1. Introduction

A high resolution γ-γ coincidence system has been developed at GBL15 for fast quantification of both cascade and single gamma emissions from CTBT relevant radionuclides. This consists of two BEGe-6530 crystals and an active cosmic veto. CAEN DT724 and Canberra LYNX digitisers collect all data in list-mode, allowing offline sorting and processing with ROOT based analysis software. Energy and time-gated coincidence, sum-coincidence and anti-coincidence acquisitions are all extracted from a single dataset alongside traditional ‘singles’ data. Substantial MDA improvements have been achieved when compared to standard CTBT detectors, and are presented here alongside a number of characterisations that are required for coincidence based measurements.

2. The Gamma-Gamma System

The BEGe-6530 detectors are situated in a face-to-face configuration, and enclosed within a 150 mm Pb cave (the inner 50 mm of Pb was specifically selected for low 208Tl/Pb content). The detector signals are passed to separate channels on a DT724D Desktop Digitiser (CAEN S.p.A., Italy), which can accommodate up to 4 inputs. The signals are also processed by two LYNX™ units from Canberra to allow a direct comparison between the electronics. All data is collected in list-mode, and schematics and photographs of the system can be seen in figures 1 & 2.

3. List-mode acquisition

Each energy deposition is time-stamped and recorded, allowing events to be reconstructed during post-processing. The amount of data is dramatically increased when compared to typical acquisition modes (GB’s instead of KB’s), however allows far more information to be extracted from the data. The software reconstructs spectra in 3 modes:

- **Singles mode**: Histograms are built and carefully gain-matched to create a single spectrum with double the effective efficiency of a single-detector
- **Coincidence mode**: Coincident events between the detectors are extracted, and the event signatures corrected for a variety of effects that can disrupt the coincidence signal (see figure 3). This is particularly useful for nuclides that decay via a cascade of γ emissions
- **Anti-coincidence mode**: Spectra are created with the coincident events removed, suppressing nuclides that decay via a γ cascade and backscattered/Compton scattered photons that interact in both detectors. This increases sensitivity for nuclides that decay via a single emission

All of these modes dramatically increase the sensitivity for a variety of nuclides, and are executed simultaneously when processing the data. Data processing has also been thoroughly optimised, requiring < 4% of the data acquisition time for a system acquiring 25k counts per second.

4. Quantifying Coincidence Signatures

Quantification of a radionuclide requires the counting of a peak area, and the calculation of the peak's shape, for the y detection efficiency, γ emission probability, and any cascade emissions that may augment/destroy the signal.

Coincidence signatures are far more complex than single emissions, and no commercially available software could calculate the required factors. A code was therefore developed that can calculate these, allowing an accurate estimate of nuclide activity. This is known as the ‘Randomised Iterative Monte-Carlo Model for ENSDF Records’ (RIMMER™), which utilises ENSDF (Evaluated Nuclear Structure Data Files) as an input, and can quickly build and inspect a coincidence library. Some features include:

- Import and translation of ENSDF records
- Monte-Carlo simulations of nuclide decay, producing all possible decay pathways through a nuclide
- Import, fitting, and plotting of peak and total efficiency characterisations produced using GEANT4-Canberra LabSOCS software
- Calculation of branching ratios for single and coincidence signatures
- Calculation of cascade summing factors for single and coincidence signatures
- Folding of efficiencies into branching ratios and summing factors to calculate efficiency and cascade summing corrected single emission/coincidence signature probabilities
- Inclusion of Electron Capture and Internal Conversion X-ray summing factors
- Extendable to any number of detectors

5. Results

The γ-γ system has been extensively tested in both singles and coincidence modes using multiple electronics configurations. The software for calculating efficiency and cascade summing detection probabilities, RIMMER, has also been validated via experimental testing. Other notable results include:

- The count time to achieve the 24 mBq 137Ba MA CTBO requirement has been reduced from 6-7 days to less than 3 in singles mode
- The previous iteration of shielding (100 mm Pb) has been improved, and once completed, should reduce the count time required to ~1 day
- In coincidence mode, the MDA has been reduced by a factor of 34, and work is ongoing to detail the MDA improvements for a wide range of radionuclides

References