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Neutron response study using poly allyl diglycol carbonate

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Abstract. The results of an experimental work aimed at improving the performance of the CR-39 nuclear track detector for neutron dosimetry applications are reported. A set of CR-39 plastic detectors was exposed to ^{252}Cf neutron source, which has the emission rate of 0.68×10^8 s^{-1}, and neutron dose equivalent rate 1 m apart from the source is equal to 3.8 mrem/h. The detection of fast neutrons performed with CR-39 detector foils, subsequent chemical etching and evaluation of the etched tracks by an automatic track counting system was studied. It is found that the track density increases with the increase of neutron dose and etching time. The track density in the detector is directly proportional to the neutron fluence producing the recoil tracks, provided the track density is in the countable range. This fact plays an important role in determining the equivalent dose in the field of neutron dosimetry. These results are compared with previous work. It is found that our results are in good agreement with their investigations.

Keywords. Neutron response; poly allyl diglycol carbonate etched track detectors; track density

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1. Introduction

The solid state nuclear track detectors (SSNTDs) are able to register the charged particles by the radiation damage caused along their interaction path in this material. These damages, under an adequate chemical etching, are enlarged and called tracks [1–3]. Utilization of SSNTDs in neutron detection and neutron dosimetry is well-known. SSNTDs have some advantages compared to other neutron detectors, such as long time stability, insensitivity to gamma radiation, small size, light weight, low price, etc. CR-39 detector has been recognized as one of the best detectors for fast neutron measurements, due to its high sensitivity to light ions, in particular to protons [4–6]. Thermal neutron dosimetry uses a fissile material as a converter to produce fission fragments and alpha particles, which are registered in the track detector placed behind the converter. With regard to the registration of fast neutrons, their sensitivity depends on recoiling nuclei within the volume of the detector itself and, in addition, on recoiling protons when hydrogen-bearing converter is placed in front of the detector. CR-39 solid state nuclear track detector with 100 keV energy threshold and nearly flat response with energy and practically insensitive to beta and gamma radiation was thought to be more suitable in a reactor environment where effective energy of neutrons is less than 500 keV [7,8]. So, CR-39 solid state nuclear track detector has gained a widespread acceptance for personnel neutron monitoring in recent years due to its high sensitivity to protons. The registration of protons in track detectors has long been recognized as the basic requirement for successful neutron personnel monitoring [7]. Furthermore, subsequent electrochemical etching leads to enlargement of the protons recoil tracks several times, which allows one to scan easily a large area of low spatial density of the tracks as it would normally be encountered in neutron dosimetry. Several reports demonstrated that the detector response depends on the external radiation of material and the hydrogen content [9]. The influence of γ-ray irradiation on the neutron detector response on CR-39 has been studied by Kobzev *et al* [10]. They found that the track density increases with the increase of neutron dose. The effects of thermal, intermediate and fast neutrons along with the dose information due to the components of the radiation field have been investigated [11]. For such purposes the etched track detectors are the most favorable: they can be used to study the spatial and energy distribution of neutron field mapping and dosimetry [12–15]: they have small dimensions, good proton sensitivity and they do not disturb the radiation field [16]. Hence, the aim of the present work is to study the ability of CR-39 detector to detect and determine its response for the fast neutron to use it in neutron dosimetry.

2. Experimental details

Poly allyl diglycol carbonate (PADC), generally referred as CR-39 in the literature, covered with a polyethylene layer was used in the present experiment. The thickness of the detector was 1 mm and it was procured from Track Analysis System Ltd., UK. Before irradiation, the polyethylene layer was removed. Five samples of the detector were exposed for nominal periods of 1, 2, 3, 4 and 5 days to neutrons from ^{252}Cf source (emission rate = 0.68×10^8 s^{-1}) at Atomic Energy Authority, Egypt, which has the neutron dose equivalent rate 1 m apart from the source is equal to 3.8 mrem/h. In all cases, the samples were suspended by a teflon bar and chemically etched under the same standard conditions during different durations in 6.25 N NaOH at 70 $\pm$ 0.1°C. The change of track density with etching time and neutron irradiation time was studied. The detector evaluation was carried out by a LEICA image analyzer which consists of PC with LEICA QWIN program, DMRE optical microscope, equipped with motorized x-y stage and autofocus options controlled by special program operated under Windows 98. This system allows us to analyse the object structures with high spatial resolution. Figure 1 shows the experimental set-up for irradiating CR-39 with ^{252}Cf source and determination of the bulk and track etch rates.

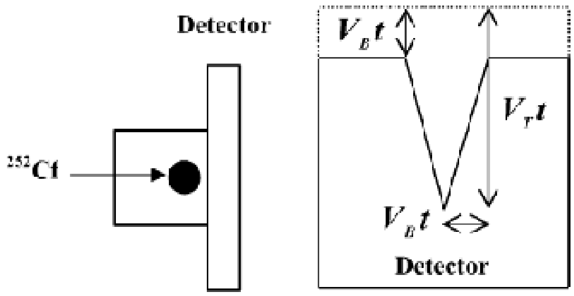

Figure 1. A schematic diagram showing the experimental arrangement and determination of bulk and track etch rates.

3. Results and discussion

To verify the supposed effect of the pre-etched detector to know detector background arising mostly from atmospheric radon, the unirradiated CR-39 detectors were etched in 6.25 N NaOH at 70°C for a duration of 1–6 h. The mean value of background for the pre-etch times above 1 h is found to be constant and the value is 163 tracks/cm^2 with a statistical error of 5%. The bulk and track etch rates are determined by the frequently used method of fission fragment. Fission fragments are easily obtained from a ^{252}Cf radioactive source. Since the ranges of fission products are relatively small, the track etch rates can be considered constant during etching. Under this condition, the following simple equation can be used, (i.e., $D = 2h = 2V_b t$), where D is the track diameter, t is the etching time and h is the removed layer. It is found that the V_b and V_t values for CR-39 detector using 6.25 N NaOH at 70°C are 1.62 μm/h and 5.24 μm/h, respectively.

The track density is also determined by visual counting and its behavior as a function of neutron irradiation time is shown in figure 2. It is clear that the track density increases with increase in the neutron irradiation time and at the same dose it increases with increase in the etching time. This fact plays an important role in determining the equivalent dose in the field of neutron dosimetry. The track density in the detector is directly proportional to the neutron fluence producing the recoil tracks, provided the track density is in the countable range. This result agrees well with the previous reports [8,17,18]. The increase in track density with increasing etching time can be attributed to some tracks formed at larger depth from the surface which need longer etching time to be revealed. However, we expect that after certain etching duration the track density will decrease, as in figure 3, because the recoiled protons have a limited range in material. From figure 3 one can see that for etching time less than 10 h, track density increases linearly with increase in etching time. It shows that the etchable tracks in the CR-39 detectors are distributed uniformly at different depth and this result is in good agreement with the result reported in [19,20].

A photomicrograph for CR-39 detector irradiated by fast neutrons and etched in 6.25 N NaOH at 70°C for 4 h is given in figure 4. The response of the dosimeter obtained from fast neutrons is summarized in table 1 at 10 h etching time in CR-39. The response is defined as the track density per neutron as a function of energy.

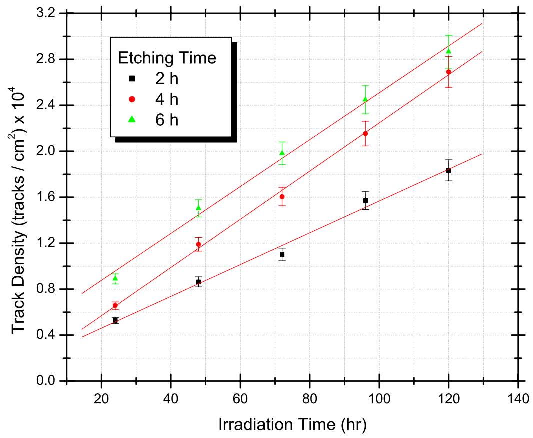

Figure 2. The dependence of the track density on the irradiation time in CR-39 plastic detector.

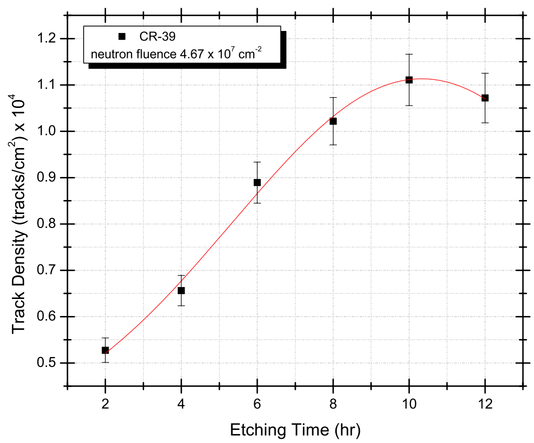

Figure 3. The variation of track density as a function of etching time for CR-39 detector.

Table 1. Response of the CR-39 dosimeter at 10 h etching time with 2.3 MeV neutron energy.

Neutron fluence ($n \cdot cm^{-2}$)	Track density ($tracks \cdot cm^{-2}$)	Response (tracks/neutron)
4.67×10^7	1.11×10^4	2.38×10^{-4}
9.35×10^7	1.84×10^4	1.96×10^{-4}
1.40×10^8	2.33×10^4	1.66×10^{-4}
1.87×10^8	2.96×10^4	1.59×10^{-4}
2.34×10^8	3.19×10^4	1.37×10^{-4}

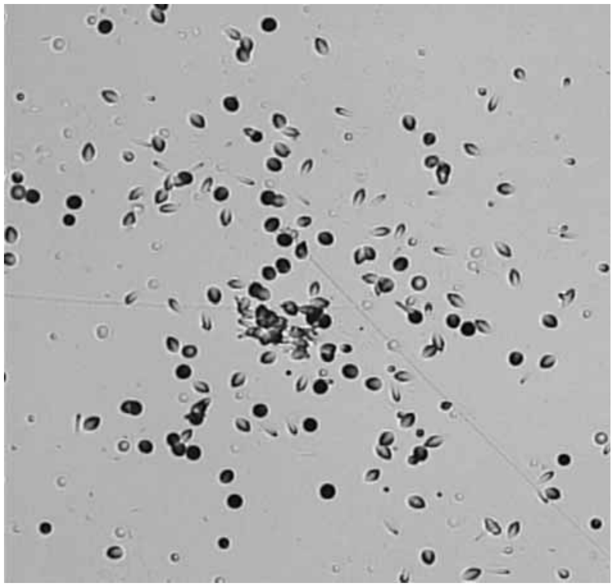

Figure 4. Photomicrograph of recoil tracks in CR-39 plastic detector irradiated with ^{252}Cf neutron source, etched in 6.25 N NaOH at 70°C for 4 h at magnification 600×.

4. Conclusions

CR-39 solid state nuclear track detector has gained widespread acceptance for personnel neutron monitoring in recent years. It is found that the track density of the CR-39 dosimeter as a function of the neutron fluences is linear. The registration of protons in CR-39 nuclear track detector has long been recognized as the basic requirement for a successful neutron dosimetery. So, CR-39 offers the best prospect for neutron dosimetry, which is due to its high sensitivity to protons.

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