REGISTRATION OF ALPHA-PARTICLES AND FISSION FRAGMENTS TRACKS IN MAKROFOL-E PLASTIC DETECTOR

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ABSTRACT

In this work, Makrofol-E plastic detectors were used in the registration of alpha particles and fission fragments from Cf-252. Different etching conditions were employed and the results showed that bulk etch-rate, V_B, was strongly dependent on the weight ratio of ethyl alcohol to KOH solutions that forming the etching solvent. An optimum etching conditions of 20% ethyl alcohol and 80% 5.25 M KOH solution at 60°C for 60 minutes were recommended for alpha tracks revelation that resulting from alpha energy values up to 4.5 MeV. An empirical relationship between track etch-rates ratio, V, and residual range, R, of alpha-particles was obtained. A mean range of fission fragments (maximum track length, L,) of about 19.5 μm was measured in Makrofol-E which is in agreement with previous measurement.

Keywords: Bulk-etch rate, alpha registration, Makrofol-E response, range of fission fragment.

INTRODUCTION

Solid State Nuclear Track Detectors (SSNTD) are being used, with a great success in various fields of radiation dosimetry. They have been proved to be applicable [1-3] in neutron dosimetry, alpha-autoradiography, radon measurements, uranium and thorium determination in natural samples, fission track dating, etc. Makrofol-E polycarbonate plastic detector is one of the currently recommended recorders that have being used by many investigators [4,5].

When charged particles pass through the plastic foil, they produce narrow damage trails. In order to make such damage zones (tracks) visible, a suitable chemical etching process should first be done. Etchants dissolve these damage regions at a faster rate than those of undamaged area. As a result a clear etch pits can then been seen under an optical microscope. The rates of chemical attacks along the particle trajectory and the bulk material are defined as track-etch rate, V_T, and bulk-etch rate, V_B, respectively. The visibility of tracks depends on the relation between V_B and V_T. V_B and V_T are functions of etching conditions i.e concentration and temperature of etchant as well as etching durations. V_T depends also on the incident particle characterization such as charge, mass, energy value and angle of incidence. Therefore, a determination of V_B and V_T is very important for understanding the track formation in plastic.

The registration of alpha - particle tracks in plastic detectors such as Lexan and Makrofol-E were studied before [6-10]. The sensitive particle energy domain was carefully discussed, for example Enge [6] reported that no alpha tracks could be registered, in these detectors, at any energy values. While Durrani [7] has shown that the revelation of alpha tracks was only possible for energies below 2.0 MeV. But using PEW (15g KOH + 45g H_2O + 40gC_2H_5OH) as an etchant solution, Somogi [8] was able to detect alpha tracks in Makrofol-E for energy values up to 3.0 MeV. Ceser et al [9] proved that the Makrofol-E detectors are sensitive for track formation for energies up to about 5.48 MeV. Using alpha energies from 0.1 to 5.8 MeV, tracks were formed [10] in Lexan under special treatment of etching [28% KOH Using ultrasonic waves].

Many attempts have been made [11-15] for the registration and separation of the two energy groups of fission fragments in SSNTD. These studies were carried out through track length or track diameter measurements using Cf-252 source.

In the present work measurements of alpha-particles registration in Makrofol-E plastic detector have been studied and the response function has been extracted.

Mean range of fission fragments from Cf-252 has also been determined and relation between mean track diameters of fission products and their initial energies have then been deduced.

EXPERIMENT

In this work, Makrofol-E polycarbonate sheets (manufactured by Bayer A.G. of W. Gerwany) of thickness 250 μm and density 1.2 g.cm^{-3} was used. Sheets were exposed to 1.0 μCi Am-241 alpha source and to fission fragments using 1.0 μCi Cf-252 open source. These sources have a 5 mm active diameter and covered with a gold layer of thichness 100 μg.cm^{-2}. Energy values of alphas and fission fragments were degraded using different air gap columns between the source and detector through a collimater of plexiglass with diameter of 1.0 mm. Ionizing particles were allowed to fall perpendicularly on the detector surface.

The mean range of fission fragments in Makrofol-E was determined using the Cf-252 source. The source was covred with Al foil which has a 0.5 mm pin hole and irradiation was performed under vacuum (about 10^{-2} torr). By this manner one was ensured that the fission products reached the detector surface without any loss in their initial kinetic energies. Also, the position of track detector could be adjusted so that fission fragments could hit the detector surface at the desired angle of incidence.

Etching reagent of alpha tracks was chosen to be a mixture of ethyl alcohol ($C_2 H_5 OH$) and 5.25 M KOH solution with varying weight ratios. Etching temperature was taken as 60°C for different duration times. While in case of fission tracks development an etchant of 6.25 M NaOH at 70°C was used. Etching was carried out using shaking Gallenkamp water bath with temperature controller of $\pm$ 0.5°C. Measurements of track diameter and length were determined using a Leitz Dialux - 20 EB transimission optical microscope with a magnification 300 and 750 X. A 15 X eyepiece screw micrometer, each division corresponded to 0.2 μm, was attached to the microscope.

RESULTS AND DISCUSSION

The bulk etch - rate, V_B, was determined by measuring the dissolved layer from one surface of the Makrofol-E detector during an etching time t, by the following relation.

$$V_B = \frac{\Delta m}{2\rho \, At} \qquad (1)$$

Where Δ m is the mass decrement of the detector as a result of etching process, ρ and A are the density and the cross-sectional area of the detector respectively. Δm was determined using an electric balance whose accuracy is 0.1 mg.

Figure (1) represent the variation of V_B with etching concentrations of ethyl alcohol and 5.25M KOH solution in the etchant mixture at 60°C. It is clear from this figure that V_B is strongly dependent on the etchant composite - ratio and shows a linearity behavior with increasing the alcohol concentration.
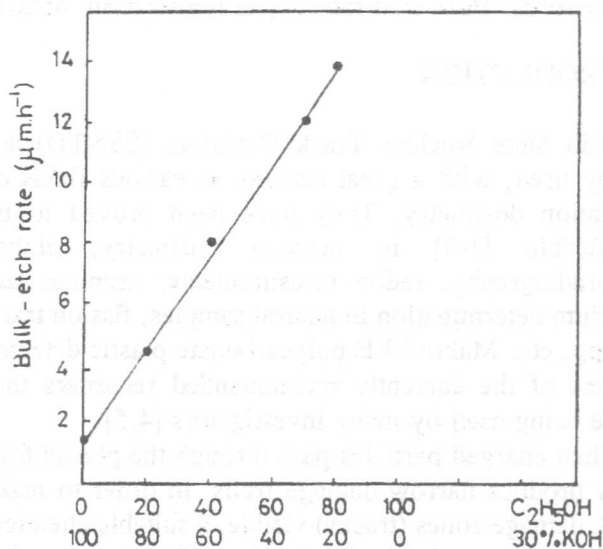

Figure 1. Variation in V_B as a function of relative concentration 5.25 M KOH solution and ethyl alcohol at 60°C.

The effect of ethyl alcohol on the sensitivity, V, of the plastic detector was studied. Sheets of Makrofol - E were exposed to normally incident alpha particles of energies 1.8, 2.5 and 4.50 MeV. Sheets were etched in a mixture of 5.25 M KOH solution and C_2H_5OH of various percentage ratios. Each detector was etched for 5 minutes and immediately washed in running water and then in distilled water for about one hour and

finally dried at room temperature. The etched detectors were examined under microscope. This processes of etching and track diameter measurement were repeated until the observed tracks became brittle and foggy, i.e. until track contour could not be defined.

Figure 2. The mean track diameters of alpha-particles as a function of etching time at different ethyl alcohol concentration:

⚪ - 20%   △ - 40%,   ◼ - 60%, ⚪ - 75%

percent by weight

Alpha particle energy:

A - 1.8 MeV,   B - 2.5 MeV, C - 4.5 MeV.

Figure (2) shows the variation of the mean track diameter of alpha-particles with etching time where Figures (2a), (2b) and (2c) represent data measured at

incident energy values of 1.8, 2.5 and 4.5 MeV. respectively. Each set of curves was determined under various condition of etching mixture solution. It is clear from the figures that the track diameters depend on both etching time and ethyl alcohol concentration. In order to reserve the defined track shape, one has to search for an optimum etching time t_{op} which meets such requirement. Table (1) summarizes the values of t_{op} for different C_2H_5OH concentrations from 20% up to 80% using alpha energies E_α of 1.8 and 4.0 MeV. From the results it is recommended to use the reagent of 20% ethyl alcohol and 80% 5.25 M KOH solution at 60°C. The etching time was 60 minutes interrupter for alpha energy value up to 4.5 MeV.

The sensitivity V (= V_T/V_B), ectch-rates ratio, was obtained as a function of residual range R, where V is given by [8]:

$$V = \frac{H^2 + r^2}{H^2 - r^2} \qquad (2)$$

Where r is the mean track radius and H (= $V_B.t$) is the dissolved out layer from the detector surface during an etching time t_{op}. The values of residual range R were calculated using the relation.

$$R = R_o - H \qquad (3)$$

Where R_o is the range of incident alpha-particles in the plastic detector. Values of R_o were taken from [16].

Figure (3) illustrates the variation of the mean track diameter in Makrofol-E versus alpha energy. Again detectors were etched under the above mentioned optimum conditions and track diameter increases with decreasing values of alpha energy. By evaluating the values of R at different initial values of alpha energy, one can correlate the values of V, obtained at the same E_α to those of R. Figure (4) displays the response function, V (R), as a function of R. V(R) was found to fit the following empirical formula

$$V(R) = 1 + \exp(-AR + B) \qquad (4)$$

Where A and B are fitting parameters which are characterized by the detector material and etching conditions. Typical values of A and B were found to be 0.015 and 1.04, respectively, with correlation coefficients of about 99%.
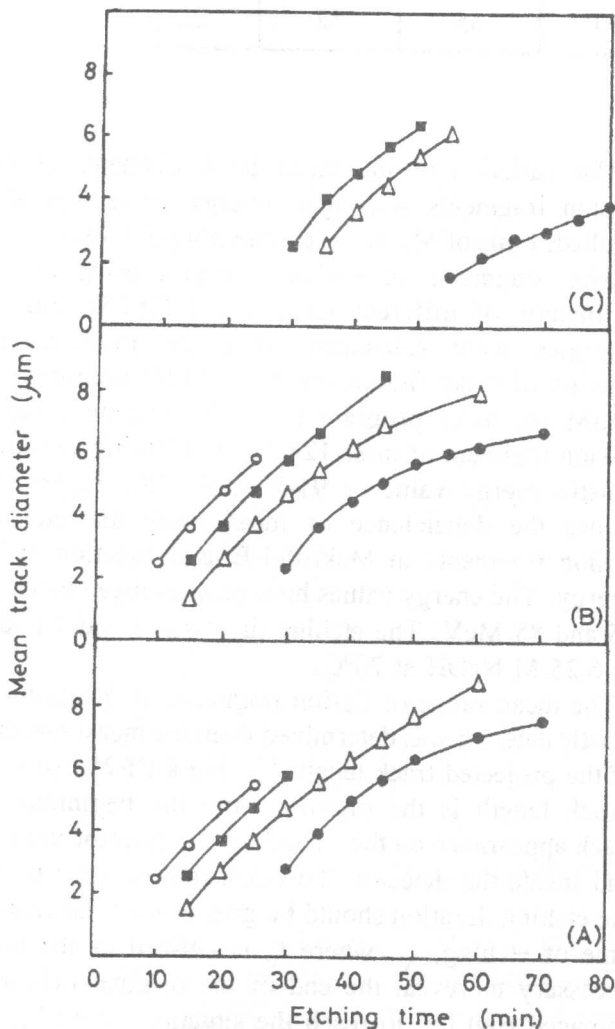
Table 1. The values of optimum etching time for revealing tracks of alpha-particles with energies 1.8 MeV and 4.0 MeV in Makrofol-E which was etched in maxture of ethyle alcohol and 5.25 M KOH solution at 60°C.

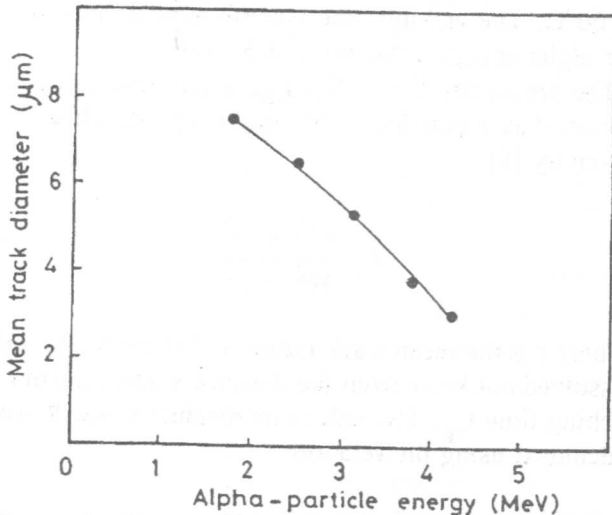| E_α(MeV)	C_2H_5OH % *	20	40	50	60	80
1.8	t_{op} (min)	35	30	30	25	10
4.0	t_{op} (min)	70	40	35	32	30

* Percent by weight.

Figure 3. The variation of mean track diameters of alpha particles in Makrofol-E vs initial energy. The Makrofol-E was etched in mixture of 20% ethyl alcohol and 80% 5.25 M KOH solution at 60°C. The etching time was 60 minutes.
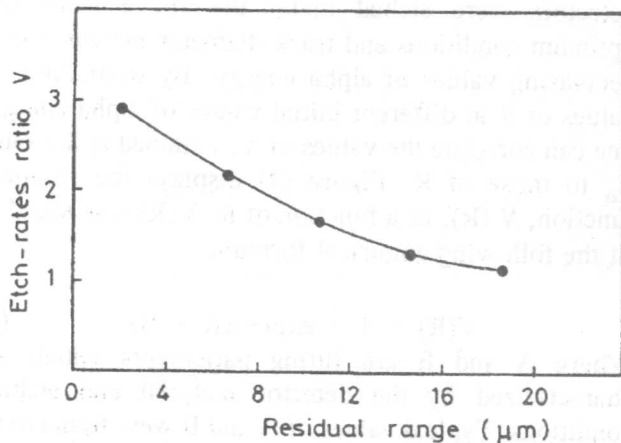

Figure 4. Etch-rates ratio V as a function of the residual range for alpha particles registered in Makrofol-E. The etching condition as in figure 3.

The variation of the mean track diameter of the fission fragments with their energy value was also studied. Foils of Makrofol-E were normally exposed to fission fragments of various energies using an air collimator of different lengths and Cf-252 source. Energies were calculated from the range-energy relation of mean fission fragments in air according to TRIM computer program [17]. Considering a mean fission fragment of mass 124.1 a m u having an initial kinetic energy value of 91.7 MeV [15]. Figure (5) shows the dependence of mean track diameter of fission fragments in Makrofol-E as a function of its energy. The energy values have been changed between 15 and 85 MeV. The etching time was 3 and 7 hours in 6.25 M NaOH at 70°C.

The mean range of fission fragments in Makrofol-E plastic detector was determined from the measurements of the projected track length l, using a Cf-252 source. Track length is the distance from the beginning of track appearance on the surface of the detector until its end inside the detector. To reach the end of a track, the etching duration should be greater than the critical time of etching, t_c, where t_c is defined as the time necessary to reveal the end of the original radiation damaged trail i.e. to reach the situation where $V_B = V_T$. To obtain t_c, foils of Makrofol-E was exposed to fission fragments with an incident angle 20°. The irradiated foils were then etched in the previously mentioned etchant solution. This process of etching was successively done every 10.0 minutes until the track became circular shape. Actually, there is a track length distribution in Makrofol-E as a result of the mass or energy distribution of the fission fragments. This distribution emerged in a form of a single peak.
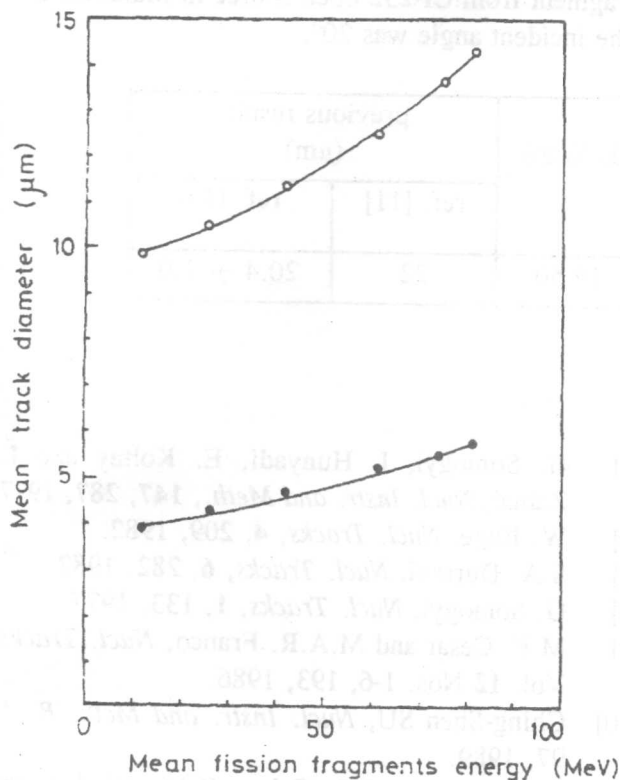
Figure 5. The variation of mean track diameter of fission fragments in Makrofol-E vs its initial energy. The Makerofol-E was etched in 6.25 M NaOH at 70°C. Etching time was:

○ - three hours and ○ - seven hours.

Figure (6) shows the variation of the projected track length, l, as a function of etching time, t. It is clear that, l increases with increasing t and reaches a proad maximum, while a further increase in t leads to a gradually decrease in l. The value of t_c can be obtained from the point at which starts to decrease linearly with t. The decrease in l may be attributed to the decrease in V_T which becomes less than $V_B/\sin 20$.

The range (maximum etchable track length, L,) of the fission fragment was determined from the maximum projected track length according to the formula [14]:

$$L = \frac{1}{\cos\theta} + \frac{V_B \cdot t}{\sin\theta} - V_B(t-t_c) \qquad (5)$$

where θ is the incident angle of fission fragment (= 20°), l is the track-length projection on the surface plane of the detector and t the duration of etching time. The second term on the right-hand side of equation (5) was used to correct for the decrease in track length due to the dissolved layer H from the detector surface during the etching processes. While the third term corrects for the extent to the actual track which has been lengthened in its original direction due to the over etching for a period of (t-t_c). Table (2) lists our measured parameters of the etched track length of fission fragments in Makrofol-E from Cf-252 in comparison with the mean range of fission fragments in polycarbonate Lexan [11,14].
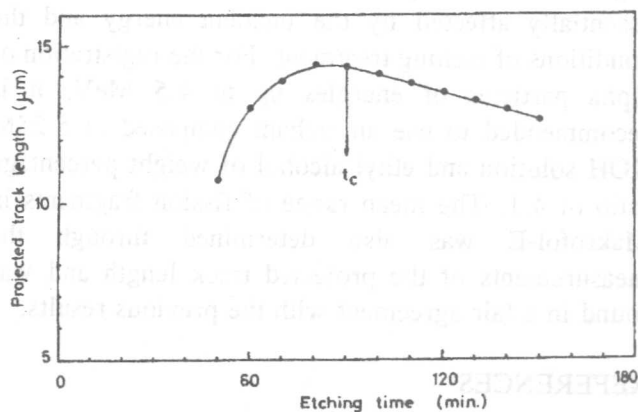

Figure 6. Variation of projected track length of fission fragments from Cf-252 source with etching time. The Makrofol-E was etched in 6.25 M NaOH at 70°C.

Instead of considering the mass distribution of fission fragments, two fragments of masses 106.4 a m u (light) and 141.7 a m u (heavy) with kinetic energies of 104.1 and 79.3 MeV [15] were considered. The ranges of these two products in Makrofol-E, calculated using TRIM computer program [17] were found to be 20.1 and 18.7 μm respectively. It is clear from the present measurement that (see table 2) the range of the fission fragment is in a good agreement with the previous values. Also, the present value of L lies between the two calculated range values obtained from the TRIM program.

Table 2. The paramters of etched track length of fission fragment from Cf-252 open source in Makr etched in 6.25 M NaOH at 70°C. The incident angle was 20°.

max.l (μm)	t_c (min)	$\dfrac{t_c\,V_B}{\sin\theta}$ (μm)	L (μm)	previous result (μm)	
				ref. [11]	ref. [14]
14.3	90	4.3	19.50	22	20.4 ± 1.0

CONCLUSION

From the present results it is concluded that, the registration of alpha tracks in Makrofol-E was essentially affected by the incident energy and the conditions of etching treatment. For the registration of alpha particles of energies up to 4.5 MeV, it is recommended to use an etchant composed of 5.25M KOH solution and ethyl alcohol of weight percentage ratio of 4.1. The mean range of fission fragments in Makrofol-E was also determined through the measurements of the projected track length and was found in a fair agreement with the previous results.

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