Proof of Principle Simulation of a Handheld Dual Particle Imager

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Introduction

Motivation

Human portable systems are needed to locate special nuclear material (SNM) and identify warheads and for:
- Safeguards
- Treaty verification
- Emergency response

Nuclear weapons contain unique shapes of SNM that distinguish them from less dangerous items. SNM emits neutrons and gamma rays spontaneously or when interrogated.

A handheld dual particle imager (H:DPI) can exploit these two signatures to identify nuclear warheads.

Scatter Camera Operation

Neutron Scatter Camera
- Neutron elastically scatters twice in hydrogenous medium
- Velocity is determined from time and distance between scatters
- Energy of inter-scat ter neutron determined from velocity and neutron mass
- Incident neutron energy determined through energy of scattered proton and energy conservation
- Scatter angle follows from conservation of energy and momentum
- Result: cone of possible incident directions

Compton Scatter Camera
- Photon Compton scatters twice in low Z material
- Energy of inter-scat ter photon is approximated by empirical function of energy deposited in second scatter
- Incident photon energy approximated by adding inter-scat ter energy to energy deposited in first scatter
- Scatter angle determined from Compton equation, follows from conservation of energy and momentum
- Result: cone of possible incident directions

Handheld Dual Particle Imager (H:DPI) Design

- Exploits recent advances in silicon photomultiplier (SiPM) technology to achieve compact form factor
- Utilizes the crystalline organic scintillator, stilbene, for sensitivity to, and discrimination between, neutrons and gamma rays
- Closely-packed multiple-pixel design enabled by previously measured stilbene/SiPM performance:
  - 0.5 cm position resolution along the length of 5 cm bar
  - Coincidence timing resolution less than 0.5 ns

Previous Experimental Results

- Measured position sensitivity within a bar of stilbene with a SiPM on either end
  - 0.5 cm x 0.8 cm x 5.0 cm
- Colimated Na22 source
  - Measured at 5 positions along bar
  - Position certainty of ± 0.5 cm

Method

Simulation Technique

- MCNPX:PuR8
- C1DOSP: spontaneous fission source
- Collect neutron and photon oscillations in image active volume

Detector Response

- Convert energy deposited to electron equivalent energy (linearly proportional to light output)
- Center X: position above SiPM
- Gaussian broadening (mean FWHM)
- Light (7.7%)
- Time (0.5 ns)
- Z position (1.2 cm)

Coincidence Pairing

- Match coincident pulses
- Require both pulses above threshold (40 keVee)
- Require interactions in different crystals
- Reject interactions in adjacent crystals for improved image quality

Core Projections

- Back project cone onto sphere
- Propagate uncertainties in measured quantities into cone width

List Mode MLEM

- Produce response matrix using cone projections as probably distribution functions
- Observation matrix is a vector of ones
- Iterate, increasing likelihood of source image with each step

Results

Simulation Setup

- CI-252 placed 1 m in front of system
- 4x10^4 fissions simulated
- Equivalent to 67 min of 10^3 fission’s source

Accurate Location Determination

- Simulated sphere sources of CI-252
- Source 25 cm in front of system
- Coupled source radius from 0 to 12 cm
- Sources more than 4 cm in radius have >3σ larger FWHM than sources that are less than 3 cm in radius
- Significance: IAEA significant quantity of plutonium is equivalent to a metal sphere that is 4.6 cm in radius

Size Estimation using Neutron Imaging

- Measured position sensitivity within a bar of stilbene with a SiPM on either end
- Measured at 5 positions along bar
- Position certainty of ± 0.5 cm

Conclusions

- Design allows accurate location determination using either neutrons or photons
- Imaging intrinsic efficiency for fission neutrons: 0.66%
- Neutron angular resolution: 10° FWHM
- Minimum distinguishable sphere radius using neutrons @ 25 cm: 4 cm

Acknowledgement

- This research was performed under appointment to the Nuclear Nonproliferation International Safeguards Graduate Fellowship Program sponsored by the National Nuclear Security Administration’s Next Generation Safeguards Initiative (NGSI).
- This work was funded in part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534
- Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000
- Approved for Unlimited Release. SAND2016-10395C

This work was funded in part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534

\[ E_{\gamma} = E_{\text{neutron}} - 2m \nu \]