Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 580 (2007) 238–241
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Correction factors to account for minor sample height variations in gamma-ray spectrometry

P. Jodłowski*

Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland

Available online 16 May 2007

Abstract

It often happens in gamma-ray spectrometry measurements that there is less sample material than required for the given measuring geometry. One approach to this problem is to stick to the original geometry, though a correction factor is to be introduced to account for the difference in the height of the sample material. This correction factor C_h is expressed as the ratio of spectrometer efficiency for the nominal sample height $\varepsilon(h_0)$ to that obtained for the actual height $\varepsilon(h)$.

The author determined the correction factor C_h for several radiation energies E, 81.0, 356.0, 661.7 and 1173.2 keV. Two measurement geometries were considered: a Marinelli beaker 710 cm^3 in volume, and a cylindrical sample 31.5 mm in height. The correction factors were obtained experimentally and by Monte Carlo simulation method for h falling within the range $h_0 \pm 8$ mm. C_h values obtained by these two methods are consistent. For $E \geqslant 356$ keV, C_h value almost does not depend on energy. C_h value varies linearly with dh. For Marinelli beaker for $E \geqslant 356$ keV, the correction is 0.9% (1.0% for $E = 81$ keV) for each millimeter of sample height change; for a cylindrical geometry the correction is 1.5% (1.7%). Monte Carlo method was further used to compute C_h values for several other cylindrical geometries. The lower the nominal height of the cylindrical samples, the more sensitive the method to sample height variations. The knowledge of the value C_h enables us to estimate the uncertainty of the measurements, associated with the sample height uncertainty.

PACS: 07.85.Fv; 29.30.Kv; 02.70.Lq

Keywords: Gamma-ray; Spectrometry; HPGe; Sample height; Correction factor; Monte Carlo

1. Introduction

It often happens in gamma-ray spectrometry measurements that there is less sample material than required for the given geometry. A simple change in the sample geometry, e.g. whereby a cylindrical sample 30 mm in height is substituted by a cylindrical sample 10 mm in height, is not a good solution as it causes the measurement time to be prolonged and the detection limit to be reduced. Another approach to this problem is to stick to the original geometry, though a correction factor is to be introduced to account for the difference in the height of the sample material.

The correction factor C_h to account for minor sample height variation is given in the formula governing the activity of a nuclide A in a sample [1]:

$$A = \frac{N(E)}{T\varepsilon(E)p(E)} C_s C_c C_h \cdots \quad (1)$$

where E is the energy of photons emitted by the nuclide, N the number of net counts in a photopeak corresponding to energy E, T the measurement time, $\varepsilon(E)$ the gamma-ray spectrometer efficiency for energy E, $p(E)$ the gamma-ray emission probability, C_s, C_c the corrections factor to account for self-absorption in the sample and for coincidence summing, respectively.

The correction factor C_h is expressed as the ratio of spectrometer efficiency $\varepsilon(h_0)$ for the nominal sample height to the one obtained for the actual sample height $\varepsilon(h)$. It is

*Tel.: +48 12 617 29 72; fax: +48 12 634 00 10.
E-mail address: jodlowski@novell.ftj.agh.edu.pl

0168-9002/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2007.05.091

convenient to express C_h not as function of height h, but of dh – the difference between the actual height h and the nominal one h_0:

$$C_h(dh) = \frac{\varepsilon(h_0)}{\varepsilon(h)} \quad dh = h - h_0 \tag{2}$$

When spectrometer efficiency is determined for various sample heights using the same radioactive solution (containing several radionuclides), the formula for the given energy assumes the form

$$C_h(dh) = \frac{\varepsilon(h_0)}{\varepsilon(h)} = \frac{n(h_0)}{n(h)(V_0/V)} \tag{3}$$

where $n(h_0)$, $n(h)$ are the net count rate in a peak corresponding to this energy for nominal and actual sample height, respectively, and V_0, V are the sample volumes, for nominal and actual sample height, respectively.

2. Materials and methods

The correction factor C_h was determined by the author [2] for several radiation energies: 81.0 keV, 356.0 keV (^{133}Ba), 661.7 keV (^{137}Cs) and 1173.2 keV (^{60}Co).

Two measurement geometries were considered:

- Marinelli beaker 710 cm^3 in volume (sample material 19 mm thick),
- cylindrical sample 121 cm^3 in volume (sample height 31.5 and 70 mm in diameter).

Measurements were carried out with a Canberra HPGe detector, with relative efficiency of 20% (4.8 cm in diameter, 5.55 cm in height).

Correction factors were obtained for this detector, by two methods:

- Experimentally, using water solution containing nuclides ^{60}Co, ^{133}Ba and ^{137}Cs. For the given geometry, gamma-ray spectrometry measurements were performed for the nominal sample height h_0 and for about 10 values of h falling within the range $h_0 \pm 8$ mm. The time of measurement was chosen in order to keep the uncertainty of the count rate n less than 0.3%. The values $n(h_0)$ and $n(h)$ were then determined for peaks corresponding to the considered energy E, yielding C_h value (see Eq. (3)).
- Computations of efficiencies $\varepsilon(h_0)$ and $\varepsilon(h)$ by the Monte Carlo simulation method. For these calculations, the MCNP4b code was used.
  While compared to techniques of computing efficiency ε, the Monte Carlo method of deriving the correction factor C_h is less biased by simplifications and uncertainties due to detector dimensions. The correction factor C_h is expressed as the ratio of spectrometer efficiencies (see Eq. (2)) and, as such, ought to be treated as a relative term. As a consequence, the errors in efficiency computations will be partially cancelled. That is why computations were performed for nominal detector dimensions, supplied by manufacturer. Unlike in efficiency ε calculations procedure [3,4], detector dimensions were not modified or optimized.
  Sample heights used in the calculations were the same as in the spectrometry measurements. Several other cylindrical geometries were considered, too. The time of calculations was chosen in order to keep the type A uncertainty of the calculated efficiency less than 0.1%. Since the efficiencies $\varepsilon(h_0)$ and $\varepsilon(h)$ are known, we easily obtain the C_h value using Eq. (2).

3. Results

C_h values obtained by the two methods show a good degree of correspondence, the relative differences do not exceed 1% for the cylindrical geometry, and 2% for the Marinelli geometry. This means that when the relationship $C_h(dh)$ is determined for a given detector–volume source system, a faster, more convenient and universal Monte Carlo method can be successfully employed. Besides, good correspondence between the measured and simulated data seems to confirm the author's assumption that no detector optimizations are necessary in C_h calculations when the Monte Carlo method is used.

The analysis of $C_h(dh)$ dependence on various energies E, suggests that C_h value depends on energy only in a minor degree.

- C_h values for 81 keV significantly differ from the corresponding C_h value for higher energies.
- For energies in excess of 356 keV, C_h depends on the energy only in a minor degree; the relative difference between C_h values at relevant energies is less than 1.0% (the measurement uncertainty is 0.4%).

This is why, only two groups of C_h values are considered in further analyses:

- 81 keV (low-energy group representation).
- energies in excess of 356 keV (356, 662, 1173 keV).

Fig. 1 shows the $C_h(dh)$ function for a Marinelli beaker 710 cm^3 and for cylindrical geometry with nominal sample height of 31.5 mm, for two energy values; 81 keV and over 356 keV. The data are the experimentally collected ones.

It was found that the value of C_h varies linearly with dh in the considered variability range of h. The correction factor is governed by the function

$$C_h(dh) = m\,dh + 1 \tag{4}$$

where m is slope of the line.

- For Marinelli beaker, for energies in excess of 356 keV $m = 0.0088$ (0.0098 for $E = 81$ keV). It means that for