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SUMMARY:
Use of Photocell Readouts in the Development of High-Resolution Scintillator Systems

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Photomultiplier-based scintillator spectrometers are the systems of choice for a multitude of X-ray and gamma radiation measurement applications. Despite widespread use, they have numerous shortcomings. The most serious is the relatively poor energy resolution that makes isotope identification problematic particularly in the case of trace quantities. Energy resolution in scintillator/photomultiplier tube (PMT) spectrometers is governed by a combination of the crystal intrinsic resolution that includes non-linearity effects, photomultiplier statistics, and the variability in the probability of a scintillation photon generating a photoelectron at the photocathode. It is evident that energy resolution in these systems is linked to both the physics of light generation in the scintillator, as well as the characteristics of the PMT. PMTs also present design problems especially in the case of handheld and portable instruments due to their considerable weight and volume. Additionally, PMTs require well-regulated high voltage and are vulnerable to magnetic fields.

The objective of this work is to provide instrument designers of scintillation-based gamma-ray spectrometers with superior energy resolution and greatly reduced weight and volume. It is planned to achieve this advancement by optimizing the performance of a new class of inorganic scintillators by matching their emission spectra with the enhanced quantum efficiency of certain photocells. The new scintillators of interest include $LaBr_3$:Ce, $LaCl_3$:Ce, LuI_3:Ce, and K_2LaBr_5:Ce. Photocells to be investigated include Si PIN, HgI_2, TlBr, and SDDs. To date, we have studied and obtained results for $LaBr_3$: Ce using Si PIN and HgI_2.

The potential for improvements is illustrated by the case of the recent development of $LaBr_3$: Ce scintillators that have provided the community with a material with about three times better energy resolution than typical NaI(Tl)/PMT units. This dramatic result is due to very high conversion efficiency (~61,000 photons/MeV) and improved linearity. However, the resolution has not been optimized. The substitution of a silicon avalanche photodiode (APD) for the PMT substantially improved resolution due primarily to the diode's higher quantum efficiency in the spectral region at 360 nm corresponding to the cerium emission. This was achieved with the APD cooled to 250 K to suppress noise [Shah 2004]. Cooling is not considered an option in this application because of power consumption, a major consideration in portable instruments. Since other photocells are available with better matches to the cerium emission spectrum than many PMTs in the region of the Ce^{3+} emission, further improvements in resolution can be expected. Mercuric iodide photocells, for example, have particularly high quantum efficiency in the region of interest. It is planned to optimize the energy resolution of the new scintillators by matching the spectrum of the cerium emission with the quantum efficiency of selected photocells.

This work reports on our efforts to match photocells and scintillators. Published emission spectra of the scintillators have been convoluted with published and, when necessary, experimentally determined quantum efficiency to guide the selection of the optimum scintillator-photocell pairing. Our preliminary investigations have revealed a number of photocells of possible interest to this project: CdS, Se, SiC Ga N, GaP, GaAs, Si-PIN, Si –APDs, Si –drift, and HgI_2. Few of these photocells, however, have all the requisite characteristic: high quantum efficiency in the spectral region of interest, response time size and availability. Mercuric iodide photocells appear to have the best characteristics for the advanced scintillators. Transparent contacts such as Indium-Tin-Oxide (ITO) as well as saline contacts have already been studied elsewhere on mercuric iodide and, based on their spectral response, seem to be the first choice. [Markakis, 1988 1&2]

Optical coupling procedures will be explored and optimized. For temporary testing a gel or silicone grease will be employed. For prototypes, the use of an epoxy-based compound or other resin-type adhesive may be appropriate. The materials will be chosen as close as possible to the condition of maximum light transmission, which is achieved when the coupling material has an index of refraction, which is the geometric mean of that of the two optical materials to be coupled. A very effective way of evaluating the efficiency of the optical coupling procedure can be estimated by measuring the photoelectric peaks of a gamma source as detected in the scintillator and directly in the photodetector with the knowledge of the light yield of the scintillator (for example, for $LaBr_3$: Ce this value is ~61,000 photons/MeV) and the energy required to produce an electron-hole pair for direct detection (for HgI_2, for example this value is 4.2 eV.) Currently a resolution of FWHM = 4.8% at 662 keV (^{137}Cs) has been achieved with a $LaBr_3$ read by an HgI_2 with a saline contact.

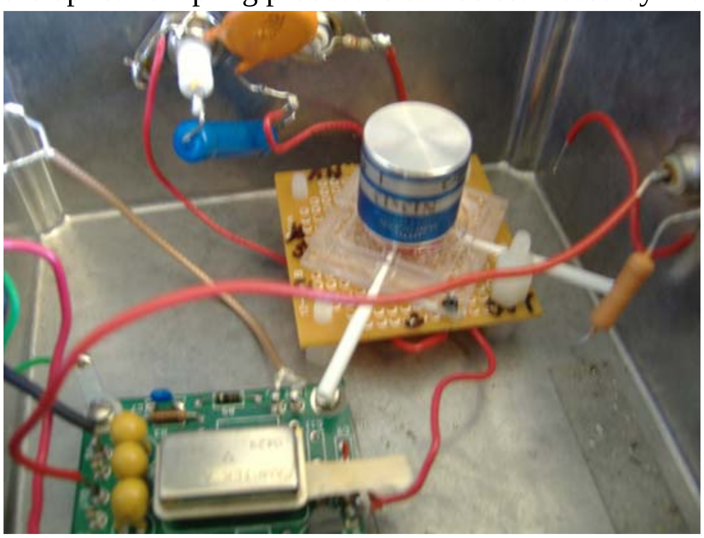

Figure 1. $LaBr_3$ mounted on an HgI_2 with saline contact

The gamma response will be measured with various radionuclides in the energy range of 100 keV to 1 MeV. Energy resolution, peak efficiencies, thermal stability, energy linearity and long-term stability of the overall device will be determined. The results will be evaluated against values obtained by us or those that have been previously reported with PMTs and silicon photodiodes.

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