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# THE ENERGY SPECTRUM OF THE DELAYED NEUTRONS FROM $O^{17}$

Evans Hayward

October 19, 1948

Special Review of Declassified Reports
Authorized by USDOE JK Bratton
Unclassified TWX P182206Z May 79

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| Patent Advisor, Washington | | 59 |
| Technical Information Division, ORDO | | 60-74 |
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# THE ENERGY SPECTRUM OF THE DELAYED NEUTRONS FROM $O^{17}$

Evans Hayward

October 19,1948

When bombarded with high energy deuterons, the elements just above oxygen in the periodic table have been found to yield delayed neutrons[1] analogous to those found in fission products[2]. The delayed neutrons are emitted with a period that corresponds to a 4.14 second half-life[1]. The nucleus responsible for this period has been identified by Alvarez[3] to be $N^{17}$ which $\beta$ -decays to give an excited state of $O^{17}$, which in turn emits a neutron and becomes $O^{16}$.

Alvarez[3] has some preliminary data which indicate that the neutrons emitted do not all have the same energy. The object of this investigation was to determine the neutron energy spectrum from the ranges of the knock-on protons in a hydrogen-filled cloud chamber[4]. The target was a LiF crystal (1/2" x 1/2" x 1/4") which was clamped to a spool and blown back and forth between the cyclotron and the cloud chamber through a pneumatic tube. The spool was stopped at a position in the tube such that the target was three feet outside of the concrete shielding and six feet from the cloud chamber. (See Fig. 1) The target was bombarded by the circulating 195 Mev deuteron beam of the cyclotron for thirty seconds and then blown out to the cloud chamber which was expanded manually a few seconds after the target came to rest. The cloud chamber clearing field was not turned off until the time of the expansion so that those ions that were formed before the target stopped moving

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[1] N. Knable, E. O. Lawrence, C. E. Leith, B. J. Moyer, and R. L. Thornton, Bul. Am. Phys. Soc., F9, April 29, 1948.

[2] Snell et al., Phys. Rev. 72, 541 and 545 (1947)

[3] L. W. Alvarez, Bul. Am. Phys. Soc. F11, April 29, 1948.

[4] Brueckner et al., to be published.

were swept out before the vapor could condense on them. The cyclotron was turned off after the bombardment, and since the target spent about ten seconds moving out to the cloud chamber, we may be certain that those events that occurred in the chamber were due to the target.

The neutron energy is related to the energy of its knock-on proton by the equation $En = Ep/\cos^2\theta$, where $\theta$ is the scatter angle. The proton range and the angle that the proton makes with the direction of the incident neutron have been measured by reprojection[4]. The range-energy curve (Fig. 2) for the chamber pressure, which was 129.4 cm of $H_2$ saturated with a 2:1 alcohol-water mixture, has been calculated by A. A. Garren.

A region in the cloud chamber was chosen for selecting the tracks such that all those that started within this region would also end in the illuminated region. All tracks having scatter angles larger than 30° were excluded in order to minimize the error which is introduced by including recoils from neutrons that have scattered first from the walls of the chamber before producing a knock-on proton in the gas. If all scatter angles are included, the neutron energy distribution contains a few neutrons with energies as high as 10 Mev but these all arise from protons with large scatter angles and hence are due to neutrons that did not come directly from the target. In the early stages of the experiment a small number of tracks, large scatter angles included, were measured. Out of twenty protons with scatter angles greater than 30°, only two gave exorbitant neutron energies. From this we estimate that about 10% of the neutrons included had undergone scattering previous to producing the recoil in the gas.

The ranges of all the protons produced by neutrons having energies greater than 0.5 Mev have been measured. The proton ranges were measured to 1 mm. This gives an error in the neutron energy small compared to that caused by the errors in measuring the angles. Tracks of all ages have been included. The energies of the neutrons corresponding to new tracks have been corrected for the fact that they were formed after the expansion. More weight should be attached to the new tracks than to the old, since their scatter angles can be measured to ± 1° whereas the old tracks were measured to only ± 3°. The errors in the neutron energies have been estimated to be ± 6% for diffuse tracks and ± 2% for sharp ones.

One factor that made the determination of the scatter angles difficult was the multiple scattering of the protons by the gas. This is unimportant in the case of the sharp tracks because they are so easy to measure, and since the neutron distributions obtained from either kinds of tracks are essentially the same (Fig. 3), we conclude that there are no large errors in the energy distribution owing to multiple scattering.

One of the checks made in the experiment was to calculate the number of neutrons scattered per unit solid angle in the center of mass system for three groups of tracks. This number should be a constant independent of the angle. The results, which agree well within the standard deviations, are 305 ± 42, 276 ± 23, and 270 ± 19. The standard deviations are based on the number of tracks.

The energy distributions of the 391 recoil protons and of the neutrons producing them, both before and after correction for the variation of the scattering cross-section with energy, are given in Figures 4, 5, and 6. Figure 7 shows the energy distributions that are obtained when the scatter angles are limited to those smaller than 20° and 10°. The errors from measurement are smaller for small angles but, of course, the statistics are bad. It should be pointed out that there are proton recoils with energies as great as 1.7 Mev so that even if the direction of the incident neutron is unknown, it must in these cases have at least 1.7 Mev. Experimental error cannot account for the large spread in energy and this experiment leads one to the conclusion that this neutron can have any energy between .6 and 1.7 Mev, 1 Mev being its most probable energy.

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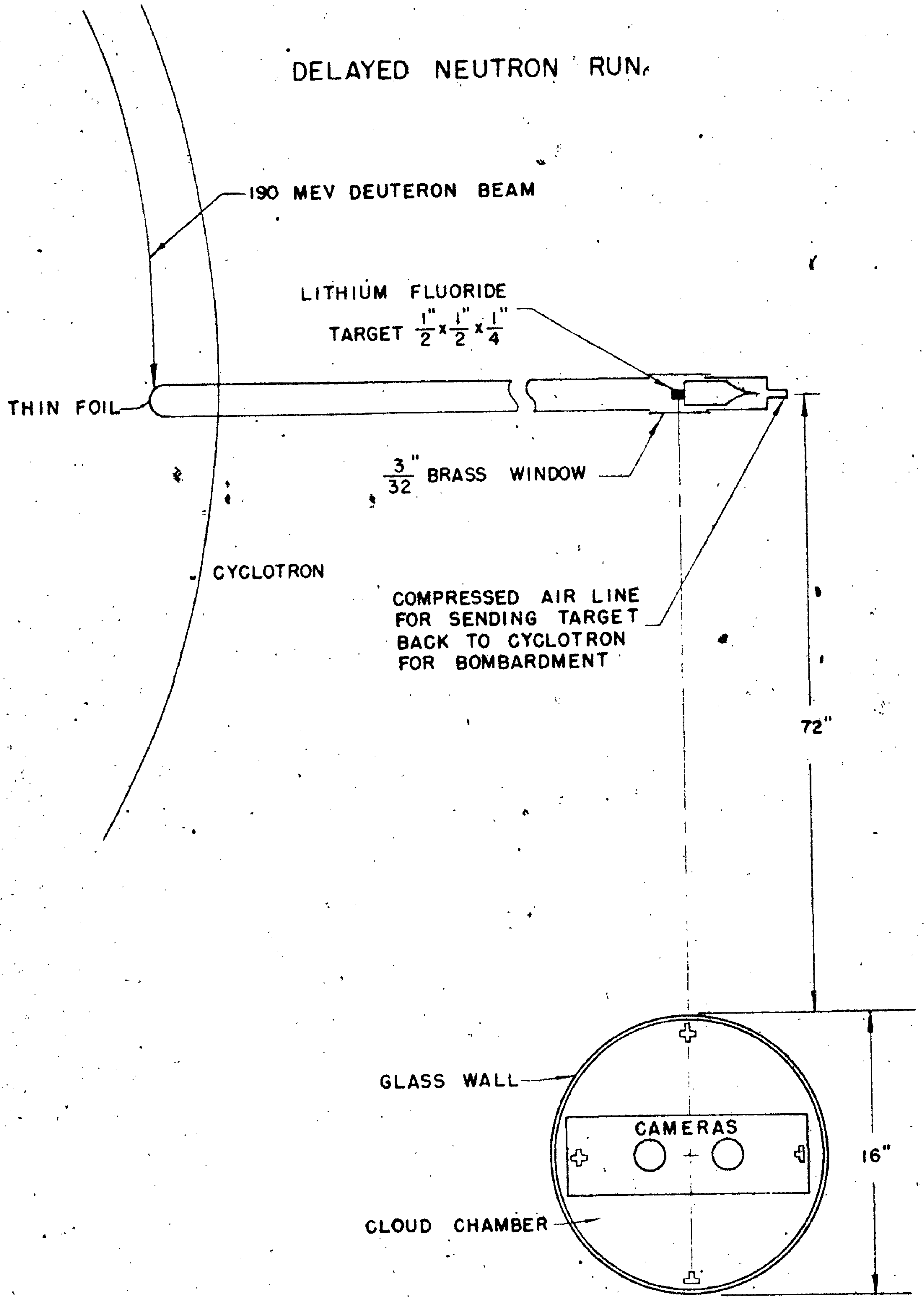

DELAYED NEUTRON RUN
190 MEV DEUTERON BEAM
LITHIUM FLUORIDE
TARGET $\frac{1''}{2} \times \frac{1''}{2} \times \frac{1''}{4}$
THIN FOIL
$\frac{3}{32}''$ BRASS WINDOW
CYCLOTRON
COMPRESSED AIR LINE
FOR SENDING TARGET
BACK TO CYCLOTRON
FOR BOMBARDMENT
72"
GLASS WALL
CAMERAS
16"
CLOUD CHAMBER

FIG. 1

12695-1

RANGE OF PROTONS IN HYDROGEN GAS, ALCOHOL AND WATER VAPOR AT A 2:1 RATIO BY VOLUME (OF THE LIQUID), AT 129.4 cm Hg AND 20° C

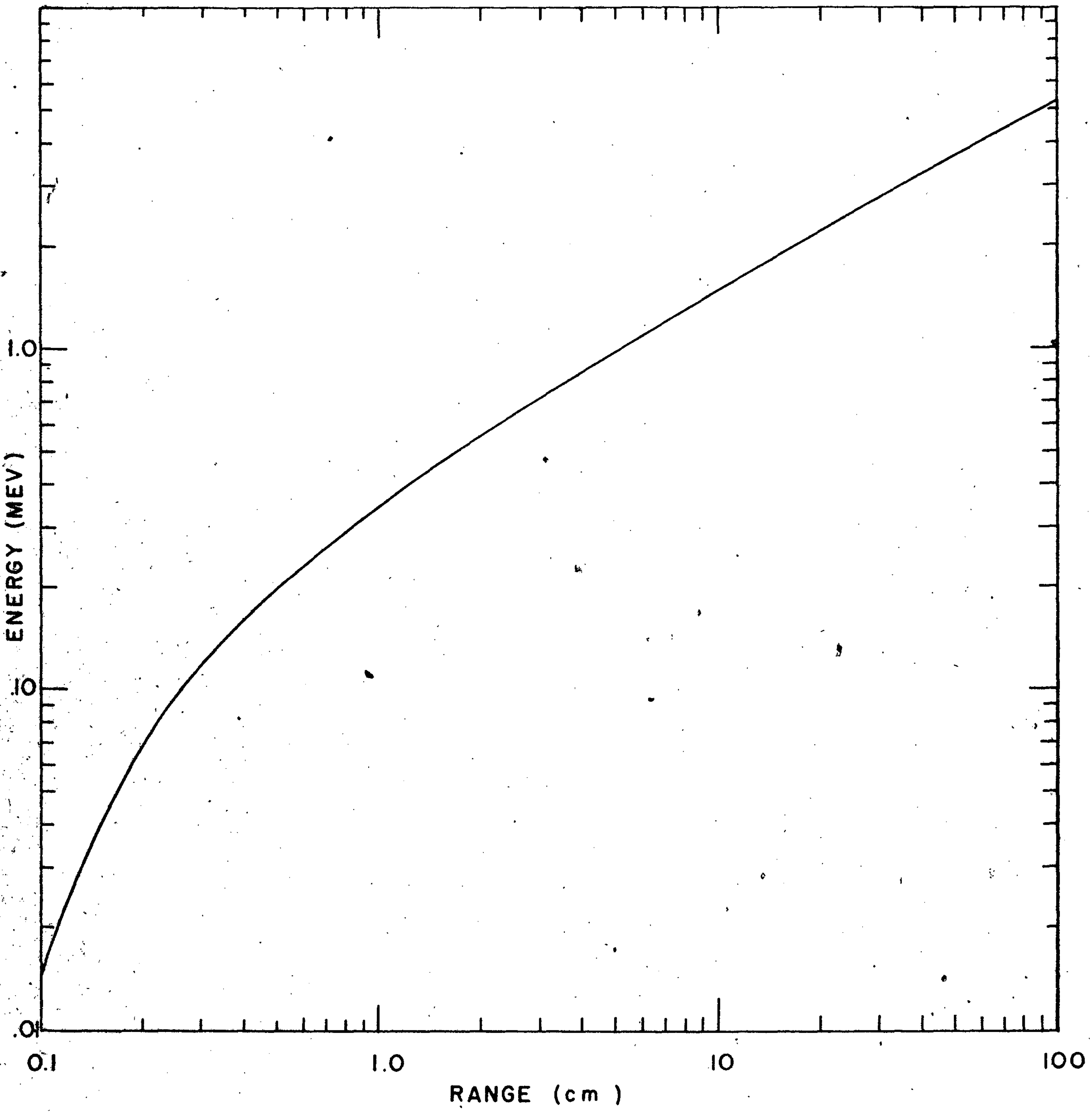


FIG. 2

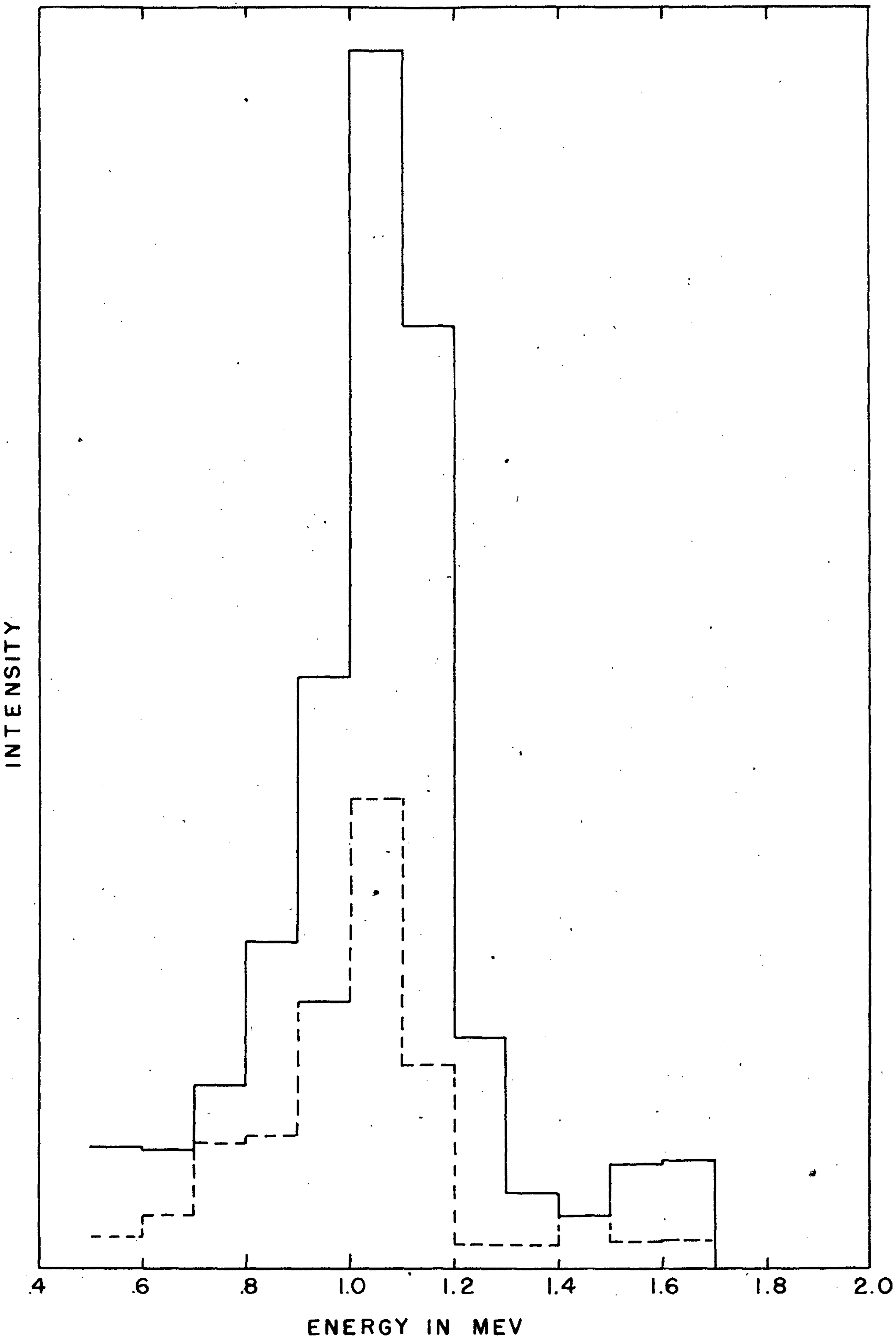


FIG 3

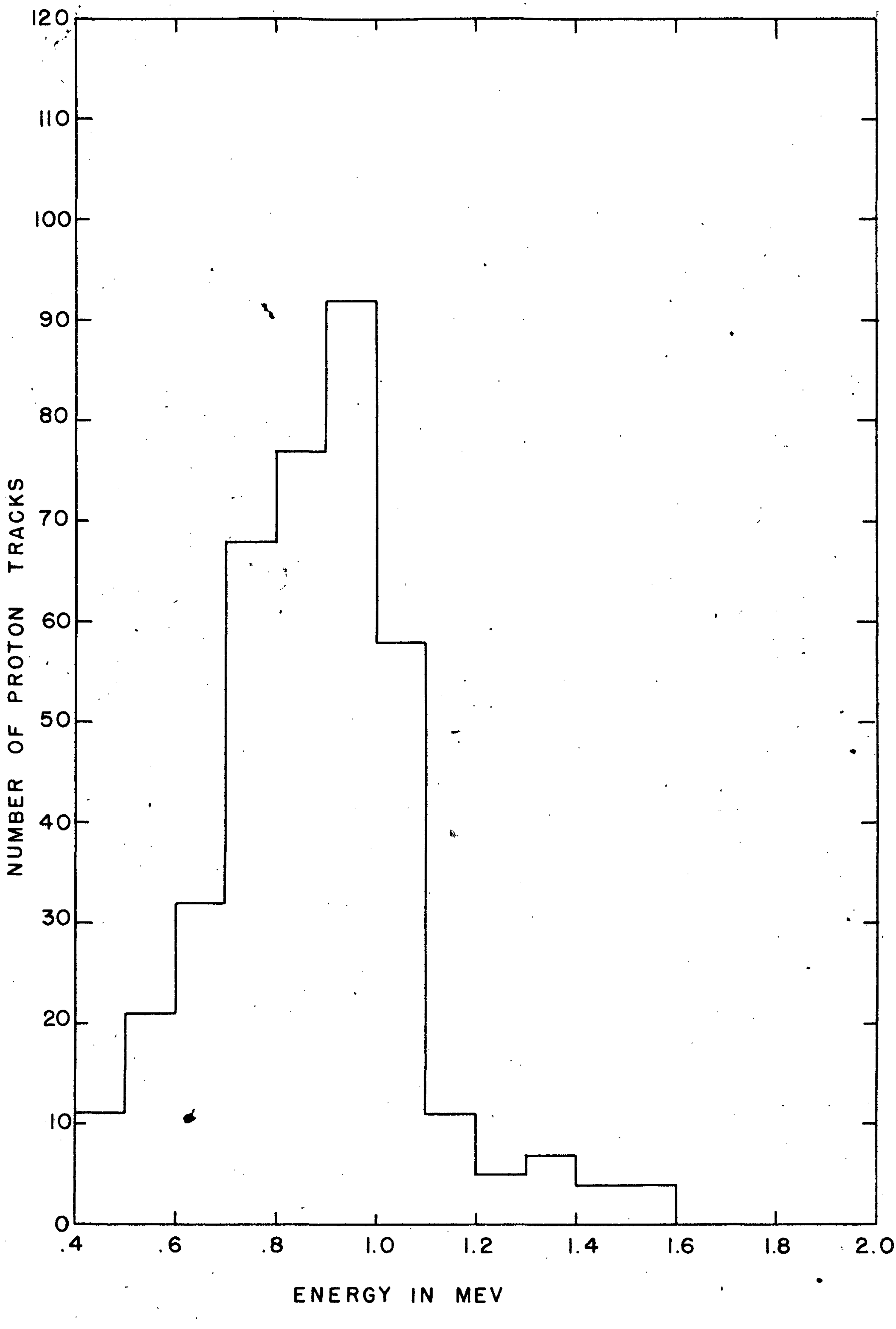
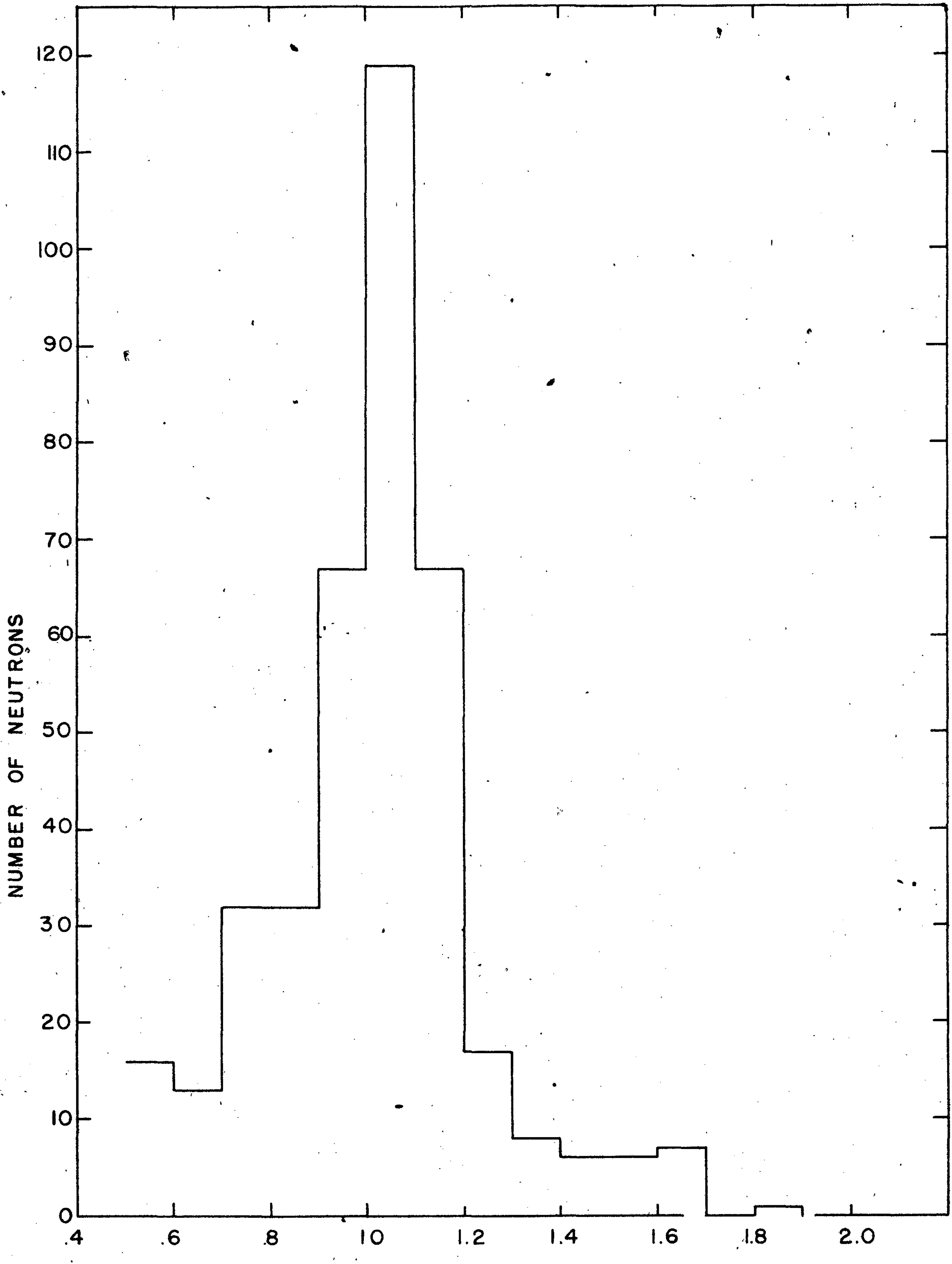

NUMBER OF PROTON TRACKS
0
10
20
30
40
50
60
70
80
90
100
110
120
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
ENERGY IN MEV

FIG 4



120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF NEUTRONS
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
ENERGY IN MEV

FIG. 5

13016-1

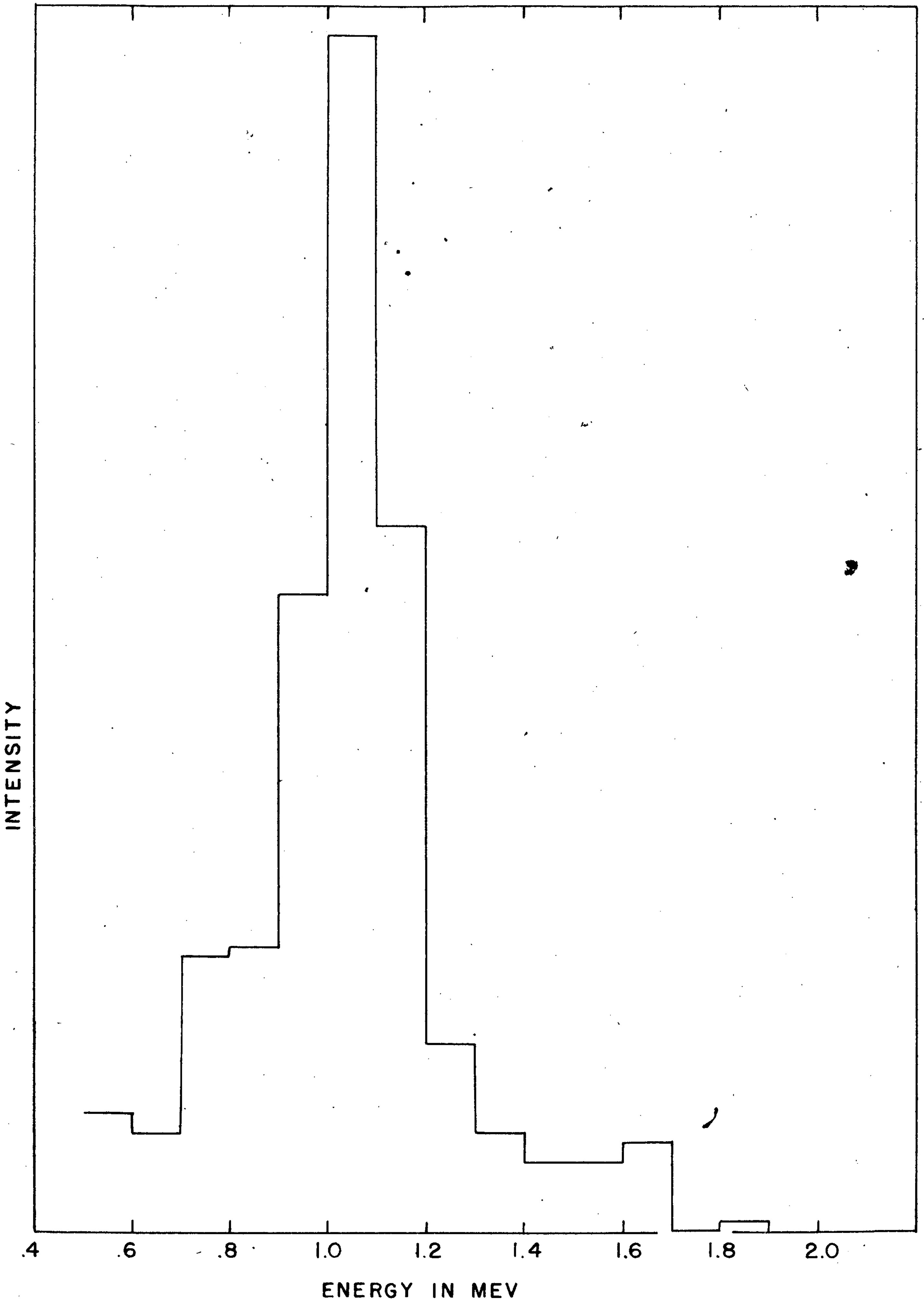


FIG 6

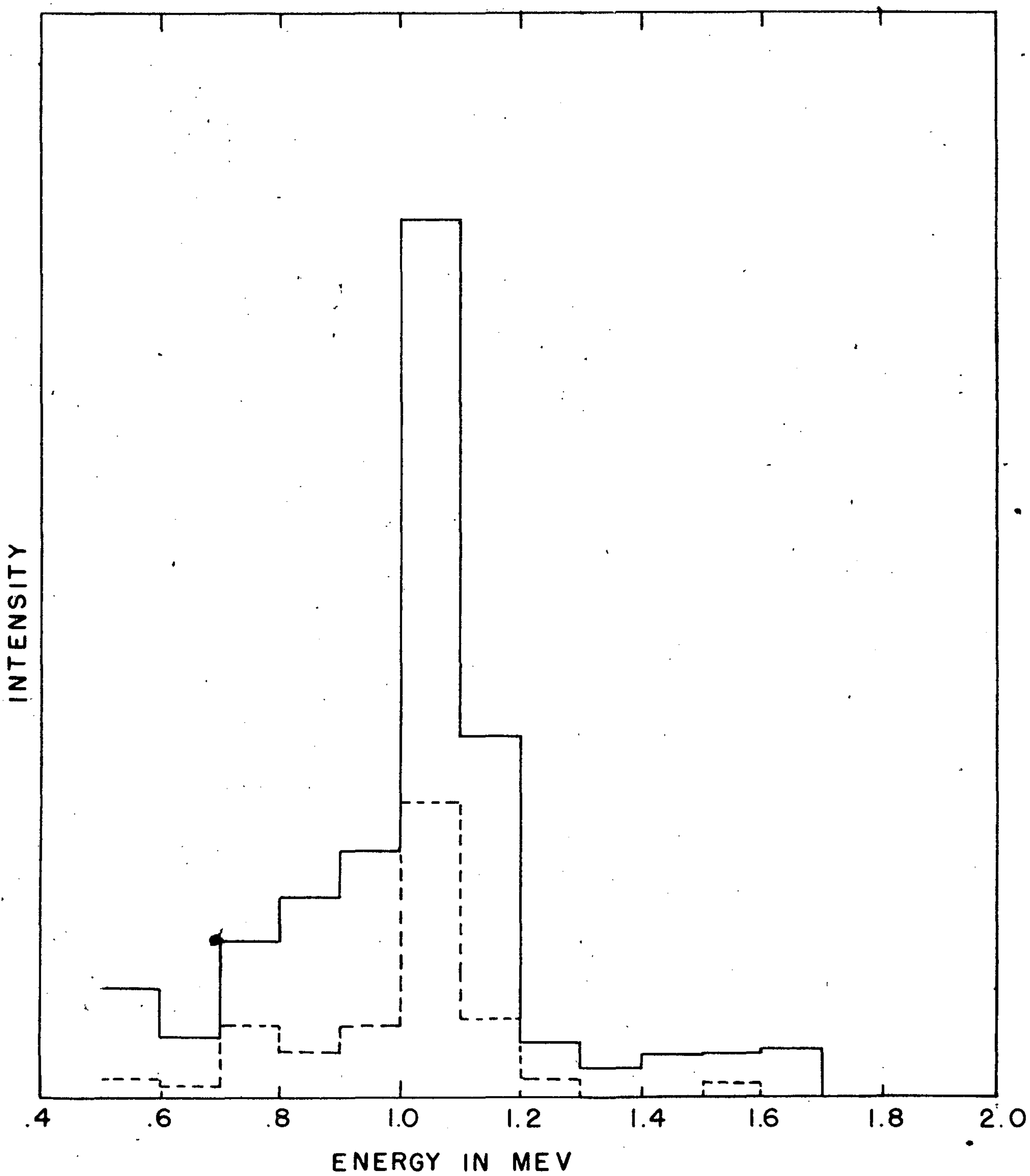


FIG 7

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