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Neutron gamma fraction imaging: Detection, location and identification of neutron sources

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ABSTRACT

In this paper imaging of neutron sources and identification and separation of a neutron source from another neutron source is described. The system is based upon organic liquid scintillator detector, tungsten collimator, bespoke fast digitiser and adjustable equatorial mount. Three environments have been investigated with this setup corresponding to an AmBe neutron source, a ^{252}Cf neutron source and both sources together separated in space. In each case, events are detected, digitised, discriminated and radiation images plotted corresponding to the area investigated. The visualised neutron count distributions clearly locate the neutron source and, relative gamma to neutron (or neutron to gamma) fraction images aid in discriminating AmBe sources from ^{252}Cf source. The measurements were performed in the low scatter facility of the National Physical Laboratory, Teddington, UK.

1. Introduction

Fast and accurate detection, location and identification of radioactive sources (particularly neutron sources) are important tasks in nuclear decommissioning, international safeguards application and security applications. For example, the threat of the illicit transport of radioactive materials across international borders by terrorists demands that precise radiation screening techniques and instrumentation are in place [1]. Similarly, in nuclear decommissioning applications, it is important to characterise contamination of structures, site and contaminated land in a fast, accurate and efficient way in order to accelerate the clean-up programme, while reducing the net cost of decommissioning.

The presence of neutrons and gamma rays is detected and characterised by various mechanisms. Radiation portal monitors and gamma radiation imaging systems are currently deployed to detect radioactive material where safety and security is vital. These systems are generally passive (not designed to generate or emit radiation with which to stimulate a response) and, often use plastic scintillators for gamma-ray detection and ^{3}He-filled gas proportional counters for neutron detection. In nuclear decommissioning applications, detection and location of radioactive materials is typically based on gamma-ray detection. Such systems are primarily equipped with NaI(Tl) or CsI(Tl) scintillation detectors, where CARTOGAM, RadScan, RadCam, and the Gamma Visor are a few example gamma-ray imaging systems currently used in decommissioning applications.

Recent advances in pulse-shape discrimination (PSD) methods and digital pulse-processing capabilities enable the use of organic liquid scintillation detectors in real-time radiation imaging applications [3,4]. Organic liquid scintillation detectors are sensitive to both neutrons and gamma rays. Pulse-shape analysis determines whether the event was caused by either a neutron or a gamma-ray event, based on the decay characteristics of the pulse. This provides an added benefit, particularly in the detection of neutron sources, where it permits both gamma rays and neutrons to be used to detect and locate the source.

In this paper, detection and location of neutron sources, and identification of one neutron source from another are described. The technique is based on a recently developed organic liquid scintillate detector based mixed-field imaging system, where neutron gamma fraction images are generated to identify the neutron source. The remainder of the paper includes the details of the experimental setup at the National Physical Laboratory (Section 2); details and the results of pulse shape discrimination and neutron gamma fraction images (Section 3); discussion of results and conclusions (Section 4).

2. Experimental method

In this work a system shown in Fig. 1 was used to collect data under three mixed-field radiation environments at the low scatter

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Fig. 1. The mixed-field imaging system used in this research [2].

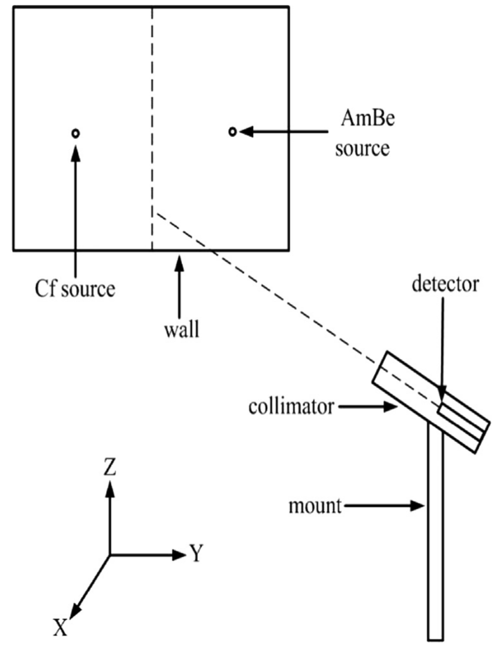

Fig. 2. Schematic of the experimental setup.

facility of the National Physical Laboratory (Teddington, UK). The system comprised an organic liquid scintillator detector (4 ml cylindrical scintillator cell), a heavy tungsten collimator (outer diameter of 57 mm, 10 mm thickness and 250 mm length), adjustable equatorial mount and a bespoke fast digitiser (500 MHz, 12 bit resolution) [2]. The detector was placed inside the tungsten collimator which was then mounted on the equatorial mount. The detector output was connected to the digitiser and samples from the digitiser were streamed to a personal computer through an Ethernet connection. The mount and digitiser were synchronised and controlled through MATLAB.

The sources (canister containing a small amount of radioactive material) used in this research were set up as shown in Fig. 2. The distance between the source plane and the detector front surface was 191 cm, where sources were approximately 45 cm apart from each other on the wall and 35 cm above the horizontal central axis of the collimator (where the height of the horizontal central axis of the collimator was 112 cm). Events were acquired under three environments: AmBe source only (NPL reference: 1000/1095; canister type X3; neutron emission rate of $2.149 \times 10^6\ s^{-1}$); ^{252}Cf source only (NPL reference: 4774; canister type X35; neutron emission rate of $2.24 \times 10^7\ s^{-1}$); both AmBe source and ^{252}Cf source. In each case, the detector (controlled by the equatorial mount) collected data at a sequence of positions in azimuth and elevation constituting a full scan of the area on which the sources were set up i.e. data were recorded for a total of 35 positions (5 in elevation and 7 in azimuth) for each of the 3 source configurations. At each position data were taken for 1 min time period. The maximum count rate of the system was approximately around 50 kilo-pulses per second. The digitiser is designed to perform sampling at 500 MHz (i.e. each sample value taken at 2 ns intervals) with an amplitude resolution of up to 12 bits. The Field-Programmable Gate Array (FPGA) in the digitiser was set up to send raw digital pulse shapes, as opposed to discriminating on the fly, in order to provide maximum flexibility in post-processing analysis.

3. Results

Organic liquid scintillator based detectors are sensitive to both neutrons and gamma rays. Experimentally collected digital samples consequently sent through a pulse shape discrimination algorithm (pulse gradient analysis was used in this research) in order to discriminate neutron events from gamma-ray events. Pulse gradient analysis is based on a comparison of the peak amplitude and the amplitude of a sample occurring at a defined time interval after the peak amplitude, generally known as the discrimination amplitude. Scatter plots (i.e. plots of discrimination amplitude versus peak amplitude) were obtained for the position giving the maximum number of counts for each of the 3 configurations to provide an indication of the mixed nature of each field investigated.

Pulse shape discrimination scatter plots shown in Figs. 3(a), 4(a) and 5 are corresponding to AmBe source, ^{252}Cf source and both sources respectively (scales of arbitrary units are common in each case). In each scatter plot the upper plume corresponds to neutron events and the lower to gamma-ray events. The discrimination line established on the basis of the previous experiments conducted for pure gamma and combined gamma and neutron sources [3].

The spatial distribution of neutron counts (after the pulse shape discrimination), for the case of the AmBe source and for the case of ^{252}Cf source, are shown in Fig. 3(a) and in Fig. 4(b) respectively. Fig. 6(a) represents the relative gamma to neutron fraction image (i.e. spatial distribution of gamma to neutron count ratio) and Fig. 6(b) represents the relative neutron to gamma fraction image (i.e. spatial distribution of neutron to gamma count ratio) for the case of both AmBe and ^{252}Cf sources. In each case the count distribution transformed to the Cartesian *xy*-plane, relative to the co-ordinates of the detector mount system, giving a spatial dependence of the field in the actual plane on which the source is located. Also, the scale on the colour map corresponding to the intensity of the parameter considered in each case (for example number of