M-296

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ELEMENTARY CALCULATION OF THE TRANSVERSE SHIELDING

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In 1957, the transverse shielding requirement for the proposed Stanford two-mile linear electron accelerator was taken to be 35 ft of earth.[1] DeStaebler[2] has recently completed a comprehensive review of progress on this problem and confirms that the 35-ft figure is probably adequate. The reader is referred to DeStaebler's report for a detailed discussion of the possible health hazard to radiation workers and to the public at large. It should be noted that the photoneutrons produced subsequent to collisions of electrons with the copper accelerator pipe and other equipment produce the dominant radiation hazard along the length of the accelerator. At the high-energy end of the machine the μ-mesons become a serious problem; however, this problem is not under consideration here.

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[1] "Proposal for a Two-Mile Linear Electron Accelerator," Stanford University, Stanford, California, April 1957.

[2] H. C. DeStaebler, Jr. "A Review of Transverse Shielding Requirements for the Stanford Two-Mile Accelerator," M Report No. 262, Project M, Stanford University, Stanford, California, April 1961.

Photoneutron yield spectra have been calculated previously[3,4] and are based on the following model. An electron strikes a very thick target and produces a soft shower. The high-energy photons in the shower occasionally interact with nuclei to produce photoneutrons. The yield is then calculated according to the deuteron model for the photo-effect, where the photon spectrum is given by the familiar "track length" formula. The resulting spectra give, for one incident electron, the number of photoneutrons per steradian per Mev of photoneutron energy as a function of the laboratory angle θ.

The neutron flux on the face of the shield is calculated here according to a very simple model.[5] The flux is considered reduced by the factor $1/r^2$, where r is the distance from the target to the observer. In addition, the flux is also reduced by a factor $\exp(-r'/\lambda)$, where r' is the distance of travel through the shield and λ is the absorption mean free path. The quantity λ is taken to be a function of the neutron energy e_n, and we shall use the plot of "half-value thicknesses" given in the Stanford Proposal.[6] These values are modified for earth shielding on multiplication by the ratio of the density of ordinary concrete (2.3 gr/cm^3) to the density of earth (assumed = 1.8 gr/cm^3).

Two different paths through the shield are considered. In the first case the neutrons are assumed to scatter on striking the inner face of the shield and then to proceed normal to the face (see Fig. 1). The attenuation is evaluated along this dog-leg path. In the second case the neutrons are considered to move in a straight line path from the target

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[3] K. Dedrick, "Deuteron Model Calculation of Photonucleon Yields," M Report No. 227, Project M, Stanford University, Stanford, California, October 1960.

[4] Reference 3 is contained as an Appendix in Ref. 2.

[5] Compare with Sec. III of Ref. 2.

[6] *Op. cit.* See also DeStaebler, *op. cit.*, Fig. 2.

to the point of observation, the attenuation being evaluated along the path through the shield.

For the first case we readily find

$$Y_1(x_1, E_o, e_n) = y_o(\theta, E_o, e_n) \frac{\sin^3\theta}{a(a + R)} \exp [- (0.693)R/b] \qquad (1)$$

and for the second case

$$Y_2(x_2, E_o, e_n) = y_o(\theta, E_o, e_n) \frac{\sin^2\theta}{(a + R)^2} \exp [- (0.693)R/(b \sin \theta)] \qquad (2)$$

where

y_o = neutron energy-angle spectrum at the target. This is the quantity calculated in M Report No. 227,[7] and is the number of neutrons per steradian that are produced at the laboratory angle θ, and having energies between e_n and $e_n + de_n$. This quantity is evaluated for one incident electron.

E_o = primary electron energy.

a = distance from beam to inner face of shield. a is taken to be six feet in the numerical work.

R = thickness of the shield.

b = "half-value thickness" of the shielding material (see above text).

$x_1 = a \cot \theta$

$x_2 = (a + R) \cot \theta$

The quantities Y_1 and Y_2 are thus expressed in the units (neutrons)/(electron-Mev-cm^2).

The energy spectrum of the neutrons emerging from the shield in this crude model is dependent only on the initial spectrum y_o and on the quantity b. The initial spectrum y_o falls off rapidly with neutron energy e_n, while the "half-value thickness" b at first increases with

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[7] Dedrick, <u>op. cit</u>.

e_n, and then is substantially constant at about 20 in. (in ordinary concrete) for values of e_n exceeding about 1 Bev.[8] These two facts conspire to peak the spectra Y_1 and Y_2 at values of e_n of about 300 Mev.

In the numerical work plotted in Figs. 2-5, we have assumed that the incident beam energy E_o is 45 Bev, and the incident beam current is 60 μa. The yields Y_1 and Y_2, <u>integrated over neutron energies</u> e_n, are plotted in these figures vs x_1 or x_2, respectively. These integrated yields are in the units (neutrons)/(cm^2 - sec). Finally, we note that the yields given here are proportional to the beam energy E_o for values of E_o greater than about 1 Bev.

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[8] In the numerical work we have used the following curve to fit the variation of b with e_n

$$b(\text{inches of ordinary concrete}) = \begin{cases} (31.6)\sqrt{e_n}; \; 0.01 \text{ Bev} < e_n < 0.085 \text{ Bev} \\ 21 - 1/e_n; \; e_n > 0.085 \text{ Bev} \end{cases}$$

In the above formula, e_n is measured in Bev. The value of b for earth shielding is taken to be 1.29 times the above value.

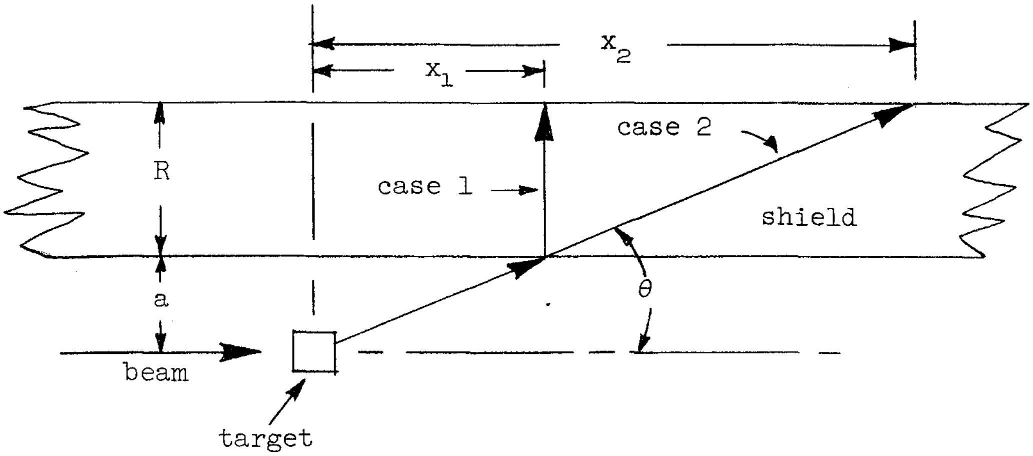

FIG. 1--Target and shield geometry.

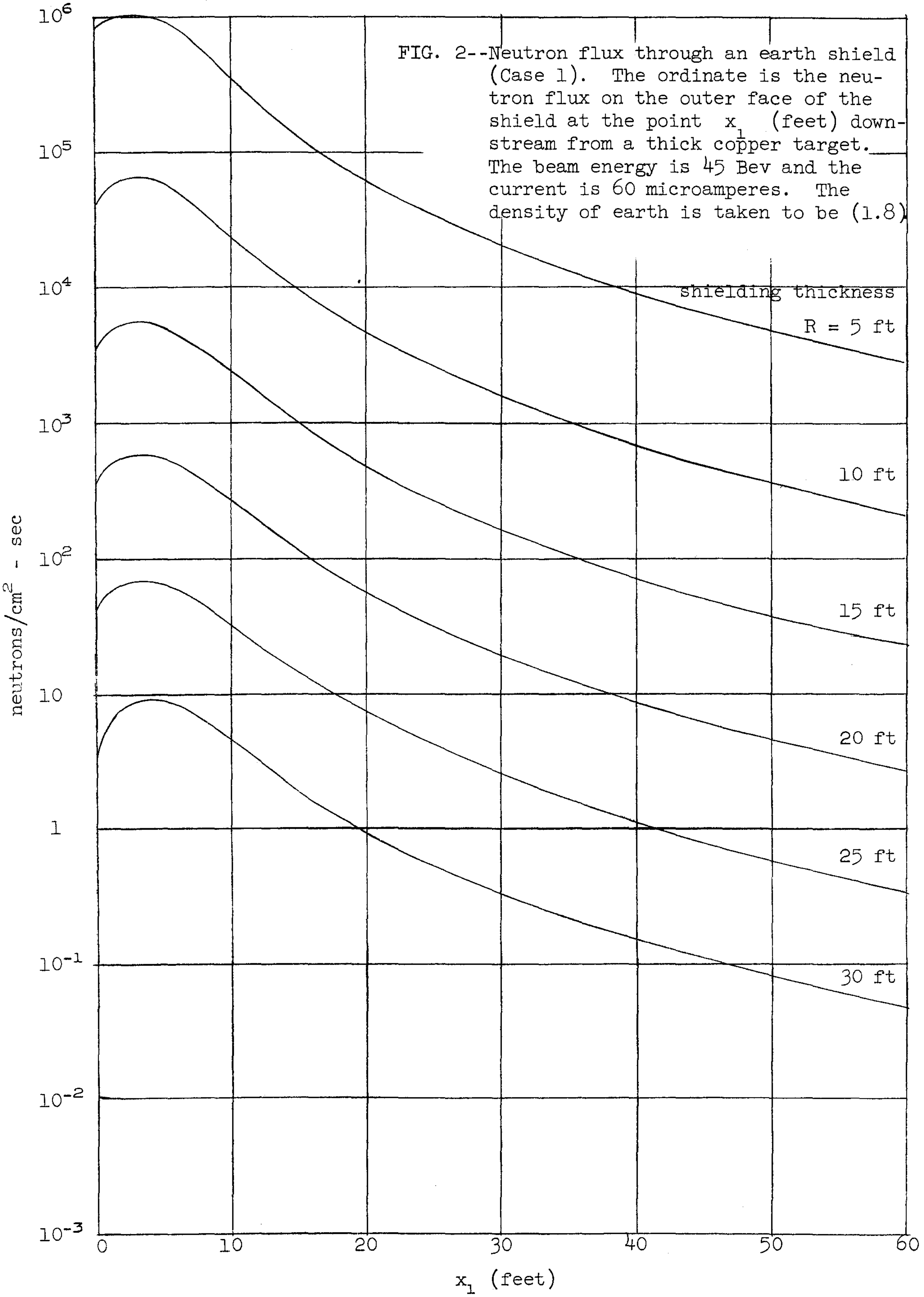

FIG. 2--Neutron flux through an earth shield (Case 1). The ordinate is the neutron flux on the outer face of the shield at the point x_1 (feet) downstream from a thick copper target. The beam energy is 45 Bev and the current is 60 microamperes. The density of earth is taken to be (1.8)

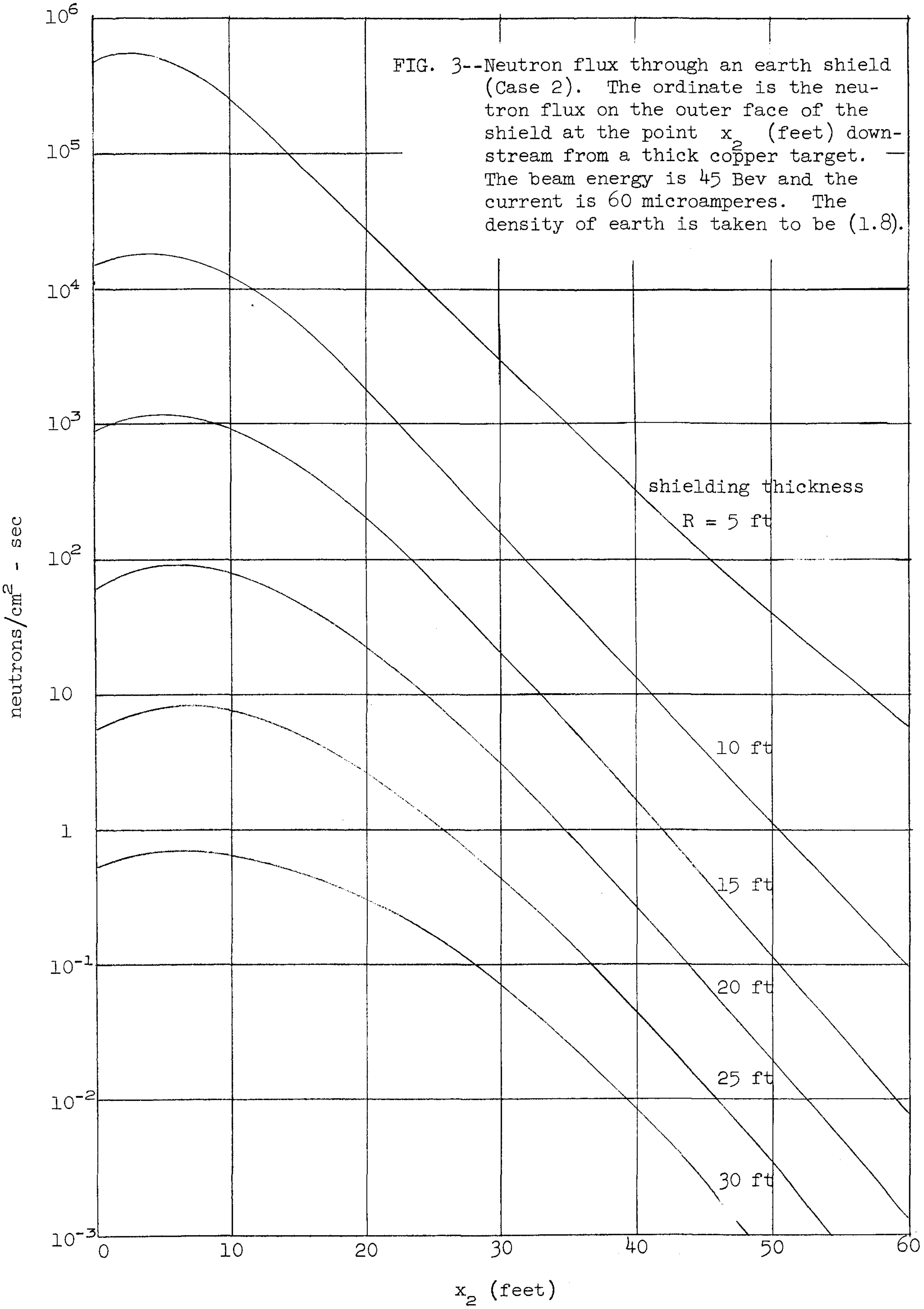

FIG. 3--Neutron flux through an earth shield (Case 2). The ordinate is the neutron flux on the outer face of the shield at the point x_2 (feet) downstream from a thick copper target. The beam energy is 45 Bev and the current is 60 microamperes. The density of earth is taken to be (1.8).

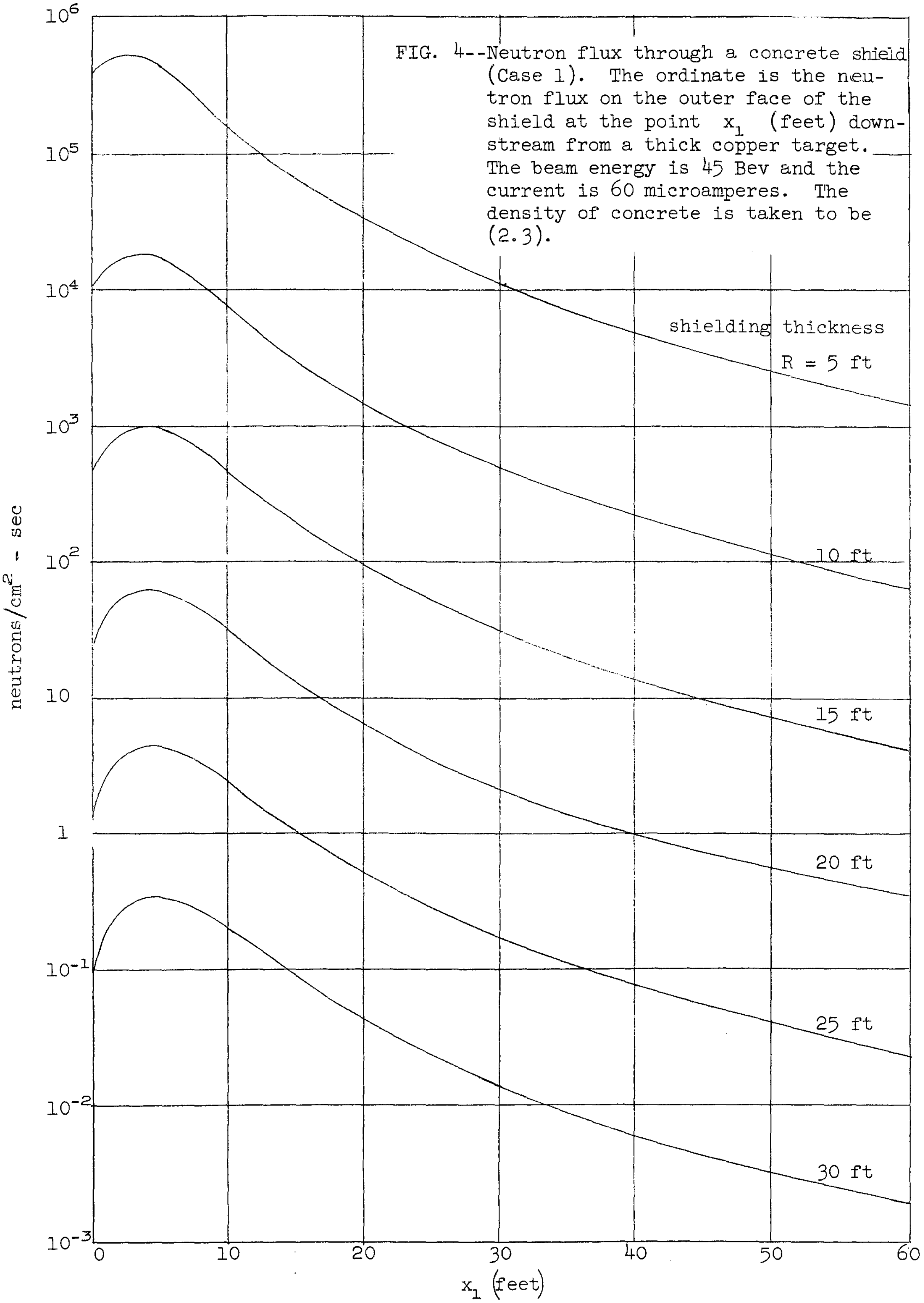

FIG. 4--Neutron flux through a concrete shield (Case 1). The ordinate is the neutron flux on the outer face of the shield at the point x_1 (feet) downstream from a thick copper target. The beam energy is 45 Bev and the current is 60 microamperes. The density of concrete is taken to be (2.3).

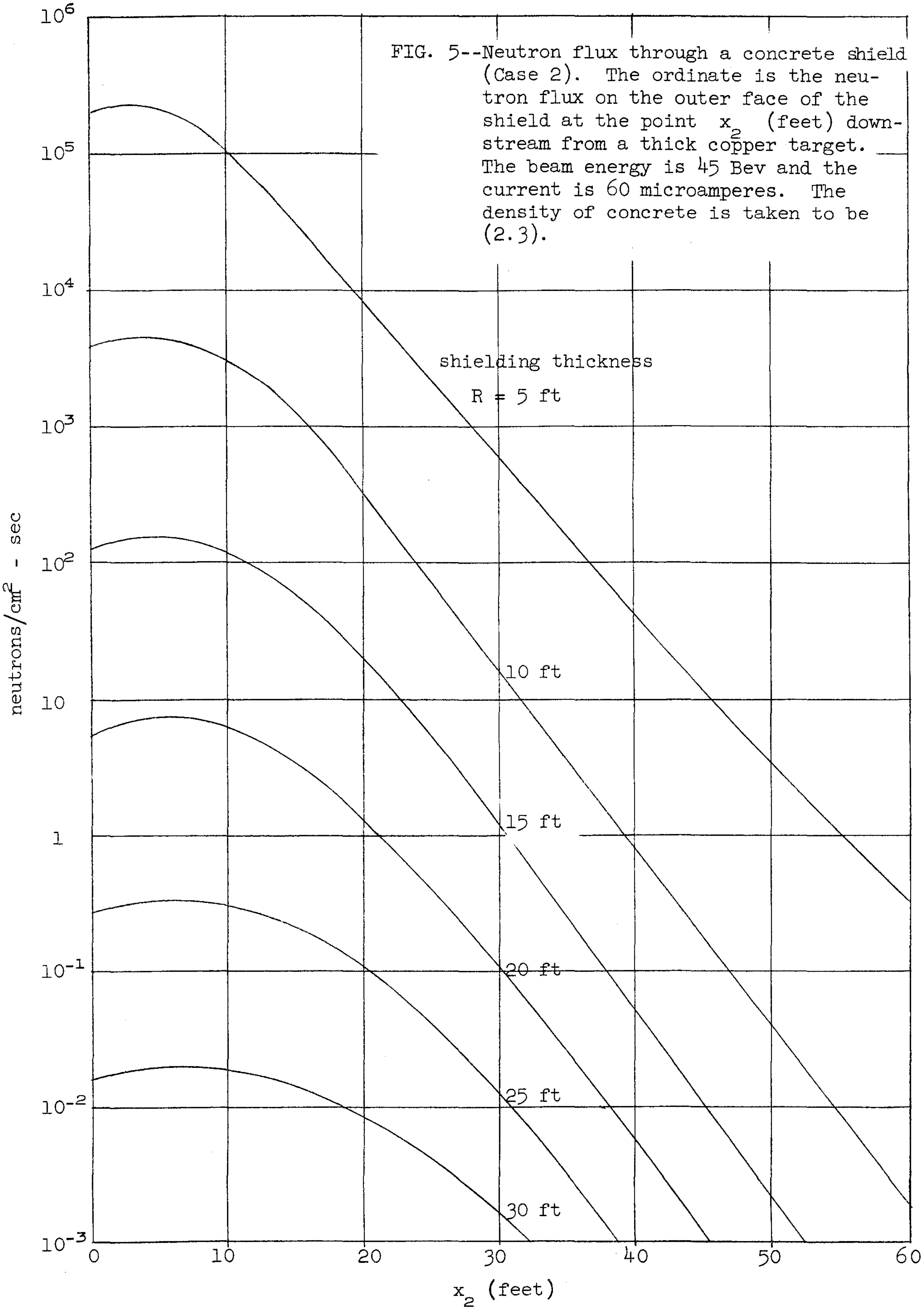

FIG. 5--Neutron flux through a concrete shield (Case 2). The ordinate is the neutron flux on the outer face of the shield at the point x_2 (feet) downstream from a thick copper target. The beam energy is 45 Bev and the current is 60 microamperes. The density of concrete is taken to be (2.3).