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Close-geometry efficiency calibration of p-type HPGe detectors with a Cs-134 point source

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Abstract

When close-geometry detector calibration is required in gamma-ray spectrometry, single-line emitters are usually used in order to avoid true coincidence summing effects. We managed to overcome this limitation by developing a method for the determination of the efficiency of p-type HPGe detectors in close-geometry with a calibrated Cs-134 point source. No separate determination of coincidence summing correction factors is required and a single measurement furnishes the full-energy-peak efficiencies in the 475–1365 keV energy range.

Keywords: Gamma-ray spectrometry; Detector calibration; True coincidence summing; Cs-134; Close geometry

1. Introduction

Point-source efficiency measurements and the construction of the corresponding calibration curve are usually carried out in gamma-ray spectrometry with the purpose of either subsequent measurement of point sources of unknown activity in the same geometry or in order to facilitate the computation of extended-source efficiency, usually in connection with the efficiency transfer method, initially proposed by Moens et al. (1981). Carrying out such measurements in close geometry has the advantage of a greater solid angle being subtended by the detector, as viewed from the position of the source, and consequently larger total and full-energy-peak efficiencies and shorter measurement times needed to achieve a certain statistical accuracy of the results. The relative uncertainty of the result of the efficiency transfer method is generally judged to be between 5% to 10% (Lépy et al., 2000) and it is therefore sensible to try keeping the uncertainty of the relevant point-source measurements at a couple of percent. In the case of subsequent application of the efficiency transfer method, close geometry calibration also resembles the actual placement of extended samples, for which the calculations are intended, more closely than does placing a calibration source at a greater distance from the detector.

The drawback of this approach, however, is the problem of true coincidence summing, which is non-significant if measurements are taken at large distances from the detector. True coincidence summing is usually thought to preclude the use of sources which emit gamma-rays in a cascade for the determination of the efficiency curve. Consequently, the construction of the calibration curve is carried out with single-energy radio-nuclides, as described by Debertin and Helmer (1988). Such radio-nuclides are, however, limited in number, and particularly in certain energy ranges. It would be advantageous to have the option of obtaining the full-energy-peak and total efficiencies from measurements with multi-energy sources.

The possibility of measuring the full-energy-peak efficiency curve in close-geometry conditions using a single radio-nuclide (Eu-152) with a complex decay scheme was first demonstrated by Andreev et al. (1972) and Andreev et al. (1973). The same approach was independently indicated by de Bruin and Korthoven (1974) and Semkow et al. (1990) developed a method similar to that of Andreev, but

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used the matrix formulation of the true coincidence summing mechanism. In all these studies the total efficiency curve had to be measured separately. This limitation was overcome by Blaauw (1993) and by Blaauw et al. (1997), who used a parameterised description of the energy dependence of the full-energy-peak efficiency curve and the peak-to-total ratio to reduce the number of the unknowns that the system of equation describing the count rates in the measured peaks has to be solved for. Their method is applicable to a calibrated or even a non-calibrated source, the activity of which is determined simultaneously with the process of obtaining the two efficiency curves.

Our method concentrates on achieving the determination of full-energy-peak efficiencies with a calibrated point source of Cs-134, since such sources are readily available in gamma-ray laboratories. The full-energy-peak efficiencies are determined individually at all the energies of the major gamma-ray lines of Cs-134, while the total-to-peak curve is modelled as a single-parameter function of the energy. The novelty of the method lies in the use of one additional measured quantity, the total count rate in the spectrum. This makes it possible to iteratively solve the system of equations which now has the same number of the unknowns (the full-energy-peak efficiencies and the total-to-peak curve parameter) and the measured quantities (the count rates in the peak and the total count rate), without making any use of pure sum peaks, which often suffer from a relatively low number of counts.

2. Method

Our determination of the full-energy-peak efficiencies is built around an iteration procedure that starts with the calculation of these efficiencies directly from the measured peak areas, without any correction for the coincidence summing effects. Given a certain parameterisation of the total-to-peak energy dependence, total efficiencies are then calculated and from these the coincidence summing correction factors can be obtained. With these factors the full-energy-peak efficiencies are multiplied in order to take the summing effects into account and a linear function is fitted through them in the log–log scale to smooth the results. For the calculation of the coincidence summing correction factors we use the matrix formalism of Semkow, but any other equivalent approach will in fact do, such as the recursive formulas of Andreev or nuclide (Cs-134) specific expressions. The procedure is then repeated iteratively, with the total count rate in the spectrum also being calculated at each step. The convergence of the total count rate to a constant value serves as the stopping criterion for the iteration.

In the above description of the iteration procedure we assumed that the energy dependence of the total-to-peak curve was fixed. In reality, this dependence needs to be determined and to do so we build a second iteration loop around the first one. The second loop serves for optimizing the parameter describing the total-to-peak ratio energy dependence in order to achieve an optimal match between the measured and calculated total count rates in the spectrum. The final result of the outer iteration loop is thus the optimal total-to-peak curve and along with it we get the full-energy-peak efficiencies from the inner loop.

The parameterisation of the energy dependence of the total-to-peak ratio used in the inner loop is based on the expression put forward by Moens et al. (1981):

$$\varepsilon/\eta(E) = (\tau(E) + K(E)\sigma(E))/\mu(E). \tag{1}$$

Here, ε is the full-energy-peak efficiency, η the total efficiency, τ, σ and μ are the photo-effect, Compton and total absorption coefficient in germanium and K is the proportion of Compton-scattered gamma-rays in the detector crystal that eventually end up depositing all of their energy inside it. This proportion can thus be treated as the full-energy-peak efficiency at the average energy E' that the gamma-rays have after scattering:

$$K = \varepsilon(E') = (\varepsilon/\eta)(E')\eta(E'). \tag{2}$$

An analytical expression for E', stemming from the Klein–Nishina formula, can be found in Leo (1987). For the total efficiency $\eta(E')$ we use a simple one-dimensional transport model and we put

$$\eta(E') = 1 - \exp(-\mu(E)l). \tag{3}$$

Here, l is the free parameter the optimal value of which is determined in the outer loop. To calculate $(\varepsilon/\eta)(E')$ we can again use Eq. (1) in a recursive fashion, with the stopping condition asserting that for low energies the total-to-peak ratio approaches unity:

$$(\varepsilon/\eta)(E) = 1, \quad E < 10\,\text{keV}. \tag{4}$$

3. Measurements

A Cs-134 point source with an activity of (723 ± 10) Bq was measured for 70908 s (live time), centred directly on the detector housing of a 25% p-type HPGe detector with the resolution of 1.9 keV at the gamma-ray energy of 1332 keV. The resulting total count rate in the spectrum was $291.2\,\text{s}^{-1}$, with the background count being $1.6\,\text{s}^{-1}$. The dead time of the measurement amounted to 1.5% of the real time and the peak areas of the Cs-134 gamma-rays used in the calculation of the efficiencies are listed in Table 1, along with their relative uncertainties, as reported by the GammaVision$^{\text{TM}}$ (1988) spectrum analysis software. The net peak area uncertainty is the uncertainty in the gross area and the uncertainty of the background added in quadrature. The background area uncertainty takes into account the uncertainty in the number of channels used to obtain the end-points of the background and the ratio of the number of channels used for peak and background area