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Annealing of $^{132}_{54}$Xe-ion tracks in Lexan and Makrofol plastic track detectors

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Abstract. Samples of Lexan and Makrofol-E polycarbonate plastic track detectors were exposed to 1·1 MeV/N $^{132}_{54}$Xe-ions to investigate the thermal track fading properties of these plastics. The experimental results show that there is no effect of annealing on the bulk etch rate while the track etch rate decreases with annealing. The track diameter decreases with increase in annealing time and temperature. It is also observed that the track density is reduced as a result of annealing. The experiments reveal that the track lengths are, in general, decreased by the application of heat and that the oblique tracks are less stable than the vertical tracks. The decrease in diameter of $^{132}_{54}$Xe-ion tracks in Makrofol-E due to heat treatment is faster than that of $^{132}_{54}$Xe-ion tracks in Lexan.

Keywords. Solid state nuclear track detectors; annealing; bulk etch rate; track etch rate; track length; track density.

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1. Introduction

One of the important properties which should be properly taken into account during the applications of solid state nuclear track detectors (SSNTDS) at a temperature higher than the normal room temperature is the thermal fading of latent damages. The subjection of SSNTDS to high temperatures after irradiation, but before etching, produces alterations in the damaged region which result in latent track shrinkage and an accompanying reduction of etching velocity along the track (Fleischer *et al* 1975; Khan and Durrani 1972, 1973; Besant and Ipson 1970). Thus, for accurate track analysis, proper temperature dependent corrections to the efficiency factor must be applied. The present study includes the influence of different annealing conditions on bulk etch rate, track etch rate, etch pit diameter, etchable length and track density of $^{132}_{54}$Xe-ions in polycarbonate plastic track detectors.

2. Experimental procedure

The samples of Lexan and Makrofol-E polycarbonate plastic track detectors exposed to 1·1 MeV/N $^{132}_{54}$Xe-ions were obtained from JINR, Dubna, USSR. The angles of exposure are 90° and 45° with respect to the detector surface. The exposed samples are divided into a large number of lots and annealed in air in an oven (the temperature range from room temperature to 500°C). The temperature of the oven was controlled to within $\pm$3°C. The annealed samples were etched in 6N NaOH at 70°C. The absence of error bars in all the figures represents the accuracy better than the size of the symbols used in the figures.

3. Results and discussions

3.1 *Variation of track diameter with etching temperature*

Lexan and Makrofol-E samples exposed vertically to $^{132}_{54}$Xe-ions are etched simultaneously in 6N NaOH solution at a particular etching temperature. Figures 1 and 2 show the results of our diameter measurements with etching time for $^{132}_{54}$Xe-ion tracks in Lexan and Makrofol-E respectively. The curves show a linear relationship between track diameter and etching time for different etching temperatures. Comparison of figures 1 and 2 shows that the diameter of $^{132}_{54}$Xe-ion tracks in Lexan is slightly greater than that in Makrofol-E at a particular etching time for a constant temperature. Dwivedi and Mukherji (1979) observed similar linear relationship between diameter of fission fragment tracks and etching time in Lexan detector for different etching temperatures. Somogyi (1972) also found a linear relationship between diameter of α-tracks in Makrofol-E and etching time for different etching temperatures.

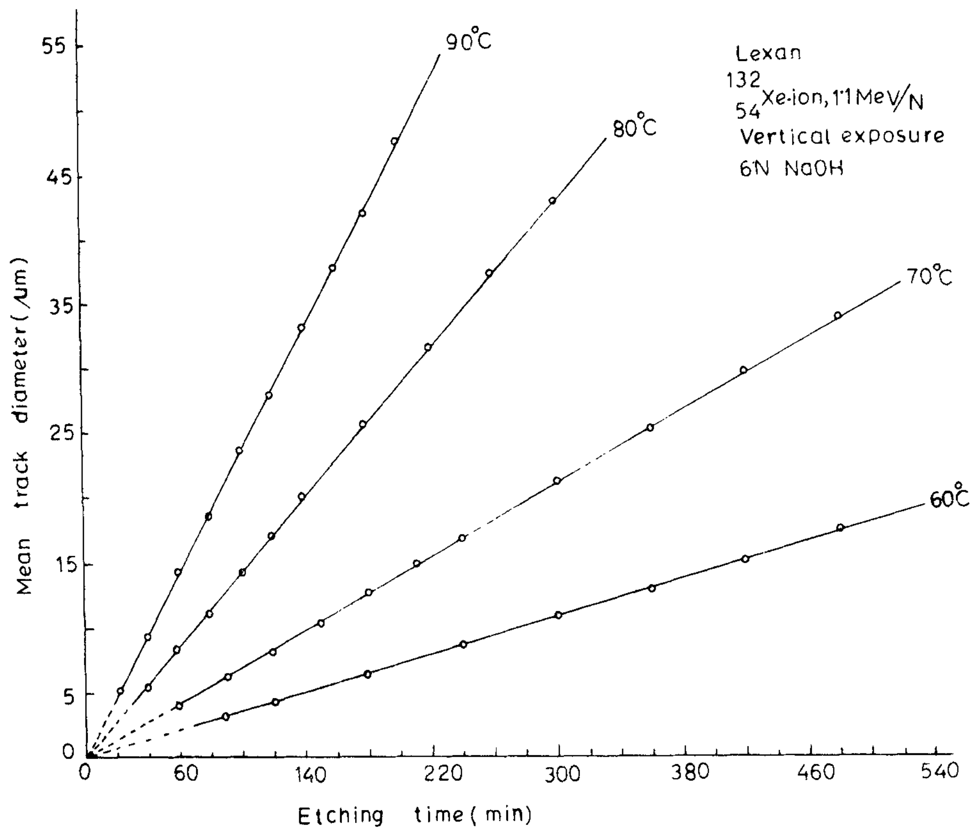

Figure 1. Variation of track diameter with etching time for $^{132}_{54}$Xe-ion tracks in Lexan for different etching temperatures.

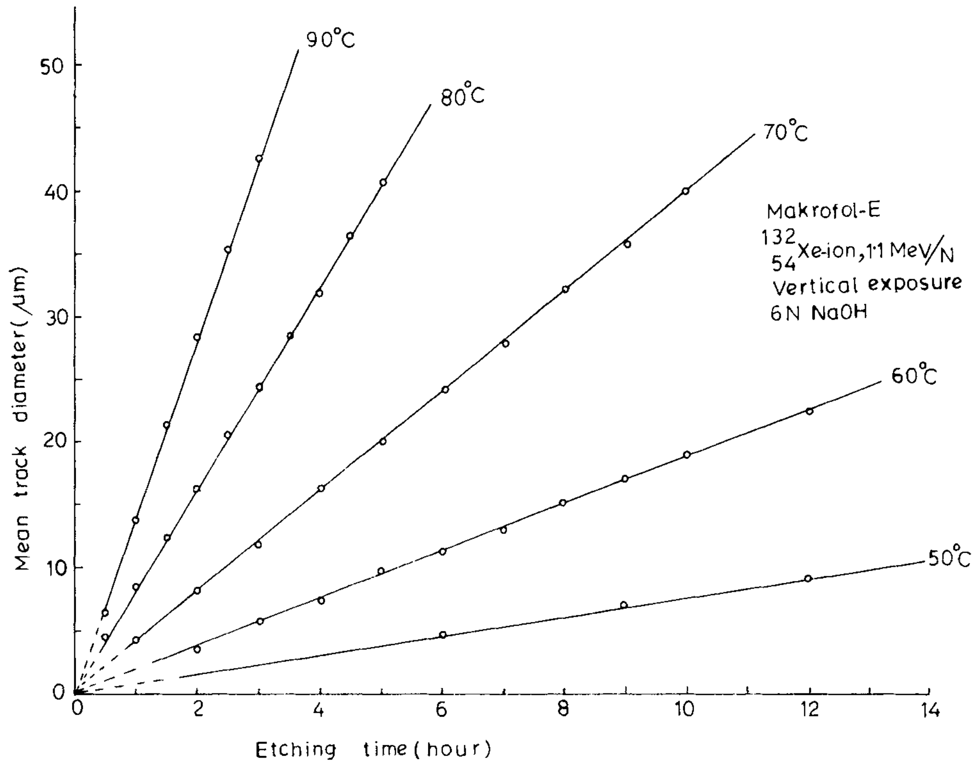

Figure 2. Variation of track diameter with etching time for $^{132}_{54}Xe$-ion tracks in Makrofol-E for different etching temperatures.

3.2 *Effect of annealing on the bulk etch rate* V_b

Unexposed samples of Lexan and Makrofol were annealed for 30 min at different temperatures. The samples were then etched simultaneously in 6N NaOH at 70°C. The removed layers of the sheets were measured using a microthickness gauge with a least count = 0·5 μm. In figure 3 the thickness removed from a single surface of the detector is plotted as a function of etching time at two annealing temperatures. It is observed that there is no change in the bulk etch rate of both the plastics up to 190°C. Even at this annealing temperature the sheets are satisfactorily elastic. Lasting deformations are observed from 175°C upwards. Annealing times longer than 30 min lead to gradual deterioration of the surface qualities of the plastic, which is undesirable in their application as track detectors.

3.3 *Effect of annealing temperature on track diameter*

After studying the general properties of bulk material subjected to thermal treatments, we extended the investigations to plastic sheets irradiated with $^{132}_{54}Xe$-ions. One of our aims is to establish the appropriate temperature suitable for the eradication of latent tracks. Samples of Lexan and Makrofol exposed vertically to $^{132}_{54}Xe$-ions were annealed at various temperatures for 10 min. From our earlier experiences and the prescription of Khan and Durrani (1972) for polycarbonate plastics, the annealing time was chosen as 10 min. The annealed samples are then etched in 6N NaOH at 70°C. The etchpit

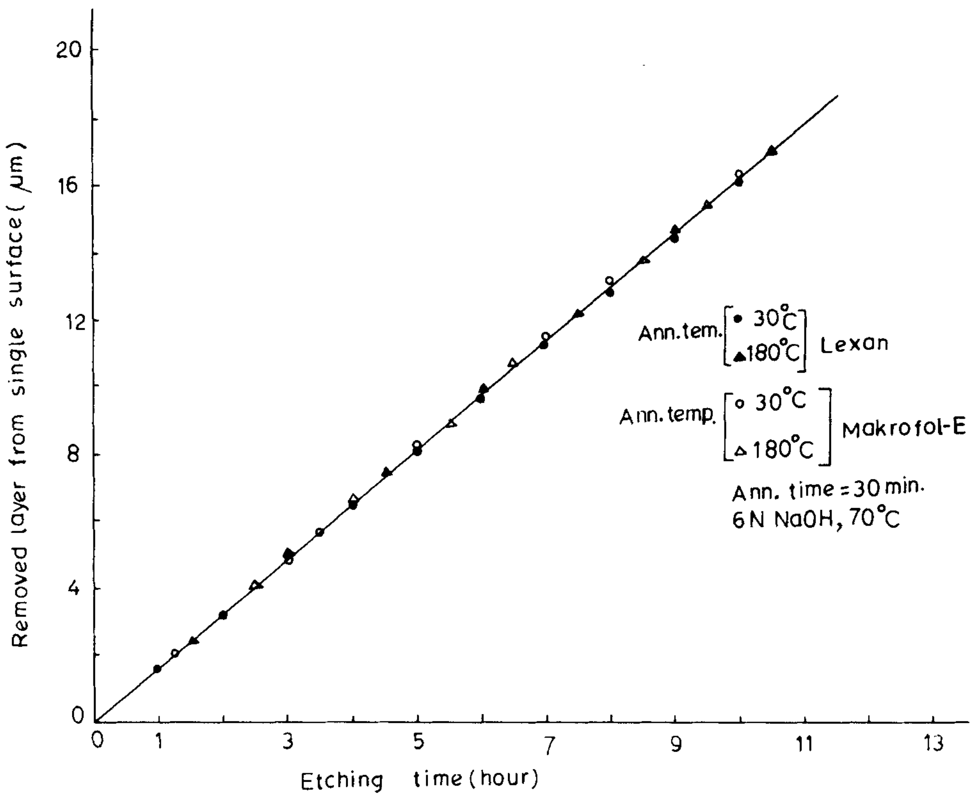

Figure 3. Removed layer *vs* etching time curves for Lexan and Makrofol-E annealed at two temperatures for 30 min.

diameters are measured as a function of the removed layer. The results are shown in figures 4 and 5 for Lexan and Makrofol-E respectively. The inset in figures 4 and 5 gives a plot of the track diameters after removing a 10 μm thick surface layer as a function of annealing temperature. Thus to eradicate $^{132}_{54}$Xe-ion tracks completely, 10 min of annealing must be applied at 195 and 200°C in Makrofol and Lexan respectively.

3.4 *Effect of annealing time on track diameter*

Exposed samples of Makrofol-E are annealed at 150 and 165°C for different lengths of time. Figure 6 shows the effects of annealing time on the etchpit diameters of 1·1 MeV/N $^{132}_{54}$Xe-ions entering vertically, after removing a 10 μm thick surface layer of the individual detector samples. The same curve for $^{132}_{54}$Xe-ion in Lexan is shown in figure 7 for an annealing temperature of 150°C. It can be observed that each curve consists of a steeply and a slowly falling component. It is apparent from the figure that a part of the radiation-damaged region produced by $^{132}_{54}$Xe-ions is already eradicated at the given temperature by short annealing, however in the more stable region persistent after the treatment, no considerable change is brought about even by a significant extension of annealing time. At a higher temperature of annealing (165°C in figure 6), the slowly falling component of the curve starts early. Since the measurements at other temperatures for $^{132}_{54}$Xe-ions display a similar tendency for both the plastics used, they

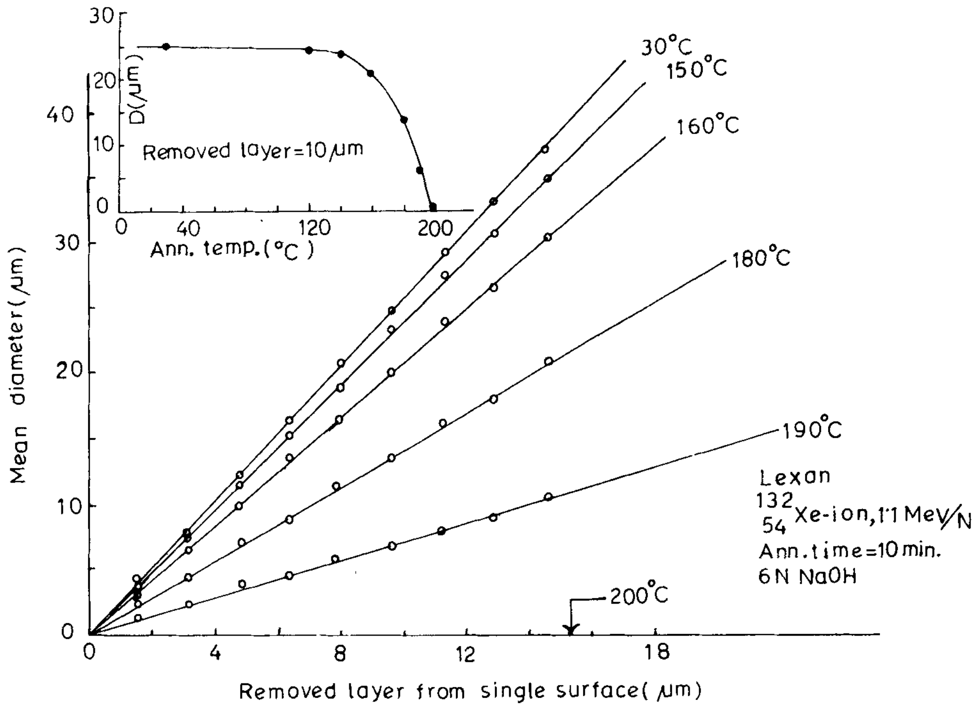

Figure 4. Relationship between track diameter and removed layer for $^{132}_{54}$Xe-ion tracks in Lexan annealed for 10 min at different temperatures.

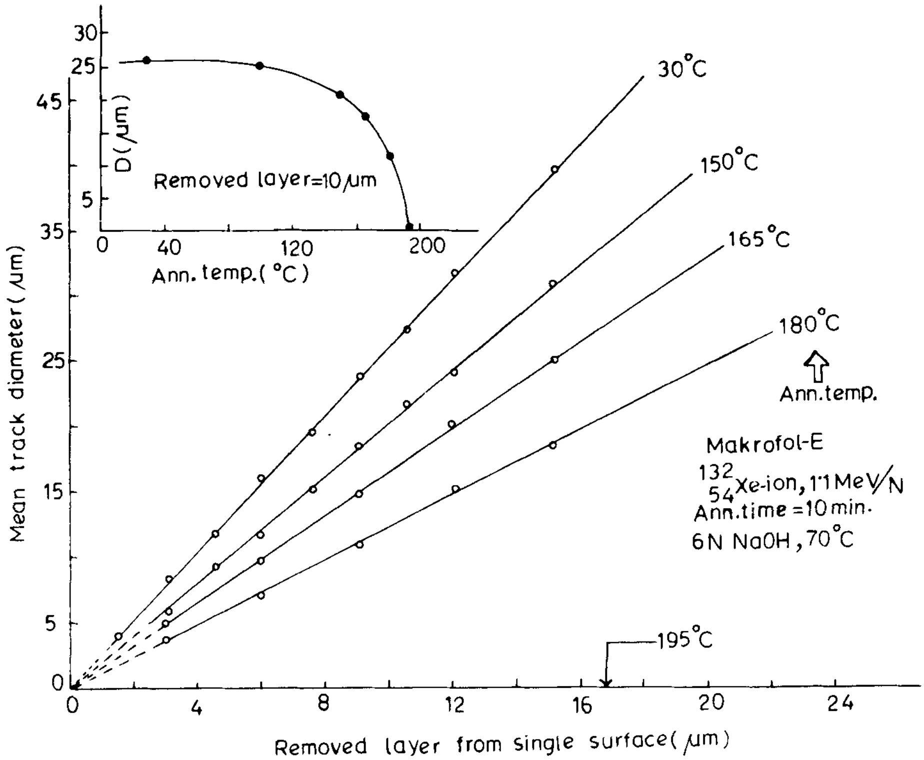

Figure 5. Relationship between track diameter and removed layer for $^{132}_{54}$Xe-ion tracks in Makrofol-E annealed for 10 min at various temperatures.

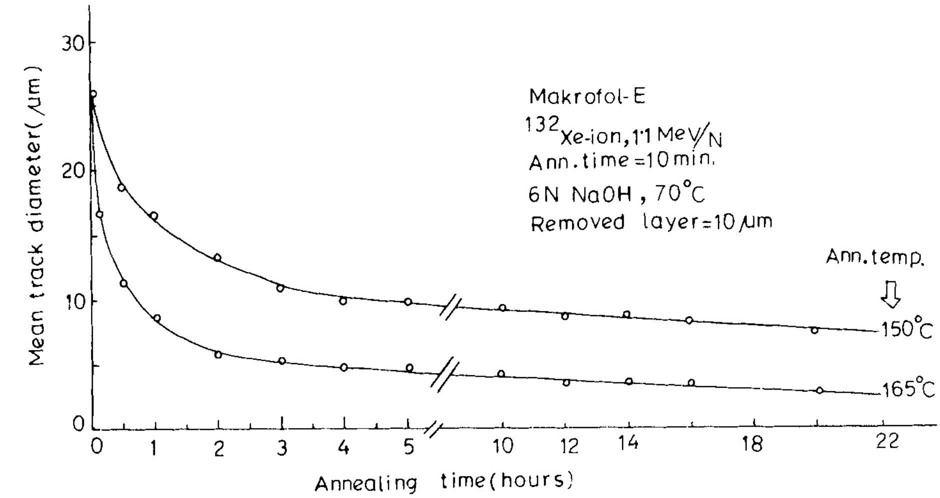

Figure 6. Relationship between track diameter and annealing time for $^{132}_{54}$Xe-ion in Makrofol-E detector annealed at 150 and 165°C.

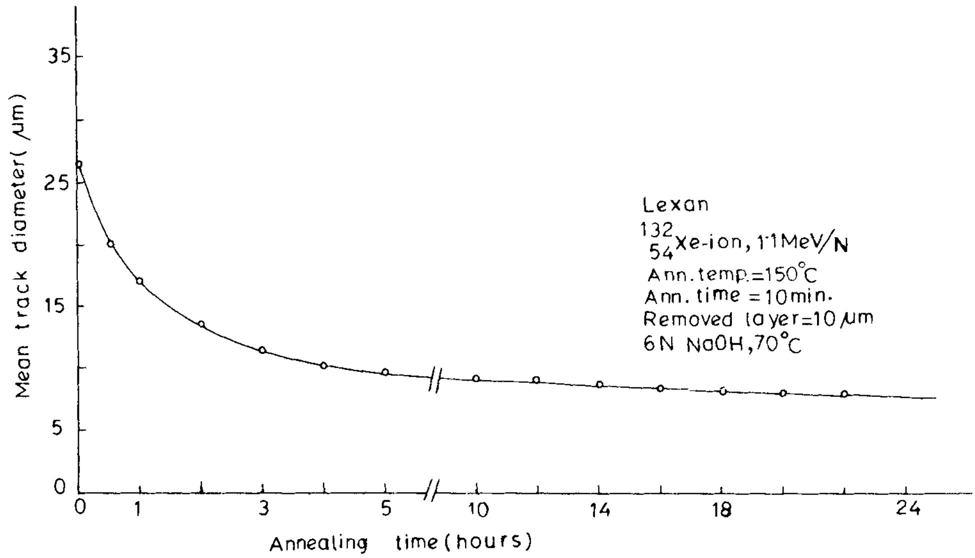

Figure 7. Relationship between track diameter and annealing time for $^{132}_{54}$Xe-ion in Lexan annealed at 150°C.

are not shown. Khan and Durrani (1972, 1973) and Somogyi (1972) also observed the decrease in diameter after annealing α-particle tracks in Lexan and Makrofol-E respectively.

3.5 *Effect of annealing temperature on track etch rate*

Experiments are conducted to show the decrease in V_t of $^{132}_{54}$Xe-ion tracks. The ratio of track and bulk etch rates ($V = V_t/V_b$) is evaluated for different temperatures from the initial slopes, S of the curves shown in figures 4 and 5 using the relation (Somogyi 1972; Luck 1974; Schlenk *et al* 1975; Somogyi and Szalay 1972),

$$V = \frac{1 + 0{\cdot}25S^2}{1 - 0{\cdot}25S^2}.$$

Then this etch rate ratio is plotted against the annealing temperature as shown in figure 8. It is observed that V_t decreases with annealing temperature.

3.6 *Effect of annealing temperature on diameter distribution*

Samples of Lexan and Makrofol-E exposed vertically to $^{132}_{54}$Xe-ions were annealed for 10 min at 150°C. The areas of annealed and unannealed samples were determined precisely to obtain the track density. The annealed and unannealed samples were etched simultaneously in 6 N NaOH at 70°C. Figure 9 shows the diameter distributions of $^{132}_{54}$Xe-ion tracks in Lexan after removing 12 μm thick surface layer of the individual detectors. The experiments reveal that after annealing, not only the track density is reduced, but also the diameters of the etched $^{132}_{54}$Xe-ion tracks are diminished as a result of lower etching velocity in the damage trail. Somogyi (1966) also made similar remarks after conducting annealing experiments on α-particle tracks in polycarbonate detectors. Since the annealing experiments conducted on Makrofol-E exposed to $^{132}_{54}$Xe-ion confirm the above conclusions, the histograms of the annealed and unannealed tracks in Makrofol-E are not presented here. The histograms of annealed $^{132}_{54}$Xe-ion tracks in Lexan and Makrofol-E are shown in figure 10 for comparison. It is evident that the

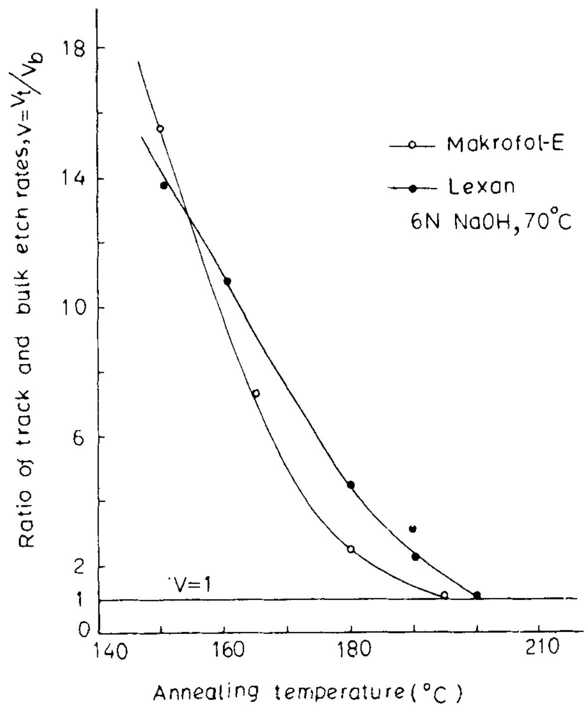

Figure 8. Etch rate ratio, $V = V_t/V_b$ as a function of annealing temperature for $^{132}_{54}$Xe-ion in Lexan and Makrofol-E detector.

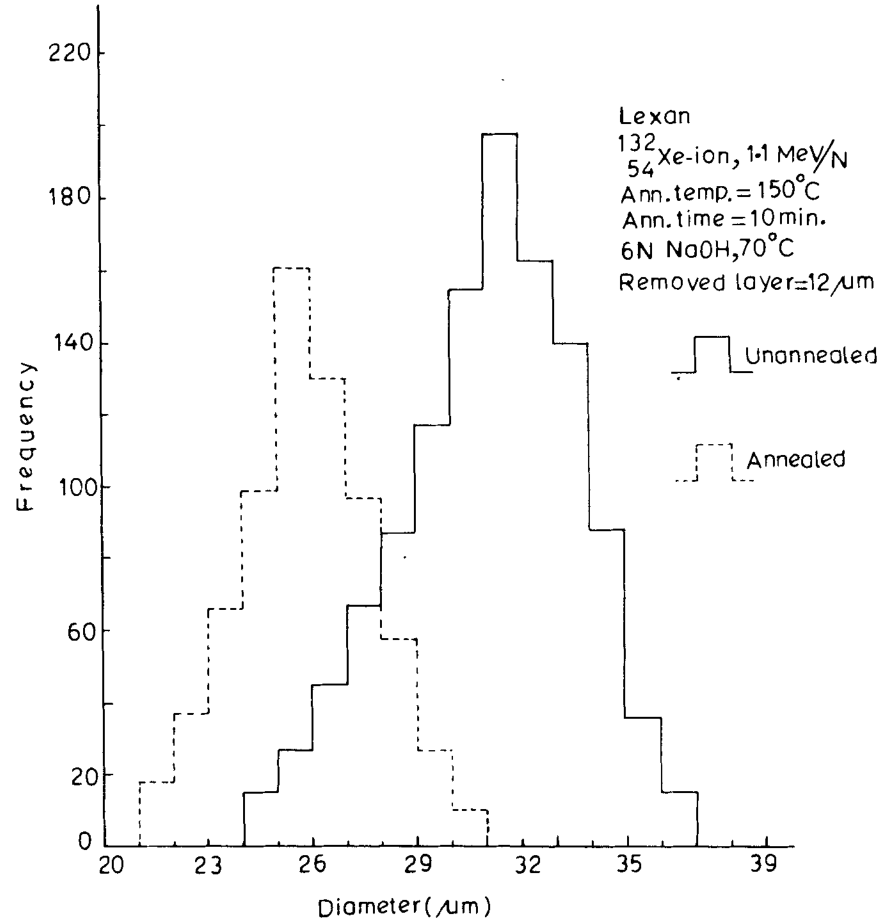

Figure 9. Diameter distribution of unannealed and annealed $^{132}_{54}$Xe-ion tracks in Lexan plastic detector.

diameters of $^{132}_{54}$Xe-ion tracks in Makrofol-E decrease at a faster rate with annealing time/annealing temperature as compared to that in Lexan.

3.7 *Effect of temperature on maximum etchable range*

Makrofol-E detector samples exposed to 1·1 MeV/N $^{132}_{54}$Xe-ions at an angle of 45° with respect to the detector surface were annealed at different temperatures for 10 min. The samples were then etched simultaneously in 6N NaOH at 70°C until the track ends become round. The maximum etched track lengths were determined following the procedure of Benton (1968), Dwivedi and Mukherji (1979), Farid and Sharma (1983, 1984). The effect of annealing temperature on maximum etchable length (*i.e.* range) of $^{132}_{54}$Xe-ions in Makrofol-E is shown in figure 11. It is clear from the figure that the track length decreases by the application of heat. Again it is noted that the tracks are completely erased out when annealed for 10 min at 186°C. From the results shown in figures 5 and 11 it can be concluded that the vertical tracks are more stable than oblique tracks and require higher temperature for their complete erasure.

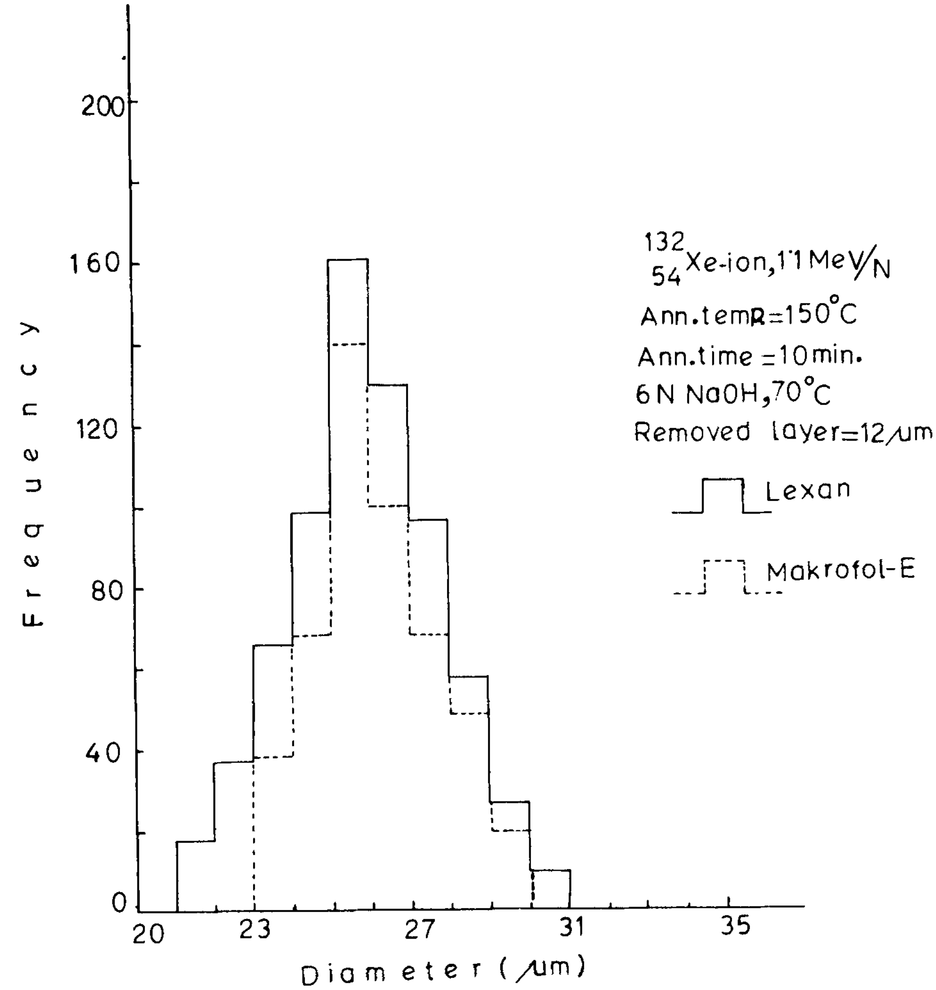

Figure 10. Diameter distribution of annealed $^{132}_{54}$Xe-ion track in Lexan and Makrofol-E plastic detectors.

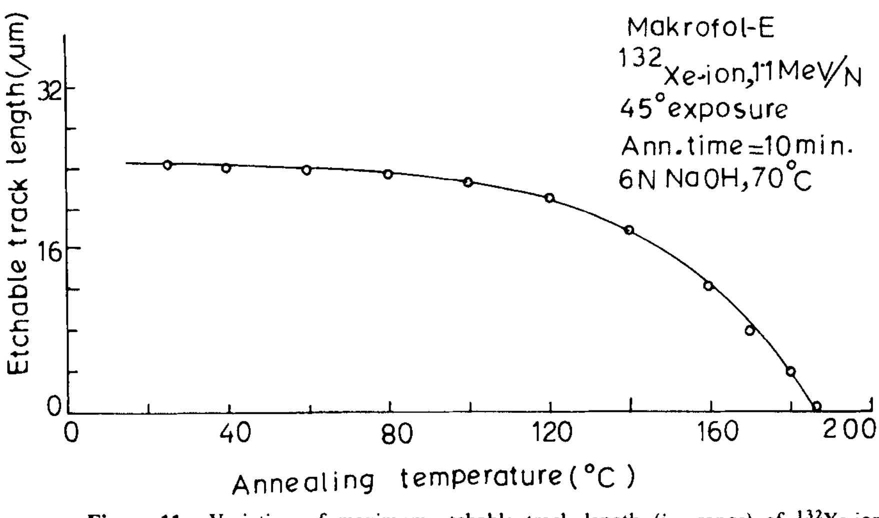

Figure 11. Variation of maximum etchable track length (*i.e.* range) of $^{132}_{54}$Xe-ion in Makrofol-E with annealing temperature.

It is noted that the thermal annealing of $^{132}_{54}Xe$-ion tracks in Lexan is different from that in Makrofol-E. The reason for this difference has to be looked for in differences in their fabrication techniques. Makrofol-E has the same chemical composition as Lexan but differs in that it contains a slight amount of a yellow dye and is prepared by a casting process whereas Lexan is an extruded product (Paretzke *et al* 1973).

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