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Study of the filter method for neutron pulse-height distributions measured with organic scintillators

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HIGHLIGHTS

- Organic scintillators sensitive to both neutrons and gamma-rays.
- The filter method includes two measurements: with and without polyethylene filter.
- Digital pulse-shape discrimination method was used as the reference method.
- The filter method is less accurate than the digital PSD method.
- The filter method has potential for robust measurement.

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ABSTRACT

Identification of neutron sources is of interest in several fields, such as homeland security or basic nuclear physics. Organic scintillators offer the possibility to unfold fast-neutron energy spectra. Since organic scintillators are sensitive to neutrons and gamma-rays, a method to discriminate these two types of particles is required. This paper is focused on investigation of the discrimination properties of the filter method by using a new procedure. We compare the results of an experimental filter method to a digital pulse-shape discrimination (PSD) method based on charge integration. In addition, these methods are compared to the simulation results obtained with the MCNPX-PoliMi code. The experimental and numerical investigations were performed with a ^{252}Cf spontaneous-fission neutron source. The integration of the number of counts gave the relative differences between the experimental filter and digital PSD neutron pulse-height distributions (PHDs) and simulated PHDs less than approximately 5% in the range between 60 keVee and 1.715 MeVee of light output. Above 1.715 MeVee, the PSD method has advantages over the filter method, due to the filter method having significantly worse counting statistics. The results show that the filter method has potential for robust neutron measurements when the PSD method cannot be applied, such as for 'old' organic plastic scintillators without PSD capability.

1. Introduction

Organic scintillators are investigated as the main components of measurement systems in various research fields to detect fast neutrons up to approximately 20 MeV (Birks, 1964; Knoll, 2010; Mihalczo et al., 2000; Klein and Neumann, 2002). Liquid organic scintillators such as NE-213, EJ-309, and BC-501A are used in some neutron spectrometry applications because of their good light output and their capability to accurately discriminate neutrons from gamma-rays (Klein and Neumann, 2002). Pulse-height distributions (PHDs) obtained with organic scintillators, which are in fact proton-recoil detectors, can be used as the input data for unfolding procedures in order to obtain the neutron energy spectra (Reginatto, 2010). Alternatively, they can be used for the identification of neutron sources without relying on unfolding procedures that are complex and time consuming (Flaska and Pozzi, 2007). The knowledge of the neutron energy spectrum is useful for identifying nuclear materials. Specifically, it is of interest in nuclear non-proliferation and nuclear-safeguards applications to identify neutron sources from the measured PHDs containing information

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on fast neutrons and photons. In the neutron-source identification applications, it is required to accurately eliminate the unwanted gamma-ray contribution to the measured neutron PHD.

Liquid organic scintillators have excellent pulse-shape discrimination (PSD) properties (Esposito et al., 2004). However, some widely-used plastic scintillators, such as NE-102A (BC-400 equivalent), do not have such capability. A plastic scintillator consists of organic scintillating molecules in a polymerized solvent. This form of organic scintillators has become a useful detector in different applications since it has a relatively large light output, it is well suited for fast timing measurements, and can be easily shaped. However, for such kind of organic scintillators it is required to apply a method for neutron/gamma-ray discrimination that does not rely on PSD, although some crude PSD is possible achieved with this scintillator (Saint-Gobain Crystals, 2011). Recent developments in plastics scintillation compositions have provided new plastic scintillators capable of neutron-gamma ray PSD (Zaitseva et al., 2012). The results presented by Pozzi and colleagues (Pozzi et al., 2013) have shown that a new type of plastic scintillator such as EJ-299-33 has very good PSD properties, but not as good as the PSD capability of liquid scintillators such as EJ-309. In this paper, we focus on a method that can be applied to ‘old’ types of plastic scintillators such as NE-102A (BC-400 equivalent), which have lower cost and some good properties for practical applications.

For the discrimination of gamma-ray pulses in a neutron-PHD measurement, we tested the so-called *filter method* with polyethylene (PE) filters (Marinkovic, 1987). This method requires two measurements. In the first measurement with a ^{252}Cf source and an EJ-309 liquid scintillation detector, without a PE filter, we measured the total (neutron and gamma ray) PHDs from a ^{252}Cf source. In the second measurement, with the addition of a PE filter, we estimate the gamma ray PHD: here, a large number of the fast neutrons are slowed down and eliminated, while gamma-rays are not significantly affected. The neutron PHD is then estimated by taking the difference between the two PHDs from the two measurements (i.e. experimental configurations without PE filter and with PE filter). By subtracting the PHDs from the two measurements in the filter method, one can efficiently discriminate fast neutrons from gamma-rays. The two experimental configurations will be described with more details in the further text.

The goal of this paper is to investigate the discrimination efficiency of the filter method described in the paragraph above. For the first time, we use a liquid scintillator with excellent PSD properties to evaluate the discrimination properties of the filter method. The experimental results obtained using the filter method were compared to the results obtained by the experimental digital PSD method, which was used as the reference. This technique is based on the acquisition of measured PHDs by using a liquid scintillation detector EJ-309 with a fast 12-bit, 250-MHz digitizer. The optimized digital PSD method applied is based on the standard charge integration method (Flaska and Pozzi, 2007).

The neutron PHDs acquired from measured data (both the filter and digital-PSD data) were compared with the simulated neutron PHDs obtained with the MCNPX-PoliMi code version 1.4.9 (Pozzi et al., 2012). This code was used for accurate simulations of PHDs, taking into account the physical processes leading to the neutron and gamma-ray pulse production. The digital-PSD, filter-method results, and simulation results were compared for an identical ^{252}Cf source.

2. Comparison of measured and simulated neutron PHDs

The measurement setup consisted of an EJ-309 liquid scintillator (cylindrical shape; length 7.6 cm, diameter 7.6 cm), two PE filters with dimensions 7.5 cm × 5 cm × 5 cm each, and a 252Cf source with activity of approximately 10 μCi. Data acquisition was performed with a CAEN V1720, 12-bit, 250 MHz, 2-V digitizer. The light output of the scintillator is usually expressed in electron equivalent (MeVee) units. The threshold of 60 keVee (corresponding to the neutron energy of approximately 350 keV) was chosen to minimize the gamma-ray background. Pulses were sampled and stored directly from the photomultiplier tube's (PMT) anode (a standard model ETL 9821B with high voltage of −1962 V). The energy calibration of the measured system was performed with a ^{137}Cs gamma-ray source. The Compton edge for ^{137}Cs gamma source was aligned to a value of approximately 0.43 V. Since the filter method requires two measurements, the geometrical arrangement of the source and detector was kept the same in both measurements. The first experimental configuration included the source and the detector, while the second configuration contained the PE filters in addition. We chose two filters with thickness of 7.5 cm and 15 cm to investigate experimentally how the thickness of a PE filter affects the resulting neutron PHD. These two thicknesses were chosen based on the results presented in Fig. 2 with assumption that the PE filter with thickness of 7.5 cm is not efficient enough to slow down fast neutrons while the PE filter of 15 cm thickness should be efficient taking into account mean free paths of moderating material.

The source was placed at a distance of 16.5 cm from the face of the detector. A schematic diagram of the EJ-309 scintillator, the PMT, and the PE filters is shown in Fig. 1.

We investigated an optimal thickness of PE filters with the MCNPX-PoliMi code (Pozzi et al., 2012). Fig. 2 shows the simulated ratio of the neutron count rates to the total count rates from a ^{252}Cf source in the light output range between 60 keVee and 2.17 MeVee depending on the PE-filter thickness. We chose a PE thickness of 15 cm as a reasonable one, taking into account the reduction of fast-neutron count rates due to slowing down in the moderator material, counting statistics, and the fact that the size of the PE blocks should be of reasonable dimensions for practical reasons.

We measured the PHD of the ^{252}Cf source in the light output range between 60 keVee and 2.17 MeVee (for neutrons, this corresponds to a neutron energy deposited of 0.24 MeV–6.17 MeV). Fig. 3 shows the measured neutron and gamma-ray PHDs obtained with the digital PSD method, as well as the total PHD. Fig. 4a shows the gamma PHD obtained with the digital PSD method for the ^{252}Cf source without filters and with one PE filter of 7.5 cm and two PE filters of 15.0 cm. Fig. 4b shows the neutron PHDs in the same experimental arrangements. Error bars in Figs. 3 and 4 are shown for ±1 σ. The results show that the gamma PHDs are less sensitive to the presence of the PE filters than the neutron PHDs. The ratio of the total neutron PHD from the bare ^{252}Cf source relatively to the

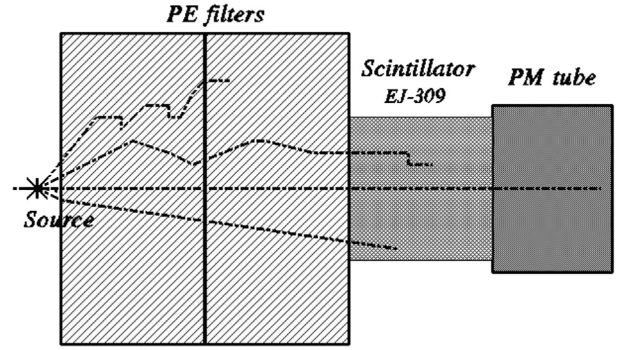

Fig. 1. The experimental configuration with the EJ-309 scintillator (cylindrical shape; length 7.6 cm, diameter 7.6 cm), PE filters (7.5 cm × 5 cm × 5 cm each) and the source at the distance of 16.5 cm from the front face of the detector.