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Technical note

Sector-shaped fast organic liquid scintillation detectors based neutron coincidence counter

K.A.A. Gamage [a,*], M.J. Joyce [a], F.D. Cave [b]

[a] Department of Engineering, Lancaster University, Lancaster LA1 4YR, UK
[b] Hybrid Instruments Ltd., The Gordon Manley Building, Lancaster University, Lancaster LA1 4YQ, UK

HIGHLIGHTS

- Sector-shaped scintillation detectors based neutron coincidence counter described.
- Suitability for neutron coincidence counting explored via MCNPX.
- Performance of the system studied considering different thicknesses of scintillators.

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ABSTRACT

A simulation based on the Monte Carlo method is described which has been performed using MCNPX 2.6.0, to model the geometry of a sector-shaped liquid scintillation detector in response to coincident neutron events. The detection of neutrons from a mixed-oxide (MOX) fuel pellet has been simulated for different thicknesses of scintillators. A layer of lead has been used to reduce the gamma-ray fluence reaching the scintillator and, the effect of lead for neutron detection has also been estimated by considering different thicknesses of lead layers.

1. Introduction

Neutron coincidence counting is an established, non-destructive method for the qualitative and quantitative analysis of nuclear materials. Several even-numbered nuclei of the actinide isotopes, and especially even-numbered plutonium isotopes, undergo spontaneous fission, resulting in the emission of neutrons which are correlated in time. The characteristics of this i.e. the multiplicity can be used to identify each isotope in question. Similarly, the corresponding characteristics of isotopes that are susceptible to stimulated fission are somewhat isotope related, and also dependent on the energy of the incident neutron that stimulates the fission event, and this can hence be used to identify and quantify isotopes also. Most of the neutron coincidence counters currently used are based on ^{3}He gas tubes. In the ^{3}He-filled gas proportional-counter, the (n,p) reaction is largely responsible for the detection of slow neutrons and hence neutrons have to be slowed down to thermal energies. As a result, moderator and shielding materials are essential components of many systems designed to assess quantities of fissile materials. The use of a moderator, however, extends the die-away time of the detector necessitating a larger coincidence window and, further, ^{3}He is now in short supply and expensive.

Recently, fast organic liquid scintillators became popular as a result of advances in digital pulse-shape discrimination methods (D'Mellow et al., 2007; Gamage et al., 2011). Pulse-shape analysis determines whether the event was caused by a neutron or a gamma-ray based on the decay characteristics of the pulse (Brooks, 1959). Fast organic liquid scintillators are easily available compared to ^{3}He and their potential use with a fast digitiser system in neutron coincidence counting has several advantages.

The efficiency and the accuracy of the measurement of the coincidence events also depend on the geometry of the detector sensitive volume. Generally, well counter type systems are used for neutron coincidence applications in order to have a high efficiency. The proposed organic liquid scintillator based neutron coincidence counter would also be a type of well counter and, samples will be inserted into a well during the assay. The shape of

* Corresponding author. Tel.: +44 1524593873; fax +44 1524381707.
E-mail address: k.gamage@lancaster.ac.uk (K.A.A. Gamage).

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the scintillant of organic liquid scintillator based detectors is usually cylindrical, however this new coincidence counter would require sector-shaped scintillators in order to build a well counter.

The optimum thickness of the sector-shaped scintillator for high efficiency coincidence counting is required to be modelled before the system build and test. An analytical approach to such a problem is also complex, considering the modelling of random nature of neutron interaction with the scintillator through elastic collisions, where it will introduce large uncertainties. Therefore, it is important to model the scintillator using a Monte Carlo based software package like MCNPX. In this research, simulations have been performed using MCNPX 2.6.0 for different thicknesses of sector-shaped scintillators. In order to reduce the gamma-ray fluence reaching the scintillator, the front surface of the scintillator is covered with a layer of lead. The effect of a lead layer for neutron detection within the scintillator is also estimated considering different thicknesses of lead layers.

2. Specifications of the proposed neutron coincidence counter

The detailed specifications of the proposed neutron coincidence counter can be summarised as follows.

2.1. Details of the geometry

The proposed neutron coincidence counter comprises of three layers of fast organic liquid scintillators, where each layer has eight segments of sector-shaped scintillators to improve high neutron detection efficiency (Fig. 1). The height of each layer is 75 mm (the total height of the instrument is 225 mm) and each sector-shaped scintillator is subtended by an angle of 45° at the central axis of the well as shown in Fig. 2.

2.2. Processing of fast scintillator detectors output

The scintillator detector outputs are proposed to connect to 6 four-channel (three PMTs per sector and 8 sectors requiring 24 signal processors) mixed field analysers (Fig. 3), developed by the Hybrid Instruments Ltd, UK. Digital pulse shape algorithms, based on pulse gradient analysis, are embedded entirely in the VHDL architecture (Joyce et al., 2012). The analyser can operate in parallel across all four channels in real-time and detector signal inputs are continuously sampled at up to 500 MHz, with an amplitude resolution of 12 bits. Each four-channel mixed field analyser can process pulses up to 3 millions per second on four channels at the same time. Dimensions of the analyser are 350 mm × 260 mm × 150 mm and weighs 3.65 kg.

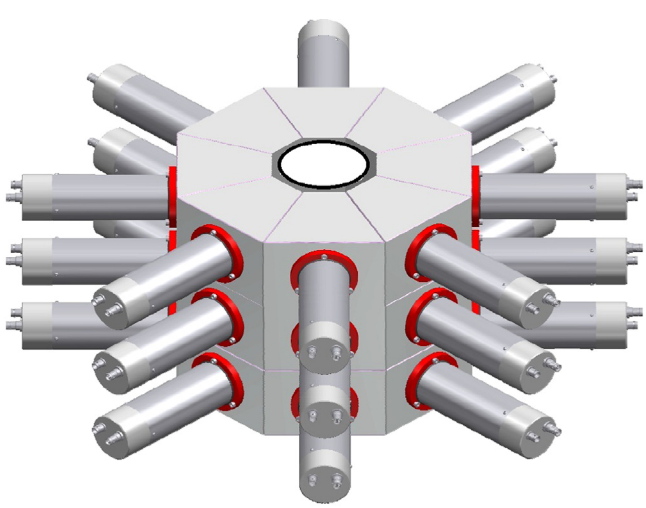

Fig. 1. Illustration of the fast organic liquid scintillator detector assembly of the proposed neutron coincidence counter.

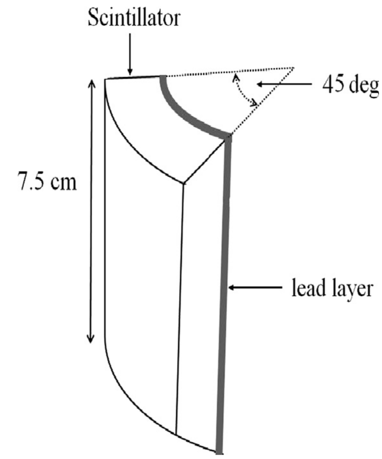

Fig. 2. A sector-shaped scintillator for the new type of neutron coincidence counter.

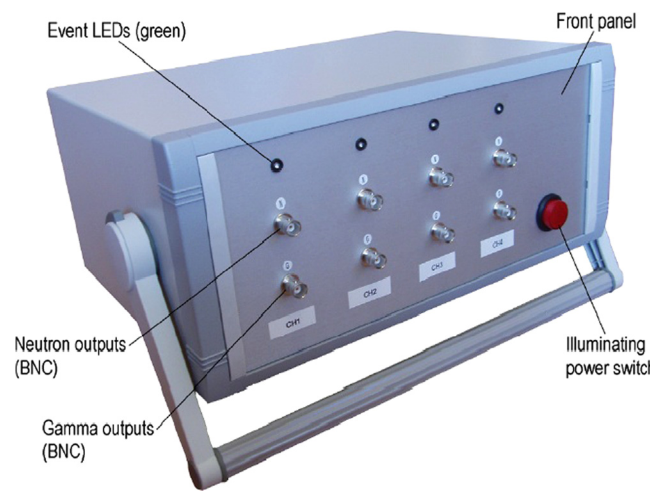

Fig. 3. Front face of the four-channel mixed field analyser with an array of BNC connectors for four pairs of neutron and gamma-ray output channels.

2.3. Specifications of the simulation model

In this research, sector-shaped scintillator suitability for neutron coincidence counter has been explored via a series of computer simulations performed with the general purpose Monte Carlo radiation transport code, MCNPX 2.6.0 (Pelowitz, 2008). The scintillator shown in Fig. 2 was modelled using MCNPX 2.6.0 code and simulated for a range of scintillator thicknesses varying from 10 mm up to 100 mm, using F4 tally (i.e. calculating flux average over scintillator cell shown in surface 1, 1, 2, 1 in Fig. 4a or 1, 3, 2, 4 in Fig. 4b). The scintillator material used was EJ-309 (density = 0.959 g cm^{-3}) with an atomic ratio (H:C) of 1.25 (EJ-309 data sheet, 2013). The thickness of the lead (density = 11.35 g cm^{-3}) layer was varied from 0 mm up to 10 mm. An increase of the lead layer thickness reduces the radius of the well and, in this case, it was varied from a minimum of 15 mm to a maximum of 25 mm.

During the simulation a mixed oxide fuel pellet was placed center of the axis of the well as shown in Fig. 4. The cylindrical fuel pellet had a diameter 10 mm and height 10 mm. The composition of the pellet was 93% depleted uranium (92.81% of ^{238}U and 0.19% of ^{235}U) and 7% plutonium (5.00% of ^{239}Pu and 2.00% of ^{240}Pu).