Jül-Conf-45 D1-4

I C A N S - V

MEETING OF THE INTERNATIONAL COLLABORATION ON

ADVANCED NEUTRON SOURCES

June 22-26, 1981

Neutron Production Yields and Spectra from 590 MeV Proton Bombardment of Thick Uranium Targets

F.Raupp, S.Cierjacks, Y.Hino, S.D.Howe,
M.T.Rainbow, M.T.Swinhoe and L.Buth

Kernforschungszentrum Karlsruhe
Institut für Kernphysik
D-7500 Karlsruhe, Postfach 3640
Federal Republic of Germany

Abstract

Time-of-flight measurements of neutrons produced by bombardment of a thick uranium target with 590 MeV protons have been performed at SIN cyclotron. Measurements were made at angles of 30^o, 90^o and 150^o relative to the incident proton beam for different penetration depths of protons in a 10 cm x 10 cm x 40 cm long target. The detector was a liquid scintillator. Differential and integral neutron data are presented and discussed.

1. INTRODUCTION

In addition to the measurements of neutrons and protons produced by bombardment of a thick lead target[1], measurements with a thick target of depleted uranium have also been carried out using 590 MeV protons obtained from the cyclotron of the Swiss Institute for Nuclear Research (SIN). In the following sections the results of the measured yields and spectra of the thick uranium target will be shown and discussed.

2. EXPERIMENTAL DETAILS

The experimental arrangement and the method of data analysis were similiar to that described previously[2]. Therefore only a brief summary is given below. The measurements of neutron yields and spectra were performed at angles of 30^o, 90^o and 150^o. The NE213 liquid scintillator was placed at the exit of a 1 m long iron collimator. At 30^o and 90^o flightpaths of 120 cm and at 150^o of 168 cm were employed. Measurements were made for 6 penetration depths into the target, staggered at 5 cm intervals.

In contrast to our previous lead target measurements with a 10 cm diameter and 60 cm long cylindrical target, a rectangular parallelepiped uranium target of 10 cm x 10 cm x 40 cm was used. This target was composed of individual blocks of 5 cm x 5 cm x 10 cm arranged as shown in Figure 1.

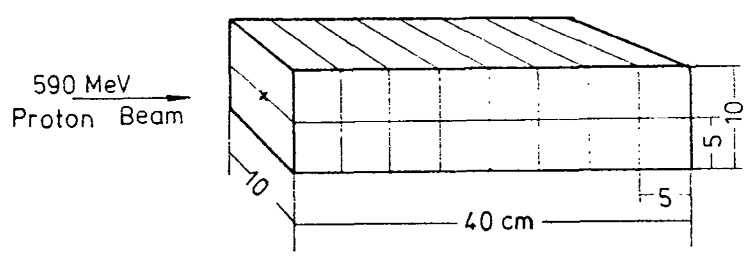

Figure 1 - Uranium target configuration used for the foreground measurements.

For background measurements in the 90^o position the respective blocks opposite the collimator entrance were removed. In the 30^o and 150^o positions a target arrangement as shown in Figure 2 was used. Blocks of 5 cm x 5 cm x 2.5 cm were used to produce the wedge-shaped volumes.

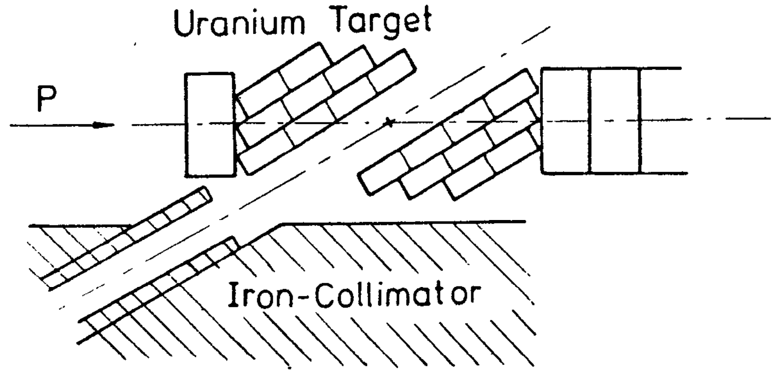

Figure 2 - Target arrangement for background measurements at 30° and 150° positions.

Data acquisition was accomplished by the same method as for lead[2]. Pulse height, pulse-shape-discrimination and time-of-flight information was stored event by event on magnetic tape.

3. RESULTS

3.1 DIFFERENTIAL NEUTRON SPECTRA

In Figures 3-5, the spectra of neutrons emitted from the first 3 blocks of the target are shown as a function of the energy of the emitted neutrons. The spectra show the typical two component shape also seen in previous measurements for lead targets[1]. The most obvious difference between lead and uranium is the considerably lower energy of the maximum yield which is below 1 MeV for uranium and about 1.5 MeV for lead. This can be seen best in the top curve in Figure 3 where we measured the spectra down to 0.7 MeV.

The spectra shown have different lower energy cutoffs because different detector thresholds were used in the measurements. The 150° measurements performed this year at SIN used the 16.9 Mhz beam pulse frequency and a detector threshold of 0.6 MeV. The 90° and 30° measurements were carried out last year with a beam pulse frequency of 50.7 Mhz and a detector [redacted]

3.2 INTEGRATED NEUTRON YIELDS

In Figure 6, the neutron flux at 90° integrated over all energies higher than 1.5 MeV has been plotted versus the penetration of protons into the target. It can be seen that the flux decreases rapidly with distance into the target. The measured distribution is in close accordance with the calculated 16.1 cm range of 590 MeV protons in uranium.

The yields of angular dependent spectra integrated over the whole target length (0 - 30 cm distance into the target) have also been calculated. The resulting spectra are plotted in Figure 7. In the lower energy region the 150° spectrum shows the higher yields compared to the 90° data and especially to the 30° spectrum. Although neutrons emitted in this energy range are expected to have an isotropic angular distribution the observed yields are greatly effected by self-shielding of the target at the different angles. Since the average mean-free-path of neutrons in uranium is about 2 cm for low energies the neutron yield at 30° should be more attenuated than at 90° or 150°. The same effect is true for the 150° measurement, but becomes important only at greater depths into the target where the neutron production is much less. Also seen in Figure 7, the high energy component of the spectra decreases rapidly with increasing emission angle as expected.

The total number of neutrons per proton was calculated by integrating over energy and over the target surface area, averaging the yields obtained from the 3 measured angles, and integrating the result over the leakage angle. In this way a value of 15.8 n/p was obtained for neutrons emitted from the target with energies higher than 1.5 MeV. An estimate of the fraction of neutrons emitted with energies below 1.5 MeV can be made by calculating the yield as a function of lethargy and extrapolating the spectrum below the experimental energy threshold. This estimation showed that the fraction of leakage neutrons below 1.5 MeV is 35 % of the total number of neutrons. This gave a total yield of 24.3 n/p.

REFERENCES

1. S. Cierjacks, M. T. Rainbow, M. T. Swinhoe and L. Buth, Contr. ICANS-IV, Tsukuba (1980).
   S. Cierjacks, M. T. Rainbow, M. T. Swinhoe and L. Buth, Report, KfK-3097B (1980)
2. S. Cierjacks, Proc. of ICANS-V Conf., Jülich (1981). (to be published)

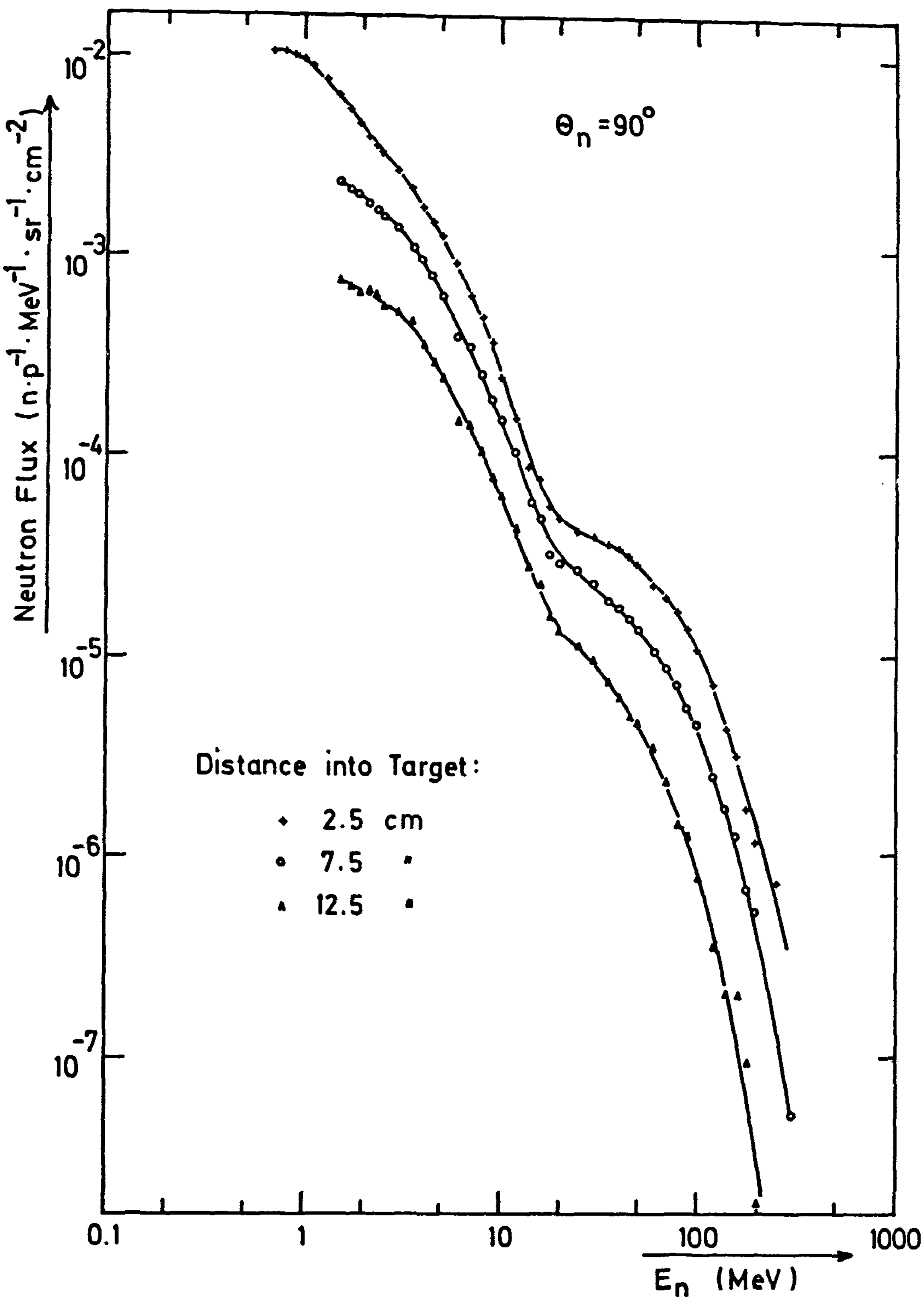

Figure 3 - Differential spectra of neutrons emitted at 90° from 590 MeV protons on a 10x10x40 cm uranium target measured at depths into the target of 2.5 cm, 7.5 cm and 12.5 cm.

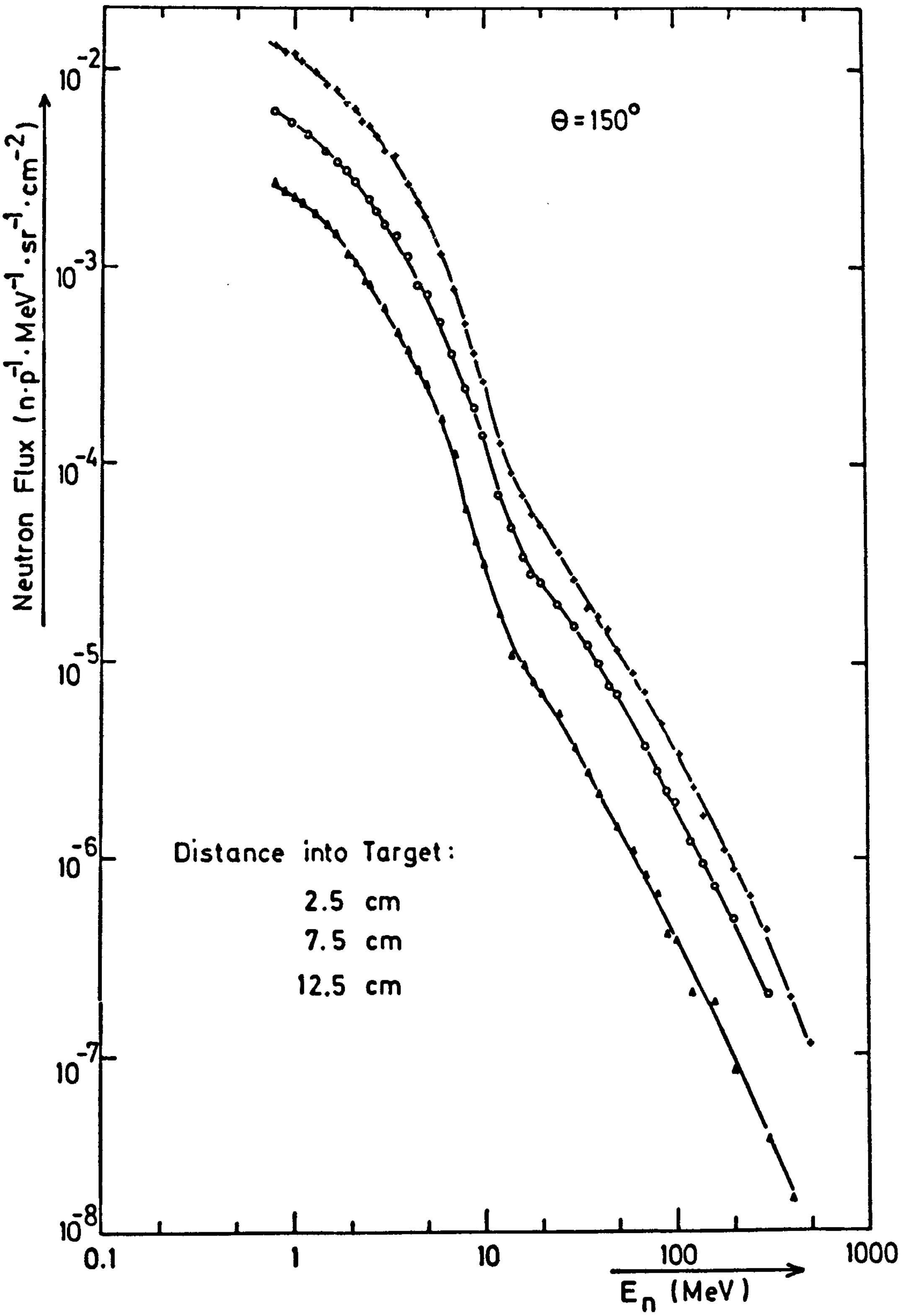

Figure 4 - Differential spectra of neutrons emitted at 150° from 590 MeV protons on a 10x10x40 cm uranium target measured at depths into the target of 2.5 cm, 7.5 cm and 12.5 cm.

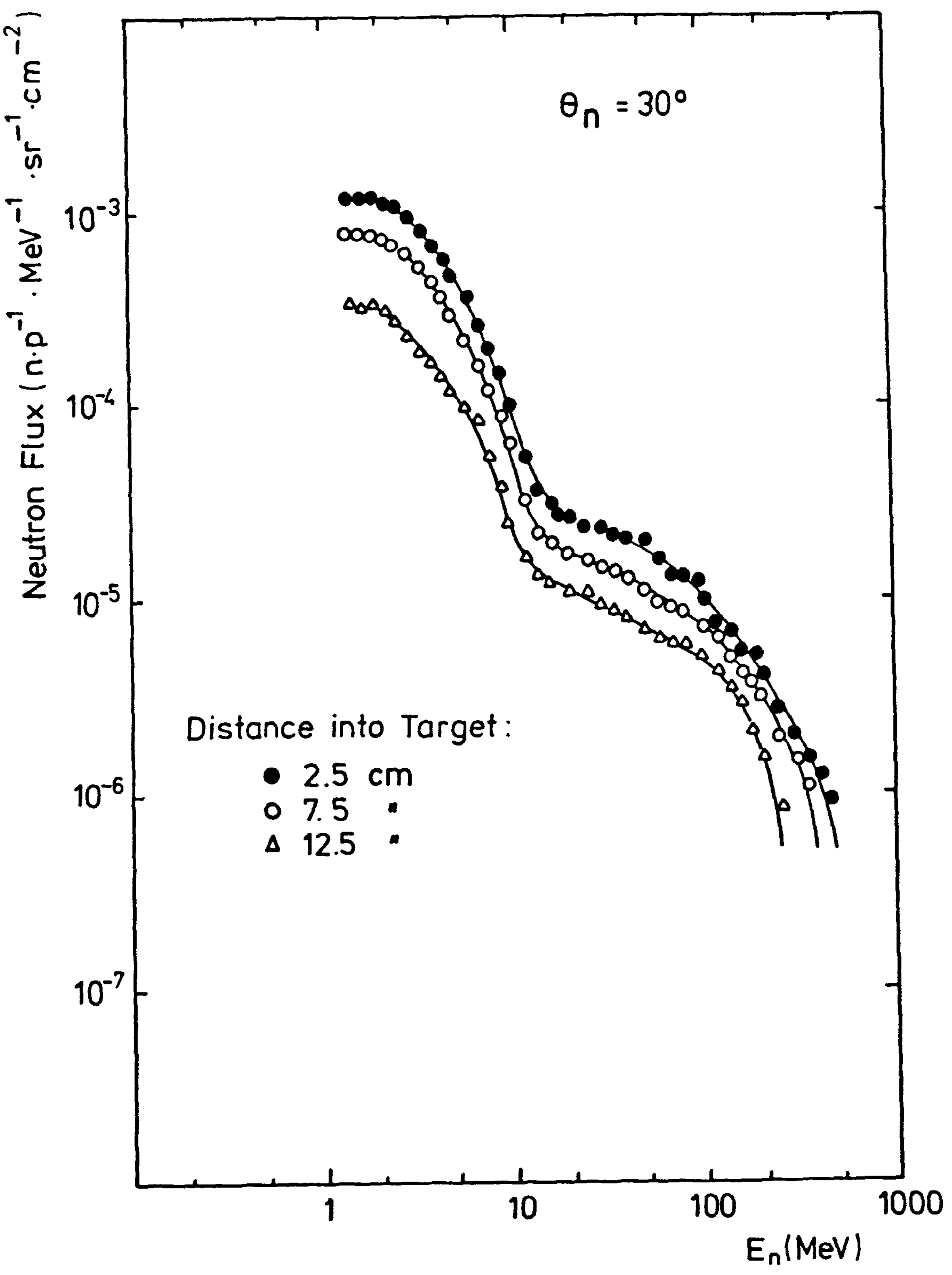

Figure 5 - Differential spectra of neutrons emitted at 30° from 590 MeV protons on a 10x10x40 cm uranium target measured at depths into the target of 2.5 cm, 7.5 cm and 12.5 cm.

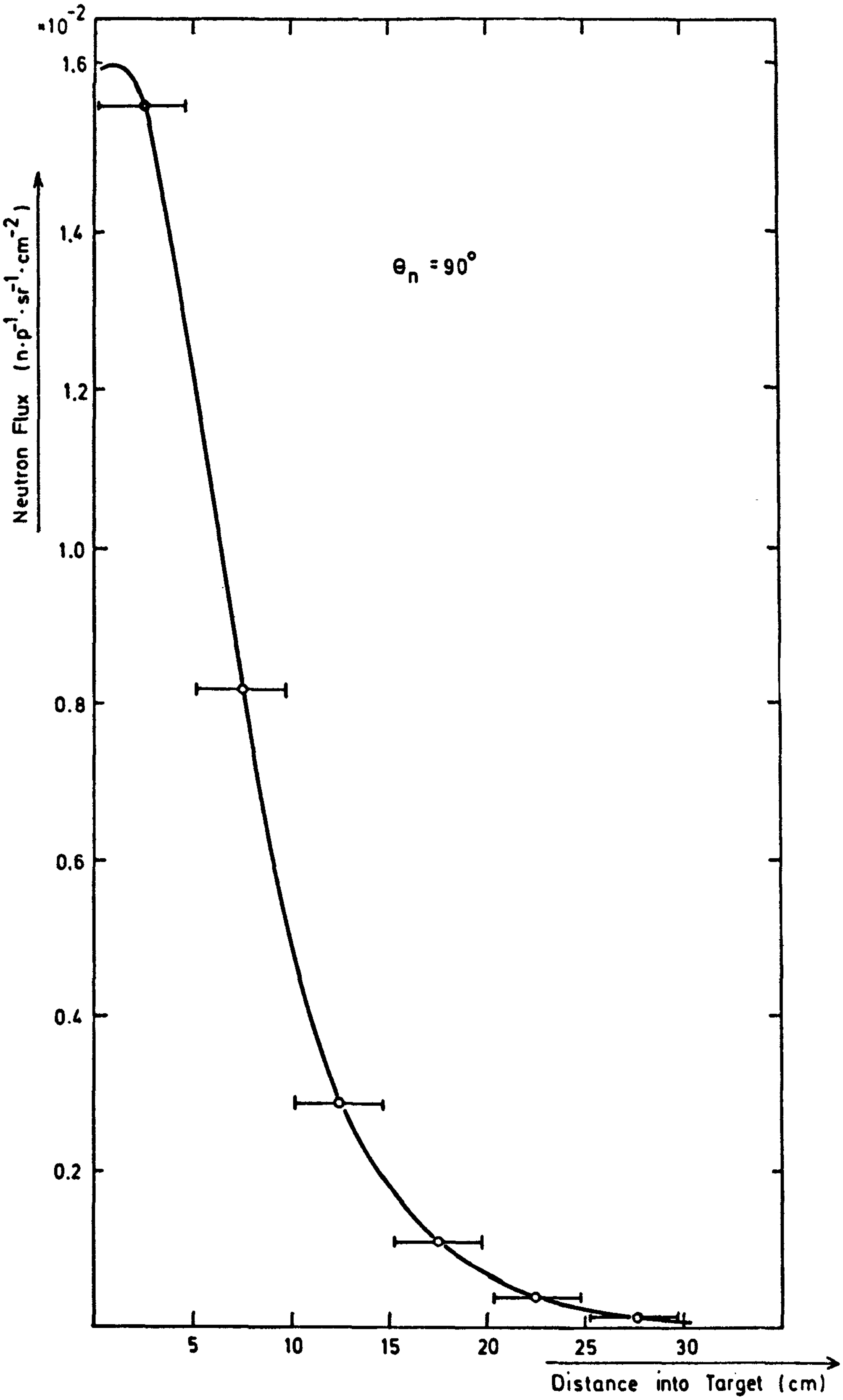

Figure 6 - Total neutron flux at 90° (E_n > 1.5 MeV) as a function of proton penetration into the uranium target.

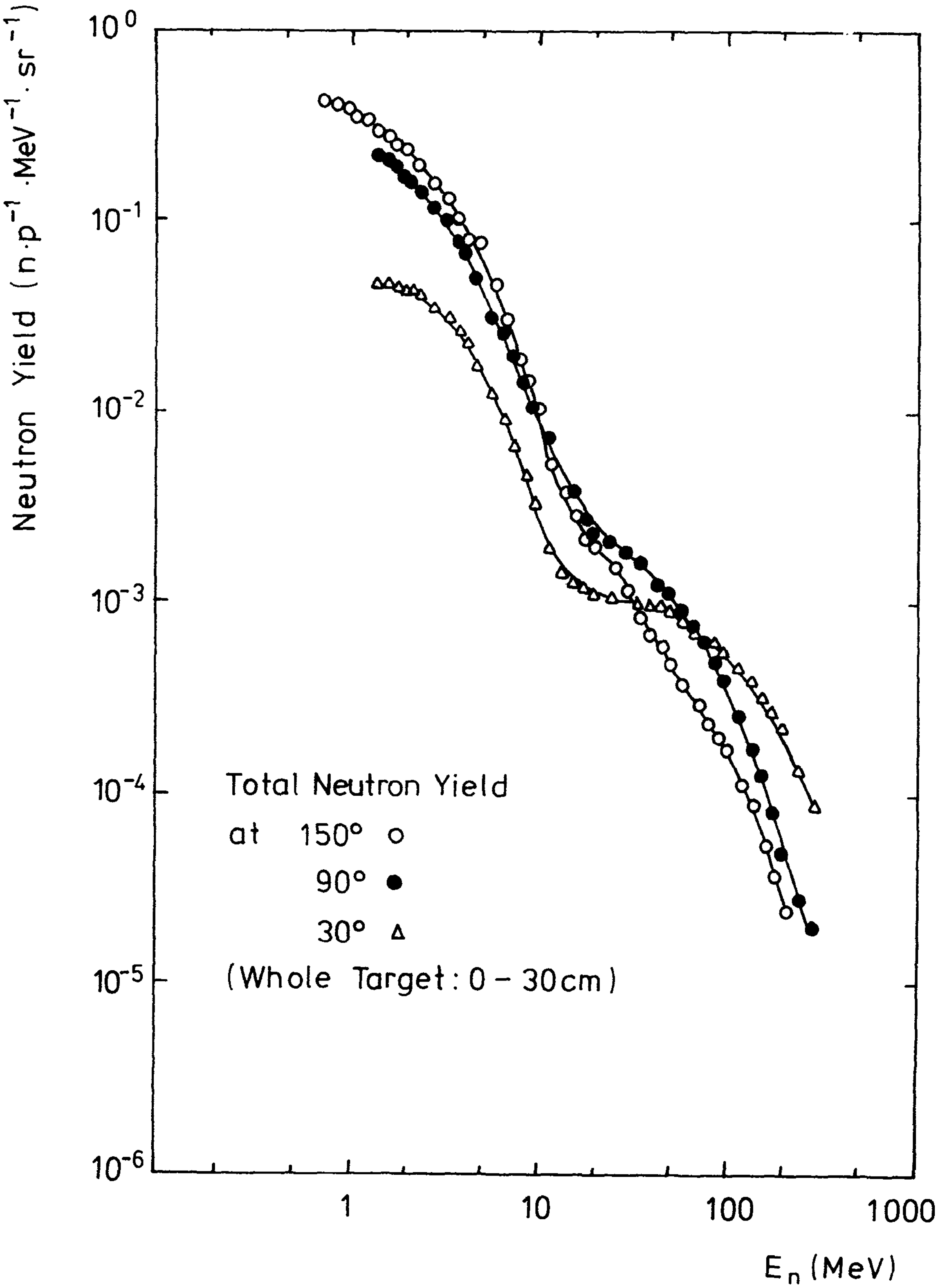

Figure 7 - Spectra of neutrons emitted at 30°,90° and 150° integrated over the first 30 cm of the uranium target. Given yield values correspond only to the fraction of neutrons which are emitted through a 4 cm high centre region of the target surface.