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Authors
Patterson, H. Wade
Hess, Wilmot N.
Mayer, Burton J.
et al.

Publication Date
1959-01-13

UNIVERSITY OF
CALIFORNIA
Ernest O. Lawrence
Radiation
Laboratory

BERKELEY, CALIFORNIA

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UCRL-8208
Revised

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

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Printed for the U. S. Atomic Energy Commission

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Abstract

A series of measurements of neutron flux as a function of altitude has been made with the following neutron detectors: bismuth fission ionization chamber, proton-recoil proportional counter, and moderated and bare BF_3 proportional counters. In addition, data were also taken with a Simpson pile. Altitudes ranged from sea level to 40,000 feet and latitudes from 28° to 49°N. Appropriate treatment of the data can be made to yield information about the neutron spectrum and the average neutron energy, and consequently about the dose rate.

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I. Introduction

When one is charged with the responsibility for the assessment of radiation fields present near an intense but shielded source of fast and high-energy neutrons, it is desirable to have a variety of neutron detectors whose sensitivity and efficiency are well known. Much of the effort of the Health Physics Department at the University of California Lawrence Radiation Laboratory is directed toward the development of such detectors.[1,2,3] The construction of a large Bi fission ionization chamber made possible the direct measurement of very small high-energy neutron fluxes,[4] and led to initiation of the experiment to be described.

Although the experimental results have consequences in shielding theory and cosmic-ray physics, these aspects are not discussed here. Instead, our concern is with the results of primary interest to a health physicist--the determination of the neutron dose rate.

II. Experiment

When primary cosmic rays enter the earth's atmosphere and interact with it, a variety of particles--including neutrons--are produced. (It is unlikely that many neutrons are present in the primary cosmic rays because of their 12-minute half life and also because of the lack of suitable accelerating mechanism.) The attenuation of high-energy cosmic-ray produced neutrons in the atmosphere is analogous to the attenuation of accelerator- or pile-produced neutrons in concrete. That this analogy holds is because after the transition region is passed the attenuation of neutrons of all energies is controlled by the attenuation of the most penetrating primary particles and secondary neutrons. In addition, for neutrons whose energy is more than a few Mev, concrete and air exhibit nearly the same attenuation property, on the basis of equal area density (grams per cm^2), because they both consist of materials of low atomic number. Thus, after equilibrium is attained, one should expect a continuous neutron spectrum, the shape of which does not vary with thickness, and the total intensity of which decreases with an attenuation rate characteristic of the most penetrating neutrons. Moreover, the spectrum should be approximately a simple reciprocal power of neutron energy, near E^{-1}, as would be inferred from slowing-down concepts.

It is possible to determine such a continuous neutron spectrum in air or concrete with fair precision by measuring the absolute flux at definite energy intervals within the spectrum. Accordingly we calibrated a BF_3 counter, a polyethylene-lined proton-recoil counter, and a Bi fission ionization chamber in known neutron fluxes. The data are given in Table I.

Table I

Calibration of detectors for determining a neutron spectrum in air or concrete

Detector	Energy interval of effective response (Mev)	Response in units of
BF_3 counter (bare)	10^{-9} and up	counts per neutron/cm^2 (varies as 1/V)
BF_3 counter + 5 cm paraffin covered by 0.020-inch Cd jacket	0.03 to 14	counts per neutron/cm^2
CH_2-lined proportional counter	0.03 to 30	counts per Mev/cm^2
Bi fission ionization chamber	100 to 1000	counts per neutron/cm^2

These counters and a Simpson pile[5] (for intercomparison with other experiments) were taken to the 10,000 foot station at the University of California High-Altitude Research Facility in the White Mountain Range in southeastern California in the summer of 1956. Subsequently they were flown in a B-36 airplane operating from Kirtland Air Force Base, Albuquerque, New Mexico at altitudes ranging from 5,000 to 40,000 feet. Figure 1 shows a curve of counting rate versus atmospheric depth that is typical of all our detectors. The slope of about 165 g/cm^2 for a 1/e reduction in intensity is also typical of the attenuation in concrete of the 270-Mev neutron produced by the 184-inch synchrocyclotron and of neutrons in the Bev energy range produced by the Bevatron. Good agreement was obtained between the counting rate at 10,000 feet on the ground and in the airplane, tending to show that the effect of ground albedo was small. In this experiment discrimination against counts caused by charged particles in the polyethylene-lined counter and the Bi fission chamber was provided by the output of a blanket of Geiger tubes used in anticoincidence.

Figure 2 shows the neutron spectrum obtained at 10,000 feet. That the shape of this spectrum is independent of altitude is evidenced by the fact that all the neutron detectors, regardless of energy sensitivity, gave the same slope for curves similar to Fig. 1. This neutron energy spectrum $\phi(E)$, is obtained from the counting rates of the various detectors in the following way. The counting rate C_x of detector x is given by

$$C_x = \int \mathcal{E}_x(E)\,\phi(E)\,dE$$

where ${}_x(E)$ is the efficiency of detector x in counts/neut/cm^2. The absolute efficiencies of all of the detectors have been measured over a wide range of energies by using several calibrated neutron sources. The neutrons energy spectrum is determined by a trial and error solution to the above integral. The intensity of $\phi(E)$ is changed in different energy regions until the calculated counting rates of all detectors agree with the experiment. Below 10 Kev the shape of the spectrum can be calculated by neutron slowing down and capture theory. The peak in the spectrum at about 1 Mev is due to the production of evaporation neutrons.

III. Dose Calculations

The dose rate due to neutrons at 10,000 feet is given by

$$\text{dose rate} = \int_{10^{-9}\ \text{Mev}}^{10^{3}\ \text{Mev}} n(E)\ 1/A(E)\ dE.$$

where $n(E)$ is the neutron flux at energy E and $A(E)$ is the flux at energy E per dose-rate unit. This integral may be approximated by

$$\text{dose rate} \cong \sum \overline{N_i(E)}\ \left[\overline{1/A_i(E)}\right]\ \Delta E.$$

Values for $[1/A_i(E)]$ can be developed from data found in NBS Handbook 63.

Figure 3 shows the percentage of the total neutron dose rate at 10,000 feet versus ΔE for the spectrum given in Figure 2. The sum, in units of rem per year, is also given. The rem dose rate at any "pressure altitude" past the transition region can be calculated by referring to Fig. 1, which indicates that the neutron spectrum is constant and thereby demonstrates the altitude dependence of dose rate. Table II gives neutron dose rates at the pressure altitudes of interest.

Table II

Neutron dose rate (rem/year)	Pressure altitude (g/cm^2)	Altitude above sea level (feet)
.025	1034	0
.073	860	5,000
.195	700	10,000
.775	470	20,000
4.47	190	40,000

Tobias gives dose rates that are about one-half these values.[6] However, his estimate is based on the counting rate of a balloon-supported BF^3 counter, and he had no direct measurement of fast-neutron flux.

Also Figure 3 shows that 75% or more of the neutron dose rate in an equilibrium spectrum in air or concrete may be determined by using a polyethylene-lined proportional counter and bare and moderated BF_3 counters.

IV. Conclusions

Conclusions of interest to health physicists are as follows:

1. Although the shapes of the neutron spectra in air and in concrete may be significantly different at energies below 10^{-2} Mev, this does not strongly affect the neutron dose rate. In any event, the determination of the thermal-neutron dose rate is not difficult.

2. By far the largest contribution to total neutron dose comes from neutrons in the energy interval 0.10 to 30 Mev. Furthermore, this portion of the neutron dose can be determined easily. Refer to Table I and notice that the energy regions of response of the polyethylene-lined counter and of the BF_3 counter with 5 cm of paraffin covered by 20-mil Cd are essentially the same. Also notice that the polyethylene-lined counter responds in units of counts per Mev/cm^2, while the moderated BF_3 counter responds in units of counts per $neutron/cm^2$. Therefore if measurements coincident in time and location are made with these two detectors, one may immediately determine the neutron flux and the mean energy per neutron,

$$Mev/cm^2/count \div (neutrons/cm^2/count) = Mev/neutron,$$

in the energy interval of greatest importance for health physics purposes.

. . . .

This work was done under the auspices of the U. S. Atomic Energy Commission.

References

1. Burton J. Moyer, Survey Methods for Neutron Fields, UCRL-1635, Jan.1952.

2. J. B. McCaslin, High-Energy Neutron Dosimeter, in Proceedings of the Health Physics Society, June 1958 Meeting.

3. Lloyd D. Stephens, Fast Neutron Surveys Using Indium Foil Activation, loc. cit.

4. W. N. Hess, H. W. Patterson, and R. W. Wallace, Delay-Line Chamber Has Large Area, Low Capacitance, Nucleonics 15, No. 3 (March 1957).

5. J. A. Simpson, W. Fonger, and S. B. Treiman, Cosmic-Radiation Intensity Time Variation, Phys. Rev. 90, 934 (1953).

6. Cornelius A. Tobias, Radiation Hazards in High-Altitude Aviation, J. Aviation Med. 23, 345 (1952)

LEGENDS

Fig. 1. Curve of relative neutron counting rate versus depth in the atmosphere, showing the slope which is typical of all our detectors.

Fig. 2. Neutron energy spectrum from cosmic rays at 10,000 ft.

Fig. 3. Histogram giving the percent of total neutron dose versus ΔE at 10,000 ft.

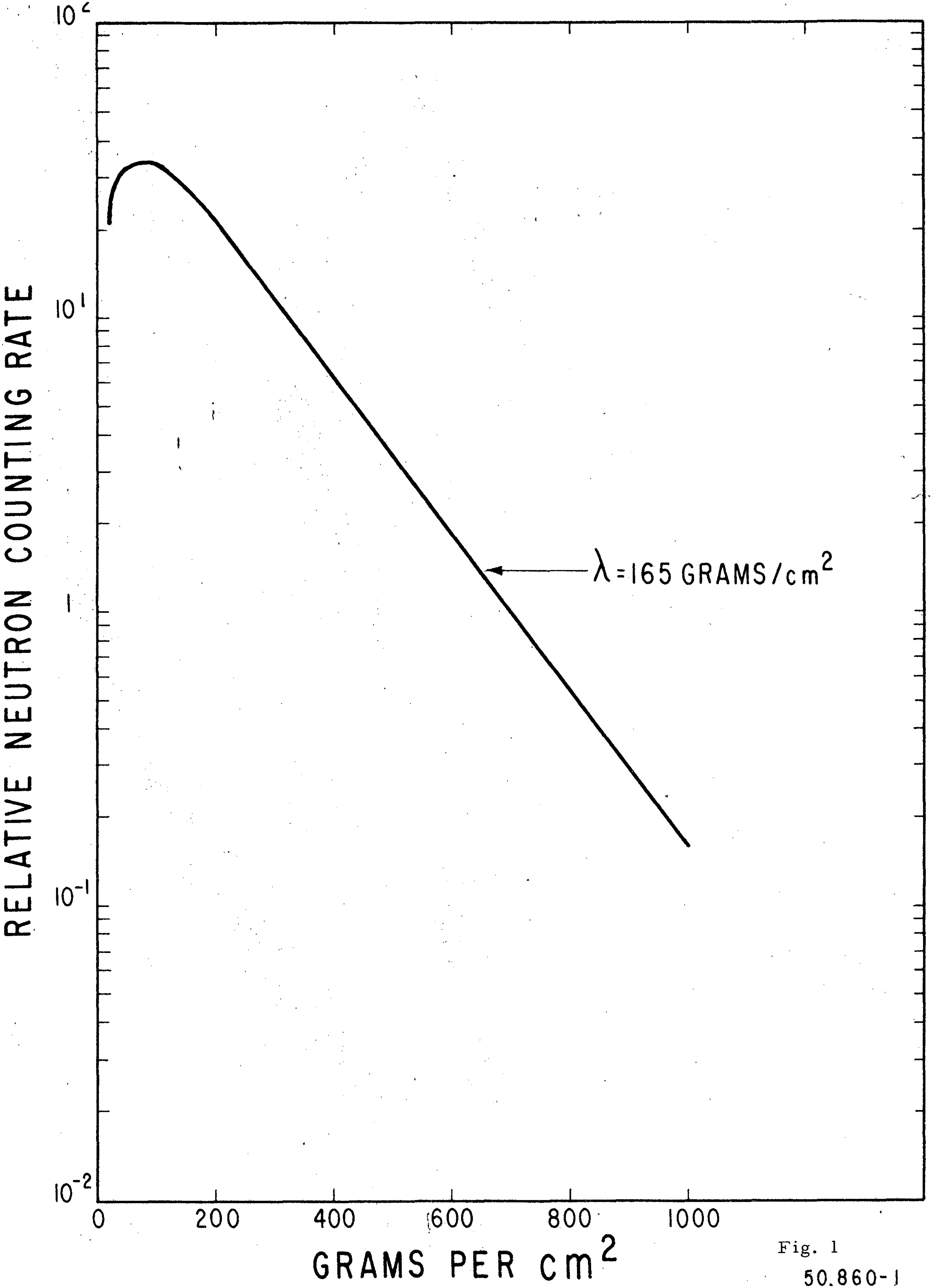
RELATIVE NEUTRON COUNTING RATE
10^2
10^1
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
GRAMS PER cm²
λ = 165 GRAMS/cm²

Fig. 1

50,860-1

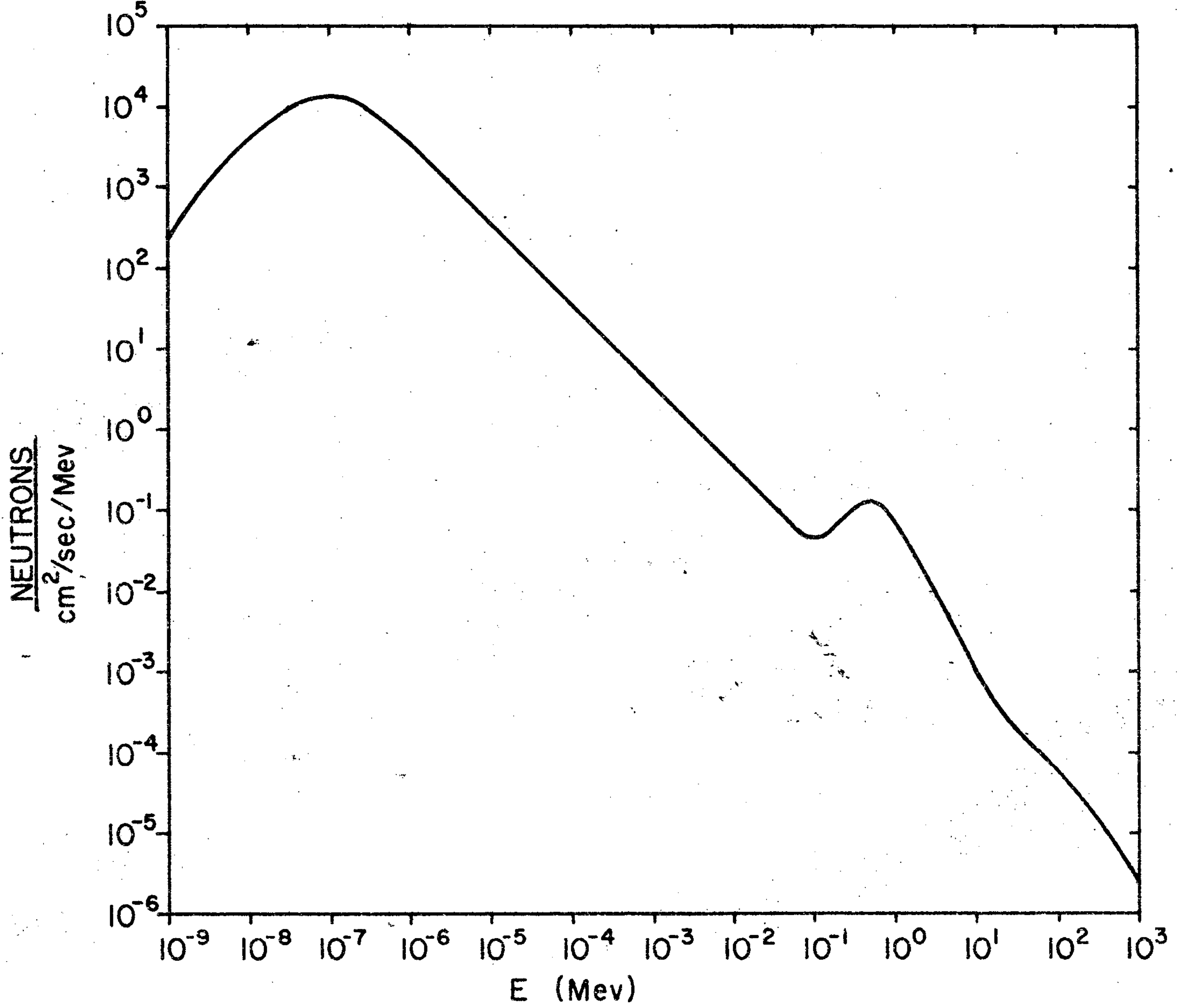
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
NEUTRONS / cm^2/sec/Mev
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
E (Mev)

Fig. 2

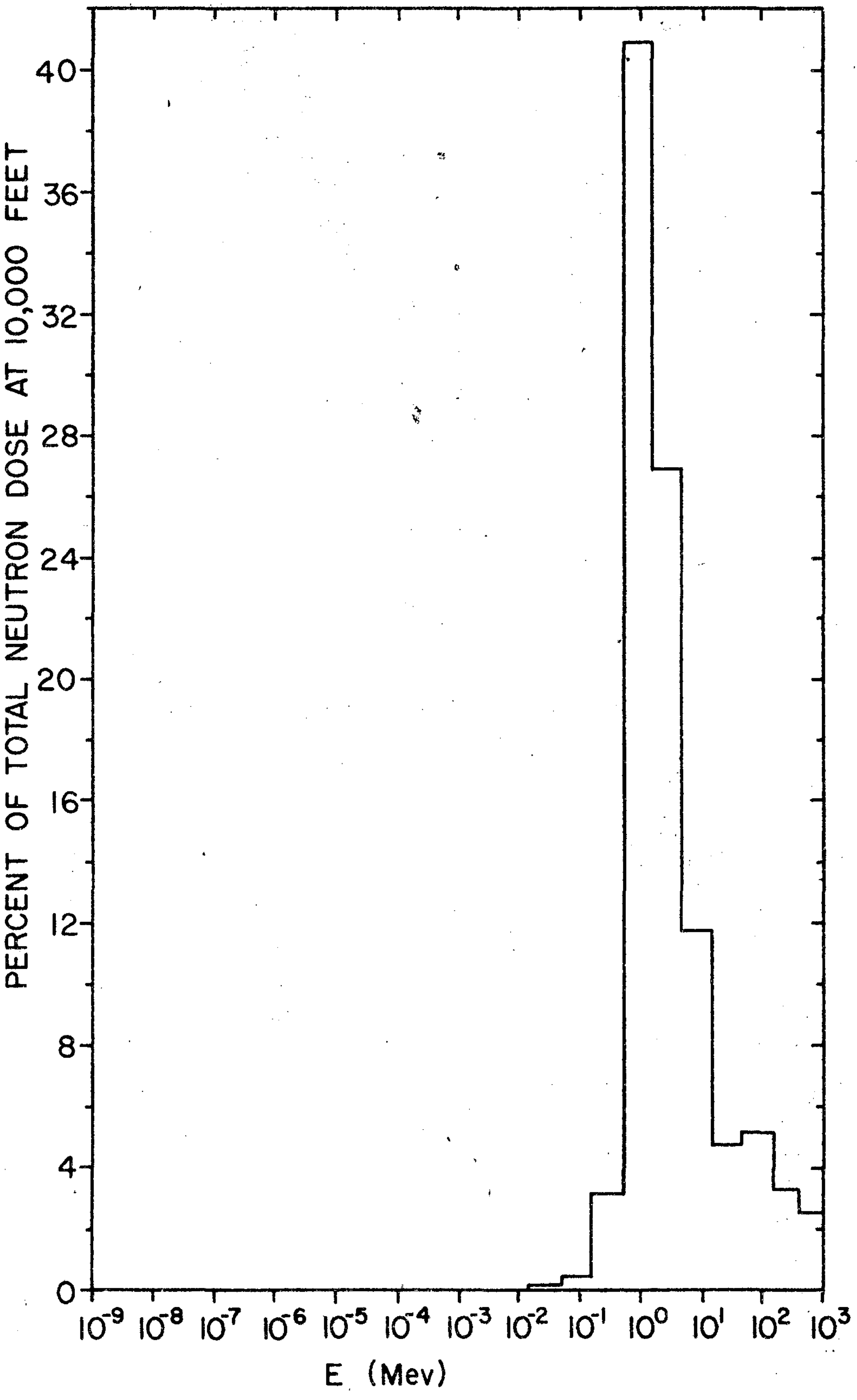
PERCENT OF TOTAL NEUTRON DOSE AT 10,000 FEET
40
36
32
28
24
20
16
12
8
4
0
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
E (Mev)

Fig. 3