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Thin Plastic Scintillating Foil for Measuring Pulsed Neutron Flux in High Gamma-Ray Environment*

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Abstract A new conception of measuring pulsed neutron flux in high gamma-ray environment with a thin plastic scintillating foil is presented. Based on the calculations of the response to neutrons and gamma-rays, a new gamma-insensitive detector for detecting fast rising, transient neutron flux has been developed and preliminarily tested, which comprises a thin plastic scintillating foil of ST401 (TPSF) and a photomultiplier tube (or a photodiode). The detector exhibits three distinct properties compared with the conventional ones: (1) high neutron sensitivity, (2) high n/γ discrimination, and (3) flat response in the given neutron energy range.

Key words thin plastic scintillator, pulsed neutron flux detection, neutron-gamma discrimination, energy response

1 Introduction

In the pulsed neutron flux measurements, when one encounters highly mixed neutron and gamma-ray fields that vary rapidly with time, it is desirable to record the neutrons efficiently and reject the gamma-rays effectively. To accomplish this task, a neutron monitor which is sufficiently sensitive to neutrons and insensitive to gamma rays is very much needed. Since various pulsed neutron fluxes usually have different energy spectra, it is also desirable for the detector response to be fairly independent of neutron energy in a given range.

In the past decades, a number of neutron detecting systems have been developed for measuring a rapidly changing, very high intensity fast neutron flux with energies of about 14 MeV[1—6], among them, some devices possess n/γ discrimination capability[2,4—6]. However, the neutron sensitivities of the existing systems are generally less than 10^{-18} C·cm^2 for 14MeV neutrons from DT reaction, therefore they cannot satisfy the requirements for measurements of lower neutron fluxes. To develop a higher efficient detector for fission neutron detection, which possesses high n/γ discrimination and flat response, further studies have to be made.

Plastic scintillators respond sufficiently to neutron and gamma radiation, and are widely used in charged-particle and neutron detection[7—17]. Unfortunately, the response to neutrons of a scintillator detector used traditionally in radiation measurements is usually about one order of magnitude lower than that to gamma-rays in the fission neutron range (0.5—5MeV), therefore it cannot serve as a high n/γ discrimination neutron detector. Furthermore, the response of traditional plastic scintillators to neutrons varies very sharply with energy, which will produce appreciable error in measuring neutron fluxes with different spectra. To eliminate gamma events from neutron flux measurement, pulse shape discrimination (PSD) is an applicable method for certain organic scintillators in the counting experiments because of the large differences in the relative slow component induced by fast neutrons (recoil protons) and gamma rays (fast electrons)[7,15,18]. However, few papers have been found published so far using plastic scintillator for detection of the pulsed neutron fluxes in highly mixed n/γ fields where pulse shape discrimination obviously does not work. The objective of this study is, through Monte

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Calro simulations and preliminary experimental tests, to explore the feasibility of using thin plastic scintillator foils as a pulsed neutron flux monitor which possesses (1) high neutron sensitivity, (2) high n/γ discrimination, and (3) flat response in the given neutron energy range.

2 Theoretical bases

Thin plastic scintillating foils respond directly to ionization induced by recoil protons and recoil electrons produced by neutrons and gamma rays as they pass through the scintillator materials, but the scintillation efficiency differs for each type of scintillator and also depends on the type of charged particle producing the ionization. The response to electrons is linear for particle energy above 125keV[7,19—20], and nonlinear to protons[6,17—22].

A semiempirical parametric formula can be used to determine the amount of deposited energy of charged particle (recoil proton) which is converted to scintillation light yield[7,21—22]:

$$\frac{\mathrm{d}L}{\mathrm{d}x}=\frac{S\dfrac{\mathrm{d}E}{\mathrm{d}x}}{1+kB\dfrac{\mathrm{d}E}{\mathrm{d}x}+C\left(\dfrac{\mathrm{d}E}{\mathrm{d}x}\right)^2}. \quad (1)$$

where $\mathrm{d}L/\mathrm{d}x$ is the fluorescent energy emitted per path length, $\mathrm{d}E/\mathrm{d}x$ is the specific energy loss for the charged particle, S is the scintillation efficiency, kB and C are the adjustable parameters to fit experimental data for a specific scintillator.

When excited by fast electrons, $\mathrm{d}E/\mathrm{d}x$ is small for sufficiently large values of electron energy E, and Eq.(1) becomes

$$\frac{\mathrm{d}L}{\mathrm{d}x}\Big|_{\mathrm{e}}=S\frac{\mathrm{d}E}{\mathrm{d}x}, \quad (2)$$

$$L=S\Delta E. \quad (3)$$

where ΔE is the total energy deposited in the scintillator by electrons. Eq.(3) shows that the light yield L is proportional to the deposited energy for gamma ray-induced electrons.

In the energy range of 0.5—5MeV in the present study, the range of gamma rays-induced electrons in scintillation material is much larger than that of protons created by fast neutrons. Due to this property, a TPSF can be employed to stop most energy of the neutron-induced recoil protons and let the gamma ray-induced recoil electrons pass through with little energy loss. Sequentially, the response of a TPSF to gamma rays is one to two orders of magnitude less than that to neutrons if the thickness of the foil is appropriately chosen. In contrast the sensitivity of a traditional scintillator detector is about one order of magnitude larger to gamma-rays than to neutrons[19,21]. The ratio of n/γ resolution of the plastic scintillating foil depends primarily on the thickness of the foil as well as the energy range of neutron and gamma ray in the fields.

3 Simulations

Neutron interaction with plastic scintillating foils is mainly through n + ^{1}H elastic scattering, n + ^{12}C elastic scattering, n + p capture and inelastic scattering processes. The light signal output from the n + ^{12}C scattering, n + p capture and inelastic scattering processes is so small that it can be neglected without producing appreciable error in our case. The light signal output from n + ^{1}H scattering is given by Eq.(1). The values of $\mathrm{d}E/\mathrm{d}x$, S, kB and C have been taken from Ref.[21]. They are the values of a NE-102 scinllator which is assumed to be equivalent to the ST-401 scintillator used in our study.

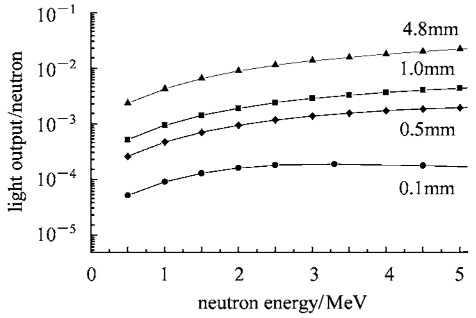

Fig. 1. The calculated responses of TPSFs to neutrons, varying with the thickness of the foils and neutron energy.

A Monte Carlo computer program has been developed to evaluate the response to neutrons of TPSFs with the thickness ranging from 0.05mm to 5mm, and the typical results are shown in Fig. 1. It can be seen that for the 0.1mm thick foil, the energy deposited for light output per incident neutron varies very slowly with the neutron energy, exhibiting a flat energy response. For a thin scintillating foil, with increasing energy of incident neutrons, the small energy loss $\mathrm{d}E/\mathrm{d}x$ is nearly compensated by a higher light production efficiency $\mathrm{d}L/\mathrm{d}E$, and the product of these two quantities, $\mathrm{d}L/\mathrm{d}x$, changes only slightly, leading to a flat response. This feature indicates that choosing proper thickness of thin plastic scintillating foil for a specific neutron energy range, a relatively flat energy response can be achieved.

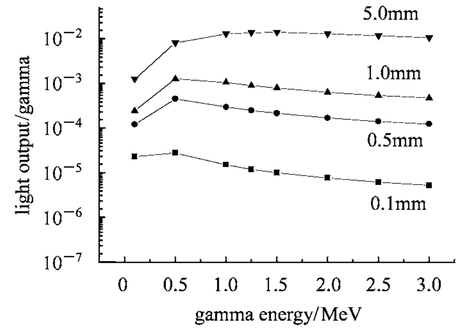

Fig. 2. The calculated responses of TPSFs to gamma rays, varying with the thickness of the foils and gamma energy.

Gamma rays interact in scintillator mainly through the photoelectric absorption, Compton scattering and pair production. In the range of energy between 0.5 and 5MeV, Compton scattering dominates. For evaluating the response of TPSFs to gamma rays and investigating the n/γ resolution capability, we have simulated the gamma ray response of various thicknesses using MCNP-4B code[23], the results are presented in Fig.2 for 0.1mm, 0.5mm, 1mm and 5mm thick ST-401 foils. The response decreases with the gamma energy and increases more rapidly with the thickness than that to neutrons in the given energy interval, displaying that a thinner foil can achieve a better n/γ resolution. But the choice of the proper thickness of a TPSF for neutron detection is a compromise between n/γ resolution and flat response. The ratio of n/γ resolution can be figured out by comparing the response between neutrons and gamma rays. As expected, 0.1mm thick ST-401 foil gives the best n/γ resolution, more than one order of magnitude in the studied foils.

4 Experimental tests

To demonstrate the above theoretical predictions, a device has been constructed which comprises a 0.1mm thick ST-401 scintillator foil and an EMI photomultiplier tube (9813, 9815, 9850 and/or a photodiode, respectively). We have investigated experimentally the n/γ resolution and energy response as functions of incident neutron energy between 0.5—2.5MeV with gamma rays of 1.25MeV from ^{60}Co, and the results are shown in Figs.3 and 4. Fig.3 represents the relative sensitivity (output charges per incident neutron or gamma) of the device to neutrons, and Fig.4 gives the measured ratios of n/γ discrimination that is about 18 obtained from its neutron sensitivity and the measured gamma ray sensitivity at 1.25MeV. Fig. 5 shows a typical waveform of the detector response to a pulsed X rays with a width of about 100ns, showing that the device built can operate well for use in the current mode.

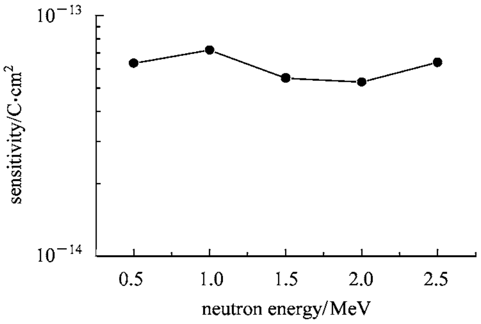

Fig. 3. The measured sensitivity as a function of incident neutron energy of our device comprising a 0.1mm thick ST-401 plastic scintillating foil and an EMI 9815 photomultiplier tube.

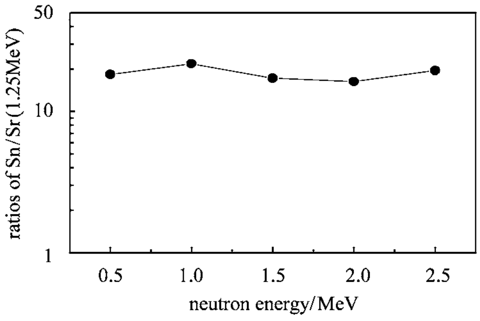

Fig. 4. The measured n/γ discrimination of the studied device, about 18 for 0.1mm thick ST-401 plastic scintillating foil coupled to an EMI 9850 photomultiplier tube.

5 Conclusions

The Monte Carlo simulations and preliminary experimental tests performed demonstrate that a thin plastic scintillator

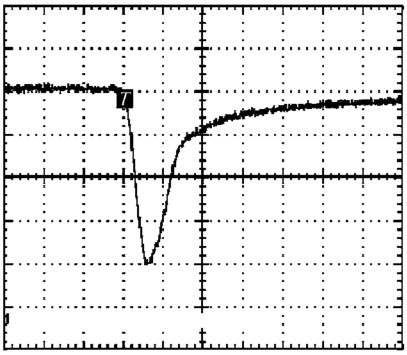

Fig. 5. A response waveform of a 0.1mm thick TPSF to a pulsed X-ray source with a width of about 100 ns(100ns/div).

foil coupled to photomultiplier tube can be used as a neutron detector for monitoring pulsed neutron flux in highly mixed neutron-gamma ray fields. The scintillator thickness for the highest n/γ resolution largely depends on the incident neutron energy, e.g. for neutron energy ranging from 0.5 to 3MeV, the optimum thickness is 0.1mm. This kind of neutron detectors offers three unique properties in addition to its simplicity. (1) The sensitivities to fission neutrons cover the range of 10^{-13}—10^{-19} $C \cdot cm^2$, which is a few orders of magnitude higher than that of the existing ones, (2) the n/γ discrimination is about 18, and (3) the neutron response is fairly independent of neutron energy. These properties potentially allow the device to be used in measuring neutron fluxes with different energy spectra in high gamma-ray background[24].

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用于强 γ 环境中测量中子参数的薄膜塑料闪烁探测器*

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摘要　提出了在强 γ 环境中脉冲中子通量的薄膜闪烁体测量方法．根据其与中子、γ 响应的理论计算结果，研制成功一种对 γ 不灵敏，用于探测快脉冲中子通量的新型探测器．该探测器由塑料薄膜闪烁体＋光电探测器构成．与传统探测器相比，该探测器具有如下特点：1．高中子灵敏度；2．高 n/γ 分辨；3．在给定能区具有平坦的能量响应．

关键词　薄塑料闪烁体　脉冲中子通量测量　n/γ 分辨　能量响应

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