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The light output and the detection efficiency of the liquid scintillator EJ-309

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HIGHLIGHTS

- New light output function for an EJ-309 detector and comparison with published data.
- Experimental neutron and gamma ray detection efficiencies for an EJ-309 detector.
- Comparison of measured efficiency with Monte Carlo calculations.
- Role of the light output function in neutron efficiency calculations.

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ABSTRACT

The light output response and the neutron and gamma-ray detection efficiency are determined for liquid scintillator EJ-309. The light output function is compared to those of previous studies. Experimental efficiency results are compared to predictions from GEANT4, MCNPX and PENELOPE Monte Carlo simulations. The differences associated with the use of different light output functions are discussed.

1. Introduction

Organic liquid scintillators are commonly employed for fast-neutron detection thanks to their pulse shape discrimination (PSD) capability, to separate neutrons from the gamma-ray component of a radiation field (Knoll, 2010). The toxicity and the low flash point that characterize liquid scintillators limit their use in security applications. Moreover, the limits in detecting neutrons in a very intense gamma-ray field have been taken in the past as a weakness of those detectors that exhibit good gamma-ray detection efficiency (Kouzes et al., 2010). Recently, new liquid scintillation material, the EJ-309 type (Eljen Technology, Sweetwater Texas, USA), have become available. It is characterized by low toxicity and high flash point, compared to the more traditional ones, such as the well-known NE213. The EJ-309 scintillator has been employed in pure and applied research confirming a PSD capability well suited to perform neutron spectroscopy (Lavietes et al., 2010; Pozzi et al., 2009), while the gamma rejection power of EJ-309 has been the subject of recent studies (Stevanato et al., 2012; Swiderski et al., 2011). It is worth noting that it has been shown by Stevanato et al. (2012) that EJ-309 can be used to detect neutrons in a gamma-ray background with a dose rate of 300 μSv/h, much higher than the requirements given in Kouzes et al. (2010).

The selection of a scintillation material is generally driven by a detailed knowledge of the light output function, because it is essential to obtain the proton-recoil spectrum, hence the neutron spectrum. In this respect, the light output of EJ-309 detectors has been reported in recent studies (Enqvist et al., 2013; Takada et al., 2011), showing a light output dependence on the detector geometry (Enqvist et al., 2013).

Discrepancies between the published light output functions (Enqvist et al., 2013; Takada et al., 2011) for identical detector geometry motivated the present study. In this work, new light output function is developed and folded into Monte Carlo simulations in order to predict neutron efficiency values to compare directly to measured ones. The gamma-ray efficiency of the EJ-309 scintillator is also studied.

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2. Experimental setup

In this work we studied a right-cylinder (51 mm diameter, 51 mm thick) cell, filled with EJ-309 liquid scintillator. The cell was coupled through an EJ-560 optical silicon rubber interface to a H8500 HAMAMATSU flat panel photomultiplier (PMT). The detector's technical characteristics and its performance are fully described in Cester et al. (2013). The detector assembly was placed at a distance of about 2 m from a 10^6 fissions/s ^{252}Cf source tagged by a 51 mm diameter, 51 mm thick plastic EJ-228 detector coupled to a PHOTONIS XP2020 photomultiplier. This fast plastic detector was positioned very close (approximately 10 mm) to the emission point to detect the burst of neutrons and gamma-rays emitted during each fission event. The front-end electronics used in this work was composed of CAEN VME modules: a V6533 Programmable HV Power Supply (6 Ch., 4 kV, 3 mA, 9 W), a Digitizer 4 Channel 10 bit 1 GS/s working in a coincidence mode, and a Bridge USB V1718 connected to a PC with a data acquisition software. The pulse height and the neutron-gamma pulse shape discrimination parameter (PSD) were obtained online by means of a digital pulse processing technique, and the time-of-flight was determined for each event offline employing a digital constant fraction discriminator technique. Details of the pulse processing procedure are given in Stevanato et al. (2012) and Cester et al. (2013).

A sample of time-of-flight spectrum measured with the aforementioned setup is illustrated in Fig. 1, showing the gamma-ray peak and the distribution of fission neutrons. The effect of performing the gamma-ray suppression by PSD is also shown, illustrating the complete disappearance of the gamma-ray peak and a significant reduction in the uncorrelated timing background. The overall timing resolution obtained with the ^{252}Cf source is $\delta t=$ 0.850 ns (FWHM), measured from the gamma-ray peak when the low energy threshold of the digital constant fraction discriminator is set at E_{th} =200 keVee (i.e. in keV electron equivalent) for EJ-309.

Detector energy calibration, which is for the correct determination of the light output function, was performed using a ^{22}Na gamma-ray source following the procedure detailed in Stevanato et al. (2011). Calibration spectra were recorded continuously during the measurements. The linearity of the setup energy response (scintillation detector and DAQ) has been tested in the energy window from 59.6 keV (^{241}Am) up to 4.4 MeV gamma-ray produced by an Am/Be source. As a test of the calibration procedure, Fig. 2 shows a comparison between the calibrated energy, obtained by using the ^{22}Na transitions, and the nominal energy for the ^{241}Am, ^{137}Cs, ^{60}Co (only the 1.17 MeV transition is reported) and 4.4 MeV from the Am/Be source. It is worth noting that nominal Compton edge values include the energy shift due to the finite resolution of the detection system (see Stevanato et al. (2011) for details). The full-energy peak is detected for the 59.6 keV transition of ^{241}Am.

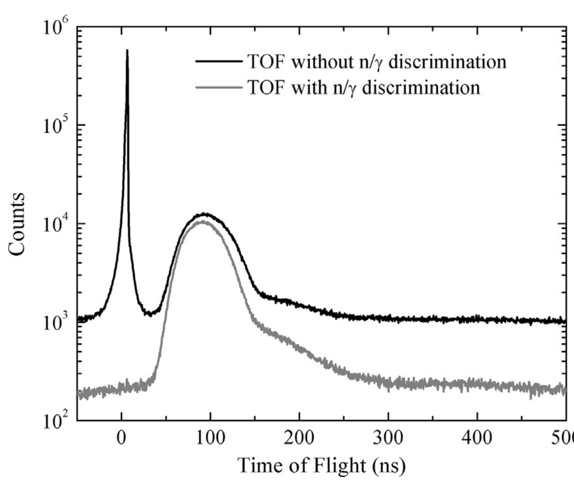

Fig. 1. Sample of the time-of-flight spectrum measured in this work. The upper (lower) curve refers to the data without (with) gamma-ray rejection by PSD. The low energy threshold in the EJ-309 detector is E_{th}=200 keVee (keV electron equivalent).

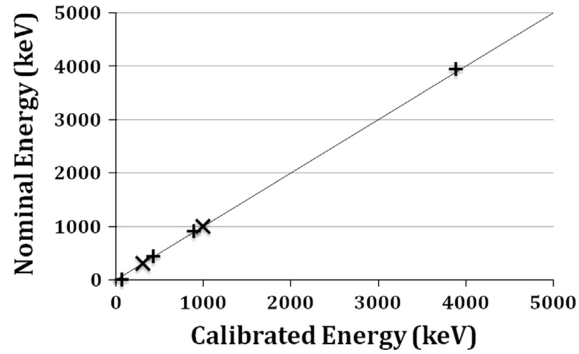

Fig. 2. Calibrated versus nominal energy. The crosses mark the ^{22}Na Compton edges used to obtain the calibration, whereas the (+) markers indicate the Compton edge positions of the other sources (^{137}Cs, ^{60}Co (1.17 MeV) and Am/Be) and the full-energy peak position of the ^{241}Am.

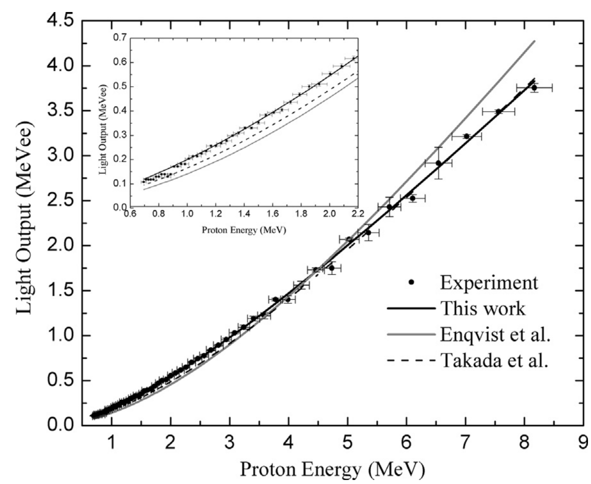

Fig. 3. Light output of our 51 mm × 51 mm EJ-309 detector compared with data from Takada et al. (2011) and Enqvist et al. (2013) relative to 127 mm × 127 mm cells.

3. Monte Carlo simulations

Several Monte Carlo simulations were performed using GEANT4 (Agostinelli et al., 2003; Allison et al., 2006), MCNPX (version 2.7) (Pelowitz, 2011) and PENELOPE (Salvat et al., 2001) codes with the aim of comparing the measured neutron and gamma efficiencies to the simulated results, and verifying the role of the light output function in the energy range upto 7 MeV. Monte Carlo simulations offer an important tool in the design of detection system and it is therefore interesting to assess the capability of such calculation by benchmarking with experimental results.

GEANT4 offers access to particle tracking (position/time of the particle, kinetic energy, deposited energy, etc.), by means of its G4Track.hh which is used to determine the kinetic energy of the recoil protons. Each neutron history in MCNPX is followed by several charged particles (recoil protons, carbon ions, etc.) that may either fully deposit their energy or undertake partial energy