Nuclear Instruments and Methods in Physics Research A 784 (2015) 364–369

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Coded moderator approach for fast neutron source detection and localization at standoff

Jennifer Littell [a], Eric Lukosi [a,b,*], Jason Hayward [a], Robert Milburn [a], Allen Rowan [a]

[a] Department of Nuclear Engineering, University of Tennessee, 305 Pasqua Engineering Building, Knoxville, TN 37996, United States
[b] Institute for Nuclear Security, University of Tennessee, 1640 Cumberland Avenue, Knoxville, TN 37996, United States

ARTICLE INFO

Available online 8 December 2014

Keywords:
Neutron imaging
Thermal neutron detection
Directional moderation
Coded moderator
Standoff detection

ABSTRACT

Considering the need for directional sensing at standoff for some security applications and scenarios where a neutron source may be shielded by high Z material that nearly eliminates the source gamma flux, this work focuses on investigating the feasibility of using thermal neutron sensitive boron straw detectors for fast neutron source detection and localization. We utilized MCNPX simulations to demonstrate that, through surrounding the boron straw detectors by a HDPE coded moderator, a source-detector orientation-specific response enables potential 1D source localization in a high neutron detection efficiency design. An initial test algorithm has been developed in order to confirm the viability of this detector system's localization capabilities which resulted in identification of a 1 MeV neutron source with a strength equivalent to 8 kg WGPu at 50 m standoff within $\pm 11^{\circ}$.

1. Introduction

A requirement in the detection of special nuclear materials (SNM) is a system which can detect characteristic signatures of SNM in the presence of background neutrons and gamma rays. Shielding of SNM makes this problem especially difficult, particularly when the source is located tens of meters away from the detector. Several SNM detection methods are in use or under evaluation for such nuclear security applications, including gamma-ray spectroscopy and imaging, fast neutron imaging, and thermal neutron detection [1–5]. It is desired for new SNM detection systems to have cheap electronics, high detection efficiency, and, considering neutrons, the highest possible gamma-neutron discrimination. For certain applications, source localization is desired and large area detectors are needed in order to detect sources that are located tens of meters away. Imaging systems made from organic scintillators can be made sensitive to Watt spectrum fission neutrons, but the requirement of very conservative pulse shape discrimination limits their detection efficiency [6]. Furthermore, scatter-based neutron imaging can reject background, but it is very inefficient, requiring long counting times for standoff detection and localization [7]. Moreover, slow neutron detectors are typically not used for combined fast neutron detection and localization because scattering in the moderator can cause a loss of neutron directionality.

In this work, we investigate the potential of a large area thermal neutron detection system which is very efficient and specific for fast neutrons at standoff and, most importantly, maintains information on source directionality. This method spatially modulates impinging fast neutrons while moderating them for efficient detection by boron straw detectors [8,9].

2. Base system design and simulation

The base structure used in defining the detection system is shown in Fig. 1. Initial detector design concepts were simulated using MCNPX v2.7 [10]. In order to extract directional information, 10 detectors were placed side-by-side and surrounded by a moderating medium of High Density Polyethylene (HDPE), with detector 1 being the top detector shown in Fig. 1 and detector 10 being the bottom. Due to the varying moderator thickness seen by impinging neutrons when striking the detector array at different angles, each detector in the array has a different response to the neutron source. With the goal of standoff detection, the source is represented by a plane wave, signifying a standoff detection scenario, which was found as an acceptable assumption for point sources greater than 11 m from the detector array. The position of the impinging plane wave source relative to the front face of the detection system is denoted by θ, and in the simulations this angle was varied between 0° and 90°. The neutron point source utilized to evaluate the coded moderator structure was set to 1 MeV with a source strength equivalent to an 8 kg mass composed of 93% Pu-239, 6.5% Pu-240, and

* Corresponding author at: Department of Nuclear Engineering, University of Tennessee, 305 Pasqua Engineering Building, Knoxville, TN 37996, United States.
E-mail address: elukosi@utk.edu (E. Lukosi).

http://dx.doi.org/10.1016/j.nima.2014.11.118
0168-9002/

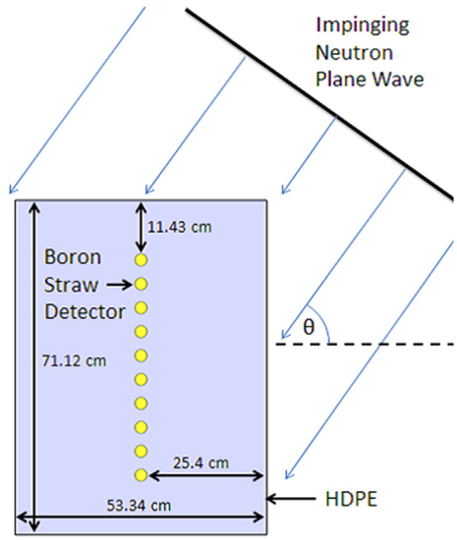

Fig. 1. Illustration of the base structure of the detection system design, where the fast neutron source is assumed to be far enough away that neutrons can be considered as a plane wave.

0.5% Pu-241 [11]. The detector array was simulated as 85 cm above the ground, where the ground was composed of 4 in. of concrete on top of 2.5 m of US average soil composition. For background count rate estimation, we used an isotropic plane source 20 m above the ground with an area of $10 \times 10\ m^2$. The source card for the background was defined by the work of Sato in 2006 [12], where both protons and neutrons were transported. The energy distribution for each was defined by assuming a latitude of 35.5° 20 m above sea level with a force field potential setting of April 15, 2013. The model described in [12] has been experimentally evaluated to agree with measured backgrounds in [13,14]. The count time for all cases was calculated at one minute, with the detector assumed to be 50 m away from the neutron source. For further details about the base structure of the detection system design, see [15].

2.1. Enhanced system designs

In order to enhance the effect of varying moderating thicknesses and investigate potential directional information from impingent fast neutrons, the base structure was modified to include air columns within the surrounding HDPE layer at various angles and locations. If appropriately designed, adding these columns of air to the HDPE will result in a higher detection efficiency when the source-detector line is near the same angle as these air columns. If the fast neutrons do not impinge near one of these angles, the detection efficiency decreases if the moderator-to-detector thickness is greater than the optimum for efficient detection, typically above 5 cm for a Watt fission distribution [16]. The simulated air columns were 1 in. in diameter with a 2 in. pitch and end four centimeters before the detector array, providing efficient moderation for the detection of fast neutrons from a Watt fission distribution. Also included in the detector system design are gadolinium foils embedded midway through the masking portion of the HDPE block on both sides. These foils serve to absorb neutrons which do not travel through the air columns to enhance the spatial response of each boron straw detector tube. To further enhance the detector system's efficiency, background suppression is included in the form of borated HDPE blocks above and below the detector array.

Two different coded moderator designs were considered. First, the entire mask was filled with air columns at 0° with respect to the front face normal of the detection system, referred to as type E1. Second, four different air column angles were considered, each in equal area quadrants from top to bottom, offset at 0°, 22°, 45°, and 77° from the detector array front face normal, referred to as type E2. Type E2 is shown in Fig. 2.

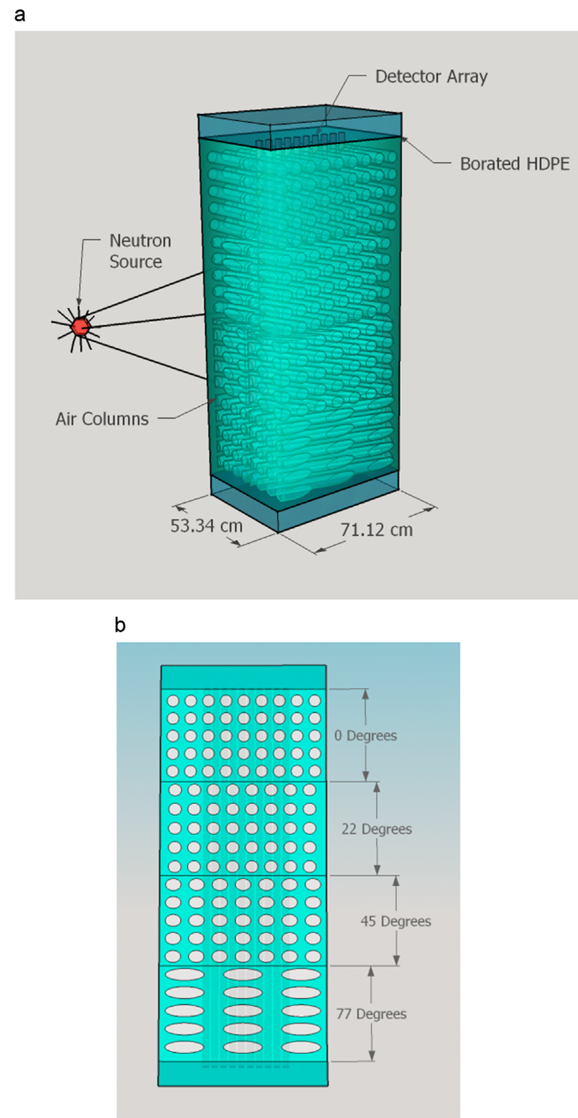

Fig. 2. (a) 3D representation and (b) front face of an enhanced detection system design with four quadrants of air columns at 0°, 22°, 45°, and 77°, from top to bottom.

3. Results

3.1. Base structure

For the base structure detection system design (see Fig. 1), a correlation of detector tube count rate as a function of incident neutron angle on the detection system was found, as illustrated in Fig. 3a. It is clear that, as the source moves around the detector array, the count rate increases in the first few detectors, corresponding to those with the least amount of HDPE masking to the impinging neutron plane wave. While this was the desired effect, the bulk variation in count rates was limited to the three closest detectors to the neutron plane wave. The remaining detectors showed little change in count rate as a function of the impingent angle and equal to the background count rate. The probability of detection with a 95% confidence level is provided in Fig. 3b for each detector in the array. Individually, each detector provides a relatively low probability of