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MICROSHIELD ANALYSIS TO CALCULATE EXTERNAL RADIATION DOSE RATES FOR SEVERAL SPENT FUEL CASKS

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ABSTRACT

The purpose of this MicroShield analysis is to calculate the external radiation, primarily gamma, dose rate for spent fuel casks. The reason for making this calculation is that currently all analyses of transportation risk assume that this external dose rate is the maximum allowed by regulation, 10mrem/hr at 2m from the casks, and the risks of incident-free transportation are thus always overestimated to an unknown extent. In order to do this, the program by Grove Software, MicroShield 7.01, was used to model three Nuclear Regulatory Commission (NRC) approved casks: HI-STAR 100, GA-4, and NAC-STC, loaded with specific source material. Dimensions were obtained from NUREG/CR-6672 and the Certificates of Compliance for each respective cask. Detectors were placed at the axial point at 1m and 2m from the outer gamma shielding of the casks. In the April 8, 2004 publication of the Federal Register, a notice of intent to prepare a Supplemental Yucca Mountain Environmental Impact Statement (DOE/EIS-0250F-S1) was published by the Office of Civilian Radioactive Waste Management (OCRWM) in order to consider design, construction, operation, and transportation of spent nuclear fuel to the Yucca Mountain repository [1]. These more accurate estimates of the external dose rates could be used in order to provide a more risk-informed analysis.

INTRODUCTION

Transportation risk assessments have traditionally used the regulatory dose limit, 10mrem/hr at 2m from the casks as the external dose rate of the casks in their studies. These values were then incorporated into many incident-free calculations, such as those pertaining to specific and total population exposures along the transportation routes, shielding, and worker dose, overestimating these risks to an unknown degree. Recently, the Nuclear Regulatory Commission (NRC) has begun to move away from such extreme conservatism in cases such as using the regulatory maximum as the external dose rate of transportation casks in developing transportation risk analyses. This MicroShield analysis calculates and reports the external radiation, primarily gamma, dose rates for three NRC approved spent fuel transportation casks. A Supplemental Yucca Mountain Environmental Impact Statement (DOE/EIS-0250F-S1) intent of preparation has been published in the April 8, 2004 Federal Register [1] to consider transportation issues as well as design, construction and operation, and will incorporate more realistic dose rates such as those studied in this report.

MicroShield 7.01 is a computer code designed to provide a model to be used for shielding calculation and design in different geometrical scenarios. MicroShield 7.01, a code developed by Grove Software, will be used to model the doses (mrem/hr) at one and two meters from three Nuclear Regulatory Commission (NRC) approved casks: HI-STAR 100, GA-4, and NAC-STC loaded with specific source material.

MODEL PARAMETERS

This analysis was performed using information gleaned from two types of documents. Most of the physical characteristics of the three casks examined in this study were obtained from tables 4.2, 4.3 and 4.4 of NUREG/CR 6672, Reference [2]. The three casks examined in this study include GA-4, NAC-STC, and HI-STAR 100 of which physical properties were found in the tables mentioned above, respectively. The second source of information utilized in this study was from the Certificates of Compliance [3,4] for Radioactive Material Packages for each of the casks. Specifically, information regarding the cask closure or head, defined as top clad in MicroShield, was obtained from these latter documents. The computer code developed by Grove Software, MicroShield 7.01, was used to three-dimensionally model the casks loaded with specific source material in order to estimate dose rates at 1m and 2m from the outer gamma shielding layer at the axial midpoint of each cask. The thickness of the neutron shield is neglected in this study.

Geometry

For each cask, the geometry of cylinder volume with side shields was employed for the analysis. In MicroShield, a cask will be oriented such that the axial length of the cylinder is in the positive y-axis direction, with the center of the cylinder's bottom placed at the origin. The appropriate layers of side shielding with their respective thicknesses surround the cylinder in MicroShield in the radial, z-axis, direction. This can be seen in Figure 1. Cask closure or head, described as top clad in MicroShield, was used from information found in the Certificates of Compliance for each respective cask [3,4], except for the HI-STAR 100 where no such information could be found and a value of 1m was used per Reference [5]. MicroShield does not allow for any cask closure on the bottom, such that the active cask volume sits on a flat, fully attenuating, black surface. The active cask length, the cask length without the impact limiters, was determined as the pressurized water reactor (PWR) spent fuel assembly length, and was used as the axial cylinder length input value obtained from Reference [2]. The radii values also from Reference [2] were input for each respective cask. Wall clad, which in MicroShield is a mixture of all the shielding materials specified, was not used since several layers of side shields were sufficient to model the casks in these cases.

Detectors

The models were built with detectors placed at 1m and 2m away from the outermost gamma shielding layer. These detectors were also centered axially since maximum dose was expected to be achieved at the axial midpoint of the active length of the cask. The doses in the air gaps between the detectors and the cask were calculated by MicroShield depending on the input cask dimensions. Figure 1 consists of the schematics of each of the three models as displayed in MicroShield [6].

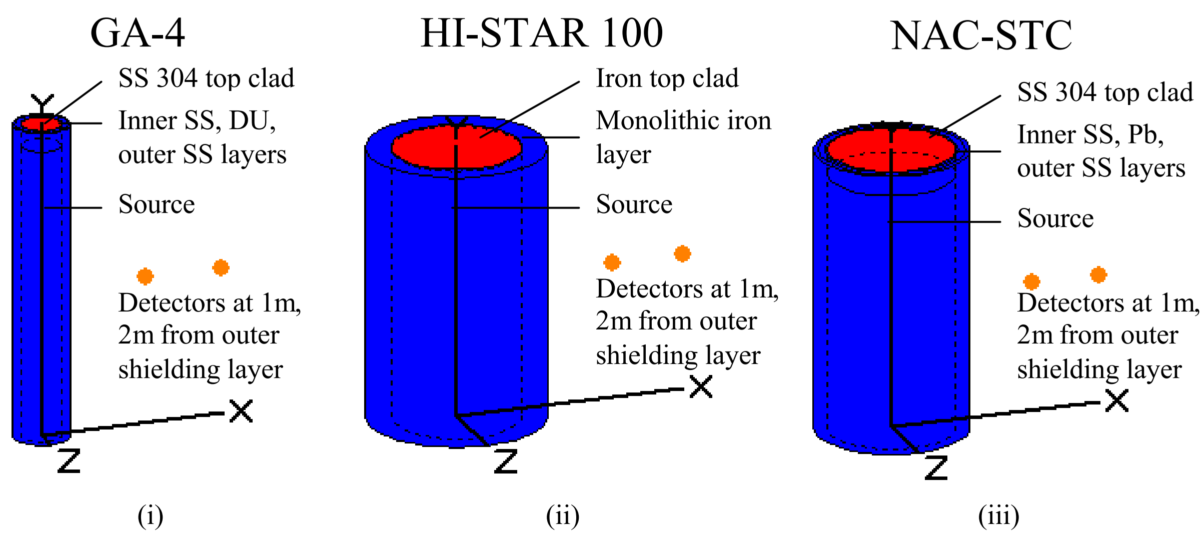

Fig. 1. Cask schematics showing models built in MicroShield 7.01 used to calculate dose rates at 1m and 2m from the axial midpoints of the three specific casks: (i) GA-4, (ii) HI-STAR 100, and (iii) NAC-STC.

Cask Materials

The material compositions of each of the cask constituents were specified under the materials tab in MicroShield. The densities provided by the internal library of MicroShield were used for air, lead, iron, and uranium. A density of 10.96 g/cm^3 was a manual input for the source material as the density of uranium oxide. The MicroShield uranium density value was used as the density of depleted uranium (DU). The MicroShield iron density value was used as the density of ferritic stainless steel. A custom material characterizing the density of stainless steel 304 specifically was used for the casks comprised of stainless steel. This external material file was set up according to its atomic structure and using the percentage of each constituent element to create SS 304 [7]. The transition gap and air gap were specified as being composed of air such that the MicroShield internal library values were again used. The neutron shielding layer was neglected in this analysis because it is assumed that the neutron dose contribution would be minimal.

Source

The source material with which each cask was loaded for modeling was a specific source built from Appendix A of the Yucca Mountain Final Environmental Impact Statement [8]. This source material is 5-year-cooled PWR spent fuel.

Build-up

Build-up is defined as the scattering interactions that contribute to the overall dose. Dose build-up factors depend on photon energy, the mean free path traveled by a photon in the material of consideration, geometry of the source, and geometry of the attenuating medium [9]. Build-up must be considered in this study as it will contribute to the external dose rate of the casks. The build-up calculated by MicroShield 7.01 taking the above-mentioned components into consideration was used in this study. The build-up values can be seen under the build-up tab in MicroShield.

Integration

MicroShield uses a method called Gauss quadrature for point-kernal numerical integration for integration calculations for the cylindrical side shield geometry specified in these models. In this method, the source is separated into a number of kernels determined by the quadrature order. In general, the greater the quadrature order, the more precise results will be output. The default values of quadrature orders used in performing the integrations are [6]:

- Radial: 10
- Circumferential: 10
- Y Direction (Axial): 20

Two runs were performed on each of the three input files, one with quadrature order values of 50, and one with quadrature order values of 100. The runs performed with 100 quadrature orders took approximately 5 times the amount of time required to compute the runs with 50 quadrature orders. According to the MicroShield User’s Manual, if the quadrature order is doubled, the accuracy is increased by 2^3 or 8 times [10]. However, the values of the outputs generated from both scenarios were identical. This suggests that the quadrature order of 50 is sufficient for these models [10]. These results are reported only once in the result section of this report.

HI-STAR Cask Specific Parameters

Table I displays the parameters used for developing the HI-STAR cask, a monolithic rail cask, input file.

Table I: HI-STAR Cask Model Parameters

Parameter	Distance/Length (m)	Material	Density (g/cm^3)
Height	3.8		
Source Radius	0.873125	UO_2	10.96
Top Clad	1	Iron	7.86
Shield 1	0.34533	Iron	7.86
Detector at 1m X Value	2.218565		
Detector at 2m X Value	3.218565		
Detector at 1m Y Value	1.9		
Detector at 2m Y Value	1.9		

GA-4 Cask Specific Parameters

Table II displays the parameters used for developing the GA-4 cask, a steel-DU-steel truck cask, input file.

Table II: GA-4 Cask Model Parameters

Parameter	Distance/Length (m)	Material	Density (g/cm^3)
Height	3.8		
Source Radius	0.24892	UO_2	10.96
Top Clad	0.2794	SS 304	8.0128
Shield 1	0.009525	SS 304	8.0128
Shield 2	0.067056	DU	18.7
Shield 3	0.0381	SS 304	8.0128
Detector at 1m X Value	1.363601		
Detector at 2m X Value	2.363601		
Detector at 1m Y Value	1.9		
Detector at 2m Y Value	1.9		

NAC-STC Cask Specific Parameters

Table III displays the parameters used for developing the NAC-STC cask, a steel-lead-steel rail cask, input file.

Table III: NAC-STC Cask Model Parameters

Parameter	Distance/Length (m)	Material	Density (g/cm^3)
Height	3.8		
Source Radius	0.9017	UO_2	10.96
Top Clad	0.36195	SS 304	8.0128
Shield 1	0.0381	SS 304	8.0128
Shield 2	0.09398	Pb	11.34
Shield 3	0.06731	SS 304	8.0128
Detector at 1m X Value	2.10109		
Detector at 2m X Value	3.10109		
Detector at 1m Y Value	1.9		
Detector at 2m Y Value	1.9		

RESULTS

Results generated were output as exposure rates (mR/hr) with and without build-up. Both results are presented below. The results were multiplied by a conversion factor of 0.88 in order to convert from the units of mR/hr to mrem/hr [9].

Table IV displays the exposure rates for each of the three casks examined in the study without build-up, while Table V lists the exposure rates for each cask with build-up considered.

Table IV: External Cask Exposure Rates without Build-Up

Cask	Exposure Rate: Detector at 1m (mrem/hr)	Exposure Rate: Detector at 2m (mrem/hr)
GA-4	5.44E-01	3.09E-01
NAC-STC	3.56E-02	2.37E-02
HI-STAR 100	7.33E-04	7.84E-05

Table V: External Cask Exposure Rates with Build-Up

Cask	Exposure Rate: Detector at 1m (mrem/hr)	Exposure Rate: Detector at 2m (mrem/hr)
GA-4	2.02E+00	1.15E+00
NAC-STC	7.22E-01	4.79E-01
HI-STAR 100	3.50E-03	3.87E-04

For the GA-4 cask design, the 1m and 2m values together range from being approximately half of 1/10th without build-up to being approximately 1/5th with build-up of the regulatory maximum of 10mrem/hr. For the NAC-STC cask design, the 1m and 2m values together range from being less than half of 1/100th without build-up to being less than 1/10th of the regulatory maximum. For the HI-STAR 100 cask design the detector values range from being about 1/10,000th without build-up to 1/1000th with build-up of the regulatory maximum of 10mrem/hr.

Overall, the detector values together range from approximately 1/10,000th to 1/10th without build-up to 1/1000th to 1/5th with build-up of NRC regulatory maximum at 2m from the cask of 10mrem/hr employed in the Transportation EIS as can be observed from Table IV and V, respectively. Values from both tables do fall well within the regulatory dose limit of 10mrem/hr at the center of the fuel bundle, verifying the conservatism of previously published transportation risk analyses, and justify this study.

CONCLUSION

The current method of using the NRC regulatory maximum of 10mrem/hr at 2m from the casks grossly overestimates the dose rate radiation workers and other roadway drivers experience from the three NRC approved casks, HI-STAR 100, GA-4, and NAC-STC, modeled in this study according to models built in MicroShield 7.01 developed by Grove Software, Inc. It is suggested that the values calculated per this study be used in place of the current regulatory maximum value of 10mrem/hr in transportation risk analyses such as the Transportation EIS. However, the assumptions used in calculating these results such as materials and material densities, and assumptions made internally in MicroShield 7.01 must be taken into consideration when these values are incorporated into future EIS updates and environmental risk studies.

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