 1989.

6-5 Oak Ridge National Laboratory, "MCNP/MCNPX – Monte Carlo N-Particle Transport Code System Including MCNP5 1.40 and MCNPX 2.5.0 and Data Libraries," CCC-730, RSICC Computer Code Collection, January 2006.

6-6 NUREG/CR-6801, "Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses," March 2003.

6-7 NUREG-1536, Rev. 1, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," July 2010.

6-8 Design Data Document DI-81001-02, NOK Document, "Technical Specification for the Supply of Transportable Casks for the Storage of Kernkraftwerk Leibstardt (KKL) Spent Fuel in ZWILAG," TS 07/01, Rev. 1.

6-9 Pacific Northwest National Laboratory, "Compendium of Material Composition Data for Radiation Transport Modeling," PNNL-15870, Rev. 1, March 2011.

6-10 ANSI/ANS-6.1.1-1977, "American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors," American National Standards Institute, Inc., New York, New York.

6-11 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *1*.

6-12 NUREG/CR-6999, "Technical Basis for a Proposed Expansion of Regulatory Guide 3.54 - Decay Heat Generation in an Independent Spent Fuel Storage Installation," February 2010.

6-13 U.S. Energy Information Administration (EIA), Spent Nuclear Fuel GC-859 Database, Accessed January 20, 2019. URL: https:/www.eia.gov/nuclear/spent_fuel/

6-14 Unused.

6-15 Interagency Agreement DE-SA09-01 SR18976/TVA No. P-01 N8A-249655-001 between the Department of Energy (DOE) and the Tennessee Valley Authority (TVA) for the Off-Specification Fuel Project, April 5, 2001.

Table 6-1
PWR (BW 15x15) Hardware Characteristics

Fuel Assembly Region and Length	Fuel Assembly Part	Material	Mass (kg)
Top Nozzle, 6.23 in.	Top nozzle/misc. steel	SS304	9.180
	Hold down spring	Inconel-718	1.800
Plenum, 8.73 in.	Upper spring	Inconel-718	4.344
	Upper end cap	Zircaloy-4	1.039
	Encompassing cladding	Zircaloy-4	5.763
	Upper end grid	Inconel-718	1.067
	Encompassing guide tube	Zircaloy-4	0.004
Active Fuel, 142.29 in.	Encompassing cladding	Zircaloy-4	101.1
	Encompassing guide tube	Zircaloy-4	6.328
	Six spacer grids	Inconel-718	4.985
	Grid Supports	Zircaloy-4	0.640
Bottom Nozzle, 8.38 in.	Lower end plug	Zircaloy-4	8.877
	Encompassing guide tube	Zircaloy-4	0.140
	Lower guide tube plugs	Zircaloy-4	1.439
	Lower end fitting	SS304	8.172
	Lower end grid	Inconel-718	1.067

Table 6-2
BWR (GE 7x7) Hardware Characteristics

Fuel Assembly Region and Length	Fuel Assembly Part	Material	Mass (kg)
Top Nozzle, 12.62 in.	Upper tie plate	SS304	2.08
	Lock tab washers and nuts	SS304	0.05
	Expansion springs	Inconel X-750	0.43
	End plugs	Zircaloy-2	1.26
Plenum, 12.93 in.	Cladding	Zircaloy-2	4.89
	Springs	SS304	1.05
Active Fuel, 144 in.	Cladding	Zircaloy-2	49.2
	Spacers	Zircaloy-2	1.95
	Spacer springs	Inconel X-750	0.36
	Channel sleeve	Zircaloy-2	37.1
	Channel spacer and rivet	SS304	0.13
	Channel fastener guard	SS304	0.46
	Channel fastener spring and bolt	Inconel X-750	0.13
Bottom Nozzle, 6.65 in.	Finger springs	Inconel X-750	0.05
	End plugs	Zircaloy-2	1.26
	Lower tie plate	SS304	4.70

Table 6-3
Fuel Assembly Material Compositions
2 Pages

Element	Zircaloy-4 (ppm)	Inconel-718 (ppm)	Inconel X-750 (ppm)	SS304 (ppm)	UO_2 (g/MTU)
Hydrogen	13	0	0	0	0
Lithium	0	0	0	0	1
Boron	0.33	0	0	0	1
Carbon	120	400	399	800	89.4
Nitrogen	80	1300	1300	1300	25
Oxygen	950	0	0	0	134454
Fluorine	0	0	0	0	10.7
Sodium	0	0	0	0	15
Magnesium	0	0	0	0	2
Aluminum	24	5992	7982	0	16.7
Silicon	0	1997	2993	10000	12.1
Phosphorous	0	0	0	450	35
Sulfur	35	70	70	300	0
Chlorine	0	0	0	0	5.3
Calcium	0	0	0	0	2
Titanium	20	7990	24943	0	1
Vanadium	20	0	0	0	3
Chromium	1250	189753	149660	190000	4
Manganese	20	1997	6984	20000	1.7
Iron	2250	179766	67846	688440	18
Cobalt	10	500	500	500	1
Nickel	20	519625	721861	89200	24
Copper	20	999	499	0	1
Zinc	0	0	0	0	40.3
Zirconium	979110	0	0	0	0
Niobium	0	55458	8980	0	0
Molybdenum	0	29961	0	0	10
Silver	0	0	0	0	0.1
Cadmium	0.25	0	0	0	25
Indium	0	0	0	0	2
Tin	16000	0	0	0	4
Gadolinium	0	0	0	0	2.5

Table 6-3
Fuel Assembly Material Compositions
2 Pages

Element	Zircaloy-4 (ppm)	Inconel-718 (ppm)	Inconel X-750 (ppm)	SS304 (ppm)	UO_2 (g/MTU)
Hafnium	78	0	0	0	0
Tungsten	20	0	0	0	2
Lead	0	0	0	0	1
Bismuth	0	0	0	0	0.4
Uranium	0.2	0	0	0	1000000

Table 6-4
Flux Scaling Factors

Region	PWR	BWR
Top Nozzle	0.1	0.1
Plenum	0.2	0.2
Active Fuel	1.0	1.0
Bottom Nozzle	0.2	0.15

Table 6-5
PWR Light Elements by Fuel Assembly Region (ORIGEN-ARP Input, grams)
2 Pages

Element	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle	Total
H	2.718E-02	1.405E+00	1.769E-02	0.000E+00	1.450E+00
Li	0.000E+00	4.919E-01	0.000E+00	0.000E+00	4.919E-01
B	6.901E-04	5.275E-01	4.492E-04	0.000E+00	5.287E-01
C	1.642E+00	5.894E+01	5.962E-01	8.055E-01	6.198E+01
N	2.567E+00	2.742E+01	1.516E+00	1.426E+00	3.293E+01
O	1.987E+00	6.623E+04	1.293E+00	0.000E+00	6.624E+04
F	0.000E+00	5.263E+00	0.000E+00	0.000E+00	5.263E+00
Na	0.000E+00	7.378E+00	0.000E+00	0.000E+00	7.378E+00
Mg	0.000E+00	9.837E-01	0.000E+00	0.000E+00	9.837E-01
Al	1.329E+00	4.068E+01	6.517E+00	1.079E+00	4.960E+01
Si	1.675E+01	1.591E+01	2.161E+00	9.528E+00	4.434E+01
P	7.345E-01	1.721E+01	0.000E+00	4.126E-01	1.836E+01
S	5.778E-01	4.132E+00	1.234E-01	2.876E-01	5.121E+00
Cl	0.000E+00	2.607E+00	0.000E+00	0.000E+00	2.607E+00
Ca	0.000E+00	9.837E-01	0.000E+00	0.000E+00	9.837E-01
Ti	1.747E+00	4.248E+01	8.674E+00	1.438E+00	5.434E+01
V	4.182E-02	3.637E+00	2.722E-02	0.000E+00	3.706E+00
Cr	3.532E+02	1.083E+03	2.071E+02	2.084E+02	1.852E+03
Mn	3.311E+01	1.295E+01	2.188E+00	1.870E+01	6.695E+01
Fe	1.167E+03	1.148E+03	1.976E+02	6.635E+02	3.176E+03
Co	9.448E-01	4.065E+00	5.547E-01	5.490E-01	6.114E+00
Ni	2.565E+02	2.604E+03	5.624E+02	1.753E+02	3.598E+03
Cu	2.550E-01	7.633E+00	1.108E+00	1.798E-01	9.177E+00
Zn	0.000E+00	1.982E+01	0.000E+00	0.000E+00	1.982E+01
Zr	2.047E+03	1.058E+05	1.333E+03	0.000E+00	1.092E+05
Nb	1.183E+01	2.765E+02	6.002E+01	9.982E+00	3.583E+02
Mo	6.394E+00	1.543E+02	3.242E+01	5.393E+00	1.985E+02
Ag	0.000E+00	4.919E-02	0.000E+00	0.000E+00	4.919E-02
Cd	5.228E-04	1.232E+01	3.403E-04	0.000E+00	1.232E+01
In	0.000E+00	9.837E-01	0.000E+00	0.000E+00	9.837E-01
Sn	3.346E+01	1.731E+03	2.178E+01	0.000E+00	1.787E+03
Gd	0.000E+00	1.230E+00	0.000E+00	0.000E+00	1.230E+00

Table 6-5
PWR Light Elements by Fuel Assembly Region (ORIGEN-ARP Input, grams)
2 Pages

Element	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle	Total
Hf	1.631E-01	8.430E+00	1.062E-01	0.000E+00	8.700E+00
W	4.182E-02	3.145E+00	2.722E-02	0.000E+00	3.214E+00
Pb	0.000E+00	4.919E-01	0.000E+00	0.000E+00	4.919E-01
Bi	0.000E+00	1.967E-01	0.000E+00	0.000E+00	1.967E-01

Table 6-6
BWR Light Elements by Fuel Assembly Region (ORIGEN-ARP Input, grams)
2 Pages

Element	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle	Total
H	2.457E-03	1.147E+00	1.271E-02	1.638E-03	1.164E+00
Li	0.000E+00	1.980E-01	0.000E+00	0.000E+00	1.980E-01
B	6.237E-05	2.271E-01	3.227E-04	4.158E-05	2.275E-01
C	5.889E-01	2.896E+01	2.851E-01	2.025E-01	3.003E+01
N	9.402E-01	1.341E+01	3.509E-01	3.425E-01	1.505E+01
O	1.795E-01	2.671E+04	9.291E-01	1.197E-01	2.671E+04
F	0.000E+00	2.119E+00	0.000E+00	0.000E+00	2.119E+00
Na	0.000E+00	2.970E+00	0.000E+00	0.000E+00	2.970E+00
Mg	0.000E+00	3.960E-01	0.000E+00	0.000E+00	3.960E-01
Al	6.440E-02	9.336E+00	2.347E-02	3.462E-01	9.770E+00
Si	7.063E+00	9.755E+00	2.097E+00	2.256E+00	2.117E+01
P	3.168E-01	7.195E+00	9.438E-02	9.573E-02	7.702E+00
S	2.184E-01	3.300E+00	9.715E-02	7.124E-02	3.686E+00
Cl	0.000E+00	1.049E+00	0.000E+00	0.000E+00	1.049E+00
Ca	0.000E+00	3.960E-01	0.000E+00	0.000E+00	3.960E-01
Ti	1.909E-01	1.418E+01	1.956E-02	1.075E+00	1.547E+01
V	3.780E-03	2.359E+00	1.956E-02	2.520E-03	2.385E+00
Cr	1.351E+02	2.964E+02	4.107E+01	4.701E+01	5.196E+02
Mn	1.414E+01	1.731E+01	4.214E+00	4.557E+00	4.022E+01
Fe	4.859E+02	6.441E+02	1.466E+02	1.500E+02	1.427E+03
Co	3.577E-01	1.620E+00	1.146E-01	1.291E-01	2.222E+00
Ni	6.822E+01	4.128E+02	1.873E+01	5.002E+01	5.498E+02
Cu	7.522E-03	2.207E+00	1.956E-02	2.398E-02	2.258E+00
Zn	0.000E+00	7.979E+00	0.000E+00	0.000E+00	7.979E+00
Zr	1.850E+02	8.640E+04	9.575E+02	1.234E+02	8.767E+04
Nb	6.735E-02	4.400E+00	0.000E+00	3.861E-01	4.854E+00
Mo	0.000E+00	1.980E+00	0.000E+00	0.000E+00	1.980E+00
Ag	0.000E+00	1.980E-02	0.000E+00	0.000E+00	1.980E-02
Cd	4.725E-05	4.972E+00	2.445E-04	3.150E-05	4.972E+00
In	0.000E+00	3.960E-01	0.000E+00	0.000E+00	3.960E-01
Sn	3.024E+00	1.413E+03	1.565E+01	2.016E+00	1.433E+03
Gd	0.000E+00	4.950E-01	0.000E+00	0.000E+00	4.950E-01

Table 6-6
BWR Light Elements by Fuel Assembly Region (ORIGEN-ARP Input, grams)
2 Pages

Element	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle	Total
Hf	1.474E-02	6.883E+00	7.628E-02	9.828E-03	6.984E+00
W	3.780E-03	2.161E+00	1.956E-02	2.520E-03	2.187E+00
Pb	0.000E+00	1.980E-01	0.000E+00	0.000E+00	1.980E-01
Bi	0.000E+00	7.920E-02	0.000E+00	0.000E+00	7.920E-02

Proprietary Information on Pages 6-58 through 6-61
Withheld Pursuant to 10 CFR 2.390

Table 6-10
PWR Source Term for the EOS-TC108, *HLZC 2* Zone 1 (Normal and Accident)

Burnup (GWd/MTU)			33.086	62	33.086	33.086
Enrichment (wt. % U-235)			2.0	3.8	2.0	2.0
Cooling Time (years)			5.00	20.13	5.00	5.00
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.168E+11	9.547E+14	1.468E+11	4.999E+10
5.00E-02	to	1.00E-01	1.735E+10	2.705E+14	1.125E+10	9.697E+09
1.00E-01	to	2.00E-01	1.626E+10	1.798E+14	1.055E+10	2.375E+09
2.00E-01	to	3.00E-01	1.067E+09	5.387E+13	6.968E+08	1.170E+08
3.00E-01	to	4.00E-01	3.136E+09	3.493E+13	2.042E+09	1.519E+08
4.00E-01	to	6.00E-01	6.461E+10	3.725E+13	4.206E+10	1.072E+07
6.00E-01	to	8.00E-01	3.483E+10	1.829E+15	2.764E+10	9.512E+08
8.00E-01	to	1.00E+00	1.144E+11	2.667E+13	2.477E+10	6.536E+10
1.00E+00	to	1.33E+00	4.803E+12	3.972E+13	3.109E+12	2.810E+12
1.33E+00	to	1.66E+00	1.356E+12	4.235E+12	8.780E+11	7.935E+11
1.66E+00	to	2.00E+00	7.184E+02	9.029E+10	1.354E+03	3.931E+02
2.00E+00	to	2.50E+00	3.245E+07	4.694E+09	2.101E+07	1.899E+07
2.50E+00	to	3.00E+00	2.773E+04	9.233E+08	1.795E+04	1.622E+04
3.00E+00	to	4.00E+00	8.044E-06	8.009E+07	3.995E-05	6.624E-06
4.00E+00	to	5.00E+00	2.247E-28	2.690E+07	1.463E-28	0.000E+00
5.00E+00	to	6.50E+00	6.475E-29	1.080E+07	4.215E-29	0.000E+00
6.50E+00	to	8.00E+00	8.236E-30	2.118E+06	5.361E-30	0.000E+00
8.00E+00	to	1.00E+01	1.099E-30	4.496E+05	7.154E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.627E+12	3.431E+15	4.253E+12	3.732E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						7.848E+08
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						1.589E+09
Treated with peaking factor 1.215 and k_{eff}=0.65 (wet)						2.724E+09

Table 6-11
PWR Source Term for the EOS-TC108, *HLZC 2* Zone 2 (Normal and Accident)

Burnup (GWd/MTU)			40	62	40	40
Enrichment (wt. % U-235)			2.5	3.8	2.5	2.5
Cooling Time (years)			4.148	7.817	4.148	4.148
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.994E+11	1.461E+15	2.025E+11	5.956E+10
5.00E-02	to	1.00E-01	2.082E+10	3.943E+14	1.368E+10	1.156E+10
1.00E-01	to	2.00E-01	2.165E+10	3.065E+14	1.410E+10	2.835E+09
2.00E-01	to	3.00E-01	1.434E+09	8.619E+13	9.387E+08	1.394E+08
3.00E-01	to	4.00E-01	4.321E+09	5.399E+13	2.816E+09	1.810E+08
4.00E-01	to	6.00E-01	8.906E+10	5.984E+14	5.798E+10	1.317E+07
6.00E-01	to	8.00E-01	4.774E+10	3.023E+15	3.674E+10	1.084E+09
8.00E-01	to	1.00E+00	2.401E+11	3.007E+14	4.680E+10	1.369E+11
1.00E+00	to	1.33E+00	5.720E+12	1.305E+14	3.757E+12	3.350E+12
1.33E+00	to	1.66E+00	1.615E+12	2.943E+13	1.061E+12	9.460E+11
1.66E+00	to	2.00E+00	1.273E+04	3.558E+11	2.738E+04	8.465E+03
2.00E+00	to	2.50E+00	3.865E+07	3.138E+11	2.538E+07	2.264E+07
2.50E+00	to	3.00E+00	3.302E+04	1.992E+10	2.169E+04	1.934E+04
3.00E+00	to	4.00E+00	1.009E-05	1.910E+09	5.011E-05	8.309E-06
4.00E+00	to	5.00E+00	5.952E-28	4.275E+07	3.874E-28	0.000E+00
5.00E+00	to	6.50E+00	1.715E-28	1.716E+07	1.116E-28	0.000E+00
6.50E+00	to	8.00E+00	2.181E-29	3.366E+06	1.420E-29	0.000E+00
8.00E+00	to	1.00E+01	2.911E-30	7.146E+05	1.895E-30	0.000E+00
Total Gamma, g/(sec*FA)			8.060E+12	6.385E+15	5.193E+12	4.508E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.247E+09
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						2.525E+09
Treated with peaking factor 1.215 and k_{eff}=0.65 (wet)						4.329E+09

Table 6-12
PWR Source Term for the EOS-TC108, *HLZC 2* Zone 3 (Normal)

Burnup (GWd/MTU)			33.086	61.536	33.086	33.086
Enrichment (wt. % U-235)			2.0	3.8	2.0	2.0
Cooling Time (years)			5.00	10.00	5.00	5.00
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.168E+11	1.289E+15	1.468E+11	4.999E+10
5.00E-02	to	1.00E-01	1.735E+10	3.490E+14	1.125E+10	9.697E+09
1.00E-01	to	2.00E-01	1.626E+10	2.627E+14	1.055E+10	2.375E+09
2.00E-01	to	3.00E-01	1.067E+09	7.484E+13	6.968E+08	1.170E+08
3.00E-01	to	4.00E-01	3.136E+09	4.663E+13	2.042E+09	1.519E+08
4.00E-01	to	6.00E-01	6.461E+10	3.000E+14	4.206E+10	1.072E+07
6.00E-01	to	8.00E-01	3.483E+10	2.574E+15	2.764E+10	9.512E+08
8.00E-01	to	1.00E+00	1.144E+11	1.629E+14	2.477E+10	6.536E+10
1.00E+00	to	1.33E+00	4.803E+12	1.001E+14	3.109E+12	2.810E+12
1.33E+00	to	1.66E+00	1.356E+12	1.794E+13	8.780E+11	7.935E+11
1.66E+00	to	2.00E+00	7.184E+02	1.685E+11	1.354E+03	3.931E+02
2.00E+00	to	2.50E+00	3.245E+07	6.186E+10	2.101E+07	1.899E+07
2.50E+00	to	3.00E+00	2.773E+04	5.154E+09	1.795E+04	1.622E+04
3.00E+00	to	4.00E+00	8.044E-06	5.137E+08	3.995E-05	6.624E-06
4.00E+00	to	5.00E+00	2.247E-28	3.836E+07	1.463E-28	0.000E+00
5.00E+00	to	6.50E+00	6.475E-29	1.540E+07	4.215E-29	0.000E+00
6.50E+00	to	8.00E+00	8.236E-30	3.020E+06	5.361E-30	0.000E+00
8.00E+00	to	1.00E+01	1.099E-30	6.412E+05	7.154E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.627E+12	5.177E+15	4.253E+12	3.732E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.117E+09
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						2.262E+09
Treated with peaking factor 1.215 and k_{eff}=0.65 (wet)						3.878E+09

Table 6-13
PWR Source Term for the EOS-TC108, *HLZC 2* Zone 3 (Accident)

Burnup (GWd/MTU)			33.086	62	33.086	33.086
Enrichment (wt. % U-235)			2.0	3.8	2.0	2.0
Cooling Time (years)			5.00	10.25	5.00	5.00
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.168E+11	1.283E+15	1.468E+11	4.999E+10
5.00E-02	to	1.00E-01	1.735E+10	3.475E+14	1.125E+10	9.697E+09
1.00E-01	to	2.00E-01	1.626E+10	2.608E+14	1.055E+10	2.375E+09
2.00E-01	to	3.00E-01	1.067E+09	7.440E+13	6.968E+08	1.170E+08
3.00E-01	to	4.00E-01	3.136E+09	4.635E+13	2.042E+09	1.519E+08
4.00E-01	to	6.00E-01	6.461E+10	2.813E+14	4.206E+10	1.072E+07
6.00E-01	to	8.00E-01	3.483E+10	2.557E+15	2.764E+10	9.512E+08
8.00E-01	to	1.00E+00	1.144E+11	1.542E+14	2.477E+10	6.536E+10
1.00E+00	to	1.33E+00	4.803E+12	9.823E+13	3.109E+12	2.810E+12
1.33E+00	to	1.66E+00	1.356E+12	1.721E+13	8.780E+11	7.935E+11
1.66E+00	to	2.00E+00	7.184E+02	1.605E+11	1.354E+03	3.931E+02
2.00E+00	to	2.50E+00	3.245E+07	5.228E+10	2.101E+07	1.899E+07
2.50E+00	to	3.00E+00	2.773E+04	4.525E+09	1.795E+04	1.622E+04
3.00E+00	to	4.00E+00	8.044E-06	4.548E+08	3.995E-05	6.624E-06
4.00E+00	to	5.00E+00	2.247E-28	3.895E+07	1.463E-28	0.000E+00
5.00E+00	to	6.50E+00	6.475E-29	1.563E+07	4.215E-29	0.000E+00
6.50E+00	to	8.00E+00	8.236E-30	3.067E+06	5.361E-30	0.000E+00
8.00E+00	to	1.00E+01	1.099E-30	6.511E+05	7.154E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.627E+12	5.120E+15	4.253E+12	3.732E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.135E+09
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						2.298E+09
Treated with peaking factor 1.215 and k_{eff}=0.65 (wet)						3.940E+09

Table 6-14
PWR Source Term for the EOS-TC125/135, *HLZC 4/6/8* Zone 1, *1.0 kW/FA*
(*Normal* and Accident)

Burnup (GWd/MTU)			33.086	62	33.086	33.086
Enrichment (wt. % U-235)			2.0	3.8	2.0	2.0
Cooling Time (years)			5.00	20.13	5.00	5.00
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.168E+11	9.547E+14	1.468E+11	4.999E+10
5.00E-02	to	1.00E-01	1.735E+10	2.705E+14	1.125E+10	9.697E+09
1.00E-01	to	2.00E-01	1.626E+10	1.798E+14	1.055E+10	2.375E+09
2.00E-01	to	3.00E-01	1.067E+09	5.387E+13	6.968E+08	1.170E+08
3.00E-01	to	4.00E-01	3.136E+09	3.493E+13	2.042E+09	1.519E+08
4.00E-01	to	6.00E-01	6.461E+10	3.725E+13	4.206E+10	1.072E+07
6.00E-01	to	8.00E-01	3.483E+10	1.829E+15	2.764E+10	9.512E+08
8.00E-01	to	1.00E+00	1.144E+11	2.667E+13	2.477E+10	6.536E+10
1.00E+00	to	1.33E+00	4.803E+12	3.972E+13	3.109E+12	2.810E+12
1.33E+00	to	1.66E+00	1.356E+12	4.235E+12	8.780E+11	7.935E+11
1.66E+00	to	2.00E+00	7.184E+02	9.029E+10	1.354E+03	3.931E+02
2.00E+00	to	2.50E+00	3.245E+07	4.694E+09	2.101E+07	1.899E+07
2.50E+00	to	3.00E+00	2.773E+04	9.233E+08	1.795E+04	1.622E+04
3.00E+00	to	4.00E+00	8.044E-06	8.009E+07	3.995E-05	6.624E-06
4.00E+00	to	5.00E+00	2.247E-28	2.690E+07	1.463E-28	0.000E+00
5.00E+00	to	6.50E+00	6.475E-29	1.080E+07	4.215E-29	0.000E+00
6.50E+00	to	8.00E+00	8.236E-30	2.118E+06	5.361E-30	0.000E+00
8.00E+00	to	1.00E+01	1.099E-30	4.496E+05	7.154E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.627E+12	3.431E+15	4.253E+12	3.732E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						7.848E+08
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						1.589E+09
Treated with peaking factor 1.215 and k_{eff}=0.65 (wet)						2.724E+09

Table 6-15
PWR Source Term for the EOS-TC125/135, *HLZC 4* Zone 2*, 1.625 kW/FA*
(Normal and Accident)

Burnup (GWd/MTU)			*40*	*62*	*40*	*40*
Enrichment (wt. % U-235)			*2.5*	*3.8*	*2.5*	*2.5*
Cooling Time (years)			*3.860*	*6.831*	*3.860*	*3.860*
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*3.276E+11*	*1.591E+15*	*2.209E+11*	*6.182E+10*
5.00E-02	*to*	*1.00E-01*	*2.168E+10*	*4.321E+14*	*1.423E+10*	*1.201E+10*
1.00E-01	*to*	*2.00E-01*	*2.312E+10*	*3.419E+14*	*1.506E+10*	*2.946E+09*
2.00E-01	*to*	*3.00E-01*	*1.536E+09*	*9.574E+13*	*1.005E+09*	*1.448E+08*
3.00E-01	*to*	*4.00E-01*	*4.685E+09*	*6.081E+13*	*3.053E+09*	*1.880E+08*
4.00E-01	*to*	*6.00E-01*	*9.580E+10*	*8.281E+14*	*6.237E+10*	*1.462E+07*
6.00E-01	*to*	*8.00E-01*	*5.127E+10*	*3.315E+15*	*3.903E+10*	*1.085E+09*
8.00E-01	*to*	*1.00E+00*	*3.027E+11*	*4.022E+14*	*5.742E+10*	*1.725E+11*
1.00E+00	*to*	*1.33E+00*	*5.940E+12*	*1.493E+14*	*3.901E+12*	*3.479E+12*
1.33E+00	*to*	*1.66E+00*	*1.678E+12*	*3.769E+13*	*1.102E+12*	*9.825E+11*
1.66E+00	*to*	*2.00E+00*	*3.531E+04*	*5.852E+11*	*7.627E+04*	*2.362E+04*
2.00E+00	*to*	*2.50E+00*	*4.014E+07*	*6.806E+11*	*2.636E+07*	*2.351E+07*
2.50E+00	*to*	*3.00E+00*	*3.430E+04*	*3.824E+10*	*2.252E+04*	*2.009E+04*
3.00E+00	*to*	*4.00E+00*	*1.015E-05*	*3.622E+09*	*5.042E-05*	*8.360E-06*
4.00E+00	*to*	*5.00E+00*	*5.952E-28*	*4.441E+07*	*3.874E-28*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*1.715E-28*	*1.782E+07*	*1.116E-28*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*2.181E-29*	*3.496E+06*	*1.420E-29*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*2.911E-30*	*7.424E+05*	*1.895E-30*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*8.446E+12*	*7.256E+15*	*5.416E+12*	*4.712E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*1.295E+09*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*2.622E+09*
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						*4.496E+09*

Table 6-16
PWR Source Term for the EOS-TC125/135, *HLZC 4* Zone 3, *1.625 kW/FA* (Normal and Accident)

Burnup (GWd/MTU)			*40*	*62*	*40*	*40*
Enrichment (wt. % U-235)			*2.5*	*3.8*	*2.5*	*2.5*
Cooling Time (years)			*3.860*	*6.831*	*3.860*	*3.860*
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*3.276E+11*	*1.591E+15*	*2.209E+11*	*6.182E+10*
5.00E-02	*to*	*1.00E-01*	*2.168E+10*	*4.321E+14*	*1.423E+10*	*1.201E+10*
1.00E-01	*to*	*2.00E-01*	*2.312E+10*	*3.419E+14*	*1.506E+10*	*2.946E+09*
2.00E-01	*to*	*3.00E-01*	*1.536E+09*	*9.574E+13*	*1.005E+09*	*1.448E+08*
3.00E-01	*to*	*4.00E-01*	*4.685E+09*	*6.081E+13*	*3.053E+09*	*1.880E+08*
4.00E-01	*to*	*6.00E-01*	*9.580E+10*	*8.281E+14*	*6.237E+10*	*1.462E+07*
6.00E-01	*to*	*8.00E-01*	*5.127E+10*	*3.315E+15*	*3.903E+10*	*1.085E+09*
8.00E-01	*to*	*1.00E+00*	*3.027E+11*	*4.022E+14*	*5.742E+10*	*1.725E+11*
1.00E+00	*to*	*1.33E+00*	*5.940E+12*	*1.493E+14*	*3.901E+12*	*3.479E+12*
1.33E+00	*to*	*1.66E+00*	*1.678E+12*	*3.769E+13*	*1.102E+12*	*9.825E+11*
1.66E+00	*to*	*2.00E+00*	*3.531E+04*	*5.852E+11*	*7.627E+04*	*2.362E+04*
2.00E+00	*to*	*2.50E+00*	*4.014E+07*	*6.806E+11*	*2.636E+07*	*2.351E+07*
2.50E+00	*to*	*3.00E+00*	*3.430E+04*	*3.824E+10*	*2.252E+04*	*2.009E+04*
3.00E+00	*to*	*4.00E+00*	*1.015E-05*	*3.622E+09*	*5.042E-05*	*8.360E-06*
4.00E+00	*to*	*5.00E+00*	*5.952E-28*	*4.441E+07*	*3.874E-28*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*1.715E-28*	*1.782E+07*	*1.116E-28*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*2.181E-29*	*3.496E+06*	*1.420E-29*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*2.911E-30*	*7.424E+05*	*1.895E-30*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*8.446E+12*	*7.256E+15*	*5.416E+12*	*4.712E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*1.295E+09*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*2.622E+09*
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						*4.496E+09*

Table 6-16a
PWR Source Term for the EOS-TC125/135, HLZC 6/8, Zone 2 or 3, 1.5 kW/FA (Normal and Accident)

Burnup (GWd/MTU)			40	62	40	40
Enrichment (wt. % U-235)			2.5	3.8	2.5	2.5
Cooling Time (years)			4.148	7.817	4.148	4.148
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.994E+11	1.461E+15	2.025E+11	5.956E+10
5.00E-02	to	1.00E-01	2.082E+10	3.943E+14	1.368E+10	1.156E+10
1.00E-01	to	2.00E-01	2.165E+10	3.065E+14	1.410E+10	2.835E+09
2.00E-01	to	3.00E-01	1.434E+09	8.619E+13	9.387E+08	1.394E+08
3.00E-01	to	4.00E-01	4.321E+09	5.399E+13	2.816E+09	1.810E+08
4.00E-01	to	6.00E-01	8.906E+10	5.984E+14	5.798E+10	1.317E+07
6.00E-01	to	8.00E-01	4.774E+10	3.023E+15	3.674E+10	1.084E+09
8.00E-01	to	1.00E+00	2.401E+11	3.007E+14	4.680E+10	1.369E+11
1.00E+00	to	1.33E+00	5.720E+12	1.305E+14	3.757E+12	3.350E+12
1.33E+00	to	1.66E+00	1.615E+12	2.943E+13	1.061E+12	9.460E+11
1.66E+00	to	2.00E+00	1.273E+04	3.558E+11	2.738E+04	8.465E+03
2.00E+00	to	2.50E+00	3.865E+07	3.138E+11	2.538E+07	2.264E+07
2.50E+00	to	3.00E+00	3.302E+04	1.992E+10	2.169E+04	1.934E+04
3.00E+00	to	4.00E+00	1.009E-05	1.910E+09	5.011E-05	8.309E-06
4.00E+00	to	5.00E+00	5.952E-28	4.275E+07	3.874E-28	0.000E+00
5.00E+00	to	6.50E+00	1.715E-28	1.716E+07	1.116E-28	0.000E+00
6.50E+00	to	8.00E+00	2.181E-29	3.366E+06	1.420E-29	0.000E+00
8.00E+00	to	1.00E+01	2.911E-30	7.146E+05	1.895E-30	0.000E+00
Total Gamma, g/(sec*FA)			8.060E+12	6.385E+15	5.193E+12	4.508E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.247E+09
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						2.525E+09
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						4.329E+09

Table 6-16b
PWR Source Term for the EOS-TC125/135, HLZC 6/8, Zone 3, 0.85 kW/FA (Normal)

Burnup (GWd/MTU)			28.71	8.298	28.71	28.71
Enrichment (wt. % U-235)			1.8	1.3	1.8	1.8
Cooling Time (years)			5.00	2.00	5.00	5.00
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	1.994E+11	1.916E+15	1.343E+11	4.636E+10
5.00E-02	to	1.00E-01	1.610E+10	6.245E+14	1.033E+10	9.001E+09
1.00E-01	to	2.00E-01	1.484E+10	6.301E+14	9.608E+09	2.205E+09
2.00E-01	to	3.00E-01	9.722E+08	1.570E+14	6.339E+08	1.086E+08
3.00E-01	to	4.00E-01	2.853E+09	1.237E+14	1.856E+09	1.410E+08
4.00E-01	to	6.00E-01	5.864E+10	4.554E+14	3.817E+10	9.964E+06
6.00E-01	to	8.00E-01	3.159E+10	7.470E+14	2.500E+10	8.492E+08
8.00E-01	to	1.00E+00	1.076E+11	1.011E+14	2.305E+10	6.149E+10
1.00E+00	to	1.33E+00	4.461E+12	5.810E+13	2.857E+12	2.608E+12
1.33E+00	to	1.66E+00	1.260E+12	2.090E+13	8.069E+11	7.365E+11
1.66E+00	to	2.00E+00	6.828E+02	3.440E+12	1.311E+03	3.843E+02
2.00E+00	to	2.50E+00	3.014E+07	1.414E+13	1.931E+07	1.762E+07
2.50E+00	to	3.00E+00	2.575E+04	2.225E+11	1.650E+04	1.506E+04
3.00E+00	to	4.00E+00	6.684E-06	1.983E+10	3.319E-05	5.504E-06
4.00E+00	to	5.00E+00	9.736E-29	1.138E+05	6.338E-29	0.000E+00
5.00E+00	to	6.50E+00	2.805E-29	4.558E+04	1.826E-29	0.000E+00
6.50E+00	to	8.00E+00	3.568E-30	8.929E+03	2.323E-30	0.000E+00
8.00E+00	to	1.00E+01	4.762E-31	1.894E+03	3.100E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.153E+12	4.851E+15	3.907E+12	3.465E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.371E+06
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						6.826E+06
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						1.170E+07

Table 6-16c
PWR Source Term for the EOS-TC125/135, HLZC 6/8, Zone 3, 0.85 kW/FA (Accident)

Burnup (GWd/MTU)			28.71	50	28.71	28.71
Enrichment (wt. % U-235)			1.8	3.1	1.8	1.8
Cooling Time (years)			5.00	15.485	5.00	5.00
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	1.994E+11	8.761E+14	1.343E+11	4.636E+10
5.00E-02	to	1.00E-01	1.610E+10	2.454E+14	1.033E+10	9.001E+09
1.00E-01	to	2.00E-01	1.484E+10	1.703E+14	9.608E+09	2.205E+09
2.00E-01	to	3.00E-01	9.722E+08	5.010E+13	6.339E+08	1.086E+08
3.00E-01	to	4.00E-01	2.853E+09	3.202E+13	1.856E+09	1.410E+08
4.00E-01	to	6.00E-01	5.864E+10	5.913E+13	3.817E+10	9.964E+06
6.00E-01	to	8.00E-01	3.159E+10	1.688E+15	2.500E+10	8.492E+08
8.00E-01	to	1.00E+00	1.076E+11	3.912E+13	2.305E+10	6.149E+10
1.00E+00	to	1.33E+00	4.461E+12	4.746E+13	2.857E+12	2.608E+12
1.33E+00	to	1.66E+00	1.260E+12	5.945E+12	8.069E+11	7.365E+11
1.66E+00	to	2.00E+00	6.828E+02	8.391E+10	1.311E+03	3.843E+02
2.00E+00	to	2.50E+00	3.014E+07	5.134E+09	1.931E+07	1.762E+07
2.50E+00	to	3.00E+00	2.575E+04	7.032E+08	1.650E+04	1.506E+04
3.00E+00	to	4.00E+00	6.684E-06	6.916E+07	3.319E-05	5.504E-06
4.00E+00	to	5.00E+00	9.736E-29	2.036E+07	6.338E-29	0.000E+00
5.00E+00	to	6.50E+00	2.805E-29	8.169E+06	1.826E-29	0.000E+00
6.50E+00	to	8.00E+00	3.568E-30	1.603E+06	2.323E-30	0.000E+00
8.00E+00	to	1.00E+01	4.762E-31	3.402E+05	3.100E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.153E+12	3.214E+15	3.907E+12	3.465E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						5.891E+08
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						1.193E+09
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						2.045E+09

Table 6-16d
PWR Source Term for the EOS-TC125/135, HLZC 5, Zone 1, 0.7 kW/FA (Normal)

Burnup (GWd/MTU)			24.54	50	24.54	24.54
Enrichment (wt. % U-235)			1.8	3.1	1.8	1.8
Cooling Time (years)			5.000	24.86	5.000	5.000
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	1.745E+11	6.875E+14	1.169E+11	4.051E+10
5.00E-02	to	1.00E-01	1.408E+10	2.015E+14	8.930E+09	7.869E+09
1.00E-01	to	2.00E-01	1.292E+10	1.254E+14	8.335E+09	1.928E+09
2.00E-01	to	3.00E-01	8.456E+08	3.811E+13	5.500E+08	9.491E+07
3.00E-01	to	4.00E-01	2.480E+09	2.518E+13	1.612E+09	1.232E+08
4.00E-01	to	6.00E-01	5.093E+10	2.093E+13	3.315E+10	8.717E+06
6.00E-01	to	8.00E-01	2.742E+10	1.327E+15	2.163E+10	7.238E+08
8.00E-01	to	1.00E+00	9.757E+10	1.365E+13	2.063E+10	5.572E+10
1.00E+00	to	1.33E+00	3.903E+12	2.149E+13	2.470E+12	2.280E+12
1.33E+00	to	1.66E+00	1.102E+12	2.208E+12	6.975E+11	6.438E+11
1.66E+00	to	2.00E+00	6.486E+02	6.470E+10	1.274E+03	3.779E+02
2.00E+00	to	2.50E+00	2.637E+07	3.335E+09	1.669E+07	1.540E+07
2.50E+00	to	3.00E+00	2.253E+04	5.679E+08	1.426E+04	1.316E+04
3.00E+00	to	4.00E+00	5.139E-06	4.256E+07	2.552E-05	4.232E-06
4.00E+00	to	5.00E+00	2.987E-29	1.436E+07	1.944E-29	0.000E+00
5.00E+00	to	6.50E+00	8.606E-30	5.763E+06	5.602E-30	0.000E+00
6.50E+00	to	8.00E+00	1.095E-30	1.130E+06	7.125E-31	0.000E+00
8.00E+00	to	1.00E+01	1.461E-31	2.400E+05	9.509E-32	0.000E+00
Total Gamma, g/(sec*FA)			5.386E+12	2.463E+15	3.379E+12	3.031E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.170E+08
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						8.444E+08
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						1.448E+09

Table 6-16e
PWR Source Term for the EOS-TC125/135, HLZC 5, Zone 2, 0.5 kW/FA (Normal)

Burnup (GWd/MTU)			18.285	40	18.285	18.285
Enrichment (wt. % U-235)			1.8	2.5	1.8	1.8
Cooling Time (yr)			5.000	28.934	5.000	5.000
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	1.356E+11	5.000E+14	9.010E+10	3.144E+10
5.00E-02	to	1.00E-01	1.095E+10	1.514E+14	6.829E+09	6.115E+09
1.00E-01	to	2.00E-01	9.930E+09	8.881E+13	6.380E+09	1.499E+09
2.00E-01	to	3.00E-01	6.494E+08	2.722E+13	4.210E+08	7.374E+07
3.00E-01	to	4.00E-01	1.903E+09	1.823E+13	1.235E+09	9.575E+07
4.00E-01	to	6.00E-01	3.899E+10	1.392E+13	2.538E+10	6.783E+06
6.00E-01	to	8.00E-01	2.097E+10	9.718E+14	1.646E+10	5.387E+08
8.00E-01	to	1.00E+00	8.011E+10	7.866E+12	1.662E+10	4.573E+10
1.00E+00	to	1.33E+00	3.036E+12	1.210E+13	1.889E+12	1.771E+12
1.33E+00	to	1.66E+00	8.574E+11	1.251E+12	5.334E+11	5.002E+11
1.66E+00	to	2.00E+00	5.999E+02	4.665E+10	1.217E+03	3.667E+02
2.00E+00	to	2.50E+00	2.051E+07	2.400E+09	1.276E+07	1.197E+07
2.50E+00	to	3.00E+00	1.753E+04	3.403E+08	1.090E+04	1.023E+04
3.00E+00	to	4.00E+00	3.127E-06	2.236E+07	1.553E-05	2.575E-06
4.00E+00	to	5.00E+00	3.270E-30	7.548E+06	2.129E-30	0.000E+00
5.00E+00	to	6.50E+00	9.423E-31	3.029E+06	6.134E-31	0.000E+00
6.50E+00	to	8.00E+00	1.198E-31	5.940E+05	7.801E-32	0.000E+00
8.00E+00	to	1.00E+01	1.599E-32	1.261E+05	1.041E-32	0.000E+00
Total Gamma, g/(sec*FA)			4.193E+12	1.793E+15	2.586E+12	2.357E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						2.193E+08
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						4.441E+08
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						7.613E+08

Table 6-16f
PWR Source Term for the EOS-TC125/135, HLZC 5, Zone 3, 2.4 kW/FA (Normal)

Burnup (GWd/MTU)			50	62	50	50
Enrichment (wt. % U-235)			3.1	3.8	3.1	3.1
Cooling Time (yr)			3.332	4.167	3.332	3.332
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	4.336E+11	2.648E+15	2.933E+11	7.280E+10
5.00E-02	to	1.00E-01	2.565E+10	7.729E+14	1.719E+10	1.414E+10
1.00E-01	to	2.00E-01	2.940E+10	6.602E+14	1.923E+10	3.470E+09
2.00E-01	to	3.00E-01	1.971E+09	1.835E+14	1.293E+09	1.705E+08
3.00E-01	to	4.00E-01	6.254E+09	1.284E+14	4.080E+09	2.213E+08
4.00E-01	to	6.00E-01	1.244E+11	2.120E+15	8.098E+10	2.582E+07
6.00E-01	to	8.00E-01	6.652E+10	4.743E+15	5.000E+10	1.284E+09
8.00E-01	to	1.00E+00	4.949E+11	9.255E+14	9.115E+10	2.819E+11
1.00E+00	to	1.33E+00	6.982E+12	2.403E+14	4.686E+12	4.096E+12
1.33E+00	to	1.66E+00	1.972E+12	8.202E+13	1.323E+12	1.157E+12
1.66E+00	to	2.00E+00	2.421E+05	3.082E+12	5.204E+05	1.609E+05
2.00E+00	to	2.50E+00	4.718E+07	5.914E+12	3.166E+07	2.768E+07
2.50E+00	to	3.00E+00	4.031E+04	2.323E+11	2.705E+04	2.365E+04
3.00E+00	to	4.00E+00	1.331E-05	2.159E+10	6.607E-05	1.096E-05
4.00E+00	to	5.00E+00	2.027E-27	4.932E+07	1.319E-27	0.000E+00
5.00E+00	to	6.50E+00	5.840E-28	1.980E+07	3.801E-28	0.000E+00
6.50E+00	to	8.00E+00	7.427E-29	3.884E+06	4.834E-29	0.000E+00
8.00E+00	to	1.00E+01	9.912E-30	8.246E+05	6.452E-30	0.000E+00
Total Gamma, g/(sec*FA)			1.014E+13	1.251E+16	6.567E+12	5.626E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.441E+09
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						2.918E+09
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						5.002E+09

Table 6-16g
PWR Source Term for the EOS-TC125/135, HLZC 5, Zone 4, 0.85 kW/FA (Normal)

Burnup (GWd/MTU)			*28.71*	*8.298*	*28.71*	*28.71*
Enrichment (wt. % U-235)			*1.8*	*1.3*	*1.8*	*1.8*
Cooling Time (yr)			*5.000*	*2.000*	*5.000*	*5.000*
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*1.994E+11*	*1.916E+15*	*1.343E+11*	*4.636E+10*
5.00E-02	*to*	*1.00E-01*	*1.610E+10*	*6.245E+14*	*1.033E+10*	*9.001E+09*
1.00E-01	*to*	*2.00E-01*	*1.484E+10*	*6.301E+14*	*9.608E+09*	*2.205E+09*
2.00E-01	*to*	*3.00E-01*	*9.722E+08*	*1.570E+14*	*6.339E+08*	*1.086E+08*
3.00E-01	*to*	*4.00E-01*	*2.853E+09*	*1.237E+14*	*1.856E+09*	*1.410E+08*
4.00E-01	*to*	*6.00E-01*	*5.864E+10*	*4.554E+14*	*3.817E+10*	*9.964E+06*
6.00E-01	*to*	*8.00E-01*	*3.159E+10*	*7.470E+14*	*2.500E+10*	*8.492E+08*
8.00E-01	*to*	*1.00E+00*	*1.076E+11*	*1.011E+14*	*2.305E+10*	*6.149E+10*
1.00E+00	*to*	*1.33E+00*	*4.461E+12*	*5.810E+13*	*2.857E+12*	*2.608E+12*
1.33E+00	*to*	*1.66E+00*	*1.260E+12*	*2.090E+13*	*8.069E+11*	*7.365E+11*
1.66E+00	*to*	*2.00E+00*	*6.828E+02*	*3.440E+12*	*1.311E+03*	*3.843E+02*
2.00E+00	*to*	*2.50E+00*	*3.014E+07*	*1.414E+13*	*1.931E+07*	*1.762E+07*
2.50E+00	*to*	*3.00E+00*	*2.575E+04*	*2.225E+11*	*1.650E+04*	*1.506E+04*
3.00E+00	*to*	*4.00E+00*	*6.684E-06*	*1.983E+10*	*3.319E-05*	*5.504E-06*
4.00E+00	*to*	*5.00E+00*	*9.736E-29*	*1.138E+05*	*6.338E-29*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*2.805E-29*	*4.558E+04*	*1.826E-29*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*3.568E-30*	*8.929E+03*	*2.323E-30*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*4.762E-31*	*1.894E+03*	*3.100E-31*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*6.153E+12*	*4.852E+15*	*3.907E+12*	*3.465E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*3.371E+06*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*6.826E+06*
Treated with peaking factor 1.215 and k-eff=0.65 (wet)						*1.170E+07*

Table 6-17
PWR Source Term for the EOS-HSM, *HLZC 4* Zone 1*, 1.0 kW/FA* (Normal and Accident)

Burnup (GWd/MTU)			33.086	33.086	33.086	33.086
Enrichment (wt. % U-235)			2.0	2.0	2.0	2.0
Cooling Time (years)			5.00	5.00	5.00	5.00
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.168E+11	1.271E+15	1.468E+11	4.999E+10
5.00E-02	to	1.00E-01	1.735E+10	3.698E+14	1.125E+10	9.697E+09
1.00E-01	to	2.00E-01	1.626E+10	3.082E+14	1.055E+10	2.375E+09
2.00E-01	to	3.00E-01	1.067E+09	8.618E+13	6.968E+08	1.170E+08
3.00E-01	to	4.00E-01	3.136E+09	6.061E+13	2.042E+09	1.519E+08
4.00E-01	to	6.00E-01	6.461E+10	7.503E+14	4.206E+10	1.072E+07
6.00E-01	to	8.00E-01	3.483E+10	2.131E+15	2.764E+10	9.512E+08
8.00E-01	to	1.00E+00	1.144E+11	3.162E+14	2.477E+10	6.536E+10
1.00E+00	to	1.33E+00	4.803E+12	1.083E+14	3.109E+12	2.810E+12
1.33E+00	to	1.66E+00	1.356E+12	3.206E+13	8.780E+11	7.935E+11
1.66E+00	to	2.00E+00	7.184E+02	1.371E+12	1.354E+03	3.931E+02
2.00E+00	to	2.50E+00	3.245E+07	2.541E+12	2.101E+07	1.899E+07
2.50E+00	to	3.00E+00	2.773E+04	1.030E+11	1.795E+04	1.622E+04
3.00E+00	to	4.00E+00	8.044E-06	9.562E+09	3.995E-05	6.624E-06
4.00E+00	to	5.00E+00	2.247E-28	1.253E+07	1.463E-28	0.000E+00
5.00E+00	to	6.50E+00	6.475E-29	5.029E+06	4.215E-29	0.000E+00
6.50E+00	to	8.00E+00	8.236E-30	9.866E+05	5.361E-30	0.000E+00
8.00E+00	to	1.00E+01	1.099E-30	2.095E+05	7.154E-31	0.000E+00
Total Gamma, g/(sec*FA)			6.627E+12	5.438E+15	4.253E+12	3.732E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.599E+08
Treated with peaking factor 1.215 and k_{eff}=0.4 (dry)						7.288E+08

Table 6-18
PWR Source Term for the EOS-HSM, *HLZC 4* Zone 2, *1.625 kW/FA*
(Normal and Accident)

Burnup (GWd/MTU)			*40*	*50*	*40*	*40*
Enrichment (wt. % U-235)			*2.5*	*3.1*	*2.5*	*2.5*
Cooling Time (years)			*3.860*	*4.887*	*3.860*	*3.860*
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*3.276E+11*	*1.834E+15*	*2.209E+11*	*6.182E+10*
5.00E-02	*to*	*1.00E-01*	*2.168E+10*	*5.259E+14*	*1.423E+10*	*1.201E+10*
1.00E-01	*to*	*2.00E-01*	*2.312E+10*	*4.388E+14*	*1.506E+10*	*2.946E+09*
2.00E-01	*to*	*3.00E-01*	*1.536E+09*	*1.224E+14*	*1.005E+09*	*1.448E+08*
3.00E-01	*to*	*4.00E-01*	*4.685E+09*	*8.409E+13*	*3.053E+09*	*1.880E+08*
4.00E-01	*to*	*6.00E-01*	*9.580E+10*	*1.275E+15*	*6.237E+10*	*1.462E+07*
6.00E-01	*to*	*8.00E-01*	*5.127E+10*	*3.373E+15*	*3.903E+10*	*1.085E+09*
8.00E-01	*to*	*1.00E+00*	*3.027E+11*	*5.632E+14*	*5.742E+10*	*1.725E+11*
1.00E+00	*to*	*1.33E+00*	*5.940E+12*	*1.676E+14*	*3.901E+12*	*3.479E+12*
1.33E+00	*to*	*1.66E+00*	*1.678E+12*	*5.192E+13*	*1.102E+12*	*9.825E+11*
1.66E+00	*to*	*2.00E+00*	*3.531E+04*	*1.761E+12*	*7.627E+04*	*2.362E+04*
2.00E+00	*to*	*2.50E+00*	*4.014E+07*	*3.142E+12*	*2.636E+07*	*2.351E+07*
2.50E+00	*to*	*3.00E+00*	*3.430E+04*	*1.315E+11*	*2.252E+04*	*2.009E+04*
3.00E+00	*to*	*4.00E+00*	*1.015E-05*	*1.224E+10*	*5.042E-05*	*8.360E-06*
4.00E+00	*to*	*5.00E+00*	*5.952E-28*	*3.039E+07*	*3.874E-28*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*1.715E-28*	*1.220E+07*	*1.116E-28*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*2.181E-29*	*2.393E+06*	*1.420E-29*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*2.911E-30*	*5.080E+05*	*1.895E-30*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*8.446E+12*	*8.442E+15*	*5.416E+12*	*4.712E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*8.782E+08*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*1.778E+09*

Table 6-19
PWR Source Term for the EOS-HSM, *HLZC 4* Zone 3*, 1.625 kW/FA*
(Normal and Accident)

Burnup (GWd/MTU)			*40*	*50*	*40*	*40*
Enrichment (wt. % U-235)			*2.5*	*3.1*	*2.5*	*2.5*
Cooling Time (years)			*3.860*	*4.887*	*3.860*	*3.860*
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*3.276E+11*	*1.834E+15*	*2.209E+11*	*6.182E+10*
5.00E-02	*to*	*1.00E-01*	*2.168E+10*	*5.259E+14*	*1.423E+10*	*1.201E+10*
1.00E-01	*to*	*2.00E-01*	*2.312E+10*	*4.388E+14*	*1.506E+10*	*2.946E+09*
2.00E-01	*to*	*3.00E-01*	*1.536E+09*	*1.224E+14*	*1.005E+09*	*1.448E+08*
3.00E-01	*to*	*4.00E-01*	*4.685E+09*	*8.409E+13*	*3.053E+09*	*1.880E+08*
4.00E-01	*to*	*6.00E-01*	*9.580E+10*	*1.275E+15*	*6.237E+10*	*1.462E+07*
6.00E-01	*to*	*8.00E-01*	*5.127E+10*	*3.373E+15*	*3.903E+10*	*1.085E+09*
8.00E-01	*to*	*1.00E+00*	*3.027E+11*	*5.632E+14*	*5.742E+10*	*1.725E+11*
1.00E+00	*to*	*1.33E+00*	*5.940E+12*	*1.676E+14*	*3.901E+12*	*3.479E+12*
1.33E+00	*to*	*1.66E+00*	*1.678E+12*	*5.192E+13*	*1.102E+12*	*9.825E+11*
1.66E+00	*to*	*2.00E+00*	*3.531E+04*	*1.761E+12*	*7.627E+04*	*2.362E+04*
2.00E+00	*to*	*2.50E+00*	*4.014E+07*	*3.142E+12*	*2.636E+07*	*2.351E+07*
2.50E+00	*to*	*3.00E+00*	*3.430E+04*	*1.315E+11*	*2.252E+04*	*2.009E+04*
3.00E+00	*to*	*4.00E+00*	*1.015E-05*	*1.224E+10*	*5.042E-05*	*8.360E-06*
4.00E+00	*to*	*5.00E+00*	*5.952E-28*	*3.039E+07*	*3.874E-28*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*1.715E-28*	*1.220E+07*	*1.116E-28*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*2.181E-29*	*2.393E+06*	*1.420E-29*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*2.911E-30*	*5.080E+05*	*1.895E-30*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*8.446E+12*	*8.442E+15*	*5.416E+12*	*4.712E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*8.782E+08*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*1.778E+09*

Table 6-19a
PWR Source Term for the EOS-HSM, HLZC 5, Zone 1, 0.7 kW/FA (Normal)

Burnup (GWd/MTU)			*24.54*	*50*	*24.54*	*24.54*
Enrichment (wt. % U-235)			*1.8*	*3.1*	*1.8*	*1.8*
Cooling Time (yr)			*5.000*	*24.860*	*5.000*	*5.000*
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*1.745E+11*	*6.875E+14*	*1.169E+11*	*4.051E+10*
5.00E-02	*to*	*1.00E-01*	*1.408E+10*	*2.015E+14*	*8.930E+09*	*7.869E+09*
1.00E-01	*to*	*2.00E-01*	*1.292E+10*	*1.254E+14*	*8.335E+09*	*1.928E+09*
2.00E-01	*to*	*3.00E-01*	*8.456E+08*	*3.811E+13*	*5.500E+08*	*9.491E+07*
3.00E-01	*to*	*4.00E-01*	*2.480E+09*	*2.518E+13*	*1.612E+09*	*1.232E+08*
4.00E-01	*to*	*6.00E-01*	*5.093E+10*	*2.093E+13*	*3.315E+10*	*8.717E+06*
6.00E-01	*to*	*8.00E-01*	*2.742E+10*	*1.327E+15*	*2.163E+10*	*7.238E+08*
8.00E-01	*to*	*1.00E+00*	*9.757E+10*	*1.365E+13*	*2.063E+10*	*5.572E+10*
1.00E+00	*to*	*1.33E+00*	*3.903E+12*	*2.149E+13*	*2.470E+12*	*2.280E+12*
1.33E+00	*to*	*1.66E+00*	*1.102E+12*	*2.208E+12*	*6.975E+11*	*6.438E+11*
1.66E+00	*to*	*2.00E+00*	*6.486E+02*	*6.470E+10*	*1.274E+03*	*3.779E+02*
2.00E+00	*to*	*2.50E+00*	*2.637E+07*	*3.335E+09*	*1.669E+07*	*1.540E+07*
2.50E+00	*to*	*3.00E+00*	*2.253E+04*	*5.679E+08*	*1.426E+04*	*1.316E+04*
3.00E+00	*to*	*4.00E+00*	*5.139E-06*	*4.256E+07*	*2.552E-05*	*4.232E-06*
4.00E+00	*to*	*5.00E+00*	*2.987E-29*	*1.436E+07*	*1.944E-29*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*8.606E-30*	*5.763E+06*	*5.602E-30*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*1.095E-30*	*1.130E+06*	*7.125E-31*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*1.461E-31*	*2.400E+05*	*9.509E-32*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*5.386E+12*	*2.463E+15*	*3.379E+12*	*3.031E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*4.170E+08*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*8.444E+08*

Table 6-19b
PWR Source Term for the EOS-HSM, HLZC 5, Zone 2, 0.5 kW/FA (Normal)

Burnup (GWd/MTU)			18.285	4.558	18.285	18.285
Enrichment (wt. % U-235)			1.8	0.7	1.8	1.8
Cooling Time (yr)			5.000	2.000	5.000	5.000
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	1.356E+11	1.148E+15	9.010E+10	3.144E+10
5.00E-02	to	1.00E-01	1.095E+10	3.762E+14	6.829E+09	6.115E+09
1.00E-01	to	2.00E-01	9.930E+09	3.779E+14	6.380E+09	1.499E+09
2.00E-01	to	3.00E-01	6.494E+08	9.494E+13	4.210E+08	7.374E+07
3.00E-01	to	4.00E-01	1.903E+09	7.512E+13	1.235E+09	9.575E+07
4.00E-01	to	6.00E-01	3.899E+10	2.496E+14	2.538E+10	6.783E+06
6.00E-01	to	8.00E-01	2.097E+10	4.000E+14	1.646E+10	5.387E+08
8.00E-01	to	1.00E+00	8.011E+10	4.424E+13	1.662E+10	4.573E+10
1.00E+00	to	1.33E+00	3.036E+12	3.614E+13	1.889E+12	1.771E+12
1.33E+00	to	1.66E+00	8.574E+11	1.217E+13	5.334E+11	5.002E+11
1.66E+00	to	2.00E+00	5.999E+02	2.164E+12	1.217E+03	3.667E+02
2.00E+00	to	2.50E+00	2.051E+07	8.459E+12	1.276E+07	1.197E+07
2.50E+00	to	3.00E+00	1.753E+04	1.430E+11	1.090E+04	1.023E+04
3.00E+00	to	4.00E+00	3.127E-06	1.280E+10	1.553E-05	2.575E-06
4.00E+00	to	5.00E+00	3.270E-30	3.560E+04	2.129E-30	0.000E+00
5.00E+00	to	6.50E+00	9.423E-31	1.424E+04	6.134E-31	0.000E+00
6.50E+00	to	8.00E+00	1.198E-31	2.786E+03	7.801E-32	0.000E+00
8.00E+00	to	1.00E+01	1.599E-32	5.904E+02	1.041E-32	0.000E+00
Total Gamma, g/(sec*FA)			4.193E+12	2.825E+15	2.586E+12	2.357E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.072E+06
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						2.171E+06

Table 6-19c
PWR Source Term for the EOS-HSM, HLZC 5, Zone 3, 2.4 kW/FA (Normal)

Burnup (GWd/MTU)			50	62	50	50
Enrichment (wt. % U-235)			3.1	3.8	3.1	3.1
Cooling Time (yr)			3.332	4.167	3.332	3.332
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	4.336E+11	2.648E+15	2.933E+11	7.280E+10
5.00E-02	to	1.00E-01	2.565E+10	7.729E+14	1.719E+10	1.414E+10
1.00E-01	to	2.00E-01	2.940E+10	6.602E+14	1.923E+10	3.470E+09
2.00E-01	to	3.00E-01	1.971E+09	1.835E+14	1.293E+09	1.705E+08
3.00E-01	to	4.00E-01	6.254E+09	1.284E+14	4.080E+09	2.213E+08
4.00E-01	to	6.00E-01	1.244E+11	2.120E+15	8.098E+10	2.582E+07
6.00E-01	to	8.00E-01	6.652E+10	4.743E+15	5.000E+10	1.284E+09
8.00E-01	to	1.00E+00	4.949E+11	9.255E+14	9.115E+10	2.819E+11
1.00E+00	to	1.33E+00	6.982E+12	2.403E+14	4.686E+12	4.096E+12
1.33E+00	to	1.66E+00	1.972E+12	8.202E+13	1.323E+12	1.157E+12
1.66E+00	to	2.00E+00	2.421E+05	3.082E+12	5.204E+05	1.609E+05
2.00E+00	to	2.50E+00	4.718E+07	5.914E+12	3.166E+07	2.768E+07
2.50E+00	to	3.00E+00	4.031E+04	2.323E+11	2.705E+04	2.365E+04
3.00E+00	to	4.00E+00	1.331E-05	2.159E+10	6.607E-05	1.096E-05
4.00E+00	to	5.00E+00	2.027E-27	4.932E+07	1.319E-27	0.000E+00
5.00E+00	to	6.50E+00	5.840E-28	1.980E+07	3.801E-28	0.000E+00
6.50E+00	to	8.00E+00	7.427E-29	3.884E+06	4.834E-29	0.000E+00
8.00E+00	to	1.00E+01	9.912E-30	8.246E+05	6.452E-30	0.000E+00
Total Gamma, g/(sec*FA)			1.014E+13	1.251E+16	6.567E+12	5.626E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.441E+09
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						2.918E+09

Table 6-19d
PWR Source Term for the EOS-HSM, HLZC 5, Zone 4, 0.85 kW/FA (Normal)

Burnup (GWd/MTU)			*28.71*	*28.71*	*28.71*	*28.71*
Enrichment (wt. % U-235)			*1.8*	*1.8*	*1.8*	*1.8*
Cooling Time (yr)			*5.000*	*5.000*	*5.000*	*5.000*
Gamma Source Term, g/(sec*FA)						
E_{min}, MeV	***to***	***E_{max}, MeV***	***Bottom Nozzle***	***In-core***	***Plenum***	***Top Nozzle***
1.00E-02	*to*	*5.00E-02*	*1.994E+11*	*1.130E+15*	*1.343E+11*	*4.636E+10*
5.00E-02	*to*	*1.00E-01*	*1.610E+10*	*3.306E+14*	*1.033E+10*	*9.001E+09*
1.00E-01	*to*	*2.00E-01*	*1.484E+10*	*2.755E+14*	*9.608E+09*	*2.205E+09*
2.00E-01	*to*	*3.00E-01*	*9.722E+08*	*7.708E+13*	*6.339E+08*	*1.086E+08*
3.00E-01	*to*	*4.00E-01*	*2.853E+09*	*5.469E+13*	*1.856E+09*	*1.410E+08*
4.00E-01	*to*	*6.00E-01*	*5.864E+10*	*6.241E+14*	*3.817E+10*	*9.964E+06*
6.00E-01	*to*	*8.00E-01*	*3.159E+10*	*1.819E+15*	*2.500E+10*	*8.492E+08*
8.00E-01	*to*	*1.00E+00*	*1.076E+11*	*2.575E+14*	*2.305E+10*	*6.149E+10*
1.00E+00	*to*	*1.33E+00*	*4.461E+12*	*9.264E+13*	*2.857E+12*	*2.608E+12*
1.33E+00	*to*	*1.66E+00*	*1.260E+12*	*2.712E+13*	*8.069E+11*	*7.365E+11*
1.66E+00	*to*	*2.00E+00*	*6.828E+02*	*1.260E+12*	*1.311E+03*	*3.843E+02*
2.00E+00	*to*	*2.50E+00*	*3.014E+07*	*2.397E+12*	*1.931E+07*	*1.762E+07*
2.50E+00	*to*	*3.00E+00*	*2.575E+04*	*9.448E+10*	*1.650E+04*	*1.506E+04*
3.00E+00	*to*	*4.00E+00*	*6.684E-06*	*8.760E+09*	*3.319E-05*	*5.504E-06*
4.00E+00	*to*	*5.00E+00*	*9.736E-29*	*8.559E+06*	*6.338E-29*	*0.000E+00*
5.00E+00	*to*	*6.50E+00*	*2.805E-29*	*3.435E+06*	*1.826E-29*	*0.000E+00*
6.50E+00	*to*	*8.00E+00*	*3.568E-30*	*6.738E+05*	*2.323E-30*	*0.000E+00*
8.00E+00	*to*	*1.00E+01*	*4.762E-31*	*1.431E+05*	*3.100E-31*	*0.000E+00*
*Total Gamma, g/(sec*FA)*			*6.153E+12*	*4.692E+15*	*3.907E+12*	*3.465E+12*
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						*2.457E+08*
Treated with peaking factor 1.215 and k-eff=0.4 (dry)						*4.975E+08*

Table 6-20
BWR Source Term for the EOS-TC108, *HLZC 2* Zone 1 (Normal and Accident)

Burnup (GWD/MTU)			17.07	62	17.07	17.07
Enrichment (wt. % U-235)			0.9	3.8	0.9	0.9
Cooling Time (years)			3.000	16.490	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	5.478E+10	4.235E+14	1.045E+11	2.552E+10
5.00E-02	to	1.00E-01	7.401E+09	1.171E+14	2.736E+09	2.729E+09
1.00E-01	to	2.00E-01	2.931E+09	8.105E+13	6.338E+09	1.404E+09
2.00E-01	to	3.00E-01	1.691E+08	2.424E+13	4.480E+08	8.636E+07
3.00E-01	to	4.00E-01	4.376E+08	1.589E+13	1.711E+09	2.576E+08
4.00E-01	to	6.00E-01	5.899E+09	2.407E+13	3.045E+10	3.932E+09
6.00E-01	to	8.00E-01	3.122E+09	8.094E+14	1.613E+10	2.101E+09
8.00E-01	to	1.00E+00	1.515E+11	1.462E+13	4.572E+10	4.680E+10
1.00E+00	to	1.33E+00	2.111E+12	1.787E+13	6.749E+11	7.732E+11
1.33E+00	to	1.66E+00	5.961E+11	2.287E+12	1.906E+11	2.184E+11
1.66E+00	to	2.00E+00	1.388E+05	4.114E+10	4.210E+04	1.017E+05
2.00E+00	to	2.50E+00	1.426E+07	2.301E+09	4.561E+06	5.225E+06
2.50E+00	to	3.00E+00	1.219E+04	3.129E+08	3.897E+03	4.464E+03
3.00E+00	to	4.00E+00	3.040E-07	3.411E+07	3.117E-08	1.713E-06
4.00E+00	to	5.00E+00	4.928E-31	1.087E+07	2.553E-30	3.289E-31
5.00E+00	to	6.50E+00	1.420E-31	4.362E+06	7.356E-31	9.477E-32
6.50E+00	to	8.00E+00	1.806E-32	8.557E+05	9.356E-32	1.205E-32
8.00E+00	to	1.00E+01	2.410E-33	1.817E+05	1.249E-32	1.609E-33
Total Gamma, g/(sec*FA)			2.933E+12	1.530E+15	1.074E+12	1.074E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.168E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						6.505E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.115E+09

Table 6-21
BWR Source Term for the EOS-TC108, *HLZC 2* Zone 2 (Normal and Accident)

Burnup (GWD/MTU)			23.4	62	23.4	23.4
Enrichment (wt. % U-235)			1.2	3.8	1.2	1.2
Cooling Time (years)			3.000	8.515	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.519E+10	5.613E+14	1.271E+11	3.062E+10
5.00E-02	to	1.00E-01	8.701E+09	1.516E+14	3.243E+09	3.225E+09
1.00E-01	to	2.00E-01	3.546E+09	1.136E+14	7.976E+09	1.721E+09
2.00E-01	to	3.00E-01	2.057E+08	3.258E+13	5.628E+08	1.063E+08
3.00E-01	to	4.00E-01	5.307E+08	2.101E+13	2.097E+09	3.140E+08
4.00E-01	to	6.00E-01	7.473E+09	1.819E+14	3.859E+10	4.981E+09
6.00E-01	to	8.00E-01	3.945E+09	1.137E+15	2.038E+10	2.655E+09
8.00E-01	to	1.00E+00	1.803E+11	8.994E+13	5.441E+10	5.569E+10
1.00E+00	to	1.33E+00	2.480E+12	4.038E+13	7.924E+11	9.128E+11
1.33E+00	to	1.66E+00	7.005E+11	9.234E+12	2.238E+11	2.578E+11
1.66E+00	to	2.00E+00	1.463E+05	1.069E+11	4.623E+04	1.071E+05
2.00E+00	to	2.50E+00	1.676E+07	7.362E+10	5.355E+06	6.167E+06
2.50E+00	to	3.00E+00	1.432E+04	4.972E+09	4.575E+03	5.270E+03
3.00E+00	to	4.00E+00	4.768E-07	4.831E+08	4.888E-08	2.687E-06
4.00E+00	to	5.00E+00	3.049E-30	1.469E+07	1.579E-29	2.035E-30
5.00E+00	to	6.50E+00	8.785E-31	5.896E+06	4.551E-30	5.863E-31
6.50E+00	to	8.00E+00	1.117E-31	1.157E+06	5.788E-31	7.458E-32
8.00E+00	to	1.00E+01	1.491E-32	2.456E+05	7.725E-32	9.953E-33
Total Gamma, g/(sec*FA)			3.451E+12	2.339E+15	1.270E+12	1.270E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.285E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						8.799E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.508E+09

Table 6-22
BWR Source Term for the EOS-TC108, *HLZC 2* Zone 3 (Normal and Accident)

Burnup (GWD/MTU)			62	62	62	62
Enrichment (wt. % U-235)			3.8	3.8	3.8	3.8
Cooling Time (years)			9.699	9.699	9.699	9.699
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	2.884E+10	5.285E+14	2.939E+10	1.222E+10
5.00E-02	to	1.00E-01	4.888E+09	1.430E+14	1.692E+09	1.848E+09
1.00E-01	to	2.00E-01	1.638E+09	1.056E+14	2.718E+09	7.473E+08
2.00E-01	to	3.00E-01	9.060E+07	3.051E+13	1.849E+08	4.356E+07
3.00E-01	to	4.00E-01	1.826E+08	1.963E+13	5.747E+08	9.977E+07
4.00E-01	to	6.00E-01	2.401E+09	1.263E+14	1.240E+10	1.600E+09
6.00E-01	to	8.00E-01	1.262E+09	1.053E+15	6.468E+09	8.900E+08
8.00E-01	to	1.00E+00	1.158E+09	6.453E+13	3.478E+08	4.128E+08
1.00E+00	to	1.33E+00	1.411E+12	3.500E+13	4.489E+11	5.314E+11
1.33E+00	to	1.66E+00	3.985E+11	7.091E+12	1.268E+11	1.501E+11
1.66E+00	to	2.00E+00	2.084E+01	7.384E+10	1.078E+02	1.390E+01
2.00E+00	to	2.50E+00	9.535E+06	3.080E+10	3.033E+06	3.591E+06
2.50E+00	to	3.00E+00	8.147E+03	2.376E+09	2.592E+03	3.068E+03
3.00E+00	to	4.00E+00	1.264E-06	2.379E+08	1.295E-07	7.119E-06
4.00E+00	to	5.00E+00	4.257E-28	1.404E+07	2.205E-27	2.840E-28
5.00E+00	to	6.50E+00	1.227E-28	5.634E+06	6.352E-28	8.184E-29
6.50E+00	to	8.00E+00	1.560E-29	1.105E+06	8.080E-29	1.041E-29
8.00E+00	to	1.00E+01	2.082E-30	2.347E+05	1.078E-29	1.389E-30
Total Gamma, g/(sec*FA)			1.850E+12	2.113E+15	6.295E+11	6.993E+11
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.094E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						8.406E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.441E+09

Table 6-23
BWR Source Term for the EOS-TC125, *HLZC 1* Zone 1 (Normal and Accident)

72.48 & Amd 1

Burnup (GWD/MTU)			17.07	62	17.07	17.07
Enrichment (wt. % U-235)			0.9	3.8	0.9	0.9
Cooling Time (years)			3.000	16.490	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	5.478E+10	4.235E+14	1.045E+11	2.552E+10
5.00E-02	to	1.00E-01	7.401E+09	1.171E+14	2.736E+09	2.729E+09
1.00E-01	to	2.00E-01	2.931E+09	8.105E+13	6.338E+09	1.404E+09
2.00E-01	to	3.00E-01	1.691E+08	2.424E+13	4.480E+08	8.636E+07
3.00E-01	to	4.00E-01	4.376E+08	1.589E+13	1.711E+09	2.576E+08
4.00E-01	to	6.00E-01	5.899E+09	2.407E+13	3.045E+10	3.932E+09
6.00E-01	to	8.00E-01	3.122E+09	8.094E+14	1.613E+10	2.101E+09
8.00E-01	to	1.00E+00	1.515E+11	1.462E+13	4.572E+10	4.680E+10
1.00E+00	to	1.33E+00	2.111E+12	1.787E+13	6.749E+11	7.732E+11
1.33E+00	to	1.66E+00	5.961E+11	2.287E+12	1.906E+11	2.184E+11
1.66E+00	to	2.00E+00	1.388E+05	4.114E+10	4.210E+04	1.017E+05
2.00E+00	to	2.50E+00	1.426E+07	2.301E+09	4.561E+06	5.225E+06
2.50E+00	to	3.00E+00	1.219E+04	3.129E+08	3.897E+03	4.464E+03
3.00E+00	to	4.00E+00	3.040E-07	3.411E+07	3.117E-08	1.713E-06
4.00E+00	to	5.00E+00	4.928E-31	1.087E+07	2.553E-30	3.289E-31
5.00E+00	to	6.50E+00	1.420E-31	4.362E+06	7.356E-31	9.477E-32
6.50E+00	to	8.00E+00	1.806E-32	8.557E+05	9.356E-32	1.205E-32
8.00E+00	to	1.00E+01	2.410E-33	1.817E+05	1.249E-32	1.609E-33
Total Gamma, g/(sec*FA)			2.933E+12	1.530E+15	1.074E+12	1.074E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.168E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						6.505E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.115E+09

Table 6-24
BWR Source Term for the EOS-TC125, *HLZC 1* Zone 2 (Normal and Accident)

72.48 & Amd 1

Burnup (GWD/MTU)			26.59	62	26.59	26.59
Enrichment (wt. % U-235)			1.3	3.8	1.3	1.3
Cooling Time (years)			3.000	6.971	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.951E+10	6.304E+14	1.360E+11	3.271E+10
5.00E-02	to	1.00E-01	9.256E+09	1.714E+14	3.458E+09	3.438E+09
1.00E-01	to	2.00E-01	3.805E+09	1.315E+14	8.658E+09	1.855E+09
2.00E-01	to	3.00E-01	2.210E+08	3.742E+13	6.104E+08	1.147E+08
3.00E-01	to	4.00E-01	5.690E+08	2.449E+13	2.254E+09	3.371E+08
4.00E-01	to	6.00E-01	8.127E+09	3.004E+14	4.197E+10	5.417E+09
6.00E-01	to	8.00E-01	4.287E+09	1.294E+15	2.214E+10	2.885E+09
8.00E-01	to	1.00E+00	1.905E+11	1.421E+14	5.750E+10	5.885E+10
1.00E+00	to	1.33E+00	2.638E+12	4.996E+13	8.425E+11	9.729E+11
1.33E+00	to	1.66E+00	7.451E+11	1.353E+13	2.379E+11	2.747E+11
1.66E+00	to	2.00E+00	1.487E+05	2.171E+11	4.786E+04	1.089E+05
2.00E+00	to	2.50E+00	1.783E+07	2.445E+11	5.694E+06	6.574E+06
2.50E+00	to	3.00E+00	1.523E+04	1.377E+10	4.865E+03	5.617E+03
3.00E+00	to	4.00E+00	5.566E-07	1.306E+09	5.706E-08	3.136E-06
4.00E+00	to	5.00E+00	6.020E-30	1.560E+07	3.119E-29	4.018E-30
5.00E+00	to	6.50E+00	1.735E-30	6.260E+06	8.986E-30	1.158E-30
6.50E+00	to	8.00E+00	2.206E-31	1.228E+06	1.143E-30	1.473E-31
8.00E+00	to	1.00E+01	2.945E-32	2.608E+05	1.525E-31	1.965E-32
Total Gamma, g/(sec*FA)			3.670E+12	2.796E+15	1.353E+12	1.353E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.553E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						9.349E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.603E+09

Table 6-25
BWR Source Term for the EOS-TC125, *HLZC 1* Zone 3 (Normal)

72.48 & Amd 1

Burnup (GWD/MTU)			21.72	21.72	21.72	21.72
Enrichment (wt. % U-235)			1.1	1.1	1.1	1.1
Cooling Time (years)			3.000	3.000	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.284E+10	8.933E+14	1.217E+11	2.945E+10
5.00E-02	to	1.00E-01	8.418E+09	2.854E+14	3.130E+09	3.116E+09
1.00E-01	to	2.00E-01	3.404E+09	2.626E+14	7.575E+09	1.646E+09
2.00E-01	to	3.00E-01	1.971E+08	7.166E+13	5.346E+08	1.016E+08
3.00E-01	to	4.00E-01	5.085E+08	5.544E+13	2.003E+09	3.004E+08
4.00E-01	to	6.00E-01	7.084E+09	4.152E+14	3.658E+10	4.722E+09
6.00E-01	to	8.00E-01	3.742E+09	7.410E+14	1.933E+10	2.518E+09
8.00E-01	to	1.00E+00	1.736E+11	1.317E+14	5.239E+10	5.363E+10
1.00E+00	to	1.33E+00	2.400E+12	4.950E+13	7.669E+11	8.822E+11
1.33E+00	to	1.66E+00	6.778E+11	1.676E+13	2.166E+11	2.491E+11
1.66E+00	to	2.00E+00	1.443E+05	1.788E+12	4.516E+04	1.057E+05
2.00E+00	to	2.50E+00	1.622E+07	4.468E+12	5.183E+06	5.961E+06
2.50E+00	to	3.00E+00	1.386E+04	1.335E+11	4.428E+03	5.093E+03
3.00E+00	to	4.00E+00	4.305E-07	1.226E+10	4.413E-08	2.426E-06
4.00E+00	to	5.00E+00	2.020E-30	2.004E+06	1.046E-29	1.348E-30
5.00E+00	to	6.50E+00	5.820E-31	8.044E+05	3.015E-30	3.884E-31
6.50E+00	to	8.00E+00	7.403E-32	1.578E+05	3.835E-31	4.941E-32
8.00E+00	to	1.00E+01	9.879E-33	3.350E+04	5.118E-32	6.594E-33
Total Gamma, g/(sec*FA)			3.338E+12	2.929E+15	1.227E+12	1.227E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						5.743E+07
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						1.179E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						2.022E+08

Table 6-26
BWR Source Term for the EOS-TC125, *HLZC 1* Zone 3 (Accident)

72.48 & Amd 1

Burnup (GWD/MTU)			21.72	62	21.72	21.72
Enrichment (wt. % U-235)			1.1	3.8	1.1	1.1
Cooling Time (years)			3.000	9.699	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.284E+10	5.285E+14	1.217E+11	2.945E+10
5.00E-02	to	1.00E-01	8.418E+09	1.430E+14	3.130E+09	3.116E+09
1.00E-01	to	2.00E-01	3.404E+09	1.056E+14	7.575E+09	1.646E+09
2.00E-01	to	3.00E-01	1.971E+08	3.051E+13	5.346E+08	1.016E+08
3.00E-01	to	4.00E-01	5.085E+08	1.963E+13	2.003E+09	3.004E+08
4.00E-01	to	6.00E-01	7.084E+09	1.263E+14	3.658E+10	4.722E+09
6.00E-01	to	8.00E-01	3.742E+09	1.053E+15	1.933E+10	2.518E+09
8.00E-01	to	1.00E+00	1.736E+11	6.453E+13	5.239E+10	5.363E+10
1.00E+00	to	1.33E+00	2.400E+12	3.500E+13	7.669E+11	8.822E+11
1.33E+00	to	1.66E+00	6.778E+11	7.091E+12	2.166E+11	2.491E+11
1.66E+00	to	2.00E+00	1.443E+05	7.384E+10	4.516E+04	1.057E+05
2.00E+00	to	2.50E+00	1.622E+07	3.080E+10	5.183E+06	5.961E+06
2.50E+00	to	3.00E+00	1.386E+04	2.376E+09	4.428E+03	5.093E+03
3.00E+00	to	4.00E+00	4.305E-07	2.379E+08	4.413E-08	2.426E-06
4.00E+00	to	5.00E+00	2.020E-30	1.404E+07	1.046E-29	1.348E-30
5.00E+00	to	6.50E+00	5.820E-31	5.634E+06	3.015E-30	3.884E-31
6.50E+00	to	8.00E+00	7.403E-32	1.105E+06	3.835E-31	4.941E-32
8.00E+00	to	1.00E+01	9.879E-33	2.347E+05	5.118E-32	6.594E-33
Total Gamma, g/(sec*FA)			3.338E+12	2.113E+15	1.227E+12	1.227E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						4.094E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						8.406E+08
Treated with peaking factor 1.232 and k_{eff}=0.65 (wet)						1.441E+09

Table 6-27
BWR Source Term for the EOS-HSM, *HLZC 1* Zone 1 (Normal and Accident)

Burnup (GWD/MTU)			17.07	40	17.07	17.07
Enrichment (wt. % U-235)			0.9	2.5	0.9	0.9
Cooling Time (years)			3.000	5.955	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	5.478E+10	4.862E+14	1.045E+11	2.552E+10
5.00E-02	to	1.00E-01	7.401E+09	1.362E+14	2.736E+09	2.729E+09
1.00E-01	to	2.00E-01	2.931E+09	1.074E+14	6.338E+09	1.404E+09
2.00E-01	to	3.00E-01	1.691E+08	3.041E+13	4.480E+08	8.636E+07
3.00E-01	to	4.00E-01	4.376E+08	2.076E+13	1.711E+09	2.576E+08
4.00E-01	to	6.00E-01	5.899E+09	2.518E+14	3.045E+10	3.932E+09
6.00E-01	to	8.00E-01	3.122E+09	9.138E+14	1.613E+10	2.101E+09
8.00E-01	to	1.00E+00	1.515E+11	1.114E+14	4.572E+10	4.680E+10
1.00E+00	to	1.33E+00	2.111E+12	3.914E+13	6.749E+11	7.732E+11
1.33E+00	to	1.66E+00	5.961E+11	1.125E+13	1.906E+11	2.184E+11
1.66E+00	to	2.00E+00	1.388E+05	3.161E+11	4.210E+04	1.017E+05
2.00E+00	to	2.50E+00	1.426E+07	4.963E+11	4.561E+06	5.225E+06
2.50E+00	to	3.00E+00	1.219E+04	2.265E+10	3.897E+03	4.464E+03
3.00E+00	to	4.00E+00	3.040E-07	2.113E+09	3.117E-08	1.713E-06
4.00E+00	to	5.00E+00	4.928E-31	6.042E+06	2.553E-30	3.289E-31
5.00E+00	to	6.50E+00	1.420E-31	2.425E+06	7.356E-31	9.477E-32
6.50E+00	to	8.00E+00	1.806E-32	4.757E+05	9.356E-32	1.205E-32
8.00E+00	to	1.00E+01	2.410E-33	1.010E+05	1.249E-32	1.609E-33
Total Gamma, g/(sec*FA)			2.933E+12	2.109E+15	1.074E+12	1.074E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.738E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						3.569E+08

Table 6-28
BWR Source Term for the EOS-HSM, *HLZC 1* Zone 2 (Normal and Accident)

Burnup (GWD/MTU)			26.59	50	26.59	26.59
Enrichment (wt. % U-235)			1.3	3.1	1.3	1.3
Cooling Time (years)			3.000	5.031	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.951E+10	7.110E+14	1.360E+11	3.271E+10
5.00E-02	to	1.00E-01	9.256E+09	2.029E+14	3.458E+09	3.438E+09
1.00E-01	to	2.00E-01	3.805E+09	1.652E+14	8.658E+09	1.855E+09
2.00E-01	to	3.00E-01	2.210E+08	4.652E+13	6.104E+08	1.147E+08
3.00E-01	to	4.00E-01	5.690E+08	3.244E+13	2.254E+09	3.371E+08
4.00E-01	to	6.00E-01	8.127E+09	4.596E+14	4.197E+10	5.417E+09
6.00E-01	to	8.00E-01	4.287E+09	1.298E+15	2.214E+10	2.885E+09
8.00E-01	to	1.00E+00	1.905E+11	1.997E+14	5.750E+10	5.885E+10
1.00E+00	to	1.33E+00	2.638E+12	5.772E+13	8.425E+11	9.729E+11
1.33E+00	to	1.66E+00	7.451E+11	1.872E+13	2.379E+11	2.747E+11
1.66E+00	to	2.00E+00	1.487E+05	6.343E+11	4.786E+04	1.089E+05
2.00E+00	to	2.50E+00	1.783E+07	1.122E+12	5.694E+06	6.574E+06
2.50E+00	to	3.00E+00	1.523E+04	4.695E+10	4.865E+03	5.617E+03
3.00E+00	to	4.00E+00	5.566E-07	4.371E+09	5.706E-08	3.136E-06
4.00E+00	to	5.00E+00	6.020E-30	1.044E+07	3.119E-29	4.018E-30
5.00E+00	to	6.50E+00	1.735E-30	4.191E+06	8.986E-30	1.158E-30
6.50E+00	to	8.00E+00	2.206E-31	8.222E+05	1.143E-30	1.473E-31
8.00E+00	to	1.00E+01	2.945E-32	1.746E+05	1.525E-31	1.965E-32
Total Gamma, g/(sec*FA)			3.670E+12	3.194E+15	1.353E+12	1.353E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						3.018E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						6.197E+08

Table 6-29
BWR Source Term for the EOS-HSM, *HLZC 1* Zone 3 (Normal and Accident)

Burnup (GWD/MTU)			21.72	40	21.72	21.72
Enrichment (wt. % U-235)			1.1	2.5	1.1	1.1
Cooling Time (years)			3.000	4.715	3.000	3.000
Gamma Source Term, γ/(sec*FA)						
E_{min}, MeV	**to**	**E_{max}, MeV**	**Bottom Nozzle**	**In-core**	**Plenum**	**Top Nozzle**
1.00E-02	to	5.00E-02	6.284E+10	6.488E+14	1.217E+11	2.945E+10
5.00E-02	to	1.00E-01	8.418E+09	1.891E+14	3.130E+09	3.116E+09
1.00E-01	to	2.00E-01	3.404E+09	1.571E+14	7.575E+09	1.646E+09
2.00E-01	to	3.00E-01	1.971E+08	4.404E+13	5.346E+08	1.016E+08
3.00E-01	to	4.00E-01	5.085E+08	3.146E+13	2.003E+09	3.004E+08
4.00E-01	to	6.00E-01	7.084E+09	3.971E+14	3.658E+10	4.722E+09
6.00E-01	to	8.00E-01	3.742E+09	1.069E+15	1.933E+10	2.518E+09
8.00E-01	to	1.00E+00	1.736E+11	1.654E+14	5.239E+10	5.363E+10
1.00E+00	to	1.33E+00	2.400E+12	5.020E+13	7.669E+11	8.822E+11
1.33E+00	to	1.66E+00	6.778E+11	1.629E+13	2.166E+11	2.491E+11
1.66E+00	to	2.00E+00	1.443E+05	7.080E+11	4.516E+04	1.057E+05
2.00E+00	to	2.50E+00	1.622E+07	1.375E+12	5.183E+06	5.961E+06
2.50E+00	to	3.00E+00	1.386E+04	5.282E+10	4.428E+03	5.093E+03
3.00E+00	to	4.00E+00	4.305E-07	4.897E+09	4.413E-08	2.426E-06
4.00E+00	to	5.00E+00	2.020E-30	6.334E+06	1.046E-29	1.348E-30
5.00E+00	to	6.50E+00	5.820E-31	2.542E+06	3.015E-30	3.884E-31
6.50E+00	to	8.00E+00	7.403E-32	4.987E+05	3.835E-31	4.941E-32
8.00E+00	to	1.00E+01	9.879E-33	1.059E+05	5.118E-32	6.594E-33
Total Gamma, g/(sec*FA)			3.338E+12	2.771E+15	1.227E+12	1.227E+12
Total Neutron Source Term, n/(sec*FA)						
Raw ORIGEN-ARP source for uniform burnup						1.821E+08
Treated with peaking factor 1.232 and k_{eff}=0.4 (dry)						3.739E+08

Table 6-30
PWR Axial Source Distributions

Axial Segment	Percentage of In-core Height (top of segment)	Burnup Profile (Gamma Profile)	Normalized Gamma Profile(1)	Neutron Profile(2)	Normalized Neutron Profile(3)
1	5.6	0.619	0.0344	0.133	0.0061
2	11.1	0.924	0.0513	0.718	0.0328
3	16.7	1.056	0.0587	1.257	0.0575
4	22.2	1.097	0.0609	1.475	0.0675
5	27.8	1.103	0.0613	1.509	0.0690
6	33.3	1.101	0.0612	1.498	0.0685
7	38.9	1.103	0.0613	1.509	0.0690
8	44.4	1.112	0.0618	1.562	0.0714
9	50.0	1.125	0.0625	1.640	0.0750
10	55.6	1.136	0.0631	1.708	0.0781
11	61.1	1.143	0.0635	1.753	0.0802
12	66.7	1.143	0.0635	1.753	0.0802
13	72.2	1.136	0.0631	1.708	0.0781
14	77.8	1.115	0.0619	1.580	0.0722
15	83.3	1.047	0.0582	1.213	0.0555
16	88.9	0.882	0.0490	0.590	0.0270
17	94.4	0.701	0.0389	0.225	0.0103
18	100.0	0.456	0.0253	0.037	0.0017
-	Sum	17.999	1.000	21.869	1.000
-	Average	1.0	-	1.215	-

Notes:

(1) The normalized gamma profile is the gamma profile divided by the sum of the gamma profile (sum=17.999).

(2) The neutron profile is the burnup profile raised to the 4.2 power.

(3) The normalized neutron profile is the neutron profile divided by the sum of the neutron profile (sum=21.869).

Table 6-31
BWR Axial Source Distributions

Axial Segment	Percentage of In-core Height (top of segment)	Burnup Profile (Gamma Profile)	Normalized Gamma Profile(1)	Neutron Profile(2)	Normalized Neutron Profile(3)
1	4	0.7144	0.0288	0.244	0.0079
2	8	1.0993	0.0443	1.488	0.0483
3	12	1.2185	0.0491	2.293	0.0745
4	16	1.2312	0.0496	2.395	0.0778
5	20	1.2200	0.0492	2.305	0.0748
6	24	1.1799	0.0475	2.003	0.0650
7	28	1.1528	0.0465	1.817	0.0590
8	32	1.1306	0.0456	1.675	0.0544
9	36	1.1140	0.0449	1.574	0.0511
10	40	1.1192	0.0451	1.605	0.0521
11	44	1.1070	0.0446	1.533	0.0498
12	48	1.0807	0.0436	1.385	0.0450
13	52	1.0722	0.0432	1.340	0.0435
14	56	1.0579	0.0426	1.267	0.0411
15	60	1.0313	0.0416	1.138	0.0370
16	64	1.0180	0.0410	1.078	0.0350
17	68	1.0180	0.0410	1.078	0.0350
18	72	1.0212	0.0412	1.092	0.0355
19	76	1.0140	0.0409	1.060	0.0344
20	80	0.9789	0.0394	0.914	0.0297
21	84	0.9169	0.0370	0.695	0.0226
22	88	0.8430	0.0340	0.488	0.0158
23	92	0.7185	0.0290	0.249	0.0081
24	96	0.5540	0.0223	0.084	0.0027
25	100	0.2025	0.0082	0.001	0.0000
-	Sum	24.814	1.000	30.801	1.000
-	Average	1.0	-	1.232	-

Notes:

(1) The normalized gamma profile is the gamma profile divided by the sum of the gamma profile (sum=24.814).

(2) The neutron profile is the burnup profile raised to the 4.2 power.

(3) The normalized neutron profile is the neutron profile divided by the sum of the neutron profile (sum=30.801).

Table 6-32
BPRA Hardware Masses

Region	SS304 (kg)	Inconel X-750 (kg)	Inconel 718 (kg)	Poison (kg)	Zr-4 (kg)
BW 15x15					
Top	3.602	0.058	0	0	0
Plenum	1.068	0	0	0.724	1.197
Core	2.468	0	0	9.146	11.98
WE 17x17 Pyrex					
Top	2.62	0	0.42	0	0
Plenum	2.85	0	0	0	0
Core	11.9	0	0	5.08	0
WE 17x17 WABA					
Top	2.95	0	0	0	0
Plenum	2.76	0	0	0	2.61
Core	0	0	0	2.5	14.8

Table 6-33
TPA Hardware Masses

Region	SS304 (kg)	Inconel X-750 (kg)	Inconel 718 (kg)	Poison (kg)	Zr-4 (kg)
WE 17x17					
Top	2.468	0	0.358	0	0
Plenum	3.266	0	0	0	0
WE 14x14 Type 1					
Top	2.03	0	0.417	0	0
Plenum	2.69	0	0	0	0
WE 14x14 Type 2					
Top	2.03	0.363	0	0	0
Plenum	2.69	0	0	0	0

Table 6-34
Elemental Constituents of Pyrex Poison

Element	Pyrex (wt. fraction)
B	0.040064
O	0.539562
Na	0.028191
Al	0.011644
Si	0.377220
K	0.003321

Table 6-35
CC ORIGEN-ARP Input Mass

Element	BPRA			TPA	
	Active Fuel (g)	Plenum (g)	Top (g)	Plenum (g)	Top (g)
B	203.525	0.000	0.000	0.000	0.000
C	9.508	0.455	0.290	2.609	2.115
N	15.450	0.740	0.475	4.240	3.670
O	2740.969	0.000	0.000	0.000	0.000
Na	143.210	0.000	0.000	0.000	0.000
Al	59.151	0.000	0.046	0.000	2.145
Si	2035.120	5.693	3.615	32.618	25.363
P	5.348	0.256	0.162	1.468	1.109
S	3.565	0.171	0.108	0.979	0.765
K	16.871	0.000	0.000	0.000	0.000
Ti	0.000	0.000	0.145	0.000	2.860
V	0.000	0.000	0.000	0.000	0.000
Cr	2258.087	108.160	69.218	619.741	536.247
Mn	237.693	11.385	7.235	65.236	50.011
Fe	8181.881	391.905	248.050	2245.548	1761.237
Co	5.950	0.285	0.183	1.633	1.413
Ni	1060.112	50.778	36.275	290.952	405.887
Cu	0.000	0.000	0.003	0.000	0.358
Zr	0.000	0.000	0.000	0.000	0.000
Nb	0.000	0.000	0.052	0.000	19.854
Mo	0.000	0.000	0.000	0.000	10.726

Note: For the BPRA ORIGEN-ARP inputs, the flux scaling factors are applied to the constituent masses. For the TPA inputs, the true masses are used in the inputs and the flux scaling factors are applied to the burnup.

Table 6-36
CC Co-60 Activity and Decay Heat

Parameter	BPRA			TPA	
	Active Fuel	Plenum	Top	Plenum	Top
Co-60 (Ci)	308	14.8	9.5	44.1	18.9
Decay Heat (watts)	4.8	0.2	0.1	0.7	0.3

Table 6-37
CC Source Term

E_{min} (MeV)	Zone[(1)]	*All Zones*	*Inner Zone*	*Peripheral Zone*	*Inner Zone*	*Peripheral Zone*
	Co-60 (Ci)	308	44.1	14.8	18.9	9.5
	E_{max} (MeV)	Active Fuel (γ/s-CC)	Plenum (γ/s-CC)	Plenum (γ/s-CC)	Top (γ/s-CC)	Top (γ/s-CC)
1.00E-02	5.00E-02	3.133E+11	4.540E+10	1.502E+10	2.061E+10	9.702E+09
5.00E-02	1.00E-01	6.183E+10	8.841E+09	2.965E+09	3.795E+09	1.911E+09
1.00E-01	2.00E-01	1.504E+10	2.145E+09	7.211E+08	9.226E+08	4.648E+08
2.00E-01	3.00E-01	7.435E+08	1.068E+08	3.565E+07	4.682E+07	2.300E+07
3.00E-01	4.00E-01	9.718E+08	1.397E+08	4.660E+07	6.024E+07	3.005E+07
4.00E-01	6.00E-01	7.218E+07	1.113E+07	3.288E+06	5.563E+06	2.144E+06
6.00E-01	8.00E-01	2.770E+07	5.117E+06	1.328E+06	1.497E+09	7.527E+06
8.00E-01	1.00E+00	1.640E+10	1.172E+09	7.865E+08	1.849E+09	5.047E+08
1.00E+00	1.33E+00	1.798E+13	2.573E+12	8.624E+11	1.100E+12	5.559E+11
1.33E+00	1.66E+00	5.078E+12	7.267E+11	2.435E+11	3.106E+11	1.570E+11
1.66E+00	2.00E+00	3.510E+00	3.100E-05	1.936E-05	2.716E-03	2.344E-04
2.00E+00	2.50E+00	1.215E+08	1.739E+07	5.827E+06	7.432E+06	3.756E+06
2.50E+00	3.00E+00	1.038E+05	1.486E+04	4.979E+03	6.350E+03	3.210E+03
3.00E+00	4.00E+00	1.322E-02	3.488E-11	1.102E-11	1.051E-06	9.764E-07
4.00E+00	5.00E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.00E+00	6.50E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6.50E+00	8.00E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8.00E+00	1.00E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	Total	2.347E+13	3.358E+12	1.125E+12	1.439E+12	7.256E+11

Note :

1. *For the analyzed PWR HLZC 4, the inner zone corresponds to Zones 1 and 2, and the peripheral zone corresponds to Zone 3.*

Proprietary Information on Pages 6-100 through 6-114
Withheld Pursuant to 10 CFR 2.390

Table 6-40
Irradiation Gases

Element	*PWR Moles of Gas*(1)	*BWR Moles of Gas*(1)
H	*6.17E-02*	*1.36E-02*
He	*1.58E+00*	*5.50E-01*
N	*2.17E-04*	*7.55E-05*
F	*3.14E-06*	*1.56E-06*
Ne	*1.43E-04*	*6.14E-05*
Cl	*1.02E-05*	*4.68E-06*
Ar	*4.33E-07*	*2.08E-07*
Br	*1.08E-01*	*4.40E-02*
Kr	*3.37E+00*	*1.39E+00*
I	*7.57E-01*	*2.95E-01*
Xe	*3.69E+01*	*1.51E+01*
Rn	*3.06E-13*	*9.48E-14*
Subtotal	*42.7*	*17.4*
He from CCs	*8.34*	*-*
He from IFBA	*8.34*	*-*
Total	*59.4*(2)	*17.4*

Notes:

(1) These gases represent gas generated by irradiation and do not include any gas present when the fuel or CC was originally fabricated.

(2) For fuel with a total unirradiated fuel length < 157 inches and maximum fuel loading < 0.450 MTU, this value is 54.3 moles.

Table 6-41
MCNP Material Compositions (wt. %)

Element	Carbon Steel	Stainless Steel	Dry Air	Water	Regular Concrete	Soil
Hydrogen	-	-	-	11.1894	1.0	-
Helium	-	-	-	-	-	-
Boron	-	-	-	-	-	-
Carbon	0.5	0.04	0.0124	-	-	-
Nitrogen	-	-	75.5268	-	-	-
Oxygen	-	-	23.1781	88.8106	53.2	51.37
Sodium	-	-	-	-	2.9	0.614
Magnesium	-	-	-	-	-	1.33
Aluminum	-	-	-	-	3.4	6.856
Silicon	-	0.5	-	-	33.7	27.118
Phosphorous	-	0.023	-	-	-	-
Sulfur	-	0.015	-	-	-	-
Argon	-	-	1.2827	-	-	-
Potassium	-	-	-	-	-	1.433
Calcium	-	-	-	-	4.4	5.117
Titanium	-	-	-	-	-	0.461
Chromium	-	19	-	-	-	-
Manganese	-	1	-	-	-	0.0716
Iron	99.5	70.173	-	-	1.4	5.629
Cobalt	-	-	-	-	-	-
Nickel	-	9.25	-	-	-	-
Copper	-	-	-	-	-	-
Zirconium	-	-	-	-	-	-
Niobium	-	-	-	-	-	-
Molybdenum	-	-	-	-	-	-
Tin	-	-	-	-	-	-
Lead	-	-	-	-	-	-
Density (g/cm^3)	7.82	8.00	0.001205	(1)	2.243	1.52

Note: (1) 0.958 g/cm^3 inside the DSC and 0.9982 g/cm^3 inside the neutron shield.

Table 6-42
MCNP Borated Polyethylene Composition

Element	Atom Density (atom/b-cm)
Hydrogen	6.1848E-02
Boron-10	5.5978E-04
Boron-11	2.2532E-03
Carbon	3.6381E-02
Oxygen	4.2195E-03
Total	1.0526E-01

Table 6-43
MCNP PWR Dry Fuel Compositions (wt. fraction)

Material	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle
Boron	2.7088E-06	3.7133E-07	1.7956E-05	7.8154E-06
Carbon	2.0552E-04	5.4215E-06	3.3783E-04	4.5158E-04
Oxygen	6.3495E-04	9.8758E-02	5.4025E-04	-
Aluminum	2.7088E-04	3.7133E-05	1.7956E-03	7.8154E-04
Silicon	2.2469E-03	2.3617E-05	2.0878E-03	4.7155E-03
Phosphorous	1.0302E-04	1.0397E-06	9.3784E-05	2.1593E-04
Sulfur	6.9824E-05	1.0397E-06	7.8651E-05	1.4844E-04
Titanium	4.8759E-04	6.6840E-05	3.2322E-03	1.4068E-03
Chromium	8.9659E-02	1.5716E-03	1.0462E-01	1.9000E-01
Manganese	4.3216E-03	2.3617E-05	3.0336E-03	8.9340E-03
Iron	3.0144E-01	1.5836E-03	1.9469E-01	6.1862E-01
Cobalt	4.9300E-04	6.7583E-05	3.2681E-03	1.4224E-03
Nickel	6.6661E-02	3.8767E-03	2.0496E-01	1.5963E-01
Copper	1.4790E-04	2.0275E-05	9.8042E-04	4.2672E-04
Zirconium	5.2126E-01	1.5811E-01	4.4352E-01	-
Niobium	2.7765E-03	3.8062E-04	1.8405E-02	8.0108E-03
Molybdenum	1.6524E-03	2.2651E-04	1.0953E-02	4.7674E-03
Tin	7.4087E-03	2.2471E-03	6.3037E-03	-
U-234	-	1.9571E-04	-	-
U-235	-	2.1989E-02	-	-
U-236	-	1.0115E-04	-	-
U-238	-	7.1069E-01	-	-
Total	1.0	1.0	1.0	1.0
Density (g/cm^3)	1.9683	3.9508	1.4454	1.8560

Table 6-44
MCNP PWR Wet Fuel Compositions (wt. fraction)

Material	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle
Hydrogen	2.9202E-02	1.4216E-02	3.8863E-02	3.1790E-02
Boron	2.0019E-06	3.2415E-07	1.1720E-05	5.5950E-06
Carbon	1.5188E-04	4.7326E-06	2.2049E-04	3.2328E-04
Oxygen	2.3225E-01	1.9905E-01	3.0881E-01	2.5232E-01
Aluminum	2.0019E-04	3.2415E-05	1.1720E-03	5.5950E-04
Silicon	1.6605E-03	2.0616E-05	1.3627E-03	3.3758E-03
Phosphorous	7.6132E-05	9.0763E-07	6.1211E-05	1.5458E-04
Sulfur	5.1601E-05	9.0763E-07	5.1334E-05	1.0626E-04
Titanium	3.6033E-04	5.8348E-05	2.1096E-03	1.0071E-03
Chromium	6.6260E-02	1.3719E-03	6.8286E-02	1.3602E-01
Manganese	3.1937E-03	2.0616E-05	1.9800E-03	6.3958E-03
Iron	2.2277E-01	1.3824E-03	1.2707E-01	4.4286E-01
Cobalt	3.6434E-04	5.8996E-05	2.1330E-03	1.0183E-03
Nickel	4.9263E-02	3.3842E-03	1.3377E-01	1.1428E-01
Copper	1.0930E-04	1.7699E-05	6.3990E-04	3.0549E-04
Zirconium	3.8522E-01	1.3802E-01	2.8948E-01	-
Niobium	2.0519E-03	3.3226E-04	1.2013E-02	5.7349E-03
Molybdenum	1.2211E-03	1.9773E-04	7.1491E-03	3.4130E-03
Tin	5.4751E-03	1.9616E-03	4.1143E-03	-
U-234	-	1.7084E-04	-	-
U-235	-	1.9196E-02	-	-
U-236	-	8.8300E-05	-	-
U-238	-	6.2040E-01	-	-
Total	1.0	1.0	1.0	1.0
Density (g/cm^3)	2.6635	4.5258	2.2146	2.5925

Table 6-45
MCNP BWR Dry Fuel Compositions (wt. fraction)

Material	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle
Boron	-	-	-	6.0000E-06
Carbon	3.1900E-04	9.5165E-07	7.1000E-05	3.0500E-04
Oxygen	2.5100E-04	9.6645E-02	9.8500E-04	3.9400E-04
Aluminum	4.2000E-05	7.0000E-06	-	5.6300E-04
Silicon	3.9370E-03	4.0000E-06	8.8400E-04	3.1460E-03
Phosphorus	1.8100E-04	-	4.1000E-05	1.4400E-04
Sulfur	1.1800E-04	-	2.7000E-05	9.9000E-05
Titanium	7.5000E-05	1.2000E-05	-	1.0130E-03
Chromium	1.5037E-01	4.3200E-04	3.4406E-02	1.2766E-01
Manganese	7.8470E-03	4.0000E-06	1.7680E-03	5.9340E-03
Iron	5.5060E-01	5.9100E-04	1.2568E-01	4.1107E-01
Cobalt	7.6000E-05	1.2000E-05	-	1.0240E-03
Nickel	7.6705E-02	6.8400E-04	1.6351E-02	1.1067E-01
Copper	2.3000E-05	4.0000E-06	-	3.0700E-04
Zirconium	2.0585E-01	1.8186E-01	8.0830E-01	3.2386E-01
Niobium	4.2600E-04	6.7000E-05	-	5.7690E-03
Molybdenum	2.5400E-04	4.0000E-05	-	3.4330E-03
Tin	2.9260E-03	2.5850E-03	1.1488E-02	4.6030E-03
U-234	-	1.9100E-04	-	-
U-235	-	2.1511E-02	-	-
U-236	-	9.9000E-05	-	-
U-238	-	6.9525E-01	-	-
Total	1.0	1.0	1.0	1.0
Density (g/cm^3)	1.980	4.201	1.006	0.663

Table 6-46
MCNP BWR Wet Fuel Compositions (wt. fraction)

Material	Bottom Nozzle	Active Fuel	Plenum	Top Nozzle
Hydrogen	2.9538E-02	1.2850E-02	5.0093E-02	6.3595E-02
Boron	-	-	-	2.0000E-06
Carbon	2.3500E-04	8.4236E-07	3.9000E-05	1.3200E-04
Oxygen	2.3463E-01	1.8754E-01	3.9814E-01	5.0492E-01
Aluminum	3.1000E-05	6.0000E-06	-	2.4300E-04
Silicon	2.8970E-03	4.0000E-06	4.8800E-04	1.3580E-03
Phosphorus	1.3300E-04	-	2.2000E-05	6.2000E-05
Sulfur	8.7000E-05	-	1.5000E-05	4.3000E-05
Titanium	5.5000E-05	1.0000E-05	-	4.3700E-04
Chromium	1.1068E-01	3.8300E-04	1.9003E-02	5.5104E-02
Manganese	5.7750E-03	4.0000E-06	9.7600E-04	2.5610E-03
Iron	4.0525E-01	5.2300E-04	6.9417E-02	1.7744E-01
Cobalt	5.6000E-05	1.1000E-05	-	4.4200E-04
Nickel	5.6456E-02	6.0600E-04	9.0310E-03	4.7773E-02
Copper	1.7000E-05	3.0000E-06	-	1.3300E-04
Zirconium	1.5151E-01	1.6098E-01	4.4643E-01	1.3980E-01
Niobium	3.1400E-04	5.9000E-05	0.0000E+00	2.4900E-03
Molybdenum	1.8700E-04	3.5000E-05	0.0000E+00	1.4820E-03
Tin	2.1530E-03	2.2880E-03	6.3450E-03	1.9870E-03
U-234	-	1.6900E-04	-	-
U-235	-	1.9041E-02	-	-
U-236	-	8.8000E-05	-	-
U-238	-	6.1541E-01	-	-
Total	1.0	1.0	1.0	1.0
Density (g/cm^3)	2.690	4.746	1.822	1.536

Table 6-47
EOS-37PTH DSC and EOS-89BTH DSC Key As-Modeled Dimensions (Inches)

Item	EOS-37PTH DSC	EOS-89BTH DSC
Carbon steel shield plug thickness	6.0	6.0
Stainless steel inner top cover plate thickness	2.0	2.0
Stainless steel outer top cover plate thickness	2.0	2.0
Stainless steel shell thickness	0.5	0.5
Stainless steel shell outer diameter	75.5	75.5
Stainless steel outer bottom cover thickness	2.0	2.0
Carbon steel inner bottom shield thickness	4.0	4.0
Stainless steel inner bottom cover thickness	2.0	2.0
Basket compartment inner width	8.86	5.85
Carbon steel basket plate thickness(1)	0.281	0.1875
Aluminum basket plate thickness	0.250	0
MMC basket plate thickness	0.164	0.175

Note:

(1) The EOS-89BTH DSC carbon steel basket plates are modeled as stainless steel. This has no effect on the results.

Table 6-48
EOS-TC108 and EOS-TC125/135 Key As-Modeled Dimensions (Inches)

Item	EOS-TC108	EOS-TC125/135
Cask inner diameter	76.25	76.25
Carbon steel inner shell thickness	0.75	0.75
Stainless steel side lead minimum thickness	2.4	3.51
Carbon steel outer shell thickness	1.0	1.0
Neutron shield water thickness	2.5	4.0
Ram port inner diameter	22.0	22.0
Carbon steel ram plate thickness	1.25	1.25
Carbon steel bottom panel thickness	0.75	0.75
Borated polyethylene thickness	2.13	2.13
Carbon steel bottom end plate thickness	2.0	2.0
Carbon steel bottom ring height	9.0	9.0
Carbon steel top ring height	16.25	16.25
Top ring lead height	5.65	5.65
Top ring lead minimum thickness	0.85	0.85
Top ring thickness (at top nozzle)	4.63	5.38
Top cover plate (lid) thickness	2.0 (Aluminum)	3.2 (Carbon Steel)

Table 6-49
EOS-TC Model Configurations

EOS-TC108							
Configuration	**Water Fill**	**Shield Plug**	**ITCP**	**OTCP**	**Annulus Water Fill**	**Neutron Shield**	**Top Cover Plate (Lid)**
Decontamination	Partial(1)	On	Off	Off	Full	Off	Off
Welding/Drying	Empty	On	On	Off	-12 inches	On/Full	Off
Downending/Transfer	Empty	On	On	On	Empty	On/Full	On
EOS-TC125/135							
Configuration	**Water Fill**	**Shield Plug**	**ITCP**	**OTCP**	**Annulus Water Fill**	**Neutron Shield**	**Top Cover Plate (Lid)**
Decontamination	Full	On	Off	Off	Full	Empty	Off
Welding/Drying	Empty	On	On	Off	-12 inches	Full	Off
Downending/Transfer	Empty	On	On	On	Empty	Full	On

Note: (1) Top nozzle and plenum are dry for EOS-37PTH DSC, top nozzle is dry for EOS-89BTH DSC.

Table 6-50
EOS-HSM Key As-Modeled Dimensions (Inches)

Item	EOS-HSM-Short	EOS-HSM-Medium
Base/roof width	116	116
Base height	178	178
Base/roof length	228	248
Base upper side wall thickness	12	12
Base upper rear wall thickness	12	12
Roof thickness	44	44
Rear/end (side) shield wall thickness	36	36
Rear/end (side)/corner shield wall height	222	222
End (side) shield wall length	117	127
Corner shield wall width (square)	36	36
Door inner steel plate thickness	1	1
Door concrete thickness (centerline)	30.5	30.5
Door outer concrete width (square)	100.375	100.375
Inlet vent height	30	30
Inlet vent width	10	10
Base outlet vent height	8	8
Base outlet vent length	128	148
Roof outlet vent opening width	8	8
Roof outlet vent opening length	132 max./116 min. (trapezoidal)	152 max./136 min. (trapezoidal)
Outlet vent cover width	48	48
Outlet vent cover length	156	176
Outlet vent cover concrete thickness	10.625	10.625
Outlet vent cover steel plate thickness	1	1
Outlet vent cover opening height	6.25	6.25
Outlet vent cover opening length	132	152
Gaps between base and shield walls	1.5	1.5

Table 6-51
ANSI/ANS-6.1.1-1977 Flux-to-Dose-Rate Conversion Factors

E (MeV)	Neutron Factors (mrem/hr)/(n/cm^2-s)	E (MeV)	Neutron Factors (mrem/hr)/(n/cm^2-s)
2.50E-08	3.67E-03	0.5	9.26E-02
1.00E-07	3.67E-03	1.0	1.32E-01
1.00E-06	4.46E-03	2.5	1.25E-01
1.00E-05	4.54E-03	5.0	1.56E-01
1.00E-04	4.18E-03	7.0	1.47E-01
0.001	3.76E-03	10.0	1.47E-01
0.01	3.56E-03	14.0	2.08E-01
0.1	2.17E-02	20.0	2.27E-01
E (MeV)	**Gamma Factors (mrem/hr)/(γ/cm^2-s)**	**E (MeV)**	**Gamma Factors (mrem/hr)/(γ/cm^2-s)**
0.01	3.96E-03	1.4	2.51E-03
0.03	5.82E-04	1.8	2.99E-03
0.05	2.90E-04	2.2	3.42E-03
0.07	2.58E-04	2.6	3.82E-03
0.1	2.83E-04	2.8	4.01E-03
0.15	3.79E-04	3.25	4.41E-03
0.2	5.01E-04	3.75	4.83E-03
0.25	6.31E-04	4.25	5.23E-03
0.3	7.59E-04	4.75	5.60E-03
0.35	8.78E-04	5.0	5.80E-03
0.4	9.85E-04	5.25	6.01E-03
0.45	1.08E-03	5.75	6.37E-03
0.5	1.17E-03	6.25	6.74E-03
0.55	1.27E-03	6.75	7.11E-03
0.6	1.36E-03	7.5	7.66E-03
0.65	1.44E-03	9.0	8.77E-03
0.7	1.52E-03	11.0	1.03E-02
0.8	1.68E-03	13.0	1.18E-02
1.0	1.98E-03	15.0	1.33E-02

Proprietary Information on Pages 6-127 through 6-136
Withheld Pursuant to 10 CFR 2.390

Table 6-58
EOS-HSM Neutron Average Fluxes and Dose Rates, EOS-89BTH DSC

Table 6-59
EOS-HSM Grout Study Results, EOS-89BTH DSC

Configuration	Side Gamma Dose Rate (mrem/hr)
No grout	1.40
3 in. grout	1.78
6 in. grout	2.20

Table 6-60
Distribution of BWR Assemblies from 2013 EIA GC-859 Database

Burn-Up, GWd/ MTU	Assembly Averaged Initial ^{235}U Enrichment, wt.%																																							
	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5
1																			1	2																				
2		50																	1	5											1									
3		365				2										2			7									1												
4		579														3	11		6	1									2											
5		298				1									1	2	19		11	38									8	1	2	6					1			
6		44		32		9									1	22	39		17	2	1	1	1				3				2	10								
7				40		135									2	57	3	2	19	20		1				1	3	1	4			4								
8				132	6	99									1	28	9	1	7	27			1				5		8					2						
9				156	17	103						2			21	50	27		31	29	9		2				7	1			2									
10				4	23	272				116		6	1		3	74	32		33	96	30		6				8			4	11					1				
11				8	70	305			8	144	8	8			2	95	54	1	29	84	7		14			2	32	2	2	3	4		1							
12				7	13	76			12	77		304			2	227	50	9	4	7	4		36		1	12	71		3		10		2	2						
13				52						168	4	171			12	441	105	2	4	14	26		110	2	2	11	114		6		15		7	5						
14				58						114	20	508			27	140	115	1	4	30	23		37	2	1	2	54	3	7	1	34	1	6	9	1		1			
15				15						24	128	197		2	137	141	108	3	9	25	8	2	14		2		57	1	4	8	30		6	17		1				
16				14							161	197	3		51	263	116	13	13	22	2	2	26	1		1	4		2	4	36		29	17						
17				18						32	50	289	12	6	53	662	95	35	4	35	5	17	12		1	2				6	62		46	7	1	1				
18				3						28	61	151	49		140	808	144	46	1	27	32	7	20			3			2	12	57		64	6						
19				5					1	8	80	249	57	6	275	726	154	92	4	121	52	19	4	1		2	1		5	9	24		3	6						
20									3		60	59	30	18	99	1047	229	111	9	417	96	20	7			1			5	13	11		3	10	1			1		
21									7		21	27	7	57	137	774	309	135	20	261	131	54	38	1		6	1	5	6	15	6		7	4	1					
22									1		35	20	3	4	85	943	209	143	44	264	164	112	82	7	1	3	4	6	7	6	1		21	7	4					
23									1		22	16	1		90	746	187	49	202	541	246	94	111	15	3	17	5	1	32	1		3	29	5	2	2				
24									8		26	24	4		80	574	302	75	224	609	434	223	203	12	5	32	3	1	48			5	34		1	3	1			
25									21	3	20	9	4	6	76	522	335	51	210	559	400	395	317	21	5	80	3	7	35			5	30	1	1					
26									7	5	16	8	1	17	103	460	152	45	300	649	439	442	474	83	30	52	11	6	34			3	92							
27											2	16	1	11	92	402	150	40	257	551	536	435	550	200	58	67	37	6	22			3	78	3	2	2				
28											6	6	1	27	3	274	181	31	265	492	752	457	1006	185	149	86	16	26	4	1		10	35	1		4				
29												7	1	15	8	169	139	35	273	348	988	289	1110	271	229	110	43	40	15			1	28		3					
30										1				24	12	126	60	7	135	183	925	276	1184	484	377	112	44	124	53	2			13		1	2				
31														24	4	38	41		144	60	797	229	1084	487	334	156	150	147	119	29	2	50	8	1	10	8				
32														3		24	17	2	36	76	686	206	1002	711	381	213	270	399	229	50	22	38	18	2	36	42		1		
33											4					9	5	1	12	76	507	177	707	879	497	391	207	484	297	54	14	74	53	3	15	1	4			
34																7			6	20	197	114	631	865	671	406	418	525	251	94	9	161	78	9	7	10	8			
35															24				1	8	105	89	307	612	451	495	776	431	310	152	18	63	125	22	11	6		1		
36																			24	4	3	81	127	404	470	731	1094	495	427	179	21	29	130	29	52	43	11	1		
37														4			1		14	4	2	34	79	269	373	892	1120	613	512	193	65	95	65	46	70	47	12	14		
38														14					11	6	1	4	36	286	468	565	909	594	484	196	72	184	160	211	220	90	68	13		
39														3						16	7	16	33	225	421	436	824	359	455	234	104	309	232	369	193	158	128	19	1	
40																					2		18	54	149	305	736	342	393	286	180	429	263	359	241	115	164	27		
41										1										4	2		34	25	77	132	508	454	381	284	381	500	356	405	405	147	165	91	1	
42																							7	47	41	111	346	263	287	506	385	532	365	709	632	368	196	39	2	
43																					1		7	51	19	72	288	151	245	430	266	407	507	761	1032	568	228	64	15	
44																					4			16	4	20	172	70	234	240	174	453	474	867	1537	1043	361	49	47	
45																									8	31	162	20	121	171	293	521	358	790	1192	1244	294	54	57	
46																										14	87	27	57	99	301	504	379	760	1009	913	242	37	8	
47																										3	62	27	20	94	226	460	364	704	1053	1180	158	43	8	
48																										1	24	18	5	81	134	266	219	674	1001	934	93	21	13	
49																											3	18	17	41	113	309	230	597	923	910	79	27	22	
50																											2	17	18	19	39	187	234	424	721	824	72	1	1	
51																											2	39	4	20	26	150	95	219	519	670	29	1		
52																											2	22		6	18	47	41	101	288	382	4			
53																											1	24		8	24	9	38	26	101	147				
54																												4		32	8	2		9	22	18				
55																														8					2	1				
56																																								
Enr.-->	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5

Note: The heavy line represents the lower enrichment boundary from Table 6-7.

Table 6-61
Distribution of PWR Assemblies from 2013 EIA GC-859 Database

Burn-Up, GWd/MTU	Assembly Averaged Initial ^{235}U Enrichment, wt.%																																													
	0.2	0.3	0.4	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
1																																														
2																																														
3		16									1								2																											
4																																							8							
5															3																1					5			16							
6															1	1				1				1			2			3	4								8							
7												1												1	2	8	5	2		1	4				9	5										
8									8	1	1					1									11	9					4		8		11	7										
9									13	7					2	1									16		2	2	3	8	20		24		9	1					2	2				
10									4				4												6	80		1	5	10	4		4			6					10	2				
11	4								4			20				13				2					13	8				11		2	32		5	7					4					
12		4					16		4	6	18	50	20	6		29	11		1	33		1			9	8	3			1	4	2			10	8				15	5	3				
13		4		2						17	8	60	49	7	39	13	4	1	2	34					1	14	1	3	1	2	2				2	12				5	2	2				
14				2						23	24	152		61	56	15	10			49					4		1			7	1			2	1	16		4		12						
15									8	5	14	84		122	36	22	48			8					15	1	5			2	16		1	2	5	11		4		14			7			
16									16		16	1		155	126	58	58	32		14		1	3		1			2		1				1		9		1		29			5			
17											2			53	90	147	230	27	9	23		14	3	1	8	1	1	2		1	22	1				1		4		25			4			
18								4	4			5		8	140	96	333	95	15			17	6	5			15		11	3	35	1	1			11	10	8			4		12			
19													1	4	39	17	242	158	2	16		17	22	11	1	1	52	10	3		1	3	9	1	1	7		12	1		12					
20				4			1	3		1				18	20	23	240	149		11	13	37	21	5	1	55	47	11	19	3		2	7	1		17		5		4					4	
21											2			15	40	19	107	52	15	39	34	84	19	3	8	13	68	3	3	5	1	2	20	1	1	20	8			1						
22						1		8			7	6		13	12	20	57	8	25	85	49	50	13	9	8	14	36	16	2	15	3	3	2	4	11	22	11			1					12	
23												2		6	6	26	83	55	80	7	42	38	22	19	23	11	44	11	3	15	39		12	4	7	24	2	1		1	1					
24								4						19	11	42	66	48	24	18	47	96	42	44	28	17	49	11	12	15	8	3	5	6	37	20	3	3	1	3		3			11	
25												1		4	8	32	61	64	54	15	59	124	52	34	18	68	77	20	5	39	2	2		14	17	47	25	3	3	3					23	
26														4	3	33	45	36	111	56	73	225	108	77	68	88	89	28	14	59	12	7		9	23	34	29	20	4	3			4	2	20	
27											4	1			20	31	18	24	72	102	99	239	96	102	79	155	76	110	9	65	5	22	1	16	32	26	23	10	4	1		15	4	4		
28											5	4				7	23	42	41	136	47	257	86	135	118	164	141	68	45	37	8	10	3	11	26	58	12	6		4		9				
29										1	3	5			2		10	27	49	21	48	293	141	183	141	259	184	76	61	93	26	49	16	19	27	27	36	9	3	5	1		2		12	
30											1	2				1	15	16	26	5	58	160	135	235	183	340	179	122	53	77	24	44	29	24	83	41	9	4	4	1	4	3	1		4	
31										1				4		2	16	1	14	5	43	106	122	247	162	351	235	209	108	157	48	48	38	17	63	34	6	11	4	2		4			4	
32														11	15	3	12				27	102	141	164	271	349	306	345	186	161	54	72	35	15	78	122		9	8	8	1				5	
33												1				2	9			9	28	48	86	163	212	330	306	364	213	239	79	75	50	34	143	153	19	10	2	3	2	9				
34																4	5	1	1	9	12	99	61	155	144	299	366	342	255	237	188	97	84	111	178	107	24	23	19	34		1			4	
35														1		2	3		5	1	2	48	112	116	80	234	356	441	291	309	172	169	109	111	228	193	40	26	28	20	7					
36																		4	2	3	5	53	75	68	96	333	252	442	339	398	181	270	103	183	154	162	63	44	31	41	13	4				
37														1		1			17	1	1	45	28	32	50	232	255	370	407	381	244	348	141	154	166	264	50	37	12	32	4	2	4			
38						1								4					4		1	38	22	26	37	128	312	266	337	442	279	318	183	233	267	212	71	100	35	41	23	17	1	3		
39				2																		12	12	27	44	71	123	217	375	450	411	397	278	247	203	299	116	84	47	46	28	10	3	5		
40				2															1			14	2	7	25	80	127	223	375	346	364	348	409	348	340	255	164	109	86	89	22	17	1	6	3	
41																						15	1	8	4	34	69	192	187	292	275	421	327	422	290	408	244	135	98	144	27	32	17	5	16	
42																						1		7	8	11	59	120	231	241	256	319	430	443	451	440	255	285	107	160	60	13	39	9	4	
43																					1			4	23	37	35	164	161	235	262	404	440	392	421	604	337	378	153	180	62	68	34	10	8	
44																				2	1					14	41	58	96	122	205	405	463	480	549	708	383	517	210	187	84	82	61	7	15	
45																						1		1	2	8	11	43	93	110	136	275	242	494	593	944	437	627	194	237	97	88	75	14	50	
46																					1	1		3	2	2	6	34	70	81	153	190	279	342	496	963	563	865	295	448	203	51	94	8	50	
47																						1		1	1	2	1	10	69	103	105	142	196	211	438	941	646	1035	456	627	235	141	151	27	41	
48																									2	4	3	3	21	34	72	120	93	143	255	782	464	1085	431	541	266	216	159	44	55	
49																			1							6	1	2	22	35	29	101	121	137	142	440	309	858	319	725	312	270	215	85	106	
50																						2					4	9	9	34	40	67	107	116	93	267	351	639	433	617	388	276	243	94	102	
51																										1	1		2	16	16	23	55	63	72	278	200	529	246	566	439	336	265	97	110	
52																						1			1				12	17	6	21	67	60	83	164	152	341	305	430	384	356	333	123	86	
53																											2		2	5	4	17	19	40	63	66	77	213	212	402	267	314	459	115	119	
54																													2	2	4	12	23	22	49	35	46	82	118	187	176	262	435	100	144	
55																													4			13	23	13	19	27	40	41	51	112	111	182	371	48	180	
56																													2				2	19	24	18	19	15	19	23	40	119	175	133	218	
57																													1	1				3	9	4	12	3	13	16	9	44	70	41	96	
58																									1						1	5	2	1	7		1	2		1		4	2	10	41	
59																															3		1		2			3	1	4		1	2		46	
60																																							1	3						
61																																								2						
62																																														
Enr.-->	0.2	0.3	0.4	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0

Note: The heavy line represents the lower enrichment boundary from Table 6-7.

		P	P	P		
	P	I	I	I	P	
P	I	I	I	I	I	P
P	I	I	I	I	I	P
P	I	I	I	I	I	P
	P	I	I	I	P	
		P	P	P		

Figure 6-1
Peripheral and Inner Fuel Locations for the EOS-37PTH DSC

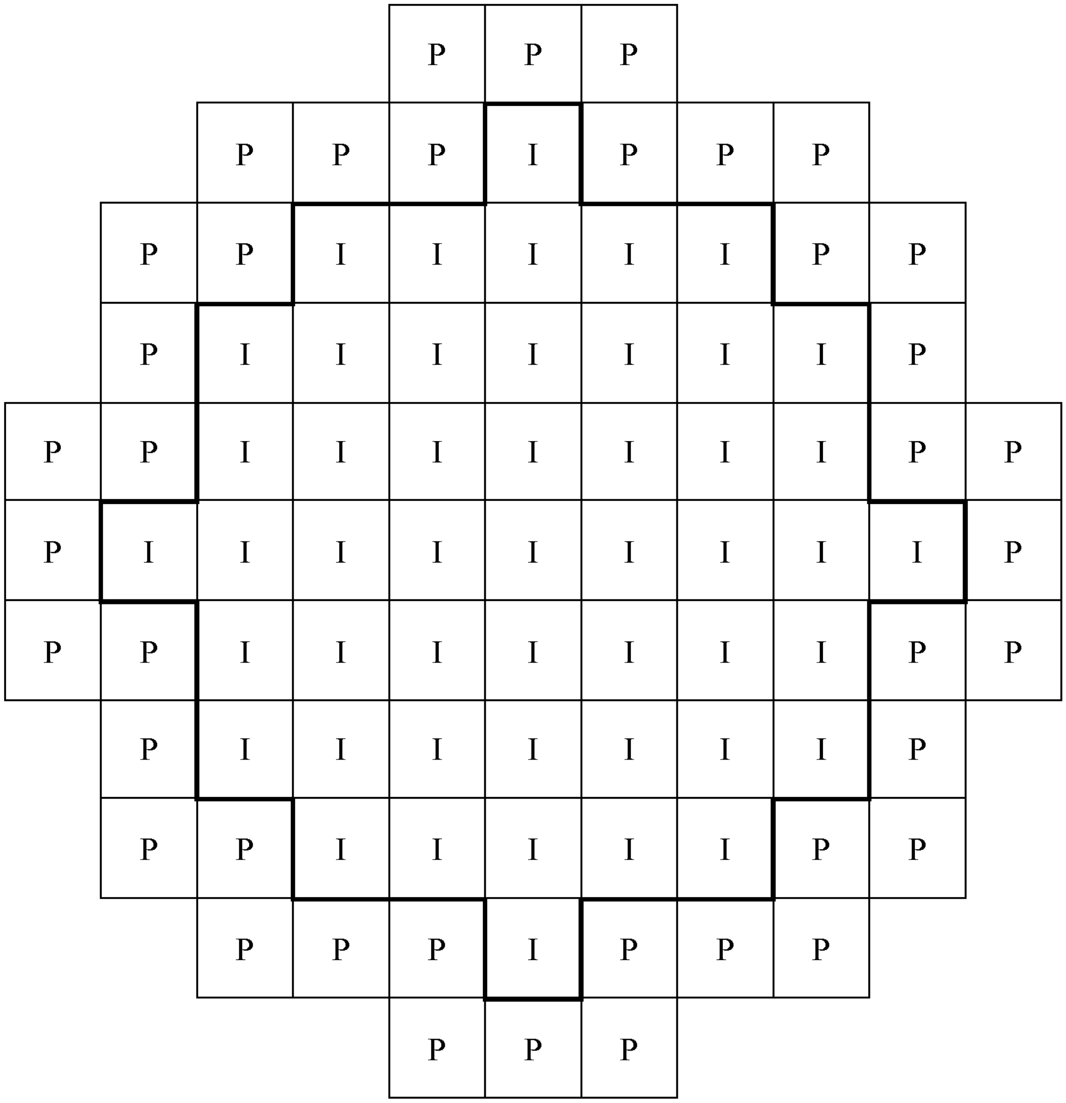

Figure 6-2
Peripheral and Inner Fuel Locations for the EOS-89BTH DSC

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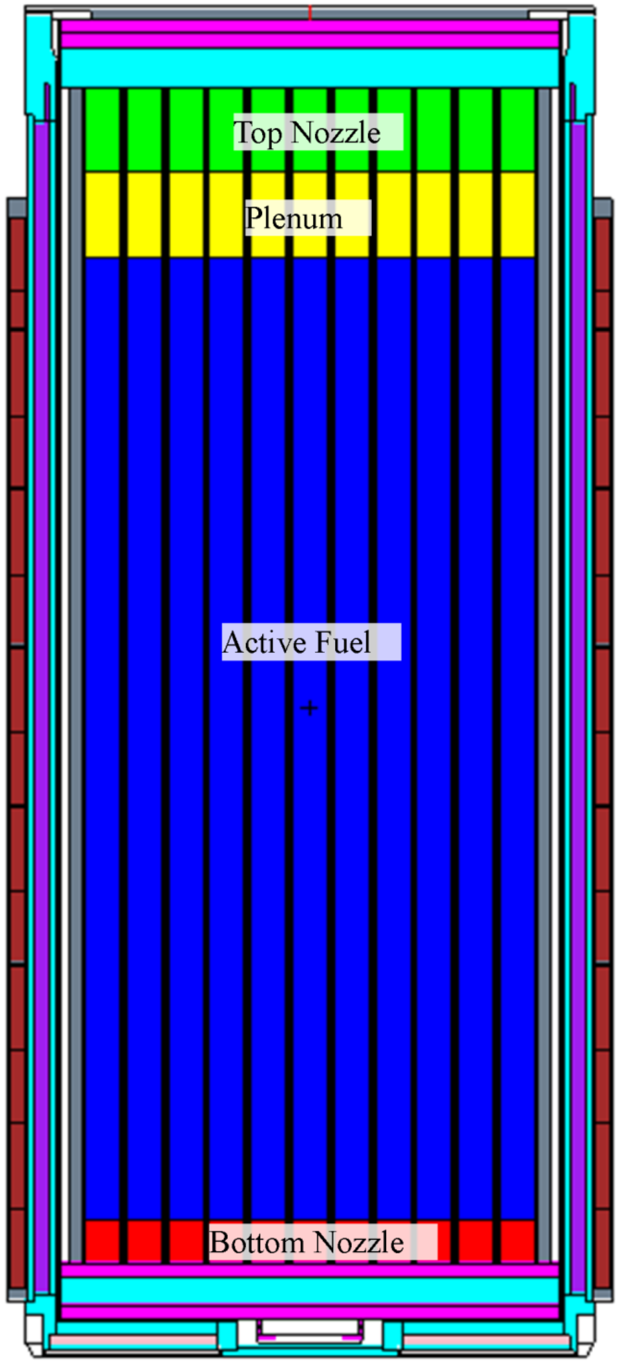
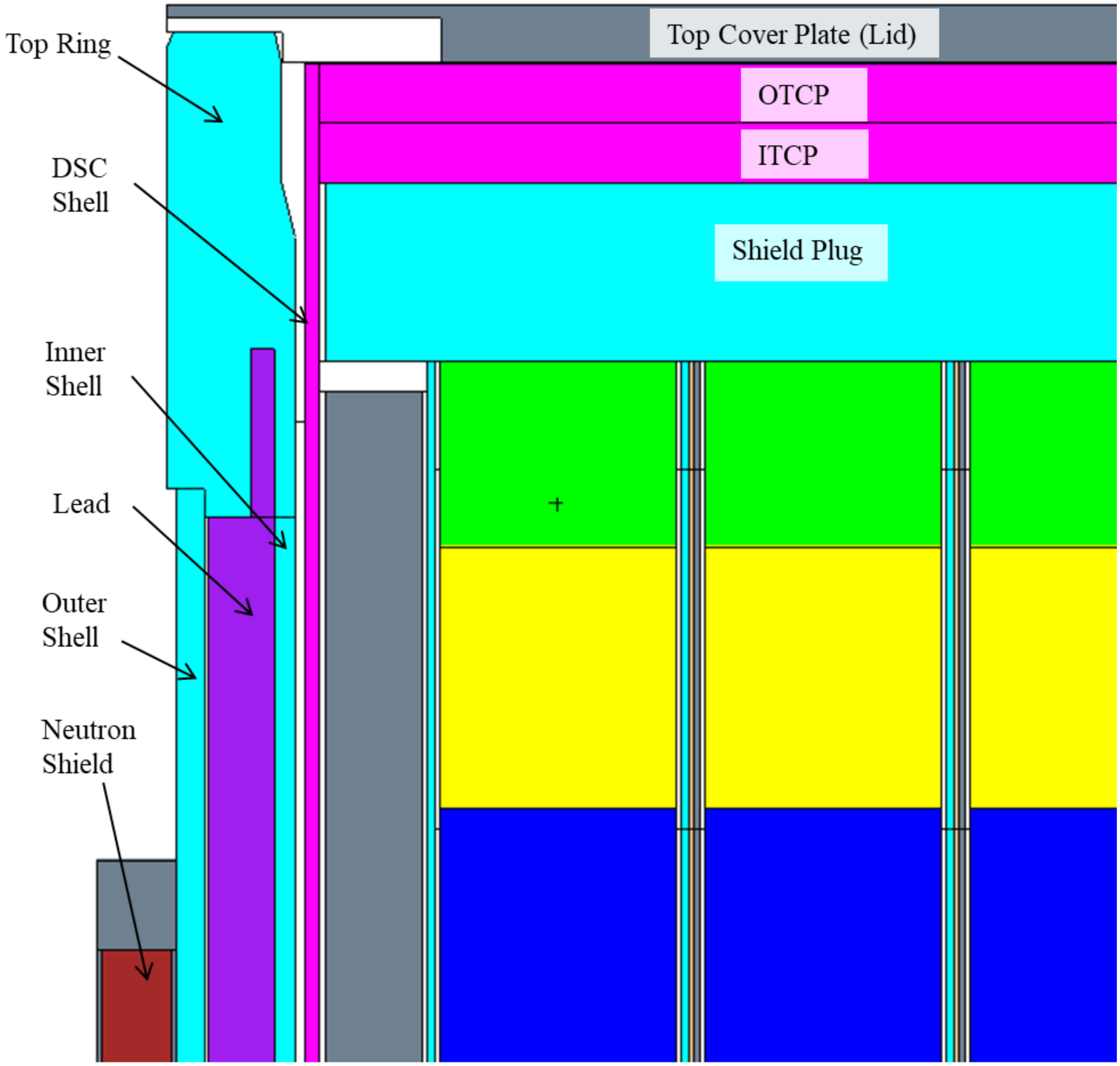


EOS-89BTH DSC in EOS-TC108 depicted; other configurations are similar.

Figure 6-4
General EOS-TC MCNP Model, x-z View



EOS-37PTH DSC in EOS-TC108 depicted; other configurations are similar.

72.48

Figure 6-5
Detailed Upper View of EOS-TC MCNP Model

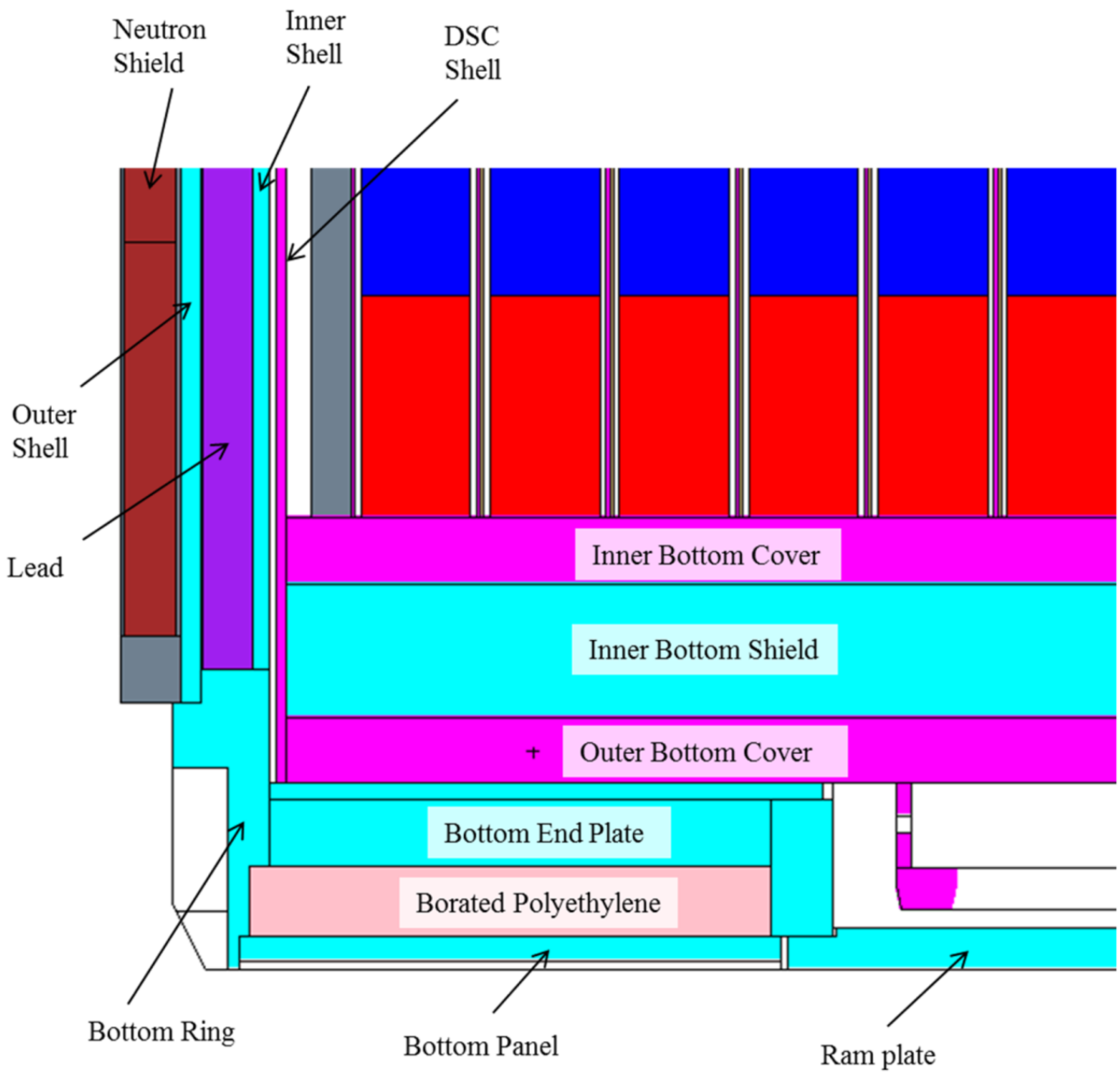
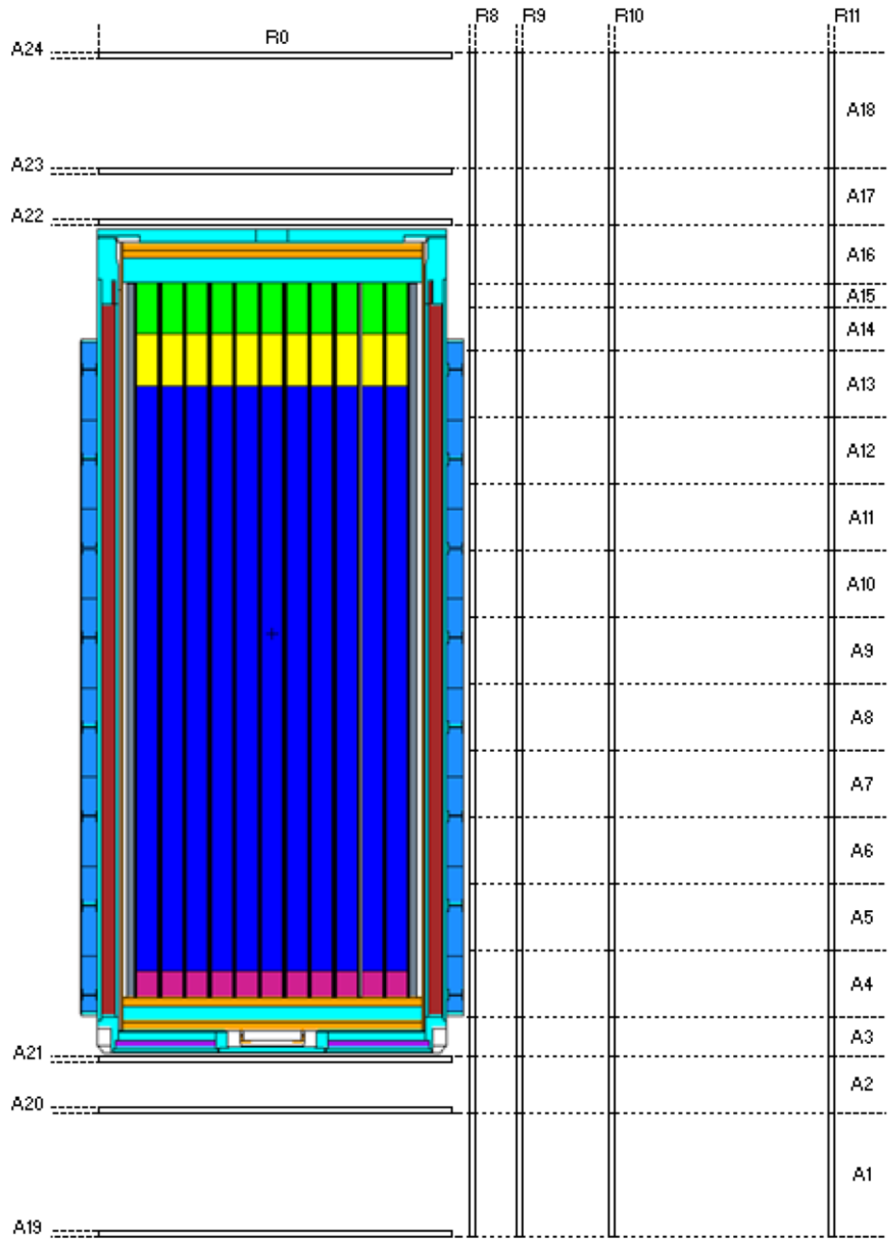
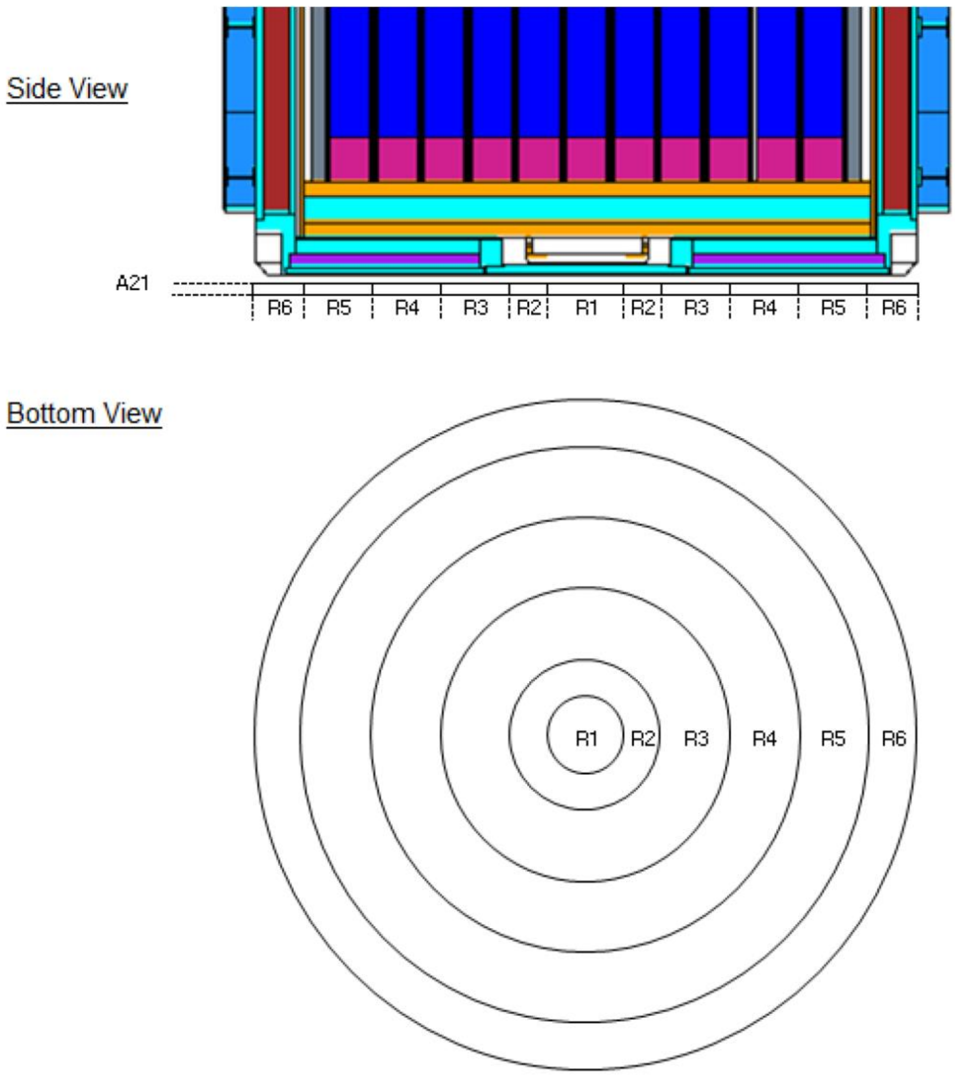


Figure 6-6
Detailed Lower View of EOS-TC MCNP Model



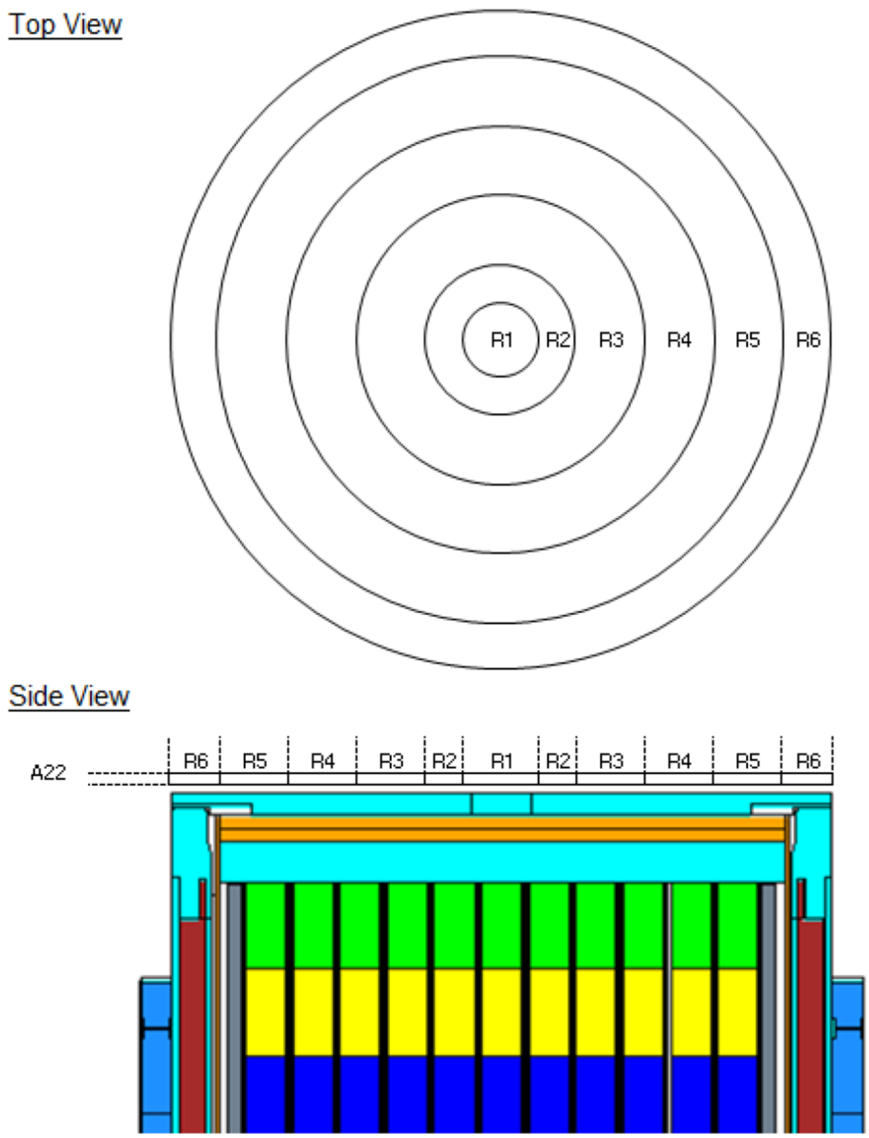
EOS-89BTH DSC in EOS-TC125/135 depicted; other configurations are similar.

Figure 6-7
EOS-TC General Dose Rate Tally Locations



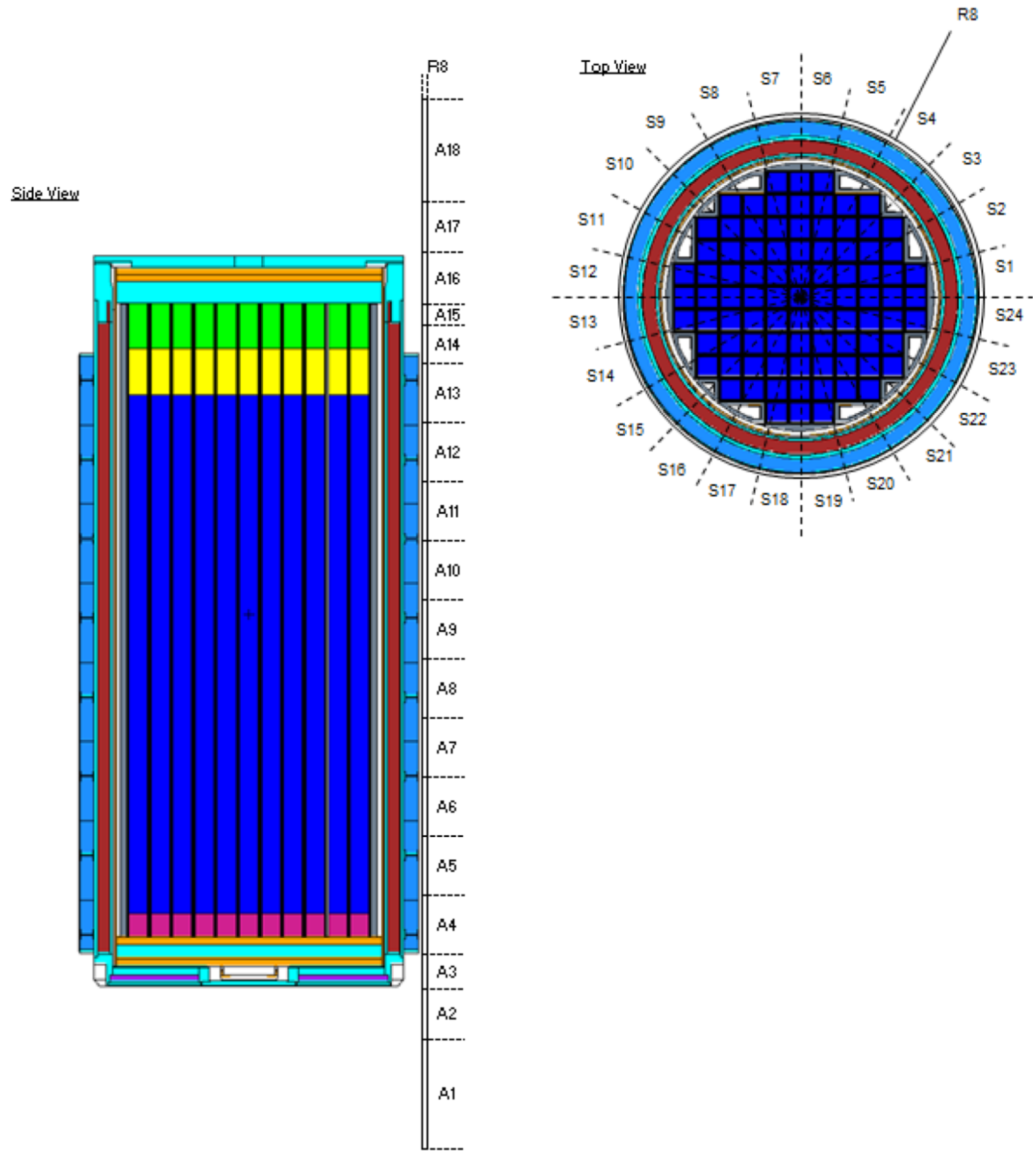
EOS-89BTH DSC in EOS-TC125/135 depicted; other configurations are similar.

Figure 6-8
EOS-TC Bottom Dose Rate Tally Locations, Transfer Configuration



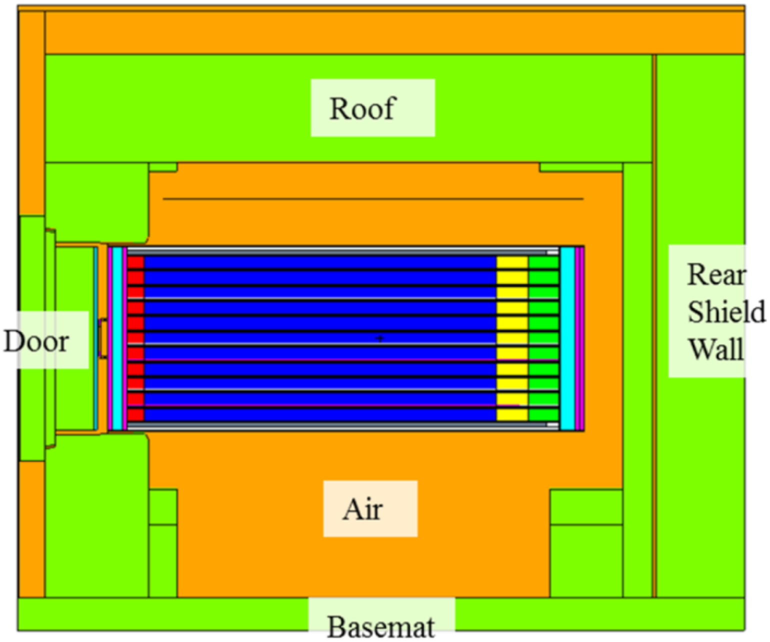
EOS-89BTH DSC in EOS-TC125/135 depicted; other configurations are similar.

Figure 6-9
EOS-TC Top Dose Rate Tally Locations, Transfer Configuration

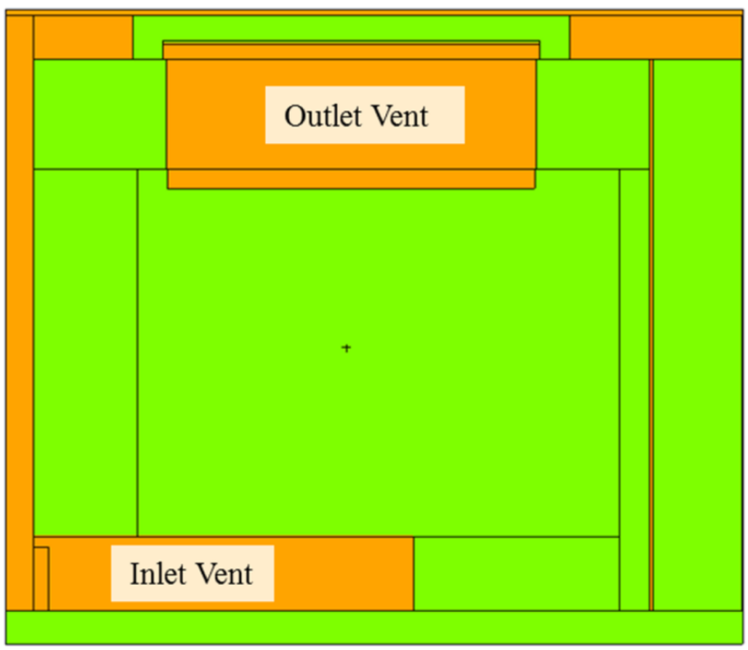


EOS-89BTH DSC in EOS-TC125/135 depicted; other configurations are similar.

Figure 6-10
EOS-TC Side Dose Rate Tally Locations, Transfer Configuration



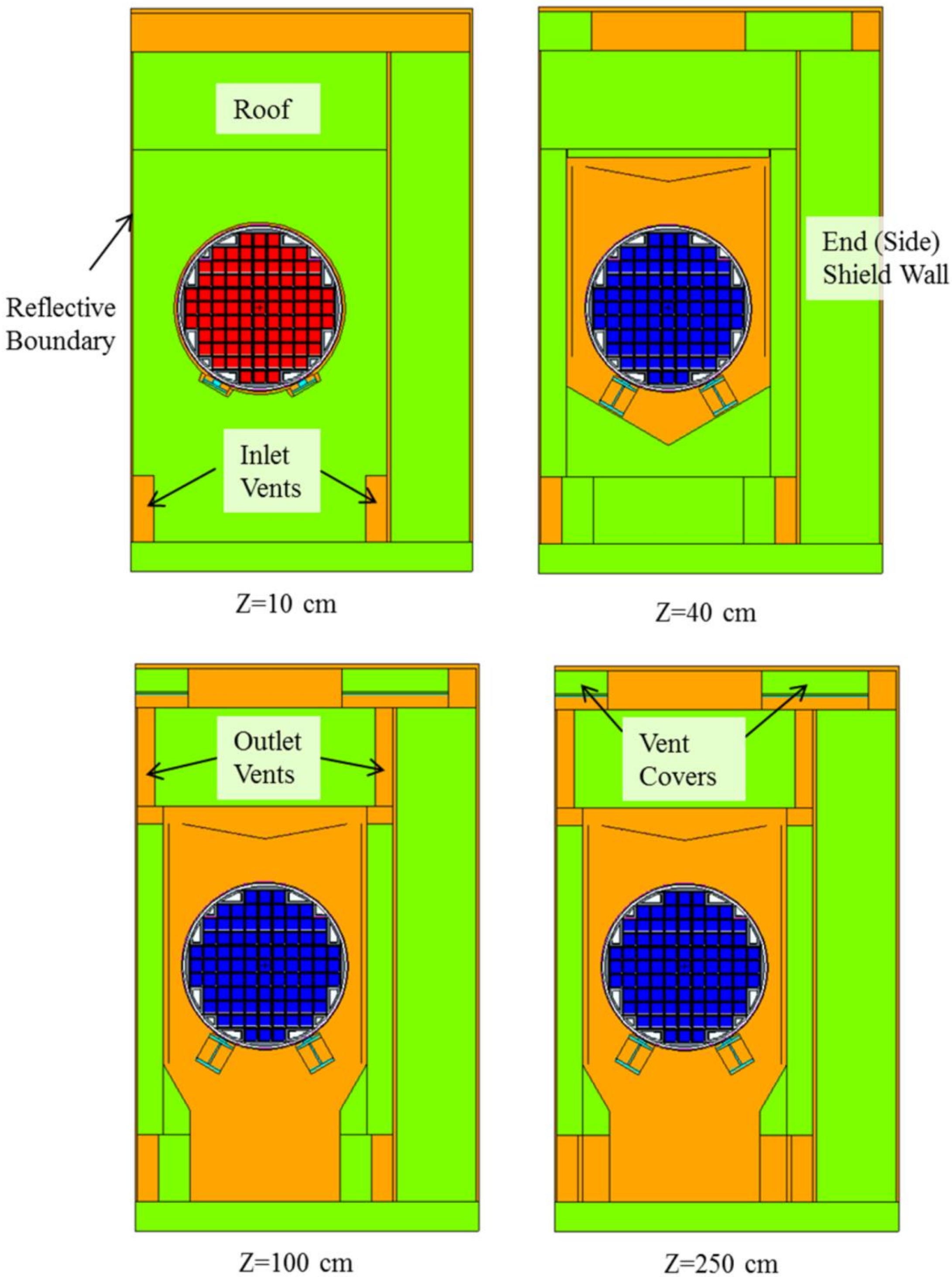
X = 0 cm



X = -143 cm

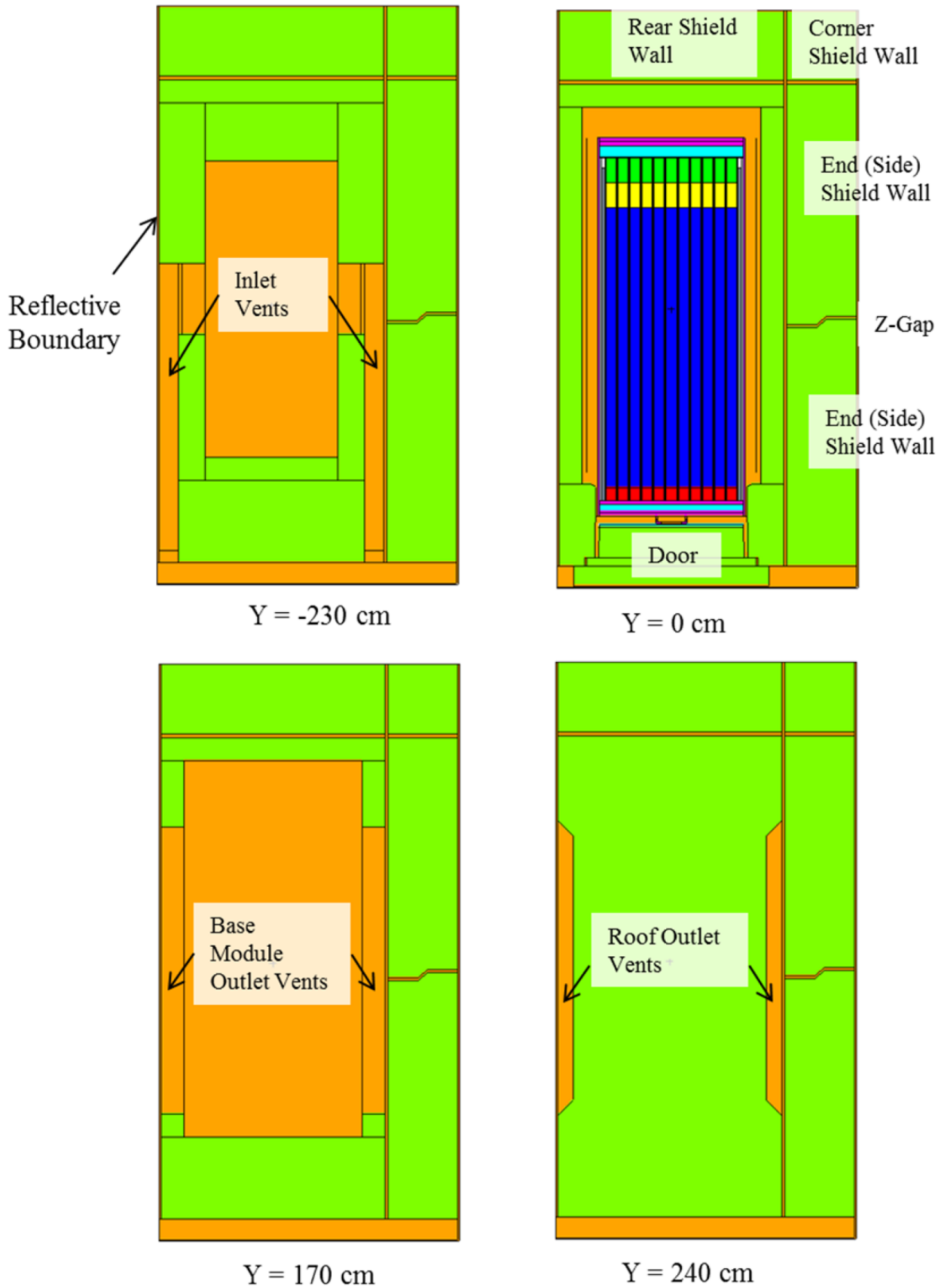
EOS-89BTH DSC in EOS-HSM-Medium depicted; other configurations are similar.

Figure 6-11
EOS-HSM MCNP Single-Reflection Model, z-y View



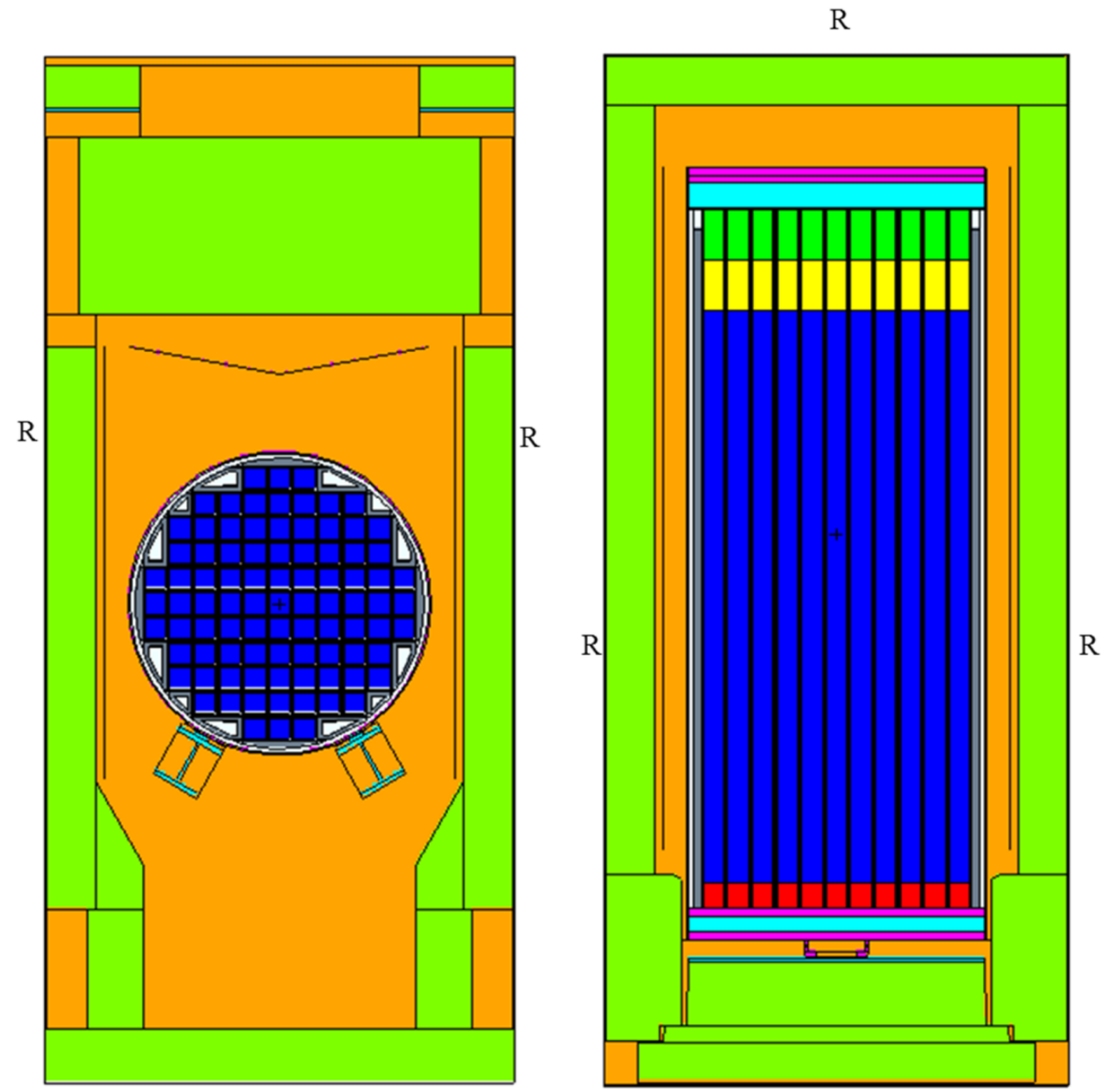
EOS-89BTH DSC in EOS-HSM-Medium depicted; other configurations are similar.

Figure 6-12
EOS-HSM MCNP Single-Reflection Model, x-y View



EOS-89BTH DSC in EOS-HSM-Medium depicted; other configurations are similar.

Figure 6-13
EOS-HSM MCNP Single-Reflection Model, x-z View



X-Y View X-Z View

Reflective surfaces are denoted with an "R".

Figure 6-14
EOS-HSM MCNP Triple-Reflection Model

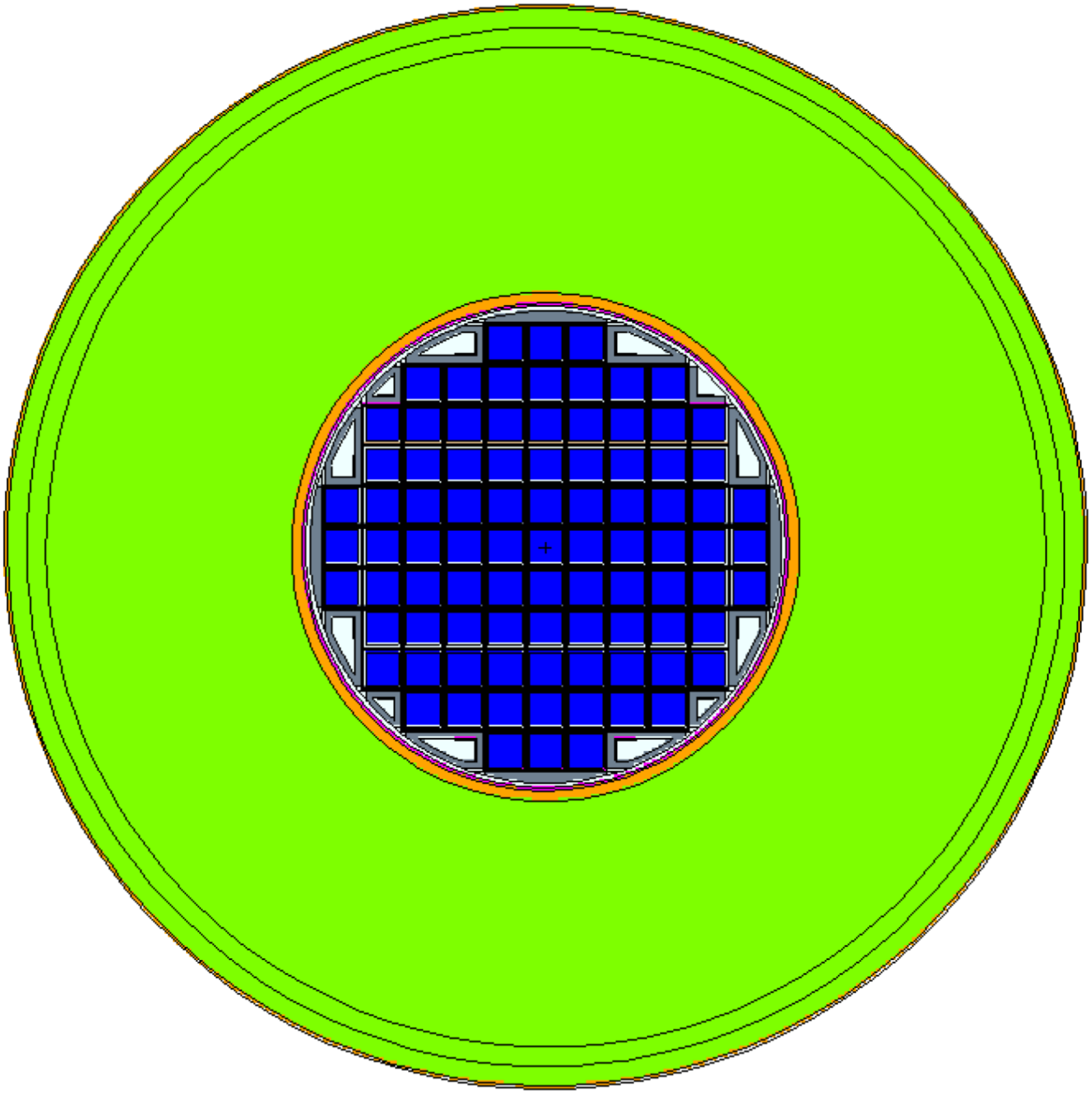


Figure 6-15
EOS-HSM MCNP Simplified Model for Grout Study

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CHAPTER 7
CRITICALITY EVALUATION

Table of Contents

List of Tables

List of Figures

7. CRITICALITY EVALUATION

NOTE: The referenced basket types throughout this chapter are based on the boron content in the poison plates. The term "basket types" in this chapter differs from the definition of the basket types in Chapter 1. The correlations between the basket types used in this chapter and the basket types identified in Chapter 1 are clarified below. *Note that damaged and failed fuel can only be loaded in the basket types A4L or B4L.*

	Basket Type Identification in Chapter 1 and Technical Specifications *[7-8]*	**Basket Type Identification in Chapter 7**
EOS-37PTH	A1/A2/A3/*A4H/A4L/A5*	A
	B1/B2/B3/*B4H/B4L/B5*	B
EOS-89BTH	A1/A2/A3	M1-A
	B1/B2/B3	M1-B
	C1/C2/C3	M2-A

The design criteria for the NUHOMS® EOS System dry shielded canisters (DSCs) require that the fuel loaded in the EOS-37PTH and EOS-89BTH DSCs remain subcritical under normal, off-normal and accident conditions as defined in 10 CFR Part 72. The criticality analyses performed to demonstrate that these DSCs *loaded with intact, damaged or failed fuel in the EOS-37PTH DSC, or loaded with intact fuel in the EOS-89BTH DSC* satisfy the stated requirements are presented in this chapter. *Failed fuel shall be loaded into a failed fuel canister (FFC) and include failed fuel assemblies (FAs), rods, rod segments, pellets, and debris.*

The DSCs consist of a shell assembly, an internal basket assembly, and extruded aluminum open section transition rails that provide the transition to a cylindrical exterior surface to match the inside surface of the shell. The EOS-37PTH DSC is designed to store and transport up to 37 pressurized water reactor (PWR) FAs with or without control components (CCs) while the EOS-89BTH is designed to store and transport up to 89 boiling water reactor (BWR) FAs with and without channels. The DSCs are of variable length to match the length of the fuel and CCs, as applicable, to be stored. The basket is composed of interlocking slotted plates to form an egg-crate type structure. The egg-crate structure forms a grid of 37 or 89 fuel compartments that house the spent fuel assemblies (SFAs). The egg-crate structure is composed of steel alloy, aluminum alloy, and poison plates.

The EOS-37PTH DSC criticality safety is ensured by fixed neutron absorbers, favorable geometry and credit for soluble boron in the pool during loading and unloading operations. The EOS-37PTH DSC uses a metal matrix composite (MMC) poison plate material, which is suitable for long-term use in radiation and thermal environments of a dry cask storage system. The EOS-37PTH DSC has two basket types, A and B that correspond to minimum B-10 loadings in mg B-10/cm^2, as shown in Table 7-1. In addition to the two different fixed poison loadings, soluble boron concentrations in the range 2000 to *2600* parts per million (ppm) are specified for the EOS-37PTH DSC as a function of fuel type and initial enrichment.

There are three basket types specified for the EOS-89BTH DSC. The EOS-89BTH DSC criticality safety is ensured by fixed neutron absorbers and favorable geometry. The baskets manufactured with MMC are designated M1-A and M1-B, while the baskets manufactured with BORAL® plates are designated M1-A, M1-B and M2-A, as shown in Table 7-2. In criticality evaluations, credit is taken only for 90% of B-10 areal density in the MMC and 75% in the BORAL® poison plates.

7.1 Discussion and Results

This section presents a general description of system application and criticality model for each DSC. The maximum allowable fuel enrichments as a function of basket type are specified for BWR and PWR fuel. Additionally, the minimum soluble boron concentrations (ppm) for the PWR fuel are also presented for each basket type.

The results of the evaluations demonstrate that the maximum calculated k_{eff}, including statistical uncertainty, are less than the upper subcritical limit (USL) determined from a statistical analysis of benchmark criticality experiments. The statistical analysis procedure includes a confidence band with an administrative safety margin of 0.05.

EOS-37PTH

The EOS-37PTH DSC consists of a shell assembly, which provides confinement and shielding, and an internal basket assembly, which locates and supports the PWR FAs. A detailed description of the DSC and Basket is found in Chapter 1, Section 1.2.1.1.

The FAs evaluated for storage in the EOS-37PTH DSC are considered intact*, damaged, or failed.* The authorized FAs are presented in Chapter 2. The payload of the EOS-37PTH DSC may include CCs that are contained within the FA. The authorized CCs are listed in Chapter 2. Reconstituted fuel assemblies with replacement rods that displace an equal amount of water as the original rods are also authorized for storage and are bounded by the intact fuel, for criticality purposes. *Also, a below capacity loading or short-loading as shown in Figure 7-13, is allowed for storage in the EOS-37PTH DSC.*

A maximum of 37 intact FAs can be stored in the EOS-37PTH DSC. In addition, a maximum of eight damaged FAs or four FFCs loaded with failed FAs or failed fuel debris, balanced with intact FAs, can be accommodated in the EOS-37PTH DSC. The loading plans are shown in Figures 1F and 1H of the Technical Specifications [7-8].

All failed fuel shall be stored in an FFC. Secondary containers, such as rod storage baskets, shall be placed in an FFC. No credit is taken for the FFC or any secondary containers, although all secondary containers must be designed to allow drainage.

The criticality analysis performed uses the most reactive configuration *for intact fuels* to determine the maximum allowable enrichment *of 37 intact fuels stored in the EOS-37PTH DSC* for each FA class, as a function of soluble boron and basket type, with and without CCs. The results are presented in Table 7-3.

Additionally, the most reactive configuration between damaged and failed fuels is used to determine the maximum allowable enrichment of up to eight damaged fuels or four failed fuels stored in the EOS-37PTH DSC with intact fuels, for each FA class, as a function of soluble boron and basket type, with and without CCs. The results are presented in Table 7-51.

EOS-89BTH

The EOS-89BTH DSC consists of a shell assembly, which provides confinement and shielding, and an internal basket assembly, which locates and supports the BWR FAs. A detailed description of the DSC and Basket is found in Chapter 1, Section 1.2.1.2.

The FAs evaluated for storage in the EOS-89BTH DSC are considered intact. The authorized FAs are presented in Chapter 2. Reconstituted fuel assemblies with replacement rods that displace an equal or greater amount of water as the original rods are also authorized for storage and are bounded by the intact fuel, for criticality purposes.

The criticality analysis performed uses the most reactive configuration to determine the maximum allowable enrichment for the representative BWR FA design as a function of basket type. The results are presented in Table 7-4.

Computer models for the EOS-37PTH DSC and EOS-89BTH DSC are discussed in Section 7.3. The SCALE 6.0 [7-1] computer code package is employed to perform the criticality calculations. The criticality evaluation is presented in Section 7.4. The criticality benchmarks are described in Section 7.5.

7.2 Package Fuel Loading

EOS-37PTH

The EOS-37PTH DSC is designed to accommodate the FAs listed in Chapter 2. Since the assemblies listed represent a wide range of fuel types and configurations, it is demonstrated first that the most reactive case is obtained for each fuel class. In this context, the fuel class is defined as a set of fuel assembly designs with the same array size and rod pitch or rod outer diameter. The most reactive case for each class is used to determine the maximum allowable enrichments *for intact, damaged, and failed fuel*.

The payload of the EOS-37PTH DSC may include CCs that are contained within the FA. The authorized CCs are listed in Chapter 2. The only change to the package fuel loading required to evaluate the addition of the CCs is to replace the borated water in the water holes with CC materials. Since the CCs displace the borated moderator in the assembly guide and/or the instrument tubes, an evaluation is performed to determine the potential impact of the storage of CCs that extend into the active fuel region on the system reactivity. CCs that extend into the active fuel regions, such as burnable poison rod assemblies (BPRAs), control rod assemblies (CRAs), axial power shaping rod assemblies (APSRAs), control element assemblies (CEAs), and neutron source assemblies (NSAs) are conservatively assumed to exhibit the neutronic properties of $^{11}B_4C$ (no credit taken for B-10 content).

Since the criticality analysis models simulate only the active fuel height, any CC that is inserted into the FA in such a way that it does not extend into the active fuel region is considered as authorized for storage without adjustment to the soluble boron content or initial enrichment, as required for CCs that extend into the active fuel region.

EOS-89BTH

The EOS-89BTH DSC is designed to accommodate the FAs listed in Chapter 2. Since the assemblies listed represent a wide range of fuel types and configurations, a representative FA is determined by comparing k_{eff} values for the FAs listed, with and without various thicknesses of channels. The representative FA is used to obtain the maximum allowable enrichment as a function of basket type.

The maximum allowable enrichment is obtained using the GNF2 10x10 FA, except for the KKL-BWR 11/16 and SVEA-96Opt2 FAs, classified with a BWR fuel identification of ABB-10-C, in Table 7-39. The maximum allowable enrichment requirements for these two assembly designs are also specified in Table 7-4.

7.3 Model Specification

The following sections describe the physical models and materials of the EOS-37PTH and EOS-89BTH DSCs as loaded and transferred in the EOS transfer casks (TCs) (i.e., EOS-TC108, -TC125 or -TC135) used for input to KENO V.a. module of the CSAS5 sequence of SCALE 6.0 [7-1] to perform the criticality evaluation. The reactivity of the canister under storage conditions is bounded by the EOS-TC analysis with a zero internal moderator density case, which bounds the storage conditions in the horizontal storage module (HSM) because: (1) the canister internals are always dry (purged and backfilled with helium) while in the HSM, and (2) the EOS-TC contains materials such as steel and lead, which provide close reflection of fast neutrons back into the basket, while the HSM materials (concrete) are much further from the sides of the DSC and thereby tend to reflect thermalized neutrons back to the canister, which are absorbed in the canister materials, reducing the system reactivity.

7.3.1 Description of Criticality Analysis Model

EOS-37PTH

The EOS-TC and DSC are explicitly modeled using the appropriate geometry options in the KENO V.a module, of the CSAS5 sequence of SCALE 6.0. Several models are developed to evaluate the fabrication tolerances of the DSC, FA type *and physical conditions (intact, damaged, and failed)*, assembly location, initial enrichment, fixed poison loading, soluble boron concentration, and storage of CCs with the fuel.

The criticality evaluation is performed using a basket section equivalent to the active fuel height with periodic axial boundary conditions, which effectively makes the model infinitely tall. The key basket dimensions utilized in the calculation are shown in Table 7-5. The basic KENO model, with a length equivalent to the active fuel height, is modeled with periodic boundary conditions axially, and reflective boundary conditions radially. The axial section essentially models an infinite active fuel height DSC. The model does not explicitly include the water neutron shield; however, the infinite array of casks without the neutron shield is conservatively modeled with unborated water between the casks and in the TC/DSC annulus. For the purpose of storage, the configuration is not expected to encounter any regions containing fresh water once the FAs are loaded. Therefore, this hypothetical configuration that models an infinite array of casks in close reflection is conservative.

The FAs within the basket are modeled as arrays of fuel pins and guide/instrument tubes. Spacer grids and subcomponents such as oversleeves are not modeled since their effect on reactivity is insignificant. The compartment plates effectively surround each FA. The basket cross section shown in Figure 7-1 illustrates that the basket is composed of eight sets of plates traversing vertically and horizontally across the DSC where this pattern occurs repeatedly in the axial region. [

] The gaps for the egg-crate included in the starting KENO model are also illustrated in Figure 7-3. In addition, up to 1 inch of active fuel length is conservatively excluded from poison coverage as shown in Figure 7-4.

The basket structure is connected to the DSC shell by perimeter transition rail assemblies. The R45 and R90 transition rails that enable the cylindrical exterior surface of the basket to match the inside surface of the DSC are attached to the basket structure using steel fasteners that are installed at set intervals axially. The R90 rails are solid aluminum, while the R45 are open aluminum sections, held against the basket with steel plates of equal length and rail spacers of equal length that bridge the gap between an adjacent wall and a rail wall. The DSC is a 0.50-inch thick stainless steel shell with an inner diameter of 74.5 inches. The DSC dimension, the TC inner and outer shell dimensions and lead shield shell thickness are provided in Table 7-6. Note that although the dimensions provided for the 108-ton TC are not utilized in the model, an evaluation is performed to establish the bounding dimensions. The TC and DSC are explicitly modeled using the appropriate geometry options in the KENO V.a. module of the CSAS5 sequence in SCALE 6.0. The DSC and TC are a simple combination of cylindrical volumes, which are modeled in a straight forward manner. The R90 rails are formed by the virtue of the definition of the inner cylindrical volume of the DSC using the KENO geometry.

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EOS-89BTH

The EOS-TC and DSC are explicitly modeled using the appropriate geometry options in KENO V.a module of the CSAS5 sequence of SCALE 6.0. Several models are developed to evaluate the fabrication tolerances of the DSC, FA locations, FA type, initial enrichments, and fixed poison loading.

The nominal dimensions of the DSC and the EOS-TC models are summarized in Table 7-5 and Table 7-6. The materials modeled are listed in Table 7-8 and Table 7-9.

The model utilized is an egg-crate segment model with 12-inch height and full radial cross section of the cask and canister with periodic boundary conditions at the axial boundaries (top and bottom) and reflective boundary conditions at the radial boundaries (sides) to represent infinite arrays of package. This axial section essentially models one building block of the egg-crate basket structure. Periodic boundary conditions ensure that the resulting KENO model is essentially infinite in the axial direction. The model does not include the water neutron shield; however, the infinite array of casks without the neutron shield may contain unborated water between the casks and in the canister/TC gap.

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The criticality calculations are performed to determine:

- The most reactive fuel (MRF),
- The most reactive configuration (MRC) and
- The maximum allowable enrichments for the various B-10 loadings in the poison plates.

The MRF and MRC evaluations make use of the design specifications of the basket that differ from the actual design as described above.

The extruded aluminum open-section transition rails, which are reinforced with internal steel as necessary, provide the transition to a rounded surface to match the inside surface of the DSC shell. The transition rail geometry is modeled as a mixture of aluminum and water in the model and calculations are performed to determine the optimal ratio of the water in the rails. Pure aluminum is assumed in the starting KENO or base model for the MRF analyses.

The basket egg-crate structure is modeled with the various radial and axial gaps that are filled with internal moderator. These gaps are illustrated in Figure 7-19. Further, the design details summarized in Table 7-11 are employed to calculate the egg-crate slot width while the gap dimensions in Table 7-12 are employed in a sensitivity evaluation as part of the MRC analysis.

Figure 7-14 and Figure 7-15 show the cross section views of the base model. The GE12 10X10 FA is used with an enrichment of 4.20 wt. % U-235. The poison plate is modeled with a B-10 areal density of 29 mg B-10 per cm^2. The dimensions for TC108 are used and a 0.12-inch thick fuel channel is included. The FA is placed inwardly in the fuel compartment to have the FAs as close as possible. Figure 7-16 shows the radial cross section of the center fuel compartment in the base model. Figure 7-17 shows the radial cross section of the fuel pin. The gap between the cladding and the fuel pin is modeled as water. Figure 7-18 shows the plate thicknesses for the horizontal plates and the vertical plate thickness are the same as the horizontal plates. Note that the plate thicknesses presented in Table 7-5 are used in the MRF and MRC evaluations.

The EOS-89BTH DSC, as transferred in the EOS-TC, is capable of housing standard BWR FAs with or without fuel channels and as intact FAs. The FAs considered as authorized contents are listed in the Chapter 2. A unique identifier is associated with a modeled FA design as described in Table 7-39. The FA layouts are shown in Figure 7-20.

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The inward placement of FAs is chosen for the MRF analysis compared to the FAs centered in their fuel compartments since it leads to a higher system reactivity, which is also confirmed in the MRC analysis. The radial cross section view of one sample model for inwardly placed FAs is shown in Figure 7-21 and Figure 7-22.

It is assumed that the gap between the DSC and TC is filled with water in the MRF analysis. The optimum water density resulting in the highest system reactivity is investigated in the MRC analysis.

The TCs are cylindrical, shielded vessels constructed from carbon steel and lead. It is assumed that the neutron shielding on the TC has vanished and is not included in the model.

The outside of the TC is assumed to be void in the MRF analysis. The optimum water density for the highest system reactivity is investigated in the MRC analysis.

7.3.2 Package Regional Densities

The Oak Ridge National Laboratory (ORNL) SCALE 6.0 [7-1] code package contains a standard material data library for common elements, compounds, and mixtures. All materials used for the TC and canister analyses are available in this data library.

A list of the relevant materials used for the criticality evaluation is provided in Table 7-8 and Table 7-9. The poison plate is MMC for the EOS-37PTH DSC. The poison plate is either MMC or BORAL® for the EOS-89BTH DSC. The poison plate material specifications are modeled considering a 90% B-10 credit for the B-10 loading in the MMC and 75% credit for the B-10 loading in BORAL®.

7.4 Criticality Calculation

This section describes the various criticality evaluations carried out for the NUHOMS® EOS System DSCs. The analyses are performed with the CSAS5 module of the SCALE 6.0 code system. The most reactive configuration for each DSC is determined with consideration of fabrication tolerances, FA location, and basket dimensions important to criticality. A series of calculations is performed to determine the relative reactivity of the various FA designs to determine the most reactive assembly type. *Additional analyses are performed to determine the relative reactivity of the various damaged and failed fuel configurations for the EOS-37PTH DSC.* Finally, the maximum allowable enrichment for the minimum required criticality control mechanism, which is soluble boron and basket type for PWR FAs, and basket type for BWR FAs, is determined *for the respective authorized loadings*.

EOS-37PTH

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7.4.1 Calculational Method

7.4.1.1 Computer Codes

The CSAS5 control module of SCALE 6.0 [7-1], is used to calculate the effective multiplication factor (k_{eff}) of the fuel in the TC (bounds fuel in HSM). The CSAS5 control module allows simplified data input to the functional modules BONAMI, NITAWL, and KENO V.a. These modules process the required cross sections and calculate the k_{eff} of the system. BONAMI performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL applies Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{eff} of a three-dimensional system. Enough neutron histories are run so that the standard deviation is below 0.0010 for all calculations.

7.4.1.2 Physical and Nuclear Data

The physical and nuclear data required for the criticality analysis include the FA data and cross section data as described below.

The pertinent data for criticality analysis for each FA evaluated in the EOS-37PTH DSC and EOS-89BTH DSC are listed in Chapter 2. The criticality analysis uses the 44-group cross section library built into the SCALE 6.0 system. Oak Ridge National Laboratory used ENDF/B-V data to develop this broad-group library, specifically for the criticality analysis of a wide variety of thermal systems.

7.4.1.3 Bases and Assumptions

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The following assumptions are employed in the criticality calculations.

EOS-37PTH and EOS-89BTH

- Fresh fuel is assumed. No credit is taken for fissile depletion, fission product poison, or burnable absorbers.
- *For intact fuels, f*uel rods are filled with full density fresh water in the pellet-clad gap.
- The neutron shield and steel neutron shield jacket (outer skin) of the cask are conservatively removed and infinite arrays of casks are pushed close together with external moderator (unborated water) in the interstitial spaces.
- The MMC poison plates are modeled with minimum specified B-10 content required for safety.
- Temperature is 20 °C (293K).
- All steel and aluminum alloys of the basket structure are modeled as SS304 and aluminum, respectively. While these compositions, which are provided in the SCALE 6.0 standard composition library, have small differences with compositions of the various steels and aluminum, they have negligible effect on the results of the calculation.
- All zirconium-based materials in the fuel are modeled as Zircaloy-4 for PWR and Zircaloy-2 for BWR fuel evaluations. The small differences in the composition of the various clad/guide compartment materials have negligible effect on the results of the calculations.
- Omission of grid plates, spacers, and hardware in the FA.
- No integral burnable absorbers, such as gadolina, erbia or any other absorbers, are included.
- The fuel rods are modeled assuming a stack density of 97.5% theoretical density with no allowance for dishing or chamfer in the fuel rod model, which conservatively bounds the total fuel content in the FA authorized for storage.

<u>EOS-37PTH Only</u>

- Non-fuel assembly hardware that extends into the active fuel regions, such as BPRAs, CRAs, APSRAs, CEAs, and NSAs, are conservatively assumed to exhibit the neutronic properties of $^{11}B_4C$ (no credit taken for B-10 content). There is negligible neutron absorption from any of this hardware and it is collectively referred to as CCs.
- Water in the EOS-37PTH DSC cavity contains soluble boron at optimum density. The soluble boron is mixed with the moderator. By varying the moderator density from 50% to 100% of full density, the density of water at which the reactivity is maximized is determined.
- *T*he maximum planar average initial fuel enrichment is modeled as uniform everywhere throughout the assembly. Natural uranium blankets and axial or radial enrichment zones are modeled as enriched uranium at the planar average initial enrichment.
- The portion of the DSC corresponding to the axial length of the active fuel is modeled for the criticality analysis. The axial ends of the DSC are not modeled.

In addition, the damaged and failed FA criticality calculations also employ the following assumptions for the EOS-37PTH DSC:

- *Single-ended shear assumes one row of fuel rods not axially severed is displaced to a new location.*
- *Double-ended shear assumes that the selected sheared row displaced with a single-ended shear is further split axially to result in an "extra" row of fuel rods in the axial region where the severed fuel rod pieces are displaced to.*
- *Bent or bowed fuel rods assume that the fuel is intact but that the rod pitch is allowed to vary from its nominal fuel rod pitch.*
- *Fuel assembly lattices with less fuel rod assume missing fuel rods.*
- *Full fuel rod lattices assume that guide and instrument tubes are replaced with fuel rods (failed fuel assumption).*
- *De-cladded fuel rods assume severe cladding damage (failed fuel assumption).*
- *No credit is taken for FFCs (failed fuel assumption).*
- *Both damaged and failed FAs are modeled as failed (total of 12), which is highly conservative because damaged and failed fuel cannot be stored in the same DSC.*

The following assumptions are employed in the criticality evaluation for failed FA debris in the EOS-37PTH DSC:

- *No credit is taken for FFC or any secondary containers.*
- *A total of four failed fuel locations is considered; remaining locations are modeled with intact fuel, see Figure 7-25.*

- *A range of pellet diameters (0.6 to 1.0 inches) and array sizes (8x8, 9x9, 10x10) is considered until the peak reactivity is identified.*

EOS-89BTH Only

- Only one section of height (12 in.) equal to one egg-crate section of the basket is modeled with periodic boundary conditions at the axial boundaries (top and bottom) and reflective boundary conditions at the radial boundaries (sides) to represent infinite long FAs an infinite arrays of package. From a criticality standpoint, modeling a repetitive egg-crate section with periodic axial boundary conditions or a full active fuel length with periodic axial boundary conditions (EOS-37PTH) that results in an infinite axial length are not different.
- For intact fuel, the pins are modeled assuming the maximum lattice average enrichment uniformily everywhere in the lattice. Natural uranium blankets, gadolinia, integral fuel burnable absorber (IFBA), erbia, or any other burnable absorber rods and axial or radial enrichment zones are modeled as uranium with the maximum lattice average enrichment.
- Water density is at optimum internal and external moderator density.
- It is assumed that the fuel rod outer diameter varies by ±0.005 inch for this evaluation.

7.4.1.4 Determination of k_{eff}

The Monte Carlo calculations performed with CSAS5 (KENO V.a) use a flat neutron starting distribution. The total number of histories traced for each calculation is at least 800,000. This minimum number of histories is sufficient to achieve source convergence and produce standard deviations of less than 0.0010. The maximum k_{eff} for the calculation is determined with the following formula:

$$k_{eff} = k_{keno} + 2\sigma_{keno}$$

Proprietary Information on Pages 7-17 through 7-21
Withheld Pursuant to 10 CFR 2.390

B. Determination of the Most Reactive Fuel Type *for Each Assembly Class*

The most reactive configuration obtained through the evaluations described in Section 7.4.2.A is used to determine the most reactive FAs for each class listed in Chapter 2.

The fuel designs listed in Chapter 2 are evaluated to determine the most reactive FA type with initial enrichment of 5.0 wt. % U-235, water with 2000 ppm soluble boron with 100% internal moderator density and poison plate B-10 content corresponding to the Type B basket specified in Table 7-1, or 31.5 mg/cm^2 B-10 in the model. The results are presented in Table 7-16 and a representative FA design from each class is selected for further evaluation. These fuel designs shown in **BOLD TEXT** in Table 7-16.

C. Determination of the Maximum *Intact* Initial Enrichment for Assembly Class

The analysis performed in this section uses the most reactive fuel type for each assembly class to determine the maximum allowable planar average initial enrichment as a function of basket assembly type (poison plate loading) and soluble boron concentration. No credit is taken for burnup. Only the fixed poison plate loading is changed for each model. In addition, for each case the internal moderator density is varied to determine the peak reactivity for the specific configuration.

The EOS-37PTH DSC/EOS-TC model for this evaluation differs from the actual design in the following ways:

- The B-10 content is at the minimum required for reactivity control for each basket assembly type,
- The neutron shield and the neutron shield jacket (outer skin) of the EOS-TC are conservatively removed and EOS-TC pushed together with fresh water between the casks,
- The dimensions with limiting fabrication tolerances, as determined by the evaluations described in this section, are modeled,

WE 17x17 Class Fuel Assemblies

The most reactive WE 17x17 class FA is the WE 17x17 LOPAR assembly. The results for the WE 17x17 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-17 and Table 7-18, respectively. The results in the Type B basket are presented in Table 7-19 and Table 7-20.

BW 15x15 Class Assemblies

The most reactive B&W 15x15 class assembly is the Mark B10 assembly. The results for the B&W 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-21 and Table 7-22, respectively. The results in the Type B basket are presented in Table 7-23 and Table 7-24.

WE 15x15 Class Assemblies

The most reactive WE 15x15 class assembly is the Tihange 1 WE 15x15 assembly. The results for the WE 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-25 and Table 7-26, respectively. The results in the Type B basket are presented in Table 7-27 and Table 7-28.

CE 15x15 Class Assemblies

The most reactive CE 15x15 class assembly is the Palisades assembly. The results for the CE 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-29 and Table 7-30, respectively. The results in the Type B basket are presented in Table 7-31 and Table 7-32.

CE 14x14 Class Assemblies

The most reactive CE 14x14 class assembly is the Framatome CE assembly. The results for the CE 14x14 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-33 and Table 7-34, respectively. These results indicate that the maximum allowable enrichment of 5.0 wt. % U-235 is obtained using type A basket and a soluble boron concentration of 2000 ppm.

14x14 Class Assemblies

The most reactive 14x14 class assembly is the WE 14x14 Std/LOPAR/ZCA/ZCB assembly. The results for the 14x14 class assembly calculations with and without CCs in the Type A basket are presented in Table 7-35 and Table 7-36, respectively. These results indicate that the maximum allowable enrichment of 5.0 wt. % U-235 is obtained using type A basket and a soluble boron concentration of 2000 ppm.

CE 16x16 Class Assemblies

The most reactive CE 16x16 class assembly is the AREVA design assembly. The results for the CE 16x16 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-37 and Table 7-38, respectively. These results indicate that the maximum allowable enrichment of 5.0 wt. % U-235 is obtained using type A basket and a soluble boron concentration of 2000 ppm.

Proprietary Information on Pages 7-24 through 7-26
Withheld Pursuant to 10 CFR 2.390

E. Determination of the Maximum Failed Initial Enrichment for Each Assembly Class

A maximum of eight damaged fuels or four failed fuels balanced with intact fuels can be accommodated in the EOS-37PTH DSC, as shown in Figures 1F and 1H of the Technical Specifications [7-8]. For criticality analyses, a single and conservative loading plan is considered to cover both damaged and failed FA loadings, as shown in the KENO model plot Figure 7-24. The most reactive configuration determined in Section 7.4.2.D.3 is considered for the 12 failed FAs in the loading. Failed fuel debris is addressed separately in Section 7.4.2.F.

The maximum allowable planar average initial enrichment of failed FAs balanced with intact FAs, for each FA class, as a function of basket assembly type (poison plate loading) and soluble boron concentration is documented in Table 7-51 with and without CCs. The maximum allowable enrichment determined for the loading of 37 intact FAs in Section 7.4.2.C applies to the intact FAs when determining the maximum allowable enrichments for the failed FAs in the loading plan shown in Figure 7-24. The failed design basis KENO model is used for each FA class evaluation. No credit is taken for burnup. The internal moderator density between 50% and 100% is varied to determine the peak reactivity for the specific configuration.

The EOS-37PTH DSC/EOS-TC model for this evaluation differs from the actual design and loadings as shown in the Technical Specification Figure 1F and Figure 1H [7-8] in the following ways:

- *The B-10 content is at the minimum required for reactivity control for each basket assembly type,*
- *Failed FAs are loaded in 12 fuel compartments,*
- *The neutron shield and the neutron shield jacket (outer skin) of the EOS-TC are conservatively removed and EOS-TC pushed together with fresh water between the casks,*
- *The dimensions with limiting fabrication tolerances, as determined by the evaluations described in this section, are modeled.*

Two different fixed poison loadings (Basket Types A and B) are analyzed in the criticality calculations as listed in Table 7-1. The soluble boron concentration is varied from 2000 ppm to 2500 ppm (2600 ppm for the BW 15x15 FA class). The maximum analyzed initial enrichment is 5.0 wt. % U-235.

WE 17x17 Class Assemblies

The results for the WE 17x17 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-52 and Table 7-53, respectively. The results in the Basket Type B basket are presented in Table 7-54 and Table 7-55.

CE 16x16 Class Assemblies

The results for the CE16x16 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-56 and Table 7-57, respectively. The results in the Basket Type B are presented in Table 7-58 and Table 7-59.

BW 15x15 Class Assemblies

The results for the BW 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-60 and Table 7-61, respectively. The results in the Basket Type B are presented in Table 7-62 and Table 7-63.

CE 15x15 Class Assemblies

The results for the CE 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-64 and Table 7-65, respectively. The results in the Basket Type B are presented in Table 7-66 and Table 7-67.

WE 15x15 Class Assemblies

The results for the WE 15x15 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-68 and Table 7-69, respectively. The results in the Basket Type B are presented in Table 7-70 and Table 7-71.

CE 14x14 Class Assemblies

The results for the CE 14x14 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-72 and Table 7-73, respectively. The results in the Basket Type B are presented in Table 7-74 and Table 7-75.

WE 14x14 Class Assemblies

The results for the WE 14x14 class assembly calculations without and with CCs in the Type A basket are presented in Table 7-76 and Table 7-77, respectively. The results in the Basket Type B are presented in Table 7-78 and Table 7-79.

As the failed FA configuration bounds the various damaged FA configurations, the maximum allowable planar average initial enrichments determined above are applicable for the loading of up to four failed FAs balanced with intact FAs, or for the loading of up to eight damaged FAs balanced with intact FAs. In addition, considering the conservatisms that have been used to create the failed design basis KENO model (i.e., guide tube locations filled with fuel rods or de-cladded fuel rods), damaged or failed FAs can be loaded either with or without CCs.

Proprietary Information on Pages 7-30 through 7-31
Withheld Pursuant to 10 CFR 2.390

7.4.3 EOS-89BTH Fuel Loading Optimization

As described in Section 7.3.1, the base model is employed to perform criticality calculations to determine the MRF design. A representative FA design is chosen based on the MRF analysis to determine the MRC of the system. By using the representative fuel and the MRC, maximum allowable and enrichment as a function of basket type (B-10 loading) for BWR FAs in the EOS-89BTH DSC are determined to ensure the system k_{eff} is below the USL.

Proprietary Information on Pages 7-33 through 7-35
Withheld Pursuant to 10 CFR 2.390

C. Determination of the Maximum Initial Enrichment for BWR Fuel Assemblies

The design basis KENO model with the GNF-2 fuel assembly design is employed to determine the maximum allowable initial enrichment for the three allowable fixed poison loadings. The KENO model employed herein incorporates the bounding modeling features evaluated in the previous evaluations and also is consistent with the actual design dimensions as discussed in the Section 7.3.1. The results of the criticality analyses are shown in Table 7-43. These results demonstrate that the maximum k_{eff} of the system remains below that USL with a maximum enrichment of 4.80 wt. % U-235.

As described in the MRF analyses, separate enrichment limits are determined for the ABB-10-C type BWR fuel assemblies and also shown in Table 7-43. These results indicate that the maximum allowable enrichment is reduced by 0.25 wt. % U-235 for the Type M1-A and Type M1-B poison loading and by 0.20 wt. % U-235 for the Type M2-A poison loading compared to that for the GNF-2 fuel assembly.

7.4.4 Criticality Results

In Table 7-44, a summary of the bounding scenarios that exist for both the EOS-37PTH and EOS-89BTH are presented. These are: dry storage condition, applicable to the DSC and placed in the EOS-HSM, normal loading or unloading operation where the DSC is in the fuel pool with 100% internal moderator density, and condition where the internal moderator density is at the optimum calculated for maximum reactivity.

For the EOS-37PTH, *loading of intact fuels only,* the most reactive case for the normal loading or unloading condition is calculated for the CE 15x15 class FA with 4.75 wt. % U-235, Type B basket, without CCs and 2000 ppm of soluble boron 100% internal moderator density, which is also the most optimum density. For the dry storage condition, this CE 15x15 case is modified by changing the internal and external moderator density to air, because this results in a bounding dry condition scenario.

For the EOS-37PTH, loading of damaged or failed fuels balanced with intact fuels, the most reactive case for the normal loading or unloading condition is calculated for the WE 17x17 class FA with 4.85 wt. % U-235 for intact fuels and 4.85 wt. % U-235 for failed fuels, (Basket Type B, without CCs and 2300 ppm of soluble boron 90% internal moderator density).

For the EOS-89BTH the most reactive case for the normal loading or unloading condition is calculated for the GNF2 FA with 4.80 wt. % U-235, Type M2-A basket and 100% internal moderator density, which is also the optimum density. For the dry storage condition, this GNF2 case is modified by changing the internal and external moderator density to air as this results in a bounding dry condition scenario.

The criterion for *subcriticality* is that:

$$k_{keno} + 2\sigma_{keno} < USL$$

where USL is the upper subcriticality limit established by an analysis of benchmark criticality experiments. From Section 7.5 the USL for the EOS-37PTH DSC is 0.9404 while the USL for the EOS-89BTH DSC is 0.9418.

From Table 7-44, the most reactive case determined for PWR *intact fuel storage only* is:

$$k_{keno} + 2\sigma_{keno} = 0.9371+2*0.0007=0.9385 < 0.9404,$$

From Table 7-44, the most reactive case determined for the storage of a maximum of up to eight damaged PWR FAs or up to four FFCs containing failed PWR fuel balanced with intact PWR FAs:

$$k_{keno} + 2\sigma_{keno} = 0.9370+2*0.0007=0.9384 < 0.9404,$$

From Table 7-44, the most reactive case determined for BWR fuel storage is:

$$k_{keno} + 2\sigma_{keno} = 0.9382+2*0.0008=0.9398 < 0.9418.$$

7.5 Critical Benchmark Experiments

The criticality safety analysis of the EOS-37PTH and EOS-89BTH system used the CSAS5 module of the SCALE 6.0 system of codes. The CSAS5 control module allows simplified data input to the functional modules BONAMI, NITAWL, and KENO V.a. These modules process the required cross section data and calcualte the k_{eff} of the system. BONAMI performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the effective neutron multiplaciton (k_{eff}) of a three-dimensional system.

The analysis presented herein uses the fresh fuel assumptions for criticality analysis. The analysis employed the 44-group ENDF/B-V cross section library because it has a small bias, as determined by the benchmark calculations. A total of 92 experiments are available. The 92 experiments are each selected for benchmarking system applications that utilize soluble boron (EOS-37PTH), while 51 of the experiments are selected to benchmark system applications that utilize water without soluble boron (EOS-89BTH). The upper subcritical limit (USL) was determined using the results of the benchmark experiments.

The experimental problems used to perform the benchmarking are selected after comparison of relevant features to the system applications as presented in Table 7-45. The comparison of fuel and structural materials in the table demonstrates the experiments utilize materials that are expected to produce a neturonic behavior found in the system applications. The experiments along with pertinent parameters are listed in Table 7-46.

The USL is dependent on the set of evaluated critical experiments where the models in the experiments must have features similar to the system evaluated. The expectation is that the final calculated k_{eff} of the the selected critical experiments. The experiments in general have similar features or parameters in common such that a trend of how these affect the final k_{eff} due to the limitations associated with modeling, calculation methodology and nuclear cross-section data, can be evaluated. The features or parameters considered are U-235 enrichment, fuel pitch (cm), energy of average lethargy of fission (EALF), average energy group causing fission (AEG), soluble boron (ppm), assembly separation (cm), and moderator-to-fuel volume ratio. Using the relevant parameters, the correlation (r-value) of the parameters to the k_{eff} of the experiments must be evaluated to assess the level of influence of the parameter on the system reactivity. The USLSTATS code [7-5] provides the means to obtain the USL functions that can be used to obtain the final USL value if it can be shown that the parameters are closely correlated with k_{eff}, that it, $|r|$, is nearly 1.0. As demonstrated in Section 7.5.2, there is no close correlation between the parameters and k_{eff}. In cases where no closely correlated parameters exist, the single-sided tolerance limit methodology described in NUREG/CR-6698 [7-6] is used, it can be shown that the k_{eff} values are normally distributed, which is demonstrated in Section 7.5.2.

Proprietary Information on Pages 7-39 through 7-41
Withheld Pursuant to 10 CFR 2.390

7.5.3 Results of the Benchmark Calculations

The k_{eff} values of the 92 experiments are examined to determine correlation against the independent parameters listed in Section 7.5.2. The results in Table 7-47 indicate that there is no close correlation. The k_{eff} values are normally distributed and therefore, a single-sided lower tolerance limit USL is computed according to the methodology described in NUREG/CR-6698. The USL for the EOS-37PTH DSC is 0.9404. The results are summarized in Table 7-48.

The highest k_{eff} obtained for fuels loaded in the EOS-37PTH DSC is 0.9371+2*0.0007=0.9385, which is less than the USL of 0.9404.

The k_{eff} values of the 51 experiments are examined to determine correlation against the independent parameters listed in Section 7.5.2. The results in Table 7-47 indicate that there is no close correlation. The k_{eff} values are normally distributed and, therefore, a single-sided lower tolerance limit USL is computed according to the methodology described in NUREG/CR 7109. The USL for the EOS-89BTH DSC is 0.9418. The results are summarized in Table 7-48.

The highest k_{eff} obtained for fuels loaded in the EOS-89BTH DSC is 0.9382+2*0.0008=0.9398, which is less than the USL of 0.9418.

7.6 References

7-1 SCALE 6: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers, Oak Ridge National Laboratory, Radiation Shielding Information Center Code Package CCC-750, February 2009.

7-2 U.S. Nuclear Regulatory Commission, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," NUREG-1536, Revision 1, July 2010.

7-3 Scaglione, J.M., Mueller, D.E., Wagner, J.C., and Marshall, W.J., "An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Criticality (k_{eff}) Predictions," NUREG/CR 7109, U.S. Nuclear Regulatory Commission, April 2012.

7-4 International Criticality Safety Benchmark Evaluation Project (ICSBEP), "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA/NSC/DOC(95)03, NEA Nuclear Science Committee, September 2009, http://icsbep.inel.gov/.

7-5 USLSTATS: A Utility to Calculate Upper Subcritical Limits for Criticality Safety Applications, Version 6, Oak Ridge National Laboratory, January 26, 2009.

7-6 Dean, J.C., Tayloe Jr., R.W., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," NUREG/CR-6698, January 2001.

7-7 *TN Americas LLC, "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," Revision 16, USNRC Docket Number 72-1004, July 2017.*

7-8 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment 1.

Table 7-1
EOS-37PTH Minimum B-10 Content in the Neutron Poison Plates

Basket Type	Minimum B-10 Content for MMC (mg/cm^2)	B-10 Content Used in Criticality Evaluation (mg/cm^2)
A	28.0	25.2
B	35.0	31.5

Table 7-2
EOS-89BTH Minimum B-10 Content in the Neutron Poison Plates

Basket Type	B-10 Content Used in Criticality Evaluation (mg/cm^2)	Minimum B-10 Areal Density (mg/cm^2)	
		MMC	BORAL®
M1-A	29.4	32.7	39.2
M1-B	37.2	41.3	49.6
M2-A	45.0	-	60.0

Table 7-3
EOS-37PTH Maximum Planar Average Initial Enrichment *(Intact Fuels)*

(2 Pages)

Fuel Assembly Class	Maximum Assembly Average Initial Enrichment (wt. % U-235) as a Function of Soluble Boron Concentration and Basket Type (Fixed Poison Loading)				
	Minimum Soluble Boron (ppm)	Basket Type			
		A		B	
		w/o CCs	w/ CCs	w/o CCs	w/ CCs
17x17 Assembly Class[1]	2000	4.35	4.35	4.50	4.45
	2100	4.50	4.45	4.65	4.60
	2200	4.60	4.55	4.75	4.70
	2300	4.70	4.65	4.85	4.85
	2400	4.85	4.80	5.00	4.95
	2500	4.95	4.90	-	5.00
CE 16x16 Assembly Class	2000	5.00	5.00	5.00	5.00
	2100	-	-	-	-
	2200	-	-	-	-
	2300	-	-	-	-
	2400	-	-	-	-
	2500	-	-	-	-
BW 15x15 Assembly Class	2000	4.25	4.20	4.40	4.35
	2100	4.40	4.30	4.55	4.45
	2200	4.50	4.45	4.65	4.60
	2300	4.60	4.55	4.80	4.70
	2400	4.75	4.65	4.90	4.85
	2500	4.85	4.75	5.00	4.90
15x15 Assembly Class[1] (excludes BW 15x15 and CE 15x15)	2000	4.45	4.40	4.55	4.55
	2100	4.60	4.55	4.65	4.65
	2200	4.70	4.65	4.80	4.80
	2300	4.85	4.75	5.00	4.95
	2400	4.95	4.90	-	5.00
	2500	5.00	5.00	-	-

Table 7-3
EOS-37PTH Maximum Planar Average Initial Enrichment *(Intact Fuels)*

(2 Pages)

Fuel Assembly Class	Maximum Assembly Average Initial Enrichment (wt. % U-235) as a Function of Soluble Boron Concentration and Basket Type (Fixed Poison Loading)				
	Minimum Soluble Boron (ppm)	Basket Type			
		A		B	
		w/o CCs	w/ CCs	w/o CCs	w/ CCs
CE 15x15 Assembly Class	2000	4.60	4.55	4.75	4.70
	2100	4.70	4.65	4.85	4.85
	2200	4.85	4.80	5.00	4.95
	2300	5.00	4.90	-	5.00
	2400	-	5.00	-	-
	2500	-	-	-	-
CE 14x14 Assembly Class	2000	5.00	5.00	5.00	5.00
	2100	-	-	-	-
	2200	-	-	-	-
	2300	-	-	-	-
	2400	-	-	-	-
	2500	-	-	-	-
14x14 Assembly Class(1) (excludes CE 14x14)	2000	5.00	5.00	5.00	5.00
	2100	-	-	-	-
	2200	-	-	-	-
	2300	-	-	-	-
	2400	-	-	-	-
	2500	-	-	-	-

Note:

1. The loading requirements apply to FAs listed in Table 2-2 and *PWR FAs in* Table 2-4 of Chapter 2.

Table 7-4
EOS-89BTH Maximum Lattice Average Initial Enrichment

Basket Type	Maximum Lattice Average Initial Enrichment (wt. % U-235) (1)
M1-A	4.10
M1-B	4.45
M2-A	4.80

Note:

1. For ABB-10-C FAs, the enrichment shall be reduced by 0.25 wt. % U-235 for Type M1-A and M2-A and 0.20 wt. % U-235 for Type M1-B.

Proprietary Information on Pages 7-48 through 7-50
Withheld Pursuant to 10 CFR 2.390

Table 7-8
Material Property Data

Material	ID	Density g/cm^3	Element	Wt. %	Atom Density (atoms/b-cm)
UO_2 (Enrichment – 1.0 to 5.0 wt. %) (1)	1	10.686	U-235	4.41	1.20668E-03
			U-238	83.74	2.26374E-02
			O	11.85	4.76881E-02
Zircaloy-4	2	6.56	Zr	98.23	4.2541E-02
			Sn	1.45	4.8254E-04
			Fe	0.21	1.4856E-04
			Cr	0.10	7.5978E-05
			Hf	0.01	2.2133E-06
Water (Pellet Clad Gap)	3	0.998	H	11.1	6.6769E-02
			O	88.9	3.3385E-02
Stainless Steel (SS304)	4	7.94	C	0.080	3.1877E-04
			Si	1.000	1.7025E-03
			P	0.045	6.9468E-05
			Cr	19.000	1.7473E-02
			Mn	2.000	1.7407E-03
			Fe	68.375	5.8545E-02
			Ni	9.500	7.7402E-03
Borated Water (2000 – 2500 ppm Boron) (2)	5	1.00	H	11.163	6.67515E-02
			O	88.587	3.33757E-02
			B-10	0.046	2.77126E-05
			B-11	0.204	1.11547E-04
$^{11}B_4C$ in CC	7	2.52	B-11	78.57	1.08305E-01
			C	21.43	2.70763E-02
Aluminum	8	2.702	Al	100.0	6.0307E-02
Water	10	0.998	H	11.1	6.6769E-02
			O	88.9	3.3385E-02
Lead	11	11.344	Pb	100.0	3.2969E-02

Note:

(1) The composition for maximum enrichment evaluated at 5.0 wt. % U-235 is provided.

(2) Applies to EOS-37PTH only. EOS-89BTH evaluated with 100% internal moderator density. The composition for the maximum soluble boron concentration at 100 % internal moderator density is provided.

Proprietary Information on Pages 7-52 through 7-54
Withheld Pursuant to 10 CFR 2.390

Table 7-13
EOS-37PTH Plate Slot Width Sensitivity Evaluation
(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Slot Width: Combination 1			
IMD 50 %	0.8900	0.0007	0.8914
IMD 60 %	0.9184	0.0007	0.9198
IMD 70 %	0.9379	0.0007	0.9393
IMD 80 %	0.9503	0.0007	0.9517
IMD 90 %	0.9567	0.0006	0.9579
IMD 100 %	0.9603	0.0008	0.9619
Slot Width: Combination 2			
IMD 50 %	0.8895	0.0007	0.8909
IMD 60 %	0.9184	0.0006	0.9196
IMD 70 %	0.9369	0.0008	0.9385
IMD 80 %	0.9510	0.0007	0.9524
IMD 90 %	0.9572	0.0006	0.9584
IMD 100 %	0.9590	0.0007	0.9604
Slot Width: Combination 3			
IMD 50 %	0.8909	0.0007	0.8923
IMD 60 %	0.9181	0.0007	0.9195
IMD 70 %	0.9370	0.0007	0.9384
IMD 80 %	0.9490	0.0007	0.9504
IMD 90 %	0.9556	0.0007	0.9570
IMD 100 %	0.9594	0.0007	0.9608
Slot Width: Combination 4			
IMD 50 %	0.8890	0.0007	0.8904
IMD 60 %	0.9182	0.0006	0.9194
IMD 70 %	0.9365	0.0007	0.9379
IMD 80 %	0.9492	0.0007	0.9506
IMD 90 %	0.9566	0.0006	0.9578
IMD 100 %	0.9591	0.0007	0.9605

Table 7-13
EOS-37PTH Plate Slot Width Sensitivity Evaluation

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Slot Width: Combination 5			
IMD 50 %	0.8900	0.0007	0.8914
IMD 60 %	0.9182	0.0007	0.9196
IMD 70 %	0.9392	0.0007	0.9406
IMD 80 %	0.9504	0.0007	0.9518
IMD 90 %	0.9590	0.0006	0.9602
IMD 100 %	0.9603	0.0007	0.9617
Slot Width: Combination 6			
IMD 50 %	0.8887	0.0006	0.8899
IMD 60 %	0.9172	0.0006	0.9184
IMD 70 %	0.9385	0.0007	0.9399
IMD 80 %	0.9506	0.0006	0.9518
IMD 90 %	0.9562	0.0006	0.9574
IMD 100 %	0.9601	0.0006	0.9613

Table 7-14
EOS-37PTH Compartment Width Variation

Case Description	k_{keno}	σ_{keno}	k_{eff}
[ ]			
IMD 50 %	0.8928	0.0007	0.8942
IMD 60 %	0.9228	0.0007	0.9242
IMD 70 %	0.9415	0.0008	0.9431
IMD 80 %	0.9541	0.0007	0.9555
IMD 90 %	0.9625	0.0007	0.9639
IMD 100 %	0.9675	0.0008	0.9691
[ ]			
IMD 50 %	0.8870	0.0007	0.8884
IMD 60 %	0.9151	0.0009	0.9169
IMD 70 %	0.9339	0.0008	0.9355
IMD 80 %	0.9464	0.0007	0.9478
IMD 90 %	0.9507	0.0009	0.9525
IMD 100 %	0.9546	0.0008	0.9562

Table 7-15
EOS-37PTH Most Reactive Configuration Evaluation

2 Pages

Case Description	k_{keno}	σ_{keno}	k_{eff}
Poison Plate Thickness			
[ ]	0.9671	0.0008	0.9687
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9632	0.0007	0.9646
Basket Plate Steel Thickness			
[ ]	0.9657	0.0007	0.9671
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9630	0.0007	0.9644
[ ]	0.9660	0.0007	0.9674
Basket Aluminum Plate Thickness			
[ ]	0.9646	0.0007	0.9660
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9652	0.0007	0.9666
Inter Egg-Crate Gap Material Variation			
Borated Water	**0.9675**	**0.0008**	**0.9691**
Steel	0.9661	0.0006	0.9673
Axial Location of 1 inch Gap			
Bottom	**0.9675**	**0.0008**	**0.9691**
Middle	0.9659	0.0008	0.9675
Top	0.9661	0.0008	0.9677
Rail Approximation Radius			
[ ]	0.9660	0.0007	0.9674
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9664	0.0007	0.9678
EOS-TC Type			
TC108	0.9648	0.0007	0.9662
TC125/TC135	**0.9675**	**0.0008**	**0.9691**

Table 7-15
EOS-37PTH Most Reactive Configuration Evaluation

2 Pages

Case Description	k_{keno}	σ_{keno}	k_{eff}
DSC Shell Thickness with TC125/TC135			
[ ]	0.9646	0.0007	0.9660
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9647	0.0008	0.9663
TC Dimension Variation: TC Inner Shell			
[ ]	0.9662	0.0007	0.9676
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9643	0.0007	0.9657
TC Dimension Variation: Lead Thickness			
[ ]	0.9664	0.0007	0.9678
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9665	0.0007	0.9679
TC Dimension Variation: TC Outer Shell			
[ ]	0.9655	0.0007	0.9669
[ ]	**0.9675**	**0.0008**	**0.9691**
[ ]	0.9656	0.0008	0.9672
Fuel Assembly Location			
Center in compartment	0.9619	0.0007	0.9633
Pushed to center of canister	**0.9675**	**0.0008**	**0.9691**
Pushed to outside of canister	0.9539	0.0008	0.9555
Material Between EOS-TCs			
Void	0.9656	0.0007	0.9670
Fresh Water	**0.9675**	**0.0008**	**0.9691**

Table 7-16
Most Reactive Fuel Evaluation

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
WE, BW Mark C, and Framatome 17x17			
	0.9678	0.0009	0.9696
	0.9627	0.0008	0.9643
	0.9675	**0.0008**	**0.9691**
	0.9467	0.0008	0.9483
	0.9491	0.0007	0.9505
	0.9655	0.0008	0.9671
	0.9651	0.0007	0.9665
	0.9637	0.0008	0.9653
	0.9657	0.0008	0.9673
	0.9672	0.0008	0.9688
	0.9653	0.0007	0.9667
	0.9630	0.0007	0.9644
	0.9675	**0.0008**	**0.9691**
	BW 15x15		
	0.9662	0.0007	0.9676
	0.9684	0.0007	0.9698
	0.9697	**0.0007**	**0.9711**
	0.9577	0.0007	0.9591
	WE 15x15		
	0.9457	0.0007	0.9471
	0.9561	**0.0008**	**0.9577**
	0.9506	0.0008	0.9522
	0.9566	0.0009	0.9584
	0.9579	**0.0007**	**0.9593**
	CE 15x15		
	0.9486	**0.0007**	**0.9500**
	0.9441	0.0008	0.9457
	WE 14x14		
	0.8808	0.0007	0.8822
	0.8804	0.0009	0.8822
	0.8755	0.0007	0.8769
	0.9020	**0.0008**	**0.9036**

Table 7-16
Most Reactive Fuel Evaluation

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
	0.9021	**0.0007**	**0.9035**
	0.8990	0.0010	0.9010
	CE 14x14		
	0.9076	0.0008	0.9092
	0.9076	0.0008	0.9092
	0.9111	**0.0007**	**0.9125**
	CE 16x16		
	0.9190	**0.0008**	**0.9206**
	0.9179	0.0007	0.9193
	0.9189	0.0009	0.9207
	0.9181	0.0007	0.9195

Table 7-17
WE 17x17 Class *Intact* Fuel Assembly without CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8731	0.0008	0.8747
IMD 60 %	0.8998	0.0008	0.9014
IMD 70 %	0.9163	0.0007	0.9177
IMD 80 %	0.9267	0.0007	0.9281
IMD 90 %	0.9331	0.0007	0.9345
IMD 100 %	0.9331	0.0007	0.9345
4.50 wt. % U-235, 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8775	0.0007	0.8789
IMD 60 %	0.9028	0.0007	0.9042
IMD 70 %	0.9208	0.0008	0.9224
IMD 80 %	0.9308	0.0007	0.9322
IMD 90 %	0.9354	0.0007	0.9368
IMD 100 %	0.9352	0.0007	0.9366
4.60 wt. % U-235, 2200 ppm, W/O CCs, Type A			
IMD 50 %	0.8801	0.0008	0.8817
IMD 60 %	0.9041	0.0007	0.9055
IMD 70 %	0.9202	0.0007	0.9216
IMD 80 %	0.9303	0.0008	0.9319
IMD 90 %	0.9337	0.0010	0.9357
IMD 100 %	0.9333	0.0008	0.9349
4.70 wt. % U-235, 2300 ppm, W/O CCs, Type A			
IMD 50 %	0.8823	0.0006	0.8835
IMD 60 %	0.9055	0.0007	0.9069
IMD 70 %	0.9210	0.0007	0.9224
IMD 80 %	0.9312	0.0006	0.9324
IMD 90 %	0.9344	0.0007	0.9358
IMD 100 %	0.9334	0.0007	0.9348

Table 7-17
WE 17x17 Class *Intact* Fuel Assembly without CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.85 wt. % U-235, 2400 ppm, W/O CCs, Type A			
IMD 50 %	0.8853	0.0008	0.8869
IMD 60 %	0.9081	0.0007	0.9095
IMD 70 %	0.9241	0.0007	0.9255
IMD 80 %	0.9323	0.0007	0.9337
IMD 90 %	0.9351	0.0007	0.9365
IMD 100 %	0.9339	0.0008	0.9355
4.95 wt. % U-235, 2500 ppm, W/O CCs, Type A			
IMD 50 %	0.8879	0.0008	0.8895
IMD 60 %	0.9116	0.0009	0.9134
IMD 70 %	0.9248	0.0008	0.9264
IMD 80 %	0.9318	0.0007	0.9332
IMD 90 %	0.9343	0.0008	0.9359
IMD 100 %	0.9332	0.0007	0.9346

Table 7-18
WE 17x17 Class *Intact* Fuel Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8581	0.0007	0.8595
IMD 60 %	0.8876	0.0008	0.8892
IMD 70 %	0.9077	0.0007	0.9091
IMD 80 %	0.9212	0.0007	0.9226
IMD 90 %	0.9305	0.0008	0.9321
IMD 100 %	0.9356	0.0007	0.9370
4.45 wt. % U-235, 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8613	0.0008	0.8629
IMD 60 %	0.8898	0.0007	0.8912
IMD 70 %	0.9079	0.0006	0.9091
IMD 80 %	0.9218	0.0007	0.9232
IMD 90 %	0.9307	0.0008	0.9323
IMD 100 %	0.9341	0.0007	0.9355
4.55 wt. % U-235, 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8637	0.0007	0.8651
IMD 60 %	0.8902	0.0007	0.8916
IMD 70 %	0.9092	0.0007	0.9106
IMD 80 %	0.9233	0.0007	0.9247
IMD 90 %	0.9304	0.0008	0.9320
IMD 100 %	0.9339	0.0007	0.9353
4.65 wt. % U-235, 2300 ppm, W/ CCs, Type A			
IMD 50 %	0.8660	0.0008	0.8676
IMD 60 %	0.8936	0.0009	0.8954
IMD 70 %	0.9117	0.0007	0.9131
IMD 80 %	0.9234	0.0007	0.9248
IMD 90 %	0.9299	0.0006	0.9311
IMD 100 %	0.9337	0.0007	0.9351

Table 7-18
WE 17x17 Class *Intact* Fuel Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.8 wt. % U-235, 2400 ppm, W/ CCs, Type A			
IMD 50 %	0.8707	0.0007	0.8721
IMD 60 %	0.8971	0.0008	0.8987
IMD 70 %	0.9162	0.0007	0.9176
IMD 80 %	0.9265	0.0009	0.9283
IMD 90 %	0.9327	0.0008	0.9343
IMD 100 %	0.9359	0.0006	0.9371
4.9 wt. % U-235, 2500 ppm, W/ CCs, Type A			
IMD 50 %	0.8728	0.0006	0.8740
IMD 60 %	0.8968	0.0008	0.8984
IMD 70 %	0.9150	0.0007	0.9164
IMD 80 %	0.9245	0.0007	0.9259
IMD 90 %	0.9328	0.0007	0.9342
IMD 100 %	0.9356	0.0007	0.9370

Table 7-19
WE 17x17 Class *Intact* Fuel Assembly without CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.5 wt. % U-235, 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8667	0.0007	0.8681
IMD 60 %	0.8952	0.0007	0.8966
IMD 70 %	0.9147	0.0008	0.9163
IMD 80 %	0.9266	0.0008	0.9282
IMD 90 %	0.9330	0.0007	0.9344
IMD 100 %	0.9347	0.0008	0.9363
4.65 wt. % U-235, 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8708	0.0008	0.8724
IMD 60 %	0.8976	0.0008	0.8992
IMD 70 %	0.9164	0.0007	0.9178
IMD 80 %	0.9295	0.0007	0.9309
IMD 90 %	0.9349	0.0007	0.9363
IMD 100 %	0.9366	0.0007	0.9380
4.75 wt. % U-235, 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8731	0.0007	0.8745
IMD 60 %	0.8987	0.0007	0.9001
IMD 70 %	0.9174	0.0006	0.9186
IMD 80 %	0.9268	0.0007	0.9282
IMD 90 %	0.9333	0.0007	0.9347
IMD 100 %	0.9349	0.0007	0.9363
4.85 wt. % U-235, 2300 ppm, W/O CCs, Type B			
IMD 50 %	0.8764	0.0007	0.8778
IMD 60 %	0.8997	0.0008	0.9013
IMD 70 %	0.9176	0.0007	0.9190
IMD 80 %	0.9288	0.0007	0.9302
IMD 90 %	0.9322	0.0007	0.9336
IMD 100 %	0.9342	0.0006	0.9354

Table 7-19
WE 17x17 Class *Intact* Fuel Assembly without CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.0 wt. % U-235, 2400 ppm, W/O CCs, Type B			
IMD 50 %	0.8791	0.0008	0.8807
IMD 60 %	0.9039	0.0007	0.9053
IMD 70 %	0.9207	0.0007	0.9221
IMD 80 %	0.9303	0.0007	0.9317
IMD 90 %	0.9352	0.0007	0.9366
IMD 100 %	0.9341	0.0007	0.9355

Table 7-20
WE 17x17 Class *Intact* Fuel Assembly with CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.45 wt. % U-235, 2000 ppm, W/ CCs, Type B			
IMD 50 %	0.8477	0.0008	0.8493
IMD 60 %	0.8785	0.0007	0.8799
IMD 70 %	0.9024	0.0008	0.9040
IMD 80 %	0.9162	0.0007	0.9176
IMD 90 %	0.9270	0.0008	0.9286
IMD 100 %	0.9323	0.0007	0.9337
4.60 wt. % U-235, 2100 ppm, W/ CCs, Type B			
IMD 50 %	0.8531	0.0007	0.8545
IMD 60 %	0.8832	0.0006	0.8844
IMD 70 %	0.9049	0.0008	0.9065
IMD 80 %	0.9204	0.0008	0.9220
IMD 90 %	0.9298	0.0007	0.9312
IMD 100 %	0.9349	0.0008	0.9365
4.70 wt. % U-235, 2200 ppm, W/ CCs, Type B			
IMD 50 %	0.8560	0.0009	0.8578
IMD 60 %	0.8857	0.0007	0.8871
IMD 70 %	0.9045	0.0008	0.9061
IMD 80 %	0.9199	0.0008	0.9215
IMD 90 %	0.9301	0.0010	0.9321
IMD 100 %	0.9325	0.0007	0.9339
4.85 wt. % U-235, 2300 ppm, W/ CCs, Type B			
IMD 50 %	0.8608	0.0008	0.8624
IMD 60 %	0.8883	0.0008	0.8899
IMD 70 %	0.9099	0.0007	0.9113
IMD 80 %	0.9238	0.0008	0.9254
IMD 90 %	0.9310	0.0007	0.9324
IMD 100 %	0.9361	0.0007	0.9375

Table 7-20
WE 17x17 Class *Intact* Fuel Assembly with CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.95 wt. % U-235, 2400 ppm, W/ CCs, Type B			
IMD 50 %	0.8639	0.0007	0.8653
IMD 60 %	0.8896	0.0008	0.8912
IMD 70 %	0.9097	0.0007	0.9111
IMD 80 %	0.9232	0.0007	0.9246
IMD 90 %	0.9318	0.0007	0.9332
IMD 100 %	0.9359	0.0008	0.9375
5.0 wt. % U-235, 2500 ppm, W/ CCs, Type B			
IMD 50 %	0.8624	0.0008	0.8640
IMD 60 %	0.8906	0.0007	0.8920
IMD 70 %	0.9087	0.0007	0.9101
IMD 80 %	0.9207	0.0007	0.9221
IMD 90 %	0.9279	0.0007	0.9293
IMD 100 %	0.9311	0.0008	0.9327

Table 7-21
B&W 15x15 Class *Intact Fuel* Assembly without CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.25 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8742	0.0007	0.8756
IMD 60 %	0.8994	0.0007	0.9008
IMD 70 %	0.9151	0.0008	0.9167
IMD 80 %	0.9274	0.0006	0.9286
IMD 90 %	0.9335	0.0007	0.9349
IMD 100 %	0.9326	0.0007	0.9340
4.40 wt. % U-235, 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8786	0.0008	0.8802
IMD 60 %	0.9023	0.0007	0.9037
IMD 70 %	0.9218	0.0007	0.9232
IMD 80 %	0.9313	0.0007	0.9327
IMD 90 %	0.9353	0.0008	0.9369
IMD 100 %	0.9345	0.0007	0.9359
4.50 wt. % U-235, 2200 ppm, W/O CCs, Type A			
IMD 50 %	0.8797	0.0007	0.8811
IMD 60 %	0.9047	0.0007	0.9061
IMD 70 %	0.9212	0.0007	0.9226
IMD 80 %	0.9305	0.0007	0.9319
IMD 90 %	0.9342	0.0008	0.9358
IMD 100 %	0.9335	0.0007	0.9349
4.60 wt. % U-235, 2300 ppm, W/O CCs, Type A			
IMD 50 %	0.8829	0.0009	0.8847
IMD 60 %	0.9057	0.0008	0.9073
IMD 70 %	0.9216	0.0009	0.9234
IMD 80 %	0.9310	0.0007	0.9324
IMD 90 %	0.9340	0.0007	0.9354
IMD 100 %	0.9319	0.0007	0.9333

Table 7-21
B&W 15x15 Class *Intact Fuel* Assembly without CCs Final Results,
Type A Basket

(2 Pages)

Case Description	$\mathbf{k_{keno}}$	$\mathbf{\sigma_{keno}}$	$\mathbf{k_{eff}}$
4.75 wt. % U-235, 2400 ppm, W/O CCs, Type A			
IMD 50 %	0.8861	0.0007	0.8875
IMD 60 %	0.9114	0.0008	0.9130
IMD 70 %	0.9252	0.0007	0.9266
IMD 80 %	0.9322	0.0007	0.9336
IMD 90 %	0.9358	0.0007	0.9372
IMD 100 %	0.9337	0.0007	0.9351
4.85 wt. % U-235, 2500 ppm, W/O CCs, Type A			
IMD 50 %	0.8897	0.0007	0.8911
IMD 60 %	0.9116	0.0007	0.9130
IMD 70 %	0.9256	0.0007	0.9270
IMD 80 %	0.9353	0.0007	0.9367
IMD 90 %	0.9357	0.0007	0.9371
IMD 100 %	0.9325	0.0008	0.9341

Table 7-22
B&W 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.20 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8570	0.0009	0.8588
IMD 60 %	0.8863	0.0008	0.8879
IMD 70 %	0.9063	0.0007	0.9077
IMD 80 %	0.9208	0.0009	0.9226
IMD 90 %	0.9301	0.0008	0.9317
IMD 100 %	0.9331	0.0007	0.9345
4.30 wt. % U-235, 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8597	0.0007	0.8611
IMD 60 %	0.8876	0.0007	0.8890
IMD 70 %	0.9078	0.0008	0.9094
IMD 80 %	0.9224	0.0007	0.9238
IMD 90 %	0.9287	0.0007	0.9301
IMD 100 %	0.9331	0.0007	0.9345
4.45 wt. % U-235, 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8638	0.0009	0.8656
IMD 60 %	0.8928	0.0008	0.8944
IMD 70 %	0.9127	0.0007	0.9141
IMD 80 %	0.9252	0.0009	0.9270
IMD 90 %	0.9318	0.0007	0.9332
IMD 100 %	0.9345	0.0008	0.9361
4.55 wt. % U-235, 2300 ppm, W/ CCs, Type A			
IMD 50 %	0.8684	0.0007	0.8698
IMD 60 %	0.8946	0.0008	0.8962
IMD 70 %	0.9129	0.0008	0.9145
IMD 80 %	0.9240	0.0007	0.9254
IMD 90 %	0.9310	0.0007	0.9324
IMD 100 %	0.9339	0.0006	0.9351

Table 7-22
B&W 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.65 wt. % U-235, 2400 ppm, W/ CCs, Type A			
IMD 50 %	0.8692	0.0008	0.8708
IMD 60 %	0.8972	0.0007	0.8986
IMD 70 %	0.9131	0.0008	0.9147
IMD 80 %	0.9249	0.0007	0.9263
IMD 90 %	0.9328	0.0007	0.9342
IMD 100 %	0.9345	0.0007	0.9359
4.75 wt. % U-235, 2500 ppm, W/ CCs, Type A			
IMD 50 %	0.8726	0.0007	0.8740
IMD 60 %	0.8967	0.0008	0.8983
IMD 70 %	0.9171	0.0007	0.9185
IMD 80 %	0.9259	0.0007	0.9273
IMD 90 %	0.9322	0.0007	0.9336
IMD 100 %	0.9348	0.0007	0.9362

Table 7-23
B&W 15x15 Class *Intact Fuel* Assembly without CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.40 wt. % U-235, 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8689	0.0008	0.8705
IMD 60 %	0.8948	0.0007	0.8962
IMD 70 %	0.9136	0.0007	0.9150
IMD 80 %	0.9257	0.0008	0.9273
IMD 90 %	0.9339	0.0007	0.9353
IMD 100 %	0.9344	0.0007	0.9358
4.55 wt. % U-235, 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8716	0.0007	0.8730
IMD 60 %	0.8986	0.0007	0.9000
IMD 70 %	0.9184	0.0007	0.9198
IMD 80 %	0.9291	0.0009	0.9309
IMD 90 %	0.9336	0.0008	0.9352
IMD 100 %	0.9352	0.0007	0.9366
4.65 wt. % U-235, 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8740	0.0008	0.8756
IMD 60 %	0.9014	0.0008	0.9030
IMD 70 %	0.9176	0.0007	0.9190
IMD 80 %	0.9288	0.0007	0.9302
IMD 90 %	0.9328	0.0005	0.9338
IMD 100 %	0.9353	0.0007	0.9367
4.80 wt. % U-235, 2300 ppm, W/O CCs, Type B			
IMD 50 %	0.8777	0.0008	0.8793
IMD 60 %	0.9048	0.0009	0.9066
IMD 70 %	0.9202	0.0008	0.9218
IMD 80 %	0.9315	0.0008	0.9331
IMD 90 %	0.9352	0.0008	0.9368
IMD 100 %	0.9358	0.0007	0.9372

Table 7-23
B&W 15x15 Class *Intact Fuel* Assembly without CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.90 wt. % U-235, 2400 ppm, W/O CCs, Type B			
IMD 50 %	0.8786	0.0007	0.8800
IMD 60 %	0.9058	0.0007	0.9072
IMD 70 %	0.9225	0.0007	0.9239
IMD 80 %	0.9302	0.0008	0.9318
IMD 90 %	0.9352	0.0008	0.9368
IMD 100 %	0.9347	0.0007	0.9361
5.00 wt. % U-235, 2500 ppm, W/O CCs, Type B			
IMD 50 %	0.8836	0.0007	0.8850
IMD 60 %	0.9063	0.0007	0.9077
IMD 70 %	0.9214	0.0007	0.9228
IMD 80 %	0.9300	0.0007	0.9314
IMD 90 %	0.9344	0.0007	0.9358
IMD 100 %	0.9328	0.0008	0.9344

Table 7-24
B&W 15x15 Class *Intact Fuel* Assembly with CCs Final Results,
Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235, 2000 ppm, W/ CCs, Type B			
IMD 50 %	0.8508	0.0008	0.8524
IMD 60 %	0.8802	0.0007	0.8816
IMD 70 %	0.9022	0.0008	0.9038
IMD 80 %	0.9182	0.0008	0.9198
IMD 90 %	0.9276	0.0008	0.9292
IMD 100 %	0.9364	0.0007	0.9378
4.45 wt. % U-235, 2100 ppm, W/ CCs, Type B			
IMD 50 %	0.8520	0.0008	0.8536
IMD 60 %	0.8828	0.0007	0.8842
IMD 70 %	0.9037	0.0008	0.9053
IMD 80 %	0.9189	0.0008	0.9205
IMD 90 %	0.9279	0.0007	0.9293
IMD 100 %	0.9337	0.0008	0.9353
4.60 wt. % U-235, 2200 ppm, W/ CCs, Type B			
IMD 50 %	0.8585	0.0006	0.8597
IMD 60 %	0.8867	0.0008	0.8883
IMD 70 %	0.9091	0.0007	0.9105
IMD 80 %	0.9231	0.0008	0.9247
IMD 90 %	0.9317	0.0007	0.9331
IMD 100 %	0.9365	0.0008	0.9381
4.70 wt. % U-235, 2300 ppm, W/ CCs, Type B			
IMD 50 %	0.8610	0.0008	0.8626
IMD 60 %	0.8883	0.0007	0.8897
IMD 70 %	0.9097	0.0007	0.9111
IMD 80 %	0.9235	0.0007	0.9249
IMD 90 %	0.9313	0.0006	0.9325
IMD 100 %	0.9356	0.0007	0.9370

Table 7-24
B&W 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.85 wt. % U-235, 2400 ppm, W/ CCs, Type B			
IMD 50 %	0.8650	0.0007	0.8664
IMD 60 %	0.8933	0.0006	0.8945
IMD 70 %	0.9123	0.0008	0.9139
IMD 80 %	0.9257	0.0007	0.9271
IMD 90 %	0.9345	0.0007	0.9359
IMD 100 %	0.9370	0.0006	0.9382
4.90 wt. % U-235, 2500 ppm, W/ CCs, Type B			
IMD 50 %	0.8654	0.0007	0.8668
IMD 60 %	0.8906	0.0007	0.8920
IMD 70 %	0.9110	0.0007	0.9124
IMD 80 %	0.9220	0.0008	0.9236
IMD 90 %	0.9307	0.0007	0.9321
IMD 100 %	0.9331	0.0008	0.9347

Table 7-25
WE 15x15 Class *Intact* Fuel Assembly without CCs Final Results, Type A Basket

(2 pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.45 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8754	0.0007	0.8768
IMD 60 %	0.9008	0.0007	0.9022
IMD 70 %	0.9191	0.0008	0.9207
IMD 80 %	0.9305	0.0007	0.9319
IMD 90 %	0.9331	0.0007	0.9345
IMD 100 %	0.9341	0.0006	0.9353
4.60 wt. % U-235, 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8810	0.0007	0.8824
IMD 60 %	0.9061	0.0008	0.9077
IMD 70 %	0.9228	0.0008	0.9244
IMD 80 %	0.9297	0.0007	0.9311
IMD 90 %	0.9344	0.0007	0.9358
IMD 100 %	0.9346	0.0007	0.9360
4.70 wt. % U-235, 2200 ppm, W/O CCs, Type A			
IMD 50 %	0.8820	0.0007	0.8834
IMD 60 %	0.9062	0.0006	0.9074
IMD 70 %	0.9223	0.0007	0.9237
IMD 80 %	0.9299	0.0008	0.9315
IMD 90 %	0.9341	0.0007	0.9355
IMD 100 %	0.9327	0.0006	0.9339
4.85 wt. % U-235, 2300 ppm, W/O CCs, Type A			
IMD 50 %	0.8860	0.0007	0.8874
IMD 60 %	0.9098	0.0007	0.9112
IMD 70 %	0.9265	0.0007	0.9279
IMD 80 %	0.9349	0.0007	0.9363
IMD 90 %	0.9368	0.0007	0.9382
IMD 100 %	0.9354	0.0007	0.9368
4.95 wt. % U-235, 2400 ppm, W/O CCs, Type A			
IMD 50 %	0.8872	0.0008	0.8888
IMD 60 %	0.9112	0.0007	0.9126
IMD 70 %	0.9251	0.0007	0.9265

Table 7-25
WE 15x15 Class *Intact* Fuel Assembly without CCs Final Results, Type A Basket

(2 pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
IMD 80 %	0.9333	0.0007	0.9347
IMD 90 %	0.9346	0.0007	0.9360
IMD 100 %	0.9319	0.0007	0.9333
5.00 wt. % U-235, 2500 ppm, W/O CCs, Type A			
IMD 50 %	0.8876	0.0007	0.8890
IMD 60 %	0.9095	0.0008	0.9111
IMD 70 %	0.9231	0.0007	0.9245
IMD 80 %	0.9292	0.0006	0.9304
IMD 90 %	0.9309	0.0007	0.9323
IMD 100 %	0.9268	0.0007	0.9282

Table 7-26
WE 15x15 Class *Intact* Fuel Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.40 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8546	0.0009	0.8564
IMD 60 %	0.8855	0.0007	0.8869
IMD 70 %	0.9061	0.0008	0.9077
IMD 80 %	0.9200	0.0008	0.9216
IMD 90 %	0.9299	0.0008	0.9315
IMD 100 %	0.9346	0.0007	0.9360
4.55 wt. % U-235, 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8608	0.0007	0.8622
IMD 60 %	0.8892	0.0008	0.8908
IMD 70 %	0.9104	0.0007	0.9118
IMD 80 %	0.9228	0.0007	0.9242
IMD 90 %	0.9324	0.0007	0.9338
IMD 100 %	0.9368	0.0007	0.9382
4.65 wt. % U-235, 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8632	0.0007	0.8646
IMD 60 %	0.8906	0.0008	0.8922
IMD 70 %	0.9106	0.0007	0.9120
IMD 80 %	0.9239	0.0008	0.9255
IMD 90 %	0.9337	0.0007	0.9351
IMD 100 %	0.9364	0.0008	0.9380
4.75 wt. % U-235, 2300 ppm, W/ CCs, Type A			
IMD 50 %	0.8649	0.0007	0.8663
IMD 60 %	0.8916	0.0007	0.8930
IMD 70 %	0.9122	0.0007	0.9136
IMD 80 %	0.9248	0.0008	0.9264
IMD 90 %	0.9309	0.0007	0.9323
IMD 100 %	0.9348	0.0008	0.9364
4.90 wt. % U-235, 2400 ppm, W/ CCs, Type A			
IMD 50 %	0.8702	0.0006	0.8714
IMD 60 %	0.8978	0.0008	0.8994
IMD 70 %	0.9145	0.0008	0.9161

Table 7-26
WE 15x15 Class *Intact* Fuel Assembly with CCs Final Results, Type A Basket

(2 Pages)

IMD 80 %	0.9263	0.0008	0.9279
IMD 90 %	0.9338	0.0008	0.9354
IMD 100 %	0.9361	0.0007	0.9375
5.00 wt. % U-235, 2500 ppm, W/ CCs, Type A			
IMD 50 %	0.8733	0.0007	0.8747
IMD 60 %	0.8986	0.0007	0.9000
IMD 70 %	0.9169	0.0007	0.9183
IMD 80 %	0.9282	0.0009	0.9300
IMD 90 %	0.9347	0.0008	0.9363
IMD 100 %	0.9362	0.0007	0.9376

Table 7-27
WE 15x15 Class *Intact* Fuel Assembly without CCs Final Results, Type B Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235, 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8658	0.0008	0.8674
IMD 60 %	0.8932	0.0007	0.8946
IMD 70 %	0.9132	0.0008	0.9148
IMD 80 %	0.9249	0.0007	0.9263
IMD 90 %	0.9302	0.0007	0.9316
IMD 100 %	0.9307	0.0007	0.9321
4.65 wt. % U-235, 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8677	0.0007	0.8691
IMD 60 %	0.8954	0.0007	0.8968
IMD 70 %	0.9144	0.0009	0.9162
IMD 80 %	0.9240	0.0008	0.9256
IMD 90 %	0.9308	0.0008	0.9324
IMD 100 %	0.9283	0.0008	0.9299
4.80 wt. % U-235, 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8740	0.0007	0.8754
IMD 60 %	0.9002	0.0009	0.9020
IMD 70 %	0.9167	0.0008	0.9183
IMD 80 %	0.9270	0.0007	0.9284
IMD 90 %	0.9304	0.0007	0.9318
IMD 100 %	0.9307	0.0007	0.9321
5.00 wt. % U-235, 2300 ppm, W/O CCs, Type B			
IMD 50 %	0.8791	0.0008	0.8807
IMD 60 %	0.9062	0.0008	0.9078
IMD 70 %	0.9215	0.0007	0.9229
IMD 80 %	0.9321	0.0008	0.9337
IMD 90 %	0.9350	0.0007	0.9364
IMD 100 %	0.9355	0.0008	0.9371

Table 7-28
WE 15x15 Class *Intact* Fuel Assembly with CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235, 2000 ppm, W/ CCs, Type B			
IMD 50 %	0.8478	0.0007	0.8492
IMD 60 %	0.8794	0.0007	0.8808
IMD 70 %	0.9020	0.0007	0.9034
IMD 80 %	0.9174	0.0008	0.9190
IMD 90 %	0.9299	0.0007	0.9313
IMD 100 %	0.9353	0.0007	0.9367
4.65 wt. % U-235, 2100 ppm, W/ CCs, Type B			
IMD 50 %	0.8499	0.0008	0.8515
IMD 60 %	0.8804	0.0007	0.8818
IMD 70 %	0.9045	0.0007	0.9059
IMD 80 %	0.9196	0.0008	0.9212
IMD 90 %	0.9284	0.0007	0.9298
IMD 100 %	0.9321	0.0007	0.9335
4.80 wt. % U-235, 2200 ppm, W/ CCs, Type B			
IMD 50 %	0.8546	0.0007	0.8560
IMD 60 %	0.8845	0.0008	0.8861
IMD 70 %	0.9055	0.0007	0.9069
IMD 80 %	0.9221	0.0007	0.9235
IMD 90 %	0.9298	0.0008	0.9314
IMD 100 %	0.9360	0.0008	0.9376
4.95 wt. % U-235, 2300 ppm, W/ CCs, Type B			
IMD 50 %	0.8598	0.0006	0.8610
IMD 60 %	0.8891	0.0007	0.8905
IMD 70 %	0.9102	0.0008	0.9118
IMD 80 %	0.9228	0.0007	0.9242
IMD 90 %	0.9326	0.0007	0.9340
IMD 100 %	0.9368	0.0006	0.9380

Table 7-28
WE 15x15 Class *Intact* Fuel Assembly with CCs Final Results, Type B Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2400 ppm, W/ CCs, Type B			
IMD 50 %	0.8592	0.0008	0.8608
IMD 60 %	0.8878	0.0008	0.8894
IMD 70 %	0.9087	0.0009	0.9105
IMD 80 %	0.9216	0.0007	0.9230
IMD 90 %	0.9293	0.0007	0.9307
IMD 100 %	0.9331	0.0007	0.9345

Table 7-29
CE 15x15 Class *Intact Fuel* Assembly without CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.60 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8634	0.0007	0.8648
IMD 60 %	0.8907	0.0008	0.8923
IMD 70 %	0.9099	0.0007	0.9113
IMD 80 %	0.9239	0.0007	0.9253
IMD 90 %	0.9304	0.0008	0.9320
IMD 100 %	0.9356	0.0007	0.9370
4.70 wt. % U-235, 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8661	0.0008	0.8677
IMD 60 %	0.8929	0.0007	0.8943
IMD 70 %	0.9120	0.0008	0.9136
IMD 80 %	0.9226	0.0007	0.9240
IMD 90 %	0.9298	0.0008	0.9314
IMD 100 %	0.9343	0.0008	0.9359
4.85 wt. % U-235, 2200 ppm, W/O CCs, Type A			
IMD 50 %	0.8691	0.0008	0.8707
IMD 60 %	0.8966	0.0007	0.8980
IMD 70 %	0.9144	0.0007	0.9158
IMD 80 %	0.9250	0.0008	0.9266
IMD 90 %	0.9332	0.0008	0.9348
IMD 100 %	0.9358	0.0007	0.9372
5.00 wt. % U-235, 2300 ppm, W/O CCs, Type A			
IMD 50 %	0.8751	0.0007	0.8765
IMD 60 %	0.8998	0.0005	0.9008
IMD 70 %	0.9166	0.0010	0.9186
IMD 80 %	0.9282	0.0007	0.9296
IMD 90 %	0.9338	0.0008	0.9354
IMD 100 %	0.9365	0.0008	0.9381

Table 7-30
CE 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8624	0.0007	0.8638
IMD 60 %	0.8886	0.0008	0.8902
IMD 70 %	0.9090	0.0008	0.9106
IMD 80 %	0.9224	0.0007	0.9238
IMD 90 %	0.9310	0.0008	0.9326
IMD 100 %	0.9367	0.0007	0.9381
4.65 wt. % U-235, 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8644	0.0007	0.8658
IMD 60 %	0.8903	0.0008	0.8919
IMD 70 %	0.9101	0.0006	0.9113
IMD 80 %	0.9221	0.0008	0.9237
IMD 90 %	0.9309	0.0008	0.9325
IMD 100 %	0.9334	0.0008	0.9350
4.80 wt. % U-235, 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8683	0.0007	0.8697
IMD 60 %	0.8945	0.0007	0.8959
IMD 70 %	0.9129	0.0007	0.9143
IMD 80 %	0.9264	0.0008	0.9280
IMD 90 %	0.9337	0.0007	0.9351
IMD 100 %	0.9363	0.0007	0.9377
4.90 wt. % U-235, 2300 ppm, W/ CCs, Type A			
IMD 50 %	0.8705	0.0008	0.8721
IMD 60 %	0.8967	0.0007	0.8981
IMD 70 %	0.9132	0.0007	0.9146
IMD 80 %	0.9256	0.0007	0.9270
IMD 90 %	0.9310	0.0007	0.9324
IMD 100 %	0.9346	0.0007	0.9360

Table 7-30
CE 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

(2 Pages)

Case Description	$\mathbf{k_{keno}}$	$\boldsymbol{\sigma_{keno}}$	$\mathbf{k_{eff}}$
5.00 wt. % U-235, 2400 ppm, W/ CCs, Type A			
IMD 50 %	0.8707	0.0007	0.8721
IMD 60 %	0.8965	0.0007	0.8979
IMD 70 %	0.9145	0.0008	0.9161
IMD 80 %	0.9247	0.0007	0.9261
IMD 90 %	0.9313	0.0007	0.9327
IMD 100 %	0.9328	0.0007	0.9342

Table 7-31
CE 15x15 Class *Intact Fuel* Assembly without CCs Final Results, Type B Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.75 wt. % U-235, 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8577	0.0008	0.8593
IMD 60 %	0.8852	0.0008	0.8868
IMD 70 %	0.9060	0.0007	0.9074
IMD 80 %	0.9213	0.0007	0.9227
IMD 90 %	0.9311	0.0007	0.9325
IMD 100 %	0.9371	0.0007	0.9385
4.85 wt. % U-235, 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8590	0.0008	0.8606
IMD 60 %	0.8860	0.0008	0.8876
IMD 70 %	0.9071	0.0007	0.9085
IMD 80 %	0.9206	0.0007	0.9220
IMD 90 %	0.9300	0.0009	0.9318
IMD 100 %	0.9345	0.0008	0.9361
5.00 wt. % U-235, 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8629	0.0008	0.8645
IMD 60 %	0.8899	0.0008	0.8915
IMD 70 %	0.9098	0.0008	0.9114
IMD 80 %	0.9236	0.0008	0.9252
IMD 90 %	0.9292	0.0007	0.9306
IMD 100 %	0.9350	0.0008	0.9366

Table 7-32
CE 15x15 Class *Intact Fuel* Assembly with CCs Final Results, Type B Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.70 wt. % U-235, 2000 ppm, W/ CCs, Type B			
IMD 50 %	0.8547	0.0007	0.8561
IMD 60 %	0.8834	0.0008	0.8850
IMD 70 %	0.9056	0.0008	0.9072
IMD 80 %	0.9207	0.0007	0.9221
IMD 90 %	0.9296	0.0007	0.9310
IMD 100 %	0.9365	0.0007	0.9379
4.85 wt. % U-235, 2100 ppm, W/ CCs, Type B			
IMD 50 %	0.8599	0.0007	0.8613
IMD 60 %	0.8868	0.0007	0.8882
IMD 70 %	0.9089	0.0007	0.9103
IMD 80 %	0.9218	0.0007	0.9232
IMD 90 %	0.9325	0.0008	0.9341
IMD 100 %	0.9359	0.0007	0.9373
4.95 wt. % U-235, 2200 ppm, W/ CCs, Type B			
IMD 50 %	0.8596	0.0007	0.8610
IMD 60 %	0.8894	0.0008	0.8910
IMD 70 %	0.9096	0.0008	0.9112
IMD 80 %	0.9216	0.0008	0.9232
IMD 90 %	0.9317	0.0007	0.9331
IMD 100 %	0.9350	0.0007	0.9364
5.00 wt. % U-235, 2300 ppm, W/ CCs, Type B			
IMD 50 %	0.8596	0.0007	0.8610
IMD 60 %	0.8876	0.0009	0.8894
IMD 70 %	0.9064	0.0007	0.9078
IMD 80 %	0.9193	0.0008	0.9209
IMD 90 %	0.9272	0.0008	0.9288
IMD 100 %	0.9324	0.0009	0.9342

Table 7-33
CE 14x14 Class *Intact Fuel* Assembly without CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8763	0.0008	0.8779
IMD 60 %	0.8996	0.0008	0.9012
IMD 70 %	0.9144	0.0008	0.9160
IMD 80 %	0.9191	0.0007	0.9205
IMD 90 %	0.9194	0.0007	0.9208
IMD 100 %	0.9199	0.0007	0.9213

Table 7-34
CE 14x14 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8637	0.0007	0.8651
IMD 60 %	0.8913	0.0009	0.8931
IMD 70 %	0.9110	0.0008	0.9126
IMD 80 %	0.9226	0.0007	0.9240
IMD 90 %	0.9329	0.0008	0.9345
IMD 100 %	0.9354	0.0007	0.9368

Table 7-35
WE 14x14 Class *Intact* Fuel Assembly without CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8662	0.0009	0.8680
IMD 60 %	0.8876	0.0008	0.8892
IMD 70 %	0.8994	0.0010	0.9014
IMD 80 %	0.9090	0.0008	0.9106
IMD 90 %	0.9097	0.0008	0.9113
IMD 100 %	0.9086	0.0008	0.9102

Table 7-36
WE 14x14 Class *Intact* Fuel Assembly with CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8505	0.0008	0.8521
IMD 60 %	0.8735	0.0008	0.8751
IMD 70 %	0.8899	0.0008	0.8915
IMD 80 %	0.9010	0.0007	0.9024
IMD 90 %	0.9057	0.0007	0.9071
IMD 100 %	0.9098	0.0008	0.9114

Table 7-37
CE 16x16 Class *Intact Fuel* Assembly without CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8694	0.0008	0.8710
IMD 60 %	0.8937	0.0007	0.8951
IMD 70 %	0.9116	0.0008	0.9132
IMD 80 %	0.9224	0.0008	0.9240
IMD 90 %	0.9275	0.0007	0.9289
IMD 100 %	0.9299	0.0008	0.9315

Table 7-38
CE 16x16 Class *Intact Fuel* Assembly with CCs Final Results, Type A Basket

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235, 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8577	0.0008	0.8593
IMD 60 %	0.8862	0.0008	0.8878
IMD 70 %	0.9059	0.0007	0.9073
IMD 80 %	0.9190	0.0007	0.9204
IMD 90 %	0.9293	0.0009	0.9311
IMD 100 %	0.9322	0.0008	0.9338

Proprietary Information on This Page
Withheld Pursuant to 10 CFR 2.390

Table 7-40
Most Reactive Fuel Lattice
(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
ABB-10-1	0.9141	0.0008	0.9157
ABB-10-1	0.9147	0.0009	0.9166
ABB-10-1	0.9170	0.0009	0.9188
ABB-10-1	0.9106	0.0011	0.9128
ABB-10-2	0.9159	0.0009	0.9177
ABB-10-2	0.9152	0.0009	0.9170
ABB-10-2	0.9187	0.0008	0.9204
ABB-10-2	0.9127	0.0009	0.9145
ABB-10-3	0.9226	0.0008	0.9242
ABB-10-3	0.9229	0.0008	0.9246
ABB-10-3	0.9262	0.0008	0.9279
ABB-10-3	0.9215	0.0009	0.9233
ABB-10-4	0.9130	0.0008	0.9147
ABB-10-4	0.9135	0.0010	0.9155
ABB-10-4	0.9162	0.0008	0.9178
ABB-10-4	0.9105	0.0009	0.9123
ABB-10-5	0.8774	0.0009	0.8792
ABB-10-5	0.8781	0.0008	0.8796
ABB-10-5	0.8788	0.0008	0.8804
ABB-10-5	0.8783	0.0008	0.8798
ABB-10-6	0.9129	0.0008	0.9146
ABB-10-6	0.9147	0.0009	0.9164
ABB-10-6	0.9154	0.0008	0.9170
ABB-10-6	0.9105	0.0008	0.9121
ABB-8-1	0.9116	0.0009	0.9134
ABB-8-1	0.9118	0.0009	0.9135
ABB-8-1	0.9135	0.0008	0.9152
ABB-8-1	0.9058	0.0008	0.9073
ABB-8-2	0.9158	0.0008	0.9175
ABB-8-2	0.9164	0.0008	0.9180
ABB-8-2	0.9175	0.0009	0.9192
ABB-8-2	0.9117	0.0008	0.9132

Table 7-40
Most Reactive Fuel Lattice

(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
ATRIUM-10	0.9266	0.0009	0.9283
ATRIUM-10	0.9271	0.0009	0.9289
ATRIUM-10	0.9301	0.0008	0.9317
ATRIUM-10	0.9215	0.0009	0.9233
ATRIUM-10	0.9323	0.0009	0.9341
ATRIUM-10	0.9317	0.0009	0.9335
ATRIUM-10	0.9353	0.0008	0.9369
ATRIUM-10	0.9257	0.0009	0.9274
ENC- IIIA	0.9234	0.0009	0.9251
ENC- IIIA	0.9226	0.0008	0.9242
ENC- IIIA	0.9260	0.0009	0.9277
ENC- IIIA	0.9182	0.0010	0.9201
ENC- IIIA	0.9205	0.0008	0.9222
ENC- IIIA	0.9238	0.0008	0.9254
ENC- IIIA	0.9240	0.0008	0.9256
ENC- IIIA	0.9166	0.0008	0.9182
ENC-III	0.9198	0.0009	0.9215
ENC-III	0.9199	0.0008	0.9215
ENC-III	0.9240	0.0009	0.9258
ENC-III	0.9136	0.0009	0.9154
ENC-III	0.9196	0.0009	0.9213
ENC-III	0.9206	0.0010	0.9225
ENC-III	0.9221	0.0009	0.9238
ENC-III	0.9174	0.0010	0.9194
ENC Va and Vb	0.9067	0.0008	0.9083
ENC Va and Vb	0.9099	0.0009	0.9118
ENC Va and Vb	0.9118	0.0009	0.9135
ENC Va and Vb	0.9023	0.0008	0.9039
FANP 9X9	0.9275	0.0008	0.9292
FANP 9X9	0.9251	0.0010	0.9270
FANP 9X9	0.9286	0.0009	0.9303
FANP 9X9	0.9218	0.0008	0.9234

Table 7-40
Most Reactive Fuel Lattice

(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
FANP 8X8-2	0.9215	0.0010	0.9235
FANP 8X8-2	0.9191	0.0009	0.9208
FANP 8X8-2	0.9232	0.0010	0.9251
FANP 8X8-2	0.9147	0.0008	0.9164
FANP 8X8-2	0.9238	0.0008	0.9254
FANP 8X8-2	0.9236	0.0009	0.9255
FANP 8X8-2	0.9265	0.0008	0.9282
FANP 8X8-2	0.9190	0.0008	0.9207
FANP 8X8-2	0.9246	0.0009	0.9264
FANP 8X8-2	0.9242	0.0008	0.9258
FANP 8X8-2	0.9264	0.0008	0.9280
FANP 8X8-2	0.9170	0.0009	0.9188
FANP 9X9-2	0.9307	0.0009	0.9324
FANP 9X9-2	0.9307	0.0008	0.9324
FANP 9X9-2	**0.9346**	**0.0009**	**0.9364**
FANP 9X9-2	0.9260	0.0010	0.9280
FANP 9X9-2	0.9280	0.0008	0.9297
FANP 9X9-2	0.9277	0.0009	0.9296
FANP 9X9-2	0.9307	0.0009	0.9325
FANP 9X9-2	0.9223	0.0010	0.9242
GE11, GE13	0.9267	0.0009	0.9285
GE11, GE13	0.9287	0.0010	0.9307
GE11, GE13	0.9307	0.0008	0.9324
GE11, GE13	0.9222	0.0008	0.9238
GE12, GE14	0.9293	0.0010	0.9312
GE12, GE14	0.9323	0.0008	0.9339
GE12, GE14	0.9328	0.0009	0.9346
GE12, GE14	0.9232	0.0009	0.9250
GE1, GE2, GE3	0.9276	0.0008	0.9293
GE1, GE2, GE3	0.9270	0.0008	0.9286
GE1, GE2, GE3	0.9302	0.0008	0.9318
GE1, GE2, GE3	0.9224	0.0008	0.9240

Table 7-40
Most Reactive Fuel Lattice
(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
GE1, GE2, GE3	0.9226	0.0008	0.9242
GE1, GE2, GE3	0.9228	0.0008	0.9244
GE1, GE2, GE3	0.9245	0.0009	0.9263
GE1, GE2, GE3	0.9171	0.0009	0.9188
GE4	0.9194	0.0009	0.9211
GE4	0.9188	0.0008	0.9204
GE4	0.9206	0.0008	0.9222
GE4	0.9107	0.0009	0.9124
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9285	0.0009	0.9302
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9281	0.0009	0.9299
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9299	0.0009	0.9316
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9209	0.0012	0.9233
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9278	0.0008	0.9294
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9282	0.0008	0.9298
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9319	0.0009	0.9336
GE-5, GE-Pres, GE-Barrier GE8 Type I	0.9209	0.0009	0.9226
GE8 Type II	0.9267	0.0009	0.9285
GE8 Type II	0.9267	0.0009	0.9284
GE8 Type II	0.9289	0.0008	0.9305
GE8 Type II	0.9206	0.0009	0.9223
GE8 Type II	0.9285	0.0009	0.9302
GE8 Type II	0.9280	0.0009	0.9297
GE8 Type II	0.9309	0.0009	0.9327
GE8 Type II	0.9202	0.0008	0.9218
GE9, GE10	0.9272	0.0008	0.9288
GE9, GE10	0.9302	0.0008	0.9318

Table 7-40
Most Reactive Fuel Lattice
(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
GE9, GE10	0.9300	0.0008	0.9316
GE9, GE10	0.9234	0.0008	0.9251
GNF2	0.9340	0.0008	0.9356
GNF2	0.9344	0.0008	0.9360
GNF2	**0.9367**	**0.0010**	**0.9386**
GNF2	0.9287	0.0010	0.9307
Japan-BWR 8x8 Step II	0.9289	0.0009	0.9306
Japan-BWR 8x8 Step II	0.9292	0.0010	0.9311
Japan-BWR 8x8 Step II	0.9315	0.0008	0.9332
Japan-BWR 8x8 Step II	0.9217	0.0009	0.9234
KKL-BWR 10/15	0.9259	0.0009	0.9277
KKL-BWR 10/15	0.9261	0.0009	0.9280
KKL-BWR 10/15	0.9278	0.0008	0.9295
KKL-BWR 10/15	0.9232	0.0008	0.9248
KKL-BWR 10/15	0.9222	0.0009	0.9239
KKL-BWR 10/15	0.9246	0.0008	0.9262
KKL-BWR 10/15	0.9265	0.0008	0.9281
KKL-BWR 10/15	0.9214	0.0008	0.9230
KKL-BWR 11/16	0.9405	0.0010	0.9424
KKL-BWR 11/16	0.9459	0.0008	0.9476
KKL-BWR 11/16	0.9447	0.0009	0.9464
KKL-BWR 11/16	0.9412	0.0008	0.9428
KKL-BWR 1/4	0.9271	0.0010	0.9291
KKL-BWR 1/4	0.9279	0.0009	0.9296
KKL-BWR 1/4	0.9304	0.0008	0.9319
KKL-BWR 1/4	0.9206	0.0008	0.9222
KKL-BWR 2/5/8	0.9268	0.0009	0.9285
KKL-BWR 2/5/8	0.9268	0.0010	0.9287
KKL-BWR 2/5/8	0.9308	0.0008	0.9324
KKL-BWR 2/5/8	0.9220	0.0010	0.9240
KKL-BWR 3/9/12/13	0.9239	0.0009	0.9258
KKL-BWR 3/9/12/13	0.9241	0.0009	0.9259

Table 7-40
Most Reactive Fuel Lattice
(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
KKL-BWR 3/9/12/13	0.9266	0.0008	0.9281
KKL-BWR 3/9/12/13	0.9194	0.0009	0.9212
KKL-BWR 6	0.9116	0.0009	0.9134
KKL-BWR 6	0.9118	0.0009	0.9135
KKL-BWR 6	0.9135	0.0008	0.9152
KKL-BWR 6	0.9058	0.0008	0.9073
KKL-BWR 6	0.9053	0.0008	0.9069
KKL-BWR 6	0.9052	0.0009	0.9069
KKL-BWR 6	0.9102	0.0008	0.9118
KKL-BWR 6	0.9010	0.0010	0.9030
KKL-BWR 7/14	0.9155	0.0008	0.9172
KKL-BWR 7/14	0.9150	0.0009	0.9167
KKL-BWR 7/14	0.9200	0.0008	0.9216
KKL-BWR 7/14	0.9130	0.0009	0.9148
SVEA-96Opt2	0.9428	0.0008	0.9445
SVEA-96Opt2	0.9434	0.0008	0.9450
SVEA-96Opt2	0.9457	0.0008	0.9473
SVEA-96Opt2	0.9427	0.0008	0.9443
SVEA-96Opt	0.9183	0.0008	0.9200
SVEA-96Opt2	0.9207	0.0008	0.9224
SVEA-96Opt2	0.9232	0.0008	0.9248
SVEA-96Opt2	0.9180	0.0010	0.9199
SVEA-96Opt2	0.9005	0.0009	0.9023
SVEA-96Opt2	0.9006	0.0009	0.9025
SVEA-96Opt2	0.9033	0.0008	0.9049
SVEA-96Opt2	0.8962	0.0009	0.8979
SVEA-96Opt	0.9187	0.0010	0.9207
SVEA-96Opt2	0.9178	0.0008	0.9194
SVEA-96Opt	0.9219	0.0008	0.9235
SVEA-96Opt	0.9163	0.0008	0.9179
SVEA-96Opt	0.9163	0.0008	0.9179
SVEA-96Opt	0.9173	0.0009	0.9190

Table 7-40
Most Reactive Fuel Lattice

(7 Pages)

GE or Equivalent Reload Fuel Designation	k_{keno}	σ_{keno}	k_{eff}
SVEA-96Opt	0.9194	0.0009	0.9211
SVEA-96Opt	0.9143	0.0009	0.9161
Siemens QFA 9x9	0.9286	0.0009	0.9303
Siemens QFA 9x9	0.9300	0.0007	0.9314
Siemens QFA 9x9	0.9324	0.0009	0.9342
Siemens QFA 9x9	0.9231	0.0009	0.9248
XXX-RCN	0.9129	0.0009	0.9147
XXX-RCN	0.9153	0.0009	0.9170
XXX-RCN	0.9157	0.0009	0.9175
XXX-RCN	0.9087	0.0010	0.9107
STD GE-4 w/ higher exp.	0.9194	0.0009	0.9211
STD GE-4 w/ higher exp.	0.9188	0.0008	0.9204
STD GE-4 w/ higher exp.	0.9206	0.0008	0.9222
STD GE-4 w/ higher exp.	0.9107	0.0009	0.9124

Table 7-41
EOS-89BTH Dimensions of System Components with Fabrication Tolerance

Components	Dimension (inch)			
	Nominal	**Minimum(1)**	**Maximum(1)**	**Tolerance (3)**
Fuel Rod OD(4)	0.424	0.419	0.429	0.005
Steel Plate(5)	[ ]	[ ]	[ ]	[ ]
	[ ]	[ ]	[ ]	[ ]
Aluminum Plate	[ ]	[ ]	[ ]	[ ]
	[ ]	[ ]	[ ]	[ ]
Poison Plate	[ ]	[ ]	[ ]	[ ]
DSC shell thickness	0.5	0.49	0.55	0.05
Lead Gamma Shield Thickness(2)	2.5		3.56	

Notes:

(1) The maximum is the nominal plus the fabrication tolerance; the minimum is the nominal minus the fabrication tolerance.

(2) The maximum lead thickness represents the TC125 (Table 7-5).

(3) The tolerance information is assumed; the nominal value is for FANP 9X9-2 FAs.

(4) The steel plate dimension used in the determination of minimum B-10 requirements is 0.27” (HVA, HVB) and 0.25" (HVC-F).

Table 7-42
Most Reactive Configuration
(4 Pages)

Model Description	k_{keno}	σ_{keno}	k_{eff}
Fuel Assemblies Position in the Fuel Compartment			
Fuel Assemblies Centered	0.9300	0.0008	0.9316
Fuel Assemblies Positioned Inwardly	**0.9346**	**0.0009**	**0.9364**
2: Fuel Rod OD			
[ ]	0.9337	0.0009	0.9355
[ ]	**0.9343**	**0.0009**	**0.9361**
[ ]	0.9346	0.0009	0.9364
Gaps at Plate Joints			
[ ]	0.9353	0.0009	0.9371
[ ]	0.9354	0.0008	0.9370
[ ]	0.9344	0.0008	0.9360
[ ]	0.9356	0.0008	0.9372
[ ]	0.9343	0.0008	0.9359
[ ]	0.9351	0.0008	0.9367
[ ]	0.9352	0.0008	0.9368
[ ]	0.9343	0.0008	0.9359
[ ]	0.9351	0.0009	0.9369
[ ]	0.9343	0.0009	0.9361
[ ]	0.9356	0.0008	0.9372
[ ]	**0.9347**	**0.0008**	**0.9363**
Steel Plate Thickness			
[ ]	0.9334	0.0009	0.9352
[ ]	0.9347	0.0008	0.9363
[ ]	0.9344	0.0008	0.9360
[ ]	**0.9355**	**0.0008**	**0.9371**
[ ]	0.9339	0.0008	0.9355

Table 7-42
Most Reactive Configuration
(4 Pages)

Model Description	k_{keno}	σ_{keno}	k_{eff}
[ ]	0.9370	0.0008	0.9386
[ ]	0.9347	0.0008	0.9363
Al Plate Thickness			
[ ]	0.9349	0.0008	0.9365
[ ]	0.9355	0.0008	0.9371
[ ]	0.9356	0.0009	0.9374
[ ]	0.9364	0.0009	0.9382
[ ]	**0.9356**	**0.0009**	**0.9374**
[ ]	0.9347	0.0008	0.9363
Poison Plate Thickness (B-10 Content is constant - 29 mg/cm^2)			
[ ]	0.9364	0.0008	0.9380
[ ]	**0.9356**	**0.0009**	**0.9374**
[ ]	0.9342	0.0009	0.9360
DSC Shell Thickness			
[ ]	0.9344	0.0009	0.9362
["]	**0.9356**	**0.0009**	**0.9374**
[ ]	0.9363	0.0008	0.9379
Lead Shield Thickness			
[ ]	**0.9356**	**0.0009**	**0.9374**
[ ]	0.9339	0.0009	0.9357
Transition Rail Material			
[ ]	0.9296	0.0008	0.9312
[ ]	0.9316	0.0009	0.9334
[ ]	0.9300	0.0008	0.9316
[ ]	0.9314	0.0009	0.9332

Table 7-42
Most Reactive Configuration
(4 Pages)

Model Description	k_{keno}	σ_{keno}	k_{eff}
[ ]	0.9321	0.0008	0.9337
[ ]	0.9329	0.0008	0.9345
[ ]	**0.9356**	**0.0009**	**0.9374**
Internal Moderator Density (IMD)			
IMD = 1% TD	0.4518	0.0004	0.4526
IMD = 10% TD	0.4882	0.0004	0.4890
IMD = 20% TD	0.5475	0.0006	0.5487
IMD = 30% TD	0.6169	0.0006	0.6181
IMD = 40% TD	0.6824	0.0007	0.6838
IMD = 50% TD	0.7408	0.0007	0.7422
IMD = 60% TD	0.7931	0.0008	0.7947
IMD = 70% TD	0.8359	0.0008	0.8375
IMD = 80% TD	0.8759	0.0009	0.8777
IMD = 90% TD	0.9073	0.0008	0.9089
IMD = 100% TD	**0.9356**	**0.0009**	**0.9374**
Gap between DSC and TC			
Gap with void	**0.9401**	**0.0008**	**0.9417**
Gap with water (1% TD)	0.9403	0.0008	0.9419
Gap with water (10% TD)	0.9393	0.0008	0.9409
Gap with water (20% TD)	0.9373	0.0008	0.9389
Gap with water (30% TD)	0.9372	0.0008	0.9388
Gap with water (40% TD)	0.9368	0.0009	0.9386
Gap with water (50% TD)	0.9364	0.0008	0.9380
Gap with water (60% TD)	0.9341	0.0009	0.9359
Gap with water (70% TD)	0.9361	0.0008	0.9377
Gap with water (80% TD)	0.9357	0.0009	0.9375
Gap with water (90% TD)	0.9346	0.0009	0.9364
Gap with water (100% TD)	0.9356	0.0009	0.9374
External Moderator Density (EMD)			
EMD = zero (void)	**0.9401**	**0.0008**	**0.9417**
EMD = 1% TD	0.9379	0.0009	0.9397
EMD = 10% TD	0.9367	0.0008	0.9383

Table 7-42
Most Reactive Configuration

(4 Pages)

Model Description	k_{keno}	σ_{keno}	k_{eff}
EMD = 20% TD	0.9368	0.0009	0.9386
EMD = 30% TD	0.9352	0.0008	0.9368
EMD = 40% TD	0.9366	0.0008	0.9382
EMD = 50% TD	0.9363	0.0008	0.9379
EMD = 60% TD	0.9344	0.0009	0.9362
EMD = 70% TD	0.9353	0.0008	0.9369
EMD = 80% TD	0.9345	0.0008	0.9361
EMD = 90% TD	0.9350	0.0008	0.9366
EMD = 100% TD	0.9356	0.0008	0.9372
Constant Poison Plate Density Definition			
EMD = zero (void)	0.9408	0.0009	0.9426

Table 7-43
Determination of Minimum Poison Loading Requirement

Basket Type	Enrichment (wt% of U-235)	B-10 Content (mg/cm^2)	k_{keno}	σ_{keno}	k_{eff}
All Fuel Except ABB-10-C					
MMC	4.1	29.4	0.9343	0.0008	0.9359
	4.45	37.2	0.9369	0.0009	0.9387
BORAL®	**4.8**	**45.0**	**0.9382**	**0.0008**	**0.9398**
ABB-10-C Fuel					
MMC	3.85	29.4	0.9271	0.0008	0.9287
	4.25	37.2	0.9329	0.0009	0.9347
BORAL®	4.55	45.0	0.9347	0.0008	0.9363

Table 7-44
Criticality Results

EOS-37PTH: Regulatory Requirements for Storage			
Configuration	k_{keno}	σ_{keno}	k_{eff}
Dry Storage (Bounded by infinite array of undamaged storage casks) *for intact fuel assemblies*	0.6203	0.0003	0.6209
Normal Loading and Unloading Conditions (Optimum Moderator Density) *for intact fuel assemblies*	0.9371	0.0007	0.9385
Normal Loading and Unloading Conditions (Optimum Moderator Density) for damaged and failed fuels balanced with intact fuels	*0.9370*	*0.0007*	*0.9384*
USL = 0.9404			
EOS-89BTH: Regulatory Requirements for Storage			
Configuration	k_{keno}	σ_{keno}	k_{eff}
Dry Storage (Bounded by infinite array of undamaged storage casks)	0.5187	0.0003	0.5193
Normal Loading and Unloading Conditions (Optimum Moderator Density)	0.9382	0.0008	0.9398
USL = 0.9418			

Table 7-45
Comparison of Materials used in Design Calculation and Benchmark Models

	System Application	Benchmark KENO V.a Models
Tank/Canister	Carbon steel	none
Support structures	6061-aluminum plates Stainless steel Concrete Poison plates in aluminium matrix	6061-aluminum plates 1100-aluminum plates 5052-aluminum plates D16-aluminum alloy plates Acrylic support plates Lucite plates
Fuel	UO_2	UO_2
Clad	Stainless steel Zircaloy-4 Zircaloy-2	Stainless steel Zircaloy-4 Zircaloy-2 6061-aluminum
Moderator	Pure water Water with soluble boron	Pure water Water with soluble boron
Reflecting material	Water Lead Steel	Water Lead Steel Depleted uranium

Table 7-46
Benchmark Experimental KENO V.a Simulation Results
(5 Pages)

Experiment Name	Enrichment (wt. % U-235)	Pitch (cm)	Assembly Separation (cm)	Soluble Boron (ppm)	Mod./Fuel Ratio	AEG	EALF (eV)	k_{eff}	σ
LCT-001-001	2.35	2.032	-	0	2.918	36.24	9.64E-02	0.9954	0.0009
LCT-001-002	2.35	2.032	11.92	0	2.918	36.26	9.56E-02	0.9951	0.0009
LCT-001-003	2.35	2.032	8.41	0	2.918	36.29	9.46E-02	0.9955	0.0009
LCT-001-004	2.35	2.032	10.05	0	2.918	36.27	9.53E-02	0.9946	0.0009
LCT-001-005	2.35	2.032	6.39	0	2.918	36.31	9.40E-00	0.9932	0.0009
LCT-001-006	2.35	2.032	8.01	0	2.918	36.27	9.53E-02	0.9955	0.0009
LCT-001-007	2.35	2.032	4.46	0	2.918	36.32	9.35E-02	0.9935	0.0008
LCT-001-008	2.35	2.032	7.57	0	2.918	36.30	9.42E-02	0.9926	0.0008
LCT-002-001	4.31	2.54	-	0	3.882	35.74	1.14E-01	0.9948	0.0010
LCT-002-002	4.31	2.54	-	0	3.882	35.74	1.14E-01	0.9977	0.0009
LCT-002-003	4.31	2.54	-	0	3.882	35.74	1.14E-01	0.9975	0.0009
LCT-002-004	4.31	2.54	10.62	0	3.882	35.77	1.13E-01	0.9969	0.0010
LCT-002-005	4.31	2.54	7.11	0	3.882	35.77	1.13E-01	0.9969	0.0010
LCT-008-001	2.459	1.636	-	1511	1.841	33.59	2.86E-01	0.9960	0.0006
LCT-008-002	2.459	1.636	-	1336	1.841	33.90	2.52E-01	0.9971	0.0008
LCT-008-003	2.459	1.636	-	1336	1.841	33.90	2.52E-01	0.9974	0.0007
LCT-008-004	2.459	1.636	-	1182	1.841	33.89	2.53E-01	0.9966	0.0006
LCT-008-005	2.459	1.636	-	1182	1.841	33.90	2.52E-01	0.9983	0.0007
LCT-008-006	2.459	1.636	-	1033	1.841	33.90	2.52E-01	0.9965	0.0006
LCT-008-007	2.459	1.636	-	1033	1.841	33.91	2.51E-01	0.9956	0.0006
LCT-008-008	2.459	1.636	-	794	1.841	33.93	2.49E-01	0.9950	0.0007

Table 7-46
Benchmark Experimental KENO V.a Simulation Results
(5 Pages)

Experiment Name	Enrichment (wt. % U-235)	Pitch (cm)	Assembly Separation (cm)	Soluble Boron (ppm)	Mod./Fuel Ratio	AEG	EALF (eV)	k_{eff}	σ
LCT-008-009	2.459	1.636	-	779	1.841	33.93	2.50E-01	0.9950	0.0008
LCT-008-010	2.459	1.636	-	1245	1.841	33.88	2.54E-01	0.9972	0.0008
LCT-008-011	2.459	1.636	-	1384	1.841	33.81	2.61E-01	0.9979	0.0007
LCT-008-012	2.459	1.636	-	1348	1.841	33.88	2.53E-01	0.9970	0.0006
LCT-008-013	2.459	1.636	-	1348	1.841	33.87	2.55E-01	0.9980	0.0007
LCT-008-014	2.459	1.636	-	1363	1.841	33.84	2.57E-01	0.9968	0.0006
LCT-008-015	2.459	1.636	-	1363	1.841	33.85	2.56E-01	0.9972	0.0007
LCT-008-016	2.459	1.636	-	1158	1.841	34.10	2.32E-01	0.9963	0.0006
LCT-008-017	2.459	1.636	-	921	1.841	34.43	2.03E-01	0.9958	0.0007
LCT-010-005	4.31	2.54	14.26	0	3.882	33.42	3.90E-01	0.9988	0.0011
LCT-010-016	4.31	1.892	15.39	0	1.597	33.39	2.94E-01	1.0005	0.0009
LCT-010-017	4.31	1.892	15.36	0	1.597	33.46	2.87E-01	0.9999	0.0009
LCT-010-018	4.31	1.892	14.97	0	1.597	33.50	2.83E-01	0.9986	0.0009
LCT-010-019	4.31	1.892	13.34	0	1.597	33.58	2.76E-01	0.9983	0.0010
LCT-017-003	2.35	2.032	10.51	0	2.918	36.29	9.46E-02	0.9985	0.0008
LCT-017-004	2.35	2.032	11.09	0	2.918	34.74	2.13E-01	0.9947	0.0009
LCT-017-005	2.35	2.032	13.19	0	2.918	35.01	1.86E-01	0.9975	0.0009
LCT-017-006	2.35	2.032	13.37	0	2.918	35.15	1.74E-01	0.9989	0.0007
LCT-017-007	2.35	2.032	12.96	0	2.918	35.24	1.66E-01	0.9977	0.0008
LCT-017-008	2.35	2.032	9.95	0	2.918	35.62	1.36E-01	0.9938	0.0010
LCT-017-009	2.35	2.032	7.82	0	2.918	36.02	1.10E-01	0.9945	0.0008

Table 7-46
Benchmark Experimental KENO V.a Simulation Results
(5 Pages)

Experiment Name	Enrichment (wt. % U-235)	Pitch (cm)	Assembly Separation (cm)	Soluble Boron (ppm)	Mod./Fuel Ratio	AEG	EALF (eV)	k_{eff}	σ
LCT-017-010	2.35	2.032	9.89	0	2.918	36.15	9.93E-02	0.9996	0.0009
LCT-017-011	2.35	2.032	10.44	0	2.918	36.20	9.75E-02	0.9994	0.0009
LCT-017-012	2.35	2.032	10.44	0	2.918	36.23	9.63E-02	0.9976	0.0008
LCT-017-013	2.35	2.032	9.6	0	2.918	36.28	9.48E-02	0.9964	0.0008
LCT-017-014	2.35	2.032	8.75	0	2.918	36.29	9.43E-02	0.9959	0.0008
LCT-017-015	2.35	1.684	8.57	0	1.600	34.74	1.79E-01	0.9962	0.0010
LCT-017-016	2.35	1.684	9.17	0	1.600	34.82	1.74E-01	0.9974	0.0009
LCT-017-017	2.35	1.684	9.1	0	1.600	34.89	1.69E-01	0.9983	0.0008
LCT-017-019	2.35	1.684	8.87	0	1.600	34.97	1.64E-01	0.9960	0.0009
LCT-017-020	2.35	1.684	8.65	0	1.600	35.00	1.63E-01	0.9933	0.0010
LCT-017-021	2.35	1.684	8.13	0	1.600	35.03	1.61E-01	0.9939	0.0008
LCT-017-022	2.35	1.684	7.26	0	1.600	35.05	1.60E-01	0.9932	0.0009
LCT-017-023	2.35	1.684	9.65	0	1.600	34.85	1.72E-01	0.9998	0.0009
LCT-017-024	2.35	1.684	9.7	0	1.600	34.93	1.67E-01	0.9977	0.0009
LCT-017-025	2.35	1.684	8.09	0	1.600	35.06	1.59E-01	0.9936	0.0009
LCT-017-028	2.35	1.684	7.65	0	1.600	33.88	3.02E-01	0.9953	0.0008
LCT-017-029	2.35	1.684	9.09	0	1.600	34.16	2.62E-01	0.9963	0.0010
LCT-042-001	2.35	1.684	8.28	0	1.600	34.86	1.72E-01	0.9965	0.0008
LCT-042-002	2.35	1.684	4.8	0	1.600	34.76	1.78E-01	0.9965	0.0009
LCT-042-003	2.35	1.684	2.69	0	1.600	34.68	1.85E-01	0.9962	0.0009
LCT-042-004	2.35	1.684	2.98	0	1.600	34.69	1.83E-01	0.9980	0.0009

Table 7-46
Benchmark Experimental KENO V.a Simulation Results
(5 Pages)

Experiment Name	Enrichment (wt. % U-235)	Pitch (cm)	Assembly Separation (cm)	Soluble Boron (ppm)	Mod./Fuel Ratio	AEG	EALF (eV)	k_{eff}	σ
LCT-042-005	2.35	1.684	3.86	0	1.600	34.74	1.79E-01	0.9975	0.0008
LCT-042-006	2.35	1.684	7.79	0	1.600	34.84	1.72E-01	0.9975	0.0009
LCT-042-007	2.35	1.684	5.43	0	1.600	34.78	1.77E-01	0.9966	0.0008
LCT-050-001	4.738	1.3	-	0	2.032	34.24	2.04E-01	0.9964	0.0010
LCT-050-002	4.738	1.3	-	0	2.032	34.35	1.95E-01	0.9939	0.0010
LCT-050-003	4.738	1.3	-	822	2.032	34.14	2.12E-01	0.9948	0.0009
LCT-050-004	4.738	1.3	-	822	2.032	34.24	2.03E-01	0.9981	0.0009
LCT-050-005	4.738	1.3	-	5030	2.032	33.96	2.28E-01	0.9979	0.0009
LCT-050-006	4.738	1.3	-	5030	2.032	34.04	2.19E-01	0.9976	0.0009
LCT-050-007	4.738	1.3	-	5030	2.032	34.09	2.15E-01	0.9975	0.0010
LCT-051-001	2.459	1.636	4.91	143	1.841	35.23	1.48E-01	0.9942	0.0007
LCT-051-002	2.459	1.636	1.64	510	1.841	34.46	2.00E-01	0.9956	0.0009
LCT-051-003	2.459	1.636	1.64	514	1.841	34.46	2.00E-01	0.9951	0.0008
LCT-051-004	2.459	1.636	1.64	501	1.841	34.46	2.01E-01	0.9966	0.0009
LCT-051-005	2.459	1.636	1.64	493	1.841	34.45	2.02E-01	0.9946	0.0007
LCT-051-006	2.459	1.636	1.64	474	1.841	34.42	2.05E-01	0.9948	0.0009
LCT-051-007	2.459	1.636	1.64	462	1.841	34.42	2.05E-01	0.9939	0.0008
LCT-051-008	2.459	1.636	1.64	432	1.841	34.43	2.05E-01	0.9963	0.0009
LCT-051-009	2.459	1.636	3.27	217	1.841	34.89	1.69E-01	0.9933	0.0008
LCT-051-010	2.459	1.636	1.64	15	1.841	34.53	1.96E-01	0.9945	0.0008
LCT-051-011	2.459	1.636	1.64	28	1.841	34.51	1.98E-01	0.9921	0.0009

Table 7-46
Benchmark Experimental KENO V.a Simulation Results

(5 Pages)

Experiment Name	Enrichment (wt. % U-235)	Pitch (cm)	Assembly Separation (cm)	Soluble Boron (ppm)	Mod./Fuel Ratio	AEG	EALF (eV)	k_{eff}	σ
LCT-051-012	2.459	1.636	1.64	92	1.841	34.48	1.99E-01	0.9901	0.0009
LCT-051-013	2.459	1.636	1.64	395	1.841	34.40	2.06E-01	0.9865	0.0009
LCT-051-014	2.459	1.636	3.27	121	1.841	34.85	1.72E-01	0.9865	0.0008
LCT-051-015	2.459	1.636	1.64	487	1.841	34.40	2.06E-01	0.9913	0.0007
LCT-051-016	2.459	1.636	3.27	197	1.841	34.84	1.73E-01	0.9893	0.0009
LCT-051-017	2.459	1.636	1.64	634	1.841	34.39	2.06E-01	0.9929	0.0008
LCT-051-018	2.459	1.636	3.27	320	1.841	34.83	1.73E-01	0.9901	0.0008
LCT-051-019	2.459	1.636	4.91	72	1.841	35.15	1.53E-01	0.9895	0.0009

Table 7-47
Correlation Coefficients |r| for Independent Parameters

Parameter	EOS-37PTH	EOS-89BTH
U-235 Enrichment	0.271	0.218
Pitch (cm)	0.170	0.053
Moderator to Fuel Volume Ratio	0.108	0.141
AEG	0.150	-
Soluble Boron (ppm)	0.506	-
EALF	-	0.340
Assembly Separation (cm)	0.612	0.487

Table 7-48
USL Evaluations

Equation Parameter	EOS-37PTH	EOS-89BTH
	Value	
$\bar{k}_{eff}$	0.9958	0.9964
S_P	2.70E-3	2.23E-3
U	2.0	2.065
Δ_{sm}	0.05	0.05
USL	**0.9404**	**0.9418**

Table 7-49
EOS-37PTH – De-Cladding Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
WE 17x17 Assembly Class – w/ clad			
IMD 50 %	0.9043	0.0009	0.9061
IMD 60 %	0.9335	0.0007	0.9349
IMD 70 %	0.9573	0.0007	0.9587
IMD 80 %	0.9734	0.0007	0.9748
IMD 90 %	0.9836	0.0007	0.9850
IMD 100 %	0.9917	0.0007	0.9931
WE 17x17 Assembly Class – w/o clad			
IMD 50 %	0.9350	0.0007	0.9364
IMD 60 %	0.9636	0.0007	0.9650
IMD 70 %	0.9815	0.0007	0.9829
IMD 80 %	0.9939	0.0008	0.9955
IMD 90 %	0.9990	0.0008	1.0006
IMD 100 %	1.0027	0.0007	1.0041
CE 16x16 Assembly Class – w/ clad			
IMD 50 %	0.8707	0.0008	0.8723
IMD 60 %	0.9001	0.0008	0.9017
IMD 70 %	0.9194	0.0007	0.9208
IMD 80 %	0.9335	0.0007	0.9349
IMD 90 %	0.9452	0.0009	0.9470
IMD 100 %	0.9503	0.0008	0.9519
CE 16x16 Assembly Class – w/o clad			
IMD 50 %	0.9052	0.0008	0.9068
IMD 60 %	0.9305	0.0010	0.9325
IMD 70 %	0.9472	0.0008	0.9488
IMD 80 %	0.9583	0.0007	0.9597
IMD 90 %	0.9637	0.0008	0.9653
IMD 100 %	0.9636	0.0008	0.9652
BW 15x15 Assembly Class – w/ clad			
IMD 50 %	0.9084	0.0006	0.9096
IMD 60 %	0.9397	0.0006	0.9409
IMD 70 %	0.9619	0.0007	0.9633
IMD 80 %	0.9780	0.0006	0.9792

Table 7-49
EOS-37PTH – De-Cladding Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
IMD 90 %	0.9896	0.0006	0.9908
IMD 100 %	0.9959	0.0008	0.9975
BW 15x15 Assembly Class – w/o clad			
IMD 50 %	0.9392	0.0007	0.9406
IMD 60 %	0.9678	0.0006	0.9690
IMD 70 %	0.9871	0.0006	0.9883
IMD 80 %	0.9982	0.0007	0.9996
IMD 90 %	1.0055	0.0007	1.0069
IMD 100 %	1.0074	0.0007	1.0088
CE 15x15 Assembly Class – w/ clad			
IMD 50 %	0.8915	0.0007	0.8929
IMD 60 %	0.9196	0.0007	0.9210
IMD 70 %	0.9398	0.0007	0.9412
IMD 80 %	0.9554	0.0008	0.9570
IMD 90 %	0.9665	0.0008	0.9681
IMD 100 %	0.9717	0.0008	0.9733
CE 15x15 Assembly Class – w/o clad			
IMD 50 %	0.9231	0.0008	0.9247
IMD 60 %	0.9491	0.0008	0.9507
IMD 70 %	0.9674	0.0007	0.9688
IMD 80 %	0.9778	0.0008	0.9794
IMD 90 %	0.9823	0.0008	0.9839
IMD 100 %	0.9825	0.0008	0.9841
WE 15x15 Assembly Class – w/ clad			
IMD 50 %	0.8983	0.0007	0.8997
IMD 60 %	0.9288	0.0007	0.9302
IMD 70 %	0.9512	0.0007	0.9526
IMD 80 %	0.9663	0.0007	0.9677
IMD 90 %	0.9804	0.0007	0.9818
IMD 100 %	0.9870	0.0008	0.9886
WE 15x15 Assembly Class – w/o clad			
IMD 50 %	0.9391	0.0008	0.9407
IMD 60 %	0.9657	0.0007	0.9671

Table 7-49
EOS-37PTH – De-Cladding Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
IMD 70 %	0.9834	0.0008	0.9850
IMD 80 %	0.9955	0.0007	0.9969
IMD 90 %	0.9989	0.0009	1.0007
IMD 100 %	0.9995	0.0006	1.0007
CE 14x14 Assembly Class – w/ clad			
IMD 50 %	0.8768	0.0007	0.8782
IMD 60 %	0.9050	0.0007	0.9064
IMD 70 %	0.9260	0.0008	0.9276
IMD 80 %	0.9390	0.0008	0.9406
IMD 90 %	0.9497	0.0009	0.9515
IMD 100 %	0.9536	0.0007	0.9550
CE 14x14 Assembly Class – w/o clad			
IMD 50 %	0.9138	0.0007	0.9152
IMD 60 %	0.9400	0.0008	0.9416
IMD 70 %	0.9548	0.0007	0.9562
IMD 80 %	0.9646	0.0007	0.9660
IMD 90 %	0.9677	0.0009	0.9695
IMD 100 %	0.9674	0.0008	0.9690
WE 14x14 Assembly Class – w/ clad			
IMD 50 %	0.8609	0.0007	0.8623
IMD 60 %	0.8854	0.0007	0.8869
IMD 70 %	0.9005	0.0007	0.9019
IMD 80 %	0.9129	0.0008	0.9145
IMD 90 %	0.9207	0.0007	0.9221
IMD 100 %	0.9237	0.0005	0.9248
WE 14x14 Assembly Class – w/o clad			
IMD 50 %	0.8838	0.0007	0.8852
IMD 60 %	0.9067	0.0008	0.9083
IMD 70 %	0.9229	0.0007	0.9243
IMD 80 %	0.9301	0.0006	0.9313
IMD 90 %	0.9342	0.0008	0.9358
IMD 100 %	0.9355	0.0008	0.9371

Table 7-50
EOS-37PTH – Rod Pitch and Missing Rod Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
17x17 array size: WE 17x17 Assembly Class			
Pitch =0.374 inch, IMD 100 %	*0.7797*	*0.0009*	*0.7815*
Pitch =0.402 inch, IMD 100 %	*0.8525*	*0.0008*	*0.8541*
Pitch =0.429 inch, IMD 100 %	*0.9131*	*0.0008*	*0.9147*
Pitch =0.457 inch, IMD 100 %	*0.9601*	*0.0009*	*0.9619*
Pitch =0.484 inch, IMD 100 %	*0.9942*	*0.0007*	*0.9956*
Pitch =0.496 inch (nominal), IMD 100 %	*1.0027*	*0.0007*	*1.0041*
Pitch =0.515 inch, IMD 90 %	*1.0073*	*0.0008*	*1.0089*
Pitch =0.534 inch, IMD 50 %	*0.9596*	*0.0007*	*0.9610*
Pitch =0.534 inch, IMD 60 %	*0.9843*	*0.0008*	*0.9859*
Pitch =0.534 inch, IMD 70 %	*0.9990*	*0.0007*	*1.0004*
Pitch =0.534 inch, IMD 80 %	*1.0065*	*0.0006*	*1.0077*
Pitch =0.534 inch, IMD 90 %	***1.0077***	***0.0006***	***1.0089***
Pitch =0.534 inch, IMD 100 %	*1.0045*	*0.0007*	*1.0059*
Pitch =0.534 inch, IMD 90 %, 1 missing rod	*1.0062*	*0.0007*	*1.0076*
Pitch =0.534 inch, IMD 90 %, 2 missing rods	*1.0054*	*0.0007*	*1.0068*
Pitch =0.534 inch, IMD 80 %, 4 missing rods	*0.9997*	*0.0007*	*1.0011*
Pitch =0.534 inch, IMD 80 %, 5 missing rods	*1.0001*	*0.0006*	*1.0013*
Pitch =0.534 inch, IMD 80 %, 9 missing rods	*0.9856*	*0.0006*	*0.9867*
16x16 array size: CE 16x16 Assembly Class			
Pitch =0.384 inch, IMD 100 %	*0.7531*	*0.0008*	*0.7547*
Pitch =0.417 inch, IMD 100 %	*0.8328*	*0.0008*	*0.8344*
Pitch =0.449 inch, IMD 100 %	*0.8943*	*0.0008*	*0.8959*
Pitch =0.480 inch, IMD 100 %	*0.9389*	*0.0008*	*0.9405*
Pitch =0.506 inch (nominal), IMD 90 %	*0.9637*	*0.0008*	*0.9653*
Pitch =0.512 inch, IMD 90 %	*0.9709*	*0.0007*	*0.9723*
Pitch =0.547 inch, IMD 80 %	*0.9806*	*0.0007*	*0.9820*
Pitch =0.570 inch, IMD 50 %	*0.9439*	*0.0008*	*0.9455*
Pitch =0.570 inch, IMD 60 %	*0.9675*	*0.0007*	*0.9689*
Pitch =0.570 inch, IMD 70 %	*0.9779*	*0.0007*	*0.9793*
Pitch =0.570 inch, IMD 80 %	***0.9818***	***0.0006***	***0.9830***
Pitch =0.570 inch, IMD 90 %	*0.9774*	*0.0007*	*0.9788*
Pitch =0.570 inch, IMD 100 %	*0.9719*	*0.0006*	*0.9731*

Table 7-50
EOS-37PTH – Rod Pitch and Missing Rod Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Pitch =0.570 inch, IMD 80 %, 1 missing rod	*0.9778*	*0.0007*	*0.9792*
Pitch =0.570 inch, IMD 80 %, 2 missing rods	*0.9772*	*0.0007*	*0.9786*
Pitch =0.570 inch, IMD 70 %, 4 missing rods	*0.9707*	*0.0007*	*0.9721*
Pitch =0.570 inch, IMD 80 %, 5 missing rods	*0.9701*	*0.0009*	*0.9719*
Pitch =0.570 inch, IMD 80 %, 9 missing rods	*0.9570*	*0.0007*	*0.9584*
15x15 array size: BW 15x15 Assembly Class			
Pitch =0.433 inch, IMD 100 %	*0.7955*	*0.0008*	*0.7971*
Pitch =0.461 inch, IMD 100 %	*0.8598*	*0.0008*	*0.8614*
Pitch =0.492 inch, IMD 100 %	*0.9212*	*0.0008*	*0.9228*
Pitch =0.512 inch, IMD 100 %	*0.9531*	*0.0007*	*0.9545*
Pitch =0.555 inch, IMD 100 %	*0.9999*	*0.0006*	*1.0011*
Pitch =0.568 inch (nominal), IMD 100 %	*1.0074*	*0.0007*	*1.0088*
Pitch =0.584 inch, IMD 50 %	*0.9530*	*0.0006*	*0.9542*
Pitch =0.584 inch, IMD 60 %	*0.9779*	*0.0006*	*0.9791*
Pitch =0.584 inch, IMD 70 %	*0.9964*	*0.0007*	*0.9978*
Pitch =0.584 inch, IMD 80 %	*1.0047*	*0.0006*	*1.0059*
Pitch =0.584 inch, IMD 90 %	***1.0113***	***0.0007***	***1.0127***
Pitch =0.584 inch, IMD 100 %	*1.0089*	*0.0006*	*1.0101*
Pitch =0.608 inch, IMD 90 %	*1.0093*	*0.0006*	*1.0105*
Pitch =0.584 inch, IMD 100 %, 1 missing rod	*1.0081*	*0.0007*	*1.0095*
Pitch =0.584 inch, IMD 90 %, 2 missing rods	*1.0076*	*0.0007*	*1.0089*
Pitch =0.584 inch, IMD 90 %, 4 missing rods	*1.0001*	*0.0007*	*1.0014*
Pitch =0.584 inch, IMD 90 %, 5 missing rods	*1.0008*	*0.0006*	*1.0021*
Pitch =0.584 inch, IMD 90 %, 9 missing rods	*0.9814*	*0.0006*	*0.9827*
14x14 array size: CE 14x14 Assembly Class			
Pitch =0.440 inch, IMD 100 %	*0.7544*	*0.0008*	*0.7560*
Pitch =0.476 inch, IMD 100 %	*0.8334*	*0.0008*	*0.8350*
Pitch =0.512 inch, IMD 100 %	*0.8950*	*0.0008*	*0.8966*
Pitch =0.547 inch, IMD 100 %	*0.9409*	*0.0010*	*0.9429*
Pitch =0.551 inch, IMD 100 %	*0.9445*	*0.0008*	*0.9461*
Pitch =0.580 inch (nominal), IMD 90 %	*0.9677*	*0.0009*	*0.9695*
Pitch =0.626 inch, IMD 80 %	*0.9871*	*0.0008*	*0.9887*
Pitch =0.657 inch, IMD 50 %	*0.9559*	*0.0007*	*0.9573*

Table 7-50
EOS-37PTH – Rod Pitch and Missing Rod Sensitivity Evaluation

(3 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Pitch =0.657 inch, IMD 60 %	*0.9753*	*0.0007*	*0.9767*
Pitch =0.657 inch, IMD 70 %	*0.9870*	*0.0007*	*0.9884*
Pitch =0.657 inch, IMD 80 %	***0.9873***	***0.0008***	***0.9889***
Pitch =0.657 inch, IMD 90 %	*0.9845*	*0.0007*	*0.9859*
Pitch =0.657 inch, IMD 100 %	*0.9743*	*0.0007*	*0.9757*
Pitch =0.657 inch, IMD 80 %, 1 missing rod	*0.9840*	*0.0008*	*0.9856*
Pitch =0.657 inch, IMD 80 %, 2 missing rods	*0.9818*	*0.0007*	*0.9832*
Pitch =0.657 inch, IMD 80 %, 4 missing rods	*0.9748*	*0.0008*	*0.9764*
Pitch =0.657 inch, IMD 70 %, 5 missing rods	*0.9762*	*0.0007*	*0.9776*
Pitch =0.657 inch, IMD 70 %, 9 missing rods	*0.9545*	*0.0007*	*0.9559*

Table 7-51

The detailed information associated with this table can be found in CoC 1042 Amendment 1 Technical Specifications Table 4

Table 7-52
WE 17x17 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

(2 Sheets)

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	*0.8848*	*0.0007*	*0.8863*
IMD 60 %	*0.9095*	*0.0007*	*0.9109*
IMD 70 %	*0.9251*	*0.0007*	*0.9266*
IMD 80 %	*0.9345*	*0.0008*	*0.9360*
IMD 90 %	*0.9370*	*0.0006*	*0.9383*
IMD 100 %	*0.9370*	*0.0007*	*0.9383*
4.50 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type A			
IMD 50 %	*0.8868*	*0.0007*	*0.8882*
IMD 60 %	*0.9101*	*0.0008*	*0.9116*
IMD 70 %	*0.9259*	*0.0008*	*0.9275*
IMD 80 %	*0.9349*	*0.0007*	*0.9363*
IMD 90 %	*0.9368*	*0.0007*	*0.9381*
IMD 100 %	*0.9361*	*0.0007*	*0.9374*
4.60 wt. % U-235 (Intact), 4.40 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type A			
IMD 50 %	*0.8901*	*0.0006*	*0.8913*
IMD 60 %	*0.9150*	*0.0008*	*0.9165*
IMD 70 %	*0.9277*	*0.0008*	*0.9294*
IMD 80 %	*0.9360*	*0.0006*	*0.9372*
IMD 90 %	*0.9368*	*0.0007*	*0.9382*
IMD 100 %	*0.9364*	*0.0006*	*0.9377*
4.70 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type A			
IMD 50 %	*0.8904*	*0.0007*	*0.8917*
IMD 60 %	*0.9143*	*0.0007*	*0.9157*
IMD 70 %	*0.9270*	*0.0007*	*0.9283*
IMD 80 %	*0.9354*	*0.0007*	*0.9368*
IMD 90 %	*0.9368*	*0.0007*	*0.9383*
IMD 100 %	*0.9345*	*0.0007*	*0.9358*
4.85 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type A			
IMD 50 %	*0.8924*	*0.0007*	*0.8938*
IMD 60 %	*0.9139*	*0.0007*	*0.9154*
IMD 70 %	*0.9290*	*0.0007*	*0.9304*

Table 7-52
WE 17x17 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

(2 Sheets)

Case Description	k_{keno}	σ_{keno}	k_{eff}
IMD 80 %	*0.9345*	*0.0007*	*0.9359*
IMD 90 %	*0.9351*	*0.0005*	*0.9362*
IMD 100 %	*0.9335*	*0.0007*	*0.9350*
4.95 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type A			
IMD 50 %	*0.8969*	*0.0007*	*0.8983*
IMD 60 %	*0.9169*	*0.0007*	*0.9182*
IMD 70 %	*0.9297*	*0.0008*	*0.9313*
IMD 80 %	*0.9345*	*0.0007*	*0.9359*
IMD 90 %	*0.9360*	*0.0007*	*0.9375*
IMD 100 %	*0.9343*	*0.0006*	*0.9356*

Table 7-53
WE 17x17 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8735	0.0007	0.8749
IMD 60 %	0.9006	0.0006	0.9018
IMD 70 %	0.9174	0.0007	0.9188
IMD 80 %	0.9290	0.0007	0.9303
IMD 90 %	0.9360	0.0009	0.9377
IMD 100 %	0.9358	0.0007	0.9373
4.45 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8744	0.0007	0.8757
IMD 60 %	0.8995	0.0007	0.9008
IMD 70 %	0.9180	0.0007	0.9194
IMD 80 %	0.9270	0.0007	0.9284
IMD 90 %	0.9331	0.0007	0.9345
IMD 100 %	0.9345	0.0007	0.9358
4.55 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8790	0.0007	0.8803
IMD 60 %	0.9031	0.0007	0.9045
IMD 70 %	0.9197	0.0007	0.9211
IMD 80 %	0.9300	0.0007	0.9315
IMD 90 %	0.9347	0.0007	0.9360
IMD 100 %	0.9350	0.0007	0.9363
4.65 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type A			
IMD 50 %	0.8796	0.0007	0.8810
IMD 60 %	0.9047	0.0006	0.9060
IMD 70 %	0.9207	0.0007	0.9221
IMD 80 %	0.9311	0.0007	0.9325
IMD 90 %	0.9350	0.0005	0.9361
IMD 100 %	0.9353	0.0007	0.9367
4.80 wt. % U-235 (Intact), 4.60 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type A			
IMD 50 %	0.8852	0.0007	0.8865
IMD 60 %	0.9085	0.0007	0.9099
IMD 70 %	0.9245	0.0007	0.9259
IMD 80 %	0.9337	0.0008	0.9354
IMD 90 %	0.9366	0.0008	0.9381
IMD 100 %	0.9370	0.0007	0.9384
4.90 wt. % U-235 (Intact), 4.70 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type A			
IMD 50 %	0.8866	0.0007	0.8880
IMD 60 %	0.9104	0.0007	0.9117
IMD 70 %	0.9246	0.0007	0.9259
IMD 80 %	0.9320	0.0007	0.9334
IMD 90 %	0.9363	0.0007	0.9377
IMD 100 %	0.9362	0.0006	0.9374

Table 7-54
WE 17x17 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.50 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8740	0.0007	0.8754
IMD 60 %	0.9019	0.0007	0.9033
IMD 70 %	0.9178	0.0007	0.9192
IMD 80 %	0.9294	0.0009	0.9311
IMD 90 %	0.9339	0.0007	0.9353
IMD 100 %	0.9354	0.0007	0.9368
4.65 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8783	0.0007	0.8797
IMD 60 %	0.9046	0.0007	0.9059
IMD 70 %	0.9210	0.0007	0.9223
IMD 80 %	0.9299	0.0007	0.9313
IMD 90 %	0.9350	0.0007	0.9364
IMD 100 %	0.9352	0.0007	0.9366
4.75 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8819	0.0007	0.8833
IMD 60 %	0.9074	0.0006	0.9087
IMD 70 %	0.9238	0.0008	0.9254
IMD 80 %	0.9325	0.0007	0.9338
IMD 90 %	0.9361	0.0008	0.9377
IMD 100 %	0.9369	0.0007	0.9383
4.85 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type B			
IMD 50 %	0.8866	0.0007	0.8880
IMD 60 %	0.9124	0.0007	0.9138
IMD 70 %	0.9258	0.0007	0.9271
IMD 80 %	0.9332	0.0007	0.9345
IMD 90 %	0.9370	0.0007	0.9384
IMD 100 %	0.9362	0.0007	0.9376
5.00 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type B			
IMD 50 %	0.8876	0.0008	0.8892
IMD 60 %	0.9108	0.0008	0.9123
IMD 70 %	0.9263	0.0007	0.9277
IMD 80 %	0.9336	0.0007	0.9351
IMD 90 %	0.9358	0.0007	0.9372
IMD 100 %	0.9357	0.0007	0.9371
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type B			
IMD 50 %	0.8905	0.0007	0.8919
IMD 60 %	0.9138	0.0007	0.9153
IMD 70 %	0.9271	0.0007	0.9285
IMD 80 %	0.9347	0.0007	0.9360
IMD 90 %	0.9362	0.0007	0.9376
IMD 100 %	0.9329	0.0006	0.9341

Table 7-55
WE 17x17 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.45 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8652*	*0.0008*	*0.8668*
IMD 60 %	*0.8928*	*0.0007*	*0.8943*
IMD 70 %	*0.9128*	*0.0007*	*0.9143*
IMD 80 %	*0.9248*	*0.0007*	*0.9262*
IMD 90 %	*0.9335*	*0.0007*	*0.9348*
IMD 100 %	*0.9361*	*0.0007*	*0.9375*
4.60 wt. % U-235 (Intact), 4.40 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type B			
IMD 50 %	*0.8698*	*0.0007*	*0.8712*
IMD 60 %	*0.8982*	*0.0007*	*0.8996*
IMD 70 %	*0.9159*	*0.0008*	*0.9175*
IMD 80 %	*0.9282*	*0.0007*	*0.9295*
IMD 90 %	*0.9339*	*0.0007*	*0.9354*
IMD 100 %	*0.9366*	*0.0007*	*0.9380*
4.70 wt. % U-235 (Intact), 4.55 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type B			
IMD 50 %	*0.8743*	*0.0008*	*0.8759*
IMD 60 %	*0.8992*	*0.0007*	*0.9006*
IMD 70 %	*0.9187*	*0.0008*	*0.9202*
IMD 80 %	*0.9295*	*0.0007*	*0.9308*
IMD 90 %	*0.9345*	*0.0007*	*0.9358*
IMD 100 %	*0.9352*	*0.0007*	*0.9365*
4.85 wt. % U-235 (Intact), 4.60 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type B			
IMD 50 %	*0.8746*	*0.0007*	*0.8759*
IMD 60 %	*0.9015*	*0.0007*	*0.9029*
IMD 70 %	*0.9193*	*0.0007*	*0.9207*
IMD 80 %	*0.9301*	*0.0009*	*0.9319*
IMD 90 %	*0.9355*	*0.0007*	*0.9368*
IMD 100 %	*0.9367*	*0.0007*	*0.9381*
4.95 wt. % U-235 (Intact), 4.75 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type B			
IMD 50 %	*0.8770*	*0.0007*	*0.8783*
IMD 60 %	*0.9041*	*0.0008*	*0.9056*
IMD 70 %	*0.9210*	*0.0007*	*0.9225*
IMD 80 %	*0.9307*	*0.0006*	*0.9320*
IMD 90 %	*0.9347*	*0.0008*	*0.9362*
IMD 100 %	*0.9363*	*0.0007*	*0.9377*
5.00 wt. % U-235 (Intact), 4.95 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type B			
IMD 50 %	*0.8803*	*0.0007*	*0.8817*
IMD 60 %	*0.9060*	*0.0007*	*0.9075*
IMD 70 %	*0.9219*	*0.0007*	*0.9232*
IMD 80 %	*0.9317*	*0.0007*	*0.9331*
IMD 90 %	*0.9360*	*0.0007*	*0.9373*
IMD 100 %	*0.9358*	*0.0007*	*0.9372*

Table 7-56
CE 16x16 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 4.75 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8867	0.0007	0.8881
IMD 60 %	0.9108	0.0008	0.9125
IMD 70 %	0.9250	0.0007	0.9265
IMD 80 %	0.9334	0.0007	0.9348
IMD 90 %	0.9358	0.0008	0.9373
IMD 100 %	0.9339	0.0007	0.9352
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8857	0.0007	0.8871
IMD 60 %	0.9096	0.0007	0.9109
IMD 70 %	0.9227	0.0008	0.9243
IMD 80 %	0.9305	0.0007	0.9319
IMD 90 %	0.9340	0.0008	0.9356
IMD 100 %	0.9304	0.0007	0.9319

Table 7-57
CE 16x16 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 4.70 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8779	0.0008	0.8795
IMD 60 %	0.9020	0.0008	0.9035
IMD 70 %	0.9202	0.0007	0.9216
IMD 80 %	0.9282	0.0007	0.9296
IMD 90 %	0.9352	0.0007	0.9366
IMD 100 %	0.9344	0.0008	0.9359
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8802	0.0007	0.8816
IMD 60 %	0.9030	0.0008	0.9045
IMD 70 %	0.9207	0.0007	0.9221
IMD 80 %	0.9295	0.0007	0.9308
IMD 90 %	0.9330	0.0008	0.9345
IMD 100 %	0.9347	0.0008	0.9362

Table 7-58
CE 16x16 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	*0.8767*	*0.0008*	*0.8782*
IMD 60 %	*0.9017*	*0.0008*	*0.9032*
IMD 70 %	*0.9189*	*0.0008*	*0.9204*
IMD 80 %	*0.9277*	*0.0008*	*0.9292*
IMD 90 %	*0.9313*	*0.0007*	*0.9327*
IMD 100 %	*0.9294*	*0.0007*	*0.9309*

Table 7-59
CE 16x16 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8680*	*0.0008*	*0.8696*
IMD 60 %	*0.8953*	*0.0007*	*0.8967*
IMD 70 %	*0.9142*	*0.0007*	*0.9157*
IMD 80 %	*0.9251*	*0.0006*	*0.9262*
IMD 90 %	*0.9312*	*0.0007*	*0.9327*
IMD 100 %	*0.9329*	*0.0008*	*0.9344*

Table 7-60
BW 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.25 wt. % U-235 (Intact), 4.05 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	*0.8794*	*0.0007*	*0.8808*
IMD 60 %	*0.9052*	*0.0006*	*0.9064*
IMD 70 %	*0.9206*	*0.0007*	*0.9220*
IMD 80 %	*0.9301*	*0.0007*	*0.9315*
IMD 90 %	*0.9350*	*0.0006*	*0.9363*
IMD 100 %	*0.9354*	*0.0006*	*0.9367*
4.40 wt. % U-235 (Intact), 4.10 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type A			
IMD 50 %	*0.8825*	*0.0006*	*0.8836*
IMD 60 %	*0.9067*	*0.0006*	*0.9079*
IMD 70 %	*0.9237*	*0.0006*	*0.9249*
IMD 80 %	*0.9337*	*0.0006*	*0.9349*
IMD 90 %	*0.9360*	*0.0006*	*0.9371*
IMD 100 %	*0.9364*	*0.0006*	*0.9375*
4.50 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type A			
IMD 50 %	*0.8849*	*0.0008*	*0.8864*
IMD 60 %	*0.9094*	*0.0007*	*0.9108*
IMD 70 %	*0.9249*	*0.0007*	*0.9263*
IMD 80 %	*0.9332*	*0.0006*	*0.9345*
IMD 90 %	*0.9359*	*0.0007*	*0.9372*
IMD 100 %	*0.9356*	*0.0007*	*0.9369*
4.60 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type A			
IMD 50 %	*0.8880*	*0.0007*	*0.8893*
IMD 60 %	*0.9116*	*0.0006*	*0.9129*
IMD 70 %	*0.9253*	*0.0006*	*0.9265*
IMD 80 %	*0.9345*	*0.0006*	*0.9357*
IMD 90 %	*0.9345*	*0.0006*	*0.9358*
IMD 100 %	*0.9339*	*0.0006*	*0.9350*
4.75 wt. % U-235 (Intact), 4.40 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type A			
IMD 50 %	*0.8902*	*0.0007*	*0.8915*
IMD 60 %	*0.9124*	*0.0006*	*0.9136*
IMD 70 %	*0.9278*	*0.0007*	*0.9292*
IMD 80 %	*0.9340*	*0.0006*	*0.9353*
IMD 90 %	*0.9352*	*0.0006*	*0.9365*
IMD 100 %	*0.9333*	*0.0007*	*0.9346*
4.85 wt. % U-235 (Intact), 4.55 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type A			
IMD 50 %	*0.8929*	*0.0006*	*0.8940*
IMD 60 %	*0.9157*	*0.0006*	*0.9169*
IMD 70 %	*0.9280*	*0.0006*	*0.9291*
IMD 80 %	*0.9346*	*0.0006*	*0.9358*
IMD 90 %	*0.9370*	*0.0007*	*0.9384*
IMD 100 %	*0.9335*	*0.0006*	*0.9346*

Table 7-61
BW 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.20 wt. % U-235 (Intact), 4.00 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	*0.8672*	*0.0006*	*0.8685*
IMD 60 %	*0.8941*	*0.0008*	*0.8956*
IMD 70 %	*0.9132*	*0.0006*	*0.9144*
IMD 80 %	*0.9252*	*0.0007*	*0.9266*
IMD 90 %	*0.9324*	*0.0006*	*0.9337*
IMD 100 %	*0.9368*	*0.0006*	*0.9381*
4.30 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	*0.8704*	*0.0006*	*0.8716*
IMD 60 %	*0.8976*	*0.0007*	*0.8990*
IMD 70 %	*0.9161*	*0.0007*	*0.9174*
IMD 80 %	*0.9284*	*0.0006*	*0.9296*
IMD 90 %	*0.9341*	*0.0006*	*0.9353*
IMD 100 %	*0.9348*	*0.0007*	*0.9361*
4.45 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type A			
IMD 50 %	*0.8733*	*0.0007*	*0.8746*
IMD 60 %	*0.8996*	*0.0006*	*0.9008*
IMD 70 %	*0.9168*	*0.0007*	*0.9182*
IMD 80 %	*0.9273*	*0.0007*	*0.9286*
IMD 90 %	*0.9341*	*0.0006*	*0.9353*
IMD 100 %	*0.9346*	*0.0006*	*0.9358*
4.55 wt. % U-235 (Intact), 4.30 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type A			
IMD 50 %	*0.8762*	*0.0006*	*0.8775*
IMD 60 %	*0.9021*	*0.0006*	*0.9034*
IMD 70 %	*0.9179*	*0.0007*	*0.9194*
IMD 80 %	*0.9282*	*0.0006*	*0.9294*
IMD 90 %	*0.9339*	*0.0006*	*0.9352*
IMD 100 %	*0.9346*	*0.0006*	*0.9359*
4.65 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type A			
IMD 50 %	*0.8794*	*0.0006*	*0.8807*
IMD 60 %	*0.9037*	*0.0006*	*0.9049*
IMD 70 %	*0.9207*	*0.0007*	*0.9221*
IMD 80 %	*0.9299*	*0.0007*	*0.9313*
IMD 90 %	*0.9353*	*0.0006*	*0.9365*
IMD 100 %	*0.9348*	*0.0007*	*0.9361*
4.75 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type A			
IMD 50 %	*0.8842*	*0.0006*	*0.8854*
IMD 60 %	*0.9084*	*0.0007*	*0.9097*
IMD 70 %	*0.9233*	*0.0006*	*0.9245*
IMD 80 %	*0.9317*	*0.0006*	*0.9330*
IMD 90 %	*0.9369*	*0.0007*	*0.9382*
IMD 100 %	*0.9371*	*0.0006*	*0.9384*

Table 7-62
BW 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.40 wt. % U-235 (Intact), 4.10 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	*0.8715*	*0.0007*	*0.8728*
IMD 60 %	*0.8997*	*0.0006*	*0.9009*
IMD 70 %	*0.9182*	*0.0006*	*0.9194*
IMD 80 %	*0.9275*	*0.0005*	*0.9286*
IMD 90 %	*0.9343*	*0.0007*	*0.9356*
IMD 100 %	*0.9354*	*0.0006*	*0.9366*
4.55 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type B			
IMD 50 %	*0.8750*	*0.0006*	*0.8762*
IMD 60 %	*0.9023*	*0.0007*	*0.9036*
IMD 70 %	*0.9196*	*0.0007*	*0.9209*
IMD 80 %	*0.9306*	*0.0006*	*0.9317*
IMD 90 %	*0.9351*	*0.0006*	*0.9363*
IMD 100 %	*0.9365*	*0.0006*	*0.9378*
4.65 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type B			
IMD 50 %	*0.8775*	*0.0007*	*0.8788*
IMD 60 %	*0.9051*	*0.0007*	*0.9064*
IMD 70 %	*0.9222*	*0.0007*	*0.9235*
IMD 80 %	*0.9315*	*0.0006*	*0.9327*
IMD 90 %	*0.9355*	*0.0006*	*0.9367*
IMD 100 %	*0.9352*	*0.0006*	*0.9364*
4.80 wt. % U-235 (Intact), 4.40 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type B			
IMD 50 %	*0.8823*	*0.0006*	*0.8836*
IMD 60 %	*0.9067*	*0.0006*	*0.9079*
IMD 70 %	*0.9233*	*0.0006*	*0.9245*
IMD 80 %	*0.9327*	*0.0007*	*0.9340*
IMD 90 %	*0.9370*	*0.0006*	*0.9383*
IMD 100 %	*0.9355*	*0.0006*	*0.9367*
4.90 wt. % U-235 (Intact), 4.55 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type B			
IMD 50 %	*0.8837*	*0.0006*	*0.8849*
IMD 60 %	*0.9086*	*0.0006*	*0.9098*
IMD 70 %	*0.9253*	*0.0006*	*0.9265*
IMD 80 %	*0.9331*	*0.0006*	*0.9343*
IMD 90 %	*0.9359*	*0.0007*	*0.9372*
IMD 100 %	*0.9349*	*0.0006*	*0.9361*
5.00 wt. % U-235 (Intact), 4.75 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type B			
IMD 50 %	*0.8874*	*0.0006*	*0.8886*
IMD 60 %	*0.9109*	*0.0006*	*0.9121*
IMD 70 %	*0.9272*	*0.0005*	*0.9282*
IMD 80 %	*0.9342*	*0.0006*	*0.9353*
IMD 90 %	*0.9366*	*0.0007*	*0.9379*
IMD 100 %	*0.9358*	*0.0007*	*0.9371*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2600 ppm, W/O CCs, Type B			
IMD 50 %	*0.8877*	*0.0006*	*0.8888*
IMD 60 %	*0.9119*	*0.0007*	*0.9134*
IMD 70 %	*0.9244*	*0.0006*	*0.9256*
IMD 80 %	*0.9338*	*0.0006*	*0.9351*
IMD 90 %	*0.9354*	*0.0006*	*0.9366*
IMD 100 %	*0.9336*	*0.0006*	*0.9348*

Table 7-63
BW 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.35 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	0.8615	0.0006	0.8627
IMD 60 %	0.8909	0.0006	0.8921
IMD 70 %	0.9114	0.0007	0.9127
IMD 80 %	0.9244	0.0006	0.9256
IMD 90 %	0.9330	0.0006	0.9341
IMD 100 %	0.9370	0.0006	0.9382
4.45 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type B			
IMD 50 %	0.8628	0.0006	0.8641
IMD 60 %	0.8924	0.0006	0.8937
IMD 70 %	0.9114	0.0007	0.9127
IMD 80 %	0.9244	0.0006	0.9256
IMD 90 %	0.9322	0.0007	0.9335
IMD 100 %	0.9350	0.0006	0.9362
4.60 wt. % U-235 (Intact), 4.30 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type B			
IMD 50 %	0.8681	0.0007	0.8694
IMD 60 %	0.8958	0.0006	0.8969
IMD 70 %	0.9137	0.0007	0.9150
IMD 80 %	0.9265	0.0006	0.9278
IMD 90 %	0.9334	0.0006	0.9346
IMD 100 %	0.9364	0.0006	0.9376
4.70 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type B			
IMD 50 %	0.8714	0.0007	0.8728
IMD 60 %	0.8983	0.0007	0.8998
IMD 70 %	0.9153	0.0006	0.9166
IMD 80 %	0.9286	0.0007	0.9299
IMD 90 %	0.9355	0.0006	0.9367
IMD 100 %	0.9363	0.0006	0.9375
4.85 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type B			
IMD 50 %	0.8723	0.0006	0.8735
IMD 60 %	0.8990	0.0007	0.9004
IMD 70 %	0.9175	0.0006	0.9187
IMD 80 %	0.9288	0.0006	0.9299
IMD 90 %	0.9344	0.0006	0.9356
IMD 100 %	0.9363	0.0006	0.9376
4.90 wt. % U-235 (Intact), 4.75 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type B			
IMD 50 %	0.8760	0.0007	0.8773
IMD 60 %	0.9019	0.0006	0.9031
IMD 70 %	0.9187	0.0006	0.9199
IMD 80 %	0.9291	0.0006	0.9303
IMD 90 %	0.9355	0.0007	0.9369
IMD 100 %	0.9364	0.0007	0.9377

Table 7-64
CE 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.60 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	*0.8755*	*0.0008*	*0.8770*
IMD 60 %	*0.9021*	*0.0008*	*0.9036*
IMD 70 %	*0.9171*	*0.0008*	*0.9187*
IMD 80 %	*0.9294*	*0.0008*	*0.9309*
IMD 90 %	*0.9353*	*0.0007*	*0.9366*
IMD 100 %	*0.9361*	*0.0009*	*0.9378*
4.70 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type A			
IMD 50 %	*0.8792*	*0.0007*	*0.8805*
IMD 60 %	*0.9034*	*0.0007*	*0.9047*
IMD 70 %	*0.9199*	*0.0008*	*0.9214*
IMD 80 %	*0.9296*	*0.0006*	*0.9308*
IMD 90 %	*0.9361*	*0.0007*	*0.9374*
IMD 100 %	*0.9353*	*0.0007*	*0.9367*
4.85 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type A			
IMD 50 %	*0.8817*	*0.0007*	*0.8831*
IMD 60 %	*0.9047*	*0.0007*	*0.9061*
IMD 70 %	*0.9222*	*0.0007*	*0.9236*
IMD 80 %	*0.9315*	*0.0006*	*0.9327*
IMD 90 %	*0.9368*	*0.0007*	*0.9381*
IMD 100 %	*0.9347*	*0.0008*	*0.9362*
5.00 wt. % U-235 (Intact), 4.55 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type A			
IMD 50 %	*0.8845*	*0.0007*	*0.8858*
IMD 60 %	*0.9079*	*0.0008*	*0.9095*
IMD 70 %	*0.9229*	*0.0007*	*0.9243*
IMD 80 %	*0.9304*	*0.0007*	*0.9319*
IMD 90 %	*0.9350*	*0.0007*	*0.9365*
IMD 100 %	*0.9346*	*0.0007*	*0.9360*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type A			
IMD 50 %	*0.8880*	*0.0008*	*0.8895*
IMD 60 %	*0.9115*	*0.0006*	*0.9128*
IMD 70 %	*0.9244*	*0.0007*	*0.9258*
IMD 80 %	*0.9338*	*0.0007*	*0.9351*
IMD 90 %	*0.9365*	*0.0007*	*0.9379*
IMD 100 %	*0.9347*	*0.0007*	*0.9362*

Table 7-65
CE 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235 (Intact), 4.20 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	*0.8735*	*0.0007*	*0.8748*
IMD 60 %	*0.8981*	*0.0007*	*0.8995*
IMD 70 %	*0.9162*	*0.0008*	*0.9178*
IMD 80 %	*0.9287*	*0.0008*	*0.9303*
IMD 90 %	*0.9340*	*0.0007*	*0.9355*
IMD 100 %	*0.9364*	*0.0007*	*0.9378*
4.65 wt. % U-235 (Intact), 4.40 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	*0.8769*	*0.0007*	*0.8783*
IMD 60 %	*0.9014*	*0.0008*	*0.9029*
IMD 70 %	*0.9180*	*0.0007*	*0.9193*
IMD 80 %	*0.9293*	*0.0007*	*0.9308*
IMD 90 %	*0.9350*	*0.0007*	*0.9364*
IMD 100 %	*0.9366*	*0.0007*	*0.9381*
4.80 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type A			
IMD 50 %	*0.8799*	*0.0007*	*0.8812*
IMD 60 %	*0.9060*	*0.0008*	*0.9076*
IMD 70 %	*0.9207*	*0.0007*	*0.9220*
IMD 80 %	*0.9312*	*0.0008*	*0.9328*
IMD 90 %	*0.9346*	*0.0006*	*0.9357*
IMD 100 %	*0.9354*	*0.0007*	*0.9369*
4.90 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type A			
IMD 50 %	*0.8832*	*0.0007*	*0.8847*
IMD 60 %	*0.9060*	*0.0008*	*0.9075*
IMD 70 %	*0.9203*	*0.0007*	*0.9218*
IMD 80 %	*0.9311*	*0.0008*	*0.9327*
IMD 90 %	*0.9365*	*0.0007*	*0.9378*
IMD 100 %	*0.9365*	*0.0008*	*0.9380*
5.00 wt. % U-235 (Intact), 4.85 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type A			
IMD 50 %	*0.8866*	*0.0007*	*0.8880*
IMD 60 %	*0.9084*	*0.0008*	*0.9100*
IMD 70 %	*0.9237*	*0.0006*	*0.9249*
IMD 80 %	*0.9331*	*0.0007*	*0.9345*
IMD 90 %	*0.9356*	*0.0007*	*0.9370*
IMD 100 %	*0.9359*	*0.0009*	*0.9378*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type A			
IMD 50 %	*0.8858*	*0.0007*	*0.8873*
IMD 60 %	*0.9078*	*0.0007*	*0.9092*
IMD 70 %	*0.9214*	*0.0007*	*0.9228*
IMD 80 %	*0.9304*	*0.0007*	*0.9318*
IMD 90 %	*0.9318*	*0.0008*	*0.9334*
IMD 100 %	*0.9323*	*0.0007*	*0.9338*

Table 7-66
CE 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.75 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	0.8678	0.0007	0.8692
IMD 60 %	0.8958	0.0007	0.8972
IMD 70 %	0.9139	0.0007	0.9153
IMD 80 %	0.9261	0.0008	0.9276
IMD 90 %	0.9339	0.0006	0.9350
IMD 100 %	0.9365	0.0007	0.9380
4.85 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type B			
IMD 50 %	0.8700	0.0007	0.8714
IMD 60 %	0.8988	0.0007	0.9001
IMD 70 %	0.9152	0.0006	0.9164
IMD 80 %	0.9267	0.0007	0.9282
IMD 90 %	0.9339	0.0007	0.9354
IMD 100 %	0.9360	0.0007	0.9375
5.00 wt. % U-235 (Intact), 4.60 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type B			
IMD 50 %	0.8739	0.0007	0.8752
IMD 60 %	0.8988	0.0008	0.9004
IMD 70 %	0.9156	0.0008	0.9172
IMD 80 %	0.9283	0.0007	0.9297
IMD 90 %	0.9338	0.0007	0.9352
IMD 100 %	0.9340	0.0007	0.9355
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type B			
IMD 50 %	0.8774	0.0007	0.8787
IMD 60 %	0.9029	0.0007	0.9043
IMD 70 %	0.9204	0.0007	0.9219
IMD 80 %	0.9305	0.0007	0.9318
IMD 90 %	0.9344	0.0008	0.9360
IMD 100 %	0.9357	0.0007	0.9371

Table 7-67
CE 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.70 wt. % U-235 (Intact), 4.30 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8662*	*0.0007*	*0.8676*
IMD 60 %	*0.8945*	*0.0007*	*0.8958*
IMD 70 %	*0.9128*	*0.0007*	*0.9141*
IMD 80 %	*0.9250*	*0.0007*	*0.9264*
IMD 90 %	*0.9323*	*0.0007*	*0.9338*
IMD 100 %	*0.9359*	*0.0007*	*0.9373*
4.85 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type B			
IMD 50 %	*0.8676*	*0.0007*	*0.8689*
IMD 60 %	*0.8955*	*0.0008*	*0.8971*
IMD 70 %	*0.9146*	*0.0007*	*0.9159*
IMD 80 %	*0.9250*	*0.0008*	*0.9265*
IMD 90 %	*0.9318*	*0.0007*	*0.9332*
IMD 100 %	*0.9344*	*0.0009*	*0.9362*
4.95 wt. % U-235 (Intact), 4.60 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type B			
IMD 50 %	*0.8722*	*0.0006*	*0.8734*
IMD 60 %	*0.9005*	*0.0008*	*0.9021*
IMD 70 %	*0.9165*	*0.0007*	*0.9179*
IMD 80 %	*0.9280*	*0.0008*	*0.9295*
IMD 90 %	*0.9338*	*0.0008*	*0.9353*
IMD 100 %	*0.9361*	*0.0008*	*0.9378*
5.00 wt. % U-235 (Intact), 4.80 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type B			
IMD 50 %	*0.8745*	*0.0007*	*0.8759*
IMD 60 %	*0.9001*	*0.0007*	*0.9014*
IMD 70 %	*0.9175*	*0.0007*	*0.9189*
IMD 80 %	*0.9266*	*0.0008*	*0.9282*
IMD 90 %	*0.9335*	*0.0009*	*0.9352*
IMD 100 %	*0.9362*	*0.0008*	*0.9379*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type B			
IMD 50 %	*0.8753*	*0.0007*	*0.8766*
IMD 60 %	*0.9000*	*0.0007*	*0.9014*
IMD 70 %	*0.9156*	*0.0007*	*0.9169*
IMD 80 %	*0.9257*	*0.0008*	*0.9272*
IMD 90 %	*0.9305*	*0.0008*	*0.9321*
IMD 100 %	*0.9305*	*0.0007*	*0.9319*

Table 7-68
WE 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.45 wt. % U-235 (Intact), 4.10 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8812	0.0007	0.8827
IMD 60 %	0.9076	0.0007	0.9089
IMD 70 %	0.9236	0.0007	0.9250
IMD 80 %	0.9323	0.0007	0.9336
IMD 90 %	0.9367	0.0007	0.9381
IMD 100 %	0.9336	0.0007	0.9350
4.60 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type A			
IMD 50 %	0.8825	0.0007	0.8839
IMD 60 %	0.9103	0.0006	0.9114
IMD 70 %	0.9255	0.0007	0.9270
IMD 80 %	0.9339	0.0007	0.9353
IMD 90 %	0.9366	0.0007	0.9380
IMD 100 %	0.9350	0.0009	0.9368
4.70 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type A			
IMD 50 %	0.8866	0.0007	0.8880
IMD 60 %	0.9111	0.0008	0.9127
IMD 70 %	0.9256	0.0008	0.9271
IMD 80 %	0.9329	0.0007	0.9342
IMD 90 %	0.9348	0.0006	0.9360
IMD 100 %	0.9326	0.0008	0.9343
4.85 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type A			
IMD 50 %	0.8897	0.0007	0.8911
IMD 60 %	0.9142	0.0007	0.9157
IMD 70 %	0.9270	0.0006	0.9282
IMD 80 %	0.9345	0.0008	0.9360
IMD 90 %	0.9359	0.0008	0.9375
IMD 100 %	0.9339	0.0008	0.9355
4.95 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type A			
IMD 50 %	0.8919	0.0007	0.8932
IMD 60 %	0.9160	0.0007	0.9174
IMD 70 %	0.9293	0.0007	0.9308
IMD 80 %	0.9351	0.0007	0.9366
IMD 90 %	0.9357	0.0007	0.9370
IMD 100 %	0.9325	0.0006	0.9338
5.00 wt. % U-235 (Intact), 4.75 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type A			
IMD 50 %	0.8953	0.0007	0.8966
IMD 60 %	0.9171	0.0007	0.9185
IMD 70 %	0.9290	0.0008	0.9306
IMD 80 %	0.9362	0.0007	0.9375
IMD 90 %	0.9355	0.0007	0.9369
IMD 100 %	0.9306	0.0006	0.9319

Table 7-69
WE 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.40 wt. % U-235 (Intact), 4.10 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	*0.8680*	*0.0007*	*0.8694*
IMD 60 %	*0.8957*	*0.0008*	*0.8973*
IMD 70 %	*0.9140*	*0.0006*	*0.9151*
IMD 80 %	*0.9274*	*0.0007*	*0.9287*
IMD 90 %	*0.9331*	*0.0008*	*0.9348*
IMD 100 %	*0.9365*	*0.0008*	*0.9380*
4.55 wt. % U-235 (Intact), 4.15 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	*0.8706*	*0.0007*	*0.8720*
IMD 60 %	*0.8965*	*0.0007*	*0.8978*
IMD 70 %	*0.9163*	*0.0007*	*0.9177*
IMD 80 %	*0.9270*	*0.0007*	*0.9285*
IMD 90 %	*0.9327*	*0.0007*	*0.9341*
IMD 100 %	*0.9354*	*0.0007*	*0.9369*
4.65 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type A			
IMD 50 %	*0.8749*	*0.0007*	*0.8763*
IMD 60 %	*0.9025*	*0.0007*	*0.9038*
IMD 70 %	*0.9197*	*0.0007*	*0.9212*
IMD 80 %	*0.9302*	*0.0007*	*0.9316*
IMD 90 %	*0.9346*	*0.0007*	*0.9359*
IMD 100 %	*0.9364*	*0.0007*	*0.9377*
4.75 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type A			
IMD 50 %	*0.8774*	*0.0007*	*0.8788*
IMD 60 %	*0.9027*	*0.0007*	*0.9042*
IMD 70 %	*0.9205*	*0.0008*	*0.9221*
IMD 80 %	*0.9309*	*0.0007*	*0.9323*
IMD 90 %	*0.9354*	*0.0007*	*0.9367*
IMD 100 %	*0.9346*	*0.0007*	*0.9360*
4.90 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type A			
IMD 50 %	*0.8792*	*0.0007*	*0.8806*
IMD 60 %	*0.9052*	*0.0007*	*0.9066*
IMD 70 %	*0.9222*	*0.0007*	*0.9235*
IMD 80 %	*0.9309*	*0.0007*	*0.9322*
IMD 90 %	*0.9357*	*0.0007*	*0.9370*
IMD 100 %	*0.9369*	*0.0007*	*0.9382*
5.00 wt. % U-235 (Intact), 4.65 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type A			
IMD 50 %	*0.8828*	*0.0007*	*0.8843*
IMD 60 %	*0.9076*	*0.0006*	*0.9089*
IMD 70 %	*0.9221*	*0.0007*	*0.9234*
IMD 80 %	*0.9321*	*0.0008*	*0.9336*
IMD 90 %	*0.9358*	*0.0007*	*0.9372*
IMD 100 %	*0.9353*	*0.0007*	*0.9367*

Table 7-70
WE 15x15 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235 (Intact), 4.30 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	*0.8751*	*0.0007*	*0.8765*
IMD 60 %	*0.9024*	*0.0007*	*0.9038*
IMD 70 %	*0.9210*	*0.0007*	*0.9224*
IMD 80 %	*0.9307*	*0.0007*	*0.9321*
IMD 90 %	*0.9356*	*0.0008*	*0.9372*
IMD 100 %	*0.9351*	*0.0007*	*0.9365*
4.65 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2100 ppm, W/O CCs, Type B			
IMD 50 %	*0.8771*	*0.0008*	*0.8786*
IMD 60 %	*0.9029*	*0.0007*	*0.9042*
IMD 70 %	*0.9223*	*0.0007*	*0.9237*
IMD 80 %	*0.9315*	*0.0007*	*0.9329*
IMD 90 %	*0.9362*	*0.0006*	*0.9375*
IMD 100 %	*0.9352*	*0.0008*	*0.9367*
4.80 wt. % U-235 (Intact), 4.55 wt. % U-235 (Failed), 2200 ppm, W/O CCs, Type B			
IMD 50 %	*0.8808*	*0.0007*	*0.8821*
IMD 60 %	*0.9065*	*0.0007*	*0.9079*
IMD 70 %	*0.9220*	*0.0007*	*0.9234*
IMD 80 %	*0.9326*	*0.0007*	*0.9339*
IMD 90 %	*0.9355*	*0.0007*	*0.9369*
IMD 100 %	*0.9342*	*0.0006*	*0.9355*
5.00 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2300 ppm, W/O CCs, Type B			
IMD 50 %	*0.8842*	*0.0007*	*0.8856*
IMD 60 %	*0.9085*	*0.0007*	*0.9098*
IMD 70 %	*0.9249*	*0.0007*	*0.9263*
IMD 80 %	*0.9343*	*0.0008*	*0.9358*
IMD 90 %	*0.9354*	*0.0007*	*0.9369*
IMD 100 %	*0.9349*	*0.0008*	*0.9365*
5.00 wt. % U-235 (Intact), 4.90 wt. % U-235 (Failed), 2400 ppm, W/O CCs, Type B			
IMD 50 %	*0.8864*	*0.0007*	*0.8877*
IMD 60 %	*0.9116*	*0.0007*	*0.9129*
IMD 70 %	*0.9238*	*0.0007*	*0.9252*
IMD 80 %	*0.9344*	*0.0006*	*0.9357*
IMD 90 %	*0.9347*	*0.0007*	*0.9361*
IMD 100 %	*0.9336*	*0.0007*	*0.9351*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2500 ppm, W/O CCs, Type B			
IMD 50 %	*0.8851*	*0.0007*	*0.8866*
IMD 60 %	*0.9087*	*0.0008*	*0.9102*
IMD 70 %	*0.9230*	*0.0007*	*0.9243*
IMD 80 %	*0.9307*	*0.0006*	*0.9318*
IMD 90 %	*0.9313*	*0.0008*	*0.9328*
IMD 100 %	*0.9289*	*0.0008*	*0.9304*

Table 7-71
WE 15x15 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
4.55 wt. % U-235 (Intact), 4.25 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8640*	*0.0007*	*0.8653*
IMD 60 %	*0.8905*	*0.0008*	*0.8920*
IMD 70 %	*0.9125*	*0.0007*	*0.9139*
IMD 80 %	*0.9271*	*0.0007*	*0.9284*
IMD 90 %	*0.9332*	*0.0008*	*0.9348*
IMD 100 %	*0.9356*	*0.0007*	*0.9369*
4.65 wt. % U-235 (Intact), 4.35 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type B			
IMD 50 %	*0.8636*	*0.0007*	*0.8650*
IMD 60 %	*0.8930*	*0.0007*	*0.8944*
IMD 70 %	*0.9112*	*0.0006*	*0.9124*
IMD 80 %	*0.9258*	*0.0008*	*0.9273*
IMD 90 %	*0.9322*	*0.0007*	*0.9335*
IMD 100 %	*0.9362*	*0.0007*	*0.9377*
4.80 wt. % U-235 (Intact), 4.45 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type B			
IMD 50 %	*0.8683*	*0.0007*	*0.8696*
IMD 60 %	*0.8957*	*0.0007*	*0.8972*
IMD 70 %	*0.9153*	*0.0007*	*0.9167*
IMD 80 %	*0.9257*	*0.0007*	*0.9271*
IMD 90 %	*0.9331*	*0.0007*	*0.9345*
IMD 100 %	*0.9363*	*0.0008*	*0.9379*
4.95 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2300 ppm, W/ CCs, Type B			
IMD 50 %	*0.8686*	*0.0007*	*0.8701*
IMD 60 %	*0.8970*	*0.0007*	*0.8984*
IMD 70 %	*0.9170*	*0.0007*	*0.9184*
IMD 80 %	*0.9286*	*0.0008*	*0.9301*
IMD 90 %	*0.9336*	*0.0008*	*0.9352*
IMD 100 %	*0.9362*	*0.0007*	*0.9376*
5.00 wt. % U-235 (Intact), 4.80 wt. % U-235 (Failed), 2400 ppm, W/ CCs, Type B			
IMD 50 %	*0.8736*	*0.0007*	*0.8750*
IMD 60 %	*0.8999*	*0.0008*	*0.9015*
IMD 70 %	*0.9193*	*0.0007*	*0.9207*
IMD 80 %	*0.9302*	*0.0007*	*0.9316*
IMD 90 %	*0.9354*	*0.0008*	*0.9371*
IMD 100 %	*0.9366*	*0.0007*	*0.9380*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2500 ppm, W/ CCs, Type B			
IMD 50 %	*0.8755*	*0.0007*	*0.8770*
IMD 60 %	*0.9009*	*0.0007*	*0.9023*
IMD 70 %	*0.9171*	*0.0007*	*0.9185*
IMD 80 %	*0.9295*	*0.0007*	*0.9309*
IMD 90 %	*0.9330*	*0.0007*	*0.9344*
IMD 100 %	*0.9338*	*0.0007*	*0.9352*

Table 7-72
CE 14x14 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	0.8997	0.0007	0.9011
IMD 60 %	0.9215	0.0007	0.9228
IMD 70 %	0.9330	0.0007	0.9344
IMD 80 %	0.9363	0.0007	0.9377
IMD 90 %	0.9371	0.0007	0.9384
IMD 100 %	0.9330	0.0006	0.9342

Table 7-73
CE 14x14 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 4.50 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	0.8812	0.0007	0.8825
IMD 60 %	0.9053	0.0007	0.9067
IMD 70 %	0.9223	0.0007	0.9237
IMD 80 %	0.9332	0.0008	0.9348
IMD 90 %	0.9350	0.0008	0.9365
IMD 100 %	0.9350	0.0008	0.9365
5.00 wt. % U-235 (Intact), 4.95 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type A			
IMD 50 %	0.8850	0.0007	0.8864
IMD 60 %	0.9097	0.0007	0.9111
IMD 70 %	0.9239	0.0007	0.9252
IMD 80 %	0.9311	0.0007	0.9325
IMD 90 %	0.9368	0.0007	0.9382
IMD 100 %	0.9358	0.0007	0.9372
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2200 ppm, W/ CCs, Type A			
IMD 50 %	0.8836	0.0007	0.8851
IMD 60 %	0.9056	0.0007	0.9070
IMD 70 %	0.9195	0.0007	0.9209
IMD 80 %	0.9271	0.0007	0.9284
IMD 90 %	0.9302	0.0008	0.9317
IMD 100 %	0.9283	0.0008	0.9298

Table 7-74
CE 14x14 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	*0.8846*	*0.0008*	*0.8861*
IMD 60 %	*0.9089*	*0.0007*	*0.9103*
IMD 70 %	*0.9204*	*0.0007*	*0.9218*
IMD 80 %	*0.9273*	*0.0007*	*0.9288*
IMD 90 %	*0.9283*	*0.0007*	*0.9297*
IMD 100 %	*0.9241*	*0.0007*	*0.9255*

Table 7-75
CE 14x14 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 4.95 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8776*	*0.0007*	*0.8790*
IMD 60 %	*0.9012*	*0.0007*	*0.9027*
IMD 70 %	*0.9194*	*0.0007*	*0.9208*
IMD 80 %	*0.9298*	*0.0008*	*0.9314*
IMD 90 %	*0.9330*	*0.0007*	*0.9344*
IMD 100 %	*0.9358*	*0.0008*	*0.9374*
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2100 ppm, W/ CCs, Type B			
IMD 50 %	*0.8725*	*0.0007*	*0.8740*
IMD 60 %	*0.8976*	*0.0007*	*0.8990*
IMD 70 %	*0.9143*	*0.0007*	*0.9158*
IMD 80 %	*0.9243*	*0.0007*	*0.9256*
IMD 90 %	*0.9267*	*0.0008*	*0.9283*
IMD 100 %	*0.9282*	*0.0007*	*0.9295*

Table 7-76
WE 14x14 Class – Failed Fuel Assembly without CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type A			
IMD 50 %	*0.8869*	*0.0007*	*0.8883*
IMD 60 %	*0.9063*	*0.0008*	*0.9078*
IMD 70 %	*0.9161*	*0.0008*	*0.9177*
IMD 80 %	*0.9206*	*0.0008*	*0.9222*
IMD 90 %	*0.9203*	*0.0007*	*0.9216*
IMD 100 %	*0.9167*	*0.0009*	*0.9184*

Table 7-77
WE 14x14 Class – Failed Fuel Assembly with CCs Final Results – Basket Type A

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type A			
IMD 50 %	*0.8770*	*0.0008*	*0.8786*
IMD 60 %	*0.8971*	*0.0008*	*0.8988*
IMD 70 %	*0.9082*	*0.0008*	*0.9098*
IMD 80 %	*0.9168*	*0.0007*	*0.9182*
IMD 90 %	*0.9174*	*0.0007*	*0.9188*
IMD 100 %	*0.9167*	*0.0007*	*0.9181*

Table 7-78
WE 14x14 Class – Failed Fuel Assembly without CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/O CCs, Type B			
IMD 50 %	*0.8720*	*0.0008*	*0.8736*
IMD 60 %	*0.8927*	*0.0008*	*0.8942*
IMD 70 %	*0.9051*	*0.0006*	*0.9063*
IMD 80 %	*0.9119*	*0.0007*	*0.9133*
IMD 90 %	*0.9109*	*0.0007*	*0.9124*
IMD 100 %	*0.9106*	*0.0008*	*0.9121*

Table 7-79
WE 14x14 Class – Failed Fuel Assembly with CCs Final Results – Basket Type B

Case Description	k_{keno}	σ_{keno}	k_{eff}
5.00 wt. % U-235 (Intact), 5.00 wt. % U-235 (Failed), 2000 ppm, W/ CCs, Type B			
IMD 50 %	*0.8632*	*0.0007*	*0.8647*
IMD 60 %	*0.8859*	*0.0007*	*0.8873*
IMD 70 %	*0.8981*	*0.0007*	*0.8996*
IMD 80 %	*0.9069*	*0.0008*	*0.9085*
IMD 90 %	*0.9094*	*0.0009*	*0.9112*
IMD 100 %	*0.9093*	*0.0008*	*0.9108*

Table 7-80
EOS-37PTH – Failed Fuel Debris Sensitivity Evaluation – BW 15x15 Assembly Class

(4 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Array size: 10x10, Fissile Rods Diameter= 0.8 inch			
Pitch =2.1 inches, IMD 80 %	0.9268	0.0008	0.9284
Pitch =2.2 inches, IMD 90 %	0.9296	0.0007	0.9309
Pitch =2.2250 inches, IMD 70 %	0.9183	0.0008	0.9199
Pitch =2.2250 inches, IMD 80 %	0.9273	0.0007	0.9287
Pitch =2.2250 inches, IMD 90 %	0.9306	0.0007	0.9319
Pitch =2.2250 inches, IMD 100 %	0.9298	0.0008	0.9313
Pitch =2.2250 inches, IMD 90 %, 1 missing rod	0.9298	0.0007	0.9312
Pitch =2.2250 inches, IMD 90 %, 2 missing rods	**0.9312**	**0.0006**	**0.9325**
Pitch =2.2250 inches, IMD 90 %, 4 missing rods	**0.9312**	**0.0007**	**0.9325**
Pitch =2.2250 inches, IMD 90 %, 6 missing rods	0.9297	0.0007	0.9310
Array size: 10x10, Fissile Rods Diameter= 0.70 inch			
Pitch =2 inches, IMD 90 %	0.9257	0.0007	0.9272
Pitch =2.15 inches, IMD 90 %	0.9301	0.0009	0.9318
Pitch =2.2 inches, IMD 70 %	0.9200	0.0007	0.9214
Pitch =2.2 inches, IMD 80 %	0.9280	0.0007	0.9294
Pitch =2.2 inches, IMD 90 %	**0.9317**	**0.0007**	**0.9331**
Pitch =2.2 inches, IMD 100 %	0.9304	0.0008	0.9319
Pitch =2.2250 inches, IMD 90 %	0.9305	0.0007	0.9319
Pitch =2.2 inches, IMD 100 %, 1 missing rod	0.9312	0.0008	0.9327
Pitch =2.2 inches, IMD 100 %, 2 missing rods	0.9315	0.0007	0.9328
Pitch =2.2 inches, IMD 90 %, 4 missing rods	0.9305	0.0007	0.9319
Pitch =2.2 inches, IMD 90 %, 6 missing rods	0.9286	0.0007	0.9300
Array size: 10x10, Fissile Rods Diameter= 0.60 inch			
Pitch =2.0 inches, IMD 90 %	0.9268	0.0008	0.9284
Pitch =2.15 inches, IMD 90 %	0.9290	0.0007	0.9304
Pitch =2.2 inches, IMD 70 %	0.9201	0.0007	0.9215
Pitch =2.2 inches, IMD 80 %	0.9287	0.0007	0.9302
Pitch =2.2 inches, IMD 90 %	**0.9299**	**0.0009**	**0.9316**
Pitch =2.2 inches, IMD 100 %	0.9283	0.0007	0.9296
Pitch =2.2250 inches, IMD 90 %	0.9295	0.0007	0.9309
Pitch =2.2 inches, IMD 90 %, 1 missing rod	0.9295	0.0007	0.9309

Table 7-80
EOS-37PTH – Failed Fuel Debris Sensitivity Evaluation – BW 15x15 Assembly Class
(4 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Pitch =2.2 inches, IMD 90 %, 2 missing rods	0.9288	0.0007	0.9302
Pitch =2.2 inches, IMD 90 %, 3 missing rods	0.9263	0.0007	0.9278
Pitch =2.2 inches, IMD 90 %, 4 missing rods	0.9262	0.0010	0.9282
Array size: 9x9, Fissile Rods Diameter= 0.9 inch			
Pitch =2.3 inches, IMD 100 %	0.9270	0.0007	0.9284
Pitch =2.4 inches, IMD 90 %	0.9284	0.0007	0.9298
Pitch =2.4722 inches, IMD 70 %	0.9189	0.0008	0.9204
Pitch =2.4722 inches, IMD 80 %	0.9268	0.0007	0.9281
Pitch =2.4722 inches, IMD 90 %	0.9306	0.0006	0.9318
Pitch =2.4722 inches, IMD 100 %	0.9279	0.0006	0.9292
Pitch =2.4722 inches, IMD 90 %, 1 missing rod	**0.9305**	**0.0007**	**0.9319**
Pitch =2.4722 inches, IMD 90 %, 2 missing rods	0.9292	0.0007	0.9306
Pitch =2.4722 inches, IMD 90 %, 3 missing rods	0.9299	0.0008	0.9314
Pitch =2.4722 inches, IMD 90 %, 4 missing rods	0.9286	0.0008	0.9301
Array size: 9x9, Fissile Rods Diameter= 0.75 inch			
Pitch =2.1 inches, IMD 90 %	0.9256	0.0007	0.9271
Pitch =2.3 inches, IMD 90 %	0.9298	0.0008	0.9314
Pitch =2.4 inches, IMD 90 %	0.9303	0.0007	0.9316
Pitch =2.4722 inches, IMD 70 %	0.9211	0.0008	0.9226
Pitch =2.4722 inches, IMD 80 %	0.9278	0.0007	0.9292
Pitch =2.4722 inches, IMD 90 %	0.9309	0.0007	0.9323
Pitch =2.4722 inches, IMD 100 %	**0.9326**	**0.0009**	**0.9343**
Pitch =2.4722 inches, IMD 90 %, 1 missing rod	0.9305	0.0008	0.9320
Pitch =2.4722 inches, IMD 90 %, 2 missing rods	0.9302	0.0007	0.9315
Pitch =2.4722 inches, IMD 90 %, 3 missing rods	0.9307	0.0007	0.9321
Pitch =2.4722 inches, IMD 90 %, 4 missing rods	0.9291	0.0008	0.9306
Array size: 9x9, Fissile Rods Diameter= 0.65 inch			
Pitch =2.1 inches, IMD 90 %	0.9255	0.0007	0.9270
Pitch =2.3 inches, IMD 90 %	0.9268	0.0007	0.9281
Pitch =2.4 inches, IMD 90 %	0.9283	0.0007	0.9296
Pitch =2.4722 inches, IMD 70 %	0.9167	0.0008	0.9183
Pitch =2.4722 inches, IMD 80 %	0.9260	0.0008	0.9277

Table 7-80
EOS-37PTH – Failed Fuel Debris Sensitivity Evaluation – BW 15x15 Assembly Class

(4 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Pitch =2.4722 inches, IMD 90 %	***0.9294***	***0.0007***	***0.9307***
Pitch =2.4722 inches, IMD 100 %	*0.9277*	*0.0007*	*0.9292*
Pitch =2.4722 inches, IMD 90 %, 1 missing rod	*0.9275*	*0.0007*	*0.9288*
Pitch =2.4722 inches, IMD 90 %, 2 missing rods	*0.9284*	*0.0007*	*0.9297*
Pitch =2.4722 inches, IMD 90 %, 3 missing rods	*0.9261*	*0.0007*	*0.9276*
Pitch =2.4722 inches, IMD 90 %, 4 missing rods	*0.9267*	*0.0007*	*0.9282*
Array size: 8x8, Fissile Rods Diameter= 1 inch			
Pitch =2.6 inches, IMD 90 %	*0.9272*	*0.0007*	*0.9286*
Pitch =2.7 inches, IMD 90 %	*0.9300*	*0.0007*	*0.9314*
Pitch =2.7813 inches, IMD 70 %	*0.9189*	*0.0007*	*0.9202*
Pitch =2.7813 inches, IMD 80 %	*0.9266*	*0.0007*	*0.9280*
Pitch =2.7813 inches, IMD 90 %	***0.9306***	***0.0007***	***0.9321***
Pitch =2.7813 inches, IMD 100 %	***0.9307***	***0.0007***	***0.9321***
Pitch =2.7813 inches, IMD 90 %, 1 missing rod	*0.9305*	*0.0007*	*0.9320*
Pitch =2.7813 inches, IMD 90 %, 2 missing rods	*0.9288*	*0.0007*	*0.9303*
Pitch =2.7813 inches, IMD 90 %, 3 missing rods	*0.9295*	*0.0007*	*0.9309*
Pitch =2.7813 inches, IMD 100 %, 4 missing rods	*0.9277*	*0.0008*	*0.9293*
Array size: 8x8, Fissile Rods Diameter= 0.9 inch			
Pitch =2.4 inches, IMD 90 %	*0.9265*	*0.0008*	*0.9280*
Pitch =2.6 inches, IMD 90 %	*0.9279*	*0.0007*	*0.9292*
Pitch =2.7 inches, IMD 90 %	*0.9299*	*0.0008*	*0.9315*
Pitch =2.7813 inches, IMD 70 %	*0.9204*	*0.0007*	*0.9217*
Pitch =2.7813 inches, IMD 80 %	*0.9303*	*0.0007*	*0.9318*
Pitch =2.7813 inches, IMD 90 %	*0.9305*	*0.0007*	*0.9319*
Pitch =2.7813 inches, IMD 100 %	*0.9300*	*0.0007*	*0.9313*
Pitch =2.7813 inches, IMD 90 %, 1 missing rod	***0.9324***	***0.0007***	***0.9338***
Pitch =2.7813 inches, IMD 90 %, 2 missing rods	*0.9297*	*0.0008*	*0.9313*
Pitch =2.7813 inches, IMD 90 %, 3 missing rods	*0.9299*	*0.0007*	*0.9313*
Pitch =2.7813 inches, IMD 90 %, 4 missing rods	*0.9296*	*0.0008*	*0.9312*
Array size: 8x8, Fissile Rods Diameter= 0.75 inch			
Pitch =2.4 inches, IMD 90 %	*0.9243*	*0.0007*	*0.9257*
Pitch =2.6 inches, IMD 90 %	*0.9273*	*0.0007*	*0.9286*

Table 7-80
EOS-37PTH – Failed Fuel Debris Sensitivity Evaluation – BW 15x15 Assembly Class

(4 Pages)

Case Description	k_{keno}	σ_{keno}	k_{eff}
Pitch =2.7 inches, IMD 90 %	0.9283	0.0006	0.9295
Pitch =2.7813 inches, IMD 70 %	0.9196	0.0007	0.9209
Pitch =2.7813 inches, IMD 80 %	0.9253	0.0008	0.9268
Pitch =2.7813 inches, IMD 90 %	**0.9283**	**0.0007**	**0.9296**
Pitch =2.7813 inches, IMD 100 %	0.9273	0.0007	0.9288
Pitch =2.7813 inches, IMD 90 %, 1 missing rod	0.9283	0.0007	0.9296
Pitch =2.7813 inches, IMD 90 %, 2 missing rods	0.9268	0.0007	0.9282
Pitch =2.7813 inches, IMD 90 %, 3 missing rods	0.9264	0.0010	0.9284
Pitch =2.7813 inches, IMD 90 %, 4 missing rods	0.9262	0.0007	0.9276

Table 7-81
EOS-37PTH - Maximum Uranium Mass per FFC, Failed Fuel Debris Analysis

Fissile Rods Diameter	***Maximum Uranium Mass***
10x10 array size	
0.8 inch	*1104 kg*
0.6 inch	*621 kg*
9x9 array size	
0.9 inch	*1132 kg*
0.6 inch	*503kg*
8x8 array size	
1 inch	*1104 kg*
0.6 inch	*397 kg*

Note: This table presents the as-modeled uranium masses in the failed fuel debris models. The MTU limits for an FFC containing failed fuel are defined in Chapter 2, Table 2-4b.

Proprietary Information on Pages 7-148 and 7-149
Withheld Pursuant to 10 CFR 2.390

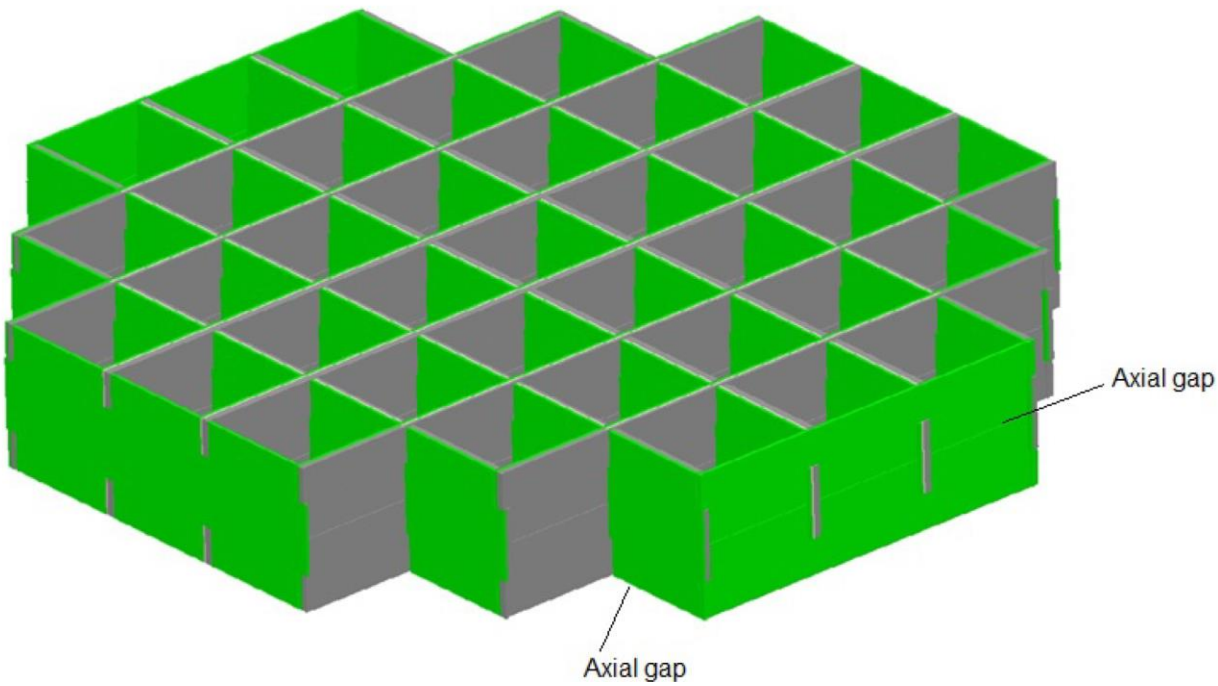

Figure 7-3
EOS-37PTH DSC Single Egg-Crate Basket Section

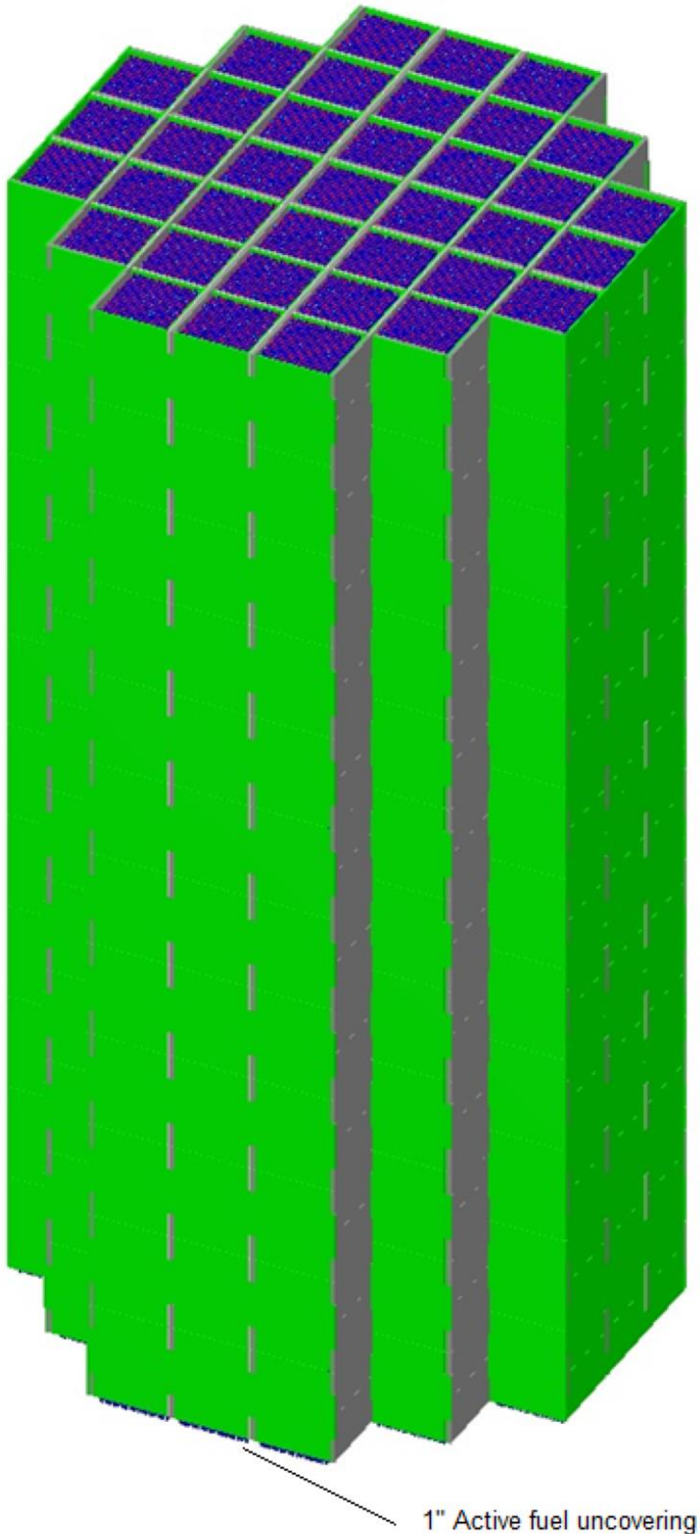

Figure 7-4
EOS-37PTH DSC Full-Length Axial Basket Structure with Fuel Assemblies

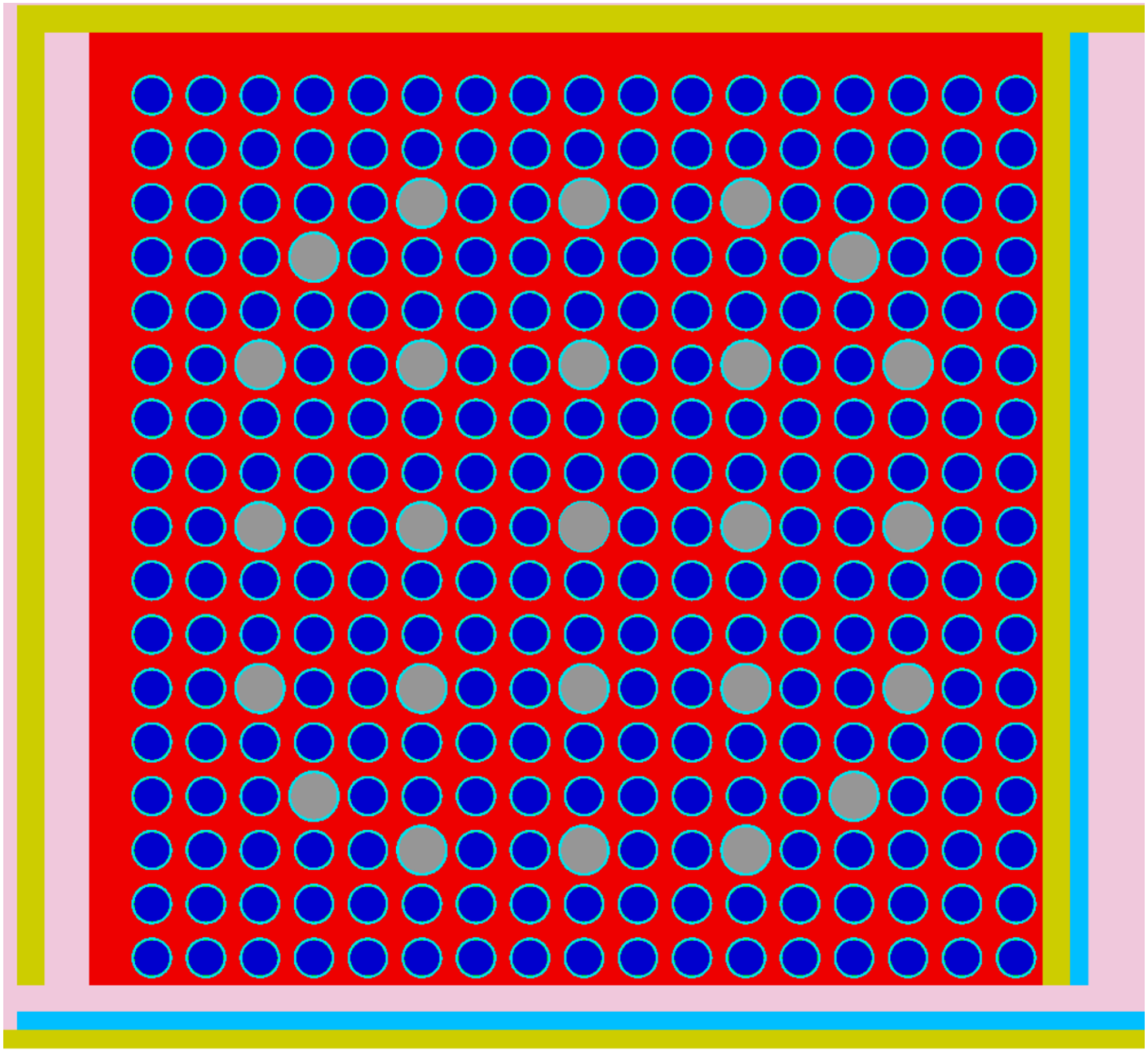

Figure 7-5
WE 17x17 Fuel Assembly with Non-Fuel Assembly Hardware

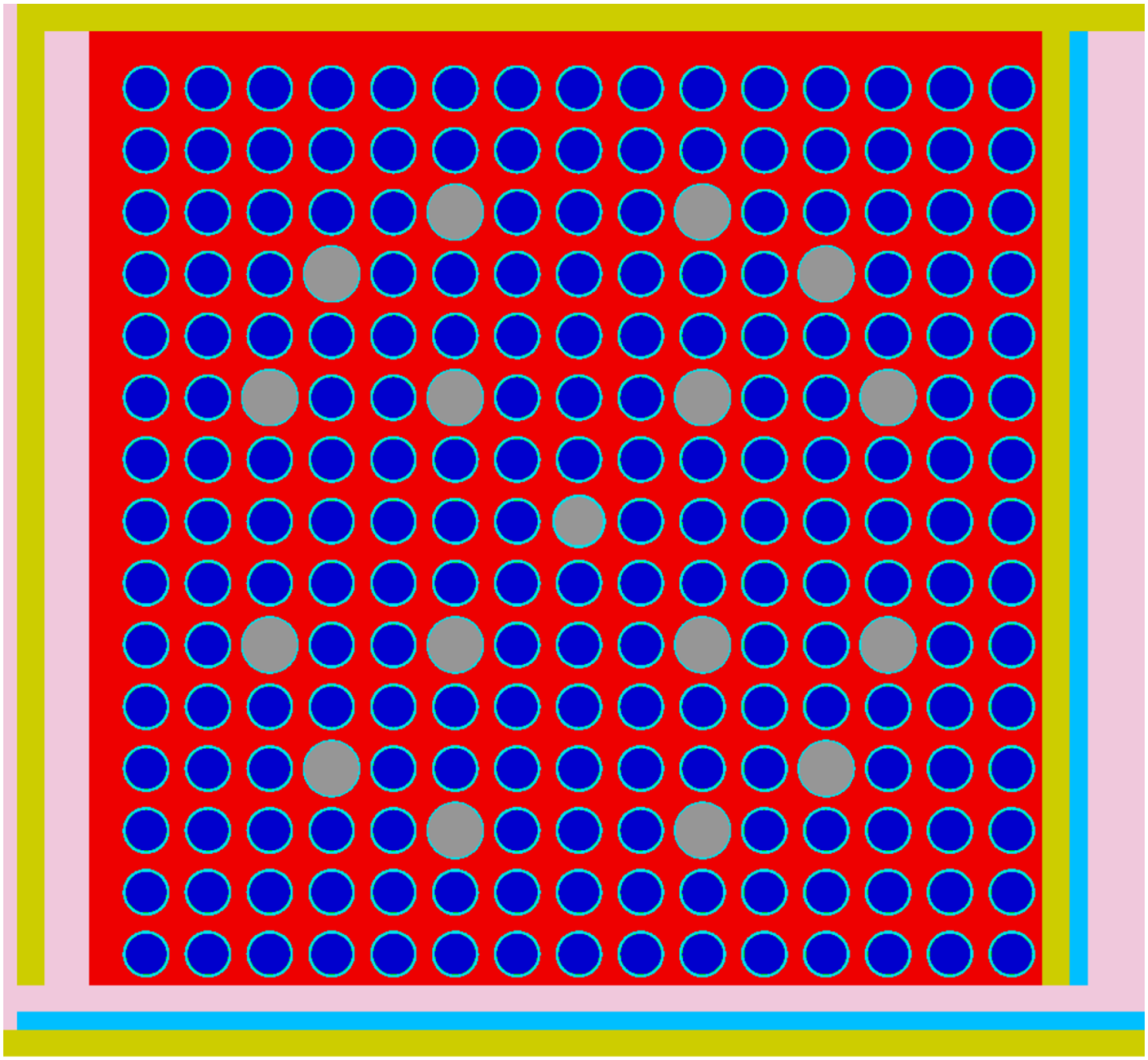

Figure 7-6
B&W 15x15 Fuel Assembly with Non-Fuel Assembly Hardware

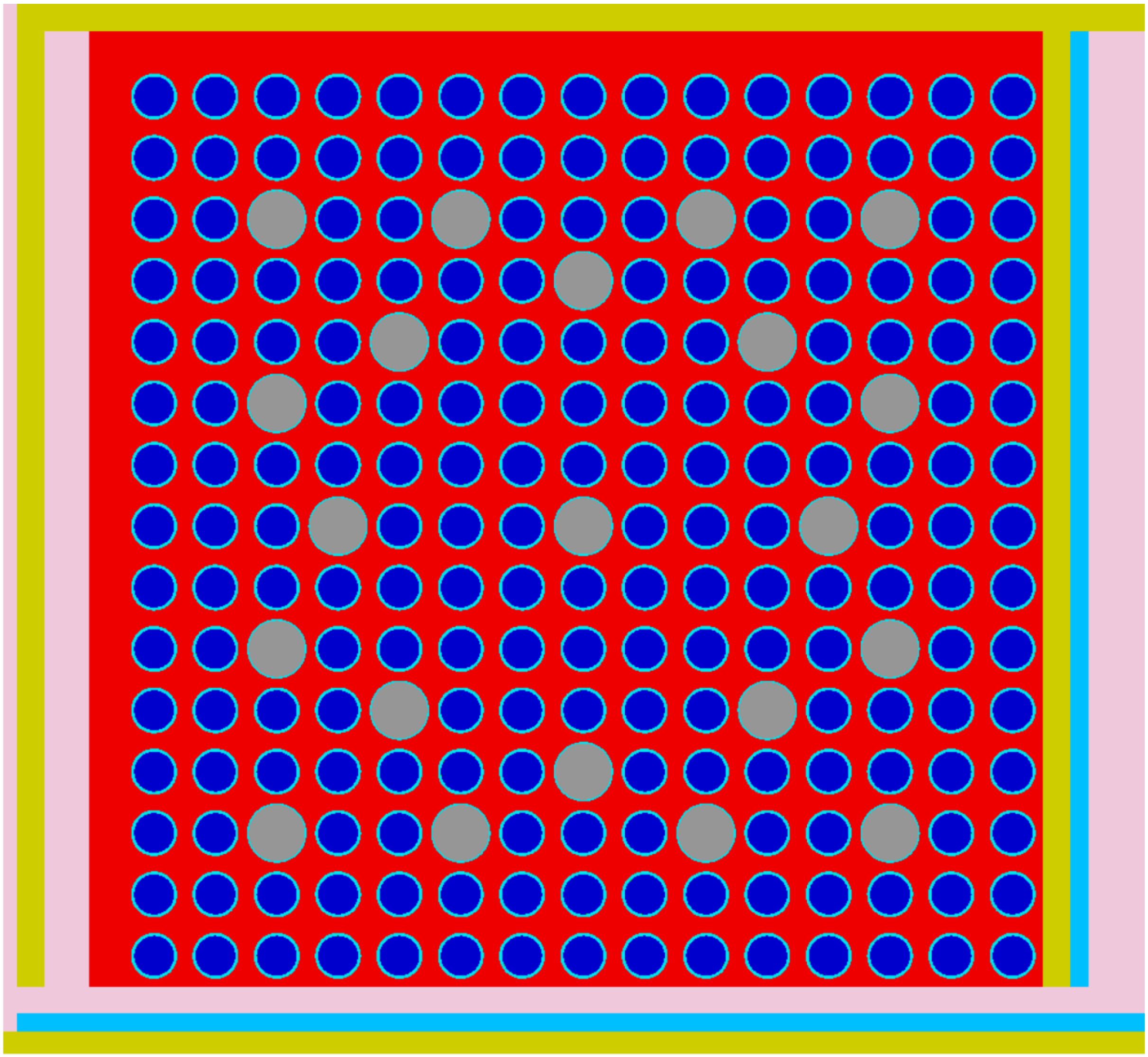

Figure 7-7
WE 15x15 Fuel Assembly with Non-Fuel Assembly Hardware

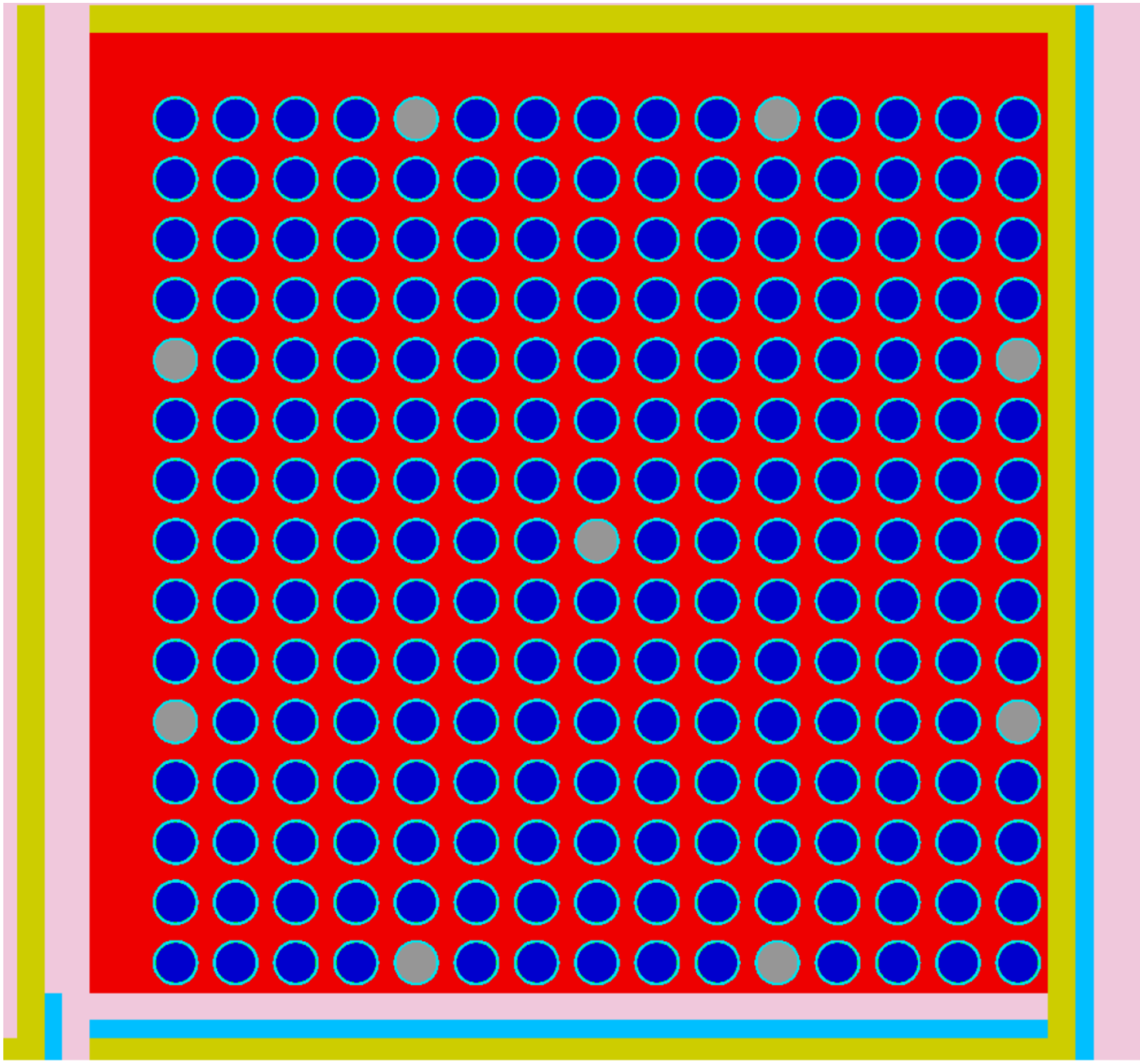

Figure 7-8
CE 15x15 Fuel Assembly with Non-Fuel Assembly Hardware

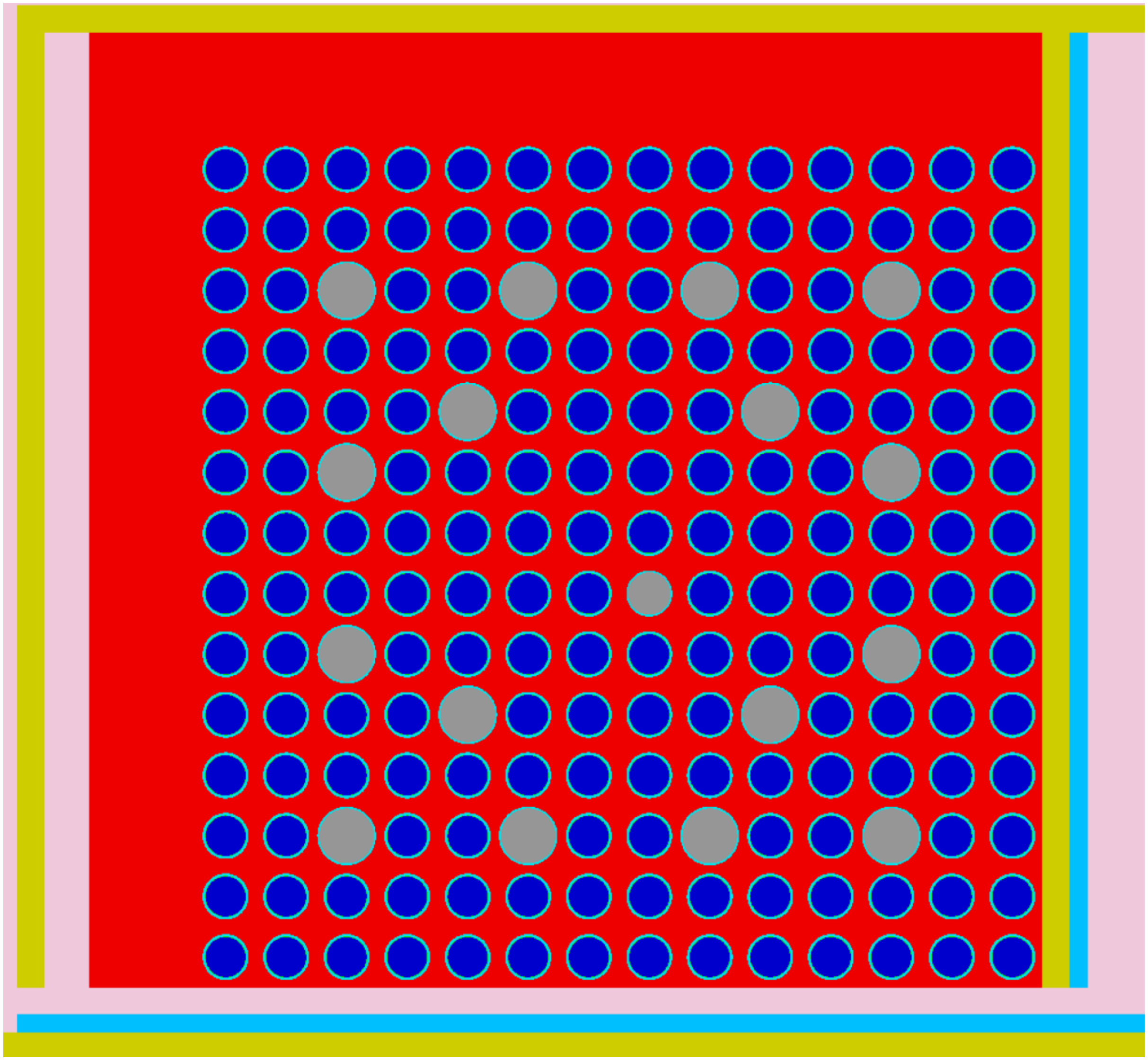

Figure 7-9
WE 14x14 Fuel Assembly with Non-Fuel Assembly Hardware

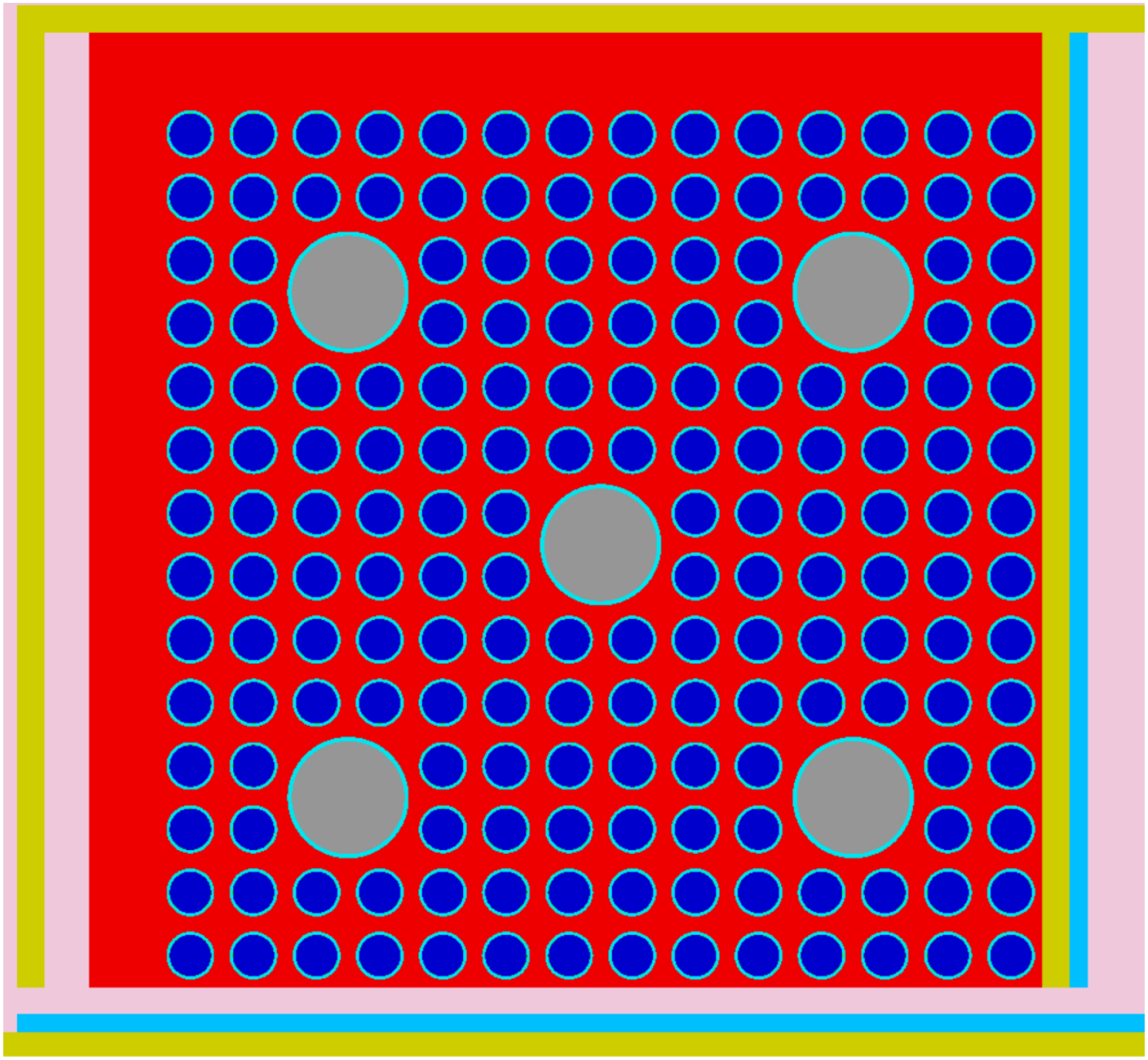

Figure 7-10
CE 14x14 Fuel Assembly with Non-Fuel Assembly Hardware

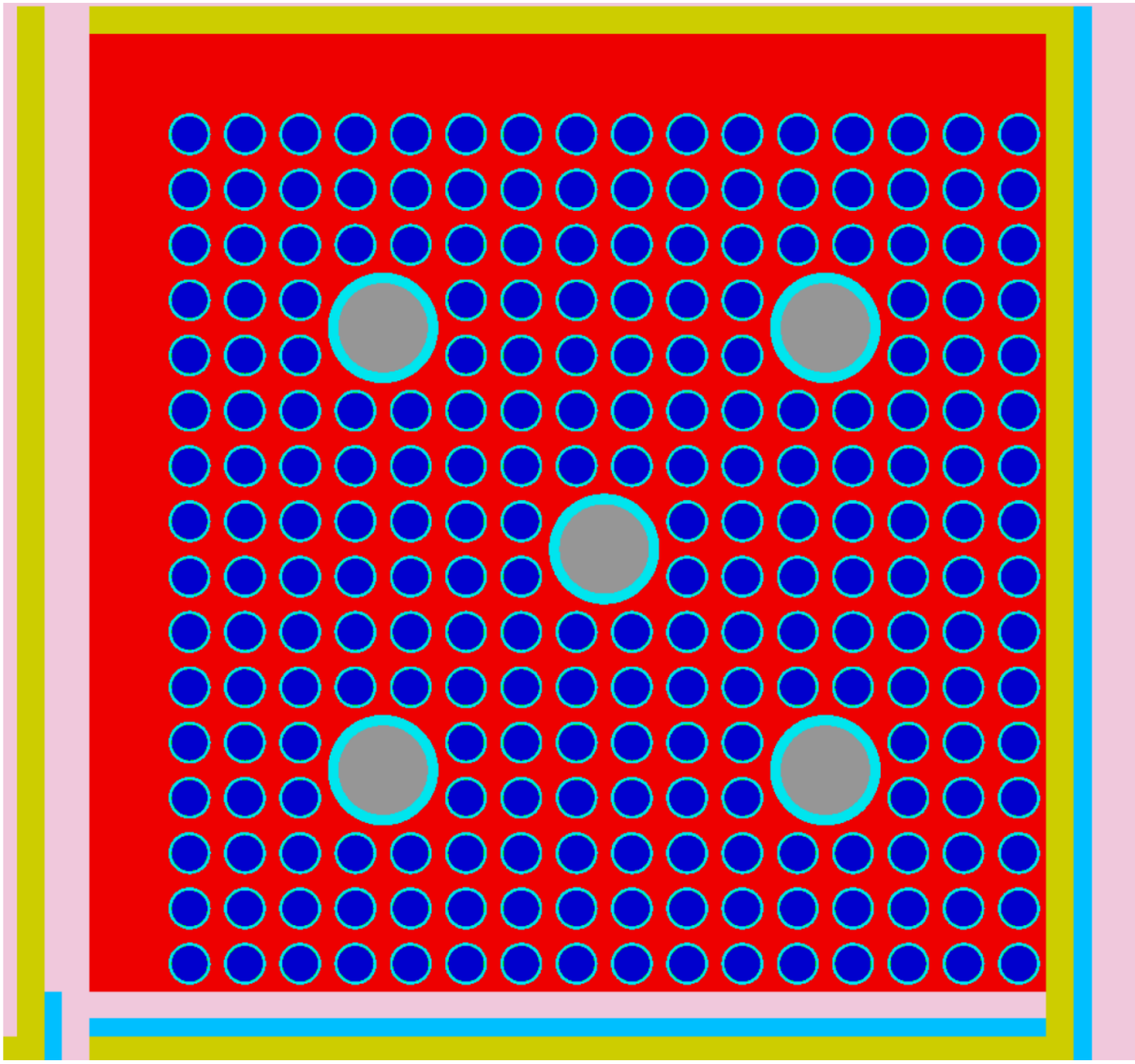

Figure 7-11
CE 16x16 Fuel Assembly with Non-Fuel Assembly Hardware

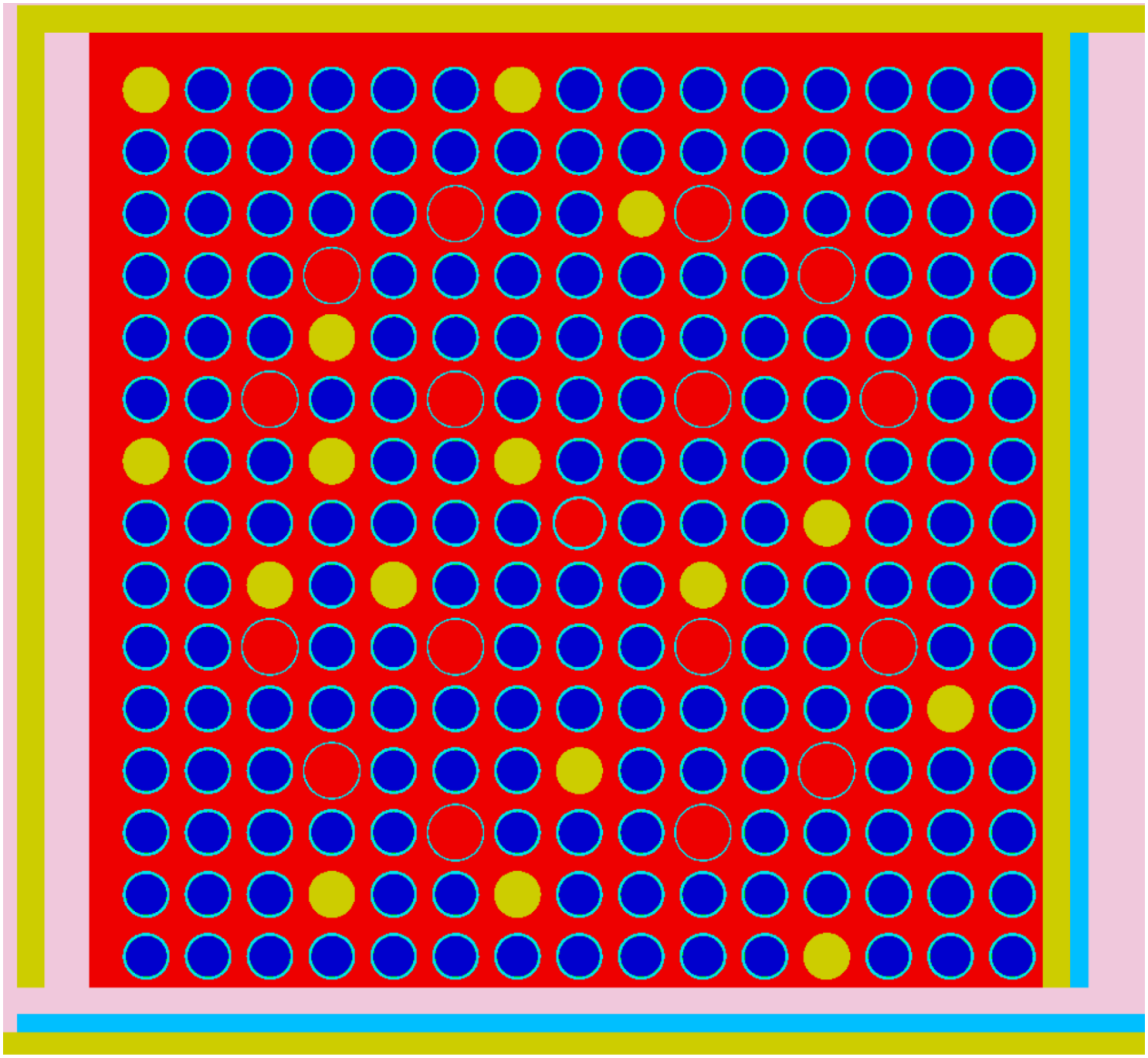

Figure 7-12
Reconstituted Fuel Assembly Study: 17 Stainless Steel Rods

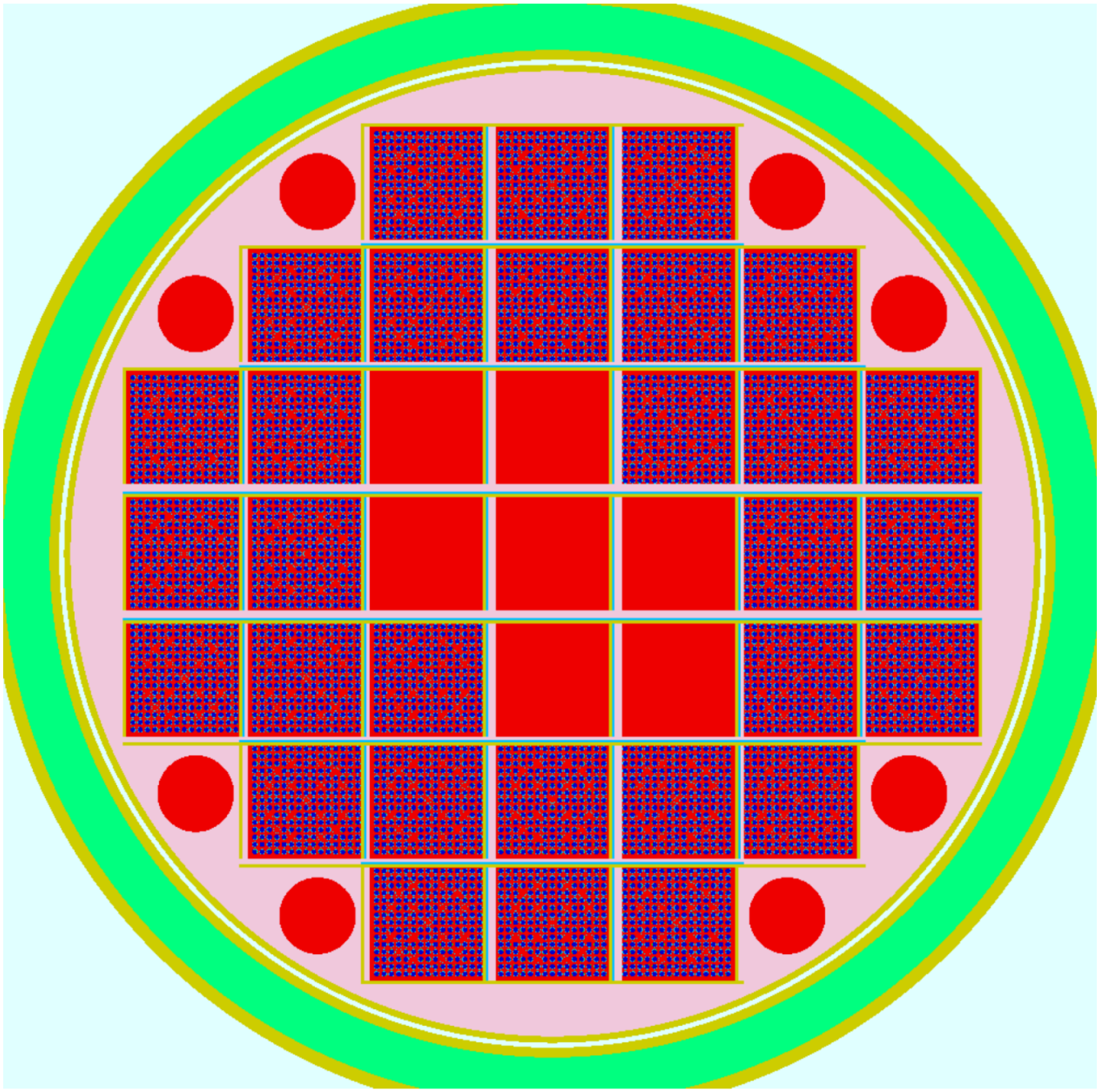

Figure 7-13
Empty Fuel Compartment Study: Seven Empty Compartments

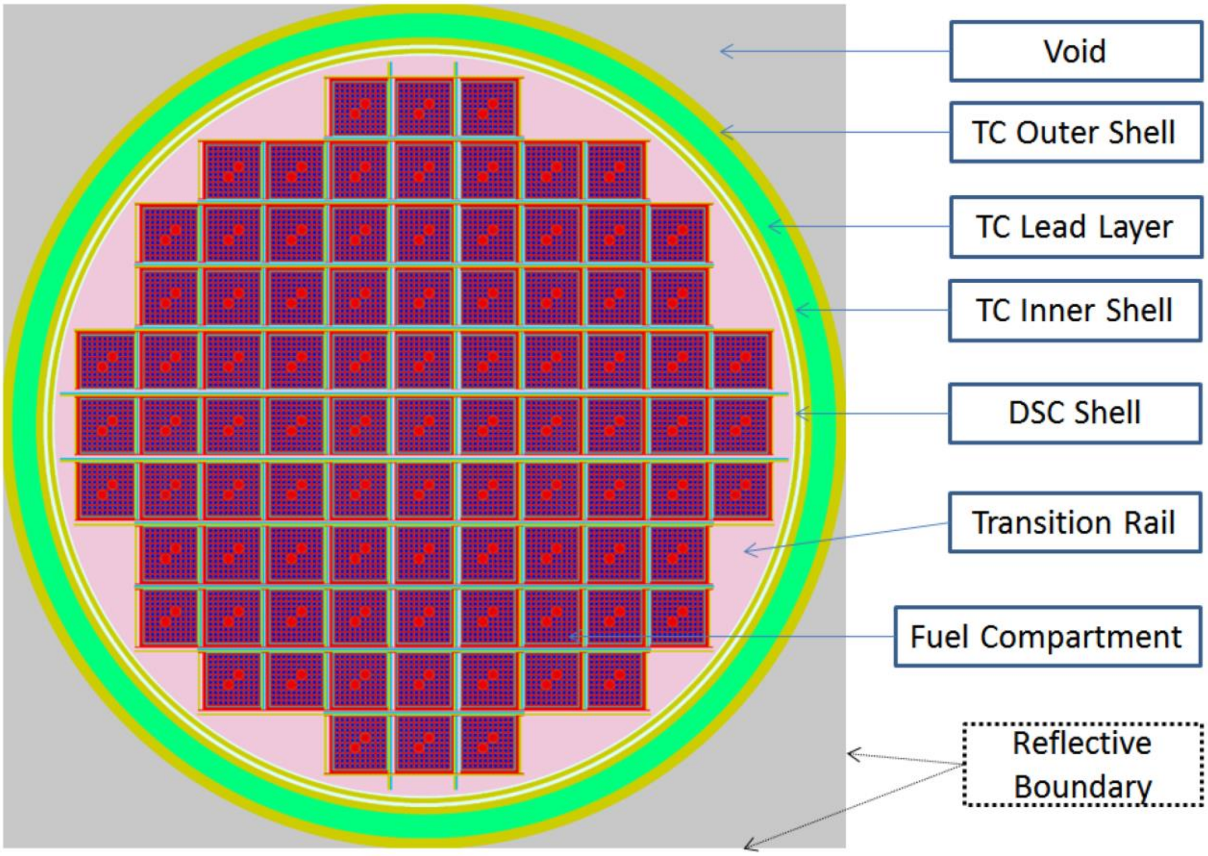

Figure 7-14
Radial Cross Section of the Model

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Withheld Pursuant to 10 CFR 2.390

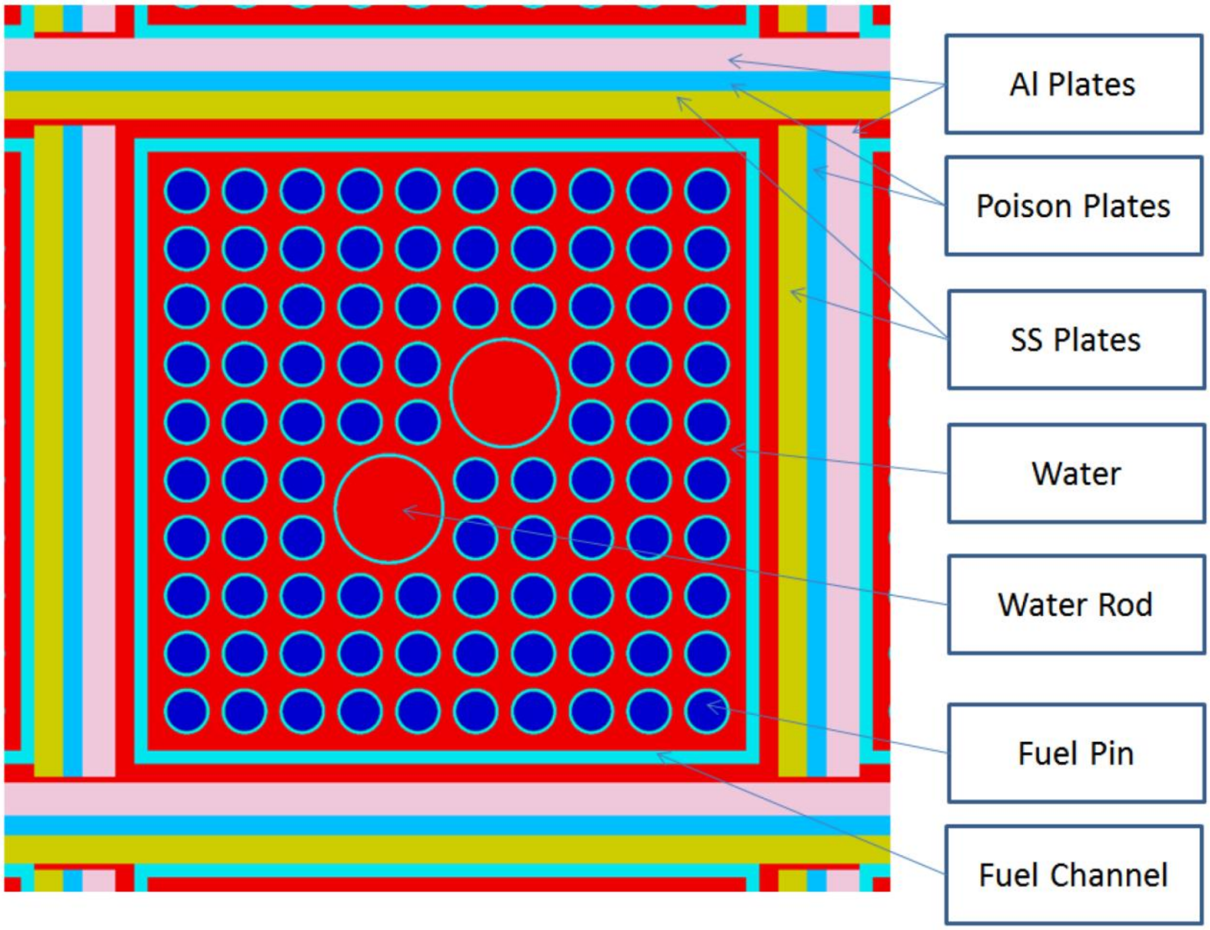

Figure 7-16
Radial Cross Section of the Fuel Compartment

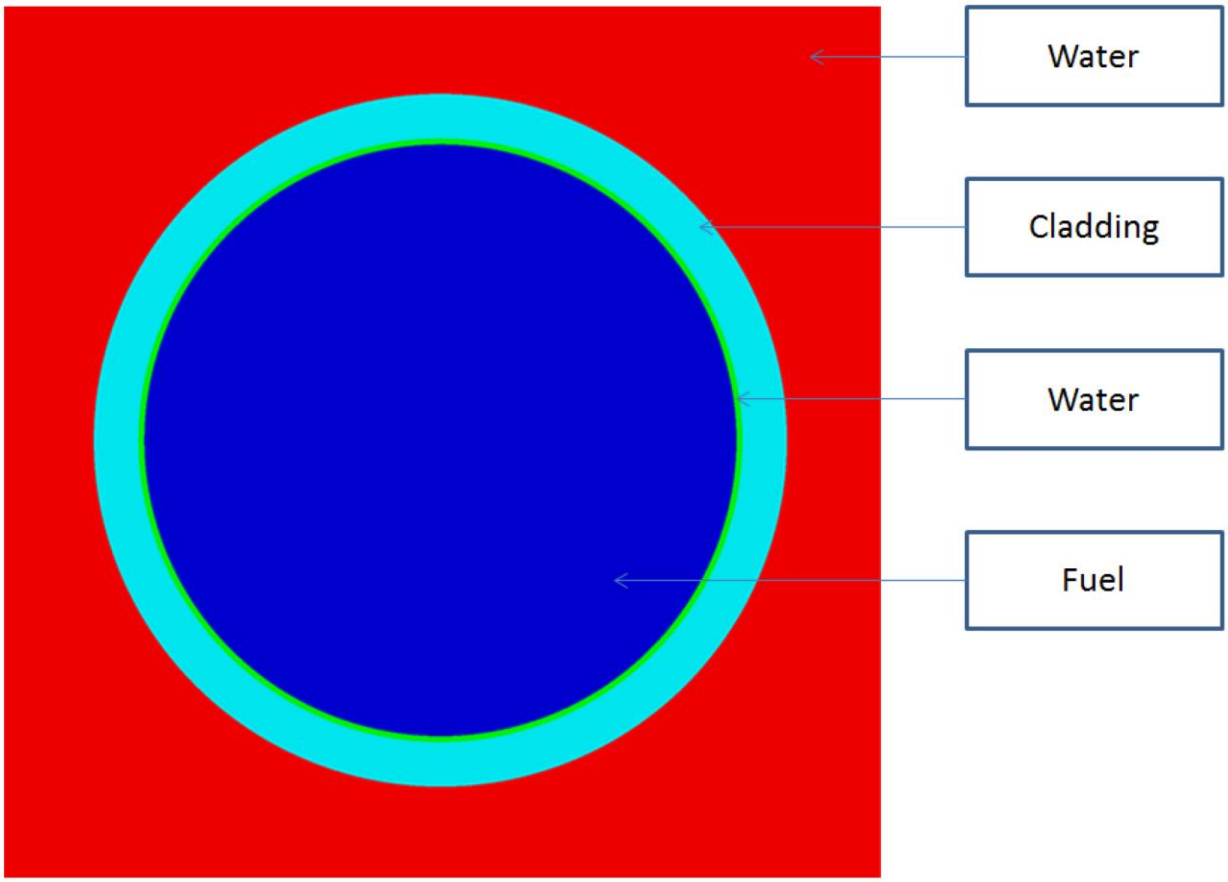

Figure 7-17
Radial Cross Section of the Fuel Pin

Proprietary Information on Pages 7-165 and 7-166
Withheld Pursuant to 10 CFR 2.390

```
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
2  2  2  2  2  4  2  2  2  2  2
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
Model set:4x5x5
1=Fuel Rod
2,3,4 = Water Rod
```

```
5  1  1  1  1  3  1  1  1  1  5
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  5  3  5  1  1  1  1
2  2  2  2  2  4  2  2  2  2  2
1  1  1  1  5  3  5  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
5  1  1  1  1  3  1  1  1  1  5
Model set:4x5x5-2
1=Fuel Rod
2,3,4,5 = Water Rod
```

```
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  5  3  5  1  1  1  1
2  2  2  2  2  4  2  2  2  2  2
1  1  1  1  5  3  5  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
1  1  1  1  1  3  1  1  1  1  1
Model set:4x5x5-1, 4x5x5-1-sq
1=Fuel Rod
2,3,4,5 = Water Rod
```

```
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1
2  2  2  2  4  2  2  2  2
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1
1  1  1  1  3  1  1  1  1

Model set:4x4x4
1=Fuel Rod
2,3,4 = Water Rod
```

```
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1

Model set:9x9-0w
1=Fuel Rod
```

```
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1

Model set:8x8-0w
1=Fuel Rod
```

```
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  2  1  1  1  1
1  1  1  2  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1

Model set:9x9-2w
1=Fuel Rod
2=Water Rod
```

```
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  2  1  1  1  1  1
1  1  1  1  1  2  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1

Model set:10x10-2w
1=Fuel Rod
2=Water Rod
```

```
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  2  2  2  1  1  1  1
1  1  1  2  2  2  1  1  1  1
1  1  1  2  2  2  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1  1

Model set:10x10-1w-sq
1=Fuel Rod
2=Water Rod
```

Figure 7-20
Fuel Assembly Layout
(Part 1 of 2)

```
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  2  2  1  1  1  1
1  1  1  2  2  2  1  1  1
1  1  1  1  2  2  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1

Model set:9x9-2w-lg
1=Fuel Rod
2=Water Rod
```

```
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  2  2  2  1  1  1
1  1  1  2  2  2  1  1  1
1  1  1  2  2  2  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1  1

Model set:9x9-1w-sq
1=Fuel Rod
2=Water Rod
```

```
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  21  21  1  1  1
1  1  1  21  21  1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1

Model set:8x8-4z
1=Fuel Rod
21=Zirc Rod
```

```
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  2  2  1  1  1
1  1  1  2  2  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1
1  1  1  1  1  1  1  1

Model set:8x8-1w-lg
1=Fuel Rod
2=Water Rod
```

```
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  22  23  1  1  1
1  1  1  23  22  1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1

Model set:8x8-4w
1=Fuel Rod
22=Water Rod 1
23=Water Rod 2
```

```
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  22  1   1  1  1
1  1  1  1   22  1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1
1  1  1  1   1   1  1  1

Model set:8x8-2w
1=Fuel Rod
22=Water Rod
```

```
1  1  1  1   1  1  1  1
1  1  1  1   1  1  1  1
1  1  1  1   1  1  1  1
1  1  1  22  1  1  1  1
1  1  1  1   1  1  1  1
1  1  1  1   1  1  1  1
1  1  1  1   1  1  1  1
1  1  1  1   1  1  1  1

Model set:8x8-1w
1=Fuel Rod
22=Water Rod
```

```
1  1  1  1   1  1  1
1  1  1  1   1  1  1
1  1  1  1   1  1  1
1  1  1  21  1  1  1
1  1  1  1   1  1  1
1  1  1  1   1  1  1
1  1  1  1   1  1  1

Model set:7x7-1z
1=Fuel Rod
21=Zirc Rod
```

```
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1
1  1  1  1  1  1  1

Model set:7x7-0w
1=Fuel Rod
```

Figure 7-20
Fuel Assembly Layout (Part 2 of 2)

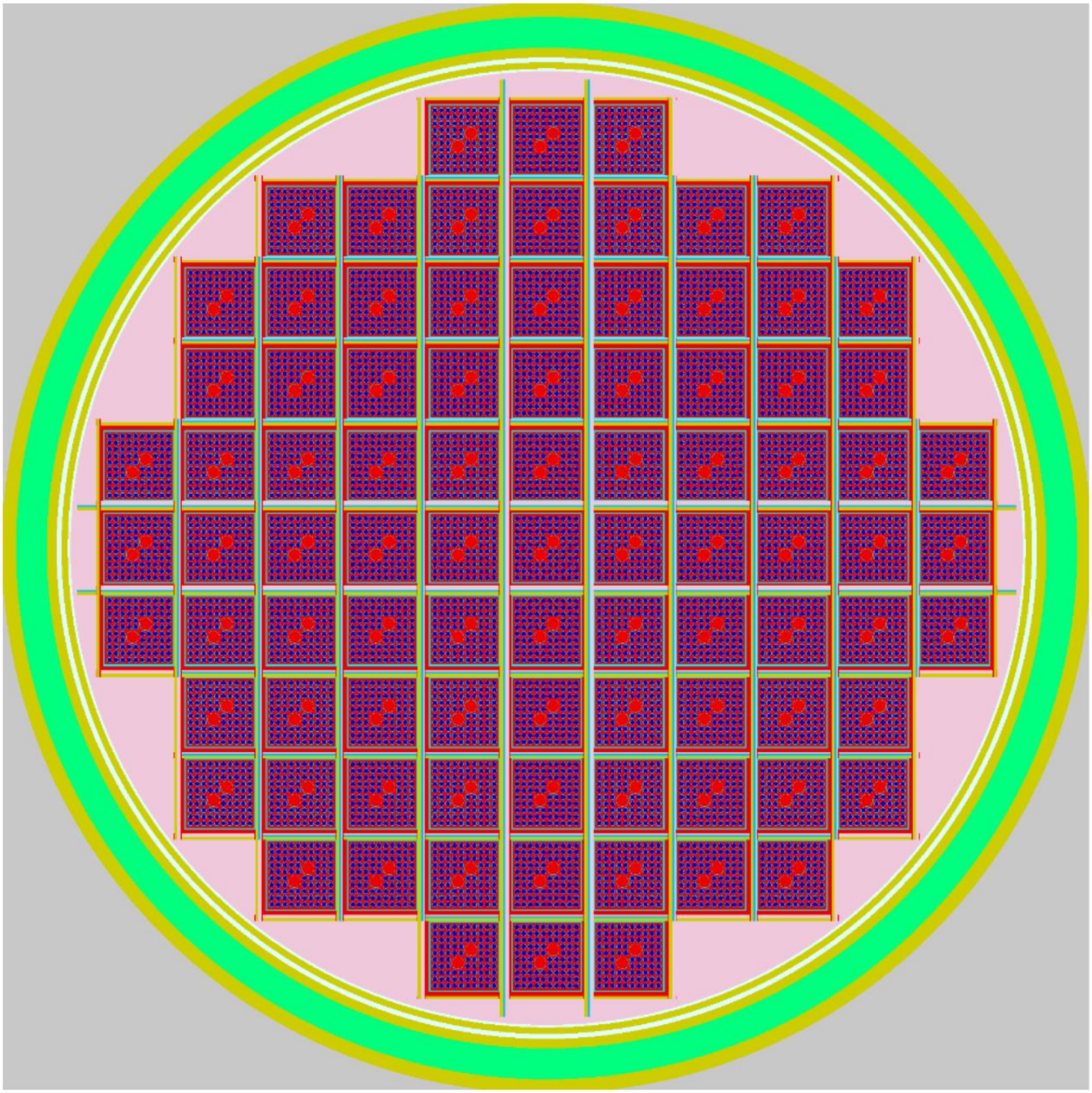

Figure 7-21
Radial Cross Section (Fuel Assemblies Placed Inwardly)

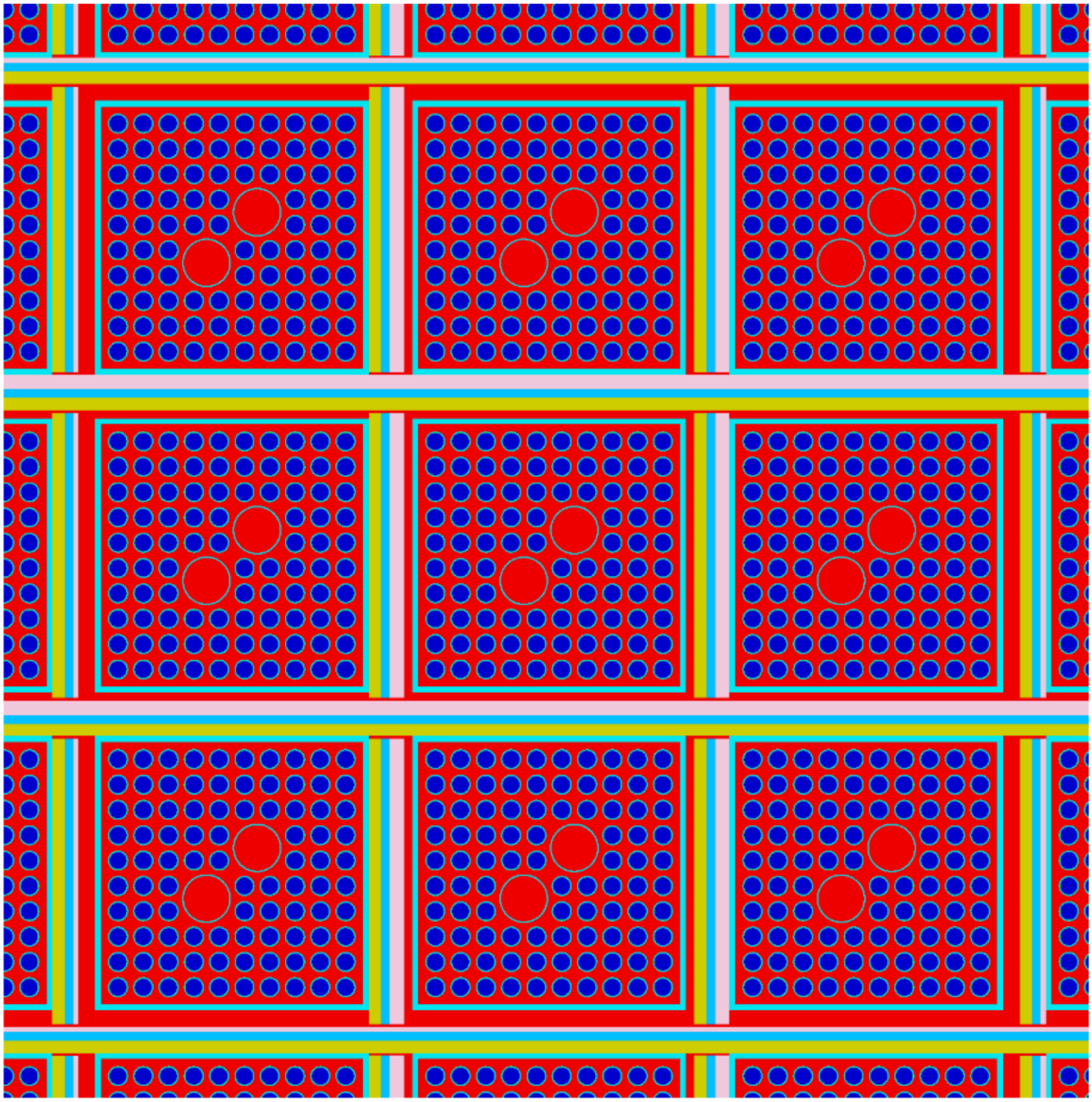

Figure 7-22
Radial Cross Section of Center 9 Fuel Compartments (Fuel Assemblies Placed Inwardly)

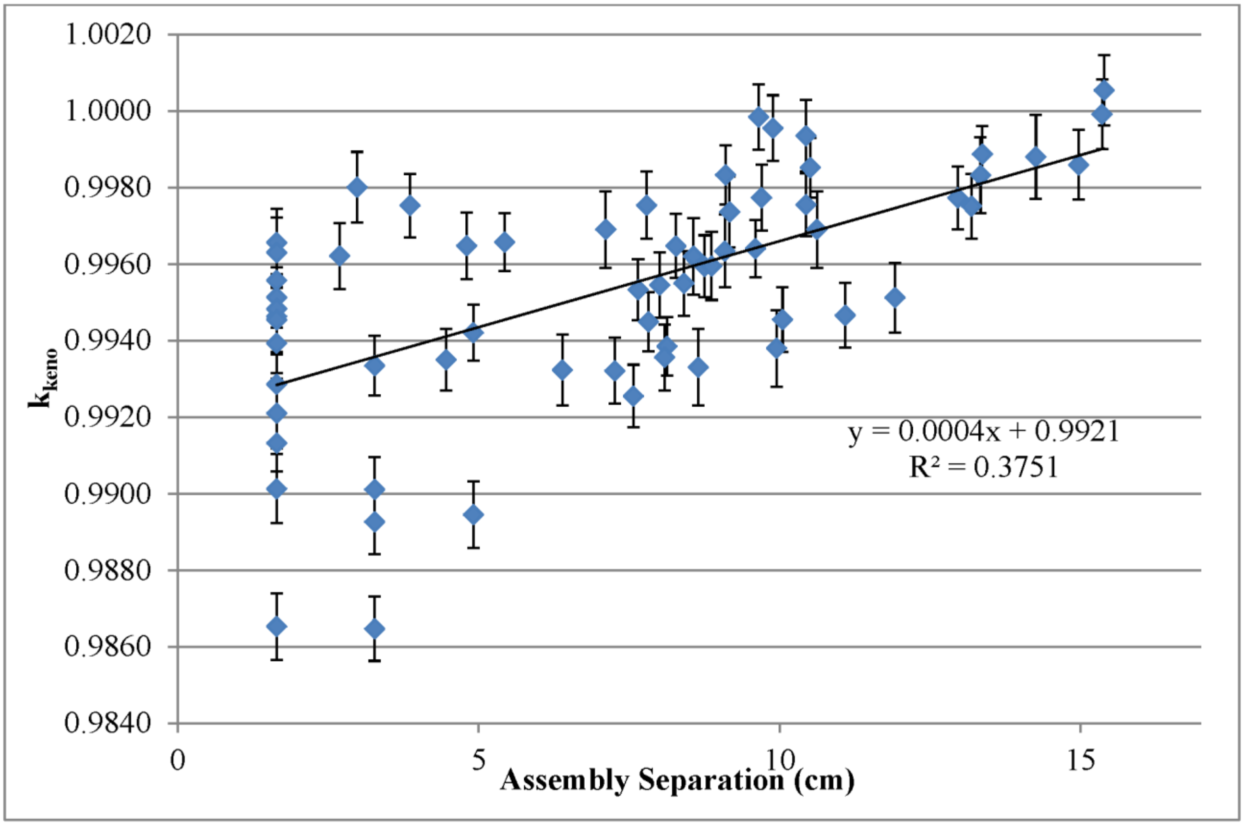

Figure 7-23
k_{KENO} versus Assembly Separation (cm) for Fresh Fuel Analysis

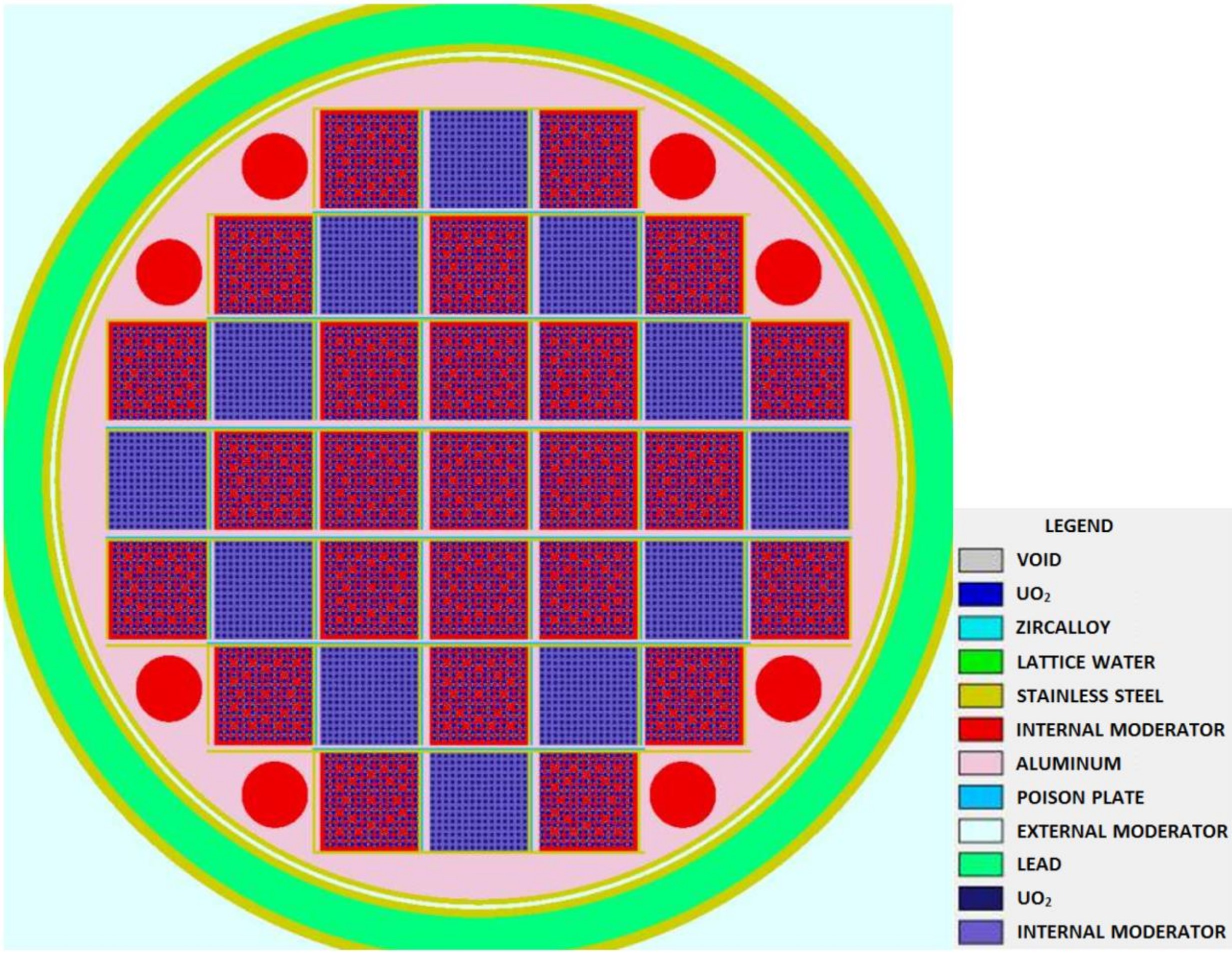

Figure 7-24
Criticality Analysis model for Damaged and Failed Fuels Loading Balanced with Intact Fuels in the EOS-37PTH DSC

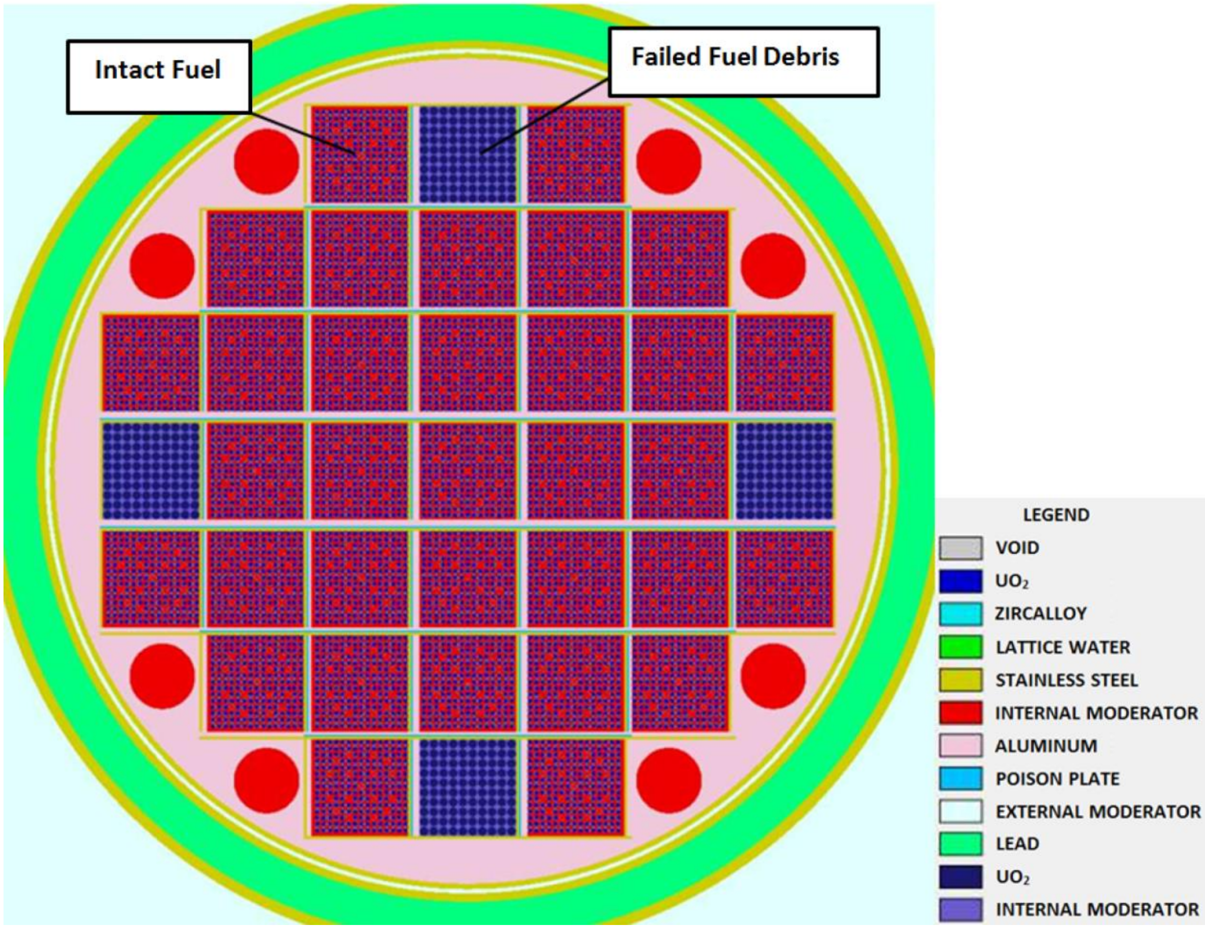

Figure 7-25
Criticality Analysis Model for Failed Fuel Debris Loading in the EOS-37PTH DSC

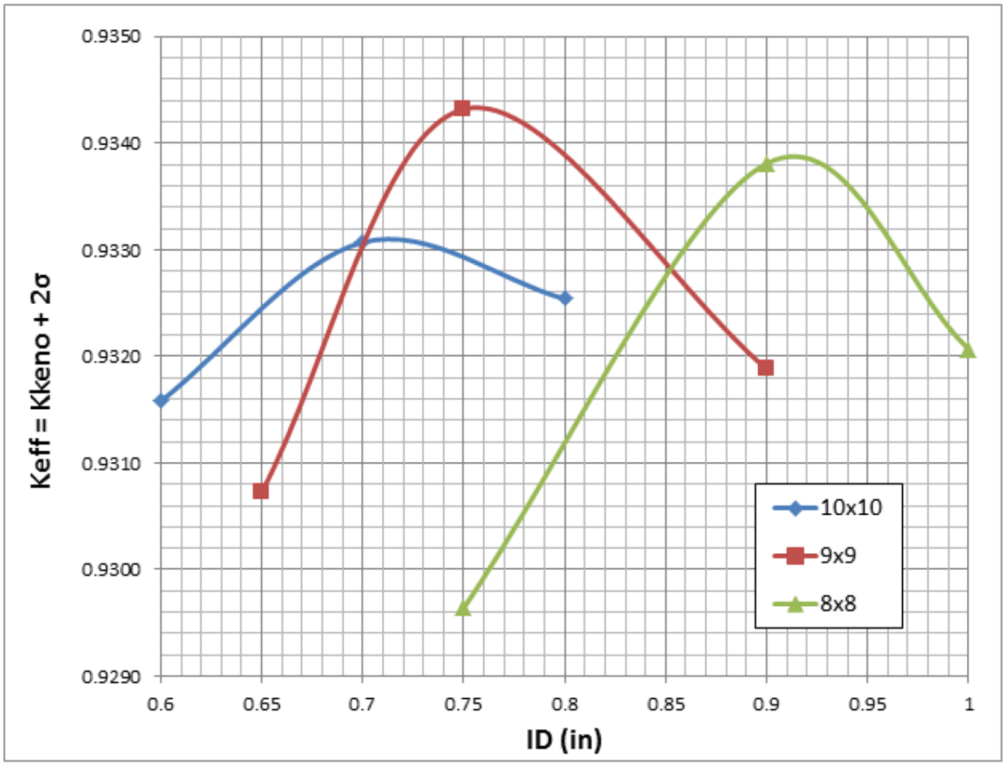

Figure 7-26
K_{eff} Variation for Failed Fuel Assembly Debris Models

CHAPTER 8
MATERIALS EVALUATION

Table of Contents

List of Tables

8. MATERIALS EVALUATION

8.1 General Information

8.1.1 NUHOMS® EOS System Materials

This chapter provides the materials evaluation for the NUHOMS® EOS System in accordance with the guidance outlined in NUREG-1536, Revision 1 [8-1]. Steel materials employed in the various components of the NUHOMS® EOS System, particularly those that are relied on for structural integrity, are based on American Society for Testing and Materials (ASTM) and American Society of Mechanical Engineers (ASME) specifications. Horizontal storage module (HSM) concrete is based on American Concrete Institute (ACI) specifications. Neutron and gamma shielding materials are relied on for their nuclear properties and are not credited in the structural analysis. Similarly, the neutron absorber and the aluminum plates in the basket are relied on for their neutron absorption and thermal conductivity and are not credited in the structural analysis.

8.1.2 Environmental Conditions

The dry shielded canister (DSC) and *EOS*-HSM are exposed to the ambient weather conditions at the licensee site for the duration of the licensing period. Depending on the licensee local conditions, the environment may include chloride aerosols, precipitation, and freezing temperatures. The roof, front wall, door, and shield walls of the *EOS*-HSM concrete are directly exposed to the weather. The *EOS*-HSM side and rear walls, interior, and the DSC exterior surfaces are sheltered from direct effects of weather, though moisture and aerosols present in the air pass through the *EOS*-HSM interior via natural convention. Material temperatures of the storage system components are presented in Chapter 4.

During loading and unloading, the DSC is placed in the fuel pool, inside the transfer cask (TC). The annulus between the TC and DSC is filled with demineralized water and an inflatable seal is used to cover the annulus between the DSC and the cask. The exterior of the DSC is not exposed to pool water. The interior of the DSC and the exterior of the TC are exposed to either demineralized water (boiling water reactor (BWR)) or diluted boric acid (pressurized water reactor (PWR)). The TC and DSC are only kept in the spent fuel pool for a short period of time, typically less than 24 hours.

The radial neutron shield of the TC is filled with potable water. The removable neutron shield of the TC108 is not immersed in the fuel pool. It is installed onto the TC after the cask is removed from the pool.

During storage, the interior of the DSC is exposed to an inert helium environment. The DSC is vacuum dried and backfilled with helium after loading the fuel and welding the inner top cover plate.

8.1.3 Engineering Drawings

The drawings for the EOS-37PTH and EOS-89BTH DSCs, TCs, and *EOS*-HSMs are provided in Chapter 1, Section 1.3. The material specification, governing code, and quality category are specified in the parts list for each component.

8.2 Materials Selection

This section discusses the materials used in the main NUHOMS® EOS System components. Table 8-1 through Table 8-3 summarize the materials selected for the EOS-DSCs, -HSMs, and -TCs, respectively. Temperature-dependent mechanical and thermal properties for the materials listed in Table 8-1 through Table 8-3 are presented in Table 8-4 through *Table 8-21* for the main structural and non-structural materials, respectively. Table 8-23 and Table 8-24 present the temperature-dependent properties for reinforced concrete. The fuel cladding temperature-dependent properties are presented in Table 8-25 and Table 8-26. Properties of helium and air used in the thermal evaluations are presented in Table 8-27 and Table 8-28, respectively. Mechanical and thermal properties of the solid neutron shielding material and material compositions for the materials used in the shielding analysis Monte Carlo N-Particle (MCNP) models are shown in Table 8-29 through Table 8-31. The material properties used for the criticality analysis, including the minimum B-10 content used in the neutron poison plates criticality evaluations, are shown in Table 8-32 through Table 8-34. Emissivity requirements for the [ ] basket plates or alternative surface treatment are provided in Table 8-35.

8.2.1 Applicable Codes and Standards and Alternatives

8.2.1.1 EOS-37PTH and EOS-89BTH DSC

The EOS-37PTH and EOS-89BTH DSC confinement boundary is designed and fabricated as a Class 1 component in accordance with the rules of the ASME Boiler and Pressure Vessel Code [8-2], Section III, Division 1, Subsection NB and the alternative provisions to the ASME Code as described in Section 4.4.4 of the Technical Specifications (TS) [8-41].

The confinement boundary materials are ASME-approved for Class 1 Components, excepting duplex stainless steels SA-240 UNS S31803 and Type 2205. The higher chromium, molybdenum and nitrogen contents give these materials significantly improved resistance to localized corrosion including intergranular, pitting and crevice corrosion, and chloride-induced stress corrosion cracking (CISCC). Therefore, these materials are used when enhanced long-term resistance to CISCC is required. ASME Code Case N-635-1 [8-3], which has been endorsed by Regulatory Guide 1.84 [8-5], is used as a basis for including duplex stainless steels as alternate DSC confinement boundary materials.

For the DSC surfaces that are exposed to the ambient atmosphere, if the standard grade Type 304 or 316 is specified, the carbon content is limited to 0.03% in order to get the tensile strength of the standard grade, with the sensitization resistance of the 304L or 316L grade material.

The primary structural material for the basket is a high-strength low-alloy (HSLA) steel, which is used for fabrication of the fuel compartments that provide structural support to the fuel assemblies (FAs). Basket component stress intensity allowables used for evaluation of normal and off-normal conditions (ASME Code Service Level A and B) are developed based on the mechanical properties (S_u and S_y) listed in Table 8-10. A strain-based criterion is used for evaluation of the basket for accident conditions (Service Level D). Thus, the basket is regarded as a non-ASME Code component. Specification and acceptance testing of the HSLA steel is included in Chapter 10 and Section 4.3.2 of the TS.

The aluminum plates in the basket perform only a heat conducting function with no credit taken for their strength. The aluminum 6061 peripheral transition rails are entrapped between the fuel compartment structure and the DSC shell. For normal and off-normal loading conditions the primary stresses are limited to S_y. For accident conditions, qualification of the fuel compartment demonstrates that the rails perform their structural support safety function. The transition rails are specified as ASTM B221 or B209 Alloy 6061. The important-to-safety (ITS) Cat C rail fasteners are specified as ASTM A193 Gr B7 material.

The fixed neutron absorber plates are composed of boron carbide/aluminum metal matrix composite or BORAL® (EOS-89BTH DSC only). These materials perform no structural function. They are subject to AREVA specification and acceptance testing described in Chapter 10 and Section 4.3.1 of the TS.

8.2.1.2 EOS-TC Transfer Cask

The TC body is designed to the stress criteria of the ASME Code, Section III, Division 1, Subarticle NF-3200. The upper lifting trunnions and trunnion welds are designed in accordance with the ANSI N14.6 [8-6] stress allowables for a non-redundant lifting device. The TC neutron shields are designed to the stress criteria of Subarticle ND-3200.

The TC structural body is composed of carbon and low-alloy steel using ASME materials. The TC top cover plate (lid) may be made of ASTM aluminum or ASME carbon steel. The trunnions are ASTM martensitic stainless steel. The radial neutron shell is carbon steel for the 125 and 135 ton TCs and aluminum for the removable neutron shield on the 108-ton TC. ASTM materials are used for the neutron shield shell.

The shielding materials in the TC perform no structural function, and therefore are not subject to any design code. The gamma shield is specified as ASTM B29 lead (any grade) and the axial bottom neutron shield as 5% boron high-density polyethylene.

8.2.1.3 EOS-HSM Horizontal Storage Module

The applicable codes for *EOS*-HSM(s) are:

- Concrete construction per ACI-318-08 [8-7].

- Concrete Design per ACI-349-06 [8-8].
- DSC support structure design per AISC Manual of Steel Construction [8-11].

Cement, aggregate, reinforcing steel, and DSC support structure steel conform to ASTM specifications.

The EOS-HSM concrete subcomponents are designed and constructed using a specified compressive strength of 5,000 psi, normal weight concrete. The specified compressive strength may be determined at 28 days or at test age designated for determination of f'c. The cement is Type II or Type III Portland cement meeting the requirements of ASTM C150. The concrete aggregate meets the specifications of ASTM C33. The reinforcing steel is ASTM A615 or A706 Gr 60 deformed bars placed vertically and horizontally at each face of the walls *and* roof.

The concrete surface temperature limits criteria are based on the provisions in Section 3.5.1.2 of NUREG-1536, as follows:

- If concrete temperatures in general or local areas are at or below 200 °F for normal/off-normal conditions/occurrences, no tests to prove capability at elevated temperatures or reduction of concrete strength are required.
- If concrete temperatures in general or local areas exceed 200 °F but do not exceed 300 °F, no tests to prove capability at elevated temperatures or reduction of concrete strength are required if the aggregates have a coefficient of thermal expansion (CTE) no greater than $6x10^{-6}$ in/in/°F, or are one of the following materials: limestone, dolomite, marble, basalt, granite, gabbro, or rhyolite.

The above criteria in lieu of the ACI 349-06 requirements do not extend above 300 °F for normal/off-normal conditions and do not modify the ACI 349-06 requirements for accident conditions. Per E.4.2 of ACI 349-06 [8-8], the accident conditions or short-term period (i.e., blocked vent accident transient) concrete temperatures are limited to 350 °F. Higher temperatures are allowed per E.4.3 if tests are provided to evaluate the reduction in strength and this reduction is applied to design allowables. *EOS*-HSM concrete compressive tests are performed on specimens heated to or above that maximum accident temperature for no less than 40 hours. *EOS*-HSM concrete temperature testing is performed whenever there is a significant change in the cement, aggregate, or water-cement ratio of the concrete mix design. See Section 5.3 of the *Technical Specifications [8-41]*.

Alternatively, per the ACI 349-13 [8-26] commentary Section RE.4, the specified 28-day compressive strength can be increased to 7,000 psi for *EOS*-HSM fabrication, in lieu of the above aggregate types or CTE requirements, so that any losses in properties (e.g., compressive strength, modulus of elasticity) resulting from long-term thermal exposure will not affect the safety margins based on the specified 5,000 psi compressive strength used in the design calculations. Additionally, also as indicated in Section RE.4, short, randomly oriented steel fibers may be used to provide increased ductility, dynamic strength, toughness, tensile strength, and improved resistance to spalling. See Section 4.4.4 of the T*echnical* S*pecification [8-41]*.

The EOS-DSC support structure is fabricated from ASTM A913 Gr 70 coated with an inorganic zinc-rich primer and a high build epoxy enamel finish. A corrosion allowance of 1/16 inch is used in the design calculations. Welding procedures are in accordance with ASME Code Section IX or AWS D1.1 [8-27].

At coastal sites with operational experience of corrosion due to atmospheric chlorides, the DSC support structure steel and weld filler metal have a minimum of 0.20% copper content. Weld material with 1% or more nickel is acceptable in lieu of 0.20% copper content. The copper content is equivalent to weathering steel [8-29], and nickel-bearing weld materials show equivalent corrosion resistance [8-30].

8.2.2 Material Properties

The material properties used in the NUHOMS® EOS System design analyses are listed in Table 8-4 through Table 8-35. Each table cites the source for the properties. Table 8-1 to Table 8-3 tie these materials to the individual components. Emissivity values for the thermal analysis are provided in Section 4.2.1(13).

8.2.2.1 EOS-37PTH and EOS-89BTH DSC

The structural material used in the baskets is a high strength low-alloy (HSLA) steel. The material properties shown in Table 8-10 are used in the structural analysis. If ASTM 829 Gr 4130 is used, AREVA test report [8-24] determines the optimum tempering for the desired toughness and the corresponding minimum yield and tensile strength. The A829 Gr 4130 steel plates are heat-treated and tempered per [ ] The requirements and acceptance criteria for HSLA steel are specified in Section 10.1.7.

The mechanical properties for the aluminum 6061 used for the basket transition rails are taken in the annealed (T0) condition to consider the effect of overaging at the service temperature near 400 °F. Therefore, the material may be supplied in any temper condition. Creep behavior of these rails is discussed in Section 8.2.6.

8.2.2.2 EOS-TC Transfer Cask

Material properties for the transfer cask body and fixed radial neutron shield shell are provided in Table 8-9 (SA-350 Gr LF3) and Table 8-11 (SA-516 Gr 70). Table 8-12 provides properties for the A182 Gr F6NM trunnion material. The mechanical properties at the welds of the TC108's removable aluminum neutron shield per Table 8-18 to account for annealing due to welding heat. The balance of the shell is analyzed and specified at the T6 condition per Table 8-17.

The lead shielding is placed in the TC as bricks or sheet. The structural properties of lead used in the drop analysis are provided in Table 8-20(a) and Table 8-20(b). The effective thermal conductivity of the layered lead brick or sheet is calculated in Chapter 4 from the thermal conductivity of lead provided in Table 8-21.

8.2.2.3 EOS-HSM Horizontal Storage Module

In accordance with ACI 349-06, Section E.4.3, the strength properties of the concrete and reinforcing steel used in the *EOS*-HSM structural analysis are taken at the maximum calculated temperature. Temperature dependent mechanical properties of concrete and reinforcing steel are taken from [8-4] and presented in Table 8-23 and Table 8-24.

The material properties of the ASTM A913 Gr 70 steel used for the DSC support structure are listed in Table 8-15. The material properties used for the Type 304 stainless steel used for the heat shields are provided in Table 8-5.

8.2.2.4 NUHOMS® EOS System Materials Employed in the Shielding Analysis

Shielding properties of steel and concrete are obtained from [8-10] and are summarized in Table 8-30. Simple materials consisting of one element are not listed in Table 8-30. Such materials include lead, which is modeled at 11.18 g/cm^3, 98.6% of theoretical density of pure lead. Aluminum is used in the basket plates with a density of 2.7 g/cm^3. The metal matrix composite (MMC) poison is modeled as pure aluminum (no boron) with a density of 2.56 g/cm^3.

Borated polyethylene is used at the bottom of the EOS-TC for neutron shielding. Boron suppresses secondary gamma radiation from hydrogen capture of neutrons. The material is 5% boron by weight. The neutron shielding performance is more sensitive to hydrogen content than boron content, so the atom density of hydrogen is reduced by 15% to account for potential hydrogen loss due to aging, although the TC components are exposed to temperature and radiation only intermittently. The borated polyethylene composition used in the EOS-TC models is provided in Table 8-31.

Concrete used in the EOS-HSM is modeled without steel rebar at a density of 140 pcf (2.243 g/cm^3).

8.2.2.5 NUHOMS® EOS System Materials Employed in the Criticality Analysis

The Oak Ridge National Laboratory (ORNL) SCALE code package [8-15] contains a standard material data library for common elements, compounds, and mixtures. All materials used for the TC and canister analyses are available in this data library.

A complete list of all the relevant materials used for the criticality evaluation is provided in Table 8-33.

8.2.3 Materials for ISFSI Sites with Experience of Atmospheric Chloride Corrosion

As noted above, austenitic stainless steels for the DSC shell are procured with a maximum 0.03% carbon for reduced sensitization of the heat affected zones. Duplex stainless steels can be substituted as alternate materials when superior resistance to atmospheric chloride induced stress corrosion cracking is required. Fabrication specifications for duplex stainless steel DSCs shall use API 938-C [8-46] and API RP-582 [8-47] to establish requirements for material procurement, weld qualification, and weld process specifications in addition to those required by ASME Code Sections III and IX.

DSC support structures at sites with operational experience of corrosion caused by atmospheric chlorides are fabricated from steels equivalent to weathering steel.

8.2.4 Weld Design and Inspection

The primary confinement boundary consists of the DSC shell, the inner top cover plate, the inner bottom cover plate, the siphon and vent port covers, and the associated welds.

The confinement boundary welds made during fabrication of the DSC include the weld of the inner bottom cover plate to the shell and the circumferential and longitudinal seams of the shell. These welds are inspected (radiographic or ultrasonic inspection, and liquid penetrant inspection) in accordance with the requirements of Subsection NB of the ASME Code. The welds applied to the vent and siphon port covers and the inner top cover plate during closure operations define the confinement boundary at the top end of the DSC. These welds are examined by multi-level penetrant testing (PT) in accordance with NUREG 1536.

Both shop and field confinement boundary welds are pressure tested and leak tested as described in Chapter 10.

The welds of the TC structural body are designed to the stress limits for ASME Subsection NF for Class 1 supports. Weld inspections are performed by magnetic particle inspection (MT) as specified on the drawings in Chapter 1 with acceptance criteria of ASME Subarticle NF-5340.

The DSC support structure is bolted inside the *EOS*-HSM. The welds of the DSC support structure are designed in accordance with the Manual of Steel Construction [8-11], and visually inspected in accordance with AWS D1.1 with acceptance criteria for statically loaded non-tubular structures.

8.2.5 Galvanic and Corrosive Reactions

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, neutron absorber, and HSLA steel while the DSC is immersed in the pool.

8.2.5.1 Behavior of Aluminum and Neutron Absorbers in Water and Boric Acid

The aluminum component of the MMC and BORAL® is a ductile metal having a high resistance to corrosion. Its corrosion resistance is provided by the buildup of a protective oxide film on the metal surface when exposed to a corrosive environment. As for aluminum, once a stable film develops, the corrosion process is arrested at the surface of the metal. The film remains stable over a pH range of 4.5 to 8.5. There are no chemical, galvanic, or other reactions that could reduce the areal density of boron in the neutron poison plates with either of the poison plate materials.

The pores in the core material exposed at the edges of BORAL® can retain water, which can cause delamination of the skin from the core during drying or storage. This has been evaluated and determined to have no effect on the criticality control function of BORAL® [8-31]. Metal matrix composites are tested to verify they will not be subject to this phenomenon.

The period of immersion is insufficient to cause significant localized corrosion such as pitting or crevice corrosion in the aluminum.

8.2.5.2 Behavior of Stainless Steel in Deionized Water and Weak Boric Acid

The DSC shell and cover plates are made from Type 304 or 316 or duplex stainless steels. Stainless steel does not exhibit general corrosion when immersed in deionized water. Reference [8-43] reports testing type 304 stainless steel for corrosion in saturated boric acid at 70 °F (5% boric acid, 8750 ppm boron) and 140 °F (13% boric acid, 22750 ppm boron). At 70 °F, there was no measureable corrosion, and at 140 °F, corrosion was measured at 7x10-4 inch/year (0.018 mm/year) for consumable electrode welds, and no measureable corrosion for other weld and plate conditions. Typical conditions for pool during loading of the EOS DSC would be up to 3000 ppm boron, water temperature <140 °F in the pool increasing until the time of draining, and duration usually <72 hours, including both immersion in the pool and the time until draining and drying the DSC. Considering the short time and the low boric acid concentration compared to the testing, stainless steel type 304 would show no measureable corrosion, and duplex 2205 would have less corrosion due to its higher chromium content and its molybdenum.

Under PWR reactor operating conditions, stress corrosion cracking has occurred in piping containing stagnant, high concentration boric acid, and stainless steel cladding has cracked [8-44], but the time, temperature, and concentration conditions described in the foregoing paragraph are insufficient to initiate stress corrosion cracking in the stainless steel shell during DSC loading. Galvanic corrosion could occur at contact between the basket perimeter's aluminum rails and the stainless steel DSC shell, with the aluminum corroding sacrificially, but this is mitigated by the passivity of the aluminum and the stainless steel in the short time the pool water is in the DSC. Also, the low conductivity of the pool water tends to minimize galvanic reactions.

8.2.5.3 Behavior of Low-Alloy Steel in Deionized Water and Weak Boric Acid

EPRI-1000975, Boric Acid Corrosion Guidebook, Revision 1 [8-42] provides available boric acid corrosion test data in aerated and deaerated water at various temperatures and soluble boron concentrations.

As noted in Section 8.1.2, the TC and DSC are only kept in the spent fuel pool for a short period of time, typically less than 24 hours. The spent fuel pool temperature is controlled during the loading operation and the pool water remains open to the atmosphere during loading. As noted in NUREG-1536 [8-1], Section 4.5.3, the maximum temperature limit of a spent fuel pool is typically 46 °C (115 °F).

The soluble boron concentration required for loading of PWR fuel assemblies in the NUHOMS® EOS system varies between 2,000 and 2,500 ppm as shown in Chapter 7, Table 7-3.

EPRI-1000975 [8-42] Figure 4-3 and Table 4-3 provide a summary of the available boric acid corrosion test data. The relevant corrosion rates retrieved from Figure 4-3 and Table 4-3 of the EPRI report are summarized in Table 8-36.

The highest corrosion rate among the relevant data shown in Table 8-36 is 0.015 in/yr (0.38 mm/yr). To account for uncertainties related to an initially high corrosion rate during a shorter period of time and assuming a loading time of 100 hours (approximately four times larger than the typical period),the thickness reduction is 0.00017 inch ($4.3x10^{-3}$ mm) based on a maximum corrosion rate of 0.015 in/yr. The evaluated thickness reduction is much lower than the standard plate tolerance of ±0.02 inch. Therefore, the amount of the evaluated thickness reduction would have no effect on the structural performance.

The basket's steel plates are [ ] or alternative surface treatment will provide short-term corrosion protection, sufficient for the manufacturing process and short-term immersion in the pool. It can be expected that a small amount of rust will form, but this will be insufficient to affect the performance of design functions or to cause turbidity in pool water during loading operations.

During storage, the interior of the DSC is exposed to an inert helium environment. The helium environment does not support the occurrence of chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur.

8.2.5.4 Lubricants and Cleaning Agents

The DSC is cleaned in accordance with approved procedures to remove cleaning residues prior to shipment to the storage site. The basket is also cleaned prior to installation in the DSC. Decontamination agents may be applied on the TC surfaces at each use. A graphite-based dry lubricant is applied to the surface of the Nitronic 60 sliding surfaces in the TC and on the *EOS*-HSM's DSC support structure. Lubricants may be used on the TC cover bolts and on the trunnion and lower rotating socket bearing surfaces. The cleaning agents have no adverse effect on the DSC materials and their design functions. Lubricants used on bolt threads and trunnions have no adverse effect on materials or design functions.

The graphite lubricant used on the *EOS-HSM* DSC support structure rails is noble relative to the rail face and to the canister shell; therefore, it could induce galvanic corrosion of DSC shell and Nitronic 60 support rail. While galvanic corrosion is possible under the correct conditions, the conditions of dry storage in NUHOMS are very unlikely to result in loss of materials due to galvanic corrosion at the *EOS-HSM* rail-DSC interface based on the results of galvanic corrosion tests for stainless steel Type 304 coupled with graphite in reference [8-45]. The corrosion rate of the stainless steel Type 304 was reported to be "nil," and no pitting was observed with a cathode-to-anode ratio of about unity in a 3.5 percent NaCl solution. The dry conditions and high anode-to-cathode ratio in the NUHOMS® system would result in an even lower corrosion rate than these experimental conditions. Unlike failures of high strength martensitic stainless steel valve components in reactor operation [8-44], there is no operating experience for galvanic corrosion of dry graphite lubricants on stainless steel in dry conditions. Therefore, the graphite lubricant does not have an adverse effect on materials or design functions.

8.2.5.5 Corrosion of Canister Shell During Storage

The DSC external surfaces are protected from direct exposure to precipitation, and are exposed only to the humidity and aerosols in the cooling air that flows through the HSM. The stainless steel outer surfaces and the rails surfaces upon which the DSC rests are not subject to general corrosion. Sites near the coast or other sources of chloride aerosols could experience pitting, stress corrosion cracking, or crevice corrosion [8-39] during long term service, but neither the accumulation of deposits nor the canister surface temperatures are expected to be sufficiently aggressive conditions of chloride concentration and deliquescence required for these corrosion mechanisms during the initial 20 year license period.

For sites near chloride aerosol sources, the NUHOMS® EOS System provides options for canisters made of duplex stainless steel, which, due to its partially ferritic grain structure, is very resistant to localized corrosion of pitting and crevice corrosion and stress corrosion cracking. An option for inspection port on the front of the HSM provides for improved aging management beyond the 20-year initial license period.

8.2.5.6 Corrosion of DSC Support Structure

The DSC support structure is protected from direct exposure to precipitation, and is exposed only to the humidity and aerosols in the cooling air that flows through the *EOS*-HSM. Epoxy enamels such as Carboguard® 890 are suitable for continuous service to 300 °F, while inorganic zinc primers such as Carbozinc 11 have much higher temperature resistance. The maximum temperature on the top of the support beam is about 270 °F per Figure 4-12. The top coat is expected to experience chalking and other effects of radiation over 10^6 rad, but the inorganic primer coat is insensitive to radiation. Inspections for license extension [8-32, 8-33] have found only minor local rusting. Nonetheless, the stress analysis removes 1/16 inch from all surfaces to account for corrosion. At ISFSIs with operational experience of corrosion with atmospheric chlorides, additional protection is provided by specifying a minimum 0.2% copper content, which results in an adherent self-protecting oxide layer equivalent to weathering steel [8-29].

8.2.5.7 Corrosion of Transfer Cask

Protective coatings, periodic inspection, and maintenance as specified by Section 10.2.1 prevent corrosion of the TC from affecting design functions.

8.2.6 Creep Behavior of Aluminum

The structural analysis of the EOS-37PTH and EOS-89BTH DSC described in Chapter 3 does not credit the neutron poison material to demonstrate mechanical integrity. For the steel components, creep is not a concern due to the operating temperature and mechanical and thermal properties of materials.

From [8-28], the allowable bearing stresses in the basket aluminum components, to limit creep strain to 0.01 in 550,000 hours, are as follows:

- 0.254 ksi in the hottest aluminum plate, with a starting temperature of 680 °F.
- 0.758 ksi in the hottest R90 rail, with a starting temperature of 470 °F.
- 0.876 ksi in a less than hottest R90 rail, based on a starting temperature of 440 °F.

Although 550,000 hours is approximately 63 years, the creep strain time curve is very flat at 550,000 hours, such that the change in allowable bearing stress for 80 years is insignificant.

In addition, from Chapter 4, for normal conditions (applicable to long-term storage conditions) at the hottest cross-section of the EOS-37PTH and EOS-89BTH baskets, the average R90 transition rail temperature is not more than 469 °F, which is less than the above temperature of 470 °F for the hottest R90 rail. Similarly, from Chapter 4, for normal conditions, the hottest basket plate temperature is not more than 676 °F, which is less than the above temperature of 680 °F for the hottest aluminum plate. Based on this favorable comparison of starting temperatures, and since the heat dissipation rate of the EOS-37PTH and EOS-89BTH baskets is better than the temperature data for the baskets evaluated in [8-28] (i.e. more favorable temperature versus time values), the allowable creep stresses given above are applicable to the aluminum components of the EOS-37PTH and EOS-89BTH baskets.

8.2.7 Bolt Applications

There are no bolts in the NUHOMS® EOS System associated with confinement, and no bolts performing quality category A functions. Bolts that perform ITS Category B and C functions are described here. No specific preload of any bolt is required by the design analysis. Therefore, all bolts are installed snug tight without a torque specification except as noted below.

[

]

The DSC support structure inside the *EOS*-HSM*, or the rear DSC support on the HSM-MX, use* SA-193 Gr B7 bolts. The heat shields are fastened to the HSM base and roof with SA-193 Gr B7 bolts. The roof, door and wall assemblies of the HSM use SA-193 Gr B7 bolts. These bolts are zinc-coated for corrosion resistance.

The top cover and bottom ram access port covers of the TC cask are retained by SA-540 Gr B23 bolts. The bolts may be plated or coated for corrosion protection. Torque values on the drawings in Chapter 1 are recommendations for assembly, not requirements based on the design analysis.

8.2.8 Protective Coatings and Surface Treatments

No coatings are applied to the DSC surface. The top shield plug of the DSCs is coated with an electroless nickel, [

] *The HSLA steel plates of other 37PTH basket types have a coating or surface treatment to provide* corrosion resistance for short-term pool immersion.

The exposed carbon steel surfaces of the EOS-TCs are coated with a painting system suitable for spent fuel pool immersion, and withstanding long-term exposure to the elevated temperatures of the TC. Stainless steel surfaces, that is, trunnions, sliding rails, and the stainless steel overlay for the ram access port sealing surfaces are not coated. The removable aluminum neutron shield shell for the TC108 is painted only on the outer diameter. The following finish enamels are used on the transfer cask:

- PPG Amerishield™ enamel or Carboline Carboguard® 890, color white, is used for the EOS-TC exterior surfaces.
- PPG Amerishield™, color white, is used for coating the exterior of the removable EOS-TC108 neutron shield. This neutron shield is not immersed.
- Carboline Thermaline® 450-EP PPG or Amercoat® 91 is used for coating the EOS-TC interior surfaces, which are exposed to higher service temperatures up to 373 °F (Tables 4-26 and 4-27).

Manufacturer's recommendations are followed for surface preparation, primer coat selection, and coating application.

Alternate coatings that are accepted by licensees for spent fuel pool immersion, and whose short-term service temperature is above the normal condition TC surface temperatures may be used. For solar absorptivity, white color must be maintained where specified.

The DSC support structure in the *EOS*-HSM*, or front and rear DSC supports on the HSM-MX, are* coated with an inorganic zinc-rich primer and a high build epoxy enamel finish, for example, Carboline Carbozinc® 11 primer with Carboguard® 890 enamel. Embedments and fasteners are coated, plated, or galvanized.

Coatings are not important to safety *except coating or surface treatment for 89BTH and 37PTH type 1, 2, 3, or 4H steel basket plate, which is ITS quality category C.*

8.2.9 Neutron Shielding Materials

During storage, all neutron shielding is provided by the concrete of the HSM. No polymeric neutron absorbers are used. Boron is not added to the concrete.

During transfer of the DSC from the pool to the HSM, neutron shielding is provided by water in a radial neutron shielding jacket of the TC. The bottom end and lid of the TC include a layer of solid neutron shielding consisting of borated high-density polyethylene, Quadrant Borotron® types HD050 [8-9], UH050, and HM050 or similar material.

Because of the short duration of the transfer operations, this material is not subjected to significant thermal or radiation-induced degradation. The shielding analysis uses a reduced hydrogen content to bound any degradation as discussed in Section 8.2.2.4.

8.2.10 Materials for Criticality Control

The EOS-37PTH uses an Aluminum/B4C MMC poison plate material, which is suitable for long-term use in radiation and thermal environments of a dry cask storage system. The NUHOMS® EOS-37PTH DSC has two neutron poison loading options A and B that correspond to minimum B-10 loadings in mg B-10/cm^2, as shown in Table 8-32. There are three neutron poison loading options specified for the EOS-89BTH corresponding to the type and boron content of the poison plates. The baskets manufactured with MMC are designated as A and B, while the basket manufactured with BORAL® plates is designated as *A, B, and* C, as shown in Table 8-32. In criticality evaluations, credit is taken only for 90% of B-10 areal density in the MMC and 75% in the BORAL® poison plates.

The control method used to prevent criticality is incorporation of neutron absorber material in the basket material and favorable geometry. The quantity and distribution of boron in the poison material is controlled by specific manufacturing and acceptance criteria of the poison plates.

Chapter 10 provides detailed information of the material specifications, qualification, and acceptance testing for the neutron absorbing materials. The essential requirements are included in Chapter 13.

8.2.11 Concrete and Reinforcing Steel

The concrete and reinforcing steel are described in Section 8.2.2.

8.2.12 Seals

The DSCs do not employ mechanical seals to demonstrate the integrity of the confinement boundary.

The only mechanical seal in the storage system is the elastomer o-ring for the bottom ram access penetration closure plate of the TC, which isolates the DSC-TC annulus water from the pool water during DSC loading in the fuel pool.

The quick connect fitting in the DSC drain port may include elastomer seals and lubricant, but this is not part of the confinement boundary. The tool for engaging the DSC's internal drain tube may include o-rings. The o-rings may be lubricated. If two o-rings were dislodged from the drain tool and remained inside the DSC cavity, the total of organic materials from the quick connect fitting, the tool o-rings, and the lubricant could contribute an estimated upper limit of 0.14 g offgassing inside the DSC. This is 0.8% of the 1 mole (18 g) of water vapor that is the basis for the vacuum drying acceptance criterion. Therefore, the incremental effect on the purity of the helium backfill, long-term corrosion of the DSC or the fuel cladding, or thermal conductivity of the backfill helium is negligible.

8.2.13 Low Temperature Ductility of Ferritic Steels

8.2.13.1 DSC Basket

The materials test report [8-24] evaluates several tempering cycles for tensile properties and fracture toughness. In accordance with the recommendation of that report and Regulatory Guide 7.11 Table 4 [8-40], the material is subject to dynamic tear testing as specified in Section 10.1.7, and on the basket parts list drawings in Chapter 1. No welding is performed on this material.

8.2.13.2 Transfer Cask

The materials in the lifting load path of the TC are the SA-350 Gr LF3 top and bottom rings, SA-516 Gr 70 inner and outer structural shells and bottom plate, and ASTM A182 Gr F6NM martensitic stainless trunnions. The minimum service (material) temperature of the TC is 0 °F. The SA-516 Gr 70 material and the procedures for all welds in the load path are subject to Charpy impact testing at 0 °F in accordance with ASME Code Section III, Article NF-2300 for Class 1 supports. SA-350 Gr LF3 is a cryogenic steel that has been used on AREVA Inc. metal casks and has consistently demonstrated nil ductility transition temperatures below -80 °F. Therefore, this material need not be impact tested for the TC application. The trunnion materials, a martensitic stainless, are subject to drop weight testing at -40 °F per ANSI N14.6 or to Charpy impact testing at 0 °F in accordance with ASME Code Section III, Article NF-2300 for Class 1 supports. More recent editions of the ASTM test specifications than those invoked by ANSI N14.6 may be used.

8.3 Fuel Cladding

8.3.1 Fuel Burnup

The limit for fuel burnup is 62 GWd/MTU.

8.3.2 Cladding Temperature Limits

The thermal design criteria for cladding integrity are described in Chapter .4, Section 4.2. The maximum fuel cladding temperature limit of 400 °C (752 °F) is applicable to normal conditions of storage and all short-term fuel loading and transfer operations including vacuum drying and helium backfilling of the EOS-37PTH and EOS-89BTH DSC per NUREG 1536. In addition, NUREG 1536 does not permit thermal cycling of the fuel cladding with temperature differences greater than 65 °C (117 °F) during drying and backfilling operations. A maximum fuel cladding temperature limit of 570 °C (1058 °F) is applicable to accidents or off- normal thermal transients.

In addition, Chapter 4, provides the evaluation of thermal cycling during loading and vacuum drying operations. The thermal analysis of the EOS37PTH and EOS-89BTH DSC during the blowdown (draining) operation assumes helium is used to drain the water from the EOS-37PTH and EOS-89BTH DSC cavity and subsequent vacuum drying occurs with a helium environment. Further, the water level in the annulus between the DSC and TC is monitored and replenished, if needed, during vacuum drying. This configuration provides adequate cooling to eliminate the thermal cycling of fuel cladding during helium backfilling of the EOS-37PTH and EOS-89BTH DSC subsequent to vacuum drying and to eliminate the need for a time limit on the vacuum drying operation. Further, the water level in the annulus between the DSC and TC is monitored and replenished, if needed, during vacuum drying. The maximum fuel cladding temperature limit of 400 °C (752 °F) in NUREG 1536 is satisfied for the EOS-37PTH and EOS89-BTH DSC.

8.4 Prevention of Oxidation Damage During Loading of Fuel

The operations described in Chapter 9 require that the canister is filled with helium as the water is pumped below the top of the fuel rods. Subsequent operations alternate evacuation and helium backfill. The use of helium will prevent oxidation of fuel cladding. The final condition of helium purity for storage is controlled by the vacuum drying acceptance criteria in Chapter 9 and Section 3.1.1 of the TS.

8.5 Flammable Gas Generation

Experience with aluminum in dry storage indicates that it will generate some hydrogen as the surface oxide layer is formed. The reaction is more pronounced in pure water (BWR pools) than in PWR pools. The general corrosion of aluminum and aluminum-based neutron absorbers is self-limiting, and does not reduce the integrity of the materials. [ ] Galvanic coupling between aluminum and stainless steel has not proven to be a problem in many years of design with these materials. Aluminum and carbon steel are closer on the galvanic scale than aluminum and stainless steel. The hydrogen generation is monitored and controlled prior and during welding operations in accordance with the operations instructions in Chapter 9.

8.6 DSC Closure Weld Testing

The field closure weld of the inner top cover plate to the shell is pressure tested as described in Section 10.1.1.1. The confinement boundary field welds are examined by root and final PT, and the structural weld of the outer top cover plate to the shell is examined by progressive PT as shown on the drawings in Chapter 1, and as described in the Code Alternatives, Section 4 of the Technical Specifications *[8-41]*. PT acceptance criteria are those of ASME Code, Section III, Subsection NB, Subarticle 5350.

The weld between the DSC shell and inner top cover and the siphon and vent cover welds are leak tested to an acceptance criterion of 1×10^{-7} ref cm^3/s at the field after the FAs are loaded in the canister. The testing is described in more detail in Chapter 10.

8.6.1 Periodic Inspections

The NUHOMS® EOS System is designed to be totally passive with minimal maintenance requirements. During fuel storage, the system requires only periodic inspection of the air inlets and outlets to ensure that no blockage has occurred, unless a means of thermal performance monitoring is employed.

The TC is designed to require only minimal maintenance. Transfer cask maintenance is limited to periodic inspection of critical components, inspection and repair of coatings, and replacement of damaged or nonfunctioning components.

8.7 References

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8-17 MIL-HDBK-5J, “Metallic Materials and Elements for Aerospace Vehicle Structures,” U.S. Department of Defense Handbook, 31 January 2003.

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Table 8-1
DSC Materials

Shell Assembly Subcomponents	**Material**
Cylindrical Shell, Inner Top Cover Plate, Inner Bottom Cover Plate (Confinement Boundary), Outer Top Cover Plate, Lifting Lug Plate	Stainless steel ASME SA-240 Type 304, 316, 2205 or UNS S31803
Drain Port Cover Plate (Confinement Boundary)	ASME SA-240 Type 304
Vent Port Plug (Confinement Boundary)	ASME SA-240 Type 304 or SA-479 Type 304
Outer Bottom Cover Plate, Lifting Lug	Stainless steel ASTM A240 Type 304, 316, or 2205 or UNS S31803
Grapple Ring, Grapple Ring Support	Stainless steel ASTM A240 Type 304, 316, or 2205 or UNS S31803, or ASTM A182 Gr F304, F316, F51, or F60
Siphon Bracket, Basket Key	Stainless steel ASTM A240 Type 304 or 316
Test Port Plug	ASTM A240, A276, or A479, Type 304, 316, UNS S31803, or UNS S32205
Top and Bottom Shield Plugs	Carbon steel ASTM A36
Miscellaneous parts (Drain Tube, Siphon Block, Port Adapter, Quick Connect, Reducing Bushing)	Stainless Steel
Basket Assembly Subcomponents	**Material**
Basket Steel Plates	Low-alloy high strength steel such as ASTM A829 Gr 4130
Basket Aluminum Plates	Aluminum ASTM B209 Alloy 1100 or 1060, or alloy 1050 (EN AW-1050A) per EN485-2 and EN573-3
Transition Rails:	
R90 and R45 Aluminum Extrusions	ASTM B221 or B209 Alloy 6061
R45 Angle Plates	ASTM A516 Gr 70
Tie Rod/Flat Head Screws	A 564 Type 630 H1100
Hex Nuts	ASTM A194 Gr 7
Miscellaneous Washers	SA-302 Gr C
Neutron absorber plates	MMC or BORAL® (89BTH only)
Fuel Spacers	*Stainless steel ASTM A240 Type 304 or Aluminum ASTM B209, Type 6061 or 1100*

Table 8-2
***EOS*-HSM Materials**

HSM Subcomponents	Material
EOS-HSM walls, roof, floor, end shield walls, rear shield walls	Reinforced concrete with ASTM A615 or A706 Gr 60 reinforcing steel
DSC Support Structure Assembly	ASTM A913 Gr 70 (W Beam Option), ASTM A572 (FPS Option)
Sliding Rail	Nitronic® 60 stainless steel, ASTM A240 UNS S21800
EOS-HSM Door Door Steel Liner Assembly Threaded Inserts Inspection Penetration Sleeve Door	Reinforced concrete Steel Steel Stainless Steel
Axial retainer assembly: Bar Steel Miscellaneous (top plate, plate embedment, DSC axial retainer)	 ASTM A588 or ASTM A913 Gr. 70 Carbon steel
EOS-HSM Heat Shields	Stainless steel ASTM A240 Type 304 or 316
EOS-HSM Roof Attachment Angles and Stiffener Plates	Carbon steel
EOS-HSM Outlet Vent Cover Outlet Vent Cover Steel Liner *EOS*-HSM Inlet Vent Screen Assembly	Reinforced concrete ASTM A36 Carbon Steel
Bird Screens and Dose Reduction Hardware	Stainless steel or Aluminum
Wind deflectors	Aluminum
Segmented *EOS*-HSM Connecting Hardware	ASTM A722 Gr 150
Fasteners: Bolts Washers Nuts	 ASTM A193 Gr B7/ A325/A563/A490/A108 ASTM A36/F436/F844/ Stainless Steel ASTM A194/A563/A194/ Carbon Steel
Threaded Embedments: Stud Bolt Sleeve Nut Nut	 ASTM A193-B8 CL 2 or ASTM A193-B8M CL 2 ASTM A194 Gr 2H or A563 Gr A ASTM A194 Gr 8M or A563 Gr A

Table 8-3
Transfer Cask Materials

TC Subcomponents	Material	
Top Cover Plate	ASME SA-516 GR 70	
Interim Top Cover Plate (TC 108)	ASTM B209 Alloy 6061- T6	
Interim Top Cover Place (TC 125 and 135)	ASTM B209 Alloy 6061-T651	
Bottom Cover Plate (TC 108)	ASTM A516 Gr 70	72.48
Bottom Cover Plate (TC 125 and 135)	ASTM A240 Type 304 or ASME SA-240 Type 304	
Top and Bottom Rings	ASME SA-350 Gr LF3	
Inner and Outer Shells	ASME SA-516 Gr 70	
Bottom End Plate	ASME SA-516 Gr 70	
RAM Access Penetration Ring	ASME SA-516 Gr 70	
Wedge Plates (TC 108)	ASTM A516 Gr 70	
Wedge Plates (TC 125 and 135)	ASTM B209 Alloy 6061-T651	
Upper Trunnion	ASTM A182 Gr F6NM	
Gamma Shielding	ASTM B29	
Neutron Shielding Side Bottom and Top Cover	 Water HDPE 5%B	
Neutron Shield Panels (NSP), NSP Top and Bottom Support Rings, Bottom Neutron Shield Plate Outer Panel (TC 125 and 135)	ASTM A516 GR 70	
Neutron Shield I Beams (TC 125 and 135)	ASTM A36	
Removable Neutron Shield Assembly (TC 108 only)	ASTM B209 Alloy 6061-T6	
Canister Rails	ASTM A240 UNS S21800 (Nitronic® 60)	
Cask Bottom Cover Plate O-Ring	Ethylene Propylene	
Neutron Shield Inlet-Outlet Side Plates (TC 125 and 135)	ASTM A516 GR 70	
Threaded Fasteners: Cask Top Cover Closure Bolts (TC 108) Cask Top Cover Closure Bolts (TC125/135) Bottom Cover Plate Closure Screws	 SA540 GR B23 Cl 1 SA540 GR B23 CL 3 SA540 GR B23 Cl 1	

Table 8-4
Material Properties, SA-36

Temp (°F)	E (103 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10-6 °F^{-1})	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20		19.3	36.0	58.0				
70	29.4	19.3	36.0	58.0	6.4		34.9	0.103
100		19.3	36.0	58.0	6.5		34.7	0.106
150			33.8		6.6		34.2	0.110
200	28.8	19.3	33.0	58.0	6.7		33.7	0.114
250			32.4		6.8		33.0	0.117
300	28.3	19.3	31.8	58.0	6.9		32.3	0.119
Xm 350					7.0		31.6	0.122
400	27.9	19.3	30.8	58.0	7.1		30.9	0.124
450					7.2	0.280	30.1	0.126
500	27.3	19.3	29.3	58.0	7.3		29.4	0.128
550					7.3		28.7	0.131
600	26.5	18.4	27.6	58.0	7.4		28.0	0.134
650		17.8	26.7	58.0	7.5		27.3	0.136
700	25.5	17.3	25.8	58.0	7.6		26.6	0.140
750			24.9	57.3	7.7		26.0	0.143
800	24.2		24.1	53.3	7.8		25.3	0.147
850			23.4	48.5	7.9		24.6	0.151
900	22.5		22.8	43.3	7.9		23.8	0.155
950			22.1	38.0	8.0		23.1	0.159
1000	20.4		21.4	33.4	8.1		22.4	0.164
ASME	Table TM-1for Carbon Steel with C≤0.3% p. 738	Table 2A Line 20 p. 270	Table Y-1 Line 2 pp. 542-543	Table U Line 46 pp. 460-461	Table TE-1 p. 708 Group 1	Table PRD p.744	Calculated based on Table TCD p. 726, Group A	

Source: ASME Section II, Part D

Table 8-5
Material Properties, SA-240 Type 304 / SA-182 Gr F304 (≤ 5" thk.)

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in³)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20		20.0	30.0	75.0				
70	28.3	20.0	30.0	75.0	8.5		8.6	0.114
100		20.0	30.0	75.0	8.6		8.7	0.114
150			26.7		8.8		9.0	0.117
200	27.5	20.0	25.0	71.0	8.9		9.3	0.119
250			23.6		9.1		9.6	0.121
300	27.0	20.0	22.4	66.2	9.2		9.8	0.122
350					9.4		10.1	0.124
400	26.4	18.6	20.7	64.0	9.5		10.4	0.126
450					9.6		10.6	0.127
500	25.9	17.5	19.4	63.4	9.7	0.290	10.9	0.129
550					9.8		11.1	0.129
600	25.3	16.6	18.4	63.4	9.9		11.3	0.130
650		16.2	18.0	63.4	9.9		11.6	0.131
700	24.8	15.8	17.6	63.4	10.0		11.8	0.132
750		15.5	17.2	63.3	10.0		12.0	0.132
800	24.1	15.2	16.9	62.8	10.1		12.3	0.133
850			16.5	62.0	10.2		12.5	0.134
900	23.5		16.2	60.8	10.2		12.7	0.134
950			15.9	59.3	10.3		12.9	0.135
1000	22.8		15.5	57.4	10.3		13.1	0.135
ASME	Table TM-1, Group G p. 738	Table 2A Lines 17, 19, 26 p. 306	Table Y-1 Lines 32, 38 pp. 610-611, Line 10 p. 612	Table U Lines 16,22,39 pp. 492-493	Table TE-1 p. 711 Group 3	Table PRD p. 744	Calculated based on Table TCD p. 727, Group J	

Source: ASME Section II, Part D
Note: Thermal conductivity is provided for information only; the design analysis is based on the thermal conductivity of SA-240 Type 316, which is lower than Type 304.

Table 8-6
Material Properties, SA-240/SA-479 Type 316 / SA-182 Gr F316 (≤ 5" thk.)

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20		20.0	30.0	75.0				
70	28.3	20.0	30.0	75.0	8.5		8.2	0.118
100		20.0	30.0	75.0	8.6		8.3	0.118
150			27.4		8.8		8.6	0.121
200	27.5	20.0	25.9	75.0	8.9		8.8	0.121
250			24.6		9.1		9.1	0.124
300	27.0	20.0	23.4	72.9	9.2		9.3	0.124
350					9.4		9.5	0.125
400	26.4	19.3	21.4	71.9	9.5		9.8	0.126
450					9.6		10.0	0.127
500	25.9	18.0	20.0	71.8	9.7	0.290	10.2	0.127
550					9.8		10.5	0.129
600	25.3	17.0	18.9	71.8	9.9		10.7	0.129
650		16.6	18.5	71.8	9.9		10.9	0.130
700	24.8	16.3	18.2	71.8	10.0		11.2	0.131
750		16.1	17.9	71.5	10.0		11.4	0.132
800	24.1	15.9	17.7	70.8	10.1		11.6	0.132
850			17.5	69.7	10.2		11.9	0.134
900	23.5		17.3	68.3	10.2		12.1	0.134
950			17.1	66.5	10.3		12.3	0.135
1000	22.8		17.0	64.3	10.3		12.5	0.136
ASME	Table TM-1 p. 738 Group G	Table 2A, p. 298 Lines 24, 26, and 33	Table Y-1, pp. 602-603 Lines 7, 10, and 19	Table U, p. 487, Lines 43 and 46; p. 489 Line 9	Table TE-1 p. 711 Group 3	Table PRD p. 744	Calculated based on Table TCD p. 728 Group K	

Source: ASME Section II, Part D
Note: Mechanical properties are provided for information only; the design analysis is based on the mechanical properties of SA-240 Type 304, which are lower than Type 316.

Table 8-7
Material Properties, SA-240/SA-479 Type 2205 / SA-182 Gr F60

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20		37.5	65.0	90.0				
70	29.0	37.5	65.0	90.0	7.0		8.2	0.122
100		37.5	65.0	90.0	7.1		8.3	0.122
150		37.5	60.5		7.2		8.6	0.123
200	28.2	37.5	57.8	90.0	7.3		8.8	0.125
250		37.0	55.5		7.3		9.1	0.128
300	27.5	35.8	53.7	86.8	7.4		9.3	0.128
350		34.9			7.5		9.5	0.129
400	27.0	34.2	51.2	83.5	7.6		9.8	0.131
450					7.6		10.0	0.132
500	26.4		49.6	81.6	7.7	0.280	10.2	0.132
550					7.8		10.5	0.134
600	26.0		47.9	80.7	7.8		10.7	0.134
650			46.9	80.5	7.9		10.9	0.135
700	25.5				7.9		11.2	0.136
750					8.0		11.4	0.137
800	25.1				8.0		11.6	0.137
850					8.1		11.9	0.139
900					8.1		12.1	0.139
950					8.2		12.3	0.140
1000					8.2		12.5	0.140
ASME	Table TM-1 p. 738 Group H	Table 5A p. 420, Lines 29, 30	Table Y-1 p. 632 Lines 1, 2, 3	Table U, pp. 502-503, Lines 7, 8, 9	Table TE-1 p. 708 Group 2	Ref. 8-48	Calculated based on Table TCD p. 728 Group K	

Source: ASME Section II, Part D

Note: These properties are provided for information only; the design analysis is based on the mechanical properties and thermal conductivity of SA-240 Types 304 and 316, which bound the duplex steel

Table 8-8
Material Properties, SA-240 UNS S31803 / SA-182 Gr F51

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F^{-1})	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20				90		0.280		
70	29.0			90	7.0		8.2	0.122
100		30	65	90	7.1		8.3	0.123
150					7.2		8.6	0.125
200	28.2	30	57.8	90	7.3		8.8	0.125
250					7.3		9.1	0.128
300	27.5	28.9	53.7	86.8	7.4		9.3	0.128
350					7.5		9.5	0.129
400	27.0	27.8	51.2	83.5	7.6		9.8	0.131
450					7.6		10.0	0.132
500	26.4	27.2	49.6	81.6	7.7		10.2	0.132
550					7.8		10.5	0.134
600	26.0	26.9	47.9	80.7	7.8		10.7	0.134
650					7.9		10.9	0.135
700	25.5				7.9		11.2	0.136
750					8.0		11.4	0.137
800	25.1				8.0		11.6	0.137
850					8.1		11.9	0.139
900					8.1		12.1	0.139
950					8.2		12.3	0.140
1000					8.2		12.5	0.140
ASME	Table TM-1 p. 738 Group H	ASME Code Case N-635-1	ASME Code Case N-635-1	Table U	Table TE-1 p. 708 Group 2	Ref. 8-48	Calculated based on Table TCD p. 728 Group K	

Sources: ASME Section II, Part D and ASME Code Case N-635-1

Note: These properties are provided for information only; the design analysis is based on the mechanical properties and thermal conductivity of SA-240 Types 304 and 316, which bound the duplex steels.

Table 8-9
Material Properties, SA-350 Gr LF3

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_u (ksi)	S_y (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100	28.6							
-20		23.3	70.0	37.5		0.280		
70	27.8	23.3	70.0	37.5	6.4		23.7	0.107
100		23.3	70.0	37.5	6.5		23.6	0.108
150				35.3	6.6		23.5	0.111
200	27.1	22.9	70.0	34.3	6.7		23.5	0.115
250				33.7	6.8		23.4	0.117
300	26.7	22.1	70.0	33.2	6.9		23.4	0.121
350					7.0		23.3	0.123
400	26.2	21.4	70.0	32.0	7.1		23.1	0.126
450					7.2		23.0	0.129
500	25.7	20.3	70.0	30.4	7.3		22.7	0.131
550					7.3		22.5	0.134
600	25.1	18.8	70.0	28.2	7.4		22.2	0.137
650		17.9	70.0	26.8	7.5		21.9	0.139
700	24.6	16.9	66.5	25.3	7.6		21.6	0.142
ASME	Table TM-1	Table 2A	Table U	Table Y-1	Table TE-1, Group 1	Table PRD	Calculated based on Table TCD group C [(1)]	

Source: ASME Section II, Part D

Notes:

1. Group C properties for thermal conductivity and specific heat used since composition of SA-350 LF 3 is bounded by the range of materials listed in Group C.

Table 8-10
Material Properties, High Strength Low Alloy Steel

Temp (°F)	E[(1)] (10^3 ksi)	S_y[(1)(2)(3)] (ksi)	S_u[(1)(4)] (ksi)	Thermal Expansion 10^{-6} in/(in-°F)[(1)]	Thermal Conductivity Btu/(hr-ft-°F)[(1)]	Specific Heat Btu/(lb-°F)[(1)]	Density lb/in^3
-20	29.3	100.2	105.2				0.283[(1)]
70	29.0	96.4	101.2				
100	28.9	95.4	100.2	6.60	23.8		
200	28.4	91.6	96.2	6.90	24.4	0.110	
300	28.0	87.7	92.1	7.20	24.6		
400	27.6	83.9	88.1	7.40	24.4	0.120	
500	27.0	80.0	84.0	7.55	24.0		
600	26.2	76.1	79.9	7.70	23.3	0.130	
700	25.2	71.3	74.9	7.80	22.7		
800	24.1	66.0	69.3	7.88	22.0	0.145	

Notes:

1. Listed values for yield stress calculated from rate of reduction provided in Figure 2.3.1.1.1, Figure 2.3.1.1.4 for modulus of elasticity, and Figure 2.3.1.0 for thermal properties from Reference [8-17].
2. Listed values based on Reference [8-17].
3. Yield stress values calculated based on 80 ksi at 500 °F.
4. Ultimate strength based on 1.05 Sy.

Table 8-10a
Material Properties, SA-500 Gr. B

Temperature (°F)	E (10^3 ksi)	S_y (ksi)
70	29.0	46.0
100	29.0	44.6
150	28.7	43.5
200	28.4	42.3
250	28.1	41.4
300	27.8	40.5
350	27.6	39.8
400	27.3	39.1
450	27.0	38.7
500	26.7	38.2

Table 8-11
Material Properties, SA-516 Gr 70 and ASTM A516 Gr 70

Temp (°F)	S_m (ksi)	S_y (ksi)	S_u (ksi)	E (10^3 ksi)	α_{INST} (10^{-6} °F $^{-1}$)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100	--	--	--	30.3	--	--	--	--	--
-20 - 100	23.3	38.0	70.0	--	--	--	0.280		
70	--	--	--	29.4	6.4	6.4		34.9	0.103
100	--	--	--	--	6.6	6.5		34.7	0.106
150	23.3	35.7	--	--	6.8	6.6		34.2	0.110
200	23.2	34.8	70.0	28.8	7.0	6.7		33.7	0.114
250	--	34.2	--	--	7.2	6.8		33.0	0.117
300	22.4	33.6	70.0	28.3	7.3	6.9		32.3	0.119
350	--	--	--	--	7.5	7.0		31.6	0.122
400	21.6	32.5	70.0	27.9	7.7	7.1		30.9	0.124
450	--	--	--	--	7.8	7.2		30.1	0.126
500	20.6	31.0	70.0	27.3	8.0	7.3		29.4	0.128
550	--	--	--	--	8.2	7.3		28.7	0.131
600	19.4	29.1	70.0	26.5	8.3	7.4		28.0	0.134
650	18.8	28.2	70.0	--	8.5	7.5		27.3	0.136
700	18.1	27.2	70.0	25.5	8.7	7.6		26.6	0.140
750	--	26.3	69.1	--	8.8	7.7		26.0	0.143
800	--	25.5	64.3	24.2	9.0	7.8		25.3	0.147
ASME	Table 2A	Table Y-1	Table U	Table TM-1 C≤0.30%	Table TE-1 Group 1		Table PRD	Calculated from Table TCD Group A	

Source: ASME Section II, Part D [8-2]

Table 8-12
SA-182, Type F6NM

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in³)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20								
70	29.2	38.3	90.0	115.0	5.9		14.2	0.106
100					6.0		14.2	0.108
150					6.1		14.3	0.112
200	28.4	38.3	86.5	115.0	6.2		14.3	0.114
250					6.2		14.4	0.116
300	27.9	38.3	84.6	115.0	6.3		14.4	0.119
350					6.4		14.4	0.121
400	27.3	37.9	82.8	113.7	6.4	.280	14.5	0.124
450					6.4		14.5	0.126
500	26.8	36.5	80.8	109.5	6.5		14.5	0.130
550					6.5		14.6	0.134
600	26.2	35.0	78.5	105.1	6.5		14.6	0.137
650					6.6		14.6	0.140
700	25.5	33.4	75.7	100.3	6.6		14.6	0.144
750					6.6		14.6	0.147
800					6.7		14.6	0.151
ASME	Table TM-1, Group F	Table 2A	Table Y-1	Table U,	Table TE-1, 13 Cr	Table PRD	Calculated based on Table TCD Group G	

Source: ASME Section II, Part D [8-2]

Table 8-13
Material Properties, SA-193 Gr B7 Bolting ≤ 2 ½ inch

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20	30.5	35.0	105.0	125.0				
70	29.6	35.0	105.0	125.0	6.4		23.7	0.107
100		35.0	105.0	125.0	6.5		23.6	0.108
150				125.0	6.6		23.5	0.111
200	29.0	32.6	98.0	125.0	6.7		23.5	0.115
250				125.0	6.8		23.4	0.117
300	28.5	31.4	94.1	125.0	6.9		23.4	0.121
350				125.0	7.0		23.3	0.123
400	28.0	30.5	91.5	125.0	7.1	0.280	23.1	0.126
450				125.0	7.2		23.0	0.129
500	27.4	29.5	88.5	125.0	7.3		22.7	0.131
550				125.0	7.3		22.5	0.134
600	26.9	28.4	85.3	125.0	7.4		22.2	0.137
650		27.7	83.0	124.4	7.5		21.9	0.139
700	26.2	26.9	80.6	119.6	7.6		21.6	0.142
750		25.9	77.6	114.3	7.7		21.3	0.145
800	25.6	24.6	73.9	108.4	7.8		21.0	0.149
ASME	Table TM-1 Group C	Table 4	Table Y-1	Table U	Table TE-1 Group 1	Table PRD	Calculated based on Table TCD Group C	

Source: ASME Section II, Part D [8-2]

Table 8-14
Material Properties, SA-540 Grade B23 Class 3 Bolting

Temp (°F)	E (10^3 ksi)	S_m (ksi)	S_y (ksi)	S_u (ksi)	α_{AVG} (10^{-6} °F^{-1})	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-20	--	43.3	130	145	--	0.280	--	--
70	27.8	43.3	130	145	6.4		21.0	0.106
100	--	43.3	130	145	6.5		21.0	0.108
150	--	--	--	--	6.6		21.2	0.112
200	27.1	41.4	124.8	145	6.7		21.3	0.115
250	--	--	--	--	6.8		21.4	0.117
300	26.7	40.2	121.6	145	6.9		21.5	0.120
350	--	--	--	--	7.0		21.5	0.122
400	26.2	38.8	119.5	145	7.1		21.5	0.124
450	--	--	--	--	7.2		21.5	0.127
500	25.7	37.6	117.8	145	7.3		21.4	0.129
550	--	--	--	--	7.3		21.3	0.132
600	25.1	35.9	115.6	145	7.4		21.1	0.135
650	--	--	113.9	--	7.5		20.9	0.138
700	24.6	33.7	111.8	139.3	7.6		20.7	0.141
750	--	--	109.2	--	7.7		20.5	0.144
800	--	--	106	*125.8*	7.8		20.2	0.147
ASME	Table TM-1 Group B	Table 4 p. 370 Line 4	Table Y-1 p. 582-583 Line 8	Table U p. 482 Line 38	Table TE-1 Group 1	Table PRD	Calculated from Table TCD Group D	

Source: ASME Section II, Part D [8-2]

Table 8-14a
Material Properties, SA-572 Gr. 65

Temp [°F]	S_y [ksi]	E [x1000 ksi]	S_u [ksi]
70	65.0	29.0	80.0
100	63.1	29.0	80.0
150	61.5	28.7	79.2
200	59.8	28.4	78.4
250	58.5	28.1	79.2
300	57.2	27.8	80.0
350	56.3	27.6	80.0
400	55.3	27.3	80.0
450	54.7	27.0	80.0
500	54.0	26.7	80.0

Table 8-14b
Material Properties, SA-302 Grade C
Nominal Composition: Mn-½Mo-½Ni

Temp [°F]	S_m [ksi]	S_y [ksi]	S_u [ksi]
-20	26.7	50.0	80.0
70	26.7	50.0	80.0
100	26.7	50.0	80.0
150	26.7	48.1	80.0
200	26.7	47.0	80.0
250	26.7	46.2	80.0
300	26.7	45.5	80.0
350	26.7	--	80.0
400	26.7	44.2	80.0
450	26.7	--	80.0
500	26.7	43.2	80.0
550	26.7	--	80.0
600	26.7	42.1	80.0
650	26.7	41.5	80.0
700	26.7	40.7	80.0
750	--	39.8	80.0
800	--	38.6	80.0
850	--	37.0	77.3
900	--	34.9	73.1
950	--	32.1	68.0
1000	--	28.4	61.7
ASME	Table 2A p. 290, Line 34	Table Y-1 p. 586-587 Line 29	Table U, p. 481, Line 35

72.48

Source: ASME Section II, Part D - Properties, 2011a Edition unless otherwise noted

Table 8-14c
Material Properties, A 564 Type 630 H1100
Nominal Composition: 17Cr-4Ni-4Cu

Temp [°F]	**S_m [ksi]**	**S [ksi]**	**S_y [ksi]**	**S_u [ksi]**	**E (10^3 ksi)**	**α_{INST} (10^{-6} °F^{-1})**	**α_{AVG} (10^{-6} °F^{-1})**	**ρ (lb/ft^3)**	**K (Btu/hr-ft-°F)**	**C_d (Btu/lb-°F)**
-20	46.7	40.0								
70	46.7	40.0	115	140	28.5	5.3	5.3		10	0.188
100	46.7	40.0	115	140	--	5.4	5.4		10.1	0.189
150	--		109.2	--	--	5.6	5.5		10.3	0.189
200	46.7	40.0	106.3	140	27.8	5.7	5.5		10.6	0.189
250	--		103.9	--	--	5.8	5.6		10.9	0.19
300	46.7	40.0	101.8	140	27.2	6	5.7	484	11.2	0.19
350	--		--	--	--	6.1	5.7		11.5	0.19
400	45.4	38.9	98.3	136.1	26.7	6.2	5.8		11.7	0.19
450	--		--	--	--	6.3	5.8		12	0.19
500	44.5	38.1	95.2	133.4	26.1	6.4	5.9		12.3	0.19
550	--		--	--	--	6.4	5.9		12.5	0.19
600	43.8	37.5	92.7	131.4	25.5	6.5	6.0		12.8	0.189
650	43.4	37.2	91.5	130.1	--	6.6	6.0		13	0.188
ASME	Table 2A p. 290 *Line* 14	Table 1A p. 48 Line 25	Table Y-1 p. 582-583 Line 8	Table U p. 479 Line 19	Table TM-1 S17400	Table TE-1 p. 710 Group F 17 Cr Steels		Table PRD	Table TCD p. 727, Group I	

72.48

Source: ASME Section II, Part D - Properties, 2011a Edition

Table 8-15
Material Properties, ASTM A913 Grade 70 High Strength Low-Alloy Steel(1)

Temp (°F)	E(2) (10^3 ksi)	S_y(3) (ksi)	S_u(4) (ksi)	α_{AVG}(5) (10^{-6} F^{-1})	ρ (lb/in^3)(6)	K(7) (BTU/hr-ft-°F)	C_p (BTU/lb-°F)
-20					0.280		
70	29.0	70.0 (1)	90.0(1)			27.3	0.106
100	29.0	67.9	90.0	6.3		27.6	0.110
150						27.8	0.114
200	28.4	64.4	88.2	6.5		27.8	0.118
250						27.6	0.121
300	27.8	61.6	90.0	6.7		27.3	0.124
350						26.9	0.126
400	27.3	59.5	90.0	6.9		26.5	0.129
450						26.1	0.131
500	26.7	58.1	90.0	7.1		25.7	0.133
550						25.3	0.135
600	26.1	57.4	86.4	7.2		24.9	0.138
650						24.5	0.141
700	25.5	56.0	81.0	7.4		24.1	0.144

Notes

1. Reference [8-14].
2. Based on lowest rate of reduction provided in [8-12] Figure 7.5.
3. Based on lowest rate of reduction provided in 8-12] Figure 7.3.
4. Based on lowest rate of reduction provided in [8-12] Figure 7.4.
5. Based on lowest rate of reduction provided in [8-12] Figure 7.6.
6. ASME Section II Part D, Table PRD.
7. ASME Section II Part D, Table TCD, Material Group B.

Table 8-16
Material Properties, Aluminum ASTM B221 or B209 Alloy 6061-O

Temp (°F)	E (10^3 ksi)	Elongation in 4D, %	S_u (ksi)	S_y (ksi)	α_{AVG} (10^{-6} °F^{-1})	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100								
-20						0.098		
70					12.1		96.1	0.213
75	9.9	30	18.0	8.0				
100					12.4		96.9	0.215
150					12.7		98.0	0.218
200					13.0		99.0	0.221
212	9.5	30	18.0	8.5				
250					13.1		99.8	0.223
300	9.1	35	15.0	9.5	13.3		100.6	0.226
350	8.9	45	12.0	8.5	13.4		101.3	0.228
400	8.6	60	10.0	7.5	13.6		101.9	0.230
450	8.3	75	8.5	6.0	13.8			
500	7.9	80	7.0	5.5	13.9			
550					14.1			
600	6.8	80	5.0	4.2	14.2			
ASME	Kaufman, p. 163(1)	Kaufman, p. 163(1)	Kaufman, p. 163(1)	Kaufman, p. 163(1)	Table TE-2 p. 714 Aluminum Alloys	Table PRD p. 744	Calculated based on Table TCD p. 735, group A96061	

Source: ASME Section II, Part D, except as noted

Notes:

1. Annealed values used for analysis are typical tensile properties from [8-16] p. 163.
2. Mechanical properties are used for design of the basket peripheral transition rails. The thermal design analysis uses values for density, thermal conductivity, and heat capacity that are lower than those in this table.
3. Thermal conductivity and heat capacity used in the design analyses are lower than those shown in the table.

Table 8-17
Material Properties, Aluminum ASTM B209 Alloy 6061-T6 and 6061-T651

Temp (°F)	E (10^3 ksi)	S (ksi)	S_u (ksi)	S_y (ksi)	α_{AVG} (10^{-6} °F^{-1})	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100	10.5							
-20		12.0	47	35.0				
70	10.0	12.0	45	35.0	12.1		96.1	0.213
100		12.0	44	35.0	12.4		96.9	0.215
150		12.0		34.6	12.7		98.0	0.218
200	9.6	12.0	42	33.7	13.0		99.0	0.221
250		9.9		32.4	13.1		99.8	0.223
300	9.2	8.4	34	27.4	13.3	0.098	100.6	0.226
350		6.3		20.0	13.4		101.3	0.228
400	8.7	4.5	19	13.3	13.6		101.9	0.230
450					13.8			
500	8.1		7.5		13.9			
550					14.1			
600			4.6		14.2			
ASME	Table TM-2	Table 1B	Ref. [8-13], p. 117	Table Y-1	Table TE-2	Table PRD	Calculated based on Table TCD group A96061	

Source: ASME Section II, Part D [8-2], except as noted.

Table 8-18
Material Properties, Aluminum ASTM B209 Alloy 6061-T6 Weld

Temp (°F)	E (10^3 ksi)	S (1) (ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in^3)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100	10.5					
-20		6.0				
70	10.0	6.0	12.1		96.1	0.213
100		6.0	12.4		96.9	0.215
150		6.0	12.7		98.0	0.218
200	9.6	6.0	13.0		99.0	0.221
250		5.9	13.1		99.8	0.223
300	9.2	5.5	13.3	0.098	100.6	0.226
350		4.6	13.4		101.3	0.228
400	8.7	3.5	13.6		101.9	0.230
450			13.8			
500	8.1		13.9			
550			14.1			
600			14.2			
ASME	Table TM-2	Table 1B	Table TE-2	Table PRD	Calculated based on Table TCD group A96061	

Source: ASME Section II, Part D [8-2]

Notes:

1. These properties are used for evaluation of the TC108 removable neutron shield fillet weld stresses.

Table 8-19
Material Properties, Aluminum ASTM B209 Alloy 1100

Temp (°F)	S_u (ksi)	S_y (ksi)	E (10^3 ksi)	α_{AVG} (10^{-6} °F $^{-1}$)	ρ (lb/in³)	K (Btu/hr-ft-°F)	C_p (Btu/lb-°F)
-100			10.5		0.098		
70	13.0	5.0	10.0	12.1		133.1	0.214
100				12.4		131.8	0.216
150				12.7		130.0	0.219
200			9.6	13.0		128.5	0.222
212	11.0	4.6					
250				13.1		127.3	0.225
300	8.5	4.2	9.2	13.3		126.2	0.227
350	7.5	3.8		13.4		125.3	0.229
400	6.0	3.5	8.7	13.6		124.5	0.232
450	5.0	3.1		13.8			
500	4.0	2.6	8.1	13.9			
550				14.1			
600	2.9	2.0		14.2			
	[8-16] p.9(1)	[8-16] p.9(1)	Table TM-2(2)	Table TE-2(2) Al Alloys	Table PRD(2)	Calculated based on Table TCD(2) group A91100	

Notes:

1. Typical tensile properties. Values taken for h=10,000, unless otherwise specified. Tensile properties are for information only; they are not credited in the structural analysis. Therefore, ASTM B209 alloy 1060 or alloy 1050 (EN AW-1050A) per EN485-2 [8-49] and EN573-3 [8-50], which have lower tensile properties, may be used in place of alloy 1100.
2. ASME Section II, Part D [8-2].

Table 8-20(a)
Static Mechanical Properties, ASTM B29 Lead

Temp. (°F)	Static Stress Properties (ksi)			E (10^6 psi)	Coefficient of Thermal Exp (10^{-6} in/in/°F)
	Yield (S_y)		Ultimate (S_u)		
	Tension	Compression	Tension		
-99	-	-	-	2.50	15.28
70	-	-	-	2.34	16.07
100	0.584	0.490	1.570	2.30	16.21
175	0.509	0.428	1.162	2.20	16.58
250	0.498	0.391	0.844	2.09	16.95
325	0.311	0.320	0.642	1.96	17.54
440	-	-	-	1.74	18.50
620	-	-	-	1.36	20.39

Notes

1. Sources: [8-18] and [8-19].

Table 8-20(b)
Dynamic Mechanical Properties, ASTM B29 Lead

Strain (in/in)	Stress (ksi)				
	At 100 °F	At 230 °F	At 300 °F	At 350 °F	At 500 °F
0.000485	1.14	1.06	1.00	0.97	0.86
0.03	2.2	2.0	1.7	1.5	1.1
0.1	3.3	2.8	2.38	2.1	1.26
0.3	4.9	3.2	2.72	2.4	1.44
0.5	5.6	3.6	3.06	2.7	1.62

Notes

1. Source: [8-20].

Table 8-21
Lead Properties

Temp. (°F)	Density (lb/in^3)	Coefficient of Thermal Exp (10^{-6}in/in/°F)	Thermal Conductivity W/mK
-99	0.41	15.28	
70		16.07	
80			35.3
100		16.21	
175		16.58	
250		16.95	
260			34.0
325		17.54	
440			32.8
500		19.14	

Notes:

Sources: [8-19] and [8-35].

Table 8-22
Not Used

Table 8-23
Material Properties, Concrete

Temp (°F)	f_c' (ksi)(1)	Modulus of Elasticity (10^3 ksi) (1)	a_{AVG} (10^{-6} F^{-1}) (1)	Density (lb/ft^3) (2)	Specific Heat (3) (Btu/lb-°F)	Thermal Conductivity(3) (Btu/hr-in-°F)
70						0.0958
100	5.0	4.0	5.5	150	0.22	
200	5.0	3.6	5.5		0.22	
300	5.0	3.3	5.5		0.22	
400	4.5	3.0	5.5		0.22	
500	4.5	2.9	5.5		0.22	
1382						0.048

Notes

1. Reference [8-12].
2. Reference [8-8]. The shielding analysis uses a density of 140 pcf.
3. Reference [8-23].

Table 8-24
Material Properties, ASTM A615 Grade 60 and ASTM A706 Grade 60 Reinforcing Steel

Temp (°F)	Yield Strength (ksi) (1)	Modulus of Elasticity (10^3 ksi) (1)	Density (lb/ft^3) (2)
100	60.0	29.0	490
200	57.0	28.4	
300	54.0	27.8	
400	51.0	27.3	
500	51.0	27.0	

Notes

1. Reference [8-12].
2. Reference [8-11].

Table 8-25
Materials Properties, Zircaloy-2

Temperature °F	Young's Modulus[1] E, (psi)	Yield Stress[1] S_y (psi)
200[2]	1.48E+07	119,601
300	1.43E+07	110,516
400	1.38E+07	101,431
500	1.33E+07	93,451
600	1.28E+07	85,810
700	1.23E+07	77,906
750	1.21E+07	73,712

Notes:

1. Values in this Table are derived from the equations provided in Section 2 of Reference [8-21] with the following values
   - Strain rate of 0.5 s^{-1}
   - Cold work (CW) ratio of 0.0
   - Oxygen content (Δ) ratio of 0.0012
   - Fast neutron fluence (Φ) of 1.2 x 10^{26} n/m^2
   - Uncertainty of 67 MPa (9.7 ksi) is not included in the Yield Stress value
2. E and S_y values at this temperature are obtained by linear extrapolation of these values at 300 and 400 ºF.

Table 8-26
Materials Properties, Zircaloy-4

Temperature (°F)	PWR, Zircaloy-4[1]	
	E (psi)	Yield Stress (psi)
300	1.22E+07	126102
350	1.19E+07	120769
400	1.17E+07	116272
450	1.14E+07	112390
500	1.12E+07	108921
550	1.09E+07	105683
600	1.07E+07	102512
625	1.06E+07	100904
650	1.04E+07	99259
675	1.03E+07	97560
700	1.02E+07	95793
725	1.01E+07	93944
750	9.93E+06	92000

Notes:

1. Values in this Table are derived from the equations provided in Section 2 of Reference [8-21] with the following values

   - Strain rate of 0.5 s^{-1}
   - Cold work (CW) ratio of 0.0
   - Oxygen content (Δ) ratio of 0.0012
   - Fast neutron fluence (Φ) of 1.2 x 10^{26} n/m^2
   - Uncertainty of 67 MPa (9.7 ksi) is not included in the Yield Stress value

Table 8-27
Material Properties, Helium

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

The above data are calculated based on the following polynomial function from [8-22].

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

For 300 < T < 500 K	
C0	-7.761491E-03
C1	8.66192033E-04
C2	-1.5559338E-06
C3	1.40150565E-09
C4	0.0E+00

for 500< T < 1050 K	
C0	-9.0656E-02
C1	9.37593087E-04
C2	-9.13347535E-07
C3	5.55037072E-10
C4	-1.26457196E-13

No heat capacity or density is considered for helium.

Table 8-28
Material Properties, Air

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

The above data are calculated based on the following polynomial function from [8-22].

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

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

$c_P = \sum A_i \, T^i$ for specific heat in (kJ/kg-K) and T in (K)

For 250 < T < 1050 K	
A0	0.103409E+1
A1	-0.2848870E-3
A2	0.7816818E-6
A3	-0.4970786E-9
A4	0.1077024E-12

$\mu = \sum B_i \, T^i$ for viscosity (N-/m2)×106 and T in (K)

For 250 < T < 600 K	
B0	-9.8601E-1
B1	9.080125E-2
B2	-1.17635575E-4
B3	1.2349703E-7
B4	-5.7971299E-11

For 600 < T < 1050 K	
B0	4.8856745
B1	5.43232E-2
B2	-2.4261775E-5
B3	7.9306E-9
B4	-1.10398E-12

$\rho = \dfrac{P}{RT}$ for density (kg/m^3)

P=101.3 kPa; R = 0.287040 kJ/kg-K; T = air temp in (K)

Table 8-29
Material Properties, Solid Neutron Shielding

Borated HDPE Mechanical Properties Reference [8-9]	
Density	.036 lb/in^3
Tensile Strength	2,407 psi
Modulus of Elasticity	111,200 psi
Flexural Strength	4,220 psi
Flexural modulus of Elasticity	126,000 psi
Flexural Yield Strength	4220 psi
Compressive Strength	957 psi

Notes:

1. All values are nominal.
2. Properties taken at 73 °F.

Borated HDPE Thermal Properties Reference [8-9]	
Coefficient of thermal expansion (-40 °F to 30 °F)	1.1 x 10^{-5}in./in./ °F
Melting Point	260 °F
Continuous service temperature in Air (max.)	180 °F

Table 8-30
MCNP Material Compositions (wt. %)

Element	Carbon Steel	Stainless Steel	Dry Air	Water	Regular Concrete	Soil
Hydrogen	-	-	-	11.1894	1.0	-
Helium	-	-	-	-	-	-
Boron	-	-	-	-	-	-
Carbon	0.5	0.04	0.0124	-	-	-
Nitrogen	-	-	75.5268	-	-	-
Oxygen	-	-	23.1781	88.8106	53.2	51.37
Sodium	-	-	-	-	2.9	0.614
Magnesium	-	-	-	-	-	1.33
Aluminum	-	-	-	-	3.4	6.856
Silicon	-	0.5	-	-	33.7	27.118
Phosphorous	-	0.023	-	-	-	-
Sulfur	-	0.015	-	-	-	-
Argon	-	-	1.2827	-	-	-
Potassium	-	-	-	-	-	1.433
Calcium	-	-	-	-	4.4	5.117
Titanium	-	-	-	-	-	0.461
Chromium	-	19	-	-	-	-
Manganese	-	1	-	-	-	0.0716
Iron	99.5	70.173	-	-	1.4	5.629
Cobalt	-	-	-	-	-	-
Nickel	-	9.25	-	-	-	-
Copper	-	-	-	-	-	-
Zirconium	-	-	-	-	-	-
Niobium	-	-	-	-	-	-
Molybdenum	-	-	-	-	-	-
Tin	-	-	-	-	-	-
Lead	-	-	-	-	-	-
Density (g/cm^3)	7.82	8.00	0.001205	(1)	2.243	1.52

Note:

1. 0.958 g/cm3 inside the DSC and 0.9982 g/cm3 inside the neutron shield.

Table 8-31
MCNP Borated Polyethylene Composition

Element	Atom Density (atom/b-cm)
Hydrogen	6.1848E-02
Boron-10	5.5978E-04
Boron-11	2.2532E-03
Carbon	3.6381E-02
Oxygen	4.2195E-03
Total	1.0526E-01

Table 8-32
Minimum B-10 Content in the Neutron Poison Plates

EOS-37PTH

Basket Type	Minimum Specified B-10 Areal Density for MMC (mg/cm^2)	B-10 Content Used in Criticality Evaluation (mg/cm^2)
A1 / A2 / A3/ *A4H /A4L / A5*	28.0	25.2
B1 / B2 / B3 *B4H /B4L / B5*	35.0	31.5

EOS-89BTH

Basket Type	Minimum B-10 Areal Density (mg/cm^2)		B-10 Content Used in Criticality Evaluation (mg/cm^2)
	MMC	BORAL®	
A1 / A2 / A3	32.7	*39.2*	29.4
B1 / B2 / B3	41.3	*49.6*	37.2
C1 / C2 / C3	-	60.0	45.0

Table 8-33
Material Property Data for Criticality Analysis
(Part 1 of 2)

Material	ID	Density g/cm^3	Element	Wt. %	Atom Density (atoms/b-cm)
UO_2 (Enrichment – 1.0 to 5.0 wt. %) [(1)]	1	10.686	U-235	4.41	1.20668E-03
			U-238	83.74	2.26374E-02
			O	11.85	4.76881E-02
Zircaloy-4	2	6.56	Zr	98.23	4.2541E-02
			Sn	1.45	4.8254E-04
			Fe	0.21	1.4856E-04
			Cr	0.10	7.5978E-05
			Hf	0.01	2.2133E-06
Water (Pellet Clad Gap)	3	0.998	H	11.1	6.6769E-02
			O	88.9	3.3385E-02
Stainless Steel (SS304)	4	7.94	C	0.080	3.1877E-04
			Si	1.000	1.7025E-03
			P	0.045	6.9468E-05
			Cr	19.000	1.7473E-02
			Mn	2.000	1.7407E-03
			Fe	68.375	5.8545E-02
			Ni	9.500	7.7402E-03
Borated Water (2000 – 2500 ppm Boron)[(2)]	5	1.00	H	11.163	6.67515E-02
			O	88.587	3.33757E-02
			B-10	0.046	2.77126E-05
			B-11	0.204	1.11547E-04
$^{11}B_4C$ in CC	7	2.52	B-11	78.57	1.08305E-01
			C	21.43	2.70763E-02
Aluminum	8	2.702	Al	100.0	6.0307E-02
Water	10	0.998	H	11.1	6.6769E-02
			O	88.9	3.3385E-02
Lead	11	11.344	Pb	100.0	3.2969E-02

Table 8-33
Material Property Data for Criticality Analysis
(Part 2 of 2)

Material	ID	Density g/cm^3	Compound	Wt. %	Element	Atom Density (atoms/b-cm)
EOS-37PTH						
MMC Poison Plate for Basket Type A1 / A2 / A3 (25.2 mg B-10/cm^2)	9	2.693	B_4C	15.57	B-10	3.63761E-03
					B-11	1.46418E-02
					C	4.56986E-03
			Al	84.43	Al	5.07473E-02
MMC Poison Plate for Basket Type B1 / B2 / B3 (31.5 mg B-10/cm^2)	9	2.693	B_4C	19.463	B-10	4.54713E-03
					B-11	1.83028E-02
					C	5.71247E-03
			Al	80.537	Al	4.84074E-02
EOS-89BTH						
MMC Poison Plate for Basket Type A1 / A2 / A3 (29.4 mg B-10/cm^2)	9	2.669	B_4C	17.18	B-10	3.97731E-03
					B-11	1.60092E-02
					C	4.99662E-03
			Al	82.82	Al	4.93353E-02
MMC Poison Plate for Basket Type B1 / B2 / B3 (37.2 mg B-10/cm^2)	9	2.660	B_4C	21.81	B-10	5.03252E-03
					B-11	2.02565E-02
					C	6.32227E-03
			Al	78.19	Al	4.64244E-02
BORAL Poison Plate for Basket Type C1 / C2 / C3 (45.0 mg B-10/cm^2)	9	2.450	B_4C	28.64	B-10	6.08772E-03
					B-11	2.45038E-02
					C	7.64789E-03
			Al	71.36	Al	3.90204E-02

Note:

1. The composition for maximum enrichment evaluate at 5.0 wt. % U-235 is provided.
2. Applies to EOS-37PTH only. EOS-89BTH evaluated with 100% internal moderator density. The composition for the maximum soluble boron concentration at 100 % internal moderator density is provided.

Table 8-34
Not Used

Table 8-35
Emissivity of the Coating on Basket Steel Plates

Table 8-36
Summary of Relevant Corrosion Rates

Condition	Soluble Boron Concentration (ppm)	Temperature °F (°C)	Corrosion Rate in/yr (mm/yr)
Aerated Water	2,500	70 (21)	0.002 (0.05)
	2,000	100 (38)	0.002 – 0.0045 (0.05 – 0.11)
	2,500	100 (38)	0.007 (0.18)
	2,000	104 (40)	0.007 (0.18)
	2,500	140 (60)	0.015 (0.38)

Note: Data are taken from Figure 4-3 and Table 4-3 of EPRI-1000975 [8-42].

CHAPTER 9
OPERATING PROCEDURES

Table of Contents

List of Figures

9. OPERATING PROCEDURES

This chapter presents the operating procedures for the NUHOMS® EOS System described in previous chapters and shown on the drawings in Chapter 1, Section 1.3. The procedures include preparation of the NUHOMS® EOS System dry shielded canister (DSC) and fuel loading, closure of the DSC, transfer to the independent spent fuel storage installation (ISFSI) using the transfer cask (TC), DSC transfer into the horizontal storage module (HSM), monitoring operations, and DSC retrieval from the HSM. The NUHOMS® EOS transfer equipment, and the existing plant systems and equipment are used to accomplish these operations. Procedures are delineated here to describe how these operations are to be performed and are not intended to be limiting. Standard fuel and cask handling operations performed under the plant's 10 CFR Part 50 operating license are described in less detail. Existing operational procedures may be revised by the licensee and new ones may be developed according to the requirements of the plant, provided that the conditions specified in the *Technical Specifications [9-5]* and the NUHOMS® EOS *Certificate of Compliance (*CoC*)* are met. Temporary shielding may be used throughout as appropriate to maintain doses as low as reasonably achievable (ALARA). Helium is the only gas that is authorized inside the canister. After water is drained from the DSC, (Sections 9.1.2 and 9.1.3), the DSC shall be backfilled only with helium.

The following sections outline the typical operating procedures for the NUHOMS® EOS System. These generic NUHOMS® EOS procedures have been developed to minimize the amount of time required to complete the subject operations, to minimize personnel exposure, and to assure that all operations required for DSC loading, closure, transfer, and storage are performed safely. Plant specific ISFSI procedures are to be developed by each licensee in accordance with the requirements of 10 CFR 72.212 (b) and the guidance of Regulatory Guide 3.61 [9-4]. The generic procedures presented here are provided as a guide for the preparation of plant specific procedures and serve to point out how the NUHOMS® EOS System operations are to be accomplished. They are not intended to be limiting, in that the licensee may evaluate that alternate acceptable means are available to accomplish the same operational objective.

Pictograms of the NUHOMS® EOS System operations are presented in Figure 9-1. The location of the various operations may vary with individual plant requirements. The steps described in this document are the recommended generic operating procedures for the NUHOMS® EOS System.

See Chapter 1 for description of components.

The generic terms used throughout this section are as follows.

- TC, or transfer cask is used for the TC108 or TC125 or TC135 transfer cask.
- DSC is used for the EOS-37PTH DSC or EOS-89BTH DSC.
- *EOS*-HSM is used for the EOS-HSM or EOS-HSMS module.

Note: If applicable to the planned DSC heat zone loading configuration per Figure 1 or 2 of the Technical Specifications [9-5], the FC system should be installed and verified operational prior to initiating the transfer operations.

9.1 Procedures for Loading the DSC and Transfer to the *EOS*-HSM

The following steps describe the recommended generic operating procedures for the NUHOMS® EOS System. Since the design of the EOS-TC includes two primary variations – the TC108 (with a removable neutron shield jacket) and the TC125/TC135 (with an integral neutron shield), some steps have alternate steps specific to one of these EOS-TC designs. A pictorial representation of key phases of this process is provided in Figure 9-1.

9.1.1 TC and DSC Preparation

1. Prior to placement of the Authorized Contents in dry storage:

   a. The candidate fuel assemblies (FAs) *or failed fuel debris* and control components (CCs), if applicable, shall be evaluated (by plant records or other means) to verify that they meet the physical, thermal and radiological criteria specified in Section 2.1 (EOS-37PTH DSC) or Section 2.2 (EOS-89BTH DSC) of the Technical Specifications [9-5].

   b. Depending on the length of the fuel assemblies to be loaded, fuel spacers may be placed within the DSC to reduce the fuel assembly/DSC cavity gap in consideration of Part 71 requirements. There are no requirements for fuel spacers under Part 72. Fuel spacers, if used to satisfy minimum gap requirements for Part 71, may be placed below the assembly, above the assembly, or both, and shall be evaluated for any adverse impact.

2. Prior to being placed in service: clean and/or decontaminate the TC as necessary to provide a surface contamination level of less than those specified in Section 3.3.1 of the Technical Specifications [9-5].

   Note: Although at this point, operations are not in Technical Specifications (TS) LOADING OPERATIONS, TS levels are referenced here to ensure that the actual TS decontamination levels are met later in the operation.

3. Place the TC in the vertical position in the designated area using the TC handling crane and the lifting yoke.

   a. TC125 or TC135: The neutron shield may need to be drained to meet the crane capacity when the loaded TC is pulled out of the pool.

   b. TC108: The neutron shield tank may be drained or removed from the TC108 and staged in an appropriate location.

4. Place scaffolding around the TC so that the top cover plate and surface of the TC are easily accessible to personnel.

   a. TC108 without neutron shield tank: Install protective cover around outer shell of the TC108 to minimize contamination of the outer shell of the TC.

5. Remove the TC top cover plate and examine the TC cavity for any physical damage and ready the TC for service.

   Note: Verify that a TC spacer of appropriate height is placed inside the TC to provide the correct airflow and interface at the top of the TC during loading, drying, and sealing operations for DSCs that are shorter than the TC cavity length.

6. Verify specified lubrication of the TC rails.

7. Examine the DSC for any physical damage that might have occurred since the receipt inspection was performed. The DSC is to be cleaned and any loose debris removed.

8. Record the DSC serial number that is located on the grapple ring. Verify the DSC type and basket type against the DSC serial number. Verify that the DSC is appropriate for the specific fuel loading campaign per the criteria specified in Section 2.1 (EOS-37PTH DSC) or Section 2.2 (EOS-89BTH DSC) of the Technical Specifications [9-5].

9. Using a crane, lower the DSC into the TC cavity by the internal lifting lugs and rotate the DSC to match the TC and DSC alignment marks.

   a. *If damaged FAs or loaded failed fuel canisters (FFCs) are included in a specific loading campaign, verify that the appropriate basket type is used and place the required number of bottom end caps provided for damaged fuel or FFCs into the cell locations per Technical Specification 2.1. Optionally, this step may be performed at any prior time.*

   b. *Verify that the fuel spacers, if required, are present in the fuel cells. Optionally, this step may be performed at any prior time.*

10. Fill the TC/DSC annulus with clean water. Place the inflatable seal into the upper TC liner recess and seal the TC\DSC annulus by pressurizing the seal with compressed air.

    Note: A TC/DSC annulus pressurization tank filled with clean water is connected to the top vent port of the TC via a hose to provide a positive head above the level of water in the TC/DSC annulus. This is an optional arrangement, which provides additional assurance that contaminated water from the fuel pool will not enter the TC/DSC annulus, provided a positive head is maintained at all times.

11. Fill the DSC cavity with water from the fuel pool or an equivalent source that meets the requirements of Section 3.2.1 of the Technical Specifications [9-5] for boron concentration, if applicable.

12. Place the top shield plug onto the DSC. Examine the top shield plug to ensure a proper fit. Optionally, the top shield plug, once fitted, may be removed and disconnected from the yoke. It may be installed later, once the DSC is loaded and prior to removing it from the pool.

13. Position the TC lifting yoke and engage the TC lifting trunnions and the rigging cables to the DSC top shield plug. Adjust the rigging cables, as necessary, to obtain even cable tension.

14. Visually inspect the yoke lifting arms to ensure that they are properly positioned and engaged on the TC lifting trunnions.

15. Move the scaffolding away from the TC as necessary.

16. Lift the TC just far enough to allow the weight of the TC to be distributed onto the yoke lifting arms. Reinspect the lifting arms to insure that they are properly positioned on the TC trunnions.

17. Optionally, secure a sheet of suitable material to the bottom of the TC to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the TC in the designated area.

18. Prior to the TC being lifted into the fuel pool, the water level in the pool should be adjusted, as necessary, to accommodate the TC/DSC volume. If the water placed in the DSC cavity was obtained from the fuel pool, a level adjustment may not be necessary.

9.1.2 DSC Fuel Loading

1. Lift the TC/DSC and position it over the TC loading area of the spent fuel pool in accordance with the plant's 10 CFR Part 50 TC handling procedures.

2. Lower the TC into the fuel pool until the bottom of the TC is at the height of the fuel pool surface. As the TC is lowered into the pool, spray the exterior surface of the TC with clean water.

3. Place the TC in the location of the fuel pool designated as the TC loading area.

4. Disengage the lifting yoke from the TC lifting trunnions and move the yoke and the top shield plug clear of the TC. Spray the lifting yoke and top shield plug with clean water if it is raised out of the fuel pool.

5. The potential for fuel misloading is essentially eliminated through the implementation of procedural and administrative controls. The controls instituted to ensure that intact FAs and CCs, if applicable, are placed into a known cell location within a DSC, will typically consist of the following:

   - A TC/DSC loading plan is developed to verify that the *damaged/failed fuel and/or* intact *FAs*, and CCs, if applicable, meet the burnup, enrichment and

cooling time parameters of Section 2.1 (EOS-37PTH DSC) or Section 2.2 (EOS-89BTH DSC) of the Technical Specifications [9-5].

- The loading plan is independently verified and approved before the fuel load.
- A fuel movement schedule is then written, verified, and approved based upon the loading plan. All fuel movements from any rack location are performed under strict compliance of the fuel movement schedule.
- *If loading damaged/failed fuel, verify that the required number of bottom end caps for damaged fuel or FFCs for failed fuel are installed in appropriate fuel compartment tube locations before fuel load.*

6. Prior to loading of a FA and CC, if applicable, into the DSC, the identity of the assembly and CC, if applicable, is to be verified by two individuals using an underwater video camera or other means. Verification of CC identification is optional if the CC has not been moved from the host FA since its last verification. Read and record the identification number from the FA and CCs, if applicable, and check this identification number against the DSC loading plan, which indicates which FAs and CCs, if applicable, are acceptable for dry storage.

7. Position the FA for insertion into the selected DSC storage cell and load the *FA*. Repeat Steps 6 and 7 for each FA loaded into the DSC. After the DSC has been fully loaded, check and record the identity and location of each *FA* and CCs, if applicable, in the DSC. *If loading damaged FAs, place top end caps over each damaged FA placed into the basket. If loading failed fuel, place top end caps over each FFC placed into the basket.*

8. After all the FAs and CCs, if applicable, have been placed into the DSC and their identities verified, position the lifting yoke and the top shield plug and lower the shield plug onto the DSC.

CAUTION: Verify that all the lifting height restrictions as a function of temperature specified in Section 5.2.1 of the Technical Specifications [9-5] can be met in the following steps that involve lifting of the TC.

9. Visually verify that the top shield plug is properly seated onto the DSC.

10. Position the lifting yoke with the TC trunnions and verify that it is properly engaged.

11. Raise the TC to the pool surface. Prior to raising the top of the TC above the water surface, stop vertical movement.

12. Inspect the top shield plug to verify that it is properly seated onto the DSC. If not, lower the TC and reposition the top shield plug. Repeat Steps 8 to 12 as necessary.

13. Continue to raise the TC from the pool and spray the exposed portion of the TC with clean water until the top region of the TC is accessible.

14. Disengage the rigging cables from the top shield plug and remove the eyebolts.

15. Drain any excess water from the top of the DSC shield plug back to the fuel pool.

16. Check the radiation levels at the center of the top shield plug and around the perimeter of the TC.

17. EOS-TC125 or TC135, or TC108 with filled neutron shield tank attached: If applicable, drain water from the DSC while filling the space inside the DSC with helium, as necessary to meet the plant lifting crane capacity limits. Helium must be used to fill the space above the water inside the DSC.

    a. EOS-TC108 without neutron shield tank: Water shall not be drained from the DSC below the top of the fuel, since the water is relied upon for shielding when the neutron shield tank is removed.

CAUTION: Do not remove water from the DSC cavity in a way that would leave the fuel uncovered if the water is drained from the neutron shield as well, or the neutron shield tank is removed.

18. Lift the TC from the fuel pool. As the TC is raised from the pool, continue to spray the TC with clean water.

19. Move the TC with loaded DSC to the designated area.

20. If applicable to keep the occupational exposure ALARA, replace the water removed from the DSC in Step 17 with spent fuel pool water or another source meeting the proper boron concentration, as specified in Section 3.2.1 of the Technical Specifications [9-5], if specified.

    a. EOS-TC108: Carefully remove the protective cover around the outer shell of the TC108 in a way that precludes cross-contamination of the outer shell of the TC. Temporary shielding may be installed, as necessary, to minimize personnel exposure.

21. Disengage the lifting yoke from the trunnions and position it clear of the TC.

    a. EOS-TC108: Using good ALARA practices, install the neutron shield tanks to the TC108.

22. Using good ALARA practices, if the neutron shield is drained, fill the neutron shield tanks of the TC with clean water.

9.1.3 DSC Drying and Backfilling

CAUTION: During performance of steps listed in Section 9.1.3, monitor the TC/DSC annulus water level and replenish if necessary. Boiling of TC/DSC annulus water is expected at high heat loads. Consider adding water from the top and ensure that a portion of the TC/DSC annulus is open to atmosphere to allow water vapor to escape. In addition, a feed and bleed system with continuous flow of fresh water can also be used to control the boiling of annulus water for high heat load systems.

1. Place scaffolding around the TC so that any point on the surface of the TC is easily accessible to personnel. Temporary shielding may be installed as necessary to minimize personnel exposure.

2. Decontaminate the exposed surfaces of the DSC shell perimeter and remove the inflatable TC/DSC annulus seal.

3. Connect the TC drain line to the TC, open the TC cavity drain port and allow water from the TC/DSC annulus to drain out until the water level is approximately twelve inches below the top edge of the DSC shell. Take swipes around the outer surface of the DSC shell and check for smearable contamination in accordance with Section 3.3.1 of the Technical Specification [9-5] limits.

CAUTION: Radiation dose rates are expected to be high at the drain and vent port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

4. Prior to the start of welding operations, drain a minimum of 60 gallons of water from the DSC back into the fuel pool or other suitable location using the vacuum drying system (VDS) or an optional liquid pump. Alternatively, all the water from the DSC may be drained if precautions are taken to keep the occupational exposure ALARA. Consistent with ISG-22 [9-6] guidance and Technical Specification 3.1.1, helium at 1-3 psig is used to backfill the DSC with an inert gas (helium) as water is being removed from the DSC. Helium must be used to fill the space above the water inside the DSC.

   Note: The tool for engaging the DSC internal drain tube may contain o-rings. The o-rings may be lubricated. If up to two o-rings come off the tool inside the DSC cavity, loading operations may continue. This is evaluated in Chapter 8, Section 8.2.12.

5. Install the automatic welding machine onto the inner top cover plate (ITCP) and place the inner top cover plate with the automatic welding machine onto the DSC. Verify proper fit-up of the inner top cover plate with the DSC shell.

6. Check radiation levels along surface of the inner top cover plate. Temporary shielding may be installed as necessary to minimize personnel exposure.

CAUTION: **Insert tubing of sufficient length and adequate temperature resistance through the vent port, to where it terminates just below the DSC shield plug. Connect the flexible tubing to a hydrogen monitor to allow continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner cover plate in compliance with Section 5.4 of the Technical Specifications [9-5]. Optionally, other methods may be used for continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner top cover plate.**

7. Attach the helium purge system to the drain port to allow purging of the atmosphere inside the DSC cavity to remove hydrogen gas.

8. Cover the TC/DSC annulus to prevent debris and weld splatter from entering the annulus.

   Note: Provision must be made to monitor the TC/DSC annulus water level and replenish if necessary.

9. Ready the automatic welding machine and tack weld the inner top cover plate to the DSC shell. Install the inner top cover plate weldment and remove the automatic welding machine.

CAUTION: **Continuously monitor the hydrogen concentration in the DSC cavity using the flexible tube arrangement or other alternate methods described in Step 6 during the inner top cover plate cutting and welding operations. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4% (60.0% of flammability limit of 4.0%) [9-1 and 9-2]. If this limit is exceeded, stop all welding operations and purge the DSC cavity with approximately 2-3 psig helium to reduce the hydrogen concentration safely below the 2.4% limit.**

10. Perform root and final dye penetrant weld examination of the inner top cover plate weld in accordance with Section 4.4.4 of the Technical Specifications [9-5].

11. Install temporary shielding to minimize personnel exposure throughout the subsequent draining and vacuum drying, and welding operations, as required.

12. Remove the hydrogen monitoring system and attach a helium supply through the vent port on the ITCP.

13. Attach the VDS or the optional liquid pump through the drain port and drain water from the DSC while filling the space inside the DSC with helium. Use of helium is required per Technical Specification 3.1.1.

14. Attach the VDS, if necessary, to vacuum dry the canister through the drain port and attach the VDS to a helium supply.

15. Close off the vent port to allow vacuum drying of the DSC.

16. Connect a hose from the discharge side of the VDS to the plant's radioactive waste system or spent fuel pool.

    Note: Proceed cautiously when evacuating the DSC to avoid freezing consequences.

17. Open the valve on the suction side of the pump, start the VDS and draw a vacuum on the DSC cavity. The cavity pressure should be reduced in steps of approximately 100 mm Hg, 50 mm Hg, 25 mm Hg, 15 mm Hg, 10 mm Hg, 5 mm Hg, and 3 mm Hg. After pumping down to each level, the pump is valved off and the cavity pressure monitored. The cavity pressure will rise as water and other volatiles in the cavity evaporate. When the cavity pressure stabilizes, the pump is valved in to complete the vacuum drying process. It may be necessary to repeat some steps, depending on the rate and extent of the pressure increase. Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less, as specified in Section 3.1.1 of the Technical Specifications [9-5].

    Note: The user shall ensure that the vacuum pump is isolated from the DSC cavity when demonstrating compliance with Section 3.1.1 of the Technical Specification [9-5] requirements. Simply closing the valve between the DSC and the vacuum pump is not sufficient, as a faulty valve allows the vacuum pump to continue to draw a vacuum on the DSC. Turning off the pump, or opening the suction side of the pump to atmosphere are examples of ways to assure that the pump is not continuing to draw a vacuum on the DSC.

CAUTION: Radiation dose rates are expected to be high at the port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

18. Open the valve and allow the helium to flow into the DSC cavity.

19. Pressurize the DSC with helium to more than 18 psig, but do not exceed 23 psig and hold for 10 minutes.

20. Helium leak test the ITCP weld for a leak rate of 1×10^{-4} atm cm^3 /sec. This test is optional.

21. If a leak is found, repair the weld, repressurize the DSC, and repeat the helium leak test.

22. Once no leaks are detected, depressurize the DSC cavity by releasing the helium through the VDS to the plant’s spent fuel pool or radioactive waste system.

23. Seal weld the prefabricated plug over the vent port and perform root and final dye penetrant weld examinations in accordance with Section 4.4.4 of the Technical Specifications [9-5].

24. Re-evacuate the DSC cavity using the VDS. The cavity pressure should be reduced to 3 mm Hg or less.

CAUTION: The addition of Helium into the DSC cavity will increase the temperature of water in the TC/DSC annulus. Therefore, continuously monitor the TC/DSC annulus for boiling while Helium is added to the DSC and add water from the top as required. Ensure that a portion of the TC/DSC annulus is open to atmosphere to allow water vapor to escape. In addition, a feed and bleed system with continuous flow of fresh water can also be used to control the boiling of annulus water.

25. Open the valve allow helium to flow into the DSC cavity to pressurize the DSC to 2.5 ± 1 psig in accordance with Section 3.1.2 of the Technical Specification [9-5] limits.

26. Close the valves on the helium source.

27. Decontaminate as necessary.

9.1.4 DSC Sealing Operations

CAUTION: During the performance of steps listed in Section 9.1.4, monitor the TC/DSC annulus water level and replenish, as necessary, to maintain cooling. Boiling of TC/DSC annulus water is expected at high heat loads. Consider adding water from the top and ensure that a portion of the TC/DSC annulus is open to atmosphere to allow water vapor to escape. In addition, a feed and bleed system with continuous flow of fresh water can also be used to control the boiling of annulus water for high heat load systems.

1. Disconnect the VDS from the DSC. Seal weld the prefabricated cover plate over the drain port, inject helium into blind space just prior to completing welding, and perform root and final dye penetrant weld examinations in accordance with Section 4.4.4 of the Technical Specification [9-5] requirements.

2. Temporary shielding may be installed as necessary to minimize personnel exposure. Install the automatic welding machine onto the outer top cover plate (OTCP) and place the OTCP with the automatic welding system onto the DSC. Verify proper fit up of the OTCP with the DSC shell.

3. Tack weld the OTCP to the DSC shell. Place the OTCP weld root pass.

4. Helium leak test the inner top cover plate and vent/drain port plug/plate welds using the leak test port in the OTCP in accordance with Section 4.4.4 of the Technical Specification [9-5] limits. Verify that the personnel performing the leak test are qualified in accordance with SNT-TC-1A [9-3]. Alternatively, this can be done with a test head prior to installing and welding the root pass for the OTCP.

5. If a leak is found, remove the OTCP root pass, the drain plugs and repair the ITCP welds. Repeat procedure steps from Section 9.1.3 Step 17.

6. Perform dye penetrant examination of the root pass weld. Weld out the OTCP to the DSC shell. Perform root and multilayer dye penetrant examination in accordance with Section 4.4.4 of the Technical Specifications [9-5].

7. Seal weld the prefabricated plug over the outer cover plate test port and perform root and final dye penetrant weld examinations.

8. Remove the automatic welding machine from the DSC.

9. Open the TC drain port valve and drain the water from the TC/DSC annulus.

   Note: The time limit for Transfer Operations, if any, starts from initiation of this step.

CAUTION: Monitor the applicable time limits of Section 3.1.3 of the Technical Specifications [9-5] until the completion of DSC transfer Step 16 of Section 9.1.6*, or Step 17 of Section A.9.1.6*.

10. Rig the TC top cover plate and lower the cover plate onto the TC.

    Note: To meet weight limits the aluminum TC top cover plate may be used during the lift to the trailer.

11. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

12. Check the exterior of the TC to verify that it meets the limits specified in Section 3.3.1 of the Technical Specifications [9-5] for surface contamination.

13. Check the surface temperature of the TC to verify the temperature limits and any resulting lifting or handling restrictions specified in Section 5.2.1 of the Technical Specifications [9-5].

9.1.5 TC Downending and Transfer to ISFSI

Note: Alternate procedure for downending of transfer cask: Some plants have limited floor hatch openings above the cask/trailer/skid, or other conditions which limit crane travel in the direction that would be needed in order to downend the TC with the trailer/skid in a stationary position. For these situations, alternate procedures are to be developed on a plant-specific basis, with detailed steps for downending.

1. Re-attach the TC lifting yoke to the crane hook, as necessary. Ready the transfer trailer and TC support skid for service.

CAUTION: Perform a functional test of the air circulation system, including the blowers, generators, and power cords, etc. per Section 3.1.3 of the Technical Specifications [9-5].

2. Move the scaffolding away from the TC as necessary. Engage the lifting yoke and lift the TC over the TC support skid on the transfer trailer.

3. The transfer trailer should be positioned so that TC support skid is accessible to the crane with the trailer supported on the vertical jacks.

4. Position the TC lower trunnions onto the transfer trailer trunnions.

5. Move the crane forward while simultaneously lowering the TC until the TC upper trunnions are just above the support skid upper trunnion pillow blocks.

6. Inspect the positioning of the TC to ensure that the TC and trunnion pillow blocks are properly aligned.

7. Lower the TC onto the skid until the weight of the TC is distributed to the trunnion pillow blocks.

8. Inspect the trunnions to ensure that they are properly seated onto the skid.

9. If used, remove the aluminum TC top cover plate and replace with the steel TC top cover plate.

10. Optionally, remove the bottom ram access cover plate from the TC and install the air flow adaptor, if a time limit for transfer is specified in Section 3.1.3 of the Technical Specifications [9-5].

    Note: This step is only applicable if the DSC and HLZC combination results in a time limit for completion of transfer per LCO 3.1.3 of the Technical Specification.

9.1.6 DSC Transfer to the EOS-HSM

1. Prior to transporting the TC to the ISFSI, verify that the wind deflectors are in place, if needed per Section 5.5 of the Technical Specifications [9-5], remove the *EOS*-HSM door, inspect the cavity of the *EOS*-HSM, removing any debris and ready the *EOS*-HSM to receive a DSC. The doors on adjacent *EOS*-HSMs should remain in place.

CAUTION: The insides of empty modules have the potential for high does rates due to adjacent loaded modules. Proper ALARA practices should be followed for operations inside these modules and in the areas outside these modules whenever the door from the empty *EOS*-HSM has been removed.

2. Inspect the *EOS*-HSM air inlet and outlets to ensure that they are clear of debris. Inspect the screens on the air inlet and outlets for damage.
3. Verify specified lubrication of the DSC support structure rails.
4. Transport the TC from the plant's fuel/reactor building to the ISFSI along the designated transfer route.
5. Once at the ISFSI, position the transfer trailer to within a few feet of the *EOS*-HSM.
6. Check the position of the trailer to ensure the centerline of the *EOS*-HSM and TC approximately coincide. If the trailer is not properly oriented, reposition the trailer, as necessary.
7. Unbolt and remove the TC top cover plate.
8. Back the trailer to within a few inches of the *EOS*-HSM, set the trailer brakes and disengage the tractor, if applicable. Extend the transfer trailer vertical jacks.
9. Use the skid positioning system to bring the TC into approximate vertical and horizontal alignment with the *EOS*-HSM. Using alignment equipment and the alignment marks on the TC and the *EOS*-HSM, adjust the position of the TC until it is properly aligned with the *EOS*-HSM.
10. Using the skid positioning system, fully insert the TC into the *EOS*-HSM access opening docking collar.
11. Secure the TC/skid to the front wall embedments of the *EOS*-HSM using the TC restraints.
12. After the TC is docked with the *EOS*-HSM, verify the alignment of the TC using the alignment equipment.

13. Position the ram behind the TC in approximate horizontal alignment with the TC and level the ram. Remove either the bottom ram access cover plate or the airflow adaptor. Extend the ram through the bottom TC opening into the DSC grapple ring.

14. Operate the ram grapple and engage the grapple arms with the DSC grapple ring.

15. Recheck all alignment marks and ready all systems for DSC transfer.

16. Activate the ram to initiate insertion of the DSC into the *EOS*-HSM. Stop the ram when the DSC reaches the support rail stops at the back of the module.

    Note: The time limit for transfer operations, if any, starts with the initiation of the TC/DSC annulus water draining described in Step 9 of Section 9.1.4 and ends when the DSC is fully inserted into the *EOS*-HSM.

CAUTION: Verify that the applicable time limits for transfer operations of Section 3.1.3 of the Technical Specifications [9-5] are met.

17. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.

18. Retract and disengage the ram system from the TC and move it clear of the TC. Remove the TC restraints from the *EOS*-HSM.

19. Using the skid positioning system, disengage the TC from the *EOS*-HSM access opening.

20. Install the DSC axial restraint through the *EOS*-HSM door opening.

21. The trailer can be moved, as necessary, to install the HSM door. Install the *EOS*-HSM door and secure it in place. Door may be welded for security. Verify that the *EOS*-HSM dose rates are compliant with the limits specified in Section 5.1.2 of the Technical Specifications [9-5].

22. Replace the TC top cover plate. Secure the skid to the trailer, retract the vertical jacks, and disconnect the skid positioning system.

23. Move the trailer and TC to the designated equipment storage area. Return the remaining transfer equipment to the storage area.

24. Close and lock the ISFSI access gate and activate the ISFSI security measures.

9.1.7 Monitoring Operations

1. Perform routine security surveillance in accordance with the licensee's ISFSI security plan.

2. Perform a daily visual surveillance of the EOS-HSM air inlets and outlets (bird screens) to verify that no debris is obstructing the *EOS*-HSM vents in accordance with Section 5.1.3.*1*(a) of the Technical Specification [9-5] requirements, or, perform a temperature measurement for each EOS-HSM in accordance with Section 5.1.3.*1*(b) of the Technical Specification [9-5] requirements.

9.2 Procedures for Unloading the DSC

The following section outlines the procedures for retrieving the DSC from the HSM and for removing the FAs from the DSC.

9.2.1 DSC Retrieval from the *EOS*-HSM

1. Ready the TC, transfer trailer, and support skid for service. Fill the TC liquid neutron shield and remove the top cover plate from the TC. Transport the trailer to the *EOS*-HSM.

   Note: Verify that a TC spacer of appropriate height is placed inside the TC to provide the correct airflow and interface at the top of the TC during cutting and unloading operations for DSCs that are shorter than the TC cavity length.

2. Remove the *EOS*-HSM door and the DSC axial restraint. Position the transfer trailer to within a few feet of the *EOS*-HSM.

3. Check the position of the trailer to ensure the centerline of the *EOS*-HSM and TC approximately coincide. If the trailer is not properly oriented, reposition the trailer as necessary.

CAUTION: High dose rates are expected in the *EOS*-HSM cavity after removal of the *EOS*-HSM door. Proper ALARA practices should be followed.

4. Back the TC to within a few inches of the *EOS*-HSM, set the trailer brakes and disengage the tractor, if applicable. Extend the transfer trailer vertical jacks.

5. Use the skid positioning system to bring the TC into approximate vertical and horizontal alignment with the *EOS*-HSM. Using alignment equipment and the alignment marks on the TC and the *EOS*-HSM, adjust the position of the TC until it is properly aligned with the *EOS*-HSM.

6. Using the skid positioning system, fully insert the TC into the *EOS*-HSM access opening docking collar.

7. Secure the TC/skid to the front wall embedments of the *EOS*-HSM using the TC restraints.

8. After the TC is docked with the *EOS*-HSM, verify the alignment of the TC using the alignment equipment.

9. Position the ram behind the TC in approximate horizontal alignment with the TC and level the ram. Remove the bottom ram access cover plate or the air flow adaptor, if installed. Extend the ram through the TC into the *EOS*-HSM until it is inserted in the DSC grapple ring.

10. Operate the ram grapple and engage the grapple arms with the DSC grapple ring.

11. Recheck all alignment marks and ready all systems for DSC transfer.

CAUTION: The time limits for the unloading of the DSC should be determined using the heat loads at the time of the unloading operation and the methodology presented in Sections 4.5 and 4.6 before pulling the DSC out of the *EOS*-HSM.

12. Activate the ram to pull the DSC into the transfer TC.

13. Disengage the ram grapple mechanism so that the grapple is retracted away from the DSC grapple ring.

14. Retract and disengage the ram system from the TC and move it clear of the TC. Remove the TC restraints from the *EOS*-HSM.

15. Using the skid positioning system, disengage the TC from the *EOS*-HSM access opening.

16. Bolt the TC cover plate into place, tightening the bolts to the required torque in a star pattern.

17. Retract the vertical jacks and disconnect the skid positioning system.

18. Ready the trailer for transfer.

19. Replace the *EOS*-HSM door and DSC axial restraint on the *EOS*-HSM.

9.2.2 Removal of Fuel from the DSC

Note that the EOS-37PTH DSC will provide the retrievability function for damaged and FFCs per ISG-2, Revision 2. However, if it is necessary to remove fuel from the DSC, *intact and damaged fuel* can be removed in a dry transfer facility or the initial fuel loading sequence can be reversed and the plant's spent fuel pool utilized.

Procedures for wet unloading of the DSC are presented here. Dry unloading procedures are essentially identical up to the removal of the DSC vent plug and drain port cover.

CAUTION: Monitor the applicable time limits determined for the unloading operation in Step 11, Section 9.2.1 above*, or Step 16 of Section A.9.2.1*, until the TC/DSC Annulus is filled with water in Step 12 of Section 9.2.2. If the time limits for unloading cannot be met, initiate forced cooling. Boiling of TC/DSC annulus water is expected at high heat loads. Consider adding water from the top and ensure that a portion of the TC/DSC annulus is open to atmosphere to allow water vapor to escape. In addition, a feed and bleed system with continuous flow of fresh water can also be used to control the boiling of annulus water for high heat load systems.

1. Transfer the loaded TC from the ISFSI to inside the plant's fuel or reactor building along the designated transfer route.

2. Position and ready the trailer for access by the crane. The trailer is supported on the vertical jacks.

3. If required to meet crane weight limits, replace steel TC cover plate with the aluminum TC cover plate.

4. Attach the TC lifting yoke to the crane hook. Then engage the TC lifting yoke with the trunnions of the TC on the transfer trailer.

5. Verify that the yoke lifting arms are properly aligned and engaged onto the TC trunnions.

6. Lift the TC approximately one inch off the saddle supports. Verify that the yoke lifting arms are properly positioned on the trunnions.

7. Move the crane in a horizontal motion while simultaneously raising the crane hook vertically and lift the TC off the trailer. Move the TC to the TC designated area.

8. Lower the TC into the TC staging area in the vertical position.

9. Clean the TC, if needed, to remove any dirt that may have accumulated on the TC during the DSC loading and transfer operations.

10. Place scaffolding around the TC.

11. Unbolt the TC cover plate and remove it.

12. Install temporary shielding to reduce personnel exposure as required. Fill the TC/DSC annulus with clean water. Place an inflatable seal into the upper TC liner recess and seal the TC\DSC annulus by pressurizing the seal with compressed air.

13. Locate the drain and vent port using the indications on the OTCP. Place a portable drill press on the top of the DSC. Align the drill over the drain port.

14. Cut or drill a hole through the OTCP to expose the drain port on the ITCP. Remove the drain port cover plate with an annular hole cutter. Repeat for the vent plug.

CAUTION: **Radiation dose rates are expected to be high at the vent and drain locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.**

15. Obtain a sample of the DSC atmosphere. Confirm acceptable hydrogen concentration and check for presence of fission gas indicative of degraded fuel cladding.

16. If degraded fuel is suspected, additional measures appropriate for the specific conditions are to be planned, reviewed, and implemented to minimize exposures to workers and radiological releases to the environment.

17. Verify that the boron content of the fill water conforms to Section 3.2.1 of the Technical Specifications [9-5], if applicable. Fill the DSC with water from the fuel pool or equivalent source through the drain port with the vent port open. The vented cavity gas may include steam, water, and radioactive material, and should be routed accordingly. Monitor the DSC vent pressure and regulate the water fill rate to ensure that the pressure does not exceed 15 psig.

18. Per Section 5.4 of the Technical Specifications [9-5], provide for continuous hydrogen monitoring of the DSC cavity atmosphere during all subsequent cutting operations to ensure that hydrogen concentration does not exceed 2.4%. Purge with helium as necessary to maintain the hydrogen concentration below this limit before resuming cutting operations.

CAUTION: **Continuously monitor the hydrogen concentration in the DSC cavity. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4% (60.0% of flammability limit of 4.0%) [9-1 and 9-2]. If this limit is exceeded, stop all cutting operations and purge the DSC cavity with approximately 2-3 psig helium to reduce the hydrogen concentration safely below the 2.4% limit.**

19. Provide suitable protection for the TC during cutting operations.

20. Using a suitable method, such as mechanical cutting, remove the weld of the OTCP to the DSC shell.

21. Remove the OTCP.

22. Remove the weld of the inner top cover/shield plug to the shell in the same manner as the OTCP. Do not remove the inner top cover/shield plug at this time unless the removal is being done remotely in a dry transfer system.

23. Remove any remaining excess material on the inside shell surface by grinding.

24. Clean the TC surface of dirt and any debris that may be on the TC surface as a result of the weld removal operation.

    a. EOS-TC125 or TC135: The neutron shield may be drained if it is necessary to meet the crane capacity when the loaded TC is placed into the pool.

    b. EOS-TC108: The neutron shield tank may be drained or removed from the TC108 and staged in an appropriate location.

25. Position the TC lifting yoke and engage the TC lifting trunnions, install eyebolts or other lifting attachment(s) into the shield plug, and connect the rigging cables to the eyebolts/lifting attachment(s).

26. Move the scaffolding away from the TC as necessary.

27. Lift the TC just far enough to allow the weight of the TC to be distributed onto the yoke lifting arms. Verify that the lifting arms are properly positioned on the trunnions.

28. Optionally, secure a sheet of suitable material to the bottom of the TC to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the TC in the designated area.

29. Prior to the TC being lifted into the fuel pool, the water level in the pool should be adjusted as necessary to accommodate the TC/DSC volume, as necessary.

30. Position the TC over the TC loading area in the spent fuel pool.

31. Lower the TC into the pool. As the transfer TC is being lowered, the exterior surface of the TC should be sprayed with clean water.

32. Lower the TC into the fuel pool leaving the top surface of the TC above the surface of the pool water. Verify correct connections of the annulus seal and annulus/neutron shield tank, if used.

33. Disengage the lifting yoke from the TC and lift the shield plug from the DSC.

34. Remove the fuel from the DSC.

    Note: Special attention should be given to unloading the FAs (especially for boiling water reactor (BWR fuel) to wait until any loose particles have settled and slowly move the FAs to minimize fuel crud dispersion in the spent fuel pool. The dry TC reflood process, during unloading of BWR fuel, has the potential to disperse crud into the pool and become airborne, creating airborne exposure and personnel contamination hazards.

    If the DSC contains damaged fuel:

    a. remove the top end caps.

b. remove the fuel using the standard fuel handling procedures.

If the DSC contains failed fuel:

a. remove the FFC top lid.
b. lift and remove the FFC from the DSC.

9.3 References

9-1 U.S. Nuclear Regulatory Commission, Office of the Nuclear Material Safety and Safeguards, "Safety Evaluation of VECTRA Technologies' Response to Nuclear Regulatory Commission Bulletin 96-04 For the NUHOMS®-24P and NUHOMS®-7P.

9-2 U.S. Nuclear Regulatory Commission Bulletin 96-04, "Chemical, Galvanic or Other Reactions in Spent Fuel Storage and Transportation Casks," July 5, 1996.

9-3 SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 2006.

9-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 3.61 "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Container," February 1989.

9-5 CoC 1042 Appendix A, NUHOMS® EOS System Generic Technical Specifications, Amendment *1*.

9-6 U.S. Nuclear Regulatory Commission, Interim Staff Guidance (ISG-22), "Potential Rod Splitting due to Exposures to an Oxidizing Atmosphere during Short-term Cask Loading Operations in LWR of Other Uranium Oxide Based Fuel."

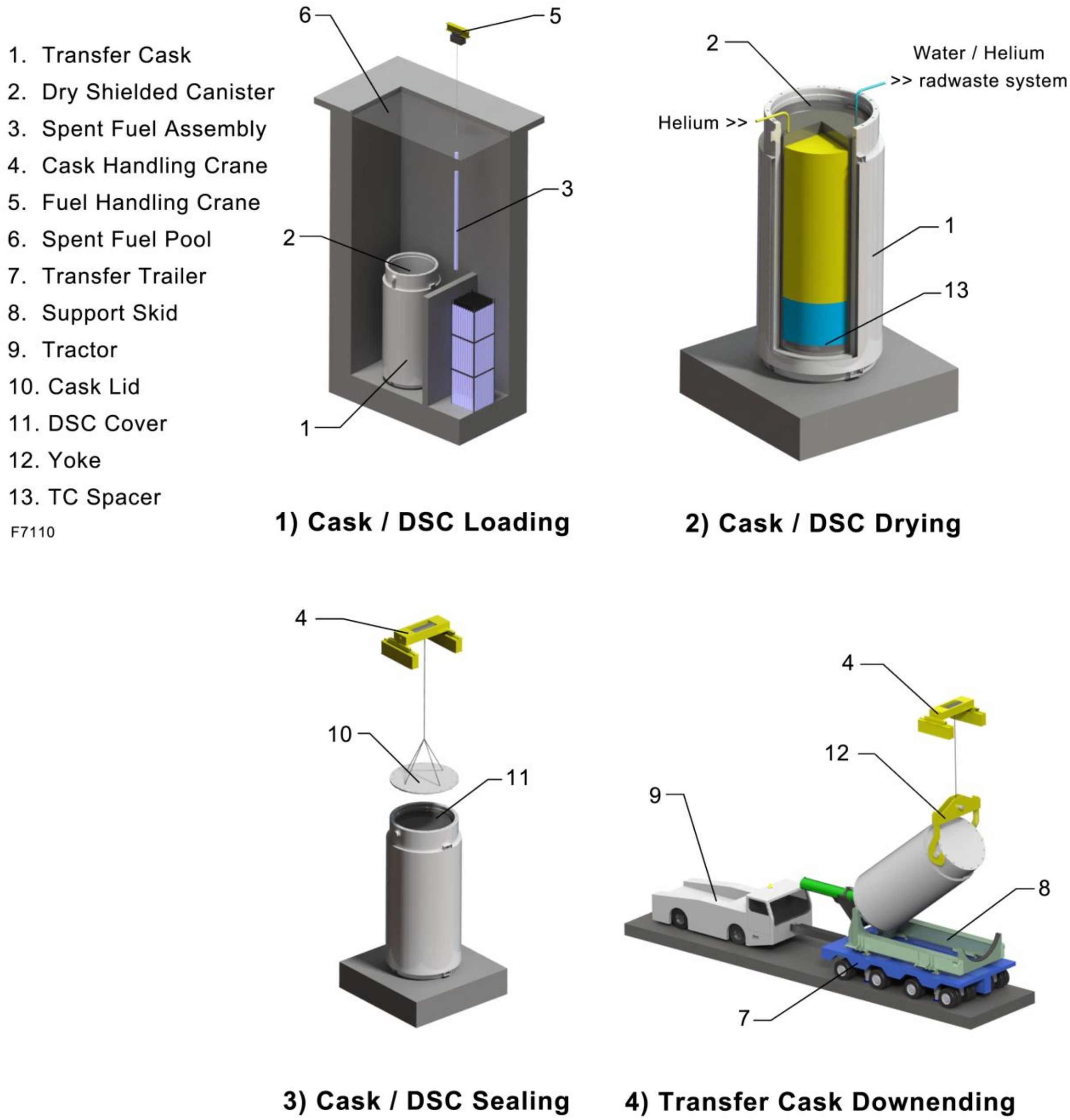

Figure 9-1
NUHOMS® EOS System Loading Operations
2 Pages

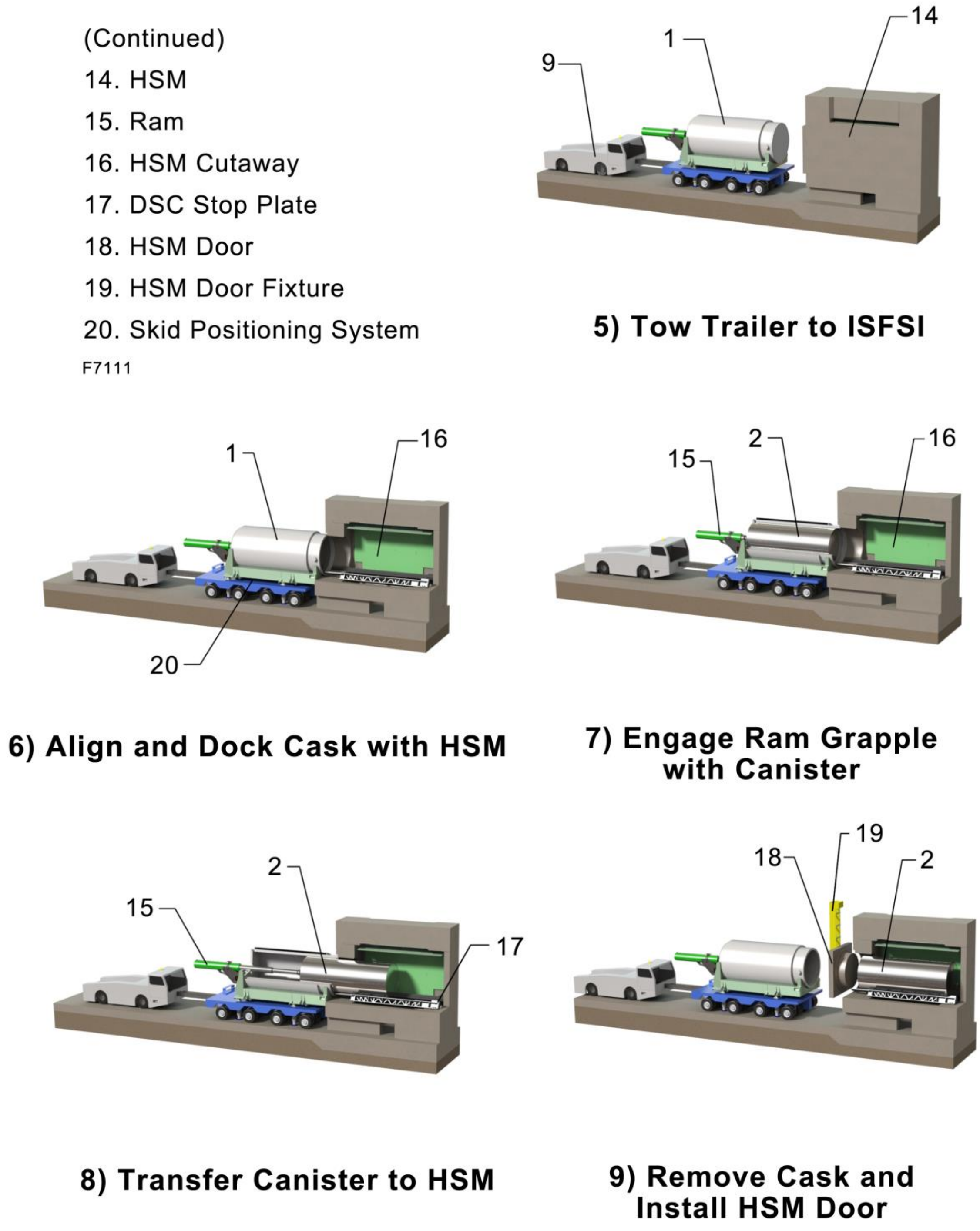

Figure 9-1
NUHOMS® EOS System Loading Operations
2 Pages

CHAPTER 10
ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Table of Contents

10. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter specifies the acceptance testing and maintenance program for important-to-safety (ITS) components of the NUHOMS® EOS System, which is the dry shielded canister (DSC), horizontal storage module (HSM), and transfer cask (TC). The testing and maintenance of the TC lift yoke are governed by 10 CFR Part 50 heavy load regulations, and are not covered here.

10.1 Acceptance Tests

10.1.1 Structural and Pressure Tests

10.1.1.1 DSC

The DSC confinement boundary is fabricated, inspected, and tested in accordance with American Society of Mechanical Engineers (ASME) Code Subsection NB [10-1] with alternatives specified in Section 4.4.4 of the Technical Specifications [10-32]. The shell and inner bottom cover plate assembly is pneumatically tested during fabrication in accordance with ASME Article NB-6300. The inner top cover plate and its weld to the shell are pneumatically tested in the field, in accordance with the above-cited ASME Code alternatives. Per ASME Article NB-6300, the pneumatic test pressure shall be 1.1 times the design pressure, which results in a test pressure of 16.5 psig. For conservatism, a test pressure of 18.0 psig is selected to bound potential conditions for transportation under 10 CFR Part 71.

DSC	Normal Pressure (psig)	Design Pressure (psig)	Test Pressure (psig)
EOS37PTH	10.5	15(1)	18.0
EOS89BTH	10.8	15(1)	18.0

(1) A pressure of 20 psig is used for structural evaluations under normal and off-normal conditions as noted in Section 3.9.1.2.7.3.

Mechanical properties of materials are tested in accordance with the American Society for Testing and Materials (ASTM), ASME, AMS, or other material specification called out on the drawings in Chapter 1. Weld procedures and welders are qualified in accordance with ASME Code Section IX. Additional material and welding requirements of ASME Code Articles NB-2000 and NB-4000 apply to the confinement boundary unless an ASME Code alternative governs.

Acceptance testing for the high-strength low-alloy steel used in the DSC baskets is specified in 10.1.7. There is no welding on the baskets.

10.1.1.2 HSM

Concrete mix design, placement, and testing are performed in accordance with ACI-318 [10-2]. The minimum concrete compressive strength is 5000 psi if controls are placed on the aggregate type or coefficient of thermal expansion as described in Section 8.2.1.3. If the alternative described in that Section is used, the minimum is 7000 psi. In accordance with American Concrete Institute (ACI) 349 Appendix E, paragraph E.4.3 [10-3], compressive testing of the concrete mix design for the base, roof, and doors is conducted after heating the test cylinders prior to testing. For the EOS-HSM, the testing of the specimens are performed at a temperature of 500 °F per Table 4-17. See Sections 4.4.4 and 5.3 of the Technical Specifications *[10-32]*.

The reinforcing steel, ITS fasteners, and steel for the door and the DSC support structure are tested for mechanical properties in accordance with the governing specifications called out on the drawings in Chapter 1.

Weld procedures and welders for the DSC support structure are qualified in accordance with ASME Code Section IX or American Welding Society (AWS) D1.1 [10-4].

10.1.1.3 Transfer Cask

The TC structural assembly welds are performed in accordance with ASME Code Section IX, and examined by magnetic particle examination (MT) to the acceptance standards of ASME Code Section III, Subarticle NF-5340. The upper trunnions are load tested at fabrication to three times the design load, and inspected afterwards in accordance with ANSI N14.6 [10-5].

The liquid neutron shield shell is hydrostatically tested to 1.25 times the pressure relief valve setting shown on the drawings in Chapter 1.

Transfer Cask	Test Load, Each Upper Trunnion (ton)	Neutron Shield Test Pressure (psig)
108 ton	162	35
125 ton	187.5	31.25
135 ton	202.5	31.25

Mechanical properties of materials are tested in accordance with the ASTM, ASME, or other material specification called out on the drawings in Chapter 1. Weld procedures and welders are qualified in accordance with ASME Code Section IX.

10.1.2 Leak Tests

Confinement welds in the DSC shell and bottom are leak tested during fabrication to the ANSI N14.5 [10-6] leaktight acceptance criterion $1x10^{-7}$ ref cm^3/s. Personnel performing the leak test are qualified in accordance with American Society for Nondestructive Testing (ASNT) SNT-TC-1A [10-7]. The DSC inner top cover plate, port covers, and their welds are leak-tested in the field to the same acceptance criterion after the fuel assemblies are loaded. Leak testing procedures follow ASME Code Section V, Article 10, Appendix IX, ASTM E1603 [10-8], or equivalent standard that provides the sensitivity required by ANSI N14.5.

10.1.3 Visual Inspection and Non-Destructive Examinations

Visual inspections are performed at the fabricator's facility to ensure that the DSC, the HSM, and the TC conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes. Requirements specific to each component follow.

10.1.3.1 DSC

Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Chapter 1. The confinement welds on the DSC are inspected in accordance with ASME Boiler and Pressure Vessel Code Subsection NB, including alternatives to ASME Code cited in Section 4.4.4 of the Technical Specifications.

Non-destructive examination personnel are qualified in accordance with SNT-TC-1A.

10.1.3.2 HSM

Reinforcing steel placement is inspected in accordance with ACI 117 [10-9] and cured concrete is visually inspected in accordance with ACI 311.4R [10-10].

Weld inspections and inspector qualifications conform to AWS D1.1.

10.1.3.3 Transfer Cask

The load-bearing welds for the EOS-TC structural body are inspected by MT as specified on the drawings in Chapter 1, with acceptance criteria of ASME Subarticle NF-5340. Non-destructive examination personnel are qualified in accordance with SNT-TC-1A.

10.1.4 Shielding Tests

10.1.4.1 DSC

The shielding performance of the top and bottom shield plugs and cover plates of the DSC is verified by their material certifications and dimensional inspections. No further testing is required.

10.1.4.2 HSM

The HSM concrete is tested in accordance with ASTM C138 [10-11] to verify a minimum density of 140 lb/ft^3.

10.1.4.3 Transfer Cask

The TC lead shielding is installed as lead sheet or interlocking lead bricks, rather than being cast in place. The neutron shield material in the lid and bottom end is also installed as solid sheets of borated high density polyethylene. Shielding performance is verified by material certification and dimensional inspection.

The radial neutron shielding is provided by filling the neutron shield shell with water during operations. No testing is necessary.

10.1.5 Neutron Absorber Tests

The neutron absorber used for criticality control in the DSC baskets may consist of one of the following materials:

- Boron carbide/aluminum metal matrix composite (MMC)
- BORAL®

The safety analyses do not rely upon the tensile strength of these materials. The neutron absorber's design function relies only on the B-10 areal density (mass of B-10 per unit area) and the thermal conductivity in the plane of the sheet. The minimum specified B-10 areal density of these materials is specified on the DSC basket drawings in Chapter 1. The criticality calculations in Chapter 7 use 90% of the minimum for MMC and 75% for BORAL.

10.1.5.1 MMC Specification and Acceptance Testing

Metal matrix composites are defined for the purpose of the NUHOMS® EOS System as a near ≥ 97% of density composite of fine boron carbide particles in an aluminum alloy matrix, with or without an aluminum skin. The d50[1] median particle size, by volume or mass, of the boron carbide feed material is less than or equal to 80 microns. The d90[1] particle size, by volume or mass, is less than or equal to 100 microns. The maximum boron carbide content in the MMC is 50 volume %.

Metal matrix composites may be supplied by any manufacturer subject to qualification testing and control of key manufacturing processes in accordance with ASTM C1671 [10-12], as described in Sections 10.1.5.3 and 10.1.5.4.

B-10 Areal Density Acceptance Testing of MMC

B-10 areal density is verified by neutron attenuation testing per ASTM E2971[10-13] or by chemical and spectrometric analysis per ASTM D3171 [10-14] and ASTM C791 [10-15], benchmarked against neutron attenuation testing. The areal density testing is performed on coupons taken adjacent to the finished panels. The sampling is either systematic or random, with a sampling rate sufficient to yield at least twenty-five coupons per DSC. For each lot of material, the lower tolerance limit at 95% probability and 95% confidence is determined in accordance with ASTM C1671. This lower tolerance limit must equal or exceed the minimum B-10 areal density specified on the drawings in Chapter 1.

Dimensional Inspections of MMC

All MMC finished panels are inspected for length, width and thickness.

Thermal Conductivity Acceptance Testing of MMC

Acceptance testing for thermal conductivity is performed at room temperature according to ASTM E1225 [10-16], ASTM E1461 [10-17], or equivalent method, on coupons taken adjacent to the finished panels. The minimum acceptable thermal conductivity is [

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If a thermal conductivity test result is below the specified minimum, at least four additional tests shall be performed on the material from that lot. If the mean value of those tests, including the original test, falls below the specified minimum, the associated lot shall be rejected.

Thermal conductivity acceptance testing is conducted until sufficient data are collected for a single supplier, manufacturing method, and material composition to validate the consistent performance of that material.

Visual Inspections of MMC

Finished panels are visually inspected to verify that there are no blisters, cracks, or surface peeling. Clad MMCs are also inspected to verify that there is no exposed core on the face of the sheet or solid aluminum at the edge of the sheet. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

10.1.5.2 BORAL Specification and Acceptance Testing

BORAL consists of a core of aluminum and boron carbide powders between two outer layers of aluminum. It is distinguished from MMCs by the interconnected porosity of the core, which is exposed at the edges of the sheet, the larger size of the boron carbide powder, and the higher boron carbide content. At least 80% by weight of the boron carbide particles in BORAL are smaller than 200 microns. The boron carbide content is limited to 67% of the core by weight.

Because there is long experience with BORAL, and because only 75% of the minimum specified areal density is used in criticality calculations, BORAL is not subject to qualification testing.

B-10 Areal Density Acceptance Testing of BORAL

B-10 areal density will be verified by chemical analysis and by certification of the B-10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on a coupon taken from the sheet produced from each ingot. If the measured areal density is below that specified, all the material produced from that ingot will be either rejected, or accepted only on the basis of alternate verification of B-10 areal density for each of the final panels produced from that ingot.

Dimensional Inspections of BORAL

All BORAL finished panels are inspected for length, width and thickness.

Thermal Conductivity Testing of BORAL

Acceptance testing for thermal conductivity parallel to the plane of the sheet is performed at room temperature according to ASTM E1225, or equivalent method, on coupons taken adjacent to the finished panels. The minimum acceptable thermal conductivity is [

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Thermal conductivity acceptance testing is conducted until sufficient data are collected to validate the consistent performance of BORAL.

Visual Inspection of BORAL

Visual inspection verifies that there are no cracks, blisters, exposed core on the face of the sheet, or solid aluminum at the edge of the sheet. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable.

10.1.5.3 Qualification Testing and Key Process Control for MMCs

Qualification testing and key process controls follow the guidance of ASTM C1671 and ISG-23 [10-18].

Applicability and Scope

Each MMC of a given manufacturer, production method, or composition is subject to qualification to verify that the product will perform its design functions in the DSC internal environments. Key process controls are identified so that the production material is equivalent to or better than the qualification test material.

Service Environment Durability

Accelerated radiation damage testing is not required. Such testing has already been performed on MMCs, and the results confirm what would be expected of MMCs due to their composition. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about 10^{15} neutrons/cm^2, nor are they susceptible to gamma radiation damage.

Thermal damage and corrosion (hydrogen generation) tests are performed unless such tests on materials of the same chemical composition have already been performed and found acceptable.

Mechanical Integrity Testing

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage system.

At least three samples, one each from approximately the two ends and middle of the qualification material run are subject to:

- Room temperature tensile testing (ASTM B557 [10-19]) demonstrating that the material has the following tensile properties:
  - Minimum yield strength, 0.2% offset: 1.5 ksi
  - Minimum ultimate strength: 5 ksi
  - Minimum elongation in 2 inches: 0.5%

As an alternative to the elongation requirement, ductility can be demonstrated by bend testing per ASTM E290 [10-20]. The radius of the pin or mandrel is no greater than three times the material thickness, and the material is bent at least 90 degrees without complete fracture.

- Testing to verify more than 97% of theoretical density (ASTM B311 [10-29], or microscopic examination verifying less than 3% by volume isolated pores).

- Testing to verify maximum interconnected porosity 0.5 volume % (ASTM B963 [10-30] or microscopic examination).

Clad MMCs are subject to additional mechanical integrity testing to demonstrate that they are not subject to water intrusion and subsequent formation of steam blisters during vacuum drying [10-21].

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Test for Uniform B-10 Distribution

Uniformity of the boron distribution is verified by measurement of B-10 areal density by neutron attenuation per ASTM E2971, or the boron carbide weight fraction per ASTM D3171, on locations distributed over the test material production run, verifying that one standard deviation in the sample is less than 10% of the sample mean.

Qualification Report

Qualification report is prepared by or is subject to approval by the Certificate Holder.

10.1.5.4 Manufacturing Key Process Controls for MMCs

Applicability and Scope

Key processing changes are subject to qualification prior to use of the material produced by the revised process. The Certificate Holder determines whether a complete or partial re-qualification program per Section 10.1.5.3 is required, depending on the characteristics of the material that could be affected by the process change.

Definition of Key Process Changes

Key process changes are those that could adversely affect the uniform distribution of the boron carbide in the aluminum, reduce density, reduce corrosion resistance, reduce thermal durability, or reduce the mechanical strength or ductility of the MMC.

The following are examples of such changes.

Potential change effect	Example
Reduction of the yield or ultimate strength or the elongation	Increase in nominal boron carbide content over that previously qualified
Adverse effect on the uniformity of boron carbide distribution at the microscopic scale	Increase in the boron carbide particle size
Adverse effect on the uniformity of boron carbide distribution at the macroscopic level	Change in the blending process
Reduced density of the final product	Change in the method of billet production or thermo-mechanical processing to plate
Adverse reaction between the boron carbide and the matrix alloy under normal and off-normal service temperatures	Change in the matrix alloy
Lower corrosion resistance or higher rate of hydrogen generation	Change in the matrix alloy

Identification and Control of Key Process Changes

The manufacturer provides the Certificate Holder with a description of materials and process controls used in producing the MMC. The Certificate Holder and manufacturer prepare a written list of key process changes that cannot be made without prior approval of the Certificate Holder.

10.1.6 Thermal Acceptance

No thermal acceptance testing is required to verify the performance of each storage unit.

10.1.7 High-Strength *Low-Alloy* Steel for Basket Structure

The basket structural material shall be a High-Strength Low-Alloy (HSLA) steel meeting one of the following requirements A, B, or C:

A. ASTM A829 Gr 4130 or AMS 6345 SAE 4130, quenched and tempered at not less than 1050 °F, 103.6 ksi minimum yield, and 123.1 ksi minimum ultimate stress. This material is qualified as described in [10-31].

B. ASME Code edition 2010 with 2011 addenda, SA-517 Gr A, B, E, F, or P. This material is qualified by the material properties at elevated temperature in ASME Section II, Part D, which exceed the values of yield and ultimate strength in UFSAR Table 8-10.

C. Other HSLA steel, with the specified heat treatment, meeting these qualification and acceptance criteria:

i. If quenched and tempered, the tempering temperature shall be at no less than 1000 °F,

ii. Qualified prior to first use by testing at least two lots and demonstrating that the fracture toughness value $K_{JIc} \geq 150$ ksi √in at -40 °F with 95% confidence based on the methodology in Reference [10-31] for HSLA steel.

iii. Qualified prior to first use by testing at least two lots and demonstrating that the 95% lower tolerance limit of yield and ultimate strengths ≥ the values in UFSAR Table 8-10 based on the methodology in Reference [10-31] for HSLA steel.

iv. Meet production acceptance criteria based on the 95% lower tolerance limit of yield strength and ultimate strength at room temperature as determined by qualification testing described in Section 10.1.7.iii.

The basket HSLA material shall also meet the following production acceptance criteria:

- *Weld repair shall not be permitted.*
- *Impact testing shall be performed at -40 °F*
  - *Charpy testing per ASTM A370, minimum absorbed energy 25 ft-lb average, 20 ft-lb lowest of three (modify these acceptance criteria for sub-size specimens per A370-17 Table 9), or*
  - *Dynamic tear testing per ASTM E604 with acceptance criterion of a minimum 80% shear fracture appearance.*
- *Test specimen location, orientation, and sampling rate per ASTM A6 or ASTM A20 for production acceptance testing.*

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10.1.8 Cask Identification

Each DSC, HSM, and TC is marked with a model number, serial number, and empty weight per 10 CFR 72.236(k).

10.2 Maintenance Program

There are no maintenance requirements for the DSC for the initial licensed period of storage. This section addresses maintenance for the HSM and the TC.

10.2.1 Inspection

10.2.1.1 Transfer Cask Inspections

The following inspections are performed prior to each loading campaign using the TC inspection of the cask exterior for cracks, dents, gouges, tears, or damaged bearing surfaces.

- Visual inspection of all threaded parts and bolts for burrs, chafing, distortion or other damage.
- Operational check of all quick-connect fittings.
- Visual inspection of the interior surface of the cask for any indications of excessive wear to bearing surfaces and for the EOS-TC125/135, adherence to acceptable coating damage per Section 4.5.12.
- Visual inspection of neutron shield jacket and for the EOS-TC125/135, adherence to acceptable coating damage per Section 4.5.12.

The following inspections and tests are performed on an annual basis:

- Leak testing of the cask cavity quick-connect fittings and ram penetration seal.
- Liquid penetrant testing (PT) examination of the trunnions welds.
- Visual inspection of all painted surfaces for damage to paint and for corrosion.

10.2.1.2 HSM Inspections

The HSM is inspected for blockage of the inlet vents by either direct visual inspection, or by temperature monitoring as specified in accordance with Section 5.1.3 of the Technical Specifications.

10.2.2 Tests

10.2.2.1 Transfer Cask Tests

There are no tests required for the transfer cask after completion of fabrication during the initial license period.

10.2.2.2 HSM Tests

There are no HSM tests during the initial license period.

10.3 Repair, Replacement, and Maintenance

10.3.1 Transfer Cask Repair, Replacement, and Maintenance

Typical repair, replacement, and maintenance activities include:

- Paint damage is repaired by surface preparation and application of the original paint system.
- Raised burrs from wear are removed by light abrasives, followed by paint repair as necessary.
- Wear damage that violates a design minimum dimension is corrected by weld repair, followed by paint repair as necessary.
- Bolts, screw thread inserts, quick connect fittings, and the ram access port o-ring are replaced as needed.
- TC 108 removable neutron shield latches, hinges and hinges are replaced as needed.
- Bolt threads and removable neutron shield hinges are lubricated as needed.
- Rust on unpainted wear surfaces at the upper trunnions and lower sockets can be limited by temporary coatings when not in use.
- The neutron shield is filled with potable water prior to each loading campaign, and drained afterwards.
  - [

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- Abrasive pads such as Scotch-Brite™ should not be used to decontaminate painted surfaces. Abrasive pads degrade the paint's ease of decontamination.

10.3.2 HSM Repair, Replacement, and Maintenance

Cracking or other damage noted by visual inspection is generally entered into the licensee's corrective action program and repair or maintenance actions are developed with the help of AREVA Inc. Examples of typical exterior surface repairs are:

- Cracks below acceptable width – verify soundness of concrete by rebound hammer, and apply concrete sealant.
- Cracks above acceptable width – Fill crack with epoxy or cement –based grout, then apply concrete sealant.
- Damage greater than cracking (spalling, corner breaks) – repair using 5000 psi grout and bonding agent.

10.3.3 Maintenance of Thermal Monitoring System

In lieu of visual inspection for vent blockage, the licensee has the option to monitor the temperature by thermocouples or resistor temperature detectors inserted into wells embedded in the HSM roof. The licensee is responsible for maintenance and calibration of this temperature monitoring instrumentation and data collection.

10.4 References

10-1 American Society of Mechanical Engineers, "ASME Boiler and Pressure Vessel Code," 2010 Edition through 2011 Addenda

10-2 ACI 318-08, "Building Code Requirements for Structural Concrete and Commentary," American Concrete Institute, Detroit, MI.

10-3 ACI 349-06, "Code Requirements for Nuclear Safety Related Structures," American Concrete Institute, Detroit, MI.

10-4 American Welding Society, AWS D1.1/D1.1M, "Structural Welding Code – Steel."

10-5 ANSI N14.6, "Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More," American National Standards Institute, 1993.

10-6 ANSI N14.5, "Leakage Tests on Packages for Shipment of Radioactive Materials," American National Standards Institute, 1997.

10-7 SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing," American Society for Nondestructive Testing.

10-8 ASTM E1603/E1603M, "Standard Practice for Leakage Measurement Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Hood Mode," ASTM International, West Conshohocken, PA, 2014.

10-9 ACI 117, Specification for Tolerances for Concrete Construction and Materials

10-10 ACI 311.4 R, Guide for Concrete Inspection

10-11 ASTM C138/C138M, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete," ASTM International, West Conshohocken, PA, 2014.

10-12 ASTM C1671, "Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorbers for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging," ASTM International, West Conshohocken, PA, 2014.

10-13 ASTM E2971, "Standard Test Method for Determination of Effective Boron-10 Areal Density in Aluminum Neutron Absorbers using Neutron Attenuation Measurements," ASTM International, West Conshohocken, PA, 2014.

10-14 ASTM D3171, "Standard Test Methods for Constituent Content of Composite Materials," ASTM International, West Conshohocken, PA, 2014.

10-15 ASTM C791, "Standard Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide," ASTM International, West Conshohocken, PA, 2014.

10-16 ASTM E1225, "Standard Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique," ASTM International, West Conshohocken, PA, 2014.

10-17 ASTM E1461, "Standard Test Method for Thermal Diffusivity by the Flash Method," ASTM International, West Conshohocken, PA, 2014.

10-18 USNRC SFST-ISG-23, Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions

10-19 ASTM B557, "Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products," ASTM International, West Conshohocken, PA, 2014.

10-20 ASTM E290-14, "Standard Test Methods for Bend Testing of Material for Ductility," ASTM International, West Conshohocken, PA, 2014.

10-21 NUREG-0933, "Resolution of Generic Safety Issues: Issue 196: Boral Degradation, (Main Report with Supplements 1–34), U.S. Nuclear Regulatory Commission, December 2011.

10-22 ASTM A829, "Standard Specification for Alloy Structural Steel Plates," ASTM International, West Conshohocken, PA, 2014.

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10-24 ASTM A370, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM International, West Conshohocken, PA, 2014.

10-25 ASTM E604, "Standard Test Method for Dynamic Tear Testing of Metallic Materials," ASTM International, West Conshohocken, PA, 2014.

10-26 Not used.

10-27 ACI 201.1R, "Guide for Conducting a Visual Inspection of Concrete in Service," American Concrete Institute, 2008.

10-28 U.S. Nuclear Regulatory Commission, Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Metal for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," June 1991.

10-29 ASTM B311, "Standard Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity," ASTM International, West Conshohocken, PA, 2014.

10-30 ASTM B963, "Standard Test Methods for Oil Content, Oil-Impregnation Efficiency, and Surface-Connected Porosity of Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle," ASTM International, West Conshohocken, PA, 2014.

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CHAPTER 11
RADIATION PROTECTION

Table of Contents

List of Tables

List of Figures

11. RADIATION PROTECTION

This chapter describes the design features of the NUHOMS® EOS System that maintain radiation exposure to site personnel as low as reasonably achievable (ALARA), as well as minimize exposure to the public. An occupational dose assessment for operation of the NUHOMS® EOS System is provided. Radiation exposures to offsite individuals are also computed for both normal and accident conditions of an independent spent fuel storage installation (ISFSI). This chapter provides an example of how to demonstrate compliance with the relevant radiological requirements of 10 CFR Part 20 [11-1], 10 CFR Part 72 [11-2], and 40 CFR Part 190 [11-3]. Each user must perform site-specific calculations to account for the actual layout of the EOS horizontal storage modules (EOS-HSMs) and fuel source.

The radiation protection evaluation for the NUHOMS® MATRIX is documented in Appendix A.11.

11.1 Radiation Protection Design Features

The NUHOMS® EOS System has design features that ensure a high degree of integrity for the confinement of radioactive materials and reduction of direct radiation exposures during storage. These features are described in Section 11.4.2.

11.2 Occupational Dose Assessment

This section provides estimates of occupational dose for typical EOS transfer cask (EOS-TC) and ISFSI loading operations. Assumed annual occupancy times, including the anticipated maximum total hours per year for any individual, and total person-hours per year for all personnel for each radiation area during normal operation and anticipated operational occurrences, will be evaluated by the licensee in a 10 CFR 72.212 evaluation to address the site-specific ISFSI layout, inspection, and maintenance requirements. In addition, the estimated annual collective doses associated with loading operations will be addressed by the licensee in a 10 CFR 72.212 evaluation.

11.2.1 EOS-DSC Loading, Transfer, and Storage Operations

The near-field dose rates are computed for the EOS-TC108 and EOS-TC125/135 in Chapter 6. Dose rates are computed at the surface (R8), 30 cm (R9), 100 cm (R10), and 300 cm (R11) at various axial locations. The dose rate locations (DRLs) are illustrated in Figure 11-1. EOS-TC dose rates are computed for three generalized operational configurations: loading/decontamination, welding/drying, and downending/transfer.

The average distance from the EOS-TC for a given operation takes into account that the operator may be in contact with the EOS-TC, but this duration will be limited. For draining activities and vacuum drying, the attachment of fittings will take place closer to the EOS-TC than the operation of the pumps. For decontamination activities, although operators could be near the EOS-TC for some activities, other activities of the operation could be performed from farther away. For this reason, the average distances used for these operations range from 30 cm to 300 cm from the EOS-TC.

The operator’s hands may be in a high dose rate location momentarily, for example, when connecting fittings at the ports. This does not translate into a whole-body exposure and, therefore, these localized streaming effects are not considered in this case. For operations near the top end of the EOS-DSC, most of the work will take place around the perimeter and a smaller portion will take place directly over the shielded inner top cover.

Based on the considerations outlined above, the region around the EOS-TC is divided into 10 general DRLs appropriate for estimation of worker whole-body exposure (DRL1 through DRL10). These DRLs and the average dose rate at each location are summarized in Table 11-1. For example, location “DRL1/Decon.” is the average dose rate for the loading/decontamination configuration in axial segment A1 through A18 at radial location R11 (300 cm from the EOS-TC). The EOS-HSM dose rate reported in Table 11-1 is the average dose rate on the front surface of an EOS-HSM that has an adjacent EOS-HSM on each side. This dose rate is also obtained from Chapter 6.

The estimated occupational exposures to ISFSI personnel during loading, transfer, and storage operations using the EOS-TC108 (time and number of workers may vary depending on individual ISFSI practices) are provided in Table 11-2 and Table 11-3 for the EOS-37PTH DSC and EOS-89BTH DSC, respectively. Similar operations for the EOS-TC125/135 are provided in Table 11-4 and Table 11-5. The task times, number of personnel required, and total doses are listed in these tables. The total exposure results are as follows:

- EOS-TC108 with EOS-37PTH DSC: 3361 person-mrem (~3.4 person-rem)
- EOS-TC108 with EOS-89BTH DSC: 3270 person-mrem (~3.3 person-rem)
- EOS-TC125/135 with EOS-37PTH DSC: *2379* person-mrem (~2.*4* person-rem)
- EOS-TC125 with EOS-89BTH DSC: 1680 person-mrem (~1.7 person-rem)

The EOS-TC108 results in larger exposures than the EOS-TC125/135 because it is a lighter cask and provides less shielding. Because the EOS-TC108 results in a total computed exposure of ~3.4 person-rem, the exposure due to an EOS-TC108 crane hang-up off-normal event is also considered. Assuming four workers for one hour and location DRL1/Decon, the additional dose due to this event is approximately 0.9 person-rem (872 person-mrem for the EOS-37PTH DSC and 776 person-mrem for the EOS-89BTH DSC).

The EOS-TC*125/*135 may utilize an optional aluminum top cover plate that is exchanged for a steel top cover plate after downending. *For the EOS-TC135, this* option is applicable only to the EOS-TC135 with the EOS-37PTH DSC, since the EOS-89BTH DSC is not an allowed content in the EOS-TC135. The exposure calculations in Table 11-4 *and Table 11-5* are based on a steel top cover plate. If the aluminum top cover plate option is used, the total exposure will increase by approximately 4%.

The exposures provided above are bounding estimates. Measured exposures from typical NUHOMS® System loading campaigns have been 600 mrem or lower per canister for normal operations, and exposures for the NUHOMS® EOS System are expected to be similar.

Regulatory Guide 8.34 [11-4] is to be used to define the onsite occupational dose and monitoring requirements.

11.2.2 EOS-DSC Retrieval Operations

Occupational exposures to ISFSI personnel during EOS-DSC retrieval are similar to those exposures calculated for EOS-DSC insertion. Dose rates for retrieval operations will be lower than those for insertion operations due to radioactive decay of the spent fuel inside the EOS-HSM. Therefore, the dose rates for EOS-DSC retrieval are bounded by the dose rates calculated for insertion.

11.2.3 Fuel Unloading Operations

The process of unloading the EOS-DSC is similar to that used for loading the EOS-DSC. The identical ALARA procedures utilized for loading should also be applied to unloading. Occupational exposures to plant personnel are bounded by the exposures calculated for EOS-DSC loading.

11.2.4 Maintenance Operations

The dose rate for surveillance activities is shown in Table 11-8 and Table 11-9 for doses rates 6.1 m from the front of an EOS-HSM. The 6.1-meter dose rate is a conservative estimate for surveillance activities. The EOS-HSM surface dose rates provided in Chapter 6 can be used for temperature sensor maintenance activities, including calibration and repair.

The general licensee will evaluate the additional dose to personnel from ISFSI operations, based on the particular storage configuration and site personnel requirements.

11.2.5 Doses during ISFSI Array Expansion

ISFSI expansion should be planned to eliminate the need for entry into a module adjacent to a loaded module with use of a minimum of one empty module with an end wall at the end of the array prior to expansion. During array expansion, prior to removing the end wall, compensatory radiation shielding measures should be utilized, such as blocking the side inlet vents and the side outlet vents of the outer module, and, personnel access to the area should be controlled. Alternatively, two empty EOS-HSM modules can be used in lieu of one empty module with an end wall, though the side inlet and outlet vents of the outer module must be blocked. The resulting dose will be less than that calculated in Chapter 6 for the side dose rate of an array with an installed shield wall.

11.3 Offsite Dose Calculations

Calculated dose rates in the immediate vicinity of the NUHOMS® EOS System are presented in Chapter 6, which provides a detailed description of source term configuration, analysis models, and bounding dose rates. Offsite dose rates and annual exposures are presented in this section. Neutron and gamma-ray offsite dose rates are computed, including skyshine, in the vicinity of the two generic ISFSI layouts containing design-basis contents.

11.3.1 Normal Conditions (10 CFR 72.104)

Offsite dose rates from the NUHOMS® EOS System are a result of direct radiation from the ISFSI. The operation of loading an EOS-HSM occurs over a very short time period and contributes negligibly to the offsite dose rates. Therefore, normal condition offsite dose rate calculations are computed only for a loaded ISFSI. No off-normal conditions have been identified that affect offsite dose rates.

Two generic ISFSI designs are considered, a 2x10 back-to-back array and a two 1x10 front-to-front array. In the 2x10 back-to-back array, the rear and corner shield walls are absent because the rears of the EOS-HSMs are in contact. In the two 1x10 front-to-front arrays, the EOS-HSMs are aligned with the rear shield walls facing outward and the front of the EOS-HSMs facing inward, separated by approximately 35 ft. This configuration has the advantage of minimizing the dose rate near the ISFSI because the inlet vents are directed inward in an area that would not normally be occupied.

It is demonstrated in Chapter 6 that EOS-HSM dose rates are larger for the EOS-89BTH DSC compared to the EOS-37PTH DSC. Therefore, offsite dose rates are computed only for the bounding EOS-DSC. This evaluation provides results for distances ranging from 6.1 to 600 m from each face of the two configurations.

The Monte Carlo computer code MCNP5 [11-5] is used to calculate the dose rates at the specified locations around the arrays of EOS-HSMs. The results of this calculation provide an example of how to demonstrate compliance with the relevant radiological requirements of 10 CFR 20, 10 CFR 72, and 40 CFR 190 for a specific site. Each user must perform site-specific calculations to account for the actual layout of the EOS-HSMs and fuel source.

The total annual exposure for each ISFSI layout as a function of distance from each face is given in Table 11-6 and plotted in Figure 11-2. The total annual exposure estimates are based on 100% occupancy for 365 days. At large distances, the annual exposure from the 2x10 back-to-back array is similar to the two 1x10 front-to-front array configuration. Per 10 CFR 72.104, the annual whole-body dose to an individual at the site boundary is limited to 25 mrem. Based on the data shown in Table 11-6, the offsite dose rate drops below 25 mrem at a distance of approximately 370 m from the ISFSI. Therefore, 370 m is the minimum distance with design basis fuel to the site boundary for a 20-cask array with the NUHOMS® EOS System, however a shorter distance can be demonstrated in a site-specific calculation. [

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The methodology, inputs, and assumptions for the Monte Carlo N-Particle (MCNP) analyses are summarized in the following paragraphs.

- The 20 EOS-HSMs in the 2x10 back-to-back array are modeled as a box enveloping the 2x10 array of EOS-HSMs, including the 3-foot shield walls on the two ends of the array. Source particles are started on the surfaces of the box. A sketch of this geometry is shown in Figure 11-3. The interiors of the EOS-HSMs and shield walls are modeled as air. Most particles that enter the interiors of the EOS-HSMs and shield walls will, therefore, pass through unhindered.
- The 20 EOS-HSMs in the two 1x10 front-to-front arrays are modeled as two boxes that envelop each 1x10 array of EOS-HSMs, including the 3-foot shield walls on the two ends and back of each array. Source particles are started on the surfaces of one of the 1x10 arrays, which is modeled as air. The opposite 1x10 array is modeled as solid concrete. A sketch of this geometry is shown in Figure 11-4. The dose field is then created for a source in both arrays by accounting for model symmetry, as indicated in Figure 11-4.
- The ISFSI approach slab is modeled as concrete. Because the ground composition has, at best, only a secondary impact on the dose rates at the detectors, any differences between this assumed layout and the actual layout would not have a significant effect on the site dose rates.
- The “universe” is a sphere surrounding the ISFSI. To account for skyshine, the radius of this sphere (r=500,000 cm) is more than 10 mean free paths for neutrons and 50 mean free paths for gammas in air, thus ensuring that the model is of a sufficient size to include all interactions, including skyshine, affecting the dose rate at the detectors.
- The 2x10 and two 1x10 surface sources are input to reproduce the average dose rate and spectrum on the surface of the EOS-HSM, as computed in Chapter 6. The surface average fluxes on the front, roof, side, and rear of the EOS-HSM are explicitly computed, and are provided in Tables 6-56 through 6-58. The primary and secondary gamma fluxes are simply summed in the gamma input file. These surface spectra are directly input to MCNP for each face.

- Source particles on the ISFSI array surface are specified with a cosine distribution. For a cosine distribution, the outward particle current is equal to half of the flux. The MCNP source description requires the number of source particles per second emitted on each face (particle current). Because the current is half of the flux for a cosine distribution, and the flux at each face is known, the input current for each face (particles/s) is computed as A*F/2, where A is the area of the face (cm^2) and F is the total flux on each face (particles/cm^2-s). The surface source calculations are summarized in Table 11-7.
- ANSI/ANS 6.1.1-1977 flux-to-dose rate factors are utilized [11-6]. These factors are provided in Table 6-51.
- For the 2x10 back-to-back array with end shield walls, the "box" dimensions are 1361 cm wide, 3129 cm long, and 564 cm high. For the two 1x10 front-to-front arrays with end and back shield walls, the "box" dimensions for each array are 772 cm wide, 3129 cm long, and 564 cm high. The two 1x10 arrays are 1067 cm (35 ft) apart.
- Dose rates are calculated for distances of 6.1 m (20 ft) to 600 m from the edges of the two ISFSI configurations. Point detectors are placed at the following locations, as measured from each face of the "box": 6.095 m (20 ft), 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, 90 m, 100 m, 200 m, 300 m, 400 m, 500 m, and 600 m. Each point detector is placed 91 cm (~3 ft) above the ground.

The MCNP results for the 2x10 back-to-back and two 1x10 front-to-front configurations are summarized in Table 11-8 and Table 11-9, respectively. At near distances, the 2x10 configuration results in larger front dose rates than the outward rear of the two 1x10 configuration. For example, the 6.1 m front dose rate is 9.51 mrem/hr for the 2x10 array compared to 3.66 mrem/hr for the two 1x10 array. However, at near distances, the two 1x10 configuration results in nominally larger side dose rates than the 2x10 array.

At large distances, the dose rates are approximately the same, regardless of configuration or direction from the ISFSI, as the dose rate at large distances is dominated by skyshine from the radiation streaming from the roof outlet vents. Also, note that the neutron dose rate is negligible compared to the gamma dose rate at all dose rate locations.

The Monte Carlo convergence is excellent due to the low uncertainty (<5%) for most dose rate locations. The Monte Carlo uncertainty is large (~15%) only for the detector 600 m from the front of the 2x10 array. However, the dose rate at this location is vanishingly small, and the result is acceptable. The annual exposures reported in Table 11-6 are simply the computed dose rates multiplied by 8760 hours (1 year).

The preceding analyses and results are intended to provide high estimates of dose rates for generic ISFSI layouts. The written evaluations performed by a general licensee for the actual ISFSI must consider the type and number of storage units, layout, characteristics of the irradiated fuel to be stored, site characteristics (e.g., berms, distance to the controlled area boundary, etc.), and reactor operations at the site in order to demonstrate compliance with 10 CFR 72.104.

11.3.2 Accident Conditions (10 CFR 72.106)

Per 10 CFR 72.106, the exposure to an individual at the site boundary due to an accident is limited to 5 rem. In an accident, the EOS-HSM outlet vent covers and wind deflectors (if required) may be lost. Only the dose rates on the roof are affected, since the front, rear, and side dose rates remain the same. As the dose rates at large distances are mostly due to skyshine from the roof, the dose rates at the site boundary are directly affected. The average EOS-HSM roof dose rates and surface fluxes in an accident are computed in Chapter 6, Tables 6-56 through 6-58. Table 11-10 shows the bounding dose rate as a function of distance from a 2x10 back-to-back array of EOS-HSMs for the accident configuration described above. These dose rates are calculated assuming that the outlet vent covers and wind deflectors (if required) for the entire array are lost.

MCNP inputs for a 2x10 ISFSI accident configuration are prepared using the same method as described for the normal condition models. At a distance of 200 m and 370 m from the ISFSI, the accident dose rate is approximately 1.1 mrem/hr and 0.1 mrem/hr, respectively. It is assumed that the recovery time for this accident is five days (120 hours). Therefore, the total exposure to an individual at a distance of 200 m and 370 m is 132 mrem and 12 mrem respectively. This is significantly less than the 10 CFR 72.106 limit of 5 rem.

The EOS-TC may also be damaged in an accident during transfer operations, which would result in an offsite dose. For accident conditions, it is assumed that the neutron shield, including the steel or aluminum shell, is absent. The EOS-TC accident calculations are documented in Section 6.4.3 and the results presented in Table 6-54. The maximum dose rate is 2.26 mrem/hr at a distance of 100 m from the EOS-TC *Based on the discussion in Section 6.2.8, the maximum accident dose rate is doubled to 4.5 mrem/hr*. If an 8-hour recovery time is assumed, the dose to an individual at the site boundary is *36* mrem, which is significantly below the 10 CFR 72.106 limit of 5 rem. This dose is also conservatively large because it is calculated as a distance of 100 m from the EOS-TC.

72.48

11.4 Ensuring that Occupational Radiation Exposures Are ALARA

11.4.1 Policy Considerations

The licensee's radiation safety and ALARA policies should be applied to the ISFSI. The ALARA program should follow the general guidelines of Regulatory Guides 1.8 [11-7], 8.8 [11-8], 8.10 [11-9], and 10 CFR 20. ISFSI personnel should be trained in the proper operation, inspection, repair and maintenance of the NUHOMS® EOS System, and updated on ALARA practices and dose reduction techniques. Implementation of ISFSI procedures should be reviewed by the licensee to ensure ALARA exposure.

11.4.2 Design Considerations

The thick inner cover of the EOS-DSC is designed to minimize exposure during draining, drying, and closure operations. The vent and drain ports are designed for maximum water flow rate and vacuum conductance to minimize the time (and thereby the exposure) associated with draining and vacuum drying. The design of the cover welds minimizes exposure during closure operations. The welds are designed to be easily performed by remote welding equipment. Because the cover welds are not used to lift the canister, they are relatively small, reducing the time needed to complete them. Because they are austenitic welds, no pre-heating is required. These welds are tested to be leak-tight as described in Chapter 8. Therefore, exposure associated with a leaking EOS-DSC is eliminated.

Lead, steel, water, and borated polyethylene in the EOS-TC provide required gamma and neutron shielding during transfer activities. The exterior of the EOS-TC is decontaminated prior to transfer to the ISFSI, thereby minimizing exposure of personnel to surface contamination.

The NUHOMS® EOS-HSM storage modules include no active components that require periodic maintenance, thereby minimizing potential personnel dose due to maintenance activities.

The shielding design features of the storage modules storage minimize occupational exposure for any activities on or near the ISFSI. These features are:

- The EOS-DSCs are loaded and sealed prior to transfer to the ISFSI. Seals are stainless steel welds with at least two layers.
- The fuel will not be unloaded, nor will the EOS-DSCs be opened at the ISFSI unless the ISFSI is specifically licensed for these purposes.
- The fuel is stored in a dry, inert environment inside the EOS-DSCs, so that no radioactive liquid is available for leakage.
- The EOS-DSCs are sealed with a helium atmosphere to prevent oxidation of the fuel. The leaktight design features are described in Chapter 8.

- The EOS-DSCs are heavily shielded on both ends to reduce external dose rates. The shielding design features are discussed in Chapter 6.
- No radioactive material will be discharged during storage since the EOS-DSC is designed, fabricated, and tested to be leaktight.
- The EOS-DSC outside surface is contamination free due to the use of clean water sealed in the annulus between the EOS-TC and EOS-DSC during loading operations.
- EOS-HSMs provide thick concrete shielding, while placement of modules immediately adjacent to one another enhances the effectiveness of this shielding.

Regulatory Position 2 of Regulatory Guide 8.8, is incorporated into the design considerations, as described below:

- Regulatory Position 2a, on access control, is met by use of a fence with a locked gate that surrounds the ISFSI and prevents unauthorized access.
- Regulatory Position 2b, on radiation shielding, is met by the heavy shielding of the NUHOMS® EOS System, which minimizes personnel exposures.
- Regulatory Position 2c, on process instrumentation and controls, is met by designing the instrumentation for a long service life and locating readouts in a low dose rate location. The use of temperature sensors for temperature measurements located in embedded thermowells provides reliable, easily maintainable instrumentation for this monitoring function.
- Regulatory Position 2d, on control of airborne contaminants, does not apply during transfer or storage because neither gaseous releases nor significant surface contamination are expected.
- Regulatory Position 2e, on crud control, is not applicable to the ISFSI because there are no systems at the ISFSI that could transport crud. The leaktight EOS-DSC design ensures that used fuel crud will not be released or transferred from the EOS-DSC. Draining back to the used fuel pool provides control over any crud that could be entrained in the outflow from the EOS-DSC draining operations.
- Regulatory Position 2f, on decontamination, is met because the EOS-TC is decontaminated prior to transfer to the ISFSI. The EOS-TC accessible surfaces are designed to facilitate decontamination.
- Regulatory Position 2g, on radiation monitoring, does not apply. There is no need for airborne radioactivity monitoring because the EOS-DSCs are sealed by leaktight welds. Area radiation monitors are not required because the ISFSI will not be occupied on a regular basis.
- Regulatory Position 2h, on resin and sludge treatment systems, is not applicable to the ISFSI because there are no radioactive systems containing resins or sludge associated with the ISFSI.

- Regulatory Position 2i concerning other miscellaneous ALARA items is not applicable because these items refer to radioactive systems not present at the ISFSI.

11.4.3 Operational Considerations

The operations description in Chapter 9 makes provision for measures that can minimize doses during operations, including:

- using temporary shielding,
- wetting equipment with clean water prior to pool immersion to improve ease of decontamination,
- preventing contamination of the EOS-DSC exterior by the use of clean water in a sealed EOS-TC/DSC annulus,
- using items such as remote equipment for welding and long-handled tools for decontamination, and
- controlling gases and liquids removed from the EOS-DSC during EOS-DSC vacuum drying and during fuel unloading.

The areas of highest operational dose are the front of a loaded EOS-HSM at the air inlet vent, at the EOS-TC side or EOS-DSC top with a partially or completely drained EOS-DSC (cover welding, transfer operations), and at the EOS-TC/DSC annulus. Operating procedures, temporary shielding, and personnel training are put into practice to minimize personnel exposure in these areas.

The EOS-DSCs contain no radioactive liquids and radioactive gases will be contained inside the fuel rods. The EOS-DSC is designed and welded to be leaktight.

The EOS-HSM and EOS-DSCs are designed to be essentially maintenance free. It is a passive system with no moving parts. The only anticipated maintenance procedures are the visual inspection of the bird screens on the EOS-HSM ventilation inlet and outlet openings, and periodic maintenance of the temperature sensors. Maintenance operations on the EOS-TC, transfer equipment and other auxiliary equipment are normally performed, in a low dose environment, during periods when fuel movement is not occurring.

The ISFSI contains no systems that process liquids or gases, or contain, collect, store, or transport radioactive liquids or solids, other than payloads identified in Chapter 2. Therefore, the ISFSI meets ALARA requirements, since there are no systems to be maintained other than the transfer and auxiliary equipment.

11.5 References

11-1 Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation."

11-2 Title 10, Code of Federal Regulations Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related greater than Class C Waste."

11-3 Title 40, Code of Federal Regulations, Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations."

11-4 U.S. Nuclear Regulatory Commission, Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," July 1992.

11-5 Oak Ridge National Laboratory, "MCNP/MCNPX – Monte Carlo N-Particle Transport Code System Including MCNP5 1.40 and MCNPX 2.5.0 and Data Libraries," CCC-730, RSICC Computer Code Collection, January 2006.

11-6 ANSI/ANS-6.1.1-1977, "Neutron and Gamma-Ray Fluence-to-Dose Factors, American Nuclear Society, LaGrange Park, Illinois, March 1977.

11-7 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.8, "Qualification and Training of Personnel for Nuclear Power Plants," Revision 2, April 1987.

11-8 U.S. Nuclear Regulatory Commission, Regulatory Guide 8.8, "Information Relevant to Ensuring That Occupational Exposures at Nuclear Power Stations will be As Low As Is Reasonably Achievable," Revision 3, June 1978.

11-9 U.S. Nuclear Regulatory Commission, Regulatory Guide 8.10, "Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As is Reasonably Achievable," Revision 1-R, May 1977.

Table 11-1
Occupational Dose Rates

			Dose Rate (mrem/hr)			
			EOS-TC108		EOS-TC125/135	
Dose Rate Location	**Averaged Segments**	**Config.**	**EOS-37PTH DSC**	**EOS-89BTH DSC**	**EOS-37PTH DSC**	**EOS-89BTH DSC**
DRL1	A1-18, R11	Decon.	218	194	*101*	62
DRL2	A3-16, R10	Decon.	-	-	*315*	181
		Transfer	726	747	*248*	239
DRL3	A17, R9	Decon.	-	-	*232*	98
		Welding	206	198	*127*	113
		Transfer	208	199	-	-
DRL4	A3-11, R9	Decon.	1191	1050	-	-
DRL5	A1-18, R10	Transfer	559	586	*196*	191
DRL6	A17-18, R9	Transfer	118	100	*58*	43
DRL7	A17-18, R10	Transfer	199	189	*97*	91
DRL8	A2, R9	Transfer	91	165	*59*	65
DRL9	A19, R0	Transfer	75	137	*76*	114
DRL10	A1, R10	Transfer	82	121	*38*	38
EOS-HSM *(HSM)*	Front face surface average	-	22	22	22	22

Table 11-2
Occupational Exposure, EOS-TC108 with EOS-37PTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
1	Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.5	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area.	Decon.	DRL1	2	0.25	218	109	3%
4	Install neutron shield. Fill neutron shield with water.	Decon.	DRL4	3	0.33	1191	1179	35%
5	Prepare and weld inner top cover plate.	Welding	DRL3	2	0.75	206	309	9%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.5	206	206	6%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.5	206	206	6%
8	Drain annulus. Install EOS-TC aluminum top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.5	559	280	8%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	726	479	14%
10	Remove aluminum top cover and replace with steel top cover.	Transfer	DRL3	2	0.33	208	137	4%
11	Ready the skid and trailer. Transfer the EOS-TC to ISFSI. Position the EOS-TC in close proximity with the EOS-HSM.	N/A	N/A	6	1.83	0	0	0%
12	Remove the EOS-TC top cover.	Transfer	HSM+DRL6	2	0.67	140	188	6%

Table 11-2
Occupational Exposure, EOS-TC108 with EOS-37PTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
13	Align and dock the EOS-TC with the EOS-HSM.	Transfer	HSM+DRL7	2	0.25	221	111	3%
14	Position and align ram with EOS-TC.	Transfer	HSM+DRL8	2	0.5	113	113	3%
15	Remove ram access cover plate.	Transfer	DRL9	1	0.08	75	6	0%
16	Transfer the EOS-DSC from the EOS-TC to the EOS-HSM.	N/A	N/A	3	0.5	0	0	0%
17	Lift the ram back onto the trailer and un-dock the EOS-TC from the EOS-HSM.	Transfer	HSM+DRL10	2	0.08	104	17	0%
18	Install EOS-HSM access door.	Transfer	HSM	2	0.5	22	22	1%
						Total	3361[(1)]	

Note:

(1) A crane hang-up off-normal event adds 872 person-mrem (DRL1/decon * 4 workers * 1 hour).

Table 11-3
Occupational Exposure, EOS-TC108 with EOS-89BTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
1	Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area.	Decon.	DRL1	2	0.25	194	97	3%
4	Install neutron shield. Fill neutron shield with water.	Decon.	DRL4	3	0.33	1050	1040	32%
5	Prepare and weld inner top cover plate.	Welding	DRL3	2	0.75	198	297	9%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	198	198	6%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	198	198	6%
8	Drain annulus. Install EOS-TC aluminum top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	586	293	9%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	747	498	15%
10	Remove aluminum top cover and replace with steel top cover.	Transfer	DRL3	2	0.33	199	133	4%
11	Ready the skid and trailer. Transfer the EOS-TC to ISFSI. Position the EOS-TC in close proximity with the EOS-HSM.	N/A	N/A	6	1.83	0	0	0%
12	Remove the EOS-TC top cover.	Transfer	HSM+DRL6	2	0.67	122	163	5%

Table 11-3
Occupational Exposure, EOS-TC108 with EOS-89BTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
13	Align and dock the EOS-TC with the EOS-HSM.	Transfer	HSM+DRL7	2	0.25	211	106	3%
14	Position and align ram with EOS-TC.	Transfer	HSM+DRL8	2	0.50	187	187	6%
15	Remove ram access cover plate.	Transfer	DRL9	1	0.08	137	11	0%
16	Transfer the EOS-DSC from the EOS-TC to the EOS-HSM.	N/A	N/A	3	0.50	0	0	0%
17	Lift the ram back onto the trailer and un-dock the EOS-TC from the EOS-HSM.	Transfer	HSM+DRL10	2	0.08	143	24	1%
18	Install EOS-HSM access door.	Transfer	HSM	2	0.50	22	22	1%
						Total	3270(1)	

Note:

(1) A crane hang-up off-normal event adds 776 person-mrem (DRL1/decon * 4 workers * 1 hour).

Table 11-4
Occupational Exposure, EOS-TC125/135 with EOS-37PTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
1	Drain neutron shield if necessary. Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.5	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area. Refill neutron shield tank if necessary.	Decon.	DRL1	2	0.25	*101*	*50*	2%
4	Decontaminate the EOS-TC and prepare welds.	Decon.	DRL2	2	1.75	*315*	*1104*	*46%*
		Decon.	DRL3	2	0.5	*232*	*232*	*10%*
5	Weld inner top cover plate.	Welding	DRL3	2	0.75	*127*	*191*	*8%*
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.5	*127*	*127*	*5%*
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.5	*127*	*127*	*5%*
8	Drain annulus. Install EOS-TC top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.5	*196*	*98*	4%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	*248*	*164*	7%
10	Ready the skid and trailer for service. Transfer the EOS-TC to ISFSI. Position the EOS-TC in close proximity with the EOS-HSM.	N/A	N/A	6	1.83	0	0	0%
11	Remove the EOS-TC top cover.	Transfer	HSM+DRL6	2	0.67	*80*	*107*	5%

Table 11-4
Occupational Exposure, EOS-TC125/135 with EOS-37PTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person -mrem)	% of Total Dose
12	Align and dock the EOS-TC with the EOS-HSM.	Transfer	HSM+DRL7	2	0.25	*119*	*60*	3%
13	Position and align ram with EOS-TC.	Transfer	HSM+DRL8	2	0.5	*81*	*81*	*3%*
14	Remove ram access cover plate.	Transfer	DRL9	1	0.08	*76*	6	0%
15	Transfer the EOS-DSC from the EOS-TC to the EOS-HSM.	N/A	N/A	3	0.5	0	0	0%
16	Lift the ram back onto the trailer and un-dock the EOS-TC from the EOS-HSM.	Transfer	HSM+DRL10	2	0.08	*60*	*10*	0%
17	Install EOS-HSM access door.	Transfer	HSM	2	0.5	22	22	1%
						Total(1)	*2379*	

Note:

(1) Use of aluminum cask lid increases total occupational dose by approximately 4 % (~*95* person-mrem).

Table 11-5
Occupational Exposure, EOS-TC125 with EOS-89BTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
1	Drain neutron shield if necessary. Place an empty EOS-DSC into an EOS-TC and prepare the EOS-TC for placement into the spent fuel pool.	N/A	N/A	6	4.00	0	0	0%
2	Move the EOS-TC containing an EOS-DSC without fuel into the spent fuel pool.	N/A	N/A	6	1.50	0	0	0%
3	Remove a loaded EOS-TC from the fuel pool and place in the decontamination area. Refill neutron shield tank if necessary.	Decon.	DRL1	2	0.25	62	31	2%
4	Decontaminate the EOS-TC and prepare welds.	Decon.	DRL2	2	1.75	181	634	38%
		Decon.	DRL3	2	0.50	98	98	6%
5	Weld inner top cover plate.	Welding	DRL3	2	0.75	113	170	10%
6	Vacuum dry and backfill with helium.	Welding	DRL3	2	0.50	113	113	7%
7	Weld outer top cover plate and port covers, perform non-destructive examination.	Welding	DRL3	2	0.50	113	113	7%
8	Drain annulus. Install EOS-TC top cover. Ready the support skid and transfer trailer.	Transfer	DRL5	1	0.50	191	96	6%
9	Place the EOS-TC onto the skid and trailer. Secure the EOS-TC to the skid.	Transfer	DRL2	2	0.33	239	159	10%
10	Ready the skid and trailer for service. Transfer the EOS-TC to ISFSI. Position the EOS-TC in close proximity with the EOS-HSM.	N/A	N/A	6	1.83	0	0	0%
11	Remove the EOS-TC top cover.	Transfer	HSM+DRL6	2	0.67	65	87	5%

Table 11-5
Occupational Exposure, EOS-TC125 with EOS-89BTH DSC
(2 Pages)

No.	Operation	Configuration	Dose Rate Location	No. of People	Duration (hr)	Dose Rate (mrem/hr)	Dose (person-mrem)	% of Total Dose
12	Align and dock the EOS-TC with the EOS-HSM.	Transfer	HSM+DRL7	2	0.25	113	57	3%
13	Position and align ram with EOS-TC.	Transfer	HSM+DRL8	2	0.50	87	87	5%
14	Remove ram access cover plate.	Transfer	DRL9	1	0.08	114	10	1%
15	Transfer the EOS-DSC from the EOS-TC to the EOS-HSM.	N/A	N/A	3	0.50	0	0	0%
16	Lift the ram back onto the trailer and un-dock the EOS-TC from the EOS-HSM.	Transfer	HSM+DRL10	2	0.08	60	10	1%
17	Install EOS-HSM access door.	Transfer	HSM	2	0.50	22	22	1%
						Total(1)	1680	

Note:

(1) Use of aluminum cask lid increases total occupational dose by approximately 4 % (~70 person-mrem).

Table 11-6
Total Annual Exposure from ISFSI

Distance (m)	2x10		Two 1x10	
	Front Total Dose (mrem)	Side Total Dose (mrem)	Back Total Dose (mrem)	Side Total Dose (mrem)
6.1	8.33E+04	2.83E+04	3.20E+04	4.22E+04
10	5.51E+04	2.14E+04	2.51E+04	2.87E+04
20	2.62E+04	1.30E+04	1.56E+04	1.56E+04
30	1.55E+04	8.93E+03	1.08E+04	1.04E+04
40	1.03E+04	6.45E+03	7.80E+03	7.41E+03
50	7.26E+03	4.87E+03	5.85E+03	5.54E+03
60	5.40E+03	3.74E+03	4.47E+03	4.22E+03
70	4.07E+03	2.92E+03	3.57E+03	3.31E+03
80	3.14E+03	2.31E+03	2.79E+03	2.63E+03
90	2.49E+03	1.85E+03	2.21E+03	2.10E+03
100	1.99E+03	1.51E+03	1.81E+03	1.72E+03
200	3.03E+02	2.43E+02	2.93E+02	2.80E+02
300	6.41E+01	5.02E+01	6.02E+01	5.94E+01
400	1.43E+01	1.30E+01	1.53E+01	1.43E+01
500	4.13E+00	3.42E+00	4.42E+00	4.08E+00
600	1.37E+00	1.04E+00	1.21E+00	1.18E+00

Table 11-7
ISFSI Surface Sources

2x10 Back-to-Back Array			
Source	**Area (cm^2)**	**Neutron Source (n/s)**	**Gamma Source (γ/s)**
Roof	4.260E+06	4.017E+08	8.802E+11
Front 1	1.765E+06	3.054E+07	5.073E+10
Front 2	1.765E+06	3.054E+07	5.073E+10
Side 1	7.677E+05	1.547E+06	1.621E+09
Side 2	7.677E+05	1.547E+06	1.621E+09
Total	9.325E+06	4.658E+08	9.849E+11
Two 1x10 Front-to-Front Arrays			
Source	**Area (cm^2)**	**Neutron Source (n/s)**	**Gamma Source (γ/s)**
Roof	2.416E+06	2.278E+08	4.992E+11
Front	1.765E+06	3.054E+07	5.073E+10
Back	1.765E+06	2.262E+06	6.164E+09
Side 1	4.354E+05	8.773E+05	9.193E+08
Side 2	4.354E+05	8.773E+05	9.193E+08
Total	6.816E+06	2.624E+08	5.580E+11

Table 11-8
2x10 Back-to-Back Dose Rates
(2 Pages)

In Front of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	9.35E+00	1.55E-01	9.51E+00	0.1%
10	6.18E+00	1.10E-01	6.29E+00	0.1%
20	2.93E+00	5.53E-02	2.99E+00	0.1%
30	1.74E+00	3.26E-02	1.77E+00	0.2%
40	1.15E+00	2.14E-02	1.17E+00	0.2%
50	8.14E-01	1.48E-02	8.29E-01	0.3%
60	6.06E-01	1.06E-02	6.17E-01	0.4%
70	4.57E-01	7.97E-03	4.65E-01	0.3%
80	3.53E-01	6.08E-03	3.59E-01	0.4%
90	2.80E-01	4.79E-03	2.84E-01	0.5%
100	2.23E-01	3.80E-03	2.27E-01	0.6%
200	3.40E-02	6.32E-04	3.46E-02	1.3%
300	7.15E-03	1.73E-04	7.32E-03	4.5%
400	1.57E-03	5.89E-05	1.63E-03	1.7%
500	4.54E-04	1.79E-05	4.72E-04	3.3%
600	1.49E-04	7.89E-06	1.57E-04	14.9%

Table 11-8
2x10 Back-to-Back Dose Rates
(2 Pages)

At Side of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	3.16E+00	7.72E-02	3.23E+00	0.1%
10	2.38E+00	5.98E-02	2.44E+00	0.2%
20	1.45E+00	3.45E-02	1.49E+00	0.2%
30	9.97E-01	2.23E-02	1.02E+00	0.2%
40	7.21E-01	1.52E-02	7.36E-01	0.3%
50	5.45E-01	1.10E-02	5.56E-01	0.3%
60	4.19E-01	8.04E-03	4.27E-01	1.0%
70	3.28E-01	6.16E-03	3.34E-01	0.4%
80	2.59E-01	4.84E-03	2.64E-01	0.4%
90	2.08E-01	3.81E-03	2.11E-01	0.4%
100	1.70E-01	2.99E-03	1.73E-01	0.6%
200	2.71E-02	6.14E-04	2.77E-02	1.1%
300	5.59E-03	1.35E-04	5.73E-03	1.6%
400	1.42E-03	6.43E-05	1.48E-03	3.5%
500	3.70E-04	2.00E-05	3.90E-04	3.8%
600	1.11E-04	7.94E-06	1.19E-04	4.1%

Table 11-9
Two 1x10 Front-to-Front Dose Rates
(2 Pages)

In Back of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	3.58E+00	7.86E-02	3.66E+00	0.1%
10	2.80E+00	6.46E-02	2.86E+00	0.1%
20	1.75E+00	3.99E-02	1.79E+00	0.2%
30	1.20E+00	2.60E-02	1.23E+00	0.3%
40	8.73E-01	1.79E-02	8.91E-01	0.2%
50	6.55E-01	1.29E-02	6.68E-01	0.4%
60	5.00E-01	9.51E-03	5.10E-01	0.3%
70	4.01E-01	7.23E-03	4.08E-01	1.5%
80	3.12E-01	5.63E-03	3.18E-01	0.4%
90	2.48E-01	4.37E-03	2.52E-01	0.4%
100	2.04E-01	3.47E-03	2.07E-01	0.5%
200	3.29E-02	6.08E-04	3.35E-02	1.0%
300	6.72E-03	1.57E-04	6.87E-03	1.4%
400	1.69E-03	5.74E-05	1.74E-03	3.0%
500	4.78E-04	2.63E-05	5.04E-04	6.4%
600	1.30E-04	8.19E-06	1.38E-04	4.1%

Table 11-9
Two 1x10 Front-to-Front Dose Rates
(2 Pages)

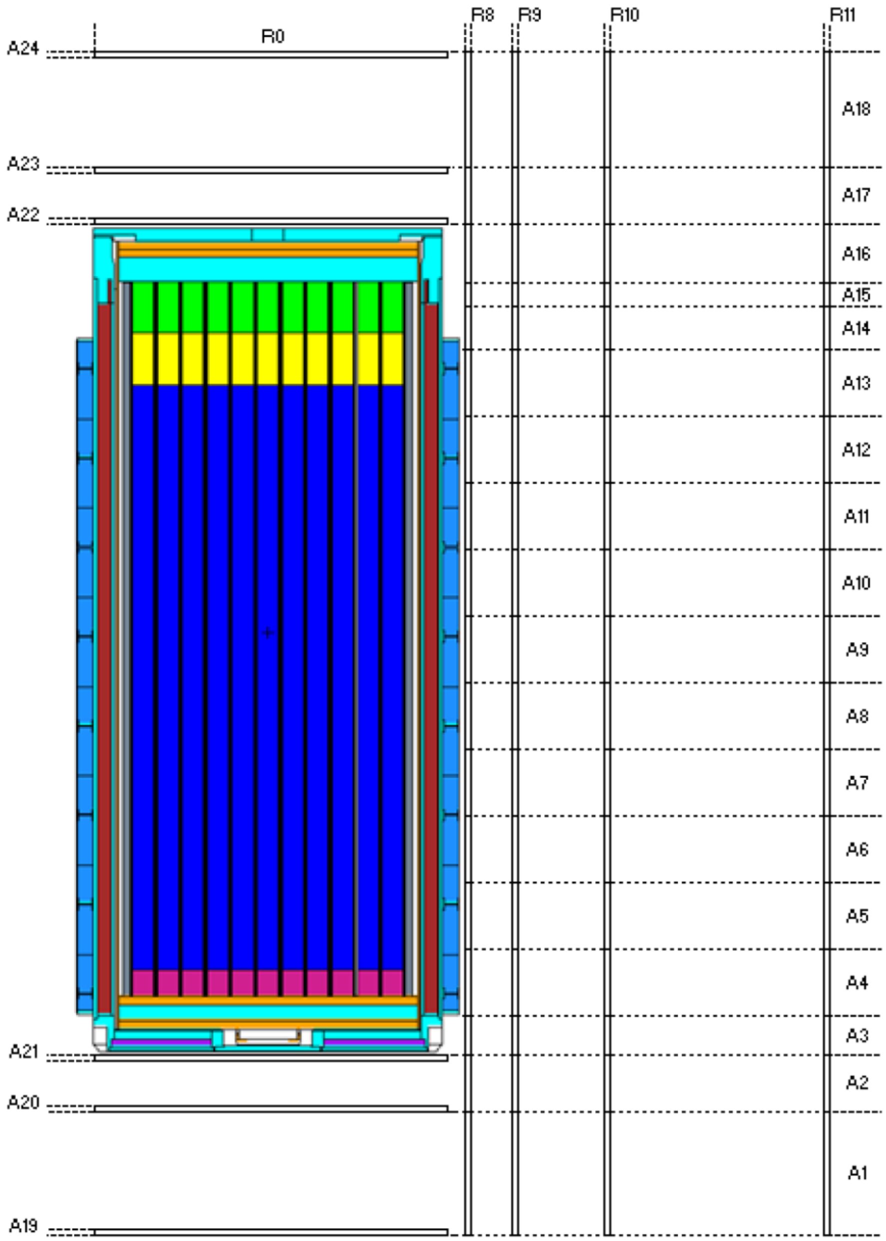
At Side of ISFSI				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	4.73E+00	9.14E-02	4.82E+00	0.2%
10	3.21E+00	6.85E-02	3.27E+00	0.2%
20	1.74E+00	3.82E-02	1.78E+00	0.3%
30	1.16E+00	2.43E-02	1.19E+00	0.3%
40	8.29E-01	1.66E-02	8.46E-01	0.4%
50	6.20E-01	1.23E-02	6.32E-01	0.5%
60	4.72E-01	8.94E-03	4.81E-01	0.4%
70	3.71E-01	6.93E-03	3.78E-01	0.5%
80	2.95E-01	5.13E-03	3.01E-01	0.8%
90	2.35E-01	4.01E-03	2.39E-01	0.7%
100	1.92E-01	3.49E-03	1.96E-01	0.8%
200	3.13E-02	6.73E-04	3.20E-02	1.5%
300	6.61E-03	1.66E-04	6.78E-03	2.9%
400	1.58E-03	4.63E-05	1.63E-03	2.8%
500	4.47E-04	1.93E-05	4.66E-04	7.0%
600	1.28E-04	7.39E-06	1.35E-04	6.7%

Table 11-10
2x10 Back-to-Back Accident Dose Rates
(2 Pages)

Accident Front Dose Rate				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	1.05E+02	4.59E-01	1.05E+02	0.2%
10	8.37E+01	3.72E-01	8.41E+01	0.1%
20	5.29E+01	2.22E-01	5.31E+01	0.2%
30	3.65E+01	1.48E-01	3.66E+01	0.2%
40	2.64E+01	1.05E-01	2.65E+01	0.3%
50	1.98E+01	7.81E-02	1.99E+01	0.4%
60	1.52E+01	5.96E-02	1.53E+01	0.3%
70	1.20E+01	4.61E-02	1.21E+01	0.4%
80	9.58E+00	3.82E-02	9.62E+00	0.8%
90	7.65E+00	3.01E-02	7.68E+00	0.4%
100	6.26E+00	2.44E-02	6.29E+00	0.6%
200	1.04E+00	4.95E-03	1.05E+00	0.8%
300	2.25E-01	1.34E-03	2.27E-01	1.5%
400	6.33E-02	5.91E-04	6.39E-02	6.4%
500	1.71E-02	1.82E-04	1.72E-02	3.3%
600	4.88E-03	9.30E-05	4.97E-03	3.6%

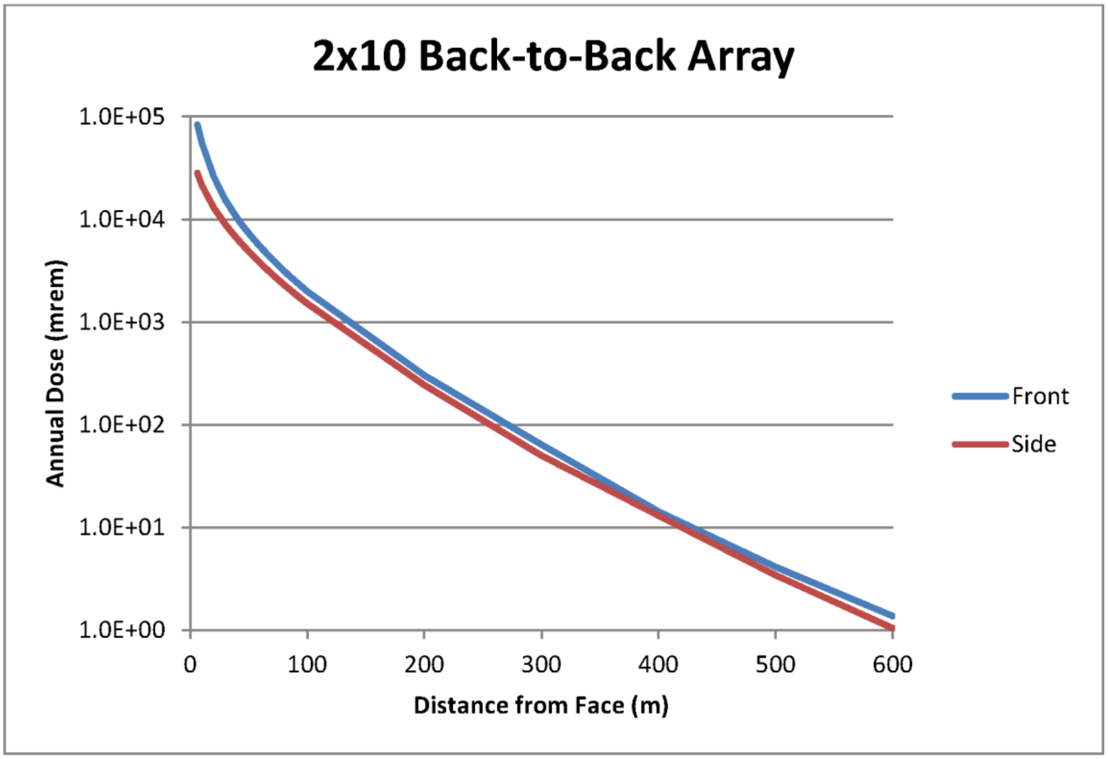
Table 11-10
2x10 Back-to-Back Accident Dose Rates
(2 Pages)

Accident Side Dose Rate				
Distance (m)	**Gamma Dose Rate (mrem/hr)**	**Neutron Dose Rate (mrem/hr)**	**Total Dose Rate (mrem/hr)**	**σ**
6.1	7.91E+01	3.11E-01	7.94E+01	0.2%
10	6.37E+01	2.64E-01	6.39E+01	0.2%
20	4.12E+01	1.67E-01	4.14E+01	0.2%
30	2.89E+01	1.15E-01	2.91E+01	0.2%
40	2.15E+01	8.25E-02	2.16E+01	0.4%
50	1.62E+01	6.30E-02	1.63E+01	0.3%
60	1.26E+01	4.88E-02	1.27E+01	0.4%
70	1.00E+01	3.88E-02	1.00E+01	0.4%
80	7.98E+00	3.12E-02	8.01E+00	0.4%
90	6.52E+00	2.57E-02	6.54E+00	0.5%
100	5.35E+00	2.20E-02	5.37E+00	0.7%
200	9.27E-01	4.32E-03	9.31E-01	1.0%
300	2.12E-01	1.30E-03	2.13E-01	2.5%
400	5.40E-02	4.13E-04	5.44E-02	2.5%
500	1.43E-02	1.82E-04	1.45E-02	3.3%
600	4.60E-03	7.45E-05	4.68E-03	4.9%



EOS-89BTH DSC in EOS-TC125/135 depicted. Other configurations are similar.

Figure 11-1
EOS-TC General Dose Rate Tally Locations



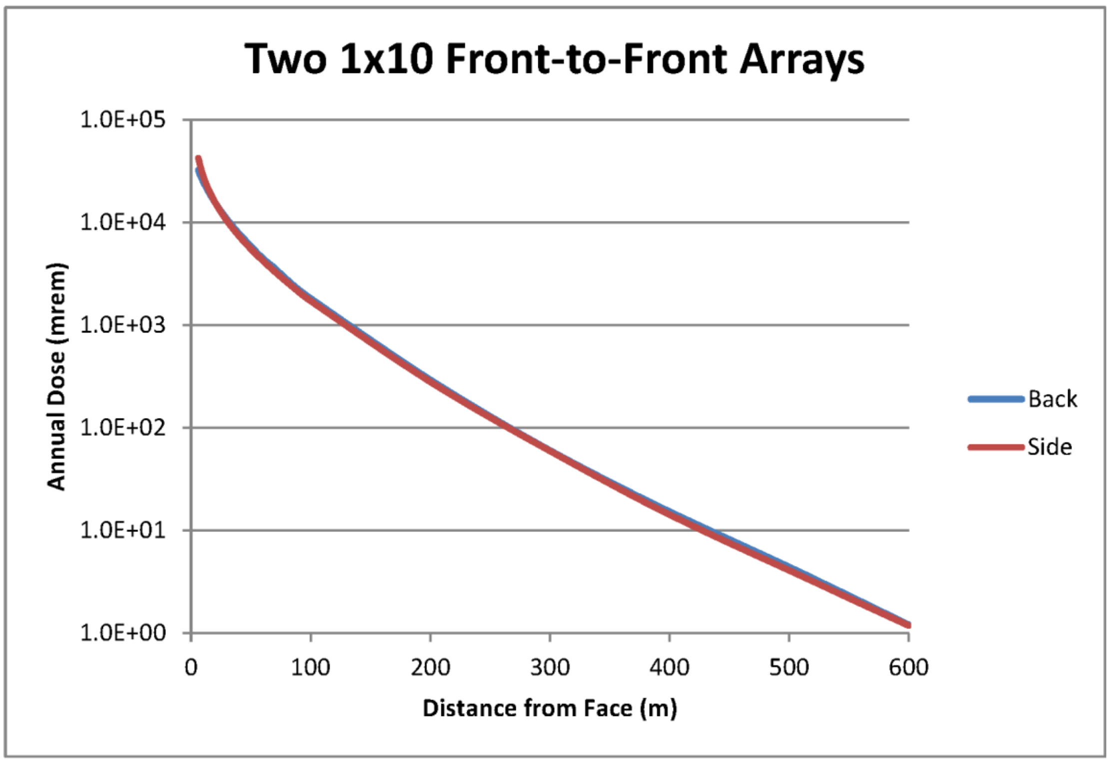


Figure 11-2
Total Annual Exposure from the ISFSI

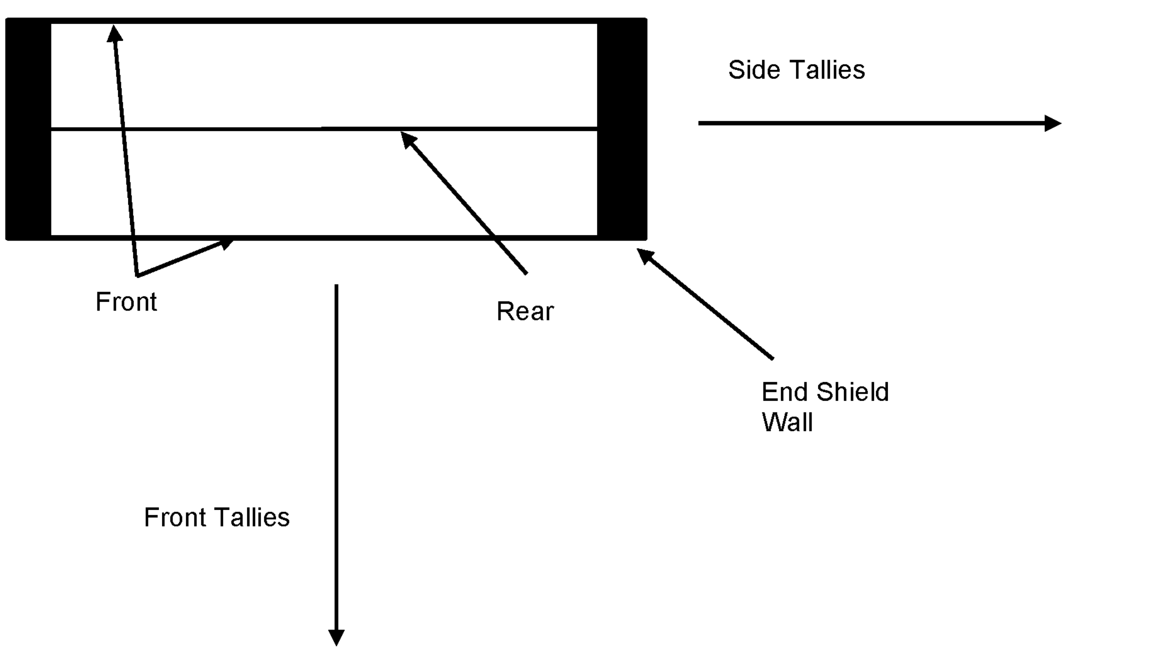
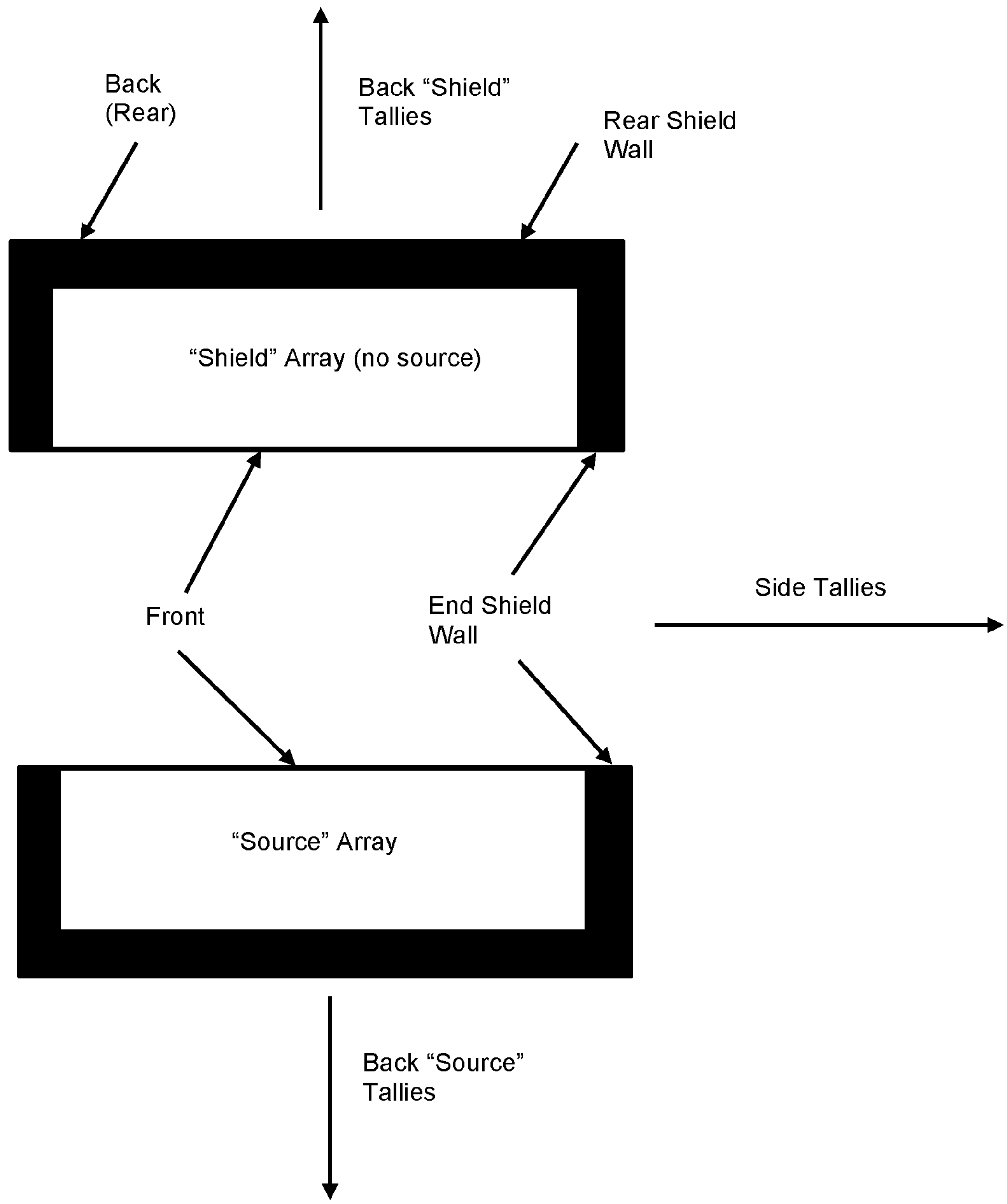


Figure 11-3
2x10 ISFSI MCNP Geometry



Note: Back "Source" Tallies and Back "Shield" Tallies are summed to create the total back dose rates. Side Tallies are multiplied by two to create the total side dose rates.

Figure 11-4
Two 1x10 ISFSI MCNP Geometry

CHAPTER 12
ACCIDENT ANALYSIS

Table of Contents

12. ACCIDENT ANALYSIS

12.1 Introduction

This Chapter describes the postulated off-normal and accident events that might occur during transfer/storage of the EOS-37PTH or EOS-89BTH dry shielded canister (DSC) to the independent spent fuel storage installation (ISFSI). This chapter also addresses the potential causes of these events, their detection and consequences, and the corrective course of action to be taken by ISFSI personnel. Off-normal and accident analyses demonstrate that the functional integrity of the system is maintained by:

- Maintaining sub-criticality within margins defined in Chapter 7.
- Maintaining confinement boundary integrity
- Ensuring fuel retrievability and
- Maintaining doses within 10 CFR 72.104 [12-1] limits for off-normal and 10 CFR 72.106 limits for accident conditions.

The accident dose calculations sections report the expected doses resulting from the postulated event in terms of whole body doses only. The leak tight DSC design and the maintenance of confinement boundary integrity under all credible off-normal and accident scenarios ensures no radiation leakage from the EOS-37PTH DSC or EOS-89BTH DSC, thereby limiting dose consequences to direct and scattered radiation doses without any associated inhalation or ingestion doses.

The accident analysis related to the NUHOMS® MATRIX (HSM-MX) is documented in Appendix A.12.

Where the term "HSM" is used without distinction, this term shall be use to apply to both the EOS-HSM and HSM-MX.

12.2 Off-Normal Events

Off-normal events are design events of the second type (Design Event II) as defined in ANSI/ANS 57.9 [12-2]. Design Event II conditions consist of a set of events that do not occur regularly, but can be expected to occur with a moderate frequency, or about once during a calendar year of ISFSI operation.

For the NUHOMS® EOS System, off-normal events could occur during fuel loading, trailer movement, EOS-37PTH DSC or EOS-89BTH DSC transfer and other operational events. The two off-normal events, which bound the range of off-normal conditions, are:

- A "jammed" DSC during loading or unloading from the EOS-HSM
- The extreme ambient temperatures of -40 °F (winter) and +117 °F (summer)

These two events envelop the range of expected off-normal structural loads and temperatures acting on the NUHOMS® EOS System.

12.2.1 Off-Normal Transfer Load

Although unlikely, the postulated off-normal handling event assumes that the leading edge of the DSC becomes jammed against some element of the support structure during transfer between the EOS transfer cask (TC) and the EOS-horizontal storage module (*EOS*-HSM).

Cause of the Event

It is postulated that if the EOS-TC is not accurately aligned with respect to the EOS-HSM and as a result the DSC binds or jams during transfer operations.

The interiors of the EOS-TC and the EOS-HSM are inspected prior to transfer operations to ensure there are no obstacles. Also, the DSC has beveled lead-ins on each end, designed to avoid binding or sticking on small (less than 0.25-inch) obstacles. The EOS-TC and the DSC support structure inside the EOS-HSM are also designed with lead-ins to minimize binding or obstruction during DSC transfer. The postulated off-normal handling load event assumes that the leading edge of the DSC becomes jammed against some element of the DSC support structure because of an unlikely gross misalignment of the EOS-TC.

The interfacing dimensions of the top end of the EOS-TC and the EOS-HSM access opening sleeve are specified so that docking the EOS-TC with the EOS-HSM is not possible should gross misalignments between the EOS-TC and EOS-HSM exist.

Detection of the Event

The normal load to push/pull the DSC in and out of the EOS-TC/EOS-HSM is less than 32 kips (135 kips x 0.2/Cos 30). This movement is performed at a very low speed. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. If the DSC were to jam or bind during transfer, the pressure for the ram increases. The off-normal load set for the "jammed DSC" for both insertion and retrieval are 135 kips and 80 kips, respectively. This load is administratively controlled to ensure that during the transfer operation this load is not exceeded.

During the transfer operation, the force exerted on the DSC by the ram is that required to first overcome the static frictional resisting force between the EOS-TC rails and the DSC. Once the DSC begins to slide, the resisting force is a function of the sliding friction coefficient between the DSC and the EOS-TC rails and/or between the DSC and the EOS-HSM support rails. If motion is prevented, the pressure increases, thereby increasing the force on the DSC until the ram system pressure limit is reached. This limit is controlled so that adequate force is available to overcome variations in surface finish, etc., but is sufficiently low to ensure that component damage does not occur.

Analysis of Effects and Consequences

The DSC and the EOS-HSM are designed and analyzed for off-normal transfer loads of 135 kips for insertion and 80 kips for retrieval during insertion and retrieval (unloading) operations. These analyses are discussed in Appendix 3.9.1 for DSC and 3.9.4 for EOS-HSM. For either loading or unloading of the DSC under off-normal conditions, the stresses on the shell assembly components are demonstrated to be within the ASME allowable stress limits. Therefore, permanent deformation of the DSC shell components does not occur. The internal basket assembly components are unaffected by these loads based on clearances provided between the basket and DSC internal cavity.

There is no breach of the confinement pressure boundary and, therefore, no potential for release of radioactive material exists.

Corrective Actions

The required corrective action is to reverse the direction of the force being applied to the DSC by the ram, and return the DSC to its previous position. Since no permanent deformation of the DSC occurs, the sliding of the DSC back to its previous position is unimpeded. The EOS-TC alignment is then rechecked, and the EOS-TC repositioned as necessary before attempts at transfer are renewed.

12.2.2 Extreme Temperature

The NUHOMS® EOS System is designed for use at ambient temperatures of -40 °F (winter) and 117 °F (summer). Even though these extreme temperatures are likely to occur for a short period of time, it is conservatively assumed that these temperatures occur for a sufficient duration to produce steady state temperature distributions in each of the affected NUHOMS® EOS System components. Each licensee should verify that this range of ambient temperatures envelopes the design basis ambient temperatures for the ISFSI site. The NUHOMS® EOS System components affected by the postulated extreme ambient temperatures are the EOS-TC and DSC during their transfer from the plant's fuel/reactor building to the ISFSI site, and the EOS-HSM during storage of a DSC.

Cause of the Event

Off-normal ambient temperatures are natural phenomena.

Detection of Event

Off-normal ambient temperature conditions are confirmed by the licensee to be bounding for their site.

Analysis of Effects and Consequences

Thermal analysis of the NUHOMS® EOS System for extreme ambient conditions is presented in Chapter 4. The effects of extreme ambient temperatures on the NUHOMS® EOS System are analyzed as follows:

Components	UFSAR Sections
EOS-37PTH DSC and EOS-89BTH DSC Shell	Appendix 3.9.1
EOS-37PTH Basket and EOS-89BTH Basket	Appendix 3.9.2
EOS-HSM	Appendix 3.9.4
EOS-TC	Appendix 3.9.5

Corrective Actions

None

12.3 Postulated Accident

The design basis accident events specified by ANSI/ANS 57.9-1984 [12-2] and other postulated accidents that may affect the normal safe operation of the NUHOMS® EOS System are addressed in this section.

The following sections provide descriptions of the analyses performed for each accident condition. The analyses demonstrate that the requirements of 10 CFR 72.122 [12-1] are met and that adequate safety margins exist for the NUHOMS® EOS System design. The resulting accident condition stresses in the NUHOMS® EOS System components are evaluated and compared with the applicable code limits set forth in Chapter 2.

Radiological calculations are performed to confirm that on-site and off-site dose rates are within acceptable limits.

The postulated accident conditions addressed in this section include:

- EOS-TC drop
- Earthquake
- Tornado wind pressure and tornado-generated missiles
- Flood
- Blockage of EOS-HSM air inlet and outlet openings
- Lightning
- Fire/Explosion

12.3.1 EOS-TC Drop

Cause of Accident

As described in Chapter 9, handling operations involving hoisting and movement of EOS-TC loaded with the EOS-37PTH DSC or EOS-89BTH DSC is typically performed inside the plant's fuel handling building. These include utilizing the crane for placement of the empty DSC into the EOS-TC cavity, lifting the EOS-TC/DSC into and out of the plant's spent fuel pool, and placement of the EOS-TC/DSC onto the transfer skid/trailer. An analysis of the plant's lifting devices used for these operations, including the crane and lifting yoke, is needed to address a postulated drop accident for the ESO-TC and its contents. The postulated drop accident scenarios addressed in the plant's 10 CFR Part 50 [12-3] licensing basis are plant-specific and should be addressed by the licensee.

Once the EOS-TC is loaded onto the transfer skid/trailer and secured, it is pulled to the EOS-HSM site by a tractor vehicle. A predetermined route is chosen to minimize the potential hazards that could occur during transfer. This movement is performed at very low speeds. System operating procedures and technical specification limits defining the safeguards to be provided ensure that the system design margins are not compromised. As a result, it is highly unlikely that any plausible incidents leading to a EOS-TC drop accident could occur. Similarly, at the ISFSI site, the transfer skid/trailer is backed-up to, and aligned with, the EOS-HSM using positioning equipment. The EOS-TC is then docked with, and secured to, the EOS-HSM access opening. The loaded DSC is transferred to or from the EOS-HSM using a ram system. The bolts that secure the transfer skid to the transfer trailer remain in place at all times when the transfer trailer is in motion. The EOS-TC is secured to the transfer skid. As a result, there is no reasonable way during these operations for a loaded EOS-TC drop accident to occur.

Lifts of the EOS-TC loaded with the dry storage canister are made within the existing heavy loads requirements and procedures of the licensed nuclear power plant. The EOS-TC design meets requirements of NUREG-0612 [12-4] and American National Standards Institute (ANSI) N14.6 [12-5].

The EOS-TC is transferred to the ISFSI in a horizontal configuration. Therefore, the only drop accident evaluated during storage or transfer operations is a side drop or a corner drop.

The EOS-TC and DSC are evaluated for a postulated side and corner drops to demonstrate structural integrity during transfer and plant handling.

Accident Analysis

Chapter 3 evaluates the structural integrity of the EOS-TC loaded with an EOS-37PTH DSC or EOS-89BTH DSC under two postulated accident drop scenarios during transfer using LS-DYNA.

Of the three EOS-TCs, TC108, TC125, and TC135, the TC108 is the bounding EOS-TC for analytical purposes, due to the higher accelerations expected from the lighter weight construction. The scenarios are a 65-inch drop onto the side of the loaded EOS-TC and another onto the corner of the EOS-TC. The second drop on the corner assumes a 30-degree angle from the horizontal side drop orientation. The drop height is based on the 65-inch height of the transfer trailer on which the EOS-TC is transferred.

Components	UFSAR Sections
EOS-TC loaded with EOS-37PTH DSC (Side and corner drop)	Appendices 3.9.1 - 3.9.3 and 3.9.5
EOS-TC loaded with EOS-89BTH DSC (Side and corner drop)	Appendices 3.9.1 - 3.9.3 and 3.9.5
EOS-37PTH DSC, PWR Fuel Cladding (Side and corner drop)	Appendix 3.9.6
EOS-89BTH DSC, BWR Fuel Cladding (Side and corner drop)	Appendix 3.9.6

All stresses are within allowable limits in both drop scenarios for the TC108, EOS-37PTH DSC and EOS-89BTH DSC. The largest strain in the basket is 0.9 % and 0.6 % for the EOS-TC*108* loaded with EOS-37PTH DSC and EOS-89BTH DSC, respectively. The maximum stresses and strains in the fuel cladding for the side and corner drops remain below the applicable yield strength, therefore there is no fuel deformations.

The strain is limited in effect given the mode of deformation as the basket plates maintain their general shape. This deformation is limited and the position of the fuel assemblies is maintained from their initial positions relative to each other. The deformations of the basket plates are approximately uniform in the direction of impact and the fuel does not change configuration. Therefore, these deformations do not have an effect on criticality control.

<u>Accident Dose Calculation</u>

Based on analysis results presented in Appendix 3.9.3, Sections 3.9.3.3 and 3.9.3.4, the accidental EOS-TC drop scenarios do not breach the EOS-37PTH or the EOS-89BTH DSC confinement boundaries. The function of EOS-TC lead shielding is not compromised by these drops. The EOS-TC neutron shield, however, may be damaged in an accidental drop.

Dose rates are computed at 100 m from the EOS-TC with the neutron shield removed, which is the minimum allowed distance to the site boundary. As presented in Chapter 6, Table 6-54, the maximum dose rate at 100 m from an EOS-TC during a loss of neutron shield and lead slump in an accidental drop accident is 2.26 mrem/hr. *Based on the discussion in Section 6.2.8, the maximum accident dose rate is doubled to 4.5 mrem/hr.* If an 8-hour recovery time is assumed, the dose to an individual at the site boundary is *4.5**8 = *36* mrem, which is significantly below the 10 CFR 72.106 dose limit of 5 rem. Amd 1 & 72.48

Corrective Actions

The DSC is inspected for damage, and the DSC opened and the fuel removed for inspection, as necessary. Removal of the EOS-TC top cover plate may require cutting of the bolts in the event of a corner drop onto the top end. These operations take place in the plant fuel building decontamination area and spent fuel pool after recovery of the EOS-TC.

Following recovery of the EOS-TC and unloading of the DSC, the EOS-TC is inspected, repaired and tested as appropriate prior to reuse.

For recovery of the EOS-TC and contents, it may be necessary to develop a special sling/lifting apparatus to move the EOS-TC from the drop site to the fuel pool. This may require several weeks of planning to ensure all steps are correctly organized. During this time, lead blankets may be added to the EOS-TC to minimize onsite exposure to site operations personnel. The EOS-TC can be roped off to ensure the safety of the site personnel.

12.3.2 Earthquake

Cause of Accident

The explicitly evaluated seismic response spectra for the NUHOMS® EOS System consist of the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.60 (Reg. Guide 1.60) [12-6] response spectra, anchored to a maximum ground acceleration of 0.45g horizontal and 0.30g for the vertical peak accelerations. The results of the frequency analysis of the EOS-HSM structure (which includes a simplified model of the DSC) yield a lowest frequency of 18.7 Hz in the transverse direction and 32.7 Hz in the longitudinal direction. The lowest vertical frequency is 60.3 Hz. Thus, based on the Reg. Guide 1.60 response spectra amplifications, and conservatively using ZPA values of 0.50g horizontal and 0.333g vertical, the corresponding seismic accelerations used for the structural design of the EOS-HSM are 0.936g and 0.628g in the transverse and longitudinal directions, respectively, and 0.333g in the vertical direction. The corresponding accelerations applicable to the DSC are 1.229g and 0.694g in the transverse and longitudinal directions, respectively, and 0.333g in the vertical direction. Stability analyses are based on accelerations of 0.45g horizontal and 0.30g vertical.

Accident Analysis

The seismic analyses of the components that are important to safety are analyzed as follows:

Components	**UFSAR Sections**
EOS-37PTH DSC and EOS-89BTH DSC Shell	Appendix 3.9.1
EOS-37PTH Basket and EOS-89BTH Basket	Appendix 3.9.2

EOS-HSM	Appendices 3.9.4 & 3.9.7
EOS-TC	Appendices 3.9.5 & 3.9.7

Note that the seismic loads are bounded by the transfer and drop loads for the basket and EOS-TC components.

The results of these analyses show that seismic stresses are well below the applicable stress limits.

Accident Dose Calculations

All the components that are important-to-safety are designed and analyzed to withstand the design basis earthquake accident. Hence, no radiation is released and there is no associated dose increase due to this event.

Corrective Actions

After a seismic event, all components are inspected for damage. Any debris is removed. An evaluation is performed to verify that the system components are still within the licensed design basis.

12.3.3 Tornado Wind and Tornado Missiles Effect on EOS-HSM

Cause of Accident

In accordance with ANSI-57.9 [12-2] and 10 CFR 72.122 [12-1], the NUHOMS® EOS System is designed for tornado effects, including tornado wind loads. In addition, the NUHOMS® EOS System is designed to withstand tornado missile effects. The NUHOMS® EOS System is designed to be located anywhere within the United States. Therefore, the most severe tornado wind and missile loadings specified by NUREG-0800 [12-7] and NRC Reg. Guide 1.76 [12-8] are selected as a design basis for this postulated accident. The determination of the tornado wind pressures and tornado missile loads acting on the NUHOMS® EOS System are detailed in Chapter 2, Section 2.3.1.

Accident Analysis

Stability and stress analyses are performed to determine the response of the EOS-HSM to tornado wind pressure loads. The stability analyses are performed using closed-form calculation methods to determine the sliding and overturning response of the EOS-HSM array. A single EOS-HSM with both the end and the rear shield walls is conservatively selected for the analyses. The stress analyses are performed using the ANSYS [12-9] finite element model of a single EOS-HSM to determine design forces and moments. These conservative generic analyses envelop the effects of wind pressures on the EOS-HSM array. These analyses are described in Appendix 3.9.7, Section 3.9.7.1. Thus, the requirements of 10 CFR 72.122 are met.

In addition, the EOS-HSM is evaluated for tornado missiles. The adequacy of the EOS-HSM to resist tornado missile loads is also addressed in Appendix 3.9.7.

Accident Dose Calculation

As shown in the above evaluations, the tornado wind and tornado missiles do not breach the EOS-HSM such that the DSC confinement boundary is compromized. Localized scabbing of the end shield wall of an EOS-HSM array may be possible.

The EOS-HSM outlet vent covers and wind deflectors (if required) may be lost due to a tornado or tornado missile event. Only the dose rates on the roof are affected, since the front, rear, and side dose rates remain the same. Information in Chapters 6 and 11 is used to determine that the EOS-HSM accident increases the average dose rate on the roof of the module to ~7400 mrem/hr.

The evaluation for the impact on public exposure, a 2 x 10 back to back array of EOS-HSMs and a distance to the site boundary of 370 m is used. As documented in Chapter 11, Section 11.3.2, for a 2x10 ISFSI configuration, the accident dose rate is approximately 1.1 mrem/hour and 0.1 mrem/hr at a distance of 200 m and 370 m respectively from the ISFSI. It is assumed that the recovery time for this accident is five days (120 hours). Therefore, the total exposure to an individual at a distance of 200 m and 370 m is 132 mrem and 12 mrem respectively. This is significantly less than the 10 CFR 72.106 limit of 5 rem.

Corrective Action

After *the accident*, the HSM is inspected for damage. Any debris is removed. Any damage resulting from impact with a missile is evaluated to verify that the system is still within the licensed design basis.

The need for temporary shielding is evaluated and HSM repairs are performed to return the HSM to pre-accident design conditions.

12.3.4 Tornado Wind and Tornado Missiles Effect on EOS-TC

Cause of Accident

The EOS-TC is evaluated for the tornado wind speed and missile whose design parameters are specified in Chapter 2, Section 2.3.2. The maximum design basis tornado (DBT) tornado wind speed of 230 mph in accordance with Reg. Guide 1.76, Revision 1 [12-10] was considered. The 4000 pound automobile, as well as a 287-pound schedule 40 pipe, and a 1-inch solid steel missiles are considered. The other types of missiles are enveloped by the schedule 40 pipe missile.

This analysis is performed for the EOS-TC, secured in the horizontal position on the support skid. The following criteria are used to evaluate the adequacy of the EOS-TC for the loads described above.

- Stability analysis
- Penetration resistance
- Impact stress analysis

Accident Analysis

The EOS-TC is evaluated for tornado wind and missile effects in Appendix 3.9.5 and 3.9.7.

The factor of safety on tip is 1.30 from the bounding DBT wind plus missile load combination on the EOS-TC while sitting on the trailer ready for transfer. The primary membrane intensity and combined membrane plus bending stresses due to DBT and missile impact are calculated, which are below the allowable stresses. The maximum missile penetration depth is found to be 0.526 inch, which is less than the thickness of EOS-TC outer shell of 1.0 inch and top cover plate thickness of 3.25 inches.

Accident Dose Calculation

Based on the above analyses, the DSC confinement boundary is not breached as a result of the missile impacts. Accordingly, no DSC damage or release of radioactivity is postulated.

The missile impact scenario may result in the loss of EOS-TC neutron shielding and local deformation/damage of the gamma shielding. The effect of loss of the neutron shielding due to a missile impact is bounded by that resulting from a EOS-TC drop scenario evaluated above in Section 12.3.1. The change in radiation dose due to local deformation/damage of the gamma shielding is negligible.

Corrective Action

After excessive high winds or a tornado, the EOS-TC is inspected for damage. These operations take place in the plant fuel building decontamination area and spent fuel pool after recovery of the EOS-TC. Following recovery of the EOS-TC and unloading of the DSC, the EOS-TC is inspected, repaired and tested as appropriate prior to reuse.

For recovery of the EOS-TC and contents, it may be necessary to develop a special sling/lifting apparatus to move the EOS-TC from the site to the fuel pool. This may require several weeks of planning to ensure all steps are correctly organized. During this time, lead blankets may be added to the EOS-TC to minimize on-site exposure to site operations personnel. The EOS-TC can be roped-off to ensure the safety of the site personnel.

12.3.5 Flood

Cause of Accident

Flooding conditions simulating a range of flood types, such as tsunami and seiches as specified in 10 CFR 72.122 (b) are considered. In addition, floods resulting from other sources, such as high water from a river or a broken dam, are postulated as the cause of the accident.

Accident Analysis

The HSM is evaluated for flooding in Appendix 3.9.4. Based on the evaluation presented in that section, the HSM can withstand the design basis flood.

Accident Dose Calculation

The radiation dose due to flooding of the HSM is negligible. Flooding does not breach the DSC confinement boundary. Therefore, radioactive material inside the DSC remains sealed in the DSC and, therefore, does not contaminate the encroaching flood water.

Corrective Actions

Because of the location and geometry of the HSM vents, it is unlikely that any significant amount of silt would enter an HSM should flooding occur. Any silt deposits are removed using a pump suction hose or fire hose inserted through the inlet vent to suck the silt out, or to produce a high velocity water flow to flush the silt through the HSM inlet vents.

12.3.6 Blockage of EOS-HSM Air Inlet and Outlet Openings or Loss/Damage of Wind Deflectors

This accident conservatively postulates the complete blockage of the ventilation air inlet and outlet openings of the EOS-HSM and complete loss of wind deflectors.

Cause of Accident

Since the EOS-HSMs are located outdoors, there is a remote probability that the ventilation air inlet and outlet openings could become blocked by debris from such unlikely events as floods and tornados. The wind deflectors could also become lost or damaged by extreme winds, tornadoes, or similar accidents. These wind deflectors are needed only for high heat load DSCs. The NUHOMS® EOS System design features, such as the perimeter security fence and the redundant protected location of the air inlet and outlet openings, reduce the probability of occurrence of such an accident. Nevertheless, for this conservative generic analysis, such an accident is postulated to occur and is analyzed.

Accident Analysis

The thermal evaluation of this event is presented in Chapter 4, Sections 4.4.5 and 4.4.11 for the EOS-37PTH DSC and EOS-89BTH DSC, respectively stored inside an EOS-HSM. The condition caused by a lost or damaged wind deflector is bounded by the blocked vent accident condition. The analysis performed for the EOS-37PTH DSC bounds the values for the EOS-89BTH DSC. Therefore, the temperatures determined for Load case #5 in Section 4.4.5, are used in the EOS-HSM structural evaluation of this event. The EOS-HSM structural analysis, presented in Appendix 3.9.4, demonstrates that the EOS-HSM component stresses remain below allowable values.

Accident Dose Calculation

There are no offsite dose consequences as a result of this accident.

Corrective Actions

Debris removal is all that is required to recover from a postulated blockage of the HSM ventilation air inlets and outlets. Cooling begins immediately following removal of the debris from the inlets and outlets. The amount and nature of debris can vary, but even in the most extreme case, manual means, or readily available equipment can be used to remove debris. The damaged or lost wind deflectors that are needed for a high heat load system must be repaired or replaced.

12.3.7 Lightning

Cause of Accident

The likelihood of lightning striking the HSM, and causing an off-normal condition is not considered to be a credible event. Lightning protection system requirements are site-specific and depend on the frequency of occurrences of lightning storms in the proposed ISFSI location, and the degree of protection offered by other grounded structures in the proximity of the HSM. The addition of simple lightning protection equipment, required by plant criteria, to HSM structures (i.e., grounded handrails, ladders, etc.) is considered a miscellaneous attachment.

Accident Analysis

Should lightning strike in the vicinity of the HSM, the normal storage operations of the HSM are not affected. The current discharged by the lightning follows the low impedance path offered by the surrounding structures. Therefore, the HSM is not damaged by the heat or mechanical forces generated by current passing through the higher impedance concrete. Since the HSM requires no equipment for its continued operation, the resulting current surge from the lightning does not affect the normal operation of the HSM.

Corrective Actions

Since no off-normal condition develops as the result of lightning striking in the vicinity of the HSM, no corrective action is necessary. Also, there are no radiological consequences.

12.3.8 Fire/Explosion

Cause of Accident

Combustible materials are not normally stored at an ISFSI. Therefore, a credible fire is very small and of short duration caused potentially by fire or explosion from a vehicle or portable crane.

Direct engulfment of the HSM is highly unlikely. Any fire within the ISFSI boundary while the DSC is in the HSM is bounded by the fire during EOS-TC movement. The HSM concrete acts as a significant insulating fire wall to protect the DSC from the high temperatures of the fire.

For both the EOS-TC and EOS-HSM, pressure drops initiated by externally initiated fires and explosions shall be assumed to be bounded by the design basis tornado generated missile and wind loads.

Accident Analysis

The evaluation of the hypothetical fire event is presented in Chapter 4, Section 4.5.5. The thermal evaluation of the fire event is bounded by the loss of neutron shield and loss of air circulation accident. 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 Chapter 4, Table 4-28, which demonstrates that the maximum component temperatures are below the allowable limits. Temperatures in this table are used for structural evaluation of the EOS-TC. The results of this EOS-TC structural analysis is presented in Appendix 3.9.5.

Accident Dose Calculation

The DSC confinement boundary is not breached as a result of the postulated fire/explosion scenario. Accordingly, no DSC damage or release of radioactivity is postulated. Because no radioactivity is released, no resultant dose increase is associated with this event.

The fire scenario may result in the loss of EOS-TC neutron shielding should the fire occur while the DSC is in the EOS-TC.

The effect of loss of the neutron shielding due to a fire is bounded by that resulting from a EOS-TC drop scenario. See Section 12.3.1 for evaluation of dose consequences of a EOS-TC drop.

Corrective Actions

Evaluation of EOS-TC neutron shield damage as a result of a fire is to be performed to assess the need for temporary shielding (if fire occurs during transfer operations) and repairs to restore the EOS-TC to pre-fire design conditions.

12.4 References

12-1 Title 10 Code of Federal Regulation Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

12-2 ANSI/ANS-57.9-1984, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," American National Standards Institute, American Nuclear Society.

12-3 Title 10, Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities."

12-4 NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980.

12-5 ANSI N14.6-1993, "American National Standard for Special Lifting Device for Shipping Containers Weighing 10,000 lbs. or More for Nuclear Materials," American National Standards Institute.

12-6 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," U.S. Atomic Energy Commission, Revision 1, December 1973.

12-7 NUREG-0800, Standard Review Plan, Section 3.5.1.4, "Missiles Generated by Natural Phenomenon," Revision 2, U.S. Nuclear Regulatory Commission, July 1981.

12-8 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," U.S. Atomic Energy Commission, Revision 0, April 1974.

12-9 ANSYS Computer Code and User's Manual, Release 14.0.

12-10 U.S. Nuclear Regulatory Commission, Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," U.S. Atomic Energy Commission, Revision 1, March 2007.

CHAPTER 13
OPERATING CONTROLS AND LIMITS

Table of Contents

List of Tables

13. OPERATING CONTROLS AND LIMITS

This chapter specifies the operating controls and limits (also broadly called the technical specifications (TS)), including their supporting bases and justification, for the NUHOMS® EOS System. These operating controls and limits provide the conditions that are deemed necessary for safe dry storage system use.

13.1 Operating Controls and Limits

13.1.1 NUREG-1536 [13-1] (Standard Review Plan) Acceptance Criteria

The TS provide the NUHOMS® EOS System operating controls and limits necessary to maintain the key design functions of criticality control, confinement and cladding integrity, shielding and radiation protection, thermal protection and heat removal, and structural integrity under normal, off-normal and accident conditions. These operating controls and limits, in addition to the specific conditions identified in the certificate of compliance (CoC), establish the commitments applicable to the design, manufacturing, and use of the NUHOMS® EOS System. Other regulatory requirements defined in 10 CFR 72 [13-2] and 10 CFR 20 [13-3], in addition to the commitments identified in the technical specifications and CoC conditions, may apply.

The technical specifications are provided in Appendix A to the CoC.

Table 13-1 provides a cross-reference of the key design functions and the applicable TS designed to provide assurance that these functions are maintained. Table 13-2 provides a list of the TS applicable to the NUHOMS® EOS System.

Where the term "HSM" is used without distinction, this term shall be use to apply to both the EOS-HSM and HSM-MX.

13.2 Development of Operating Controls and Limits

This section provides a discussion of the development of operating controls and limits and training requirements for the usage and maintenance of the NUHOMS® EOS System.

13.2.1 Training Program

All personnel working at the independent spent fuel storage installation (ISFSI) receive training and indoctrination aimed at providing and maintaining a well-qualified work force for safe and efficient operation of the ISFSI. The licensee may utilize the existing plant training program to provide this training and indoctrination. Additional sections are added to the program to include information specific to the ISFSI.

13.2.1.1 Training for Operations Personnel

Generalized training should be provided to plant operations personnel on the applicable regulations and standards and the engineering principles of passive cooling, radiological shielding, and structural characteristics of the ISFSI. Detailed operator training will be provided for dry shielded canister (DSC) preparation and handling, fuel loading, transfer cask (TC) preparation and handling, and transfer trailer loading.

13.2.1.2 Training for Maintenance Personnel

Generalized training should be provided to plant maintenance personnel on the applicable regulations and standards and in the engineering principles of passive cooling, radiological shielding, and structural characteristics of the ISFSI. Specific training is provided for:

- Use of the vacuum drying system,
- Automated welding equipment,
- Operation of the transfer trailer,
- Alignment of the TC skid with the *EOS*-HSM *or operation of the loading crane (LC) and alignment with the HSM-MX*,
- Assembly of the hydraulic ram system, and
- Normal and off-normal operation of the hydraulic ram.

Specific training is also provided for cleaning the *EOS-HSM and HSM-MX* air inlet and outlet vents.

13.2.1.3 Training for Health Physics Personnel

Generalized training should be provided to plant health physics personnel on the applicable regulations and standards and on the engineering principles of passive cooling, radiological shielding, and structural characteristics of the ISFSI. Specific training should be provided on the radiological shielding design of the system, particularly the DSC top shield plug, the TC, and the *EOS*-HSM *or HSM-MX*.

13.2.1.4 Training for Security Personnel

Details of the training program for security personnel are provided in the security plan to be maintained by the licensee, which is to be withheld from public disclosure in accordance with 10 CFR 2.790(d) and 10 CFR 73.21.

13.2.2 Retraining Program

Retraining is generally consistent with the retraining requirements in effect at the plant for personnel involved in fuel handling operations.

13.2.3 Administration and Records

The licensee's plant training organization is the organization responsible for training programs and for maintaining up-to-date records on the status of personnel training.

13.2.4 Dry Run Training

A dry run utilizing a DSC loaded with mock-up fuel assemblies (FAs) will be performed prior to loading the first canister by each licensee to demonstrate the adequacy of training, familiarity of system components and operational procedures.

The operations include loading and identifying FAs, confirming that FAs meet the fuel acceptance criteria, drying, welding, sealing, backfilling and pressurizing the DSC, and transferring the loaded canister to the *EOS*-HSM *or HSM-MX*.

13.2.5 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings

During dry storage of the spent fuel, no active systems are required to monitor the spent fuel and no monitoring instruments are required. In order to prevent conditions that could cause a reduction in heat removal capabilities, the general licensee may either implement (1) a temperature monitoring system, or (2) visual inspection of the inlet air vents, and birdscreens to verify no blockage of the air cooling passive inlet ducts for the loaded HSM components, in accordance with *the applicable portions of* TS 5.1.3. In addition, limits are placed on the dose rate limits at locations around a loaded HSM and the entire ISFSI to provide protection of employees against occupational radiation exposure, as provided in TS 5.1.2 (a)(b)(c) and (d).

13.2.6 Limiting Conditions for Operation (LCO)

Limiting Conditions for Operation (LCO) specify the minimum capability or level of performance that is required to provide assurance that the NUHOMS® EOS System can be operated safely.

13.2.7 Surveillance Requirements

The frequency and scope of the actions to verify the performance and availability of structures, systems, and components (SSCs) important-to-safety during loading, unloading, and storage operations are provided in the Surveillance Requirements (SRs) to support the Limiting Conditions for Operation (LCO). Analyses documented in this Safety Analysis Report (SAR) show that the NUHOMS® EOS System fulfills its safety functions, provided that the technical specifications and the CoC conditions are satisfied.

13.2.8 Design Features

The specifications in this section include the design characteristics of special importance to each of the physical barriers and to maintenance of safety margins in the NUHOMS® EOS System design. The principal objective of this section is to describe the design envelope that may constrain any physical changes to essential equipment. These features provide design and fabrication controls. Commitments are provided to follow specified industry codes and standards, including code alternatives (with justification) for those that vary from typical U.S. Nuclear Regulatory Commission (NRC) accepted codes for these components. Also included in this section are the site environmental parameters that provide the bases for design, but are not inherently suited for description as LCO. *Finally, this section includes the design, operation, fabrication, testing, inspection, and maintenance requirements for the LOADING CRANE.*

13.2.9 Administrative Controls

This section provides administrative controls, including organizational and management procedures, recordkeeping and reporting necessary to provide assurance that the NUHOMS® EOS System will be operated and maintained in a safe and reliable manner. These controls include those assumptions that are necessary to support the accident analyses, including cask lifting heights.

13.3 Technical Specifications

Table 13-2 provides an outline of the technical specifications for the NUHOMS® EOS System. The detailed contents of the TS are provided in Appendix A to the CoC. Bases applicable to the TS are provided in the Updated Final Safety Analysis Report (FSAR) Appendix 13A. The format and content of these TS are based on the guidance in NUREG-1745 [13-5], Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance.

13.4 References

13-1 NUREG-1536, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems at a General License Facility," Revision 1, U.S. Nuclear Regulatory Commission, July 2010.

13-2 Title 10, Code of Federal Regulations, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

13-3 Title 10, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation."

13-4 Title 10, Code of Federal Regulations, Part 73, "Physical Protection of Plants and Materials."

13-5 NUREG-1745, "Standard Format and Content for Technical Specifications for 10 CFR Part 72 Cask Certificates of Compliance," Revision 0, U.S. Nuclear Regulatory Commission, June 2001.

Table 13-1
NUHOMS® EOS System Design Functions and Controls

Design Function	Applicable Technical Specifications	
Criticality Control	3.2.1	Soluble Boron Concentration
	4.3	Canister Criticality Control
	4.3.1	Neutron Absorber Tests
	4.3.2	High Strength *Low Alloy* Steel for Basket Structure
	5.2.2	Cask Drop
Confinement and Cladding Integrity	3.1.1	Fuel Integrity during Drying
	3.1.2	DSC Helium Backfill Pressure
	3.1.3	Time Limit for Completion of DSC Transfer
	5.4	Hydrogen Gas Monitoring
	5.5	EOS-HSM Wind Deflectors
Shielding / Radiation Protection	3.3.1	DSC and Transfer Cask Surface Contamination
	4.5.1	Storage Configuration
	5.1.1	Radiological Environmental Monitoring Program
	5.1.2	Radiation Protection Program
Thermal Protection and Heat Removal	3.1.1	Fuel Integrity during Drying
	3.1.3	Time Limit for Completion of DSC Transfer
	5.1.3	HSM Thermal Monitoring Program
	5.5	EOS-HSM Wind Deflectors
Structural Integrity	5.1.3	HSM Thermal Monitoring Program
	5.2.1	*TC*/DSC Lifting Height and Temperature Limits
	5.2.2	Cask Drop
	5.3	Concrete Testing

Table 13-2
NUHOMS® EOS System Technical Specifications
2 Pages

NUMBER	TECHNICAL SPECIFICATION
1.0	*Use and Application*
1.1	Definitions
1.2	Logical Connectors
1.3	Completion Times
1.4	Frequency
2.0	*Functional and Operating Limits*
2.1	Fuel To Be Stored In The EOS-37PTH DSC
2.2	Fuel To Be Stored In The EOS-89BTH DSC
2.3	Functional And Operating Limits Violations
3.0	*Limiting Condition for Operation* (LCO) *and Surveillance Requirement* (SR) *Applicability*
3.1	DSC Fuel Integrity
3.1.1	Fuel Integrity *during* Drying
3.1.2	DSC Helium Backfill Pressure
3.1.3	Time Limit for Completion of DSC Transfer
3.2	Cask Criticality Control
3.2.1	Soluble Boron Concentration
3.3	Radiation Protection
3.3.1	DSC and *TRANSFER CASK* Surface Contamination
4.0	*Design Features*
4.1	Site
4.1.1	Site Location
4.2	Storage System Features
4.2.1	Storage Capacity
4.2.2	Storage Pad
4.3	Canister Criticality Control
4.3.1	Neutron Absorber Tests
4.3.2	*High Strength Low Alloy* Steel for Basket Structure
4.4	Codes and Standards
4.4.1	*HORIZONTAL STORAGE MODULE* (HSM)
4.4.2	*DRY SHIELDED CANISTER* (EOS-37PTH and EOS-89BTH DSC)
4.4.3	*TRANSFER CASK* (TC)
4.4.4	Alternatives to Codes and Standards

Table 13-2
NUHOMS® EOS System Technical Specifications
2 Pages

NUMBER	TECHNICAL SPECIFICATION
4.5	Storage Location Design Features
4.5.1	Storage Configuration
4.5.2	Concrete Storage Pad Properties to Limit DSC Gravitational Loadings Due to Postulated Drops
4.5.3	Site-Specific Parameters and Analyses
5.0	Admin*i*strative Controls
5.1	Programs
5.1.1	Radiological Environmental Monitoring Program
5.1.2	Radiation Protection Program
5.1.3	HSM Thermal Monitoring Program
5.1.3.1	*EOS-HSM Thermal Monitoring Program*
5.1.3.2	*HSM-MX Thermal Monitoring Program*
5.2	Lifting Controls
5.2.1	*TC*/DSC Lifting Height and Temperature Limits
5.2.2	Cask Drop
5.3	Concrete Testing
5.4	Hydrogen Gas Monitoring
5.5	EOS-HSM Wind Deflectors

APPENDIX 13A

TECHNICAL SPECIFICATION BASES

TECHNICAL SPECIFICATION BASES

TABLE OF CONTENTS

B 2.0 SAFETY LIMITS (SLs)

BASES

BACKGROUND	The DRY SHIELDED CANISTER (DSC) design for the EOS System (EOS-37PTH and EOS-89BTH) requires certain limits on spent fuel parameters, including fuel type, maximum allowable enrichment prior to irradiation, maximum burnup, and minimum acceptable cooling time prior to storage in the DSC. Other important limitations are the radiological source terms from Control Components (CCs). These limitations are included in the thermal, structural, radiological, and criticality evaluations performed for these DSC designs.
APPLICABLE SAFETY ANALYSES	Various analyses have been performed that use these fuel parameters as assumptions. These assumptions are included in the thermal, criticality, structural, shielding and confinement analyses. Technical Specification Tables 1 through *6 and* 8, and Figures 1*A through 1I, 2,* and *3* provide the key fuel parameters that require confirmation prior to DSC loading.
FUNCTIONAL AND OPERATING LIMITS VIOLATIONS	If Functional and Operating Limits are violated, the limitations on the fuel assemblies in the DSC have not been met. Actions must be taken to place the affected fuel assemblies in a safe condition. This safe condition may be established by returning the affected fuel assemblies to the spent fuel pool. However, it is acceptable for the affected fuel assemblies to remain in the DSC if that is determined to be a safe condition. Notification of the violation of a Functional and Operating Limit to the NRC is required within 24 hours. Written reporting of the violation must be accomplished within 60 days. This notification and written report are independent of any reports and notification that may be required by 10 CFR 72.75.
REFERENCES	1. SAR Chapters 2, 4, 6*,* 12*, A.4, A.6, and A.12*.

B 3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs	LCO 3.0.1, 3.0.2, 3.0.4 and 3.0.5 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.
LCO 3.0.1	LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the canister is in the specified conditions of the Applicability statement of each Specification).

LCO 3.0.2

LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS Condition is applicable from the point in time that an ACTIONS Condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that:

a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and

b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified.

There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. If this type of Required Action is not completed within the specified Completion Time, the canister may have to be placed in the spent fuel pool and unloaded. (Whether stated as a Required Action or not, correction of the entered Condition is an action that may always be considered upon entering ACTIONS). The second type of Required Action specifies the remedial measures that permit continued operation of the unit that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

BASES

LCO 3.0.2 (continued)

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

Individual Specifications may specify a time limit for performing an SR when equipment is removed from service or bypassed for testing. In this case, the Completion Times of the Required Actions are applicable when this time limit expires if the equipment remains removed from service or bypassed.

When a change in specified Condition is required to comply with Required Actions, the equipment may enter a specified Condition in which another Specification becomes applicable. In this case, the Completion Times of the associated Required Actions would apply from the point in time that the new Specification becomes applicable and the ACTIONS Condition(s) are entered.

LCO 3.0.3

This specification is not applicable to the NUHOMS® EOS System. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.4

LCO 3.0.4 establishes limitations on changes in specified Conditions in the applicability when an LCO is not met. It precludes placing the NUHOMS® EOS System in a specified Condition stated in that applicability (e.g., Applicability desired to be entered) when the following exist:

a. Conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and

b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in the equipment being required to exit the Applicability desired, to be entered to comply with the Required Actions.

BASES

LCO 3.0.4 (continued)

Compliance with Required Actions that permit continued operation of the equipment for an unlimited period of time in specified Condition provides an acceptable level of safety for continued operation. Therefore, in such cases, entry into a specified Condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified Condition in the Applicability.

The provisions of LCO 3.0.4 shall not prevent changes in specified Conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified Conditions in the Applicability that are related to the unloading of a canister.

Exceptions to LCO 3.0.4 are stated in the individual Specifications.

Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.

Surveillances do not have to be performed on the associated equipment out of service (or on variables outside the specified limits), as permitted by SR 3.0.1. Therefore, changing specified Conditions while in an ACTIONS Condition, either in compliance with LCO 3.0.4, or where an exception to LCO 3.0.4 is stated, is not a violation of SR 3.0.1 or SR 3.0.4 for those Surveillances that do not have to be performed due to the associated out of service equipment.

LCO 3.0.5

LCO 3.0.5 establishes the allowance for restoring equipment to service under administrative controls when it has been removed from service or not in service in compliance with ACTIONS. The sole purpose of this Specification is to provide an exception to LCO 3.0.2 (e.g., to not comply with the applicable Required Action(s)) to allow the performance of required testing to demonstrate:

a. The equipment being returned to service meets the LCO; or

b. Other equipment meets the applicable LCOs.

BASES

LCO 3.0.5 (continued)

The administrative controls ensure the time the equipment is returned to service in conflict with the requirements of the ACTIONS is limited to the time absolutely necessary to perform the allowed required testing. This Specification does not provide time to perform any other preventive or corrective maintenance.

LCO 3.0.6 This specification is not applicable to the NUHOMS® EOS System. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.7 This specification is not applicable to the NUHOMS® EOS System. The placeholder is retained for consistency with the power reactor technical specifications.

B 3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs

SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications in Sections 3.1, 3.2 and 3.3 and apply at all times, unless otherwise stated.

SR 3.0.1

SR 3.0.1 establishes the requirement that SRs must be met during the specified Conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify systems and components, and that variables are within specified limits. Failure to meet a Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; or

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the equipment is in a specified Condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment that has been determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning equipment to service.

BASES

SR 3.0.1 (continued)

Upon completion of maintenance, appropriate post maintenance testing is required to declare equipment within its LCO. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2. Post-maintenance testing may not be possible in the current specified Conditions in the Applicability due to the necessary equipment parameters not having been established. In these situations, the equipment may be considered to meet the LCO provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function.

This will allow operation to proceed to a specified Condition where other necessary post maintenance tests can be completed.

SR 3.0.2

SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per..." interval.

SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers plant operating conditions that may not be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications. The requirements of regulations take precedence over the TS. Therefore, when a test interval is specified in the regulations, the test interval cannot be extended by the TS, and the SR includes a Note in the Frequency stating, "SR 3.0.2 is not applicable."

BASES

SR 3.0.2 (continued)

As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the equipment in an alternative manner.

The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals (other than those consistent with refueling intervals) or periodic Completion Time intervals beyond those specified.

SR 3.0.3

SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when a Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of a Surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance. The basis for this delay period includes consideration of unit conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements.

When a Surveillance with a Frequency based not on time intervals, but upon specified unit conditions or operational situations, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

BASES

SR 3.0.3 (continued)

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified Conditions in the Applicability imposed by Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility that is not intended to be used as an operational convenience to extend Surveillance intervals.

If a Surveillance is not completed within the allowed delay period, then the equipment is considered not in service or the variable is considered outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If a Surveillance is failed within the delay period, then the equipment is not in service, or the variable is outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance. Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4

SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified Condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry in the Applicability for which these systems and components ensure safe operation of the facility.

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components to an appropriate status before entering an associated specified Condition in the Applicability. However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified Condition. When a system, subsystem, division, component, device, or variable is outside its specified limits, the associated SR(s) are not required to be performed, per SR 3.0.1, which states that Surveillances do not have to be performed on such equipment. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the

BASES

SR 3.0.4 (continued)

specified Frequency does not result in an SR 3.0.4 restriction to changing specified Conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified Condition changes.

The provisions of SR 3.0.4 shall not prevent changes in specified Conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of SR 3.0.4 shall not prevent changes in specified Conditions in the Applicability that are related to the unloading of an EOS-HSM or DSC.

The precise requirements for performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and Conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite Condition(s) specified in a Surveillance procedure require entry into the specified Condition in the Applicability of the associated LCO prior to the performance or completion of a Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific Conditions needed are met. Alternatively, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further discussion of the specific formats of SR annotation is found in Technical Specifications Section 1.4, operation to proceed to a specified condition where other necessary post maintenance tests can be completed.

B.3.1 DSC FUEL INTEGRITY

B.3.1.1 Fuel Integrity during Drying

BASES

BACKGROUND

A DSC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A shield plug is then placed on the DSC. Subsequent operations involve moving the DSC to the decontamination area and removing water from the DSC (using helium as a cover gas for assisting in the drainage of bulk water). After welding and non-destructive examination of the DSC inner top cover plate, vacuum drying of the DSC is performed, and the DSC is backfilled with helium. During normal storage conditions, the fuel assemblies are stored in the DSC with an inert helium atmosphere, which results in lower fuel cladding temperatures and provides an inert atmosphere during storage conditions.

DSC vacuum drying is utilized to remove residual moisture from the cavity after the DSC has been drained of water. Any water which was not drained from the DSC evaporates from fuel or basket surfaces due to the vacuum. This vacuum drying operation is aided by the temperature increase due to the heat generation of the fuel.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a DSC is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are the fuel pellet matrix, the fuel cladding tubes in which the fuel pellets are contained, and the DSC in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This protective environment is accomplished by removing water from the DSC (using helium for assisting in the drainage of bulk water) and backfilling the DSC with helium. The removal of water is necessary to prevent phase change–related pressure increase upon heatup. The analysis in Chapter 4 demonstrates that if helium is used as a cover gas for bulk water removal operations, the conductivity of helium during vacuum drying operations provides assurance that the cladding temperature remains below the cladding temperature limit. The DSC/TC annulus contains water during the vacuum drying process. This Safety Analysis Report (SAR) evaluates and documents that the DSC confinement boundary is not compromised due to any normal, off-normal or accident condition postulated (SAR Chapter 3, 12*, A.3, and A.12* structural analyses) and the fuel cladding temperature remains below allowable values (SAR Chapter*s* 4 *and A.4*).

BASES

APPLICABLE SAFETY ANALYSIS (continued)

The potential exists for oxidation of fuel pellets if they are exposed to air for a sufficient duration at a high temperature. Use of helium for blowdown or draindown operations will help prevent oxidation of fuel pellets due to air by replacing air with helium, which is an inert gas.

LCO

A stable vacuum pressure of ≤3 torr further ensures that all liquid water has evaporated in the DSC cavity, and that the resulting inventory of oxidizing gases in the DSC is below 0.25 volume %.

Technical Specification 3.1.1 requires the use of helium during the bulkwater removal process. Therefore, water from the DSC cavity is replaced by helium during the bulkwater removal process. Fuel cladding temperatures are low during this short duration process due to the presence of liquid water and helium.

Therefore use of helium during bulkwater removal, vacuum drying and long-term storage operations assures that the fuel assemblies will have limited (or no) exposure to the oxidizing environment.

APPLICABILITY

This is applicable to all DSCs during LOADING OPERATIONS but before TRANSFER OPERATIONS.

ACTIONS

The actions specified require restoring the vacuum drying system to an operable status or ensuring the integrity of the DSC shell/ITCP weld or the establishment of a helium pressure of at least 0.5 atmosphere within the DSC or flooding the DSC to submerge the fuel assemblies, within 30 days. The specified value of helium atmosphere allows the transfer of decay heat from the DSC while allowing implementation of corrective actions to return the DSC to an analyzed condition. The 15 psig limit in the Actions section is conservatively below the maximum analyzed blowdown pressure. The basis for 30 days is as follows: LCO 3.1.1 requires the use of helium for all water removal from the DSC before vacuum drying. Therefore, vacuum drying operations are carried out with water replaced by helium. The SAR thermal analysis demonstrates that if helium is used as a cover gas for water removal, the conductivity of helium during vacuum drying operations assures that cladding temperatures remain below the cladding temperature limit. The DSC/TC annulus also contains water during the vacuum drying process. Because the cladding

BASES

ACTIONS (continued)

temperatures are below the cladding temperature limits, the criterion of 30 days is used as a reasonable time period for identifying and repairing vacuum drying system or seal welds.

SURVEILLANCE REQUIREMENTS

Ensure that vacuum pressure remains sufficiently low for a sufficient timeframe to provide a minimum oxidizing gas content, and to ensure that the DSC is dry.

REFERENCES

1. SAR Chapters 3, 4, 12*, A.3, A.4, 12*.

B.3.1 DSC FUEL INTEGRITY

B.3.1.2 DSC Helium Backfill Pressure

BASES

BACKGROUND	A DSC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A shield plug is then placed on the DSC. Subsequent operations involve moving the DSC to the decontamination area and removing water from the DSC using helium to assist in the drainage of bulk water. After the DSC inner top cover is welded, vacuum drying of the DSC is performed and the DSC is backfilled with helium, resulting in lower fuel cladding temperatures. In addition, it provides an inert atmosphere during storage conditions. The inert helium environment protects the fuel from potential oxidizing environments.
APPLICABLE SAFETY ANALYSIS	Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. SAR Section 3.5 evaluates the effect of long-term storage and short term temperature transients on fuel cladding integrity. Credit for the helium backfill pressure is taken to limit the potential for corrosion of the fuel cladding. Leak testing of the DSC welds is performed to ensure that an inert helium atmosphere will be maintained within the DSC, surrounding the fuel, to limit radiological consequences. SAR Chapter*s* 4 *and A.4* evaluate the DSC maximum pressure under normal, off-normal, and accident conditions.
LCO	DSC backfill pressure is maintained within a range of pressure during initial backfill that will ensure maintenance of the helium backfill pressure over time and will not result in excessive DSC pressure in normal, off-normal and accident conditions.
APPLICABILITY	This specification is applicable to all DSCs during LOADING OPERATIONS but before TRANSFER OPERATIONS.

BASES

ACTIONS	The actions required and associated Completion Times are associated with ensuring that the DSC remains in a safe condition and within its design pressure limits and time limits established in the SAR. These limits are imposed to ensure that the DSC confinement integrity is maintained. The thermal analysis in Chapter 4 demonstrates that with water in the DSC/cask annulus and helium atmosphere in the DSC cavity, fuel cladding temperatures are below the cladding material temperature limits. Note that no credit is taken for any convection of helium in the DSC cavity. These time limits are imposed to ensure that there is sufficient time to complete the required actions for identifying and repairing vacuum drying system or seal welds. The fuel cladding will not exceed maximum allowable temperatures during this time.
SURVEILLANCE REQUIREMENTS	The DSC backfill pressure is monitored during the initial DSC loading to ensure that: (1) the atmosphere surrounding the irradiated fuel is a non-oxidizing inert helium gas; and (2) the helium backfill pressure level maintains a helium atmosphere that is favorable for the transfer of decay heat and consistent with the SAR thermal analysis.
REFERENCES	1. SAR Chapters 3*, 4, A.3,* and *A*.4.

B.3.1 DSC FUEL INTEGRITY

B.3.1.3 Time Limit for Completion of DSC Transfer

BASES

BACKGROUND	After a DSC has been loaded with fuel assemblies, vacuum dried and sealed, it is ready for transfer to the ISFSI. The design of a loaded TC/DSC system provides sufficient passive heat rejection capacity to ensure that the integrity of the fuel cladding is maintained provided the specified time limits for completion of the transfer are met.
APPLICABLE SAFETY ANALYSIS	Long-term integrity of the fuel cladding depends on storage in an inert atmosphere and maintaining fuel cladding temperature below an acceptable limit. The TC/DSC transient thermal analysis provided in Chapter 4 of the SAR evaluates the fuel cladding temperatures under normal, off-normal, and accident conditions during the transfer of a loaded TC/DSC. The time limits for transfer operations are based on the EOS-37PTH DSC in the TC125 with the maximum allowable heat load of 50 kW. The use of these time limits during the transfer operation is bounding for all DSC/EOS-TC configurations. Longer time limits can be calculated based on the as loaded heat load of the DSC.
LCO	The time to complete the transfer of a loaded TC/DSC is monitored to ensure that the fuel cladding does not exceed the NUREG-1536, Revision 1, limit of 752 °F during transfer.
APPLICABILITY	This specification is applicable to a loaded NUHOMS® EOS-37PTH or EOS-89BTH DSC when transferred in an EOS-TC. Those DSCs with lower heat loads as identified in LCO 3.1.3 have no time limit for completion of DSC transfer. The thermal analysis performed at those lower heat load as documented in SAR Chapter 4 demonstrate that the steady state cladding temperatures during TRANSFER OPERATIONS are below the cladding temperature limit. Those DSCs with higher heat loads identified in LCO 3.1.3 have associated time limits for the DSC transfer based on the associated thermal analyses.
ACTIONS	The actions required and the specified Completion Time *for Actions A.1or A.2 or A.3* are associated with ensuring that the fuel cladding does not exceed 752 °F during transfer.

BASES

SURVEILLANCE REQUIREMENTS	The specified monitoring of the time duration for the completion of the transfer step ensures that the fuel cladding temperatures remain below the regulatory limit of 752 °F during this operation.
REFERENCES	1. SAR Chapter 4.

B.3.2 CASK CRITICALITY CONTROL

B.3.2.1 Soluble Boron Concentration

BASES

BACKGROUND	During loading and unloading of an EOS-37PTH DSC, the DSC cavity is filled with borated water having a minimum boron concentration, which is a function of the DSC basket type, fuel assembly class, and maximum planar average initial enrichment. This specification ensures that a subcritical configuration is maintained in the event of an accidental loading of a DSC with unirradiated fuel.
APPLICABLE SAFETY ANALYSIS	The EOS-37PTH DSC has been designed for unirradiated fuel with a specified maximum planar average initial enrichment while taking credit for the soluble boron concentration in the DSC cavity water and the boron content in the neutron absorber plates. The criticality analysis provided in Chapter 7 of the SAR evaluates the DSC to ensure that a subcritical configuration is maintained.
LCO	The minimum boron concentration limits of the water in the DSC cavity as specified in the LCO ensure that a subcritical configuration is maintained in the event of an accidental loading of a DSC with unirradiated fuel.
APPLICABILITY	This specification is applicable to the EOS-37PTH DSC during LOADING OPERATIONS and UNLOADING OPERATIONS.
ACTIONS	The actions required and the specified Completion Times for the required actions are associated with ensuring that either the dissolved boron concentration is restored above the specified minimum or the fuel is removed from the DSC.
SURVEILLANCE REQUIREMENTS	Performance of two separate independent analysis of the water used to fill the DSC cavity (a) within 4 hours of initiation of loading/unloading operations and (b) subsequent analysis at intervals not exceeding 48 hours until the conclusion of such loading/unloading operations provides assurance that a subcritical DSC configuration is always maintained.

BASES

REFERENCES	1.	SAR Chapter 7.

B.3.3 RADIATION PROTECTION

B.3.3.1 DSC and TRANSFER CASK (TC) Surface Contamination

BASES

BACKGROUND	Since the TC with DSC in its interior is placed in the spent fuel pool in order to load the spent fuel assemblies, the exterior of the surface of the TC and the outer top surface of the DSC may become contaminated from radioactive material in the spent fuel pool water. The TC/DSC annulus is filled with clean water and sealed prior to placement in the spent fuel pool; therefore, only the outer top 1-foot surface of the DSC and the inner surface of the TC is susceptible to contamination by the water from the spent fuel pool. After placing the top shield plug onto the DSC, the loaded DSC with TC is lifted out of the pool into the decontamination area. The outer surface of the TC is decontaminated. Following sealing of the inner top cover plate, vacuum drying and backfill with helium, the DSC outer top cover plate is installed and sealed. After the draining of the TC/DSC annulus, the DSC smearable surface contamination on the outer top 1-foot surface of the DSC and the exterior surface of the TC are checked. Contamination on these surfaces is removed to a level that is as low as reasonably achievable (ALARA) and below the LCO limits in order to minimize radioactive contamination to personnel and the environment.
APPLICABLE SAFETY ANALYSYS	This radiation protection measure assures that the surfaces of the TC and the DSC have been decontaminated. This keeps the dose to occupational personnel ALARA.
LCO	The contamination limits on the outer top 1-foot surface of the DSC and the exterior surface of the TC are based on the allowed removable external radioactive contamination specified for spent fuel shipping containers in 49 CFR 173.443 (as referenced in 10 CFR 71.87(i)). Consequently, these contamination levels are considered acceptable for exposure to the general environment. This level will also ensure that the contamination levels of the inner surfaces of the HSM and potential releases of radioactive material to the environment are minimized. In addition, the NUHOMS® EOS storage system provides significant additional protection for the DSC surface than the transportation configuration. The HSM will protect the DSC from direct exposure to the elements and will, therefore, limit potential releases of removable contamination. The probability of any removable contamination being entrapped in the HSM airflow path released outside the HSM is considered extremely small.

BASES

LCO (continued)	The use of an inflatable seal in the upper cask liner recess ensures that the TC/DSC annulus area below the seal remains clean during the subsequent fuel loading steps inside the spent fuel pool. Hence, the only area that needs to be checked for contamination on the DSC is the top 1 foot of the DSC external surface. However, in the unlikely event that contamination is found that exceeds the specified levels, the entire length of the DSC surface will be checked and decontaminated. The number and location of surface swipes used to determine compliance for this LCO for both the exterior surface of the TC and outer top 1-foot surface of the DSC is based on standard industry practice and the licensee's plant-specific radiation protection program.
APPLICABILITY	Measurement and comparison of the removable contamination levels for both the TC and the outer top 1-foot surface of the DSC is performed during LOADING OPERATIONS.
ACTIONS	A note has been added that a separate Condition entry is allowed for each DSC and TC. Separate ACTIONS are provided for the DSC outer top surface and the exterior surface of the TC. If the removable surface contamination is not within the LCO limits, action must be taken to decontaminate either the DSC or TC, as appropriate, to bring the contamination level to within the limits. The Completion Time Prior to TRANSFER OPERATIONS is appropriate given that sufficient time is required to prepare for and perform the decontamination once the limit has been determined to be exceeded.
SURVEILLANCE REQUIREMENTS	The measurement of the removable surface contamination on both the TC and the DSC is performed once, prior to TRANFER OPERATIONS, to verify it is less than the established LCO limits. This Frequency is necessary in order to confirm that the loaded TC can be moved safely to the ISFSI without releasing loose contamination to the environment or causing excessive operational doses to personnel.
REFERENCES	None.

CHAPTER 14
QUALITY ASSURANCE

Table of Contents

List of Tables

List of Figures

14. QUALITY ASSURANCE

The TN Americas LLC (TN) Quality Assurance (QA) program has been established in accordance with the requirements of 10 CFR 72, Subpart G [14-1]. The QA program applies to the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of the NUHOMS® EOS System and components identified as “important-to-safety” and “safety-related.” These components and systems are defined in Chapter 2.

14.1 Introduction

The complete description and specific commitments of the QA program are contained in the QA program description manual [14-2]. This manual has been approved by the U.S. Nuclear Regulatory Commission (NRC) for performing 10 CFR Part 72-related activities. Changes to the program will be submitted to the NRC for approval within 30 days of implementation. Changes to the QA program, which decrease or delete previously approved QA commitments will be submitted to the NRC for approval prior to implementation.

The matrix in Table 14-1 shows the 10 CFR 72, Subpart G criteria and the respective sections of the QA program description manual that address the criteria.

Figure 14-1 shows the organizational structure for the NUHOMS® EOS System project.

14.2 “Important-to-Safety and “Safety-Related” NUHOMS® EOS System Components

TN will apply its QA program to the NUHOMS® EOS System components within its scope of responsibility, which are defined as “important-to-safety” and “ safety-related,” as delineated in Section 2.1. Quality assurance procedures are used to establish the quality category of components, subassemblies, and piece parts according to the importance to safety of each item.

In Table 2-1, each component is identified as “important-to-safety,” “not important-to-safety,” or “safety-related”. During the design process, items that are considered “important-to-safety” are further categorized using a graded quality approach. When the graded quality approach is used, a list will be developed for each “important-to-safety” item, which includes an assigned quality category consistent with the importance to safety of that item. Quality categories are determined based on the following description of categories, and on the guidance provided in NUREG/CR-6407 [14-3]:

- Category A items are critical to safe operation. These items include structures, components, and systems whose failure or malfunction could directly result in a condition adversely affecting public health and safety. This would include conditions such as loss of primary containment with subsequent release of radioactive material, loss of shielding, or an unsafe geometry compromising criticality control.
- Category B items have a major impact on safety. These items include structures, components, and systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. An unsafe operation could result only if a primary event occurs in conjunction with a secondary event, or other failure or environmental occurrence.
- Category C items have a minor impact on safety. These items include structures, components, and systems whose failure or malfunction would not significantly reduce the packaging effectiveness and would be unlikely to create a condition adversely affecting public health and safety.

For “safety-related” items, the QA program is applied as described for Category A items. The QA program, as described in Section 14.3, is applied to each “important-to-safety” graded category and is limited as follows.

Category A

A. The design is based on the most stringent industrial codes or standards. Design verification will be accomplished by prototype testing or formal design review.

B. Vendors for items and services for this category may only be selected from the Approved Suppliers List.

C. TN suppliers and sub-tier suppliers must have a QA program based on applicable criteria in Subpart G to 10 CFR Part 72, or equivalent.

D. Complete traceability of raw materials and the use of certified welders and processes is required.

E. All personnel performing QA-related inspections, tests, and examinations will be qualified and certified in accordance with the requirements of the QA program.

F. Only qualified and certified auditors and lead auditors will perform audits.

G. TN QA personnel will be required to inspect and/or approve supplier-fabricated components prior to authorizing shipment release.

H. Welding consumables will be procured as a Category A item if the intended use is unknown. If purchased for a specific Category B or C application, the material must be identified, and its use restricted to fabrication of the same level.

Category B

A. The design is based on the most stringent industrial codes and standards. But design verification may be accomplished by use of alternate calculations or computer codes.

B. The procurement of items may be from suppliers on the Approved Suppliers List or QA program requirements for the supplier may be based on the inspection and test requirements of the procured item.

C. Traceability of materials is not required; however, specified welds require completion by qualified, certified welders.

D. Quality Assurance verification activities will be performed by personnel qualified and certified in accordance with the requirements of the QA program.

E. Only lead auditor personnel require certification in accordance with the QA program.

Category C

A. Items may be purchased from a catalog or “off-the-shelf.”

B. When received, the item will be identified and checked for both compliance with the purchase order and for damage.

Items not considered important-to-safety will be controlled in accordance with good industrial practices.

If a utility elects to perform construction, and has an NRC-approved QA program (10 CFR 50) [14-4] that is equivalent to or exceeds TN’s program, then the utility QA program is considered an acceptable substitute for their scope of responsibility.

14.3 Description of TN Americas LLC 10 CFR 72, Subpart G QA Program

14.3.1 Project Organization

The NUHOMS® EOS System has been designed by a dedicated TN project organization.

Quality assurance (QA) duties are performed by the TN project organization, the Senior Manager, Quality Assurance, and the Quality Assurance staff.

The organization structure for the NUHOMS® EOS System project is presented in Figure 14-1. A description of the TN organizational structure, functional responsibilities, levels of authority, and lines of internal and external (client and supplier) communication may be found in the QA program description manual.

Project QA controls are determined by the Project Manager and approved by QA. All Project Plans, regardless of the indicated applicability of QA requirements, are reviewed by QA to verify that QA controls are commensurate with the specific activity, item complexity, importance to safety and client-imposed contractual requirements.

Project personnel are indoctrinated, trained, and qualified in accordance with the QA program.

14.3.2 QA Program

TN will apply the QA program to components defined in Table 2-1 as "important-to-safety" and "safety-related," in accordance with the QA program description manual.

TN has established and implemented a QA program for the control of quality in the design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair, and modification of storage containers for nuclear products. Training and/or evaluation of personnel qualifications in accordance with written procedures are required for personnel performing activities affecting quality. The QA program verifies that all quality requirements, engineering specifications and specific provisions of any package design approval are met. The characteristics that are critical to safety are emphasized.

The TN Senior Manager, Quality Assurance regularly evaluates the QA program for adherence to the 18-point criteria in scope, implementation and effectiveness. In addition, the TN President requires that the QA program, including the QA program description manual and associated implementing procedures, be implemented and enforced on all applicable projects at TN.

Annually, a Management Audit of the Quality Assurance organization is conducted by an organization independent of the TN Quality Assurance organization.

14.3.3 Design Control

"Important-to-safety" and "safety-related" NUHOMS® EOS System design activities will be implemented in accordance with the QA program. Design verification will be performed by a competent individual with the appropriate skill level. However, the skill level of this individual may not be the same as the originator, but must be equivalent.

Errors and deficiencies in the design, including the design process, are documented in the form of Corrective Action Reports.

Industry standards and specifications are used for the selection of suitable materials, parts, equipment and processes for "important-to-safety" and "safety-related" structures, systems, and components, as defined in the various chapters and sections of this Updated Final Safety Analysis Report.

14.3.4 Procurement Document Control

Procurement documents are prepared in accordance with the QA program, which delineates the actions to be accomplished in the preparation, review, approval, and control of procurement documents. Review and approval of procurement documents by QA are indicated on the procurement documents, prior to release, to confirm the adequacy of quality requirements stated therein. This review determines that quality requirements are correctly stated, inspectable, and controllable; that there are adequate acceptance and rejection criteria; and that the procurement document has been prepared, reviewed, and approved in accordance with QA program requirements. Refer to Section 14.2 for supplier selection requirements.

The procurement documents will identify the documentation required to be submitted for information, review, or approval by TN or a client of TN. The time of submittal will also be established. When TN requires the supplier to maintain specific QA records, the retention times and disposition requirements will be prescribed.

When purchasing commercial calibration and testing services subject to the requirements for commercial- grade dedication, TN procurement documents include necessary technical and quality requirements based on NRC endorsed industry guidance.

When applicable, TN procurement documents include the reporting requirements of 10 CFR Part 21 for the Reporting of Defects and Noncompliances.

14.3.5 Procedures, Instructions, and Drawings

As required by the QA program, activities affecting quality are prescribed in approved, written procedures, instructions, or drawings and these procedures, instructions, and drawings will be followed.

14.3.6 Document Control

The issuance, distribution, and receipt of documents that prescribe activities affecting quality are controlled in accordance with the QA program. Controlled documents include, but are not limited to, the TN design specifications and criteria documents, drawings, instructions, and test procedures.

The individuals or groups responsible for reviewing, approving, and issuing documents and revisions thereto are identified in the “Responsibilities” sections of the TN QA program implementing procedures.

14.3.7 Control of Purchased Items and Services

The control of purchased items and services will be implemented in accordance with the QA program.

Surveillance of subcontracted activities is planned and performed in accordance with written procedures to ensure conformance to the purchase order. These procedures provide for instructions that specify the characteristics to be witnessed, inspected or verified, and accepted; the method of surveillance and the extent of documentation required; and the individuals responsible for implementing these instructions.

TN suppliers will furnish documentation that identifies any procurement requirements that have not been met, together with a description of those nonconformances dispositioned as “use-as-is” or “repair.”

Documentation from TN suppliers that demonstrates compliance with procurement requirements (such as material test reports, NDE results, performance test results, etc.) is periodically evaluated by audits, independent inspections, or tests, as necessary, to verify its validity.

14.3.8 Identification and Control of Materials, Parts, and Components

Materials, parts, and components will be identified and controlled in accordance with the QA program. Hardware identification requirements are determined during the generation of design drawings and specifications in such a way that the location and method of identification do not affect the form, fit, function, or quality of the item being identified.

14.3.9 Control of Special Processes

The control of special processes, such as nondestructive examination, chemical cleaning, welding, and heat-treating will be performed in accordance with the QA program.

14.3.10 Inspection

Receipt inspections, and in-process and final inspections of TN-fabricated, -constructed, or -erected items, systems, components, or structures will be performed in accordance with the QA program.

14.3.11 Test Control

Test control will be accomplished in accordance with the QA program.

14.3.12 Control of Measuring and Test Equipment

The QA program defines the requirements for calibration of measuring and test equipment. Calibration is against certified measurement standards that have known relationships to national standards, where such standards exist. Where such standards do not exist, the basis for calibration will be documented.

14.3.13 Handling, Storage and Shipping

Handling, storage, and shipping will be conducted in accordance with the QA program. Special handling, preservation, storage, cleaning, packaging, and shipping requirements are established and accomplished by qualified individuals in accordance with predetermined work and inspection instructions.

14.3.14 Inspection and Test Status

The use of inspection and test status tags will be implemented in accordance with the QA program.

14.3.15 Control of Nonconforming Items

The QA program defines the requirements and assigns the responsibilities for the control, identification, segregation, documentation, and close-out of nonconforming items to prevent their inadvertent installation or use in fabrication, construction, or erection.

Nonconformance reports identify the item description and quantity, the disposition of the nonconformance, the inspection requirements, and signature approval of the disposition. They are periodically analyzed to show quality trends and help identify root causes of nonconformances. Significant results are reported to responsible management for review and assessment.

Nonconforming items are segregated from acceptable items and tagged to prevent inadvertent use until properly dispositioned and closed out.

14.3.16 Corrective Action

Corrective action for conditions adverse to quality will be taken in accordance with the QA program. For significant conditions adverse to quality, the cause is determined and action to preclude recurrence is taken and reported to the appropriate levels of management.

14.3.17 Records

The QA program defines the scope of the records program so that sufficient records are maintained to provide documentary evidence of the quality of items and activities affecting quality.

14.3.18 Audits and Surveillances

A comprehensive system of planned and documented audits, including audits of suppliers and site construction activities, verifies compliance with all aspects of the QA program and determines the effectiveness of the program.

Audits are performed by certified lead auditors and are planned, performed, and documented in accordance with the QA program.

The TN Senior Manager, Quality Assurance or his designee may perform unannounced QA surveillances on activities affecting quality, on an as-needed basis, to further ensure compliance with QA requirements.

14.4 Conditions of Approval Records

As required by 10 CFR 72, Subpart L, TN will establish and maintain records for each storage component fabricated under a certificate of compliance as required by §72.234(d). The records will be available for inspection as required by §72.234(e). Written procedures and appropriate tests will be established prior to use of the storage components, which will be provided to each NUHOMS® EOS System user as required by §72.234(f).

14.5 Supplemental Information

14.5.1 References

14-1 Title 10 Code of Federal Regulations, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste."

14-2 "TN Americas LLC Quality Assurance Program Description Manual for 10 CFR Part 71, Subpart H and 10 CFR Part 72, Subpart G," current revision.

14-3 NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety," U.S. Nuclear Regulatory Commission, February 1996.

14-4 Title 10 Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities."

Table 14-1
Quality Assurance Program Description Manual Sections

10 CFR 72, Subpart G	QA Program Section
.142	1.0 Organization
.144	2.0 Quality Assurance Program
.146	3.0 Design Control
.148	4.0 Procurement Document Control
.150	5.0 Instructions, Procedures and Drawings
.152	6.0 Document Control
.154	7.0 Control of Purchased Material, Equipment and Services
.156	8.0 Identification and Control of Materials, Parts and Components
.158	9.0 Control of Special Processes
.160	10.0 Inspection
.162	11.0 Test Control
.164	12.0 Control of Measuring and Test Equipment
.166	13.0 Handling, Storage and Shipping
.168	14.0 Inspection, Test and Operating Status
.170	15.0 Nonconforming Material, Parts or Components
.172	16.0 Corrective Action
.174	17.0 Quality Assurance Records
.176	18.0 Audits

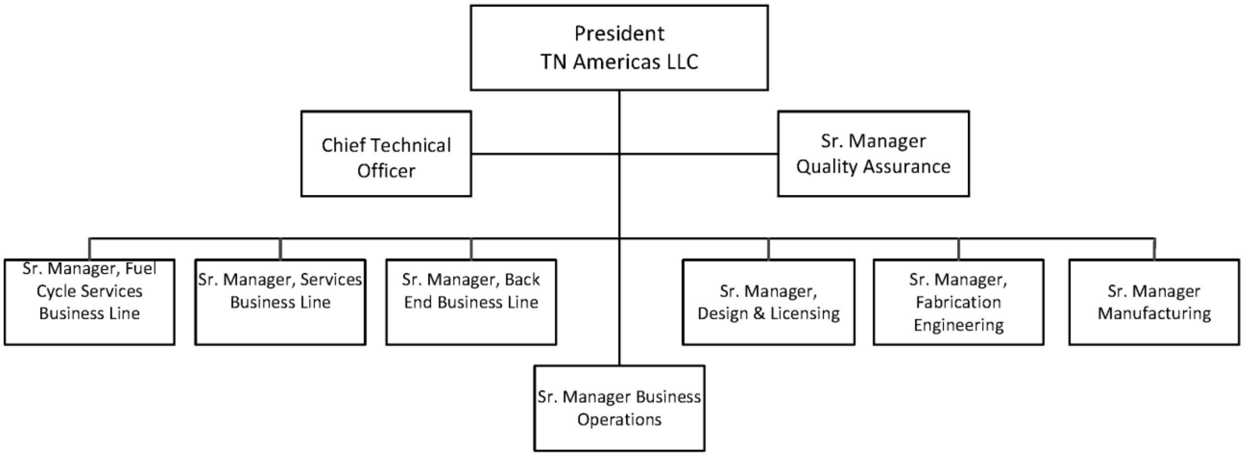


Figure 14-1
TN Americas LLC Functional Organization for Quality Assurance Program Activities