Enclosure 3 to E-25259

Transnuclear, Inc. Calculation NUH32PTH1-0450, “Thermal Analysis of OS200 Transfer Cask Loaded with 32PTH1 DSC,” Revision 0
(Non-proprietary version, without discs)

TRANSNUCLEAR AN AREVA COMPANY	**Calculation**	**Calculation No.:** NUH32PTH1-0450 **Revision No.:** 0 **Page:** 1 of 124
CALCULATION TITLE:	**Thermal Analysis of OS200 Transfer Cask Loaded with 32PTH1 DSC**	**Project:** NUH32PTH1
		DCR: N/A

SUMMARY DESCRIPTION:

The NUHOMS® OS200 Transfer Cask (TC) is used to transfer loaded dry shielded canisters (DSCs) between the fuel building and the horizontal storage module (HSM). The design of the OS200 TC is similar to the design of the OS187 TC with primary differences being a longer length and design modifications to the cask's closure lid and the addition of wedge-shaped spacers at the cask's bottom to accommodate forced air circulation in the TC-DSC annulus. The thermal performance of the TC is evaluated under normal, off-normal, and accident conditions of operation with and without forced air circulation.

While provision is made for the use of forced air circulation to improve the systems' thermal performance, forced air circulation is to be used only as one possible recovery mode if the operational limits established herein are exceeded. Forced air circulation is not relied on for accident conditions.

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

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

This calculation is one of the design basis calculations to support the current licensing amendment submittal for the NUHOMS® 32PTH1 system. Therefore, a 72.48 review by Transnuclear is not necessary.

Software Utilized:	Version:	Number of CDs:
Thermal Desktop® and SINDA/FLUINT	4.7	2

Calculation is complete: Gregory Banken *Gregory J Banken*	8/1/06 (Date)
Calculation has been checked for consistency, completeness and correctness: Larry Nielsen *LH Nielsen*	8/2/06 (Date)
Calculation is approved for use: Miguel A Manrique *Miguel A. Manrique* (Project Engineer Signature)	8/3/06 (Date)

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REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	8/3/06	Initial Release	ALL	N/A

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[redacted]

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LIST OF FIGURES

1. INTRODUCTION

1.1 Objective

The objectives of this calculation are to develop a thermal model of the NUHOMS® OS200 On-site Transfer Cask (TC) and to determine the thermal performance of the OS200 TC under a combination of heat loads, operating assumptions, and ambient conditions.

The thermal model of the NUHOMS® OS200 TC provides a 3-D representation of the cask and its 32PTH1 dry shielded canister (DSC) payload. The thermal model also includes the heat transfer mechanisms between the DSC and the inner shell of the cask with and without forced air circulation. Under the forced air circulation option, air from an external fan enters through the ram access hole at the base of the cask, flows in the annular space between the DSC and the inner shell of the cask, and exits out slots in the closure lid. Besides improving the heat transfer coefficients from the air to the DSC and the inner shell of the cask, the forced air system will remove a significant amount of the decay heat via a mass transport process.

The thermal performance of the NUHOMS® OS200 TC is to be evaluated under normal, off-normal, and accident conditions of operation. If forced air circulation is required to maintain the system temperatures within normal operational limits for steady-state operations, the available time to initiate the forced air circulation or to re-store the forced air circulation in case of system failure is to be determined.

1.2 Purpose

The purpose of these evaluations is to demonstrate compliance with the applicable regulatory requirements for the NUHOMS® OS200 TC and its 32PTH1 DSC payload and to provide design data for associated calculations.

1.3 Scope

This scope of this calculation is limited to the OS200 TC loaded with a 32PTH1 DSC and with a maximum heat dissipation of 40.8 kW. The thermal performance of the TC under the option for helium gas backfill is not covered by this calculation.

2. DESIGN INPUTS & ASSUMPTIONS

2.1 Design Configuration

The NUHOMS® OS200 TC is used to transfer the 32PTH1 DSC between the fuel building and the horizontal storage module (HSM) at the ISFSI site. If the provision for forced air circulation is not needed, then the OS200 TC outfitted with a standard top cover may be used to accomplish the transfer. However, if the need for forced air circulation is anticipated due to the combination of decay heat load and the fuel basket configuration of the 32PTH1 DSC payload exceeding the limits established in this calculation, then the OS200 cask must be outfitted with a top cover that offers the design provisions necessary to accommodate the forced air circulation with the 32PTH1 DSC. A full description of the design requirements for the NUHOMS®-32PTH1 DSCs is provided in [6.1].

[redacted]

[redacted]

3) [redacted]

[redacted]

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[redacted]

The TC is designed to function in both the vertical and horizontal orientation. The vertical orientation typically occurs during canister loading and closure operations, while the horizontal orientation

occurs during transfer operations [redacted]

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[redacted]

2.2 Design Assumptions

The principal assumptions used in this calculation are as follows:

- When the TC is in the horizontal orientation, the DSC is supported by the four canister rails depicted in Figure 2-2. [redacted] For conservatism, only the lowest pair of canister rails is assumed to be in contact with the DSC. [redacted]

- The effective density and specific heat of the combined fuel and fuel basket thermal mass [redacted] conservatively bounds the values computed in [6.4] for the range of fuel baskets and fuel types considered for the 32PTH1 DSC. [redacted]
- Due to differences in thermal expansion between lead and stainless steel, a gap will tend to form at the outer surface of the lead shield after the lead pour. For conservatism, this calculation assumes the potential gap is uniform over the entire outer surface of the lead shield. [redacted]
- The forced air circulation introduced in the annular gap between the DSC and the cask will distribute itself based upon the flow area and hydraulic diameter [redacted]

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- [redacted] For conservatism, the short DSC length is assumed for this calculation since this configuration results in the highest surface heat flux on the DSC shell [redacted]

2.3 Design Criteria

The design criterion for the TC is established by the thermal limits associated with its most temperature sensitive components. These components are the lead in the gamma shield, the water in the neutron shield, and the NS-3 solid neutron shielding material. The temperature limits associated with the elastomeric seal used with the alternate cask closure lid design are not applicable to this calculation since operation of the TC when this closure lid is used is not addressed by this calculation.

The ASTM B29 lead used in the gamma shield has a melting point of approximately 620°F.

[redacted]

[redacted]

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2.4 Design Load Cases

The thermal performance of the TC is evaluated for a range of thermal load cases. These load cases involve normal (i.e., 106 °F and 0 °F) and off-normal (i.e., 117 °F) ambient temperatures, with and without insolation, and with and without forced air circulation. Operations within the fuel handling building assume a peak ambient temperature of 120 °F for normal conditions and 140 °F for off-normal conditions. No solar loads are considered for operations within the fuel handling building.

Four accident scenarios are also evaluated for the TC. The first accident scenario involves the loss of the forced air circulation system. The time to re-establish the forced air circulation, complete the transfer operation, or initiate some other recovery mode is established. The second accident scenario involves the loss of both the forced air circulation system and the water in the neutron shield. The evaluation establishes the transient heat up trend and the ultimate temperatures achieved under steady-state conditions. The third accident scenario involves a 15-minute hypothetical fire. The maximum duration of the fire event will be controlled by limiting the available fuel sources within the vicinity of the TC. The evaluation establishes the maximum temperatures reached as a result of the fire event, as well as the post-fire, steady-state conditions. The fourth final accident scenario involves an undamaged TC under an elevated ambient condition of 133 °F. The evaluation addresses the maximum steady-state temperatures that would be achieved.

[redacted]

2.5 Thermal Loads

The thermal loads imposed on the TC arise from the decay heat within the DSC and insolation on its exterior. As described in [6.1], the 32PTH1 DSC has 3 possible heat zone configurations for the various fuel basket designs with a maximum heat load of 40.8 kW. Alternative designs for the fuel basket are qualified for maximum heat loads of 31.2 and 24.0 kW. Since the combination of the 32PTH1 DSC and OS200 TC permits steady-state operations for some combinations of fuel basket design and decay heat loading, but not others, the results presented in Section 5 establish the operational time limits that address the thermal requirements of the various combinations of fuel basket design and decay heat loading. [redacted]

The insolation loading is varied by the surface orientation and absorptivity, with vertical surfaces [redacted] and curved surfaces facing upward [redacted]. These insolation levels are based on regulatory insolation averaged over 12 hours [redacted].

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Table 2-1 - Design Load Cases for 32PTH1 Basket and HZC #1

[redacted]

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[redacted]

Table 2-2 - Design Load Cases for 32PTH1 Basket and HZC #2

[redacted]

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Table 2-3 - Design Load Cases for 32PTH1 Basket and HZC #3

[redacted]

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Figure 2-1 - Elevation View of NUHOMS® OS200 Transfer Casks

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Figure 2-2 - Cross-Section through NUHOMS® OS200 Transfer Cask

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Figure 2-3 - Location of Neutron Shield Support Rings

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Figure 2-4 - Enlarged View of Typical Neutron Shield Support Ring

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Figure 2-5 - Cone Adapter for Forced Air Entrance at Ram Access Cover

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Figure 2-6 - Illustration of Wedge Segments at Bottom of TC

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Figure 2-7 - Cask Lid with Slots for Air Exhaust, Plan, X-Section, & Detail Views

3. MATERIAL THERMAL PROPERTIES

Table 3-1 lists the thermal conductivity and specific heat as a function of temperature for SA-240, Type 304/304L stainless steel, ASTM B29 lead, and the NS-3 neutron shielding material. [redacted]

Table 3-3 lists the thermal conductivity, specific heat, and dynamic viscosity for air and water as a function of temperature. [redacted]

[redacted]

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[redacted]

The Table 3-4 values are applicable to the radial heat transfer within a water-filled shield under the normal conditions of transfer. [redacted]

The effective thermal properties of the neutron shield under accident conditions (i.e., an air-filled shield and for the hypothetical fire event) are presented in Table 3-5. [redacted]

Table 3-6 lists the surface emissivity assumed for the various surface finish types under normal and accident conditions. [redacted]

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Table 3-1 - Material Properties, Solids

[redacted]

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[redacted]

Table 3-2 - Effective Thermal Properties for 32PTH1 Basket

[redacted]

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[redacted]

Table 3-3 - Thermal Properties, Fluids

[redacted]

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Table 3-4 - Effective Water Filled Neutron Shield Thermal Conductivity for Normal Conditions

[redacted]

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[redacted]

Table 3-5 - Effective Neutron Shield Thermal Conductivity for Accident Conditions

[redacted]

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[redacted]

Table 3-6 - Material Emissivity Values

[redacted]

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4. CALCULATION METHODOLOGY

4.1 General Code Description

The analytical thermal model of the NUHOMS® OS200 TC and its 32PTH1 DSC payload is developed for use with the Thermal Desktop® [6.21] and SINDA/FLUINT [6.22] computer programs. These programs, validated for safety basis thermal analysis [6.23], are designed to function together to build, exercise, and post-process a thermal model. The Thermal Desktop® computer program is used to provide graphical input and output display function, as well as to compute the radiation exchange conductors for the defined geometry and optical properties. Since Thermal Desktop® runs as an extension module under the AutoCAD™ design program, all of the CAD tools available for generating geometry within AutoCAD™ can be used for generating a thermal model. In addition, the use of the AutoCAD™ layers tool provides a convenient means of segregating the thermal model into its various elements.

The SINDA/FLUINT computer program is a general purpose code suitable for either finite difference or finite-element models. The code can be used to compute the steady-state and transient behavior of the modeled system. SINDA/FLUINT has been validated for simulating the thermal response of spent fuel packages and has been used in the safety analysis of numerous packages for both spent nuclear fuel and nuclear material.

The Thermal Desktop® and SINDA/FLUINT codes provide the capability to simulate steady-state and transient temperatures using temperature dependent material properties and heat transfer via conduction, convection, and radiation. Complex algorithms may be programmed into the solution process for the purposes of computing heat transfer coefficients as a function of the local geometry, gas thermal properties as a function of species content, temperature, and pressure, or, for example, to estimate the effects of forced air circulation in the cask-DSC annulus as a function of the flow geometry.

4.2 OS200 Transfer Cask Thermal Model

The thermal model used to simulate the thermal response of the OS200 TC represents a 180° segment of the cask. The use of a 180° model permits the accurate simulation of the temperature distribution within the cask when the cask is in the horizontal orientation and the axis of the DSC is eccentric to that of the cask.

[redacted]

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[redacted]

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4.2.1 Gap between Lead Shield and Cask Outer Shell

The OS197FC and OS200 Transfer Cask designs incorporate a lead gamma radiation shield. The shield is formed by a controlled pour of molten lead into the annular gap between the inner liner and structural shell. Under this controlled lead pour procedure the inner liner and structural shell are heated to a temperature above the melting point of lead before the lead is introduced into the annular gap. This ensures that a complete fill is accomplished with no cavities as a result of pre-mature solidification of the lead. However, due to differences in thermal expansion between lead and stainless steel, a gap will tend to form at the outer surface of the lead shield as the lead solidifies. For conservatism, the potential gap is assumed to exist uniformly over the entire outer surface of the lead shield since just the lack of intimate contact between the lead and the outer shell will introduce a

significant thermal resistance. The same difference in thermal expansion will keep the interface between the inner steel shell and the lead shield in intimate contact.

[redacted]

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4.2.2 Forced Air Circulation Simulation

The NUHOMS® OS200 Transfer Cask contains design provisions for the use of forced air circulation to improve its thermal performance. For heat loads and/or time periods exceeding values determined in Section 5, the normal operating conditions will require that a fan system be connected to the cask and operating. The system will consist of redundant, industrial grade pressure blowers and power systems, ducting, etc. When operating, the fan system is expected generate a flow rate of 450 cfm or greater which will be ducted to the ram access cover location at the bottom of the cask, flow in the annulus between the DSC and the cask's inner liner, and exit through 'slots' in the cask lid. The thermal benefit of the forced flow arises from an increase in the heat transfer rate from the DSC and cask liner surfaces and from the mass transport of a significant portion of the decay heat from the cask via the exiting airflow.

[redacted]

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[redacted]

4.2.2.1 Pressure Drop Calculations

The pressure drop experienced by the forced air from the fan discharge, through the DSC and cask annulus, and its subsequent exhausting back into the ambient is computed [redacted].

[redacted]

Since the pressure drop calculations are integrated with the temperature calculations within the SINDA/FLUINT model, the impact of the temperature rise within each angular segment on the density and flow velocities is incorporated into the results.

4.2.2.2 Convection Heat Calculations

The convection heat transfer within the DSC-cask annulus is computed using the relationships for flow within ducts and pipes. The convection heat transfer coefficients are computed as a function of the local hydraulic diameter, the Reynolds number, and the thermophysical properties of air or water. [redacted]

[redacted]

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[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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[redacted]

4.3 DSC Thermal Model

[redacted]

[redacted]

4.4 Convection Heat Transfer

Convection heat transfer occurs from various exterior surfaces of the TC under all conditions of transfer. [redacted]

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[redacted]

[redacted]

[redacted]

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[redacted]

Table 4-1 - Effective Thermal Conductivity in Gamma Shield & Structural Shell Gap

[redacted]

Table 4-2 - Cask-DSC Gap Calculation as Function of Circumferential Position

[redacted]

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[redacted]

Table 4-3 – Forced Air Pressure Drop

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Figure 4-1 - Thermal Model of OS200 TC / 32PTH1 DSC Shell, Perspective View

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Figure 4-2 - Thermal Model of OS200 TC Body, Perspective View

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Figure 4-3 - Thermal Model of Inner Liner, Structural Shell, & Upper/Lower Forging

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Figure 4-4 - Thermal Model for Closure End Lid & NS-3, Perspective View

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Figure 4-5 - Solid View of Closure Lid Underside

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Figure 4-6 - Gamma Shield - Structural Shell Gap Size vs. Temperature

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Figure 4-7 - Thermal Model for 32PTH1 DSC Shell, Ends, & Cask Spacer, Perspective View

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Figure 4-8 - Thermal Model for DSC Shell, Ends, & Fuel Basket, Perspective View

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Figure 4-9 - Layout of Gas Nodes and Flow Paths within DSC-Cask Annulus

5. CALCULATIONS

5.1 Evaluations for the 32PTH1 Fuel Basket w/ HZC #1 (40.8 kW)

5.1.1 Transient Load Operations w/ HZC #1 (40.8 kW)

The thermal analyses presented under this section of the calculation addresses the thermal performance of the OS200 TC with the 32PTH1 fuel basket and with a heat zone configuration that is bounded by that for HZC #1 (40.8 kW) [6.1]. The level of decay heat dissipation under this heat zone configuration is too high to permit steady-state operations within the DSC due to excessive fuel cladding temperatures unless the TC-DSC annulus is filled with water or unless forced air circulation is used. As such, operational time limits will be used to ensure that the transfer operation is completed within the allotted time or some form of recovery operation is initiated. The evaluations are conducted for loading operations inside the fuel handling facility, and normal hot, normal cold, and off-normal hot conditions of operation outside the facility. The parameters for each of these conditions are defined in Section 2.4.

[redacted]

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[redacted]

[redacted]

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[redacted]

Table 5-1 presents the maximum component temperatures achieved under the evaluated transient operating conditions. As seen, all component temperatures are within their associated maximum allowable temperature limits. [redacted]

[redacted]

Since all components are seen in Table 5-1 to remain within their allowable temperature limits at the identified operational time limits, the results demonstrate that an undamaged OS200 TC can accommodate the 32PTH1 DSC with a heat zone configuration that is bounded by that for HZC #1 (40.8 kW) [6.1]. [redacted]

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5.1.2 Steady-State Operations Using Forced Air Circulation w/ HZC #1 (40.8 kW)

Steady-state conditions of the OS200 TC with the 32PTH1 DSC and with decay heat loadings up to 40.8 kW will require the use of force air circulation to limit the system temperatures. Application of the forced air circulation option entails using an external fan to force air to enter the TC via the ram access hole at the base of the cask and then to flow in the annular space between the DSC and the inner shell of the cask before exiting out slots in the closure lid. Besides improving the heat transfer coefficients from the air to the DSC and the inner shell of the cask, the forced air system will remove a significant portion of the decay heat via a mass transport process.

The forced circulation of air through the TC-DSC annulus will allow steady-state operation of the OS200 TC under any Normal or Off-Normal condition of transfer and for heat loads up to 40.8 kW. Table 5-2 presents the maximum component temperatures achieved under the three evaluated operating conditions (i.e., Load Cases 1-5, 1-6, and 1-7) for the OS200 TC with a 32PTH1 DSC, 40.8 kW of heat dissipation, and 450 cfm of forced air circulation. As seen from the table, all of the TC component temperatures are well below their associated maximum allowable temperature limit. The results in Table 5-2 also demonstrate that the forced air circulation option will yield steady-state DSC shell temperatures that are below the target value of 450°F for all conditions.

[redacted]

[redacted]

[redacted]

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[redacted]

5.1.3 Accident Conditions w/ HZC #1 (40.8 kW)

5.1.3.1 Loss of Forced Circulation

As demonstrated in Section 5.1.2, forced air circulation (FC) will provide the ability to accommodate the 32PTH1 DSC within the OS200 TC for indefinite periods under any condition of transfer. Should the FC be lost for some reason, a limited time period will be available either to complete the transfer, re-establish the FC, or to initiate some other recovery mode. The predicted heat up rate for the OS200 TC with the 32PTH1 DSC and 40.8 kW of decay heat (i.e., Load Case 1-8) is illustrated in Figure 5-11. [redacted]

5.1.3.2 Loss of Neutron Shielding

A transient evaluation (i.e., Load Case 1-9) was conducted to establish the ability of the OS200 TC to accommodate the 32PTH11 DSC with a decay heat load of 40.8 kW or less for an indefinite period of time when the water in the neutron shield is lost. [redacted] The analysis concludes with a steady-state evaluation.

[redacted]

[redacted]

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It should be noted that the target DSC temperature limit of 450 °F assumed prior to the start of the accident scenario is associated with maintaining the peak fuel cladding temperature below 700 °F. As such, a higher DSC shell temperature can be accommodated under accident conditions without exceeding the accident temperature limits for the fuel cladding. [redacted]

5.1.3.3 Fire Accident Evaluation

The predicted TC thermal performance under a 15-minute hypothetical fire accident scenario (i.e., Load Case 1-10) is illustrated in Figure 5-13. The maximum duration of the fire event will be controlled by limiting the available fuel sources within the vicinity of the TC. [redacted]

The analysis demonstrates that, with the exception of the exterior surfaces of the cask, the thermal mass of the DSC and cask components is sufficient to absorb the heat flux from the fire without a significant increase in temperature. [redacted]

[redacted]

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[redacted]

Table 5-4 present the peak component temperatures achieved at the pre-fire condition, at the end of the fire (i.e., 15 minutes into the transient), and for the post-fire steady-state condition. [redacted]

5.1.3.4 Accident Ambient Conditions

The fourth and final accident condition evaluated consists of steady-state operations under the accident ambient conditions of 133 °F, with regulatory solar (i.e., Load Case 1-11). [redacted] Further, in actual practice, the solar shade will be used as a partial recovery operation should this condition arise. Deployment of the shade is predicted to drop the average neutron shield water temperature to 281 °F.

Table 5-1 - Transient Operations, HZC #1 (40.8 kW)

Component	Temperature (°F) [1]				
	Case 1-1 [1] Vert. Load	Case 1-2 [2] Normal Hot	Case 1-3 [3] Normal Cold	Case 1-4 [4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	450	450	450	450	800
Inner Liner	277	305	277	310	800
Gamma Shield	275	299	270	304	620
Structural Shell	240	247	205	254	800
Neutron Shield, Max. / Avg.	236 / 217	242 / 215	199 / 147	248 / 210	- / 290
Bulk Average NS-3	216	175	86	169	250
Closure Lid	223	217	158	214	800
Top Forging	219	243	205	247	800
Bottom Forging	228	193	127	195	800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	229	232	186	239	-
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table Notes:
1) Vertical operation within the facility.
2) 106 °F ambient with insolation.
3) 0 °F ambient without insolation.
4) 117 °F ambient with sunshade.

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Table 5-2 - Steady-State Operations with FC, HZC #1 (40.8 kW)

	Temperature (°F) [1]				
Component	Vert. Load [1]	Case 1-5 [2] Normal Hot	Case 1-6 [3] Normal Cold	Case 1-7 [4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	n/a	431	341	444	800
Inner Liner	n/a	339	247	348	800
Gamma Shield	n/a	333	241	342	620
Structural Shell	n/a	283	184	293	800
Neutron Shield, Max. / Avg.	n/a	278 / 210	180 / 89	288 / 211	- / 290
Bulk Average NS-3	n/a	206	85	202	250
Closure Lid	n/a	272	147	274	800
Top Forging	n/a	299	206	305	800
Bottom Forging	n/a	169	56	181	800
Forced Air, Inlet / Exit	n/a	106 / 275	0 / 152	117 / 283	n/a
Neutron Shield Outer Skin	n/a	267	169	278	-
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table Notes:
1) Forced air circulation for vertical operation within the facility is not possible since air duct can not be connected.
2) 106 °F ambient with insolation and 450 cfm of forced air circulation.
3) 0 °F ambient without insolation and 450 cfm of forced air circulation.
4) 117 °F ambient with sunshade and 450 cfm of forced air circulation.

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Table 5-3 - Loss of Neutron Shielding with HZC #1 (40.8 kW)

Component	Temperature (°F)	
	Case 1-9[1]	Max. Allowable
Max. DSC Shell	651	800
Inner Liner	544	800
Gamma Shield	539	620
Structural Shell	518	800
Neutron Shield, Max. / Avg.	n/a	-
Bulk Average NS-3	263	300[2]
Closure Lid	383	800
Top Forging	417	800
Bottom Forging	317	800
Forced Air, Inlet / Exit	n/a	n/a
Neutron Shield Outer Skin	308	-

Table Notes:

1) Steady-state conditions for with no water in neutron shield jacket, no forced air circulation, 117 °F ambient with insolation.
2) Short term allowable temperature for NS-3.

Table 5-4 - Fire Accident Temperatures with HZC #1 (40.8 kW)

Component	Temperature (°F)			
	Case 1-4 Pre-Fire[1]	Case 1-10 End of Fire[2]	Case 1-10 Post-Fire Steady-State[3]	Max. Allowable, Short / Long Term
Max. DSC Shell	450	451	646	1000 / 800
Inner Liner	310	313	536	1000 / 800
Gamma Shield	304	309	531	620
Structural Shell	254	423	506	1000 / 800
Neutron Shield, Max. / Avg.	248 / 210	n/a	n/a	-
Bulk Average NS-3	169	899	252	1300 /250
Closure Lid	214	772	371	1000 / 800
Top Forging	247	1067	401	1000 / 800
Bottom Forging	195	1164	303	1000 / 800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	239	958	294	-

Table Notes:

1) Assumes initial conditions with 32PTH1 with 40.8 kW, 117 °F ambient with sunshade, @ 16.5 hours after drain down of TC-DSC annulus.
2) Component temperatures at end of 15 minute fire transient
3) Assumes no forced air circulation and no water in the neutron shield, 117 °F ambient with insolation

Table 5-5 - Accident Ambient Temperatures with HZC #1 (40.8 kW)

Component	Temperature (°F)	
	Case 1-11 [1]	Max. Allowable
Max. DSC Shell	558	800
Inner Liner	399	800
Gamma Shield	393	620
Structural Shell	341	800
Neutron Shield, Max. / Avg.	334 / 296 [2]	- / 290
Bulk Average NS-3	245	250
Closure Lid	338	800
Top Forging	339	800
Bottom Forging	254	800
Forced Air, Inlet / Exit	n/a	n/a
Neutron Shield Outer Skin	322	-

Table Notes:

1) Steady-state conditions with water in neutron shield jacket, no forced air circulation, 133 °F ambient with insolation
2) Deployment of the solar shade will lower the average neutron shield water temperature to 281 °F.

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Figure 5-1 - Vertical Loading Transient w/ 40.8 kW, 140°F Facility Ambient/No Insolation (Case 1-1)

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Figure 5-2 - Normal Hot Horizontal Transient w/ 40.8 kW, 106°F Ambient/Insolation (Case 1-2)

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Figure 5-3 - Normal Cold Horizontal Transient w/ 40.8 kW, 0°F Ambient/No Insolation (Case 1-3)

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Figure 5-4 - Off-Normal Hot Horizontal Transient w/ 40.8 kW, 117°F Ambient/Sun Shade (Case 1-4)

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Figure 5-5 - DSC Temperature Distribution – Vertical Loading w/ HZC #1 (40.8 kW, Case 1-1)
Alternate Perspective Views

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Figure 5-6 - TC Temperature Distribution - Vertical Loading w/ HZC #1 (40.8 kW, Case 1-1) Alternate Perspective Views

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Figure 5-7 - DSC Temperature Distribution - Normal Hot Transfer w/ HZC #1 (40.8 kW, Case 1-2), Alternate Perspective Views

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Figure 5-8 - TC Temperature Distribution - Normal Hot Transfer w/ HZC #1 (40.8 kW, Case 1-2), Alternate Perspective Views

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Figure 5-9 - DSC Temperature Distribution - Normal Hot Transfer w/ Forced Air Circulation and HZC #1 (40.8 kW, Case 1-5), Alternate Perspective Views

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Figure 5-10 - TC Temperature Distribution - Normal Hot Transfer w/ Forced Air Circulation and HZC #1 (40.8 kW, Case 1-5), Alternate Perspective Views

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Figure 5-11 - Loss of Forced Circulation Transient w/ 40.8 kW, (Case 1-8)

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Figure 5-12 - Loss of Neutron Shield w/ 40.8 kW, (Case 1-9)

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Figure 5-13 - Hypothetical Fire Accident Transient (40.8 kW, Case 1-10)

5.2 Evaluations for the 32PTH1 Fuel Basket w/ HZC #2 (31.2 kW)

5.2.1 Transient Load Operations w/ HZC #2 (31.2 kW)

The thermal analyses presented under this section of the calculation addresses the thermal performance of the OS200 TC with the 32PTH1 fuel basket and with a heat zone configuration that is bounded by that for HZC #2 (31.2 kW) [6.1]. The level of decay heat dissipation under this heat zone configuration is too high to permit steady-state operations within the DSC due to excessive fuel cladding temperatures unless fuel basket utilizes solid aluminum rails, the TC-DSC annulus is filled with water, or unless forced air circulation is used. Otherwise, operational time limits will be used to ensure that the transfer operation is completed within the allotted time or some form of recovery operation is initiated. The evaluations are conducted for loading operations inside the fuel handling facility, and normal hot, normal cold, and off-normal hot conditions of operation outside the facility. The parameters for each of these conditions are defined in Section 2.4.

[redacted]

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The allowable time limit for completing the transfer of the DSC to the storage cask (including the actual time it takes to complete the cask closure operations and place the cask on the trailer) is set by the time it takes for the maximum DSC shell temperature to reach temperatures of 400 °F, if left in the vertical orientation, and 420 °F, if rotated to the horizontal position. These target temperature points are established as the limiting DSC shell temperatures required to support the heat zone configuration #2 (31.2 kW) DSC by a separate, detailed analysis [6.4] of the temperature rise within the DSC fuel basket.

[redacted]

[redacted]

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Table 5-6 presents the maximum component temperatures achieved under the evaluated transient operating conditions. The component temperatures are taken at the identified time point in the transient evaluation. As seen from the tables, all component temperatures are within their associated maximum allowable temperature limits.

[redacted]

[redacted]

5.2.2 Steady-State Operations for HZC #2 (31.2 kW) without Forced Air Circulation

If the transfer operation is not completed within the time periods established in Section 5.2.1, the temperatures within the TC and DSC will continue to rise until steady-state conditions are achieved. The ultimate temperature levels achieved within the major components under steady-state conditions are presented in Table 5-7. [redacted]

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[redacted]

Figure 5-21 to Figure 5-24 illustrate the associated temperature distributions within the DSC and the TC at steady-state conditions for the Vertical Loading and Normal Hot conditions of transfer.

5.2.3 Steady-State Operations with Type 2 (31.2 kW) DSC with Forced Air Circulation

The forced circulation of air (FC) through the TC-DSC annulus will allow steady-state operation of the OS200 TC under any Normal or Off-Normal condition of transfer. Table 5-8 presents the maximum component temperatures achieved under the three (3) evaluated operating conditions for the OS200 TC with a 32PTH1 DSC, 31.2 kW of heat dissipation, and 450 cfm of forced air circulation (note that the FC option can not be used with the TC in the vertical orientation since a connection can not be made to the ram access). As seen from the table, all component temperatures are well below their associated maximum allowable temperature limit. The results in Table 5-8 also demonstrate that the forced air circulation option will result in steady-state DSC shell temperatures well below target value of 420 °F for all conditions.

Figure 5-25 and Figure 5-26 illustrate the expected temperature distribution within the DSC shell and the TC for the Load Case 2-5 condition (i.e., 106 °F ambient, with insolation, 31.2 kW decay heat, and 450 cfm of forced air circulation). Both figures show the expected shift in the peak temperature locations that result from the airflow in the TC-DSC annulus.

5.2.4 Accident Conditions w/ HZC #2 (31.2 kW)

5.2.4.1 Loss of Forced Circulation

As demonstrated in Section 5.2.3, forced air circulation (FC) will provide the ability to accommodate the 32PTH1 DSC within the OS200 TC for indefinite periods under any condition of transfer. Should the FC be lost for some reason, a significant time period will be available either to complete the transfer, re-establish the FC, or to initiate some other recovery mode. The predicted heat up rate for the OS200 TC with the 32PTH1 DSC and 31.2 kW of decay heat is illustrated in Figure 5-27. [redacted]

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5.2.4.2 Loss of Neutron Shielding for HZC #2 (31.2 kW)

A transient evaluation (i.e., Load Case 2-9) was conducted to establish the ability of the OS200 TC to accommodate the 32PTH11 DSC with a decay heat load of 31.2 kW or less for an indefinite period of time when the water in the neutron shield is lost. [redacted] The analysis concludes with a steady-state evaluation.

[redacted]

It should be noted that the target DSC temperature limit of 420 °F assumed prior to the start of the accident scenario is associated with maintaining the peak fuel cladding temperature below 752 °F. As

such, a higher DSC shell temperature can be accommodated under accident conditions without exceeding the accident temperature limits for the fuel cladding. [redacted]

5.2.4.3 Fire Accident Conditions with HZC #2 (31.2kW) DSC

The predicted TC thermal performance under a 15-minute hypothetical fire accident scenario (i.e., Load Case 2-10) is illustrated in Figure 5-29. [redacted]

The results of the analysis are similar to those seen for the HZC #1 evaluation (see Section 5.1.3.3) in that the thermal mass of the DSC and cask components is sufficient to absorb the heat flux from the fire without a significant increase in the interior component temperatures. [redacted]

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Table 5-10 present the peak component temperatures achieved at the pre-fire condition, at the end of the fire (i.e., 15 minutes into the transient), and for the post-fire steady-state condition. [redacted]

5.2.4.4 Accident Ambient Conditions with HZC #2 (31.2kW) DSC

The fourth and final accident condition evaluated consists of steady-state operations under the accident ambient conditions of 133 °F, with regulatory solar (i.e., Load Case 2-11). As seen from Table 5-11, the peak component temperatures achieved under this accident condition remain within even their associated short term limits.

Table 5-6 - Transient Operations, HZC #2 (31.2 kW)

Component	Temperature (°F) [1]				
	Case 2-1 [1] Vert. Load	Case 2-2 [2] Normal Hot	Case 2-3 [3] Normal Cold	Case 2-4 [4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	401	420	429	420	800
Inner Liner	255	288	265	295	800
Gamma Shield	254	283	259	290	620
Structural Shell	225	239	200	247	800
Neutron Shield, Max. / Ave.	222 / 208	234 / 211	195 / 145	243 / 207	- / 290
Bulk Average NS-3	209	173	92	166	250
Closure Lid	212	213	171	210	800
Top Forging	210	235	207	240	800
Bottom Forging	219	190	120	190	800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	217	227	182	235	-
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table Notes:
1) Vertical operation within the facility.
2) 106°F ambient with insolation.
3) 0°F ambient without insolation.
4) 117°F ambient with sunshade.

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Table 5-7 - Steady-State Operations without FC, HZC #2 (31.2 kW)

Component	Temperature (°F)[1]				
	Case 2-1[1] Vert. Load	Case 2-2[2] Normal Hot	Case 2-3[3] Normal Cold	Case 2-4[4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	492	485	429	476	800
Inner Liner	330	337	265	340	800
Gamma Shield	328	332	259	335	620
Structural Shell	293	285	200	288	800
Neutron Shield, Max. / Ave.	289 / 262	281 / 248	195 / 145	283 / 241	- / 290
Bulk Average NS-3	269	204	92	196	250
Closure Lid	299	278	171	270	800
Top Forging	267	286	207	288	800
Bottom Forging	289	215	120	214	800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	280	272	182	272	-
[redacted]					

Table Notes:
1) Vertical operation within the facility.
2) 106°F ambient with insolation.
3) 0°F ambient without insolation.
4) 117°F ambient with sunshade.

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Table 5-8 - Steady-State Operations with FC, HZC #2 (31.2 kW)

	Temperature (°F) [1]				
Component	Vert. Load [1]	Case 2-5 [2] Normal Hot	Case 2-6 [3] Normal Cold	Case 2-7 [4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	n/a	370	274	374	800
Inner Liner	n/a	293	197	299	800
Gamma Shield	n/a	289	192	294	620
Structural Shell	n/a	247	146	254	800
Neutron Shield, Max. / Ave.	n/a	243 / 192	142 / 69	251 / 188	- / 290
Bulk Average NS-3	n/a	188	66	182	250
Closure Lid	n/a	236	113	233	800
Top Forging	n/a	263	165	267	800
Bottom Forging	n/a	156	43	162	800
Forced Air, Inlet / Exit	n/a	106 / 243	0 / 120	117 / 241	n/a
Neutron Shield Outer Skin	n/a	235	134	243	-
[redacted]					

Table Notes:
1) Forced air circulation for vertical operation within the facility is not possible since air duct can not be connected.
2) 106°F ambient with insolation and 450 cfm of forced air circulation.
3) 0°F ambient without insolation and 450 cfm of forced air circulation.
4) 117°F ambient with sunshade and 450 cfm of forced air circulation.

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Table 5-9 - Loss of Neutron Shielding with HZC #2 (31.2 kW)

Component	Temperature (°F)	
	Case 2-9 [1]	Max. Allowable
Max. DSC Shell	578	800
Inner Liner	482	800
Gamma Shield	478	620
Structural Shell	456	800
Neutron Shield, Max. / Avg.	n/a	-
Bulk Average NS-3	240	250
Closure Lid	335	800
Top Forging	373	800
Bottom Forging	288	800
Forced Air, Inlet / Exit	n/a	n/a
Neutron Shield Outer Skin	277	-

Table Notes:
1) Steady-state conditions for with no water in neutron shield jacket, no forced air circulation, 117 °F ambient with insolation.

Table 5-10 - Fire Accident Temperatures with HZC #2 (31.2 kW)

Component	Temperature (°F)			
	Case 2-4 Pre-Fire [1]	Case 2-10 End of Fire [2]	Case 2-10 Post-Fire Steady-State [3]	Max. Allowable, Short / Long Term
Max. DSC Shell	420	421	574	1000 / 800
Inner Liner	295	298	475	1000 / 800
Gamma Shield	290	295	471	620
Structural Shell	247	419	448	1000 / 800
Neutron Shield, Max. / Avg.	243 / 207	n/a	n/a	-
Bulk Average NS-3	166	898	232	1300 /250
Closure Lid	210	771	326	1000 / 800
Top Forging	240	1065	360	1000 / 800
Bottom Forging	190	1163	276	1000 / 800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	235	956	268	-

Table Notes:
1) Assumes initial conditions with 32PTH1 with 31.2 kW, 117 °F ambient with sunshade, @ 25.5 hours after drain down of TC-DSC annulus.
2) Component temperatures at end of 15 minute fire transient
3) Assumes no forced air circulation and no water in the neutron shield, 117 °F ambient with insolation

Table 5-11 - Accident Ambient Temperatures with HZC #2 (31.2 kW)

Component	Temperature (°F)	
	Case 2-11 [1]	Max. Allowable
Max. DSC Shell	495	800
Inner Liner	354	800
Gamma Shield	349	620
Structural Shell	305	800
Neutron Shield, Max. / Avg.	301 / 269	- / 290
Bulk Average NS-3	226	250
Closure Lid	299	800
Top Forging	304	800
Bottom Forging	236	800
Forced Air, Inlet / Exit	n/a	n/a
Neutron Shield Outer Skin	292	-

Table Notes:

1) Steady-state conditions with water in neutron shield jacket, no forced air circulation, 133 °F ambient with insolation.

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Figure 5-14 - Vertical Loading Transient w/ 31.2 kW, 140°F Facility Ambient/No Insolation (Case 2-1)

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Figure 5-15 - Normal Hot Horizontal Transient w/ 31.2 kW, 106°F Ambient/Insolation (Case 2-2)

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Figure 5-16 - Off-Normal Hot Horizontal Transient w/ 31.2 kW, 117°F Ambient/Sun Shade (Case 2-4)

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Figure 5-17 - DSC Temperature Distribution – Vertical Loading w/ HZC #2 (31.2 kW, Case 2-1) Alternate Perspective Views

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Figure 5-18 - TC Temperature Distribution - Vertical Loading w/ HZC #2 (31.2 kW, Case 2-1) Alternate Perspective Views

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Figure 5-19 - DSC Temperature Distribution - Normal Hot Transfer w/ HZC #2 (31.2 kW, Case 2-2), Alternate Perspective Views

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Figure 5-20 - TC Temperature Distribution - Normal Hot Transfer w/ HZC #2 (31.2 kW, Case 2-2), Alternate Perspective Views

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Figure 5-21 - DSC Temperature Distribution – Steady-State, Vertical Loading w/ HZC #2 (31.2 kW, Case 2-1) Alternate Perspective Views

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Figure 5-22 - TC Temperature Distribution - Steady-State, Vertical Loading w/ HZC #2 (31.2 kW, Case 2-1) Alternate Perspective Views

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Figure 5-23 - DSC Temperature Distribution - Steady-State, Normal Hot Transfer w/ HZC #2 (31.2 kW, Case 2-2), Alternate Perspective Views

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Figure 5-24 - TC Temperature Distribution - Steady-State, Normal Hot Transfer w/ HZC #2 (31.2 kW, Case 2-2), Alternate Perspective Views

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Figure 5-25 - DSC Temperature Distribution - Normal Hot Transfer w/ Forced Air Circulation and HZC #2 (31.2 kW, Case 2-5), Alternate Perspective Views

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Figure 5-26 - TC Temperature Distribution - Normal Hot Transfer w/ Forced Air Circulation and HZC #2 (31.2 kW, Case 2-5), Alternate Perspective Views

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Figure 5-27 - Loss of Forced Circulation Transient w/ 31.2 kW, (Case 2-8)

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Figure 5-28 - Loss of Neutron Shield w/ 31.2 kW, (Case 2-9)

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Figure 5-29 - Hypothetical Fire Accident Transient (31.2 kW, Case 2-10)

5.3 Evaluations for the 32PTH1 Fuel Basket w/ HZC #3 (24.0 kW)

The thermal analyses presented under this section of the calculation addresses the thermal performance of the OS200 TC with the 32PTH1 fuel basket and with a heat zone configuration that is bounded by that for HZC #3 (24.0 kW) [6.1]. At this level of decay heat dissipation, steady-state operations are permitted for all transfer conditions and for any fuel basket configuration. The evaluations are conducted for loading operations inside the fuel handling facility, and normal hot, normal cold, and off-normal hot conditions of operation outside the facility. Each of these conditions is defined in Section 2.4.

Table 5-12 presents the maximum component temperatures achieved under the evaluated steady-state operating conditions. All component temperatures are within their associated maximum allowable temperature limits.

The thermal performance of the OS200 TC under accident conditions (i.e., loss of neutron shielding, the 15 minute on-site fire, and the accident ambient conditions) and with a decay heat loading of 24 kW are bounded by those presented in Section 5.2.4.

Table 5-12 - Steady-State Operations without FC, HZC #3 (24.0 kW)

	Temperature (°F)[1]				
Component	Case 3-1[1] Vert. Load	Case 3-2[2] Normal Hot	Case 3-3[3] Normal Cold	Case 3-4[4] Off-Normal Hot	Max. Allowable
Max. DSC Shell	436	429	365	419	800
Inner Liner	295	298	220	300	800
Gamma Shield	293	294	215	296	620
Structural Shell	264	257	164	256	800
Neutron Shield, Max. / Ave.	261 / 239	254 / 226	160 / 118	252 / 218	- / 290
Bulk Average NS-3	244	189	74	180	250
Closure Lid	266	246	134	237	800
Top Forging	244	257	172	258	800
Bottom Forging	260	201	99	197	800
Forced Air, Inlet / Exit	n/a	n/a	n/a	n/a	n/a
Neutron Shield Outer Skin	253	247	150	244	-
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table Notes:
1) Vertical operation within the facility.
2) 106°F ambient with insolation.
3) 0°F ambient without insolation.
4) 117°F ambient with sunshade.

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5.4 Conclusions

The analyses presented in this calculation demonstrate that NUHOMS® OS200 TC is qualified for on-site fuel transfer operations with the 32PTH1 DSC with decay heat loads up to 40.8 kW. The 32PTH1 DSC is available in three lengths and with two fuel basket configurations (i.e., with and with solid aluminum rails). The analyses provided in this calculation is bounding for all DSC lengths, but are dependent on the combination of fuel basket configuration and decay heat loading.

Steady-state operations under all conditions are permissible for heat loads of 24 kW or less for either fuel basket configuration. Likewise, steady-state operations under all conditions are permissible for heat loads of 24 kW to 31.2 kW if fuel basket configuration utilizes solid aluminum rails. However, if the decay heat load exceeds 24 kW and the fuel basket configuration does not utilize solid aluminum rails or if the decay heat loading exceeds 31.2 kW, a limited period of operation is permitted before the transfer operations must be completed or some form of recovery operation initiated. The allowable duration for the transfer operations (defined as from the time when the TC-DSC annulus water is drained to when the DSC is loaded into the storage module) will vary depending on the DSC fuel basket configuration and the heat load, and whether or not the forced air circulation option for the TC is utilized. [redacted]

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5.5 Conservatisms

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