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COINCIDENCE GAMMA-RAY SPECTROMETRY

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INTRODUCTION

Gamma-ray spectrometry with high-purity germanium (HPGe) detectors is often the technique of choice in an environmental radioactivity laboratory. It is non-destructive, special radio-chemical sample preparation is not needed and many radionuclides can be determined in single measurement so it is used for fast and routine determination of radionuclides. When measuring environmental samples associated activities are usually low so an important parameter that describes the performance of the spectrometer for a nuclide of interest is the minimum detectable activity (MDA), the lowest activity which ensures a specified probability of being detectable by the measurement procedure (following the ISO11929 standard). To lower the detection limits and MDAs, spectrometers with higher efficiencies are used, larger sample sizes are counted for longer time and spectrometer background is reduced. There are many methods for background reduction and they can be roughly divided into the passive and active ones. Passive methods include placing detectors in lead shields made of special radiopure lead to reduce the outside background component. To reduce Pb X-rays produced in the shield, inner graded lining of Cd/Sn and Cu is introduced. Nitrogen boiling-off from Dewar flask is used for flushing inside the shield and making overpressure thus reducing the inflow of airborne radon from outside the shield. Special radiopure materials are used in low-level detectors production and detectors are made with remote preamplifiers to minimize the presence of radio-impurities within the shield. Finally, for the ultimate low-level measurements, detectors are placed deep underground to remove the cosmic-ray induced background component [1]. Active background reduction includes special veto detectors surrounding the shield operated in anticoincidence with the HPGe detector for cosmic background reduction [2,3], pulse-shape analysis (PSA) methods [4,5] and additional detectors placed inside the shield around the main detector for reduction of the incompletely absorbed photons (Compton) background component [6–8] and the use of multiple HPGe detectors operated in coincidence. When coincidence gamma-spectrometry is used, coincident signals coming from cascade emitting nuclides can be extracted thus significantly reducing the background as random coincidences are very unlikely. This is especially evident when there is high activity of other nuclides in the sample contributing to high Compton background. When the nuclide of interest is a single-gamma emitter, coincidence signal can be subtracted from the total to lower the background.

Recent developments of fast and compact digital acquisition systems, with equivalent or better energy resolution when compared to standard analog electronics, led to growing number of applications in which multiple detectors are used. Majority of the applications are within the Comprehensive-Nuclear-Test Ban Treaty (CTBTO) programme where rapid and sensitive determination is needed [9,10] but there is also justification for the use in the standard environmental radioactivity measurement laboratories [11,12].

In this work, we present a new method for increasing the efficiency of two detector coincidence system by summing the coincident signal to reconstruct the full energy of a photon that is Compton scattered between the two detectors.

MATERIAL AND METHODS

The Gamma Laboratory at the Radioecology Section at Center for Nuclear Technologies (DTU Nutech) is a surface laboratory operating around 20 HPGe detectors. Two of those are part of a coincidence gamma system NUCLeGeS [11]. The detectors are placed in 20 cm thick lead shied with 5 mm Sn and 3 mm Cu inner lining. Both detectors are in remote preamplifier configurations. The lower detector has an integral U-type cryostat, while the upper has integral vertical cryostat with the detector facing down. This configuration enables easy movement of the upper detector thus allowing various sample heights to fit in between the detectors. The detectors are low-energy (Canberra GL3825R), with 0.5 mm carbon window. A two channel digital multichannel analyser CAEN N6781A is used for acquisition. The preamplifier signal from each of the detectors is fed into the separate input of the digital multichannel analyser, data is recorded in a list mode file with 10 ns time resolution (100 MS/s sampling rate) and each event is saved with its energy and trigger timestamp. This way all the acquired information is saved and data is analysed in post-processing enabling optimal setting of coincidence and energy gating parameters. From only one measurement multiple spectra can be produced with the parameter settings matching the nuclide of interest. Post-processing analysis is based on the software developed in MATLAB that does the coincidence identification and optional energy gating, calculates all the necessary spectra parameters like acquisition start time, live and dead time, and prepares in GENIE2000.CAM format ready for the analysis.

RESULTS

To examine the possibility of a full energy reconstruction for photons that are Compton scattered between the detectors, list mode measurements with ^{60}Co and ^{137}Cs point sources are done. Point sources were placed between the detectors and the detectors were set around 4 cm apart. A coincidence map is generated in post-processing, Figure 1a, showing all the events detected within the time window of 1.8 μs. Gamma-gamma coincidences contribute to vertical and horizontal line in the map, while coincidences originating from single photon depositing its energy in both detectors are in diagonal lines. In Figure 1b, two possible gamma traces for a photon interacting with both of the detectors are shown. Such a photon would be represented on a diagonal line in the 2D coincidence spectrum. The sum of X and Y axis energies from the events in diagonal lines gives the total gamma energy.

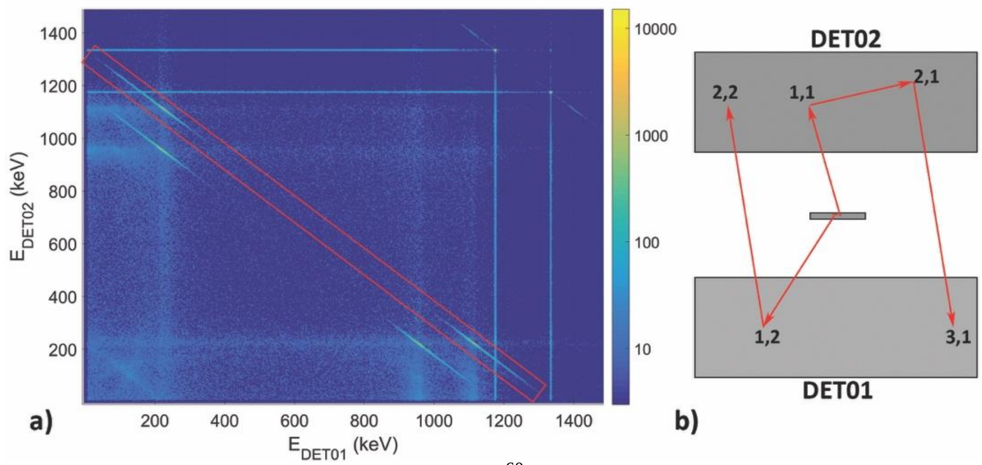

Figure 1. a) 2D coincidence spectrum of ^{60}Co point source. Coincidences that are coming from a single 1332.5 keV gamma line depositing its energy in both detectors are shown in red square. b) Example of two gamma ray traces leading to diagonal lines in the left.

Total gamma spectrum from both detectors and reconstructed spectrum obtained by summing the energies of coincident events are shown in Figure 2. When the peak areas from both spectra are added, an efficiency increase of around 9 % for each of the lines is achieved. The same was tested with ^{137}Cs point source. The efficiency increase for 661.7 keV line is around 9.5 %. A ^{226}Ra point source was used to test the low energy part where only 3.3 % gain is observed at 186.2 keV. The detectors are low-energy types, with thin crystals and not intended for high energy applications where Compton scattering is more probable. More pronounced effects can be expected at higher energies and with bigger detectors. The method works for both single gamma and cascade-emitting nuclides, but with cascade-emitting nuclides special care has to be taken so that the coincidence sum of two photons in cascade is not attributed to the line coming from direct transition to the ground state (as for example ^{214}Bi 1764.5 keV line).

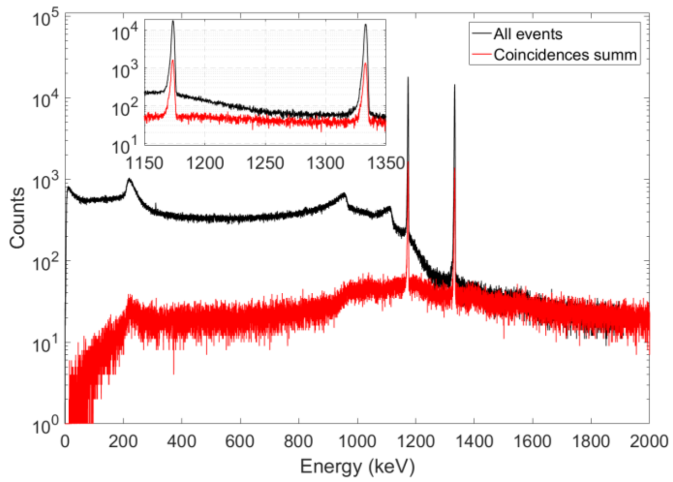

Figure 2. ^{60}Co spectrum of total events from both detectors (black) and spectrum generated by adding energies of coincident signals to reconstruct the full photon energy.

CONCLUSION

Up to 10 % increase in efficiency is achieved by taking the sum of coincident events from a low-energy dual HPGe spectrometer system. The effect of this on MDA is probably slightly lower because there is also an increase in background around the peaks, but if developed further this could be a nice addition to the coincidence analysis toolbox.

REFERENCES

[1] Hult M. Low-level gamma-ray spectrometry using Ge-detectors, Metrologia 2007;44:S87–S94.

[2] Theodorsson P, Heusser G. External guard counters for low-level counting systems, Nucl. Inst. Methods Phys. Res. B. 1991;53:97–100.

[3] Mrđa D, Bikit I, Zikić-Todorović N, Forkapić S, Slivka J, Vesković M. First tests of the active shield for a gamma ray spectrometer, Radiat. Meas. 2007;42:1361–1367.

[4] González De Orduña R, Hult M, Andreotti E, Budjáš D, Schönert S, Misiaszek M. Pulse shape analysis to reduce the background of BEGe detectors, J. Radioanal. Nucl. Chem. 2010;286:477–482.

[5] Mi YH, Ma H, Zeng Z, Cheng JP, Li JL, Zhang H. Compton suppression in BEGe detectors by digital pulse shape analysis, Appl. Radiat. Isot. 2017;121:96–100.

[6] Murray AS, Aitken MJ. Analysis of Low-level Natural Radioactivity in Small Mineral Samples for use in Thermoluminescence Dating, using High-resolution Gamma Spectrometry, Appl. Radiat. Isot. 1988;39:145–158.

[7] Britton R. Compton suppression systems for environmental radiological analysis, J. Radioanal. Nucl. Chem. 2012;292:33–39.

[8] Marković M, Roos P, Nielsen SP. Low-level gamma-ray spectrometry for the determination of 210Pb, J. Radioanal. Nucl. Chem. 2017;311:1473–1478.

[9] Britton R, Davies AV, Burnett JL, Jackson MJ. A high-efficiency HPGe coincidence system for environmental analysis, J. Environ. Radioact. 2015;146:1–5.

[10] Cagniant A, Delaune O, Réglat M, Douysset G, Gross P, Le Petit G. Ground surface ultralow background spectrometer: Active shielding improvements and coincidence measurements for the Gamma3 spectrometer, Appl. Radiat. Isot. 2017;doi:10.1016/j.apradiso.2017.01.044.

[11] Marković N, Roos P, Nielsen SP. Digital gamma-gamma coincidence HPGe system for environmental analysis, Appl. Radiat. Isot. 2017; doi:10.1016/j.apradiso.2016.12.017.

[12] Paradis H, Ott AdeV, Cagant X, Piquemal F, Gurriaran R. Leda: a gamma-gamma coincidence spectrometer for the measurement of environment samples, Appl. Radiat. Isot. 2017;doi:10.1016/j.apradiso.2016.12.049.