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RADIATION SHIELDING ANALYSIS FOR THE PRIVATE FUEL STORAGE FACILITY FOR PRIVATE FUEL STORAGE L.L.C.

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by

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Executive Summary

The shielding analysis of the Private Fuel Storage Facility is presented in this report. The facility consists of 4000 HI-STORM 100 casks with design basis fuel of 40,000 MWD/MTU and 10 year cooling. The results of the analysis are presented below. These results fully indicate that the dose rates from this facility are well below the limits imposed by the client and 10CFR72.104.

Dose Rates on the Surface of the HI-STORM 100
(mrem/hr)

Location	Neutron	Photon†	Cobalt	Total
Bottom duct	2.07	3.47	10.71	16.25
Fuel midplane	0.60	5.64	0.02	6.27
Top duct	2.31	2.38	9.23	13.92
Top of overpack	1.87	0.64	1.53	4.03

† photons from neutron interactions are included in the photon dose

Dose Rates at 1 meter from the HI-STORM 100
(mrem/hr)

Location	Neutron	Photon†	Cobalt	Total
Bottom duct	0.26	0.68	1.95	2.89
Fuel midplane	0.27	2.82	0.10	3.19
Top duct	0.22	0.53	1.39	2.15
Top of overpack	0.44	0.17	0.47	1.08

† photons from neutron interactions are included in the photon dose

The dose rates at the security fence and the site boundary are listed below. The site boundary is 600 meters from the security fence. The contributions to the total dose rate from particles that leave the tops of the overpacks and the sides of the overpacks are explicitly stated. The site boundary dose rates are in mrem/yr and are based on a 2000 hr occupancy factor.

Dose Rates at the Security Fence
(mrem/hr)

	Dose from Side	Dose from Top	Total
North and South Faces	1.13	6.09E-02	1.20
East and West Faces	9.15E-01	6.01E-02	0.975
Limit			2.0

Dose Rates at the Site Boundary
(mrem/yr)
2000 hr occupancy assumed

	Dose from Side	Dose from Top	Total
North and South Faces	3.73	1.38E-01	3.87
East and West Faces	2.21	1.23E-01	2.34
10CFR72.104 Limit			25.0

The final dose rate presented is the dose rate at 2 miles from the facility. This dose was estimated by extrapolating the dose rate at the site boundary out to a distance of 2 miles using a power curve. The result is presented below.

Dose Rate at 2 miles from the Facility
(mrem/yr)
2000 hr occupancy assumed

	Dose Rate
Site boundary	3.87
2 miles	5.38E-03
10CFR72.104 Limit	25.0

1.0 Introduction

This report documents the radiation shielding analysis that was performed for the Private Fuel Storage Facility (PFSF). This facility consists of 4000 HI-STORM casks loaded with either the MPC-24 or MPC-68. The design basis fuel burnup and cooling time is 40,000 MWD/MTU and 10 year cooling. The results indicate that all regulatory requirements for both normal (10CFR72.104) and accident conditions (10CFR72.106) are met at the 600 meter site boundary. In addition, an analysis has been performed to estimate the dose rate at a distance of 2 miles from the facility and at distance of 150 feet from the casks, which is the location of the security fence.

2.0 General Methodology

The Topical Safety Analysis Report for the HI-STORM 100 System [4] shows that a HI-STORM overpack containing an MPC-24 has higher contact dose rates on the top and at the duct openings than a HI-STORM overpack containing an MPC-68. This comparison is based on MPCs containing fuel of identical burnup and cooling times. Reference 4 shows that the dose rate at the midplane for an overpack with an MPC-24 is essentially the same as the dose at the midplane for an overpack containing an MPC-68. Based on these results, the MPC-24 was the only MPC used in the analysis of the PFSF. Therefore, these dose rates will conservatively bound the dose rates from a HI-STORM 100 containing an MPC-68.

The analysis of the 4000 cask Private Fuel Storage Facility can be separated into two distinct parts. The first is the generation of the radiation source terms to represent the spent nuclear fuel at the appropriate burnup and cooling times. The second part is the radiation transport simulation to calculate the dose rates near and far from a cask and an array of casks.

The radiation source terms were calculated using the SAS2H and ORIGEN-S modules from the SCALE 4.3 [1,2] code system from Oak Ridge National Laboratory. This is a widely accepted means of generating radiation source terms from spent nuclear fuel.

The radiation transport simulation was performed with MCNP 4A [3] from Los Alamos National Laboratory. This is a state of the art Monte Carlo code that offers coupled neutron-gamma transport using continuos energy cross sections in a full three-dimensional geometry.

The specifics of the radiation source term calculations and radiation transport simulation are discussed below.

3.0 Acceptance Criteria

The acceptance criteria for these analysis are dictated by 10CFR72.104 and 10CFR72.106 and are summarized here.

Normal condition requirements from 10CFR72.104.

1. During normal operations and anticipated occurrences, the annual dose equivalent to an individual who is located beyond the controlled area, must not exceed 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other organ.
2. Operational restrictions must be established to meet as low as reasonably achievable (ALARA) objectives for radioactive materials in effluents and direct radiation.

Accident condition requirements from 10CFR72.106

> Any individual located on or beyond the nearest boundary of the controlled area shall not receive a dose greater than 5 Rem to the whole body or any organ from any design basis accident.

An additional acceptance criteria of 2 mrem/hr at the security fence was imposed by the client.

Reference 4 demonstrates that there are no accidents which would significantly affect shielding effectiveness of the HI-STORM. Therefore, explicit analysis of an accident scenario was not performed. Reference 4 offers further discussion on this topic.

This report demonstrates that the Private Fuel Storage Facility meets the above stated acceptance criteria.

4.0 Assumptions

It is assumed that the occupancy factor for the site boundary calculations is 2000 hr.

Other assumptions are stated in the text as necessary. Since this report uses MCNP models from the HI-STAR and HI-STORM analyses, additional assumptions and discussion can be found in references 4, 5, 6, 7, and 8.

5.0 Input Data

The input data for generating the radiation source terms is provided in references 4, 5, 6, and 7. The input data for the MCNP models of the overpack and the MPC, including the density and composition of all materials used in the models is available in these references.

5.1 Private Fuel Storage Facility Geometry

The only other input data needed was the arrangement of the PFSF. This data was provided in reference 9 and the geometry of the facility is illustrated in this report.

The PFSF consists of 4000 HI-STORM 100 overpacks arranged on 500 concrete pads with 8 overpacks per pad. A picture of a concrete pad with 8 overpacks is shown in Figure 1.

The pad dimensions are 30 feet by 64 feet. The spacing between the overpacks is 15 feet center to center. This dimension was set by Holtec and is larger than reference 9 indicates. An overpack is 11 feet 1/2 inch in diameter.

Figure 2 shows the configuration of concrete pads at the PFSF. The spacing between individual pads is 5 feet and the spacing between columns of pads is 30 feet. The distance between quadrants is 150 feet and the distance to the security fence (the dashed line in Figure 2) is 150 feet from the nearest concrete pad.

It is conservatively assumed that there are no obstructions (ex. earth berm) between the security fence and the site boundary which is 600 meters away from the fence.

6.0 Computer Codes

The only computer codes used for these calculations were the following.

1. SAS2H module from SCALE 4.3 - reference 1
2. ORIGEN-S module from SCALE 4.3 - reference 2
3. MCNP 4A - references 3 and 8

7.0 Analysis and Results

This section of the report describes the calculations that were performed to determine the dose rates at the security fence and site boundary. The basic development of the MCNP models, including source terms and tally normalization, had already been accomplished during the HI-STAR 100 and HI-STORM 100 projects. This information is appropriately referenced as needed.

7.1 Source Terms

There are three distinct primary radiation source terms that must be accounted for in the analysis of the HI-STORM 100 system. These are:

1. Neutron source from the decay of fission products.
2. Photon source from the decay of fission products.
3. Photons from the decay of Cobalt-60 in the end-fittings of the fuel assemblies. This source represents the activation of the steel components in the fuel assemblies.

These radiation source terms were calculated during the HI-STAR 100 project using the SAS2H and ORIGEN-S modules of SCALE 4.3. A full description of the methodology can be found in references 4,5,6, and 7. The source terms for the 40,000 MWD/MTU and 10 year cooling design basis fuel can be found in references 5 and 7.

A secondary source of radiation is from the following:

1. Secondary neutrons from fast fission in the fuel.
2. Secondary photons from prompt neutron interactions in the MPC and overpack.

These secondary sources are automatically accounted for during the MCNP calculation by running a coupled neutron-gamma calculation.

7.2 MCNP Modeling of the MPC and HI-STORM Overpack

The MPC and the overpack were modeled in full three-dimensional detail using MCNP. The description of the modeling process can be found in references 4, 5, 6, and 7.

References 4 and 8 identify a number of modeling discrepancies between the MCNP model of the overpack and the design basis drawings. Most of these modeling discrepancies have been removed for this analysis. The following are the only modeling discrepancies that remain.

1. The steel channels were modeled as a homogenous region fully encompassing the MPC. The total mass of the channels is conserved; the thickness has been reduced. The only portion of the channel that was used in the modeling process was the curved portion of the channel that could contact the MPC.
2. The overpack baseplate was modeled as circular. The cut-outs below and on the outside of the vents were modeled as steel. Since the baseplate is at the bottom of the overpack, this discrepancy will have negligible impact on the calculated dose rates.
3. The bolt anchor blocks were not explicitly modeled. Concrete was used instead. These are small localized items and will not impact dose rates.

7.3 Method of Tallying

In MCNP, the calculation of a user requested quantity (ex. dose rate) is referred to as tallying. The tally results calculated in MCNP are normalized per starting particle. Therefore, the MCNP results must be normalized to the actual source strength for the system being analyzed. This normalization is done after the computer runs are completed and is done in EXCEL. The method of the tally normalization is described in references 7 and 8.

7.4 MCNP Surface Source Calculations

MCNP offers the capability to generate a surface source file in one calculation which can then be used in other calculations. The surface source file contains information for particle tracks that cross user designated surfaces. This method of using a surface source file has a major benefit because the user can generate a surface source file for particles leaving the overpack and then use this file in different runs with different overpack arrangements. The advantage is that, for each overpack arrangement, the user does not have to waste valuable computer time tracking particles out of the overpack since this information is already contained on the surface source file.

Reference 8 describes in detail the use of the surface source file for analysis of the HI-STORM 100 system.

Since there are three separate radiation sources (neutron, gamma, and Cobalt-60) a minimum of three different MCNP calculations had to be performed. There were actually 5 separate MCNP calculations performed to generate the surface source files that would be used in the later calculations. These 5 runs are described here. The computer input file names are listed in section 8.0.

1. A coupled neutron-gamma calculation using the neutron source was performed to generate a surface source file for particles leaving the side and top of the overpack.
2. A gamma only calculation was performed using the decay gamma source. This run generated a surface source file for particles leaving the side and top of the overpack. The energy range of starting particles was 0.7 MeV to 1.5 MeV.
3. A gamma only calculation was performed using the decay gamma source. This run generated a surface source file for particles leaving the side and top of the overpack. The energy range of starting particles was 1.5 MeV to 3.0 MeV.
4. A gamma only calculation using the Cobalt-60 source was performed. This calculation generated a surface source file for particles leaving the side of the overpack.
5. A gamma only calculation using the Cobalt-60 source was performed. This calculation generated a surface source file for particles leaving the top of the overpack. The source only contained particles originating in the upper portion of the fuel assemblies.

7.5 Dose Rates Adjacent to the Overpack

MCNP calculations were performed to determine the dose rate at the surface of the overpack and at a distance of 1 meter from the overpack. The computer input files used for the calculations are listed in section 8.0.

Appendix A contains the EXCEL output showing the doses at the surface and 1 meter from the overpack. Theses dose rates are in mrem/hr. A summary of the important dose locations is provided in the Executive Summary.

7.6 Cask Configurations for Dose Versus Distance Calculations

Figure 2 shows a diagram of the PFSF. The estimation of the off-site dose from a facility of this size and orientation is a complicated calculation. It is almost impossible and certainly impractical to try to model the entire facility in MCNP or any other computer code. Therefore, numerous smaller calculations had to be performed. The results from these smaller calculations were combined in a conservative fashion to accurately estimate the off-site dose from this facility.

The radiation source from this facility can be separated into two components. The first will be referred to as the top-dose. This is the dose off-site from radiation that leaves the tops of the overpacks. The second component will be referred to as side-dose. This is the off-site dose from radiation that leaves the sides of the overpacks.

The geometry of the facility will impact each of these dose components in a different fashion. The total top-dose will be a summation of the top-doses from all 4000 casks where the actual distance from the site-boundary to the individual cask is accounted for. Since the combined width of all of the casks is approximately 400 meters, the distance from the first cask to the site boundary is approximately 650 meters (600 meters + 150 feet) and the distance from the last cask is approximately 1050 meters.

The total side-dose will be a summation of the side-doses from all 4000 casks where the distances within the facility and the self-shielding of one row of casks to another row are accounted for. Since the side-dose is from particles leaving the side of the overpack, this dose contribution will be greatly reduced if the cask is situated behind another cask. The front cask blocks radiation from reaching the site-boundary. It is incorrect to say that front cask completely blocks all radiation from the back cask. The fraction of radiation blocked was therefore calculated with MCNP and used in the determination of the total side-dose.

The self-shielding effects are different along the North and East faces since the facility geometry is different in these directions. Figure 3 shows six different overpack configurations that were analyzed to determine the self-shielding effects. Since particles leaving the top of the overpack are not self-shielded, only particles leaving the side of the overpack were used in the sources for these configurations. Therefore, the results from these configurations will apply only to the side-dose. These configurations are described in detail below.

In each of the configurations described, only the overpack and surrounding air/dirt regions were present in the model. The MPC was not modeled in order to reduce computational time. This modeling detail will not affect the final dose rates because of two reasons. First, the source being used in these calculations is being started on the outside of the overpack and is immediately going into the surrounding air regions. Second, the probability of any particle re-entering an overpack and going into the MPC and then exiting the overpack is extremely small.

Configuration 1

Configuration 1 is a single cask surrounded by 1050 meters or air in the radial direction and 700 meters of air in altitude. The cask is sitting on an infinite slab of dirt. This configuration was used to calculate the average dose rate versus distance for a single cask. The dose rate from particles leaving the side of the cask was calculated separately from the dose rate from particles leaving the top of the cask. The total dose rate was also calculated.

These dose rates were combined in a manner, which is discussed later, to determine the dose rate from the entire facility at the site boundary and security fence.

The MCNP input files used to analyze this configuration are listed in section 8.0. All three sources (neutron, photon, and cobalt) were analyzed in this configuration. The results for this configuration are presented in Appendix B.

Configuration 2

Configuration 2 represents an infinite line of casks. The reflective boundary conditions placed on either side of the cask are spaced 7.5 feet from the center of the cask. This spacing is equal to the cask pitch. This configuration effectively represents the casks along the East and West faces.

The dose rate as a function of distance from the cask was calculated for this configuration. The ratio of the dose rates from this configuration to the dose rates calculated in configuration 1 indicate how many casks are considered to be infinite as a function of the distance away from the facility. This is an important piece of information for the determination of the doses at the security fence since the number of casks considered to be infinite at 150 feet from a cask is far less than the number of casks along a face of the facility.

The surrounding air region, for configurations 2 through 6, was modeled as 550 meters of air in the radial direction and 500 meters of air in altitude. The cask is sitting on an infinite slab of dirt. The air region was reduced relative to configuration 1 to reduce computation time. Reference 8 provides justification for this reduction.

The neutron and cobalt sources were used in the MCNP calculations of configurations 2 through 6. The photon source was not used in order to reduce the overall computational time. It is assumed that the behavior of the dose rates due to the photon source will be identical to the behavior of the dose rates from the cobalt source. This assumption is valid because the average energies of the sources are similar and both sources are photons.

Appendix C presents the results of the calculations of this configuration.

Configuration 3

Configuration 3 represents two infinite lines of casks, one behind the other. The reflective boundary conditions placed on the three sides of the cask are spaced 7.5 feet from the center of the cask. This spacing is equal to a cask pitch of 15 feet. This configuration effectively represents the casks in a column of concrete pads along the East and West faces of the facility.

The dose rate as a function of distance from the cask was calculated for this configuration. The ratio of the dose rates calculated from this configuration to the dose rates calculated with configuration 2 indicate the fractional increase in the dose rate when a second line of casks is added. This ratio will always be greater than 1 since adding more source can not reduce the dose rate. The exact dose rate contribution of the second line of casks can be calculated using this ratio.

Dose rate from second line of casks = [(ratio config 3 to config 2) -1] * dose rate from first line

This dose rate is the dose rate that a shielded line of casks will contribute.

Appendix C presents the results of the calculations of this configuration.

Configuration 4

Configuration 4 represents four infinite lines of casks. The parallel reflective boundary conditions are spaced 7.5 feet from the centers of the casks. This is equal to the cask pitch. The third reflective boundary condition is 22.5 feet from the center of the nearest cask. This distance places the reflective boundary condition half way between two columns of concrete pads along the East and West faces of the facility. Therefore this geometry represents two infinite lines of concrete pads each containing two lines of casks.

The dose rate as a function of distance from the cask was calculated for this configuration. The ratio of the dose rates calculated from this configuration to the dose rates calculated with configuration 3 indicate the fractional increase in the dose rate when a second set of casks is added behind the first set of casks. This ratio will always be greater than 1 since adding more source can not reduce the dose rate. The exact dose rate contribution of the second set of casks can be calculated using this ratio.

Dose rate from second set of casks = [(ratio config 4 to config 3)-1] * dose rate from first set of casks which is determined using configuration 3

This dose rate is the dose rate that a shielded set of casks (a line of concrete pads) will contribute.

Appendix C presents the results of the calculations of this configuration.

Configuration 5

Configuration 5 represents an infinite line of casks. The reflective boundary condition closest to the cask is 7.5 feet from the center of the cask. This is equal to half of the cask pitch. The second reflective boundary condition is 22.5 feet from the center of the cask. This spacing is equal to half the distance between casks situated on different pads. This configuration effectively represents the casks along the North and South faces.

The dose rate as a function of distance from the cask was calculated for this configuration. The ratio of the dose rates from this configuration to the dose rates calculated in configuration 1 also indicate how many casks are considered to be infinite as a function of the distance away from the facility. This is an important piece of information for the determination of the doses at the security fence since the number of casks considered to be infinite at 150 feet from a cask is far less than the number of casks along a face of the facility.

Appendix C presents the results of the calculations of this configuration.

Configuration 6

Configuration 6 represents two infinite lines of casks, one behind the other. The parallel reflective boundary conditions are spaced the same as in configuration 5. The third reflective

boundary condition is 7.5 feet from the center of the cask. This configuration effectively represents the two lines of casks along the North or South faces of the facility.

The dose rate as a function of distance from the cask was calculated for this configuration. The ratio of the dose rates calculated from this configuration to the dose rates calculated with configuration 5 indicate the fractional increase in the dose rate when a second line of casks is added. This ratio will always be greater than 1 since adding more source can not reduce the dose rate. The exact dose rate contribution of the second line of casks can be calculated using this ratio.

Dose rate from second line of casks = [(ratio config 6 to config 5)-1] * dose rate from first line

This dose rate is the dose rate that a shielded line of casks will contribute.

Appendix C presents the results of the calculations of this configuration.

7.7 Final Dose Rate Calculations

The ratios that were calculated using configurations 2 through 6 were used in conjunction with the dose rates calculated from configuration 1 to determine the dose rate at the security fence and site-boundary. These ratios apply only to the side-dose. Appendix C presents the results of the calculations of configurations 2 through 6 and shows the ratios that were calculated. The only assumption made in relation to these ratios is that the ratios are valid beyond the maximum 500 meters at which they were calculated. This assumption is perfectly valid since the ratios calculated remain flat from 100 meters to 500 meters indicating that the ratio will remain flat beyond 500 meters. In addition, it is physically impossible for the ratios to increase with distance.

Appendix D presents the results of the calculations to determine the dose rate at the security fence and the site boundary as well as 2 miles from the site boundary. The final calculations were performed with EXCEL and the EXCEL sheets showing these calculations are provided.

The dose at a distance of 2 miles was estimated by extrapolation using a power curve. This curve was calculated by fitting the data from the total dose rate versus distance for a single cask for distances between 100 and 1000 m. The curve underestimates the dose rate at distances less than 700 meters and overestimates the dose at distances greater than 700 meters. Since the distance in question is 2 miles, this curve will be conservative. The curve was then normalized to the maximum site boundary dose rate from the facility at a distance of 650 meters from the first cask. Using the newly normalized curve, the dose at 2 miles was calculated.

8.0 Computer Files

The following is a list of the MCNP runs that were used to generate the data presented in this report. The {n,p,c} in the description below refers to separate runs. For example, hs24{n,p,c}21 is actually three runs, hs24n21, hs24p21, and hs24c21

MCNP Run	Description
hs24n21	MPC-24 neutron run - generate surface source for side and top
hs24c21	MPC-24 cobalt run - generate surface source for side
hs24c31	MPC-24 cobalt run - generate surface source for top
hs24p31	MPC-24 gamma only run - generate surface source for side and top - starting energy 0.7 -1.5 MeV
hs24p41	MPC-24 gamma only run - generate surface source for side and top - starting energy 1.5 -3.0 MeV
hs24{c,n}22	MPC-24 {cobalt, neutron} run using surface source files from hs24{c,n}21 - surface and 1 meter doses calculated
hs24{c,p}32	MPC-24 {cobalt, photon} run using surface source files from hs24{c,n}31 - surface and 1 meter doses calculated
hs24p42	MPC-24 run using the surface source file from hs24p41 - surface and 1 meter doses calculated
hs24c24	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 1
hs24n23	MPC-24 - neutron run using surface source file from hs24n21 - side-dose versus distance was calculated - configuration 1
hs24p33	MPC-24 - photon run using surface source file from hs24p31 - side-dose versus distance was calculated - configuration 1
hs24p43	MPC-24 - photon run using surface source file from hs24p41 - side-dose versus distance was calculated - configuration 1
hs24c34	MPC-24 - cobalt run using surface source file from hs24c31 - top-dose versus distance was calculated - configuration 1
hs24n24	MPC-24 - neutron run using surface source file from hs24n21 - top-dose versus distance was calculated - configuration 1
hs24p34	MPC-24 - photon run using surface source file from hs24p31 - top-dose versus distance was calculated - configuration 1
hs24p44	MPC-24 - photon run using surface source file from hs24p41 - top-dose versus distance was calculated - configuration 1
hs24c25	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 2
hs24n25	MPC-24 - neutron run using surface source file from hs24n21 - side-dose versus distance was calculated - configuration 2
hs24c26	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 3
hs24n26	MPC-24 - neutron run using surface source file from hs24n21 - side-

	dose versus distance was calculated - configuration 3
hs24c27	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 4
hs24n27	MPC-24 - neutron run using surface source file from hs24n21 - side-dose versus distance was calculated - configuration 4 - error in area used for tally in input file - corrected in EXCEL sheet
hs24c28	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 5
hs24n28	MPC-24 - neutron run using surface source file from hs24n21 - side-dose versus distance was calculated - configuration 5 - error in area used for tally in input file - corrected in EXCEL sheet
hs24c29	MPC-24 - cobalt run using surface source file from hs24c21 - side-dose versus distance was calculated - configuration 6
hs24n29	MPC-24 - neutron run using surface source file from hs24n21 - side-dose versus distance was calculated - configuration 6

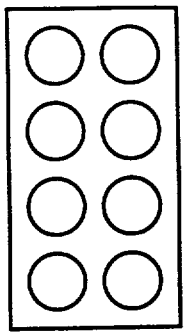

Figure 1. A concrete pad with eight HI-STORM 100 overpacks in place.

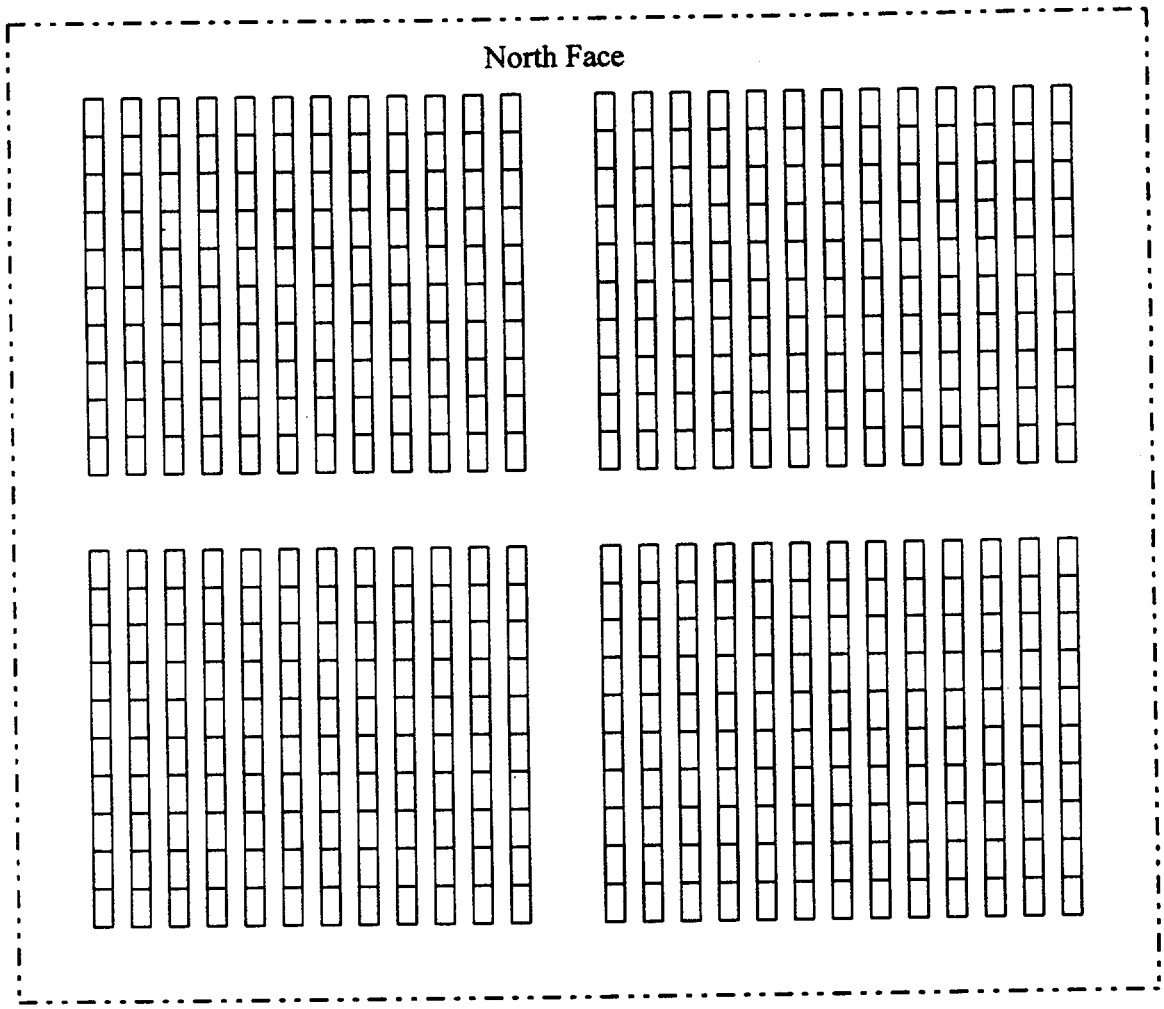

Figure 2. The Private Fuel Storage Facility concrete pad arrangement is shown. The distance between quadrants is 150 feet. The dashed line on the perimeter is the security fence and is located 150 feet from the casks.

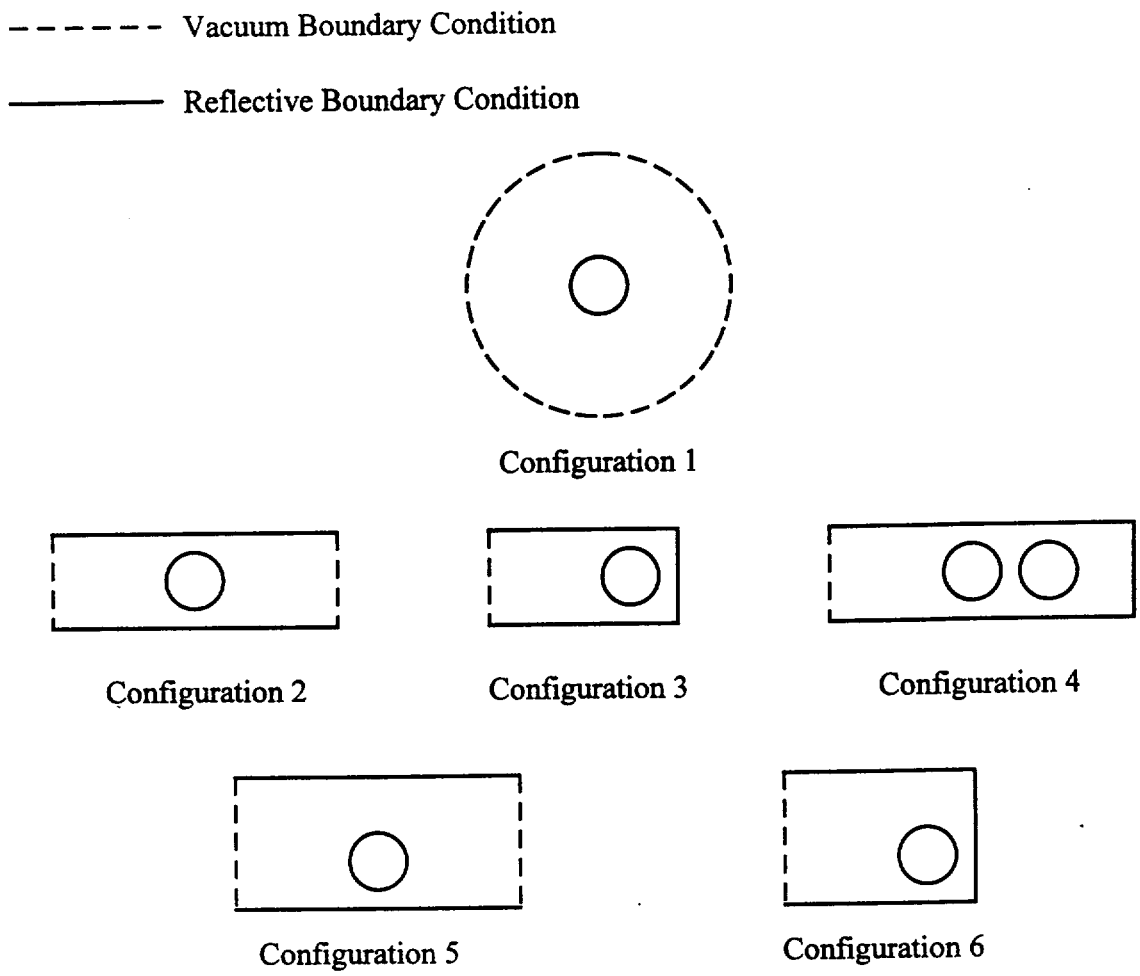

Figure 3. The six different MCNP models used in the analysis of the Private Fuel Storage Facility are depicted above.

9.0 References

1. O. W. Hermann, C. V. Parks, *SAS2H: A Coupled One-Dimensional Depletion and Shielding Analysis Module*, NUREG/CR-0200, Revision 5, (ORNL/NUREG/CSD-2/V2/R5), Oak Ridge National Laboratory, September 1995.

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8. E. L. Redmond II, *HI-STORM Shielding Design and Analysis for Storage*, HI-971608 Rev 0, Holtec International, February 1997.

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Appendix A. Near Dose Rates

This appendix presents the dose rates calculated at the surface and 1 meter from the overpack. This output, which is at the end of this section, is in the form of tables printed from EXCEL.

A more detailed discussion of the calculations is provided in section 7.

The format of the EXCEL pages is described here.

The first two lines are title lines indicating the burnup and decay time. On the same line as the decay time is another reference that has little meaning. The third line lists the runs from which the data is taken. The fourth line describes which dose component each column represents. The phot(n,p) means photons from neutron interactions in the surrounding material. Phot refers to photons coming from decay of fission products in the fuel region and cobalt refers to the cobalt source in the end fittings. The fifth line titles the columns value or rel err. The value means dose and the rel err refers to relative error which is defined as the standard deviation over the mean. In order to calculate the standard deviation of a value listed in the value column, one would take the associated rel err number and multiply by the number in the value column. The numbers listed under the total column are total doses. The rel err of the total values are statistically calculated from the standard deviations of the components.

On the far left are labels "sur". These refer to MCNP surfaces. The following is a description of the surfaces.

Surface	Description
720	Outer radial surface of overpack
724	Surface 1 meter from outer radial surface of overpack
934	Top surface of overpack. This surface is the top of the shield blocks that rest on top of the overpack
935	Surface 1 meter from surface 934.
718	Bottom duct opening at the surface of the overpack - 150 sq inches
722	Bot. Duct opening at 1 meter from the surface of overpack - 150 sq in.
719	Top duct opening at the surface of the overpack - 150 sq inches
723	Top duct opening at 1 meter from the surface of overpack - 150 sq in.

The following table describes the segmentation that was used.

Tally Segments

Axial

Segment	start MCNP pos cm	finish MCNP pos cm	start pos rel to bottom feet	finish pos rel to bottom feet	
1	-45.72	-15.24	0	1	
2	-15.24	15.24	1	2	
3	15.24	45.72	2	3	
4	45.72	76.2	3	4	
5	76.2	106.68	4	5	
6	106.68	137.16	5	6	
7	137.16	167.64	6	7	
8	167.64	198.12	7	8	
9	198.12	228.6	8	9 <------	center of bwr fuel 223.227 cm
10	228.6	259.08	9	10 <------	center of pwr fuel 236.16 cm
11	259.08	289.56	10	11	and center of MPC-GTCC 247.65 cm
12	289.56	320.04	11	12	
13	320.04	350.52	12	13	
14	350.52	381	13	14	
15	381	411.48	14	15	
16	411.48	441.96	15	16	
17	441.96	472.44	16	17	
18	472.44	502.92	17	18	
19	502.92	533.4	18	19	
20	533.4	563.88	19	20 <------	top of overpack
21	563.88	594.36	20	21	
22	594.36	624.84	21	22	
23	624.84	655.32	22	23	
24	655.32	656.895	23	23.05167	

Radial

Segment	start MCNP pos cm	finish MCNP pos cm	start pos rel to center feet	finish pos rel to center feet	
1	0	15.24	0	0.5	
2	15.24	45.72	0.5	1.5	
3	45.72	76.2	1.5	2.5	
4	76.2	106.68	2.5	3.5 <------	Annulus between MPC and overpack
5	106.68	137.16	3.5	4.5	is between 86.83625 and 93.345 cm
6	137.16	167.64	4.5	5.5	
7	167.64	198.12	5.5	6.5	
8	198.12	228.6	6.5	7.5	
9	228.6	259.08	7.5	8.5	
10	259.08	268.525	8.5	8.809875	

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0 10.0 YR	10.0 YR				mpc24					
		hs24n22m		hs24n22m		hs24p32m	hs24p42m	hs24c22m	hs24c32m		
		neutron		phot (n,p)		phot		cobalt		total	
		value	rel err	value	rel err	value	rel err	value	rel err	value	rel err
sur		720									
	1	0.337	0.026	0.066	0.032	0.433	0.079	1.581	0.017	2.418	0.019
	2	0.107	0.045	0.127	0.029	0.171	0.046	2.037	0.014	2.443	0.012
	3	0.167	0.051	0.263	0.024	0.900	0.062	4.309	0.022	5.639	0.019
	4	0.301	0.051	0.407	0.021	2.231	0.048	3.742	0.020	6.682	0.020
	5	0.482	0.043	0.561	0.018	3.862	0.047	1.141	0.030	6.046	0.030
	6	0.562	0.038	0.688	0.016	4.437	0.048	0.195	0.068	5.882	0.037
	7	0.615	0.037	0.760	0.016	4.822	0.053	0.031	0.116	6.227	0.041
	8	0.624	0.036	0.801	0.015	4.136	0.055	0.018	0.101	5.579	0.041
	9	0.604	0.036	0.801	0.016	4.843	0.056	0.017	0.165	6.266	0.043
	10	0.619	0.036	0.785	0.015	4.226	0.055	0.015	0.145	5.645	0.041
	11	0.605	0.037	0.787	0.015	4.471	0.054	0.012	0.112	5.874	0.041
	12	0.638	0.037	0.745	0.016	4.686	0.054	0.020	0.225	6.089	0.041
	13	0.535	0.038	0.685	0.017	4.197	0.051	0.039	0.133	5.456	0.039
	14	0.502	0.041	0.568	0.017	3.679	0.050	0.238	0.056	4.986	0.037
	15	0.384	0.049	0.450	0.020	2.763	0.044	1.238	0.028	4.835	0.026
	16	0.214	0.053	0.295	0.021	1.247	0.045	2.646	0.024	4.402	0.020
	17	0.099	0.050	0.196	0.022	0.349	0.040	2.669	0.019	3.312	0.016
	18	0.046	0.045	0.117	0.023	0.078	0.059	1.350	0.017	1.591	0.015
	19	0.410	0.013	0.069	0.028	0.309	0.051	1.519	0.009	2.307	0.009
	20	0.289	0.014	0.027	0.029	0.041	0.201	0.186	0.010	0.544	0.017
	21	0.291	0.015	0.025	0.016	0.031	0.126	0.005	0.112	0.352	0.017
	22	0.321	0.018	0.030	0.014	0.048	0.157	0.005	0.186	0.404	0.024
	23	0.308	0.019	0.030	0.019	0.052	0.072	0.005	0.161	0.395	0.017
	24	0.281	0.042	0.028	0.041	0.052	0.083	0.014	0.768	0.374	0.044
sur		724.000									
	1	0.134	0.030	0.096	0.034	0.437	0.061	0.967	0.016	1.634	0.019
	2	0.142	0.028	0.124	0.027	0.645	0.052	1.206	0.018	2.117	0.019
	3	0.145	0.029	0.173	0.027	0.954	0.050	1.194	0.021	2.466	0.022
	4	0.168	0.027	0.211	0.021	1.247	0.043	1.125	0.021	2.751	0.021
	5	0.203	0.026	0.269	0.019	1.841	0.042	0.846	0.022	3.159	0.025
	6	0.229	0.026	0.306	0.019	1.964	0.038	0.548	0.025	3.047	0.025
	7	0.257	0.025	0.339	0.018	2.205	0.040	0.319	0.030	3.120	0.029
	8	0.269	0.024	0.362	0.017	2.309	0.042	0.195	0.040	3.135	0.031
	9	0.277	0.023	0.363	0.017	2.295	0.039	0.124	0.045	3.060	0.030
	10	0.270	0.023	0.376	0.017	2.444	0.039	0.102	0.048	3.193	0.030
	11	0.272	0.024	0.365	0.017	2.338	0.041	0.121	0.050	3.096	0.031
	12	0.251	0.024	0.332	0.017	2.278	0.041	0.163	0.041	3.025	0.031
	13	0.232	0.025	0.308	0.018	1.993	0.041	0.253	0.032	2.786	0.030
	14	0.202	0.026	0.275	0.020	1.723	0.041	0.423	0.027	2.623	0.027
	15	0.167	0.028	0.222	0.020	1.372	0.044	0.621	0.024	2.382	0.027
	16	0.133	0.030	0.181	0.024	0.959	0.046	0.763	0.022	2.036	0.023
	17	0.115	0.032	0.137	0.024	0.675	0.054	0.777	0.021	1.703	0.023
	18	0.113	0.026	0.101	0.025	0.353	0.054	0.765	0.017	1.332	0.018

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0 10.0 YR	10.0 YR			mpc24					
	hs24n22m		hs24n22m		hs24p32m hs24p42m hs24c22m hs24c32m					
	neutron		phot (n,p)		phot		cobalt		total	
	value	rel err	value	rel err	value	rel err	value	rel err	value	rel err
19	0.132	0.023	0.074	0.028	0.312	0.061	0.797	0.012	1.314	0.017
20	0.121	0.023	0.050	0.031	0.152	0.080	0.459	0.014	0.782	0.018
21	0.106	0.018	0.035	0.038	0.086	0.130	0.185	0.019	0.412	0.029
22	0.107	0.017	0.026	0.046	0.086	0.270	0.113	0.026	0.333	0.071
23	0.112	0.018	0.024	0.072	0.063	0.355	0.064	0.039	0.263	0.086
24	0.108	0.055	0.022	0.129	0.125	0.588	0.042	0.147	0.298	0.249
tal	112.000									
sur	934.000									
1	0.828	0.040	0.207	0.036	0.010	0.182	0.032	0.272	1.077	0.032
2	0.893	0.019	0.212	0.015	0.011	0.112	0.048	0.083	1.163	0.015
3	0.944	0.017	0.188	0.011	0.023	0.084	0.068	0.051	1.223	0.013
4	1.869	0.020	0.187	0.013	0.448	0.073	1.531	0.042	4.034	0.020
5	1.234	0.016	0.107	0.010	0.196	0.076	1.012	0.039	2.549	0.018
6	0.346	0.016	0.028	0.018	0.021	0.093	0.072	0.049	0.468	0.015
7	0.243	0.017	0.025	0.028	0.039	0.120	0.012	0.054	0.319	0.020
8	0.159	0.017	0.033	0.044	0.061	0.101	0.001	0.094	0.254	0.027
9	0.130	0.022	0.039	0.029	0.098	0.081	0.001	0.073	0.268	0.032
10	0.124	0.040	0.042	0.056	0.113	0.109	0.001	0.109	0.279	0.048
sur	935.000									
1	0.436	0.030	0.103	0.049	0.049	0.083	0.175	0.053	0.763	0.023
2	0.461	0.017	0.096	0.020	0.055	0.069	0.213	0.035	0.825	0.014
3	0.467	0.016	0.083	0.015	0.073	0.069	0.274	0.034	0.898	0.014
4	0.463	0.017	0.068	0.023	0.110	0.083	0.371	0.038	1.012	0.018
5	0.437	0.023	0.050	0.014	0.119	0.077	0.472	0.047	1.079	0.024
6	0.348	0.021	0.036	0.014	0.076	0.066	0.334	0.038	0.793	0.020
7	0.249	0.017	0.025	0.016	0.049	0.089	0.161	0.036	0.485	0.018
8	0.180	0.020	0.021	0.017	0.033	0.105	0.085	0.038	0.319	0.019
9	0.137	0.016	0.019	0.021	0.032	0.105	0.050	0.039	0.238	0.019
10	0.118	0.023	0.019	0.053	0.059	0.227	0.036	0.043	0.233	0.059
tal	122.000									
sur	718.000									
1	2.071	0.028	0.204	0.038	3.264	0.084	10.710	0.020	16.248	0.022
sur	722.000									
1	0.259	0.071	0.123	0.122	0.557	0.097	1.946	0.038	2.885	0.033
sur	719.000									
1	2.314	0.014	0.159	0.020	2.221	0.054	9.228	0.011	13.923	0.011
sur	723.000									
1	0.223	0.042	0.072	0.076	0.459	0.149	1.392	0.024	2.146	0.036

Appendix B: Single Cask Dose Rates Versus Distance

The pages in this appendix are the output from the EXCEL files used to analyze the data from the calculations of the configuration 1 geometry. This output is dose versus distance from a single HI-STORM 100 cask. Appendix A describes some of the format of these pages.

The first two pages of the output are the dose rates in mrem/yr based on a 2000 hour occupancy factor. Near the top of the page the number of hours in a year is shown to be 2000.

The second two pages of the output are the dose rates in mrem/hr. Near the top of the page the number of hours in a year is shown to be 1 which results in mrem/hr.

The output show the dose rate versus distance for particles leaving the top of the overpack and also for particles leaving the side of the overpack. The total dose versus distance is also provided. These results are used in Appendix D to determine the total dose at the security fence and site boundary from the facility.

A more detailed discussion of the calculations is provided in section 7.

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR 0 10.0 YR 10.0 YR

hs24n23m hs24n23m hs24p33m hs24p43m hs24c24m

hours/yr 2000

Side Dose mrem/year

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	2.37E+00	0.027	2.33E+00	0.027	1.81E+01	0.043	8.50E+00	0.022	3.13E+01	0.026
250 ft	7.56E-01	0.030	7.82E-01	0.037	5.78E+00	0.056	2.71E+00	0.028	1.00E+01	0.034
100 m	4.17E-01	0.034	4.16E-01	0.043	3.14E+00	0.064	1.40E+00	0.031	5.37E+00	0.039
150 m	1.64E-01	0.054	1.70E-01	0.058	9.63E-01	0.059	4.63E-01	0.038	1.76E+00	0.035
200 m	7.14E-02	0.051	8.88E-02	0.065	4.03E-01	0.059	1.90E-01	0.040	7.54E-01	0.035
250 m	3.52E-02	0.057	4.53E-02	0.066	2.12E-01	0.069	9.21E-02	0.043	3.84E-01	0.041
300 m	1.88E-02	0.064	2.77E-02	0.073	1.02E-01	0.066	4.96E-02	0.049	1.98E-01	0.038
350 m	1.13E-02	0.062	1.69E-02	0.081	5.71E-02	0.066	2.70E-02	0.050	1.12E-01	0.038
400 m	7.24E-03	0.064	1.12E-02	0.089	3.25E-02	0.069	1.49E-02	0.055	6.59E-02	0.040
450 m	4.93E-03	0.087	7.05E-03	0.099	1.82E-02	0.073	8.26E-03	0.059	3.84E-02	0.043
500 m	3.01E-03	0.062	5.06E-03	0.118	1.09E-02	0.064	4.92E-03	0.053	2.39E-02	0.041
550 m	1.95E-03	0.067	3.97E-03	0.128	6.54E-03	0.073	2.83E-03	0.060	1.53E-02	0.048
600 m	1.28E-03	0.065	3.10E-03	0.138	4.14E-03	0.074	1.67E-03	0.061	1.02E-02	0.053
650 m	8.54E-04	0.069	1.94E-03	0.104	2.58E-03	0.066	9.42E-04	0.064	6.31E-03	0.044
700 m	5.42E-04	0.051	1.37E-03	0.121	1.62E-03	0.068	5.88E-04	0.058	4.12E-03	0.049
750 m	3.81E-04	0.060	1.08E-03	0.132	1.29E-03	0.070	4.09E-04	0.061	3.15E-03	0.055
800 m	2.86E-04	0.059	8.02E-04	0.133	8.25E-04	0.086	2.73E-04	0.070	2.19E-03	0.060
850 m	1.83E-04	0.065	6.27E-04	0.139	5.18E-04	0.069	1.70E-04	0.091	1.50E-03	0.064
900 m	1.37E-04	0.057	4.87E-04	0.147	3.68E-04	0.074	1.14E-04	0.065	1.11E-03	0.070
950 m	7.47E-05	0.060	3.75E-04	0.157	2.47E-04	0.085	7.13E-05	0.077	7.68E-04	0.082
1000 m	5.03E-05	0.069	2.86E-04	0.160	1.68E-04	0.084	4.11E-05	0.079	5.45E-04	0.088

Top Dose mrem/year

hs24n24m hs24n24m hs24p34m hs24p44m hs24c34m

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	4.67E-01	0.015	2.08E-02	0.022	1.64E-02	0.066	6.41E-02	0.035	5.68E-01	0.013
250 ft	2.00E-01	0.015	9.95E-03	0.021	8.17E-03	0.065	3.27E-02	0.035	2.51E-01	0.013
100 m	1.15E-01	0.017	6.13E-03	0.024	5.23E-03	0.066	2.07E-02	0.035	1.47E-01	0.014
150 m	4.28E-02	0.020	2.59E-03	0.023	2.30E-03	0.067	9.26E-03	0.036	5.70E-02	0.016
200 m	1.83E-02	0.020	1.35E-03	0.021	1.13E-03	0.066	4.47E-03	0.036	2.52E-02	0.016
250 m	8.72E-03	0.024	6.84E-04	0.021	5.48E-04	0.064	2.25E-03	0.037	1.22E-02	0.018
300 m	4.32E-03	0.025	4.35E-04	0.027	2.92E-04	0.069	1.20E-03	0.037	6.25E-03	0.019
350 m	2.26E-03	0.033	2.54E-04	0.026	1.55E-04	0.071	6.27E-04	0.038	3.30E-03	0.024
400 m	1.17E-03	0.030	1.59E-04	0.028	8.55E-05	0.068	3.51E-04	0.038	1.77E-03	0.022
450 m	6.18E-04	0.034	1.04E-04	0.025	4.60E-05	0.069	1.88E-04	0.039	9.56E-04	0.024
500 m	3.52E-04	0.036	7.16E-05	0.025	2.61E-05	0.075	1.04E-04	0.040	5.54E-04	0.024
550 m	2.16E-04	0.043	4.76E-05	0.026	1.43E-05	0.073	5.97E-05	0.040	3.38E-04	0.029
600 m	1.19E-04	0.042	3.52E-05	0.037	8.00E-06	0.070	3.36E-05	0.041	1.96E-04	0.028
650 m	6.69E-05	0.045	2.47E-05	0.030	4.73E-06	0.077	1.92E-05	0.043	1.15E-04	0.028

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR							
	hs24n23m		hs24n23m		hs24p33m	hs24p43m	hs24c24m			
700 m	3.72E-05	0.045	1.77E-05	0.035	2.64E-06	0.074	1.10E-05	0.042	6.86E-05	0.027
750 m	2.31E-05	0.059	1.36E-05	0.086	1.56E-06	0.085	6.39E-06	0.043	4.46E-05	0.041
800 m	1.73E-05	0.061	9.70E-06	0.031	8.96E-07	0.073	3.70E-06	0.045	3.16E-05	0.035
850 m	9.66E-06	0.068	7.89E-06	0.061	5.27E-07	0.084	2.22E-06	0.047	2.03E-05	0.040
900 m	5.51E-06	0.061	5.59E-06	0.036	3.15E-07	0.079	1.31E-06	0.048	1.27E-05	0.031
950 m	3.94E-06	0.068	4.34E-06	0.035	1.70E-07	0.085	7.05E-07	0.046	9.16E-06	0.034
1000 m	2.08E-06	0.081	3.32E-06	0.042	1.06E-07	0.094	4.26E-07	0.051	5.93E-06	0.037

Total Dose mrem/year

dis	neutron		phot (n,p)		phot		cobalt		total	
	value	rel err	value	rel err	value	rel err	value	rel err	value	rel err
150 ft	2.84E+00	0.022	2.35E+00	0.027	1.81E+01	0.043	8.57E+00	0.022	3.19E+01	0.025
250 ft	9.56E-01	0.024	7.92E-01	0.037	5.79E+00	0.056	2.75E+00	0.028	1.03E+01	0.033
100 m	5.32E-01	0.027	4.22E-01	0.042	3.15E+00	0.064	1.42E+00	0.031	5.52E+00	0.038
150 m	2.07E-01	0.043	1.73E-01	0.057	9.66E-01	0.059	4.72E-01	0.038	1.82E+00	0.034
200 m	8.97E-02	0.041	9.01E-02	0.064	4.05E-01	0.059	1.95E-01	0.040	7.79E-01	0.033
250 m	4.39E-02	0.046	4.60E-02	0.065	2.12E-01	0.069	9.44E-02	0.042	3.97E-01	0.039
300 m	2.31E-02	0.053	2.81E-02	0.072	1.03E-01	0.065	5.08E-02	0.048	2.05E-01	0.037
350 m	1.35E-02	0.052	1.71E-02	0.080	5.72E-02	0.066	2.77E-02	0.049	1.16E-01	0.037
400 m	8.41E-03	0.055	1.13E-02	0.088	3.26E-02	0.069	1.53E-02	0.054	6.76E-02	0.039
450 m	5.54E-03	0.078	7.15E-03	0.097	1.82E-02	0.073	8.45E-03	0.058	3.94E-02	0.042
500 m	3.36E-03	0.056	5.13E-03	0.116	1.09E-02	0.064	5.03E-03	0.052	2.44E-02	0.040
550 m	2.16E-03	0.060	4.02E-03	0.126	6.56E-03	0.073	2.89E-03	0.058	1.56E-02	0.047
600 m	1.40E-03	0.059	3.14E-03	0.136	4.15E-03	0.074	1.70E-03	0.059	1.04E-02	0.052
650 m	9.21E-04	0.064	1.96E-03	0.103	2.58E-03	0.066	9.62E-04	0.063	6.43E-03	0.043
700 m	5.79E-04	0.048	1.39E-03	0.119	1.62E-03	0.068	5.99E-04	0.057	4.19E-03	0.049
750 m	4.04E-04	0.057	1.09E-03	0.131	1.29E-03	0.070	4.15E-04	0.061	3.20E-03	0.054
800 m	3.03E-04	0.056	8.12E-04	0.131	8.26E-04	0.086	2.76E-04	0.069	2.22E-03	0.059
850 m	1.93E-04	0.062	6.35E-04	0.137	5.18E-04	0.069	1.72E-04	0.090	1.52E-03	0.063
900 m	1.42E-04	0.055	4.93E-04	0.146	3.68E-04	0.074	1.15E-04	0.064	1.12E-03	0.069
950 m	7.87E-05	0.057	3.79E-04	0.155	2.48E-04	0.085	7.20E-05	0.077	7.77E-04	0.081
1000 m	5.23E-05	0.067	2.89E-04	0.158	1.68E-04	0.084	4.15E-05	0.078	5.51E-04	0.087

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR				
	hs24n23m		hs24n23m	hs24p33m	hs24p43m	hs24c24m	
hours/yr	1						

Side Dose mrem/hr

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	1.19E-03	0.027	1.16E-03	0.027	9.05E-03	0.043	4.25E-03	0.022	1.56E-02	0.026
250 ft	3.78E-04	0.030	3.91E-04	0.037	2.89E-03	0.056	1.36E-03	0.028	5.02E-03	0.034
100 m	2.09E-04	0.034	2.08E-04	0.043	1.57E-03	0.064	6.98E-04	0.031	2.69E-03	0.039
150 m	8.20E-05	0.054	8.50E-05	0.058	4.82E-04	0.059	2.31E-04	0.038	8.80E-04	0.035
200 m	3.57E-05	0.051	4.44E-05	0.065	2.02E-04	0.059	9.52E-05	0.040	3.77E-04	0.035
250 m	1.76E-05	0.057	2.27E-05	0.066	1.06E-04	0.069	4.61E-05	0.043	1.92E-04	0.041
300 m	9.40E-06	0.064	1.38E-05	0.073	5.11E-05	0.066	2.48E-05	0.049	9.92E-05	0.038
350 m	5.64E-06	0.062	8.44E-06	0.081	2.85E-05	0.066	1.35E-05	0.050	5.61E-05	0.038
400 m	3.62E-06	0.064	5.60E-06	0.089	1.63E-05	0.069	7.46E-06	0.055	3.29E-05	0.040
450 m	2.46E-06	0.087	3.52E-06	0.099	9.09E-06	0.073	4.13E-06	0.059	1.92E-05	0.043
500 m	1.51E-06	0.062	2.53E-06	0.118	5.44E-06	0.064	2.46E-06	0.053	1.19E-05	0.041
550 m	9.73E-07	0.067	1.99E-06	0.128	3.27E-06	0.073	1.42E-06	0.060	7.65E-06	0.048
600 m	6.41E-07	0.065	1.55E-06	0.138	2.07E-06	0.074	8.35E-07	0.061	5.10E-06	0.053
650 m	4.27E-07	0.069	9.69E-07	0.104	1.29E-06	0.066	4.71E-07	0.064	3.16E-06	0.044
700 m	2.71E-07	0.051	6.84E-07	0.121	8.10E-07	0.068	2.94E-07	0.058	2.06E-06	0.049
750 m	1.91E-07	0.060	5.38E-07	0.132	6.43E-07	0.070	2.04E-07	0.061	1.58E-06	0.055
800 m	1.43E-07	0.059	4.01E-07	0.133	4.13E-07	0.086	1.36E-07	0.070	1.09E-06	0.060
850 m	9.17E-08	0.065	3.13E-07	0.139	2.59E-07	0.069	8.48E-08	0.091	7.49E-07	0.064
900 m	6.85E-08	0.057	2.44E-07	0.147	1.84E-07	0.074	5.71E-08	0.065	5.53E-07	0.070
950 m	3.74E-08	0.060	1.87E-07	0.157	1.24E-07	0.085	3.56E-08	0.077	3.84E-07	0.082
1000 m	2.51E-08	0.069	1.43E-07	0.160	8.41E-08	0.084	2.05E-08	0.079	2.73E-07	0.088

Top Dose mrem/year

	hs24n24m		hs24n24m		hs24p34m	hs24p44m	hs24c34m			
dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	2.34E-04	0.015	1.04E-05	0.022	8.18E-06	0.066	3.20E-05	0.035	2.84E-04	0.013
250 ft	9.99E-05	0.015	4.98E-06	0.021	4.08E-06	0.065	1.63E-05	0.035	1.25E-04	0.013
100 m	5.76E-05	0.017	3.06E-06	0.024	2.62E-06	0.066	1.04E-05	0.035	7.37E-05	0.014
150 m	2.14E-05	0.020	1.30E-06	0.023	1.15E-06	0.067	4.63E-06	0.036	2.85E-05	0.016
200 m	9.13E-06	0.020	6.73E-07	0.021	5.64E-07	0.066	2.24E-06	0.036	1.26E-05	0.016
250 m	4.36E-06	0.024	3.42E-07	0.021	2.74E-07	0.064	1.12E-06	0.037	6.10E-06	0.018
300 m	2.16E-06	0.025	2.17E-07	0.027	1.46E-07	0.069	6.00E-07	0.037	3.12E-06	0.019
350 m	1.13E-06	0.033	1.27E-07	0.026	7.76E-08	0.071	3.14E-07	0.038	1.65E-06	0.024
400 m	5.85E-07	0.030	7.96E-08	0.028	4.27E-08	0.068	1.76E-07	0.038	8.83E-07	0.022
450 m	3.09E-07	0.034	5.21E-08	0.025	2.30E-08	0.069	9.42E-08	0.039	4.78E-07	0.024
500 m	1.76E-07	0.036	3.58E-08	0.025	1.30E-08	0.075	5.20E-08	0.040	2.77E-07	0.024
550 m	1.08E-07	0.043	2.38E-08	0.026	7.16E-09	0.073	2.99E-08	0.040	1.69E-07	0.029
600 m	5.97E-08	0.042	1.76E-08	0.037	4.00E-09	0.070	1.68E-08	0.041	9.81E-08	0.028
650 m	3.34E-08	0.045	1.23E-08	0.030	2.36E-09	0.077	9.60E-09	0.043	5.77E-08	0.028

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR							
	hs24n23m		hs24n23m		hs24p33m	hs24p43m	hs24c24m			
700 m	1.86E-08	0.045	8.87E-09	0.035	1.32E-09	0.074	5.49E-09	0.042	3.43E-08	0.027
750 m	1.16E-08	0.059	6.79E-09	0.086	7.82E-10	0.085	3.19E-09	0.043	2.23E-08	0.041
800 m	8.65E-09	0.061	4.85E-09	0.031	4.48E-10	0.073	1.85E-09	0.045	1.58E-08	0.035
850 m	4.83E-09	0.068	3.94E-09	0.061	2.63E-10	0.084	1.11E-09	0.047	1.01E-08	0.040
900 m	2.76E-09	0.061	2.80E-09	0.036	1.57E-10	0.079	6.53E-10	0.048	6.36E-09	0.031
950 m	1.97E-09	0.068	2.17E-09	0.035	8.48E-11	0.085	3.53E-10	0.046	4.58E-09	0.034
1000 m	1.04E-09	0.081	1.66E-09	0.042	5.28E-11	0.094	2.13E-10	0.051	2.97E-09	0.037

Total Dose mrem/year

dis	neutron		phot (n,p)		phot		cobalt		total	
	value	rel err	value	rel err	value	rel err	value	rel err	value	rel err
150 ft	1.42E-03	0.022	1.17E-03	0.027	9.06E-03	0.043	4.28E-03	0.022	1.59E-02	0.025
250 ft	4.78E-04	0.024	3.96E-04	0.037	2.89E-03	0.056	1.37E-03	0.028	5.14E-03	0.033
100 m	2.66E-04	0.027	2.11E-04	0.042	1.57E-03	0.064	7.08E-04	0.031	2.76E-03	0.038
150 m	1.03E-04	0.043	8.63E-05	0.057	4.83E-04	0.059	2.36E-04	0.038	9.09E-04	0.034
200 m	4.48E-05	0.041	4.51E-05	0.064	2.02E-04	0.059	9.75E-05	0.040	3.90E-04	0.033
250 m	2.20E-05	0.046	2.30E-05	0.065	1.06E-04	0.069	4.72E-05	0.042	1.98E-04	0.039
300 m	1.16E-05	0.053	1.41E-05	0.072	5.13E-05	0.065	2.54E-05	0.048	1.02E-04	0.037
350 m	6.77E-06	0.052	8.56E-06	0.080	2.86E-05	0.066	1.38E-05	0.049	5.78E-05	0.037
400 m	4.20E-06	0.055	5.67E-06	0.088	1.63E-05	0.069	7.64E-06	0.054	3.38E-05	0.039
450 m	2.77E-06	0.078	3.58E-06	0.097	9.12E-06	0.073	4.23E-06	0.058	1.97E-05	0.042
500 m	1.68E-06	0.056	2.56E-06	0.116	5.46E-06	0.064	2.51E-06	0.052	1.22E-05	0.040
550 m	1.08E-06	0.060	2.01E-06	0.126	3.28E-06	0.073	1.45E-06	0.058	7.82E-06	0.047
600 m	7.01E-07	0.059	1.57E-06	0.136	2.08E-06	0.074	8.52E-07	0.059	5.20E-06	0.052
650 m	4.60E-07	0.064	9.82E-07	0.103	1.29E-06	0.066	4.81E-07	0.063	3.21E-06	0.043
700 m	2.90E-07	0.048	6.93E-07	0.119	8.11E-07	0.068	2.99E-07	0.057	2.09E-06	0.049
750 m	2.02E-07	0.057	5.45E-07	0.131	6.43E-07	0.070	2.08E-07	0.061	1.60E-06	0.054
800 m	1.51E-07	0.056	4.06E-07	0.131	4.13E-07	0.086	1.38E-07	0.069	1.11E-06	0.059
850 m	9.65E-08	0.062	3.17E-07	0.137	2.59E-07	0.069	8.59E-08	0.090	7.59E-07	0.063
900 m	7.12E-08	0.055	2.46E-07	0.146	1.84E-07	0.074	5.77E-08	0.064	5.59E-07	0.069
950 m	3.93E-08	0.057	1.89E-07	0.155	1.24E-07	0.085	3.60E-08	0.077	3.89E-07	0.081
1000 m	2.62E-08	0.067	1.44E-07	0.158	8.42E-08	0.084	2.08E-08	0.078	2.76E-07	0.087

Appendix C. Results of Various Overpack Configuration Analyses

The pages at the end of this appendix are EXCEL sheets that show the results of the MCNP calculations for overpack configurations 2 through 6. The general format of these pages was described in Appendix A.

The EXCEL file used to produce these results is listed in the upper left hand corner of the page. There is one page of output for each configuration which results in a total of 5 pages from 5 different EXCEL files.

A brief discussion of each page is given below. The page is referenced by the EXCEL file name.

As mentioned in section 7, MCNP calculations of configurations 2 through 7 were not performed using the photon source. Rather the behavior of the dose rate from the photon source is assumed to be identical to the behavior of the dose rate from the cobalt source. This is discussed further below.

A more detailed discussion of all calculations is provided in section 7.

h24dis_c.xls

This output contains the results from the MCNP calculations of configuration 2. The ratios calculated for the individual dose components are the ratio of the dose rate from configuration 2 to the dose rate from configuration 1 (the configuration 1 data is in Appendix B and is labeled his24dis.xls). The photon doses listed in the output were calculated by taking the photon doses from his24dis.xls and multiplying by the cobalt ratio calculated in h24dis_c.xls.

The final ratio calculated was the ratio of the total dose from configuration 2 to the total dose from configuration 1. This is the column labeled *total h24dis_c.xls div by total his24dis.xls.* This ratio is the number of casks that represent an infinite line at the distances calculated. These results represent the East and West faces of the facility.

h24dis_d.xls

This output contains the results from the MCNP calculations of configuration 3. The ratios calculated for the individual dose components are the ratio of the dose rate from configuration 3 to the dose rate from configuration 2. The photon doses listed in the output were calculated by taking the photon doses from his24dis.xls and multiplying by the cobalt ratio calculated in h24dis_d.xls.

The final ratio calculated was the ratio of the total dose from configuration 3 to the total dose from configuration 2. This is the column labeled *total h24dis_d.xls div by total*

h24dis_c.xls. This ratio shows how many times the dose at a given distance increases when an additional line of casks is added. The average ratio was calculated over the distances of 100 to 500 meters. The average ratio minus one indicates the fractional increase in the dose rate when an additional line of casks is added. This also means that the dose rate from the second line of casks is equal to the product of this fractional increase and the dose rate from the first line of casks. These results represent the East and West faces.

Since there is statistical fluctuations in the ratios calculated at each distance, the fractional increase value was raised by 10%. This increase was chosen so that one plus the new value would bound a minimum of 6 of the 9 ratios calculated at distances from 100 to 500 meters.

h24dis_e.xls

This output contains the results from the MCNP calculations of configuration 4. The ratios calculated for the individual dose components are the ratio of the dose rate from configuration 4 to the dose rate from configuration 3. The photon doses listed in the output were calculated by taking the photon doses from his24dis.xls and multiplying by the cobalt ratio calculated in h24dis_e.xls.

The final ratio calculated was the ratio of the total dose from configuration 4 to the total dose from configuration 3. This is the column labeled *total h24dis_e.xls div by total h24dis_d.xls.* This ratio shows how many times the dose at a given distance increases when an additional two lines of casks are added to an already existing two lines of casks. The average ratio was calculated over the distances of 100 to 500 meters. The average ratio minus one indicates the fractional increase in the dose rate when an additional two lines of casks is added. This also means that the dose rate from the second two lines of casks is equal to the product of this fractional increase and the dose rate from the first two lines of casks. The two lines of casks represent a column of concrete pads in the facility that contain 2 lines of casks. The columns of concrete pads are North-South orientated in Figure 2. Therefore, this fractional increase would be used in calculating the final dose rates along the East and West faces.

Since there is statistical fluctuations in the ratios calculated at each distance, the fractional increase value was raised by 10%. This increase was chosen so that one plus the new value would bound a minimum of 5 of the 9 ratios calculated at distances from 100 to 500 meters.

h24dis_f.xls

This output contains the results from the MCNP calculations of configuration 5. The ratios calculated for the individual dose components are the ratio of the dose rate from configuration 5 to the dose rate from configuration 1 (the configuration 1 data is in Appendix B and is labeled his24dis.xls). The photon doses listed in the output were

calculated by taking the photon doses from his24dis.xls and multiplying by the cobalt ratio calculated in h24dis_f.xls.

The final ratio calculated was the ratio of the total dose from configuration 5 to the total dose from configuration 1. This is the column labeled *total h24dis_f.xls div by total his24dis.xls.* This ratio is the number of casks that represent an infinite line at the distances calculated. These results represent the North and South faces of the facility.

h24dis_g.xls

This output contains the results from the MCNP calculations of configuration 6. The ratios calculated for the individual dose components are the ratio of the dose rate from configuration 6 to the dose rate from configuration 5. The photon doses listed in the output were calculated by taking the photon doses from his24dis.xls and multiplying by the cobalt ratio calculated in h24dis_g.xls.

The final ratio calculated was the ratio of the total dose from configuration 6 to the total dose from configuration 5. This is the column labeled *total h24dis_g.xls div by total h24dis_f.xls.* This ratio shows how many times the dose at a given distance increases when an additional line of casks is added. The average ratio was calculated over the distances of 100 to 500 meters. The average ratio minus one indicates the fractional increase in the dose rate when an additional line of casks is added. This also means that the dose rate from the second line of casks is equal to the product of this fractional increase and the dose rate from the first line of casks. These results represent the North and South faces.

Since there is statistical fluctuations in the ratios calculated at each distance, the fractional increase value was raised by 10%. This increase was chosen so that one plus the new value would bound a minimum of 6 of the 9 ratios calculated at distances from 100 to 500 meters.

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR	
	hs24n25m		hs24n25m	hs24c25m
hours/yr	2000			

NOTE: Photon dose is equal to dose from single cask times ratio for cobalt which is listed below

Side Dose mrem/year

dis	neutron		phot (n,p)		phot		cobalt		total	
	value	rel err	value	rel err	value	rel err	value	rel err	value	rel err.
150 ft	5.58E+01	0.031	5.62E+01	0.039	3.99E+02	0.043	1.87E+02	0.030	6.98E+02	0.026
250 ft	2.74E+01	0.034	3.13E+01	0.059	1.79E+02	0.056	8.39E+01	0.034	3.21E+02	0.033
100 m	1.84E+01	0.041	2.11E+01	0.061	1.19E+02	0.064	5.28E+01	0.038	2.11E+02	0.038
150 m	9.43E+00	0.053	1.07E+01	0.066	5.16E+01	0.059	2.48E+01	0.047	9.66E+01	0.035
200 m	5.13E+00	0.058	6.47E+00	0.069	3.05E+01	0.059	1.44E+01	0.056	5.65E+01	0.036
250 m	3.18E+00	0.083	4.22E+00	0.084	1.81E+01	0.069	7.88E+00	0.068	3.34E+01	0.043
300 m	1.96E+00	0.067	2.74E+00	0.091	9.11E+00	0.066	4.41E+00	0.074	1.82E+01	0.040
350 m	1.18E+00	0.082	2.03E+00	0.103	5.52E+00	0.066	2.61E+00	0.080	1.13E+01	0.042
400 m	7.59E-01	0.072	1.50E+00	0.100	3.42E+00	0.069	1.57E+00	0.081	7.24E+00	0.043
450 m	5.05E-01	0.079	1.01E+00	0.094	2.13E+00	0.073	9.67E-01	0.085	4.61E+00	0.044
500 m	3.18E-01	0.080	7.06E-01	0.109	1.26E+00	0.064	5.69E-01	0.108	2.85E+00	0.045

Ratio	single cask reflective	to	single cask no reflective - side dose	
	hs24n25m	hs24n25m	hs24c25m	total h24dis_c.xls
	div by	div by	div by	div by
	hs24n23m	hs24n23m	hs24c24m	total his24dis.xls
150 ft	2.35E+01	2.41E+01	2.20E+01	2.23E+01
250 ft	3.63E+01	4.01E+01	3.09E+01	3.20E+01
100 m	4.42E+01	5.07E+01	3.79E+01	3.93E+01
150 m	5.75E+01	6.32E+01	5.36E+01	5.49E+01
200 m	7.19E+01	7.29E+01	7.56E+01	7.49E+01
250 m	9.03E+01	9.30E+01	8.55E+01	8.68E+01
300 m	1.04E+02	9.90E+01	8.90E+01	9.19E+01
350 m	1.04E+02	1.21E+02	9.67E+01	1.01E+02
400 m	1.05E+02	1.34E+02	1.05E+02	1.10E+02
450 m	1.03E+02	1.44E+02	1.17E+02	1.20E+02
500 m	1.06E+02	1.40E+02	1.16E+02	1.19E+02

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR	
	hs24n26m		hs24n26m	hs24c26m
hours/yr	2000			

NOTE: photon dose is dose from hs24dis_c.xls times ratio for cobalt listed below

Side Dose mrem/year

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err.
150 ft	7.04E+01	0.034	6.27E+01	0.051	4.29E+02	0.043	2.01E+02	0.035	7.63E+02	0.026
250 ft	3.96E+01	0.041	3.47E+01	0.071	2.15E+02	0.056	1.01E+02	0.041	3.91E+02	0.034
100 m	2.76E+01	0.054	2.39E+01	0.065	1.38E+02	0.064	6.11E+01	0.046	2.50E+02	0.038
150 m	1.30E+01	0.063	1.29E+01	0.081	5.86E+01	0.059	2.82E+01	0.053	1.13E+02	0.036
200 m	7.27E+00	0.056	7.88E+00	0.088	3.40E+01	0.059	1.61E+01	0.060	6.52E+01	0.036
250 m	4.24E+00	0.064	4.91E+00	0.101	1.99E+01	0.069	8.65E+00	0.066	3.77E+01	0.042
300 m	2.47E+00	0.070	3.31E+00	0.110	1.04E+01	0.066	5.02E+00	0.074	2.12E+01	0.041
350 m	1.70E+00	0.090	2.39E+00	0.143	6.04E+00	0.066	2.86E+00	0.071	1.30E+01	0.045
400 m	1.07E+00	0.079	1.83E+00	0.165	3.82E+00	0.069	1.75E+00	0.076	8.48E+00	0.051
450 m	5.87E-01	0.077	1.39E+00	0.179	2.51E+00	0.073	1.14E+00	0.077	5.62E+00	0.058
500 m	4.27E-01	0.081	1.05E+00	0.176	1.47E+00	0.064	6.66E-01	0.100	3.61E+00	0.061

Ratio	hs24n26m div by hs24n25m	hs24n26m div by hs24n25m	hs24c26m div by hs24c25m	total h24dis_d.xls div by total h24dis_c.xls
150 ft	1.26E+00	1.12E+00	1.08E+00	1.09E+00
250 ft	1.44E+00	1.11E+00	1.20E+00	1.22E+00
100 m	1.50E+00	1.13E+00	1.16E+00	1.18E+00
150 m	1.38E+00	1.20E+00	1.14E+00	1.17E+00
200 m	1.42E+00	1.22E+00	1.12E+00	1.15E+00
250 m	1.33E+00	1.16E+00	1.10E+00	1.13E+00
300 m	1.26E+00	1.21E+00	1.14E+00	1.16E+00
350 m	1.45E+00	1.17E+00	1.09E+00	1.15E+00
400 m	1.41E+00	1.22E+00	1.12E+00	1.17E+00
450 m	1.16E+00	1.37E+00	1.18E+00	1.22E+00
500 m	1.34E+00	1.49E+00	1.17E+00	1.27E+00

Average of values from 100 meters to 500 meters	1.18E+00
Fractional increase	0.178
Value used = fractional increase * 1.10	0.195

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR	
	hs24n27m		hs24n27m	hs24c27m
hours/yr	2000			

NOTE: photon dose is dose from hs24dis_d.xls times ratio for cobalt listed below

Side Dose mrem/year

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	8.83E+01	0.031	6.49E+01	0.059	4.54E+02	0.043	2.13E+02	0.040	8.20E+02	0.026
250 ft	4.93E+01	0.037	3.76E+01	0.077	2.23E+02	0.056	1.05E+02	0.044	4.14E+02	0.033
100 m	3.52E+01	0.040	2.70E+01	0.093	1.56E+02	0.064	6.90E+01	0.047	2.87E+02	0.038
150 m	1.78E+01	0.046	1.55E+01	0.121	7.23E+01	0.059	3.47E+01	0.052	1.40E+02	0.036
200 m	9.98E+00	0.047	9.00E+00	0.127	3.90E+01	0.059	1.84E+01	0.054	7.65E+01	0.037
250 m	6.64E+00	0.065	5.26E+00	0.132	2.45E+01	0.069	1.06E+01	0.069	4.70E+01	0.043
300 m	3.79E+00	0.057	4.02E+00	0.158	1.38E+01	0.066	6.69E+00	0.069	2.83E+01	0.043
350 m	2.65E+00	0.064	3.13E+00	0.191	8.54E+00	0.066	4.04E+00	0.075	1.84E+01	0.049
400 m	1.77E+00	0.059	2.20E+00	0.197	5.18E+00	0.069	2.38E+00	0.061	1.15E+01	0.051
450 m	1.15E+00	0.079	1.53E+00	0.111	3.31E+00	0.073	1.51E+00	0.064	7.50E+00	0.043
500 m	7.12E-01	0.070	1.11E+00	0.119	2.01E+00	0.064	9.09E-01	0.069	4.75E+00	0.042

Ratio	hs24n27m div by hs24n26m	hs24n27m div by hs24n26m	hs24c27m div by hs24c26m	total h24dis_e.xls div by total h24dis_d.xls
150 ft	1.25E+00	1.03E+00	1.06E+00	1.07E+00
250 ft	1.24E+00	1.08E+00	1.04E+00	1.06E+00
100 m	1.28E+00	1.13E+00	1.13E+00	1.15E+00
150 m	1.37E+00	1.20E+00	1.23E+00	1.25E+00
200 m	1.37E+00	1.14E+00	1.15E+00	1.17E+00
250 m	1.56E+00	1.07E+00	1.23E+00	1.25E+00
300 m	1.54E+00	1.22E+00	1.33E+00	1.34E+00
350 m	1.56E+00	1.31E+00	1.41E+00	1.41E+00
400 m	1.65E+00	1.20E+00	1.35E+00	1.36E+00
450 m	1.96E+00	1.10E+00	1.32E+00	1.33E+00
500 m	1.67E+00	1.06E+00	1.37E+00	1.31E+00

Average of values from 100 meters to 500 meters	1.29E+00
Fractional increase	0.285
Value used = fractional increase * 1.10	0.314

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR	
	hs24n28m		hs24n28m	hs24c28m
hours/yr	2000			

NOTE: Photon dose is equal to dose from single cask times ratio for cobalt which is listed below

Side Dose mrem/year

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err.
150 ft	3.01E+01	0.031	2.96E+01	0.037	2.16E+02	0.043	1.02E+02	0.029	3.77E+02	0.026
250 ft	1.43E+01	0.033	1.67E+01	0.054	9.56E+01	0.056	4.49E+01	0.033	1.71E+02	0.033
100 m	9.62E+00	0.038	1.09E+01	0.053	6.42E+01	0.064	2.85E+01	0.039	1.13E+02	0.038
150 m	5.20E+00	0.056	5.77E+00	0.058	2.79E+01	0.059	1.34E+01	0.046	5.23E+01	0.035
200 m	2.77E+00	0.056	3.30E+00	0.063	1.53E+01	0.059	7.22E+00	0.057	2.86E+01	0.036
250 m	1.56E+00	0.073	2.10E+00	0.075	9.23E+00	0.069	4.02E+00	0.062	1.69E+01	0.042
300 m	1.04E+00	0.062	1.39E+00	0.071	5.17E+00	0.066	2.51E+00	0.065	1.01E+01	0.039
350 m	6.87E-01	0.069	1.11E+00	0.095	3.03E+00	0.066	1.44E+00	0.072	6.26E+00	0.041
400 m	4.61E-01	0.071	8.11E-01	0.110	1.94E+00	0.069	8.91E-01	0.085	4.11E+00	0.044
450 m	2.47E-01	0.070	5.87E-01	0.120	1.23E+00	0.073	5.60E-01	0.089	2.63E+00	0.048
500 m	1.68E-01	0.082	4.49E-01	0.132	6.71E-01	0.064	3.03E-01	0.087	1.59E+00	0.050

Ratio single cask reflective to single cask no reflective - side dose

	hs24n28m div by hs24n23m	hs24n28m div by hs24n23m	hs24c28m div by hs24c24m	total h24dis_f.xls div by total his24dis.xls
150 ft	1.27E+01	1.27E+01	1.19E+01	1.21E+01
250 ft	1.89E+01	2.13E+01	1.65E+01	1.71E+01
100 m	2.31E+01	2.62E+01	2.04E+01	2.11E+01
150 m	3.17E+01	3.39E+01	2.90E+01	2.97E+01
200 m	3.88E+01	3.72E+01	3.79E+01	3.79E+01
250 m	4.43E+01	4.64E+01	4.36E+01	4.40E+01
300 m	5.52E+01	5.02E+01	5.06E+01	5.10E+01
350 m	6.09E+01	6.55E+01	5.31E+01	5.58E+01
400 m	6.37E+01	7.25E+01	5.97E+01	6.23E+01
450 m	5.00E+01	8.33E+01	6.77E+01	6.83E+01
500 m	5.57E+01	8.88E+01	6.16E+01	6.66E+01

40,000 MWD/MTU burnup - B&W 15x15 fuel element

10.0 YR	0	10.0 YR	10.0 YR	
	hs24n29m		hs24n29m	hs24c29m
hours/yr	2000			

NOTE: photon dose is dose from hs24dis_f.xls times ratio for cobalt listed below

Side Dose mrem/year

dis	neutron value	rel err	phot (n,p) value	rel err	phot value	rel err	cobalt value	rel err	total value	rel err
150 ft	4.57E+01	0.033	3.92E+01	0.045	2.78E+02	0.043	1.31E+02	0.033	4.93E+02	0.026
250 ft	2.21E+01	0.034	2.33E+01	0.065	1.29E+02	0.056	6.04E+01	0.040	2.34E+02	0.033
100 m	1.49E+01	0.041	1.55E+01	0.058	8.54E+01	0.064	3.79E+01	0.043	1.54E+02	0.038
150 m	7.49E+00	0.059	8.27E+00	0.069	3.46E+01	0.059	1.66E+01	0.050	6.70E+01	0.035
200 m	4.03E+00	0.054	5.26E+00	0.086	2.01E+01	0.059	9.49E+00	0.054	3.89E+01	0.036
250 m	2.40E+00	0.060	3.11E+00	0.104	1.18E+01	0.069	5.11E+00	0.059	2.24E+01	0.042
300 m	1.44E+00	0.060	2.11E+00	0.102	6.63E+00	0.066	3.21E+00	0.067	1.34E+01	0.040
350 m	8.98E-01	0.067	1.62E+00	0.115	3.81E+00	0.066	1.81E+00	0.078	8.14E+00	0.043
400 m	6.05E-01	0.063	1.17E+00	0.120	2.51E+00	0.069	1.15E+00	0.080	5.44E+00	0.045
450 m	4.28E-01	0.064	8.54E-01	0.132	1.48E+00	0.073	6.71E-01	0.077	3.43E+00	0.049
500 m	2.55E-01	0.075	6.98E-01	0.152	9.87E-01	0.064	4.46E-01	0.079	2.39E+00	0.054

Ratio	hs24n29m div by hs24n28m	hs24n29m div by hs24n28m	hs24c29m div by hs24c28m	total h24dis_g.xls div by total h24dis_f.xls
150 ft	1.52E+00	1.33E+00	1.29E+00	1.31E+00
250 ft	1.54E+00	1.40E+00	1.35E+00	1.37E+00
100 m	1.55E+00	1.42E+00	1.33E+00	1.36E+00
150 m	1.44E+00	1.43E+00	1.24E+00	1.28E+00
200 m	1.45E+00	1.59E+00	1.32E+00	1.36E+00
250 m	1.54E+00	1.48E+00	1.27E+00	1.32E+00
300 m	1.39E+00	1.51E+00	1.28E+00	1.32E+00
350 m	1.31E+00	1.46E+00	1.26E+00	1.30E+00
400 m	1.31E+00	1.44E+00	1.29E+00	1.33E+00
450 m	1.74E+00	1.45E+00	1.20E+00	1.31E+00
500 m	1.52E+00	1.55E+00	1.47E+00	1.50E+00

Average of values from 100 meters to 500 meters	1.34E+00
Fractional increase	0.342
Value used = fractional increase * 1.10	0.376

Appendix D: Final Dose Rate Calculations

The results presented in this appendix were generated with EXCEL. The sheets at the end of this appendix provide the detailed calculation of the dose rate at the security fence and site-boundary as well as 2 miles from the facility. The MCNP results presented in Appendices B and C were used in these final calculations.

The dose rates were calculated separately for the North-South faces and the East-West faces since the geometry of the facility is different in these directions. The final answers are listed in bold throughout these calculations.

In the top center of each page is a designator that identifies the sheet. The pages labeled *sit-boun* are the pages that show the calculation of the site-boundary dose rates. The pages labeled *sec-fence* show calculations of the dose rate for the security fence location and finally the page labeled *sum-fit-comp* is the page showing the estimate of the dose at 2 miles.

A more detailed discussion of the calculations is provided in section 7.

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