Infinite slab-shield dose calculations

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ABSTRACT: I calculated neutron and gamma-ray equivalent doses leaking through a variety of infinite (laminate) slab-shields. In the shield computations, I used, as the incident neutron spectrum, the leakage spectrum (< 20 MeV) calculated for the LANSCE tungsten production target at 90° to the target axis. The shield thickness was fixed at 60 cm. The results of the shield calculations show a minimum in the total leakage equivalent dose if the shield is 40-45 cm of iron followed by 20-15 cm of borated (5%B) polyethylene. ***High-performance*** shields can be attained by using multiple laminations. The calculated dose at the shield surface is very dependent on shield material.

Introduction

I performed a series of equivalent dose calculations for a variety of shield laminates bombarded by a neutron spectrum characteristic of the LANSCE tungsten production target. The computations were done using the Los Alamos Monte Carlo code MCNP[1]. I chose infinite slab geometry (see Fig. 1) to simplify problem execution and develop a "feel" for the issues involved. The incident spectrum was that calculated leaking below 20 MeV from the LANSCE 10-cm-diam tungsten target at 90° to the target axis[2] (see Fig. 2). A point source of mono-directional neutrons was assumed incident normal to the inner shield surface. I calculated neutron and gamma-ray surface-fluxes at the opposite (outer) shield surface and converted to equivalent dose using the flux-to-dose conversion factors in Ref 2. I also looked at albedo neutrons and leakage gamma rays at the inner shield surface.

I investigated a variety of shield materials. The overall shield thickness was fixed at 60 cm (a typical shield-size at LANSCE). The intent of this study was to analyze the sensitivity of the dose at the outer shield surface to variations in shield laminate composition. The primary motivation for the work was to recommend a shield configuration for the LANSCE FP-5 shield.[3]

In neutron beam line shield design, consideration must be give to neutron and gamma-rays at ***both the inner and outer shield surfaces.*** Inner-surface radiations can affect neutron instrument backgrounds; outer-surface radiations may contribute to instrument backgrounds, but are definitely a biological dose concern.

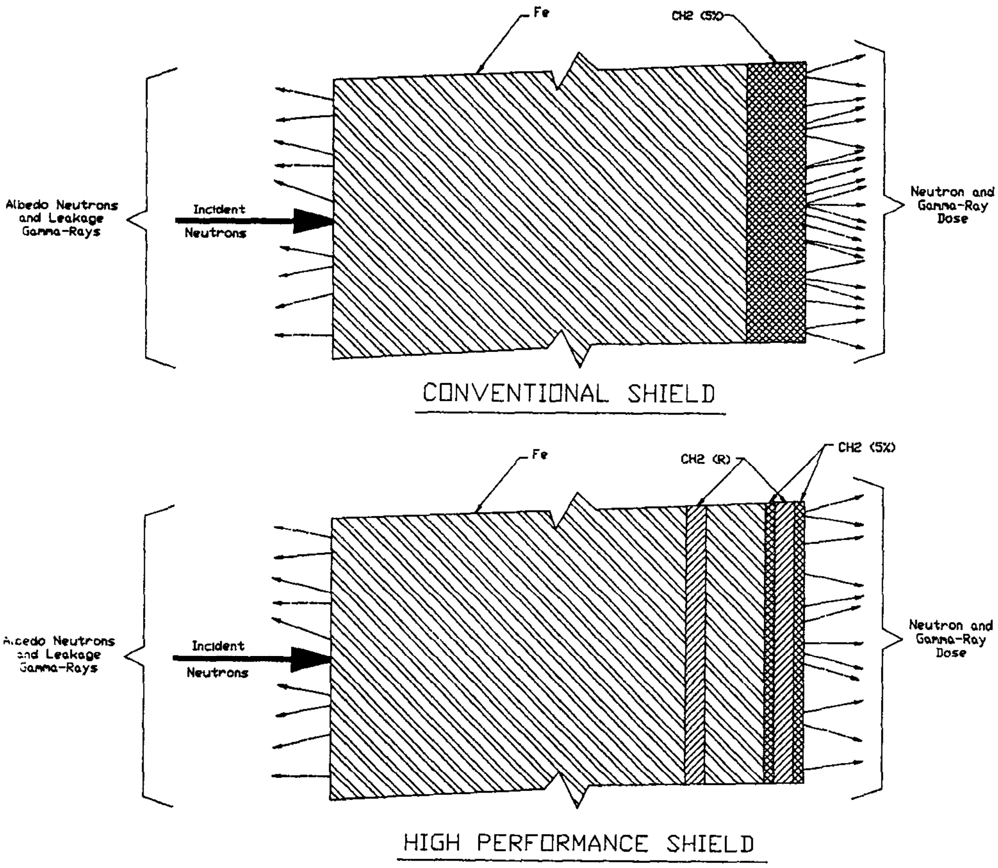

Fig. 1. Infinite slab-shield mockup showing conventional and high-performance shield configurations.

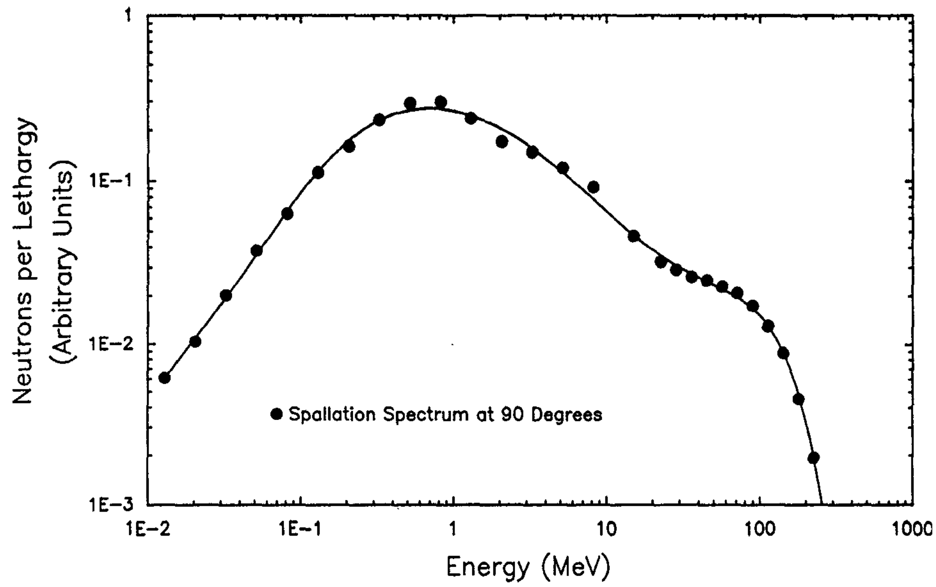

Fig. 2. Calculated neutron leakage (at 90°) from the 10-cm-diam LANSCE tungsten production target bombarded by 800-MeV protons. The neutron spectrum below 20 MeV was used in the shield studies.

Results

A summary of the shields studied are given in Tables I and II. The "conventional" method of constructing neutron beam line shielding at spallation sources is to have an inner iron zone followed by a borated outer region of wax or polyethylene.[4] We mocked up this conventional shield and varied the iron thickness from 0 cm (an all polyethylene shield) to 60 cm (an all iron shield). The results are shown in Fig. 3. There is a minimum in the total equivalent dose curve for a laminate shield of 40-45 cm of iron followed by 20-15 cm of polyethylene (5%B). I also studied other shield laminates. The results for two of these laminates are also shown in Fig. 3; ***significant gains can be achieved by multiple (> 2) laminations.*** No attempt was made to find the "optimum" laminate.

In Fig. 4, I show the neutron and gamma-ray equivalent dose components for the conventional shield configuration as a function of iron thickness. The neutron and gamma-ray dose components are equal at ≈40 cm of iron. Except for the iron thickness range of ≈35-50 cm, the total dose is dominated by the neutron dose. In the region of iron thickness where the gamma-ray dose component is significant, multiple laminates can be use to reduce the gamma-ray dose component (see Table I). For the all-iron shield, the total dose is nearly entirely due to neutrons; presumably, "windows" in the iron cross section are important in this context.

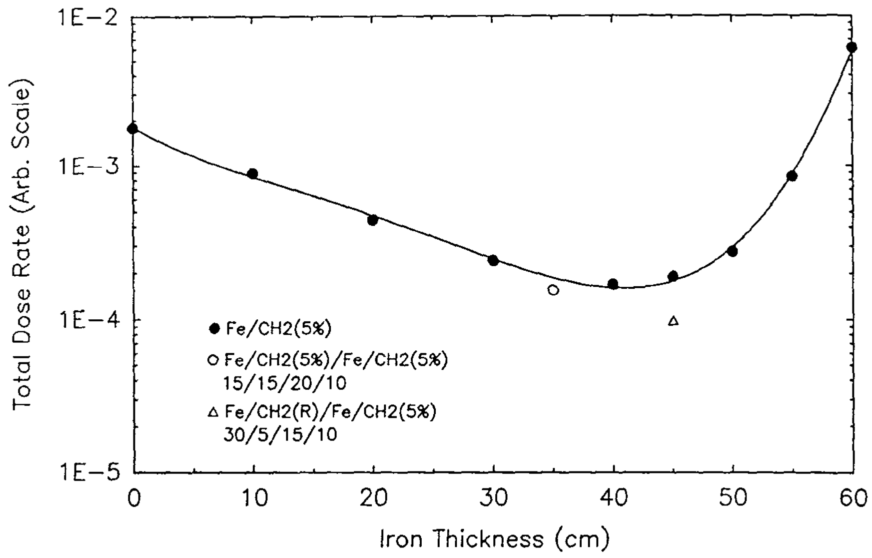

Fig. 3. Calculated total equivalent dose rates at the outer surface of infinite slab-shield laminates. The curve is drawn as a guide-to-the-eye.

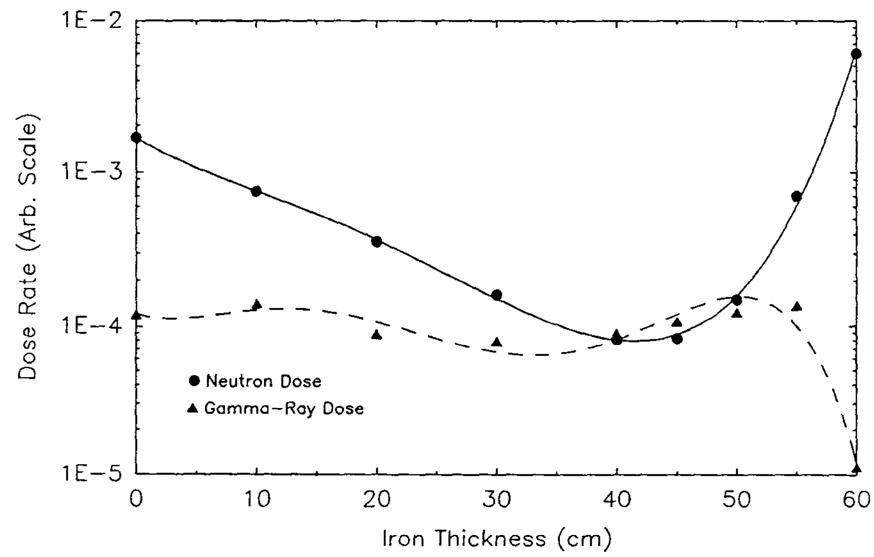

Fig. 4. Calculated neutron and gamma-ray equivalent dose rate components at the outer surface of infinite slab-shield laminates. The curves are drawn as guides-to-the-eye.

Table I. Calculated Doses at the Outer Shield Surface

Shield Configuration	Neutron Dose (Arb. Units)	Gamma-Ray Dose (Arb. Units)	Total Dose (Arb.Units)
(Reference) Fe/CH2(R)/Fe/CH2(5%)/CH2(R)/CH2(5%)	6.49E-05	2.69E-05	9.18E-05
30/5/15/2.5/5/2.5 cm			
% of Total	70.7	29.3	
Fe/CH2(R)/Fe/CH2(R)/Pb/CH2(7%)	8.31E-05	1.08E-05	9.39E-05
30/5/15/5/2.5/2.5 cm			
% of Total	88.5	11.5	
Fe/CH2(R)/Fe/CH2(5%)	7.49E-05	2.33E-05	9.82E-05
30/5/15/10 cm			
% of Total	76.3	23.7	
Fe/CH2(R)/Fe/CH2(R)	6.09E-05	4.80E-05	1.09E-04
30/5/15/10 cm			
% of Total	55.9	44.1	
Fe/CH2(5%)/Fe/CH2(5%)	1.44E-04	1.22E-05	1.56E-04
15/15/20/10 cm			
% of Total	92.2	7.8	
Fe/CH2(5%)	8.12E-05	8.88E-05	1.70E-04
40/20 cm			
% of Total	47.8	52.2	
Fe/CH2(5%)	8.27E-05	1.08E-04	1.91E-04
45/15 cm			
% of Total	43.4	56.6	
Fe/CH2(5%)	1.63E-04	7.90E-05	2.42E-04
30/30 cm			
% of Total	67.3	32.7	
Fe/CH2(5%)	1.51E-04	1.25E-04	2.76E-04
50/10 cm			
% of Total	54.9	45.1	
Fe/CH2(5%)	3.57E-04	8.80E-05	4.45E-04
20/40 cm			
% of Total	80.2	19.8	
Pb/CH2(5%)	5.87E-04	1.14E-04	7.02E-04
45/15 cm			
% of Total	83.7	16.3	
Fe/CH2(5%)	7.05E-04	1.38E-04	8.43E-04
55/5 cm			
% of Total	83.6	16.4	
Fe/CH2(5%)	7.50E-04	1.41E-04	8.91E-04
10/50 cm			
% of Total	84.2	15.8	
CH2(5%)	1.67E-03	1.19E-04	1.79E-03
60 cm			
% of Total	93.3	6.7	
Regular Concrete	5.05E-03	2.28E-04	5.28E-03
60 cm			
% of Total	95.7	4.3	
Fe	6.08E-03	1.12E-05	6.10E-03
60 cm			
% of Total	99.8	0.2	

Table II. Calculated Relative Shield Performance

Shield Configuration	Neutron Dose	Gamma-Ray Dose	Total Dose
(Reference) Fe/CH2(R)/Fe/CH2(5%)/CH2(R)/CH2(5%) 30/5/15/2.5/5/2.5 cm	1.00	1.00	1.00
Fe/CH2(R)/Fe/CH2(R)/Pb/CH2(7%) 30/5/15/5/2.5/2.5 cm	1.28	0.40	1.02
Fe/CH2(R)/Fe/CH2(5%) 30/5/15/10 cm	1.15	0.87	1.07
Fe/CH2(R)/Fe/CH2(R) 30/5/15/10 cm	0.94	1.78	1.19
Fe/CH2(5%)/Fe/CH2(5%) 15/15/20/10 cm	2.21	0.45	1.70
Fe/Ch2(5%) 40/20 cm	1.25	3.30	1.85
Fe/CH2(5%) 45/15 cm	1.27	4.01	2.07
Fe/CH2(5%) 30/30 cm	2.51	2.94	2.63
Fe/CH2(5%) 50/10 cm	2.33	4.63	3.01
Fe/CH2(5%) 20/40 cm	5.50	3.27	4.84
Pb/CH2(5%) 45/15 cm	9.04	4.26	7.64
Fe/CH2(5%) 55/5 cm	10.9	5.14	9.18
Fe/CH2(5%) 10/50 cm	11.6	5.24	9.70
CH2(5%) 60 cm	25.7	4.43	19.5
Regular Concrete 60 cm	77.9	8.47	57.5
Fe 60 cm	93.7	0.42	66.4

In Table I, you can see the dramatic increase in dose for lead/polyethylene and regular concrete shields compared to an iron/polyethylene shield. There may be some benefit in sublamination of the outer polyethylene zone. This is particularly true if minimizing neutron dose is more important than decreasing gamma-ray dose.

Note in Table II that regular polyethylene at the outer surface of a conventional shield is more effective (by ≈22%) than borated polyethylene in reducing neutron dose at the outer shield surface. However, the gamma-ray dose and escaping gamma-ray energy are higher for regular polyethylene.

Conclusions

In general, gamma-ray equivalent dose is not explicitly considered in the context of neutron beam line shielding at spallation neutron sources.[4] ***It is important to contemplate the total (neutron plus gamma ray) equivalent dose in neutron beam line shield design.*** For a conventional shield laminate of iron followed by borated (5%) polyethylene, I have shown that the minimum total equivalent dose is achieved when the lamination is 40-45 cm of iron followed by 20-15 cm of polyethylene. This is for an overall shield thickness of 60 cm, and for an incident neutron spectrum (< 20 MeV) characteristic of the LANSCE tungsten production target at 90° to the target axis.

I have shown that multiple laminates significantly improve shield performance, producing ***high-performance shields***. No attempt was made to find the "optimum" laminate. The calculations indicate that (for dose considerations at the outer shield surface) caution should be exercised in using regular concrete and lead in neutron beam line shield applications.

No attention was explicitly given here to the importance of albedo neutrons and gamma-rays at the inner shield surface. These latter radiations are important in neutron beam line shield design because they can affect instrument backgrounds. For infinite slab-geometry, the magnitude of these albedo neutrons can be significant. For example, calculated neutron albedo currents at the inner shield surface are about 0.18, 0.56, 0.78, and 0.91 n/n for the polyethylene, regular concrete, iron, and lead shields, respectively.

For thicker shields, multiple laminations should provide high-performance shields. This work is essentially a "progress report" of what has been done to date. Considerable work needs to be done to explain all the effects found. I am studying shield laminates in spherical geometry for neutron beam line, chopper, and beam stop applications. In these deliberations, albedo neutrons can significantly affect total equivalent doses at the outer shield surface. For a fixed shield thickness, improvements in shield performance by factors of two or more (vis-avis high-performance shields) can have significant economic consequences.

We have evidence that shield performance is quite sensitive to the incident neutron spectrum; there appears to be significant shield performance enhancements for softer incident neutron spectra.

Acknowledgements

I acknowledge the continued support of Roger Pynn and Dick Woods for this work, and for useful discussions with Gail Legate and Harold Robinson. I thank Teri Cordova for her typing help.

This work was performed under the auspices of the U. S. Department of Energy, Office of Basic Energy Sciences.

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