AP0 Target Vault Shielding Study

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I. Introduction and Summary

Efforts are currently underway to redesign the neutron covers [Ref. 1] to meet radiation-safety guidelines, with the goal of reducing the radiation level over the vault by at least a factor of 100. This note describes the results of measurements of radiation attenuation by sample shields. The purpose of the shielding study is to provide data for the redesign of the neutron covers.

The radiation escaping from the neutron covers appears to be predominantly gammas. In addition, there is a small, more penetrating component, which may consist of energetic (>200 MeV) neutrons leaking past the neutron covers. Reduction of the measured radiation by more than an order of magnitude is easily achieved by placing a 6-inch steel plate over the existing neutron covers. However, the desired reduction by two orders of magnitude requires further attenuation of the more penetrating component. The conclusion of the study is that 48" of concrete should adequately attenuate the radiation.

II. Shielding Calculations

Reference 2 contains information on the radiation diffusing through the 6-ft steel shield modules over the target pit. Two conclusions may be drawn from that work. First, the neutron covers greatly reduce the neutron flux that impinges on them. Second, the ratio of gamma-ray flux to neutron flux above the neutron covers appears to be at least 10.

(a) Gammas

Transmission of gamma rays through a shield of thickness x may be calculated as [Refs. 3, 4]

$$T(x) = B \exp(-u x)$$

where B is the build-up factor (a function of photon energy, shield thickness, material, and geometry), and u is the gamma-ray absorption coefficient. The energy of gammas emitted in neutron-capture processes depends on the material; they typically range in energy up to about 2 MeV, but some materials (such as Fe) generate gammas up to 10 MeV. In the absence of a measurement of the gamma spectrum, we must be prepared to shield throughout the range 0.48-10 MeV.

(b) Neutrons

Some neutrons are leaking past the existing neutron cover, as shown in Ref. 2. Neutron scattering/attenuation calculations are more complicated than the equivalent gamma-ray calculations. Therefore, no detailed neutron transmission curves were calculated. However, design procedures discussed in the references are useful for determining the appropriate amount of shielding (see below). For example, concrete is a more effective neutron absorber, and therefore would be preferable over steel, because of the presence of hydrogen in the concrete.

III. Experiment

A study was performed to measure the transmission of ionizing radiation through several test shields. The test setup is shown in Fig. 1. Shields (18" or 36" concrete blocks; 6" to 10" of steel plates in 2" increments) were placed on the upstream and downstream neutron covers, approximately over the beam path. An ionization chamber (chipmunk) was placed on the shield, and was in turn covered by the cover of a lead-lined (2.5" thick) coffin. The coffin was used to prevent scattered radiation from entering the radiation detector. Results from the tests are shown in Table 1. The unshielded dose rate data are in rough agreement with previous measurements (Ref. 5). The ratios of counts with shielding to counts without shielding are plotted as a function of shield thickness, in Fig. 2 for the case of steel, and in Fig. 3 for the case of concrete. Also plotted are the expected gamma-ray transmission curves, as calculated above. Measured transmission is in most cases higher than expected, and the addition of incremental shielding is fairly ineffective, in disagreement with the gamma-ray model. (The 36" concrete test is a special case -- because of its square (36" wide) cross section, the block cannot be treated as a uniform shield.) The discrepancy is quantified in Fig. 4. There is agreement between model and data under the assumption that an additional component (0.024 of total upstream; 0.032 of total downstream), unaffected by the steel shields, is present.

IV. Interpretation of the Results

Adding 18" (46 cm) of concrete under 8" of steel reduces the flux of the unaccounted-for radiation by roughly 1/2. It is interesting to note that this result is in agreement with published curves [Ref. 6] of shielding effectiveness for high-energy neutrons in ordinary concrete (Fig. 5), which show a half-value thickness of 48 cm. Hence the penetrating radiation may consist of these energetic neutrons.

A general-purpose shield can be constructed of concrete. Neutrons of energy less than 1 MeV should be eliminated in approximately the first 20 cm. (The precise rate of attenuation depends on the moisture content of the concrete.) Gamma rays of energy 2 MeV are eliminated in the first 70 cm. Finally, the penetrating component is attenuated very slowly. The initial, unattenuated level is not well known. However, if we estimate the unshielded level to be in the range of 0.04, it should be attenuated to less than 0.01 after 120 cm of concrete. Based on this prediction, a proposed shield, consisting of 48" (122 cm) of concrete, is shown in Fig. 6. Because of the attenuation of neutrons in the concrete, the new shield may replace the existing neutron covers.

References

1. P. Hurh, AP0 Target Hall Vault Shielding Upgrade Design Report, Accelerator Division Mechanical Support Department, Spec. #1321-ES-296053, April 15, 1991.

2. P. Yurista and A. Elwyn, Radiation Physics Note #73, June 2, 1988.

3. H. Goldstein, The Attenuation of Gamma Rays and Neutrons in Reactor Shields, US Atomic Energy Commission, May 1, 1957.

4. H. Etherington, ed., Nuclear Engineering Handbook, McGraw-Hill 1958.

5. M. Halling, Summary of PBAR Radiation Studies, memo 4/9/90

6. R. G. Jaeger, ed., Engineering Compendium on Radiation Shielding, Vol III, IAEA, Springer Verlag, NY 1968.

TABLE 1

Condition	Counts (backg. subtr.)	# Protons (E13)	Dose*
	Downstream Data		
No Shield	822	0.145	6803 mR/hr
18" Concrete	245.5	0.663	444
36" Concrete	161	1.075	180
8" Steel	274	1.111	296
10" Steel	264	1.363	228
8" Steel + 18" Concrete	90	1.099	98
	Upstream Data		
No Shield	1099	0.358	3684
6" Steel	63.7	0.663	115
8" Steel	80	1.075	89

*Scaled to 3E12 protons per pulse, 2 seconds per pulse.

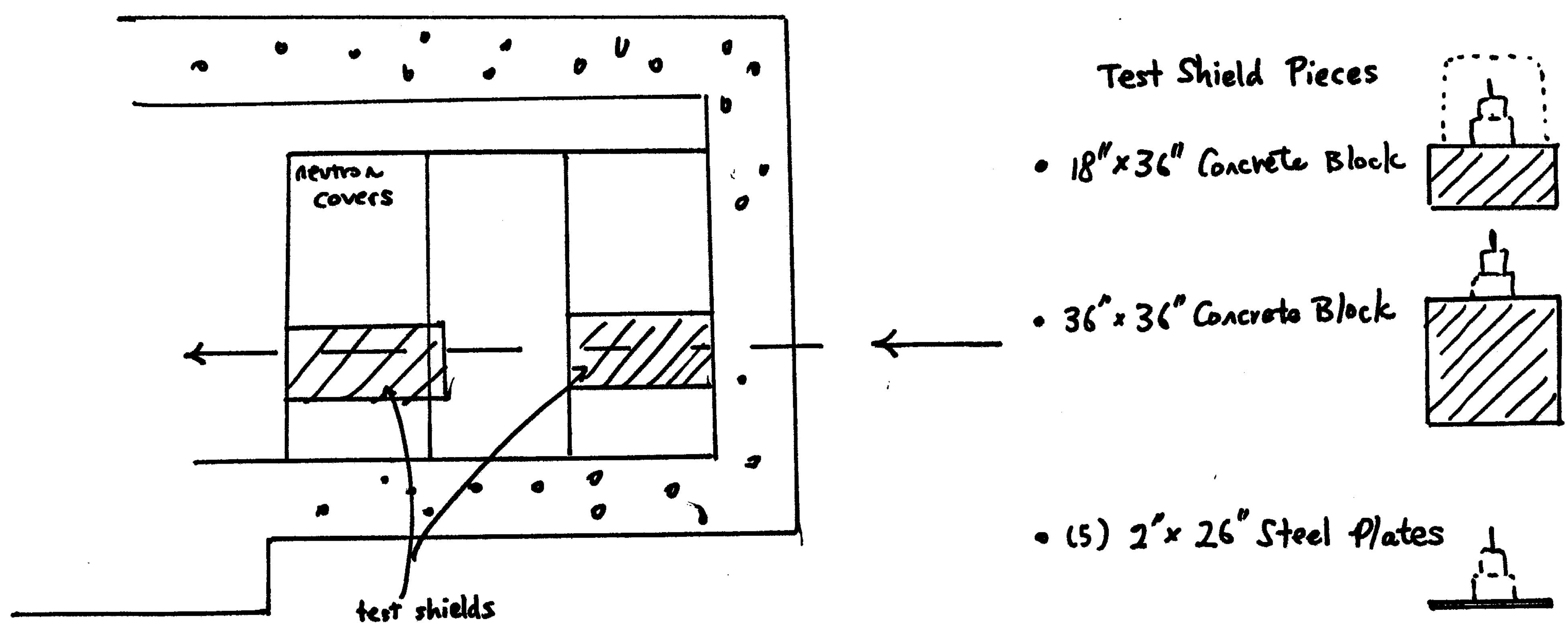

FIGURE 1. Geometry and positions of test shields.

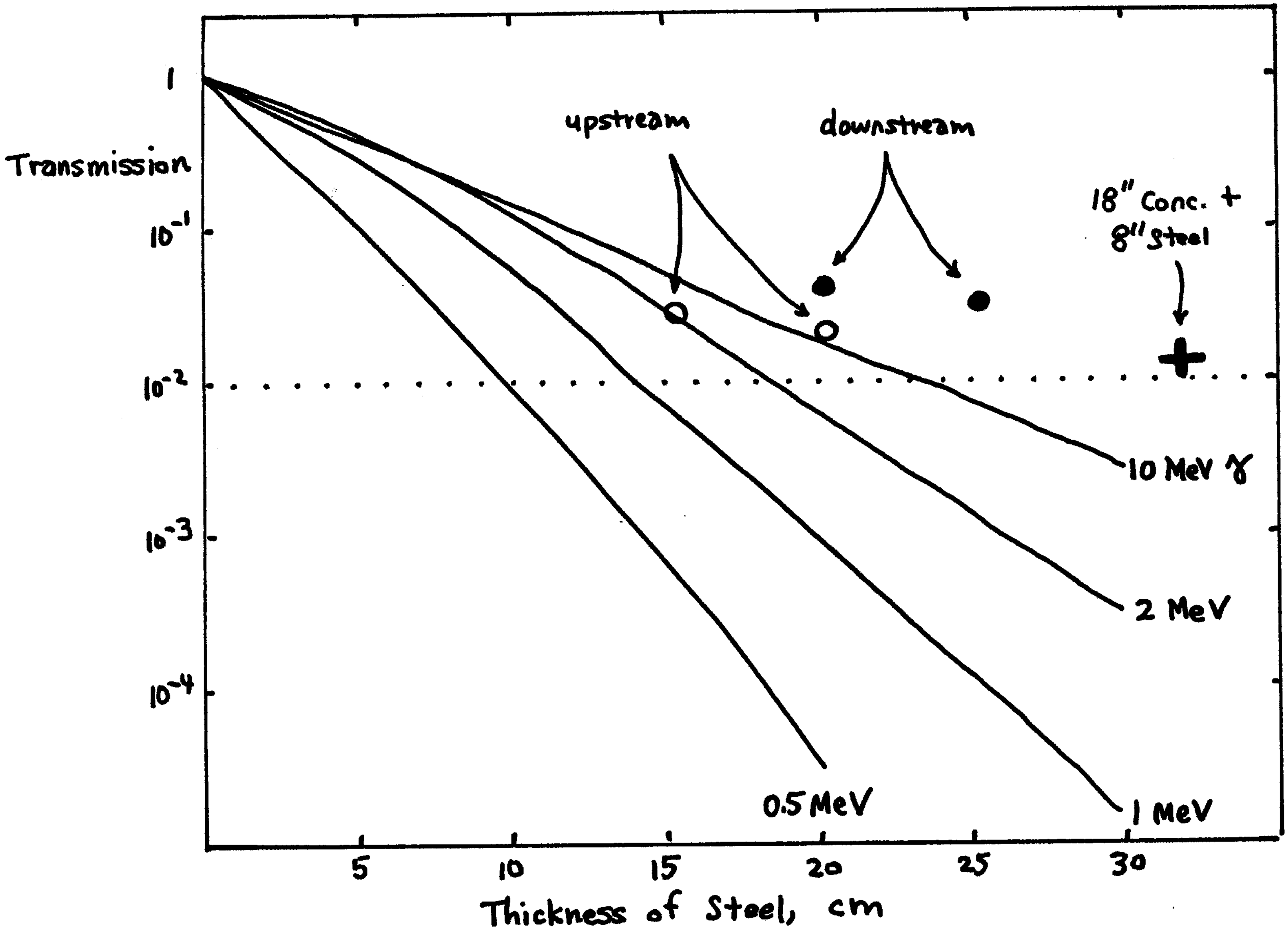

FIGURE 2. Comparison of data with gamma-ray transmission: steel.

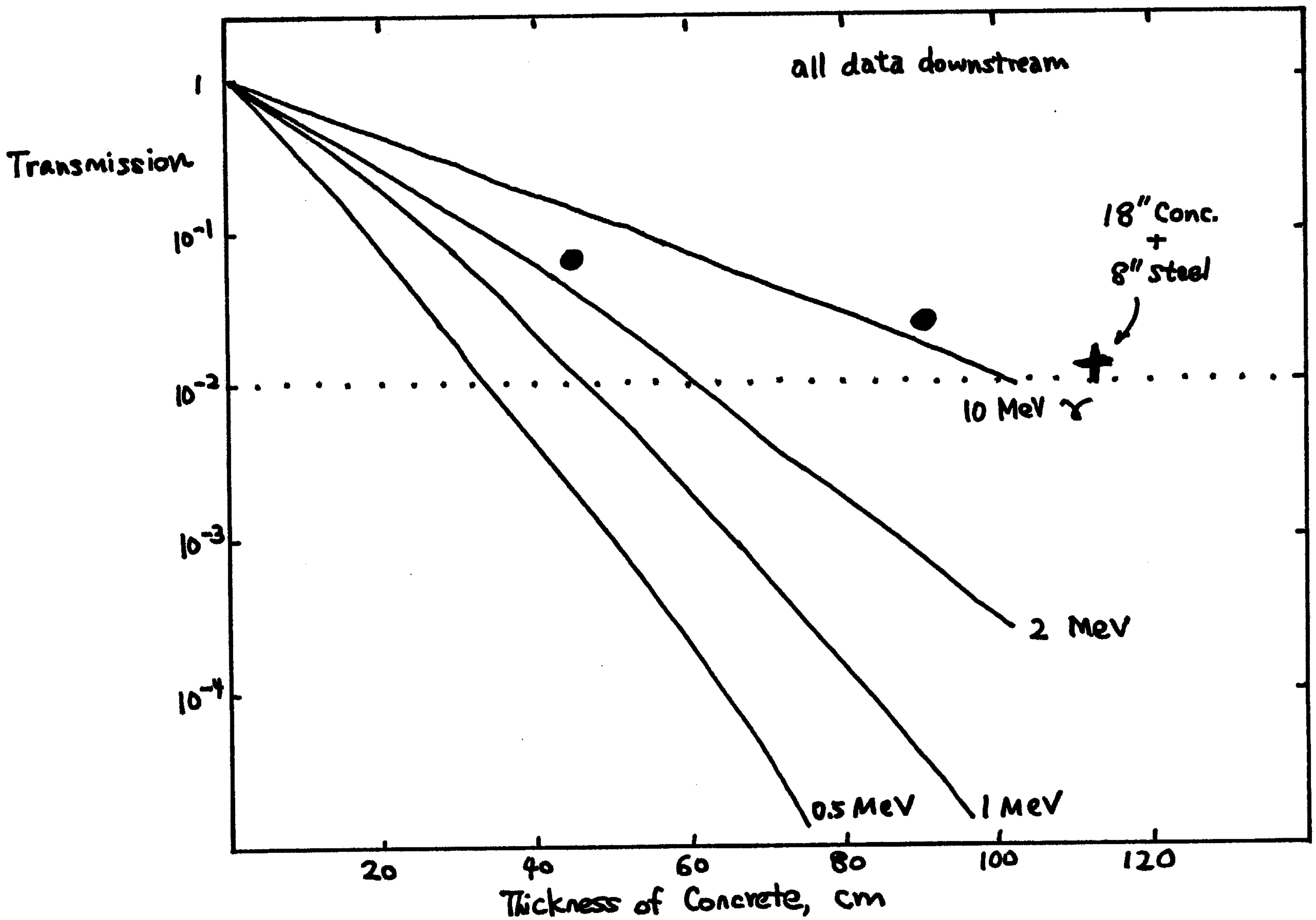

FIG. 3. Comparison of data with gamma-ray transmission: concrete

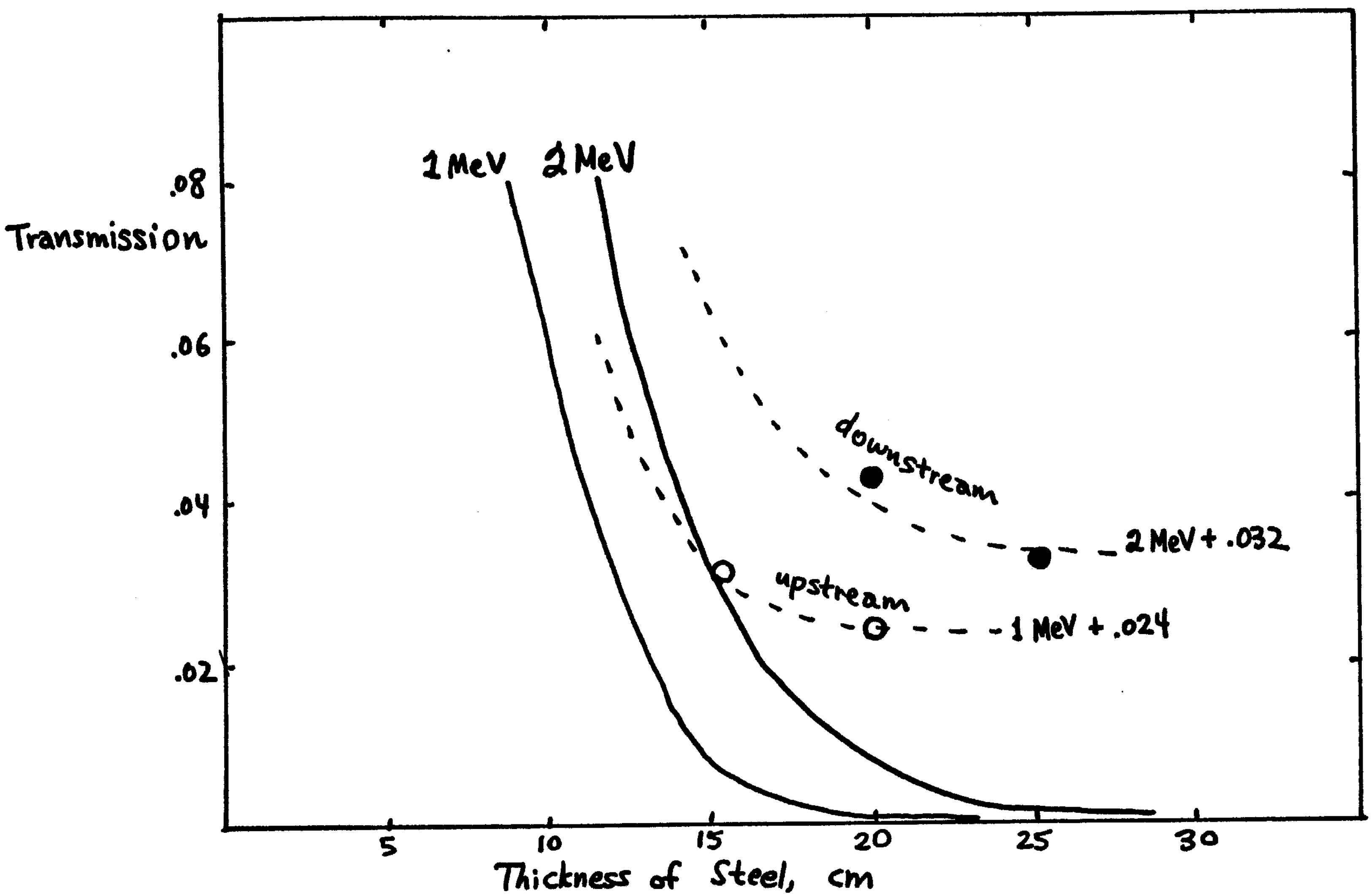

FIGURE 4. Discrepancy between data and gamma-ray transmission.

because neutrons of lower energy have attenuation lengths substantially shorter than those with energies above 150 MeV. It is only this penetrating high-energy component that determines the shield thickness, as can be seen in Figs. 10.7.–13 and –14.

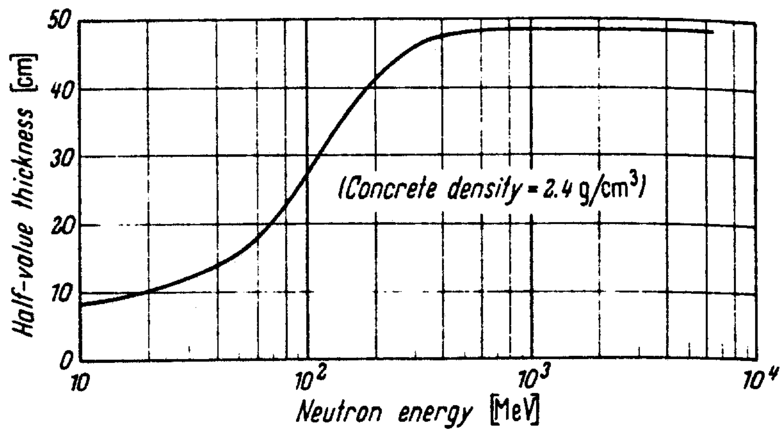

Fig. 10.7.–13. Half-value thickness for high-energy neutrons in ordinary concrete.

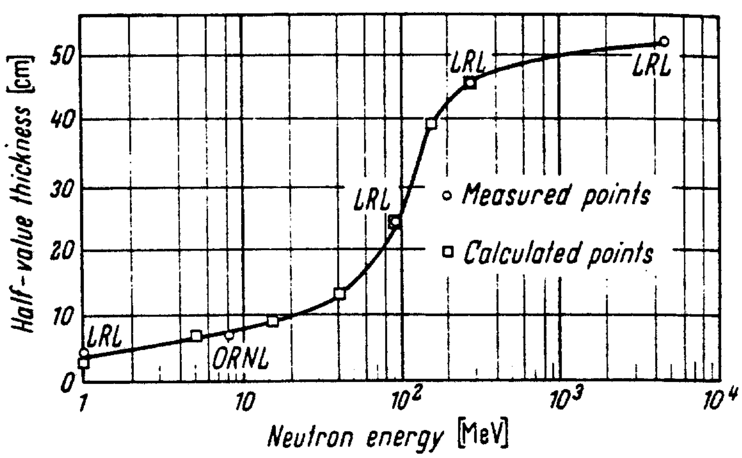

Fig. 10.7.–14. Attenuation of neutrons in ordinary concrete. At 90 and 270 MeV, measurements were made at the 184-inch 340-MeV cyclotron. At 4.5 GeV the measurement was made at the Bevatron.

Engineering Compendium on Radiation Shielding, Vol III
R.G. Jaeger, ed. ,1968 p. 158.

FIGURE 5. Attenuation of neutrons in ordinary concrete.

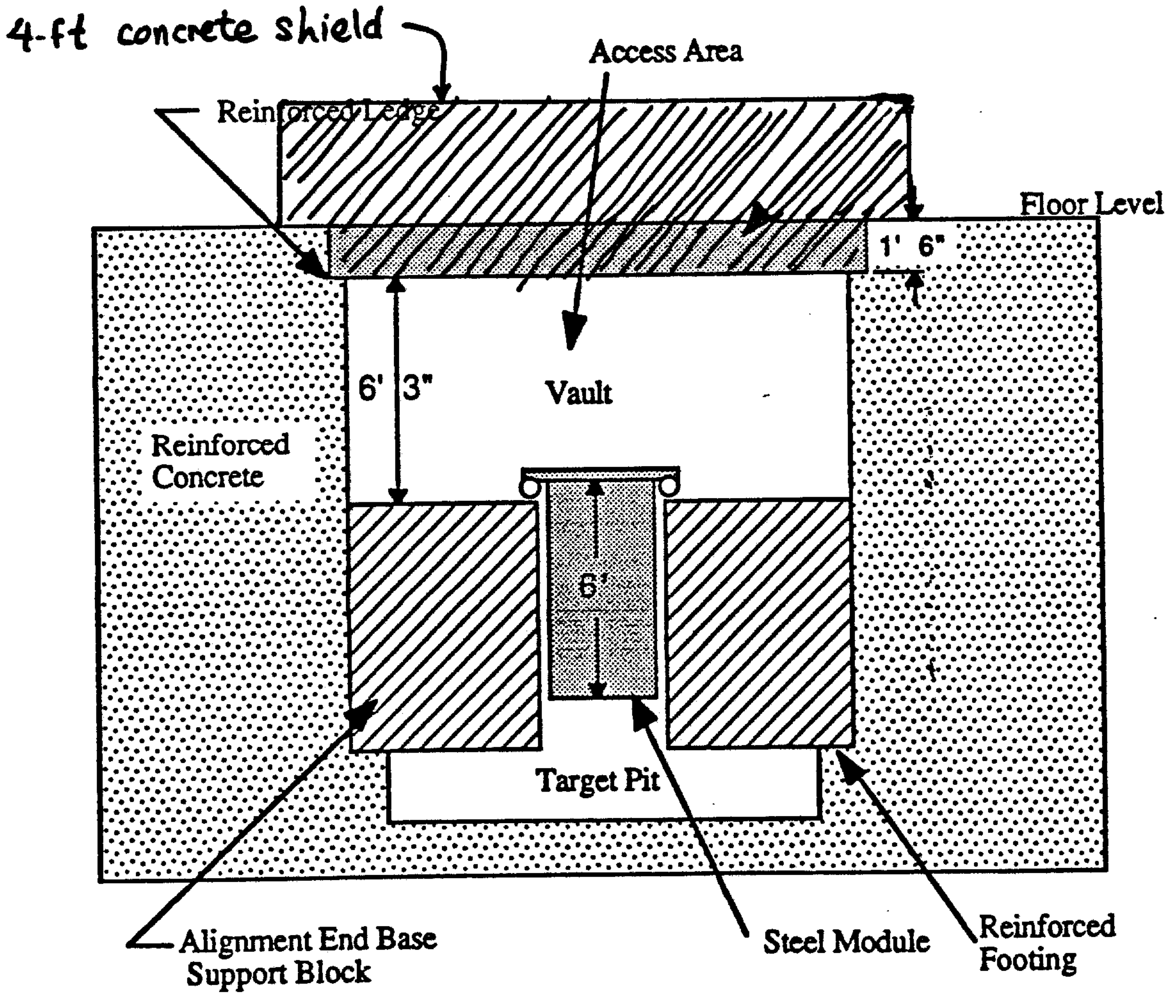

FIGURE 6. Elevation schematic of vault showing proposed 4-ft. concrete shield.