Response of CR-39 SSNTD to high energy neutrons using zirconium convertors – A Monte Carlo and experimental study.

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Introduction

Neutron dosimetry in ion accelerators is a challenging field as the neutron spectrum varies from thermal, to fast and high-energy neutrons usually extending beyond 20 MeV. Solid-state Nuclear Track Detectors (SSNTDs) have been increasingly used in numerous fields related to nuclear physics. Extensive work has also been carried out on determining the response characteristics of such detectors as nuclear spectrometers. In nuclear reaction studies, identification of reaction products according to their type and energy is frequently required. For normally incident particles, energy-dispersive track-diameter methods have become useful scientific tools using CR-39 SSNTD [1]. CR-39 along with 1 mm polyethylene convertor can cover a neutron energy range from 100 keV to 10 MeV. The neutron interacts with the hydrogen in CR-39 producing recoil protons from elastic collisions. This detectable neutron energy range can be increased by modification in the radiator/convertor used along with CR-39. CR-39 detectors placed in conjunction with judiciously chosen thicknesses of a polyethylene radiator and a lead absorber (or degrader) are used to increase energy range upto 19 MeV [2]. A portable neutron counter has been proposed for high-energy neutron measurement with 1 cm thick Zirconium (Zr) as the converter outside a spherical HDPE shell of 7 inch diameter [3].

Zr metal has been found to show (*n*,*2n*) cross-section for energies above 10 MeV starting from 0.01 barns for 8 MeV upto 1 barns for 22 MeV. Above these energies, the experimental data is scarce. In this paper, Zr was used in conjunction with CR-39 which showed an enhancement of track density on the CR-39. This paper demonstrates the enhancement of neutron response using Zr on CR-39 with both theoretical and experimental studies.

Material and Methods

Theoretical simulation

The study was carried out using Monte Carlo code FLUKA 2011.2C.3 version [4, 5]. Different thicknesses of Zr convertors ranging from 0.1 upto 2 mm were kept over CR-39 detectors (625 micron thick) for simulation. A parallel beam of mono-energetic neutrons were made to impinge on the bare CR-39 (without Zr convertor) as well as the combination of Zr convertor and CR-39. The neutron energy was varied from 10 MeV to 500 MeV. 1E+08 histories were simulated and and USRTRACK card was used to score the neutron and proton fluence. The proton fluence inside the CR-39 formed by the incident neutron fluence was estimated. The increase of the proton fluence in CR-39 with Zr convertor as compared with the bare CR-39 is termed as the enhancement in the response and an enhancement factor has been generated.

Experiment

CR-39 track detectors procured from M/s TASL Ltd. of dimensions 3 x 3 cm in contact with Zr (purity > 99.8%) sheet from M/s Advent, U.K was used. The Zr sheet of varying thicknesses from 0.1 mm to 2 mm was kept over CR-39 and sealed in triple laminated pouches consisting of three layers of plastic paper and aluminium to prevent moisture, dust and alphas from radon from reaching the detector. The detectors were exposed to 14 MeV neutrons produced by D-T generator at 25cm distance from the target with the known yield 3.5E+08 n/s. The energy deposited by recoil protons creates damage (breakage of bonds in the polymer) in this detector. These damages get enlarged and appear as tracks if subject to electrochemical etching. After irradiation, CR-39 detectors were processed along with control (un-irradiated) with optimized etching conditions of 1 h pre-etching followed by 3h low frequency (100Hz), 50 min high frequency (3.5 kHz) at 1300 V in 7N KOH solution kept at a constant temperature of 60^oC and evaluated in an optical image analysis system [6].

Results and Discussion.

Zirconium (^{90}Zr) has a higher cross-section at 13.0 MeV for (*n*,*2n*) reaction. Simulation studies were carried out to observe the rise in neutron number in 14 MeV monoenergetic neutrons with 1mm of Zr and 0.1 mm of Zr. It was observed that both neutron and proton number increased with Zr thickness. FLUKA studies have shown that for 14 MeV monoenergetic beams the enhancement factor (i.e. increase in proton number) is 1.05 with 0.1 mm Zr and 1.18 with 1mm thick Zr as shown in Fig.1.

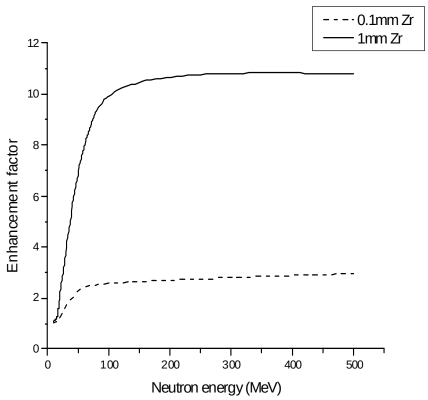

Fig. 1 Graph representing an enhancement in response of CR-39 with 0.1 mm and 1 mm zirconium.

The graph shows the increasing proton enhancement with Zr upto 500MeV where the enhancement factor is 10.8 with 1 mm Zr. Measurements carried out at 14 MeV D-T generator showed increase in track density from 0.5 mm Zr onwards. It was 7% enhancement with 0.5 mm thick Zr and 27% enhancement with 1 mm thick Zr on CR-39 as compared to bare detector. Further studies are continued for optimizing the thickness of Zr convertors for high energy neutrons.

Conclusion

The paper concludes that there is an enhancement in proton number with zirconium degrader over CR-39 as revealed by simulation studies and experimental measurements. The high energy neutrons can be degraded by (*n, 2n*) reactions to produce tracks in CR-39.

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