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The active area shadow-shielding effect on detection efficiency of collimated broad energy germanium detectors

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ABSTRACT

The ISOCS calibration, when utilized for a BEGe detector with a small angled collimator, produces inaccuracies of about 19% for gamma rays with energies greater than 0.4 MeV. Such a discrepancy is caused by the collimator algorithms currently utilized in the ISOCS software which, originally developed for HPGe detectors, are less suited for BEGe detectors. ISOCS's errors are due to the different crystal configurations of broad energy detectors compared to coaxial detectors, i.e. to a different importance of the active area portion obscured by the collimator. This work proposes some solutions for the problem, either using the ISOCS software or implementing a stochastic calibration procedure. In particular, the present work considers a virtual collimator that, maintaining its angular aperture, is capable of continuously enlarging its bottom collimator's aperture cone radius, to expose growing active area portions. In such a way two goals may be achieved: the mathematical characterization of ISOCS' errors and the minimization of observed errors by means of the stochastic calibration procedure.

Different reference set-ups are considered in order to test source geometry effects, source materials and different detectors. In particular, a 220 L drum, a 2 m^3 box filled with uniformly contaminated cellulose or PVC, and small BE3825 and large BE5030 Canberra detectors are considered. Detection efficiencies calculated by ISOCS software are compared against a completely stochastic MCNPX simulation procedure, that is unaffected by any algorithmic correction. MCNPX simulations demonstrate, when widening collimators' cone but maintaining the angular aperture unchanged, that ISOCS and MCNPX difference percentage between efficiency data points reduces, depending on energy, by more than 50%. This happens as far as the shadow-shielded portion of detector's active area reduces.

1. Introduction

As is well known, the potentialities of in situ gamma-ray spectrometry have been strongly enhanced by the introduction of BEGe detectors, which join together the spectral advantages of low energy and coaxial detectors to extend assay energy range from 3 keV to 3 MeV in the same measurement. Accurate descriptions of these kinds of detectors are given by Luis et al. [1], Mueller et al. [2], Budjas et al. [3], and Barrientos et al. [4]. For in situ applications the natural complements of BEGe detectors are the software tools based on mathematical models aimed at simulating a wide variety of sample shapes, which eliminate the need of radionuclide standards for detector's efficiency calibration, such as the well known ISOCS® software [5].

ISOCS® systems (ISOCS software and Canberra's detectors) are probably the most widely used detectors all over the world for their unique characteristics; an average of 150–200 detectors' characterizations is performed yearly which means that 150–200 ISOCS detectors are used in several fields like waste characterization, clearance measurements, decommissioning activities, land field remediation and radionuclide laboratories activities covering the nuclear research field. Considering the year of its invention (1998–1999), approximately 1500/2000 ISOCS detectors have been used in all the previous fields.

The advantage of using ISOCS efficiency calibration software can be translated to allowing the elimination of traditional calibration sources, providing significant savings in cost and measurement time. In addition the flexibility of this tool allows excellent replication of the measured sample geometry, resulting in improved accuracy over industrial calibration source standards.

The traditional efficiency calibration of a high purity germanium detector needs an accurate selection of the sources (energy range, half-life, cascade effects and activity) and the measurement geometry (beakers and vials in case of laboratory measurements and 3D models in case of in situ measurements) requiring a lot of money. On the contrary, using the ISOCS software, the cost of source-based calibration (purchase of sources, replacement, disposal, licensing, calibration program and sample preparation)

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can be completely avoided. Detection efficiency responses, based on the physical parameters of the experimental set-up, can be calculated using mathematical models to accurately compute the transport of gamma-rays through different media and geometries. Further, with software modeling it is possible to rapidly produce geometries that represent many real shapes for which source standards may not be readily available. In particular, as described by Venkataraman et al. [6,7] the ISOCS calibration method is based on a detailed Monte Carlo radiation transport model of a specific germanium detector created using the nominal dimensions provided by the production facility. The detector model is validated by comparing Monte Carlo detection efficiencies to measured efficiencies for several source geometries and ranges of energies. These two efficiency data sets are then meshed together into a single characterization file, which contains a series of equations defining the detector response that are then implemented in the ISOCS software.

Recently, authors have pointed out [8] that with a BEGe detector having a small angled collimator, the ISOCS calibration produces inaccuracies of about 19% for gamma rays with energies greater than 0.4 MeV. Authors have suggested that such a discrepancy may be caused by the collimator algorithms [9] currently utilized in the ISOCS software which, originally developed for HPGe detectors, seem to be less suited for BEGe detectors. Authors advanced the hypothesis that ISOCS' errors might be due to the different crystal configurations of broad energy detectors compared to coaxial detectors, i.e. to a different importance of the active area portion obscured by the collimator. To stress such a hypothesis, the present work considers a virtual collimator that, maintaining its angular aperture, is capable of continuously enlarging its bottom collimator's aperture cone radius, to expose growing active area portions. Such a virtual collimator is part of a reference geometry that has been modeled by means of both ISOCS Geometry Composer [10] and the completely stochastic MCNPX™ [11] simulation procedures that authors have described and validated against experimental data in Ref. [8]. In the present work different reference set-ups were considered in order to test source geometry effects, source materials and different detectors. In particular, a 220 L drum, a 2 m^3 box filled with uniformly contaminated cellulose or PVC, and small BE3825 and large BE5030 Canberra detectors [12] were considered. The detectors' simulation methodology by MCNPX code is the same as that considered in Ref. [8].

The tests carried out have allowed quantifying the mathematical trend of ISOCS' errors and proposing some solutions of the problem, either using the ISOCS software or implementing the stochastic calibration procedure; further, an example of correction factor for ISOCS' errors is given.

2. Simulation procedure

The outstanding feature of all the simulations carried out for this work consisted in considering a virtual collimator capable of assuming different geometries to change the shadow-shielding degree on detector's active area; i.e. a conical collimator that starting from its real dimensions and maintaining its angle of view is able to move its cone vertex position away from the detector's window, to consider different values of the radius of its bottom aperture, as depicted in Fig. 1 for the case of BE3825 detector; note that the largest R value is able to expose the entire active area (89 mm diameter).

In order to account for eventual perturbing effects, sources of different geometries and materials have been considered, as well as different detectors' dimensions. Henceforth different measurement set-ups have been evaluated, and each one has been reproduced by both MCNPX and ISOCS' Geometry Composer software, to obtain couples of detection efficiency values for comparison. For each test the source term given in Table 1 is considered. It is worth remarking that ISOCS' Geometry Composer gives values that are subjected to the deterministic correction operated by the ISOCS' collimator algorithms [5,6], while MCNPX gives purely stochastic values.

All MCNPX simulations were completely analog; no variance reduction technique has ever been used. Number of histories ranged from 400×10^6 to 2×10^9, depending on the simulated radionuclide's energy: low energy gamma rays simulations required higher number of histories to maintain a constant relative error in the whole energy range. Simulations' relative errors were always far below 4%.

3. Simulation tests

Considering the source term of Table 1 homogeneously dispersed amid the matrix material, the following simulation tests have been carried out:

- 3825 detector
    - 220 L drum filled with cellulose;
    - 220 L drum filled with PVC.
- 5030 detector
    - 220 L drum filled with PVC;
    - 2 m^3 box filled with PVC.

Table 1
220 L drum source term.

Radionuclide	Energy (MeV)	Yield
^{210}Pb	0.04650	0.04050
^{241}Am	0.05954	0.35780
^{109}Cd	0.08803	0.03626
^{57}Co	0.12206	0.85510
^{139}Ce	0.16585	0.79900
^{113}Sn	0.39169	0.64940
^{85}Sr	0.51400	0.98500
^{137}Cs	0.66165	0.84990
^{54}Mn	0.83490	0.99975
^{88}Y	0.89802	0.93900
^{65}Zn	1.11560	0.50600
^{60}Co	1.17322	0.99850
^{60}Co	1.33249	0.99983
^{88}Y	1.83610	0.99380

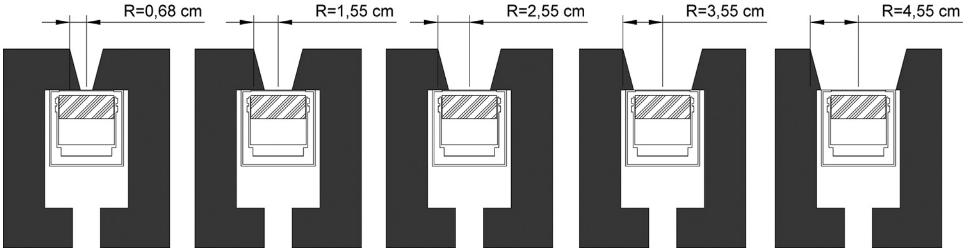

Fig. 1. The virtual collimator capable of assuming different values of the bottom collimator's aperture cone radius, to expose growing portions of the detector's active area. Numerical values are referred to a BE3825 detector