Radiation Physics and Chemistry 103 (2014) 53–56

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

A study on activity determination of volume sources using point-like standard sources and Monte Carlo simulations

Feng Xie *, Wengang Jiang, Tao Bai, Min Bao, Gongsuo Yu

Northwest Institute of Nuclear Technology, Xi'an 710024, China

HIGHLIGHTS

- The activities were determined using point-like sources and MC simulations.
- Ratios of efficiency were calculated by MC simulations based on GEANT4 codes.
- The obtained activities were in good agreement with the reference values.

ARTICLE INFO

Article history:
Received 28 October 2013
Accepted 17 May 2014
Available online 24 May 2014

Keywords:
Gamma-ray spectrometry
HPGe
True coincidence summing
Monte Carlo simulations
GEANT4

ABSTRACT

In this paper, the activities of volume sources were determined using point-like sources and Monte Carlo simulations. Three point-like sources (^{137}Cs, ^{60}Co and ^{152}Eu) were measured as standard at the different distances from the detector window, and two volume sources, one containing ^{137}Cs and ^{60}Co, and another containing ^{152}Eu, were measured directly on the detector window. After the ratios of efficiency between point-like sources and volume sources were calculated by Monte Carlo simulations based on GEANT4 codes, the activities of two volume sources were determined. Experimental verifications had shown that the activities obtained by this method for volume sources were in good agreement with the reference values.

1. Introduction

Gamma-ray spectrometry with high-purity germanium (HPGe) detectors is a basic tool for the measurement of weak radioactivity in environmental samples. Due to the low activity concentration of environmental samples to be measured, large sample volumes and close sample to detector distances are required. Under these conditions, the efficiency determination for complex muti-gamma nuclides is strongly affected by true coincidence summing (TCS) (Debertin and Helmer, 1988). Thus, TCS correction is a key factor in activity determination of environmental samples.

When the sample is compared directly with a standard source measured in the same geometry at the same distance from the detector window, the TCS is the same for sample and standard, and TCS correction can be canceled out. That is so-called the classical relative method for activity measurement, which is by far the most accurate method (Gilmore, 2008). The relative method, however, has a basic requirement that the standard source should be exactly to the same as the sample under investigation in its size, composition and density, as well as the radionuclide contents, so the preparation of the standard sources is costly and time consuming, and is difficult for all the geometrical arrangements used in environmental samples measurements. Thus it is a fact that the classical relative method may be incompatible with the demands of routine measurements.

In 2010, Vidmar et al. (2010) developed an extended relative method of activity determination which has been successfully applied to samples differing in their characteristics and radionuclide contents from those of the standard with the help of Monte Carlo simulations. However, the authors gave the confined conditions for the method application, which the reference geometry and the geometry of the measured sample should not differ too much from each other, such as using a point source as the standard for activity determination of extended sources. It was true that the method proposed by Vidmar effectively extended the application scope of classical relative method for activity measurement. However, the confined condition and recommendation given by them would restrict the application of the method. In order to enlarge farther application scope of the method, this study aimed in checking the validity of relative measurement of volume sources activity using both point-like standard sources and Monte Carlo simulations. In this paper, three point-like sources (^{137}Cs, ^{60}Co and ^{152}Eu) were used as standard for activity determination of volume sources.

* Corresponding author.

http://dx.doi.org/10.1016/j.radphyschem.2014.05.042
0969-806X/© 2014 Elsevier Ltd. All rights reserved.

The method of activity determination for volume sources adopted in this work was basically the same as one proposed by Vidmar. A brief description was given below. The activity A of the measured sample is:

$$A = A_0 \frac{N}{N_0} \frac{R_0}{R} \quad (1)$$

where the activity A_0 of point-like standard source is known; N and N_0 are the number of counts per second in the full-energy peak of the measured spectra corresponding to the sample and the point-like standard source, respectively; R and R_0 are the number of counts per one sampled event in the full-energy peak of the simulated spectra relative to measured sample and standard source, which have been corrected for the TSC and the self-absorption effect by Monte Carlo stimulation. Since the ratio of two computed quantities (R and R_0) is used in Eq. (1), we can thus expect that the imperfections in our detector model, such as uncertainties in nuclear data (interaction cross section, decay half-lives and gamma-ray emission probabilities, etc.) and TCS correction, may tend to be canceled out to a large extent.

2. Experimental

Measurements were performed with a p-type coaxial HPGe detector from ORTEC Company. The detector had a nominal 60% relative efficiency and a resolution of 2.0 keV for the ^{60}Co gamma ray at 1332 keV. The characteristics of the detector given by manufacturer are shown in Table 1. A lead shield (10 cm thick standard lead) and an inner copper layer (2 mm) surround the detector to protect it against environmental radiation. Gamma-rays spectra were obtained by a digital multichannel analyzer type DSPEC^{PLUS} and were analyzed with GammaVision V5.2 software.

The point-like sources (^{137}Cs, ^{60}Co and ^{152}Eu) standardized by China Institute of Atom Energy (CIAE) were measured at 0, 10, 20, 52, 74, 104 and 250 mm distances from HPGe detector window. The diameter of point-like sources was 10 mm and the height was 1 mm. The sources were embedded in 1 mm thick cylindrical polystyrene containers with a diameter of 28 mm and a height of 10 mm. The relative standard uncertainty of activities for point-like sources is 1.5% given by CIAE. Two volume sources, one containing ^{137}Cs and ^{60}Co, and another containing ^{152}Eu, were measured directly on the HPGe detector window in 1 mm thick cylindrical polystyrene containers. The characteristics of the volume sources are listed in Table 2.

Table 1
The characteristics of the detector from the manufacturer. All numerical values are given in millimeter (mm).

Description	Nominal value
Crystal material	Ge
Crystal diameter	74.4
Crystal length	69.2
Front Ge dead layer thickness	0.7
Side Ge dead layer thickness	0.7
Inner hole diameter	9.1
Inner hole depth	62.9
Al end cap thickness	1.0
Al end cap to crystal distance	4.0

3. Monte Carlo simulation

Some computer codes can be used for simulating the interactions of gamma-rays with the HPGe detector and also performing a complete simulation of a decay scheme, including GESPECOR (Arnold and Sima, 2004), MCNP code with the MCNP-CP (Berliaov, 2005) radionuclide decay add-on, GEANT4 code (Agostinelli et al., 2003), PENELOPE code (Salvat et al., 2008), etc. Compared with other codes, GEANT4 is a free software toolkit and can be easily obtained from CERN's website. So GEANT4 codes of version 4.9.6 were used for Monte Carlo simulations in this work.

The "Standard" model of Geant4 was employed for modeling the electromagnetic (EM) interactions. The following physics processes were used: G4ComptonScattering, G4GammaConversion, G4PhotoElectricEffect, G4eMultipleScattering, G4eIonisation and G4eBremsstrahlung. The general particle source (GPS) module was used as the particle generator. In particular, G4RadioactiveDecay class provided by GEANT4 was used to simulate the entire decay process of a given radionuclide by alpha, beta-plus and beta-minus emissions and electron capture. The secondary production threshold in the range was set to 0.001 mm for both photons and electrons in order to simulate all possible physics interactions. The corresponding secondary production thresholds in energy are 250 eV and 1.9 keV, respectively.

The HPGe detector model was established without any parameter alteration from the manufacturer given in Table 1. The model of the detector, drawn by the GEANT4 visualization package and shown in Fig. 1, reproduced a realistic germanium crystal with a dead layer, the central hole and the aluminum housing. The characteristics of point-like standard sources and volume sources were taken from the above.

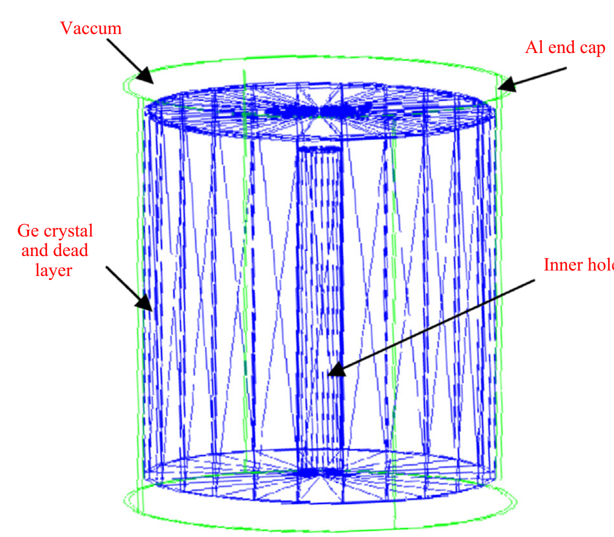

Fig. 1. Picture of HPGe detector performed by the GEANT4 visualization package.

Table 2
The characteristics of volume sources (The activities and uncertainties (1σ) of ^{137}Cs , ^{60}Co and ^{152}Eu are supplied by CIAE).

Sample	Diameter (mm)	Thickness (mm)	Matrix	Density (g/m^3)	Nuclides and Activity (Bq)	Reference Date
1	75	50	River mud	1.08	^{137}Cs:19.7 ± 0.4 ^{60}Co:33.3 ± 0.7	2012–9–1
2	75	50	Soil	1.43	^{152}Eu:2268 ± 64	2011–10–1