ENCLOSURE 9

Non-Proprietary TN Calculation NUH32PHB-0503, HSM-HB Shielding Analysis for NUHOMS 32PHB System

Calvert Cliffs Nuclear Power Plant, LLC
December 8, 2011

NON-PROPRIETARY VERSION

AREVA TRANSNUCLEAR INC.	**Form 3.2-1** **Calculation Cover Sheet** TIP 3.2 (Revision 4)	Calculation No.:	NUH32PHB-0503
		Revision No.:	1
		Page: 1 of 108	

DCR NO (if applicable): NUH32PHB-003	PROJECT NAME: NUHOMS® 32PHB System
PROJECT NO: 10955	CLIENT: CENG - Calvert Cliff Nuclear Power Plant (CCNPP)

CALCULATION TITLE: HSM-HB Shielding Analysis for NUHOMS 32PHB System

SUMMARY DESCRIPTION:

1) Calculation Summary

Surface dose rate calculation for HSM-HB containing NUHOMS 32PHB

2) Storage Media Description

Secure network server initially, then redundant tape backup

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

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

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

Software Utilized (subject to test requirements of TIP 3.3):	**Version:**
MCNP5 v1.40	C00730MNYCP00
Calculation is complete: Originator Name and Signature: Andrew Gerlach	Date: 07/01/10
Calculation has been checked for consistency, completeness and correctness: Checker Name and Signature: Philippe Pham (MCNP Model) Mike Mason (Results)	Date: 07/01/10
Calculation is approved for use: Project Engineer Name and Signature: Kamran Tavassoli	Date: 07/01/10

REVISION SUMMARY

REV.	DESCRIPTION OF CHANGES	AFFECTED PAGES	AFFECTED Computational I/O
0	Initial Issue	All	All
1	Incorporate design review comments, changes are marked with rev bars.	All, as marked	None

SUMMARY DESCRIPTION

The calculation performs Shielding Analysis of Horizontal Storage Module (HSM-HB) loaded with NUHOMS 32PHB bounding Dry Shielded Canister (DSC) containing design basis fuel loaded in accordance with the bounding heat zoning configuration. This is a fictitious loading configuration. However it results in HSM-HB dose rates that are bounding for all specified Design Criteria Document (DCD) DSC types and heat loading configurations.

Maximum and average dose rate values are calculated for gamma, neutron and for total radiation.

Spectral characteristics of fluxes at different segments on HSM-HB surface are calculated.

The section to be imported into shielding analysis section in the Safety Analysis Report (SAR) is completed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 PURPOSE

The purpose of this calculation is to determine gamma and neutron radiation dose rates at various locations around the Horizontal Storage Module (HSM-HB) containing bounding NUHOMS®- 32PHB Storage Dry Shielded Canister (DSC). The system is loaded with high burnup fuel assemblies, up to 62 GWD/MTU with a maximum assembly average initial enrichment of 5% wt U-235. The system will be licensed for storage in accordance with the requirements of Title 10, Part 72 (10 CFR 72) of the Code of Federal Regulations, via licensing amendment to the Calvert Cliffs Nuclear Power Plant ISFSI Final Safety Analysis Report , reference [5].

Maximum and surface averaged dose rates are calculated using bounding NUHOMS®-32PHB shielding\radiological source terms, reference [4] for Calvert Cliffs Independent Spent Fuel Installation Update Safety Analysis Report (ISFSI USAR).

MCNP5 version 1.40 computer software, reference [2] was used. For simplicity, it will be referred to as MCNP throughout the calculation.

2.0 REFERENCES

1. Transnuclear Design Criteria Document (DCD), NUH32PHB-0101, for the NUHOMS®- 32PHB System, Revision 0

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

3. Transnuclear Calculation, NUH32PHB-0201. "NUHOMS®- 32PHB Weight Calculation of DSC/TC System", Revision 0

4. Transnuclear Calculation, NUH32PHB-0501, Source Terms and Material Densities for Shielding Evaluation of NUHOMS®- 32PHB System, Revision 0

5. Calvert Cliffs Nuclear Power Plant ISFSI, "Updated Safety Analysis Report," Docket Numbers 50-317 and 50-318, Revision 17

6. Transnuclear Calculation, 1095-50. "NUHOMS®- 32P - HSM Dose Rates for Calvert Cliffs ISFSI". Revision 0

7. Transnuclear, Inc., "Updated Final Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel," NRC Docket No. 72-1004, Transnuclear Document No. NUH-003, Revision 10

8. Transnuclear Inc., "Updated Final Safety Analysis Report for the NUHOMS® HD Horizontal Modular Storage System for Irradiated Nuclear Fuel", NRC Docket No. 72-1030, Revision 1

9. K.Ueki, N. Nariyama, A. Ohashi, A. Yamaji. "Measurement of Dose-Equivalent Rates around a Cask and Monte Carlo Analysis with Actual Configuration of Fuel Basket". Journal of Nuclear Science and Technology, (Supplement 1, p.324-328), Atomic Energy Society of Japan, March 2000, ISSN 0022-3131

10. Transnuclear Calculation, NUH32PTH1.0600. "NUHOMS®-32PTH1 Transportable Dry Shielded Canister Criticality Analysis", Revision 0

11. Constellation Energy Nuclear Group Memo DE10269. "Axial Burnup Distribution of VAP Assemblies with and without Axial Blankets," Jan 23, 2009.

12. Transnuclear Calculation, NUH24PTH.0501. "Radiological Source Term Calculation for PWR Fuel with High Burn-Up. Fuel Qualification Tables for OS-197 Transfer Cask and HSM-H Loaded with 24PTH DSC", Revision 1

13. Oak Ridge National Laboratory, RSICC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for

Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6

14. MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory, LA-UR-03-0245, 2003

15. "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors". ANSI/ANS-6.11-1977, American Nuclear Society, La Grange Park, Illinois. March 1977

16. Transnuclear Calculation, NUH32PTH1.0502. "Surface Dose Rates Calculation for HSM-H Containing NUHOMS®-32PTH1 DSC With High Burn-up, up to 62 GWD/MTU, PWR Fuel", Revision 0

17. Transnuclear Calculation, 11064-050. "Millstone ISFSI Phase 1 and Phase 2 Dose Rates and Annual Exposure Calculation", Revision 0

18. Transnuclear Calculation, NUH61BTH.0502. "Surface Dose Rates Calculation for HSM-H and HSM Model 102 Containing NUHOMS®- 61BTH DSC Type 1 and Type 2 Loaded with High Burn-up, up to 62 GWD/MTU, BWR Fuel", Revision 1

19. Transnuclear Calculation, NUH32PTH1.0504. "Site Dose Rates of HSM-H Loaded with 32PTH1 Bounding DSC Containing Design Basis Fuel", Revision 0

20. M. D. DeHart, "Sensitivity and Parametric Evaluations of Significant Aspects of Burn-up Credit for PWR Spent Fuel Packages", ORNL/TM-12973, May 1996.

3.0 METHODOLOGY

The current calculation analyzes the shielding performance of the NUHOMS®- 32PHB system using MCNP5 version 1.40 computer software. The NUHOMS®- 32PHB system consists of the 32PHB DSC and the HSM-HB.

The following are sources of conservatism applied in this calculation.

3.1 Source Term Consideration

The bounding radiological source terms for fuel assemblies provided by CCNPP are shown in reference [1]. They are based on a decay heat limit of 0.8 kWt and 1 kWt.

The bounding DSC loading configuration considered in this calculation is an artificial heat zoning configuration that results in a total 32 kWt/DSC, which is slightly greater than the maximum allowable value in the Design Criteria Document (DCD) of 29.6 kWt/DSC. Then the DSC loading consists of 32 fuel assemblies with 1 kWt of decay heat.

3.2 Treatment of Neutron Multiplication

For the shielding calculations it is permissible to homogenize fuel assemblies within fuel compartments of the DSC inner structural grid. This is based on a study in reference [9]. It allows simplified modeling of fuel assembly internals as a homogenized mixture in MCNP models. One effect is that homogenization of the in-core region can result in innaccurate and often over-conservative neutron multiplication during MCNP runs. An MCNP user can turn-off neutron multiplication in MCNP input decks and multiply total neutron source term strength by the factor of $1/(1-k_{eff})$ to correct for neutron radiation dose rate. Here k_{eff} is an effective neutron multiplication factor, determined using specialized computer codes that involved more detailed analysis and treatment of fuel region. This was done as described in Section 4.2.

4.0 ASSUMPTIONS

4.1 Energy Mapping (Neutron and Gamma Source Energy Spectra)

The spontaneous fission spectrum of ^{244}Cm is used to represent the spectral distribution of the neutron source. Spontaneous fission of ^{244}Cm is responsible for more than 90% of the fixed neutron source for the PWR fuel considered. The only neutron sources are regions containing fuel materials. The source term consists primarily of spontaneous fission neutrons (largely from ^{244}Cm) with $(\alpha,^{18}O)$ sources of lesser importance, both causing secondary fission neutrons. The overall spectrum is represented well by the ^{244}Cm-fission spectrum.

4.2 Effective Neutron Multiplication Factor

Effective neutron multiplication factors are calculated in reference [10]. It was established throughout numerous criticality calculations performed by TN that $k_{eff}=0.40$ is a reasonably conservative representation of neutron multiplication for dry fuel in a dry DSC. This value is used for shielding performance analysis of the 32PHB DSC inside of the HSM-HB. A user can turn-off neutron multiplication in MCNP input decks. In order to account for the neutron multiplication in the dose rates, one should multiply total neutron source term strength or neutron and (n,g) dose rates after an MCNP run is complete by the factor of $1/(1-k_{eff})=1/(1-0.4)=1.67$.

4.3 Other Miscellaneous Assumptions

The major assumptions and conservative simplifications that are implicit in the MCNP model are as follows:

- The fuel assembly is homogenized, assuming no blankets, burnable absorbers or fission product poisons.

- The axial burn-up profile used in the current calculation is based on fuel with a low burnup (near 45 GWD/MTU), see reference [11]. This ensures that radiological source sampling along the DSC axis during MCNP calculations will be more concentrated

around the middle of the in-core region of the fuel assembly compared to sampling based on high burn-up profile. That means more radiation will enter the vent openings facing the HSM-HB inner cavity, which in turn results in higher dose rates near the vent openings outside the HSM-HB.

- The fixed poison plates in the basket are modeled as aluminum.

- Reconstituted fuel assemblies are not analyzed in this calculation. However, since they would represent a lower source term, they are allowed and the resulting dose rates are bounded by this calculation.

- The attachment access holes and the various weld studs on the rails and fuel compartment are not modeled.

- The contribution to the HSM-HB surface dose rate due to capture gamma sources is insignificant compared to the direct gamma sources and can be neglected. It was accounted for in this calculation, however, to obtain a detailed understanding of spectral and directional distribution of gamma radiation on the HSM-HB surface.

5.0 COMPUTATION

The NUHOMS® 32PHB DSC design is similar to the NUHOMS® 32P DSC design documented in reference [5] with the maximum decay heat load per canister increased from 21.12 kW to 29.6 kW. However, there are no parameters that are taken from NUHOMS® 32P DSC [6] and used directly in the current calculation.

The NUHOMS® 32PHB DSC has a nominal outside diameter and length (including grapple ring) of 67.25 inches and 176.5 inches (or 172.93 inches if not including the grapple ring plate), respectively. The DSC is 0.57 inches thick on the sides. Solid aluminum transition rails are incorporated into the 32PHB basket to accommodate heat loads up to 29.6 kW. The NUHOMS® 32PHB DSC consists of a shell assembly, which provides confinement and shielding, and an internal basket assembly, which locates and supports the fuel assemblies, transfers the heat to the cask body wall, and provides for criticality control as necessary to satisfy nuclear criticality safety requirements. The basket is a tube assembly, with aluminum and poison plates in between the tubes for heat transfer and criticality control. Except for the solid aluminum rails, the 32PHB basket is identical to the 32P basket documented in [5].

The HSM-HB to be used for the 32PHB system is the same as the horizontal storage module HSMH with flat stainless steel heat shields described in the UFSAR for standardized NUHOMS® System [7], Appendix P and the UFSAR for NUHOMS® HD System [8].

Since the maximum length of a 32PHB DSC (including the grapple ring) is 176.5", the HSM-HB internal cavity design has the flexibility to accommodate a shorter canister

length with minor changes to the design of the canister stop plate at the back end of the steel support structure.

The models are presented in Figure 5-1 through Figure 5-5.

The design inputs for the shielding analyses include material properties for the HSM-HB, DSC contents (spent fuel), the source term distributions and associated peaking factors, and the flux-to-dose conversion factors. The design inputs are described in the following sub-sections.

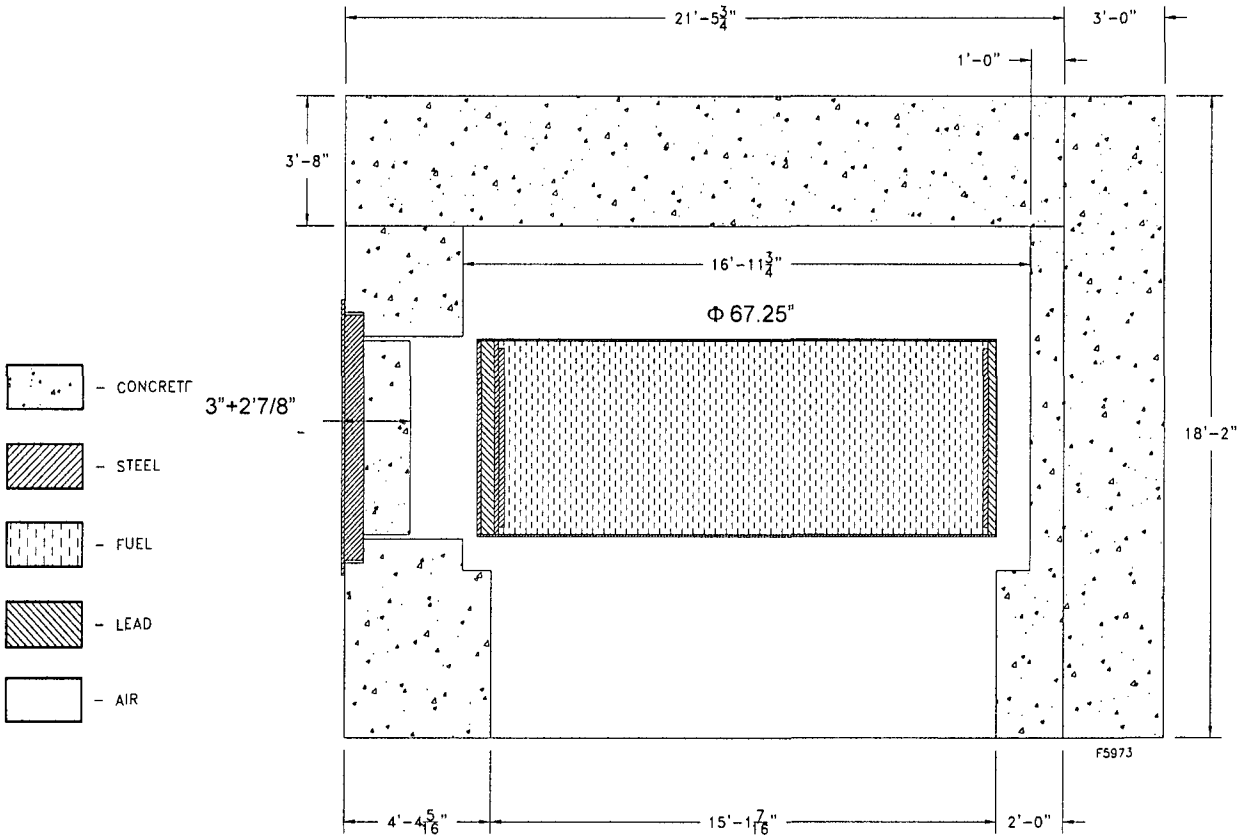


Figure 5-1
32PHB DSC within HSM-HB, Side View at Centerline of DSC

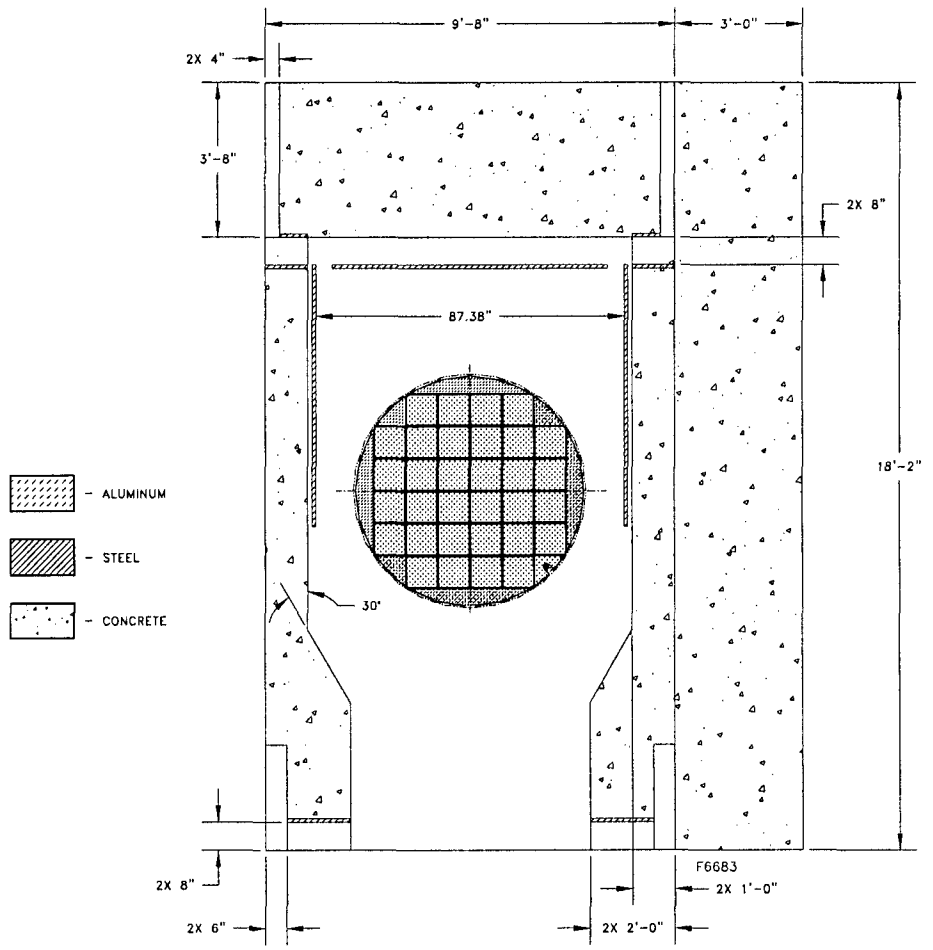


Figure 5-2
32PHB DSC within HSM-HB, Head-on View at Z=300 (Top Vents Caps are not Shown)

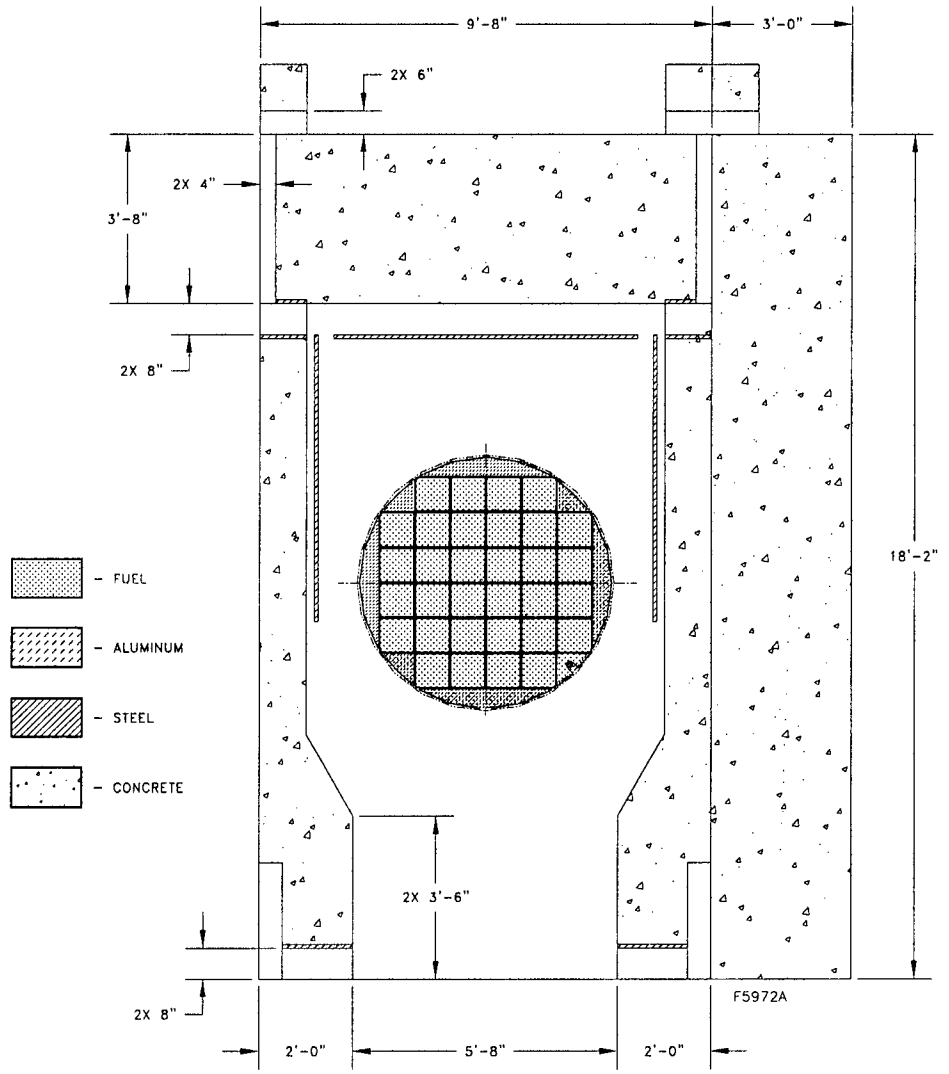


Figure 5-3
32PHB DSC within HSM-HB, Head-on View Showing Top Vents (Z=300 cm.)

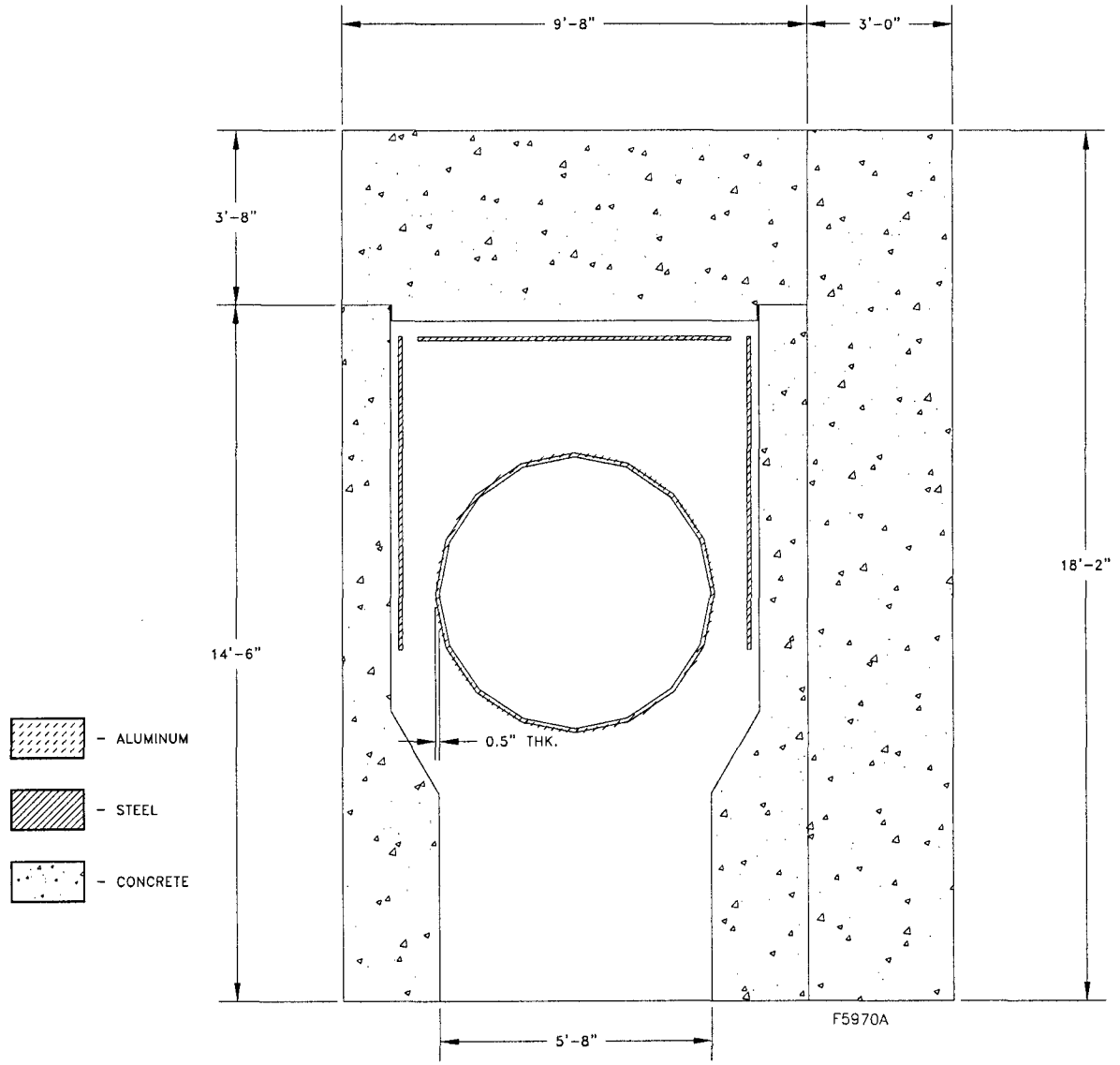


Figure 5-4
32PHB DSC within HSM-HB, Head-on View at Lid End of DSC (Z=560 cm)

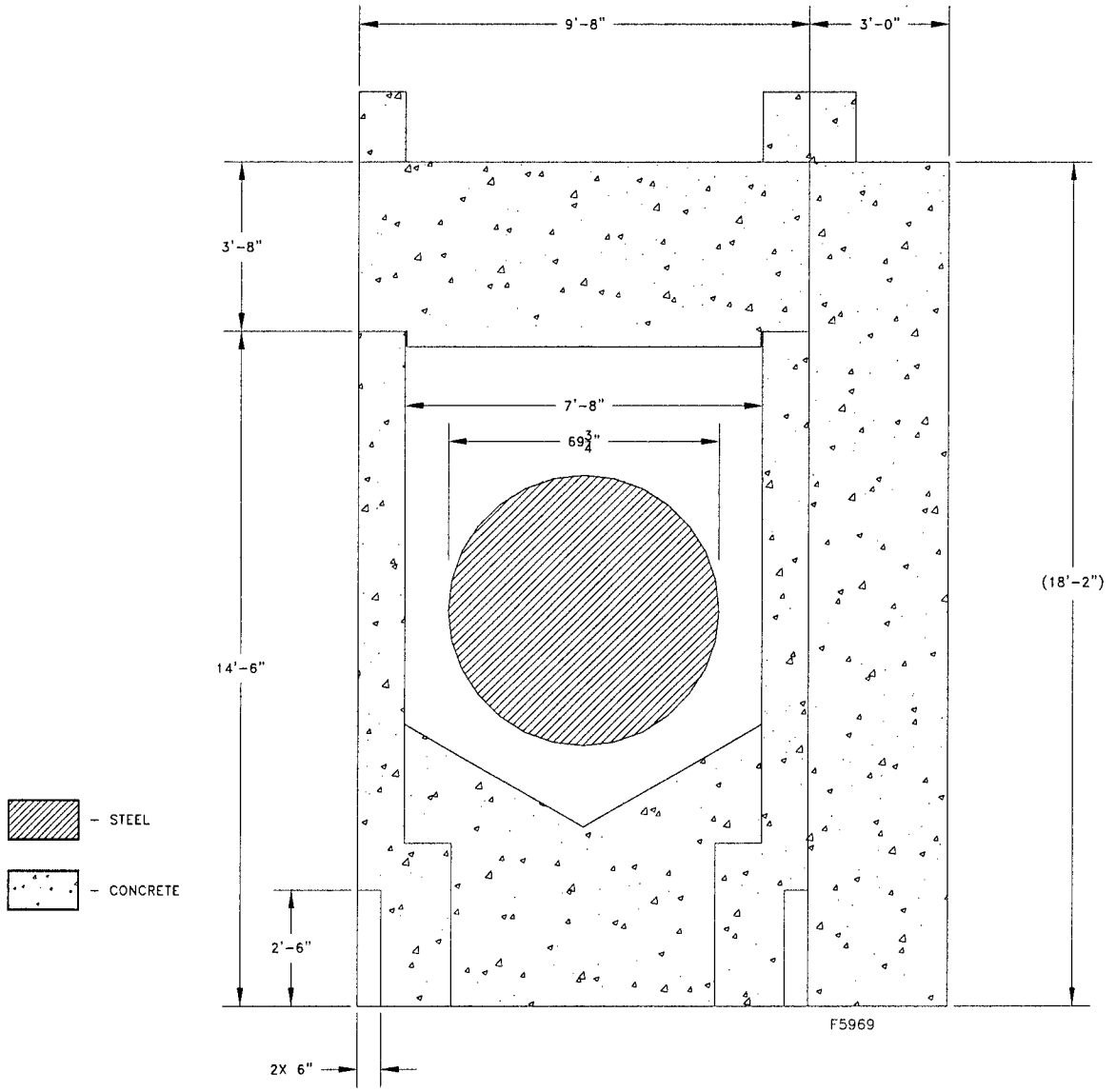


Figure 5-5
32PHB DSC within HSM-HB, Head-on View at Bottom End of DSC (Z=120 cm)

5.1 Axial Profile of Radiological Source Term

The axial source distribution from reference [11] has been utilized for the gamma source in the current calculation. It can be viewed in Table 5-1. The neutron source was taken from reference [20] and is shown in Table 5-2. Also, the way axial distribution was mapped along the in-core region axis can be viewed in the ***si6*** and ***sp6*** cards in the MCNP input decks. This distribution is simply the design basis axial distribution multiplied by the fractional core height. The gamma peaking factor is 1.000 and the neutron peaking factor is 1.13. This implies that a user should either multiply the total neutron radiation source term strength or neutron dose rates after the MCNP run is complete by a factor of 1.13. Note, however, that a factor of 1.152, reference [16], was conservatively used instead. The total adjustment factor for the neutron sources is calculated as 1.152/(1-0.40)=1.92.

Table 5-1
Source Term Peaking Factors Used for HSM-HB Shielding Analysis Summary [11]

Zone Number [11]	Zone Center in % of Height [11]	Zone Center Mapped on the Axis of the Active Fuel Zone (in.)	Lower Fuel Height (in.)	Upper Fuel Height (in.)	Burn-Up Profile[1] [11]
1	2.2	3.00	0.00	6.00	0.469
2	5.9	8.00	6.00	10.00	0.833
3	7.5	10.25	10.00	10.50	0.911
4	8.2	11.25	10.50	12.00	0.939
5	9.5	13.00	12.00	14.00	0.982
6	12.5	17.02	14.00	20.04	1.046
7	16.9	23.06	20.04	26.08	1.094
8	21.3	29.10	26.08	32.12	1.111
9	25.7	35.14	32.12	38.16	1.114
10	30.1	41.18	38.16	44.20	1.113
11	34.5	47.22	44.20	50.24	1.111
12	39.0	53.26	50.24	56.28	1.108
13	43.4	59.30	56.28	62.32	1.107
14	47.8	65.34	62.32	68.36	1.109
15	52.3	71.49	68.36	74.62	1.122
16	56.9	77.75	74.62	80.88	1.124
17	61.5	84.01	80.88	87.14	1.124
18	66.0	90.27	87.14	93.40	1.123
19	70.6	96.53	93.40	99.66	1.121
20	75.2	102.79	99.66	105.92	1.115
21	79.8	109.05	105.92	112.18	1.103
22	84.4	115.31	112.18	118.44	1.071
23	88.9	121.57	118.44	124.70	0.996
24	91.8	125.45	124.70	126.20	0.911
25	92.5	126.45	126.20	126.70	0.882
26	94.1	128.70	126.70	130.70	0.804
27	97.8	133.70	130.70	136.70	0.456

1. This profile was incorrectly calculated by dividing by a straight average of the burn-up profile values. A height weighted average should have been employed, which would result in a flatter profile. Therefore the burn-up profile given here is conservative because it is more highly peaked.

Table 5-2
Neutron Peaking Used for HSM-HB Shielding Analysis Summary [20]

Zone Number	Zone Center in % of Height	Zone Center Mapped on the Axis of the Active Fuel Zone, cm	Neutron Peaking Factor
1	1.2	152.98	0.184
2	5.0	166.00	0.689
3	10.0	183.36	1.036
4	15.0	200.72	1.174
5	20.0	218.08	1.306
6	25.0	235.44	1.321
7	30.0	252.81	1.321
8	35.0	270.17	1.316
9	40.0	287.53	1.311
10	45.0	304.89	1.306
11	50.0	322.25	1.306
12	55.0	339.61	1.301
13	60.0	356.97	1.301
14	65.0	374.33	1.306
15	70.0	391.69	1.301
16	75.0	409.05	1.291
17	80.0	426.41	1.174
18	85.0	443.78	0.976
19	90.0	461.14	0.597
20	95.0	478.50	0.167
21	98.8	491.52	0

5.2 Design Basis Radiological Source Term.

Design basis gamma and neutron radiation sources were presented in Tables 4-4 through 4-6 of reference [1]. The heat load zone configuration for the maximum heat load of 29.6 kWt per DSC is shown on Figure 4-1 of reference [1]. The gamma and neutron radiation source terms can be viewed in Table 5-3 and Table 5-4.

Conservatively, the heat load zone configuration considered in this calculation is a one zone load of 32 fuel assemblies at 1 kWt of decay heat per fuel assembly. The resulting maximum heat load is 32 kWt per DSC. Gamma radiation sources can be retrieved from cards ***sp10*** through ***sp17*** in the MCNP input decks.

It was shown in reference [12] that most of the neutron radiation source is due to spontaneous fission of the ^{244}Cm isotope. Spectral distribution of this source can be approximated with an analytical function $f(E) = \exp(-E/a) \cdot \sinh[(bE)^{0.5}]$. Here E is a neutron energy in MeV, a=0.906 MeV and b=3.848 MeV^{-1}. This function is built into MCNP. To account for critical multiplication of neurons during MCNP runs, one needs to multiply total neutron source strength by $1/(1-k_{eff})$ if the **nonu** card present in the input deck. Here k_{eff} –is the effective neutron multiplication factor.

Table 5-3
Bounding Radiological Source Term for the HSM-HB Based on a Decay Heat Limit of 0.8 kW, particles/(sec*FA)

0.420 MTU initial mass of uranium, **27 GWD/MTU** Burn-up, an **2.0 wt. %** U-235 enrichment and a cooling time of **3.6** years.						
Emin, MeV	to	E_{max}, MeV	Bottom Nozzle	In-core	Plenum	Top Nozzle
0.00E+00	to	2.00E-02	9.758E+11	1.513E+15	2.145E+11	4.748E+11
2.00E-02	to	3.00E-02	3.958E+12	3.326E+14	1.189E+11	3.876E+12
3.00E-02	to	4.50E-02	7.767E+11	3.944E+14	3.788E+10	7.202E+11
4.50E-02	to	7.00E-02	7.485E+10	2.659E+14	1.938E+10	2.638E+10
7.00E-02	to	1.00E-01	3.576E+10	1.887E+14	9.202E+09	1.275E+10
1.00E-01	to	1.50E-01	3.372E+10	2.079E+14	4.774E+09	2.270E+10
1.50E-01	to	3.00E-01	2.511E+11	1.686E+14	6.577E+09	2.484E+11
3.00E-01	to	4.50E-01	1.472E+12	8.958E+13	3.292E+10	1.472E+12
4.50E-01	to	7.00E-01	1.893E+12	2.257E+15	4.197E+10	1.893E+12
7.00E-01	to	1.00E+00	8.461E+10	4.627E+14	1.047E+11	1.178E+10
1.00E+00	to	1.50E+00	2.077E+13	8.671E+13	7.375E+12	1.848E+12
1.50E+00	to	2.00E+00	8.592E+03	3.702E+12	4.039E+03	1.908E+03
2.00E+00	to	2.50E+00	1.096E+08	2.907E+12	3.893E+07	9.751E+06
2.50E+00	to	3.00E+00	1.700E+05	7.189E+10	6.036E+04	1.512E+04
3.00E+00	to	4.00E+00	5.226E-10	8.869E+09	1.037E-13	1.320E-12
4.00E+00	to	6.00E+00	0.000E+00	3.477E+06	0.000E+00	0.000E+00
6.00E+00	to	8.00E+00	0.000E+00	4.003E+05	0.000E+00	0.000E+00
8.00E+00	to	11.00E+00	0.000E+00	4.604E+04	0.000E+00	0.000E+00
Total Gamma:			3.033E+13	5.973E+15	7.966E+12	1.061E+13
Total Neutrons			5.12E+08			

Table 5-4
Bounding Radiological Source Term for the HSM-HB Based on a Decay Heat Limit of 1.0 kW, particles/(sec*FA)

0.420 MTU initial mass of uranium, 37 GWD/MTU Burn-up, an 2.0 wt. % U-235 enrichment and a cooling time of 4.4 years.						
Emin, MeV	to	E_{max}, MeV	Bottom Nozzle	In-core	Plenum	Top Nozzle
0.00E+00	to	2.00E-02	1.198E+12	1.831E+15	2.601E+11	5.965E+11
2.00E-02	to	3.00E-02	5.012E+12	4.034E+14	1.487E+11	4.913E+12
3.00E-02	to	4.50E-02	9.523E+11	4.781E+14	4.591E+10	8.848E+11
4.50E-02	to	7.00E-02	9.054E+10	3.225E+14	2.327E+10	3.252E+10
7.00E-02	to	1.00E-01	4.315E+10	2.307E+14	1.105E+10	1.560E+10
1.00E-01	to	1.50E-01	4.105E+10	2.584E+14	5.742E+09	2.787E+10
1.50E-01	to	3.00E-01	3.085E+11	2.069E+14	8.050E+09	3.052E+11
3.00E-01	to	4.50E-01	1.809E+12	1.107E+14	4.044E+10	1.809E+12
4.50E-01	to	7.00E-01	2.326E+12	2.789E+15	5.157E+10	2.326E+12
7.00E-01	to	1.00E+00	1.139E+11	6.418E+14	1.412E+11	1.588E+10
1.00E+00	to	1.50E+00	2.486E+13	1.143E+14	8.848E+12	2.214E+12
1.50E+00	to	2.00E+00	1.970E+04	4.936E+12	8.729E+03	5.217E+03
2.00E+00	to	2.50E+00	1.312E+08	3.817E+12	4.670E+07	1.168E+07
2.50E+00	to	3.00E+00	2.035E+05	1.003E+11	7.241E+04	1.812E+04
3.00E+00	to	4.00E+00	1.540E-09	1.241E+10	1.714E-13	2.177E-12
4.00E+00	to	6.00E+00	0.000E+00	6.846E+06	0.000E+00	0.000E+00
6.00E+00	to	8.00E+00	0.000E+00	7.884E+05	0.000E+00	0.000E+00
8.00E+00	to	11.00E+00	0.000E+00	9.068E+04	0.000E+00	0.000E+00
Total Gamma:			3.68E+13	7.40E+15	9.58E+12	1.31E+13
Total Neutrons			6.66E+08			

5.3 Densities of Materials Employed in MCNP Models

Materials nomenclature employed in MCNP models include standard composition Air, Aluminum, Carbon Steel, Stainless Steel SS304, Water, Lead, and Concrete. Atomic composition, mass fractions and densities for such materials are taken from reference [4]. Densities for radiological source regions were also determined in reference [4]. They are not reproduced here but can be easily retrieved from the attached MCNP input\output decks and also can be verified in the standard material composition library in reference [13].

5.4 ANSI 6.1.1-1977 Flux-to-Dose Rate Conversion Factors

Flux-to-Dose rate conversion factors used in MCNP calculations in this analysis are taken from the MCNP manual [14]. They also can be calculated directly following the instructions outlined in ANSI 6.1.1-1977 standard [15]. Table 5-5 provides the values from the MCNP manual.

Table 5-5
ANSI/ANS-6.1.1-77 Flux to Dose Conversion Factors Used in MCNP Input Files

Gamma Radiation Energy E, MeV	Gamma Radiation Flux-Dose ANSI/ANS-6.1.1-1977 (mrem/hr)/(γ/cm^2-sec)	Neutron Radiation Energy E, MeV	Neutron Radiation Flux-Dose ANSI/ANS-6.1.1-1977 (mrem/hr)/(particle/cm^2-sec)
0.01	3.96E-03	2.5E-08	3.67E-03
0.03	5.82E-04	1E-07	3.67E-03
0.05	2.90E-04	1.00E-06	4.46E-03
0.07	2.58E-04	1.00E-05	4.54E-03
0.1	2.83E-04	1.00E-04	4.18E-03
0.15	3.79E-04	0.001	3.76E-03
0.2	5.01E-04	0.01	3.56E-03
0.25	6.31E-04	0.1	2.17E-02
0.3	7.59E-04	0.5	9.26E-02
0.35	8.78E-04	1	1.32E-01
0.4	9.85E-04	2.5	1.25E-01
0.45	1.08E-03	5	1.56E-01
0.5	1.17E-03	7	1.47E-01
0.55	1.27E-03	10	1.47E-01
0.6	1.36E-03	14	2.08E-01
0.65	1.44E-03	20	2.27E-01
0.7	1.52E-03		
0.8	1.68E-03		
1	1.98E-03		
1.4	2.51E-03		
1.8	2.99E-03		
2.2	3.42E-03		
2.6	3.82E-03		
2.8	4.01E-03		
3.25	4.41E-03		
3.75	4.83E-03		
4.25	5.23E-03		
4.75	5.60E-03		
5	5.80E-03		
5.25	6.01E-03		
5.75	6.37E-03		
6.25	6.74E-03		
6.75	7.11E-03		
7.5	7.66E-03		
9	8.77E-03		
11	1.03E-02		
13	1.18E-02		
15	1.33E-02		

5.5 General Procedure Outline

The radiation dose rates on the various surfaces of the HSM-HB containing the NUHOMS®-32PHB DSC are determined in this calculation. The three-dimensional, Monte Carlo particle transport computer code, MCNP has been utilized to calculate the dose rates.

The MCNP model employed in this calculation uses HSM-HB geometry originated from reference calculation [16]. It is essentially the same except for the door, the DSC support rails and the roof oulet vent. The methodology used in this calculation is not different from that in reference [16].

The MCNP model consists of the NUHOMS®-32PHB DSC inside the HSM-HB. The DSC is modeled with the explicit representation of the fuel compartments with homogenized fuel assemblies. The rails and the hold-down ring are homogenized.

Similar to reference [16], a refined approach for calculating dose rates on the HSM-HB surfaces was used in this analysis. This was achieved by utilizing MCNP5 mesh tally capabilities. In addition to the mesh tallies, regular MCNP tallies were applied over the entire regions where the mesh tally grids were superimposed. Such an approach provides an additional assurance in reliability of the mesh tallies results because regular MCNP tallies are subject to 10 statistical checks as described in the MCNP manual. Definition of the tallies and locations where dose rates on the HSM-HB surface are calculated are provided in Section 6.1.

5.6 MCNP Model for the NUHOMS®-32 PHB DSC

A three-dimensional, discrete fuel assembly model of the NUHOMS®-32PHB DSC was developed for this purpose. In the MCNP model, the DSC axis is modeled along the Z-direction. The X and Y axes in the MCNP model represent the DSC in the radial direction. The MCNP model for this calculation is based on a discrete basket with the homogenized fuel assemblies (with an active height of 136.7 inches) positioned within fuel compartments. The DSC cavity is 160.5" long and the basket extends to about 158" in the axial direction (Z-axis). The basket is modeled discretely using the advanced geometry features of MCNP. The fuel compartment inside dimension is 8.50" and is modeled with stainless steel. The borated aluminum (or any other poison material) plates were modeled as pure aluminum. Peripheral rails are modeled as aluminum at 0.95% of full density. A small air gap was assumed between the basket and the DSC shell. Both end shield plugs are in stainless steel with a lead core to reduce occupational dose levels. The grapple ring plate is not modeled.

5.7 MCNP Model for the HSM-HB containing the DSC

The HSM-HB length was designated as the Z axis (North-South direction), the width as the X axis (East-West direction), and the HSM-HB height as the Y axis. The HSM door is designated as the S side and the –Z direction, with the W wall as the –X direction.

The roof is the +Y direction. The W wall is designated as a reflective boundary and an end shield wall (3 ft thick) is attached to the E wall. The MCNP model is a full 3-D representation of a single DSC inside the HSM with the reflective boundary, end and side shield walls. A three foot thick concrete shield wall is placed at the rear of the HSM-HB. A NUHOMS®-32PHB DSC MCNP model was developed as described in section 5.6. The DSC (Z= 599.44 cm) lid is located 17" from the HSM-HB rear wall which places the bottom of the DSC at Z=116.33 cm, about 20.80 in from the door interior. The DSC support rails are included in the model. The following figures show the MCNP model of the HSM-HB containing the 32PHB DSC. The heat shields are modeled as flat plates without fins or louvers, and horizontal vent "liner" plates (2 cm thick) are modeled in the top side vents.

The door design utilized in the MCNP model is shown in Figure 5-6 and Table 5-6.

The DSC support rails are modeled.

The roof vents have stainless steel plates of 1" thickness. Dose rates are also evaluated to estimate the effect of those plates, see Section 11.0.

The MCNP model utilized in this calculation is shown in Figure 5-7 through Figure 5-11.

Two MCNP models are developed for this calculation. The gamma model containing a detailed segmentation of the thicker DSC steel end shields and HSM-HB door is utilized to calculate the gamma dose rates. The neutron model is utilized to calculate the neutron dose rates.

5.8 Deviations and discrepancies in MCNP model

The input decks used in the neutron analysis have some deviations and discrepancies. However, those are small regarding the system and the methodology. The results presented in Sections 6.0, 8.0 through 11.0 aren't greatly affected by those deviations and discrepancies, particularly because gamma is the dominant contributor to dose rates.

The deviations and discrepancies in MCNP model are:

- Fuel section is 8.1" instead of 8.25", as stated in Table 4-2 of reference [1]. Fuel section is determined as fuel rod pitch multiplied by 14.
- Bottom, plenum and top fuel lengths modeled (5", 9.33" and 5.98") are different from those in reference [4], respectively, 4.25", 10.525" and 5.766".
- Bottom, in-core region, plenum and top fuel densities modeled (1.43 g/cm^3, 3.94 g/cm^3, 1.70 g/cm^3 and 1.07 g/cm^3) are different from reference [4] respectively, 1.65 g/cm^3, 3.87 g/cm^3, 1.48 g/cm^3 and 1.09 g/cm^3.
- A generic neutron source was utliziled which contains a slightly different axial profile [20] and a source strength of 1.073E+9, 1.6 times greater than the bouding neutron source give in Table 5-3. However, the generic source profile is slightly flatter than the actual profile. These factor offset to some degree while remaining conservative.

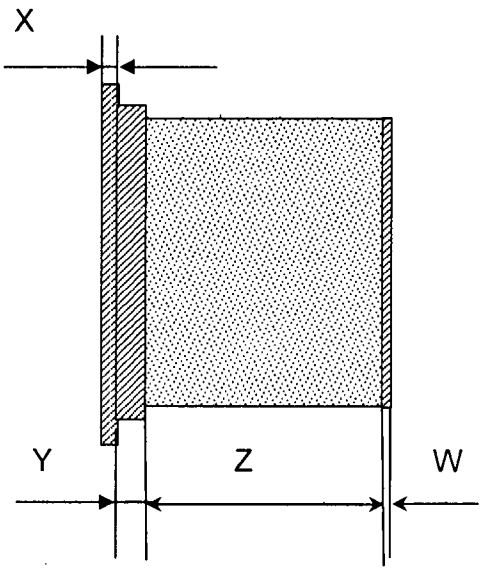


Figure 5-6
HSM-HB Door Shielding Configuration

Table 5-6
HSM-HB Door Shielding Configuration

	Material and Dimension			
	Steel	Steel	Concrete	Steel
	X	Y	Z	W
Door Design	3"	0"	2'-7/8" (Z+Y)	Not modelled

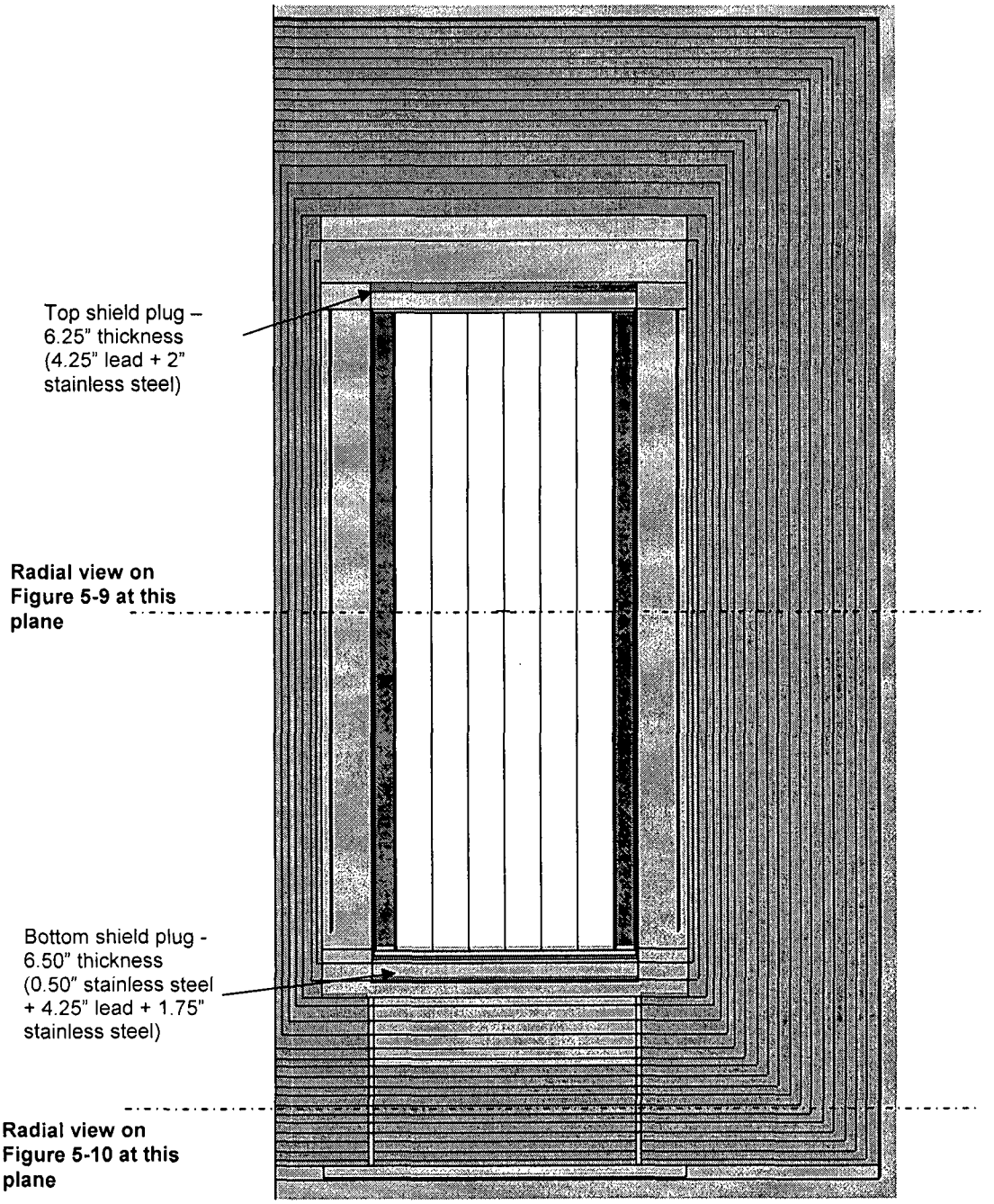


Figure 5-7
MCNP MODEL 32PHB DSC within HSM-HB, X-Z View, Cut-through at Y=0

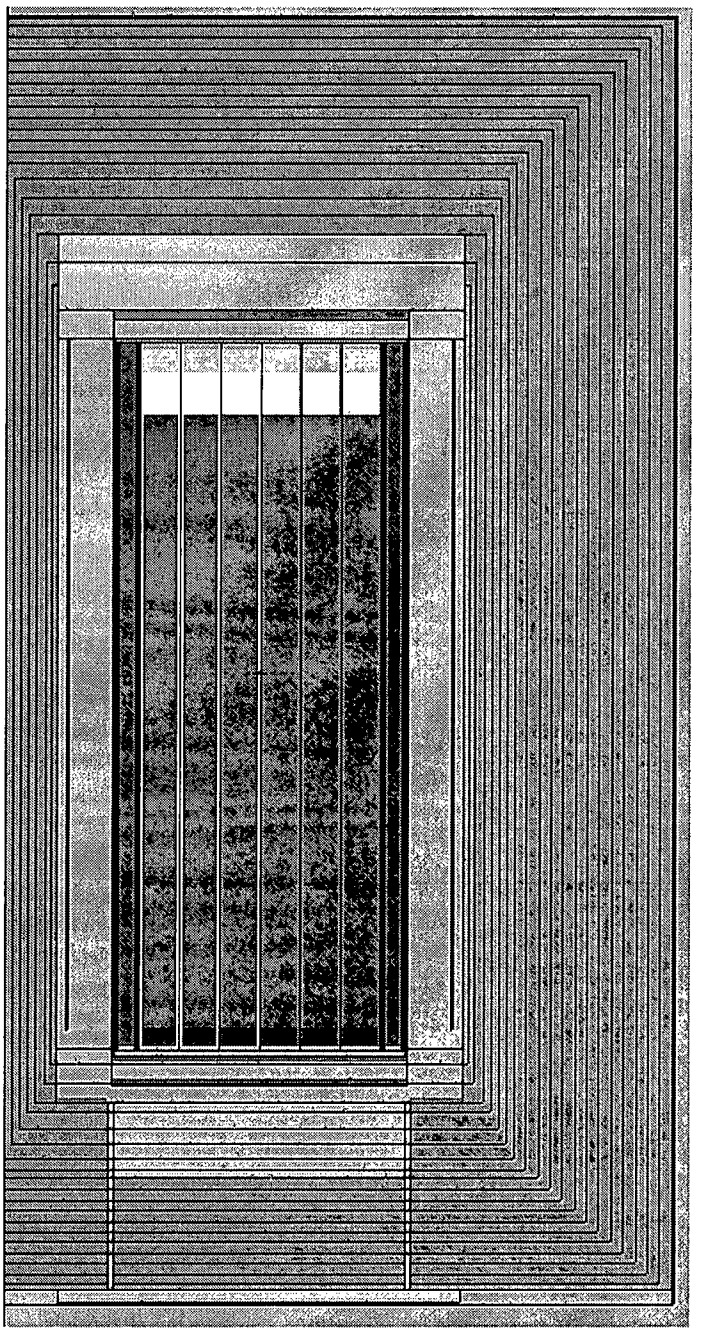


Figure 5-8
MCNP MODEL 32PHB DSC within HSM-HB, X-Z View, Cut-through at Y=5

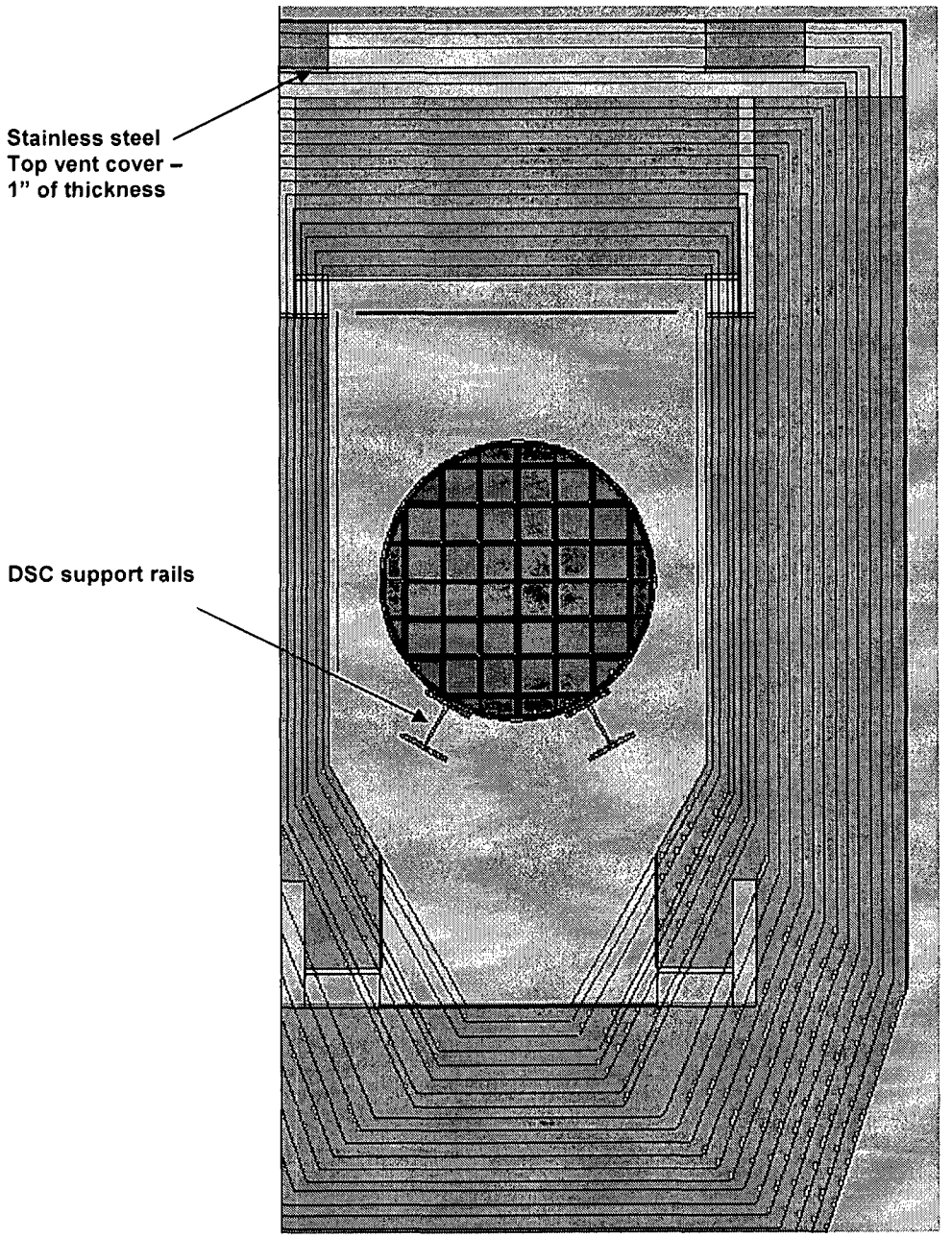


Figure 5-9
MCNP MODEL 32PHB DSC within HSM-HB, X-Y View, Cut-through at Z=300

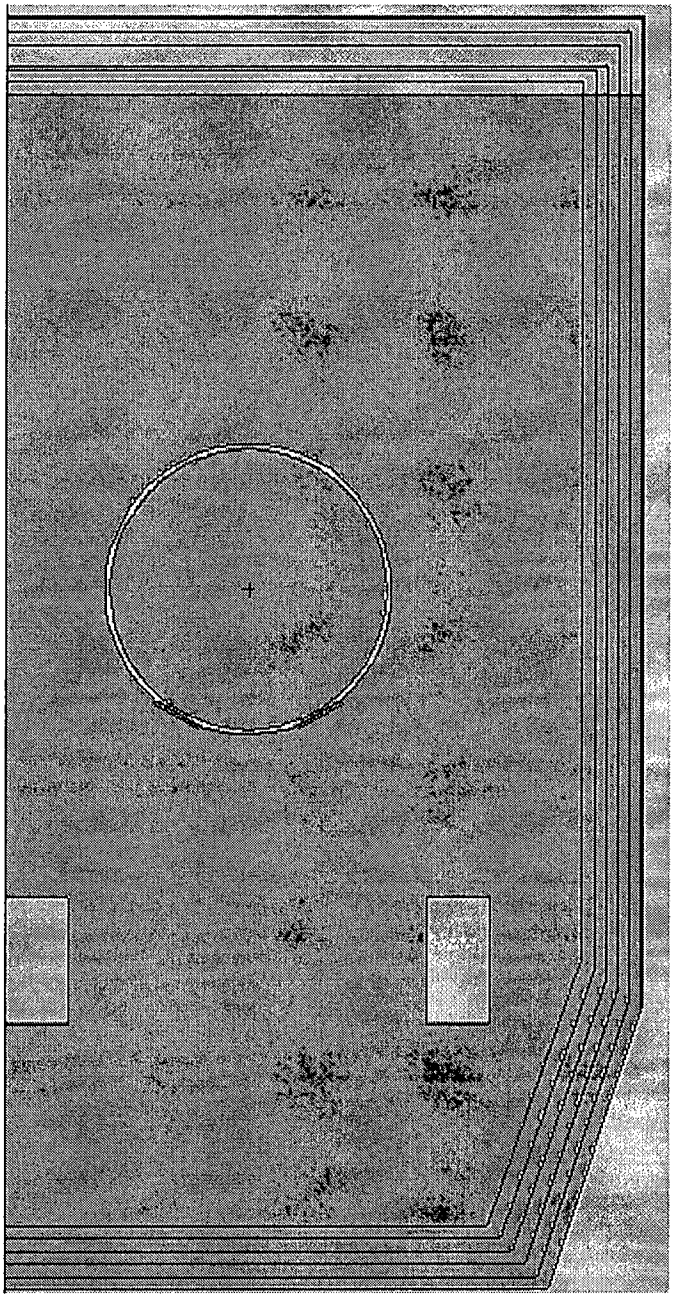


Figure 5-10
MCNP MODEL 32PHB DSC within HSM-HB, X-Y View, Cut-through at Z=30

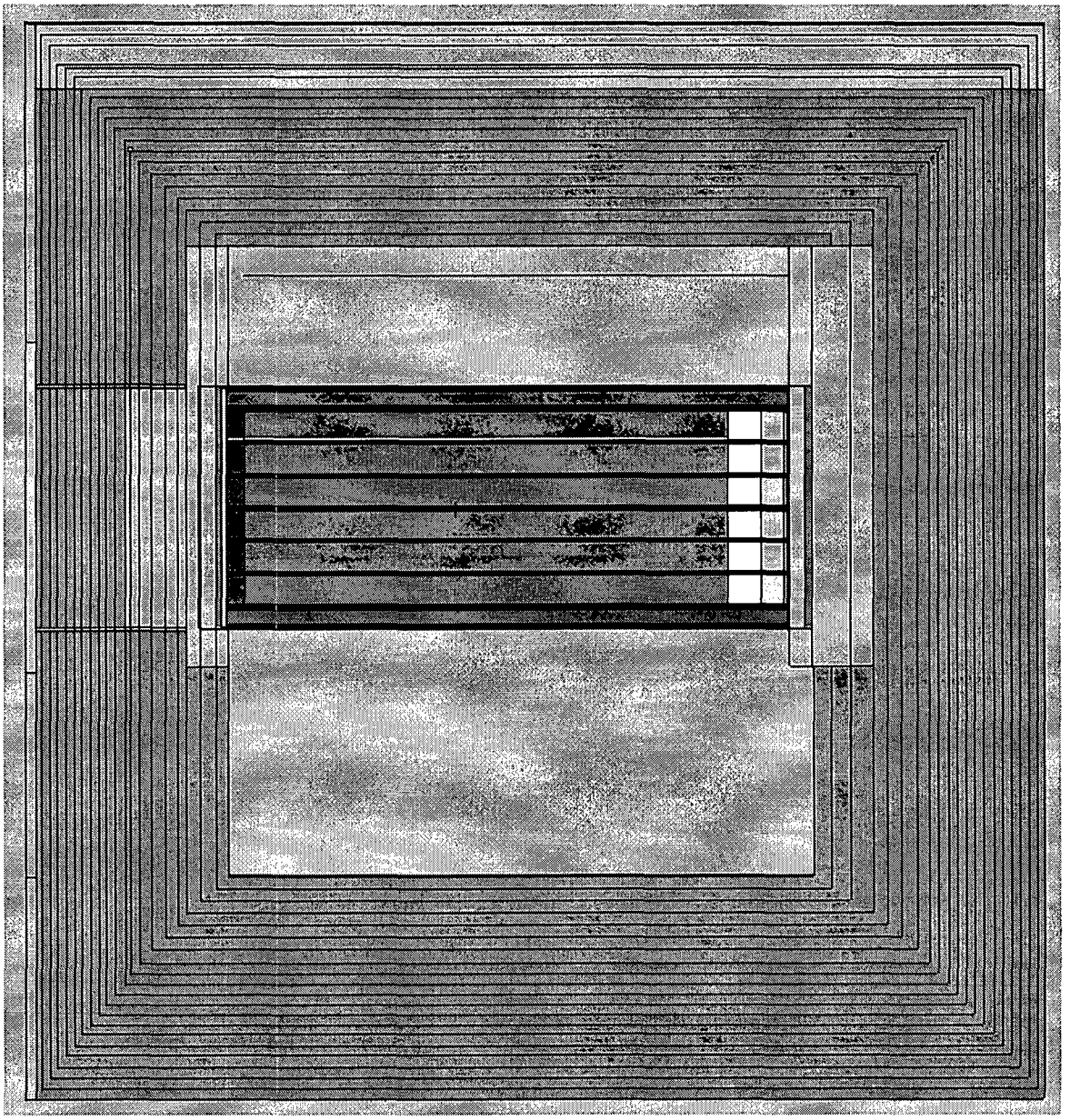


Figure 5-11
MCNP MODEL 32PHB DSC within HSM-HB, Z-Y View, Cut-through at X=5

6.0 RESULTS

This section summarizes results of MCNP runs and provides brief descriptions when necessary.

6.1 MCNP Tallies

Table 6-1 through Table 6-3 provide a cross reference matrix for MCNP tallies. They also map the tallies on the HSM-HB surface. The locations where tallies are mapped are shown on Figure 6-1.

MCNP run IDs are provided in tables starting in Section 6.1. These IDs refer to MCNP runs from which the given tallies are calculated.

Table 6-1
Cross Reference Matrix and Definition of MCNP Regular Tallies

MCNP Tally # (for neutrons)	MCNP Reference Cell or Surface ID	Definition of tally and what it is used for.
1 (201)	90	Angular distribution of integrated **current** on HSM-HB **front vents**, use segment 4 and 6 for vents on LHS (Left Hand Side) and RHS (Right Hand Side), respectively, see Figure 6-1.
11 (211)	76	Angular distribution of integrated **current** on HSM-HB **top** at vent opening level, use segment 4 through 7.
4 (204)	347	Averaged surface **dose rate** on HSM-HB **roof** at the level just on **top of vent caps**.
14 (214)	348	Averaged surface **dose rate** on HSM-HB 3' thick End Module Side Shield Wall (EMSSW)
24 (224)	353	Average surface **dose rate** at the HSM-HB **entire front**.
104 (304)	349	Average surface **dose rate** at the 3' thick HSM-HB **entire** Rear Shield Wall (RSW).
844 (944)	351	Average surface **dose rate** just over area bounded by perimeter of the HSM-HB **bottom vent opening on LHS**, see Figure 6-1
404 (504)	347	Averaged surface **flux** on HSM-HB roof at the level just on **top of vent caps**.
414 (514)	348	Averaged surface **flux** on HSM-HB 3' thick End Module Side Shield Wall (EMSSW)
424 (524)	353	Average surface **flux** at the HSM-HB entire **front**.
604 (704)	349	Average surface **flux** at the 3' thick HSM-HB **entire** Rear Shield Wall (RSW).
614 (714)	351	Average surface **flux** just in front of HSM-HB bottom **vent opening** that is formed between two adjacent HSMs
624 (724)	350	Average surface **flux** just in front of HSM-HB bottom **vent opening** that is formed between end module and 3' thk. End Module Side Shield Wall.

Table 6-2
Cross Reference Matrix and Definition of MCNP Regular Tallies to Study Contribution to Dose Rates near HSM-HB Vents Openings

MCNP Tally # (neutrons)	MCNP Reference Cell or Surface ID	* ID of Flagged Cell	Definition of tally and what it is used for
814 (914)	351	709 through 714	Contribution from **RHS** segment of a cell on bottom of HSM-HB **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs.
824 (924)	351	906	Contribution from **mid** segment of a cell on bottom of HSM-HB **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs.
834 (934)	351	715 through 720	Contribution from **LHS** segment of a cell on bottom of HSM-HB **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs.
844 (944)	351	20	Contribution from radiation entering only HSM-HB bottom vent inlet from **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs
854 (954)	351	615 through 619	Contribution from segment on **RHS** of HSM-HB **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs
864 (964)	351	609 through 613	Contribution from segment on **LHS** of HSM-HB **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between two adjacent HSMs
874 (974)	347	81	Contribution from radiation entering only HSM-HB **top vent inlet** from **inner cavity** to averaged dose rate just in front of the HSM-H bottom vent opening that is formed between two adjacent HSMs.
884 (984)	347	80	Contribution from radiation entering only HSM-HB **top vent inlet** from **inner cavity** to averaged dose rate just in front of the HSM-HB bottom vent opening that is formed between end module and 3' thick End Module Side Shield Wall (EMSSW).

* -- "Flagged Cell" means that dose rates are calculated for radiation coming from that particular, flagged cell only.

Table 6-3
Cross Reference Matrix and Definition of MCNP Mesh Tallies

Mapping on Figure 6-1	Tally *ID #	Corresponding Tables, 1 or 2D Plots	Definition of Tally and what it is Used for
C-C'	34 (234)	Table 6-8	Mesh on HSM-HB Front Centerline (1D, ~30 cm. wide grid from bottom to top): Also Calculates Maximum Dose Rate at Door Center (DSC axis)
F-F'	44 (244)	Table 6-18	Mesh on HSM-HB Rear Shield Wall Centerline
Bottom Vent 1	54 (254)	Table 6-4	2D Mesh on RHS Frontal Vent (End Module Side Shield Wall is at RHS, vent is 6" wide)
Bottom Vent 2	64 (264)	Table 6-4	2D Mesh on LHS Frontal Vent (Two adjacent HSM-Hs case, vent is 12" wide)
A-A'	84 (284)	Table 6-10	2D Mesh on HSM-HB 3 feet thick End Module Side Shield Wall: maximum at the level of DSC center
B-B'	84 (284)	Table 6-9	2D Mesh on HSM-HB 3 feet thick End Module Side Shield Wall: maximum at the level of DSC axis
D-D'	94 (294)	Table 6-12	2D Mesh on HSM-HB roof slab top: maximum at ~14 cm on the LHS from roof centerline (j-segment 1).
H-H'	94 (294)	Table 6-11	2D Mesh on HSM-HB top: maximum at the level just above top vent covers (j-segment 3, at X=~-13.9 cm from roof centerline)
E-E'	94 (294)	Table 6-15	2D Mesh on HSM top: maximum on top of LHS top vent cover (j-segment 3, at X=~-132 cm)
J-J'	94 (294)	Table 6-16	2D Mesh on HSM-HB top: maximum on top of RHS top vent cover (j-segment 3 at X=~135 cm)
G-G'	94 (294)	Table 6-13	2D Mesh on HSM-HB top: maximum at~ 13 cm. from bird screen of LHS vent cover (j-segment 1, which is just on top of HSM-H roof slab).
I-I'	94 (294)	Table 6-14	2D Mesh on HSM-HB top: maximum at~ 11 cm. from bird screen of RHS vent cover (j-segment 1, which is just on top of HSM-H roof slab).
**X-X'	94 (294)	Table 6-17	2D Mesh on HSM-HB top: maximum at about 3 feet above top of HSM-H roof slab (j-segment 5, at X=~-14 cm)

* -- tallies in parenthesis correspond to neutron radiation

** --X-X' is an imaginary line on a plane 3' above top of HSM-HB roof slab. This imaginary line is parallel to D-D'

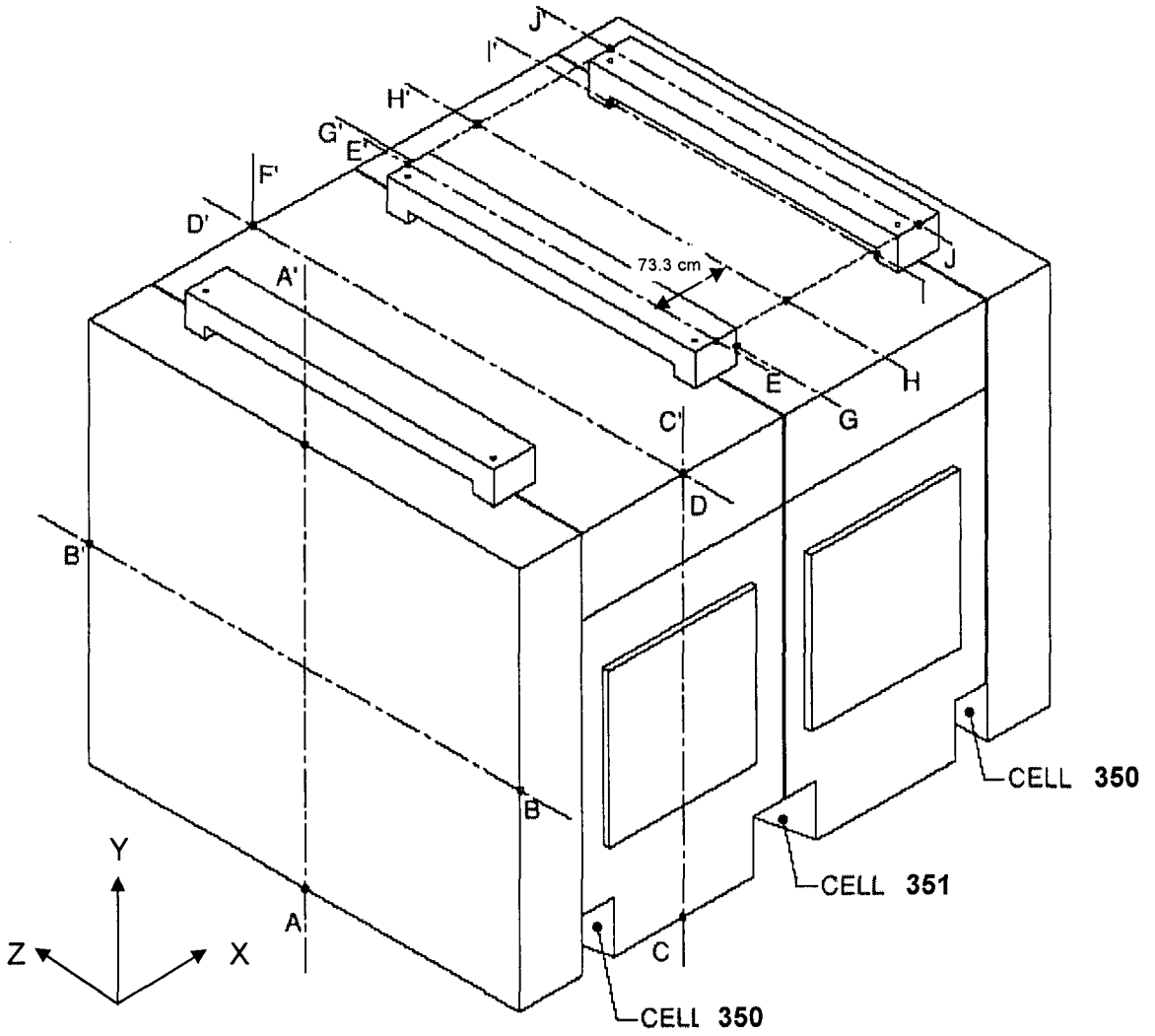


Figure 6-1
2x1 Array of HSM-Hs

The MCNP model used to simulate 2x1, side-by-side array of HSM-HBs is shown in Figure 6-1. More detailed drawings of the HSM-HB model analyzed with MCNP are shown in Figure 5-1 through Figure 5-5.

The X-axis is labeled as "Coordinate Measured from HSM-HB Front (or Roof\Rear) Centerline". The Y and Z-axes are labeled as "Vertical Elevation from DSC Axis Level" and "Distance Measured from HSM-HB Front to Rear" respectively. Figure 6-2 shows

cross reference mapping of DSC fuel compartments to the fuel matrix indices used for description of radiological source in the MCNP models.

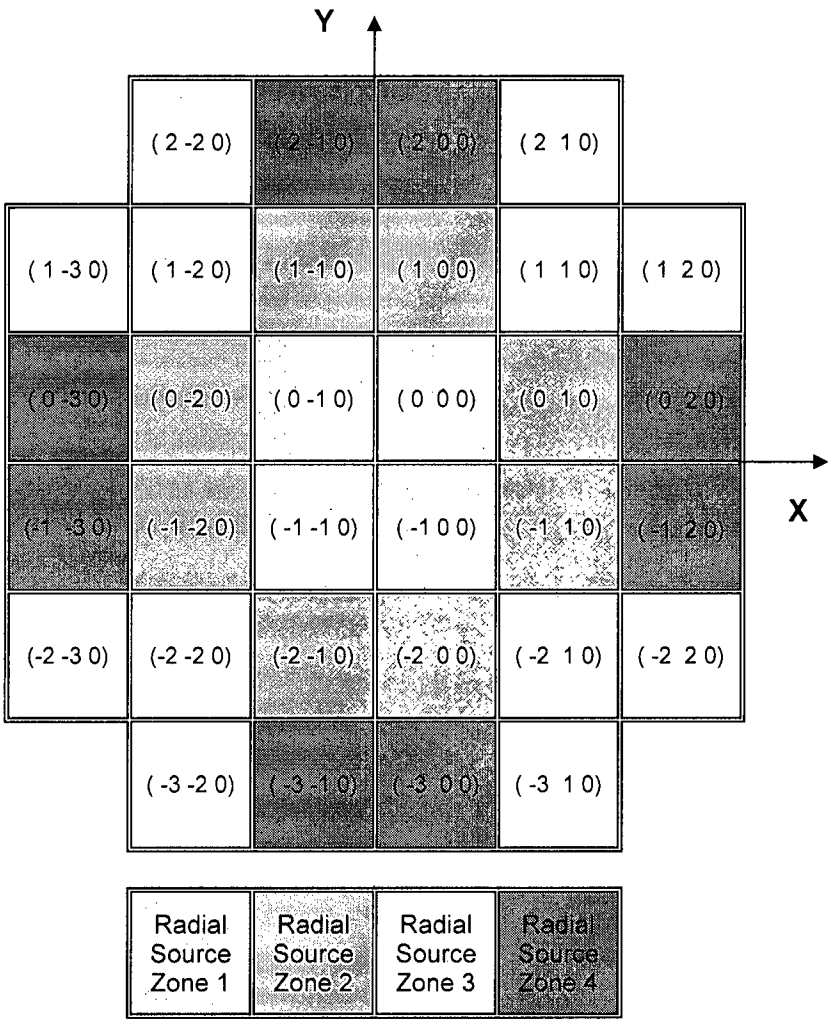


Figure 6-2
Mapping of DSC Fuel Compartments to MCNP Fuel Matrix Indices

Figure 6-2 also shows the definition of Radial Zones 1 through 4, designated with different colors.

Note that dose rates presented starting from Section 6.2 are due to radiological sources from Design Basis (DB) fuel assemblies. They do not account for contribution from DB BPRAs. This is permissible in this analysis because relative contribution from BPRA sources to the total HSM-HB dose rates at the important locationsdoes not exceed 5%.

6.2 Surface Averaged and Maximum Values for HSM-HB Dose Rates

Maximum dose rate values for dose rate locations listed in Table 6-3 are shown in Table 6-4. Refer to Table 6-3 and Figure 6-1 to understand where dose rate maximums are located.

Table 6-4
Summary of NUHOMS®-32PHB DSC (Bounding DSC with DB Fuel Loaded as in Bounding Configuration) in HSM-HB: Maximum Dose Rates

Mapping on Figure 6-1	Run ID	(*)"HSM-go, and "HSM-no		HSM-no		N/A		N/A	
	MCNP Tally ID (neutrons	Due To Gamma Radiation		Due To Neutron Radiation		Total: Gamma+Neutron Radiation		Gamma\Neutron Ratio	
		Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	"Gamma/ Neutron" Dose Rates Ratio	Absolute Error for the Ratio
F-F'	44 (244)	0.47	0.14	0.10	0.02	0.57	0.04	4.82	0.68
Door Center	44 (244)	0.60	0.03	0.38	0.04	0.98	0.02	1.61	0.07
*C-C'	34 (234)	0.85	0.09	2.61	0.34	3.24	0.28	0.33	0.12
Bottom Vent 1	54 (254)	19.9	0.10	2.87	0.09	21.9	0.09	6.93	0.93
Bottom Vent 2	64 (264)	110	0.11	10.3	0.01	121	0.01	10.7	0.15
D-D'	94 (294)	4.93	0.14	1.34	0.02	6.27	0.11	3.68	0.50
H-H'	94 (294)	8.34	0.06	1.77	0.01	10.1	0.05	4.70	0.30
E-E'	94 (294)	5.21	0.18	1.34	0.03	6.55	0.14	3.88	0.72
J-J'	94 (294)	1.22	0.09	0.43	0.04	1.59	0.06	2.81	0.27
G-G'	94 (294)	35.2	0.06	11.9	0.01	47.1	0.03	2.95	0.19
I-I'	94 (294)	7.49	0.09	2.92	0.02	10.2	0.06	2.57	0.23
See Table 6-3 (X-X')	94 (294)	6.69	0.10	1.36	0.01	7.99	0.08	4.92	0.47
B-B'	84 (284)	0.64	0.17	0.12	0.02	0.76	0.15	5.42	0.91

* -- Gamma and Neutron dose rate peaks do not always occur at the same location; therefore, the total dose rate is not always the sum of the gamma plus neutron dose rate.

Table 6-5
Summary of NUHOMS®-32PHB DSC (Bounding DSC with DB Fuel Loaded as in Bounding Configuration) in HSM-HB: Averages over Entire Surface Dose Rates

Run ID	"HSM-go", "HSM-no"		"HSM-no"		N/A		N/A	
MCNP Tally ID or Location	Due To Gamma Radiation		Due To Neutron Radiation		Total: Gamma+Neutron Radiation		Gamma/Neutron Dose Rate Ratio	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	"Gamma/ Neutron" Dose Rates Ratio	Absolute Error for the Ratio
4 (204)	2.71	0.02	0.66	0.007	3.37	0.02	4.1	0.1
14 (214)	0.20	0.01	0.04	0.005	0.24	0.01	4.6	0.1
24 (224)	1.87	0.06	0.29	0.02	2.16	0.05	6.4	0.4
104 (304)	0.05	0.01	0.008	0.009	0.06	0.01	6.3	0.1
814 (914)[1]	2.56	0.41	0.83	0.30	3.39	0.31	3.1	1.6
824 (924)[1]	5.63	0.40	1.35	0.18	6.98	0.33	4.2	1.8
834 (934)[1]	26.4	0.14	3.11	0.03	29.6	0.12	8.5	1.2
844 (944)[1]	70.4	0.08	7.27	0.05	77.7	0.07	9.7	0.9
854 (954)[1]	8.73	0.27	2.07	0.03	10.8	0.22	4.2	1.1
864 (964)[1]	12.7	0.20	1.72	0.05	14.5	0.17	7.4	1.5
874 (974)[1]	1.46	0.03	0.38	0.01	1.84	0.03	3.8	0.1
884 (984)[1]	0.25	0.05	0.09	0.01	0.34	0.03	2.7	0.1
LHS Vent Inlet[2]	77.1	0.07	9.53	0.04	86.7	0.07	8.1	0.7

1. Tally IDs 814 thru 884 are flagged tallies (see table 6-3) and the dose rates shown in this table are the dose rates from the flagged cells only.
2. This is a tally averaged over a cell covering the HSM-H front vent between two adjacent HSMs in a side-by-side array. It is referred to as LHS Vent in this analysis, see definition in Table 6-3.

Dose rates averaged over a half portion of the HSM-HB front, roof or rear surface are also needed for ISFSI dose rates analysis. Dose rates presented in Table 6-6 are averaged over segments located at the left hand and right hand side from centerline on those surfaces, respectively. Spectral distributions of gamma and neutron radiation flux for tallies in Table 6-5 and Table 6-6 are provided in Section 10.0.

Table 6-6
Summary of NUHOMS®-32PHB DSC (Bounding DSC with DB Fuel Loaded as in Bounding Configuration) in HSM-HB: Averages over Segment on the LHS and RHS from Centerline Dose Rates

Run ID	"HSM-go", "HSM-no"		"HSM-no"		N/A		N/A	
MCNP Tally ID	Due To Gamma Radiation		Due To Neutron Radiation		Total: Gamma+Neutron Radiation		Gamma/Neutron Dose Rate Ratio	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate mrem/hr	Dose Rate Relative Error	"Gamma/ Neutron" Dose Rates Ratio	Absolute Error for the Ratio
4 (204)	4.59	0.03	1.08	0.008	5.67	0.02	4.2	0.1
24 (224)	4.30	0.07	0.59	0.03	4.90	0.07	7.3	0.6
104 (304)	0.05	0.01	0.009	0.01	0.06	0.01	6.1	0.1
*4 (204)	1.55	0.03	0.41	0.006	1.96	0.02	3.8	0.1
*24 (224)	0.57	0.05	0.13	0.01	0.70	0.04	4.4	0.2
*104 (304)	0.04	0.01	0.007	0.010	0.05	0.01	6.4	0.1

*-- These tallies correspond to dose rates averaged over segments on the right hand side (RHS) from centerlines.

The gamma and neutron radiation fluxes are needed for the ISFSI analysis. These are provided in Section 10.0. It was analyzed during preparation of this calculation and reference [17] that TN methodology provides an accurate representation of the ISFSI dose rates in front of the HSM-HB array bottom vent inlets at distances greater than 6 meters.

MCNP allows not only calculating dose rates but also determining contribution to the dose rate due to radiation coming through specified cells. Such an approach in calculating dose rates is referred to as flagging. The MCNP cells for which a user needs to quantify contribution to the total dose rate are referred to as flagging cells. The flagging cells are shown in the third column of Table 6-2. For example tally 874 (974) and 844 (944) is flagged with MCNP cell 81 and 20, respectively. Cell 81 is at an opening of the top vent. The vent is between two adjacent HSMs in a side-by-side array. Cell 20 is at an opening of the bottom vent that is between two adjacent HSMs in a side-by-side array. Tally 874 (974) calculates surface averaged dose rate on top of the HSM-HB. Because it is flagged with cell 81, it will also calculate how much of the HSM-HB surface averaged dose on top of HSM-HB is due to radiation entering the top vent opening from the inner HSM-H cavity only. Similarly, tally 844 (944) allows to determine how much of the gamma (neutron) radiation dose rate in front of the vent opening is due to radiation entering the vent inlet from inside the HSM-HB.

Dose rates on top of the HSM-HB roof slab and in front of the front vent opening that are due to radiation entering vents inlets from the HSM-HB inner cavity are quantified in Table 6-7. The total dose rate for the cell is is labeled as "Net", and the component that is due to penetration through the concrete structure is referred to as "Net"-"Flagged" in the table. One can determine from the table that 63% of gamma radiation (74 % for

neutrons) dose rate on the HSM-HB top is due to radiation entering the top vent inlets from the HSM-HB inner cavity. On the other hand it was established in reference [18] that more than 80% of the dose rates near the HSM-HB top are due to radiation streaming through top vent shafts. These results suggest that a substantial portion of radiation penetrates the vertical shafts of top vents through the HSM-H roof slab and possibly the concrete structure side walls.

Dose rates from tally 844 (944) suggest that gamma and neutron radiation entering the bottom vent between two adjacent HSMs in a side-by-side array from the HSH-HB inner cavity account for 93% (76%), respectively, of the gamma and neutron dose rate in front of the front vent opening.

Quantative knowledge on how much radiation scattered from different segments inside of the HSM-HB contributes to dose rates in front of the HSM-HB front vents represents a practical value if one is interested in reducing dose rates near the HSM-H front. This might be especially useful for the ISFSI dose rate calculations when strict dose rate limits are imposed.

Differences between numerous sets of MCNP input\output decks, designated with Run IDs in the tables of this section, are explained in Section 13.1.

Table 6-7
Summary of NUHOMS® 32PHB DSC (DB Fuel Loaded in Bounding DSC as in Bounding Configuration) in HSM-HB: Net vs. "Flagged" Dose Rates

Run ID	"HSM-go", "HSM-no"		"HSM-no"		N/A		N/A	
F4 Type Tally	Due To Gamma Radiation		Due To Neutron Radiation		Total: Gamma+Neutron Radiation		Gamma/Neutron Dose Rates Ratio	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	"Gamma/ Neutron" Dose Rates Ratio	Absolute Error for the Ratio
"Flagged" Values								
814-834 (914-934)	34.6	0.13	5.30	0.07	39.9	0.11	6.5	0.9
844 (944)	70.4	0.08	7.27	0.05	77.7	0.07	9.7	0.9
854 (954)	8.73	0.27	2.07	0.03	10.8	0.22	4.2	1.1
864 (964)	12.7	0.20	1.72	0.05	14.5	0.17	7.4	1.5
874 (974)	1.46	0.03	0.38	0.01	1.84	0.03	3.8	0.1
884 (984)	0.25	0.05	0.09	0.01	0.34	0.03	2.7	0.1
"Net" Values								
814-864 (914-964)	77.1	0.07	9.53	0.04	86.7	0.07	8.1	0.7
874-884 (974-984)	2.71	0.01	0.66	0.007	3.37	0.01	3.70	0.04
"Net"-"Flagged" Values								
814-834 (914-934)	42.5	0.17	4.23	0.13	46.7	0.15	10	2.1
844 (944)	6.70	1.18	2.25	0.25	8.96	0.89	3.0	3.6
854 (954)	68.4	0.09	7.45	0.05	75.9	0.08	9.2	1.0
864 (964)	64.4	0.10	7.81	0.05	72.2	0.09	8.2	0.9
874 (974)	1.25	0.04	0.28	0.02	1.54	0.04	4.4	0.2
884 (984)	2.46	0.01	0.57	0.01	3.03	0.01	4.3	0.1
"Flagged"/"Net" Ratio								
814-834 (914-934)	0.45	0.15	0.56	0.08	0.46	0.13	0.8	0.1
844 (944)	0.91	0.11	0.76	0.07	0.90	0.10	1.2	0.2
854 (954)	0.11	0.28	0.22	0.05	0.12	0.23	0.5	0.1
864 (964)	0.17	0.21	0.18	0.06	0.17	0.18	0.9	0.2
874 (974)	0.54	0.04	0.57	0.01	0.54	0.03	0.9	0.0
884 (984)	0.093	0.05	0.14	0.01	0.10	0.04	0.7	0.0

6.3 Distributions of Calculated Dose Rates

Maximum values of dose rates shown in tables of Section 6.2 are obtained from 2D spatial distributions (mesh tallies).

Using the same coordinate system to display data in Table 6-8, Table 6-10 and Table 6-18, the bottom and top of the HSM-HB roof slab are at vertical elevations of 182.88 and 294.64 cm, respectively. The range of coordinates between those two planes is shaded in the tables. One would expect a steady decrease of dose rates within the

range of shaded cells, as the tables indicate, except for Table 6-18. This phenomenon is discussed in the text below Table 6-18.

The coordinate system used to display data in miscellaneous plots and tables from this calculation is shown in Figure 6-1. Its origin is at an intersection between the DSC axis and front face of the HSM-HB front wall (not to be confused with the front face of the HSM-HB door). Consider the data in Table 6-9 and Table 6-11 through Table 6-17. The HSM-H inner cavity starts at the Z (horizontal, along DSC axis) coordinate equal to 123.84 cm and ends at 539.70 cm. The range of coordinates beyond those two planes in the tables lies within concrete. It is shaded in the tables. One would expect a steady decrease of dose rates within the range of shaded cells as the tables indicate.

6.3.1 Dose Rate in front of HSM-HB Bottom Vents and HSM-HB Front

Using the coordinate system employed to display data in Table 6-8, the top of the HSM-HB roof slab is at vertical elevation of 294.64 cm. At vertical elevations greater than that, radiation streaming through the top vents and scattered from the top vent covers contributes to the dose rates. That is why one can see an increase in dose rates in the shaded cells of Table 6-8.

Table 6-8
Dose Rate on HSM-HB in Vertical Elevation along Centerline on HSM-HB Front (along C-C' line in Figure 6-1)

MCNP Run ID	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	34		234		N/A	
Segment or bin #	12		12		N/A	
Vertical Elevation Measured from Level of DSC Axis, cm	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
-254.50	1.26E-01	0.21	4.55E-02	0.03	1.71E-01	0.16
-245.35	1.31E-01	0.14	4.76E-02	0.03	1.79E-01	0.10
-236.19	1.55E-01	0.15	4.88E-02	0.03	2.04E-01	0.11
-227.04	1.51E-01	0.13	4.77E-02	0.03	1.99E-01	0.10
-217.89	1.45E-01	0.13	5.04E-02	0.03	1.96E-01	0.10
-208.73	1.56E-01	0.16	5.17E-02	0.03	2.07E-01	0.12
-199.58	1.63E-01	0.13	5.31E-02	0.03	2.16E-01	0.10
-180.00	1.98E-01	0.09	6.00E-02	0.03	2.58E-01	0.07
-150.00	3.25E-01	0.05	1.04E-01	0.03	4.29E-01	0.04
-120.00	4.41E-01	0.06	2.16E-01	0.08	6.58E-01	0.04
-90.00	6.25E-01	0.16	2.61E+00	0.34	3.24E+00	0.28
-60.00	5.24E-01	0.04	4.95E-01	0.13	1.02E+00	0.07
-30.00	5.73E-01	0.03	3.74E-01	0.04	9.47E-01	0.02
0.00	6.05E-01	0.03	3.77E-01	0.04	9.81E-01	0.02
27.33	5.99E-01	0.03	3.78E-01	0.04	9.77E-01	0.03
52.00	5.62E-01	0.02	4.03E-01	0.04	9.65E-01	0.02
76.67	8.49E-01	0.09	2.12E+00	0.17	2.97E+00	0.12
100.22	5.07E-01	0.11	9.39E-01	0.15	1.45E+00	0.11
125.04	6.33E-01	0.04	2.66E-01	0.05	8.99E-01	0.03
152.24	4.60E-01	0.03	1.41E-01	0.03	6.01E-01	0.02
179.43	3.07E-01	0.05	8.75E-02	0.02	3.94E-01	0.04
207.00	2.08E-01	0.08	5.73E-02	0.03	2.65E-01	0.06
234.94	1.17E-01	0.10	3.31E-02	0.03	1.50E-01	0.08
262.89	6.42E-02	0.12	2.11E-02	0.03	8.53E-02	0.09
290.83	2.03E-01	0.13	6.15E-02	0.02	2.64E-01	0.10
320.04	6.04E-01	0.10	1.55E-01	0.02	7.59E-01	0.08
350.52	1.33E+00	0.10	2.31E-01	0.02	1.56E+00	0.09
381.00	7.87E-01	0.11	2.20E-01	0.02	1.01E+00	0.09

6.3.2 Dose Rate on Side of 3' thick End Module Side Shield Wall

Table 6-9 displays the dose rates along the line designated as B-B' on Figure 6-1. The rear shield wall extends up to the outer edge of the EMSSW. Conservatively, it is extended to the edge of the HSM-HB side wall only in the MCNP models. Because of

that, there is only about 2 feet of concrete at the area near the HSM-HB EMSSW and rear shield wall interface. That is the reason the dose rates in the shaded cells of Table 6-9 are high.

Table 6-10 corresponds to dose rate distributions along the line designated as A-A' on Figure 6-1. At vertical elevation greater than that, radiation streaming through top vents and scattered from top vent covers contributes to the dose rates. That is why one can see an increase in dose rates in the shaded cells of Table 6-10.

Table 6-9
Dose Rate on Side of 3' thick End Module Side Shield Wall at DSC Axis Level (along B-B' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	84		284		N/A	
Segment or bin #	1 (at Y=-2.88 cm.)		1 (at Y=-2.88 cm.)		N/A	
Distance Measured on HSM-HB EMSSW in Horizontal Direction at Level of DSC Axis, (HSM-HB front is at 0.0 cm.), cm.	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	3.18E-02	0.14	5.68E-03	0.04	3.75E-02	0.12
84.38	9.57E-02	0.10	1.07E-02	0.04	1.06E-01	0.09
113.97	2.64E-01	0.10	2.24E-02	0.05	2.86E-01	0.10
143.56	4.49E-01	0.14	3.96E-02	0.03	4.89E-01	0.13
173.15	5.07E-01	0.13	6.35E-02	0.04	5.70E-01	0.12
202.74	6.07E-01	0.13	8.60E-02	0.03	6.93E-01	0.11
232.33	5.77E-01	0.12	1.02E-01	0.02	6.78E-01	0.10
261.91	5.93E-01	0.15	1.15E-01	0.02	7.08E-01	0.13
291.50	6.07E-01	0.08	1.18E-01	0.02	7.25E-01	0.07
321.09	6.41E-01	0.09	1.17E-01	0.02	7.58E-01	0.07
350.68	5.74E-01	0.08	1.18E-01	0.02	6.92E-01	0.07
380.27	5.52E-01	0.13	1.13E-01	0.02	6.65E-01	0.11
409.86	6.17E-01	0.14	1.03E-01	0.02	7.20E-01	0.12
439.45	5.09E-01	0.13	8.40E-02	0.02	5.93E-01	0.11
469.03	4.77E-01	0.13	6.00E-02	0.03	5.37E-01	0.11
498.62	3.45E-01	0.17	3.69E-02	0.03	3.82E-01	0.15
528.21	1.75E-01	0.10	2.08E-02	0.03	1.96E-01	0.09
557.80	1.09E-01	0.15	1.22E-02	0.04	1.21E-01	0.13
587.39	6.08E-02	0.10	7.13E-03	0.04	6.79E-02	0.09
616.98	3.54E-02	0.11	4.07E-03	0.04	3.94E-02	0.10
646.57	1.38E-02	0.16	2.61E-03	0.05	1.64E-02	0.13
678.03	6.33E-03	0.28	1.79E-03	0.04	8.13E-03	0.22
711.36	1.99E-03	0.20	1.47E-03	0.05	3.45E-03	0.12
744.69	1.94E-03	0.14	2.33E-04	0.05	2.18E-03	0.13

Table 6-10
Dose Rate on Side of 3' thk. End Module Side Shield Wall in Vertical Elevation (along A-A' line on Figure 6-1)

MCNP Run ID	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	84		284		N/A	
Segment or bin #	1 (at Z=321.1 cm.)		1 (at Z=321.1 cm.)		N/A	
Distance Measured on HSM-HB EMSSW in Vertical Elevation from Level of DSC Axis (most negative coordinate is near HSM-HB bottom), cm.	Gamma Radiation		Neutron Radiation		Total Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
-244.01	9.15E-02	0.02	2.07E-02	0.04	1.12E-01	0.02
-213.87	9.17E-02	0.02	1.99E-02	0.03	1.12E-01	0.02
-183.73	8.70E-02	0.05	1.85E-02	0.03	1.05E-01	0.05
-153.59	1.45E-01	0.11	2.91E-02	0.03	1.74E-01	0.09
-123.44	2.42E-01	0.11	5.13E-02	0.02	2.93E-01	0.09
-93.30	4.19E-01	0.17	7.85E-02	0.02	4.97E-01	0.14
-63.16	5.77E-01	0.14	9.98E-02	0.02	6.77E-01	0.12
-33.02	6.06E-01	0.09	1.13E-01	0.02	7.18E-01	0.08
-2.88	6.41E-01	0.09	1.17E-01	0.02	7.58E-01	0.07
27.26	6.01E-01	0.08	1.17E-01	0.02	7.18E-01	0.07
57.40	5.82E-01	0.09	1.05E-01	0.02	6.87E-01	0.07
87.55	4.46E-01	0.08	9.36E-02	0.02	5.40E-01	0.07
117.69	4.32E-01	0.13	8.28E-02	0.02	5.15E-01	0.11
147.83	3.45E-01	0.04	9.35E-02	0.02	4.38E-01	0.03
177.97	3.16E-01	0.03	1.05E-01	0.02	4.21E-01	0.02
211.67	2.70E-01	0.05	7.56E-02	0.03	3.46E-01	0.04
248.92	1.28E-01	0.10	3.09E-02	0.03	1.58E-01	0.08
286.17	3.40E-01	0.09	1.13E-01	0.02	4.53E-01	0.07
316.23	1.15E+00	0.12	3.24E-01	0.02	1.47E+00	0.09
339.09	1.01E+00	0.15	3.07E-01	0.02	1.32E+00	0.11

Table 6-11
Dose Rate above HSM-HB Roof at Level above Top Vents Covers (along H-H' line on Figure 6-1)

MCNP Run ID	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	3 (at X=-13.9 cm)		3 (at X=-13.9 cm)		N/A	
Distance Measured Along HSM-HB Roof (HSM-HB front is at 0.0 cm), cm	Gamma Radiation		Neutron Radiation		Total Gamma+Neutron Radiation	
	Dose Rate mrem/hr	Dose Rate Relative Error	Dose Rate mrem/hr	Dose Rate Relative Error	Dose Rate mrem/hr	Dose Rate Relative Error
54.79	2.16E+00	0.13	4.09E-01	0.02	2.57E+00	0.11
84.38	3.03E+00	0.11	5.73E-01	0.02	3.61E+00	0.09
113.97	3.77E+00	0.09	7.70E-01	0.02	4.54E+00	0.08
143.56	5.43E+00	0.09	9.94E-01	0.01	6.43E+00	0.08
173.15	5.83E+00	0.09	1.22E+00	0.01	7.05E+00	0.07
202.74	6.50E+00	0.07	1.43E+00	0.01	7.93E+00	0.06
232.33	7.56E+00	0.07	1.56E+00	0.01	9.12E+00	0.06
261.91	8.23E+00	0.06	1.66E+00	0.01	9.89E+00	0.05
291.50	7.44E+00	0.06	1.77E+00	0.01	9.21E+00	0.05
321.09	7.81E+00	0.06	1.77E+00	0.01	9.58E+00	0.05
350.68	7.85E+00	0.07	1.73E+00	0.01	9.59E+00	0.05
380.27	8.34E+00	0.09	1.71E+00	0.01	1.00E+01	0.07
409.86	6.84E+00	0.07	1.55E+00	0.01	8.39E+00	0.05
439.45	6.63E+00	0.10	1.41E+00	0.01	8.04E+00	0.08
469.03	6.27E+00	0.08	1.23E+00	0.01	7.50E+00	0.06
498.62	4.75E+00	0.09	1.01E+00	0.01	5.76E+00	0.07
528.21	3.79E+00	0.10	7.68E-01	0.02	4.56E+00	0.08
557.80	2.45E+00	0.10	5.77E-01	0.02	3.03E+00	0.08
587.39	2.12E+00	0.15	4.09E-01	0.02	2.53E+00	0.13
616.98	1.56E+00	0.17	3.06E-01	0.03	1.87E+00	0.14
646.57	1.18E+00	0.21	2.26E-01	0.03	1.40E+00	0.17
678.03	6.22E-01	0.23	1.61E-01	0.04	7.83E-01	0.18
711.36	8.40E-01	0.24	1.30E-01	0.04	9.69E-01	0.21
744.69	3.43E-01	0.32	9.15E-02	0.05	4.34E-01	0.25

Table 6-12
Dose Rate along HSM-HB Roof Centerline (along D-D' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
[1]Segment or bin #	1 (at X=-14 cm.)		1 (at X=-14 cm.)		N/A	
Distance Measured Along HSM-HB Roof, (HSM-HB front is at 0.0 cm.), cm.	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	1.20E+00	0.23	2.68E-01	0.04	1.47E+00	0.19
84.38	1.26E+00	0.20	3.95E-01	0.03	1.66E+00	0.15
113.97	2.14E+00	0.16	5.39E-01	0.03	2.68E+00	0.13
143.56	2.93E+00	0.14	7.08E-01	0.02	3.64E+00	0.12
173.15	3.81E+00	0.13	8.90E-01	0.02	4.70E+00	0.11
202.74	3.45E+00	0.10	1.04E+00	0.02	4.49E+00	0.08
232.33	3.11E+00	0.11	1.19E+00	0.02	4.31E+00	0.08
261.91	3.94E+00	0.11	1.24E+00	0.02	5.19E+00	0.08
291.50	4.49E+00	0.12	1.29E+00	0.02	5.78E+00	0.09
321.09	4.19E+00	0.09	1.34E+00	0.02	5.53E+00	0.07
350.68	4.87E+00	0.14	1.34E+00	0.02	6.21E+00	0.11
380.27	4.93E+00	0.11	1.30E+00	0.02	6.23E+00	0.09
409.86	3.86E+00	0.10	1.17E+00	0.02	5.02E+00	0.08
439.45	3.42E+00	0.16	1.07E+00	0.02	4.49E+00	0.13
469.03	2.84E+00	0.12	9.18E-01	0.02	3.76E+00	0.09
498.62	2.69E+00	0.14	6.92E-01	0.02	3.38E+00	0.11
528.21	1.24E+00	0.13	5.23E-01	0.03	1.76E+00	0.09
557.80	1.16E+00	0.15	3.83E-01	0.03	1.54E+00	0.11
587.39	7.56E-01	0.20	2.74E-01	0.04	1.03E+00	0.15
616.98	7.39E-01	0.51	1.89E-01	0.04	9.29E-01	0.41
646.57	4.17E-01	0.42	1.34E-01	0.06	5.51E-01	0.31
678.03	3.39E-01	0.40	1.01E-01	0.06	4.41E-01	0.31
711.36	1.71E-01	0.41	7.11E-02	0.07	2.42E-01	0.29
744.69	3.18E-02	0.24	4.94E-02	0.07776	8.12E-02	0.11

[1] The dose rates reported for the HSM-H roof centerline are actually along a line that is a bit (~5.5"), closer to the HSM-H top vent opening between adjacent HSMs in 2x1 side-by-side array. Therefore the reported results are slightly conservative.

Table 6-13
Dose Rate on Side of HSM-HB Top Vent Covers (along G-G' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	1 (at X=-103.1 cm.)		1 (at X=-103.1 cm.)		N/A	
Distance Measured Along HSM-HB Roof (HSM-HB front is at 0.0 cm.), cm.	Gamma Radiation		Neutron Radiation		Total Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	1.16E+00	0.30	2.04E-01	0.04	1.36E+00	0.26
84.38	2.38E+00	0.15	5.31E-01	0.02	2.91E+00	0.12
113.97	9.10E+00	0.08	2.65E+00	0.02	1.17E+01	0.06
143.56	1.93E+01	0.06	5.99E+00	0.02	2.53E+01	0.05
173.15	2.55E+01	0.05	7.98E+00	0.01	3.35E+01	0.04
202.74	2.86E+01	0.05	9.50E+00	0.01	3.81E+01	0.04
232.33	3.11E+01	0.05	1.07E+01	0.01	4.18E+01	0.03
261.91	3.14E+01	0.04	1.15E+01	0.01	4.28E+01	0.03
291.50	3.37E+01	0.06	1.18E+01	0.01	4.55E+01	0.05
321.09	3.52E+01	0.08	1.19E+01	0.01	4.71E+01	0.06
350.68	3.48E+01	0.04	1.19E+01	0.01	4.67E+01	0.03
380.27	3.30E+01	0.05	1.15E+01	0.01	4.44E+01	0.03
409.86	3.04E+01	0.04	1.06E+01	0.01	4.09E+01	0.03
439.45	2.95E+01	0.06	9.67E+00	0.01	3.92E+01	0.05
469.03	2.99E+01	0.06	8.65E+00	0.01	3.86E+01	0.05
498.62	2.12E+01	0.12	6.51E+00	0.02	2.77E+01	0.09
528.21	7.17E+00	0.11	1.98E+00	0.02	9.15E+00	0.08
557.80	1.62E+00	0.17	4.65E-01	0.03	2.08E+00	0.13
587.39	7.47E-01	0.19	2.24E-01	0.04	9.71E-01	0.15
616.98	5.50E-01	0.31	1.24E-01	0.06	6.74E-01	0.26
646.57	3.88E-01	0.49	8.20E-02	0.06	4.70E-01	0.40
678.03	1.32E-01	0.43	6.26E-02	0.08	1.95E-01	0.29
711.36	3.66E-02	0.24	4.18E-02	0.08	7.84E-02	0.12
744.69	8.15E-02	0.39	2.89E-02	0.10	1.10E-01	0.29

Table 6-14
Dose Rate above HSM-HB Roof at Level above Top Vent Covers (along I-I' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	1 (at X=105.0 cm.)		1 (at X=105.0 cm.)		N/A	
Distance Measured Along HSM-HB Roof, (HSM-HB front is at 0.0 cm.), cm.	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	6.19E-01	0.32	1.50E-01	0.05	7.68E-01	0.26
84.38	1.39E+00	0.24	2.47E-01	0.04	1.63E+00	0.20
113.97	2.68E+00	0.16	7.32E-01	0.02	3.41E+00	0.13
143.56	4.32E+00	0.12	1.43E+00	0.02	5.75E+00	0.09
173.15	6.19E+00	0.09	1.91E+00	0.02	8.10E+00	0.07
202.74	7.02E+00	0.08	2.25E+00	0.02	9.27E+00	0.06
232.33	6.56E+00	0.07	2.57E+00	0.02	9.13E+00	0.05
261.91	6.87E+00	0.07	2.78E+00	0.02	9.65E+00	0.05
291.50	6.42E+00	0.06	2.91E+00	0.02	9.34E+00	0.04
321.09	6.07E+00	0.07	2.92E+00	0.02	8.98E+00	0.05
350.68	7.03E+00	0.08	2.84E+00	0.02	9.87E+00	0.05
380.27	7.49E+00	0.09	2.69E+00	0.02	1.02E+01	0.06
409.86	6.42E+00	0.08	2.61E+00	0.02	9.03E+00	0.06
439.45	6.11E+00	0.08	2.36E+00	0.02	8.47E+00	0.06
469.03	5.17E+00	0.11	2.03E+00	0.02	7.20E+00	0.08
498.62	3.69E+00	0.09	1.58E+00	0.02	5.27E+00	0.06
528.21	1.63E+00	0.14	6.11E-01	0.02	2.24E+00	0.11
557.80	7.41E-01	0.20	2.38E-01	0.04	9.79E-01	0.15
587.39	4.33E-01	0.30	1.49E-01	0.05	5.82E-01	0.22
616.98	3.63E-01	0.31	1.10E-01	0.06	4.73E-01	0.24
646.57	3.86E-01	0.56	9.66E-02	0.08	4.82E-01	0.45
678.03	1.63E-01	0.49	6.92E-02	0.07	2.32E-01	0.35
711.36	1.25E-01	0.75	4.69E-02	0.07	1.72E-01	0.54
744.69	3.76E-02	0.36	3.93E-02	0.09	7.69E-02	0.18

Dose rates along E-E' and J-J' are presented in Table 6-15 and Table 6-16.

Table 6-15
Dose Rate above HSM-HB Roof at Level above Top Vent Covers (along E-E' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	3 (at X= -132.8 cm.)		3 (at X= -132.8 cm.)		(at X=-132.8 cm.)	
Distance Measured Along HSM-HB Roof (HSM-HB front is at 0.0 cm.), cm	Gamma Radiation		Neutron Radiation		Total Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	2.88E-01	0.18	1.28E-01	0.03	4.16E-01	0.12
84.38	2.57E-01	0.11	9.77E-02	0.03	3.54E-01	0.08
113.97	5.55E-01	0.10	2.78E-01	0.05	8.34E-01	0.07
143.56	1.94E+00	0.16	6.66E-01	0.04	2.60E+00	0.12
173.15	2.46E+00	0.11	8.69E-01	0.04	3.33E+00	0.08
202.74	3.71E+00	0.14	1.02E+00	0.03	4.73E+00	0.11
232.33	3.71E+00	0.12	1.21E+00	0.03	4.93E+00	0.09
261.91	3.26E+00	0.15	1.29E+00	0.03	4.55E+00	0.11
291.50	4.40E+00	0.19	1.29E+00	0.03	5.69E+00	0.15
321.09	4.79E+00	0.16	1.34E+00	0.03	6.13E+00	0.13
350.68	5.21E+00	0.16	1.33E+00	0.03	6.55E+00	0.13
380.27	3.43E+00	0.12	1.28E+00	0.03	4.71E+00	0.09
409.86	2.95E+00	0.13	1.19E+00	0.03	4.14E+00	0.09
439.45	3.05E+00	0.18	1.07E+00	0.03	4.12E+00	0.14
469.03	2.93E+00	0.17	8.92E-01	0.03	3.82E+00	0.13
498.62	1.48E+00	0.11	6.62E-01	0.04	2.14E+00	0.07
528.21	9.41E-01	0.30	2.63E-01	0.04	1.20E+00	0.24
557.80	7.00E-01	0.16	2.30E-01	0.04	9.30E-01	0.12
587.39	7.23E-01	0.17	2.08E-01	0.03	9.31E-01	0.13
616.98	3.56E-01	0.20	1.64E-01	0.06	5.20E-01	0.14
646.57	3.26E-01	0.24	1.11E-01	0.04	4.37E-01	0.18
678.03	1.95E-01	0.25	8.35E-02	0.04	2.79E-01	0.17
711.36	1.24E-01	0.38	6.27E-02	0.04	1.86E-01	0.25
744.69	8.70E-02	0.32	4.86E-02	0.06	1.36E-01	0.21

Table 6-16
Dose Rate above HSM-HB Roof at Level above Top Vent Covers (along J-J' line on Figure 6-1)

MCNP Run ID	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	3 (at X=134.7 cm.)		3 (at X=134.7 cm.)		(at X=134.7 cm.)	
Distance Measured Along HSM-HB Roof (HSM-HB front is at 0.0 cm.), cm.	Gamma Radiation		Neutron Radiation		Total Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	5.29E-01	0.23	1.63E-01	0.04	6.92E-01	0.17
84.38	5.38E-01	0.22	1.08E-01	0.04	6.47E-01	0.18
113.97	3.73E-01	0.15	1.24E-01	0.03	4.98E-01	0.11
143.56	6.88E-01	0.16	2.09E-01	0.04	8.98E-01	0.12
173.15	1.00E+00	0.12	2.68E-01	0.03	1.27E+00	0.09
202.74	1.11E+00	0.14	3.14E-01	0.03	1.43E+00	0.11
232.33	9.68E-01	0.09	3.51E-01	0.03	1.32E+00	0.06
261.91	1.03E+00	0.12	4.08E-01	0.03	1.44E+00	0.09
291.50	1.06E+00	0.11	4.34E-01	0.04	1.49E+00	0.08
321.09	9.26E-01	0.11	4.25E-01	0.03	1.35E+00	0.07
350.68	9.67E-01	0.09	3.95E-01	0.03	1.36E+00	0.06
380.27	9.72E-01	0.10	3.86E-01	0.03	1.36E+00	0.07
409.86	1.22E+00	0.13	3.70E-01	0.03	1.59E+00	0.10
439.45	1.09E+00	0.18	3.37E-01	0.04	1.43E+00	0.14
469.03	6.98E-01	0.10	2.94E-01	0.03	9.92E-01	0.07
498.62	5.33E-01	0.14	2.28E-01	0.04	7.61E-01	0.10
528.21	3.15E-01	0.19	1.21E-01	0.03	4.36E-01	0.14
557.80	6.94E-01	0.21	1.68E-01	0.03	8.62E-01	0.17
587.39	6.39E-01	0.23	1.72E-01	0.03	8.12E-01	0.18
616.98	4.54E-01	0.21	1.39E-01	0.04	5.93E-01	0.16
646.57	6.04E-01	0.28	1.14E-01	0.04	7.18E-01	0.23
678.03	3.40E-01	0.26	9.20E-02	0.04	4.32E-01	0.20
711.36	3.64E-01	0.38	8.31E-02	0.05	4.47E-01	0.31
744.69	1.51E-01	0.34	6.29E-02	0.06	2.14E-01	0.24

Table 6-17
Dose Rate along HSM-HB Roof Centerline at Vertical Elevation ~3 feet above Top of HSM-H Roof Slab (distribution along a line parallel to D-D' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	94		294		N/A	
Segment or bin #	5 (at X=-14 cm.)		5 (at X=-14 cm.)		N/A	
Distance Measured Along HSM-HB Roof (HSM-HB front is at 0.0 cm.), cm	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
54.79	1.87E+00	0.13	3.76E-01	0.02	2.24E+00	0.11
84.38	2.46E+00	0.12	5.00E-01	0.02	2.96E+00	0.10
113.97	3.29E+00	0.10	6.20E-01	0.01	3.91E+00	0.08
143.56	4.31E+00	0.10	7.85E-01	0.01	5.09E+00	0.08
173.15	4.87E+00	0.07	9.23E-01	0.01	5.79E+00	0.06
202.74	5.66E+00	0.09	1.07E+00	0.01	6.73E+00	0.08
232.33	5.51E+00	0.08	1.19E+00	0.01	6.70E+00	0.07
261.91	5.62E+00	0.07	1.27E+00	0.01	6.89E+00	0.06
291.50	6.10E+00	0.06	1.35E+00	0.01	7.45E+00	0.05
321.09	6.46E+00	0.07	1.36E+00	0.01	7.82E+00	0.06
350.68	6.12E+00	0.06	1.33E+00	0.01	7.45E+00	0.05
380.27	6.69E+00	0.10	1.30E+00	0.01	7.99E+00	0.08
409.86	5.39E+00	0.06	1.20E+00	0.01	6.59E+00	0.05
439.45	5.98E+00	0.11	1.10E+00	0.01	7.08E+00	0.10
469.03	4.87E+00	0.08	9.45E-01	0.01	5.81E+00	0.07
498.62	4.08E+00	0.10	7.95E-01	0.01	4.88E+00	0.08
528.21	3.18E+00	0.12	6.39E-01	0.02	3.82E+00	0.10
557.80	2.32E+00	0.11	4.96E-01	0.02	2.81E+00	0.09
587.39	1.78E+00	0.14	3.75E-01	0.02	2.16E+00	0.12
616.98	1.24E+00	0.16	2.80E-01	0.02	1.52E+00	0.13
646.57	9.56E-01	0.16	2.09E-01	0.02	1.17E+00	0.13
678.03	1.01E+00	0.20	1.64E-01	0.03	1.17E+00	0.17
711.36	5.94E-01	0.23	1.25E-01	0.03	7.19E-01	0.19
744.69	3.85E-01	0.44	9.24E-02	0.04	4.77E-01	0.36

Table 6-17 displays dose rate distributions at 3 feet above the line designated as D-D' on Figure 6-1. Compare the dose rates with those in Table 6-12.

6.4 Spatial Distribution of Gamma Radiation Dose Rate on HSM-H Rear Shield Wall

Table 6-18
Dose Rate on HSM-HB in Vertical Elevation Along Centerline on HSM-HB Rear Shield Wall (along F-F' line on Figure 6-1)

MCNP Run ID:	"HSM-go" and "HSM-no"		"HSM-no"		N/A	
Tally	44		244		N/A	
Segment or bin #	1 (at X=0 cm.)		1(at X=0 cm.)		N/A	
Vertical Elevation Measured from Level of DSC Axis, cm.	Gamma Radiation		Neutron Radiation		Total: Gamma+Neutron Radiation	
	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error	Dose Rate, mrem/hr	Dose Rate Relative Error
-243.1	4.07E-03	0.23	4.14E-04	0.12	4.48E-03	0.21
-211.0	4.42E-03	0.21	5.05E-04	0.10	4.93E-03	0.19
-180.0	7.42E-03	0.12	7.90E-04	0.09	8.21E-03	0.11
-150.0	1.17E-02	0.13	1.18E-03	0.07	1.29E-02	0.12
-120.0	1.82E-02	0.10	1.98E-03	0.06	2.01E-02	0.09
-90.0	2.70E-02	0.09	2.91E-03	0.05	2.99E-02	0.09
-60.0	3.69E-02	0.06	3.81E-03	0.04	4.07E-02	0.05
-30.0	4.49E-02	0.07	4.36E-03	0.04	4.93E-02	0.07
0.0	4.98E-02	0.06	5.04E-03	0.03	5.48E-02	0.06
27.3	5.42E-02	0.05	5.98E-03	0.03	6.02E-02	0.04
52.0	5.95E-02	0.06	7.07E-03	0.03	6.66E-02	0.05
76.7	6.28E-02	0.05	8.04E-03	0.03	7.08E-02	0.04
100.2	7.24E-02	0.07	9.05E-03	0.03	8.14E-02	0.07
125.0	6.82E-02	0.06	9.86E-03	0.04	7.81E-02	0.05
152.2	5.93E-02	0.05	9.62E-03	0.04	6.90E-02	0.05
179.4	5.26E-02	0.07	7.84E-03	0.04	6.04E-02	0.06
207.0	3.57E-02	0.07	5.45E-03	0.04	4.12E-02	0.06
234.9	2.30E-02	0.14	3.68E-03	0.04	2.66E-02	0.12
262.9	1.54E-02	0.17	2.98E-03	0.04	1.84E-02	0.14
290.8	9.57E-02	0.22	2.31E-02	0.03	1.19E-01	0.18
320.0	2.33E-01	0.15	6.62E-02	0.02	2.99E-01	0.11
350.5	4.70E-01	0.14	9.74E-02	0.02	5.67E-01	0.11
381.0	4.58E-01	0.17	9.68E-02	0.02	5.55E-01	0.14

Dose rates shown in Table 6-18 are along the F-F' line and displayed in Figure 6-1. The rear shield wall extends up to the top of HSM-HB roof slab. The bottom and top of the HSM-HB roof slab are at vertical elevations of 182.88 and 294.64 cm cm, if measured from the level of the DSC axis, respectively. As one can see from Table 6-18, dose rates increase rapidly starting at the top of the roof slab. This is due to radiation scattering from the top vent caps.

According to the MCNP manual, F4 type tallies calculated with statistical errors greater than 10% are questionable. As can be observed from Table 6-18, dose rates at many locations have relative errors greater than this. To assure that the estimated values are a reasonable representation of the dose rates on the HSM-HB rear shield wall, consider dose rate distribution in Table 6-9. It is along the B-B' line on the HSM-HB side, see Figure 6-1. Dose rates at the middle of the end module side shield wall are entirely due to radiation from the in-core region. Radiation penetrates through the DSC structural shell, HSM-HB 1' thick side and 3' thick end module side shield wall before reaching the middle of the side shield wall surface. Radiation penetrates through DSC top cover plates, shield plug, HSM-HB 1' rear and 3' thick rear shield wall before reaching surface of the rear shield wall. Besides, the rear shield wall faces radiological sources in the plenum and top axial regions of the fuel assemblies, which are substantially weaker there than in-core region. Table 5-4 indicates that the gamma radiation source term strength is the largest contributor to the dose rates energy groups (from 1.0 to 2.5 MeV, depending on burn-up and cooling time) is by a factor of ~10 to ~20 stronger in in-core than in plenum and top regions. Therefore dose rates in Table 6-18 would never exceed those shown in Table 6-9. It would be reasonable to select dose rates in Table 6-18 that correspond to the locations near ~90 to ~150 cm below or above level of DSC axis. First, these locations face the hottest, 1 kWt/FA, assemblies in the MCNP model. Second dose rates at these locations are calculated with relatively small statistical errors and can be considered more reliable if comparing with dose rates at other coordinates. Dose rates there do not exceed 0.07 mrem/hr.

6.5 Spectral Characteristics of Dose Rates on HSM-HB surfaces

Surface averaged dose rates obtained in this calculation are used to generate surface sources for the ISFSI dose rate. It was determined in reference [17] that the methodology employed by TN gives accurate predictions when calculating dose rates as a function of distance at locations that are greater than 6 to 10 meters. It also provides acceptable accuracy for the closer locations if the points of interest are not in the line of radiation streaming from vent openings or scattered from top vent covers or other obstacles. The analysis performed in Millstone ISFSI [17] suggests, however, that the methodology can be improved for handling these special cases by using spectral and directional characteristics of the flux\current related to the HSM surface segments where streaming of radiation occurs.

7.0 CONCLUSION

Gamma and neutron radiation dose rates at various locations around the Horizontal Storage Module (HSM-HB) containing bounding NUHOMS®- 32PHB Storage Dry Shielded Canister (DSC) have been determined. The system is loaded with low burnup fuel assemblies (around 45 GWD/MTU) with a maximum assembly average initial enrichment of 5% wt U-235. This is a fictitious loading configuration resulting in HSM-HB dose rates that are bounding for all specified Design Criteria Specification (DCS) DSC types and heat loading configurations.

Maximum and average dose rate values for gamma, neutron and total radiation have been calculated, see Section 6.3.

Spectral characteristics of fluxes at different segments on the HSM-HB surface are also calculated for ISFSI dose rates estimation, see Section 10.0.

A section of this calculation is dedicated to results to be imported into the shielding analysis section in the Safety Analysis Report (SAR), see Section 8.0. Seciton 8.0 also evaluates the dose rates against the dose rate requirements and determines that the requirements are met.

Dose rates presented in Sections 6.3 and 8.0 are calculated with stainless steel plates of 1" thickness in the top vent covers. Without those plates, gamma dose rates will increase by about 44% and 74% on the HSM-HB roof centerline and bird screen, respectively.

8.0 HSM-HB SHIELDING EVALUATION (SAR SECTION)

This section summarizes dose rates to be imported into the shielding analysis section in the Safety Analysis Report (SAR) for the HSM-HB loaded with NUHOMS 32PHB bounding DSC containing PWR design basis fuel loaded conservatively with the bounding heat zoning configuration in Table 5-4.

The dose rate requirements, which can be found in reference [1], are

- Contact dose rate on the exterior surface of the HSM-HB shield door ≤ 100 mrem/hr
- Contact dose rate on the exterior surface of the HSM-HB sides and roof, excluding the vents ≤ 20 mrem/hr

All dose rates given in Table 8-1 meet these requirements.

The dose rates given in the second section of the table are used for calculating site doses. However, that calculation was completed before the final source terms were available. The dose rates utilized by the site dose calculation are given in Table 8-2. The dose rates for the front and roof are conservative compared to the correct dose rates given in Table 8-1, which makes them acceptable to use for site dose calculation. The side dose rate is slightly unconservative. However, due to the significant conservatism introduced by the treatment of source particle energy in the site dose calculation, the side dose rate will actually be conservative in comparison to the value given in Table 8-1.

Table 8-1
Summary of NUHOMS®-32PHB Bounding DSC (with DB Fuel Loaded as in Bounding Configuration + CCs) in HSM-HB, Bounding Maximum and Average Dose Rates (2)

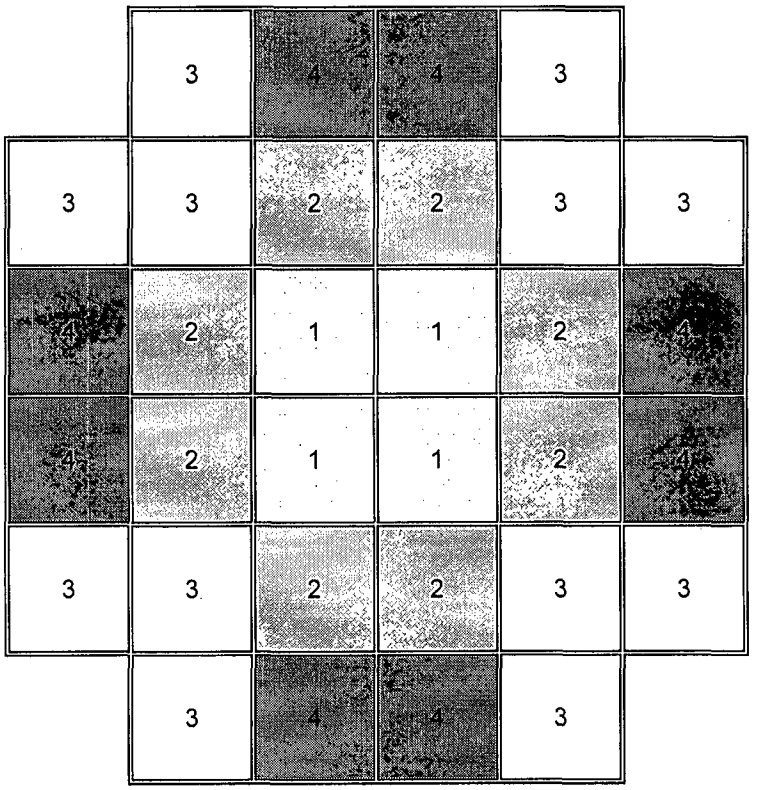
Dose Rate Location	Maximum Gamma (mrem/hr)	Gamma MCNP 1σ Error	Maximum Neutron (mrem/hr)	Neutron MCNP 1σ Error	Maximum Total(1) (mrem/hr)	Total MCNP 1σ Error
HSM-HB Roof Bird screen	35.2	0.09	11.9	0.01	**47.1**	0.07
HSM-HB Roof (centerline)	4.93	0.14	1.34	0.02	**6.27**	0.11
HSM-HB End (Side) Shield Wall Surface	0.64	0.16	0.12	0.02	**0.76**	0.14
HSM-HB Door Exterior Surface (centerline)	0.60	0.20	0.38	0.04	**0.98**(3)	0.12
HSM Door Exterior 1 m (centerline)	0.63	0.34	0.38	0.04	**1.01**(3)	0.21
HSM Door opened 1 ft inside (centerline)	1.64E+4	0.02	1.27E+3	0.04	**1.76E+4**	0.02
HSM-HB Front Bird screen	110	0.009	10.3	0.01	**121**	0.01

Dose Rate Location	Gamma Average (mrem/hr)	Gamma MCNP 1σ Error	Average Neutron (mrem/hr)	Neutron MCNP 1σ Error	Average Total (mrem/hr)	Total MCNP 1σ Error
HSM-HB Roof	4.59	0.03	1.08	0.008	**5.67**	0.02
HSM-HB End (Side) Shield Wall Surface	0.20	0.01	0.04	0.005	**0.24**	0.01
HSM-HB Front	4.30	0.07	0.59	0.03	**4.90**	0.07
HSM-HB Back Shield Wall	0.01	0.09	0.009	0.01	**0.02**	0.05

Notes:
(1) Gamma and Neutron dose rate peaks do not always occur at thesame location; therefore, the maximum of total dose rate is not always the sum of the gamma plus neutron dose rate maximums.
(2) Dose is calculated using 32PHB bounding, from the shielding performance stand point, DSC. This DSC contains the design basis assembly source loaded in accordance with bounding loading configuration depicted on Figure 8-1.
(3) The dose rates on the door centerline are nearly equal at the surface and 1m due primarly to streaming from the front vents, which does not contribute to the surface dose rate, but contributes significantly to the 1m dose rate.
(4) Dose rates are calculated including stainless steel plates of 1" of thickness in the cap vent.

Table 8-2
Summary of NUHOMS®-32PHB Bounding DSC (with DB Fuel Loaded as in Bounding Configuration + CCs) in HSM-HB, Bounding Maximum and Average Dose Rates

Dose Rate Location	Gamma Average (mrem/hr)	Gamma MCNP 1σ Error	Average Neutron (mrem/hr)	Neutron MCNP 1σ Error	Average Total (mrem/hr)	Total MCNP 1σ Error
HSM-HB Roof	5.11	0.07	1.08	0.008	**6.84**	0.06
HSM-HB End (Side) Shield Wall Surface	0.14	0.04	0.04	0.005	**0.28**	0.03
HSM-HB Front	6.41	0.15	0.59	0.03	**7.28**	0.14



Heat Zone	Zone 1	Zone 2	Zone 3	Zone 4
Number of Fuel Assemblies	4	8	12	8
Maximum Decay Heat (kW/FA)	1.0	1.0	1.0	1.0
Maximum Decay Heat per Zone (kW)	4.0	8.0	12.0	8.0
Maximum Decay Heat per DSC (kW)	32.0			

Figure 8-1
32PHB DSC Bounding Heat Zone Configuration Used for HSM-HB Shielding Analysis

9.0 APPENDIX A: EVALUATION OF HSM-HB DOSE RATES DUE TO CONTROL COMPONENTS (CC).

The dose rate summary in Table 8-1 represents cumulative contribution from radiological sources due to design basis FAs. FA design basis sources are given in Table 5-3 and Table 5-4. The sources due to the non-feul assembly hardware can be found in reference [1] and are reproduced in Table 9-1. This section quantifies those contributions from each of the sources separately.

Table 9-1
Non-Fuel Assembly Hardware Radiological Characteristics

CASK-81 Energy Group	E_{upper} (MeV)	E_{mean} (MeV)	Top Region γ/s/Assm.	Plenum Region γ/s/Assm.	Fuel Region γ/s/Assm.
23	11	9.5	0.000E+00	0.000E+00	0.000E+00
24	8	7	0.000E+00	0.000E+00	0.000E+00
25	6	5	0.000E+00	0.000E+00	0.000E+00
26	4	3.5	1.540E-09	1.710E-13	2.180E-12
27	3	2.75	2.030E+05	7.240E+04	1.810E+04
28	2.5	2.25	1.310E+08	4.670E+07	1.170E+07
29	2	1.75	1.970E+04	8.730E+03	5.220E+03
30	1.5	1.25	2.490E+13	8.850E+12	2.210E+12
31	1	0.85	1.140E+11	1.410E+11	1.590E+10
32	0.7	0.575	2.330E+12	5.160E+10	2.330E+12
33	0.45	0.375	1.810E+12	4.040E+10	1.810E+12
34	0.3	0.225	3.080E+11	8.050E+09	3.050E+11
35	0.15	0.125	4.110E+10	5.740E+09	2.790E+10
36	0.1	0.085	4.320E+10	1.100E+10	1.560E+10
37	0.07	0.0575	9.050E+10	2.330E+10	3.250E+10
38	0.045	0.0375	9.520E+11	4.590E+10	8.850E+11
39	0.03	0.025	5.010E+12	1.490E+11	4.910E+12
40	0.02	0.01	1.200E+12	2.600E+11	5.960E+11

10.0 APPENDIX B: SPECTRAL DISTRIBUTION

This section presents spectral distribution of gamma and neutron radiation on the HSM-HB surfaces. Consult Table 6-1 for the definition and description of MCNP cells and tallies that are shown in the headers of the tables in this section.

10.1 Spectrum on HSM-HB Front

Table 10-1
Spectral Distribution of Gamma Radiation Flux on HSM-HB Front, g/(cm^2*sec)

MCNP Run ID:		HSM-go / HSM-no		HSM-go / HSM-no		HSM-go / HSM-no		HSM-go / HSM-no		HSM-go / HSM-no	
MCNP Cell ID		351, LHS Frontal Vent		350, RHS Frontal Vent		353, Entire Front		Half of Front on the LHS from Centerline		Half of Front on the RHS from Centerline	
Cell Volume, cm^3		3,492.3		3,492.3		561,101.0		198,348.0		362,752.0	
Tally		614		624		424		424, segment 1		424, segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error
1	0.05	4.33E+03	0.37	1.08E+03	0.37	1.05E+02	0.28	2.30E+02	0.35	3.87E+01	0.28
2	0.1	8.76E+04	0.12	2.29E+04	0.09	2.06E+03	0.09	4.56E+03	0.11	7.27E+02	0.08
3	0.2	9.16E+04	0.09	1.50E+04	0.11	2.05E+03	0.10	5.02E+03	0.11	4.64E+02	0.10
4	0.3	2.18E+04	0.22	2.99E+03	0.25	4.49E+02	0.19	1.11E+03	0.21	9.64E+01	0.21
5	0.4	3.50E+03	0.30	9.23E+02	0.48	8.58E+01	0.23	1.89E+02	0.27	3.11E+01	0.37
6	0.6	1.48E+03	0.44	3.40E+01	0.06	4.38E+01	0.32	1.12E+02	0.36	7.37E+00	0.05
7	0.8	4.29E+01	0.07	1.36E+01	0.09	6.47E+00	0.10	1.08E+01	0.16	4.14E+00	0.08
8	1.0	3.12E+01	0.08	8.83E+00	0.11	4.02E+00	0.05	6.28E+00	0.06	2.82E+00	0.07
9	1.33	4.17E+01	0.08	1.39E+01	0.10	4.65E+00	0.03	7.29E+00	0.05	3.24E+00	0.05
10	1.66	2.49E+01	0.09	8.67E+00	0.13	3.13E+00	0.03	4.79E+00	0.04	2.25E+00	0.05
11	2.0	2.84E+01	0.10	7.81E+00	0.11	2.87E+00	0.03	4.55E+00	0.04	1.98E+00	0.06
12	2.5	4.74E+01	0.07	2.12E+01	0.09	4.07E+00	0.03	6.48E+00	0.03	2.79E+00	0.04
13	3.0	2.08E+01	0.13	5.40E+00	0.15	2.28E+00	0.04	3.78E+00	0.07	1.48E+00	0.02
14	4.0	4.72E+01	0.07	1.63E+01	0.09	4.46E+00	0.01	7.21E+00	0.02	2.99E+00	0.02
15	5.0	4.49E+01	0.09	1.39E+01	0.12	3.88E+00	0.02	6.42E+00	0.03	2.53E+00	0.02
16	6.5	3.58E+01	0.08	1.03E+01	0.14	3.46E+00	0.02	5.65E+00	0.03	2.29E+00	0.02
17	8.0	2.37E+01	0.12	7.50E+00	0.19	2.47E+00	0.03	4.00E+00	0.04	1.66E+00	0.03
18	10.0	1.24E+00	0.32	1.40E+00	0.52	3.81E-01	0.07	5.56E-01	0.11	2.88E-01	0.09
19	15.0	3.75E-01	0.70	1.13E-02	0.20	1.79E-02	0.26	3.26E-02	0.40	1.01E-02	0.13
Total		2.11E+05	0.07	4.30E+04	0.07	4.83E+03	0.06	1.13E+04	0.08	1.39E+03	0.06

Table 10-2
Spectral Distribution of Neutron Radiation Flux on HSM-HB Front, n/(cm^2*sec)

MCNP Run ID		HSM-no		HSM-no		HSM-no		HSM-no		HSM-no	
MCNP Cell ID		351, LHS Frontal Vent		350, RHS Frontal Vent		353, Entire Front		Half of Front on the LHS from Centerline		Half of Front on the RHS from Centerline	
Cell Volume, cm^3		3,492.3		3,492.3		561,101.0		198,348.0		362,752.0	
Tally		714		724		524		524, segment 1		524, segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Neutron Radiation Flux, n/(sec* cm^2)	Flux Relative Error	Neutron Radiation Flux, n/(sec* cm^2)	Flux Relative Error	Neutron Radiation Flux, n/(sec* cm^2)	Flux Relative Error	Neutron Radiation Flux, n/(sec*cm^2)	Flux Relative Error	Neutron Radiation Flux, n/(sec* cm^2)	Flux Relative Error
1	4.14e-7	9.687E+02	0.02	3.347E+02	0.02	3.176E+01	0.02	6.150E+01	0.02	1.594E+01	0.01
2	1.12e-6	4.257E+01	0.06	1.205E+01	0.09	1.196E+00	0.04	2.462E+00	0.05	5.234E-01	0.06
3	3.06e-6	3.912E+01	0.06	1.364E+01	0.12	1.175E+00	0.05	2.323E+00	0.05	5.645E-01	0.08
4	1.01e-5	4.907E+01	0.06	1.534E+01	0.09	1.410E+00	0.04	2.852E+00	0.05	6.437E-01	0.06
5	2.90e-5	3.747E+01	0.06	1.155E+01	0.09	1.096E+00	0.04	2.213E+00	0.05	5.018E-01	0.06
6	1.01e-4	4.340E+01	0.06	1.284E+01	0.10	1.241E+00	0.04	2.540E+00	0.05	5.502E-01	0.06
7	5.83e-4	6.031E+01	0.06	1.602E+01	0.08	1.677E+00	0.04	3.479E+00	0.05	7.182E-01	0.05
8	3.35e-3	5.607E+01	0.05	1.421E+01	0.06	1.557E+00	0.03	3.275E+00	0.04	6.437E-01	0.04
9	1.11e-1	9.449E+01	0.03	2.497E+01	0.03	2.685E+00	0.02	5.599E+00	0.03	1.135E+00	0.02
10	5.50e-1	3.435E+01	0.04	8.039E+00	0.04	9.758E-01	0.03	2.064E+00	0.04	3.971E-01	0.03
11	1.11	7.857E+00	0.05	1.942E+00	0.08	2.484E-01	0.04	5.090E-01	0.05	1.098E-01	0.05
12	1.83	4.642E+00	0.40	7.414E-01	0.11	1.381E-01	0.23	2.996E-01	0.30	5.214E-02	0.06
13	2.35	3.962E+00	0.54	3.266E-01	0.18	1.043E-01	0.35	2.436E-01	0.43	3.026E-02	0.06
14	2.46	2.310E-01	0.25	8.022E-02	0.35	1.331E-02	0.16	2.551E-02	0.23	6.822E-03	0.11
15	3.01	5.174E-01	0.19	1.172E-01	0.31	1.853E-02	0.11	3.818E-02	0.14	8.079E-03	0.13
16	4.06	3.100E-01	0.26	1.051E-01	0.33	1.053E-02	0.15	2.092E-02	0.20	5.009E-03	0.21
17	4.96	4.832E-02	0.42	3.092E-02	0.55	3.416E-03	0.14	5.427E-03	0.20	2.346E-03	0.20
18	6.36	1.280E-02	0.44	2.206E-03	0.93	2.011E-03	0.09	3.170E-03	0.13	1.395E-03	0.11
19	8.18	4.404E-03	0.98	3.975E-03	1.00	8.196E-04	0.17	1.073E-03	0.27	6.848E-04	0.20
20	10.0	0.000E+00	0.00	0.0E+00	0.00	9.987E-05	0.18	1.414E-04	0.26	7.779E-05	0.21
21	12.2	0E+00	0.00	0.0E+00	0.00	2.657E-05	0.47	3.021E-05	0.91	2.464E-05	0.50
22	14.9	0E+00	0.00	0.0E+00	0.00	2.010E-06	0.87	8.366E-07	1.00	2.634E-06	1.00
Total		1.443E+03	0.02	4.667E+02	0.02	4.532E+01	0.01	8.945E+01	0.02	2.184E+01	0.01

10.2 Spectrum on HSM-HB End Module Side Shield Wall

Table 10-3
Spectral Distribution of Gamma Radiation Flux on HSM-HB End Module Side Shield Wall, g/(cm^2*sec)

MCNP Run ID		HSM-go / HSM-no	
MCNP Cell ID		348 (Entire Side)	
Cell Volume, cm^3		451 311.0	
Tally		414	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Gamma Radiation	
		Flux, g/(sec*cm^2)	Flux Relative Error
1	0.05	1.92	0.11
2	0.1	49.9	0.03
3	0.2	59.0	0.04
4	0.3	20.9	0.05
5	0.4	10.9	0.05
6	0.6	12.5	0.03
7	0.8	7.67	0.03
8	1.0	5.45	0.03
9	1.33	6.61	0.03
10	1.66	4.06	0.03
11	2.0	3.43	0.03
12	2.5	3.77	0.04
13	3.0	1.59	0.03
14	4.0	2.74	0.02
15	5.0	2.33	0.004
16	6.5	2.20	0.005
17	8.0	1.38	0.01
18	10.0	0.22	0.02
19	15.0	0.01	0.06
Total		196	0.02

Table 10-4
Spectral Distribution of Neutron Radiation Dose Rate on HSM-HB End Module Side Shield Wall

MCNP Run ID:		HSM-no	
MCNP Cell ID		348 (Entire Side)	
Cell Volume, cm^3		451,311.0	
Tally		514	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Neutron Radiation	
		Flux, $n/(sec^* cm^2)$	Flux Relative Error
1	4.14e-7	4.837	0.004
2	1.12e-6	0.121	0.02
3	3.06e-6	0.122	0.02
4	1.01e-5	0.143	0.02
5	2.90e-5	0.119	0.02
6	1.01e-4	0.134	0.02
7	5.83e-4	0.173	0.02
8	3.35e-3	0.148	0.01
9	1.11e-1	0.226	0.01
10	5.50e-1	0.087	0.01
11	1.11	0.036	0.01
12	1.83	0.031	0.01
13	2.35	0.032	0.01
14	2.46	7.40E-03	0.01
15	3.01	6.41E-03	0.01
16	4.06	3.17E-03	0.02
17	4.96	2.60E-03	0.02
18	6.36	2.60E-03	0.03
19	8.18	9.54E-04	0.05
20	10.0	1.15E-04	0.09
21	12.2	1.74E-05	0.18
22	14.9	2.46E-06	0.53
Total		6.232	0.005

10.3 Spectrum on HSM-HB Top

Table 10-5
Spectral Distribution of Gamma Radiation Dose Rate on HSM-HB Top, g/(cm^2*sec)

MCNP Run ID		HSM-go / HSM-no		HSM-go / HSM-no		HSM-go / HSM-no	
MCNP Cell ID		347 (Entire Roof)		Half of Roof on the LHS from Centerline		Half of Roof on the RHS from Centerline	
Cell Volume, cm^3		296,256.0		112,753.0		183,503.0	
Tally		404		404, Segment 1		404, Segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error	Gamma Radiation Flux, g/(sec*cm^2)	Flux Relative Error
1	0.05	64.9	0.07	102	0.08	42.1	0.09
2	0.1	1870	0.02	2990	0.02	1180	0.03
3	0.2	1930	0.03	3200	0.03	1150	0.03
4	0.3	569	0.04	994	0.05	308	0.06
5	0.4	263	0.06	479	0.06	131	0.08
6	0.6	191	0.06	355	0.07	90.3	0.07
7	0.8	75.6	0.07	147	0.08	31.9	0.08
8	1.0	43.6	0.07	80.2	0.08	21.1	0.09
9	1.33	39.1	0.07	67.5	0.09	21.7	0.09
10	1.66	20.1	0.09	30.4	0.12	13.7	0.12
11	2.0	17.4	0.09	26.0	0.13	12.1	0.14
12	2.5	20.1	0.11	34.6	0.15	11.2	0.12
13	3.0	5.88	0.06	8.18	0.01	4.46	0.13
14	4.0	11.2	0.03	17.0	0.01	7.59	0.08
15	5.0	9.01	0.01	14.3	0.01	5.77	0.01
16	6.5	8.59	0.01	13.7	0.01	5.46	0.01
17	8.0	6.75	0.01	10.9	0.01	4.20	0.01
18	10.0	1.69	0.02	2.81	0.02	1.00	0.02
19	15.0	0.04	0.12	0.05	0.15	0.03	0.20
Total		5,150	0.02	8,570	0.03	3,042.71	0.02

Table 10-6
Spectral Distribution of Neutron Radiation Dose Rate on HSM-HB Top, n/(cm^{2}*sec)

MCNP Run ID:		HSM-no		HSM-no		HSM-no	
MCNP Cell ID		347 (Entire Roof)		Half of Roof on the LHS from Centerline		Half of Roof on the RHS from Centerline	
Cell Volume, cm^{3}		296,256.0		112,753.0		183,503.0	
Tally		504		504, Segment 1		504, Segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Neutron Radiation Flux, n/(sec*cm^{2})	Flux Relative Error	Neutron Radiation Flux, n/(sec*cm^{2})	Flux Relative Error	Neutron Radiation Flux, n/(sec*cm^{2})	Flux Relative Error
1	4.14e-7	63.31	0.008	101.7	0.01	39.71	0.007
2	1.12e-6	4.009	0.01	6.508	0.01	2.474	0.01
3	3.06e-6	3.935	0.01	6.392	0.01	2.426	0.01
4	1.01e-5	4.531	0.01	7.346	0.01	2.801	0.01
5	2.90e-5	3.829	0.01	6.184	0.01	2.381	0.01
6	1.01e-4	4.281	0.01	6.971	0.01	2.629	0.01
7	5.83e-4	5.386	0.01	8.635	0.01	3.390	0.01
8	3.35e-3	4.523	0.01	7.261	0.01	2.841	0.01
9	1.11e-1	6.364	0.008	10.26	0.01	3.971	0.008
10	5.50e-1	2.094	0.01	3.402	0.01	1.291	0.01
11	1.11	0.560	0.02	0.928	0.02	0.334	0.02
12	1.83	0.297	0.02	0.497	0.02	0.174	0.02
13	2.35	0.187	0.02	0.312	0.03	0.110	0.02
14	2.46	0.046	0.03	0.077	0.04	0.026	0.03
15	3.01	0.059	0.04	0.101	0.04	0.033	0.04
16	4.06	0.029	0.05	0.050	0.06	0.016	0.05
17	4.96	0.017	0.06	0.030	0.07	0.009	0.06
18	6.36	0.014	0.07	0.023	0.09	0.008	0.08
19	8.18	0.005	0.11	0.008	0.14	0.003	0.11
20	10.0	8.902E-04	0.26	0.001	0.37	5.502E-04	0.23
21	12.2	1.543E-04	0.50	3.061E-04	0.59	6.106E-05	0.48
22	14.9	2.164E-04	0.78	5.017E-04	0.82	4.103E-05	0.60
Total		103.5	0.007	166.7	0.008	64.63	0.007

10.4 Spectrum on HSM-HB Rear Shield Wall

Table 10-7
Spectral Distribution of Gamma Radiation Dose Rate on HSM-HB Rear Shield Wall, g/(cm^2*sec)

MCNP Run ID:		HSM-go / HSM-no		HSM-go / HSM-no		HSM-go / HSM-no	
MCNP Cell ID		349 (Entire HSM RSW)		Half of HSM RSW on the LHS from Centerline		Half of HSM RSW on the RHS from Centerline	
Cell Volume, cm^3		231,420.0		88,309.5		143,111.0	
Tally		604		604, Segment 1		604, Segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Gamma Radiation		Gamma Radiation		Gamma Radiation	
		Flux, g/(sec*cm^2)	Flux Relative Error	Flux, g/(sec*cm^2)	Flux Relative Error	Flux, g/(sec*cm^2)	Flux Relative Error
1	0.05	0.49	0.23	0.24	0.19	0.64	0.28
2	0.1	14.8	0.07	15.8	0.10	14.2	0.09
3	0.2	16.3	0.07	15.7	0.09	16.7	0.08
4	0.3	3.93	0.11	3.96	0.16	3.91	0.14
5	0.4	1.95	0.15	1.60	0.21	2.17	0.19
6	0.6	1.62	0.10	1.67	0.10	1.59	0.16
7	0.8	0.64	0.06	0.87	0.12	0.49	0.05
8	1.0	0.49	0.06	0.62	0.07	0.41	0.10
9	1.33	0.58	0.04	0.73	0.06	0.49	0.06
10	1.66	0.43	0.03	0.54	0.05	0.37	0.04
11	2.0	0.39	0.03	0.50	0.04	0.32	0.04
12	2.5	0.50	0.04	0.64	0.05	0.42	0.05
13	3.0	0.35	0.02	0.44	0.01	0.29	0.04
14	4.0	0.64	0.01	0.83	0.02	0.52	0.01
15	5.0	0.55	0.01	0.71	0.02	0.46	0.01
16	6.5	0.54	0.01	0.70	0.02	0.45	0.02
17	8.0	0.36	0.02	0.46	0.03	0.30	0.03
18	10.0	0.08	0.07	0.10	0.10	0.06	0.08
19	15.0	0.00	0.21	0.00	0.23	0.00	0.31
Total		44.7	0.04	46.1	0.05	43.8	0.05

Table 10-8
Spectral Distribution of Neutron Radiation Flux on HSM-HB Rear Shield Wall, n/(cm^2*sec)

MCNP Run ID		HSM-no		HSM-no		HSM-no	
MCNP Cell ID		349 (Entire HSM RSW)		Half of HSM RSW on the LHS from Centerline		Half of HSM RSW on the RHS from Centerline	
Cell Volume, cm^3		231,420.0		88,309.5		143,111.0	
Tally		704		704, Segment 1		704, Segment 2	
Energy Group #	Energy Group Upper Limit E_{upper}, MeV	Neutron Radiation		Neutron Radiation		Neutron Radiation	
		Flux, n/(sec*cm^2)	Flux Relative Error	Flux, n/(sec*cm^2)	Flux Relative Error	Flux, n/(sec*cm^2)	Flux Relative Error
1	4.14e-7	0.936	0.007	1.131	0.009	0.816	0.008
2	1.12e-6	0.033	0.029	0.036	0.042	0.032	0.037
3	3.06e-6	0.032	0.032	0.035	0.045	0.031	0.039
4	1.01e-5	0.038	0.030	0.040	0.045	0.036	0.037
5	2.90e-5	0.030	0.032	0.031	0.047	0.030	0.040
6	1.01e-4	0.037	0.031	0.037	0.047	0.037	0.038
7	5.83e-4	0.046	0.029	0.048	0.043	0.045	0.034
8	3.35e-3	0.040	0.022	0.041	0.031	0.039	0.027
9	1.11e-1	0.057	0.013	0.059	0.018	0.056	0.015
10	5.50e-1	0.019	0.015	0.020	0.020	0.019	0.018
11	1.11	0.006	0.024	0.006	0.033	0.005	0.030
12	1.83	0.004	0.028	0.005	0.038	0.003	0.036
13	2.35	0.003	0.037	0.004	0.051	0.003	0.047
14	2.46	6.994E-04	0.050	9.004E-04	0.067	5.754E-04	0.068
15	3.01	5.963E-04	0.057	7.884E-04	0.074	4.777E-04	0.077
16	4.06	2.935E-04	0.081	3.638E-04	0.117	2.502E-04	0.102
17	4.96	1.949E-04	0.095	2.633E-04	0.138	1.528E-04	0.118
18	6.36	1.747E-04	0.118	2.688E-04	0.161	1.166E-04	0.150
19	8.18	5.100E-05	0.211	7.130E-05	0.288	3.848E-05	0.262
20	10.0	6.330E-06	0.392	1.340E-05	0.445	1.967E-06	0.631
21	12.2	0.000E+00	0.000	0.000E+00	0.000	0.000E+00	0.000
22	14.9	0.000E+00	0.000	0.000E+00	0.000	0.000E+00	0.000
Total		1.283	0.007	1.495	0.008	1.152	0.008

11.0 APPENDIX C, ADDITIONAL DOSE RATES

Additional dose rates are calculated around the HSM-HB loaded with NUHOMS 32PHB bounding DSC containing PWR design basis fuel loaded conservatively with the bounding heat zoning configuration in Table 5-4. However, these dose rates are calculated with a conservative, generic source. Dose rates locations are indicated in Figure 11-1.

Dose rates are calculated using the MCNP point detector capability.

Table 11-1 gives dose rates at 10', 20', 40' and 80' from HSM-HB door.

Table 11-1
Dose Rates from HSM-HB Front

Distance, foot	Gamma, mrem/h	Relative Error	Neutron, mrem/h	Relative Error	Total Gamma + Neutron mrem/h	Relative Error
10	0.35	0.09	0.13	0.11	0.48	0.07
20	0.81	0.06	8.60E-02	0.07	0.89	0.05
40	0.37	0.04	3.28E-02	0.06	0.40	0.04
80	0.11	0.04	9.59E-03	0.06	0.12	0.04

Table 11-2 gives dose rates at 10', 20', 40' and 80' from HSM-HB side.

Table 11-2
Dose Rates from HSM-HB Side

Distance, foot	Gamma, mrem/h	Relative Error	Neutron, mrem/h	Relative Error	Total Gamma + Neutron mrem/h	Relative Error
10	0.15	0.02	1.90E-02	0.02	0.17	0.02
20	7.65E-02	0.02	8.95E-03	0.02	8.54E-02	0.02
40	2.97E-02	0.02	3.18E-03	0.02	3.29E-02	0.02
80	9.71E-03	0.02	9.53E-04	0.02	1.07E-02	0.02

Table 11-3 gives dose rates at 10', 20', 40' and 80' from HSM-HB corner.

Table 11-3
Dose Rates from HSM-HB Corner

Distance, foot	Gamma, mrem/h	Relative Error	Neutron, mrem/h	Relative Error	Total Gamma + Neutron mrem/h	Relative Error
10	0.15	0.07	8.36E-02	0.12	0.23	0.06
20	5.59E-02	0.05	2.52E-02	0.10	8.11E-02	0.05
40	2.09E-02	0.06	7.44E-03	0.09	2.84E-02	0.05
80	6.91E-03	0.07	1.84E-03	0.10	8.75E-03	0.06

Table 11-4 gives dose rates at 10', 20', 40' and 80' from HSM-HB front, side and corner with the door opened.

Table 11-4
Dose Rates from HSM-HB Door opened

HSM-HB Door opened	Distance, foot	Gamma, mrem/h	Relative Error	Neutron, mrem/h	Relative Error	Total Gamma + Neutron mrem/h	Relative Error
Front at 66.7 ft (on axis)	66.7	12.4	0.03	2.22	0.02	14.6	0.03
Front	10	962	0.02	75.9	0.02	1040	0.02
	20	244	0.02	23.6	0.02	267	0.02
	40	47.8	0.02	6.36	0.02	54.1	0.02
	80	8.06	0.03	1.49	0.02	9.55	0.03
Side	10	2.41	0.03	0.28	0.02	2.69	0.03
	20	1.69	0.03	0.13	0.02	1.82	0.03
	40	0.86	0.04	9.62e-2	0.02	0.96	0.04
	80	0.29	0.04	3.01e-2	0.02	0.32	0.04
Corner	10	517	0.02	38.4	0.02	555	0.02
	20	145	0.02	8.50	0.02	154	0.02
	40	40.3	0.03	1.99	0.02	42.3	0.03
	80	9.91	0.04	0.45	0.02	10.4	0.04

Table 11-5 shows dose rates at HSM-HB roof centerline and bird screen without stainless steel vent cap, see Figure 5-9. Only gamma dose rates are reevaluated, neutron dose rates are identical than those on Table 8-1. Gamma dose rates increase by about 44% and 74% on the HSM-HB roof centerline and bird screen, respectively.

Table 11-5
Dose Rates on HSM-HB Roof without Stainless Steel plates in Vent

Dose Rate Location	Maximum Gamma (mrem/hr)	Gamma MCNP 1σ Error	Maximum Neutron (mrem/hr)	Neutron MCNP 1σ Error	Maximum Total (mrem/hr)	Total MCNP 1σ Error
HSM-HB Roof (centerline)	10.4	0.15	1.34	0.02	**11.8**	0.13
HSM-HB Roof Bird screen	86.0	0.06	11.9	0.01	**97.9**	0.05

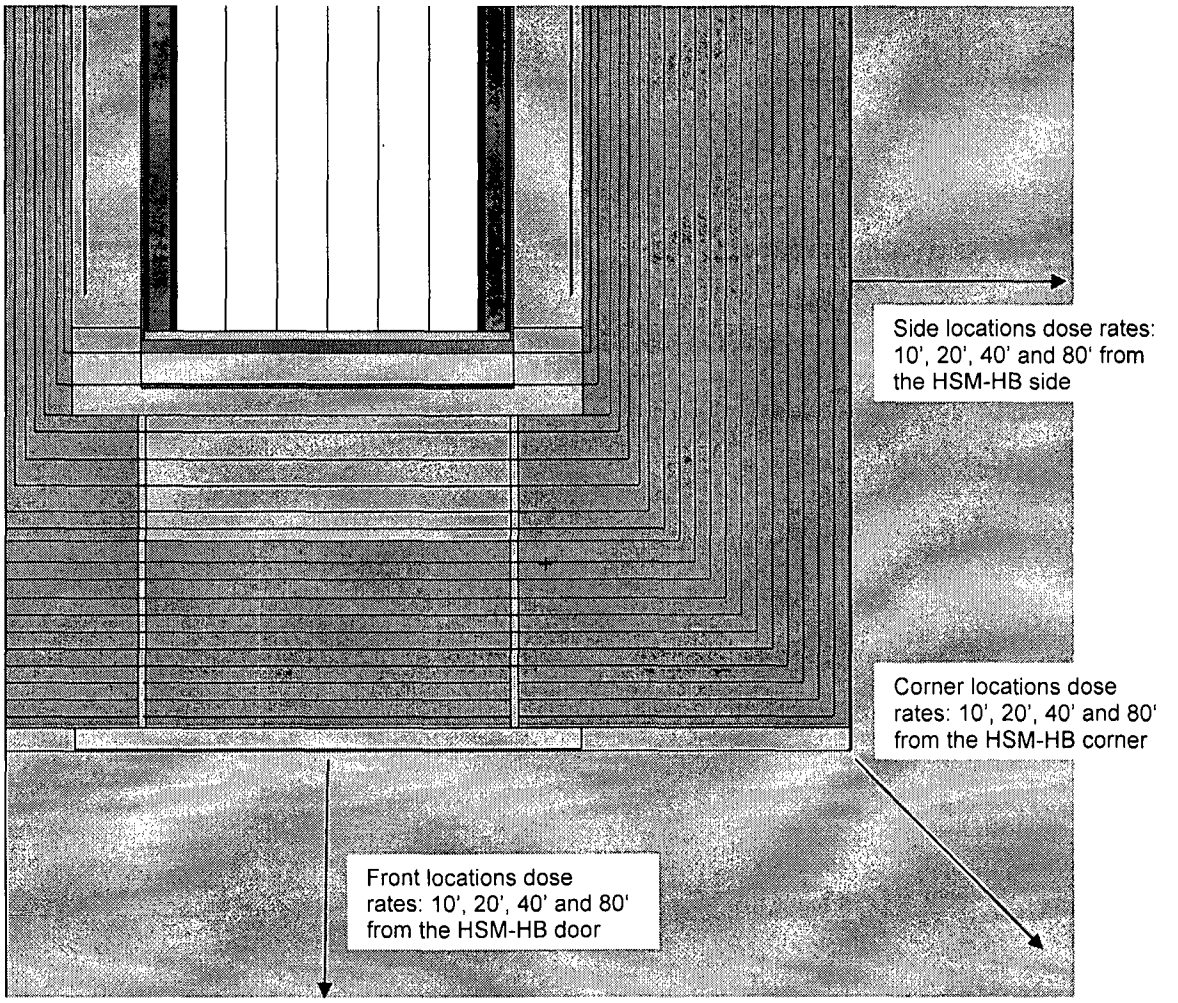


Figure 11-1
Dose Rates Locations around HSM-HB

12.0 APPENDIX D, FRONT VENT DOSE RATE REDUCTION

This Appendix considers adjustments to the HSM-HB geometry to attenuate radiation in front of the front vents (front birdscreens), particularly the LHS vent. The LHS vent is directly adjacent to another vent from the neighboring HSM, which doubles the size of the vent opening and greatly increases the dose rate in comparison to the RHS vent, as can be seen in Table 6-4. The MCNP model was modified to include a series of pipes in the vents to determine the effect on dose rates.

Since approximately 90% of the dose rate in front of the vents is due to primary gamma, it is not necessary to analyze the dose rate due to neutrons or secondary gamma to determine the effectiveness of the pipes. The results presented in this section only consider the dose rate contributions from primary gamma.

Three 16" pipes were modeled in the two adjacent vents stacked in a triangle formation. This implies that there are 1.5 pipes in each vent, as shown in Figure 12-1. The pipes are 6" long and are flush with the front of the HSM, extending into the vents (+Z direction). A series of MCNP runs were analyzed to determine the optimal configuration.

The base case considered the pipes to be 16" diameter schedule 10 (0.25" thick walls) stainless steel pipes stacked as shown in Figure 12-1. The second case replaced the stainless steel with aluminum to determine the effect of material. The third case used stainless steel once again, but inverted the triangle to determine the effect of geometry. The final case used stainless steel in the original configuration, but with schedule 5 (0.165" thick walls) pipes.

The maximum and average dose rates in front of the LHS vent are are summarized inTable 12-1 for these four configurations. It is important to note that these dose rates were calculated with a generic source term, so the actual dose rates are far less important than the relative reduction. As can be seen in Table 12-1, there is little variation between the four configurations, so the material, geometry, and thickness of the pipes have minimal impact on the results. However, all configurations provide a significant gamma dose reduction in front of the LHS vent.

The base case with 16" schedule 10 stainless steel pipes in a triangle formation was selected for further investigation. The MCNP model with the correct source terms used to determine the dose rates in Table 6-4 and Table 6-5 was modified to include the pipes in this configuration. Table 12-2 shows that the pipes reduce the maximum gamma dose rate by 43% and the average gamma does rate by 31%.

Due to tolerances in the HSM dimensions, it may not be possible possible to fit three 16" pipes in the vents as shown in Figure 12-1. As shown by the final sensitivity study in Table 12-1, the dose rate reduction is not extremely sensitive to the amount of material, so utilizing pipes with a 14" diameter will have a similar impact on dose rates.

Table 12-1
Primary Gamma Dose Rates in Front of LHS Vent Sensitivity

Configuration			Maximum		Average	
			Dose Rate (mrem/hr)	Reduction	Dose Rate (mrem/hr)	Reduction
No Pipes			202	-	136	-
Material	Geometry	Wall Thickness				
Steel	Triangle	0.25"	144	29%	97.8	28%
Aluminum	Triangle	0.25"	154	24%	107	21%
Steel	Inverted Triangle	0.25"	147	27%	99.9	26%
Steel	Triangle	0.165"	147	27%	99.9	26%

Table 12-2
Primary Gamma Dose Rates in Front of LHS Vent Sensitivity

Configuration	Maximum		Average	
	Dose Rate (mrem/hr)	Reduction	Dose Rate (mrem/hr)	Reduction
w/o Pipes	109	-	79.0	-
w/ Pipes	62.0	43%	54.7	31%

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Figure 12-1
Stainless Steel Pipes in the Front Vents of HSM-HB – Cut Through Views from VisEd

13.0 APPENDIX E, FILE LISTING

13.1 MCNP Runs

The following files are used in Table 6-8 through Table 6-18, Table 8-1, Table 10-1 through Table 10-8, and Table 12-2

Date	/Gamma/	Size (bytes)
April 9, 2010	HSM-g	114,836
April 12, 2010	HSM-gm	59,202
April 12, 2010	HSM-go	2,397,834
April 12, 2010	meshtal	298,506

Date	/Neutron/	size (bytes)
October 29, 2009	HSM-n	131,412
November 01, 2009	HSM-nm	134,098
November 01, 2009	HSM-no	3,307,791
November 01, 2009	meshtal	596,806

The following files are used in Table 8-1

Date	/Gamma-door-opened-b/	Size (bytes)
April 27, 2009	HSM-g	105,913
April 27, 2009	HSM-gm	12,411
April 27, 2009	HSM-go	1,860,026

Date	/Neutron-door-opened-b/	Size (bytes)
April 27, 2009	HSM-n	106,286
April 27, 2009	HSM-nm	24,662
April 27, 2009	HSM-no	2,711,586

The following files are used in Table 8-2, Table 11-1 through Table 11-3, and Table 12-1.

Date	/Gamma-old/	Size (bytes)
October 30, 2009	HSM-g	114,255
November 01, 2009	HSM-gm	52,674
November 01, 2009	HSM-go	2,387,964
November 01, 2009	meshtal	298,506

The following files are used in Table 11-1 through Table 11-3.

Date	/Neutron-bis/	size (bytes)
April 23, 2010	HSM-n	131,412
April 23, 2010	mctal	114,514
April 23, 2010	HSM-nmo	3,753,667
April 23, 2010	HSM-nmes	596,806

The following files are used in Table 11-4.

Date	/Gamma-door-opened/	Size (bytes)
November 05, 2009	HSM-g	105,850
November 06, 2009	HSM-gm	12,199
November 06, 2009	HSM-go	1,799,895

Date	/Neutron-door-opened/	Size (bytes)
November 05, 2009	HSM-n	105,760
November 06, 2009	HSM-nm	25,564
November 06, 2009	HSM-no	2,642,536

The following files are used in Table 11-5.

Date	/ HSM-32PHB-1Zone-withoutventcap-g/	Size (bytes)
November 05, 2009	HSM-g	105,850
November 06, 2009	HSM-gm	12,199
November 06, 2009	HSM-go	1,799,895

The following files are used in Table 12-1.

Date	/Dose-reduction-1/	Size (bytes)
April 8, 2010	g3p5	115,449
April 9, 2010	g3p5m	22,299
April 9, 2010	g3p5o	1,143,648
April 9, 2010	meshtal	222,288

Date	/Dose-reduction-2/	Size (bytes)
April 8, 2010	g3p6	115,449
April 9, 2010	g3p6m	22,299
April 9, 2010	g3p6o	1,133,778
April 9, 2010	meshtal	222,288

Date	/Dose-reduction-3/	Size (bytes)
April 8, 2010	g3p7	115,449
April 9, 2010	g3p7m	22,860
April 9, 2010	g3p7o	1,141,622
April 9, 2010	meshtal	222,288

Date	/Dose-reduction-4/	Size (bytes)
April 8, 2010	g3p8	115,452
April 10, 2010	g3p8m	22,299
April 10, 2010	g3p8o	1,148,577
April 10, 2010	meshtal	222,288

The following files are used in Table 12-2.

Date	/Dose-reduction-final/	Size (bytes)
April 12, 2010	g3p5	116,089
April 14, 2010	g3p5m	65,730
April 14, 2010	g3p5o	2,419,798
April 14, 2010	meshtal	298,506

13.2 Miscellaneous Spreadsheets

The following spreadsheets are utilized to process MCNP outputs and include the results tables presented in this calculation

2,440,704 bytes April 28, 2010, Final DED.xls
1,243,648 bytes April 12, 2010, DoseRates.xls
1,815,040 bytes November 09, 2009, Final DED - without vent cap.xls
73,728 bytes April 21, 2010, results.xls
2,442,752 bytes April 23, 2010, FinalDEDdr.xls

13.3 Sample HSM-HB MCNP 5 Model

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Pages 76 to 108
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