STUDY ON THE ENERGY RESPONSE OF PLASTIC SCINTILLATION DETECTOR TO 0.75-14.75 MEV NEUTRONS

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ABSTRACT

The energy response to neutrons of plastic scintillation detector has been studied in the energy range 0.75-14.75 MeV by using experiments together with Monte Carlo simulations. The neutron source was produced by ^{9}Be(d, n)^{10}B reaction on HI-13 tandem accelerator at China Institute of Atomic Energy. A model of Monte Carlo simulation was set up to calculate the absolute energy response to neutrons, and the NRESP Code was developed to calculate the relative energy response to neutrons. The experimental data were compared to the results from the Monte Carlo simulations, and the accuracy in the calibration was discussed. Using the thinner scintillator, the energy response to neutrons of plastic scintillation detector varies relative slightly with the neutron energy.

1. Introduction

Plastic scintillators have been widely used in fast neutron diagnostics because of their fast time response, high detection efficiency and favorable mechanical properties. Thin plastic scintillation detectors are very useful in the pulsed fission neutron flux measurements because of its good neutron-to-gamma sensitivity ratio and a relative flat energy response [1]. For intense pulsed neutron flux detection, the detector must be operated in current mode. Calibration of neutron response function of the thin plastic scintillation detector is very important before it is used for neutron flux measurements. In this work, the response as a function of neutron energy was measured using neutron time-of-flight (TOF) to select quasi-monoenergetic neutrons which was produced by ^{9}Be(d, n)^{10}B reaction over a wide energy range of 0.75-14.75 MeV. A model of Monte Carlo (MC) simulation was set up to calculate the absolute energy response to neutrons, and the NRESP Code [2] was developed to calculate relative energy response to neutrons. This work describes the experiments and simulations for determining the energy response to neutrons of the thin plastic scintillators. In addition, it discusses the results of the experimental data as well as the simulations.

2. Monte Carlo simulation

The sensitivity $S_n(E_n)$ of the plastic scintillation detector, as a function of neutron energy, can be defined by

$$S_n(E_n) = \frac{Q(E_n)}{\Phi(E_n)}, \qquad (1)$$

where $S_n(E_n)$ is the sensitivity of the detector to neutron energy E_n, $Q(E_n)$ is the charge output of the detector (coulomb), $\Phi(E_n)$ is the neutron fluence at the detector position (n/cm^2).

Neutron interaction with plastic scintillator is mainly through *n-p* elastic scattering. Because of the decreased scintillation efficiency for high energy loss *dE/dx* particles, carbon recoils produced by neutron elastic scattering do not contribute much to the detector charge output. With the neutron energy increasing, the two competing reactions ^{12}C(n, α)^{9}Be and

$^{12}C(n, n')3\alpha$ occurs. If the light output for alpha particles is not relative small compared to that for recoil protons, it should be considered in the sensitivity calculation of scintillators.

The sensitivity calculation of the plastic scintillation detector to neutrons can be expressed from:

$$S_n(E_n) = A \times \eta \times c \times q \times G \times e \times L(E_n)\,, \tag{2}$$

where A is the effective area of the scintillator, η is the fraction of scintillation light that reaches to the photocathode of photomultiplier tube (PMT), c is the collection efficiency of the photocathode, q is the quantum efficiency of the photocathode, G is the gain of the PMT, e is the electron charge in coulombs, and $L(E_n)$ is the light output of the scintillator per neutron with energy E_n.

The light output of plastic scintillators to protons can be best described by following expression [3]:

$$L(E) = S\int_0^E \left(1 + kB\frac{dE}{dx} + C\left(\frac{dE}{dx}\right)^2\right)^{-1} dE\,, \tag{3}$$

where S is the normal scintillation efficiency, dE/dx is the specific energy loss for the charged particle. The product kB is treated as a single adjustable parameter to fit experimental data for specific scintillator. C is again treated as an empirically fitted parameter.

The light output of plastic scintillator depends on the type of particle. Since the light output of plastic scintillator is linearly related to the fast electron energy, the light output $L(E_n)$ can be expressed in terms of *MeV equivalent electron energy* (MeVee), which is the light output given by 1 MeV fast electrons. If we know the relevance between the proton energy and 1 MeVee of light, then, the light output $L(E_n)$ in relation to the electron light output scale is given by

$$L(E_n) = S_e \cdot E_{MeVee}(E_n)\,, \tag{4}$$

where E_{MeVee} is the equivalent electron energy deposited in the scintillator, S_e is the electron scintillation efficiency. For a given detector, only S_n (E_n) and $L(E_n)$ are functions of the neutron energy E_n. If we define

$$K = A \times \eta \times c \times q \times G \times e_e; \tag{5}$$

Then Eq. (2) can be written in the form:

$$S_n(E_n) = K \cdot E_{MeVee}(E_n)\,, \tag{6}$$

where K is a factor, which can be obtained from calculation or by fitting the experimental data. Fig. 1 shows the light output for protons depositing their entire energy in the BC408 plastic scintillator [4]. BC418 plastic scintillator has a similar light output characteristic to BC408 plastic scintillator. Therefore, this light output function for protons was adopted in the MC simulations.

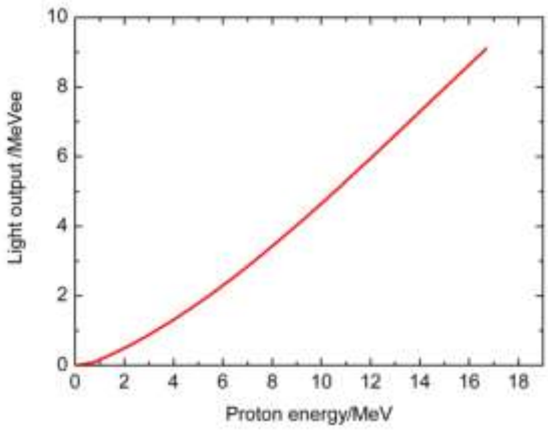

Fig. 1 Light output for protons depositing their entire energy in the BC408 plastic scintillator.

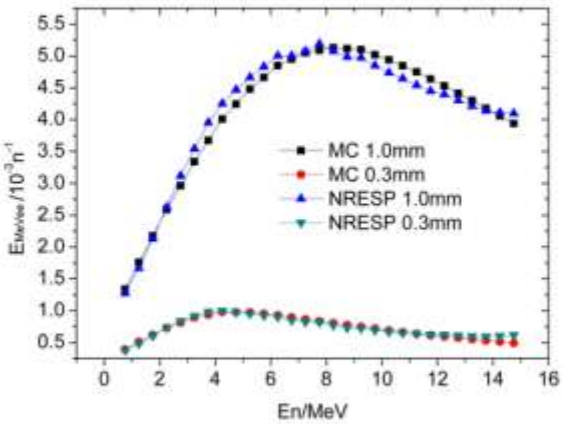

Fig. 2 The calculated light output of thin plastic scintillator as a function of neutron energy.

A MC model was set up to calculate the absolute energy response to neutrons. Fig. 2 shows the calculated light output of thin plastic scintillator as a function of neutron energy. The results calculated by using NRESP code were normalized to the MC results. To simplify the MC model, only *n-p* elastic scattering was considered. The simulation by using NRESP code includes the contribution of alpha. For thinner scintillator, the contribution of alpha should be considered.

The thin plastic scintillation detector mainly consists of the BC418 (manufactured by Saint-Gobain Ceramics & Plastics, Inc.) thin plastic scintillator and the PMT. The use of thin plastic scintillator less than 1 mm thickness will decrease the sensitivity to neutrons (decrease sensitivity to gamma rays more, thus good neutron-to-gamma discrimination can be achieved). Therefore, the sensitivity to neutrons of the PMT cannot be neglected. To decrease the background of direct irradiation, the PMT was set to collect the luminescence at the side of scintillator. This makes the factor η to be small. The PMT (9813B, manufactured by Electron Tubes Ltd) has an outer diameter of 5.15 cm and an active photocathode area with diameters of 4.6 cm. Thus, c=0.89, q=0.29 and G 7.0×10^7 was used in the calibration. The effective diameter of the thin plastic scintillator is 55 mm, and then A is 23.75 cm^2. For BC418 plastic scintillator, S_e=10000 photons/MeVee. According to the geometry of the plastic scintillation detector, η is estimated to be 3%. Putting these data in Eq.(5), we can obtain the $K_{cal}=2.06\times10^{-8}$ C·cm^2/MeVee. Thus, we can calculate the absolute neutron response of the thin plastic scintillation detector by using $S_n(E_n)=2.06\times10^{-8}\times E_{MeVee}(E_n)$.

3. Calibration

3.1 Measurement of the fluence

A white neutron source, which was produced by bombarding a 3 mm thickness Be metal target with 20 MeV deuteron beam, was used in the calibration of the neutron energy response of the plastic scintillation detector. Before calibration, the neutron fluence and energy spectrum was measured. The measurement was performed at HI-13 tandem accelerator facility of CIAE [5]. The neutron energy spectrum for the ^{9}Be(d, n)^{10}B reaction source was absolutely determined using the well-calibrated BC501A liquid scintillation detector. In the calibration, the pulse height (PH), pulse shape discrimination (PSD) and neutron TOF were recorded by the data acquisition system (DAQ) based on CAMAC. The PH spectrum was used to determine neutron detection efficiency. The two-dimensional PSD spectrum was used to eliminate gamma background. The TOF branch (TAC, ADC) was used to determine the neutron energy spectrum by using signals from the experimental detector and signal pickup system. Fig. 3 shows the neutron energy spectrum of the ^{9}Be(d, n)^{10}B reaction measured at an angle of 0°, for the neutron flight path of 6.33 m. During the measurement, the stilbene scintillation detector at 60° was calibrated and normalized to the BC501A liquid scintillation detector to monitor the source neutron fluence.

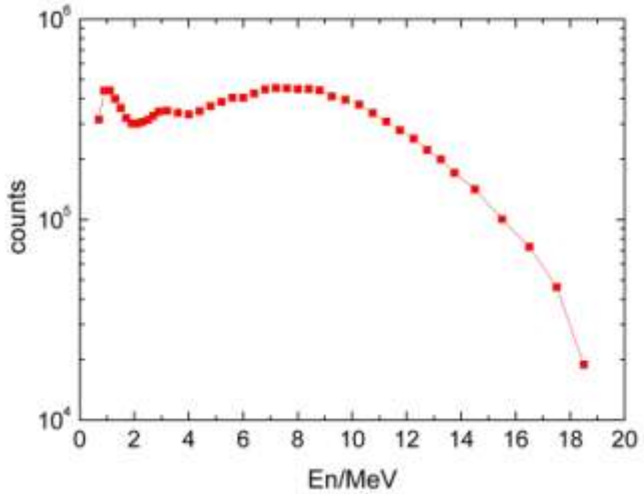

Fig. 3 Neutron energy spectrum of the ^{9}Be(d, n)^{10}B reaction measured by using BC501A liquid detector.

3.2 Experimental principle

The calibration was performed with the neutron TOF technique at HI-13 tandem accelerator facility of CIAE. The plastic detector was also positioned at an angle of 0° with respect to the beam direction as well as a distance of 6.69 m from the neutron source. When experiments, two parameters (charge Q and TOF) for every event which induced by neutrons are recorded by using CAMAC DAQ. The charge Q was measured with a charge ADC (Philips PS7166). With the combination of the neutron TOF spectrum and PH spectrum measurement, the charge Q for a certain E_n can be deduced from the measured PH spectrum, by selecting the appropriate energy bin from the TOF spectrum. Fig. 4 shows the measured PH spectrum (a), TOF spectrum (b) and corresponding charge Q spectrum (c) deduced from different neutron energy bins (1, 2 and 3). The neutron energy E_n is determined by the TOF spectrum. The absolute neutron fluence is determined by the monitor. Then the neutron sensitivity $S_n(E_n)$ defined by *Eq.* (1), as well as the background sensitivity to neutrons, can be obtained by

$$S_n(E_n) = \frac{Q_A(E_n) N_Q(E_n) D_t}{N_m \Phi(E_n)}, \tag{7}$$

where E_n is the average energy of the neutrons within the energy bin, D_t is the dead time factor, N_m is the total neutrons detected by the monitor, $\Phi(E_n)$ is the neutron fluence at the detector position with E_n per unit neutron detected by the monitor, $N_Q(E_n)$ is the number of neutrons within the energy bin E_n and $Q_A(E_n)$ is the deduced average charge.

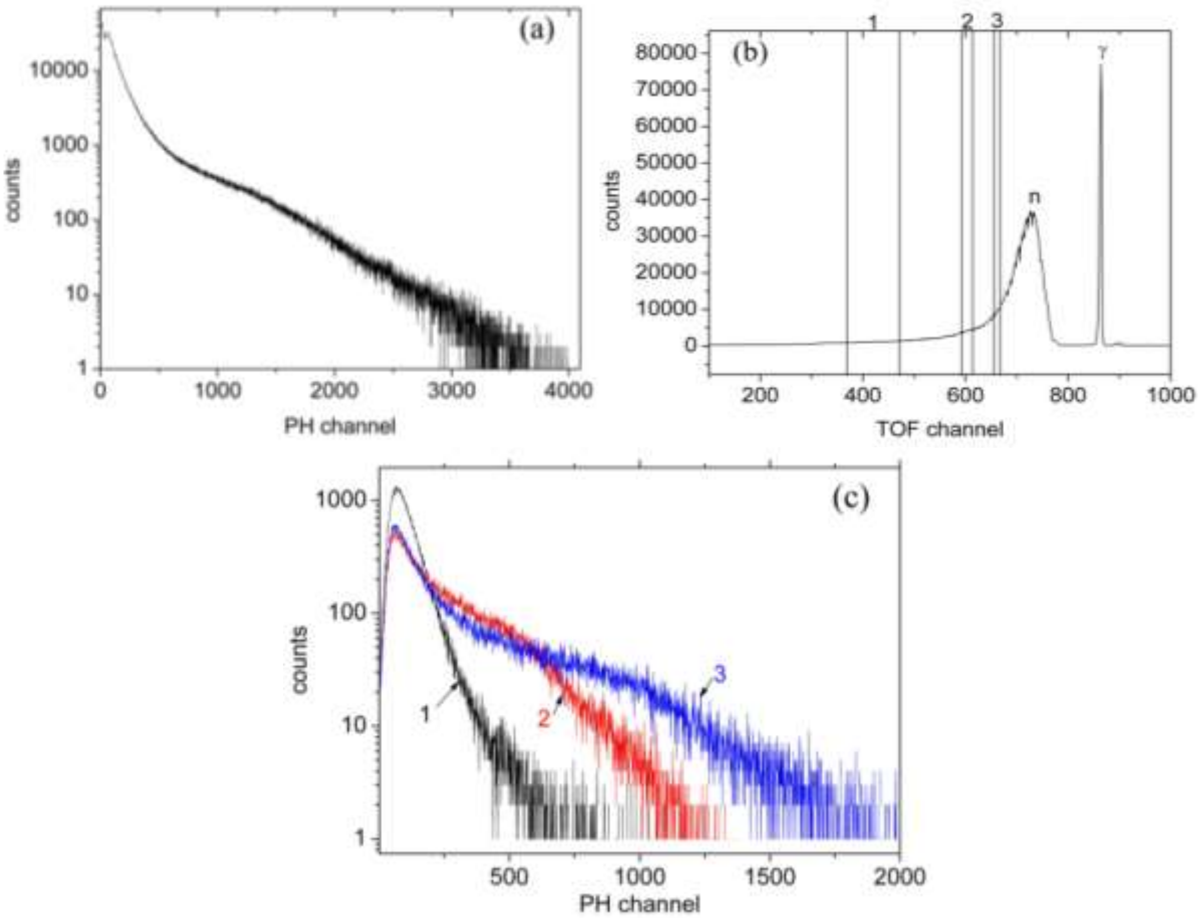

Fig. 4 The measured charge PH spectrum (a), TOF spectrum (b) and corresponding charge Q spectrum (c) deduced from different neutron energy bins (1, 2 and 3).

4. Results and discussion

Fig. 5 shows the experimental data of the sensitivity at given neutron energies for two thickness thin plastic scintillators compared with the results obtained from MC simulations and NRESP Code. The absolute neutron energy response of the detector was obtained by fitting the experimental data. The factor K_{exp} determined by fitting the experimental data are 1.86×10^{-8} C·cm^2/MeVee and 2.03×10^{-8} C·cm^2/MeVee respectively for 1.0 mm and 0.3 mm thickness scintillator. The absolute response of the thin plastic scintillation detector was calculated by using K_{cal}=2.06×10^{-8} C·cm^2/MeVee and MC calculated light output. The results calculated by using NRESP code were normalized to the experimental data. The experimental and the calculated energy response agree well within the uncertainty.

Fig. 5 shows that the sensitivity to neutrons increases and then begins to fall with increasing the neutron energy. Thinner plastic scintillator can achieve better flat performance of neutron energy response. For a thin plastic scintillator, the range of protons produced by neutrons is usually larger than the thickness, which means that the full energy of the neutron cannot be deposited. Therefore, the response to neutrons does not follow directly from the energy of incident neutrons. In addition, the energy loss *dE/dx* in the scintillator decreases with increasing energy of incident neutrons. However, the energy distribution deposited in the scintillator increases, resulting in increasing the light output. Therefore, using appropriate thickness of scintillator, the response to neutrons of the thin plastic scintillation detector can vary relative slightly with the neutron energy.

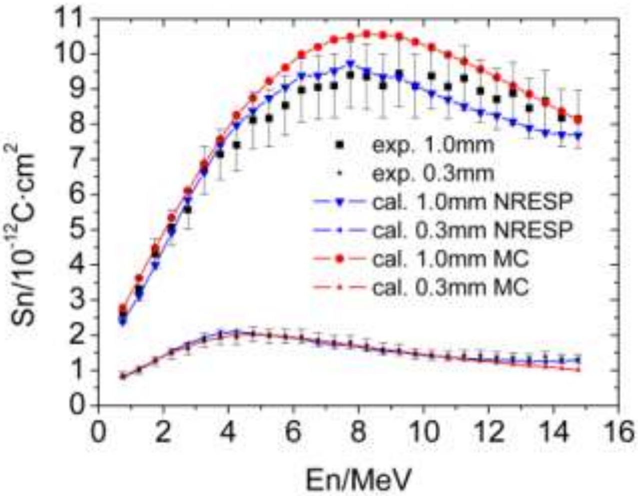

Fig. 5 The experimental data and the calculated neutron energy response curve.

The experimental uncertainty is mainly due to the statistics uncertainty, including the measurement of neutron fluence and charge Q derived from different neutron energy bins. One important source of the relative uncertainty for neutron fluence is about 8%, including the neutron detection efficiency of the BC501A liquid scintillation detector and the normalization of the stilbene scintillation detector. Another main source is the correction for the charge Q below the threshold, as shown in Fig. 6. This correction factor varies with neutron energy from 1.02 to 1.15, with relative uncertainty less than 5%. The relative uncertainty of the correction for the background from scattering neutrons and gamma rays (as shown in Fig. 7) is estimated to be 1-2%, depending on the neutron energy and the thickness of the scintillator. Other relative uncertainty sources are estimated to be less than 1%. The total relative uncertainty is 8-10%.

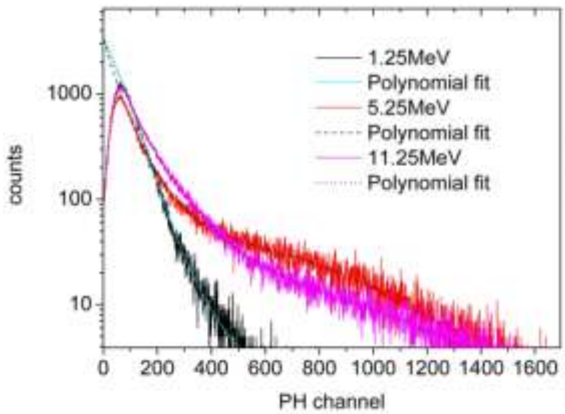

Fig. 6 The correction for the charge Q below the threshold using polynomial fit.

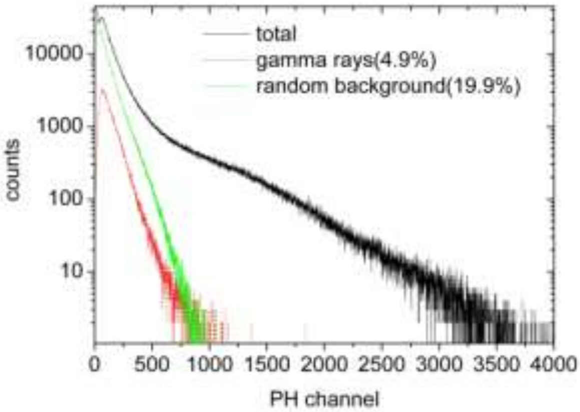

Fig. 7 Charge component of the background from scattering neutrons and gamma rays

5. Summary

The neutron energy response of the thin plastic scintillation detector has been studied in the energy range 0.75-14.75 MeV by using white neutron source produced by $^{9}Be(d, n)^{10}B$ reaction together with MC simulations. The experimental data agree well with the simulations, and both describe the trend of the response with the energy dependence. For the thinner scintillator, the response to neutrons in the given energy range varies relative slightly with the neutron energy. The MC model can be used to calculate the absolute neutron energy response, and the NRESP Code is suit to calculate the relative neutron energy response.

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