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Detectors for Active Interrogation Applications

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Abstract

Active interrogation creates an environment that is particularly challenging from a radiation-detection standpoint: the elevated background levels from the source can mask the desired signatures from the SNM. Neutron based interrogation experiments have shown that nanosecond-level timing is required to discriminate induced-fission neutrons from the scattered source neutrons. Previous experiments using high-energy bremsstrahlung X-rays have demonstrated the ability to induce and detect prompt photofission neutrons from single target materials; however, a real-world application would require spectroscopic capability to discern between photofission neutrons emitted by SNM and neutrons emitted by other reactions in non-SNM. Using digital pulse-shape discrimination, organic liquid scintillators are capable of reliably detecting neutrons in an intense gamma-ray field. Photon misclassification rates as low as 1 in 10^6 have been achieved, which is approaching the level of gaseous neutron detectors such as ^{3}He without the need for neutron moderation. These scintillators also possess nanosecond-timing resolution, making them candidates for both neutron-and photon-driven active interrogation systems. We have applied an array of liquid and NaI(Tl) scintillators to successfully image 13.7 kg of HEU interrogated by a DT neutron generator; the system was in the direct presence of the accelerator during the experiment.

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Keywords: Organic scintillator; active interrogation; neutron imaging

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1. Introduction

In a time when peaceful uses of nuclear energy are globally increasing, technology for monitoring nuclear materials is needed more than ever. There are also ongoing initiatives in nuclear weapons states to reduce worldwide nuclear stockpiles, creating an urgent need for accurate and robust technologies for characterizing special nuclear material (SNM). Most existing detection systems operate in passive mode. However, highly enriched uranium, which is widely regarded as the most accessible SNM, has few easily detectable passive emissions. To overcome this difficulty, an external source may be employed to produce secondary particles that can then be detected [Runkle et al., 2012]. This approach creates an environment that is particularly challenging from a radiation-detection standpoint: the elevated background levels from the source can mask the desired signatures from the SNM [Gozani, 1981].

Active interrogation can be driven by either a neutron or photon source. In either case, the interrogation will create a mixed radiation field that could overwhelm the desired signatures. Detection systems can be designed sensitive to secondary neutrons and/or photons generated during the interrogation. The most commonly explored active interrogation system uses a source of high energy photons to induce photofission in nuclear material; the resulting neutrons are then detected using arrays of detectors. The challenges of this approach are the extreme radiation level produced by the interrogating accelerator, and the relatively few neutrons relative to the photon flux created by the accelerator. Consequently, the neutron detectors employed in these applications have been photon insensitive, such as ^{3}He gas tubes. Here, organic scintillators are investigated as an alternative to ^{3}He tubes for active interrogation applications.

2. Organic Scintillation Detectors

Organic scintillation detectors have been used for decades for a variety of applications, such as nuclear physics, radiation imaging, nuclear nonproliferation and nuclear safeguards. [Brooks, 1979; Dolan et al., 2014; Clarke et al., 2016]. Neutrons are primarily detected by elastic scattering on hydrogen, while gamma ray are primarily detected by Compton scattering on electrons. These two interaction types excite different ratios of singlet and triplet scintillation states, which results in very different decay times: states excited by proton recoils have significantly shorter decay times than those excited by electron recoils; the results voltage pulses from these two particle types also have different decay times. An analysis technique called “pulse shape discrimination” (PSD) can then be applied to each voltage pulse to classify it as a “neutron” or “gamma ray” pulse [Birks, 1964; Knoll, 2010].

One common PSD approach is “charge integration”, whereby each voltage pulse is integrated over to pre-determined time range: the total pulse, and the tail-region of the pulse. When projected, these two integrals reveal two distinct distributions: one for neutrons and one for photons. Figure 1a shows the ratio of these two integrals (tail over total) as a function of the pulse amplitude. In this experiment, a ^{252}Cf was measured along with a ^{60}Co source such that approximately 1000 gamma rays were incident per incident neutron detected. The prominent region around a ratio of approximately 0.15 is from the detection of ^{60}Co gamma rays. One expects the detected neutrons to appear at ratios above this line; however, in this case they are obscured by a nearly constant background. This background comes from double pulses, which occur when multiple particles are detected within the decay time of a single pulse (approximately 200 ns). Integrating such pulses produces erroneously large ratios, obscuring the true neutron pulses.

We have previously developed an algorithm to digitally identify, and reject double pulses in the experimental data [Bourne, et al., 2015]. The algorithm uses pre-measured pulse templates that are applied to each pulse in the raw data; any pulse that does not sufficiently fit the template is rejected. Figure 1b shows the PSD distribution after applying the double-pulse rejection algorithm. The neutron pulse region is now clearly visible at ratios above the gamma-ray region, between 0.3 and 0.4. This approach results in a gamma misclassification rate of approximately 1 in 10^{6} [Bourne, et al., 2015]. While the algorithm is demonstrated here for neutron detection in a high gamma-ray field, it can be applied to double-pulse rejection in any scenario.