MP197HB Transport Cask

Shielding Analysis

MP197HB Shielding Analysis

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Safety Analysis Overview

- **Shielding Analysis performed in a three-step process**
- **First Step–Response Function Calculations–Calculated for all DSCs that are authorized for Transportation in the MP197HB**
- **Second Step–Fuel Qualification for Shielding–Performed for all DSCs to determine Burnup, Enrichment and Cooling Time (BECT) combinations for spent fuel contents**
- **Third Step–Shielding Evaluation–Performed with bounding source terms for NCT and HAC to meet Part 71 limits**

Shielding Materials

Parameter / Methodology Description	References Reviewed by the NRC
DSC / Basket / Cask Materials except neutron shielding modeled using SCALE Standard Composition Library	Identical to the materials / composition utilized in the OS 197 Transfer Cask in the Standardized NUHOMS® System (CoC-1004)
Neutron Shielding Resin	Similar to the neutron shielding material in OS187H Transfer Cask in the NUHOMS® HD System (CoC-1030)

Computer Codes

Parameter / Methodology Description	Implementation in MP197HB Analysis	References Reviewed by the NRC
Source Term Calculations including calculation of decay heat	SAS2H / ORIGEN-S	Identical to those utilized in the NUHOMS® HD System for 32PTH DSC (CoC-1030) and Standardized NUHOMS® System, CoC 1004, Amendment 10, for 24PTH DSC (Appendix P.5) / 61BTH DSC (Appendix T.5) / 32PTH1 DSC (Appendix U.5)

Computer Codes

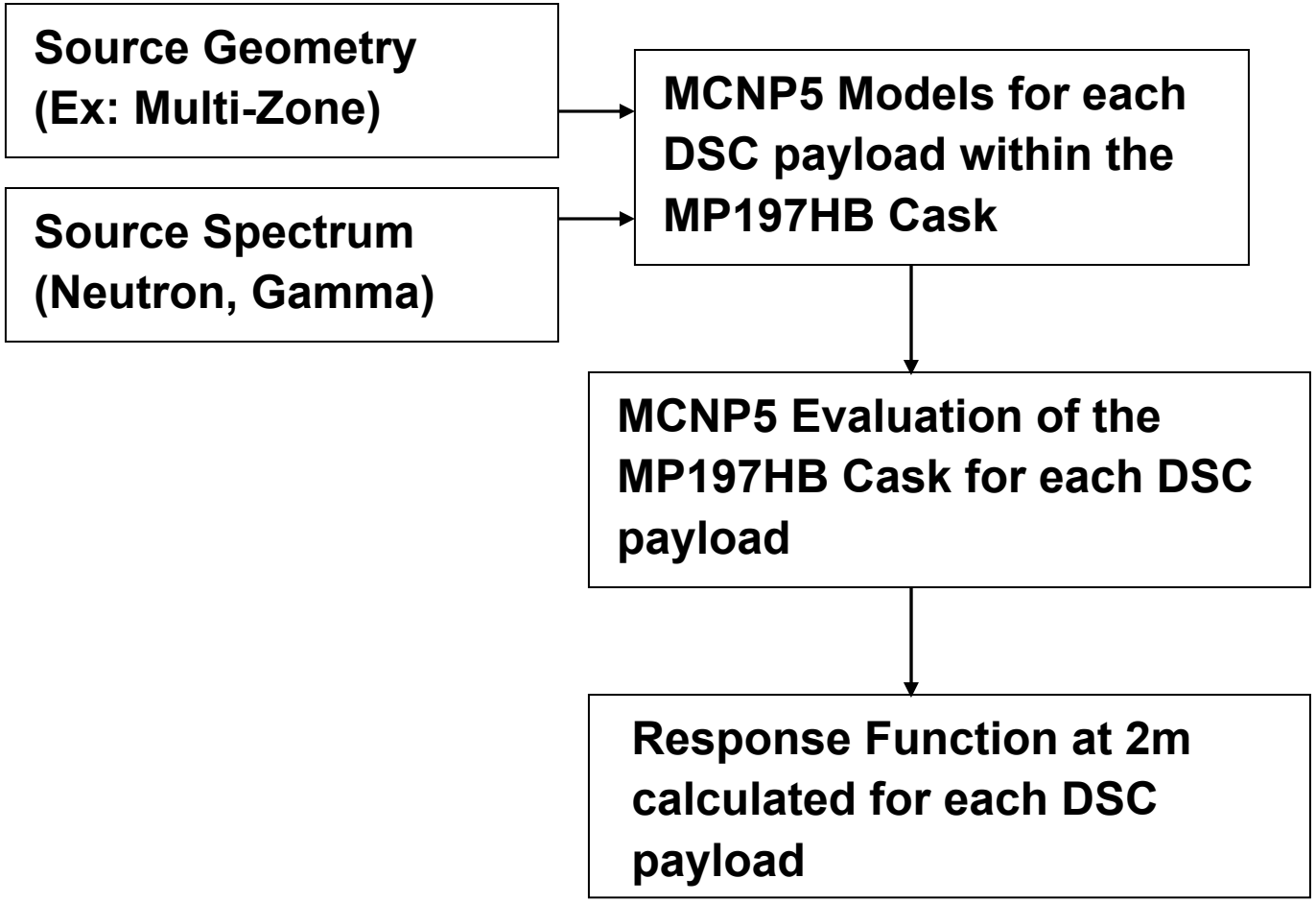
Parameter / Methodology Description	Implementation in MP197HB Analysis	References Reviewed by the NRC
Shielding Evaluation / Dose Rate Calculation including Response Function Calculation	MCNP5	Identical to that utilized in the Standardized NUHOMS® System CoC 1004, Amendment 10, for 61BTH DSC (Appendix T.5) / 32PTH1 DSC (Appendix U.5)

Response Functions

- Response Functions are essentially "source-to-dose" conversion factors for a given shielding configuration
- Response Function is the dose rate at a particular location due to a source of 1 particle/second for a given shielding configuration

Parameter / Methodology Description	References Reviewed by the NRC
Response Function Methodology / Approach	Standardized NUHOMS® System (CoC-1004, Amendment 10) – Appendices K.5 (61BT), M.5 (32PT), P.5 (24PTH), T.5 (61BTH) and U.5 (32PTH1) and Advanced NUHOMS® System (CoC-1029) Appendix A.5 (24PT4)

Response Functions



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Response Functions

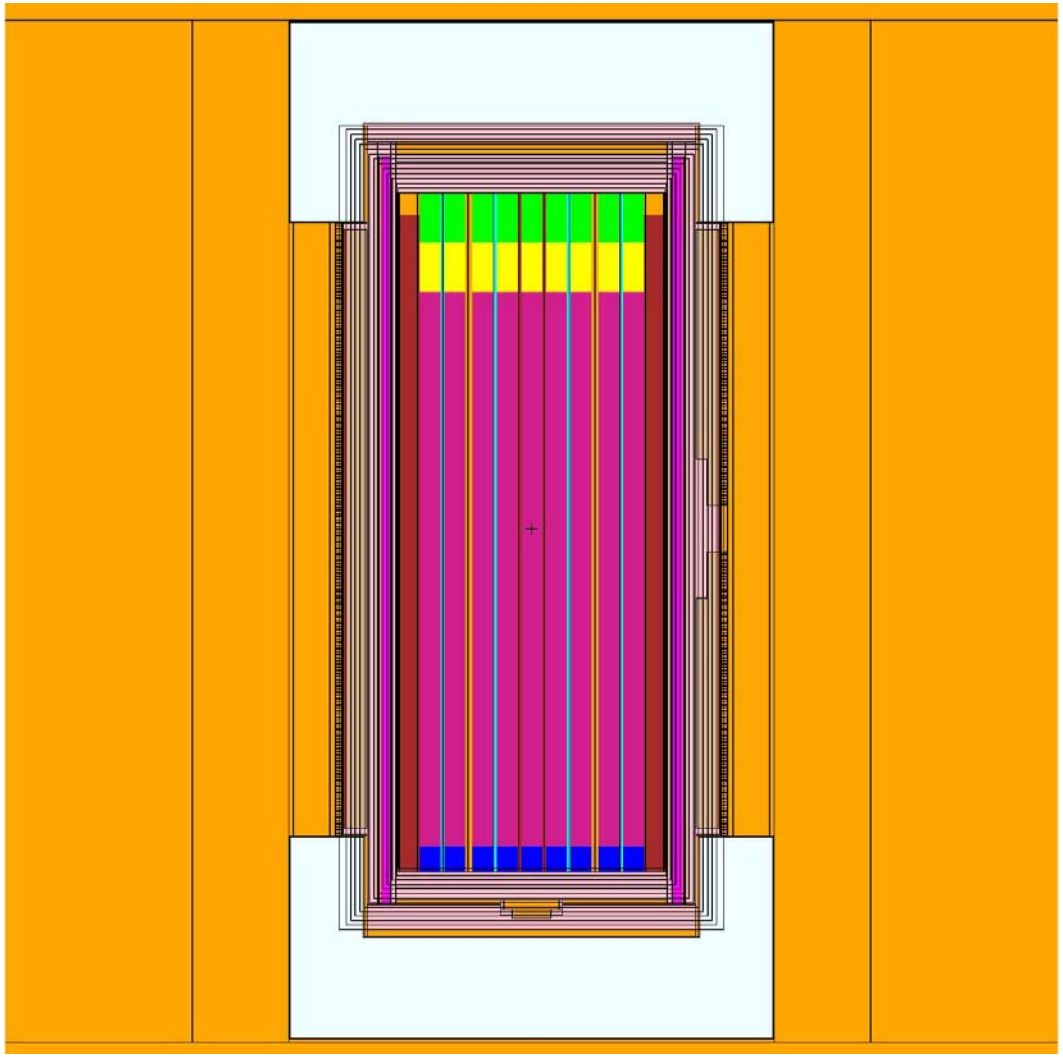
- **MCNP5 Version 1.40 computer code with ENDF/B-VI cross-section library utilized for response function calculation**
- **DSC, Basket and Cask geometry modeled as shown in Figure 1 and Figure 2**
- **Two or more radial zones are utilized to group fuel assemblies within the basket and response functions are calculated for each radial zone (Shown in Figure 3)**
- **MCNP5 built-in Cm-244 spectrum utilized for neutrons and secondary gamma response function calculations**
- **Four significant energy groups (1.00 to 3.00 MeV) utilized for primary gamma response functions – these groups contribute to more than 99% of the total primary gamma dose**

Response Functions

- Response functions calculated at 2m from the radial surface of the cask (conservative compared to 2m from the edge of the transport vehicle) at the midplane of the active fuel length
- This dose point is selected because it represents the bounding dose point–for Part 71 dose rate limits compliance–Results from Chapter 5 of the MP197 SAR
- Angular dependence is also included in the response function results
- Two or more radial zones are utilized to group fuel assemblies within the basket and response functions are calculated for each radial zone
- This approach is validated using full MCNP5 model with the 18 group gamma spectrum (SCALE/SAS2H). 2m dose rate calculations using response functions are within 2% of the actual dose rate

Response Functions
MCNP Model of 69BTH/MP197HB

Figure 1: MCNP5 Model Plot



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Response Functions
MCNP Model of 69BTH/MP197HB

Figure 2: MCNP5 Model Plot

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Fuel Qualification

Figure 3: 4-Zone Loading for Response Functions

		4	4	4	4	4		
	3	3	3	3	3	3	3	
4	3	2	2	2	2	2	3	4
4	3	2	1	1	1	2	3	4
4	3	2	1	1	1	2	3	4
4	3	2	1	1	1	2	3	4
4	3	2	2	2	2	2	3	4
	3	3	3	3	3	3	3	
		4	4	4	4	4		

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Response Functions

- Example 4-Zone Response Function (2m radial dose point) for the 69BTH DSC is shown in the table below

Zone	Neutron	Capture Gamma	Primary Gamma Energy Range (MeV)			
			1.00 to 1.33	1.33 to 1.66	2.00 to 2.50	2.50 to 3.00
1	4.65E-10	4.88E-10	6.05E-19	4.72E-18	1.45E-16	5.75E-16
2	1.61E-09	1.20E-09	5.18E-17	1.71E-16	5.5E-15	1.69E-14
3	4.17E-09	2.22E-09	2.95E-16	5.12E-15	8.01E-14	1.77E-13
4	1.04E-08	3.61E-09	9.89E-15	8.92E-14	8.14E-13	1.64E-12

Fuel Qualification

- **Fuel qualification is a process of determining the acceptable combinations of BECT to ensure that the resulting dose rates for these combinations meet applicable Part 71 limits for shielding**

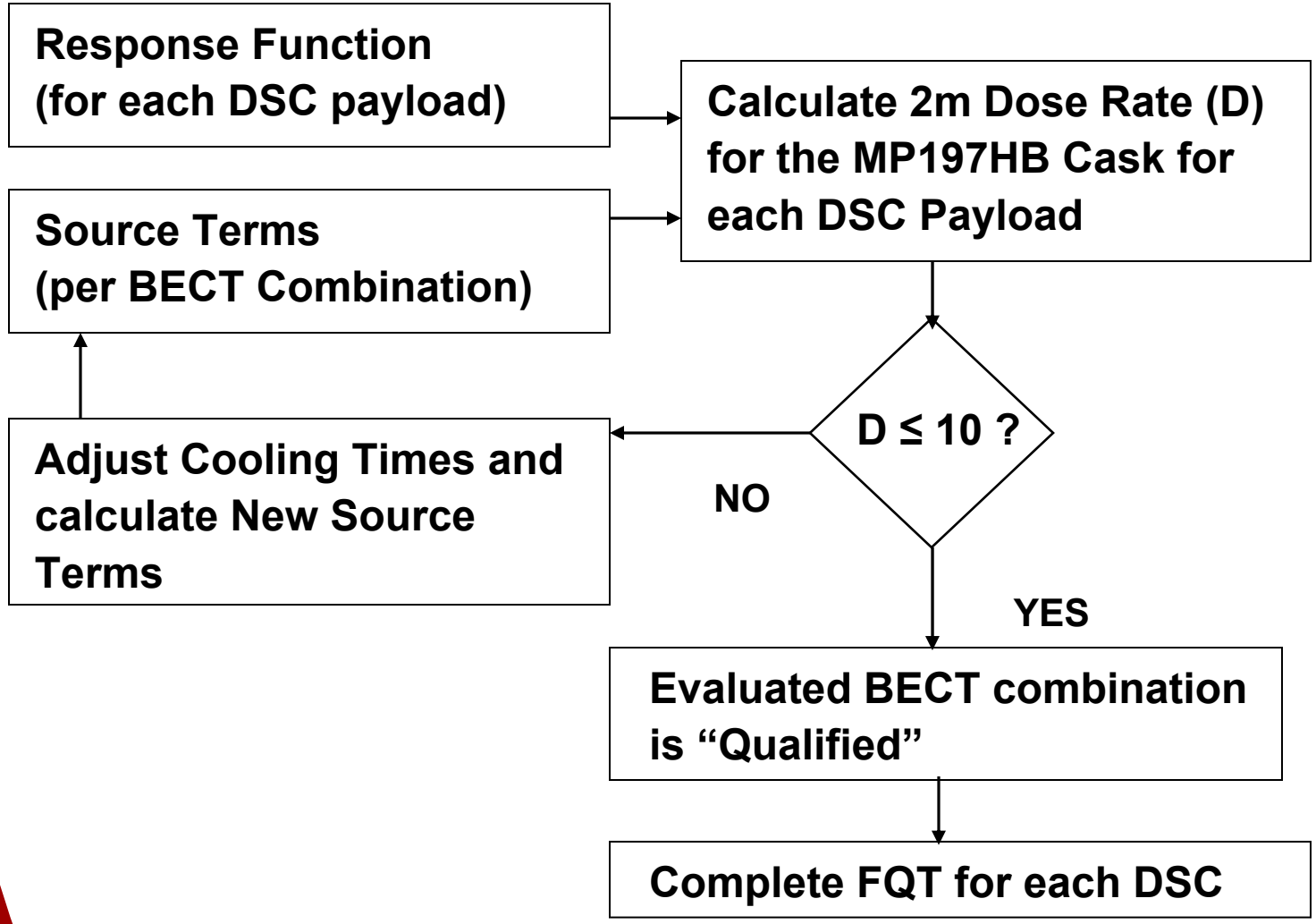
Parameter / Methodology Description	References Reviewed by the NRC
Fuel Qualification Methodology / Approach	Standardized NUHOMS® System (CoC-1004, Amendment 10) – Appendices K.5 (61BT), M.5 (32PT), P.5 (24PTH), T.5 (61BTH) and U.5 (32PTH1) and Advanced NUHOMS® System (CoC-1029) Appendix A.5 (24PT4) ▶MP197 Cask, CoC 9302, Chapter 5 for Transport

Fuel Qualification

- An Example Fuel Qualification Table is shown below
- The minimum cooling times (in years) as a function of burnup and enrichment are shown in the Table

	50	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	51	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0
	52	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0
	53	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0	6.5	6.0	6.0	6.0
	54	9.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	6.5	6.0	6.0
BURNUP (GWD/MTU)	55	10.5	9.5	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.0	6.0	6.0
	56	11.0	10.5	9.5	9.0	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.0
	57	12.0	11.0	11.0	10.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.0	8.0	7.0
	58	13.5	12.5	11.5	10.5	10.5	9.5	9.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.0	7.5
	59	14.5	13.5	12.5	12.0	11.0	10.5	9.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.5
	60	16.0	15.0	14.0	13.0	12.0	11.0	11.0	10.0	9.5	9.5	9.5	9.0	9.0	9.0	9.0	9.0
	61	17.0	16.0	15.0	14.5	13.5	12.5	11.5	10.5	10.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
	62	18.5	17.5	16.5	15.5	14.5	13.5	13.0	12.0	11.0	11.0	10.0	10.0	10.0	10.0	9.5	9.5
		3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
		ENRICHMENT (Wt. % U-235)															

Fuel Qualification



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Fuel Qualification

- **Fuel Qualification Tables (FQTs) for dose rate compliance are developed for each DSC that shows the minimum cooling time required as a function of burnup and enrichment**
- **All the cooling times in each FQT ensure that the resulting dose rates are below the part 71 limit of 10 mrem/hour at 2m**
- **Dose rates for the FQT calculations are obtained from response functions**
- **Several entries in the FQT result in "calculated dose rates" (from response functions) that are significantly lower than the part 71 limit**

Fuel Qualification

- **SAS2H/ORIGEN-S Modules from the SCALE44 computer code system with the 44 Group ENDF/B-V cross section library is utilized to determine source terms for these calculations**
- **Source terms are calculated using the GE 7x7 lattice with an initial loading of 198 KgU for BWR fuel assemblies and the B&W 15x15 design with an initial loading of 490 KgU for PWR fuel assemblies**
- **The fuel assemblies authorized for NUH32PTH DSC, NUH32PT DSC and NUH24PT4 DSC are covered conservatively because the maximum KgU loading is lower. For the fuel assemblies authorized for the other DSCs, the maximum KgU loading is identical**

Fuel Qualification

- **The FQTs are based on uniform loading throughout the basket**
- **Adaptability to multi-zone loading is possible since response functions are calculated using multi-zone loading**
- **For multi-zone loading, the FQT will provide the appropriate changes to cooling times to meet dose rate limits (Example multi-zone is shown in Figure 1)**
- **In cases where cooling times to meet FQT limits are interpolated or extrapolated, new SAS2H source term runs are performed and the results verified using response functions**

Fuel Qualification

- **In summary, FQT methodology includes a calculation and a verification sequence ensuring that the results are acceptable**
- **A separate fuel qualification to meet applicable decay heat limits is required**

Decay Heat Calculations

- **A separate fuel qualification to meet applicable decay heat limits is required since FQTs determined earlier only ensure that applicable dose rate limits are met**
- **Fuel Assembly Decay Heat is Calculated as a function of BECT using a Decay Heat Equation (DHE)**
- **The SAS2H/ORIGEN-S results (for source terms) also include Decay Heat results and are utilized to determine the DHE**
- **The DHE methodology and mathematical equation similar to those approved by the NRC for NUHOMS® HD System, CoC-1030 (for PWR fuel assemblies) and TN-68 HB Cask CoC-1027 (for BWR fuel assemblies)**

Decay Heat Calculations

- Bounding BWR and PWR SAS2H models are employed to calculate the Decay Heat
- Separate DHEs are developed for BWR and PWR fuel assemblies
- The Decay Heat (DH) for PWRs is given below
  - $F1 = A + B*X1 + C*X2 + D*X1^2 + E*X1*X2 + F*X2^2$
  - $DH = F1*Exp(\{[1-(1.8/X3)]*G\}*[(X3-4.5)^H]*[(X2/X1)^I])$
    - where,
    - F1 Intermediate Function
    - X1 Assembly Burnup in GWD/MTU
    - X2 Initial Enrichment in wt. % U-235
    - X3 Cooling Time in Years
    - A, B, C, D, E, F, G, H and I are coefficients

NCT Payload for Shielding

Response Functions at 2m calculated for each DSC payload

↓

FQT for each DSC Determined to ensure NCT Dose Rate Limits are met using Response Functions

↓

This ensures that all DSC payloads result in approximately the same dose rates–the maximum dose rates for each DSC will be slightly below the limits

↓

The 69BTH DSC is “selected” as the NCT payload for shielding

NCT Source Terms for Shielding

- Determination of FQT for shielding for each DSC design ensures that the source term/DSC combination within the MP197HB results in approximately the same dose rates for NCT
- The FQT methodology adjusts cooling times such that the maximum dose rate at 2m is within the part 71 limit
- Therefore only one source term/DSC configuration needs to be evaluated–all other source term/DSC configurations will be equivalent
- The 69BTH DSC is “selected” as the DSC for evaluation
- SAS2H is utilized to determine the NCT source terms for the BWR fuel assembly

HAC Payload for Shielding

Response Functions at 2m calculated for each DSC payload

↓

The HAC configuration is based on loss of MP197HB cask neutron shielding

↓

For all DSC/source term configurations allowable by FQT, determine dose rates from Response Functions that maximize the contribution from neutron and secondary gamma

↓

Select the DSC/source term configuration resulting in the highest dose rate from neutron and secondary gamma contribution

↓

The dose contribution for the 69BTH DSC ensures that it is the HAC payload for shielding

HAC Source Terms for Shielding

- The HAC source term/DSC payload configurations, unlike the NCT source term/DSC payload configurations, are not "equivalent"
- The source term/DSC payload configurations for HAC are based on those that maximize the dose contribution from neutron and capture gamma
- HAC results for the MP197 Transport Package also validate the same conclusions regarding dose rate contribution
- Response Function evaluations for maximum neutron and capture gamma dose ensure that 69BTH DSC is the design basis DSC (bounds all other DSC payloads) for HAC
- SAS2H is utilized to determine the HAC source terms for the BWR fuel assembly

Shielding Calculations for NCT

- The NCT shielding calculations are performed with the 69BTH DSC within the MP197 HB cask using MCNP5 Code
- The cask geometry is modeled in full 3D including Impact Limiters (ILs) and Trunnion Plugs (TPs)
- Fuel assemblies are modeled as cuboids with "homogenized" material representing four axial zones– bottom nozzle, active fuel, plenum and top nozzle
- Separate models are employed for neutron (including secondary gamma) and gamma dose rate calculations
- MCNP5 built-in Cm-244 spectrum utilized for neutrons and secondary gamma dose rate calculations
- The 18-energy group gamma spectrum from SCALE is utilized for primary gamma dose rate calculations

Shielding Calculations for NCT

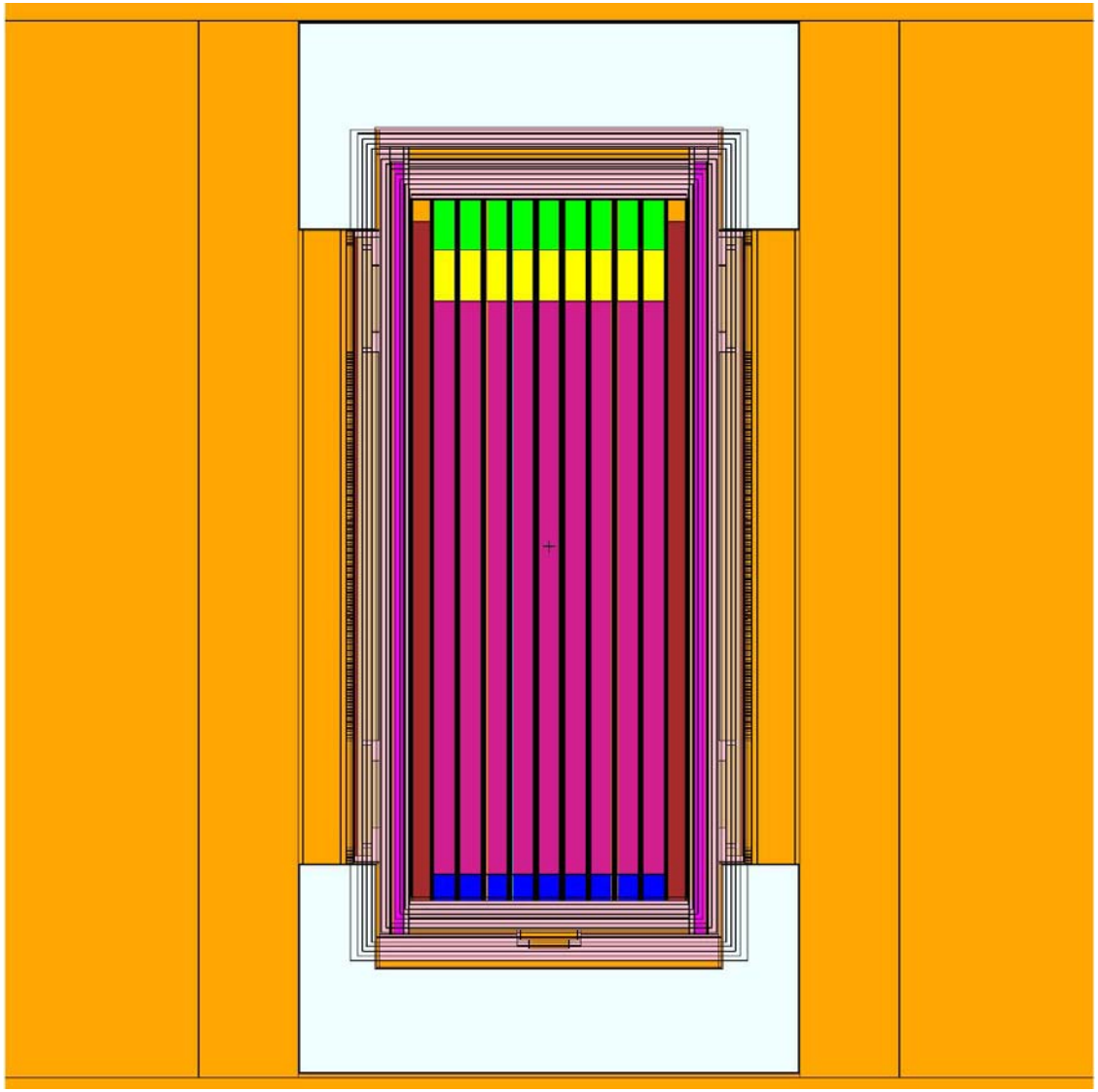
- **Mesh Tallies (cylindrical mesh at cask side and rectangular mesh at the top and bottom ends) are employed to determine the axial and angular dependence on dose rates at various distances**
- **Sufficient Axial and Angular mesh tallies ensure that the maximum dose rates are determined**
- **The dose rates are calculated with the MCNP5 uncertainty of ±5% and result in a well converged solution**
- **MCNP5 Model plots are shown in Figure 4 through Figure 10**

Shielding Calculations for HAC

- **The HAC calculations are performed with the 69BTH DSC within the MP197 HB cask using MCNP5 Code**
- **The MCNP5 models and methods are identical to those of the NCT calculations *except* for source terms and cask geometry – the geometry changes as described below**
  - **Axial and Radial Lead Slump calculated by structural analysis accounted in Models**
  - **The wood materials in the Impact Limiters are conservatively replaced with air**
  - **The neutron shielding resin is reduced conservatively to 25%–a loss of 75% of the neutron shielding is employed in the models although qualification tests have indicated that more than 75% of the resin is available for shielding after the fire transient**

Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 4:
MCNP5 Plot



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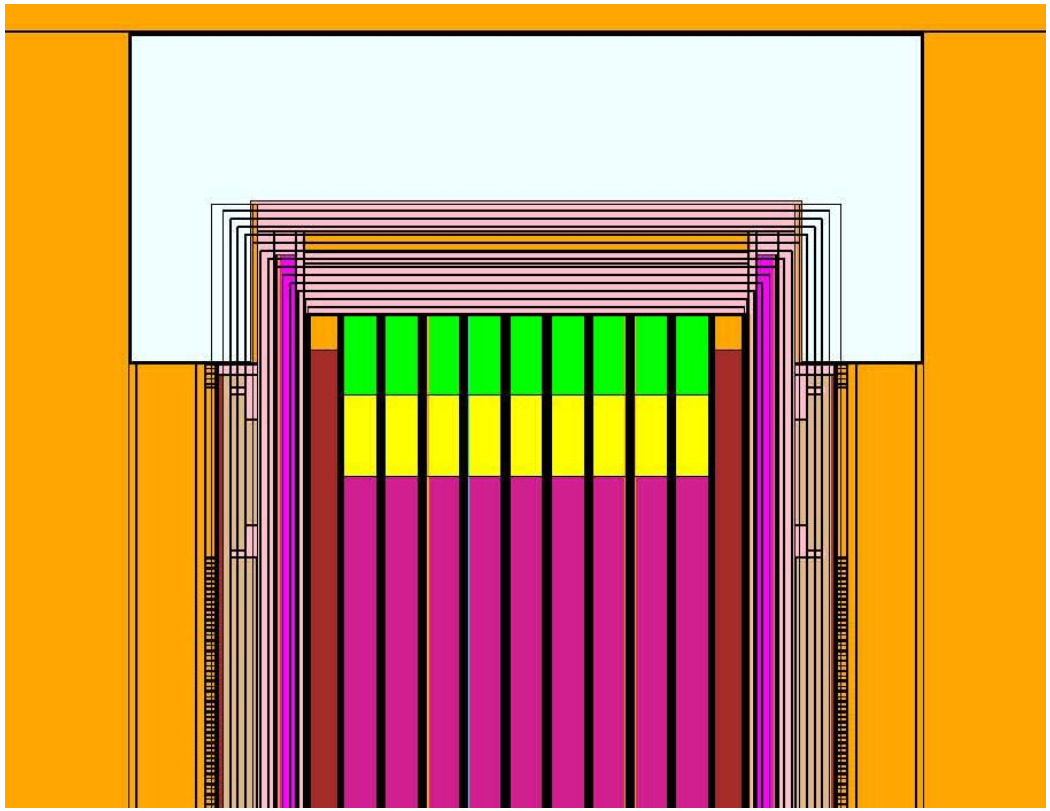
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 5:
MCNP5 Plot



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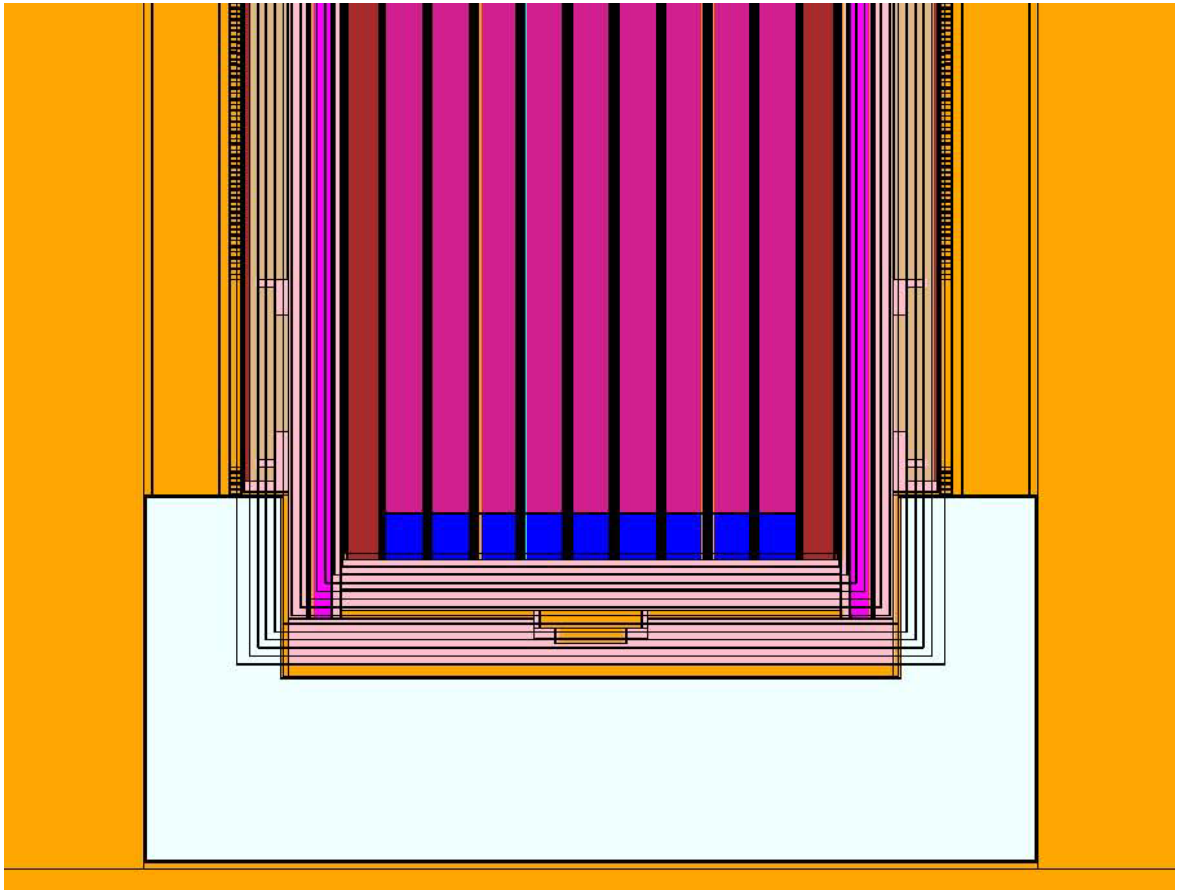
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 5:
MCNP5 Plot



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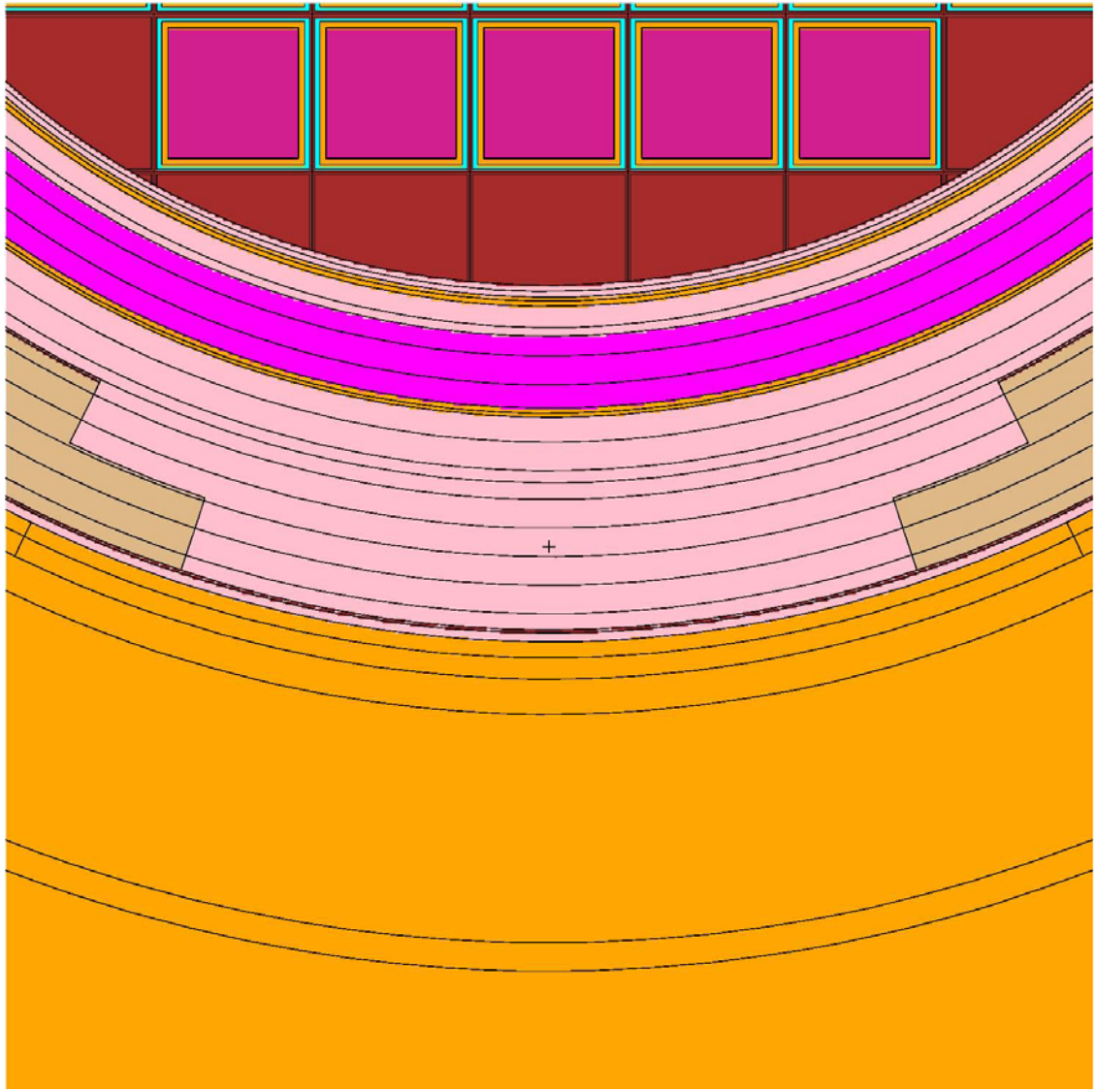
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 7:
MCNP5 Plot



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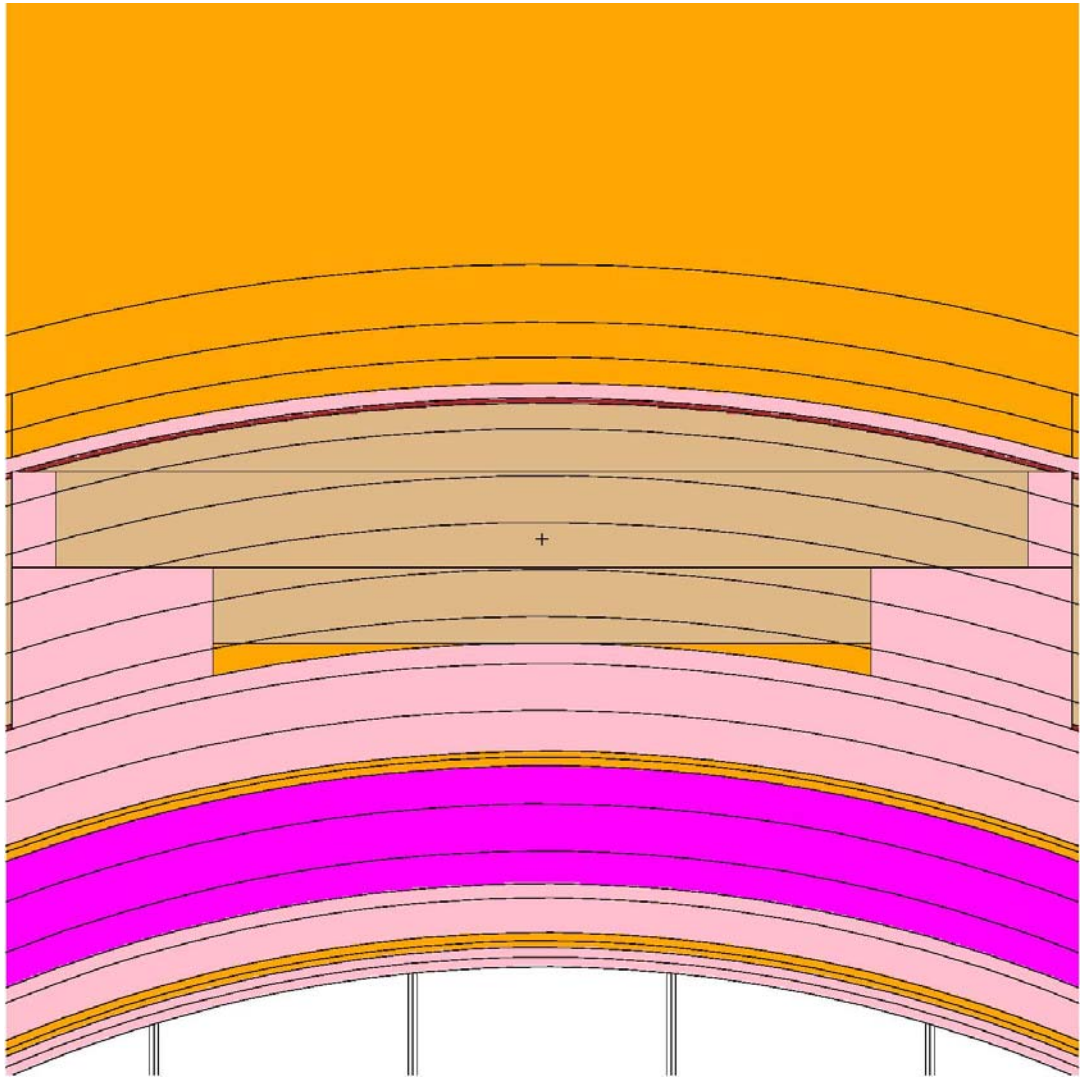
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 8:
MCNP5 Plot



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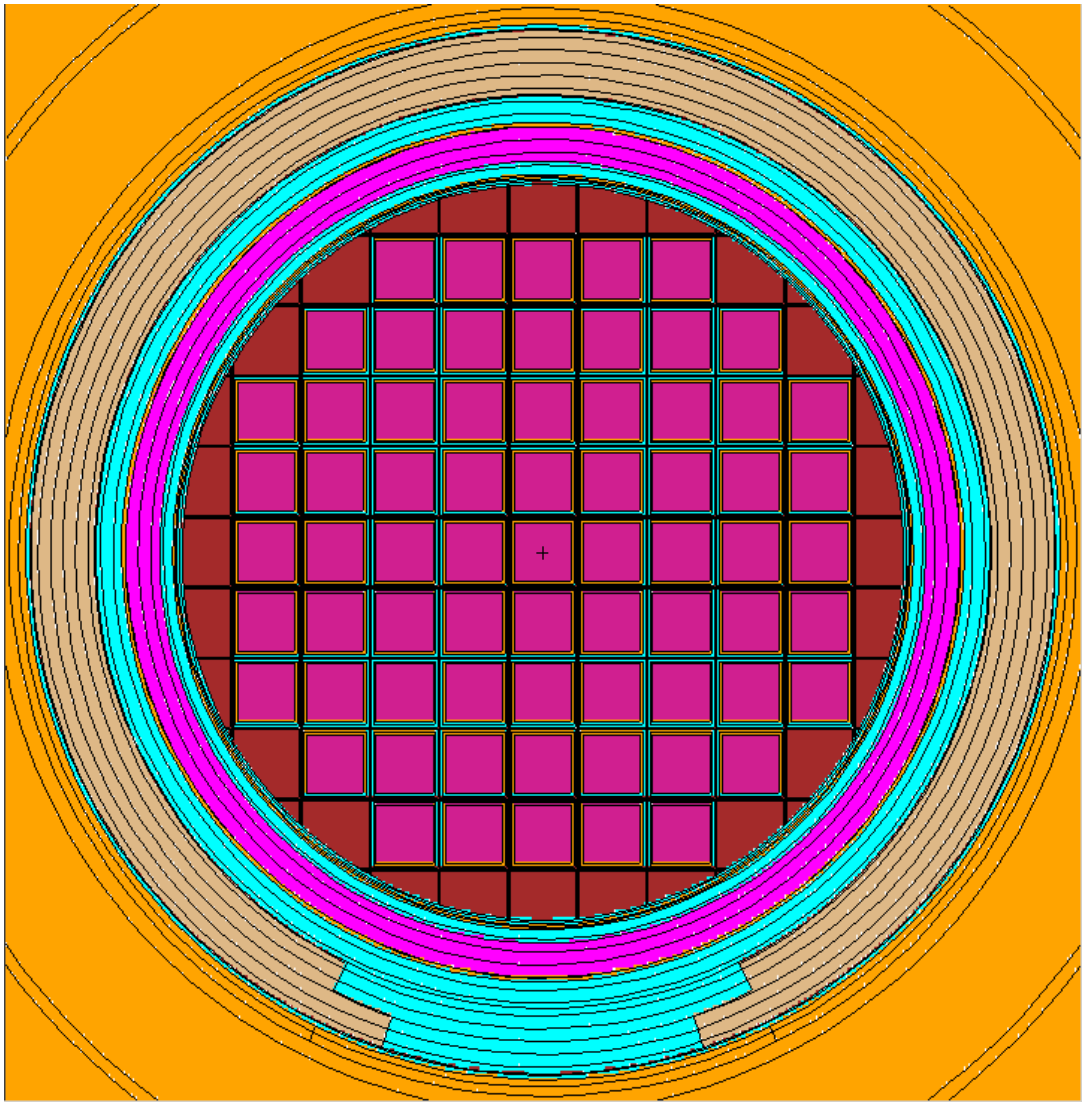
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 9: MCNP5 Plot



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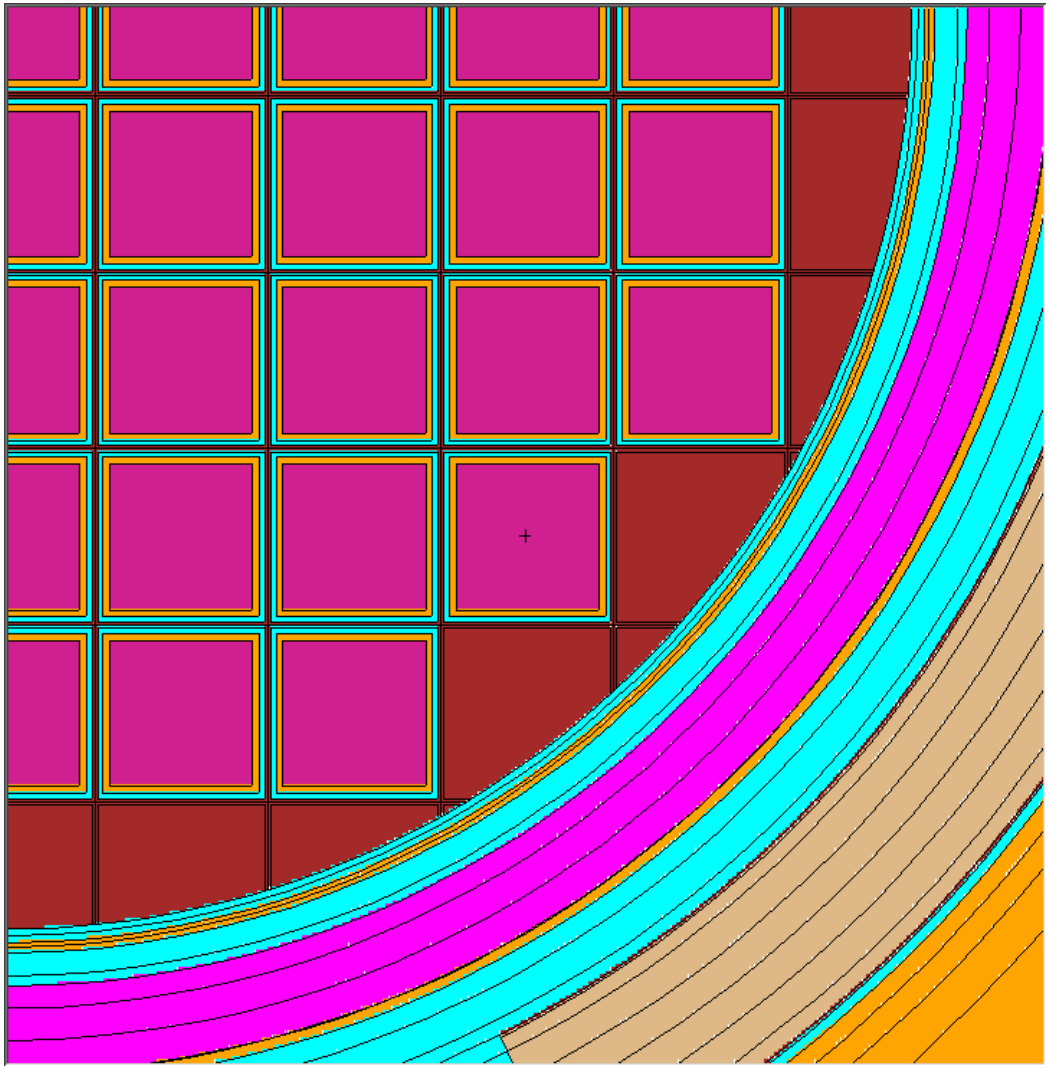
Shielding Calculations
MCNP Model of 69BTH/MP197HB

Figure 10: MCNP5 Plot



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NCT Results

Radiation	Transport Package Surface, mSv/h (mrem/h),			2 Meters from Vehicle Edge[1], mSv/h (mrem/h),		
	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.03 (2.7)	0.59 (58.7)	0.16 (16.0)	0.01 (0.6)	0.05 (5.5)	0.02 (1.8)
Neutron	0.02 (2.4)	1.51 (150.7)	0.16 (16.0)	0.01 (0.8)	0.05 (4.7)	0.02 (2.4)
Total	0.05 (5.1)	1.91 (191.2)	0.32 (32.0)	0.01 (1.2)	0.98 (9.8)	0.04 (4.2)
Limit	10 (1000)	10 (1000)	10 (1000)	0.1 (10)	0.1 (10)	0.1 (10)

[1] The outer surface of the impact limiters is conservatively utilized as the vehicle edge

Results
NCT Dose Rate from MP197HB Side

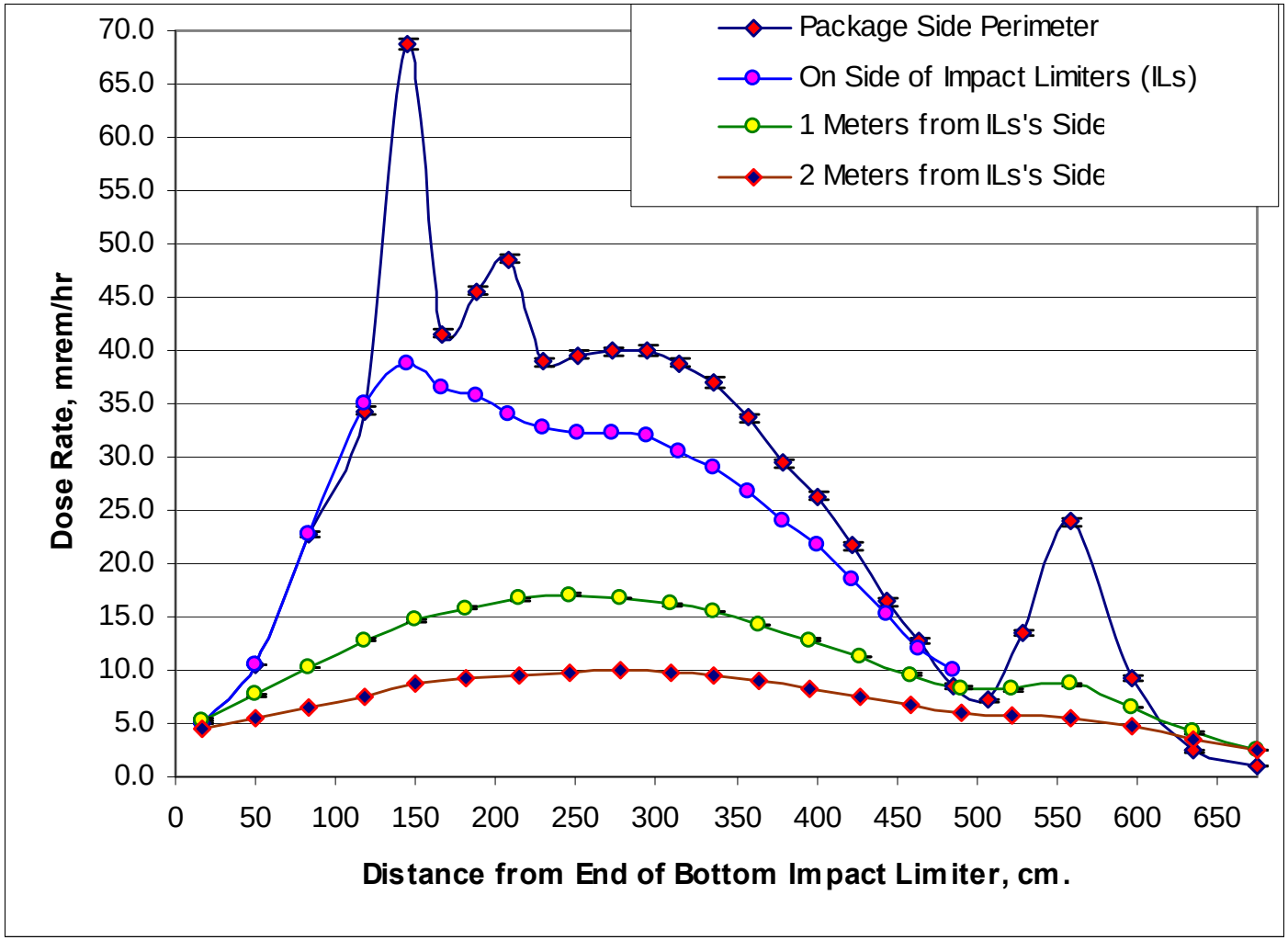

Figure 11: Dose Rate Results

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Results
NCT Dose Plot for MP197HB at 2m from Side

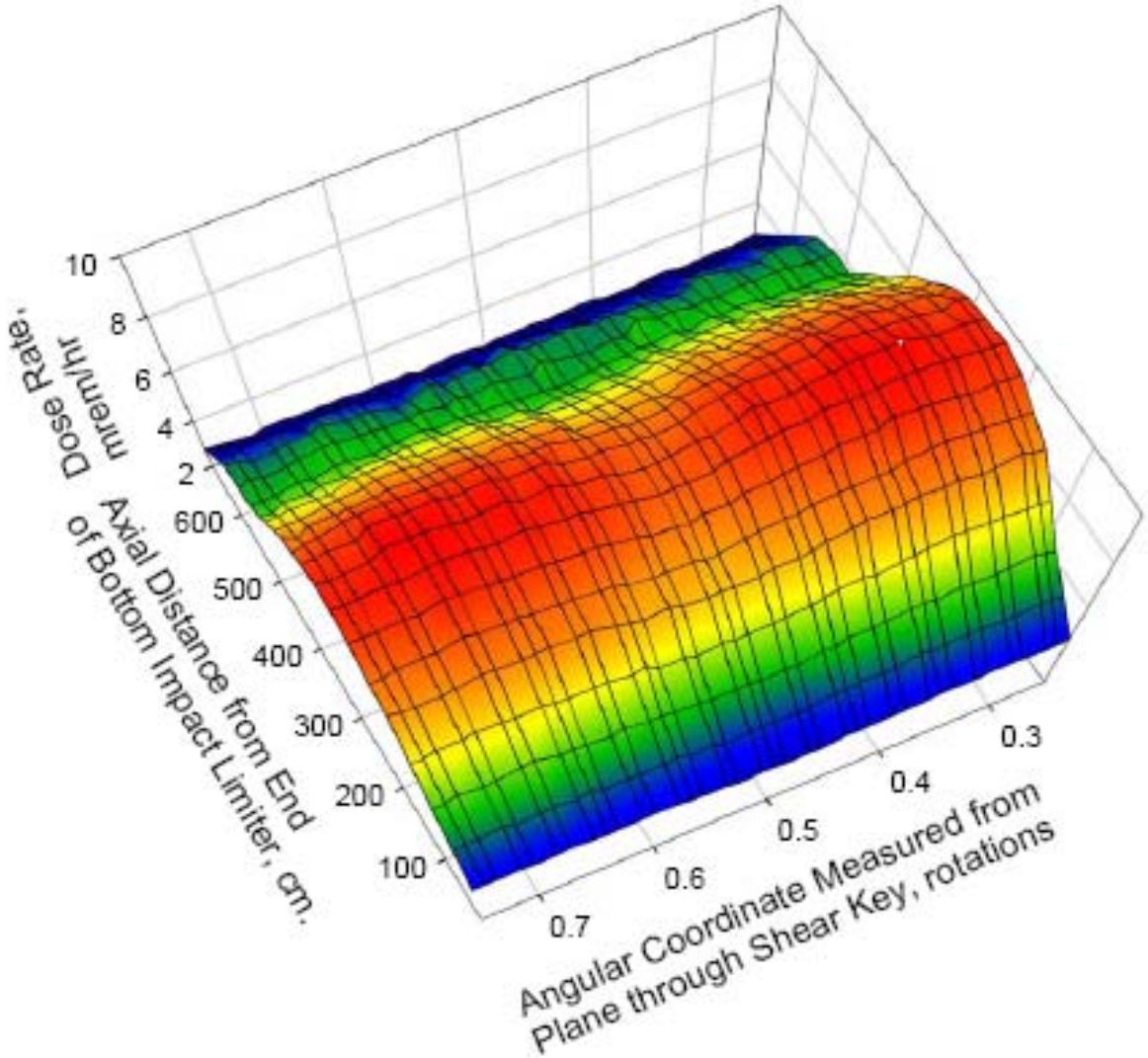

Figure 12: Dose Rate Results

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HAC Results

Radiation	1 Meter from Package Surface, mSv/h (mrem/h),		
	Top	Side (1)	Bottom
Gamma	0.02 (1.5)	0.18 (17.9)	0.02 (1.8)
Neutron	0.17 (17.4)	2.94 (293.7)	0.56 (55.8)
Total	0.19 (18.5)	3.12 (311.7)	0.57 (57.3)
Limit	10 (1000)	10 (1000)	10 (1000)

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Results

- The bounding dose rate for Part 71 compliance for the MP197HB is the 2m NCT dose rate
- All calculated dose rates meet the applicable Part 71 limits for NCT and HAC

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