Photo-Neutron Detection Using Cr-39 Solid State Nuclear Track Detector

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Abstract. Photo-neutrons are produced when high energy x-rays interact with various elements by the (ɤ,n) reaction. The production is dependent upon the cross section and binding energy for the (ɤ,n) reaction to occur. The threshold energy required to overcome the binding energy for the production of photo-neutrons is different for different elements. Compared to the direct emission process, most of the photo-neutrons are produced by the evaporation process following resonance in heavy nuclei. Evaporation neutrons are emitted isotropically and have a broad range of energies. In this work, photo-neutron production from lead (Pb) and copper (Cu) were analyzed using CR-39 SSNTD. The 15 MV bremstrahlung x-rays from a Siemens Primus Plus medical linear accelerator was used as the photon source. The passive method developed for the determination of the photo-neutron spectrum from various elements gives comparable results with the theoretical predictions.

INTRODUCTION

A nucleus can be excited by the absorption of a high energy photon so that it emits a neutron, a proton or an alpha particle. This process is called photo disintegration. A typical and most probable photo disintegration process is the (ɣ,n) reaction. All (ɣ,n) reactions have a threshold energy. Above the threshold energy, the cross section for the (ɣ,n) reactions increases with the incident photon energy, until the cross section reaches its maximum value and then falls off with an increasing photon energy. The shape of the cross section peak is called the giant resonance 1. For light nuclei; such as carbon, nitrogen, oxygen and aluminium, energy of maximum cross section (Em) is about 20 to 25 MeV, and for heavy nuclei such as iron , copper, tungsten and lead it is about 14 to 20 MeV. For all nuclei the full width at half maximum (FWHM) of the giant resonance peak is from 4 to 10 MeV, independently on atomic number or mass number of the absorber.

A nucleus (A, Z) can reach an excited state by absorbing a photon of energy Er. It will then decay and produce a neutron and a daughter nucleus (A-1, Z). The spectrum of the emitted neutrons depends on the state of the daughter nucleus. The maximum energy of the excited state of a daughter nucleus that can be reached the decay is given by Ex(max) = Er – Sn-Δr, where Sn is the neutron separation energy or threshold energy and $\Delta r = \frac{E_r^2}{2AM_c^2}$ is the centre of mass recoil energy where M is the mean nuclear mass [4]. Therefore, the energy of the emitted neutron can vary from 0 to E_x (max).

MATERIALS AND METHODS

The CR39 SSNTD used in this work is a 250 μm thick film and density 1.3 g/cc. The film was cut into 1cm*1cm using a diamond cutter. Neutrons with energies between 0.7 and 20 MeV can be detected through recoil protons produced in elastic interactions between neutrons and the hydrogen nuclei of the polymer. Lead and copper with size

5cm * 5cm and thickness 3mm where taken for irradiation. The linac was set to produce 15MV X-rays with a field size of 10*10cm^2 and MU 1000.The piece of lead was kept on the table at a distance of 1m at the central axis of the beam. The CR 39 SSNTD was placed exactly at the bottom of the lead piece to detect the photo-neutrons produced from it. The Lateral view of the experimental setup is shown in figure 1. The radiation was delivered to the pre-set time and after completion, the CR39 film was taken out and tagged for chemical etching. The same process was repeated for Cu and the films were properly tagged.

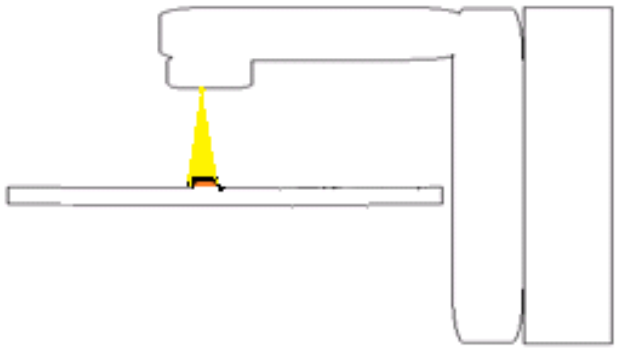

FIGURE 1. Lateral view of the experimental setup

The films are then chemically etched at standard etching conditions such as 6N NaOH solution at a constant temperature of 60^{0}C. The etching time was 6hrs with a constant stirring of 30 rotations per minute. After the CR39 SSNTD has been etched, it is removed from the NaOH solution and is viewed with an optical microscope with 40X magnification. The size of the elliptical opening of the conical pit is proportional to the LET of the particle which formed in the latent trail. The images of the etched films are then analysed using a programme, TRIAC II [1]. TRIAC II is based on a segmentation method that groups image pixels according to their intensity value (brightness) is a number of grey level groups. The major axes, minor axes and orientation of each track then be obtained using the programme.

The recoil proton energy can be calculated from the track diameter by using a calibration graph. The calibration graph is obtained by plotting track diameter and known proton energy [2, 3]. Then the corresponding neutron energy is calculated using the equation $EP= E_N\cos^2\Theta$, where E_p is the energy of proton, evaluated in the previous step, E_n is the neutron energy and Θ will be the recoil angle. Thus the neutron energy corresponding to each track can be calculated. The neutron energy is binned with 200 KeV and the average energy for each bin is calculated. The number of photo-neutrons for each average energy is counted. This is then corrected with the efficiency as $Y=n\sigma\varphi$.Here n is the number of hydrogen atoms present in 1cm2 unit of CR39 film, σ is the cross section for (γ, n) reaction obtained from EXFOR ENDS, φ is the efficiency corrected number of photo-neutrons and Y is the number of tracks formed in the CR39 film in 1 cm2 area. The spectrum is then plotted with energy along X axis and corrected counts along Y axis.

RESULTS AND DISCUSSIONS

The irradiated films were chemically etched and the images of tracks obtained using an optical microscope. The track parameters were calculated using TRIAC II.The recoiled proton energy is calculated with the help of track diameter and the corresponding neutron energy is calculated .The photo-neutron energy is binned with a range of 200 MeV and efficiency corrections are applied. The photo-neutron spectrum of lead and copper were obtained and are plotted as shown in figure2.

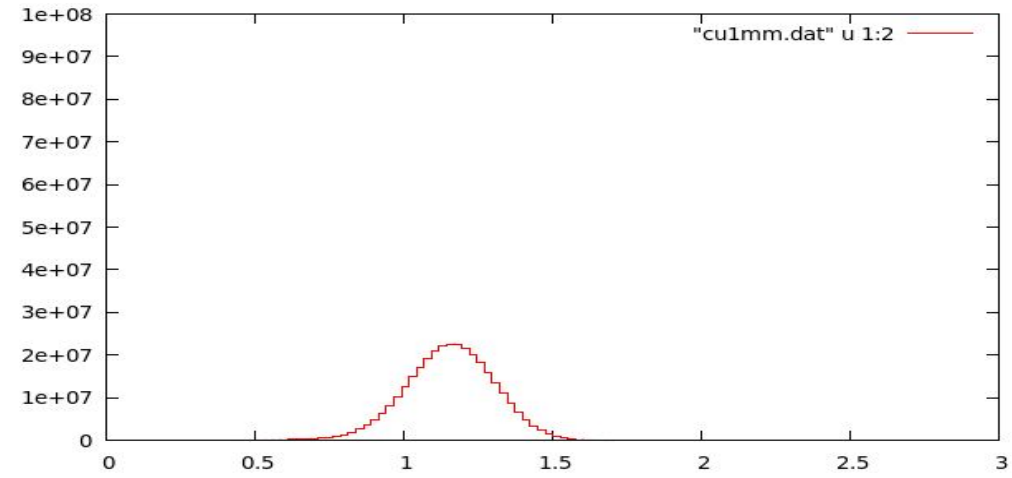

Figure 2(a)

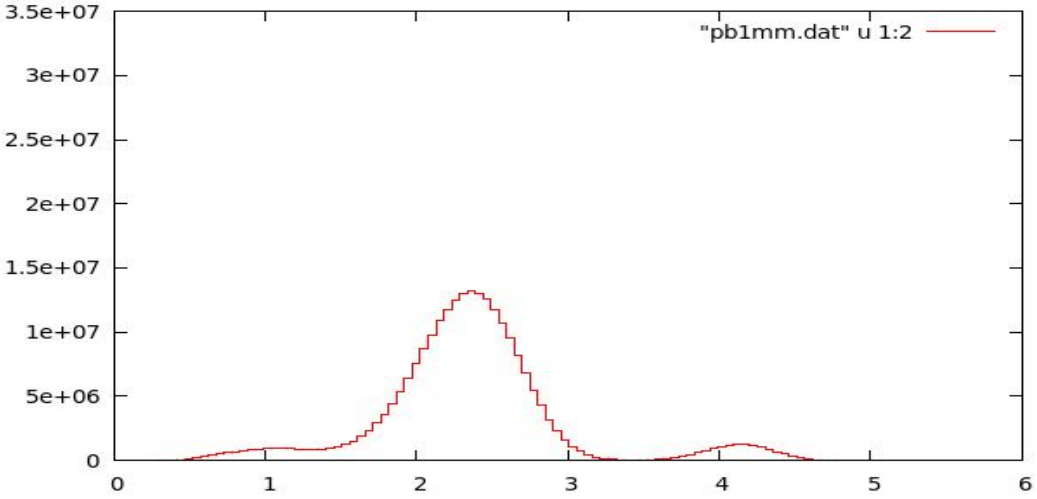

Figure 2(b)

FIGURE 2. Photo-neutron spectrum from (a) Copper (b) Lead

CONCLUSION

The continuous spectrum with definite peaks and the maximum energy of photo-neutrons gives an idea about the photo-nuclear reaction. The method can be used to study the photo-neutron spectrum produced from other elements which are present in our body, so that the dose can be calculated. The photo-neutron spectrum can be given as an input to the Monte Carlo simulation programme and the dose can be calculated within 2% accuracy. The present method does not require a calibration in a known neutron spectrum. The CR39 SSNTD also gives an advantage in the sense it is a passive detector and can be placed easily anywhere and is also tissue equivalent. The method can be used to find out the photo-neutron dose, during cancer treatment, by the interaction of high energy bremsstrahlung X-rays with different machine parts made of lead, tungsten etc and from the patient body by the interaction of C, O, H, N etc [4, 5]. It can also be used to find out the different reaction channels responsible for photo-neutron production.

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