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The impact of fluorescent dyes on the performances of polystyrene-based plastic scintillators

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ABSTRACT

To investigate the influence of both the first luminescent additive and the wavelength-shifter on the performance of plastic scintillator, a series of polystyrene-based scintillator had been prepared by thermal polymerization. Three first luminescent additives (PPO, p-TP and b-PBD) and four wavelength-shifters (POPOP, Bis-MSB, Me-MSB and DPA) were added to the scintillators respectively. The comparison results showed that PPO and POPOP were the most adequate fluorescent dyes for the polystyrene-based plastic scintillator. Moreover, with the increase of the concentration of PPO and POPOP, the fluorescence intensity and light yield were increased firstly and then decreased. The plastic scintillator containing 2% PPO and 0.02% POPOP had the highest fluorescence intensity and light yield.

1. Introduction

The detection of radioactivity is very important in many fields, such as energy production in nuclear power plants, medicine in diagnosis and treatment, customs inspection, homeland security [1–5]. Plastic scintillators are widely employed in Scintillator-photomultiplier Neutron Detectors which play a vital role in the measurement of radiation. Plastic scintillators could be processed into a large volume and complex shapes with simple and economical ways [6–9].

A transparent polymer base (matrix) embedding one or several fluorescent dyes is defined as a plastic scintillator. The molecular chain of the matrix contains a large number of benzene rings as the pendent group along the polymer backbone [10]. Aromatic structures are required for the fluorescence process of both the matrix and fluorescent dyes in the plastic scintillator. Generally, two organic fluorescent dyes which called first luminescent additive and wavelength-shifter respectively are added to the plastic scintillator [11–15]. The absorption band of the first luminescent additive is overlapped with the fluorescence emission band of the matrix. The maximum emission wavelength of the plastic scintillator is shifted to the response range of the photomultiplier tube by the wavelength-shifter [5,16–20].

With the development of science and technology, the application field of plastic scintillators had grown so extensive that it's significant to improve the performance of plastic scintillators. In this paper, a series of polystyrene-based scintillators had been prepared by thermal polymerization. The performance of plastic scintillators doped with different types and concentrations of fluorescent dyes were studied. The impact of the first luminescent additive and wavelength-shifter on the performance of polystyrene-based plastic scintillators had been experimentally determined.

2. Experimental

2.1. Materials

Styrene was purchased from ChengDu Kelong Chemical Co., Ltd. and it was used after removing the inhibitor by vacuum distillation. Initiator AIBN (Azodiisobutyronitrile), POPOP (1,4-bis-[2-(5-Phenyl)oxazolyl]benzene), Bis-MSB (1,4-bis(2-Methylstyryl) benzene), Me-MSB (1,4-Bis(4-methylstyryl)benzene) used in the experiment was purchased from TCI(Shanghai) Development Co., Ltd. PPO (2,5-Diphenyloxazole), p-TP (*p*-Terphenyl), b-PBD (2-(4-tert-Butylphenyl) – 5-(4-biphenyl) – 1,3,4-oxadiazole), and DPA (9,10-Diphenylanthracene) were purchased from Sigma Aldrich

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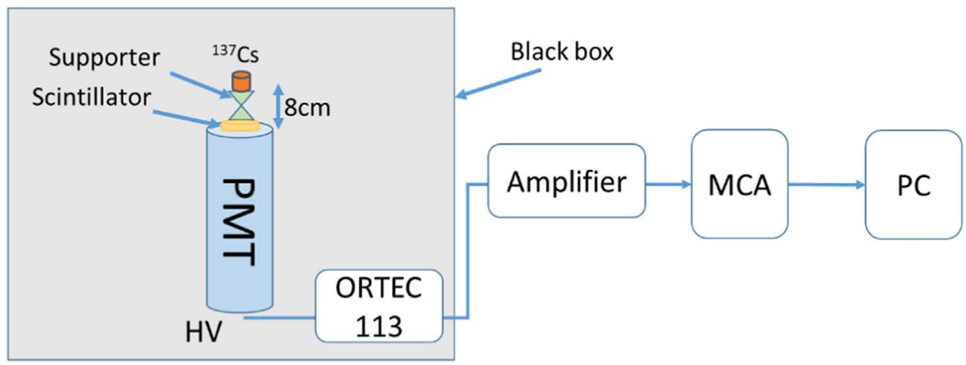

Fig. 1. Schematic diagram of the experimental setup for measuring scintillation yield. HV: high voltage.

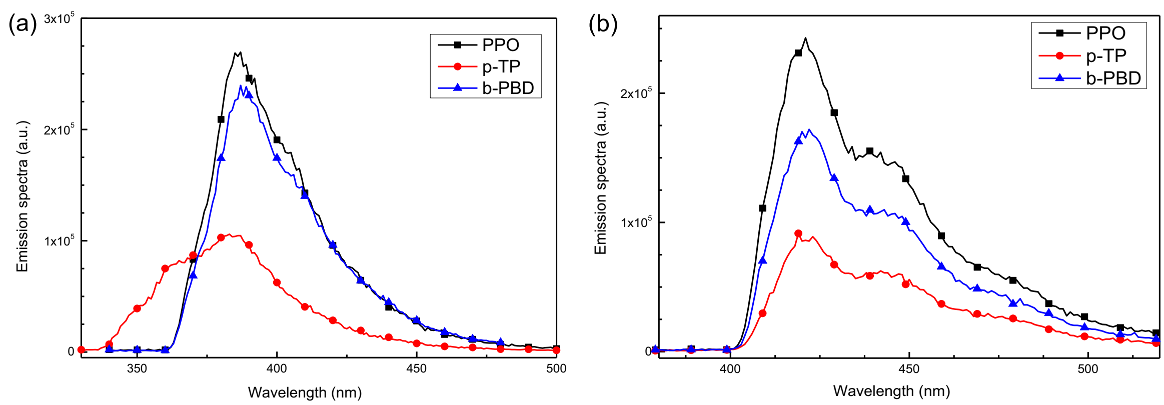

Fig. 2. The emission spectra of plastic scintillators containing different first fluorescent additive. The weight ratios of PPO, p-TP and b-PBD were all 2%. (a) No wavelength-shifter was added to the scintillators. (b) Adding wavelength-shifter POPOP (0.02 wt%) to the scintillators.

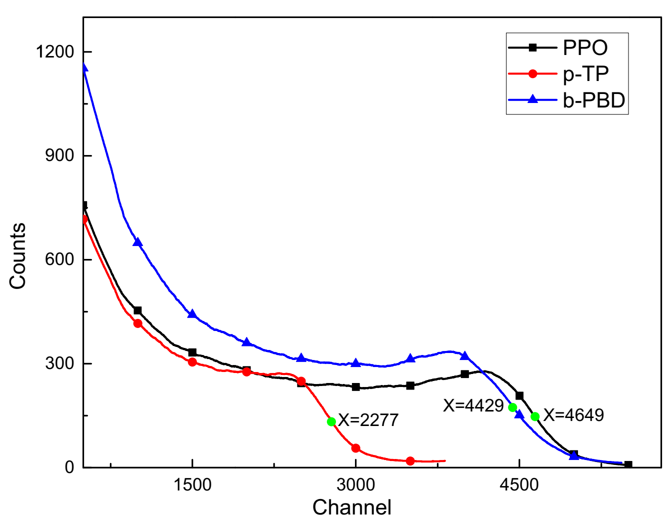

Fig. 3. The pulse height spectrum of plastic scintillators containing different first fluorescent additive. The weight ratios of PPO, p-TP and b-PBD were all 2%. The weight ratio of wavelength-shifter POPOP was 0.02%.

China. A commercial plastic scintillator ST-401 (Φ40 mm⁎10 mm) was purchased from CNNC Beijing Nuclear Instrument Factory.

2.2. The preparation of the plastic scintillator

Styrene monomer was purified by vacuum distillation before using it. Different kinds and weight ratios of first luminescent additive and wavelength-shifter were added to styrene. A glass bottle containing the mixed solution was sealed off after pumping and filling in with Nitrogen. To prevent the occurrence of explosive polymerization, the glass bottle was placed in the oven at 55 °C for 36 h. Then the temperature of the oven was raised up to 85 °C at the rate of 3 °C/h. Five days later, the polymerization of the mixed solution was completed. The temperature of the oven was reduced to room temperature at the rate of 3 °C/h. To prevent the crack and the generation of bubbles, the temperature of the plastic scintillator should be raised slowly before polymerization and reduced slowly after the polymerization. Removing the glass bottle from the oven when the plastic scintillator had cool completely. Finally, a transparent plastic scintillator could be obtained after broken the glass bottle.

2.3. Characterization

The florescent spectra of the plastic scintillator were measured by an Edinburgh Instruments F900 fluorescence spectrophotometer.

The measurement equipment of the light yield was shown in Fig. 1. All the devices were covered with a black iron box and used in a darkroom. The ET9814B photomultiplier tube(PMT) used in this instrument was purchased from ET Enterprises Limited in England. The radioactive source ^{137}Cs was placed on the scintillator. To reduce the pulse accumulation for ensuring the accuracy of testing, an 8 cm high supporter was placed between the scintillator and ^{137}Cs. The photomultiplier converted the light energy signal into a continuous electrical signal. Then the signal was amplified by a charge sensitive preamplifier ortec113 and a main amplifier. The multichannel analyzer (MCA) could receive the amplified signal. Finally, the pulse height spectrum of the scintillator was recorded in the computer by the software Gamma Vision.

The light yield is the most important parameter to evaluate the performance of scintillators. In this paper, the light yield of plastic