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Neutron light output response and resolution functions in EJ-309 liquid scintillation detectors

Andreas Enqvist [a,*], Christopher C. Lawrence [a], Brian M. Wieger [a], Sara A. Pozzi [a], Thomas N. Massey [b]

[a] Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor 48109, USA
[b] Institute of Nuclear and Particle Physics, Ohio University, Athens, OH 45701, USA

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ABSTRACT

Neutron light output response functions and detector resolution functions were measured at Ohio University's tandem Van de Graaff generator for three cylindrical EJ-309 liquid scintillator cells, having dimensions 12.7(⌀)-by-12.7, 7.6-by-7.6, and 7.6-by-5.1 cm. A 7.44 MeV deuteron beam was used on an ^{27}Al target generating a continuous spectrum over the energy range from a few hundred keV to over 10 MeV. The light output response functions are determined using an exponential fit. Detector resolution functions are obtained for the 12.7-by-12.7 and 7.6-by-7.6 cm detectors. It is demonstrated that the dependence on detector size is important for the light output response functions, but not to the same extent for the resolution function, even when photomultiplier tubes, detector material, and other detector characteristics are carefully matched.

1. Introduction

Fast neutron detectors such as organic liquid scintillation detectors are commonly used for characterizing material emitting neutrons. Due to a nonlinear conversion of energy deposited in each collision into light pulses along with variation in collision sequence, each detection event will give rise to highly variable pulse heights. Monte Carlo simulations of the liquid scintillation detectors rely heavily on measured light output functions for converting deposited energy into pulse heights. Earlier work which details how a ^{252}Cf source could be used for characterizing the light output response functions and other parameters can be found in Refs. [1,2].

Ohio University's (OU) Edwards Accelerator Facility is an excellent facility for investigation of detector parameters when detecting neutrons. A 7.44 MeV deuteron beam was used on a ^{27}Al target generating a continuous spectrum of neutrons of energies from a few hundred keV to over 10 MeV [3]. A variety of different detector assemblies based on EJ-309 organic liquid in different sizes were characterized specifically for the purpose of measuring the neutron light output response function. Simulations using MCNPX-PoliMi [4] have also been performed to investigate the variation of pulse height distributions (PHD) with respect to different functional forms of the obtained light output response function.

The high accuracy of our measurements at OU enables analysis techniques that cannot be used on data measured in simpler laboratory environments. Nevertheless, time constraints at facilities such as OU's Van de Graaff accelerator often motivate simpler laboratory measurements, where neutron-energy precision is somewhat compromised due to shorter flight paths. In order to evaluate this compromise, additional neutron time-of-flight (TOF) measurements with ^{252}Cf were conducted at University of Michigan (UM) using a flight-path of 1.5 m. Light output response functions from these simpler measurements are compared with those obtained from our OU data.

2. Description of experimental setups

2.1. Ohio University setup

The Edwards Accelerator Facility at Ohio University offers flight paths at various angles from the Tandem Van de Graaff generator. The flight path utilized for these experiments extends into an underground tunnel providing a very noticeable reduction of background from cosmic rays. The tunnel is covered by approximately 3 m of earth. The flight path used for the neutron TOF measurements offers lengths exceeding 20 m, but in our configuration we used TOF distances of approximately 10 m. Fig. 1 shows

* Corresponding author. Tel.: +1 734 660 9398; fax: +1 734 763 4540.
E-mail addresses: enqvist@umich.edu (A. Enqvist), cclawr@umich.edu (C. C. Lawrence), brianmwi@umich.edu (B.M. Wieger), pozzisa@umich.edu (S.A. Pozzi), massey@ohio.edu (T.N. Massey).

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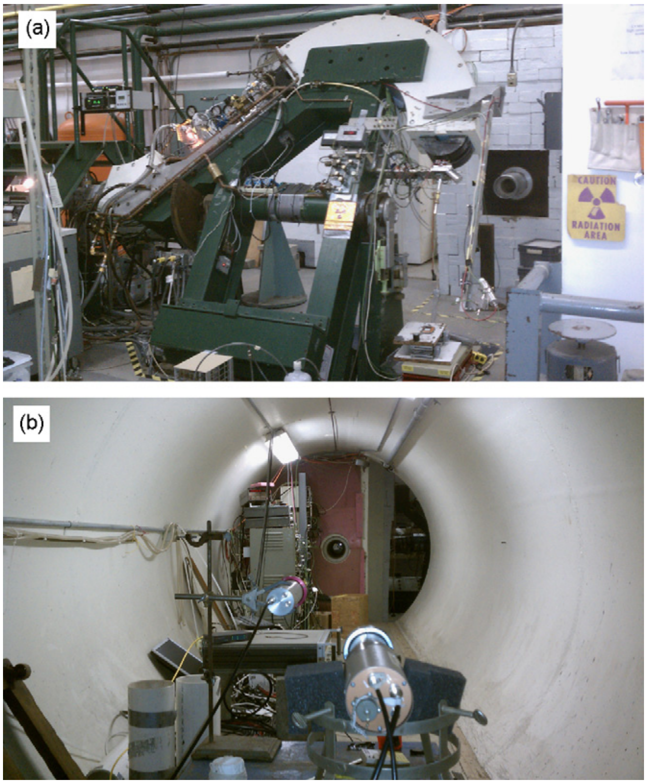

Fig. 1. Measurement setup showing the tandem Van de Graaff generator (a) and the beam tunnel (b) as seen from two of our detectors in the direction of the pulsed neutron source.

the Van de Graaff generator and the beam-tunnel behind a collimator wall. The collimated beam is narrow enough not to hit the walls of the tunnel before 20 m, which creates a very low scattered background when measuring at a distance of 10 m from the target.

The neutron beam was generated by 7.44 MeV deuterons impinging on an ^{27}Al target [3]. The generator is normally pulsed at 200-ns intervals (5 MHz). The beam was pulsed with a frequency of 1/1600 ns^{-1} to allow time for the slowest neutrons from each beam pulse to reach the detector before the next pulse. A dedicated data acquisition computer was placed near the detectors in the tunnel to limit cable lengths and signal delays. The Van de Graaff generator is coupled to a beam swinger [5], which enables measurements at any angle from −4° to 180°. These measurements were taken at the 120-degree angle.

The data acquisition was performed with a 250-MHz, 12-bit (~11-bit effective), eight-channel, CAEN V1720 digitizer. Two channels of the digitizer were used: one for the detector and one for a beam-pulse pick-off signal. The detector channel was selected as the system trigger and the beam-channel was recorded during a time-window allowing a very small overlap between pulses (1608 ns) to ensure that a beam trigger was always observed. The beam pulse signal is not taken at the aluminum target but rather earlier along the deuteron path. That, in combination with a discriminator circuit and cable length, resulted in a fixed time delay of the beam signal, which was characterized by identifying the main gamma-flash in the TOF-spectrum.

The beam was tuned with fast detectors close to the target. The beam pick-off signal showed very good temporal resolution, which, when combined with the time resolution of our detectors, gave a gamma-ray peak full width half maximum (FWHM) of approximately 1.6 ns. The timing of the scintillation detector pulses is performed by a constant fraction discrimination algorithm which operates on the fast and relatively linear middle section of the leading edge of the pulses. Fig. 2 shows the measured TOF spectrum. The excellent time resolution of the gamma-peak along with the high resolution of features in the neutron part of the spectrum is evident. The pulse shape discrimination (PSD) error is on the order of approximately 1 in 1000 judging from the erroneous neutron peak at the gamma-flash timing. It is further apparent that the PSD is of vital importance as the gamma-ray counts in the neutron-TOF region are on a similar magnitude as the amounts of neutrons detected.

Various detector compositions and sizes were tested at OU with the focus being on EJ-309 organic liquid scintillation detectors. The EJ-309 liquid has a high flash point (144 °C) and low chemical toxicity, while being optimized for PSD performance. Three different cylindrical detector geometries were tested: 12.7(⌀)-by-12.7, 7.6-by-7.6 and 7.6-by-5.1 cm. The 12.7-cm detector was mounted on a 5-in. (12.7 cm) Photonis XP4512B photomultiplier tube (PMT). The 7.6-by-7.6 and 7.6-by-5.1 cells are mounted on 3-in. (7.6 cm) ET-Enterprises 9821B PMTs. The detectors were all manufactured by Eljen Corporation. Calibration was performed using a ^{137}Cs source. Their gamma-response linearity was tested previously using multiple gamma-check sources and the same CAEN V1720 digitizer. Each detector was measured using a single setup except for the 12.7-by-12.7 cm detector, where the data is taken from two setups. One of which used a much higher gain to enable a lower threshold for observing low energy neutron pulses. Conversely, the timing of the beam pulses was widened to 3.2 μs to ensure all the neutrons arrive at the detector before the next pulse. The acquired data was taken during approximately 5 h of measurement time for the 12.7-by-12.7 cm and approximately 15 h for the smaller detectors.

As the neutron beam is a white source containing a wide range of energies, it is of vital importance to have excellent timing of the neutron events. Fig. 3 shows the reported experimental flux and the energy-binned detected flux (converted from the time spectrum). The reported experimental flux [3] was measured using thin uranium foils. The energy dependent flux was found using the mass spectroscopic data on the ^{235}U enriched material used for the deposits. All of the uranium cross-sections were then used to determine the flux from the fission chamber results. For the sake of the neutron light output functions however, there is no need for absolute normalization, eliminating that source of uncertainty.

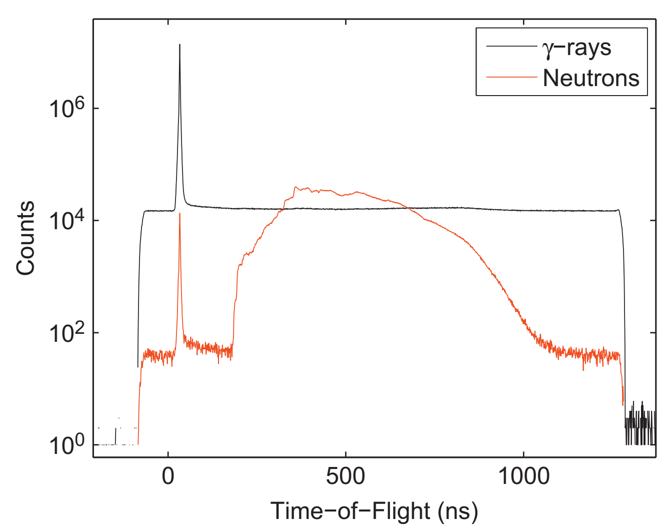

Fig. 2. The TOF spectrum shows excellent statistics and the low neutron background is apparent which is a result of the beam tunnel being situated underground. The data shown is divided into 1 ns wide bins.