Sci. J. Fac. Sci. Menoufia Univ, Vol. VIII (1994). 29-43

ALPHA TRACK REGISTRATION AND RANGE DETERMINATION IN PLASTIC TRACK DETECTORS

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ABSTRACT

Alpha track registration in 500 μm *thick Lexan and 3 mm CR-39 polymeric detectors has been studied at different alpha energies from 1.5 to 5.4 MeV. The dependence of track etch rate and critical angles of etching on alpha energy has been studied using Lexan foils. A method for critical angle determination, based on normalized track density measurements, has also been introduced.*

Alpha range determination in the studied plastic foils has been measured at various energies using the over etched track profile method where an extended etching was proceeded beyond the track range. Data was discussed within the framework of track formation in plastics and a comparison between the extracted range values and the corresponding theoretical ones was also included.

INTRODUCTION

Solid state nuclear track detectors have been increasingly used [1-5] in the fast-expanding field of radiation dosimetry. Different kinds of plastic detectors have been used and proven to be successfully applicable in light and heavy particle detections with a wide energy range. The response of such detectors to radiations is of great importance, it varies with energies and incident angles. The attractive features of using these recorders lie in their advantages, such as relatively low cost, easily to be used even for long-term exposure, low background level, no fading is detected under normal storage conditions, etc.

The sensitivity of a plastic detector to nuclear radiation reflects its ability of forming tracks as a result of radiation-detector interaction. These tracks can then be seen under an optical microscope after detector etching. Etching is a diffusion prcoess and can be either chemical or electrochemical or both together[6-9]. Different chemical solvents have been recommended and etching sensitivity depends on the etching conditions. Essentially two etchant solutions are commonly being in use : NaOH and KOH. As a result of radiation interaction with plastic detectors, a developed damaged zones (track core) are created which are formed of weakened bonds. When plastic detectors are subjected to etching process. the etchent attacks the damaged area more faster than the bulk material with speed V_T > the bulk etching speed. V_B. The resultant tracks in plastics are formed of intensive ionizing zones and mainly dependent on the energy deposited in the detector and the etching conditions.

The use of plastic detectors in particle identification and dosimetric applications is of great importance. In the present work. determinations of the upper alpha energy limit registration. track etch rate and critical angles in Lexan detectors have been studied under various conditions. A new method for critical angle determination in

CR-39 detectors has been introduced. Also, an overetched track profile method has been employed for alpha range determination in the studied plastic detectors exposed to different energies.

EXPERIMENTAL PROCEDURE

Sheets of Lexan polycarbonate of thicknesses 500 μm each (supplied by General Electrical Company of USA) and foils of 3 mm thick of Homalite CR-39 (supplied by Wilmington, DE, USA) were used in the present experiments. Plastic detectors were exposed to alpha particles using 0.1 μCi ^{241}Am thin source and our constructed irradiation chamber. Lexan foils were chemically etched in 6N KOH at 70°C, while an etchant solution of 6.25 N NaOH at 70°C was used for the CR-39 detectors. Track counting and diameter measurements were performed using an Olympus optical microscope whose an eye piece attached to a micrometer of each division corresponded to 0.22 μm at a magnification of 600 X.

Average values of V_B for each detector was determined using the mass decrement method[8] and V_T was obtained[1] from the relation:

$$V_T = V_B \frac{h^2 + r^2}{h^2 - r^2}$$

where h and r are the dissolved layer thickness and the track radius, respectively. The etching sensitivity of a detector is obtained from the measurements of V_B and V_T and equals to $(1-1/V)$, where $V = V_T/V_B$. The critical angle of etching (θ_c) is given by[1]: $\theta_c = \sin^{-1}(V_B/V_T)$

RESULTS AND DISCUSSION

Track development and track parameter evaluation are mainly dependent on dissolution speeds of the etchant solution along the bulk and the track regions in the plastic foils used. The etching and energy registration sensitivities of Lexan detectors have been studied. In this work, an attempt for alpha track registration of various energies in Lexan detectors has been tested up to an energy of 5.4 MeV. A revelation of alpha tracks has been obtained up to an upper energy limit of 3.5 MeV. While in case of 4, 4.5 and 5.4 MeV alphas, no tracks could be registered in Lexan detectors etched in 6N KOH at 70°C even for a prolonged etching time.

Figure 1 shows the variation of track etch rate, V_T, with the restricted energy loss, REL (MeV. Cm^2 g^{-1}), evaluated at a cut off ceiling of delta ray energy of 300 eV using Lexan foils exposed normally to different alpha energies. Detectors were etched in 6N KOH at 70°C for thickness removal layers, h, of 9.3, 11.3 and 13.3 μm. It is clear from Fig. 1 that at each value of h, V_T increases as energy decreases (i.e REL increases) since V_T is mainly dependent on the rate of energy loss within the detector when etching conditions are fixed. Figure 2 represents the variation of the critical angle of etching, θ_c, as a function of alpha energy at various values of h using Lexan foils.

Using our constructed irradiation chamber, a different method was employed for θ_c determination in CR-39 detectors. This method is based on irradiation of CR-39 detectors with various alpha energies keeping the source-to-detector distance fixed, just by changing the pressure inside the chamber. In this case the incident alpha flux on the detector can approximately be considered the same at each irradiation energy. By registering the observed track densities (ρ), at each energy value, resulting from various angles of incidence, one can normalize each ρ to that registered at $90°(\rho_{90})$ and find the normalized track density i.e. $\rho_n = \rho/\rho_{90}$.

Figure 3 displays the relation between ρ_n and θ for alpha energies of 3 and 4 MeV and h = 7 μm using CR-39 detector etched in 6.25 N NaOH at 70°C. where θ was measured with respect to the surface of the detector. θ_c can then be determined at points where $\rho_n = 0$ by extrapolating the low-ρ_n points to intercept the θ axis. Values of θ_c = 11.5 and 20° were resulted at alpha energies of 3 and 4 MeV, respectively. The present experimental results show a reasonable agreement with those obtained from etching parameter determination, where values of θ_c = 12.5 and 22° were resulted at energies 3 and 4 MeV, respectively. More experimental work is planned to investigate the applicability of this method under wide range of energies and at different etching conditions before we can make a definite final judgment.

The determination of alpha range in plastic detector has been measured using the overetched track profile method[10]. In this approach track was considered as an envelope of revelation spheres and etching was proceeded beyond the end of the track range, i.e. in the spherical phase region where the etching velocity is only V_B in all directions within the plastic material. Figure 4 represents an overetched track profile beyond the track range (R) where t is the etching time used to develop a track of radius r and t_R is the time needed to etch out a thickness equivalent to R. From the geometry of Fig. 4 one can relate the track radius, r, or the track diameter, d, with the other parameters shown. The d^2 relationship can then be simplified and written in the following form:

$$d^2 = (2r)^2 = 8\, V_B\,(R - V_B\, t_R)\, t + 4(V_B^2\, t_R^2 - R^2) \quad (1)$$

It is clear from Eqn. 1 that d^2 changes linearly with t within the overetched region. Assuming the slope and the intercept parts in Eqn. 1 to be m and c, respectively so one can then write the range, R, and the time t_R in the following forms:

$$R = (m/16V_B - c.V_B/m) \quad \& \quad t_R = (-m/16V_B^2 - c/m) \qquad (2)$$

Samples of CR-39 track detectors were exposed to normally incident alphas of energies 1.5, 2.25, 3.0, 3.25, 4.0, 4.75 and 5.4 MeV and etched in 6.25 N NaOH at 70°C. Figure 5(a&b) represents the relation between the track diameter square, d^2 (μm^2), and etching time, t (hr). Values of R can be obtained from the slope and the intercept resulting from the extrapolation of the linear part of each curve in Fig. 5 to t = 0 axis. Knowing the slope and the intercept of these lines and with the aid of Eqn. 2, one can solve for R and t_R. The average track etch rate, ($\overline{V}_T = R \quad t_R$) can then be calculated. Figure 6 represents the variation of d^2 with t using Lexan detectors etched in 6 N KOH at 70°C and exposed to various alpha energies. From the data of Fig. 6 one can extrapolate the linear part and solve for R and t_R as mentioned above. Fig. 7(a&b) shows the measured and calculated alpha ranges as a function of energy in CR-39 (Fig. 7a) and Lexan (Fig. 7b). The theorectical calculations were obtained using a TRIM computer program[11] and are represented in Fig. 7. It is clear from Fig. 7 that there are some differences between the experimental and theoretical range values and this might be due to the fact that in the theoretical calculation the contribution of energy deposited from δ-rays is not all included.

As a closing remark, it can be said that the initial results of θ_c determination from the normalized track density are encouraging and can be used in detector sensitivity evaluation. Finally, the use of the overetched track profile method in particle identification has been extensively tested through a large set of experiments and proved to work quite well in alpha range determination.

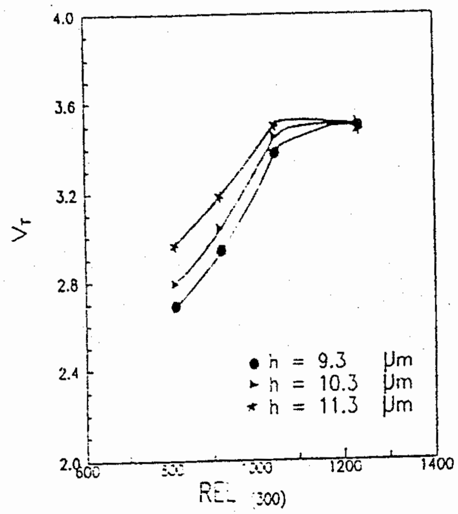

Fig. (1): Variation of track etch rate, V_T, with restricted energy loss, REL_{300}, using Lexan foils exposed to alpha energy and etched in 6N KOH at 70°C for different removal thickness layers, h.

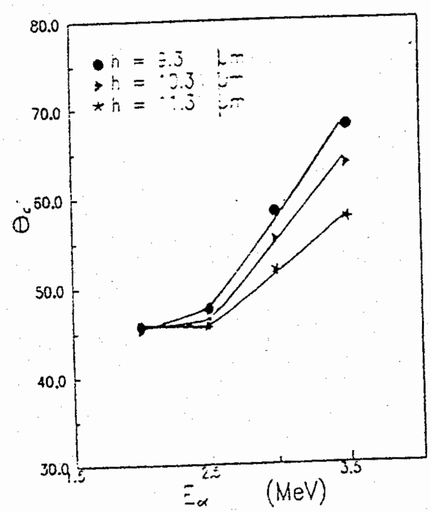

Fig. (2): Dependence of the critical angle of etching, θ_c, on alpha energy using Lexan detector.

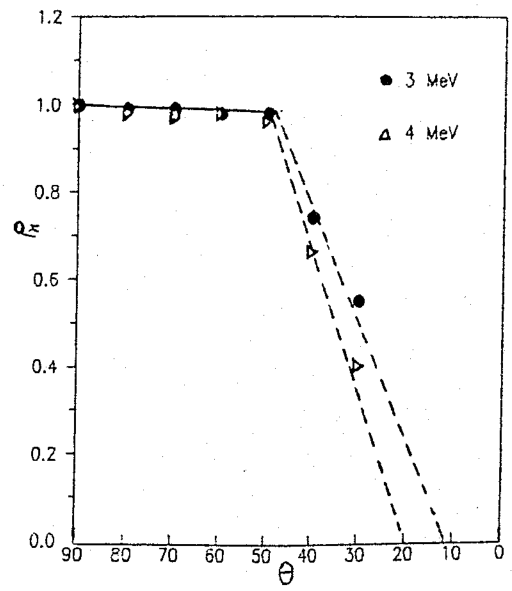

Fig. (3): Dependence of the normalized track density, ρ_n , on alpha incident angle, θ, using CR-39 detector etched for h = 7 µm.

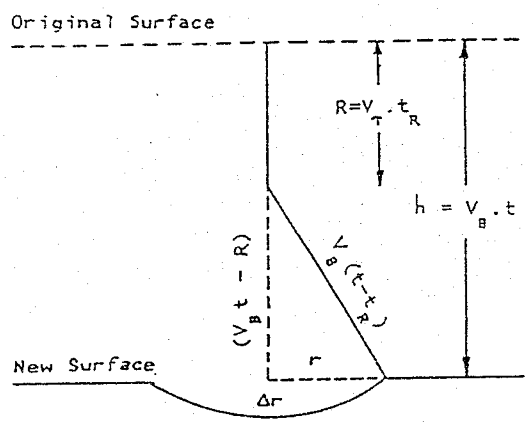

Fig. (4): An overetched alpha track profile of radius r.

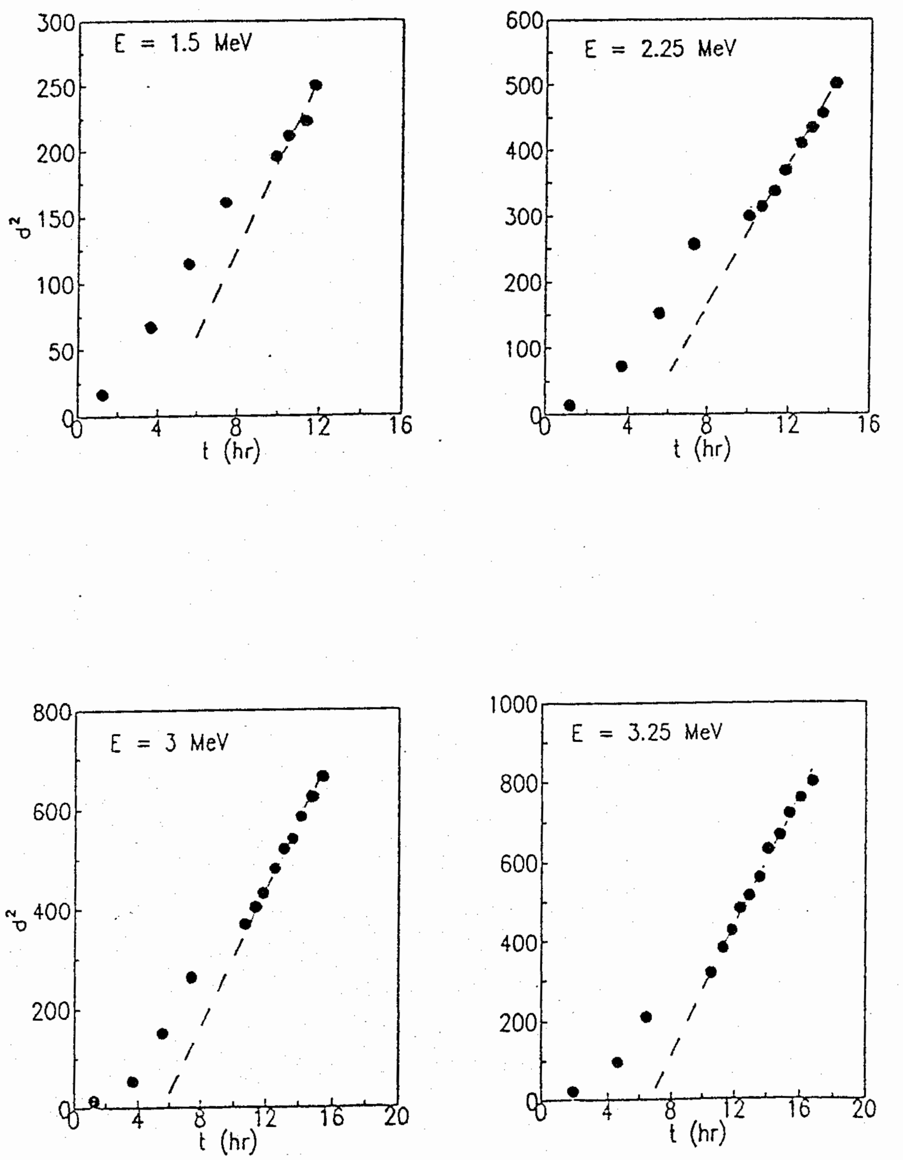

Fig. (5a): Variation of track diameter square, d^2 (μm^2), with etching time, t, at alpha energies of 1.5, 2.25, 3 and 3.25 MeV using 3 mm thick CR-39 detectors etched in 6.25 N NaOH at 70°C.

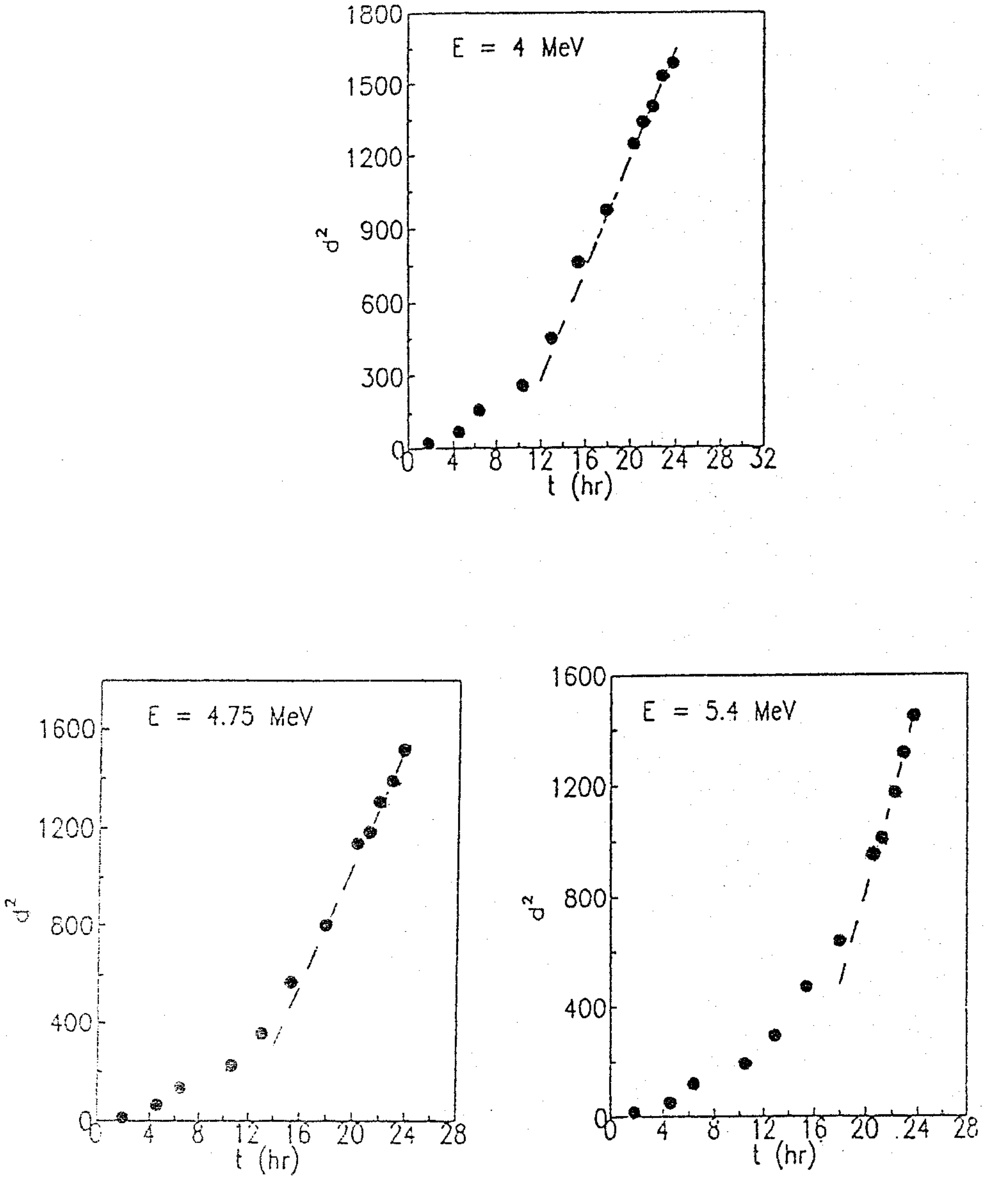

Fig. (5b): Same as in caption of Fig. 5a but at alpha energies of 4, 4.75 and 5.4 MeV.

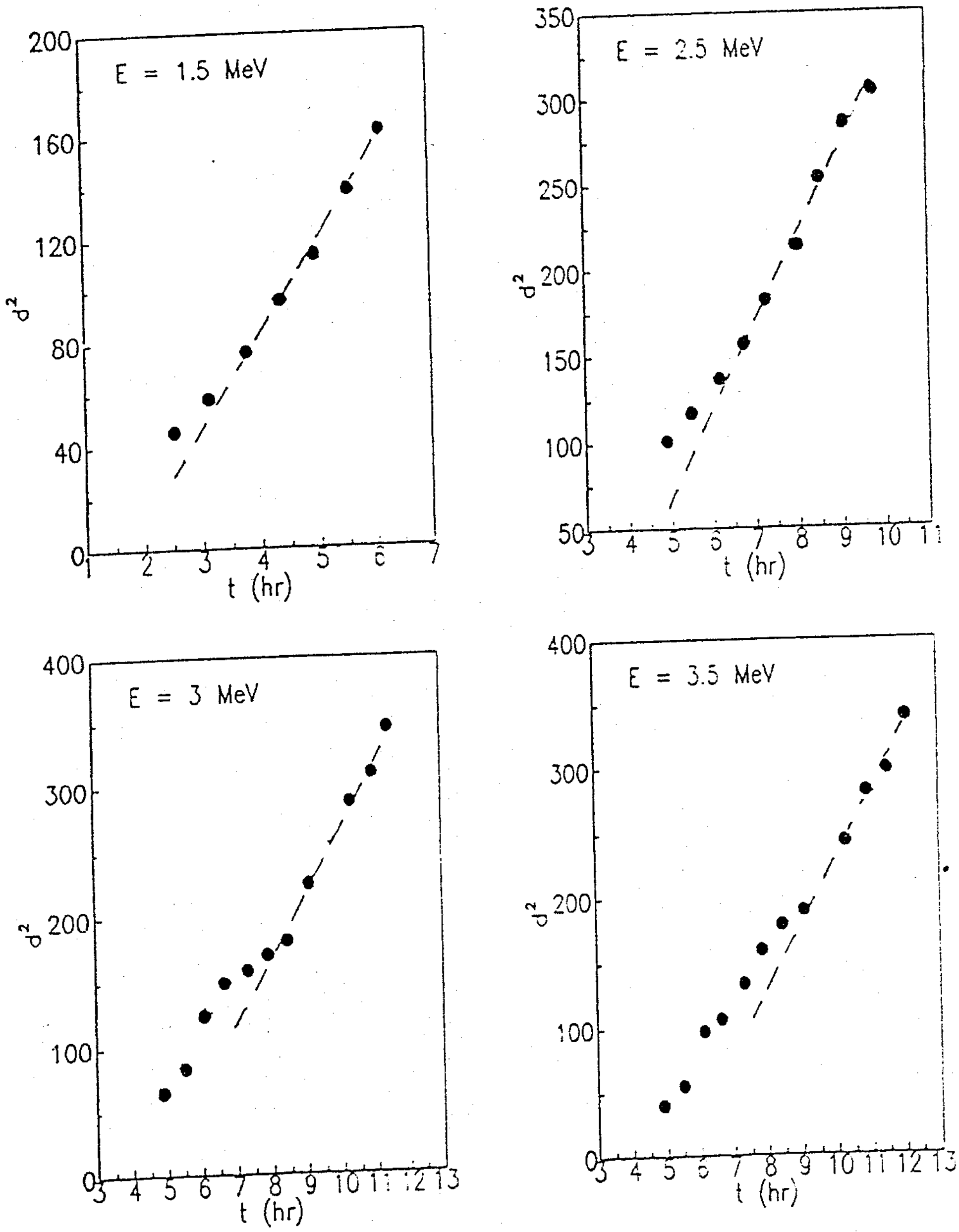

Fig.6

Fig. (6): Variation of d^2 (μm^2) with t at alpha energies of 1.5, 2.5, 3 and 4 MeV using Lexan foils etched in 6N KOH at 70°C.

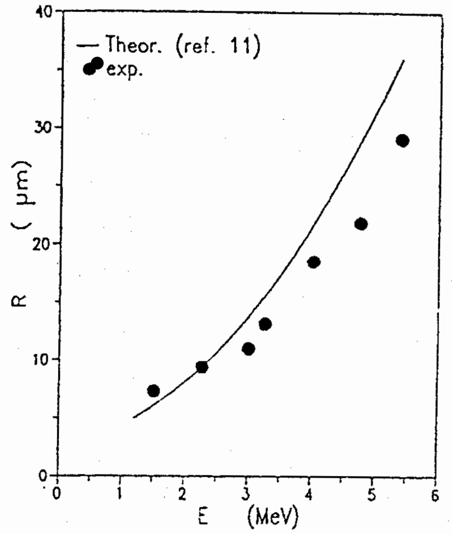

Fig. (7a): Measured and calculated alpha ranges as a function of energy using CR-39 foils etched in 6.25 N NaOH at 70°C.

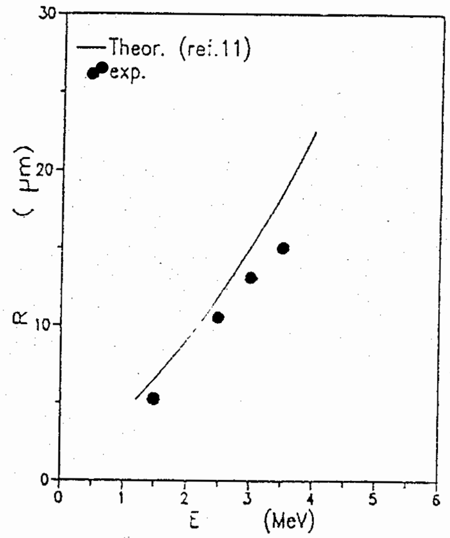

Fig. (7b): Same as in caption of Fig. 7a but using Lexan foils etched in 6 N KOH at 70°C.

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تسجيل آثار ألفا وتعيين المدى لها خلال الكواشف البلاستيكية

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فى هذه الدراسة تم تسجيل جُسيمات ألفا خلال كواشف الحالة الجامدة للأثر النووى (الليكسان ، س ر-٣٩) وذلك فى مدى الطاقة من ١,٥ إلى ٥,٤ م.أ.ف وقد أمكن تحسين قيمة طاقة التسجيل العظمى لكواشف الليكسان حتى ٣,٥ م.أ.ف كذلك أمكن قياس زوايا الحفر الحرجة بطريقة مستحدثة من خلال تشعيع عينات من س ر-٣٩ فى غرفة التشعيع المصممة لدينا وذلك عند زوايا سقوط مختلفة لجسيمات ألفا وقياس كثافة الأثر النووى النسبى بالمقارنة بنظيره الساقط بزاوية ٩٠ °. وباستخدام طريقة الحفر الكيميائى المتتابع بأزمنة كبيرة تم تعيين قيم المدى لجسيمات ألفا بطاقات مختلفة ومقارنة ذلك بالحسابات النظرية لكواشف الليكسان و س ر-٣٩ .