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Measurement of neutron response function for thin plastic scintillators using white neutron source from d–D breakup reaction

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Abstract

The neutron response function for thin plastic scintillators has been measured using the white neutron source produced by the d–D breakup reaction. Deuteron energies of 9, 12 and 14 MeV were chosen to produce the neutron energy range from 0.5 to 17 MeV. The intensity of the neutron beam was measured by a well-calibrated BC-501A liquid scintillation detector at 0°. The measured results were compared with Monte Carlo simulations and verified by additional experiments at a neutron generator and the 2×1.7 MV 5SDH-2 tandem accelerator. The results obtained from these experiments all agree well with the simulations.

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Keywords: d + D breakup reaction; Thin plastic scintillator; Neutron response function

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. In an n/γ mixed field, a thin scintillator exhibits much higher sensitivity to fast neutrons than to gammas, thus good n/γ discrimination can be achieved. However, the neutron response function must be well calibrated before the scintillator can be used for fast neutron diagnostics in mixed n/γ fields.

In the past, the commonly used method to calibrate a scintillation neutron detector was to measure the light output function and the neutron detection efficiency (for instance, see Refs. [1,2]). This is very important for neutron energy spectrum measurements. However, the single-particle sensitivity of the neutron detector, defined as the average charge produced by unit neutron flux irradiation at a certain neutron energy E_n ($S_n(E_n) = Q/\mathrm{n\,cm^{-2}}$), is also important in some cases, especially for neutron diagnostics in a high neutron flux radiation field, where the current mode was usually used (i.e., measure the charge or current induced by neutrons to diagnose the neutron field from the pulsed reactor or single shot pulsed neutron generator). In this paper we have measured the single-particle sensitivity as a function of neutron energy for some thin plastic scintillators in the range of 0.5–17 MeV, using the white neutron source produced by d–D breakup reaction at the HI-13 tandem accelerator at the China Institute of Atomic Energy (CIAE). The results obtained with the d–D breakup reaction were also compared with the results obtained using the T(p,n) reaction neutron source at the 5SDH-2 (2×1.7 MV) small tandem accelerator (from 0.5 to 5 MeV), and with the results measured

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at the CPNG (CIAE Pulsed Neutron Generator) neutron generator.

2. Experimental principle and arrangement

The $D(d,n)^3He$ reaction is widely used in neutron physics and neutron dosimetry. It can provide high intensity and very good monoenergetic neutron sources between 2.5 and 8 MeV. However, when the neutron energy is greater than 8 MeV by using this reaction, the breakup channels will open and the neutron source will become quasi-monoenergetic (i.e., the emission neutrons will be contaminated by breakup neutrons). The reactions are

$$\begin{aligned} D + d &\longrightarrow n + {}^3He + 3.27\,MeV \\ &\longrightarrow n + p + D - 2.22\,MeV \\ &\longrightarrow n + p + n + p - 4.44\,MeV. \end{aligned} \tag{1}$$

In most cases, the breakup neutrons are a drawback of the source because they contaminate the monoenergetic neutrons. In this work the breakup neutrons were used to calibrate the response function of our neutron detectors. The advantage of using the breakup neutrons is that the neutron energy range of interested can easily be covered by choosing the appropriate incident deuteron energies. Thus we can calibrate the detectors for many energy points in one run which greatly reduces the beam time. In this work, deuteron energies of 9, 12 and 14 MeV were chosen. The breakup neutrons and the monoenergetic neutrons then cover the energy range from 0.5 to 17 MeV with reasonable intensity. The absolute neutron fluences were determined by a well-calibrated BC-501A neutron detector (standard neutron detector) and the neutron energy spectra were measured by time-of-flight (TOF) technique using signals from the detectors and from the pulsed-beam pick-off system. The charge of the single event for plastic scintillators was measured with a charge ADC (Philips PS7166 CAMAC QDC), which was calibrated by a precise pulse generator. With the combination of TOF and single event charge measurement, the single-particle sensitivity as a function of neutron energy can be determined as

$$S_n(E_n) = \frac{Q_t(E_n)}{\phi_n(E_n)} \tag{2}$$

where $Q_t(E_n)$ is the integral charge induced by neutrons and $\phi_n(E_n)$ represents the time-integrated neutron flux at the detection position. Both of them are functions of the neutron energy E_n. The $Q_t(E_n)$ for a certain E_n can be deduced from the measured charge spectra, by selecting the appropriate windows from the TOF spectra.

The experimental setup is schematically shown in Fig. 1. A deuterium gas target was used to produce neutrons with d–D reaction. The deuteron beam was accelerated in pulsed mode with a repetition rate of 1 MHz and 200 nA averaged current. The source neutrons were shielded and collimated at 0°. The neutron detectors were placed at the end of the collimator. ST-401 and BC-418 thin plastic scintillators (with different thickness but all <1 mm and 60 mm in diameter) were used. The scintillators were coupled with EMI-9813B PMT directly. A neutron monitor ($\Phi 2'' \times 2''$ BC501A liquid scintillator coupled directly with XP-2020 PMT with a base of ORTEC-269) was placed at 150° and 2 m away from the source to monitor the source neutron fluence.

Fig. 2 shows the diagram of the electronics and data acquisition system. Two parameters (charge (Q) and TOF) for every event were recorded in list mode for the plastic scintillators. For the neutron energy spectra and fluence measurement, the standard neutron detector was placed at the same position as the plastic scintillators (i.e., the standard neutron detector replaced the plastic scintillators). The standard neutron detector is also a BC501A liquid scintillator with the same size as the monitor. Good n/γ discrimination can be achieved by pulse shape discrimination (PSD) with the neutron energy $> \sim 0.5$ MeV. Fig. 3 shows the n/γ separation spectra for the standard neutron detector (measured at 0° and $E_d = 12$ MeV using d–D neutron source). The pulse height (PH), PSD and neutron TOF were recorded by the data acquisition system (DAQ) during the data taking. The PH was used to determine the neutron detection threshold and the corresponding neutron detection efficiency. The PSD was used to suppress γ background and the TOF was used to determine the neutron energy spectra. The monitor counts were used for normalizations.

Using the measured neutron fluence and energy spectra by the standard liquid scintillator, the single-particle sensitivity could be acquired via

$$S_n(E_n) = \frac{\bar{Q}(E_n) N_Q(E_n) D_t}{\Phi(E_n)} \tag{3}$$

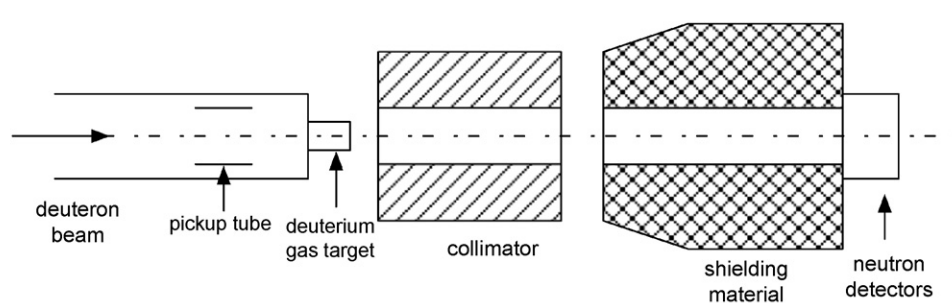

Fig. 1. Schematic diagram of the experimental arrangement.