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ENERGY DEPENDENCE OF FAST NEUTRON DOSIMETRY USING ELECTROCHEMICAL ETCHING

by

MASTER

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Abstract

Registration of fast-neutron induced recoil tracks by the electrochemical etching technique as applied to sensitive Lexan polycarbonate foils provides a simple and inexpensive means of fast neutron personnel dosimetry.

The sensitivity (tracks/neutron) of recoil particle registration is given as a function of neutron energy. Neutrons of < 4,3 MeV, 14 MeV and 22 MeV were produced by the reactions ^{7}Li (p,n) ^{7}Be, ^{3}T (d,n) ^{4}He and ^{9}B, respectively. Results are compared with other studies using other neutron sources and conventional etching method.

EXPERIMENTAL METHODS

The foils were irradiated in air to fast neutron of different energy spectra from the Van de Graaff accelerator at Institute of Nuclear Energy Research of Taiwan, 14 MeV neutrons from the Cockcroft-Walton accelerator at National Taiwan University and the Texas A&M University cycloton by the ^{9}Be (d,n) ^{10}B reaction. The neutron dose estimate given in these studies were based upon dosimetry reports provided by the above facilities. (1,2,3)

The irradiated foils were etched by an electrochemical etching system.(4,5) Unlike conventional etching methods, which can be carried out by immersing the foils in a chemical solution of a certain concentration and temperature, electrochemical etching requires special etching equipment. This etching system consists of an etching chamber and a high voltage power supply to provide the necessary voltage and frequency across the chamber. The chamber used in this study consists of two cylindrical Lucite containers, each 5 cm in length and 13 cm in diameter, and has the capacity to etch seven foils simultaneously. The irradiated foils to be etched are placed between the containers. They are held in place at each window connecting the two containers (the number of foils is equal to the number of windows) by two packings in such a way as to isolate the two containers electrically. The chamber is filled with 45% KOH etchant solution at room temperature. A high voltage is applied across the chamber by means of two stainless steel electrodes. The high voltage is generated by an audiofrequency oscillator, the output of which is amplified by a push-pull amplifier to supply the necessary voltage and frequency (e.g. 800 V, 2 KHz). After the proper etching time

(e.g. 4 Hours), the foils are removed from the chamber, washed and dried for track counting. The track densities reported here were obtained by a microfiche reader at X53 magnification, and the track densities are the sum of the track densities appearing on both sides of a foil. A Poisson distribution assumption is employed for the counting error estimation.[6]

NEUTRON SOURCES

Table 1 summarized some characteristics of fast neutron sources used in this study. Monoenergetic neutron sources below 4.335 MeV were produced with a 7 MV Van de Graaff accelerator using d.c. beam via the $^{7}Li\ (p,n)\ ^{7}Be$ reaction (Q - value = -1.644 MeV). Neutrons emitted at different angles with respect to the Van de Graaff beam were used for the irradiations. The lithium targets were prepared by vacuum evaporation of metallic lithium on tantalum backing. The thickness of the metallic lithium target used was 500 $\mu g/cm^2$. Four polycarbonate foils of 10 x 24 cm each were supported around the target (from -135^{o} to 135^{o}) by a wooden shelf. The distance between the target and the sample was 20 cm. The target was at the level of the samples during the irradiation, 1.4 meters above the floor. For these exposures the currents of protons were varied from 0.5 μA up to 2.0 μA and the energies were varied from 3 MeV up to 6 MeV. Figure 1 shows the neutron energies as a function of laboratory angles at different bombarding proton energies.[7] A proton recoil telescope was used for the absolute determination of monoenergetic neutron flux.[1] The telescope consists principally of a solid radiator and n-type silicon surface barrier detector. The pulse from a charge-sensitive pre-amplifier located to the silicon detector is shaped and amplified by

TABLE 1 FAST NEUTRON SOURCES USED IN THIS STUDY

Source	Facility	Neutron Energy (MeV)	Fluence ($^n/cm^2$)	Distance Between Target & Sample (cm)
1. Fission Neutrons	Ga. Tech Atlanta, Ga.	1.2	10^7-10^9	10
2. ^7Li (p,n) ^7Be	INER Taiwan	0.7-4.3	10^6-10^9	20
3. ^3T (d,n) ^4He	National Taiwan U. Taiwan	14.1-15.0	$4.5x10^8$	15
4. ^9Be (d,n) ^{10}B	Texas A & M U. College Station, Texas	22	10^6-10^{10}	

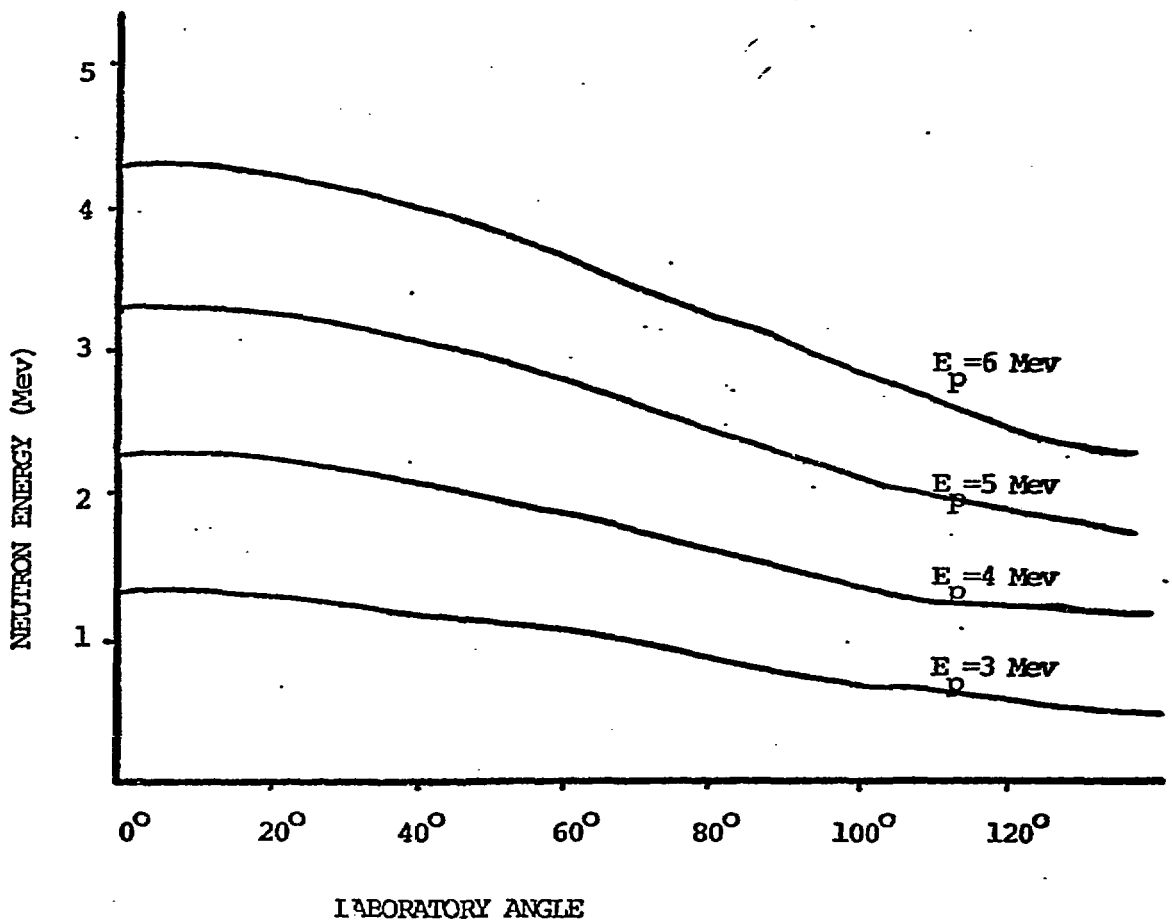

Fig. 1 Neutron Energies from the $^{7}Li(p,n)^{7}Be$ Reactions As A Function of Bombarding Energy and Laboratory Angle

a linear amplifier and then analyzed and recorded in a multichannel analyzer.

Sources of error are from (1) total n-p cross section (2) thickness of radiator, (3) telescope geometry, (4) efficiency calculation, (5) statistical uncertainty of proton counts and (6) uncertainty of background. The total error estimated is about 3%.

Neutrons emitted at different angles with respect to the deuteron beam were produced at the 250 KV Cockcroft-Walton accelerator in National Taiwan University by the D-T reaction[2], (Fig. 2). The absolute measurement of neutron yield and angular distribution were carried out by a counting α- particles with a thin (0.1mm) ZnS crystal, which was placed at the position 1 m distant from Zirconium-tritium target.

The very high Q value of T (d,n) reaction, 17.586 MeV, makes possible the production of high neutron energy with relatively low input energy. The neutron energy is relatively insensitive to the angle of emission for the region of low deuteron bombarding energy. At a deuteron energy of 200 KeV the neutron energies varied around 14.15 MeV at 90^{o} by only about $\pm$ 7 per cent. The total neutron fluences irradiated to our polycarbonate foils varied from 4.78×10^{8} n/cm^{2} to 4.25×10^{8} n/cm^{2} at different angles.

RESULTS AND DISCUSSION

Figure 3 shows fast neutron induced recoil particle track diameter distributions in 250 μm Texan polycarbonate foils for three different neutron sources: 2.20 MeV, 4.25 MeV, and 14 MeV. Each distribution was obtained from 200 randomly scanned tracks. All track diameters were measured under a light microscope with micrometer. Obviously, there are distinct differences in the distributions and the

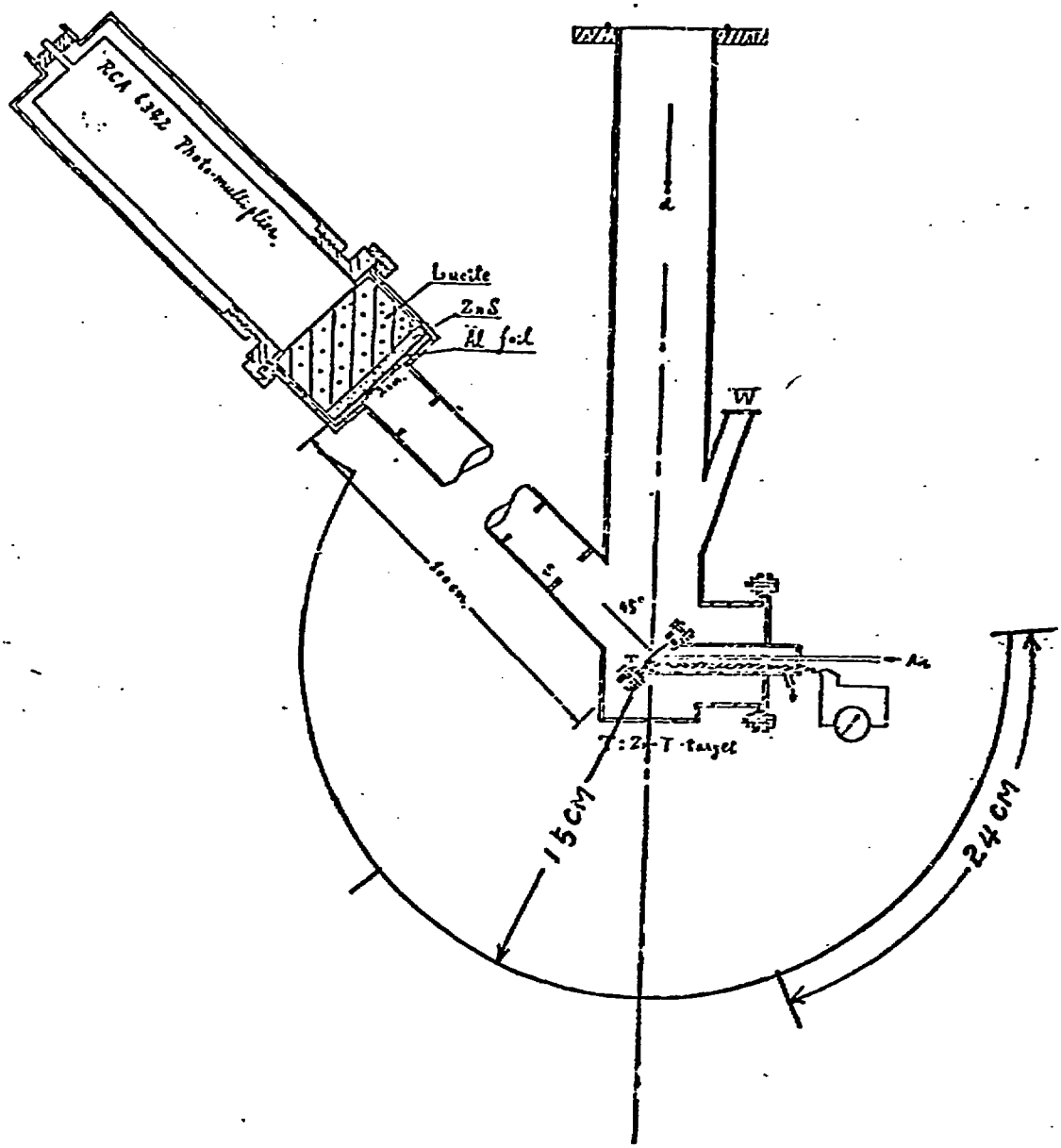

Fig. 2 Irradiation Facilities for T (d,n)^{4}He

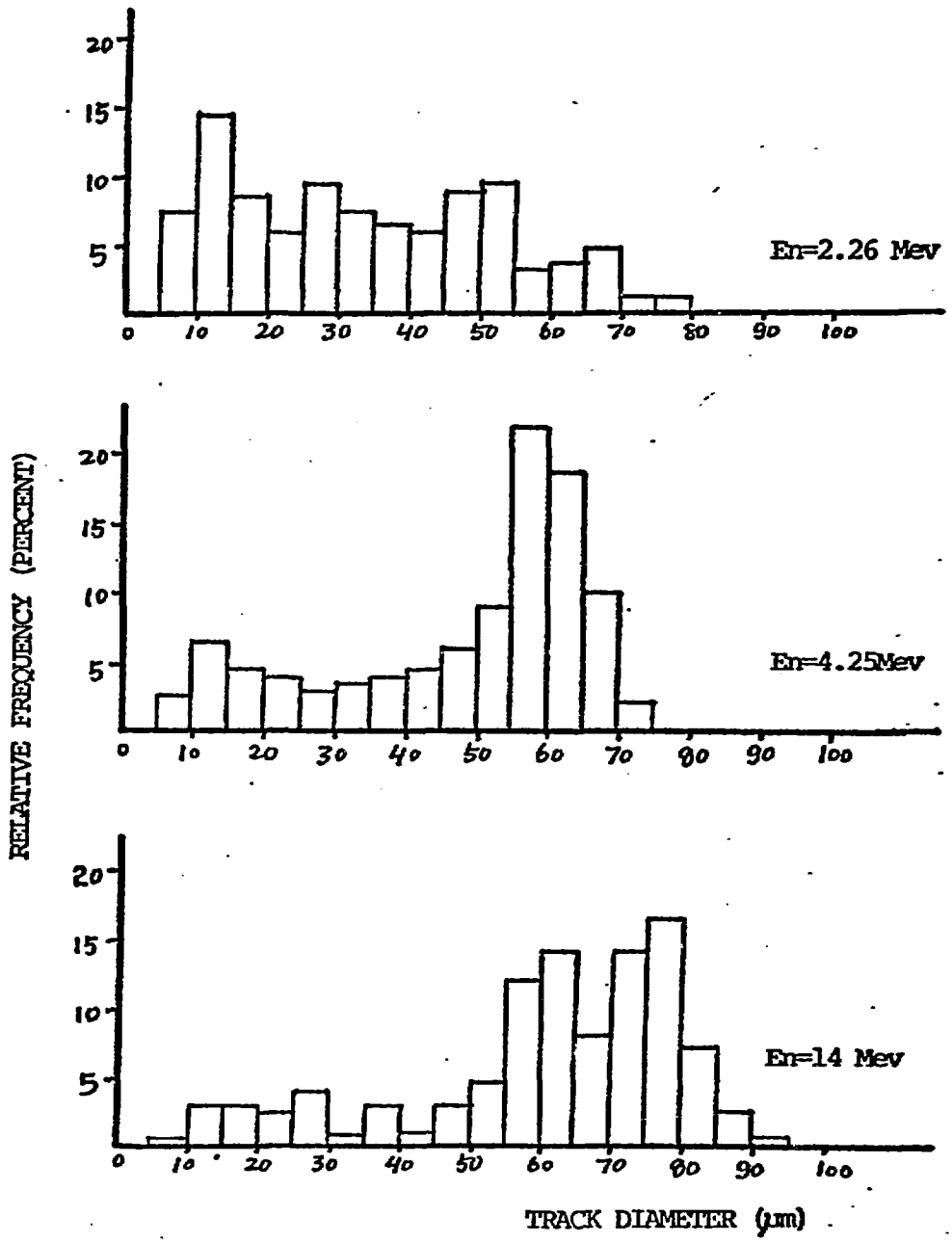

Fig. 3 Track Diameter Distribution in 250 μm Polycarbonate Foils

distributions are skewed more to the right as the neutron energy increases. The mean track diameters for the three neutron sources are, 34.7, 48.1, and 60.7 μm respectively, for 2.26 MeV, 4.25 MeV, and 14 MeV. Thus the mean track diameters and the track diameter distributions can be used as a measurement of neutron energy.

In Figure 4, sensitivity (tracks/n) of recoil particle track registration is given as a function of neutron energy by three different investigations, reported by Becker,[8] Sohrabi,[4] and this study. The first neutron energy dependence studied by Becker was carried out using the conventional etching method. The sensitivities obtained by electrochemical etching of Sohrabi and this study are lower than the valued obtained by conventional etching. The reasons could be (1) the recoil tracks registered on the surface layers are electrochemically etched under non-equilibrium conditions, (2) conventional etching carried out at a higher temperature than electrochemical etching.

Both theoretical and experimental results show a neutron threshold energy of about 1.4 MeV for fast-neutron-induced recoil particle track registration in polycarbonate. Polycarbonate foils are able to register fast neutrons by recording carbon and oxygen recoil atoms from neutron elastic collisions as well as alpha particles from C (n, α) and O (n, α) reactions. The (n, α) reactions in C and O take place for neutron energy values exceeding several MeV.[9] The neutron elastic collision with atoms of polymer take place for neutrons of all energies. Katz and Kabetich [10] calculated for several ions the ionization energy dosage at the critical distance from the ion's path depending on the particle energy. Based on the curves drawn for Lexan polycarbonate with the marked limits of the critical value of ionization energy dosage one can find that carbon and

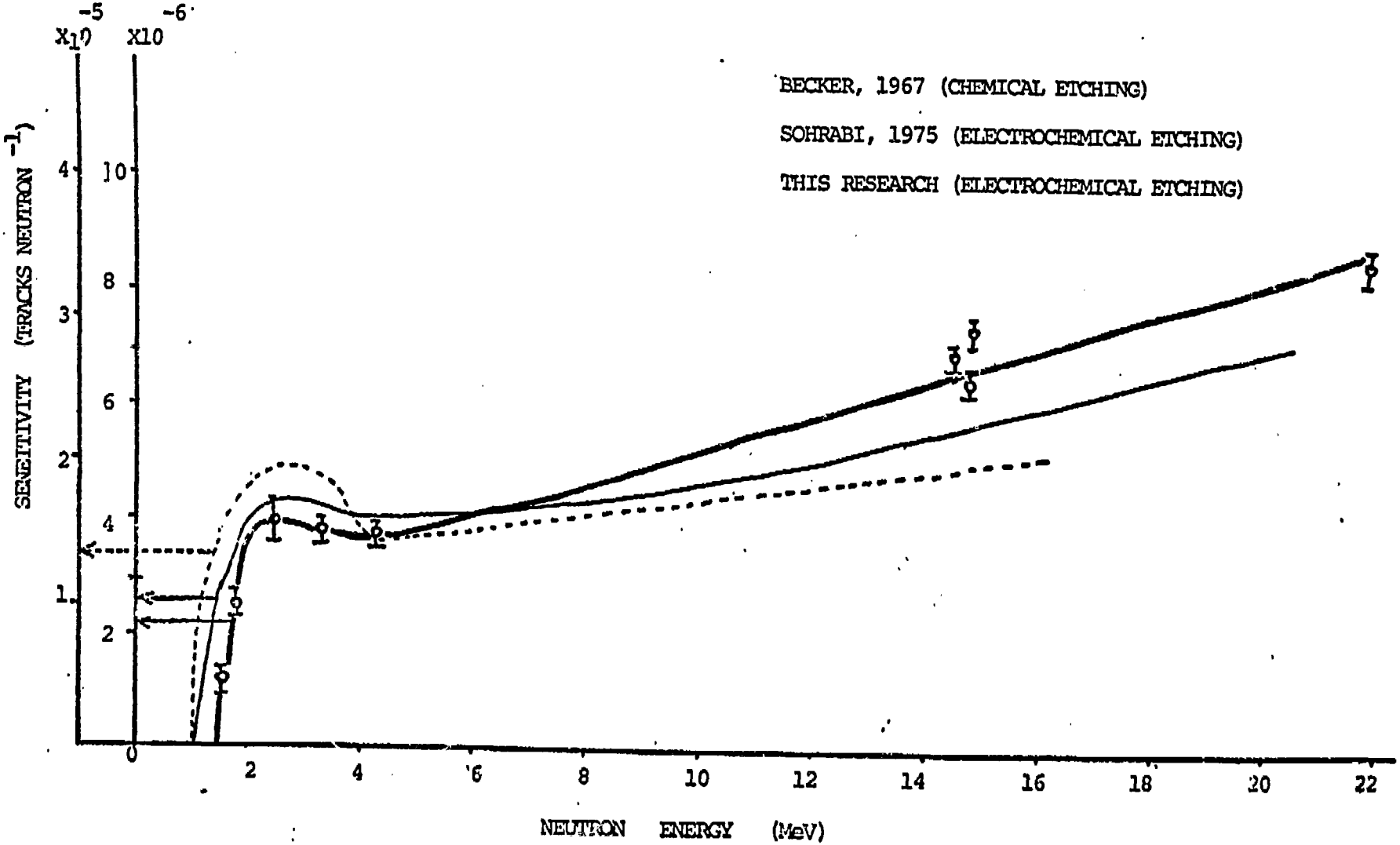

Fig. 4 Neutron Sensitivity(tracks/n) as a Function of Neutron Energy

oxygen recoils could form etchable tracks if their energy exceeds the limits of 2.6 ~ 2.9 x 10^{-2} MeV/amu, i.e., 0.32 ~ 0.35 MeV for carbon, and 2.3 ~ 2.5 x 10^{-2} MeV/anu, i.e., 0.37 ~ 0.40 MeV for oxygen.

Maximum energy transfer in "head on" collision is equal to 0.284 for neutron-carbon collision and 0.222 for neutron-oxygen collision. Thus the minimum neutron energy needed for carbon recoil registration in polycarbonate will be in the limits of 1.13 ~ 1.23 MeV. for oxygen recoil, 1.65 ~ 1.80 MeV.

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