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Design and Preliminary Monte Carlo Calculations of an Active Compton Suppressed $LaBr_3(Ce)$ Detector System for TRU Assay in Remote-Handled Wastes

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Abstract

Recent studies indicate $LaBr_3(Ce)$ scintillation detectors have desirable attributes, such as room temperature operability, which may make them viable alternatives as primary detectors (PD) in a Compton suppression spectrometer (CSS) used for remote-handled transuranic (RH-TRU) waste assay. A CSS with a $LaBr_3(Ce)$ PD has been designed and its expected performance evaluated using Monte Carlo analysis. The unique design of this unit minimizes the amount of "dead" material between the PD and the secondary guard detector. The analysis results indicate that this detector will have a relatively high Compton-suppression capability, with greater suppression ability for large angle-scattered photons in the PD.

Keywords: Gamma-ray spectrometry; Compton suppression; Scintillation detectors; MCNP
PACS: 07.85.Nc; 29.40.Mc; 5.10.Ln

1. Introduction

RH-TRU waste is currently restricted from disposal in the Waste Isolation Plant (WIPP) due to an inability to characterize appropriately the radiological, radiographic, and Resource Conservation and Recovery Act (RCRA) properties of the waste, resulting in significant public safety and cost implications. The dominant RH-TRU waste forms in the Idaho National Laboratory inventory are

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derived from hot cell examinations of spent reactor fuel [1]. As much of the inability to characterize appropriately the properties of these RH-TRU wastes is attributed to the intense ^{137}Cs Compton background that obscures the photopeaks of fissile materials, the goal of this research project is to design and analyze an active, Compton-suppressed, room-temperature gamma-ray detector for RH-TRU assay.

It has been shown that the suppression of Compton background can be achieved by operating, in either coincidence or anti-coincidence mode, a primary detector (PD), such as a germanium detector, having high resolution, placed inside the annulus of a large annular secondary detector (SD), such as NaI(TI), having high efficiency [2]. Systems employing germanium PDs are often used but also have high atomic number material, such as Cu, between the PD and SD for cooling purposes, which absorbs much of the scattered gamma rays from the PD and thus limits the ability to suppress the Compton continuum [3]. Another disadvantage with germanium detectors, in addition to their cost, is that liquid nitrogen is required. Therefore, for this research project, a $LaBr_3$(Ce) scintillation detector is being used for the PD. $LaBr_3$(Ce) detectors have good light yield at 61 000 photons per MeV of absorbed gamma ray energy (ph/MeV), good timing properties with a decay time of 35 ns, and great resolution of approximately 3% FWHM at 662 keV [4]. Also, compared with germanium, $LaBr_3$(Ce) is less costly, does not require liquid nitrogen, and requires less photon-absorbing dead material between the PD and SD. Although a path to the photodector must be provided in the SD, for a relatively short scintillation PD placed in the center of a relatively long SD annulus, a nearly 4π solid angle of the SD with respect to gamma rays, scattered from the PD, can be achieved.

2. Methodology

2.1. Detector design

The detector has been modelled using MCNPX version 2.5.0 [5], where the cross section of the unique detector system is sketched in Fig. 1 The four PMTs for the SD, connected to the optical windows at the top of the detector, have been omitted. The ~25 mm diameter by 75 mm long $LaBr_3$(Ce) PD is inserted in the 25.4 mm diameter well of a 175 mm by 175 mm NaI(Tl) SD and is viewed by a 38 mm diameter PMT. The top of the PD will protrude from .175" to .184" above the NaI(TI). An important feature of this arrangement is the lack of any "can" between the primary and secondary detectors. These primary and secondary detectors are optically isolated by a thin layer (.003") of aluminized Kapton, but the hermetic seal and thus the aluminum can surrounds the outer boundary of the detector system envelope. The hermetic seal at the primary detector PMT is at the PMT wall. The NaI(TI) reflector material consists of .010" of Teflon. This arrangement virtually eliminates the "dead" material between the primary and secondary detectors, a feature that modeling indicates will substantially improve the Compton suppression capability of this device [7].

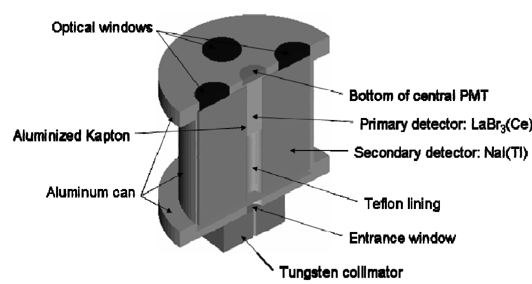

Fig. 1 MCNPX cross section of the $LaBr_3$(Ce) detector system, drawn using SABRINA [6].

2.2. Monte Carlo analysis

The expected detector performance has been modelled using the anticoincidence pulse-height tally option. The Gaussian broadening feature of MCNPX was also used to model the resolution of an available $LaBr_3$(Ce) detector, for which the FWHM was measured and recorded for photopeaks of various energies. The resolution at 662 keV was measured to be ~2.8 %, consistent with previous work [8]. A cutoff energy of 10 keV was simulated, the minimum amount of energy deposited in the SD required to reject a Compton event. Furthermore, to model the experimental apparatus that will be used for this CSS, a 4”×4”×2” tungsten block with a 5 mm diameter aperture collimator assembly was also included in the MCNPX detector system model, as shown in Fig. 1. A point source, 20 cm below the entrance of the collimator was implemented in the model. In order to reduce calculation time, the point source only emitted photons within the solid angle of the aperture of the collimator, as photons outside this range have a negligibly small probability of interacting with the detector.

3. Results

The figure of merit used to measure the level of suppression obtained with CSS is the suppression factor, defined as:

$$\text{Suppression Factor} = \frac{P(\Delta E)NS}{P(\Delta E)S} \quad (1)$$

Here, P(ΔE)NS is the probability of events in the energy range ΔE without using suppression, and P(ΔE)S is the probability of events in energy range ΔE using suppression.

3.1. ^{137}Cs suppression

The MCNPX results for the suppressed and unsuppressed ^{137}Cs spectrum are shown in Fig. 3. The 662 keV characteristic photopeak (1) is accompanied by another, smaller peak (2) on its left shoulder, visible in both suppressed and unsuppressed spectra. This peak is due to the escape of lanthanum X-rays from the PD after the absorption of the 662 keV gamma ray [9]. The peak (3) is the result of source photons interacting in the PD and scattering back toward the entrance aperture. The backscatter peak (4) at approximately 190 keV, results from gamma rays scattering off of the aluminum casing, PMT, and other materials outside the PD and SD prior to interacting in the PD.

Fig. 4 shows the suppression ratio as a function of energy collected in the PD for the ^{137}Cs spectra shown in Fig. 3. As shown in Fig. 4., the suppression factor is lower for lower energies, but then increases sharply until the Compton edge is reached. Photon-tracking results obtained with SABRINA using MCNPX output, which are not presented here, show that many of the photons that undergo small-angle scatters in the PD escape through the top of the detector system without interacting in the SD, explaining the large discrepancy in suppression factors seen in Fig. 4 with respect to energy.

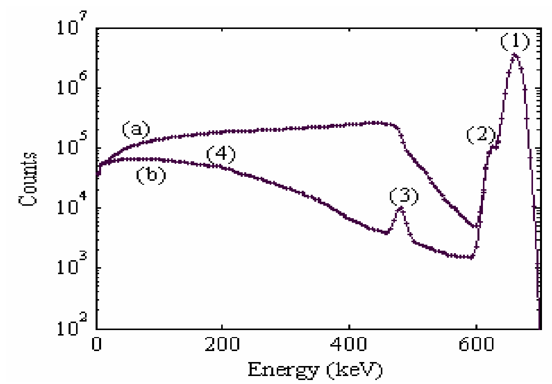

Fig. 3 Unsuppressed (a) and suppressed (b) ^{137}Cs spectra for the detector system.

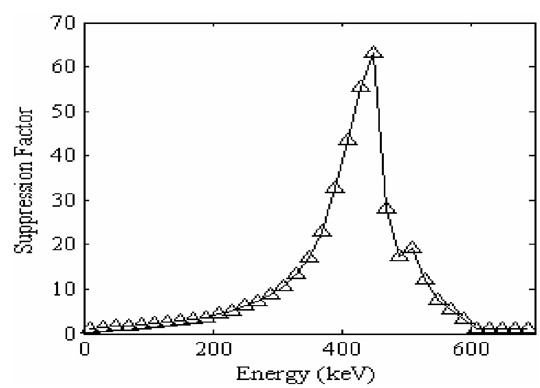

Fig. 4 Suppression factor as a function of energy collected in the PD for the ^{137}Cs spectra in Fig. 3.

3.2. ^{239}Pu lines

Of particular interest of this research is the amount of activity of ^{239}Pu relative to ^{137}Cs required in order to be able to identify the ^{239}Pu photopeaks in the pulse height spectrum. ^{239}Pu has characteristic gamma rays of 129.3 keV and 413.7 keV. The suppressed spectra calculated with MCNPX for activity ratios of 129 keV gamma rays to 662 keV gamma rays of 1:10^6 (1), 1:10^3 (2), and 1:10^2 (3) are included along with the suppressed spectrum for ^{137}Cs alone in Fig. 5, for the energy region of interest. Likewise, calculated, Compton-suppressed spectra for ratios of 413 keV gamma rays to 662 keV gamma rays of 1:10^6 (1), 1:10^4 (2), 1:10^3 (3) and 1:10^2 (4) are shown in Fig. 6.

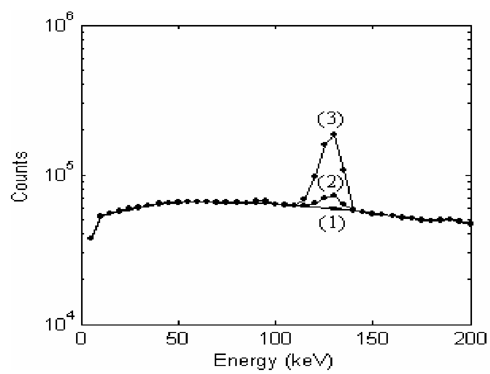

Fig. 5 Spectra for various ratios of 129 keV and 662 keV gamma rays, shown for energies up to 200 keV.

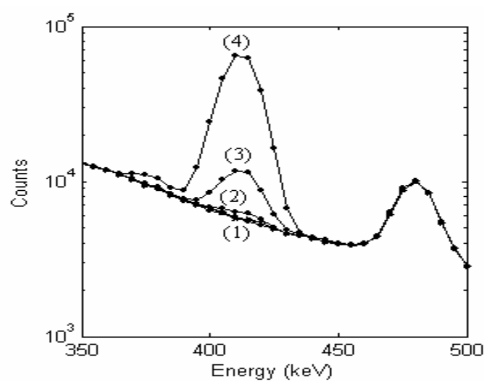

Fig. 6 Spectra for various ratios of 413 keV and 662keV gamma rays for energies between 350 keV and 500 keV.

4. Conclusion

The results indicate that excellent Compton-suppression can be achieved with this detector system with greater suppression ability for gamma rays which scatter at larger angles in the PD, and thus deposit less energy in the PD. These results are similar to Monte Carlo results obtained with other CSS designs having geometries similar to this one [10]. Calculations, which are not presented here, show that placing the PD near the center of the SD annulus will significantly improve the Compton-suppression ability of this device, particularly for lower energy regions in the spectrum. This should enhance the detection of photopeaks, particularly ones of lower energy, such as the ^{239}Pu, 129 keV gamma ray shown in Fig. 5.

Acknowledgments

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