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Investigation on ^{252}Cf Fission Fragment Tracks in Polycarbonate Detectors

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ABSTRACT

Registration and development of fission fragments emitted from ^{252}Cf source have been carried out in three different polycarbonate detectors. The detectors have been characterised in terms of bulk etch rate and its behaviour. Maximum etchable cone lengths have been compared with the theoretically computed values. Identification of the fission fragments in terms of their mass and charge has been done with the help of the computer programme 'FFR'.

NOMENCLATURE

D_c Critical diameter
L track length
L_{MH} length of medium heavy fragments
L_{ML} length of light medium fragments
S_d plot slope μm/hr
S_t slope of thickness versus etching time plot
t_c time taken to etch the track
V_G bulk etch rate
V_T track etch rate
θ_c cone angle

1. INTRODUCTION

Polycarbonates are found to be suitable for the preparation of ion track filters[1] because of their uniformity in pore size and regular pore shape. They have been applied to prepare 'weak links' of a potential barrier to observe the superfluid analogue of the superconductive Josephson effect[2]. They are also applied in the fields where microapertures are a basic requirement as in microbiology and virology[3,4]. Thus microapertures of regular size and shape are of utmost importance. To create such microapertures of desired size and shape, the knowledge of various track parameters like track etch rate (V_T), bulk etch rate (V_G) and maximum etchable track lengths is essential.

Keeping in view the above facts, the present study involves

(a) Registration and development of the latent damage trails created by ^{252}Cf in three different polycarbonate detectors, viz Makrofol-E, Makrofol-KG, Makrofol-N;

(b) Investigation on isotropic behaviour of bulk etching in these detectors by the comparison of V_G determined by two methods, viz track diameter and thickness;

(c) Measurement of the most probable track lengths of fission fragments in these detectors and comparison with the theoretically obtained values*;

(d) Attempting to calibrate the detectors by the correlations: track etch rate V_T as a function of etched track length and LR plot method;

(e) Determination of critical parameters, such as critical cone angle, critical diameter (essential to determine the etching efficiency[5] under a specified etching condition) from t_c (time to completely etch the tracks); and

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(f) Identification of fission fragments from the maximum etchable track lengths with the help of the computer code 'FFR'*. Further work of correlating V_T with other parameters after mass identification is in progress.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of Detectors and Irradiation

For the proposed experiment, various polycarbonate detectors selected were: yellow Makrofol-N; colourless Makrofol-E; and greenish yellow coloured Makrofol-KG; chemically known as bishenol—a polycarbonate having the molecular formula $C_{16}H_{14}O_3$, molecular weight 254.0 and density 1.23, 1.14 and 1.18, respectively. Several rectangular pieces of size (2 × 2) cm^2 were cut from the sheets manufactured by Bayer AG, Leverkusen, Germany. They were then washed thoroughly with luke warm soap solution and deionized water to remove surface contamination.

The detectors were exposed to the fission fragments emitted from a 20 ng ^{252}Cf source with a fission activity 6×10^3 s^{-1} at inclinations of 30, 45 and 90 degrees to the direction of the flux. Exposures were carried out in vacuum.

2.2 Chemical Etching for Track Development

The irradiated samples were etched in 6N *NaOH* at 55 ± 0.5 °C after washing the detectors in luke warm soap solution to avoid non-uniformity in etching due to surface contamination.

2.3 Measurement of Track Parameters

Etched track lengths and diameters in each of the detectors were measured with the help of Leitz optical microscope at 100X and 40X object magnifications.

The detectors were etched successively to measure the rate of increase of track length and diameter with time. For 10–15 identified tracks the track diameters were measured as minor axis of the elliptical face of the track and projected track lengths were measured from centre of the track face to the end of the track. Successive etching is helpful in determining t_c.

2.4 Determination of V_G

2.4.1 Track Diameter Method[6]

The detectors irradiated at 90° to the fission fragment flux were etched in a suitable etching condition (6N *NaOH* at 55 °C) successively to measure the rate of increase of diameter with time. V_G was determined from the slope of the plot (diameter vs etching time in Fig. 1) with the help of the equation

$$V_G = S_d/2 \tag{1}$$

2.4.2 Thickness Method using Heidenhain Depth Measuring Device

Measuring gauze (CT-60): The measuring length of gauze (CT-60) of Heidenhain depth measuring device has a glass scale with a DIADUR line grating (grating with a pitch 10 μm). The glass scale has a rigid connection to the plunger. The scale grating is photoelectrically scanned. Measuring gauze CT-60 is connected to the digital VRZ 210 display unit. The accuracy of this device is ± 0.1 μm.

The thickness of the samples was measured at 10-15 different places chosen at random. Similar measurements were carried out after every successive etching. From the slope of the plot of thickness vs etching time (Fig. 1) V_G was calculated by the equation

$$V_G = S_t/2 \tag{2}$$

2.5 Isotropy and Anisotropy of Bulk Etching

Comparison of V_G determined by two methods as explained in the previous sections has been done in the three detectors to find the isotropic behaviour of bulk etching.

2.6 Determination of V_T

The V_T was determined from the plots of true track length vs etch time in the three detectors.

2.7 Determination of Most Probable Track Lengths

Maximum etchable track lengths for nearly 500-800 fully etched tracks in these detectors were measured. Real lengths of these tracks were determined with the help of the equations given by Dwivedi and Mukherji[7]. From the distribution curves, the most probable track lengths were determined and compared with the theoretically obtained values from the computer code 'RF'.

2.8 Determination of Critical Track Parameters

The time (t_c) for complete etching of fission fragment tracks in each detecting solid was determined. The

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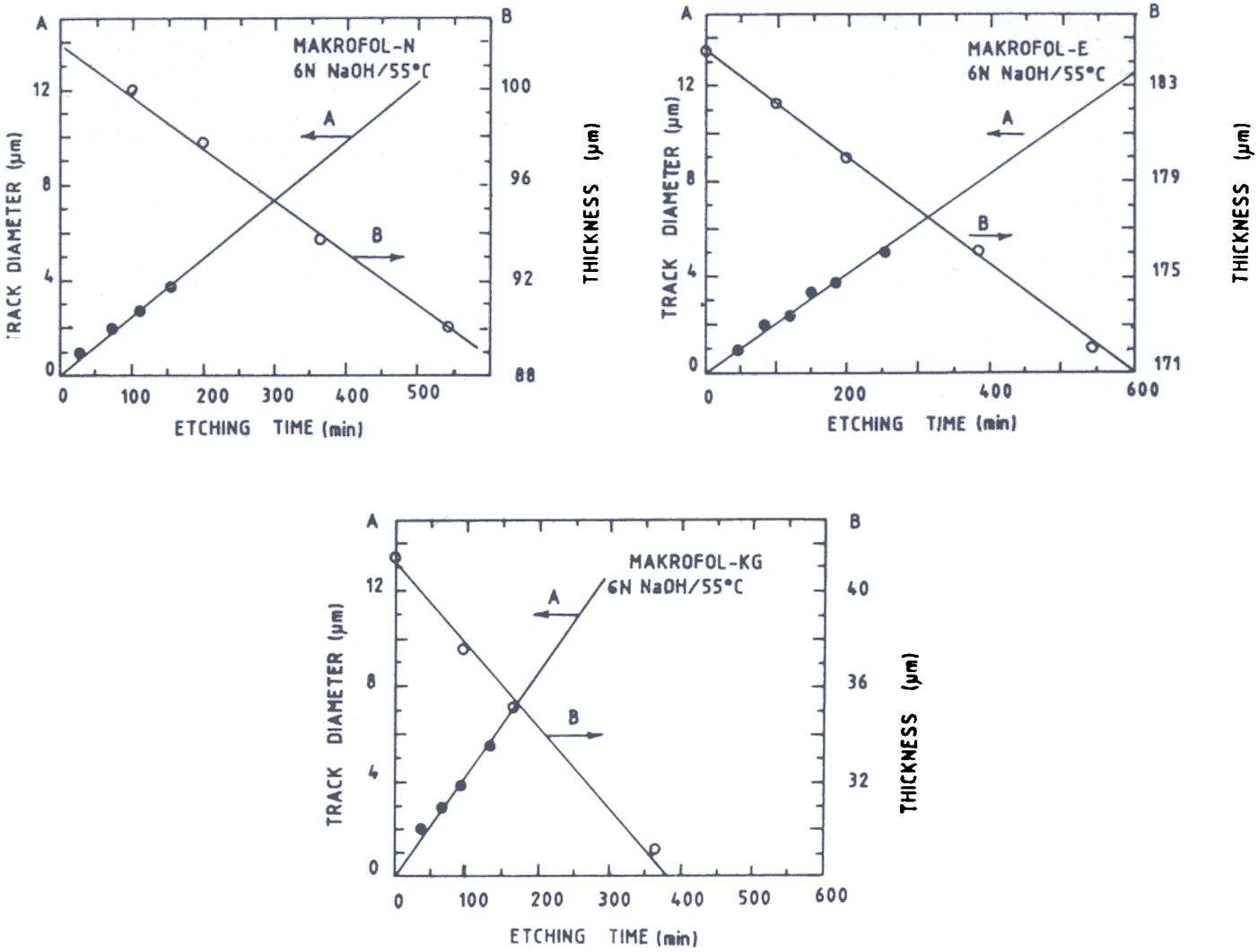

Figure 1. Plot of track diameter and thickness vs time for the three polycarbonate detectors.

critical diameter D_c and critical cone angle θ_c of the completely developed tracks are evaluated from equations

$$D_c = 2 * V_G * t_c \quad (3)$$

and

$$\theta_c = \tan^{-1} (D_c/2L) \quad (4)$$

2.9 Error Analysis

The track lengths were measured to an accuracy of ± 0.5 μm leading to an error of ± 3.4 μm in V_T determination. Considering the dip angle error of ± 2°, the systematic error in true track length measurement is ± 1.2 μm. Track diameters were measured to an accuracy of ± 0.23 μm leading to an error of 0.3 μm/hr in V_G determination in both the methods. The error in t_c, D_c and θ_c determination is less than 10 per cent. The standard error determined in the most probable track length is 2.0 μm.

3. RESULTS AND DISCUSSION

3.1 Bulk Etch Rate and Etching Isotropy

Rate of dissolution of the normal material by the etchant i.e., V_G under the specified etching condition (6N *NaOH*/55 °C) determined by two methods (Section 2.4) for the polycarbonate detectors are given in Table 1. The fairly comparable values of V_G obtained by both the methods indicate that the polycarbonate detectors behave isotropically towards bulk etching under the specified etching condition.

Table 1 Values of measured bulk etch rate by thickness and track diameter methods under etching condition of 6N *NaOH* at 55 °C

Track detector	V_G (μm/hr) Thickness method	Track diameter method
Makrofol-N	0.74 ± 0.07	0.82 ± 0.1
Makrofol-E	0.67 ± 0.07	0.63 ± 0.06
Makrofol-KG	0.34 ± 0.10	1.42 ± 0.11

3.2 Critical Track Parameters

Successive etching leads to the determination of t_c. Table 2 lists the values of t_c along with those of D_c and θ_c. From these values, it can be observed that though different time intervals were taken to completely etch the tracks, D_c has remained while θ_c is comparable withi errors which idicates that th detectors are identical un mentioned earlier.

Table 2. Values of citical etching parameters for ^{252}Cf fission fragment tracks in the three track detectors

Track detector	t_c (min)	D_c	θ_c
Makrofol-N	45.0 ± 4.0	1.1 ± 0.1	3.0 ± 0.4
Makrofol-E	70.0 ± 5.0	1.4 ± 0.1	4.0 ± 0.5
Makrofol-KG	35.0 ± 3.0	1.5 ± 0.1	4.0 ± 0.5

3.3 Most Probable Track Lengths and Comparison with Theoretical Data

Most probable track lengths in the three detectors were obtained from the gaussian distribution curves (Fig. 2) of maximum etchable track lengths. Figure 2 also shows the tracks registered at two dip angles (θ = 30 and 45 degrees). Though the mass yield curve of ^{252}Cf fission fragment shows two peaks when measured with semiconductor detector[8], the observed track distribution however, always show a single peak. The most probable track lengths obtained in these detectors have been tabulated along with the theoretically computed values by the computer code 'RF'. In Table 3 theoretical $<L>$ has been obtained by the equation

$$<L> = (L_{MH} + L_{ML})/2 \quad (5)$$

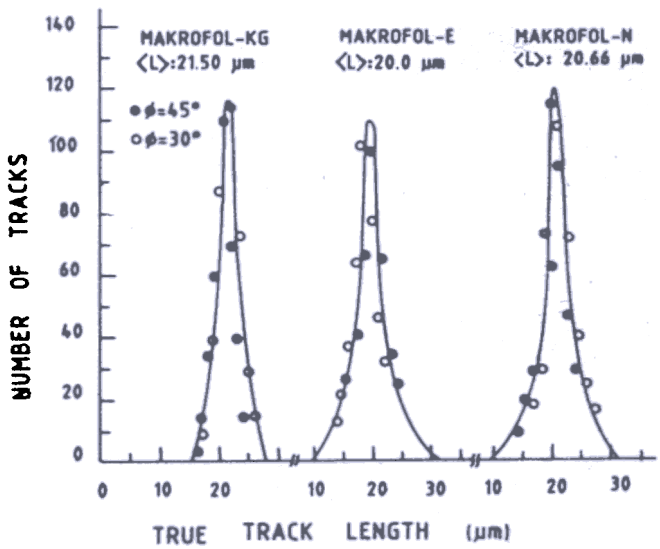

Figure 2 Plot showing true track length distribution of ^{252}Cf fission fragments in the three polycarbonate detectors.

3.4 Calibration of Detectors

Calibration of the track detectors has been done by two methods: (i) LR plot method, and (ii) correlating V_T with mean track length ($\bar{L}$).

Figure 3 shows the LR plots for calibrating the three detectors and Fig. 4 shows V_T as a function of mean track length ($\bar{L}$).

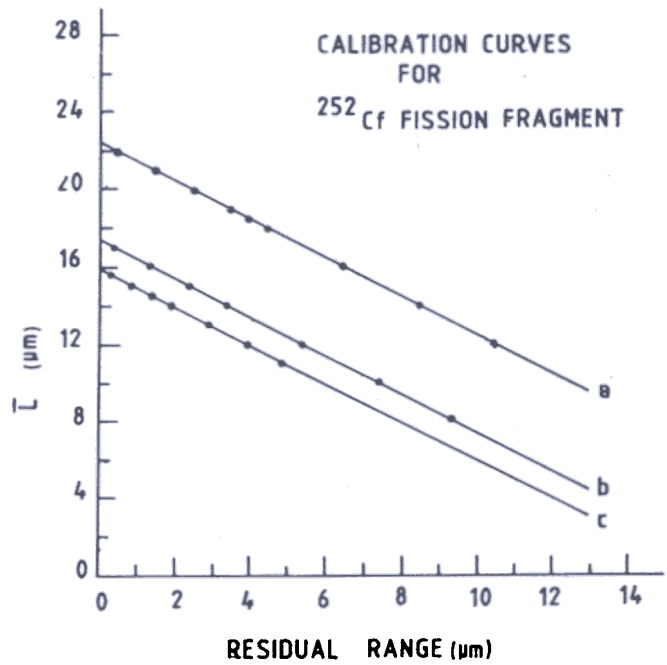

Figure 3 Calibration curves by LR plot method for ^{252}Cf fission fragments in (a) Makrofol-KG, (b) Makrofol-N, and (c) Makrofol-E.

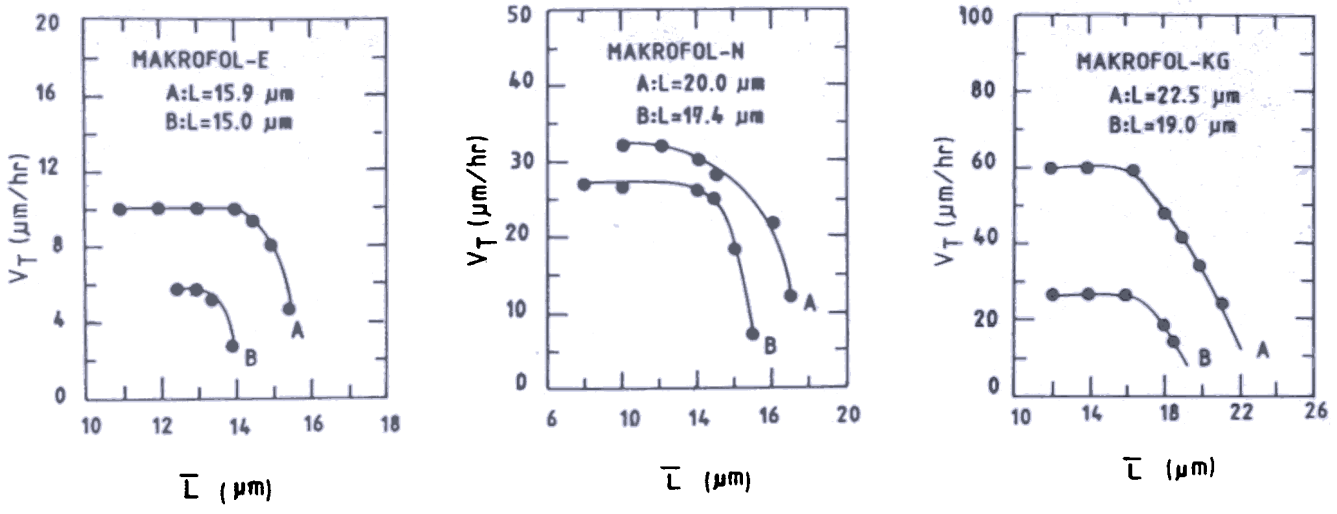

Figure 4. Calibration curves by correlating track etch rate as a function of mean track length in the three polycarbonate detectors.

Table 3. Experimental and theoretical values of the most probable track lengths of ^{252}Cf fission fragments in the three detectors

Track detector	Most probable track length (μm)	
	Experimental	Theoretical*
Makrofol-N	20.7 ± 1.0	21.34
Makrofol-E	20.0 ± 1.0	22.94
Makrofol-KG	21.5 ± 1.0	22.94

*From computer code 'RF'

3.5 Identification of Mass and Charge of the Fragments corresponding to $<L>$:

The mass and charge of the fission fragments corresponding to the most probable track lengths $<L>$ have been identified with the help of the programme 'FFR' and are tabulated in Table 4 for the three detectors.

Table 4. Mass and charge corresponding to the most probable track length in the detectors with the help of compuer code 'FFR'

Track detector	Track length Expt. $<L>$ (μm)	Charge	Mass
	20.7 ± 1.0	49.6 ± 1.6	127.0 ± 3.0
	20.0 ± 1.0	54.4 ± 1.6	139.0 ± 3.0
	21.5 ± 1.0	50.6 ± 1.6	130.0 ± 3.0

4. CONCLUSIONS

The three polycarbonates, viz Makrofol-E, Makrofol-KG, Makrofol-N behave isotropically towards bulk etching in 6N *NaOH* at 55 ± 0.5 °C. All the three detectors are found to be having similar etching efficiency under the mentioned etching condition. Comparable values of maximum etchable track lengths with the theoretical values prove the validity of the computer code 'RF' and the equations[9-12] on which the code is based.

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