Efficiency of CR39 SSNTD for fast neutron detection

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Due to high sensitivity to fast neutrons and low energy threshold for track formation, CR39 solid state track detectors (SSNTD) have been extensively employed in the past, as personal dosimeters, or neutron fluence controllers in fusion reactors, and detectors in ICF experiments. The neutron efficiencies, reported in literature, are strongly depending on experimental conditions and, in some cases, highly dispersed The present work analyses the dependence of efficiency as a function of various parameters and experimental conditions in both the radiator-assisted and the stand-alone CR39 configurations. MONTECARLO calculations of the neutron detection efficiency are shown and discussed.

1. Introduction

CR39 solid state track detectors (SSNTD) have been extensively employed in the past, as personal dosimeters, or neutron fluence controllers in fusion reactors, and detectors in ICF experiments. With the availability of higher intensities (≥10^{16} Watt/cm^2), the laser thin-target interaction has evidenced nuclear events whose emitted neutrons can be detected by tracks indirectly left into CR39 samples [1],[2],[3],[4]. The neutron efficiencies, reported in literature, are highly depending on experimental conditions and, in some cases, widely dispersed,[1], [5], [6]. So, it is very difficult the using of the mentioned data to extract deeper information on nuclear mechanisms or on plasma properties (temperature, density, etc.). The present work analyses the dependence of efficiency as a function of various parameters and experimental conditions in both the radiator-assisted (RADIATOR) and the stand-alone (NO-RADIATOR) CR39 configurations. To handle the neutron energies of D+D reaction, D+T reaction and Am-Be sources, we consider an energy range 0f 0.5 MeV to 15 MeV. The MONTECARLO results of neutron efficiency calculations are shown and discussed.The detection of a fast neutron occurs in two steps. The first step is the generation of a moving charged particle, inside a suitable radiator foil (as CH2) or within the CR39 sample (H18C12O7); the second one is the optical detection of the track of the charged particle which is formed into the CR39 sample.

2.1 Charged particle production.

Concerning the first step, to maximize the probability of generation of charged particles, it is convenient to exploit the elastic scattering process with cross section σ, of the order of barn, and particularly, to use recoiling H ions to maximize linear momentum transfer. Generation of charged particles through nuclear reactions have also to be taken into account depending on neutron energy and of sample. When a number of neutron N_o crosses a polycarbonate or PET sample of d thickness, with M_H, M_C, M_O atomic densities for Hydrogen, Carbon and Oxygen respectively, the number of recoiling nuclei N_j (supposing multiple scattering to be negligible), are expressed by the equation : $Nj = No(1\text{-}exp^{-\sigma jMjd})$, (where j stands for j = H, C, O). For each specie, the intrinsic efficiency for neutrons detection can be defined as: $\varepsilon j = 1\text{-}exp^{-\sigma jMjd}$ and, analogously, the average intrinsic efficiency, derived. To first approximation, recoiling nuclei can be supposed to have isotropic emission in the center of mass system (CM) and the energy distribution in laboratory reference system (LAB) are simply related to the recoil θ-angle in LAB, to recoil ion mass A and neutron energy, E_n. It can be shown how, for H ions, the energy distribution is constant in the range $0 \leq E_H \leq En$. Slowing down of ions goes on until the Bragg peak position or the border of sample is reached. A recoiling ion will contribute to neutron effective efficiency if its path lies in part into the region of the detector useful for track formation and its track can become visible to optical observation system.

2.2 Track formation along the ion path.

When a recoiling ion crosses a polycarbonate sample as CR39, a break is produced of the polymeric bonds in the damaged region which extends to few tens of nm along the trajectory. After a chemical etching, this break increases the etching rate along the track (V_T) with respect to the etching rate of undamaged bulk (V_B) and the ion path along the damaged trail is revealed by a conical pitch which is visible to microscopic analysis. The pitch characteristics (mainly diameter and length) depend on properties of the etching solution (chemical composition, concentration, temperature and etching time duration) and on travelling ion, so that determination of ion properties is possible. Parameterization of the track etching rate can be performed following the results of B. Dorschel et al.[7]. related to the behavior of the ratio $V=V_T/V_B$, for protons and alpha particles versus the restricted energy loss.

3.1 Neutron detection: RADIATOR option.

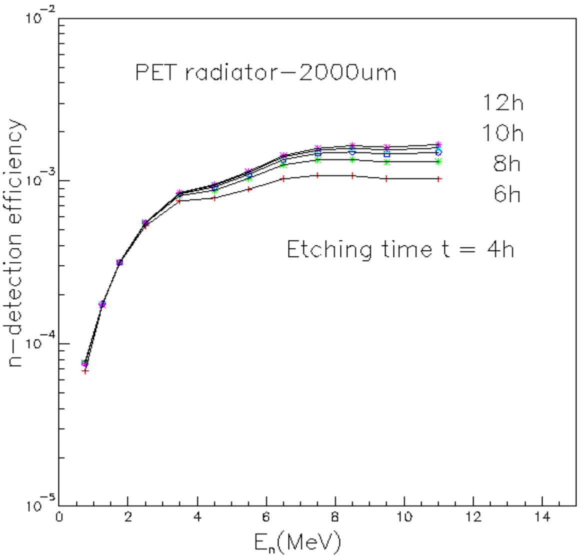
Many papers have been devoted to the detection of fast neutrons by using suitable RADIATOR foils (i.e. PET) to convert neutron in recoiling charged particles followed by the CR39 sample where visible tracks can be formed. To contribute to the detection efficiency, each recoil charged particle must exit from the radiator and go into the CR39 to form a track visible to the microscope observation system. Therefore following the neutron energy, the thickness of the of radiator must maximize the number of charged particles which can be observed by the microscope.The etching characteristics, namely: composition, concentration, temperature, time etching will determine the bulk rate value V_B and the constant part of track etching rate V_T, whereas the part of V_T which is dependent on recoil particle energy and species, will follow the restricted energy loss behavior along the ion trajectory. In this schema, observation is done at front side (side where particle is entering from). Focusing sensitivity of microscope system determines the possibility to distinguish a track pitch from background.

3.2 Neutron detection NO-RADIATOR option.

Recently some authors, [1],[8], have introduced the possibility to detect fast neutrons by using the track sample as producer of recoil charged particles and, at same time, to reveal the formed tracks. Because the tracks rest latent to optical observation until the etching process makes them visible, it is necessary sure to some extent the track length exceeds that of the bulk. This 'extent' is a crucial parameter to limit the efficiency values. Values of 0.4 um and 1.0 um are used depending the microscope sensitivity. Due to very small absorption cross sections, neutron can produce charged particles as long as going through the whole sample, so that the total CR39 thickness can play an important factor on neutron efficiency. Etching time also influences largely the neutron efficiency. In this case of no-radiator option, the back observation can be applied so that neutron efficiency can be defined for FRONT SIDE as well for BACK SIDE.

4.1 MONTECARLO calculations.

To handle on the basis of same framework the efficiency values related to different options, a Fortran77 Code has been written at LNS, (Neutroneff2014), which allows to perform simulations and comparisons taking into account all parameters concerning the n-charged particle conversion options, the etching process characteristics as well as the FRONT and BACK observations and optical microscope sensitivity. Figure 1 and Figure 2 show some peculiar results related to RADIATOR option and NO-RADIATOR option, respectively.



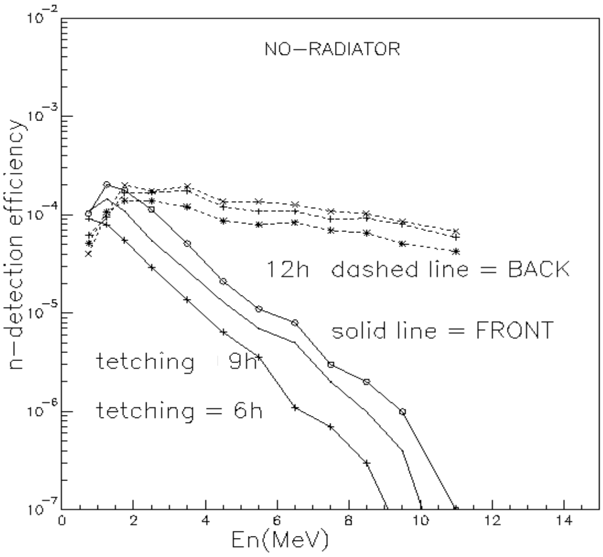


Figure1 and Figure 2 Neutron efficiency v/s Neutron energy for some etching time values. On the left RADIATOR option with PET foil 2000um thick; on the right: NO-RADIATOR option; dashed lines BACK observation, solid lines FRONT observation. CR39 samples 1050 um thick; 6.25N NaOH solution at 70 ^{o}C.

From inspection of these figures some conclusions can be drawn: In the RADIATOR option, for very low energy values, neutron efficiency is ≅ 3-7.10^{-4}. It increases strongly with the neutron energy reaching values of ≅2.10^{-3}. In the No-RADIATOR option, the BACK observation allows for larger efficiency values with respect to the FRONT observation ones, except for very low energy values where values of ≅1-2 10^{-4} are attained.

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