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December 9, 1964

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ABSTRACT

Local neutron spectra inside human phantoms exposed 25 to 200 m from a bare pulsed reactor have been measured by use of nuclear track emulsion. Under the conditions of open terrain, flat for at least 800 m in all directions, and of a bare reactor located 2 m above the ground, it was found that (a) the exposing neutron energy spectrum above 500 keV does not change with depth in a human phantom, and (b) to a distance of at least 200 m along the air-ground interface, the exposing neutron energy spectrum above 500 keV closely resembles the emission spectrum of the neutron source.

*Work done under the auspices of the U. S. Atomic Energy Commission.

I. INTRODUCTION

Roberts [1] first reported the use of nuclear track emulsion in measuring the spectra of anisotropic fast neutron sources. The power of this method has been considerably increased by two recent advances: the development of automatic coordinate-readout microscopes, and the development of a scanning technique for rapidly selecting unbiased track samples [2, 3].

By virtue of their small size, nuclear emulsions are able to measure the neutron-generated proton track energy spectra and dose in the material which immediately surrounds them during exposure. Such local proton dose spectra, obtained from pieces of nuclear emulsion exposed at various positions inside and around human phantoms 10 to 200 m from a bare pulsed reactor [a], were recently reported [4]. At that time preliminary measurements of the local fast neutron spectra in the immediate vicinity of the emulsions were described. Since then the methods have been developed more fully and applied to the measurement of various fast neutron spectra (2,3,5). Recently six of the emulsions exposed to fission neutrons from the pulsed reactor were rescanned in order to carefully determine the local fast neutron spectra at various positions inside the phantoms.

(a) The Sandia Pulsed Reactor Facility (SPRF), Albuquerque, New Mexico.

Knowledge of the local neutron spectrum is important in the evaluation of the internal radiation doses received by persons exposed to fission neutrons.

II. MATERIALS AND METHODS

One by 3/4 in. pieces of 600 μ Ilford L.4 emulsions were wrapped with black paper, sealed in individual 20 mm polyvinyl packets, and suspended by use of fine wire at the center plane of a right elliptical cylinder 20 by 36 cm by 60 cm high, made of 0.65 cm polyethylene and filled with water. During the burst-exposure the phantoms stood atop their wooden packing crates 92 cm above the ground, at distances of 25, 100, and 200 m from the reactor.

The SPRF reactor is a bare metal oralloy assembly constructed in 1960. During a 2-day period in October, 1961, the reactor was pulsed six times at its outdoor burst site. A rubber-tired trailer frame held the reactor head 2 m above the ground. The surrounding terrain was flat for a radius of at least 800 m, and the nearest structure was the control room building, 730 m from the burst site.

The developing, fixing, mounting, and computing procedures have been reported earlier [(7)], and full details of the present experiment are given in the paper reporting the local proton doses and spectra [(4)].

In order to test for a track-sampling bias, which could strongly influence the measurements, each emulsion was scanned twice: once by the random-walk method (in which that track is measured next one of whose ends is nearest the end of the track just previously selected and measured), and once by the total-volume method (in which every track within a prechosen volume of emulsion is scanned). When the track distributions obtained by these two methods were compared, no significant differences were found. The reported distributions are composed of the sum of the tracks scanned by each method.

Emulsions at six completely different exposure locations were so scanned. Films D-36, D-32 and D-33, and D-40 had been exposed to a single pulse (1.48×10^{16} fissions) at respectively the front outside, center inside, and back outside of a water-filled phantom 25 m from the reactor. Films D-11, D-25, and D-16 had been exposed to six pulses (9.35×10^{16} fissions) at respectively the center inside and back outside of a phantom at 100 m, and the front inside of a phantom at 200 m.

RESULTS

The experimental track-length distributions from emulsions at six exposure locations, and the local fast-neutron energy spectra derived from them, are presented in Figs. 1-6. In general, the spectra follow closely the pure U^{235} fission spectrum except that they have a higher percentage of low-energy neutrons. Such a modified emission spectrum has been predicted for reactors of the type used in this experiment[8].

There is no simple analytical method for evaluating the local uncertainty in the neutron energy spectra. In this work, the derived spectra were expected to be smooth and continuous, however, and to reflect local trends in the proton-recoil distributions rather than random variations between adjacent points. On this basis the uncertainty in the neutron spectra is estimated to equal roughly the width of the heavy lines in the figures.

DISCUSSION

Considering the differences in the exposure location of the emulsions, the spectra are remarkably similar. There was no appreciable hardening of the exposing spectrum with depth in the phantoms or with distance to 200 m. The only hint of a change in the exposing spectrum was found in the emulsion (D-25) at the back of the phantom at 100 m. This spectrum had more 0.5 to 2-MeV neutrons and fewer 3- to 6-MeV neutrons than the others, which indicates a softening in the spectrum of the neutrons scattered from the air and ground into the back surface of the phantom.

It should be emphasized that these measurements apply to the special conditions of open terrain, flat for at least 800 m in all directions, and to a bare reactor situated 2 m above the ground. The presence of structures or hills, or elevation of the reactor, may appreciably change the measured local spectra. Because the measurements do not extend reliably to protons with energy below 500 keV, they provide no information about the distribution of neutrons below this energy.

However, the following conclusions may be stated:

(a) the exposing fission-neutron spectrum above 500 keV does not change with depth in a human phantom, and

(b) to a distance of at least 200 m along a flat air-ground interface, the exposing fission-neutron spectrum above 500 keV closely resembles the emission spectrum of the neutron source.

A simple argument based on the macroscopic cross section for scattering of fast neutrons in air suffices to show that these conclusions do not necessarily imply that the fission neutrons have achieved an "equilibrium" energy distribution. Earlier measurements of neutron fluxes by use of threshold detectors situated 300 to 1500 yards from a nuclear test explosion failed to reveal a hardening of the energy spectrum, which was interpreted to mean that an equilibrium was obtained at these ranges[9].

By use of the $E^{-0.3}$ scattering probability in air for fast neutrons of energy E between 0.5 and 10 MeV, and the value of 2.5 barns at 1 MeV[10], it can be estimated that a typical neutron reaching our 200 m phantom was scattered only twice (5 MeV neutron) or three times (1 MeV neutron) by the air-molecule nuclei <u>en route</u>. Because the mean fractional energy loss per scattering is about 0.1 for these nuclei, the total effect on the neutron spectrum is expected to be small. A similar argument gives the same expectation for the effect of a 5 or 10 cm water path on a fast neutron spectrum. In the case of water the scattering probability follows an $E^{-0.7}$ dependence in the region of interest. For this reason, water is considerably more efficient than an equivalent amount of air in hardening a fission neutron spectrum.

For comparison, the differential scattering of visible light by the air obeys an E^4 law; even so, an exceedingly long light path through the atmosphere (as in sunrise or sunset) is required to remove most of the blue and green from the solar spectrum.

The observation that the fast neutron spectrum does not change with depth in a human phantom, and that it closely resembles the emission spectrum of the neutron source over distances of interest in nuclear accidents should greatly facilitate the evaluation of personnel doses. Taken together with measured local proton tissue doses[4], accurate skin and organ <u>rem</u> doses from fast neutrons may now be quickly found by knowledge of the distance (10-200m) and orientation of the victim relative to the neutron source during exposure, and the fission yield.

FIGURE CAPTIONS

Fig. 1. The track-length energy distribution in film D-36 and the local neutron spectrum derived from it, based on 1887 measured tracks. A, peak from 0.6 MeV protons released by the nuclear reaction of emulsion nitrogen with thermal neutrons, $N^{14}(n,p)C^{14}$. B, corrected proton-recoil spectrum; C, derived neutron spectrum; ○, measured points of the proton track spectrum; △, points corrected for measuring bias against short tracks. The ordinate $\Delta N/p\Delta E$ gives the number ΔN of proton tracks or neutrons within the energy interval ΔE, with the geometry correction factor p. For comparison, the expected proton-recoil distribution D and the neutron spectrum E from a pure U^{235} source are given.

Fig. 2 The track-length energy distribution in film D-32 and D-33 and the local neutron spectrum derived from it, based on 950 tracks.

Fig. 3 The track-length energy distribution in film D-40 and the local neutron spectrum derived from it, based on 1716 tracks.

Fig. 4 The track-length energy distribution in film D-11 and the local neutron spectrum derived from it, based on 1938 tracks.

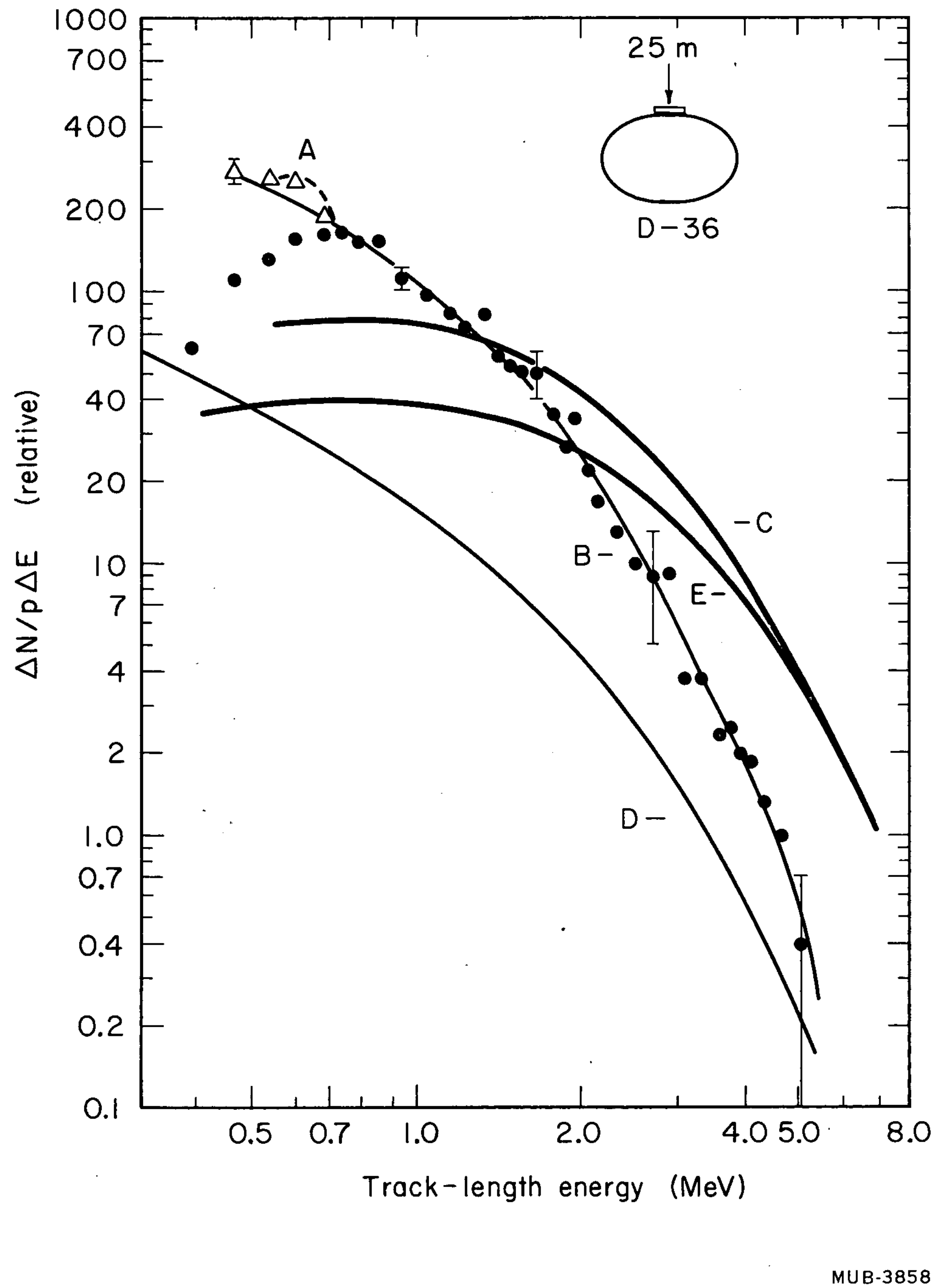
Fig. 5 The track-length energy distribution in film D-25 and the local neutron spectrum derived from it, based on 1713 tracks.

Fig. 6 The track-length energy distribution in film D-16 and the local neutron spectrum derived from it, based on 1876 tracks.

REFERENCES

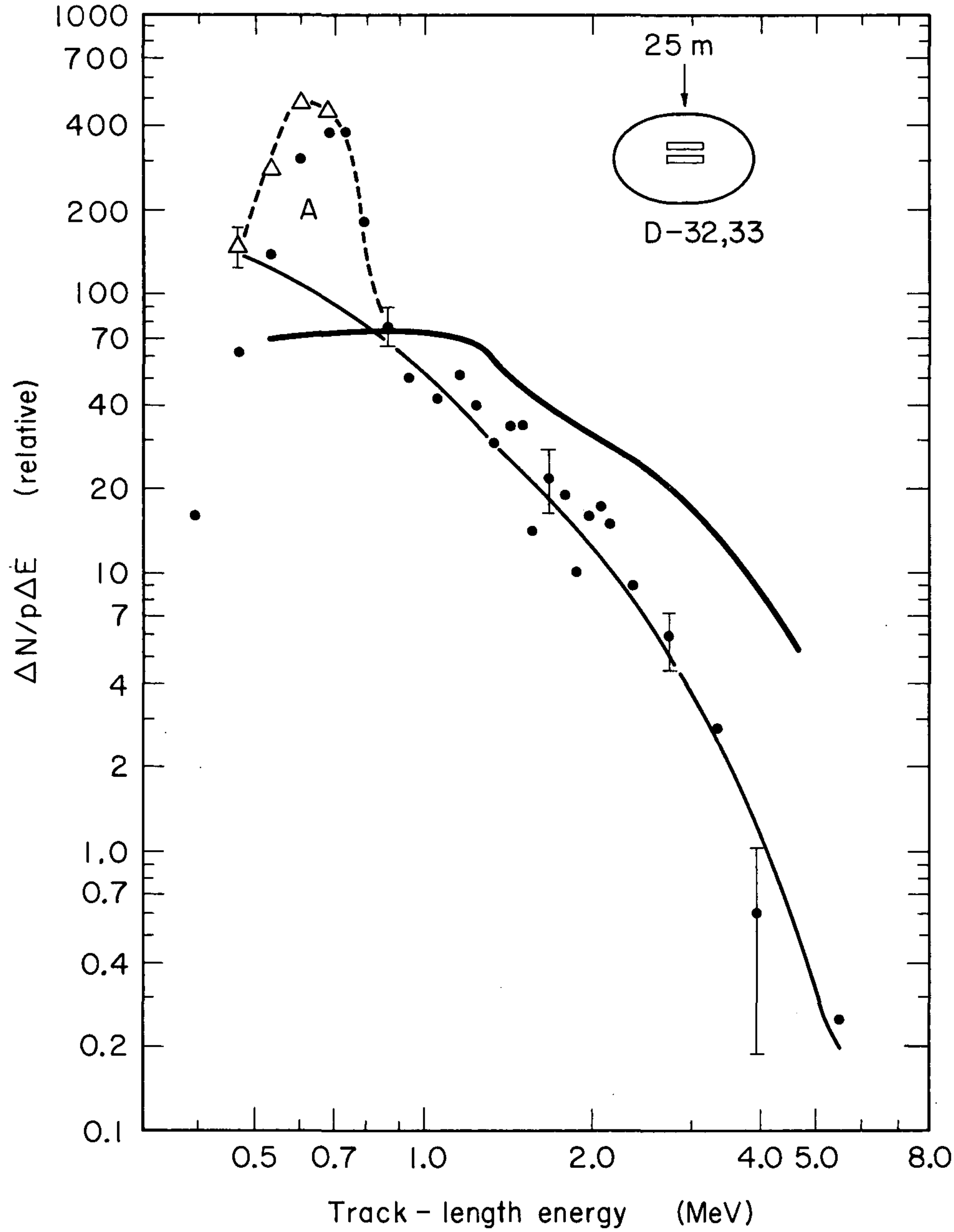
1. J.H. Roberts, Absolute Flux Measurements of Anisotropic Neutron Spectra with Proton Recoil Tracks in Nuclear Emulsions, Rev. Sci. Inst. 28, 677-680 (1957).
2. R.L. Lehman, O.M. Fekula and J.R. Wayland, Jr., Sampling Bias in Scanning of Proton-Recoil Tracks in Nuclear Emulsion (Lawrence Radiation Laboratory Report UCRL-11703, September 1964), unpublished.
3. R.L. Lehman and O.M. Fekula, Energy Spectra of Stray Neutrons from the Bevatron, Nucleonics 24 (11), 35-39 (1964).
4. R.L. Lehman, H. Akagi and O.M. Fekula, Neutron Dosimetry Near a Bare Pulsed Reactor, Health Physics 10 (8), 517-537 (1964).
5. R.L. Lehman, unpublished data on α, n neutron spectra.
6. J.L. Colp and P.D. O'Brien, The Sandia Pulsed Reactor Facility, Sandia Corporation Report SCR-229, Albuquerque, N.M. Aug., 1960 (unpublished).
7. Hiroaki Akagi and Richard L. Lehman, Neutron Dosimetry in and around Human Phantoms by use of Nuclear Track Emulsion, Health Physics 9, 207-220 (1963).
8. R.A. Peterson and G.A. Newby, An Unreflected U^{235} Critical Assembly, Nucl. Sci. Eng. 1, 112-125 (1956).
9. Samuel Glasstone, Ed., The Effects of Nuclear Weapons p 405-407, U.S. Atomic Energy Commission, Washington, D. C. (1962).

10. R. J. Howerton, Semi-Empirical Neutron Cross Sections, Part II Vol. 1, Univ. California Lawrence Radiation Laboratory Report UCRL-5351, Nov. 1958 (unpublished).



25 m
D-36
A
B
C
D
E
ΔN/p ΔE (relative)
Track-length energy (MeV)
1000
700
400
200
100
70
40
20
10
7
4
2
1.0
0.7
0.4
0.2
0.1
0.5
0.7
1.0
2.0
4.0
5.0
8.0
MUB-3858

Fig. 1



MUB-3859

Fig. 2

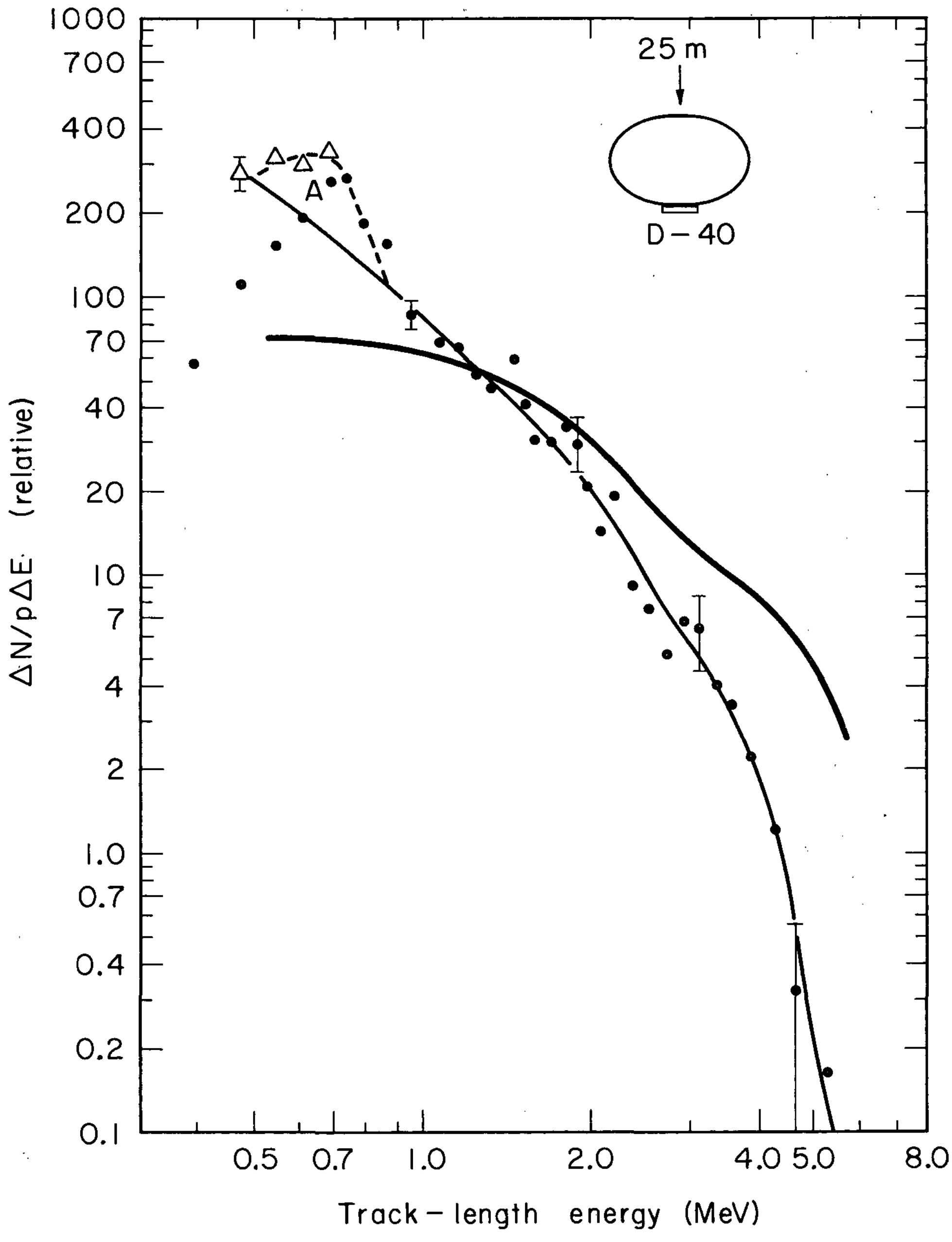


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Fig. 3

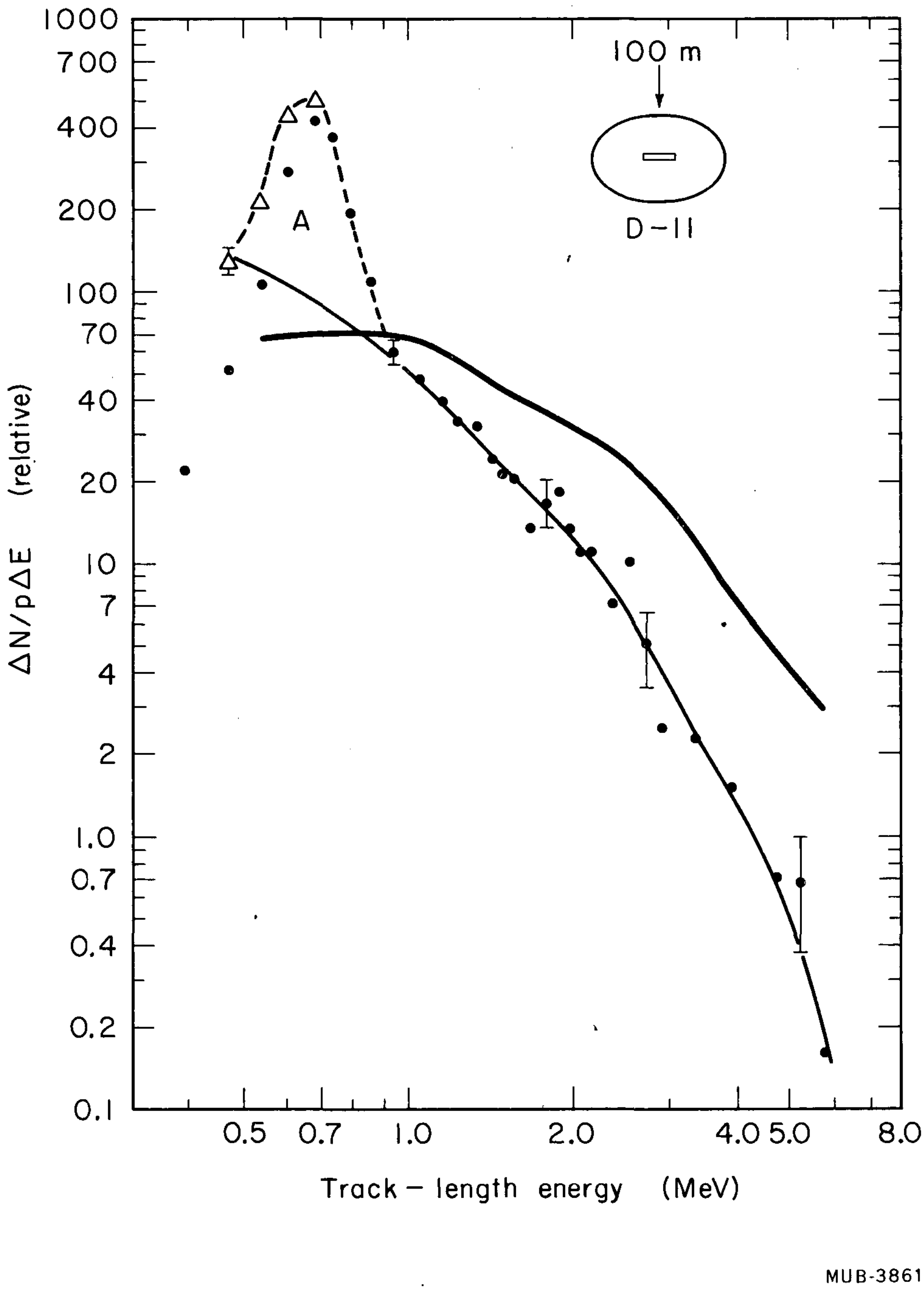

Fig. 4

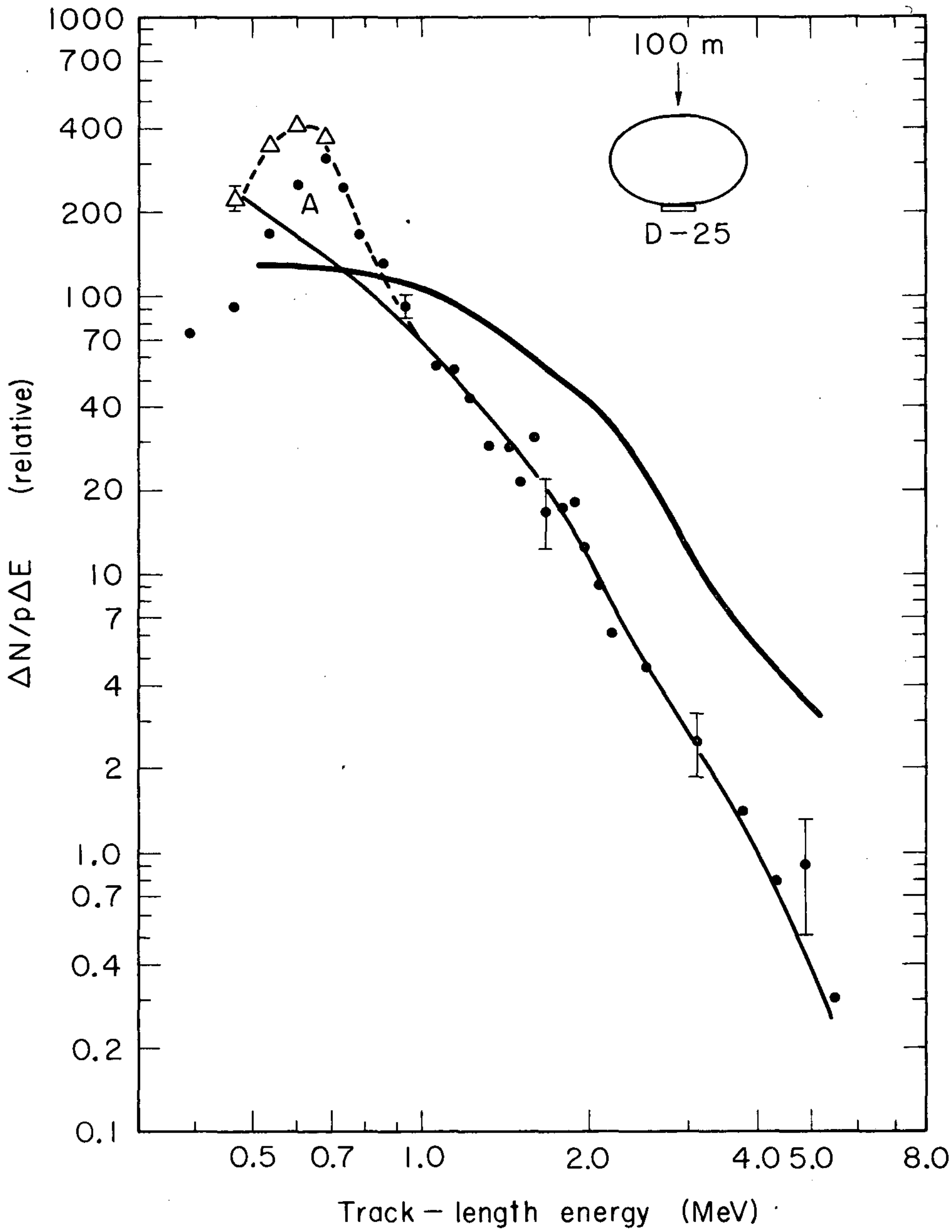

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Fig. 5

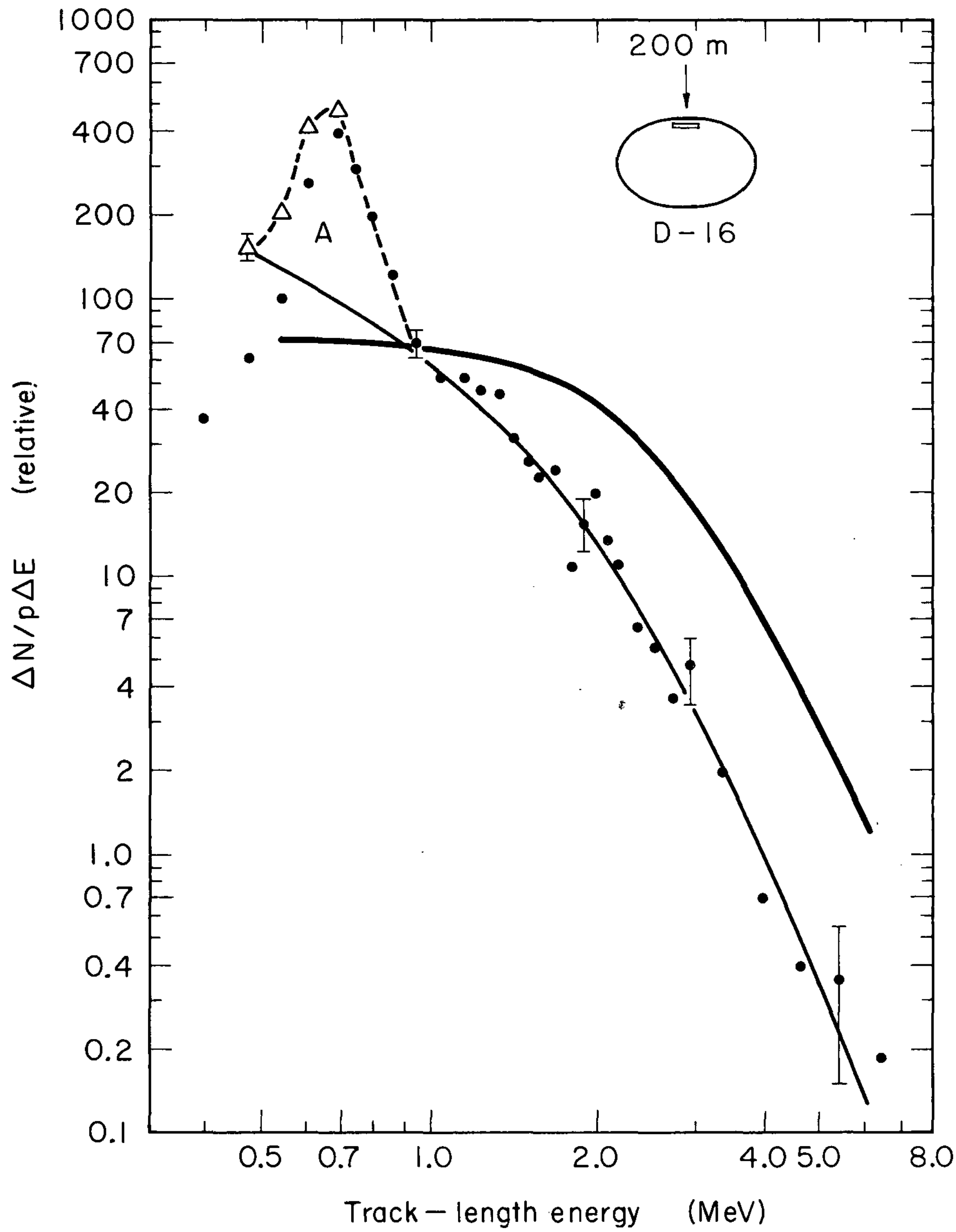

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Fig. 6