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Improving the effectiveness of a low-energy Compton suppression system

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ABSTRACT

A novel method for collecting and processing coincidence data from a Compton Suppressed Low Energy Photon Spectrometer (LEPS) is presented, greatly simplifying the current setup and extending the suppression abilities of the system. Offline analysis is used, eliminating the need to discard coincidence data when vetoing coincident events with fast-timing electronics. Additional coincident events are identified that are usually missed, and which represent interactions in the active NaI(Tl) shield prior to an interaction in the LEPS detector. By suppressing these events, the Compton Suppression factor was improved by 144% for the 661.66 keV decay line in a ^{137}Cs source. The geometry used for this particular Compton suppression system is highly sensitive to these effects, however similar event profiles are expected in all coincidence systems.

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1. Introduction

Gamma (γ) spectroscopy allows the non-destructive identification of radionuclides in environmental samples, however the sensitivity of these systems is dependent on many factors. This includes the resolution and efficiency of the detector, and the amount of background radiation seen [1]. The Compton continuum (which arises due to the incomplete energy deposition of a Compton scattered γ decay in the crystal) also obscures lower energy decays, reducing the observed Peak to Count (P/C) ratio for these transitions [2]. Many radionuclides of interest fall into this category, and methods employed to improve the low-energy performance of γ-spectroscopy systems are discussed below.

Low-Energy HPGe (LEGe) crystals allow for greater relative efficiency in the low-energy region where the Compton continuum dominates the spectra. The crystals are typically quite small, reducing the contribution from higher energy decays. The electrical contacts on the crystal are also optimised to reduce the detector capacitance (and therefore the pre-amplifier noise), improving the low energy resolution [3]. These improvements, however, come at a cost; due to the size of the LEGe crystal the efficiency is typically lower than that of an equivalent coaxial or broad energy design, and many photons Compton scatter out of the crystal. To suppress these events, additional NaI(Tl) detectors are used to ‘capture’ the escaping photons. As the timescales of these atomic processes are infinitesimally smaller than the corresponding timescales for charge collection and pulse formation in the detector and associated electronics, such events are seen in coincidence between the LEGe and the NaI(Tl) crystals.

Events in coincidence can be discriminated using fast-timing electronics, which are typically employed [4] to set up a ‘delay window’. If an event is detected in the LEGe, and another event is seen in the NaI(Tl) detector (within the predefined time window), the original event in the LEGe is discarded. This limits the system, as the delay window must be characterised before any data collection, and cannot be modified during a run. All coincidence and temporal information is also lost.

The work presented in this report describes the use of a LEGe based Compton suppression system in conjunction with List-mode acquisition software [5] and a customised post-processor [6], to substantially improve the suppression factors gained in comparison to a ‘standard’ electronics based Compton veto system.

2. Materials and methods

2.1. Experimental setup

The LEGe detector (model GL0510) and associated electronics are supplied by Canberra UK (Harwell, Oxfordshire). The detector is optimised for low energy photons, and is set up to cover a range of 10–700 keV (above this value the efficiency is $<0.5\%$). The detector also has a carbon epoxy window to minimise the attenuation of low energy photons, which allows ~82% transmission at 10 keV [3]. The crystal is fairly small (an active diameter of 25.5 mm, and a thickness

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of 10.5 mm), minimising the contribution from higher energy decays. An ultra-low background cryostat (model 7915-30-ULB) is used, and a preamplifier (model I-TRP) processes the initial signal data.

The preamplifier output is sent to a LYNX^{TM} digital signal processing unit from Canberra, which controls all further amplification, pole-zero correction and digitisation of the pulse. Data is collected in 'list mode', which time-stamps each event in the detector and writes these to a text file [5].

The NaI(Tl) shield detectors are from Scionix (Utrecht, Netherlands), and comprise of a cylindrical annulus with a removable plug that is positioned above the primary detector. This is not the most effective geometry for a Compton suppression system, as there may be a large number of false coincidences due to γ radiation emitted in cascade, chance coincidences due to the activity of the source, and to a lesser extent, background radiation. Suppression will also be reduced when compared to higher energy decays, as dead layers in the setup (including crystal dead layers, detector casings, etc.) greatly reduce the detection efficiency for low energy photons. Note that while the LEGe has a thin entrance window at the top, Compton scattered photons will typically exit the detector through the Aluminium casing, and will therefore be attenuated before entering the NaI(Tl) veto detector (through another thin layer of Steel).

The cylinder has five Photo-multiplier Tubes (PMT's) for efficient charge collection, and the plug one. The outputs are combined from all of the PMT's, and passed to a preamplifier (model 2005). Again, the preamplifier output is sent to a LYNX^{TM} unit, where the data is collected in 'list-mode'. A synchronisation cable also runs between the two LYNX^{TM} units to allow synchronisation of the clocks used to record the events in each detector.

The LEGe and NaI(Tl) combination is placed within a 80 mm thick lead shield, with tin and copper liners to reduce fluorescence from lead and tin x-rays. This reduces the background to ~2 counts per second (cps). A simulated image of the setup (including the lead cave, but excluding some internal detail of the detectors due to graphics limitations) is shown below in Fig. 1.

2.2. Compton Suppression

Several methods are available for quantifying the levels of suppression achieved [2], however the main ones used in this document will be the Peak to Count ratio (P/C), Peak to Total ratio (P/T) and the Compton Suppression Factor (CSF).

- **Peak to Count (P/C) ratio** – This is defined as the ratio of the counts in the highest photopeak channel to the counts in a typical channel of the Compton continuum. This is usually taken to be a flat, representative portion just to the left of the Compton edge.
- **Peak to Total (P/T) ratio** – The peak-to-total ratio (P/T) is expressed as the ratio of the counts in the full-energy peak to the total counts in the spectrum.
- **Compton Suppression Factor (CSF)** – This is the ratio of P/C for unsuppressed and suppressed spectra, which also takes into account the reduction in photopeak efficiency as well as the suppression of the continuum;

$$CSF = (P/C_{suppressed})/(P/C_{unsuppressed}) \quad (1)$$

2.3. Measurement and analysis

Calibration sources were chosen to cover the 37–662 keV energy range to fully characterise the energy response and efficiency of the LEGe crystal. Several single γ emitters were used, as well as a NIST (National Institute of Standards and Technology) traceable complex γ source. The isotopes that comprised these were ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{133}Ba (302.85 keV, 356.01 keV), ^{113}Sn (391.68 keV), and ^{137}Cs (661.67 keV). Apparent peak efficiencies and isotopic abundances were calculated as in Ref. [7].

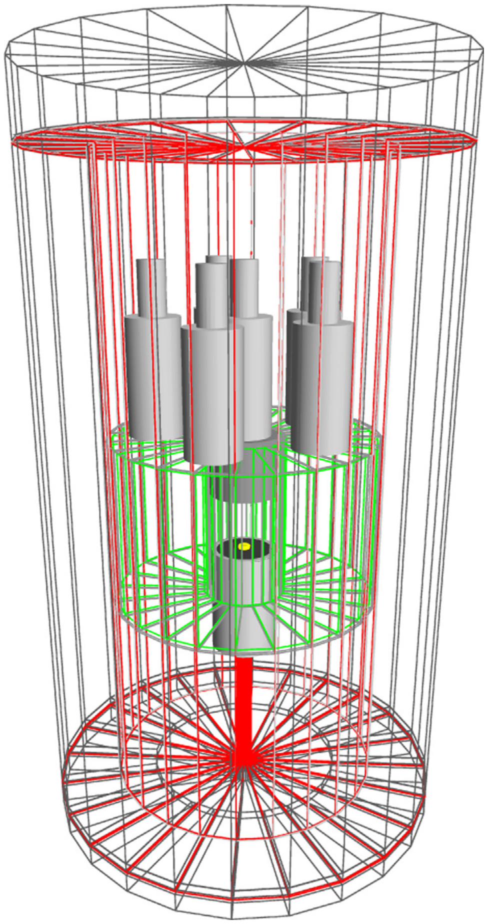

Fig. 1. A simulated image of the experimental setup. The primary detector is shown in the centre, with an example source (the small yellow cylinder) above. The cylindrical NaI(Tl) crystal is shown in green (with a thin grey aluminium casing), and the PMT's are shown above the crystal as light grey cylinders. The NaI(Tl) plug is shown in the centre of the NaI(Tl) annulus as a dark grey cylinder. The surrounding lead shield and liner is also shown, with grey corresponding to lead, silver to tin, and red to copper. For a full colour image please see the online version of this paper. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

Analysis was completed using the post-processor detailed in Ref. [6] to sort the data, and ROOT [8] for matrix manipulation and peak searching/fitting. Coincidences were identified by searching for all events in the NaI(Tl) detector with a time delay (t) between $-10\mu s$ and $+10\mu s$ (with $t=0$ defined as the interaction time in the LEGe). This is achieved by reading the LEGe output file, and comparing the timestamp of each event with those in the NaI (Tl) output file. To speed up this process, the data is presorted by timestamp, and the software 'remembers' how far into the NaI(Tl) file it has read. This allows a full comparison to take place while only ever comparing a small subset of the data files. These coincidences were then recorded into a 3D matrix with the energy deposited in the LEGe, energy deposited in the NaI(Tl) detector, and the time delay on each axis ($E_{\gamma 1}$, $E_{\gamma 2}$, t). This allows a delay spectrum to be created, with peaks identifying characteristic delays where there are a large number of coincident events. As they are in a matrix, time and energy gates can also be set to extract information from the dataset.

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