UCRL-11599

University of California

Ernest O. Lawrence Radiation Laboratory

NEUTRON SPECTRA MEASURED INSIDE HUMAN PHANTOMS

Berkeley, California

DISCLAIMER

To be published in Health Physics.

UCRL-11599

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

NEUTRON SPECTRA MEASURED INSIDE HUMAN PHANTOMS

Richard L. Lehman and Olga M. Fekula

August 3, 1964

NEUTRON SPECTRA MEASURED INSIDE HUMAN PHANTOMS*

Richard L. Lehman† and Olga M. Fekula

Lawrence Radiation Laboratory
University of California
Berkeley, California

August 3, 1964

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.

† Now at the Department of Biophysics and Nuclear Medicine, University of California, Los Angeles.

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

INTRODUCTION

The local differential proton dose from fission neutrons, as measured by use of nuclear track emulsion inside human phantoms 10 to 200 m from a bare pulsed reactor,[a] was recently reported.(1) At that time a method based on the distribution of proton-recoil tracks was described for obtaining the local fast-neutron energy spectrum. Since then this method has been developed more fully and applied to the measurement of stray neutron spectra in the vicinity of the Bevatron.(2,3) Recently some of the emulsions exposed inside phantoms to fission neutrons were rescanned in order to verify the earlier conclusion that the local neutron spectra were remarkably similar.

SCANNING AND EMULSIONS

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, 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

[a] The SPRF pulsed reactor facility at Sandia Base, Albuquerque, New Mexico.

the center inside and back outside of a phantom at 100 m, and the front inside of a phantom at 200 m. The track densities in the emulsions, and other details of the scanning and exposure, were reported earlier.[1]

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.[4]

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.

REFERENCES

1. R. L. Lehman, H. Akagi, and O. M. Fekula, Neutron Dosimetry Near a Bare Pulsed Reactor, Health Physics 10 (8), 517-537 (1964).
2. R. L. Lehman and O. M. Fekula, Semiautomatic Scanning of Proton-Recoil Tracks in Nuclear Emulsion (Lawrence Radiation Laboratory Report UCRL-11321, March 1964), submitted to Rev. Sci. Instr.
3. R. L. Lehman and O. M. Fekula, Some Energy Spectra of Stray Neutrons from the Bevatron (Lawrence Radiation Laboratory Report UCRL-11322, June 1964), Submitted to Nucleonics.
4. R. A. Peterson and G. A. Newby, An Unreflected U^{235} Critical Assembly, Nucl. Sci. Eng. 1, 112-125 (1956).

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 nuclear n, p protons; B, corrected recoil proton-recoil and neutron spectra; C, neutron spectrum; D, E, pure U^{235} proton-recoil and neutron spectra; o, measured points of the proton track spectrum; Δ, points corrected for measuring bias against short tracks. The vertical (uncertainty) bars about some of the points amount to $\pm N^{-1/2}$ Y, where N is the number of tracks of this energy and Y is the ordinate value of the point.

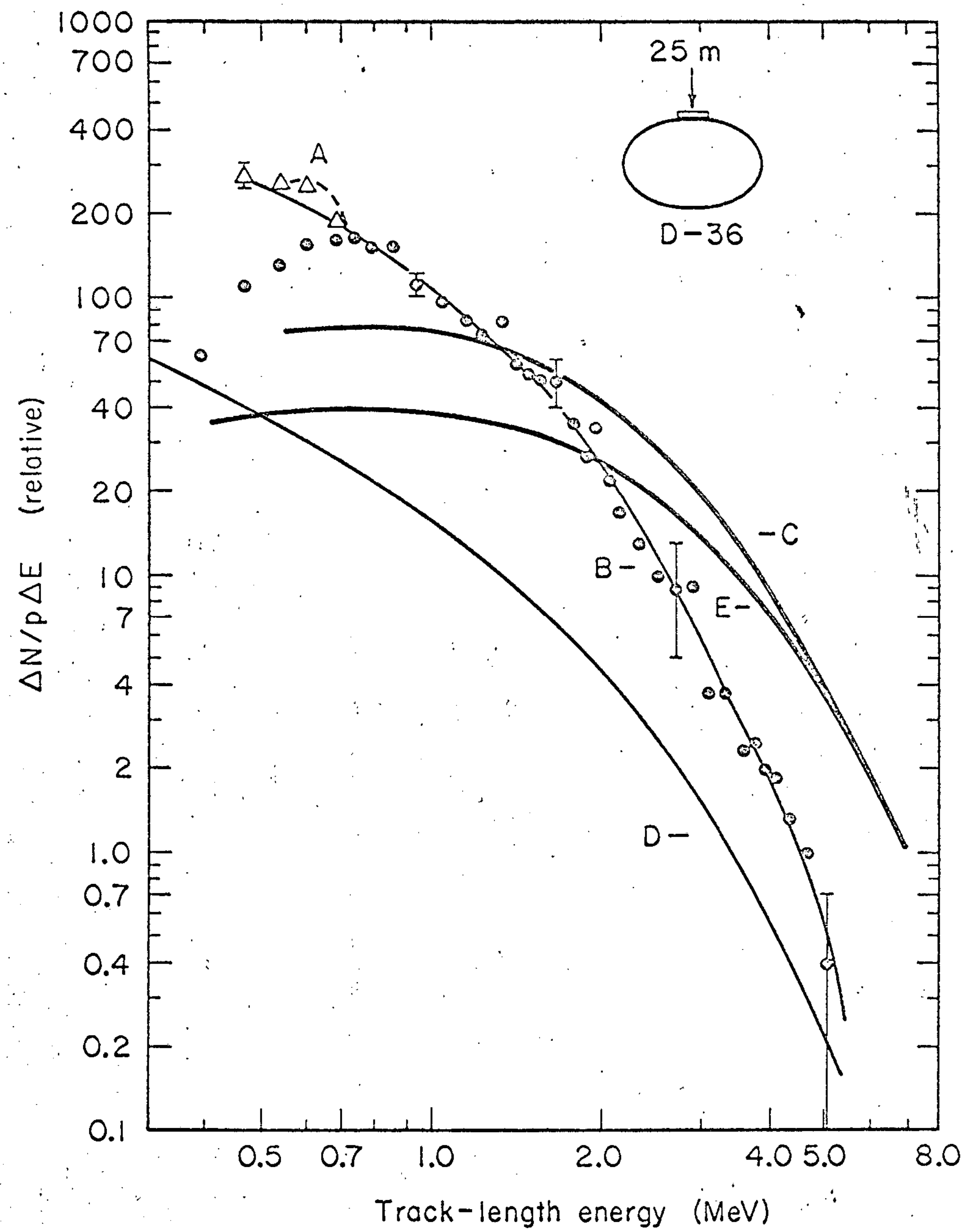
Fig. 2. The track-length energy distribution in films D-32 and D-33 and the local neutron spectrum derived from it, based on 950 tracks. (For symbols see Fig. 1)

Fig. 3. The track-length energy distribution in film D-40 and the local neutron spectrum derived from it, based on 1716 tracks. (For symbols see Fig. 1)

Fig. 4. The track-length energy distribution in film D-11 and the local neutron spectrum derived from it, based on 1938 tracks. (For symbols see Fig. 1)

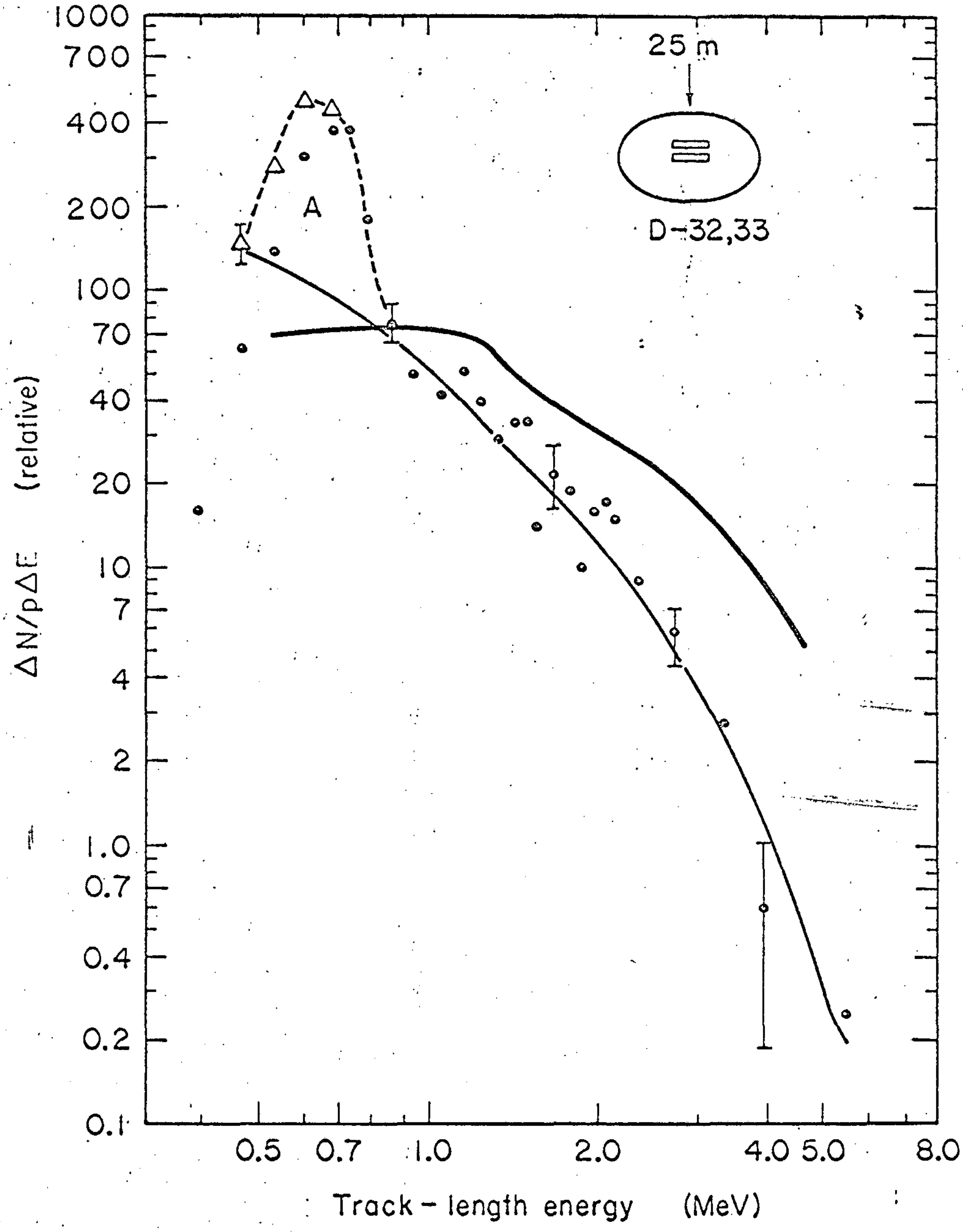
Fig. 5. The track-length energy distribution in film D-25 and the local neutron spectrum derived from it, based on 1713 tracks. (For symbols see Fig. 1)

Fig. 6. The track-length energy distribution in film D-16 and the local neutron spectrum derived from it, based on 1876 tracks. (For symbols see Fig. 1)



MUB-3858

Fig. 1



MUB-3859

Fig. 2

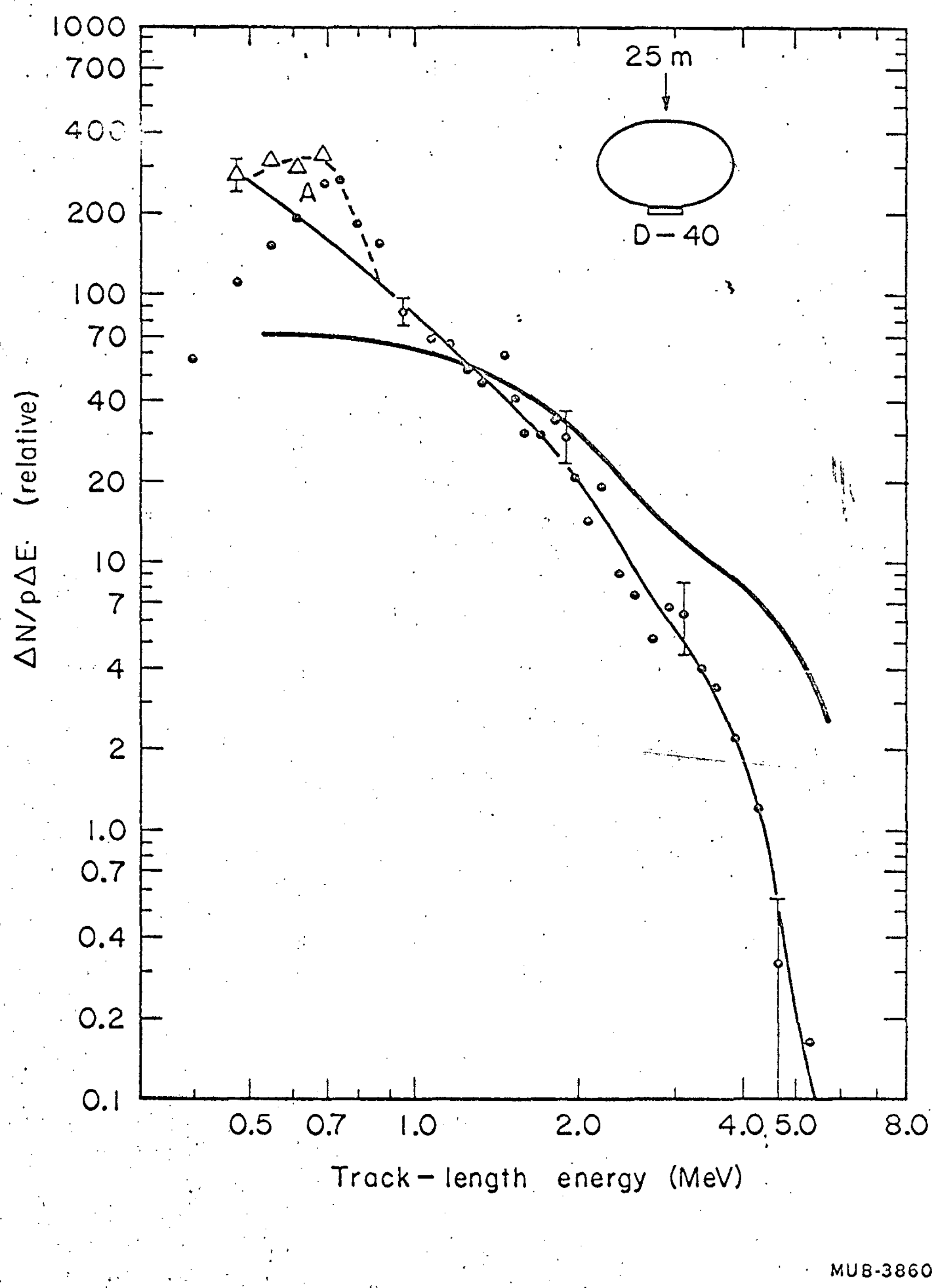
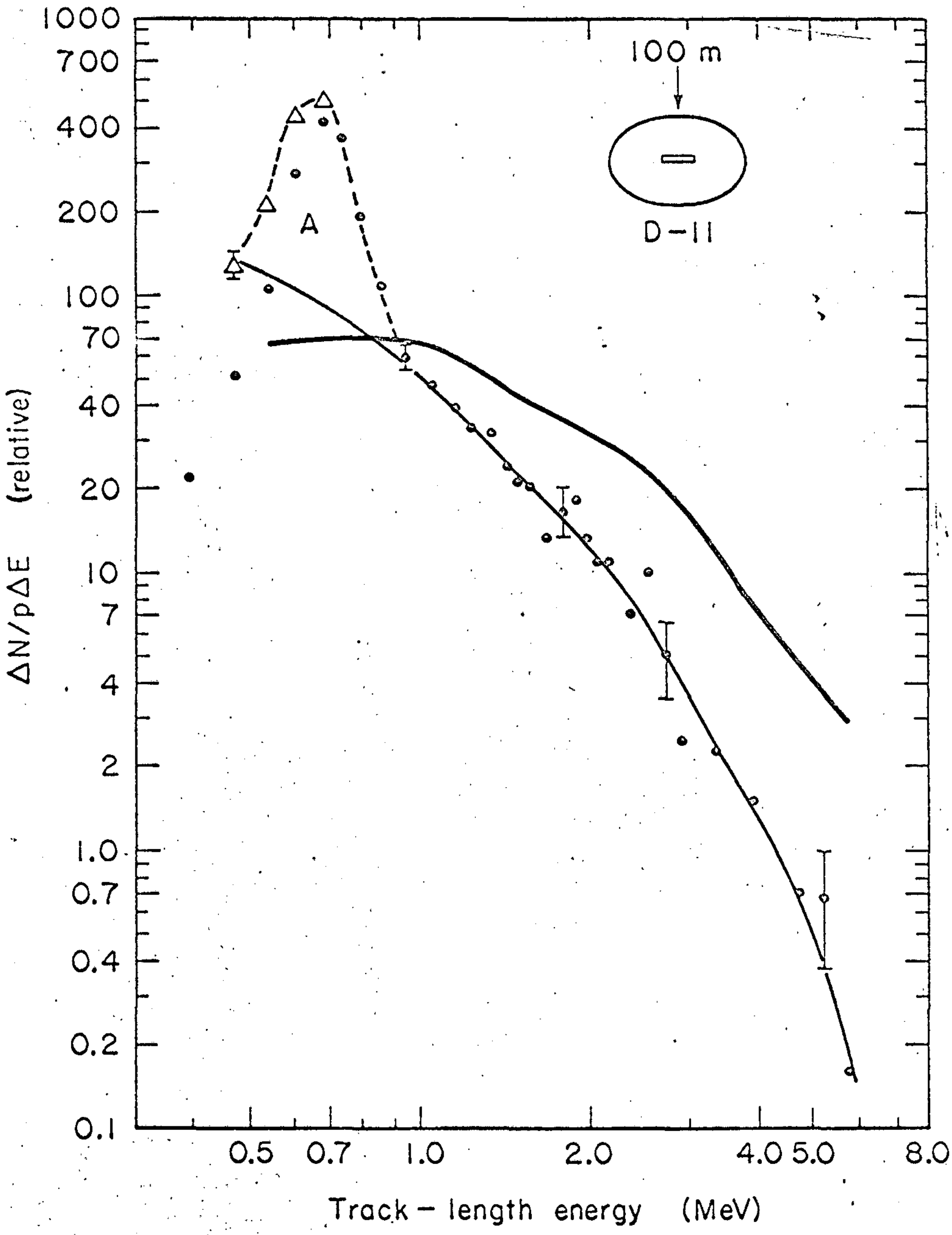

1000
700
400
200
100
70
40
20
10
7
4
2
1.0
0.7
0.4
0.2
0.1
ΔN/pΔE (relative)
25 m
D-40
A
0.5
0.7
1.0
2.0
4.0
5.0
8.0
Track-length energy (MeV)
MUB-3860

Fig. 3



MUB-3861

Fig. 4

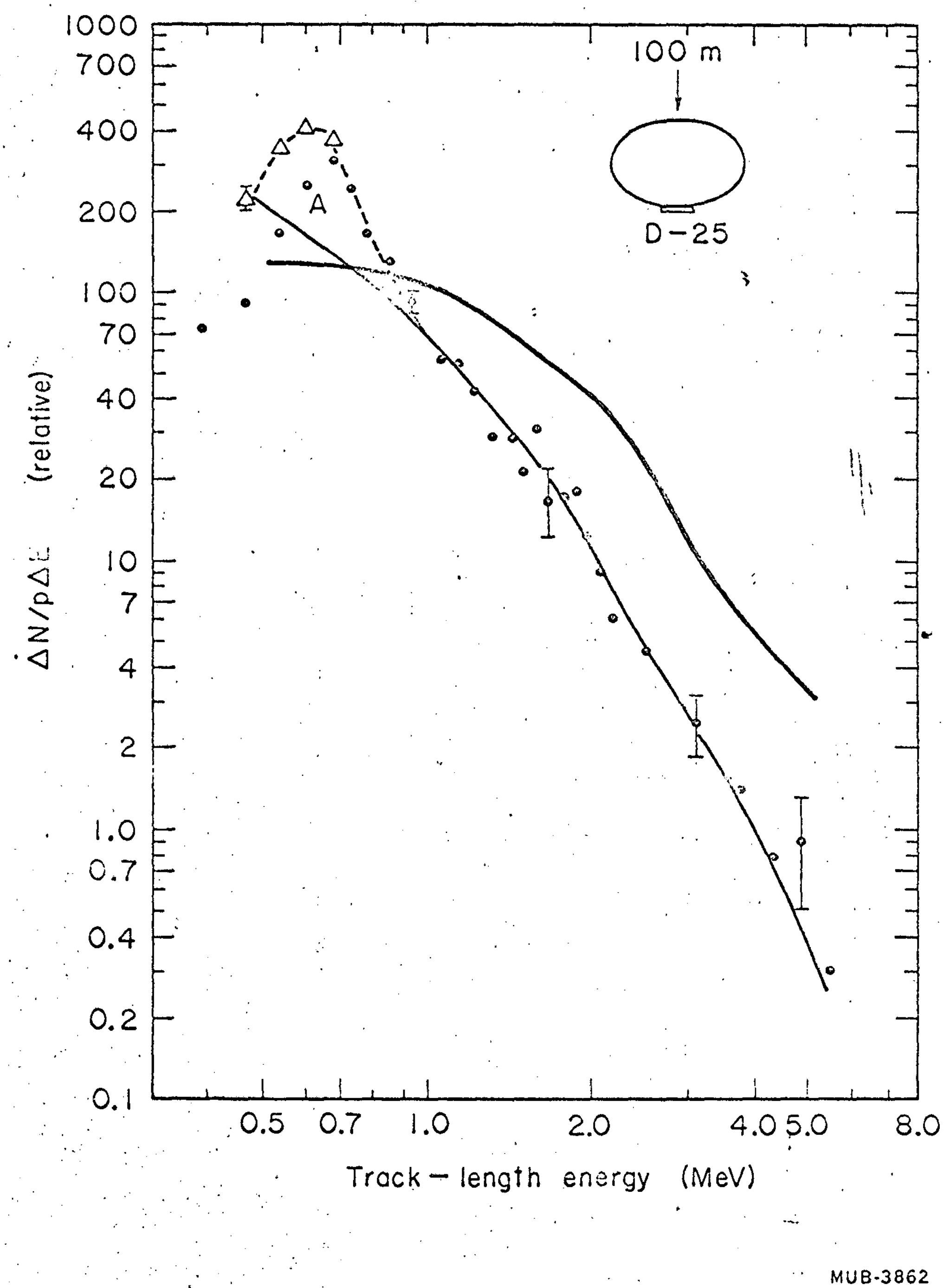
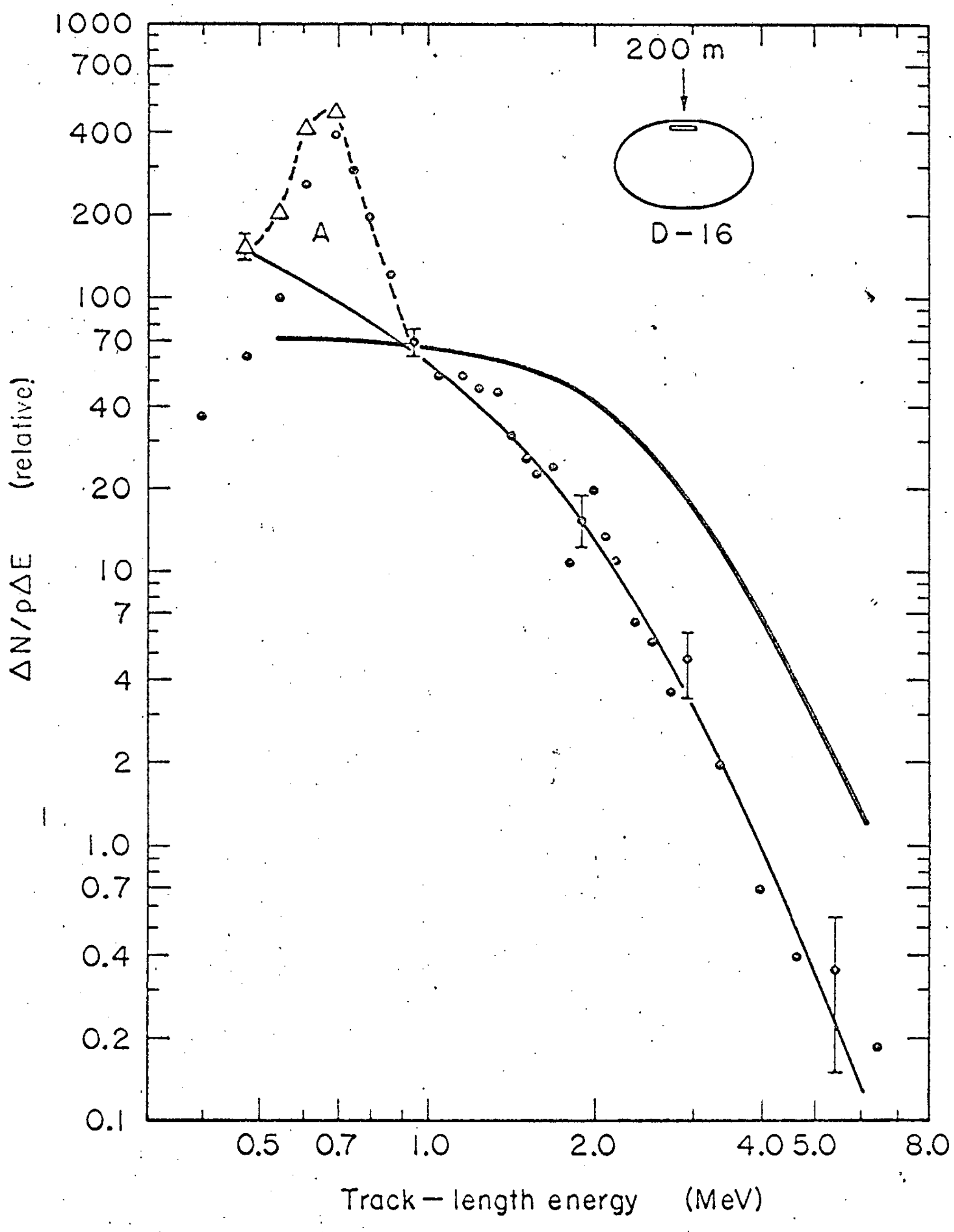

1000
700
400
200
100
70
40
20
10
7
4
2
1.0
0.7
0.4
0.2
0.1
ΔN/pΔE (relative)
100 m
D-25
A
0.5
0.7
1.0
2.0
4.0
5.0
8.0
Track — length energy (MeV)
MUB-3862

Fig. 5



MUB-3863

Fig. 6