Advanced Radiation Detection Sensor Development at TAMU

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Introduction

The growing violence in terrorist attacks has resulted in a greater awareness of the threat of nuclear and radiological terrorism. Securing the borders from any attempt to transport a nuclear or radiological device into the U.S. is a critical need and requires the application of the vast array of technical capabilities at U.S. universities. Current detector technology is inadequate for several important smuggling scenarios including the interdiction of shielded high-enriched uranium (HEU) being smuggled in cargo or on a vehicle into the U.S. [1]. This necessitates the development of advanced detector systems that fully integrate all available signal information with inverse analysis simulations to provide revolutionary improvements in the state of border monitoring technology.

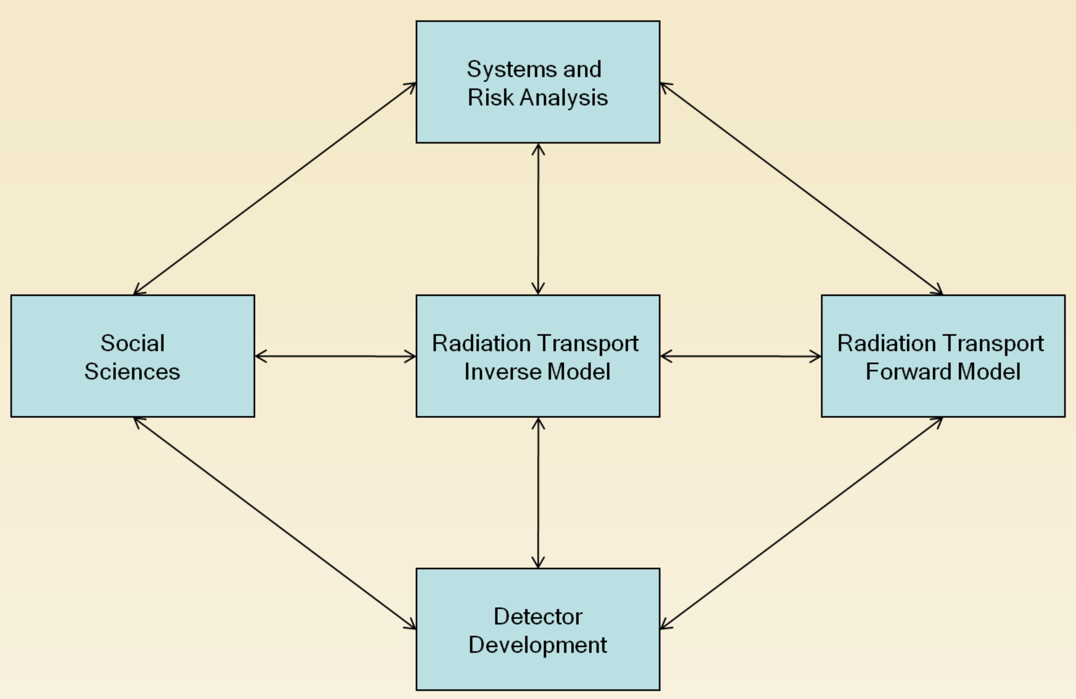
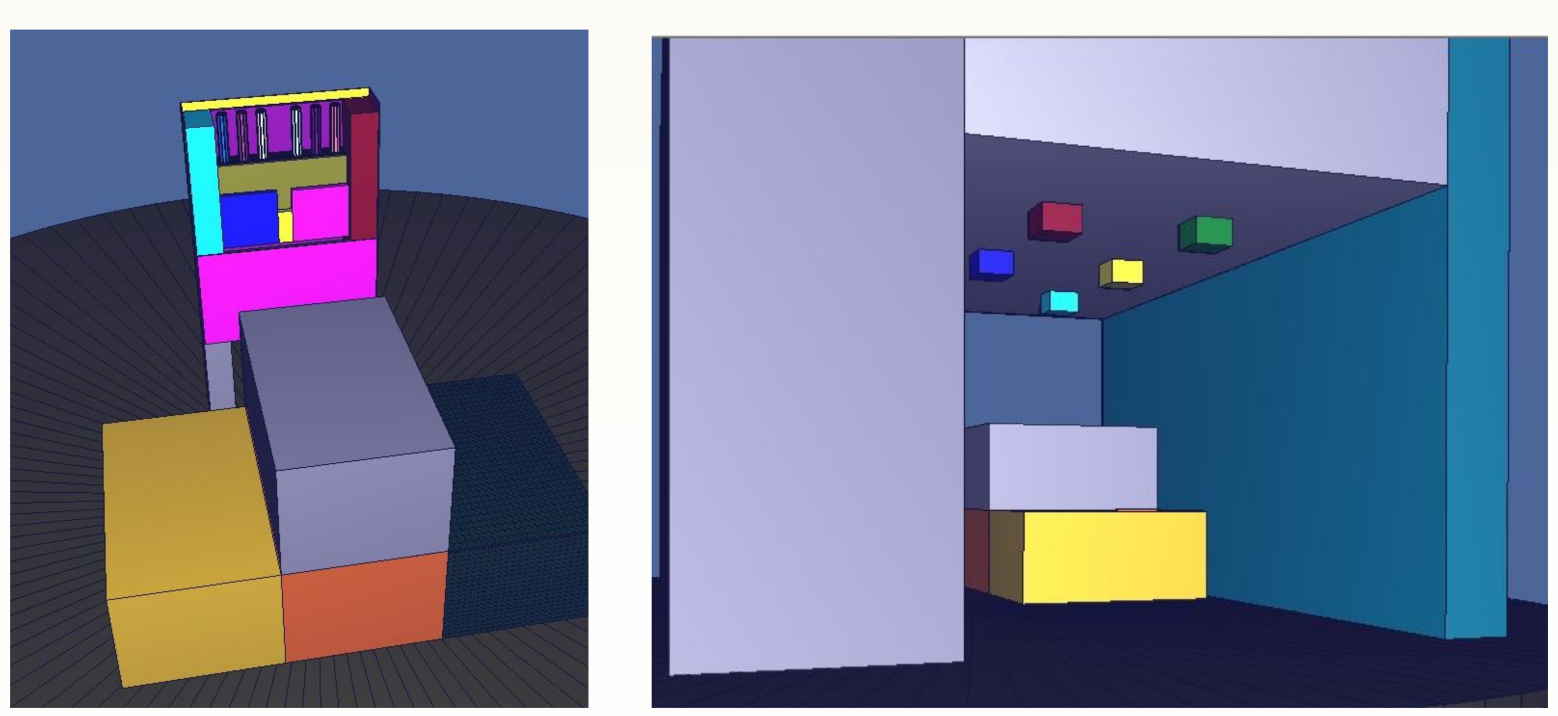


Fig. 1. Information distribution in the TAMU-ARI framework.

Researchers at TAMU are developing advanced radiation detection sensors and detector deployment approaches using a coupled system-of-systems method (Fig. 1). Monte Carlo simulations have been used along with signal processing coupled to inverse transport algorithms and informed by social science modules.

Baseline Simulations

Prior to developing new detector concepts and detection approaches, a baseline simulation was performed for currently deployed detector systems. For this simulation, one of several implemented border monitors was modeled. This monitor which contains six cylindrical He-3 tubes surrounded by polyethylene for neutron detection as well as plastic scintillator detectors for photon counting. The simulation was performed using MCNP and an image of the detector setup can be seen in Fig. 1(a). The object adjacent to the detector is a mockup of a car with shielded HEU sample in the trunk. The HEU sample was composed of a 70% enriched HEU sphere (500 g of U) coated with polyethylene and lead. The results for the baseline case are shown in Table 1. As can be seen, the neutron count rates due to the source are negligible; however, the photon count rates, while low, are statistically significant.



(a) (b)

Fig. 2. Visual representation of MCNP model: (a) Baseline concept and (b) New detector approach.

Table 1. Simulated neutron and gamma count rates (counts/sec) from baseline model with and without 500 g HEU source present.

	Without Source	*With Source*
Neutron	0.25±0.22	0.25±0.22
Gamma	577±22	353±9

New Approaches

One result from the integrated system-of-systems is that increasing the neutron count rate might provide significant advances in detection capability. This of course translates to an increase in overall detector efficiency in counting neutrons. Inverse transport analysis suggested that small, mobile detectors used in a distributed and adaptable detector array might increase detection efficiency. An example of this is shown in Fig. 1(b) where a set of mobile detectors are placed above the cars. This way if one detector receives a small signal, others can move to its location to try and increase detector efficiency. This was enhanced even farther by considering correlated events [2]. This may allow for increasing the signal-to-noise ratio due to the source material.

Direction Sensitive Detector Concept

Exploration of correlated events also led to the examination of using a direction sensitive neutron detector to help eliminate background sources. A detector concept for this system was developed which is theoretically capable of measuring incident angular fluxes on the detector (that is, the detector provides counts as a function of neutron position, energy, and angle).

Angular dependence is generated based on the Doppler broadening effect on the 477 keV gamma ray produced in flight following an (n,α) reaction in ^{10}B. This reaction produces an α-particle and ^{7}Li nucleus. The ^{7}Li nucleus is in an excited state 94% of the time. It will decay to the ground state by emitting a 477 keV gamma ray. This gamma ray will also be affected by the kinetic energy (and the direction) of the Li particle from which it originated. Fig. 3 shows the Doppler broadened spectrum of this gamma-ray measured with a HPGe. It should be noted that the photopeak from this gamma ray is significantly broadened from an expected Gaussian shape; however, the degree of broadening is highly dependent upon the detector medium.

If this 477 keV gamma ray can be detected and the sum of the original kinetic energies of the Li and α particle be measured, then the directional plane plane the original neutron came from can be unfolded. Fig. 4 shows a 2-D schematic of the (n,α) reaction in ^{10}B with the production of the 477 keV gamma ray during the flight of the ^{7}Li nucleus. Also shown to the right of Fig. 4 are the equations resulting from a simple conservation of energy and momentum solution for this system. One should note that in this derivation it was assumed that the reaction occurred in a vacuum and the slowing down of the Li particle was not considered. Of course in a real system this will have to be considered and will require excellent timing measurements to account for this effect.

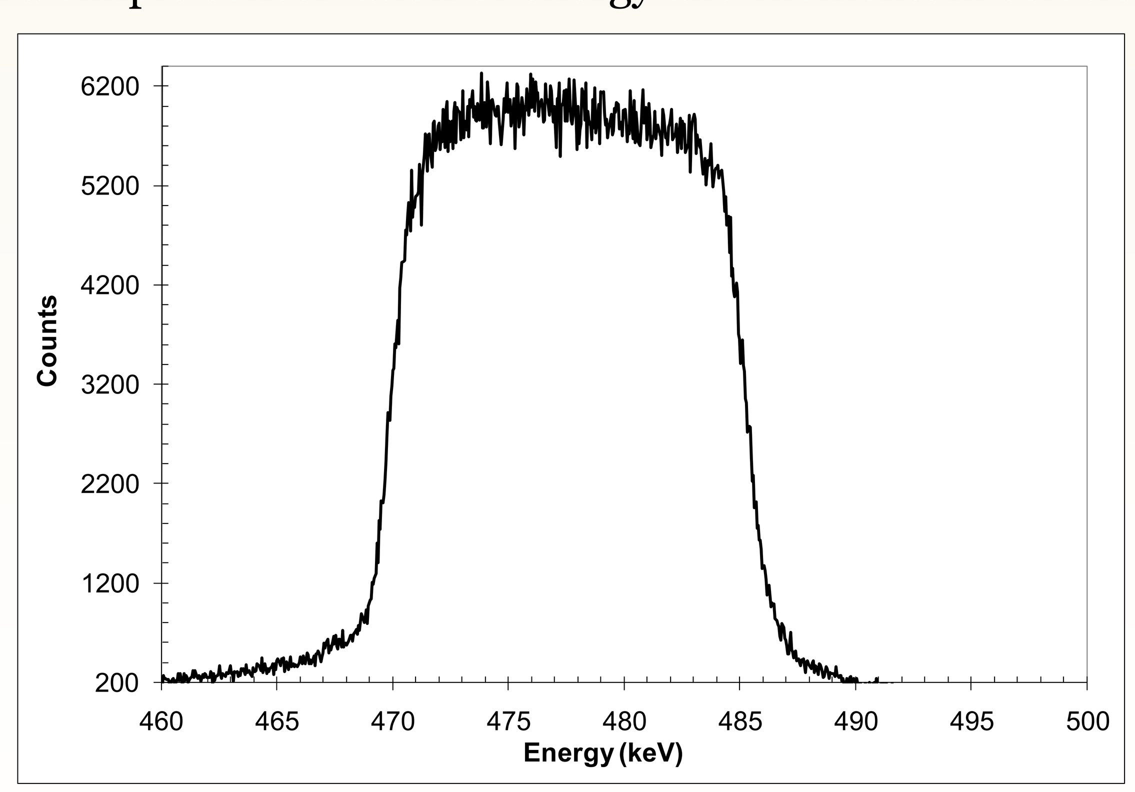


Fig. 3. Counts versus energy for 477 keV gamma-ray measured with an HPGe for slow neutrons incident on BF_3 gas showing the Doppler broadening effect.

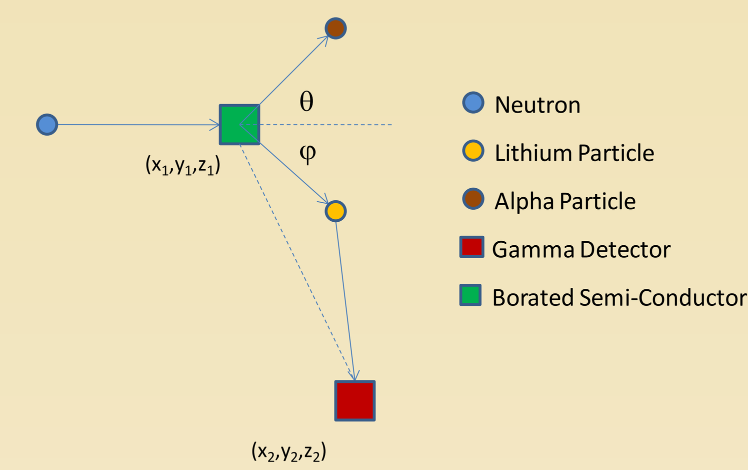


Fig. 4. Geometric layout of the ^{10}B (n,α) reaction used in the derivation of the incident neutron angle from correlated neutron and gamma detector measurements.

$$E_{Li} = \frac{\sqrt[3]{2}B^2}{3\sqrt[3]{27C^2A^4 + 2B^3A^3 + 3\sqrt{3}\sqrt{27C^4A^8 + 4B^3C^2A^7}}} - \frac{2B}{3A} - \frac{\sqrt[3]{27C^2A^4 + 2B^3A^3 + 3\sqrt{3}\sqrt{27C^4A^8 + 4B^3C^2A^7}}}{3\sqrt[3]{2}A^2}$$

$$A = 2 * (m_{Li} - m_{\propto})$$

$$B = 2 * (m_n E_n - m_{\propto} E_n - m_{\propto} BE)$$

$$C = -4\sqrt{m_n E_n m_{Li}} * (E_\gamma^M - E_\gamma^C)$$

$$E_{\propto} = E_n^{Calculated} + BE^{Known} - E_{Li}$$

$$\cos\varphi = \frac{E_\gamma^M - E_\gamma^C}{E_{Li}}$$

To measure the kinetic energy of the charged particles and the 477 keV gamma ray, both an energy and position sensitive neutron gamma ray detector are needed. This leads to the need for a solid-state neutron detector "doped" with boron. Several devices of this type have been considered previously [3-6], but in this work an advanced version of this detector concept using nanoparticles of boron within a Si-based semiconductor is being developed. It is expected that this detector can measure the incident neutron energy to a resolution of approximately 15 keV; however, this detector is still mainly at the conceptual phase. A high-resolution gamma ray detector is also needed; however, it is expected that this system will be developed by others, so little effort was made to consider additional technologies for that detector. Lastly, the detector system signals must be processed in coincidence with a fast timing system. Currently existing technology should be sufficient for the signal processing from this detector system.

Conclusions

In this project, an integrated system-of-systems concept was used to help drive detector technology development. Results suggested that two advanced detector concepts may provide increased detection capability: (1) small, mobile, and adaptable distributed detector arrays and (2) direction sensitive neutron detectors. While these are by far not the only concepts which could increase capability, these systems show some promise for helping to increase the probability of detecting shielded HEU in vehicles or cargo. This may also allow for quicker and more efficient determination of the location of any radiation source, allowing border crossings or other high traffic areas to operate more efficiently.

References

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