Time-Encoded Imagers

SL11-TimeImager-PD2Jh

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1. INTRODUCTION

We have developed two neutron detector systems based on time-encoded imaging and demonstrated their applicability toward non-proliferation missions. The 1D-TEI system was designed for and evaluated against the ability to detect Special Nuclear Material (SNM) in very low signal to noise environments; in particular, very large stand-off and/or weak sources that may be shielded. We have demonstrated significant detection (>5 sigma) of a 2.8e5 n/s neutron fission source at 100 meters stand-off in 30 min. If scaled to an IAEA significant quantity of Pu, we estimate that this could be reduced to as few as ~5 minutes. In contrast to simple counting detectors, this was accomplished without the need of previous background measurements. The 2D-TEI system was designed for high resolution spatial mapping of distributions of SNM and proved feasibility of two-dimensional fast neutron imaging using the time encoded modulation of rates on a single pixel detector. Because of the simplicity of the TEI design, there is much lower systematic uncertainty in the detector response typical coded apertures.

Other imaging methods require either multiple interactions (e.g. neutron scatter camera or Compton imagers), leading to intrinsically low efficiencies, or spatial modulation of the signal (e.g., Neutron Coded Aperture Imager (Hausladen, 2012)), which requires a complicated, high channel count, and expensive position sensitive detector. In contrast, a single detector using a time-modulated collimator can encode directional information in the time distribution of detected events. This is the first investigation of time-encoded imaging for nuclear nonproliferation applications.

2. ONE-DIMENSIONAL TIME ENCODED IMAGING SYSTEM

We investigated the use of large liquid scintillator (LS) cells as TEI detection elements. Various cell configurations were studied, primarily using different photomultiplier tube (PMT) candidates. Scintillation light collection from the cell and PMT characteristics were identified as the most important variables. Comparisons between different cell configurations, and a description of the selected cell configuration, a 11"D x 15" LS volume coupled to three 5" PMTs, are described in further detail in references (Brennan, 2013) and (Nowack, 2012).

Figure 1 shows the 1-D TEI system installed into a 20 foot long trailer at Sandia National Laboratories, CA for a series of large stand-off experiments. A ^{252}Cf source with strength of ~2.8e5 n/s was measured at a 100 meter stand-off. The plots shown in Figure 2 reflect a random 1 hour of raw neutron rates vs. background rates for each cell (left) and a reconstructed source distribution (right) using an iterative Maximum Likelihood Expectation Maximizer (MLEM) algorithm (Shepp, 1982). The results of a point source hypothesis test analysis shown in Figure 3 indicate significant detection of the source (>5 sigma) at the expected location in a 30 minute measurement period.

If scaled to an IAEA significant quantity of WGPu, the demonstrated performance represents a 5 sigma significant detection over background in ~19 minutes. If PSD could be improved and systematic uncertainties could be reduced through improvements in the system response matrix, we estimate that this could be reduced to as few as ~5 minutes.

Figure 1 – Photograph of the TEI system installed in a 20 ft. trailer for field measurements (left) and photograph of the 20 ft. trailer containing the TEI system (right). The ^{252}Cf neutron source is contained in the locked shipping container that can be seen 100 m behind the trailer in the empty field.

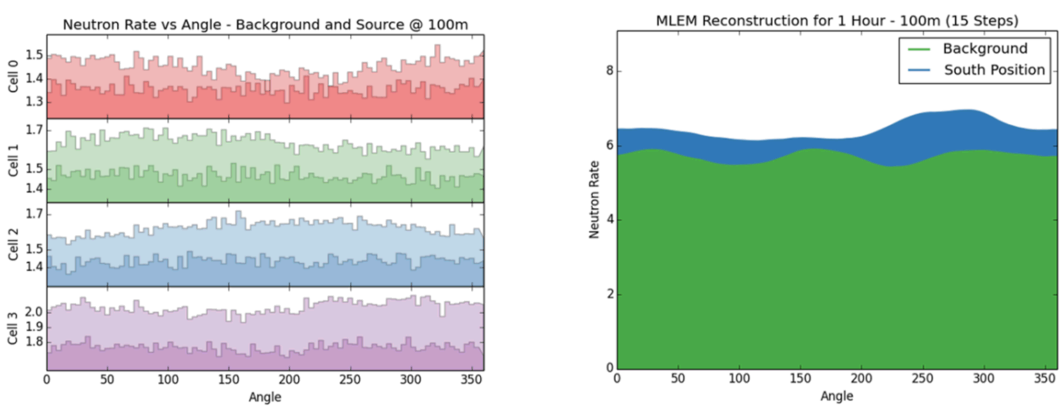

Figure 2 – (Right) Neutron rates in each of the four LS cells as a function of rotation angle for a ^{252}Cf source at 100 m stand-off (light background colors) and background (darker foreground colors). (Left) MLEM reconstructed source distribution over azimuthal angles using these neutron rates for the ^{252}Cf source (blue) and background (green). All measurements were taken with one hour dwell-time.

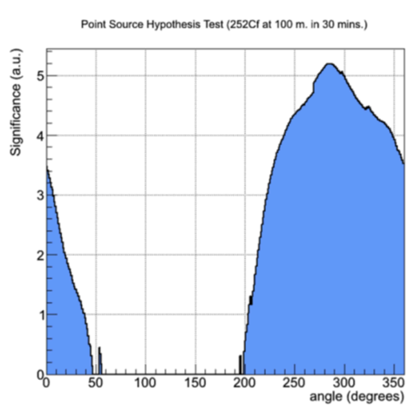

Figure 3 – Result of the point source hypothesis test as a function of the assumed angular position of the source

3. TWO-DIMENSIONAL TIME ENCODED IMAGING SYSTEM

The focus of the 2-D time encoded imaging prototype is to demonstrate proof of feasibility for high resolution image reconstruction. The final design is shown in Figure 4 (left) has an expected intrinsic angular resolution of ~2.5 degrees. As the mask is rotated around two central 1” diameter x 1” deep liquid organic cells, the direction of any sources present are uniquely imprinted on their count rates as a function of time. The MLEM reconstructed image from a 1 hour dwell time shown in Figure 4 (right) clearly resolves two ^{252}Cf neutron sources separated by 5 degrees.

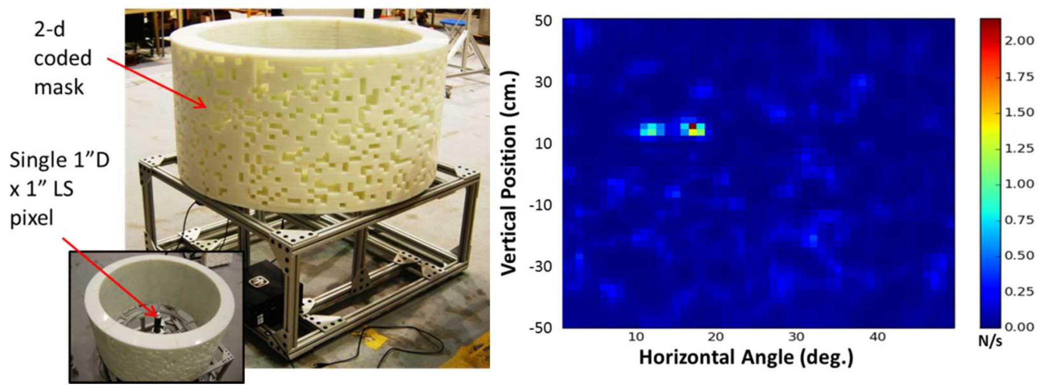

Figure 4 – (Left) Photograph of the 2-D time-encoded imager. Two central liquid organic scintillator detectors (seen in inset) are surrounded by a rotating high density polyethylene mask. (Right)MLEM reconstruction of two ^{252}Cf point sources separated by 5 degrees at 2.0 meter stand-off in 1 hour.

4. RESULTS, DISCUSSION AND CONCLUSIONS

We have achieved two major accomplishments with prototype TEI systems:

1. Significant detection (>5 sigma) of a 2.8e5 n/s neutron fission source at 100 meters stand-off in 30 min without the need of previous background measurements.
2. Proven feasibility of 2-D fast neutron imaging using the time encoded modulation of rates on a single pixel detector. Because of the simplicity of the TEI design, there is much lower systematic uncertainty in the detector response typical coded apertures.

5. WORKS CITED

Brennan, J. B. (2013). Time-encoded imaging of energetic radiation. *Proc. SPIE 8852, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XV*. San Diego, CA.

Hausladen, P. B. (2012). Fast Neutron Coded-Aperture Imaging of Special Nuclear Material Configurations. *INMM Anual Meeting*.

Marleau, P. B. (2012). High Resolution Imaging of Fission Energy Neutrons. *INMM Annual Meeting*.

Nowack, A. B. (2012). Fast Neutron Time-Encoded Imaging for Special Nuclear Material Detection. *SORMA*. Oakland.

Shepp, L. V. (1982, October). Maximum Likelihood Reconstruction for Emission Tomography. *IEEE Transactions on Medical Imaging, 1*(2), 113-122.

Struck. (2013). *SIS3316 manual.* Retrieved from http://www.struck.de/sis3316-2013-06-24.pdf