Experimental Study of Glass Plate as a Nuclear Fission Track Detector for Fast and Slow Neutron Flux Measurement

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Abstract

In the present work, glass plate of sodalime is used as a nuclear fission track detector to record the fission fragments of Uranium produced by fast and thermal neutrons. Samples of glass plate, each of size 10 mm x 5 mm x 0.14 mm are used. Each glass plate before the use is cleaned with rinsed water and dried. Pure analytical grade Uranyl nitrate is used as a target material for fission. Uranyl nitrate is deposited on each glass plate sample. The prepared samples are irradiated with thermal neutrons from Cf-252 source and 14 mev neutrons obtained from D-T reaction. The thermal neutron flux is estimated using pure MnO_2 powder. The induced gamma ray activity of ^{56}Mn (Gamma energy = 0.84 MeV, Half life = 2.58 h) produced through the nuclear reaction: $^{55}Mn(n, \gamma)^{56}Mn$ is measured using NaI(Tl) gamma ray spectrometer coupled to personal computer base multi channel analyzer available in the Department of Physics of H. V. Desai College. The 14 MeV neutron flux is estimated using the pure (99.99 %) aluminium foil. The induced gamma ray activity of ^{27}Mg (Gamma energy = 0.84 mev, Half life = 10 min.) Produced through the nuclear reaction: $^{27}Al(n,p)^{27}Mg$ is measured using the NaI(Tl) gamma ray spectrometer coupled to personal computer based 8K multi channel analyzer. Each exposed glass plate detector after etching is observed under optical research microscope and fission track density is measured and correlated with neutron flux obtained by neutron activation technique.

Keywords: Fission; Glass plate as fission track detector; Gamma-ray spectrometer; Multi Channel Analyzer; Neutron Flux.

Introduction

The technique of optical detection of charged particle tracks in insulators using chemical etching has undergone a phenomenal growth in the last decade and achieved the status of a scientific discipline in its own right. The applications of solid state nuclear track detectors to (i) measurement of neutron fluence and fission yield (ii) angular distribution of 14 MeV neutrons, heavy charged particles and fission fragments and (iii) neutron dosimetry are increasing mainly due to their certain advantages, such as high degree of reproducibility, long term stability, low cost and insensitivity to beta and gamma radiations [9, 7]. A literature survey indicates that so far no work has been reported on the use of glass detector to record the fission fragments produced by 14 MeV neutrons and the present paper is an effort in this direction. Cross sections for production of protons and alpha particles through interaction of 14 MeV neutrons with plastic and the surrounding materials have appreciable values, whereas these cross sections are negligible for thermal neutrons. In most of plastic detectors energetic protons and alpha particles produce tracks, which in fission studies may act as interfering background. However, glass plate is not sensitive to protons and alpha particles, and therefore it offers a unique advantage over plastic detectors in studies with 14 MeV neutrons.

Experimental Work

2.1 Sample preparation and irradiation process

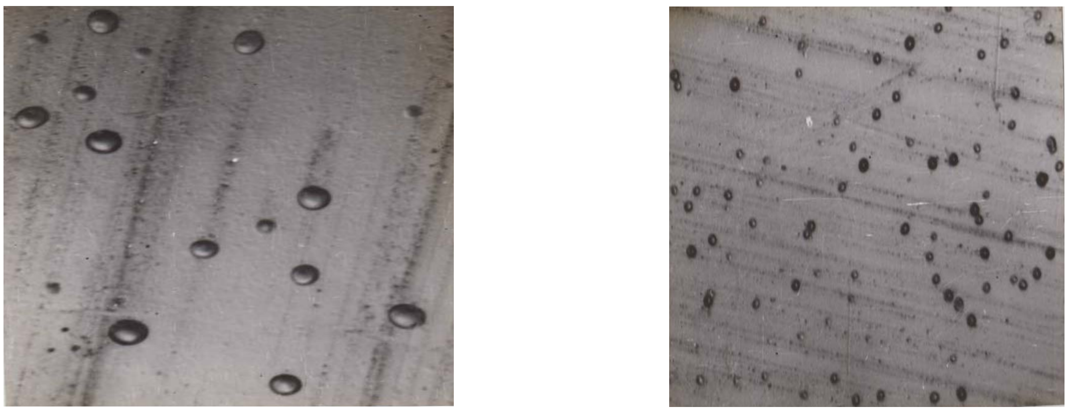
Neutron generator facility [2] of this laboratory was used for these experiments. Neutrons of 14.7 MeV energy were produced by inducing D -T reaction at 175 KeV deuteron energy. Samples were prepared by sand witching a known amount of pure uranyl nitrate between two chemically cleaned glass plates of dimensions 50 mm long, 20 mm wide and 0.13 mm thick. Such twenty samples were made by varying weight of uranyl nitrate from 60 to 100 mg, spread over a circular area of 3 to 5 mm diameter. These samples were grouped on the basis of uranium weight for neutron irradiation. Each sample was wrapped in a pure (99.9 %) thin aluminium foil and irradiated with 14.7 MeV neutrons of flux ~10^8 n/cm^2-s. For the samples having same amount of uranyl nitrate (100 mg), the time of irradiation was varied from sample to sample in the range 5 to 60 minutes. For another set, in which samples had different weights of uranyl nitrate, the period of irradiation for each sample was kept ten minutes. Special care was taken to position the sample around zero degree with reference to the direction of the incident deuteron beam, to enable irradiation with almost monoenergetic neutrons. In each case neutron fluence was estimated [1, 13] by measuring the gamma ray activity of ^{27}Mg produced in the aluminium foil through the ^{27}Al(n,p)^{27}Mg reaction, for which the cross section is precisely known [3]. The thermal neutron flux is estimated using pure MnO_2 powder. The induced gamma ray activity of ^{56}Mn (Gamma energy = 0.84 MeV, half life = 2.58 h) produced through the nuclear reaction: ^{55}Mn(n, γ)^{56}Mn is measured using NaI(Tl) gamma ray spectrometer coupled to personal computer based 8K MCA available in the Department of Physics of H. V. Desai College. For comparison, a few CR-39 plastic detectors, each carrying 60 mg weight of uranyl nitrate were also irradiated with 14 MeV neutrons of flux ~ 10^8 n/cm^2-s for ten minutes.

Fission track counting

Each exposed glass plate was first washed with water and then etched in 36 % HF at room temperature. To study the variations in track diameter and density, a few glass plates in which equal amount of uranium was kept and exposed to the same neutron fluences were etched for different periods in the range 10 to 210 seconds. By carrying out similar experiment, optimum etching conditions were also found out. The etched glass plates were studied under an optical research microscope. A photomicrograph of the revealed tracks is shown in the Figure 1 (photograph - I) and for constant etching time of 90 seconds, variations in the density of the induced fission tracks is given by the following relation [6, 12].

$$\rho_i i = (n((t \quad \ldots (1)$$

where ρ_i - the induced fission track density (cm^{-2}), n - the number of target nuclei (cm^{-3}), σ - the fission cross section (cm^2), Φ - the neutron flux (n/cm^2-s), t - the time of irradiation (s) and K - the efficiency for track registration (cm), which depends upon the mean range of fission fragments. For the glass detector, K was determined by substituting other measured parameters in relation (1) and using cross section value for fission of U - 238 equal to 1210 mb as reported earlier [4]. To obtain average value of K, several plates were analyzed for which parameters such as weight of uranium, neutron fluence and etching time were kept different.



Magnification 500

Figure 1. A photomicrograph of revealed tracks of U-238 fission fragments recorded by a glass plate (Photograph I)

Measurement of track diameter and etching parameters

Fission track diameters were measured with an optical microscope having magnification of 1000 and least count of 0.5 micrometer. A calibrated graticule was used in one of the eye piece of the microscope. A set of irradiated glass plates was etched under identical conditions and the period of etching was varied in the range 10 to 210 second and at each stage it was increased by 10 seconds. After each etching process, the samples were cleaned and diameter and density of the tracks were measured. For a glass plate, variation in a track diameter and track density with period of etching are shown in figures 3 and 4 respectively. The accuracy achieved in measurement of diameter is less than 1 %. To obtain a rough estimate of mass distribution of fission fragments, of few glass plates were etched for 100 seconds. In each glass plate diameters of all the tracks were measured and groups of tracks on the basis of diameter were made. The observed diametric distribution versus number of the fission tracks is shown in

Figure 5. Similarly, bulk etching rate, track etching rate, and etching efficiency for glass plate were determined by following usual standard methods [10].

Results and Discussions

Average value of the track registration efficiency (K) is found to be 1.44 x 10^{-2}. Similarly the measured values of bulk etching rate, track etching rate, and etching efficiency are found to be 0.052μ/s, 0.610μ/s and 90 % respectively. As seen from the photograph - I (Figure 1), etching pits have both circular and elliptical shapes, which might have been formed respectively due to normal and oblique incidence of fission fragments on the glass plate. It is observed from Figure 2 that glass plate exhibits almost linear response for the fission track registration over a wide range of 14 MeV neutron dosimeter and flux monitor.

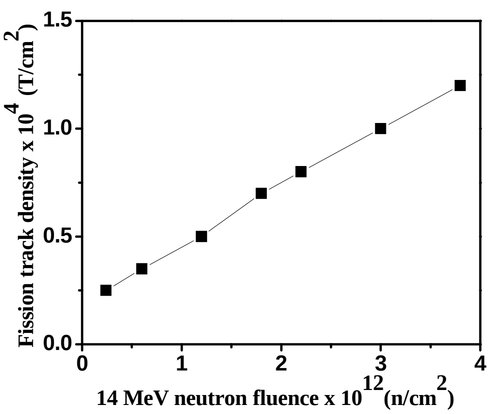


Figure 2. Variation of track density with 14 MeV neutron fluence

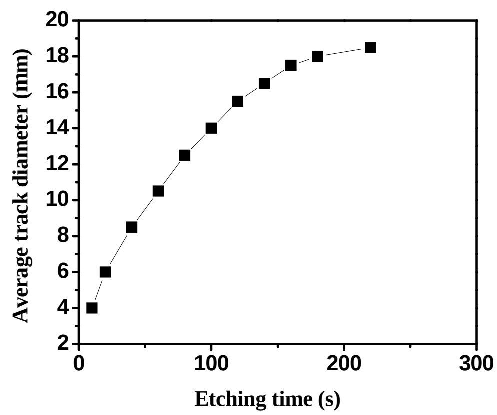


Figure 3. Variation in average diameter of fission tracks with time of etching

The response of the glass detector in terms of variation in the track diameter and the density with time of etching is established from the results shown respectively in figures 3 and 4. As revealed from the figure 3, the density of the tracks becomes almost constant after an etching period of about 90 seconds. It appears from the Figure 4 that the glass detector responded well to the two probable mass groups, light and heavy of nuclei formed in fission of U- 238.

The nature of figure did not change even after varying etching time period beyond 100 seconds. In order to know which nuclei were produced in fission of U - 238, energies of the gamma- rays emitted from an irradiated uranium sample were measured with an HPGe detector and results are shown in Figure 6. From the gamma-ray spectrum, the identified radionuclides were ^{91}Sr, ^{92}Sr, ^{99}Mo, ^{117m}Cd, ^{126}Sb, ^{141}La, ^{143}La, ^{143}Ce and ^{157}Eu indicating clearly the presence of two mass groups of nuclei. The fission tracks on a glass plate, as shown in the Figure 1 (photograph – I) are clearly visible, where as fission tracks on a CR-39 detector as shown in Figure 7 (photograph - II) are surrounded by several background tracks, making it difficult to identify real fission tracks. The problems of similar nature have been encountered while working with other plastic detectors. Line joining the peak points indicates presence of fission fragments of two mass groups.

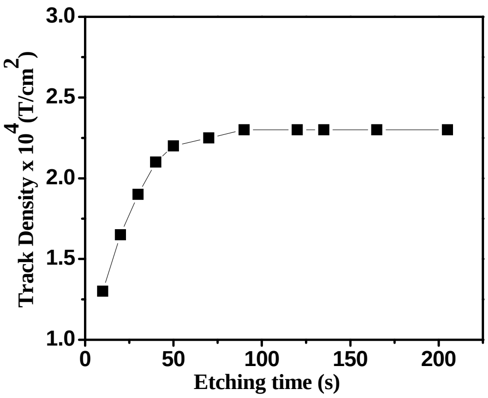


Figure 4. Variation of track density with time of etching

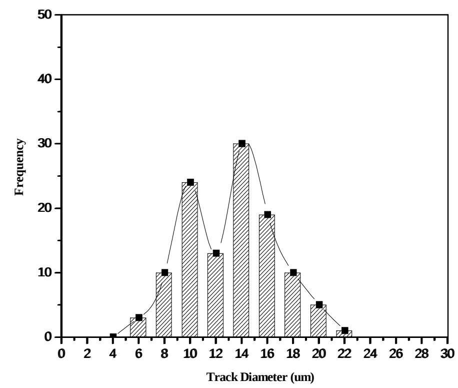


Figure 5. Diametric distribution of the observed fission tracks of U-235 induced by thermal neutrons.

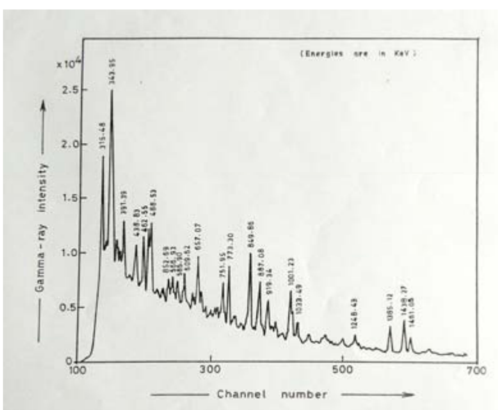


Figure 6. Gamma ray spectrum of a 14 MeV neutron irradiated Uranium sample.

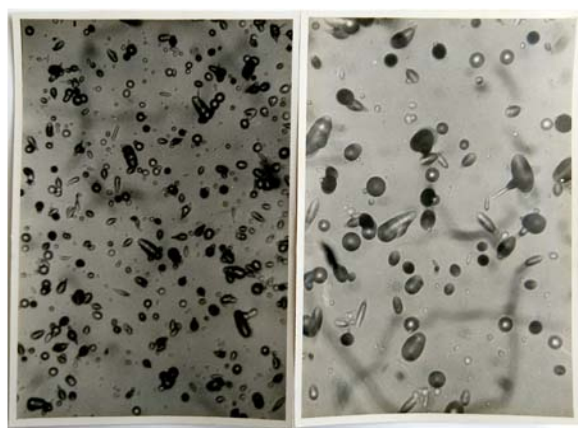


Figure 7. A photomicrograph of revealed tracks of U-238 fission fragments recorded by CR-39 Detector (Photograph - II)

Conclusions

These results indicate that glass detector is superior to plastic detectors in studies of fission induced by 14 MeV neutron.

Acknowledgement

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