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SUMMARY:

Development of High Resolution Scintillator Systems Based on Photocell Technology

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Inorganic scintillator/photomultiplier-based 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 shortcoming 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 and 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 include $LaBr_3$(Ce), $LaCl_3$(Ce), LuI_3(Ce), K_2 La Br_5(Ce). Photocells to be investigated include Si PIN, HgI_2, CdS, and GaP. The potential for improvements is illustrated by the case of the recent development of La Br_3(Ce) scintillators that have provided the community with a material with about 3 times better energy resolution than typical NaI(Tl)/PMT units. This dramatic result is due to very high conversion efficiency (>60,000 photons/MeV) and improved linearity. However, data indicate that 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. Cooling is not considered an option in this application because of power consumption, a major consideration in portable instruments, and, perhaps more importantly, the temperature dependence of light emission in many scintillators. 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 of emission spectrum of the cerium emission with the quantum efficiency of all available photocells.

This work reports on efforts to match photocells and scintillators. Published emission spectra of the scintillators will be convoluted with published and, when necessary, experimentally determined quantum efficiency to guide the selection of the optimum scintillator-photocell pairing. 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.

Indium-Tin-Oxide (ITO) contacts have already been studied on mercuric iodide and seem to be the first choice [J. M. Markakis, "Mercuric Iodide Photodetector-Cesium Iodide Scintillator Gamma Ray Spectrometers," IEEE Transactions on Nuclear Science, Vol. 35, No. 1, 356, 1988], [J. Markakis, "High resolution scintillation spectroscopy with HgI_2 as the photodetector," Nucl. Instr. Meth. in Phys. Res., A263, 499, 1988].

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 will be appropriate. The materials will be chosen as close 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 the two optical materials to be coupled. A very effective way of estimating the efficiency of the optical coupling procedure is 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 ~61000 photons/MeV) and the energy required to produce an electron-hole pair for direct detection (for example, for HgI_2 this value is 4.2 eV.)

Gamma response will be measured with various radionuclides in the energy range of 100 keV to 1 MeV, and energy resolution, peak efficiencies, thermal stability, energy linearity, and long-term stability of the overall device will be determined for all scintillators of interest. The results will be evaluated against best results obtained by us or reported with PMTs and silicon photodiodes.

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