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Measurement of fast neutron induced fission cross section of thorium using Lexan plastic track detector

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Abstract. Fission-track registration characteristics of Lexan solid state nuclear track detectors have been used to measure the fast neutron induced fission cross section of ^{232}Th. The fast neutrons ($\cong$ 14.2 MeV) were produced with the help of an AN-400 model Van-de-Graaff accelerator at Banaras Hindu University laboratory using $^{3}\mathrm{H}(^{2}\mathrm{H}, n)^{4}\mathrm{He}$ reaction and were used to irradiate the fissile target deposited on the plastic detector. The track density T, registered on the plastic detector is related to the fission cross section σ_f, through the relation $T = kn\sigma_f\phi t$ where n is the number of fissile atoms per cm^2 in the deposit, ϕ is the neutron flux, k is fission track registration efficiency and t is the time of irradiation. The fission cross section σ_f of ^{232}Th, relative to the well measured fission cross section of ^{238}U, was found to be 0.36 ± 0.04 barn.

Keywords. Nuclear track detectors; induced fission; cross section; neutron flux; track density; Lexan; thorium.

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1. Introduction

Walker *et al* [1] were the first to suggest that the fluence of neutrons can be measured by counting the fission tracks in a thin, track-recording sheet in contact with a foil of fissionable material. This method has a number of attractions. The foremost of these is that single fission produces a large amount of energy ($\sim$ 200 MeV) which is not very dependent on the energy of the neutron producing the reaction [2, 3]. Most of this energy ($\sim$ 160 MeV) is shared between two easily detected fission fragments which travel in opposite directions and which for most nuclides and neutrons ($E_n \sim 7$ MeV), are approximately isotropically distributed with respect to the direction of the incident neutron [4, 5]. Fission fragment 'tracks' can be seen with an optical microscope in a number of insulating materials (SSNTDs) when properly etched [6]. By choosing a suitable material, for example, Lexan plastic, the fission events can be recorded with essentially a zero background from competing nuclear events.

Taking advantage of these attractive features, in the present work, the fission cross section of ^{232}Th has been determined relative to the standard fission cross section of ^{238}U by comparing the fission track densities produced in Lexan plastic in both the cases. The method employed uses a thin deposit of thorium solution on the Lexan plastic in a 2π geometry [7].

2. Experimental details

Several pieces (2 cm × 2cm) of Lexan plastic were cut from a sheet of uniform thickness ($\sim 200\,\mu m$). A known weight (1 gm of $UO_2(NO_3)_2 \cdot 6H_2O$) of the fissile material uranyl nitrate was first dissolved in $10\,cm^3$ of distilled water and a known amount ($0.25\,cm^3$) of this solution was deposited on five Lexan plastic foils and dried with the help of an infrared lamp. In the same way thorium nitrate ($ThO_2(NO_3)_2 \cdot 6H_2O$) solution under the same condition was prepared and the same amount ($0.25\,cm^3$) of the solution was deposited on five other Lexan plastic foils. It was ensured that the thickness of fissile material in each case was so small that the errors due to self-absorption effects are negligible. These coated plastics were exposed to the fast neutrons for different lengths of time ranging from one hour to several hours. The corresponding neutron fluences varied from 1×10^{10} to $6.7 \times 10^{10}\,n/cm^2$. All the pieces of the Lexan plastics were irradiated with 14.2 MeV neutrons produced with the help of a 400 kV Van de Graaff accelerator, at a distance of about 1.5 cm from the place of the tritium target. Tritium target was at right angle to the deutron beam. Both the uranium and thorium targets are irradiated together using the same fluence. For an independent determination of the flux, an aluminium foil of the same area as that of target was also irradiated sandwiched between the thorium and uranium targets. After irradiation, the plastic pieces along with an unirradiated (control) plastic were etched in 6.25 N NaOH solution at 60°C for 1–2 hours in a thermostatically controlled oven. Etched fission fragment tracks in plastics were counted to determine track density by viewing under an optical microscope (Olympus, Model BH-2) using a magnification of 600×. In each plastic foil, equal area were scanned ($6.25 \times 10^{-2}\,cm^2$). During scanning, proper care was taken not to count the same area of the detector more than once in any case.

3. Results and discussion

The neutron flux, as monitored by the gamma spectrometric measurement of irradiated ^{27}Al foil at the site where all the detector pieces were irradiated was found to be typically $3 \times 10^6\,n\,cm^{-2}s^{-1}$. Table 1 shows the irradiation time and number of tracks in $6.25 \times 10^{-2}\,cm^2$ for uranium and thorium and table 2 shows the irradiation time, fluence and track density for uranium and thorium. The microphotographs of fission tracks registered in Lexan plastic for uranium and thorium are shown in figures 1 and 2 respectively. Figure 3 shows the fission track density vs. neutron fluence for uranium and thorium. It can be seen that the track density varies linearly as the fluence and the slope of the straight line gives track density per unit fluence. Thus the ratio of the slopes of the two lines, δ_U/δ_{Th}, gives the ratio of track densities T_U/T_{Th}, on a relative basis. Since the detector is in contact with the fissile material in 2π geometry one has for ^{238}U and ^{232}Th,

$$T_U = (k\phi t) n_U \sigma_{fU}, \tag{1}$$

$$T_{Th} = (k\phi t) n_{Th} \sigma_{fTh}. \tag{2}$$

Table 1. Number of fission fragments measured in Lexan plastics for uranium and thorium.

Irradiation time (hrs)	Number of tracks for ^{238}U	Number of tracks for ^{232}Th
1.00	1127	375
2.25	2556	856
3.00	3412	1137
4.50	5162	1700
6.50	7387	2462

Scanned area is $6.25 \times 10^{-2} \mathrm{cm}^2$.

Table 2. Track density measured in Lexan plastic for both uranium and thorium.

Irradiation time (hrs)	Fluence $10^{10}\,\mathrm{n/cm^2}$	Track density for $^{238}\mathrm{U}(\times 10^4/\mathrm{cm}^2)$	Track density for $^{232}\mathrm{Th}(\times 10^4/\mathrm{cm}^2)$
1.00	1.0	1.82	0.60
2.25	2.3	4.09	1.37
3.00	3.1	5.46	1.82
4.50	4.6	8.17	2.72
6.50	6.7	11.82	3.94

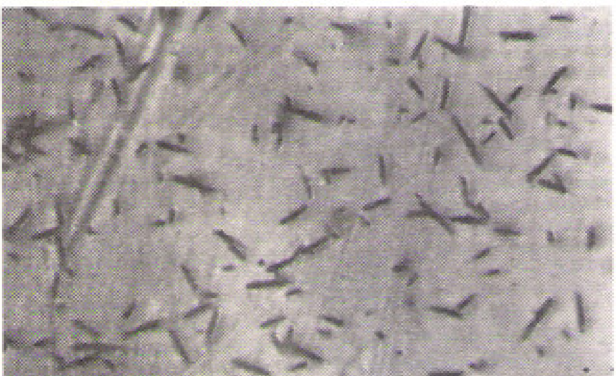

Figure 1. Microphotograph of fission tracks found in Lexan plastic coated with uranium, irradiated with fast neutrons for 6.5 hrs.

Here, the factor $k\phi t$, the product of efficiency, flux and irradiation time, is the same for both cases, because they were irradiated together under the same conditions. In (1) σ_{fU} is fission cross section for ^{238}U and n_{U} is number of atoms per cm^2 of ^{238}U and in (2) σ_{fTh} is fission cross section for ^{232}Th and n_{Th} is number of atoms per cm^2 of ^{232}Th. From eqs (1) and (2)

$$\frac{T_{\mathrm{U}}}{T_{\mathrm{Th}}} = \frac{n_{\mathrm{U}}\sigma_{\mathrm{fU}}}{n_{\mathrm{Th}}\sigma_{\mathrm{fTh}}}. \tag{3}$$

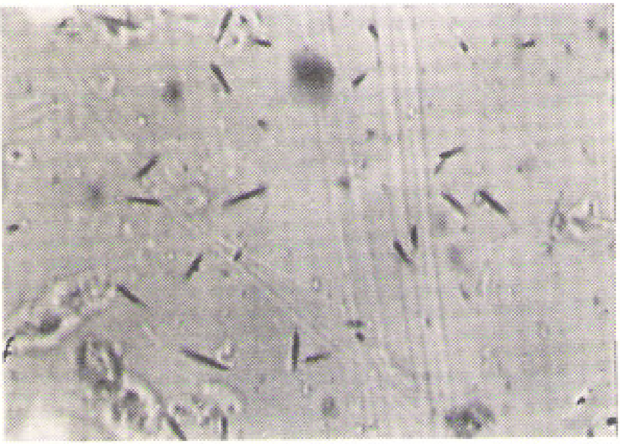

Figure 2. Microphotograph of fission tracks found in Lexan plastic coated with thorium, irradiated with fast neutrons for 6.5 hrs.

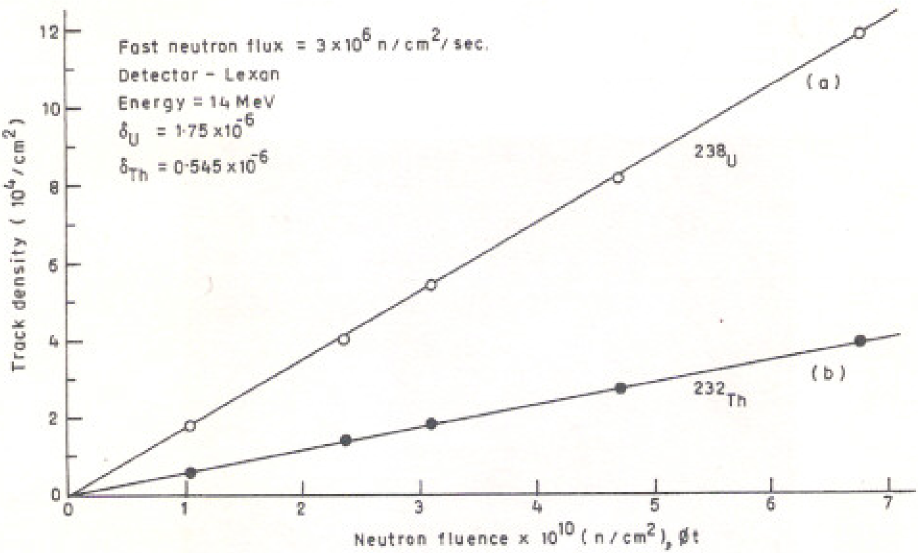

Figure 3. Variation of fission track density vs. neutron fluence for Lexan coated with (a) ^{238}U and (b) ^{232}Th.

The value of δ_U/δ_{Th} was obtained from figure 3 as explained above. The ratio, n_U/n_{Th}, was determined from the relative weights of the uranium and thorium deposits both having the same area. n_T (number of atoms per cm^2 of the fissile target) can be defined by

$$n_T = \frac{W_i N_a P_i}{A_i}, \tag{4}$$

where W_i is the weight of the fissile material per unit area, P_i is the isotopic abundance of the target isotope and N_a is the Avagadro's number (6.03×10^{23} per gm mole). Thus the fission cross section of ^{232}Th is given by

$$\sigma_{\mathrm{fTh}} = \frac{n_{\mathrm{U}}\sigma_{\mathrm{fU}}\delta_{\mathrm{Th}}}{n_{\mathrm{Th}}\delta_{\mathrm{U}}}. \tag{5}$$

In this way the fission cross section of ^{232}Th was found to be 0.36 ± 0.04 barn, with the standard fission cross section of ^{238}U taken as 1.205 ± 0.020 barn from White and Warner [8]. The present experimental value of fission cross section of thorium by 14.2 MeV neutrons, agrees well within errors with earlier value of 0.34 ± 0.03 barn, obtained by Chowdhuri *et al* [9], using Lexan detector but by a different method of studying the angular distributions and integrating them.

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