CONF-970322-5

LA-UR- 97-750

SHIELDING MATERIALS FOR HIGH-ENERGY NEUTRONS

Hsiao–Hua Hsu
Health Physics Measurements Group
Los Alamos National Laboratory
Los Alamos, New Mexico, 87545 USA

Abstract

We used the Monte Carlo transport code Los Alamos High-Energy Transport (LAHET) to study the shielding effectiveness of common shielding materials for high-energy neutrons. The source neutron spectrum was from the interaction of an 800-MeV proton beam and iron target. In a normal incident, the neutrons collided with walls made of six common shielding materials: water, concrete, iron, lead, polyethylene, and soil. The walls were of four different thicknesses: 25, 50, 75 and 100 cm. We then tallied the neutron spectra on the other side of the shielding wall and calculated the neutron doses. For the high-Z materials—iron and lead—we find that many neutrons with energies between 1–10 MeV are created when high-energy neutrons interact with shielding materials. For materials containing low-Z elements—water, soil, concrete, and polyethylene—the spectra show higher energy peaks at about 100 MeV. Our studies show that for a given wall thickness, concrete is more effective than the other materials. We also studied the effectiveness of combinations of materials, such as concrete and water, concrete and soil, iron and polyethylene, or iron polyethylene and concrete.

Introduction

Neutron shielding for high-energy accelerators is an important issue in health physics for, in general, massive shielding is required to reduce neutron dose.The purpose of this simple study is to find out the relative effectiveness of common shielding materials by using Monte Carlo simulations. If we know the shielding effectiveness of materials, we will be able to properly design neutron sheilding. While we know atoms of materials containing low-Z elements will transfer most of the neutron energy during a collision process, high-energy nuclear reactions may have different characteristics.

Monte Carlo simulations

For our simulations, we used the Los Alamos High-Energy Transport code (LAHET)[1]. The neutron source simulates the interaction of an 800-MeV proton beam with an iron target. Figure 1 shows the spectrum that results.

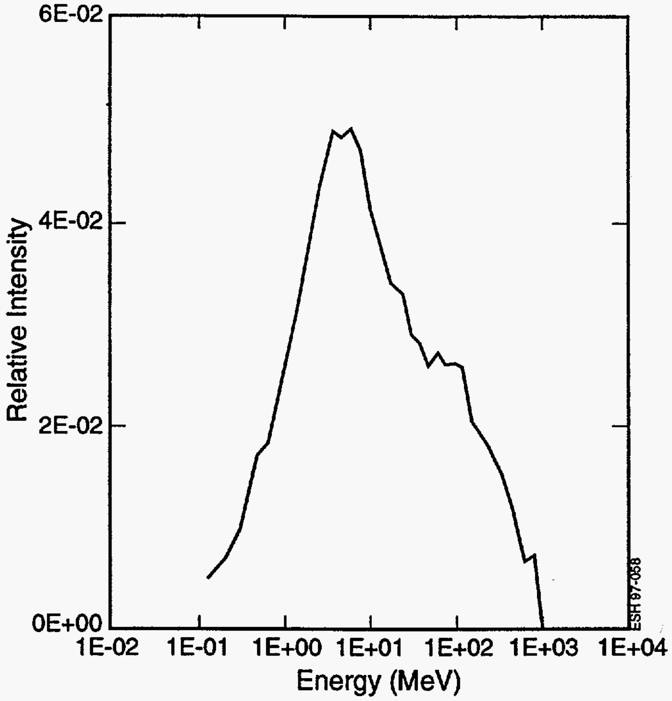

Fig.1. Neutron spectrum 800-MeV proton on iron target

In a normal incident, the neutron collides with a wall. For the wall, we used water, concrete, iron, lead, polyethylene, and soil, each at four different thicknesses: 25, 50, 75 and 100 cm. We then tallied the neutron spectra on other side of the wall and calculated the neutron doses. In LAHET calculations, when the energy of a neutron reaches 20 MeV, the code records all information on a tape. We used the tape as input for a MCNP[2] calculation, which provides more detailed neutron interaction cross sections.

Results and discussion

In figures 2–7, we show the neutron spectra for six materials and four wall thickness.

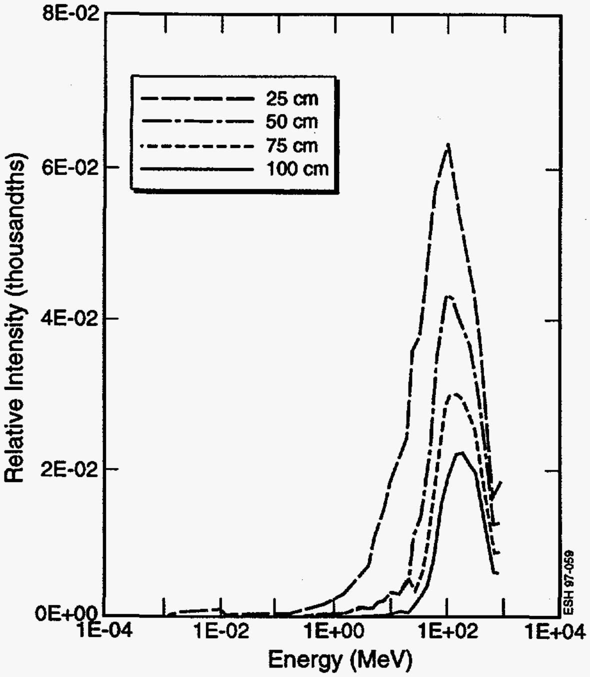

Fig. 2. Neutron spectra CH_2 slab

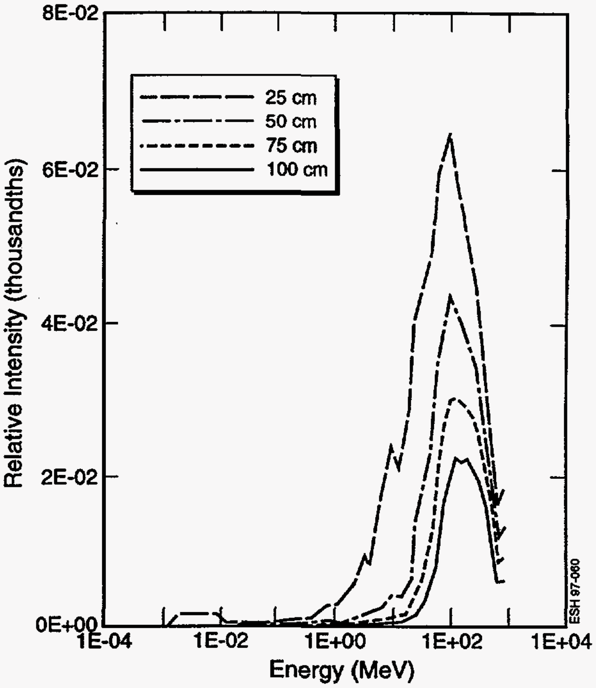

Fig. 3. Neutron spectra water slab

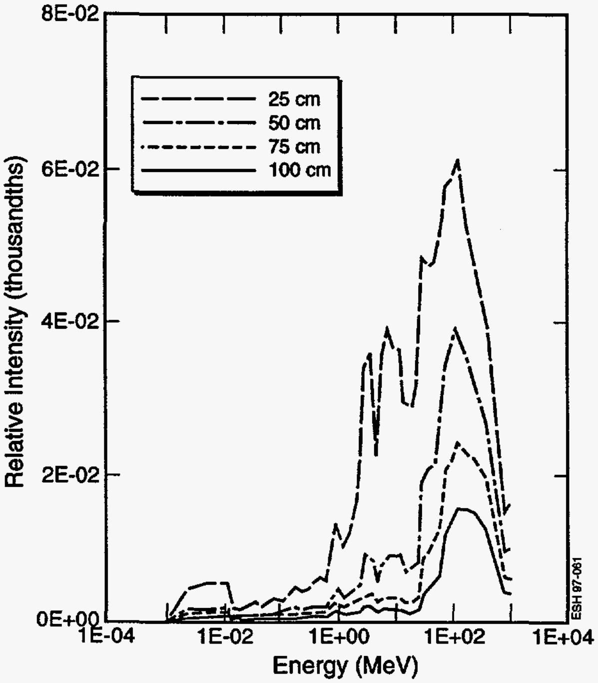

Fig. 4. Neutron spectra soil slab

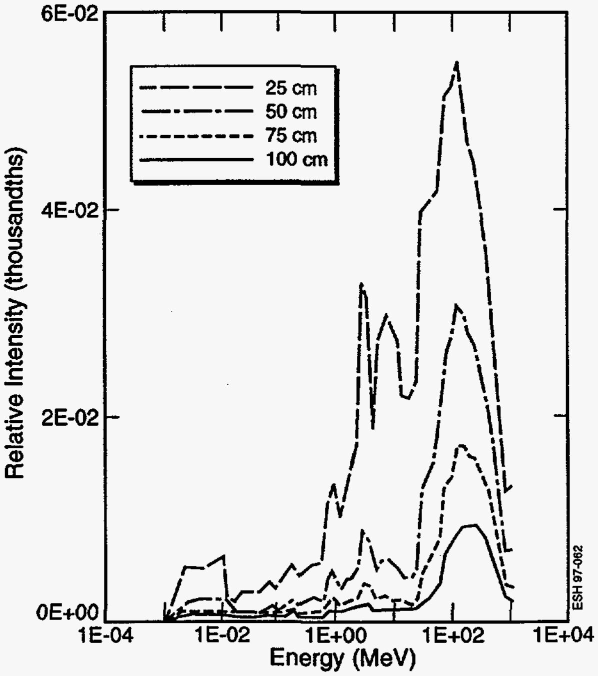

Fig. 5. Neutron spectra concrete slab

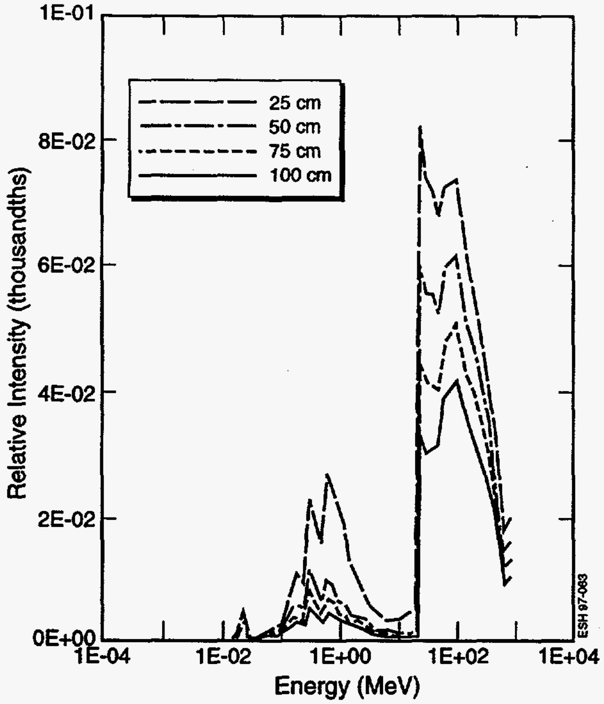

Fig. 6. Neutron spectra iron slab

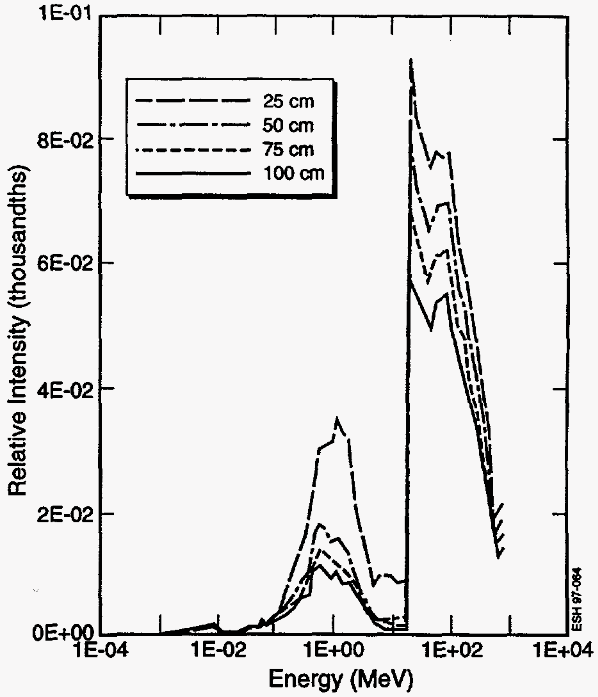

Fig. 7. Neutron spectra lead slab

For water and polyethylene, the spectra maintain a single peak at about 100 MeV. For soil and concrete, two extra peaks between 5 and 8 MeV derive from silicon (both contain about 30% by weight). For iron and lead, the discontinuity at 20 MeV is not real but comes from the differences in cross sections when we link LAHET to MCNP. However, the neutron peaks at about 1 MeV are real, the result of (n, xn) reactions. We then fold the resulting spectra to the neutron fluence-to-dose function, calculating neutron doses on the other side of the walls. Table 1 is a summary of our results, which show that materials consisting of low-Z elements are more effectively to reduce neutron doses. The material density is also an important factor; the calculation for water and for concrete with a density of 1 gm/cm^3 shows almost identical results in neutron spectrum and neutron dose.

Table 1. Neutron doses with different walls

Material	Density (gm/cm^3)	Doses (pSv per source neutron) Wall thickness			
		25 cm	50 cm	75 cm	100 cm
Polyethylene	0.90	3.16e–1	1.59e–1	1.08e–1	6.64e–2
Water	1.00	3.39e–1	1.69e–1	1.04e–1	6.98e–2
Soil	1.70	4.24e–1	1.81e–1	9.85e–2	5.70e–2
Concrete	2.25	3.73e–1	1.46e–1	7.15e–2	3.77e–2
Iron	7.87	4.18e–1	2.96e–1	2.32e–1	1.84e–1
Lead	11.4	5.07e–1	3.81e–1	3.28e–1	2.86e–1

Combinations of materials

We considered the following combinations of two or three materials:
(1) 50-cm iron + 50-cm CH_2,
(2) 25-cm iron + 75-cm CH_2,
(3) 25-cm iron + 50-cm CH_2 + 25-cm concrete,
(4) 25-cm iron + 25-cm CH_2 + 50-cm concrete,

(5) 25-cm concrete + 50-cm water + 25-cm concrete,
(6) 25-cm concrete + 25-cm water + 50-cm concrete,
(7) 25-cm concrete + 50-cm soil + 25-cm concrete,
(8) 25-cm concrete + 25-cm soil + 50-cm concrete.

Figures 8 and 9 show neutron spectra. Table 2 summarizes dose results.

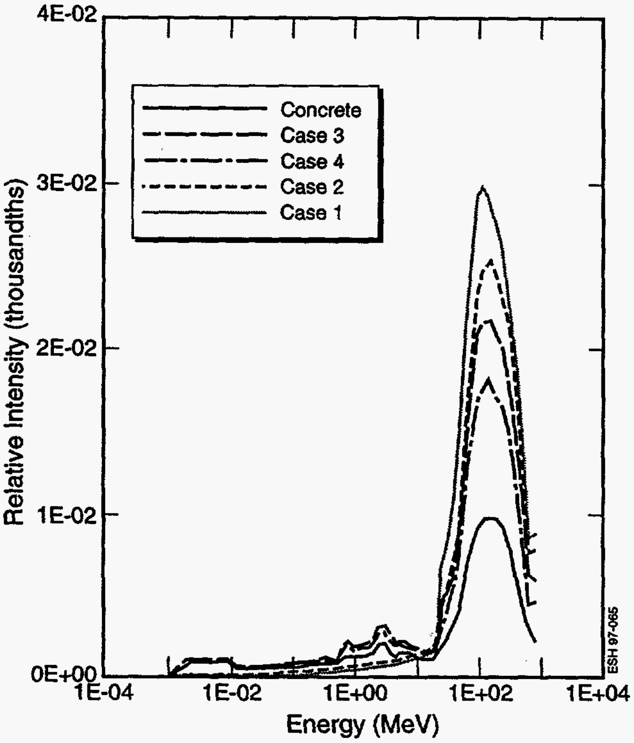

Fig. 8. Neutron spectra combination slab

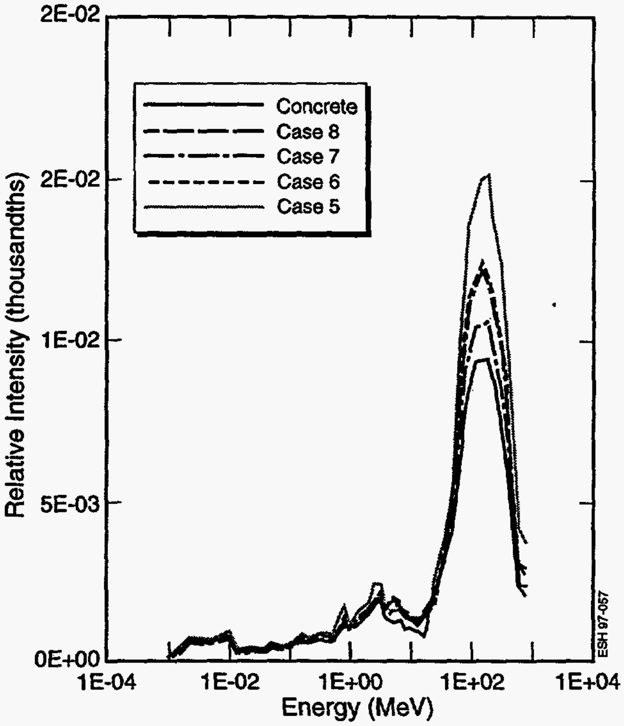

Fig. 9. Neutron spectra combination slab

Table 2. Neutron doses for shielding walls of combined materials

CASE	DOSE (pSv per source neutron)
1	1.01e–1
2	8.01e–2
3	8.16e–2
4	6.80e–2
5	5.71e–2
6	4.76e–2
7	4.85e–2
8	4.33e–2

They confirm further that

- higher Z elements, such as iron, are not as effective as the concrete shown in cases 1–4 or as compared with cases 5–8; and
- higher density materials are more effective, as shown in cases 3 and 4, than the concrete compared with CH$_2$ in cases 1 and 2; and also more effective, as shown in cases 7 and 8, than the soil as compared with water in cases 5 and 6.

Conclusion

For high-energy neutron shielding, we should use high-density materials that consist of low-Z elements. Concrete is a good choice; in some cases, an acceptable choice is in replacing part of the concrete with soil.

References

1. R. E. Prael and H. Lichtenstein, The LAHET Code System, Los Alamos National Laboratory, LA–UR–89–3014, 1989.

2. J. F. Briesmeister, (ed) MCNP—A General Monte Carlo N–Particle Transport Code, Version 4A, Los Alamos National Laboratory, LA–12625–M, 1993.