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R04-1 Direction-Sensitive Hand-Held Gamma-Ray Spectrometer

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ABSTRACT

A novel, light-weight, hand-held gamma-ray detector with directional sensitivity is being designed. The detector uses a set of multiple rings around two cylindrical surfaces, which provides precise location of two interaction points on two concentric cylindrical planes, wherefrom the source location can be traced back by back projection and/or Compton imaging technique. The detectors are 2.0 × 2.0 mm europium-doped strontium iodide (SrI_2:Eu^{2+}) crystals, whose light output has been measured to exceed 120,000 photons/MeV, making it one of the brightest scintillators in existence. The crystal's energy resolution, less than 3% at 662 keV, is also excellent, and the response is highly linear over a wide range of gamma-ray energies.

The emission of SrI_2:Eu^{2+} is well matched to both photomultiplier tubes and blue-enhanced silicon photodiodes. The solid-state photomultipliers used in this design (each 2.0 × 2.0 mm) are arrays of active pixel sensors (avalanche photodiodes driven beyond their breakdown voltage in reverse bias); each pixel acts as a binary photon detector, and their summed output is an analog representation of the total photon energy, while the individual pixel accurately defines the point of interaction.

A simple back-projection algorithm involving cone-surface mapping is being modeled. The back projection for an event cone is a conical surface defining the possible location of the source. The cone axis is the straight line passing through the first and second interaction points.

BACKGROUND

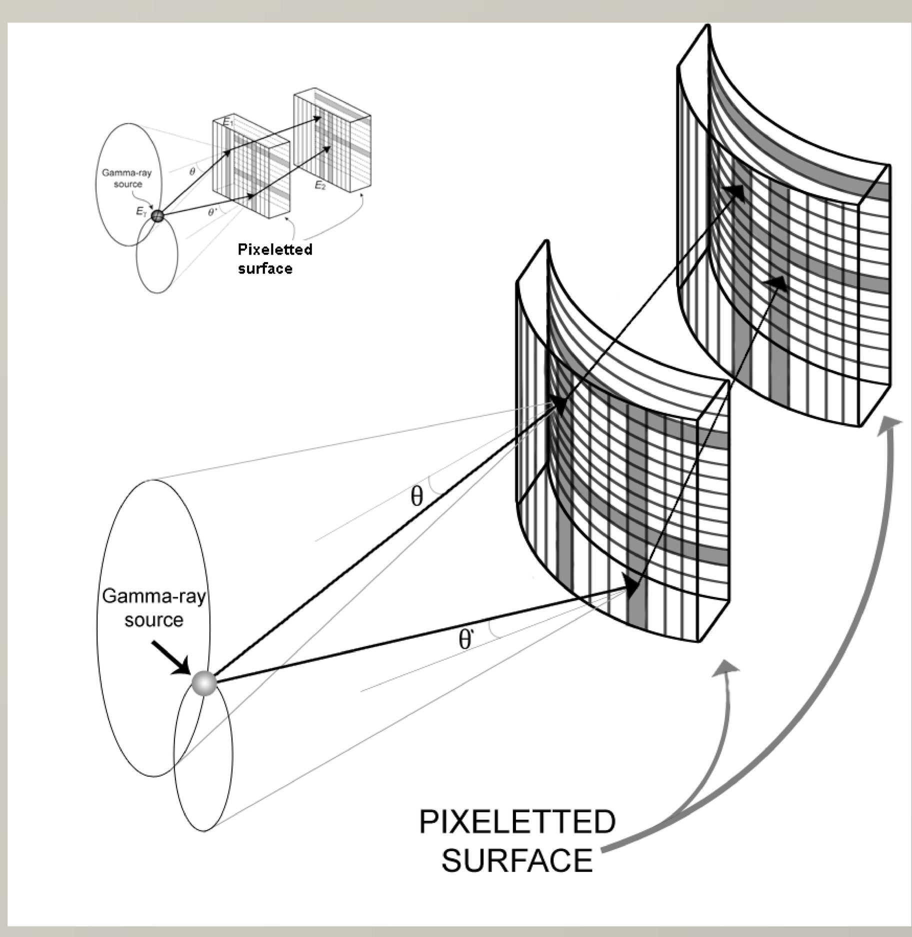
A hand-held, short-range directionally sensitive gamma sensor with the capability of imaging the gamma ray source is being built. Directionally sensitive hand-held gamma sensor with imaging capability does not exist within the NA-42, DHS/DNDO and DTRA communities. The nearest competitor, the Gamma Tracker from PNL, is not ready for deployment. The proposed device is going to be more sensitive and selective in terms of gamma energy spectral sensitivity with higher energy range and higher angular resolution.

First responders need directionally sensitive hand-held gamma-ray detection systems that are prompt, highly responsive, and easy to use for monitoring crowds in major public events. A hand-held directional tool for the Render Safe community for initial assessment and imaging will be something new and much appreciated. A quick estimate of the location of the sources in cargo containers, while screening at the second line of defense portals, would be an added benefit for NA-25. If full energy reconstructions of photo peaks are possible, then using energy windowing and positional windowing will increase the definition of the imaged gamma-ray source tremendously.

SELECTING THE SCINTILLATOR

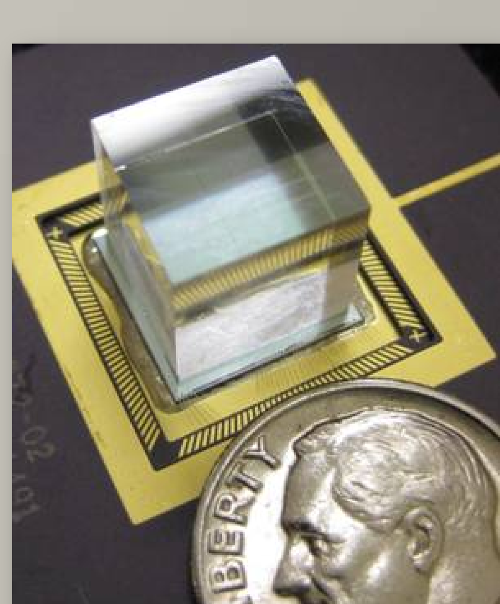
The basic design concept is borrowed from medical imaging systems such as positron emission tomography that produces a three-dimensional picture image of functional processes in a body. SrI_2:Eu^{2+} is a scintillator material of interest for gamma-ray detection and spectroscopy because of its high density and Z-number of its constituent atoms, as well as the high intensity of the Eu^{2+} emission. SrI_2:Eu^{2+} yields >100,000 photons/MeV in the Eu^{2+} luminescence band (435 nm central wavelength), with a decay time of ~1.2 microseconds, and exhibits excellent light yield proportionality (and hence intrinsic energy resolution) that is superior to that of Ce-doped lanthanum bromide. Of the alkaline earth halides, SrI_2:Eu^{2+} appears most promising due to its very high light yield, good optical properties, ease of growth, high achievable doping with Eu^{2+}, Z_{eff} higher than $LaBr_3$(Ce), excellent light yield proportionality, and demonstrated energy resolution of 2.6% at 662 keV.

An intriguing factor appears relevant to the excellent performance of SrI_2 (Eu). That is, the lattice constants for SrI_2 and EuI_2 are nearly identical, thus permitting high, uniform doping of Eu in SrI_2. Other favorable aspects of SrI_2 include its low melting point, 538°C, and its orthorhombic crystal structure, which will likely be readily growable to large sizes.



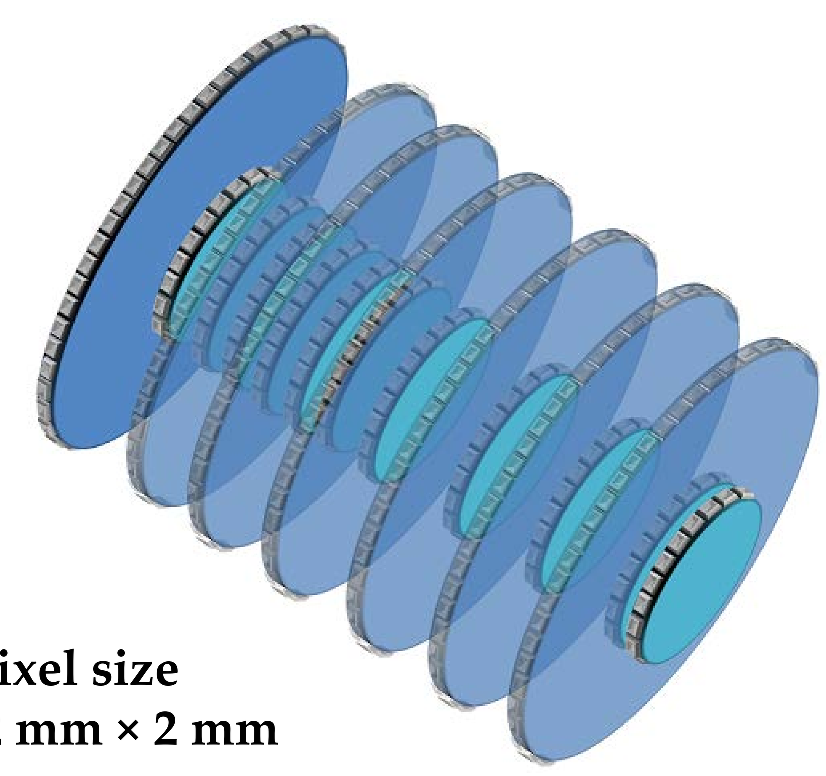
Simple back-projection for Compton imaging with two coaxial cylindrical sensor planes

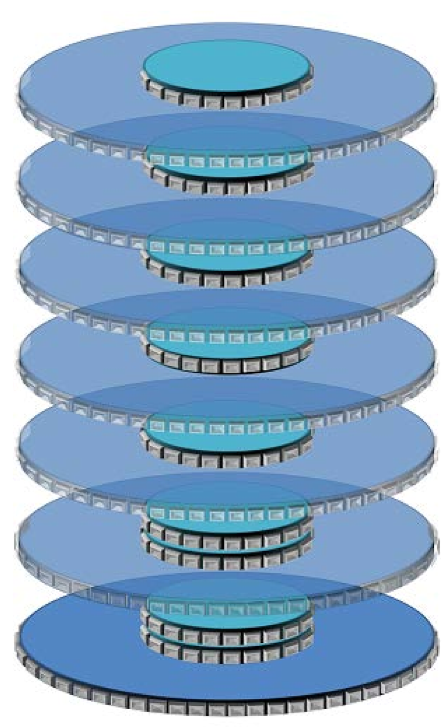
SOLID-STATE PHOTOMULTIPLIERS (SSPMS)



Solid-state photomultipliers (SSPMs) have performance characteristics similar to conventional PMTs, while benefiting from the practical advantages of solid-state technology: low operating voltage, robustness, compactness, and insensitivity to magnetic fields and light over-exposure. This truly revolutionary detector is leading the way for smaller, safer, higher-performance and lower-cost systems in the marketplace. The modern-day SSPMs are designed to meet the needs of a variety of applications, such as analytical instruments, hazard and threat detection, nuclear medicine, and process monitoring.

Proposed Detector Assembly





Pixel size
2 mm × 2 mm

Number of rows
~ 18

Length of cylinders
~ 38 mm

Outer diameter
~ 38 mm

Inner diameter
~ 20 mm

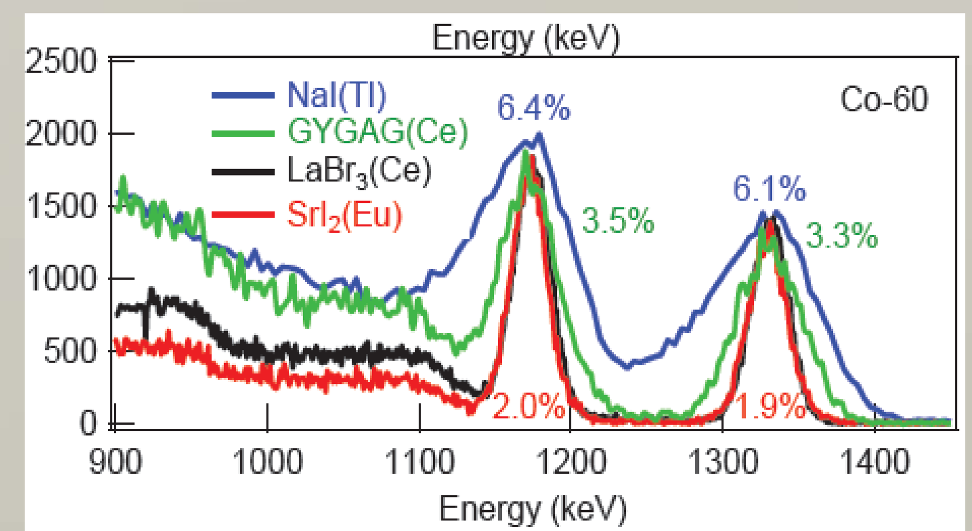
Proposed Capability

A rapid-prototyped hand-held spectrometer that would be able to provide directional location of a gamma-emitting source with energy spectral information will be built. For static target source it would be able to image the gamma source. It will be a low-cost, quick, and responsive light-weight device, with the size of an identiFINDER, (commercially manufactured hand-held gamma-ray energy spectrometer by FLIR, Inc.), having large vertical and horizontal opening angles able to image in 5 minutes two distinct gamma-ray emitting sources (50 μCi strong) 15 cm apart and 3 meters away.

Crystal Properties, Light Yields, and Non-Proportionality of Photon Output of SrI_2: Eu^{2+} Compared to $LaBr_3$: Ce[I]

Crystal	Z_{eff}	Light Yield (photons/keV)	Energy Resolution at 661.6 keV (FWHM)	Emission Range (nm)	Decay Time (ns)	Light Output Non-Proportionality
SrI_2: 0.5% Eu^{2+}	50	68	5.3%	~400–600	1100	4.8%
SrI_2: 2% Eu^{2+}	50	84	3.9%	~400–600	1100	6.2%
SrI_2: 5% Eu^{2+}	50	120	2.8%	~400–600	1100	2.0%
SrI_2: 8% Eu^{2+}	50	80	4.9%	~400–600	1100	5.1%
$LaBr_3$: Ce	45.7	63	2.8%	~325–425	15 (97%), 66 (3%)	4% (60–1274 keV)
SrI_2: 0.5% Ce^{3+}/Na^+	50	16	6.4%	~350–475	25 (47%), 159 (53%)	8% (60–1274 keV)
SrI_2: 2% Ce^{3+}/Na^+	50	11	12.3%	~325–425	32 (46%), 450 (53%)	6% (60–1274 keV)

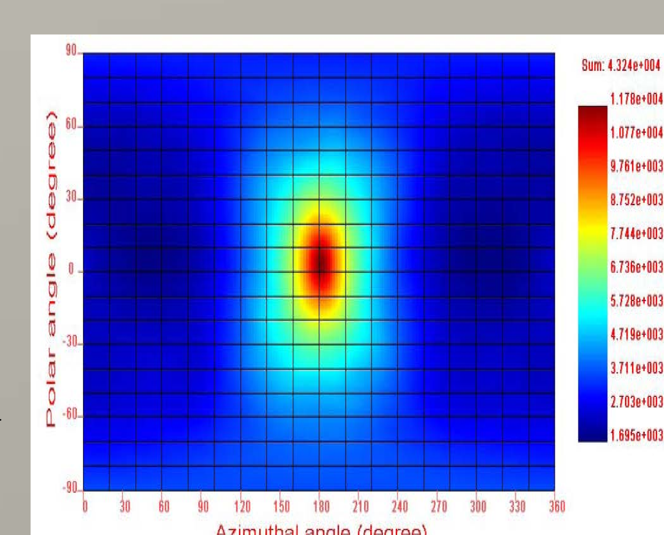
RESOLUTION COMPARISON AMONG SCINTILLATORS[2]



SSPM FEATURES[3]

- Very high gain (>10^5), very simple electronic readout
- Low bias operation (~30 V)
- Fast response (sub-nanosecond rise time)
- Very low excess and electronic noise (<1 electron level)
- Dark noise not a problem at ambient light levels
- Insensitive to magnetic fields
- Position-sensitive structures possible
- Fabricated by CMOS process, hence the cost of production is quite low during mass production
- On-chip integration of readout electronics possible

SSPMS FOR THE GAMMA-RAY SPECTROMETER



Simple back-projection image of a point source object[4]

SSPMs chosen for this design (each 2 × 2 mm) are arrays of active pixel sensors (avalanche photodiodes driven beyond their breakdown voltage in reverse bias); each pixel acts as a binary photon detector and their summed output is an analog representation of the total photon energy, while the individual pixel accurately defines the point of interaction. A benefit of using these ring-shaped bands of SSPMs is that they will provide very accurate position information. By looking at coincidence signals from a few (2 or 3) SSPMs firing about the same time, one can reconstruct the full energy deposition and reconstruct the full energy peak with high resolution (this will increase the gamma-ray energy resolution of the detector and will surpass the nominal value of the intrinsic gamma energy resolution of sodium iodide). By comparing the pulse heights, one can determine the depth of interaction, which in turn defines the ray-projections back to the source. The coincidence signals from the inner cylinder SSPMs' signal will be used to reduce the cross talk between the SSPMs (signals from SSPMs will be accepted only when the inner cylinder senses a light).

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