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Range and energy-loss measurement of ^{238}U in Makrofol-N using CR-39 track detector

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Abstract. A simple experimental technique has been described for measuring range and energy-loss of any heavy ion in any complex medium with the help of a sensitive solid state nuclear track detectors (SSNTDs). In this paper we present the results obtained from our measurements of ranges and energy-loss of 16·34 MeV/u ^{238}U in Makrofol-N using CR-39 track detector. Experimental ranges are compared with the corresponding theoretical values. The significance and scope of the present work are discussed.

Keywords. CR-39 detector; energy-loss rate; ranges; Makrofol-N; track length; ^{238}U.

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1. Introduction

It has been shown earlier (Saxena *et al* 1985) that apart from several other applications of SSNTDs, a few sensitive detectors are quite useful to measure ranges and energy-loss rate of heavy ions in elemental media. Such measurements are possible for all heavy ions whose entire range could be revealed as tracks in the detector foils. A few well-known track detectors such as CR-39, cellulose nitrate, Lexan and ZnP-glass are highly sensitive for the detection of heavy ions. These detectors are inexpensive small pieces of either plastic sheets or thin glass plates and are easily available. In comparison to other experimental techniques the one based on these SSNTDs for measuring heavy ion ranges and energy-loss rate is very simple and does not involve any sophisticated instrumentation.

In the last couple of years thin sheets of polycarbonates have been used to produce microfilters and single-pore membranes for their remarkable applications in the field of environmental (Fischer and Spohr 1983 and references therein), bio-medical (Roggenkamp *et al* 1981) and superfluidity (Gamota 1973). Such devices are produced by bombarding polycarbonate foils with highly ionizing ions (viz. ^{238}U) at energies above 10 MeV/u. Since Makrofol-N is quite suitable for its use in the production of microfilters and single-pore membranes and as no experimental data are available in literature, it is worthwhile to measure energy-loss and penetration depth of ^{238}U in Makrofol-N. Here, we present our experimental results on ranges and energy-loss rate of 16·34 MeV/u ^{238}U in Makrofol-N foils employing CR-39 as track detector. An attempt is also made to compare our measured data with the corresponding theoretical values obtained from data tables of Northcliffe and Schilling (1970) and from stopping-power equations of Mukherji and Nayak (1979).

2. Experimental

2.1 *Preparation of detector and targets*

2.1.1 *CR-39 detector*—Cast sheets of CR-39 are produced from allyl diglycol carbonate (composition: $C_{12}H_{18}O_7$ and sp. gr. 1·32 g/ml) and are manufactured by Homalite Corporation, Wilmington, Del. (USA). Small detector plates were obtained from commercially available sheets (thickness $\approx 1{\cdot}5$ mm) by cutting into the size of 20×20 mm^2. After removing the surface protecting layers, these detector plates were washed in warm soap solution and then dried inside a vacuum desiccator.

2.1.2 *Makrofol-N targets*—Makrofol-N (composition: $C_{16}H_{14}O_3$ and sp. gr. 1·23 g/ml) is a trade name of yellow polycarbonate, manufactured by Bayer AG, West Germany. Several rectangular foils in the size of 15×20 mm^2 were cut from 20 μm thin sheets of Makrofol-N. The stacks of varied thicknesses (20–240 μm) were prepared by mounting 1 to 12 foils successively on CR-39 detectors. These stacks were then fixed on slide glass backing for irradiation.

2.2 *Irradiation*

The target-detector assemblies were exposed with a well collimated beam of 16·34 MeV/u ^{238}U ion at XO channel of UNILAC, G.S.I., Darmstadt. All irradiations were done at an incident angle of 45° to the detector surface as shown in figure 1. An optimum flux of $\sim 10^4$ ions/cm^2 was used. A number of CR-39 detectors (without target foils) were also irradiated under similar conditions with different energies of ^{238}U to obtain a calibration curve.

2.3 *Chemical etching*

After irradiation, the target foils of Makrofol-N were removed from CR-39 detectors. The detectors were then etched in 6N NaOH at 55°C for 2–4 hr to develop narrow conical tracks. The etching was continued till rounded track tips were observed. After complete etching and thorough washing the detectors were dried under vacuum.

2.4 *Measurement of track length*

Well defined narrow tracks were observed at ordinary magnification. Etchable track lengths were measured at random all over the detector surface to average out the effects due to non-uniformity of targets. Projected track lengths and diameters were measured at a magnification of 675× and 1500× respectively. Using the measured

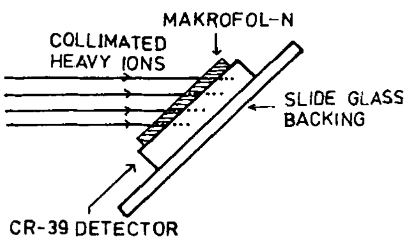

Figure 1. Schematic diagram showing the irradiation of target-detector assembly.

data the true maximum etchable track lengths were obtained from the equation given by Dwivedi and Mukherji (1979).

2.5 *Detector calibration*

CR-39 track detectors were calibrated for energy measurements of ^{238}U in terms of maximum etchable track lengths. Figure 2 shows the calibration curve of ^{238}U ion in CR-39 detector. A few high energy points are taken from Dwivedi *et al* (1986). With the help of this calibration curve the energy of ^{238}U ions has been obtained from the values of maximum etchable track lengths in CR-39.

2.6 *Measurement of energy-loss and ranges*

An energy-loss curve for a heavy ion in any medium may be constructed by plotting ion energy as a function of target thickness. For a given target thickness (Δx) the energy lost by a heavy ion may be obtained by

$$\Delta E = (E_i - E_x), \tag{1}$$

where E_i is the initial energy of the ion before entering the foil and E_x is the degraded energy of the ion after penetrating through the target of thickness Δx. A one-dimensional polynom of third order seems to show a best fit for energy-loss data. By extrapolation of the curve till $E_x = 0$, one can easily obtain the range (R_i) of a heavy ion of energy E_i in any target. From this range value (R_i), the range $R(E)$ at any energy E may simply be obtained from

$$R(E) = R_i - x(E), \tag{2}$$

where $x(E)$ is the target thickness which reduces the ion energy from E_i to E and is obtained from energy-loss curve.

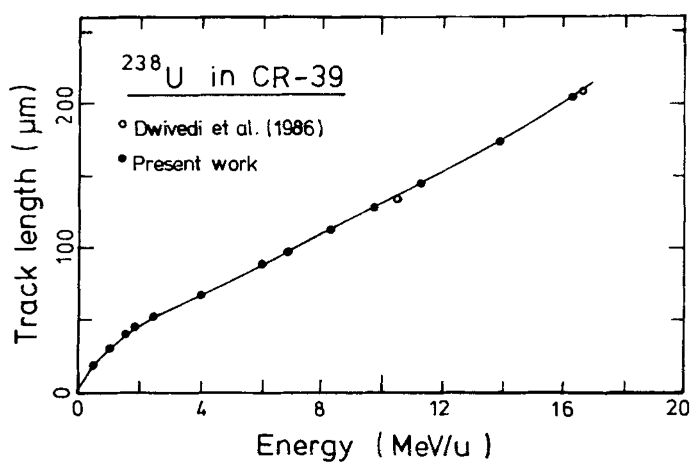

Figure 2. A plot showing calibration curve between the energy of ^{238}U and the measured track length in CR-39.

2.7 *Experimental errors*

The uncertainties in determining the beam energies are very small ($\approx 0{\cdot}1\%$). The uniformity of the foils was checked by weighing method as well as by Heidenhain depth measuring device with an accuracy of ± 1 μm. It was found that the stacks of Makrofol-N targets were uniform within 5%. The standard deviation in track length measurement was found ≈ 3 μm.

3. Results and discussion

Table 1 lists the values of target thickness (Δx), maximum etchable track lengths (L) of ^{238}U ions emerged out through Makrofol-N targets, corresponding ion energies (E_x) obtained from calibration curve (figure 2), total energy (ΔE) lost by the ions in targets of different thicknesses and experimental ranges along with theoretical values obtained (a) from stopping power equations of Mukherji and Nayak (1979) and (b) from data tables of Northcliffe and Schilling (1970). An energy-loss curve is drawn between target thickness and ion energy (E_x) and is shown in figure 3. From the energy-loss curve, it has been found that 16·34 MeV/u ^{238}U has a range of 230 ± 2 μm in Makrofol-N whereas the maximum etchable track length is measured to be 226 ± 4 μm. This indicates that the entire length of latent tracks are revealed by etching the Makrofol-N foils. Using (2), the ranges of ^{238}U ions are obtained at different energies and are shown in figure 4 along with corresponding theoretical values.

In view of the fact that generally 30–60 μm thick films of different polymers are used for the production of microfilters and single-pore membranes, our measured range data predict that uniform microholes in Makrofol-N may be produced by ^{238}U ions having initial energies more than 10 MeV/u.

Table 1. Values of Makrofol-N thickness, maximum etchable track length of ^{238}U ions in CR-39 detector, energy of the transmitted ^{238}U ion, total energy-lost by the ions and the ranges obtained in Makrofol-N.

				^{238}U-ranges in Makrofol-N (μm)		
Target thickness Δx (μm)	Track length L (μm)	Ion energy E_x (MeV/u)	Total energy-lost ΔE (MeV/u)	Experimental (present work)	Theoretical (a)	(b)
Without target	204 ± 2	16·34	0·0	$230{\cdot}0 \pm 2{\cdot}0$	223·5	—
$28{\cdot}3 \pm 1{\cdot}4$	195 ± 3	$15{\cdot}70 \pm 0{\cdot}25$	$0{\cdot}64 \pm 0{\cdot}25$	$216{\cdot}0 \pm 2{\cdot}4$	215·0	—
$56{\cdot}6 \pm 2{\cdot}0$	161 ± 3	$13{\cdot}00 \pm 0{\cdot}25$	$3{\cdot}34 \pm 0{\cdot}25$	$176{\cdot}7 \pm 2{\cdot}8$	180·0	—
$84{\cdot}9 \pm 2{\cdot}4$	128 ± 3	$9{\cdot}95 \pm 0{\cdot}26$	$6{\cdot}39 \pm 0{\cdot}26$	$144{\cdot}0 \pm 3{\cdot}1$	140·0	153·0
$113{\cdot}1 \pm 2{\cdot}8$	104 ± 3	$7{\cdot}72 \pm 0{\cdot}27$	$8{\cdot}62 \pm 0{\cdot}27$	$118{\cdot}0 \pm 3{\cdot}4$	112·0	120·0
$141{\cdot}4 \pm 3{\cdot}2$	82 ± 3	$5{\cdot}55 \pm 0{\cdot}28$	$10{\cdot}79 \pm 0{\cdot}28$	$90{\cdot}0 \pm 3{\cdot}8$	89·5	88·0
$169{\cdot}7 \pm 3{\cdot}5$	59 ± 3	$3{\cdot}26 \pm 0{\cdot}24$	$13{\cdot}08 \pm 0{\cdot}24$	$62{\cdot}0 \pm 4{\cdot}0$	65·0	57·0
$198{\cdot}0 \pm 3{\cdot}7$	32 ± 3	$1{\cdot}08 \pm 0{\cdot}18$	$15{\cdot}26 \pm 0{\cdot}18$	$28{\cdot}7 \pm 4{\cdot}2$	34·0	27·0
$226{\cdot}3 \pm 4{\cdot}0$	14 ± 3	$0{\cdot}32 \pm 0{\cdot}11$	$16{\cdot}02 \pm 0{\cdot}11$	$11{\cdot}3 \pm 4{\cdot}5$	16·0	14·5
$254{\cdot}6 \pm 4{\cdot}2$	No tracks	—	—	—	—	—

(a) Mukherji and Nayak (1979); (b) Northcliffe and Schilling (1970).

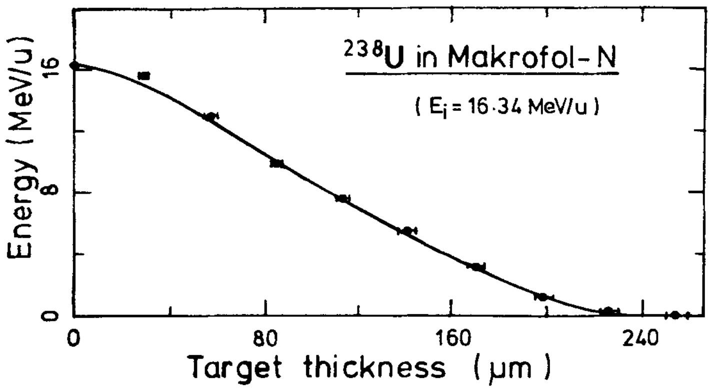

Figure 3. The energy-loss curve for ^{238}U in Makrofol-N. The initial energy (E_i) of the ^{238}U is 16·34 MeV/u.

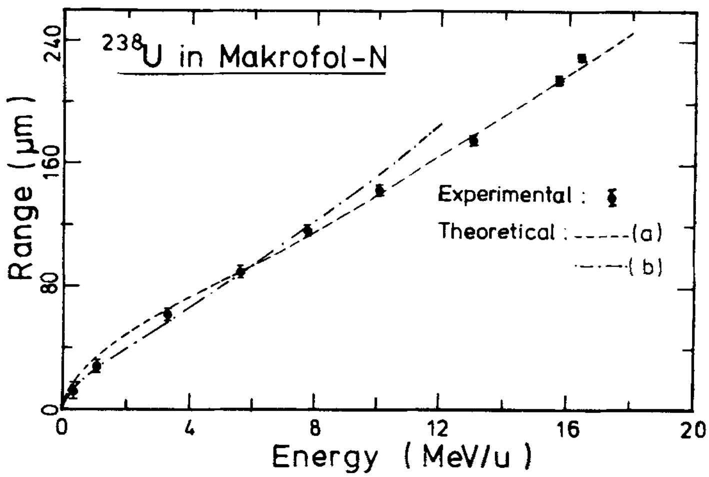

Figure 4. Measured range-energy data are shown along with the theoretical values obtained from (a) Mukherji and Nayak (1979) and (b) Northcliffe and Schilling (1970).

In the last couple of years, several stopping-power measurements (Varley *et al* 1976; Forster *et al* 1976; Güttner *et al* 1977; Bimbot *et al* 1978, 1980, 1986; and Geissel *et al* 1982) have shown significant discrepancies with the calculated or tabulated values, particularly for heavy ions. For example, the tabulated stopping-power values of ^{84}Kr in carbon for 4 to 6 MeV/u obtained from Northcliffe and Schilling (1970) were found to be 30% lower than the measured values (Bimbot *et al* 1978) and thus resulted in overestimation of range values. On the other hand, the range values computed from stopping-power equations proposed by Mukherji and Srivastava (1974), Srivastava and Mukherji (1976) and Mukherji and Nayak (1979) are in good agreement (within 5%) with the measured track lengths for several heavy ions (Tripier *et al* 1974; Dwivedi and Mukherji 1979 and Dwivedi *et al* 1986) in a few track detectors. Here, we compare our measured ranges of ^{238}U in Makrofol-N with the corresponding theoretical values from Northcliffe and Schilling (1970) and Mukherji and Nayak (1979). It has been observed that up to about 8 MeV/u the measured ranges are in good agreement with the values derived from data tables of Northcliffe and Schilling (1970) whereas above 8 MeV/u our results are fairly comparable with the theoretical values from Mukherji and Nayak (1979).

4. Conclusion

The present investigation offers a simple and fairly accurate method for measuring energy-loss rate and ranges of any heavy ion in any complex medium using CR-39 track detector. We also present our measured range values of ^{238}U in Makrofol-N up to 16·34 MeV/u. From these results it is observed that ^{238}U ions with energies above 10 MeV/u are suitable to produce micro-filters and single-pore membranes using Makrofol-N films. By comparing our measured ranges with the corresponding theoretical values, it has been further confirmed that stopping-power equations of Mukherji and Nayak (1979) predict more reliable range values for heavy ions in complex media especially above 8 MeV/u.

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