NUHOMS®-MP197 TRANSPORT PACKAGING

CHAPTER 3

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THERMAL EVALUATION

3.1 Discussion

The NUHOMS®-MP197 packaging is designed to passively reject decay heat under normal conditions of transport and hypothetical accident conditions while maintaining appropriate packaging temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- limits to ensure components perform their intended safety functions;
- Determination of temperature distributions to support the calculation of thermal stresses;
- Determination of the cask and the DSC cavity gas pressures;
- Determination of the maximum fuel cladding temperature. Determination of maximum and minimum temperatures with respect to cask materials

To establish the heat removal capability, several thermal design criteria are established for the packaging. These are:

- Containment of radioactive material and gases is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the containment function during normal transport and hypothetical accident conditions. A maximum long-term seal temperature limit of 400 °F is set for the Flourocarbon O-Rings [8] & [15].
- Maximum temperatures of the containment structural components must not adversely affect the containment function.
- To maintain the stability of the neutron shield resin during normal transport conditions, an allowable temperature range of -40 to 300 °F (-40 to 149 °C) is set for the neutron shield.
- In accordance with 10CFR71.43(g) the maximum temperature of accessible package surfaces in the shade is limited to 185 °F (85 °C).
- A maximum fuel cladding temperature limit of 570 °C (1058 °F) is set for the fuel assemblies with an inert cover gas [9].
- A maximum temperature limit of 327 °C (620 °F) is set for the lead, corresponding to the melting point [11].

The ambient temperature range for normal transport is –20 to 100 °F (-29 to 38 °C) per 10CFR71(b). 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, as required by 10CFR71(c)(2).

The NUHOMS®-MP197 is analyzed based on a maximum heat load of 15.86 kW from 61 fuel assemblies. The analyses consider the effect of the decay heat load varying axially along a fuel assembly. The decay heat profile for a fuel assembly with a peak power factor of 1.2 and an active length of 144 in. is used for the evaluation. A description of the detailed analyses performed for normal transport conditions is provided in Section 3.4 and accident conditions in Section 3.5. A thermal analysis performed for vacuum drying conditions is described in Appendix 3.7.4. A summary of the analysis is provided in Table 3-1. The thermal evaluation concludes that with this design heat load, all design criteria are satisfied.

3.2 Summary of Thermal Properties of Materials

The analyses use interpolated values when appropriate for intermediate temperatures where the temperature dependency of a specific parameter is deemed significant. The interpolation assumes a linear relationship between the reported values.

1. BWR Fuel

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)		Specific Heat (Btu/lbm-F)	Density (lbm/in^3)
	Transverse	Axial		
116.804	0.0137	0.0437	0.0574	0.105
214.424	0.0160	...	...	...
312.419	0.0186	...	...	...
410.726	0.0215	...	...	...
509.254	0.0249	...	...	...
608.009	0.0288	...	...	...
707.002	0.0329	...	...	...
806.149	0.0375	...	...	...
905.419	0.0425	...	...	...
1005.000	0.0461	0.0437	0.0574	0.105

The fuel conductivity analysis, including determination of specific heat and density values, is presented in Appendix 3.7.1.

2. Helium

Temperature		Conductivity	
(K) [2]	(°F)	(W/m-K) [2]	(Btu/hr-in-°F)
100	-280	0.0073	0.0004
150	-190	0.0095	0.0005
200	-100	0.1151	0.0055
250	-10	0.1338	0.0064
300	80	0.1500	0.0072
400	260	0.1800	0.0087
500	440	0.2110	0.0102
600	620	0.2470	0.0119
800	980	0.3070	0.0148
1000	1340	0.3630	0.0175

3. Neutron Shielding (Polyester Resin)

Thermal Conductivity (Btu/hr-in-°F) [3]	Specific Heat (Btu/lbm-°F) [3]	Density (lbm/in^3) [3]
0.0087	0.3107	0.051

4. SA-240, Type 304 Stainless Steel

Temperature [1] (°F)	Thermal Conductivity [1] (Btu/hr-ft-°F)	Thermal Conductivity (Btu/hr-in-°F)	Diffusivity [1] (ft^2/hr)	Specific Heat (Btu/lbm-°F)	Density [1] (lbm/in^3)
70	8.6	0.717	0.151	0.117	0.282
100	8.7	0.725	0.152	0.117	...
150	9.0	0.750	0.154	0.120	...
200	9.3	0.775	0.156	0.122	...
250	9.6	0.800	0.158	0.125	...
300	9.8	0.817	0.160	0.126	...
350	10.1	0.842	0.162	0.128	...
400	10.4	0.867	0.165	0.129	...
450	10.6	0.883	0.167	0.130	...
500	10.9	0.908	0.170	0.131	...
550	11.1	0.925	0.172	0.132	...
600	11.3	0.942	0.174	0.133	...
650	11.6	0.967	0.177	0.134	...
700	11.8	0.983	0.179	0.135	...
750	12.0	1.000	0.181	0.136	...
800	12.2	1.017	0.184	0.136	...
850	12.5	1.042	0.186	0.138	...
900	12.7	1.058	0.189	0.138	...
950	12.9	1.075	0.191	0.138	...
1000	13.2	1.100	0.194	0.139	...
1050	13.4	1.117	0.196	0.140	...
1100	13.6	1.133	0.198	0.141	...
1150	13.8	1.150	0.201	0.141	...
1200	14.0	1.167	0.203	0.141	...
1250	14.3	1.192	0.205	0.143	...
1300	14.5	1.208	0.208	0.143	...
1350	14.7	1.225	0.210	0.143	...
1400	14.9	1.242	0.212	0.144	...
1450	15.1	1.258	0.214	0.145	...
1500	15.3	1.275	0.216	0.145	0.282

7. Air

Temperature		v [2]	μ [2]	Pr [2]	Conductivity		Kin. Visc.
(K) [2]	(°F)	(m^3/kg)	(Pa-s)	(---)	(W/m-K)[2]	(Btu/hr-ft-°F)	(ft^2/s)
200	-100	0.573	1.33E-5	0.740	0.0181	0.0105	8.203E-05
300	80	0.861	1.85E-5	0.708	0.0263	0.0152	1.715E-04
400	260	1.148	2.30E-5	0.694	0.0336	0.0194	2.842E-04
500	440	1.436	2.70E-5	0.688	0.0404	0.0233	4.173E-04
600	620	1.723	3.06E-5	0.690	0.0466	0.0269	5.675E-04
800	980	2.298	3.70E-5	0.705	0.0577	0.0333	9.152E-04
1000	1340	2.872	4.24E-5	0.707	0.0681	0.0393	1.311E-03

8. Wood

Thermal Conductivity (i) (Btu/hr-in-°F)	
Min.	Max.
0.0019	0.0378

(i) The conductivity of wood is affected by a number of basic factors e.g., density, moisture content, and grain direction. The wood conductivity decreases for lower moisture content and lower specific gravity.

The lowest wood conductivity reported in Reference 4 is 0.275 Btu-in/hr-ft^2-°F. This value is measured perpendicular to wood grains in a wood with 0% moisture content and 0.08 specific gravity. Specific gravity of dry balsa is 0.13, and specific gravity of red wood is 0.35-0.4 (Reference 4). The lowest wood conductivity is used to analyze the thermal performance under normal transport conditions, and during the pre- and post-fire accident condition.

The wood conductivity parallel to the grain is 2.0 to 2.8 times greater than the value perpendicular to the grains. The highest conductivity perpendicular to wood grains with 30% moisture content and a specific gravity of 0.8 is 1.950 Btu-in/hr-ft^2-°F (Reference 4). Multiplying this value by 2.8 results in the greatest wood conductivity (5.46 Btu-in/hr-ft^2-°F). The maximum wood conductivity is used during the fire accident condition.

The values in Reference 5 are also bounded y the minimum and the maxim thermal conductivities given in the above table.

(ii) Wood is conservatively given no thermal mass (ρ=0, $C_p = 0$)

9. Poison Plates

Specific Heat	Density
Btu/lbm-°F	lbm/in^3
0.214	0.098

Properties are from Reference 2 for aluminum. The thermal conductivities are specified in Section 3.3 for the neutron poison plates and will be verified via testing.

10. Aluminum Alloy 6063-T5

Temperature[1] (°F)	Thermal Conductivity [1] (Btu/hr-ft-°F)	Thermal Conductivity (Btu/hr-in-°F)	Diffusivity [1] (ft^2/hr)	Specific Heat (Btu/lbm-°F)	Density [1] (lbm/in^3)
70	120.8	10.067	3.34	0.216	0.097
100	120.3	10.025	3.30	0.217	...
150	119.7	9.975	3.23	0.221	...
200	119.1	9.925	3.18	0.223	...
250	118.3	9.858	3.13	0.225	...
300	118.3	9.858	3.09	0.228	...
350	117.9	9.825	3.04	0.231	...
400	117.6	9.800	3.00	0.234	0.097

11. Lead

Temperature		Conductivity		Specific Heat		Density	
(K) [2]	(°F)	(W/m-K) [2]	(Btu/hr-in-°F)	(kJ/kg-K) [2]	(Btu/lbm-°F)	(kg/m^3) [2]	(lbm/in^3)
200	-100	36.7	1.767	0.125	0.030	11,330*	0.409
250	-10	36.0	1.733	0.127	0.030	...	...
300	80	35.3	1.700	0.129	0.031	...	...
400	260	34.0	1.637	0.132	0.032	...	...
500	440	32.8	1.579	0.137	0.033	...	...
600	620	31.4	1.512	0.142	0.034	11,330*	0.409

12. Emissivities and Absorptivities

Thermal radiation effects at the external surfaces of the packaging are considered. Impact limiter external surfaces are painted white. The emissivity of white paint varies between 0.93-0.95 and the solar absorptivity varies between 0.12-0.18 ([2] & [6]). To account for dust and dirt, the thermal analysis uses a solar absorptivity of 0.30 and an emissivity of 0.90 for the exterior surfaces of the impact limiters.

The external surface of the cask body is weathered stainless steel (emissivity = 0.85, [6]). To account for dust and dirt and to bound the problem, the thermal analysis uses a solar absorptivity of 0.9 and an emissivity of 0.8 for the cask body external surface.

After a fire, the cask surface will be partially covered in soot (emissivity = 0.95, [7]). Painted surfaces are given a post-fire emissivity of 0.90. The cask body surfaces are given a post-fire emissivity of 0.80. To bound the problem all surfaces are given a solar absorptivity of unity after the fire accident condition.

within the impact limiters are modeled as an isotropic material containing bounding material properties as described in Section 3.2 for wood.

The finite element plot of the cask body model is shown in Figure 3-1.

Generally, good surface contact is expected between adjacent components. However, to bound the heat conductance uncertainty between adjacent components, the following gaps at thermal equilibrium are assumed:

- 0.0100" radial gaps between resin boxes and adjacent shells
- 0.0300" radial gap between lead and cask body
- 0.0600" radial gap between cask lid and cask body
- 0.0625" axial gap between cask lid and cask body
- 0.0600" radial and axial gaps between ram plate and cask body
- 0.0625" axial gap between rear impact limiter and thermal shield
- 0.0625" axial gap between thermal shield and cask body
- 0.1250" axial gap between front impact limiter and cask body
- 0.0625" axial gap between thermal shield and impact limiter

All heat transfer across the gaps is by gaseous conduction. Other modes of heat transfer are neglected.

Heat Dissipation

Heat is dissipated from the surface of the packaging by a combination of radiation and natural convection.

Heat dissipation by natural convection is described by the following equations for the average Nusselt number [11]:

$$\overline{N}_{u_L} = \overline{H}_c \frac{L}{k} = 0.13(Gr_L Pr)^{1/3} \quad \text{for } Pr\,Gr_L > 10^9 \qquad \text{(Horizontal cylinders and vertical surfaces)}$$

$$\overline{N}_{u_L} = \overline{H}_c \frac{L}{k} = 0.59(Gr_L Pr)^{1/4} \quad \text{for } 10^4 < Pr\,Gr_L < 10^9 \qquad \text{(vertical surfaces)}$$

where,

Gr_L	= Grashof number = $\rho^2 g\beta(T_s\text{-}T_a)L^3/\mu^2$
ρ	= density, lb/ft^3
g	= acceleration due to gravity, ft/sec^2
β	= temperature coefficient of volume expansion, 1/R
μ	= absolute viscosity, lb/ft-sec
L	= characteristic length, ft
Pr	= Prandtl number
H_c	= natural convection coefficient

The heat transfer coefficient, H_r, for heat dissipation by radiation, is given by the equation:

$$H_r = G_{12}\left[\frac{\sigma(T_1^4 - T_2^4)}{T_1 - T_2}\right] Btu/hr - ft^2 \cdot {}^\circ F$$

where,

G_{12} = the gray body exchange coefficient
= (surface emissivity) (view factor)
T_1 = ambient temperature, °R
T_2 = surface temperature, °R

The total heat transfer coefficient $H_t = H_r + H_c$, is applied as a boundary condition on the outer surfaces of the finite element model.

3.4.1.2 Basket Model

To determine component temperatures within the canister and its contents during normal conditions of transport a finite element model is developed. The three-dimensional model represents a 90° symmetric section of the packaging and includes the geometry and material properties of the canister, basket, fuel assembly active lengths, basket peripheral inserts, and the helium between the canister and the cask body.

The finite element plot of the basket model is shown in Figure 3-2.

To bound the heat conductance uncertainty between adjacent packaging components the following gaps at thermal equilibrium are assumed:

- 0.0100" surrounding outside of the fuel compartments
- 0.0100" between the fuel compartment wrap and plates parallel to the wrap
- 0.0400" between the fuel compartment wrap and plates perpendicular to the wrap
- 0.0950" between perpendicular plates
- 0.0100" between plates and basket rails
- 0.1250" axial gap between bottom of canister and cask body

Maximum Fuel Cladding Temperature

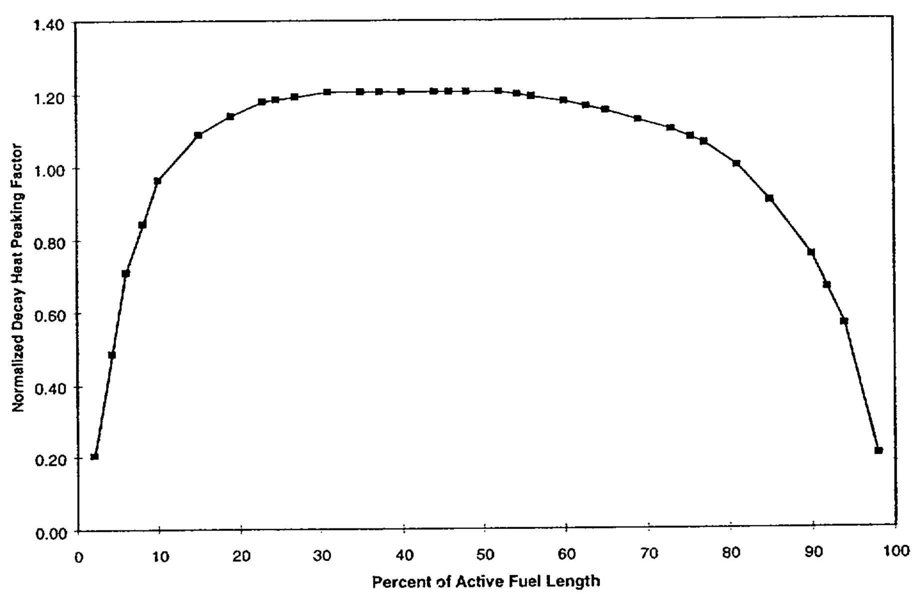
The finite element model includes a representation of the spent nuclear fuel that is based on a fuel effective conductivity model. The decay heat of the fuel with a peaking factor of 1.2 was applied directly to the fuel elements. The maximum fuel temperature reported is based on the results of the temperature distribution in the fuel region of the model. As described in Appendix 3.7.1, the homogenized fuel properties are chosen to match both the temperature drop between basket walls and fuel assembly center pin, and the effective conductivity of the fuel assemblies.

Average Cavity Gas Temperature

The cavity gas temperatures are calculated using maximum component temperatures under normal and hypothetical accident conditions of transport. For simplicity and conservatism, the average gas temperature within the canister is assumed to be the average of the maximum fuel cladding and canister wall temperatures. Within the cask body the average cavity gas temperature is taken to be the average of the maximum cask body and canister wall temperatures.

3.4.1.3 Decay Heat Load

The decay heat load corresponds to a total heat load of 15.86 kW from 61 assemblies (0.260 kW/assy.) with a peaking factor of 1.2. A typical heat profile for spent BWR fuel with an axial peaking factor of 1.2 was used to distribute the decay heat load in the axial direction within the active length regions of the models. This heat profile is shown below. Within the basket model, the decay heat load is applied as volumetric heat generation in the elements that represent the homogenized fuel. Within the Cask Body model the heat is applied as heat fluxes into the elements that model the cask cavity wall.



The elements representing the homogenized fuel assemblies are divide into 12 equal size intervals. Every interval is 12" long. Average peaking factors are calculated for these intervals based on the typical heat profile. Heat generating rate per unit volume of the homogenized fuel assembly is calculated as follows:

$$Q''' = \frac{Q}{V} = \frac{Q}{a \times a \times L_a} = \frac{0.26 \times 3412.3}{6.0 \times 6.0 \times 144} = 0.171 \qquad \text{Btu/in}^3$$

Where,

Q = Decay heat load per assembly = 0.26 kW

V = Volume of one homogenized assembly considering active fuel length
a = width of homogenized fuel assembly = 6.0"
L_a = Active fuel length = 144"

The volumetric heat generating value is multiplied by the average peaking factor of each interval. The average peaking factors and the resultant heat generating rates are listed in the following table.

Interval No. from Top of Active Fuel	Average Peaking Factor	Heat Generating Rate (Btu/in^3)
1	0.51	0.087
2	1.07	0.183
3	1.17	0.200
4	1.20	0.205
5	1.20	0.205
6	1.19	0.204
7	1.17	0.200
8	1.14	0.195
9	1.10	0.188
10	1.02	0.175
11	0.84	0.144
12	0.41	0.070

3.4.1.4 Solar Heat Load

The total insolation for a 12-hour period in a day is 1475 Btu/ft^2 for curved surfaces and 738 Btu/ft^2 for flat surfaces not transported horizontally as per 10CFR Part 71.71(c). This insolation is averaged over a 24-hr period (daily averaged value) and applied as a constant heat flux to the external surfaces of the cask body model. Daily averaging of the solar heat load is justified based on the large thermal inertia of the NUHOMS®-MP197 packaging. Solar absorptivities of 0.30 and 0.9 are used for the painted and stainless steel surfaces of the packaging, respectively. Multiplying the total insolation by the solar absorptivity values gives the maximum amount of insolation that can be absorbed on each surface. The following table shows the applied solar heat fluxes in the finite element models.

Location in FE-Model	Surface Shape	Total Insolance Per 10CFR 71.71 ($gcal/cm^2$) / (Btu/ft^2)	Conditions	Surface Absoptivity	Solar Heat Flux applied over Surface Effect Elements ($Btu/hr\text{-}in^2$)
Radial Surface of Impact Limiter	Curved	400 / 1475	Steady State (Pre Fire)	0.3	0.128
			Post Fire	1.0	0.427
Top & Bottom Surfaces of Impact Limiter	Flat, Vertical	200 / 738	Steady State (Pre Fire)	0.3	0.064
			Post Fire	1.0	0.216
Radial Surface of Cask Body	Curved	400 / 1475	Steady State (Pre Fire)	0.9	0.384
			Post Fire	1.0	0.427

3.4.2 Maximum Temperatures

Steady state thermal analyses are performed using the maximum decay heat load of 0.260 kW per assembly (15.86 kW total), 100°F ambient temperature and the maximum insolation. The temperature distributions within the cask body and basket models are shown in Figures 3-3 and 3-4, respectively. The temperature distribution within the basket is shown in Figure 3-5. The fuel assembly temperature distribution is shown in Figure 3-6. A summary of the calculated cask component temperatures is listed in Table 3-1.

3.4.3 Maximum Accessible Surface Temperature in the Shade

The accessible surfaces of the NUHOMS®-MP197 packaging consist of the personnel barrier and outermost vertical and radial surfaces of the impact limiters. The cask body model is run without insolation to determine the accessible surface temperature of the impact limiters in the shade. The maximum accessible surface temperature of the impact limiters in the shade does not exceed 110 °F.

The personnel barrier surrounds approximately one fourth of the cask body and has an open area of at least 80%. Heat transfer between the cask and barrier will be minimal due to the small radiation view factor between the cask and barrier. The personnel barrier rises 90 in. above the base of the transport frame and limits the accessible packaging surfaces to only the impact limiter surfaces. Accessible surfaces of the packaging remain below the design criteria of 185 °F (85 °C).

3.4.4 Minimum Temperatures

Under the minimum temperature condition of -40°F (-40°C) ambient, the resulting packaging component temperatures will approach -40°F if no credit is taken for the decay heat load. Since the package materials, including containment structures and the seals, continue to function at this temperature, the minimum temperature condition has no adverse effect on the performance of the NUHOMS®-MP197.

Temperature distributions under the minimum ambient temperatures of –20°F and -40°F with no insolation and the maximum design heat load are determined. Table 3-2 lists the results of these analyses.

3.4.5 Maximum Internal Operating Pressure

The maximum internal pressures within the NUHOMS®-MP197 cask body and DSC during normal conditions of transport are calculated within Appendix 3.7.3.

3.4.6 Maximum Thermal Stresses

The maximum thermal stresses during normal conditions of transport are calculated in Chapter 2.

3.4.7 Evaluation of Cask Performance for Normal Conditions of Transport

The thermal analysis for normal transport concludes that the NUHOMS®-MP197 packaging design meets all applicable requirements. The maximum component temperatures calculated using conservative assumptions are low. The maximum seal temperature (217°F, 103°C) during normal transport is well below the 400°F long-term limit specified for continued seal function. The maximum neutron shield temperature is below 300°F (149°C) and no degradation of the neutron shielding is expected. The predicted maximum fuel cladding temperature is well within allowable fuel temperature limit of 1058°F (570°C). The comparison of the results with the allowable ranges is tabulated below:

Component	Temperature, °F		
	Maximum	**Minimum**	**Allowable Range**
Seal	217	-40	-40 to 400
Neutron Shield	249	-40	-40 to 300
Fuel Cladding	598	-40	1058 max.
Lead	299	-40	620 max.

3.5 Thermal Evaluation for Accident Conditions

The NUHOMS®-MP197 packaging is evaluated under the hypothetical accident sequence of 10CFR71.73. In order to demonstrate that the seal, fuel cladding, and lead temperatures remain below thermal design requirements, four analytical models are developed as discussed below.

3.5.1 Fire Accident Evaluation

The fire thermal evaluation is performed primarily to demonstrate the containment integrity of the packaging. This is assured as long as the containment seals remain below 400°F and the cavity pressure is less than 50 psig (4.4 atm absolute pressure). Four models are used for the evaluation:

- A cask cross-section model for the determination of the peak fuel cladding temperature.
- A cask body model to evaluate the performance of the seals under hypothetical accident conditions.
- A trunnion-region model to demonstrate that lead remains below its melting point during hypothetical accident conditions.
- A bearing block-region model to demonstrate that lead remains below its melting point during hypothetical accident conditions.

During the free drop and puncture conditions, the steel encased wood impact limiters are locally deformed but remain firmly attached to the cask. Because of the very low conductivity of wood, a minimal amount of wood is required to provide adequate insulation during the fire accident condition. Therefore, there is a negligible change in the thermal performance of the impact limiters due to dimensional changes caused by the hypothetical accident conditions of 10CFR71.73. Under exposure to the thermal accident environment the wood at the periphery of the impact limiter shell would char but not burn.

An average convective heat transfer coefficient of 2.75 Btu/hr-ft^2-°F is utilized for the fire accident evaluation as calculated in Appendix 3.7.2.

3.5.2 Cask Cross Section Model

To demonstrate that the peak fuel cladding temperature remains below thermal design limits, a cask cross-section finite element model of the NUHOMS®-MP197 packaging was developed. The three-dimensions, quarter-symmetry model includes the cask body, canister, basket, and fuel along the 144" active fuel length. To bound the heat conductance uncertainty between adjacent packaging components the same gap assumptions made in sections 3.4.1.1 and 3.4.1.2 are applied to the model.

During the pre-fire condition, convection and radiation from the external surface of this model are as in normal conditions of transport (100°F ambient). During the fire phase, a constant convective heat transfer coefficient of 2.75 Btu/hr-ft^2-°F is used. As per 10CFR71.73, a 30 minute 1,475°F flame temperature with an emittance of 0.9 and a surface absorptivity of 0.8 is used during the fire accident condition. During the fire accident condition, gaps within the cask body and basket were removed to maximize heat input into the model from the fire. These gaps are included during the pre- and post-fire accident conditions. See Section 3.4.1 for a detailed description of the model including the method used to calculate the maximum fuel cladding temperature and the average cavity gas temperature. The decay heat load is applied as per Section 3.4.1.3.

The Cask Cross Section finite element model and the temperature distribution at the end of the fire accident condition are shown in Figures 3-7 and 3-9, respectively. The maximum temperature distribution within the fuel assemblies is shown in Figure 3-10.

3.5.3 Cask Body Model

To demonstrate the integrity of the seals during the fire accident, the cask body finite element model of the NUHOMS®-MP197 packaging developed in Section 3.4.1.1 was run under hypothetical accident conditions. Pre-Fire, Fire accident, and Post-Fire cool-down boundary conditions are determined as per Section 3.5.2. During the fire accident condition, gaps within the packaging were removed to maximize heat input into the model from the fire. These gaps are included during the pre- and post-fire accident conditions. The decay heat load is applied as per Section 3.4.1.3.

The Cask Body finite element model and the temperature distribution at the end of the fire accident condition are shown in Figures 3-1 and 3-8, respectively.

3.5.4 Trunnion Region Model

To determine the peak transient lead temperature in the region of the trunnions, a trunnion region finite element model was developed. The two-dimensional, axisymmetric model represents the geometry and material properties of the trunnion block, trunnion plug, and cask body in the region of the trunnion.

To bound the heat conductance uncertainty between adjacent packaging components the following gaps at thermal equilibrium are assumed:

- 0.0100" between the trunnion plug and the neutron absorbing resin
- 0.0100" between the trunnion plug and the trunnion block
- 0.0100" between the resin and the cask outer shell
- 0.0100" between the trunnion block and the cask outer shell
- 0.0300" radial gap between lead and cask body

Pre-Fire, Fire accident, and Post-Fire cool-down boundary conditions are determined as per Section 3.5.2. During the fire accident condition, gaps within the packaging were removed to maximize heat input into the model from the fire. These gaps are included during the pre- and post-fire accident conditions. The decay heat load is applied as a flux including a peaking factor of 1.2.

The trunnion region finite element model and the temperature distribution at the time of peak lead temperature are shown in Figures 3-11 and 3-12, respectively.

3.5.5 Bearing Block Region Model

To determine the peak transient lead temperature in the region of the bearing block, a bearing block region finite element model was developed. A three-dimensional quarter-symmetry finite element model was created of the bearing block including the geometry and material properties of the adjacent neutron shielding and the corresponding portion of the cask body. Solid entities were modeled by SOLID70 three-dimensional thermal elements.

To bound the heat conductance uncertainty between adjacent packaging components the following gaps at thermal equilibrium are assumed:

- 0.0100" radial gaps between resin boxes and adjacent shells
- 0.0300" radial gap between lead and cask body
- 0.0600" gap between the bearing block and the resin/resin boxes in radial, axial, and circumfrential directions

Pre-Fire, Fire accident, and Post-Fire cool-down boundary conditions are determined as per Section 3.5.2. During the fire accident condition, gaps within the packaging were removed to maximize heat input into the model from the fire. These gaps are included during the pre- and post-fire accident conditions. The decay heat load is applied as a flux including a peaking factor of 1.2.

The bearing block region finite element model and the temperature distribution at the time of peak lead temperature are shown in Figures 3-13 and 3-14, respectively.

3.5.6 Maximum Internal Operating Pressure

The maximum internal pressures within the NUHOMS®-MP197 cask body and DSC during hypothetical accident conditions of transport are calculated within Appendix 3.7.3.

3.5.7 Summary of Results

Table 3-3 presents the maximum temperatures of the cask components during the fire event. The maximum temperatures calculated for the seals and the fuel cladding are 279°F and 680°F, respectively.

3.5.8 Evaluation of Package Performance during Fire Accident Conditions

It is concluded that the NUHOMS®-MP197 packaging maintains containment during the postulated accident conditions. The maximum seal temperature is below the 400°F limit specified for seal function and the fuel cladding temperature is well below the limit of 1058°F (570°C).

A comparison of the results with the temperature limits is tabulated below:

Component	Temperature, °F	
	Maximum	**Limit**
Seal	279	400 max.
Fuel Cladding	680	1058 max.
Lead	478	620 max.

3.6 References

1. *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, Section II, 1998.

2. *Handbook of Heat Transfer Fundamentals*, W. Rohsenhow and J. Harnett, McGraw-Hill Publishing, New York, 1985.

3. *TN-24 Dry Storage Cask Topical Report*, Transnuclear, Inc., Revision 2A, Hawthorne, NY, 1989.

4. *Wood Handbook: Wood as an Engineering Material*, U.S. Department of Agriculture, Forest Service, March 1999.

5. NUREG/CR-0200, Vol. 3, Rev. 6, SCALE, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation.

6. *Principles of Heat Transfer, Fourth Edition,* Kreith et. al., Harper & Row, Publishers, New York, 1986.

7. *Standard Handbook for Mechanical Engineers, Seventh Edition,* Baumeister & Marks, McGraw-Hill Book Co., New York, 1969

8. *Parker O-Ring Handbook 5700,* Y2000 Edition, 1999

9. PNL-4835, Johnson et. al., Technical Basic for Storage of Zircalloy-Clad Spent Fuel in Inert Gases, Pacific Northwest Laboratory, 1983.

10. ANSYS Engineering Analysis System, *User's Manual for ANSYS Revision 5.6,* ANSYS, Inc., Houston, PA.

11. *Chemical Engineers' Handbook, Fifth Edition*, Perry P.H. and Chilton C.H., McGraw-Hill Book Co., New York, 1973.

12. *TN-68 Dry Storage Cask Final Safety Analysis Report*, Transnuclear Inc., Revision 0, Hawthorne, NY, 2000.

13. *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel*, NUREG-1617, 2000.

14. NUHOMS COC 1004 Amendment No. 3, 2000

15. Material Report Number KJ0835, Parker O-Ring Division, 1989.

TABLE 3-1

COMPONENT TEMPERATURES IN THE NUHOMS®-MP197 PACKAGING

Component	Normal Transport			Fire Accident	
	Maximum (°F)	Minimum* (°F)	Allowable Range(°F)	Peak(°F)	Allowable Range(°F)
Thermal Shield	186	-40	**	1172	**
Impact Limiters	195	-40	**	1456	N/A
Resin	249	-40	-40 to 300	N/A	N/A
Lead	299	-40	620 max.	478	620 max.
Cask Body	302	-40	**	535	**
Outer Shell	263	-40	**	N/A	**
Flourocarbon Seals, Ram Plate	217	-40	-40 to 400	270	-40 to 400
Flourocarbon Seals, Lid	204	-40	-40 to 400	279	-40 to 400
Canister	388	-40	**	485	**
Basket Peripheral Inserts	482	-40	**	564	**
Basket	578	-40	**	661	**
Fuel Cladding	598	-40	1058 max.	680	1058 max.
Average Cavity Gas (Cask Body)	345	-40	N/A	504	N/A
Average Cavity Gas (Canister)	493	-40	N/A	583	N/A

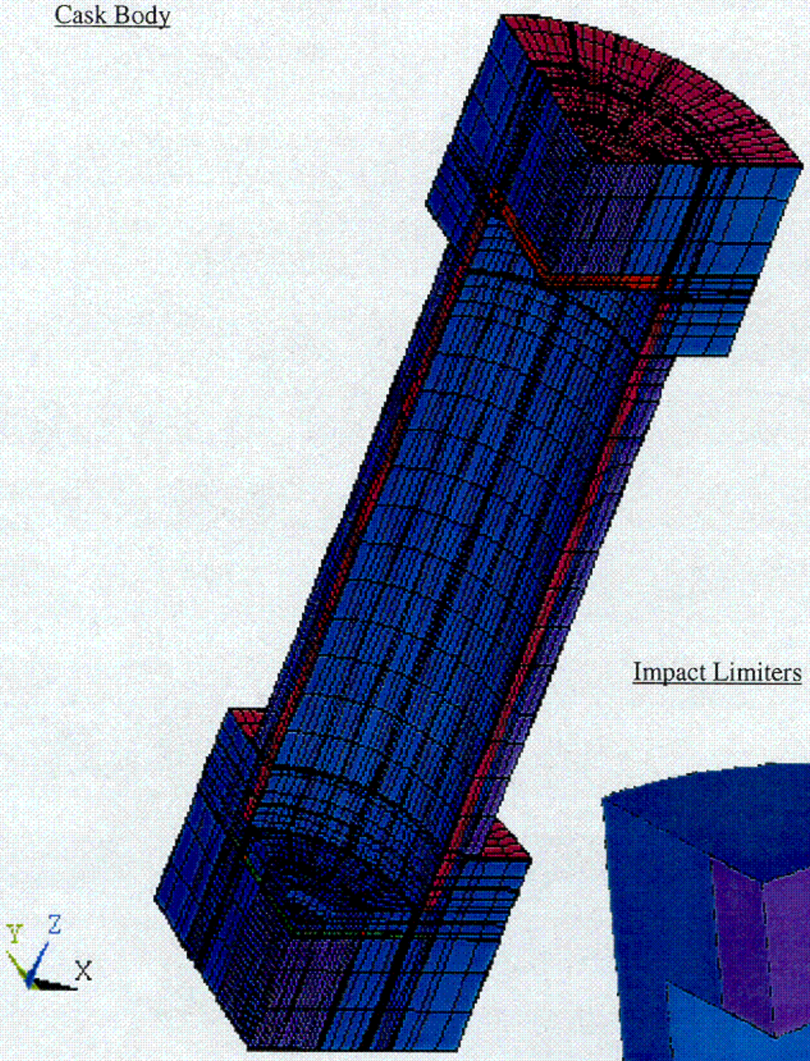
* Assuming no credit for decay heat and an ambient temperature of -40°F

** The components perform their intended safety function within the operating range.

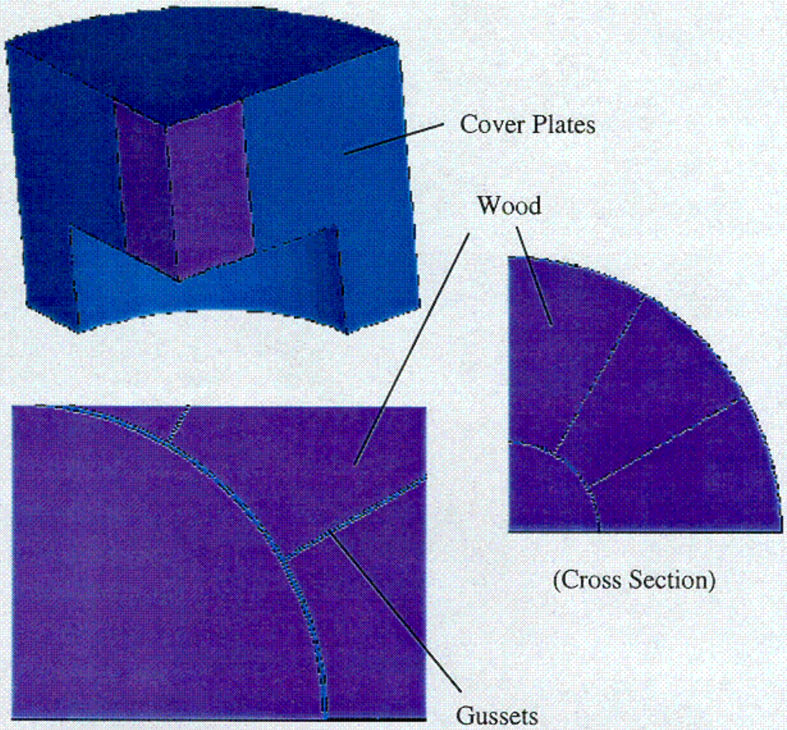
FIGURE 3-1

FINITE ELEMENT PLOT,
CASK BODY MODEL

Cask Body



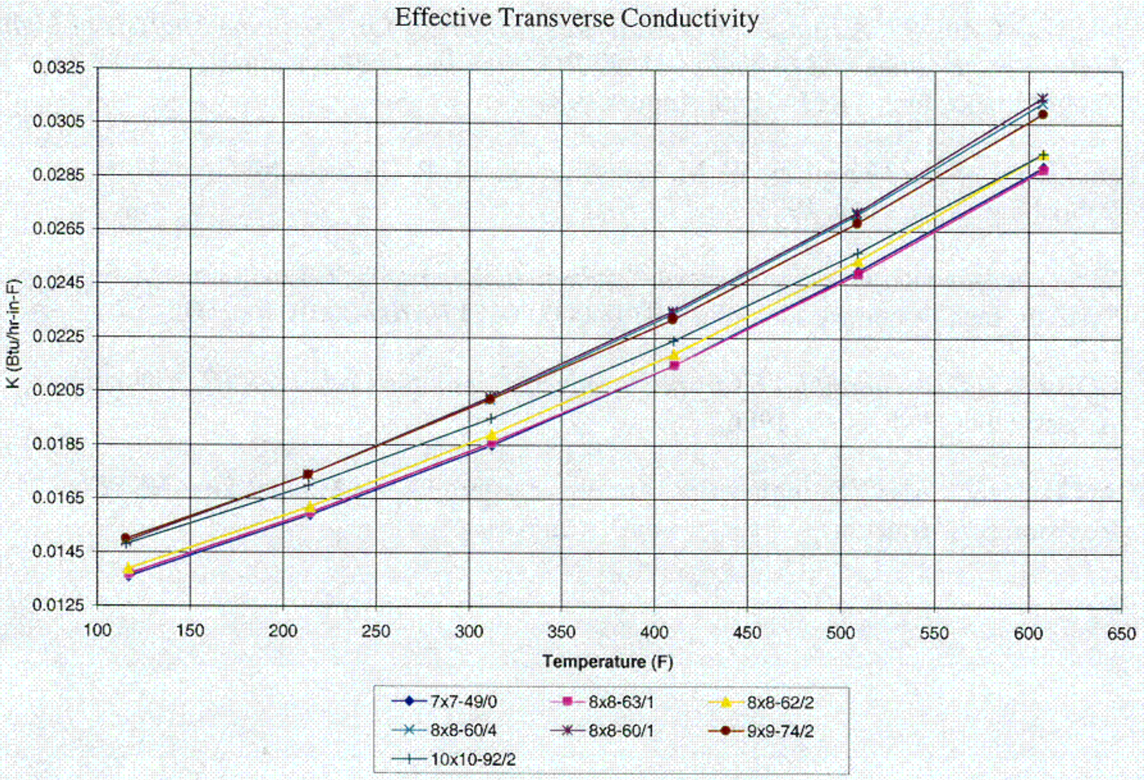
Impact Limiters



C01

3.7.1.6 Conclusion

The transverse effective conductivities for the fuel assemblies configurations are plotted below. For temperatures above 400°F, the 8×8 (GE4) fuel assembly has the lowest conductivity.



The transverse effective conductivity of the 8×8 (GE4) fuel assembly, and the bounding axial conductivity, density, and specific heat calculated in Sections 3.7.1.2 through 3.7.1.5 are used in the thermal analysis.

Average Fuel Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)		Density (lbm/in^3)	Specific Heat (Btu/lbm-°F)
	Transverse	Axial		
116.8	0.0137	0.0437	0.105	0.0574
214.4	0.0160	...	...	...
312.4	0.0186	...	...	...
410.7	0.0215	...	...	...
509.3	0.0249	...	...	...
608.0	0.0288	...	...	...
707.0	0.0329	...	...	...
806.1	0.0375	...	...	...
905.4	0.0425	...	...	...
1005.0	0.0461	0.0437	0.105	0.0574

C02

3.7.1.7 References

1. NUREG/CR-0200, Vol. 3, Rev. 6, SCALE, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation.

2. NUREG/CR-0497, *A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior, MATPRO - Version 11* (Revision 2), EG&G Idaho, Inc., TREE-1280, August 1981.

3. *Handbook of Heat Transfer*, W. M. Rohsenow and J. P. Hartnett, McGraw-Hill Publishing, New York, 1973.

4. *Spent Nuclear Fuel Effective Thermal Conductivity Report,* TRW Environmental Safety Systems, Inc., Document Identifier BBA000000-01717-5705-00010 Rev 00.

5. COBRA-SFS: *A Thermal – Hydraulic Analysis Computer Code, Vol. III,* Validation Assessments, PNL-6049, 1986.

6. ANSYS, Inc., ANSYS Engineering Analysis System User's Manual for ANSYS Revision 5.7, Houston

APPENDIX 3.7.4

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APPENDIX 3.7.4

THERMAL EVALUATION FOR VACUUM DRYING CONDITIONS

3.7.4.1 Discussion

All fuel transfer operations occur when the packaging is in the spent fuel pool. The fuel is always submerged in free-flowing pool water permitting heat dissipation. After fuel loading is complete, the packaging is removed from the pool, drained and dried.

The loading condition evaluated is the heatup of the cask before its cavity can be backfilled with helium. This typically occurs during the performance of the vacuum drying operation of the cask cavity. A transient thermal analysis is performed for the vacuum drying procedure. The analysis determines the component temperatures after 86 hours of vacuum drying with the maximum decay heat load of 15.86 kW.

3.7.4.2 Finite Element Model

The cask cross-section finite element model developed in Section 3.5.2 is modified for this transient analysis. The vacuum drying of the cask generally does not reduce the pressure sufficiently to reduce the thermal conductivity of the air in the cask cavity. All gaseous heat conduction within the cask cavity is through air instead of helium. Radiation heat transfer within the cask cavity is neglected. The fuel properties were recalculated using air properties instead of helium. All temperatures in the cask are initially assumed to be at 100°F. Radiation and natural convection heat transfer are from the cask outer surface to the building environment at a temperature of 100°F.

3.7.4.3 Material Properties

BWR Fuel w/ Air Backfill

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)		Specific Heat (Btu/lbm-F)	Density (lbm/in^3)
	Transverse	Axial		
150.796	0.0045	0.0437	0.105	0.0574
239.954	0.0058	...	...	...
331.555	0.0073	...	...	...
425.095	0.0092	...	...	...
520.134	0.0114	...	...	...
616.315	0.0141	...	...	...
713.356	0.0173	...	...	...
811.049	0.0209	...	...	...
909.232	0.0250	0.0437	0.105	0.0574

3.7.4.4 Evaluation of the Transient Analysis

The modified cask-cross section model was run to determine maximum component temperatures after 86 hours of vacuum drying. Total decay heat load is 15.86 kW in this analysis. The component temperatures after 86 hours of vacuum drying conditions are listed below.

Component	Maximum Temperature (°F)
Fuel Cladding	831
Basket	796
Basket Peripheral Inserts	659
Canister Shell	486
Cask Body	201
Lead	199
Resin	168
Outer shell	156

The results show that at the end of 86 hours, the basket temperature do not exceed 800°F. The resulting fuel cladding temperature is 831°F, well below the short-term fuel cladding temperature limit of 1058°F.

3.7.4.5 References

1. ANSYS Engineering Analysis System, *User's Manual for ANSYS Revision 6.0*, ANSYS, Inc., Houston, PA.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

4.3.1 Fission Gas Products

The following equations from NUREG/CR-6487 [6] are used to determine the source term available for release.

$$C_{volatiles} = \{N_A f_B A_V f_v\} / V$$
$$C_{gases} = \{N_A\, f_B\, A_F\, f_F\} / V$$
$$C_{fines} = \{N_A\, f_B\, A_F\, f_F\} / V$$
$$C_{crud} = \{f_C\, S_C\, N_R\, N_A\, S_{AR}\}$$
$$C_{total} = C_{crud} + C_{volatiles} + C_{gases} + C_{fines}$$

Table 4-1 shows the free activity available for release from typical BWR spent fuel rods. Table 4-2 shows the activity concentration from each of the sources available for release. The release fractions for the radionuclides are taken from NUREG/CR-6487. Under hypothetical accident conditions, the cladding of 100% of the fuel rods is assumed to fail (f_B=1.0).

4.3.2 Containment of Radioactive Material

The NUHOMS®-MP197 cask is designed and tested to be "leak tight". The MP197 contains a sealed (welded) canister (DSC) which is also tested to a "leak tight" criteria. The results of the structural and thermal analyses presented in Chapters 2 and 3, respectively, verify the package will meet the leakage criteria of 10CFR71.51 for the hypothetical accident scenario.

4.3.3 Containment Criterion

This package has been designed and is verified by leak testing, to meet the "leak tight" criteria of ANSI N14.5. The results of the structural and thermal analyses presented in Chapters 2 and 3, respectively, verify the package will meet the leakage criteria of 10CFR71.51 for all the hypothetical accident conditions.

4.4 SPECIAL REQUIREMENTS

Solid plutonium in the form of reactor elements is exempt from the double containment requirements of 10 CFR 71.63.

NUHOMS® -MP197 TRANSPORT PACKAGING

CHAPTER 5

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The source terms are generated for the active fuel regions, the plenum region, and the end regions. Irradiation of the fuel assembly structural materials (including the channel, plenum, and end fittings) are included in the irradiation of the fuel zone. The fuel assembly hardware materials and masses on a per assembly basis are listed in Table 5.2-2. Table 5.2-3 provides the material composition of fuel assembly hardware materials. Cobalt impurities are included in the SAS2H model. In particular, the cobalt impurities in Inconel, Zircaloy and Stainless Steel are 0.649%, 0.001% and 0.08%, respectively [2].

The masses for the materials in the top end fitting, the plenum, and the bottom fitting regions are multiplied by 0.1, 0.2 and 0.15, respectively [4]. These factors are used to correct for the spatial and spectral changes of the neutron flux outside of the fuel zone. The material compositions of the fuel assembly hardware are included in the SAS2H/ORIGEN-S model on a per assembly basis.

Axial variation in the moderator density along the BWR fuel assembly was considered by including a volume averaged density for the moderator around the fuel pins. The following axial variation of temperatures and moderator densities were used to calculated the volume average moderator density for use in the BWR source term models [1]:

Distance from bottom of Active Fuel Length	Average Density in Zone (g/cc)	Average Water Temp (K)
30.83	0.743	552
43.17	0.600	558
55.5	0.494	558
67.83	0.417	558
80.17	0.360	558
98.67	0.309	558
123.33	0.264	558
148	0.234	558
Assembly data –water, volume-average density	0.4234 g/cc	558 K

Gamma and neutron source terms are calculated for each of the four groups. Table 5.2-4 presents the gamma and neutron source terms for a 10 year cooling time. The 7x7 fuel assembly is the most conservative source/configuration and is utilized to determine the bounding source terms for the NUHOMS®-MP197 shielding analysis.

As shown in Section 1.2.3, four different groups of fuel assembly parameters are chosen as representative of the fuel to be transported in the MP197. SAS2H/ORIGEN-S analyses are performed for each of these four groups of fuel assemblies and the bounding source term identified and chosen for the shielding analysis. The Group 2 fuel assembly (lattice enrichment 2.65 wt% and 35,000 MWD/MTU burnup) with a cooling time of 12 years is selected as the bounding source for the shielding analysis.

5.2.1 Axial Source Distribution

Axial source term peaking factors are determined based on typical axial burnup distributions for BWR assemblies and based upon typical axial water density distribution that occurs during core operation. Using the base SAS2H/ORIGEN-S input for the 7x7 BWR, selected as the design basis assembly above, neutron and gamma source terms are generated for axial zones as a function of burnup and moderator density. This estimates both the non-linear behavior of the neutron source with burnup and the core operating moderator density effects on the actinide isotopics (neutron source).

In-core data from an operating BWR facility forms the basis for the evaluation. The data provided the burnup and moderator density for 25 axial locations along the fuel assembly. Five assemblies located in different locations in the reactor core were utilized to generate a burnup (peaking factor) distribution for the assembly. Figure 5.2-1 represents this distribution.

For water densities, the nodal data provided was examined and 7 assemblies with the lowest densities were selected for evaluation. Of these seven, the assembly with the lowest densities was chosen. The water density data provided shows densities ranging from 0.7608 g/cc at the bottom node to 0.3607 at the top node.

The peaking factors and water densities for the 25 axial locations were collapsed into 12 axial zones and utilized in determining the source terms and axial profiles of the sources for the shielding evaluation. The top and bottom 10% of the assembly was divided into two zones each and the middle 80% divided into 8 equal zones. The peaking factors ranged from 0.2357 and 0.2410 at the bottom and top respectively, to a maximum of 1.20 just below the middle. The water densities ranged from 0.3609 at the top zone to 0.7603 at the bottom.

The burnup and water density axial distribution data was utilized to prepare a 12 axial zone fuel assembly model. Twelve SAS2H calculations were performed for the design basis fuel with the power and water density being variables for each zone. The specific power input was the product of the nominal specific power, (5 MW) and the peaking factor. The water density was that value calculated for the zone as described above. Therefore, the fuel assembly was divided into 12 zones, with each zone having a unique gamma and neutron source term, specifically calculated for the burnup and water density in that zone. This data is presented in Table 5.2-7. (Note: the axial profile data is for 10 year cooled fuel, but the profile is equally applicable for longer cooled fuel.)

5.2.2 Gamma Source

The primary gamma source spectrum for the Group 2 fuel assembly is provided in Tables 5.2-5,. Table 5.2-5 present spectra for a 7x7 assembly with an initial bundle average enrichment of 2.65wt%, maximum bundle-average burnup of 35,000 MWD/MTU and 12 year decay. The gamma source spectra are presented in the 18-group structure consistent with the SCALE 27n-18γ cross section library.

The conversion of the source spectra from the default ORIGEN-S energy grouping to the SCALE 27n-18γ energy grouping is performed directly through the ORIGEN-S code. The SAS2H/ORIGEN-S input file for the Group 2 7x7 fuel assembly is provided in Section 5.5.

The gamma source for the fuel assembly hardware is primarily from the activation of cobalt. This activation contributes primarily to SCALE Energy Groups 36 and 37. Based on the weight fraction of cobalt in each zone of the fuel assembly model (as adjusted by the appropriate flux ratio), the gamma source term in SCALE Energy Groups 36 and 37 are redistributed accordingly. The gamma source for the plenum region, the top fitting region and the bottom fitting region is provided in Tables 5.2-5.

An axial burnup profile has been developed as discussed in Section 5.2.1 above. Table 5.2-7 provides design axial gamma peaking factors and source terms that were utilized in the MCNP shielding model.

5.2.3 Neutron Source

Tables 5.2-6 provides the total neutron source spectra for the Group 2 fuel assembly under the irradiation/decay history described above in 5.2.2. The SAS2H/ORIGEN-S code provides the neutron spectra in the SCALE 27n-18γ energy groups. The SAS2H/ORIGEN-S input file for the 7x7 fuel assembly is provided in Section 5.5.

The neutron source is not linearly dependent with burnup, and therefore analyses were performed to determine the axial neutron source distribution (Section 5.2.1). The axial neutron source distribution as a function of burnup and water density is shown in Table 5.2-7.

5.3 MODEL SPECIFICATION

The monte carlo code MCNP is used for calculating the gamma and neutron doses immediately around the cask.

5.3.1 Description of Radial and Axial Shielding Configuration

A single geometric model was developed for MCNP. This model was used to calculate both the axial and radial dose rates. In order to determine the total dose rate around a single cask, three separate runs were performed, each with a different source; 1) primary gamma, 2) neutron and 3) hardware gamma (end fittings).

Sections 5.3.1.1 and 5.3.1.2 describe the shielding model (for the vicinity immediately around the cask) developed for the NUHOMS®-MP197 under normal, off-normal and accident conditions.

5.3.1.1 Radial and Axial Shielding Configuration under Normal Conditions of Transport

Under normal conditions, one shielding configuration is used for the NUHOMS®-MP197 design. The model is illustrated in Figures 5.3-1 and 5.3-2 for the transport configuration of the MP197. The dimensions of this shielding model correspond to the dimensions of the MP197 design. The metal trunnions are replaced with the trunnion plugs. The impact limiter wood is assumed to all be balsa. The hold down ring was not included in the model. A 0.06" radial air gap is assumed at the lead (gamma shield) and outer shell interface to account for possible lead shrinkage during fabrication.

The axial locations of the plenum and the end fittings for the fuel assembly are taken from Reference 3; these are the same regardless of fuel assembly type.

The modeled active fuel length is 144 inches and the plenum length is 16.5 inches. The stainless steel rails are included as an equivalent layer of material (0.44") within the canister.

The impact limiters are modeled as wood surrounded by a 0.25" thick steel shell. The interior steel gussets are neglected. The wood is assumed to be balsa. The thermal shield under the bottom impact limiter is not included in the model, this is conservative since shielding material is neglected.

The fuel region is assumed to consist of uranium dioxide. The fuel cladding and one half of the steel and aluminum basket mass are included in the homogenized fuel region for the radial model. Only 20% of the basket mass is included in the axial model. The fuel channels are not included in the homogenization. (However, the fuel channels are included in the source term.) The fuel and basket region are modeled as a cylinder within the DSC. The actual DSC ID is reduced by the 0.44" equivalent steel rail layer so that the homogenized source region is modeled with a reduced diameter of 65.37".

The plenum region is assumed to consist of the cladding, plenum springs and the steel and aluminum basket. The hydrogen getters within the plenum are neglected. One-half of the basket mass in this region is homogenized through the plenum region for the radial model, 20% for the axial model.

Similarly, the bottom fitting region is homogenized with one-half the basket for the radial model and 20% for the axial model. Because the basket does not extend above the top fitting, the homogenized top fitting hardware does not contain any basket mass.

The key-way at the bottom of the cask that interfaces the cask to the transporter is included in the model. The key-way is assumed to be filled with the steel "key" on the transporter since the cask in normal transport mode is modeled. Voids are neglected within the fuel assembly. The voids within the cask cavity are modeled.

5.3.1.2 Radial and Axial Shielding Configuration under Hypothetical Accident Conditions of Transport

For accident conditions, it is assumed the neutron shield and shield shell are removed. The accident model also includes a 3.5" air gap at the top and bottom of the lead shield to account for the lead slump calculated in Chapter 2. The model utilizes the same regional densities and shield thickness as the model for normal conditions.

5.3.2 Shield Regional Densities

For the MCNP model, four source areas, shown in Figures 5.3-1 and Figure 5.3-2 are utilized: fuel zone, plenum, upper fitting and lower fitting. The sources are uniformly homogenized over the reduced canister diameter (65.37") and the appropriate length. One-half of the fuel basket mass is homogenized over the source diameter and appropriate length (of the fuel zone, plenum and bottom fitting) for the radial model and 20% is homogenized into the axial model.

The radial resin and aluminum boxes are homogenized into a single composition based on the mass of each component. Measured dose rates around the TN-24P [7], the TN-40, and the TN-32 casks have shown no streaming effects around the neutron shield. This is because the neutrons will not generally travel in a direct path, but scatter, such that the majority of the neutrons will not be able to travel through the aluminum box wall for the full 6 inches of resin box thickness. The material input for the MCNP model is listed in Table 5.3-1.

5.4 SHIELDING EVALUATION

Dose rates around the MP-197 are determined by choosing the most conservative source and using it within a three dimensional MCNP model. The MCNP dose is calculated as surface flux (F2) tallies and converted into dose rates using energy dependent dose conversion factors [6], (Tables 5.4-1and 5.4-2). The shielding evaluation accounts for subcritical neutron multiplication. The generation of secondary gamma dose due to neutron interactions in the shielding materials, principally the neutron shield resin, is neglected because the resin is surrounded by a steel shell and previous evaluations have shown the secondary gamma dose to be small fraction (< 3%) of the total calculated contact dose.

For the doses around the NUHOMS®-MP197, the source is divided into four separate regions: fuel, plenum, top fitting, and bottom fitting. The model is utilized in three separate computer runs consisting of contributions from the following sources:

- Primary gamma radiation from the active fuel (axial and radial directions).
- Neutron radiation from the active fuel region (axial and radial directions).
- Gamma radiation from activated hardware within the top fitting, plenum region and bottom fitting (axial and radial directions).

The sources in the active fuel region (gamma and neutron) are uniform radially but vary axially. The sources in the structural hardware regions (plenum, top fitting, and bottom fitting) are uniform both radially and axially. The results from the individual runs are summed to provide the total gamma, neutron and total dose for the cask.

Detector surfaces were placed in several radial and axial locations in order to evaluate the dose rate around the cask body. These surfaces provide an averaged surface dose rate based on the size of the detector (surface). The surfaces are subdivided into segments in order to determine the location and magnitude of maximum dose rates. Approximately 25 cm length "detector" segments were utilized both axially and radially.

For normal conditions, the contribution of each source to each dose point is summed to calculate the total gamma and/or neutron dose for each location. Table 5.1-2 presents the maximum calculated dose at contact, at the vehicles outer edge (assumed 10 ft wide vehicle), and at 2 m from the vehicle's outer edge. The calculated neutron and gamma dose rates at the various dose points are illustrated in Figures 5.4-1 through 5.4-4.

For accident conditions, Table 5.1-2 also presents the maximum calculated doses at 1 m from the cask body.

5.6.2 MCNP Neutron Model Input File

```
TransNuclear NU-61B cask:   Near-Field model
c
c    This model calculates doses for neutrons
c
c ***********************  BLOCK 1: CELL CARDS ************************
c GEOMETRY (r-z)
c
c  ^ z-axis
c  .
c  | ------------------   |  tally surfaces @
c  .____________________. |     contact,
c  |    impact limiter  | |     1m and
c  ._______________.    | |     2m from surface IL
c  |-------------+--+   | |     for the radial (side)
c  .-------------+  |   | |     and 1 cm from the top and
c  |.............|  |___| |     bottom of the ILs axially
c  .  BASKETS    |  |+    |
c  |.............|  ||    |           VOID
c  .             |  ||    |
c  |             |  ||    |
c  .   FUEL      |  ||    |
c  O ------------|--||------------------------------> y-axis
c  |  (12 sub    |  ||    |
c  .   regions)  |  ||    |
c  |             |  ||    |
c  .             |  ||
c  |.............|  ||
c  .  BASKET     |  |__.
c  |-------------+  |  |
c  .=---------------+  |
c  |   impact limiter  |
c  .___________________|
c  |
c                                M Mason 4/01
c
c ****** Cask cells
  1  8   -7.92   1 -2 -260 #35   imp:n,p=1   $ Fe cask bottom
  2  8   -7.92   2 -12 25 -21 imp:n,p=1  $ Inner shell
  3  7   -1.284   18 -5 -28       imp:n,p=1  $ bottom basket
  4  6   -0.790    7 -8 -28       imp:n,p=1  $ top plenum basket
  5  5   -0.446    8 -11 -28      imp:n,p=1  $ top fitting
  8  1  -0.0013  11 -19 -28       imp:n,p=1  $ Void between top and canister
  9  1  -0.0013  20 -12 -27  imp:n,p=1  $ Void between canister and lid
  10  8   -7.92 2 -18 -27          imp:n,p=1  $ bottom of canister
  11  8   -7.92  12 -14 -260        imp:n,p=1  $ Fe cask lid - part1
  12  8   -7.92 19 -20 -27   imp:n,p=1  $ top of canister
  25  8   -7.92  18 -19 28 -27    imp:n,p=1   $ The canister
  26  1  -0.0013  2 -12 27 -25  imp:n,p=1  $ Void between canister and inner
shell
  27  16    -11.34   333 -12 21 -222 332 -17 2   imp:n,p=1  $ Gamma shield
 627  1  -0.0013  333 -12 -22 222  332 -17  2   imp:n,p=1  $ gap at gamma
shield ..
  16  8   -7.92  21 2 -12 -22 #27 #627 imp:n,p=1  $ Gamma shield CS
```

```
 28  8    -7.92  2 -12 22 -260  imp:n,p=1 $ Outer shell
c  29  12   -1.687  149 -166 260 -202 #37 #38 #39 #99 #240 #241 #242 #243
c             #260 #261 #262 #263 imp:n,p=1 $ neutron shield
 29  12  -1.687  198 -199 260 -202 #37 #38 #39 #99 #260 #261
                 #262 #263 #265 #266 #267 #268 #244 imp:n,p=1  $ neutron
shield
 36  8   -7.92  149 -166 202 -201 #265 #266 #267 #268 imp:n,p=1 $ SS Skin
over NS
  6  8   -7.92  (-166 199 260 -202)#37 #38 :
                (149 -198 260 -202) #39 #99  imp:n,p=1  $ top & bot ss plate
on NS
 30  0    150 -149 -201 260         imp:n,p=1 $ void space between BL & NS
 31  0    161 -14 260 -251          imp:n,p=1 $ void btw side of TL and csk
 32  0    155 -150 260 -251         imp:n,p=1 $ void btw side of BL and csk
 33  0    155 -1 -260               imp:n,p=1 $ void btw csk bottom and BL
 34  0    166 -161 260 -201         imp:n,p=1 $ void btw top of NS and TL
 35  0    167 -2 -255               imp:n,p=1 $ canister plug
c ****** trunnion blocks with trunnion plugs ********
 37  8   -7.92 (195 -344 345 -166 196 -341 260)#260 :
            (195 -330 260 -341 -196) #260 imp:n,p=1 $ TR trun block
260  17   -0.90 195  -336 260 -341  imp:n,p=1       $ PP trunnion plug
265  8   -7.92  -334 -300 341  imp:n,p=1          $ Fe trunnion plug
 38  8   -7.92  (-195 -344 345 -166 196 342 260)#261:
           (-195 -330 260 342 -196) #261 imp:n,p=1 $ TL trun block
261  17   -0.90  -195 -336 260  342  imp:n,p=1     $ PP trunnion plug
266  8   -7.92  -334 301 -342  imp:n,p=1         $ Fe trunnion plug
 39  8   -7.92 (195 -344 345 149 -197 -341 260)#262 :
            (195 -331 260 -341 197) #262 imp:n,p=1 $ BR trun block
262  17   -0.90  195 -337 260 -341  imp:n,p=1      $ PP trunnion plug
267  8   -7.92  -335 -300 341  imp:n,p=1         $ Fe trunnion plug
 99  8   -7.92 (-195 -344 345 149 -197 342 260)#263:
           (-195 -331 260 342 197) #263 imp:n,p=1  $ BL trun block
263  17   -0.90  -195 -337 260  342  imp:n,p=1     $ PP trunnion plug
268  8   -7.92  -335 301 -342  imp:n,p=1         $ Fe trunnion plug
c ******* transport key/pad on cask under-side
244  8   -7.92   (-348 -349 351 -352 -202 256):(-353 -354 355 -356 260 -256)
                     imp:n,p=1 $ key plus pad on body
c **** impact limiters  *****
c  bottom limiter
   80 8  -7.92    (156 -155 -254):(155 -151 -254 251) imp:n,p=1 $ inside skin
   81 8  -7.92    (153 -152 -250):(152 -151 -250 253) imp:n,p=1 $ outside
skin
   82 8  -7.92     151 -150 -250 251      imp:n,p=1 $ outside skin
   83 15 -0.125      156 -151 -253 254     imp:n,p=1 $ balsa instead of
redwood
   84 15 -0.125      154 -156 -253 252     imp:n,p=1 $ balsa instead of
redwood
   85 15 -0.125      154 -156 -252         imp:n,p=1 $ balsa instead of
redwood
   86 15 -0.125      152 -154 -253 252     imp:n,p=1 $ balsa instead of
redwood
   87 15 -0.125      152 -154 -252         imp:n,p=1 $ balsa
c  top limiter
   90 8  -7.92    (14 -165 -254):(160 -14 -254 251) imp:n,p=1 $ inside steel
   91 8  -7.92    (162 -163 -250):(160 -162 -250 253) imp:n,p=1 $ outside
steel
   92 8  -7.92      -160 161 -250 251      imp:n,p=1 $ outside steel
```

```
c -------------------------------------------------------------------------
de0    2.500E-08 1.000E-07 1.000E-06 1.000E-05 1.000E-04 1.000E-03
       1.000E-02 2.000E-02 5.000E-02 1.000E-01 2.000E-01 5.000E-01
       1.000E+00 1.500E+00 2.000E+00 3.000E+00 4.000E+00 5.000E+00
       6.000E+00 7.000E+00 8.000E+00 1.000E+01 1.400E+01 1.700E+01
       2.000E+01
df0    8.000E-12 1.040E-11 1.120E-11 9.200E-12 7.100E-12 6.200E-12
       8.600E-12 1.460E-11 3.500E-11 6.900E-11 1.260E-10 2.580E-10
       3.400E-10 3.620E-10 3.520E-10 3.800E-10 4.090E-10 3.780E-10
       3.830E-10 4.030E-10 4.170E-10 4.460E-10 5.200E-10 6.100E-10
       6.500E-10
c -------------------------------------------------------------------------
c  ambient photon dose equiv. H*(10mm) Sv (from T-D1 of S&F)
c -------------------------------------------------------------------------
c de24   1.000E-02 1.500E-02 2.000E-02 3.000E-02 4.000E-02 5.000E-02
c       6.000E-02 8.000E-02 1.000E-01 1.500E-01 2.000E-01 3.000E-01
c       4.000E-01 5.000E-01 6.000E-01 8.000E-01 1.000E+00 1.500E+00
c       2.000E+00 3.000E+00 4.000E+00 5.000E+00 6.000E+00 8.000E+00
c        1.000E+01
c df24   7.690E-14 8.460E-13 1.010E-12 7.850E-13 6.140E-13 5.260E-13
c       5.040E-13 5.320E-13 6.110E-13 8.900E-13 1.180E-12 1.810E-12
c       2.380E-12 2.890E-12 3.380E-12 4.290E-12 5.110E-12 6.920E-12
c       8.480E-12 1.110E-11 1.330E-11 1.540E-11 1.740E-11 2.120E-11
c        2.520E-11
c
c     ***** MATERIAL CARDS
c     ************************************************************
c      AIR: ANSI/ANS-6.4.3, Dry air;  density = 0.0012 g/cm^3
c           Composition by mass fraction
c     ************************************************************
c
m1     7014.50c  -.75519
       8016.60c  -.23179
       6000.60c  -.00014
      18000.35c  -.01288
c
c
c     ************************************************************
c      Fuel-Basket Nu-61b Cask
c           Density = 2.511 g/cm^3;  Composition by atom fraction
c     ************************************************************
m4     92238.50c  0.19053
       92235.50c  0.00773
       40000.60c  0.13149
       28000.50c  0.01470
       26000.50c  0.11116
       25055.50c  0.00331
       24000.50c  0.03318
       13027.50c  0.11140
        8016.60c  0.39652
c
c     ************************************************************
c      Top Fitting NU-61b Cask
c           Density = 0.446 g/cm^3;  Composition by atom fraction
c     ************************************************************
m5     26000.50c  0.50879
       28000.50c  0.06722
       25055.50c  0.01512
```

```
     24000.50c  0.15180
     40000.60c  0.25707
c
c    ************************************************************
c     Plenum/Basket Nu-61b Cask
c         Density = 0.790 g/cm^3;   Composition by atom fraction
c    ************************************************************
m6   26000.50c  0.32657
     28000.50c  0.04318
     40000.60c  0.25966
     25055.50c  0.00971
     24000.50c  0.09746
     13027.50c  0.26343
c
c    ************************************************************
c     Bottom/Basket Nu-61b
c         Density = 1.284 g/cm^3;  Composition by atom fraction
c    ************************************************************
m7   26000.50c  0.51974
     28000.50c  0.06872
     25055.50c  0.01545
     24000.50c  0.15512
     13027.50c  0.15415
     40000.60c  0.08682
c
c    ************************************************************
c     Basket Periphery (SS304) TN-68 (Table 5.3-1)
c         Density = 7.92 g/cm^3;   Composition by atom fraction
c    ************************************************************
m8   26000.50c  0.68826
     25055.50c  0.02013
     24000.50c  0.20209
     28000.50c  0.08952
c
c    ************************************************************
c     Carbon Steel TN-68 (Table 5.3-1)
c         Density = 7.8212 g/cm^3;  Composition by atom fraction
c    ************************************************************
m9   26000.50c  0.95510
      6000.60c  0.04490
c
c    ************************************************************
c     Outer Basket/Rails TN-68 (Table 5.3-1)
c         Density = 2.702 g/cm^3;   Composition by atom fraction
c    ************************************************************
m10  13027.50c  1.00000
c
c    ************************************************************
c     Resin/Aluminum Composite for TN-68 (Table 5.3-1)
c         Density = 1.687 g/cm^3;   Composition by atom fraction
c    ************************************************************
m12  13027.50c  0.10331
      6012.50c  0.24658
      8016.60c  0.21985
      1001.50c  0.42207
      5010.60c  0.00164
      5011.60c  0.00655
```

```
        5011.60c  0.00655
c
c
c     *************************************************************
c      Balsa for Impact Limiter  (Standard Composition SCALE4.4)
c          density = 0.125 g/cm^3;  Composition by atom fraction
c     *************************************************************
m15      6012.50c   0.2857
         8016.60c   0.2381
         1001.50c   0.4762
c     *************************************************************
c      Lead for Gamma Shield  (Standard Composition SCALE4.4)
c          density = 11.34 g/cm^3;  Composition by atom fraction
c     *************************************************************
m16      82000.50c   1.0
c
c
c     *************************************************************
c      Polypropylene Disk TN-68 (Table 5.3-1)
c         Density = 0.90 g/cm^3;   Composition by atom fraction
c     *************************************************************
m17     6012 .33480
        1001 .66520
c
c  prdmp 2j 1
c  print
□
```

5.6.3 MCNP Primary Gamma Input File

```
TransNuclear NU-61B cask:    Near-Field model
c
c    This model calculates doses for fuel gammas
c    at the side of the cask
c
c ***********************  BLOCK 1: CELL CARDS ***********************
c GEOMETRY (r-z)
c
c  ^ z-axis
c  .                        |
c  | ------------------     |  tally surfaces @
c  .___________________.    |     contact,
c  |    impact limiter |    |     1m and
c  .____________.      |    |     2m from surface IL
c  |-------------+--+  |    |     for the radial (side)
c  .-------------+  |  |    |
c  |.............|  |__|    |
c  .  BASKETS    |  |+      |
c  |.............|  ||      |           VOID
c  .             |  ||      |
c  |             |  ||      |
c  .   FUEL      |  ||      |
c  0 ------------|--||-----------------------------> y-axis
c  |  (12 sub    |  ||      |
c  .   regions)  |  ||      |
c  |             |  ||      |
```

```
c  |.............|  ||
c  .  BASKET      |  |__.
c  |-------------+  |  |
c  .=---------------+  |
c  |   impact limiter  |
c  .___________________|
c  |
c                              M Mason 4/01
c
c ****** Cask cells
  1  8   -7.92  1 -2 -260 #35   imp:n,p=1  $ Fe cask bottom
  2  8   -7.92  2 -12 25 -371 imp:n,p=20  $ Inner shell
 65 8   -7.92  2 -12 371 -21 imp:n,p=45  $ Inner shell
  3  7   -1.284   18 -5 -28       imp:n,p=1  $ bottom basket
  4  6   -0.790   7 -8 -28        imp:n,p=1  $ top plenum basket
  5  5   -0.446   8 -11 -28       imp:n,p=1  $ top fitting
  8  1  -0.0013  11 -19 -28       imp:n,p=1  $ Void between top and canister
  9  1  -0.0013  20 -12 -27  imp:n,p=2  $ Void between canister and lid
  10  8   -7.92 2 -18 -27           imp:n,p=2  $ bottom of canister
  11  8   -7.92  12 -14 -260         imp:n,p=2  $ Fe cask lid - part1
  12  8   -7.92 19 -20 -27   imp:n,p=2  $ top of canister
  25  8   -7.92  18 -19 28 -370   imp:n,p=2   $ The canister
  66  8   -7.92  18 -19 370 -27   imp:n,p=4   $ The canister
  26  1  -0.0013  2 -12 27 -25  imp:n,p=8  $ Void between canister and inner
shell
  27  16   -11.34   333 -12 21 -372 332 -17 2  imp:n,p=100  $ Gamma shield
  64  16   -11.34   333 -12 372 -373 332 -17 2  imp:n,p=250  $ Gamma shield
  63  16   -11.34   333 -12 373 -374 332 -17 2  imp:n,p=600  $ Gamma shield
  62  16   -11.34   2 -17 374 -222 imp:n,p=1500  $ Gamma shield
 662  1    -0.0013  2 -17 222 -22 imp:n,p=1500  $ Gamma Shield gap (.06")
  16  8   -7.92  21 2 -12 -22 #27 #64 #63 #62 #662 imp:n,p=250  $ Gamma
shield CS
  28  8   -7.92  2 -12 22 -375  imp:n,p=4000 $ Outer shell
  67  8   -7.92  2 -12 375 -376  imp:n,p=10000 $ Outer shell
  68  8   -7.92  2 -12 376 -260  imp:n,p=25000 $ Outer shell
c  29  12  -1.687  149 -166 260 -202 #37 #38 #39 #99 #240 #241 #242 #243
c          #260 #261 #262 #263 imp:n,p=60000 $ neutron shield
  29  12  -1.687  198 -199 260 -202 #37 #38 #39 #99 #260 #261
                 #262 #263 #265 #266 #267 #268 #244 imp:n,p=6E4  $ neutron
shield
  36  8  -7.92 149 -166 202 -201 #265 #266 #267 #268 imp:n,p=150000 $ SS Skin
over NS
   6  8   -7.92  (-166 199 260 -202)#37 #38 :
                 (149 -198 260 -202) #39 #99  imp:n,p=1.5E5  $ top & bot ss
plate on NS
  30  0    150 -149 -201 260         imp:n,p=25000 $ void space between BL &
NS
  31  0    161 -14 260 -251          imp:n,p=25000 $ void btw side of TL and
csk
  32  0    155 -150 260 -251         imp:n,p=25000 $ void btw side of BL and
csk
  33  0    155 -1 -260               imp:n,p=25000 $ void btw csk bottom and
BL
  34  0    166 -161 260 -201         imp:n,p=25000 $ void btw top of NS and
TL
  35  0    167 -2 -255               imp:n,p=2 $ canister plug
  c ****** trunnion blocks with trunnion plugs ********
```

```
FC2  Doses at contact averaged over subsurfaces
F2:p  201
FS2    -71 -39 -40 -41 -42 -43 -44 -45 -46 -47 -48 -49 -72 -8 -11
SD2   3.0E7 18552.00 13353.64 26699.98 26707.28 26736.49
       26670.78 26670.78 26736.49 26707.28 26699.98
        13353.64 25853.06 18048.22 15463.65 3.0E7
FC12     Doses at 1 meters from cask averaged over subsurfaces
F12:p    65
FS12   -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
        -48 -49 -72 -8 -11 -165 -164 -162
SD12    1.0E8 76825.71 43985.79 72757.22 34517.57 24845.59 49677.59
          49691.17 49745.51 49623.25 49623.25 49745.51 49691.17
          49677.59 24845.59 48101.82 33580.26 28771.43
          59648.43 51783.15 71697.65 8.0E7
FC22     Doses at 2 meters from rail car averaged over subsurfaces
F22:p    64
FS22   -152 -154 -155 -71 -39 -40 -41 -42 -43 -44 -45 -46 -47
        -48 -49 -72 -8 -11 -165 -164 -162
SD22    1.0E8 126147.67 72224.59 119467.23 56677.79 40796.41 81570.51
          81592.81 81682.04 81481.29 81481.29 81682.04 81592.81
          81570.51 40796.41 78983.09 55138.72 47242.64
          97942.61 85027.83 117727.41 8.0E7
c
c
 mode p
 phys:p 20.0 0.0
c cut:n j 0.0
c phys:p 0 1 1
c esplt:n 0.5 0.1 0.5 0.01 0.25 0.001
c wwp:n 5 3 5 0 0.5
 nps   300000000
c  void
c
c ------------------------------------------------------------
c  ambient photon dose equiv. H*(10mm) Sv (from T-D1 of S&F)
c ------------------------------------------------------------
de0    1.000E-02 1.500E-02 2.000E-02 3.000E-02 4.000E-02 5.000E-02
       6.000E-02 8.000E-02 1.000E-01 1.500E-01 2.000E-01 3.000E-01
       4.000E-01 5.000E-01 6.000E-01 8.000E-01 1.000E+00 1.500E+00
       2.000E+00 3.000E+00 4.000E+00 5.000E+00 6.000E+00 8.000E+00
        1.000E+01
df0    7.690E-14 8.460E-13 1.010E-12 7.850E-13 6.140E-13 5.260E-13
       5.040E-13 5.320E-13 6.110E-13 8.900E-13 1.180E-12 1.810E-12
       2.380E-12 2.890E-12 3.380E-12 4.290E-12 5.110E-12 6.920E-12
       8.480E-12 1.110E-11 1.330E-11 1.540E-11 1.740E-11 2.120E-11
        2.520E-11
c
c     ***** MATERIAL CARDS
c     ***********************************************************
c      AIR: ANSI/ANS-6.4.3, Dry air;  density = 0.0012 g/cm^3
c           Composition by mass fraction
c     ***********************************************************
m1     7014   -.75519
       8016   -.23179
       6000   -.00014
      18000   -.01288
c
```

```
c       ************************************************************
c        Fuel-Basket Nu-61b Cask
c             Density = 2.511 g/cm^3;  Composition by atom fraction
c       ************************************************************
m4       92238   0.19053
         92235   0.00773
         40000   0.13149
         28000   0.01470
         26000   0.11116
         25055   0.00331
         24000   0.03318
         13027   0.11140
          8016   0.39652
c
c       ************************************************************
c        Top Fitting NU-61b Cask
c             Density = 0.446 g/cm^3;  Composition by atom fraction
c       ************************************************************
m5       26000   0.50879
         28000   0.06722
         25055   0.01512
         24000   0.15180
         40000   0.25707
c
c       ************************************************************
c        Plenum/Basket Nu-61b Cask
c            Density = 0.790 g/cm^3;   Composition by atom fraction
c       ************************************************************
m6       26000   0.32657
         28000   0.04318
         40000   0.25966
         25055   0.00971
         24000   0.09746
         13027   0.26343
c
c       ************************************************************
c        Bottom/Basket Nu-61b
c            Density = 1.284 g/cm^3;  Composition by atom fraction
c       ************************************************************
m7       26000   0.51974
         28000   0.06872
         25055   0.01545
         24000   0.15512
         13027   0.15415
         40000   0.08682
c
c       ************************************************************
c        Basket Periphery (SS304) TN-68 (Table 5.3-1)
c             Density = 7.92 g/cm^3;   Composition by atom fraction
c       ************************************************************
m8       26000   0.68826
         25055   0.02013
         24000   0.20209
         28000   0.08952
c
```

TABLE 5.1-1

NUHOMS® MP-197/61BT SHIELD MATERIALS

Component	Material	Density (g/cm^3)	Thickness (inches)
Cask Body Wall	Stainless Steel Lead	7.92 11.34	3.75 3.25
Cask Lid	Stainless Steel	7.92	4.50
Cask Bottom	Stainless Steel	7.92	6.50
Resin [a]	Polyester Resin Styrene Aluminum Hydrate Zinc Borate	1.58	4.56
Aluminum Box [a]	Aluminum	2.7	0.12
Outer Shell	Stainless Steel	7.92	0.19
Basket [b]	Stainless Steel Aluminum Neutron Poison Material [b]	7.92 2.7	Homogenized into source region
Rails	Stainless Steel	7.92	0.44"
Impact Limiter	Stainless Steel Redwood Balsa Wood	7.92 0.387 0.125	0.25 19.25[c] 15.25[c]
Canister Wall	Stainless Steel	7.92	0.5"
Canister Lids	Stainless Steel	7.92	8.92"
Canister Bottom	Stainless Steel	7.92	7.5"

a The neutron shielding is borated polyester resin compound with a density of 1.58 g/cc. and is homogenized with the aluminum box to a combined thickness of 4.56".

b This is modeled as plain aluminum for shielding purposes .

c Thickness of wood is variable, redwood modeled as balsa.

TABLE 5.1-2

SUMMARY OF DOSE RATES
(Exclusive Use)

Normal Conditions	Package Surface mSv/h (mrem/h)			Vehicle Edge mSv/h (mrem/h)			2 Meter from Vehicle mSv/h (mrem/h)		
Radiation	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.011 (1.1)	0.13 (13)	0.014 (1.4)	-	0.054 (5.4)	-	-	0.029 (2.9)	-
Neutron	0.009 (0.9)	1.25 (125)[1]	0.023 (2.3)	-	0.170 (17.0)	-	-	0.071 (7.1)	-
Total	0.020 (2.0)	1.38(137)	0.037 (3.7)	-	0.22 (22)	-	-	0.1 (10)	-
Limit	10 (1000)	10 (1000)	10 (1000)		2 (200)			0.1 (10)	

Hypothetical Accident Conditions	1 Meter from Package Surface mSv/h (mrem/h)		
Radiation	Top	Side	Bottom
Gamma	< 0.008 (0.8)	0.15 (15)	< 0.011 (1.1)
Neutron	< 0.009 (0.9)	4.25 (425)	< 0.020 (2.0)
Total	< 0.017 (1.7)	4.41 (440)	< 0.031 (3.1)
Limit	10 (1000)	10 (1000)	10 (1000)

(1) Dose around key-way on cask

TABLE 5.3-1

MATERIALS INPUT FOR MCNP

Zone	Material	Density (g/cc)	Element/Nuclide	Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel/Basket*	UO_2	1.727	U-235	92235	1.502E-04
			U-238	92238	3.703E-03
			O	8016	7.706E-03
	Zircaloy	0.394	Zr	40302	2.556E-03
	SS304	0.293	Cr	24304	6.448E-04
			Mn	25055	6.424E-05
			Fe	26304	2.160E-03
			Ni	28304	2.856E-04
	Aluminum	0.097	Al	13027	2.165E-03
Plenum/Basket*	Zircaloy	0.329	Zr	40302	2.134E-03
	SS304	0.364	Cr	24304	8.010E-04
			Mn	25055	7.980E-05
			Fe	26304	2.684E-03
			Ni	28304	3.548E-04
	Aluminum	0.097	Al	13027	2.165E-03
Top Fitting/Basket	Zircaloy	0.163	Zr	40302	1.056E-03
	SS304	0.283	Cr	24304	6.237E-04
			Mn	25055	6.214E-05
			Fe	26304	2.901E-03
			Ni	28304	2.762E-04
Bottom Fitting/Basket*	Zircaloy	0.188	Zr	40302	2.179E-03
	SS304	0.999	Cr	24304	2.170E-04
			Mn	25055	7.300E-03
			Fe	26304	9.651E-04
			Ni	28304	1.219E-03
	Aluminum	0.0.097	Al	13027	2.165E-03
Basket Periphery (rails)	SS304	7.92	Cr	24304	1.743E-02
			Mn	25055	1.736E-03
			Fe	26304	5.936E-02
			Ni	28304	7.721E-03
Resin/Aluminum	Resin (1.58 g/cc) & Al (2.702 g/cc)	1.687	O	8016	2.245E-02
			Al	13027	1.055E-02
			C	6012	2.518E-02
			H	1001	4.310E-02
			B-10	5010	1.662E-04
			B-11	5011	6.692E-04
(gamma shield)	Lead	11.34	Pb	82000	3.296E-02
Impact Limiter	Balsa Wood	0.125	C	6012	2.787E-03
			O	8016	2.323E-03
			H	1001	4.646E-03

* - One-half of basket mass in the region for radial, 20% for axial (data not shown)

TABLE 5.4-1

RESPONSE FUNCTIONS FOR GAMMA

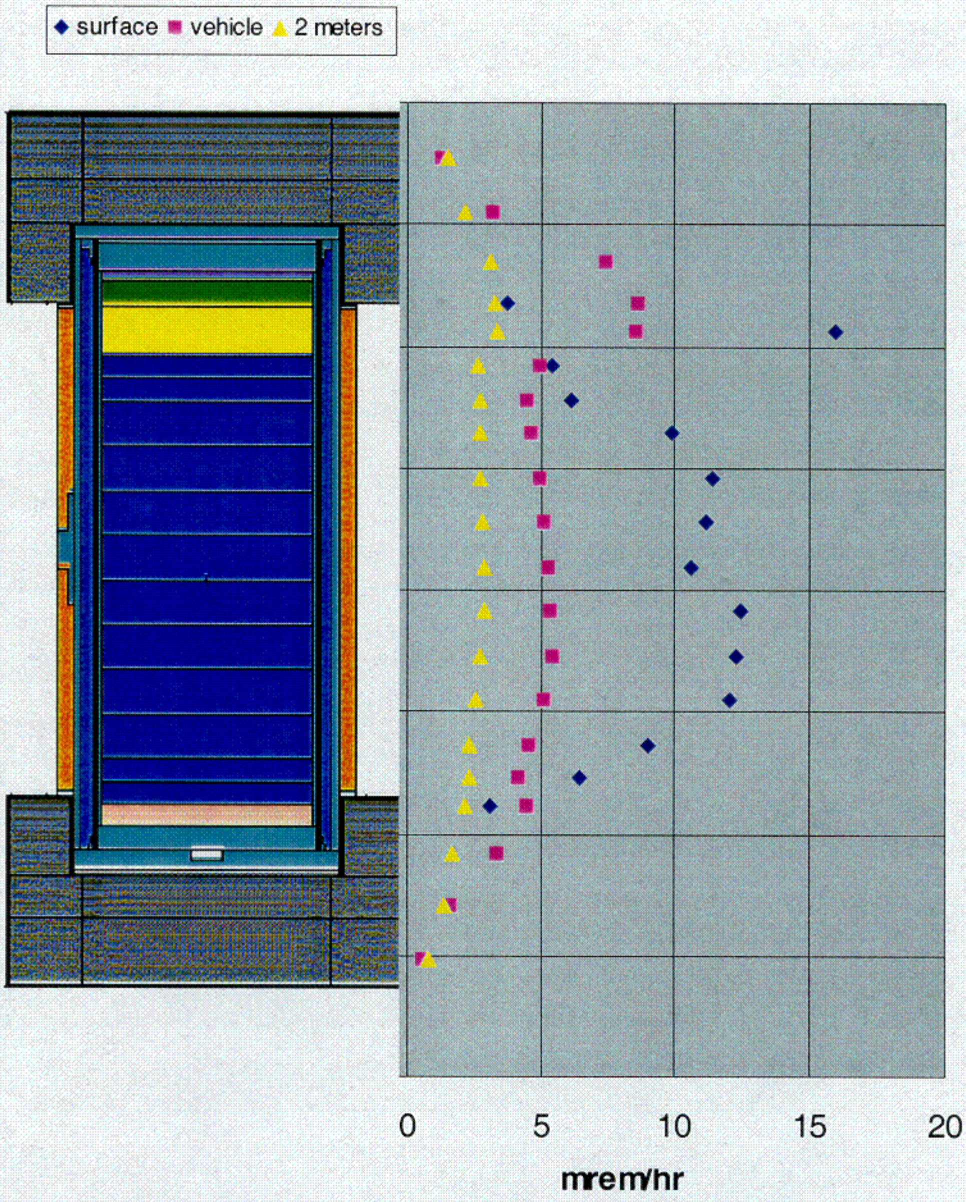
Photon Energy (MeV)	Response (10^{-12} Sv cm^2)
0.01	0.0769
0.015	0.846
0.02	1.01
0.03	0.785
0.04	0.614
0.05	0.526
0.06	0.504
0.08	0.532
0.10	0.611
0.15	0.890
0.20	1.18
0.30	1.81
0.40	2.38
0.50	2.89
0.60	3.38
0.80	4.29
1.0	5.11
1.5	6.92
2.0	8.48
3.0	11.1
4.0	13.3
5.0	15.4
6.0	17.4
8.0	21.2
10.0	25.2

FIGURE 5.1-1

NUHOMS®-MP197 CASK SHIELDING CONFIGURATION

FIGURE WITHHELD UNDER 10 CFR 2.390

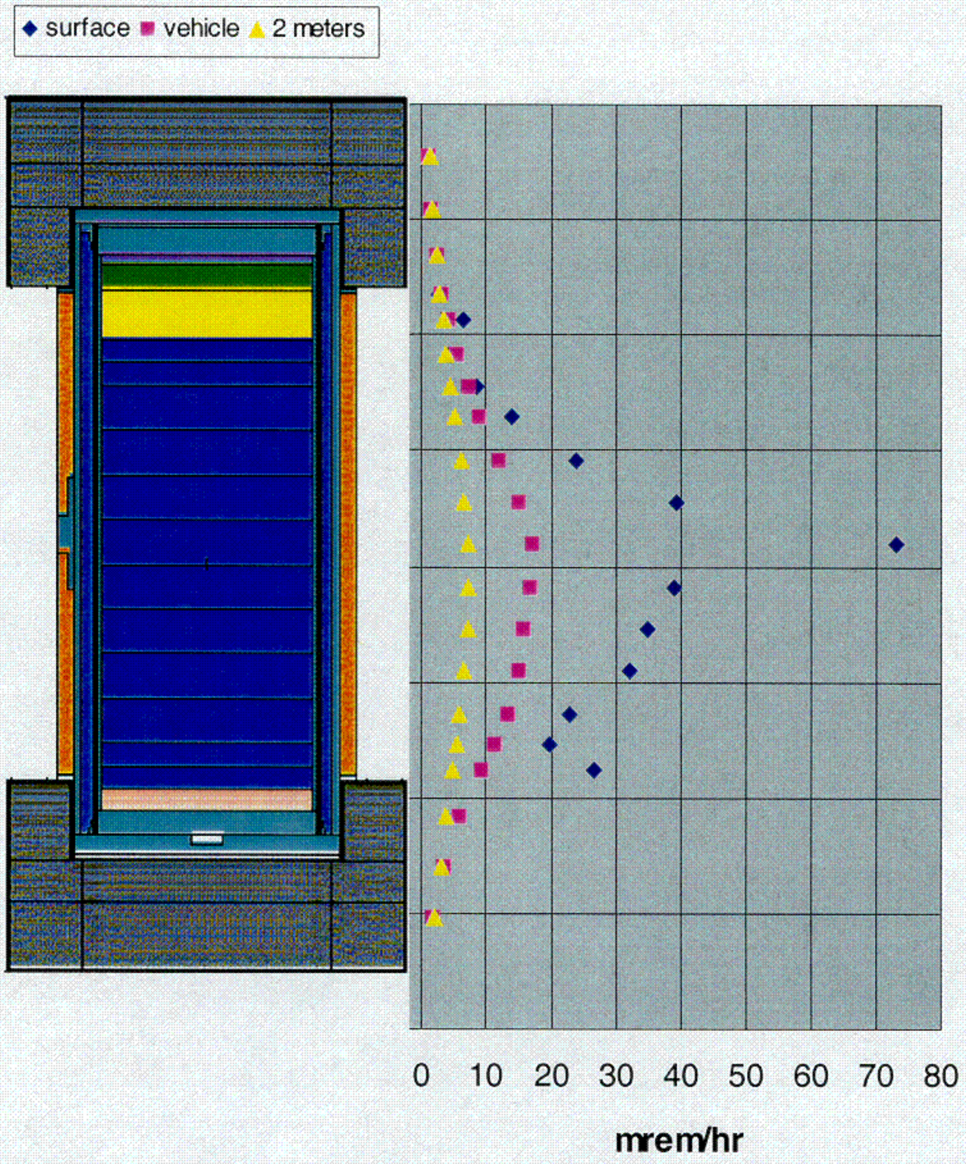
FIGURE 5.4-1
NUHOMS®-MP197 RADIAL GAMMA DOSE RATE PROFILE



C03

FIGURE 5.4-2

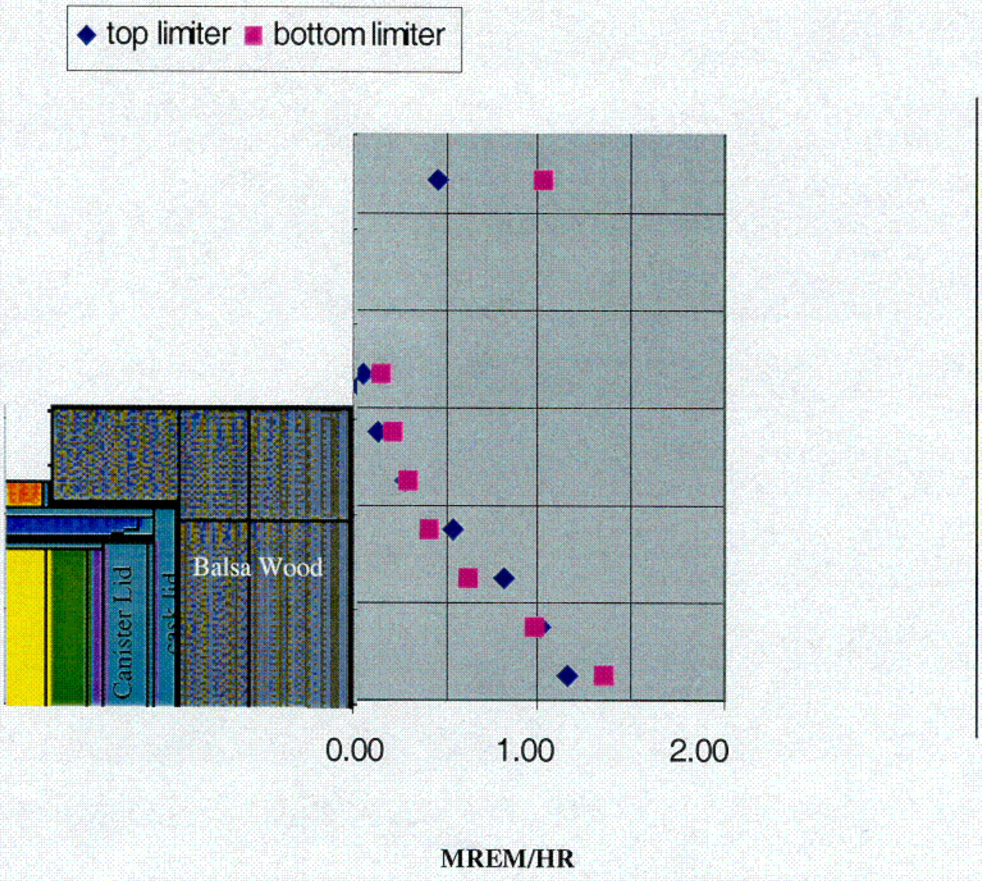
NUHOMS®-MP197 RADIAL NEUTRON DOSE RATE PROFILE



C04

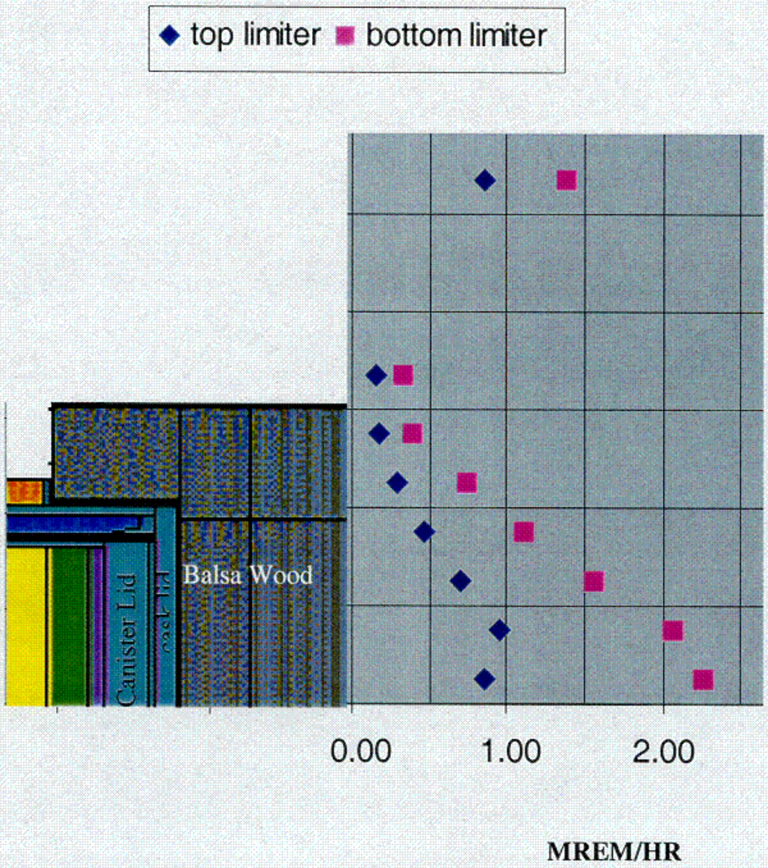
FIGURE 5.4-3

NUHOMS®-MP197 GAMMA DOSE RATE
IMPACT LIMITER SURFACE



C05

FIGURE 5.4-4
NUHOMS®-MP197 NEUTRON DOSE RATE
IMPACT LIMITER SURFACE



C06

NUHOMS®-MP197 TRANSPORT PACKAGING

CHAPTER 6

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CHAPTER 6

CRITICALITY EVALUATION

6.1 Design

The design criteria for the NUHOMS®-61BT Dry Shielded Canister (DSC) to be transported in the NUHOMS®-MP197 transport package require that the package remain subcritical under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) as defined in 10CFR Part 71.

The NUHOMS®-61BT System's criticality safety is ensured by both fixed neutron absorbers and favorable geometry. Burnup credit is not taken in this criticality evaluation. The fixed neutron absorber may be one of several different types of borated metallic plates. The materials description, acceptance testing, and the boron 10 credit allowed for the various fixed absorber materials are included in Chapter 8.

No credit is taken for moderator exclusion by the DSC.

6.1.1 Discussion and Results

Figure 6-1 shows the cross section of the NUHOMS®-61BT DSC. The analysis presented herein is performed for a NUHOMS®-61BT DSC in a the MP-197 transportation cask. The cask consists of an inner stainless steel shell, and lead gamma shield, a stainless steel structural shell and a hydrogenous neutron shield. The NUHOMS®-MP197 configuration is shown to be subcritical under NCT and HAC.

The calculations determine k_{eff} with the CSAS25 control module of SCALE-4.4 [6.1] for various configurations and initial enrichments, including all uncertainties to assure criticality safety under all credible conditions.

The results of the evaluation demonstrate that the maximum k_{eff} - including statistical uncertainty - is 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.

6.2 Package Fuel Loading

The NUHOMS®-MP-197 is capable of transporting intact BWR fuel assemblies with or without fuel channels. The maximum lattice-averaged enrichment of the fuel depends on the boron content in the fixed poison plates in the basket, as shown in Table 6-1. The fuel assemblies considered as authorized contents are listed in Table 6-2.

Table 6-3 lists the fuel parameters for the standard BWR fuel assemblies. The design basis fuel chosen for the NUHOMS®-MP197 Packaging criticality analysis is the GE 10×10 fuel assembly because it is the most reactive fuel assembly of the authorized contents, as demonstrated in the appendix to this chapter.

An infinite array of packages with optimal internal and interspersed moderation is evaluated to demonstrate compliance with 10CFR71.55(b), 10CFR71.59(a)(1), 10CFR71.59(a)(2). Because an infinite array of packages is used to evaluate both NCT and HAC, the transport index for criticality safety is zero.

6.3 Model Specification

The following subsections describe the physical models and materials of the NUHOMS®-MP197 packaging used for input to the CSAS25 module of SCALE-4.4 [6.1] to perform the criticality evaluation.

6.3.1 Description of Calculational Model

The cask and the DSC were explicitly modeled using the appropriate geometry options in KENO V.a of the CSAS25 module in SCALE-4.4.

Two models were developed. The first model is a full-active fuel height model and full-radial cross section of the DSC alone with water boundary conditions on the ends and reflective boundary conditions on the sides. The model does not include the gaps between the poison plates. This model is more fully described in Section 6.6.2. This model is only used to determine the most reactive fuel assembly/channel combination and to justify use of the lattice average enrichment for the intact fuel analysis. The second model is a full-active fuel height model and full radial cross section of the cask and DSC with reflective boundary conditions on all sides. This model includes the worst case gaps between the poison plates and the basket internals modeled at minimum material conditions. This model includes the GE12 10×10-fuel assembly only because this assembly type is determined to be the most reactive fuel assembly type of the authorized contents. The GE12 10×10-fuel assembly is modeled as a 10×10 array comprising 92 fuel rods, including fuel, gap and cladding and two large water holes. The fuel cladding OD is also reduced by 0.010 inches in the final models to conservatively bound fuel manufacturing tolerances.

Figure 6-2 is a sketch of each KENO V.a unit showing all materials and dimensions for each unit and an annotated cross section map showing the assembled geometry units in the radial direction of the model. The assembly-to-assembly pitch is a variable in the model with the fuel assemblies modeled in the center of the fuel cells and pushed towards the center and away from the center of the basket. The poison plates are modeled with minimum plate thickness, width and length. The maximum gap between the plates is modeled in the worst case orientation to maximize the amount of "uncovered" fuel. The gaps between the poison plates are due to the need to provide space for thermal expansion of the poison plates relative to the stainless steel parts of the basket and to allow for fabrication tolerances in the basket. In addition, the NUHOMS®-61BT DSC design allows the poison plates to be fabricated in sections, rather than one continuous piece. In the axial direction, all gaps are modeled at the maximum width. Table 6-4 provides the axial position of the assembled KENO V.a geometry units. Figure 6-3 shows the second model in the bounding configuration.

An infinite array of damaged packages in a rectangular lattice is modeled by the use of mirror reflection on all six sides of a cuboid surrounding the package model (the second model described above). Neither the neutron shield nor the impact limiters are modeled, which reduces the pitch between packages in the array.

6.3.2 Package Regional Densities

The Oak Ridge National Laboratory (ORNL) SCALE code package [6.1] contains a standard material data library for common elements, compounds, and mixtures. All the materials used for the cask and DSC analysis are available in this data library. The neutron shield material in the MP197 is modeled as water and the neutron shield skin is not modeled.

Table 6-5 provides a complete list of all the relevant materials used for the criticality evaluation. The B-10 areal density specified for manufacturing of the poison plates will be larger than the areal density used in the calculations (and listed in this table), in order the satisfy the 75% or 90% B10 credit allowance as specified in Chapter 8. The cask neutron shield material is conservatively modeled as water. The actual neutron shield hydrogen atom density is lower than that of water; therefore, replacing the neutron shield with water is slightly conservative.

6.4 Criticality Calculation

This section describes the models used for the criticality analysis. The analyses were performed with the CSAS25 module of the SCALE system. A series of calculations were performed to determine the most reactive fuel and configuration. The most reactive fuel, as demonstrated by the analyses, is the GE12 10×10 assembly. The most reactive credible configuration is an infinite array of flooded casks with minimum assembly-to-assembly pitch and the poison plate gaps located near the center of the basket and at the centerline of the active fuel region.

6.4.1 Calculational Method

6.4.1.1 Computer Codes

The CSAS25 control module of SCALE-4.4 [6.1] was used to calculate the effective multiplication factor (k_{eff}) of the fuel in the cask. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-S, and KENO V.a. These modules process the required cross sections and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the k_{eff} of a three-dimensional system. A sufficiently large number of neutron histories are run so that the standard deviation is below 0.0020 for all calculations.

6.4.1.2 Physical and Nuclear Data

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

The criticality analysis used the 44-group cross-section library built into the SCALE system. ORNL used ENDF/B-V data to develop this broad-group library specifically for criticality analysis of a wide variety of thermal systems.

6.4.1.3 Bases and Assumptions

The analytical results reported in chapter 2 demonstrate that the cask containment boundary and DSC basket structure do not experience any significant distortion under hypothetical accident conditions. Therefore, for both normal and hypothetical accident conditions the cask geometry is identical except for the neutron shield and skin. As discussed above, the neutron shield and skin are conservatively modeled as water.

The cask was modeled with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries. The following conservative assumptions were also incorporated into the criticality calculations:

1. Omission of grid plates, spacers, and hardware in the fuel assembly.

2. No burnable poisons accounted for in the fuel.

3. Water density at optimum internal and external moderator density.

4. Unirradiated fuel – no credit taken for fissile depletion due to burnup or fission product poisoning.

5. Where fuel pins have variable axial enrichment, the average is calculated for each axial zone (lattice), and the lattice with the highest average enrichment is used to characterize the entire bundle for criticality purposes. The average enrichment is defined as the simple arithmetic average of pin enrichments:

$$E_{avg} = \sum_{i=1,n} E_i \Big/ n$$

Where E_i is the enrichment of pin i, and n is the number of fuel pins in the lattice. There is no averaging of the axial enrichment variation in this evaluation; "bundle average" enrichments, which are an average enrichment over the entire fuel bundle, including natural uranium blankets, are not used to qualify fuel for criticality purposes.

The lattice average fuel enrichment is modeled as uniform everywhere throughout the assembly. Natural Uranium blankets and axial or radial enrichment zones are modeled as enriched uranium.

6. All fuel rods are assumed to be filled with 100% moderator in the pellet/cladding gap.

7. Only the active fuel length of each assembly type is explicitly modeled. The presence of the plenum materials, end fittings, channel material above and below the active fuel reduce the k_{eff} of the system, therefore; these regions are modeled as water or the reflective boundary conditions. For the cases with reflective boundary conditions, the model is effectively infinitely long.

8. It is assumed that for all Hypothetical Accident Conditions (HAC) cases the neutron shield and stainless steel skin of the cask are stripped away and replaced with moderator.

9. The least material condition (LMC) is assumed for the fuel clad OD, fuel compartment, poison plates and wrappers. This minimizes neutron absorption in the steel sheets and poison plates.

10. The maximum allowed gap between the poison plates in the worst case position is explicitly modeled to maximize k_{eff}.

11. The active fuel region is conservatively assumed to start level with the bottom of the poison plates.

12. Temperature at 20 °C (293 K).

13. Used 95% theoretical density for fuel although this assumption conservatively increases the total fuel content in the model.

6.4.1.4 <u>Determination of k_{eff}.</u>

The criticality calculations were performed with the CSAS25 control module in SCALE-4.4. The Monte Carlo calculations performed with CSAS25 (KENO V.a) used a flat neutron starting distribution. The total number of histories traced for each calculation was approximately 500,000. This number of histories was sufficient to converge the source and produce standard deviations of less than 0.2% in k_{eff}. The maximum k_{eff} for the calculation was determined with the following formula:

$$k_{eff} = k_{KENO} + 2\sigma_{KENO}.$$

6.4.2 Fuel Loading Optimization

A. Determination of the Most Reactive Fuel Lattice

All fuel lattices, with and without channels, listed in Table 6-3 are evaluated to determine the most reactive fuel assembly type. The lattices are analyzed with water in the fuel pellet cladding annulus and are centered in the fuel compartments. Each lattice is also analyzed with a 0.065, 0.080 and 0.120 inch thick channel to determine the most reactive configuration. The results show that the reactivity change due to the fuel channels is within the statistical uncertainty of the KENO V.a calculations. Finally, this model is used for three cases that demonstrate that the use of lattice average enrichment is conservative for intact fuel. One case each for the GE2 (7x7 Array), GE5 (8x8 Array) and the GE9 (8x8 Array). Figure 6-5 provides a lattice map of the three assemblies evaluated including the enrichment modeled for each fuel pin. The following results are extracted from Table 6-6.

Lattice Average Compared to Variable Enrichment Models

Assembly Version	Lattice Average Case k_{eff}	Explicit Variable Enrichment Case k_{eff}
GE2 (7x7 Array)	0.9061	0.8971
GE5 (8x8 Array)	0.9031	0.8973
GE9 (8x8 Array)	0.9069	0.9034

For this analysis, only the DSC is modeled. The DSC is modeled over the active fuel height of the fuel with water reflectors at the ends (z) and reflective boundary conditions outside the DSC (infinite array in the x-y directions) The DSC model for this evaluation differs from the actual design in the following ways:

- the boron 10 areal density specified for manufacturing the poison plates will be greater than that used in the model, as described in Chapter 8,
- no gaps between poison plates are modeled,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

In all other respects, the model is the same as that described in Sections 6.3.1 and 6.3.2. The sole purpose of this model is to determine the *relative* reactivity of different fuel lattices in a configuration similar to the actual DSC.

A typical input file is included in Section 6.6.3. The results of these calculations are listed in Table 6-6. The most reactive fuel lattice evaluated for the DSC design is the GE generation 12 lattice, 10×10 array, without a fuel channel.

B. Determination of the Most Reactive Configuration

The fuel-loading configuration of the DSC/cask affects the reactivity of the package. Several series of analyses determined the most reactive configuration for the DSC/cask.

For this analysis, the DSC/cask is modeled. The DSC/cask is modeled over the active fuel height of the fuel with reflective boundary conditions on all sides of the model, this represents and infinite array in the x-y direction of DSC/casks that are infinite in length. The DSC/cask model for this evaluation differs from the actual design in the following ways:

- the boron 10 areal density specified for manufacturing the poison plates will be greater than that used in the model, as described in Chapter 8,
- maximum gaps between poison plates are modeled in their worst case configuration,
- the stainless steel basket rails, which hold the basket together, are modeled as water.

The models are fully described in Section 6.3.1. The purpose of these models is to determine the most reactive configuration for intact fuel assemblies. A typical input file is included in Section 6.6.3.

The first series of analyses determined the most reactive fuel assembly-to-assembly pitch. The maximum lattice average fuel enrichment (4.4 wt. % U-235) and a poison plate boron-10 areal density of 0.036 g/cm^2 are used in the model. The results in Table 6-7 show the most reactive configuration occurs with minimum assembly-to-assembly pitch. The model is similar to the model shown in Table 6-4 and Figure 6-2 except that the nominal fuel cell size, nominal poison sheet thickness, fuel clad OD are used and the assemblies are moved within the fuel compartment to vary the assembly-to-assembly pitch.

The second set of analysis evaluates the effect of canister shell thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the canister shell thickness is varied from 0.49 to 0.55 inches. As demonstrated by the results the variation of shell thickness within the tolerance range is statistically insignificant. The nominal shell thickness is used throughout the rest of the analysis except that one additional case is added for the most reactive canister configuration (minimum poison plate thickness and minimum fuel cell size) to demonstrate that the slightly higher result for the maximum shell thickness is indeed a result of the statistics of the calculation.

The third set of analysis evaluates the effect of poison plate thickness on the system reactivity. The model starts with the most reactive assembly-to-assembly pitch (minimum pitch) case above and the poison plate thickness is modeled at 0.3 inches (minimum). The poison plate B-10 volume density is increased from 0.046 to 0.04724 g B10/cm^3 to maintain the areal density of 36 mg B10/cm^2 for the reduced plate thickness. Based on the results of this evaluation the balance of the calculations will use the minimum poison plate thickness because it represents a more reactive condition.

The fourth set of analysis evaluates the sensitivity of the system reactivity on fuel cladding OD. The model starts with the minimum poison plate case above and the fuel cladding OD is varied from 0.404 to 0.394 inches. Based on the results of this analysis, it is conservative to model the GE12 10x10 assembly cladding as 0.010 inches less than that reported in Table 6-3 for the balance of this evaluation.

The fifth set of analysis evaluates the effect of fuel cell size on the system reactivity. The model starts with the most reactive fuel clad OD case above and the canister fuel cell width is varied from 5.8 to 6.1 inches. The results show that the most reactive configuration is with the minimum fuel cell size. One additional run is made to verify that the canister maximum shell thickness does not increase reactivity. The balance of this evaluation will use the minimum cell size because it represents the most reactive configuration.

The sixth set of analyses evaluates the effect of internal moderator density on reactivity. The model starts with the most fuel cell width (minimum fuel cell width) case above. The internal moderator is varied from 100 to 0 percent full density. The results in Table 6-7 confirm that the most reactive condition occurs at full internal moderator density.

The seventh set of analyses evaluates the effect of external moderator density on reactivity. The model uses the most reactive case with internal moderator (full density) density and the external internal moderator is varied from 100 to 0 percent full density. The results in Table 6-7 show that the system reactivity is not affected by external moderator density. The variation in the results is due entirely to the statistical uncertainties in Keno V.a. Nonetheless, the apparent maximum value of k_{eff}, which occurs at 70% external moderator density, is the value reported for the damaged package array.

Finally, minimum boron 10 areal density in the poison plate as a function of lattice average initial enrichment is evaluated. These models represent the most reactive intact fuel assembly (GE12, 10x10) with a minimum assembly-to-assembly pitch, nominal shell thickness, minimum poison plate thickness, minimum fuel clad OD, minimum fuel cell width with full internal and external moderator density. The initial lattice average fuel enrichment is varied as well as the boron-10 density in the poison plates. These cases are used to specify a minimum boron-10 areal density as a function of maximum lattice average assembly enrichment. The results are reported in Table 6-7.

6.4.3 Criticality Results

Table 6-8 lists the results that bound all normal and hypothetical accident conditions. These criticality calculations were performed with CSAS25 of SCALE-4.4. For each case, the result includes (1) the KENO-calculated k_{KENO}; (2) the one sigma uncertainty σ_{KENO}; and (3) the final k_{eff}, which is equal to $k_{KENO} + 2\sigma_{KENO}$. Table 6-8 lists the poison plate boron-10 areal density used in the calculations as a function of the initial lattice average enrichment for the fuel assemblies.

The criterion for subcriticality is that

```
end bounds
read plot
   ttl='cask material plot  - plan view all poison'
   pic=mat
   nch=' fzmcsblxg'
   xul=-105  yul=105   zul=20
   xlr=105   ylr=-105  zlr=20
   uax=1.0    vdn=-1.0
   nax=650
end plot
end data
end
```

6.6.3.2 Evaluation of Varied Pin Enrichment

```
GE5 (8x8 Array) ) Input file:
=csas25
61B Confirmatory Fuel Enrichment Analysis with GE5 8x8, Jack
Boshoven 12/28/00
44groupndf5 latticecell
uo2    1 0.95 293 92235 2.33 92238 97.67 end
zirc2  2 1.0  293 end
h2o    3 1.0  293 end
carbonsteel 4 1.0 293 end
ss304  5 1.0  293 end
h2o    6 1.0  293 end
h2o    7 1.0  293 end
b-10   8 den=0.046 1.0 293 end
al     8 0.9  293 end
uo2    9 0.95 293 92235 3.01 92238 96.99 end
uo2   10 0.95 293 92235 3.57 92238 96.43 end
uo2   11 0.95 293 92235 4.85 92238 95.15 end
end comp
squarepitch 1.6256  1.0414 11 3 1.22682 2 1.06426 6 end
more data res=9  cylinder 0.5207 dan(9)=0.18804820
          res=10 cylinder 0.5207 dan(10)=0.18804820
          res=1  cylinder 0.5207 dan(1)=0.18804820
end more data
Keno Title Card
read param
gen=500 npg=1000 nsk=5 nub=yes run=yes plt=yes
end param
read geom
unit 1      com='Fuel Rod w/2.33 wt%'
cylinder  1   1  0.5207        381.00       0.0
cylinder  6   1  0.53213       381.00       0.0
cylinder  2   1  0.61341       381.00       0.0
cuboid    3   1  4p0.8128      381.00       0.0
unit 2      com='GE 8x8 Center Assembly'
```

```
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  4p8.3566       381.00         0.0
unit 3     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00          0.0
unit 4     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566        381.00          0.0
unit 5     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  4p8.3566       381.00         0.0
unit 6     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566        381.00          0.0
unit 7     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00          0.0
unit 8     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  4p8.3566       381.00         0.0
unit 9     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  2p8.3566          7.9629 -8.3566 381.00          0.0
unit 10    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00          0.0
unit 11    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00          0.0
unit 12    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  4p8.3566       381.00         0.0
```

```
unit 13     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00          0.0
unit 14     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00          0.0
unit 15     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  7.9629 -8.3566 2p8.3566       381.00          0.0
unit 16     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00          0.0
unit 17     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566       381.00          0.0
unit 18     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00          0.0
unit 19     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00          0.0
unit 20     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00          0.0
unit 21     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  8.3566 -7.9629 2p8.3566       381.00          0.0
unit 22     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
cuboid    8   1  4p8.3566       381.00        0.0
unit 23     com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00        0.0
cuboid    5   1  4p7.9629       381.00        0.0
```

```
cuboid    8   1  7.9629 -8.3566 2p8.3566        381.00            0.0
unit 24    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00             0.0
unit 25    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00            0.0
unit 26    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00             0.0
unit 27    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00             0.0
unit 28    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00             0.0
unit 29    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00             0.0
unit 30    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00             0.0
unit 31    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00            0.0
unit 32    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00             0.0
unit 33    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
cuboid    5   1  4p7.9629       381.00         0.0
cuboid    8   1  8.3566 -7.9629 8.3566 -7.9629 381.00             0.0
unit 34    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62         381.00         0.0
```

```
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  2p8.3566 8.3566 -7.9629       381.00         0.0
unit 35    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  7.9629 -8.3566 8.3566 -7.9629 381.00        0.0
unit 36    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  8.3566 -7.9629 7.9629 -8.3566 381.00        0.0
unit 37    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  2p8.3566        7.9629 -8.3566 381.00        0.0
unit 38    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9629      381.00          0.0
cuboid    8   1  7.9629 -8.3566 7.9629 -8.3566 381.00        0.0
unit 39   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 40  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 41  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  8.3185 -7.9248 7.9248 -8.3185 381.00        0.0
unit 42  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  7.9248 -8.3185 7.9248 -8.3185 381.00        0.0
unit 43    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  8.3185 -7.9248 8.3185 -7.9248 381.00        0.0
unit 44  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid    3   1  4p7.62        381.00          0.0
cuboid    5   1  4p7.9248      381.00          0.0
cuboid    8   1  7.9248 -8.3185 8.3185 -7.9248 381.00        0.0
unit 45  com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
```

```
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   8.3185 -7.9248 7.9248 -8.3185 381.00          0.0
unit 46   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   7.9248 -8.3185 7.9248 -8.3185 381.00          0.0
unit 47    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   8.3185 -7.9248 8.3185 -7.9248 381.00          0.0
unit 48   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   7.9248 -8.3185 8.3185 -7.9248 381.00          0.0
unit 49   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   8.3185 -7.9248 7.9248 -8.3185 381.00          0.0
unit 50   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   7.9248 -8.3185 7.9248 -8.3185 381.00          0.0
unit 51    com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   8.3185 -7.9248 8.3185 -7.9248 381.00          0.0
unit 52   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   7.9248 -8.3185 8.3185 -7.9248 381.00          0.0
unit 53   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   8.3185 -7.9248 7.9248 -8.3185 381.00          0.0
unit 54   com='GE 8x8 Assembly'
array 1 -6.50240 -6.50240 0.0
cuboid     3    1   4p7.62          381.00          0.0
cuboid     5    1   4p7.9248        381.00          0.0
cuboid     8    1   7.9248 -8.3185 7.9248 -8.3185 381.00          0.0
unit 55   com='center 9x9 array'
array 2 -24.6761 -24.6761 0.0
cuboid     5    1   4p24.9428       381.00          0.0
cuboid     8    1   4p25.7302       381.00          0.0
unit 56   com='right 9x9 array'
array 3 -24.6761 -24.6761 0.0
```

```
cuboid    5   1  4p24.9428    381.00          0.0
unit 57  com='top 9x9 array'
array 4 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00          0.0
unit 58  com='left 9x9 array'
array 5 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00          0.0
unit 59  com='bottom 9x9 array'
array 6 -24.6761 -24.6761 0.0
cuboid    5   1  4p24.9428    381.00          0.0
unit 60  com='upper right 2x2 array'
array 7 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00          0.0
unit 61  com='upper left 2x2 array'
array 8 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00          0.0
unit 62  com='lower right 2x2 array'
array 9 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00          0.0
unit 63  com='lower right 2x2 array'
array 10 -16.2433 -16.2433 0.0
cuboid    5   1  4p16.51      381.00          0.0
unit 64  com='0.31" poison plate'
cuboid    8   1  2p16.51 2p0.3937 381.00      0.0
unit 65  com='0.31" poison plate'
cuboid    8   1  2p0.3937 2p16.51 381.00      0.0
unit 66  com='water hole'
cylinder  3  1  0.67437   381.00    0.0
cylinder  2  1  0.75057   381.00    0.0
cuboid    3  1  4P0.8128  381.00    0.0
unit 67    com='Fuel Rod w/3.01 wt%'
cylinder  9   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
unit 68    com='Fuel Rod w/3.57 wt%'
cylinder 10   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
unit 69    com='Fuel Rod w/4.85 wt%'
cylinder 11   1  0.5207        381.00          0.0
cylinder  6   1  0.53213       381.00          0.0
cylinder  2   1  0.61341       381.00          0.0
cuboid    3   1  4p0.8128      381.00          0.0
global unit 70
cylinder  3   1  84.757        381.00          0.0
    hole 55   0.0       0.0       0.0
    hole 56   50.673    0.0       0.0
    hole 57   0.0       50.673    0.0
    hole 58  -50.673    0.0       0.0
    hole 59   0.0      -50.673    0.0
    hole 60   42.2404   42.2404   0.0
    hole 61  -42.2404   42.2404   0.0
```

```
   hole 62  -42.2404 -42.2404 0.0
   hole 63   42.2404 -42.2404 0.0
   hole 64   42.2404  25.3366 0.0
   hole 64  -42.2404  25.3366 0.0
   hole 64  -42.2404 -25.3366 0.0
   hole 64   42.2404 -25.3366 0.0
   hole 65   25.3366  42.2404 0.0
   hole 65  -25.3366  42.2404 0.0
   hole 65  -25.3366 -42.2404 0.0
   hole 65   25.3366 -42.2404 0.0
cylinder  5   1  86.027       381.00         0.0
cuboid    7   1  4p86.03      381.00         0.0
end geom
read array
  com='GE 8x8 fuel assembly slice, sd, fuel regions'
  ara=1       nux=8       nuy=8       nuz=1
  fill
      67 68 68 68 68 68 67  1
      68 69 69 69 69 69 68 67
      69 69 69 69 69 69 69 68
      69 69 69 66 69 69 69 68
      69 69 69 69 66 69 69 68
      69 69 69 69 69 69 69 68
      69 69 69 69 69 69 69 68
      68 69 69 69 69 69 68 67
  end fill
  com='Center 9x9 Array of Fuel'
  ara=2       nux=3       nuy=3       nuz=1
  fill
       18 19 20
        6  2  3
       11  9 10
  end fill
  com='Right 9x9 Array of Fuel'
  ara=3       nux=3       nuy=3       nuz=1
  fill
       27 28 29
        4  5  3
       30 31 32
  end fill
  com='Top 9x9 Array of Fuel'
  ara=4       nux=3       nuy=3       nuz=1
  fill
       16 13 14
       17 12 15
       11  9 10
  end fill
  com='Left 9x9 Array of Fuel'
  ara=5       nux=3       nuy=3       nuz=1
  fill
       33 34 35
        6  8  7
       36 37 38
  end fill
```

```
   com='Bottom 9x9 Array of Fuel'
   ara=6       nux=3       nuy=3       nuz=1
   fill
        18 19 20
        21 22 23
        24 25 26
   end fill
   com='Upper Right 2x2 Array of Fuel'
   ara=7       nux=2       nuy=2       nuz=1
   fill
        39 40
        41 42
   end fill
   com='Upper Left 2x2 Array of Fuel'
   ara=8       nux=2       nuy=2       nuz=1
   fill
        43 44
        45 46
   end fill
   com='Lower Left 2x2 Array of Fuel'
   ara=9       nux=2       nuy=2       nuz=1
   fill
        47 48
        49 50
   end fill
   com='Lower Right 2x2 Array of Fuel'
   ara=10      nux=2       nuy=2       nuz=1
   fill
        51 52
        53 54
   end fill
end array
read bounds
   xyf=specular
   zfc=water
end bounds
read plot
   ttl='cask material plot  - plan view'
   pic=mat
   nch=' fzmcsblxg'
   xul=-87    yul=87    zul=200
   xlr=87     ylr=-87   zlr=200
   uax=1.0     vdn=-1.0
   nax=650
end plot
end data
end
```

CHAPTER 7

OPERATING PROCEDURES

This chapter contains NUHOMS-MP197 loading and unloading procedures that are intended to show the general approach to cask operational activities. A separate Operations Manual (OM) will be prepared for the NUHOMS-MP197 to describe the operational steps in greater detail. The OM, along with the information in this chapter, will be used to prepare the site-specific procedures that will address the particular operational considerations related to the cask.

7.1 Procedures for Loading the Package

The NUHOMS®-MP197 Cask will be used to transport fuel off-site. This mode of use requires (1) preparation of the cask for use; (2) verification that the fuel assemblies to be loaded meet the criteria set forth in this document; and (3) installation of a DSC and fuel assemblies into the cask.

Offsite transport involves (1) preparation of the cask for transport; (2) assembly verification leakage-rate testing of the package containment boundary; (3) placement of the cask onto a transportation vehicle; and (4) installation of the impact limiters.

During shipment, the packaging contains up to 61BWR spent fuel assemblies in the NUHOMS-61BT DSC. Procedures are provided in this section for transport of (1) the cask/DSC directly from the spent plant fuel pool and (2) transport of a NUHOMS 61BT DSC after storage in a NUHOMS® Horizontal Storage Module (HSM). A glossary of terms used in this section is provided in Section 7.1.6.

7.1.1 Preparation of the NUHOMS®-MP197 Cask for Use

Procedures for preparing the cask for use after receipt at the site are provided in this section.

a. Remove the impact limiter attachment bolts from each impact limiter and remove the impact limiters from the cask.

b. Anytime prior to removing the lid, sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

c. Remove the personnel barrier(s) from the transport frame.

d. Remove the transportation skid tie down straps.

e. Take contamination smears on the outside surfaces of the cask. If necessary, decontaminate the cask until smearable contamination is at an acceptable level.

f. Inspect the cask hardware (including vent/drain/test port plugs) for damage which may have occurred during transportation. Repair or replace as required.

g. Install the front and rear trunnions. Lubricate, install and preload the trunnion bolts and torque them to 250 ft-lbs in the first pass and to 520 - 540 ft-lbs in the final pass following the torquing sequence shown in Figure 7-1.

h. Place suitable slings around the cask front and rear trunnions, lift cask and place on the onsite transfer trailer.

i. Remove the slings from the cask.

j. Install the onsite transfer trailer trunnion block covers.

7.1.2 Wet Loading the NUHOMS®-MP197 Cask and 61BT DSC

The procedure for wet loading the cask and 61BT DSC is summarized in this section. This procedure is intended to describe the type and quality of work performed to load and seal a DSC. Actual DSC loading procedures may vary slightly from tasks described below. The NUHOMS®-MP197 Cask is designed to transport one NUHOMS-61BT DSC containing 61 BWR fuel assemblies. All fuel assembly locations are to be loaded with design basis fuel assemblies. Verification that the burnup, enrichment, and cooling time of the assemblies are all within acceptable ranges will be performed by site personnel, prior to shipment, as discussed below. All basket compartments must be filled with a fuel assembly or a dummy fuel assembly as specified in the C of C.

7.1.2.1 Preparation of the Transport Cask and DSC

a. Verify the basket type A, B, or C, by inspecting the last digit of the serial number on the grapple ring at the bottom of the DSC.

b. Verify that the fuel assemblies to be placed in the DSC meet the maximum burnup, maximum initial enrichment, minimum cooling time, and maximum decay heat limits for fuel assemblies as specified in Section 1.2.3 of this document and the C of C. The enrichment limit must correspond to the basket type verified in step "a".

c. Using a suitable prime mover, position the cask and onsite transfer trailer below the plant crane.

d. Remove the onsite transfer trailer trunnion block covers.

e. Engage the cask front trunnions with the lifting yoke using the plant crane, rotate the cask to a vertical orientation, lift the cask from the onsite transfer trailer, and place the cask in the plant decon area.

f. Place scaffolding around the cask so that the top closure lid and surface of the cask are easily accessible to personnel.

g. Remove the top closure lid and examine the cask cavity for any physical damage and ready the cask for service.

h. Examine the DSC for any physical damage which might have occurred since the receipt inspection was performed. The DSC is to be cleaned and any loose debris removed.

i. Using a crane, lower the DSC into the cask cavity by the internal lifting lugs and rotate the DSC to match the cask and DSC alignment marks.

j. Fill the cask-DSC annulus with clean, demineralized water. Place the inflatable seal into the upper cask liner recess and seal the cask-DSC annulus by pressurizing the seal with compressed air.

k. Fill the DSC cavity with water from the fuel pool or an equivalent source. For BWR fuel, demineralized water may be used.

   Note: A Cask/DSC annulus pressurization tank filled with clean demineralized water is connected to the top vent port of the cask via a hose to provide a positive head above the level of water in the Cask/DSC annulus. This is an optional arrangement, which provides additional assurance that contaminated water from the fuel pool will not enter the Cask/DSC annulus, provided the positive head is maintained at all times.

l. Position the cask lifting yoke and engage the cask lifting trunnions.

m. Visually inspect the yoke lifting hooks to insure that they are properly positioned and engaged on the cask lifting trunnions.

n. Move the scaffolding away from the cask as necessary.

o. Lift the cask just far enough to allow the weight of the cask to be distributed onto the yoke lifting hooks. Reinspect the lifting hooks to insure that they are properly positioned on the cask trunnions.

p. Optionally, secure a sheet of suitable material to the bottom of the transport cask to minimize the potential for ground-in contamination. This may also be done prior to initial placement of the cask in the decon area.

q. Prior to the cask being lifted into the fuel pool, the water level in the pool should be adjusted as necessary to accommodate the Cask/DSC volume. If the water placed in the DSC cavity was obtained from the fuel pool, a level adjustment may not be necessary.

<u>7.1.2.2 DSC Fuel Loading</u>

a. Lift the Cask/DSC and position it over the cask loading area of the spent fuel pool in accordance with the plant's 10CFR50 cask handling procedures.

b. Lower the cask into the fuel pool until the bottom of the cask is at the height of the fuel pool surface. As the cask is lowered into the pool, spray the exterior surface of the cask with clean water.

c. Place the cask in the location of the fuel pool designated as the cask loading area.

d. Disengage the lifting yoke from the cask lifting trunnions and move the yoke clear of the cask. Spray the lifting yoke with clean water if it is raised out of the fuel pool.

e. Move a candidate fuel assembly from a fuel rack in accordance with the plant's 10CFR50 fuel handling procedures.

f. Prior to insertion of a spent fuel assembly into the DSC, the identity of the assembly is to be verified by two individuals using an underwater video camera or other means. Read and record the fuel assembly identification number from the fuel assembly and check this identification number against the DSC loading plan which indicates which fuel assemblies are acceptable for transport.

g. Position the fuel assembly for insertion into the selected DSC storage cell and load the fuel assembly. Repeat Steps e through g for each SFA loaded into the DSC. After the DSC has been fully loaded, check and record the identity and location of each fuel assembly in the DSC.

h. After all the SFAs have been placed into the DSC and their identities verified, install the hold down ring and the top shield plug into the DSC.

i. Visually verify that the top shield plug is properly seated in the DSC.

j. Position the lifting yoke with the cask trunnions and verify that it is properly engaged.

k. Raise the transport cask to the pool surface. Prior to raising the top of the cask above the water surface, stop vertical movement.

l. Inspect the top shield plug to verify that it is properly seated onto the DSC. If not, lower the cask and reposition the top shield plug. Repeat Steps k and l as necessary.

m. Continue to raise the cask from the pool and spray the exposed portion of the cask with clean water until the top region of the cask is accessible.

n. Drain any excess water from the top of the DSC shield plug back to the fuel pool.

o. Check the radiation levels at the center of the top shield plug and around the perimeter of the cask.

p. As required for crane load limitations, drain water from the DSC by pumping at the siphon port.

q. Lift the cask from the fuel pool. As the cask is raised from the pool, continue to spray the cask with clean water.

r. Move the transport cask with loaded DSC to the cask decon area.

s. Water removed at step "p" may be replaced with spent fuel pool water or equivalent.

7.1.2.3 DSC Drying and Backfilling

a. Check the radiation levels along the perimeter of the cask. The cask exterior surface should be decontaminated as required. Temporary shielding may be installed as necessary to minimize personnel exposure.

b. Place scaffolding around the cask so that any point on the surface of the cask is easily accessible to personnel.

c. Disengage the rigging cables from the top shield plug and remove the eyebolts. Disengage the lifting yoke from the trunnions and position it clear of the cask.

d. Decontaminate the exposed surfaces of the DSC shell perimeter and remove the inflatable cask/DSC annulus seal.

e. Connect the cask drain line to the cask, open the cask cavity drain port and allow water from the 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 as required.

f. Drain as required such that the net amount drained by steps 7.1.2.2 "p" and "s" and this step is approximately 1100 gallons.

g. Place the inner top cover plate onto the DSC. Verify proper fit-up of the inner top cover plate with the DSC shell.

h. Check radiation levels along surface of the inner top cover plate. Temporary shielding may be installed as necessary to minimize personnel exposure.

i. CAUTION: Connect a hydrogen monitor to the vent port to allow continuous monitoring of the hydrogen atmosphere in the DSC cavity during welding of the inner cover plate.

j. Cover the cask/DSC annulus to prevent debris and weld splatter from entering the annulus.

k. Weld the inner top cover plate to the DSC shell.

   CAUTION: Continuously monitor the hydrogen concentration in the DSC cavity using the arrangement described in step "i" during the inner top cover plate cutting/welding operations. Verify that the measured hydrogen concentration does not exceed a safety limit of 2.4%. If this limit is exceeded, stop all welding operations and purge the DSC cavity with helium (or any other inert medium) via the vent or the siphon port to reduce the hydrogen concentration safely below the 2.4% limit.

l. Perform dye penetrant weld examination of the inner top cover plate weld.

m. Place the strongback so that it sits on the inner top cover plate and is oriented such that:

   - the DSC siphon and vent ports are accessible
   - the strongback stud holes line up with the cask lid bolt holes.

n. Lubricate the studs and, using a crossing pattern, adjust the strongback studs to snug tight ensuring approximately even pressure on the cover plate.

o. Install temporary shielding to minimize personnel exposure throughout the subsequent welding operations as required.

p. Engage the compressed air, nitrogen or helium supply and open the valve on the vent port and allow compressed gas to force the water from the DSC cavity through the siphon port. Note: a pressure regulator set to a maximum of 20 psig must be installed on the compressed gas supply.

q. Once the water stops flowing from the DSC, close the DSC siphon port and disengage the gas source.

r. Connect either the vent port or the siphon port or both to the intake of the vacuum drying system (VDS). Vent the discharge side of the VDS to the plant's radioactive waste system, spent fuel pool, or other appropriate system. Connect the VDS to a helium source.

s. 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.

t. Open the valve to either or both ports and allow helium to flow into the DSC cavity.

u. Pressurize the DSC with helium to about 24 psia not to exceed 34 psia (10 – 20 psig).

v. Helium leak test the inner top cover plate weld for leakage to a sensitivity of 1 x 10^{-5} ref cm^3/sec. (This is a preliminary test, for information only; the final leak test is performed at 7.1.2.4 step "d".)

w. If a leak is found, repair the weld, repressurize the DSC and repeat the helium leak test.

x. Once no leaks are detected, depressurize the DSC cavity by releasing the helium through the VDS to the plant's spent fuel pool, radioactive waste system, or other appropriate system.

y. Re-evacuate the DSC cavity . Vacuum drying is complete when the pressure stabilizes for a minimum of 30 minutes at 3 mm Hg or less.

z. Open the valve to either or both ports and allow helium to flow into the DSC cavity to pressurize the DSC to about 17.2 psia (2.5 psig).

aa. Close the valves on the helium source.

bb. Remove the strongback, decontaminate as necessary, and store.

7.1.2.4 DSC Sealing Operations

a. Disconnect the VDS from the DSC. Seal weld the prefabricated plugs over the vent and siphon ports and perform a dye penetrant weld examination.

b. Place the outer top cover plate onto the DSC. Verify proper fit up of the outer top cover plate with the DSC shell.

c. Tack weld the outer top cover plate to the DSC shell. Place the outer top cover plate weld root pass.

d. Helium leak test the inner top cover plate and vent/siphon port plate welds using the leak test port in the outer top cover plate with an acceptance criterion of 1×10^{-7} ref cm^3/sec.

e. If a leak is found, remove the outer cover plate root pass, the vent and siphon port plugs and repair the inner cover plate welds. Then install the strongback and repeat procedure steps from section 7.1.2.3 step "t".

f. Perform dye penetrant examination of the root pass weld. Weld out the outer top cover plate to the DSC shell and perform dye penetrant examination on the weld surface.

g. Seal weld the prefabricated plug over the outer cover plate test port and perform dye penetrant weld examinations.

h. Remove the cask drain port screw and drain the Cask/DSC annulus.

i. Install the drain port screw and tighten it to 65 ft-lbs. Install and tighten the drain port plug.

j. Install the cask lid. Lubricate, install and preload the lid bolts and torque them to 200 ft-lbs. Follow the torquing sequence shown in Figure 7-1. Repeat the torquing process following the sequence of Figure 7-1. Torque to 600 ft-lbs in second pass, 1000 ft-lbs in third pass and between 1440 and 1510 ft-lbs in the final pass. A circular pattern of torquing may be used, to eliminate further bolt movement.

k. Evacuate the cavity between the cask and the DSC, backfill with helium and perform the assembly verification leakage rate testing as specified in Section 7.4. This test must be performed within 12 months prior to the shipment.

l. Verify that the cask surface removable contamination levels meet the requirements of 49 CFR 173.443 [2] and 10 CFR 71.87 [3].

7.1.2.5 Transport Cask Downending

a. Re-attach the transport cask lifting yoke to the crane hook, as necessary. Ready the transport trailer and cask support skid for service.

b. Move the scaffolding away from the cask as necessary. Engage the lifting yoke and lift the cask over the cask support skid on the transport trailer.

c. The transport trailer should be positioned so that cask support skid is accessible to the crane with the trailer supported on the vertical jacks.

d. Position the cask rear trunnions onto the transfer trailer support skid pillow blocks.

e. Move the crane forward while simultaneously lowering the cask until the cask front trunnions are just above the support skid upper trunnion pillow blocks. For plants with limited space or crane travel, such that the downending cannot be completed with the trailer stationary, alternate procedures may be developed.

f. Inspect the positioning of the cask to insure that the cask and trunnion pillow blocks are properly aligned.

g. Lower the cask onto the skid until the weight of the cask is distributed to the trunnion pillow blocks.

h. Inspect the trunnions to insure that they are properly seated onto the skid and install the trunnion tower closure plates.

7.1.3 Loading the DSC into the Cask from an HSM

The procedure for loading a DSC into the cask from a NUHOMS® Horizontal Storage Module (HSM) is summarized in this section. Depending on the most recent use of the cask, several of the initial steps listed below may not be necessary.

a. Using a suitable prime mover, bring the onsite transfer trailer (and cask) to the ISFSI site and back the trailer in front of the module face.

b. Remove the ram closure plate and the lid.

c. Install the ram trunnion support assembly.

d. Remove the HSM door and the DSC seismic restraint assembly from the HSM.

e. Use the trailer skid positioning system and optical surveying transits to align and dock the cask with the HSM.

f. Install the cask/HSM restraints.

g. Install and align the hydraulic ram cylinder in the ram trunnion support assembly.

h. Extend the ram hydraulic cylinder until the grapple contacts the DSC bottom cover.

i. Engage the DSC grapple ring with the ram grapple.

j. Retract the ram hydraulic cylinder until the DSC is fully seated in the cask.

k. Disengage the grapple from the DSC.

l. Remove the hydraulic ram and ram trunnion support assembly from the cask.

m. Install the cask ram closure plate with new o-rings. Lubricate, install and preload the ram closure bolts and torque them to 65 ft-lbs in the first pass and to 100 – 125 ft-lbs in the final pass follow the torquing sequence shown in Figure 7-1.

n. Remove the cask/HSM restraints.

o. Using the skid positioning system, move the cask to the transfer position and secure the onsite support skid to the onsite transfer trailer.

p. Verify that the lid O-ring seals are new. Discard any seals that have previously been installed in the cask.

q. If necessary, apply vacuum grease to the seals and the adjoining sealing surfaces on the cask lid.

r. Install the cask lid. Lubricate, install and preload the lid bolts and torque them to 200 ft-lbs. Follow the torquing sequence shown in Figure 7-1. Repeat the torquing process following the sequence of Figure 7-1. Torque to 600 ft-lbs in second pass, 1000 ft-lbs in third pass and between 1440 and 1510 ft-lbs in the final pass. A circular pattern of torquing may be used, to eliminate further bolt movement.

s. Prepare the cask for transportation in accordance with the procedure described in Section 7.1.4.

7.1.4 Preparing the Cask for Transportation

Once a loaded DSC has been placed inside the NUHOMS®-MP197 Cask, the following tasks are performed to prepare the cask for transportation. The cask is assumed to be seated horizontally in the onsite support skid.

a. Verify that the fuel assemblies meet the burnup, initial enrichment, cooling time, and decay heat criteria set forth in Section 1.2.3 and the C of C.

b. Verify that the cask surface removable contamination levels meet the requirements of 49 CFR 173.443 [2] and 10 CFR 71.87 [3].

c. Perform the assembly verification leakage rate testing specified in Section 7.4. This test must be performed within 12 months prior to the shipment. This test includes drawing a vacuum in the cavity between the cask and DSC, which ensures that any water has been removed.

7.1.5 Placing the Cask onto the Railcar

The procedure for placement of the cask on the railcar.

a. Using a suitable prime mover, bring the cask and onsite transfer trailer to the transportation railcar.

b. Remove the onsite transfer trailer trunnion block covers.

c. Install suitable slings around the cask front and rear trunnions.

d. Lift the cask from the onsite transfer trailer.

e. Place the cask onto the railcar transportation skid.

f. Remove the lifting slings from the cask.

g. Remove the cask front and rear trunnions and install the trunnion plugs.

h. Install the skid tie down strap.

i. Install the front and rear impact limiters onto the cask. Lubricate the attachment bolts with Nuclear Grade Neolube or equivalent and torque to 100 ft-lbs, diametrically in the first pass, and between 140 – 160 ft-lbs in the final pass.

j. Inspect the personnel barrier(s) to assure there are no holes or gaps in the material. Repair/replace as required and install on the transport frame.

k. Install the cask tamperproof device.

l. Monitor the cask radiation levels per 49 CFR 173.441 [2] and 10 CFR 71.47 [3] requirements.

Note: The procedure outlined above may also be used to transfer the cask directly from the fuel pool to a rail car, without using the transfer trailer, should appropriate facilities be available for such a transfer. The procedures outlined in Section 7.1.5 would also be applicable to such a scenario.

7.1.6 Glossary

The following terms, used in the above procedures, are defined below.

a.	Horizontal Storage Module (HSM):	Concrete shielded structure used for onsite storage of DSCs.
b.	Onsite Transfer Trailer:	A hydraulically supported trailer used for onsite movements of the cask.
c.	Onsite Support Skid:	Skid present on the onsite transfer trailer used to support the cask during onsite movements.
d.	Cask/DSC Annulus Seal:	Pneumatic seal placed between the cask and DSC during operations in the fuel pool.

7.2.2 Unloading the NUHOMS®-MP197 Cask to a Staging Module

The procedure for unloading a DSC from the cask into an HSM is summarized in this section. This procedure is typical of NUHOMS® ISFSIs and some of the steps listed below may be performed in a different order.

a. Position the onsite transfer trailer in front of the module face.

b. Sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

c. Remove the cask ram closure plate. Discard the ram closure seals.

d. Install the ram trunnion support assembly.

e. Remove the HSM door.

f. Use the skid positioning system and optical surveying transits to align the cask with the HSM.

g. Remove the cask lid. Discard the lid seals.

h. Dock the cask with the HSM and install the cask/HSM restraints.

i. Install and align the hydraulic ram cylinder in the ram trunnion support assembly.

j. Extend the ram hydraulic cylinder until the grapple contacts the DSC bottom cover.

k. Engage the DSC grapple ring with the ram grapple.

l. Extend the ram hydraulic cylinder until the DSC is fully inserted in the HSM.

m. Disengage the grapple from the DSC.

n. Remove the hydraulic ram from the cask.

o. Remove the cask from the HSM.

p. Install the HSM door and DSC seismic restraint.

q. Move the onsite transfer trailer and cask to a low-dose maintenance area.

r. Inspect the cask hardware (including vent/drain/test port plugs) for damage that may have occurred during transportation. Repair or replace as necessary.

7.2.3 Unloading the NUHOMS®-MP197 Cask to a Fuel Pool

The procedure for unloading the cask and DSC into a fuel pool is summarized in this section. This procedure is intended to describe the type and quality of work performed to unload a DSC. Actual DSC unloading procedures may vary slightly from the tasks described below.

a. Tow the onsite transfer trailer to the fuel receiving area.

b. Remove the onsite support skid pillow block covers.

c. Using the cask lifting yoke, engage the front trunnions, rotate the cask to a vertical orientation, lift the cask from the onsite support skid, and place the cask in the decon pit.

d. Sample the cask cavity atmosphere through the vent port. Flush the cask interior gases to the site radwaste systems if necessary.

e. Remove the bolts from the cask lid and lift the lid from the cask.

f. Remove and discard the cask lid seals.

g. Locate the DSC siphon and vent ports using the indications on the DSC outer top cover plate.

h. Drill a hole in the DSC outer top cover plate and remove the siphon closure plug to expose the siphon port quick connect.

i. Drill a hole in the DSC outer top cover plate and remove the vent closure plug to expose the vent port quick connect.

j. Sample the DSC cavity atmosphere. If necessary, flush the DSC cavity gases to the site radwaste systems.

k. Fill the DSC with fuel pool or equivalent water through the siphon port with the vent port open and routed to the plant's off-gas system or other appropriate system.

7.3 Preparation of an Empty Cask for Transport

Previously used and empty NUHOMS®-MP197 casks shall be prepared for transport per the requirements of 49 CFR 173.427 [2].

7.4 Leakage rate Testing of the containment Boundary

The procedure for leak testing the cask containment boundary prior to shipment is given in this section. Assembly verification leak testing shall conform to the requirements of Section 6.5 and Section A3.5 of ANSI N14.5-1997, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment [1]". The order in which the leak tests of the various seals are performed may vary. If more than one leak detector is available then more than one seal may be tested at a time. Assembly verification leak test flow chart is presented in Figure 7-2.

a. Remove the cask vent port plug.

b. Install the cask port tool in the cask vent port. (The port tool is designed to replace the vent/drain and test port plugs and provide a means for loosening the vent/drain and test port screw in a controlled volume. This volume can be isolated from the cask volume by an externally accessible valve to ensure personnel protection during cask venting operations.)

c. Turn the cask port tool handle to open the cask vent port.

d. Attach a suitable vacuum pump to the cask port tool.

e. Reduce the cask cavity pressure to below 1.0 psia.

f. Attach a source of helium to the cask port tool.

g. Fill the cask cavity with helium to pressure of 3.5 psig.

h. Close the vent port screw by turning the cask port tool handle. Tighten the vent port screw to 65 ft-lbs.

i. Remove the helium saturated cask port tool and install a clean (helium free) cask port tool.

j. Connect a mass spectrometer leak detector capable of detecting a leak of $5x10^{-8}$ ref cm^3/sec to the cask port tool.

k. Evacuate the vent port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations.

l. Perform the leak test. If the leakage rate is greater than $1x10^{-7}$ ref cm^3/sec repair or replace the vent port screw and/or seal as required and retest.

Note: Upon removing the vent port screw, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port.

m. Remove the leak detection equipment from the cask vent port.

n. Remove the cask port tool from the vent port and replace the vent port plug.

o. Remove the top test port plug.

p. Install the cask port tool in the top test port.

q. Turn the cask port tool handle to open the top test port screw.

r. Connect the vacuum pump to the cask port tool.

s. Connect the leak detector to the cask port tool.

t. Evacuate the top test port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations. Perform a pressure rise leak test to confirm leakage past the outer seal is less than 7×10^{-3} ref cm^3/sec.

u. Perform the helium leak test. If the leakage rate is greater than 1×10^{-7} ref cm^3/sec repair or replace the cask top lid O-ring seals as required and retest.

Note: Upon removing and reinstalling the cask top closure, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

v. Remove the leak detection equipment from the top test port.

w. Tighten the top test port screw to 65 ft-lbs. Remove the cask port tool from the top test port and replace the top test port plug.

x. Remove the cask drain port plug.

y. Install the cask port tool in the cask drain port.

z. Turn the cask port tool handle to verify that the cask drain port is closed.

aa. Connect the vacuum pump to the cask port tool.

bb. Connect the leak detector to the cask port tool.

cc. Evacuate the drain port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations.

dd. Perform the leak test. If the leakage rate is greater than $1x10^{-7}$ ref cm^3/sec repair or replace the drain port screw and/or seal as required and retest.

Note: Upon removing the drain port screw, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

ee. Remove the leak detection equipment from the drain port.

ff. Tighten the drain port screw to 65 ft-lbs. Remove the cask port tool from the cask drain port and replace the drain port plug.

gg. Remove the bottom test port plug.

hh. Install the cask port tool in the bottom test port.

ii. Turn the cask port tool handle to open the bottom test port screw.

jj. Connect the vacuum pump to the cask port tool.

kk. Connect the leak detector to the cask port tool.

ll. Evacuate the bottom test port until the vacuum is sufficient to operate the leak detection equipment per the manufacturer's recommendations. Perform a pressure rise leak test to confirm leakage past the outer seal is less than $7x10^{-3}$ ref cm^3/sec.

mm. Perform the helium leak test. If the leakage rate is greater than $1x10^{-7}$ ref cm^3/sec repair or replace the cask ram closure O-ring seals as required and retest.

Note: Upon removing the cask ram closure, it will be necessary to reduce the cask cavity pressure below 1.0 psia and refill with helium through the vent port. The vent port assembly verification test must also be retested as described above.

nn. Remove the leak detection equipment from the bottom test port.

oo. Tighten the bottom test port screw to 65 ft-lbs. Remove the cask port tool from the bottom test port and replace the bottom test port plug.

This concludes the assembly verification leak test procedure.

7.5 References

1. ANSI N14.5-1997, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment," American National Standards Institute, Inc., New York

2. Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), "Shippers - General Requirements for Shipments and Packaging."

3. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), "Packaging and Transportation of Radioactive Material."

plates. Because the inner shell will not be accessible for leak testing after lead is poured, leak testing will be performed during the fabrication process, as permitted by ANSI N 14.5 Table 1. As one means of performing this test, the interior of the cask cavity may be flooded with a helium atmosphere while vacuum is drawn on the lead cavity to determine the leak rate. If a leak is discovered the source will be determined, repaired and the shells retested to ensure that the measured leak rate is less than $1x10^{-7}$ ref cm^3/s.

The test will be performed in conjunction with the non-destructive examination of the inner shell welds in accordance with ASME BPVC, Section III, Subsection NB, a PT examination of every weld layer in the shell to top forging closure weld, and a PT examination of all final machined weld surfaces of the inner shell per the ASME Code.

Fabrication Leak Test

The fabrication leak tests include the following:

- Testing the Cask Vent Port Closure seal Integrity
- Testing the Cask Drain Port Closure seal Integrity
- Testing the Cask top Closure Plate (Lid) seal Integrity
- Testing the Cask Ram Closure seal Integrity

The tests will be performed as described in Section 7.4, in accordance with the ANSI N 14.5. The acceptance criterion is each component must be individually leaktight, that is, the leak rate must be less than $1x10^{-7}$ ref-cc/s.

8.1.3.2 NUHOMS®-61BT DSC

The NUHOMS®-61BT DSC containment is leak tested to verify it is leaktight in accordance with ANSI N14.5.

The leak tests are typically performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved.

8.1.4 Components Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

There are no valves or couplings in the NUHOMS®-MP197 packaging.

8.1.4.2 Gaskets

The lid and all the other containment penetrations are sealed using double elastomer seals. The inner seal forms part of the containment boundary. Leak testing of the seals is described in section 8.1.3.

8.1.4.3 Impact Limiter Leakage Test

The following test will be performed, after all the seal welds are completed on the impact limiter, to verify that the impact limiter wood has been protected from any moisture exchange with the environment.

Pressurize each impact limiter container to a pressure of approximately 3 psig. Test all the weld seams and surfaces for leakage using a soap bubble test.

8.1.4.4 Functional Tests

The following functional tests will be performed prior to first use of the cask. Generally these tests will be performed at the fabrication facility.

a. Installation and removal of the lid, penetration covers, and other fittings will be observed. Each component will be checked for difficulties in installation and removal. After removal, each component will be visually examined for damage. Any defects will be corrected prior to acceptance of the cask.

b. After installation of the fuel basket into the DSC, each basket compartment will be checked by gauge to demonstrate that the fuel assemblies will fit in the basket.

8.1.5 Shielding Tests

Chapter 5 presents the analyses performed to ensure that the NUHOM®-MP197 package shielding integrity is adequate.

8.1.5.1 Neutron Shield Tests

The radial neutron shield is protected from damage or loss by the aluminum and steel enclosure. The neutron shield material is a proprietary, borated, reinforced polymer.

The primary function of the resin is to shield against neutrons, which is performed primarily by the hydrogen content in the resin. The sole function of the boron is to suppress n-γ reactions with hydrogen. The resin also provides some gamma shielding, which is a function of the overall resin density, and is not sensitive to composition.

The shielding performance of the resin can be verified adequately by chemical analysis and verification of density. Uniformity is assured by installation process control.

The following are acceptance values for density and chemical composition for the resin. The values used in the shielding calculations of Chapter 5 are included for comparison.