White Paper for DIA NCMR FY08

Title:	Modular Compton Gamma-Ray Camera for Detecting Hidden Special Nuclear Materials
Proposal Type:	University White Paper
Primary Technical Areas:	The technical area is WMD, with a focus on detection of hidden special nuclear materials.
Estimated Budget:	$598,389 over three years, with $205,092 for the first year.
Lead:	University of Maryland, PI: Dr. Pamela Abshire, Department of Electrical and Computer Engineering and Institute for Systems Research
Partners:	Dr. Irving Weinberg, Fast Imaging Company Dr. Marco Moscovitch, Director of Nuclear Non-Proliferation Program, Georgetown University
POC:	Dr. Pamela Abshire, 301-405-6629, pabshire@umd.edu

Budget needed for the first year and for completion:

$205,092 for the first year, $598,389 for three years.

	Year 1	Total (Years 1-3)
Student (incl. tuition ben.)	$36,558	$114,621
PI (Abshire)	$15,041	$47,415
Consultants	$80,750	$242,250
Travel	$5000	$15000
Supplies	$14,000	$41,500
Equipment	$8,000	$22,000
Indirect Costs	$45,744	$115,603
Total Costs	$205,092	$598,389

Basic Concept of Proposed Work:

We propose construction of a new class of cost-effective low-voltage low-power gamma-ray detectors, enabled by advances in commercial nanofabrication techniques and novel image reconstruction methods that are well-matched to the energies emitted by hidden special nuclear materials. The detector design has the strong advantage of modularity, enabling the construction of mobile configurations of discreet compact detector banks (e.g., hidden in cellphones or laptops), as well as fixed sites for portal or truck-mounted use.

Description of Proposed Work:

Background. Gamma-ray detection is an important element in the process of finding hidden nuclear materials (HNM). Most methods of detecting hidden nuclear material depend on detection and characterization of gamma rays emitted by uranium or plutonium isotopes [1]. In some cases, the gamma radioactivity is emitted naturally by the radionuclide, while for other schemes the gamma-ray emission is induced by neutron or x-ray bombardment. Gamma-ray energies required for detection of HNM (including shielded highly-enriched uranium) are in the one to four MeV range. Typical detection approaches for these high energies employ classical scintillator techniques borrowed from high-energy physics, with bulky photodetectors that require high voltages. These techniques provide relatively poor energy resolution with no imaging capabilities, often leading to false positive identifications that waste time and dilute the attentiveness of security personnel.

Recently, alternatives have been proposed that combine inexpensive scintillators and silicon readout materials to achieve low cost, high-resolution systems [2]. These alternatives have been impossible to implement up to now, due to practical difficulties in fabrication. Furthermore, these solutions envision large cameras that may not be appropriate for discreet operations as might be carried out by military intelligence operatives.

Proposed Novel Approach. We propose construction of a new class of cost-effective low-voltage gamma-ray detectors, building on prior concepts, and enabled by advances in commercial nanofabrication techniques and novel flexible image reconstruction methods [3]. This class of low-cost detectors could be deployed at all scales, ranging from tiny detectors that could be placed in cell phone clusters, to intermediate detector banks that could be placed in laptops, or to large-scale portal or truck-mounted installations. In all cases, flexible GPS-enabled reconstruction methods would provide images with the aid of Compton camera operation. This Compton camera operation has been demonstrated to be effective even at high energies [2].

Unlike typical scintillator-based monitoring methods, we would use an extension of the well-known Compton camera approach to form images of the HNM deposits, thereby increasing diagnostic confidence. Our use of solid-state photodetectors enables highly accurate spatial and energy resolution, needed for accurate localization and characterization of HNM sources. The timing capabilities of current silicon detectors are a good match for the physical problem of radiation detection from HNM (e.g., few kHz per modular detector). The proposed architecture for readout allows on-board analysis packages at the detector level, providing the ability to update algorithms in the field for improved isotopic characterization.

The basic element of the proposed system is a smart detector node with imaging radiation detector (Figure 1), GPS for location tracking, and fast computing for estimation and reconstruction (Figure 2). The radiation detector is a Compton camera consisting of high-resolution silicon active-pixel arrays [4-6] coupled to thin layers of low-cost scintillating material and high resistivity silicon. Gamma rays are Compton scattered in the silicon layers and absorbed by the scintillating layers. The fast computing is implemented by a field programmable gate array or microcontroller that processes data to selectively identify signatures of HNM. Such data processing includes algorithms for reconstruction of source locations [3] as well as estimation and deconvolution algorithms for narrowing the energy

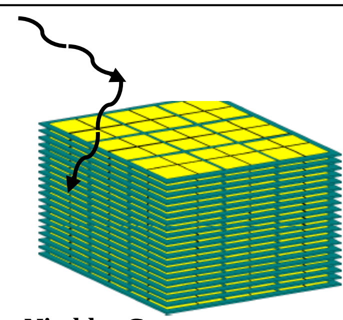

Figure 1. Nimble Compton camera design. Figure adapted from work by Kroeger et al [2]. Camera module is comprised of stacks of silicon and scintillator layers. Gamma ray (black track) is shown interacting with an upper layer via Compton scattering and then depositing its energy via photoelectric absorption in lower layers.

resolution [7, 8]. The GPS receiver and wireless transmitters allow us to integrate information across space and time and from multiple nodes, which is required for reconstructing an image of the HNM. Small, low-power GPS receivers are commercially available and achieve accuracy on the order of one meter [9].

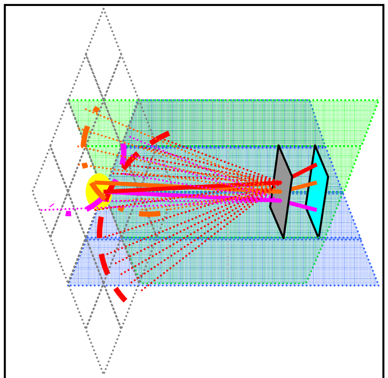

Figure 2: Reconstruction of source location. Radiation source (yellow sphere) emits gamma rays γ_i (solid lines) that strike a section of the Compton camera module (gray). Gamma rays scatter via Compton interactions, depositing energy ΔE_i. Rays deposit the rest of their energy via photoelectric absorption in a separate layer (bright blue). Computer calculates the cones of rays (dotted lines) that could have resulted in angular deflections corresponding to ΔE_i. Set of cone intersections forms basis for a reconstructed image of the source.

Competitive Technologies. There are already existing technologies that address the needs for portable, personal gamma ray detection and for exquisite energy resolution for isotope identification of special nuclear materials. For example, Polismart Inc. offers personal, portable gamma ray detectors in a cellphone platform that achieve energy resolution of 8% at Cs-137 [10]. At the other extreme, the National Institute of Standards and Technology has developed microcalorimeter sensors that are able to achieve energy resolution of well under 0.1%, albeit at a sensor operating temperature of 0.1 K [11] and with limited prospects for portable operation. The proposed technology fills a niche somewhere in between, offering the possibility of a portable and covert detector that has good energy resolution, good sensitivity, robustness, and imaging of sources.

Specific Objectives and Work Plan. Our overall approach will be to exploit commercially-available materials and devices in order to achieve rapid results that can lead to a product with dual-uses (surveillance, medical imaging) in a three-year time frame. In Year I, we would build and characterize performance of a single detector (e.g., 1 square cm), while designing the overall data collection architecture and infrastructure. In Year II we would develop and refine the software and algorithmic reconstruction architecture in order to collect images from the small-scale system. In Year III we would construct a small-scale system, using fabrication through trusted foundries and commercial backing to accomplish significant milestones and move rapidly towards commercialization.

Identify Proposed Partner Institutions and Their Roles:

Pamela Abshire, PhD, PI
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Dr. Abshire is an expert in low power mixed-signal integrated circuit (IC) design, adaptive ICs and IC sensors [4-6]. In cooperation with the proposed partners, Dr. Abshire has developed advanced radiation detectors with quantum sensitivity [5] and associated readout electronics for use in positron emission tomography and homeland security. Also with her partners, she has demonstrated that the use of appropriate digital signal processing algorithms can effectively improve the energy resolution of radiation detectors [7]. This energy improvement will be important for high resolution imaging as well as isotopic characterization.

Irving Weinberg, MD PhD
Fast Imaging Company, Bethesda MD

Dr. Weinberg is a physician scientist who founded several companies with core products in the radiation detection field. These companies have built compact low-cost imaging products that have been used by tens of thousands of cancer patients worldwide. For this effort, Dr. Weinberg is supplying expertise in radiation detection hardware and image reconstruction. He invented the technique of incorporating position-sensing devices within configurable imaging devices [3] and has developed algorithmic approaches to improving energy resolution for solid state detectors operating at room temperature [7].

Marko Moscovitch, PhD
Program for Health Physics and Nuclear Non-Proliferation, Georgetown University, Washington DC

Dr. Moscovitch is the founder and Director of the DOE-sponsored Nuclear Non-Proliferation Program at Georgetown. This program instructs graduate students in the technology and policy of nuclear nonproliferation including radiation sensing, with particular emphasis on spectroscopic measurements for radioactive material detection. Dr. Moscovitch is the author or co-author of several works on radiation detection algorithms, and is the designer of a line of radiation detection/dosimetry systems in use at many nuclear energy facilities worldwide. In collaboration with Oak Ridge national Laboratory and the Naval Research Laboratory, Dr. Moscovitch recently developed a remote sensing system for plutonium detection capable of identifying weapons grade plutonium and distinguishing it from other "non-weapon" neutron sources [12].

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