SHIELDING CALCULATIONS FOR A U.S. DEPARTMENT OF ENERGY TRANSPORT CASK

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ABSTRACT

Shielding calculations were performed for a prototype National Spent Nuclear Fuel Program transport cask for the shipment of Department of Energy spent nuclear fuel and high-level waste. This analysis is intended for use in the selection of the cask shield material and for an estimate of shielding thickness. The results are intended to provide a technical basis for determining an optimal design for the prototype cask.

The radiation source term was modeled as cobalt-60 with radiation exposure strength of 100,000 R/hr. Cobalt-60 was chosen as a surrogate source because it simultaneously emits two high-energy gammas. This gamma spectrum will upper bound the spectra of all the various spent nuclear fuels types expected to be shipped within the prototype cask. Point-kernel shielding calculations were performed for a range of shielding thicknesses of lead and depleted uranium. The shielding calculations were performed with the use of an automated computational code (SHIELD), written specifically for these analyses. Sensitivity results were obtained for a wide variation of radiation source gamma energies. The code was designed to generate results for inclusion of stainless steel liners as shielding material and for use in estimating the cask weight as a function of shielding thickness. The computational results were compared to three shielding limits: 1) 200 mrem/hr dose rate at the cask surface, 2) 50 mR/hr exposure rate at one meter from the cask surface, and 3) 10 mrem/hr dose rate at two meters from the cask surface.

The results indicate that a shielding thickness of 8.5 cm is required for depleted uranium and 14 cm for lead in order to satisfy all three shielding requirements. The system analysis also indicates that required shielding thicknesses are strongly dependent upon the gamma energy spectrum from the radiation source term. This latter finding suggests that shielding material thickness, and hence cask weight, can be significantly reduced if the radiation source term can be shown to have a softer gamma energy spectrum than that due to cobalt-60.

SHIELDING ANALYSES

The United States Department of Energy Office of Environment Management (DOE/EM) National Spent Nuclear Fuel Program (NSNFP), through a collaboration between Sandia National Laboratories (SNL) and Idaho National Engineering and Environmental Laboratory (INEEL), conducted a systematic shielding sensitivity analysis for a prototype transport cask [1]. This cask is intended for use in shipping spent nuclear fuel (SNF) and high-level waste (HLW) with a contact exposure rate of up to 100,000 R/hr. The analysis results from this study identify the shielding requirements necessary to meet the governing regulatory limits for various radiation source term

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[1] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE- ACO4-94AL85000.

spectra. These results are intended to provide DOE/EM with a technical basis for determining an optimal design for the prototype cask design.

This paper describes point-kernel shielding calculations for a prototype transportation cask for use with DOE-owned SNF and HLW, which are planned to be disposed of in a potential repository. The shielding calculations were performed with use of a computational code (SHIELD), which was automated so that sensitivity results were obtained for several shielding materials with a wide variation of radiation source gamma energies. The code was also designed to generate results for inclusion of stainless steel liners for the cask shielding material. Also incorporated into the computer code design was the robustness for easy modifications for possible future use in estimating the transport cask weight.

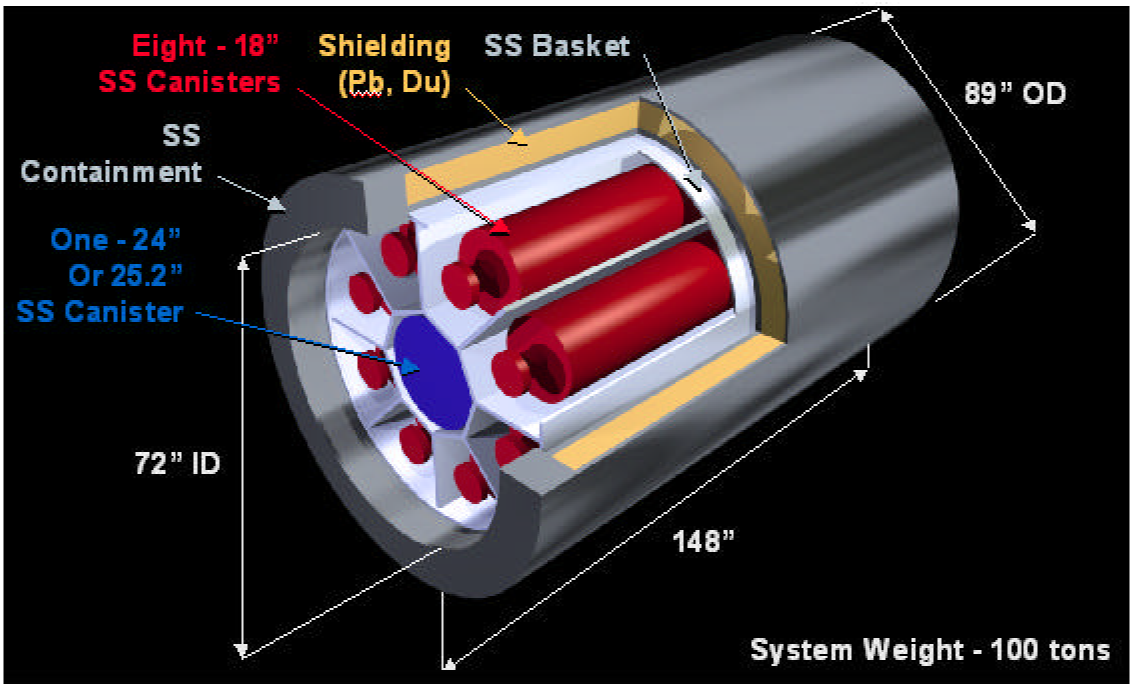

Figure 1. Schematic of a prototype DOE SNF transport cask. (Prototype designs include casks of 5.54 m and 3.76 m in length. Inner basket shown is one of several preliminary designs.)

The design for the prototype cask used in the shielding analyses is constructed from two layers of stainless steel, with a layer of either lead or depleted uranium between the stainless steel to provide gamma shielding (Figure 1). The inner layer of stainless steel is 2.54 cm (1.00 in.) thick and the outer is 3.81 cm (1.50 in.). The shielding model for the prototype cask is comprised of three zones. The shield consists of a right-circular cylinder of inner diameter of 182 cm (71.7 in.) with the inner most zone corresponding to the 2.54 cm (1.00 in.) thick stainless steel liner. The lead or depleted uranium-shielding zone surrounds the inner liner. The two inner zones are then encased within a 3.81 cm (1.50 in.) stainless steel liner. The overall dimensions of the prototype cask are 2.28 m (89.9 in.) diameter by either 5.54 m (218 in.) or 3.76 m (148 in.) in length. The maximum radiation dose rates and exposures will occur at the cask mid-length, because the top and bottom of the cask has additional shielding due to cask end effects. Thus, only one-dimensional shielding calculations are necessary to investigate the maximum radiation field outside of the transport cask at this location and to perform sensitivity analyses. The variations in radiation field along the length of the cask are neglected for conservatism and do not take part in the calculations.

The actual radioactive source term may be comprised of several different types of high-level wastes, spent nuclear fuels and/or reactor components. Current design criteria require the radiation source to be bound by an exposure rate of 100,000 R/hr with a gamma spectrum corresponding to Co-60. This spectrum is used since it is expected that some of the reactor components to be transported will contain significant quantities of Co-60 due to neutron activation of cobalt-alloy materials. The major significance of the source term is the gamma-ray energy of Co-60. This radionuclide emits two high-energy gamma-rays per disintegration, one at 1.17 MeV and the other at 1.33 MeV.

There are three shielding limits that were considered as part of this study:

1. In accordance with 10 CFR 71.43, the dose rate at the surface of the cask must be less than 200 mrem/hr.
2. A design criterion for cask handling, used for illustrative purposes, was that the radiation exposure rate be less than 50 mR/hr at one meter from the external surface of the cask. (Although not a radiation standard, per se, this corresponds to the determination of a Transport Index [TI] of 50 given in 10 CFR 71.4.)
3. In accordance with 10 CFR 71.43, the dose rate at two meters from the cask surface must be less than 10 mrem/hr.

A computer program called SHIELD was developed to calculate the dose rates. SHIELD is completely self-contained and at present is programmed to perform on the order of one thousand calculations for each of the three shielding limits.

The computational results indicate that the shielding thickness is strongly dependent upon the gamma-ray energy of the source term. To emphasize this finding, the results are shown for a wide variation of gamma-ray energies.

The shielding calculations were performed only for gamma radiation because betas and alphas would not penetrate the stainless steel liners that surround the radiation shielding material. Neutrons are not included because they typically have a dose equivalent rate that is about two or three orders of magnitude less than that from gammas.

Figures 2 and 3 show the comparison of the exposure rate at one meter from the cask surface for a cask using lead shielding, without and with shielding credit, respectively, for the stainless steel liner.

Similarly, Figures 4 and 5 show the comparison of the exposure rate at one meter from the cask surface for a cask using depleted uranium shielding, without and with shielding credit, respectively, for the stainless steel liner.

Figures 6 and 7 also compare the relative effectiveness of the lead and depleted uranium shielding materials (with credit for the stainless steel liners) as a function of dose rate and gamma energy.

SUMMARY

The results obtained from the shielding calculations in this study indicate the following major findings:

1. A shielding thickness of 8.5 cm is required for depleted uranium and 14 cm for lead in order to satisfy all three shielding requirements when the stainless steel liners are included in the shielding calculations.
2. It is advantageous to take shielding credit for the stainless steel liners. By obtaining credit for the stainless steel liners, it is possible to reduce the shielding material thickness (Pb or DU) by over 2 centimeters. This results in a significant reduction in total cask weight.
3. The required shielding thickness is strongly dependent upon the gamma-ray energy and, hence, accurate determination of the source term (cask payload) may preclude an overly conservative amount of shielding material in the cask design.

ACKNOWLEDGMENT

The authors would like to thank Adrián Cuadra, Santa Clara University, for assistance in the preparation of this paper.

REFERENCES

[1] Sanchez L. and McConnell P., "Estimation of Shielding Thickness for a Prototype Department of Energy National Spent Nuclear Fuel Program Transport Cask", Sandia National Laboratories Report SAND2000-1595, July 2000.

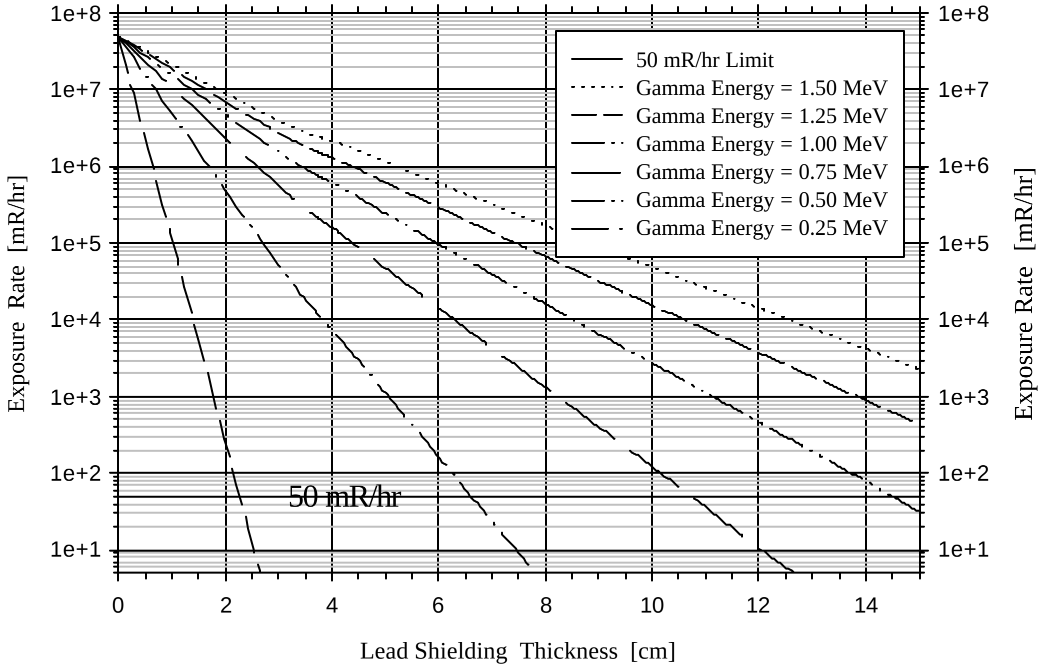

Figure 2. Exposure rate at one meter from cask surface as a function of lead shielding thickness for selected gamma-ray energies without shielding credit for stainless steel liners. The exposure rate limit of 50 mR/hr at one meter from cask surface is shown.

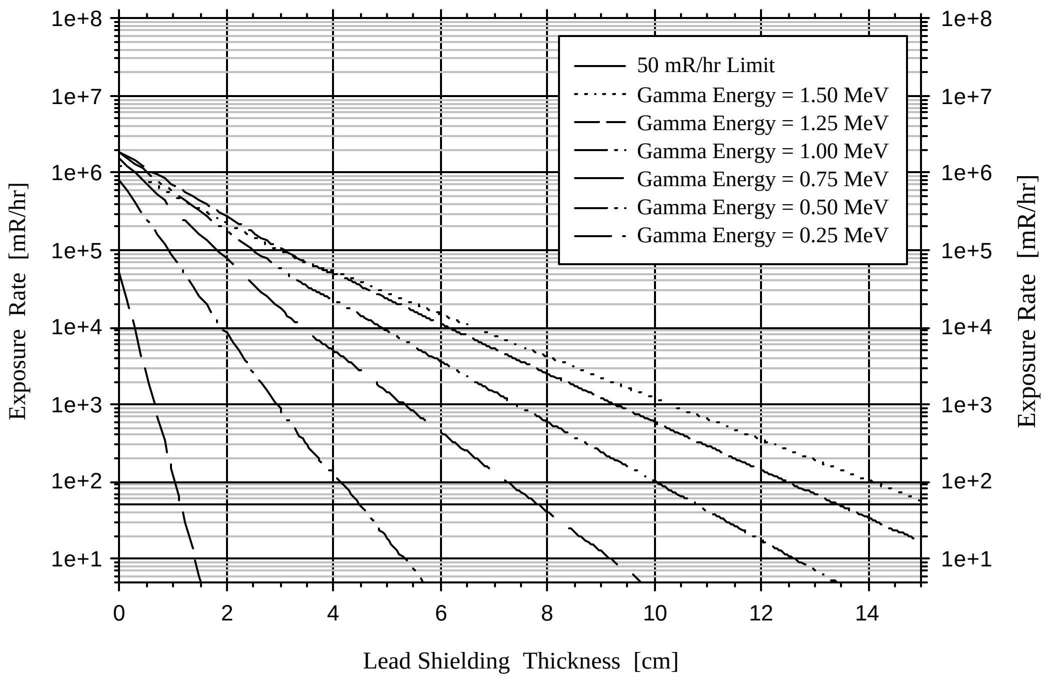

Figure 3. Exposure rate at one meter from cask surface as a function of lead shielding thickness for selected gamma-ray energies with shielding credit for stainless steel liners. Compare the required shielding at 50 mR/hr with the shielding required in Figure 2.

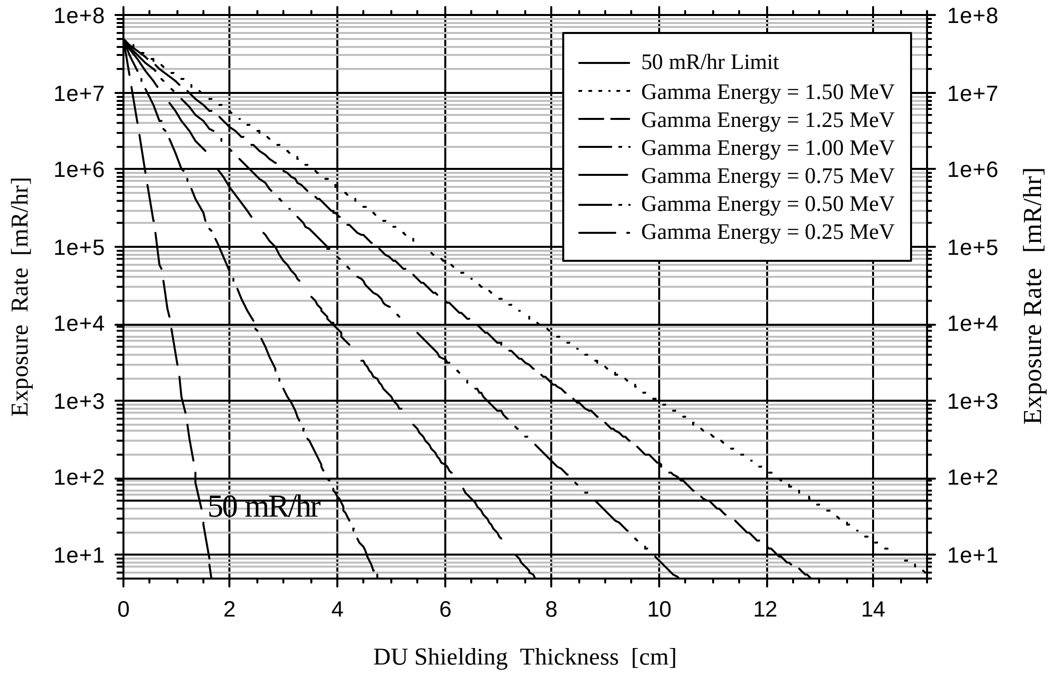

Figure 4. Exposure rate at one meter from cask surface as a function of depleted uranium shielding thickness for selected gamma-ray energies without shielding credit for stainless steel liners. The exposure rate limit of 50 mR/hr at one meter from cask surface is shown.

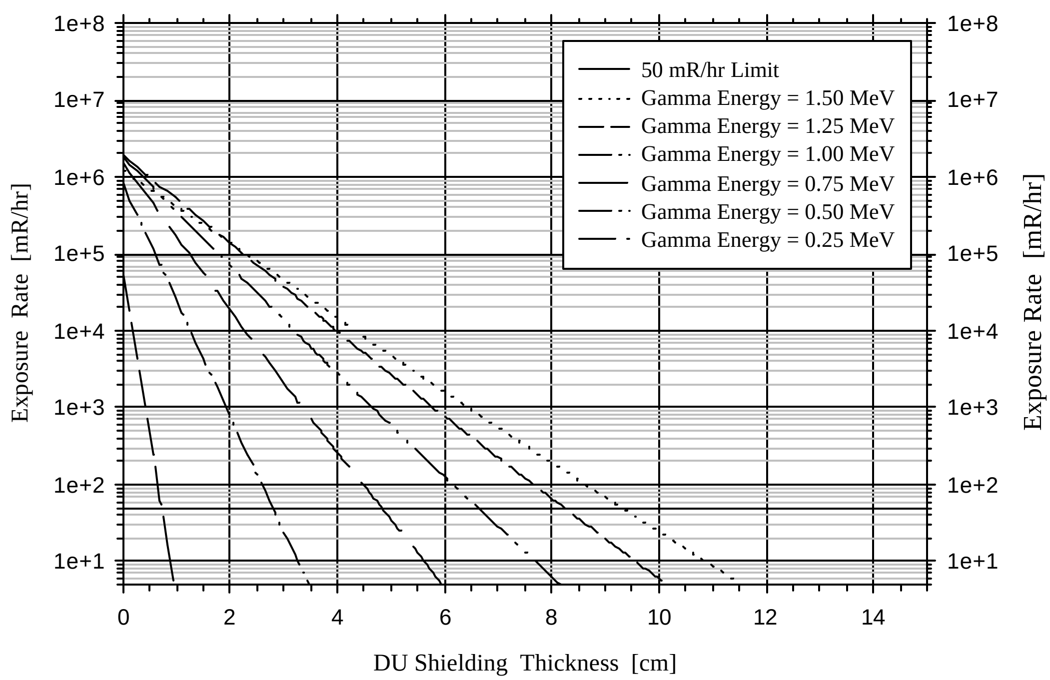

Figure 5. Exposure rate at one meter from cask surface as a function of depleted uranium shielding thickness for selected gamma-ray energies with shielding credit for stainless steel liners. Compare the required shielding at 50 mR/hr with the shielding required in Figure 4.

Dose Rate at Cask Surface for Lead Shielding

(2.54 & 3.81 cm SS liners)

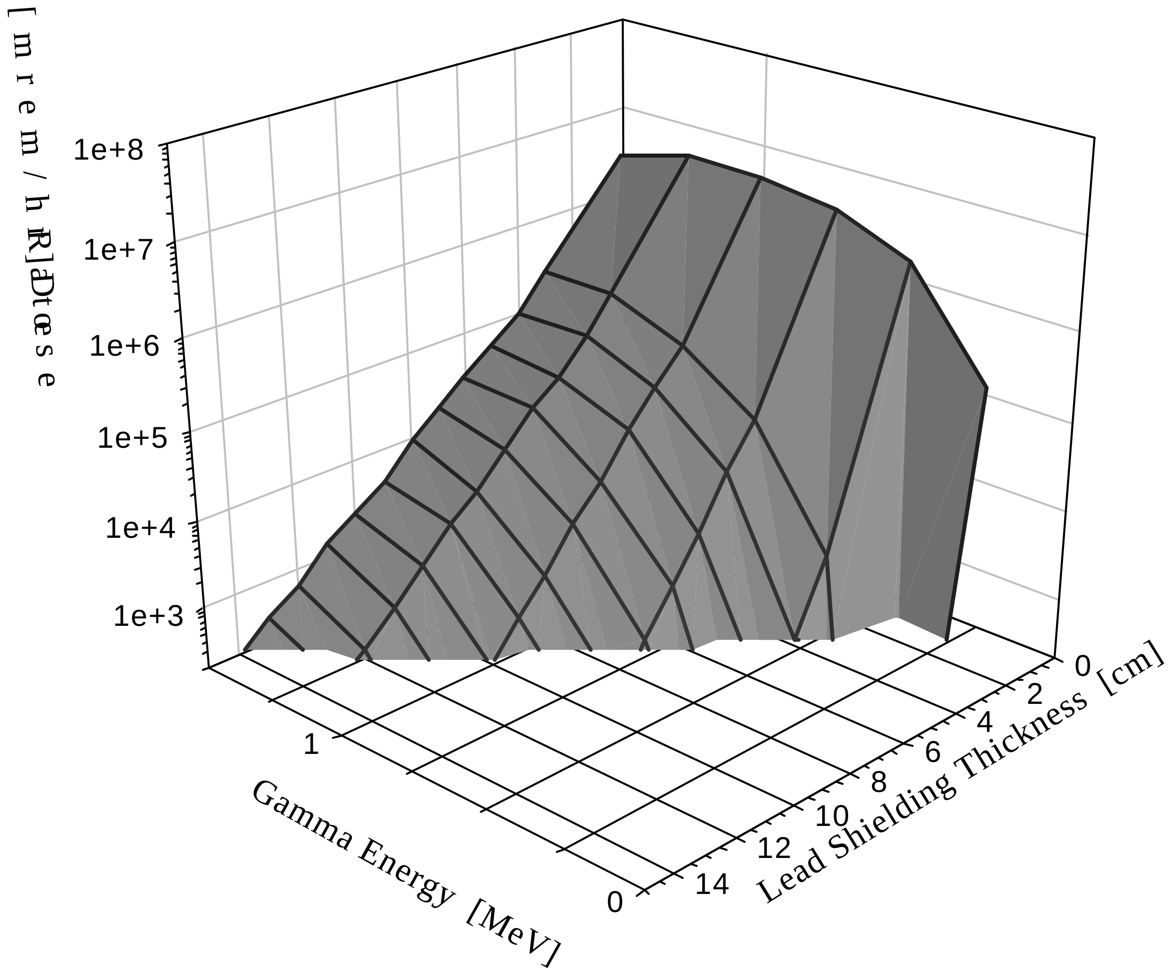

Figure 6. 3D plot of dose rate at cask surface as a function of gamma-ray energy (up to 1.5 MeV) and lead shielding thickness with shielding credit for stainless steel liners. Plot floor corresponds to cask surface dose rate limit of 200 mrem/hr limit.

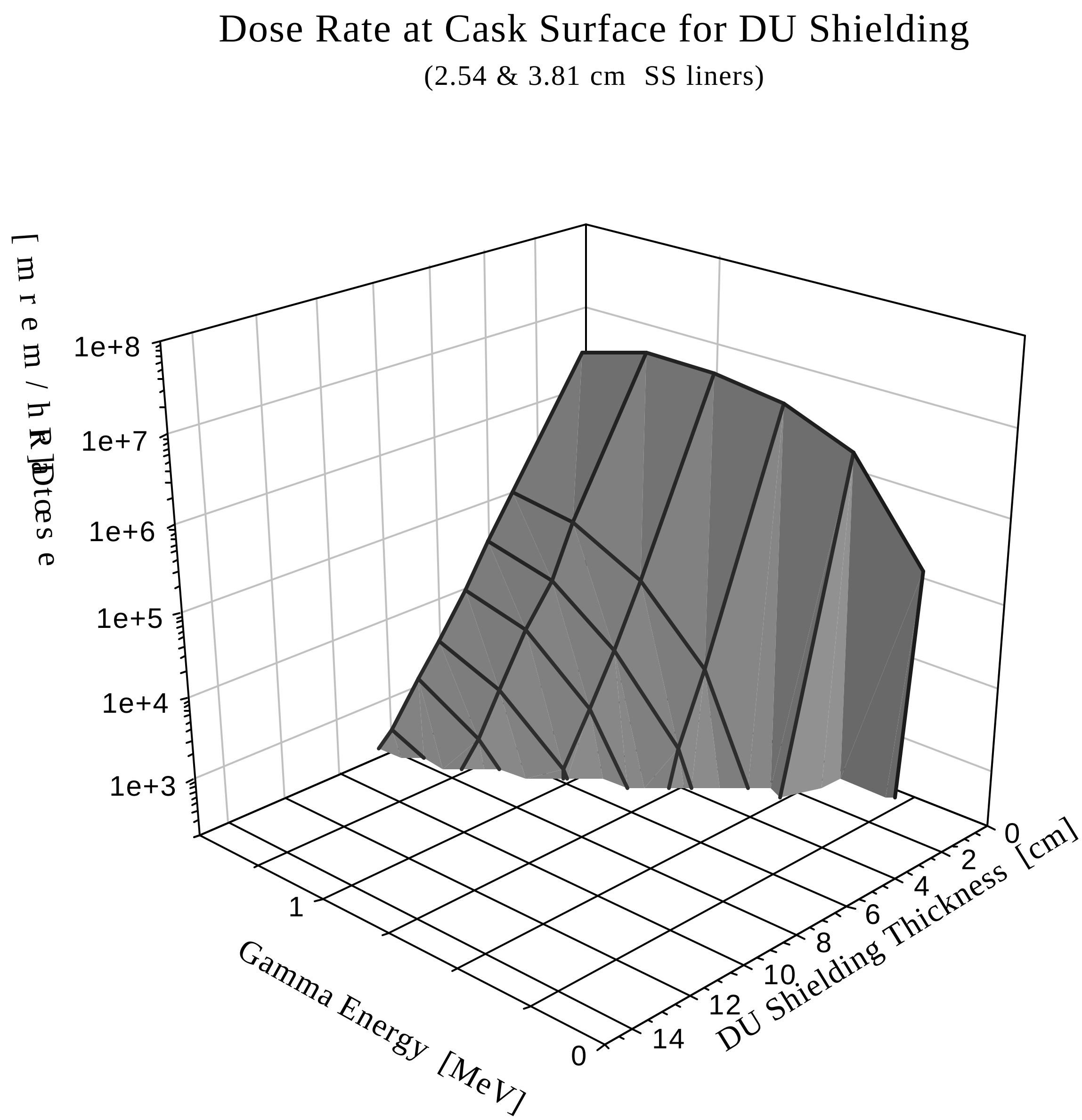

Figure 7. 3D plot of dose rate at cask surface as a function of gamma-ray energy (up to 1.5 MeV) and depleted uranium shielding thickness with shielding credit for stainless steel liners. Plot floor corresponds to cask surface dose rate limit of 200 mrem/hr limit.