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Optimization of the marinelli beaker dimensions using genetic algorithm

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ABSTRACT

A computational code, based on the genetic algorithm and MCNPX version 2.6 code was developed and used to investigate the effects of some important parameters of HPGe detector (such as Al cap thickness, dead-layer thickness and Ge hole size) on optimum dimensions of marinelli beaker. In addition, the effects of detector material on optimal beaker dimensions were also investigated. Finally, the optimized beaker dimensions at various beaker volumes (300, 500, 700, 1000 and 1500 cm^3) were determined for some conventional Ge detectors with different crystal sizes (16 sizes). These sets of data then were used to drive mathematical formulas (obtained by best fitting to data sets).

The results showed that, there is no meaningful correlation between the optimum dimensions of the beaker and each of the dead-layer thickness, Al cap thickness and the Ge-crystal hole size. On the other hand, the optimum beaker radius increases with decreasing the density of the detector material while the beaker height decreases.

1. Introduction

Gamma-ray spectrometry is a common technique widely used for identification and quantification of radionuclides in samples of different matrices and geometries. The use of High Purity Germanium (HPGe) detectors with high energy resolution allows identification and activity measurement of natural and artificial radionuclides in biological, geological and environmental samples, with the highest possible sensitivity (Azbouche et al., 2015).

To analysis the environmental samples with low radioactive concentrations, a sample with high mass is required to obtain accurate and precise results. In order to increase the net counts due to the samples, in addition to a good shielding method, the various measurement parameters should be optimally balanced. The use of marinelli beakers in environmental samples permits one to obtain greater net count by positioning the sample volume as close as possible to active volume of the detector. In a constant sample volume, the detector efficiency varies at different geometrical dimensions of the beaker due to self-attenuation of photon in sample and out-scattering from the detection region. Therefore, dimensions of the marinelli beaker should be optimum to increase the efficiency of the detector (Ahmed et al., 2009; Shweikani et al., 2014).

Several researchers have tried to develop convenient methods for determining the optimum dimensions of the marinelli beaker. Chung et al. (1991) have measured the optimum geometry of marinelli-like samples (0.1–4 L) using a 20% relative efficiency HPGe detector. They reported that the optimum geometry of larger samples (5–60 L) held in marinelli beaker can be extrapolated from their work. Sima (1990) used a Monte Carlo algorithm and auto absorption (self-absorption) factors to determine the semi-conductor detector efficiency for marinelli geometry. Ahmed et al. (2009) have studied optimization of marinelli beaker for increasing efficiency of an Ortec GMX S Gamma-X HPGe detector using MCNP code. They recommended that the optimum dimensions for 200–500 mL sample volumes should be used for better measurement. Melquiades and Appoloni (2001) have measured self-absorption factors vs. density for five marinelli beakers containing powdered milk samples with ^{40}K and ^{208}Tl. They have verified the relation $y = 1.96608x-74813$ for ^{40}K line of 1460.8 keV and $y = 1.4484x-0.83258$ for ^{208}Tl line of 2614.47 keV, where x and y were density (g/cm^3) and self-absorption factor, respectively. Debertin and Jianping (1989) calculated self-absorption in marinelli beakers mathematically. Azbouche et al. (2015) developed a computational procedure for gamma ray spectroscopy of large volume sample based on achieving

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Abbreviations

DL	Dead-Layer
GA	Genetic Algorithm
HPGe	High Purity Germanium
r	Beaker Radius
h_1	Cylinder Height (height of the cylinder part of the beaker)
h_2	Ring Height (height of the ring part of the beaker surrounding the detector)
r_{max}	Maximum Limit of r
h_{max}	Maximum Limit of h_2

agreement between ^{152}E source packed in marinelli beaker and MCNP5 simulation. They concluded that their method can be used in determination of the specific activities of radionuclides in soil. In the framework of environmental measurements, an application based on efficiency trfpansfer (ET) method have been described by Vidmar et al. (2010) as a means of calculating the full-energy-peak efficiencies (FEPE) and the ET method have been validated for marinelli geometries by Ferreux et al. (2013).

After developing genetic algorithm (GA) by john Holland and his colleagues, the algorithm was considered as one of the best optimization tools in various scientific applications (Do and Nguyen, 2007; Goldberg, 1989; Haupt and Haupt, 2004; Pham and Karaboga, 2000). A combination of GA and MCNP simulation were used to obtain the maximum detector efficiency by Huy et al. (2012). They reported the optimum dimensions of a 450 cm^3 marinelli beaker for the GC1518 HPGe detector. They suggested that the effects of gamma energy, chemical composition of the sample and the sample density on optimum dimensions are negligible. In this study, we also used a combination of GA and MCNP simulation to investigate the effects of some important detector parameters, such as thickness of Al cap, dead-layer (DL) and crystal size, on optimum dimensions of marinelli beaker.

2. MCNPX simulation of the detector and marinelli beaker

The MCNPX version 2.6 (Pelowitz, 2008) was used for the simulation of the HPGe detector and marinelli beaker. This computational code is routinely used by many researchers to obtain the efficiency of the HPGe detector (Azli, 2015; Chham et al., 2015; Elanique et al., 2012; Salgado et al., 2006; Saraiva et al., 2016). The HPGe detector model was based on Canberra GC1518 HPGe detector, as schematically shown in Fig. 1. The materials and dimensions of the detector (Table 1) were described by Huy et al. (2007). It was assumed that the dimensions of the sample are equivalent to those of the marinelli beaker. The marinelli beaker consist of the three dimensional parameters: radius, cylinder height and ring height (r, h_1 and h_2, respectively, in Fig. 1). The optimization of these dimensional parameters will be resulted in maximum efficiency of the detector (Ahmed et al., 2009).

The pulse height tally (F8) was used to obtain the absolute efficiency. The output was binned by E card in order to give the peak absolute efficiency (Knoll, 2010).

For validation of the simulation results, the energy-dependent detector efficiency curve (obtained from the MCNP simulation) was compared with the simulation results reported by Huy et al. (2012) for the same model of the HPGe detector. The energy-dependent detector efficiency curve was obtained by defining the mono-energetic point sources located at the central axis of detector

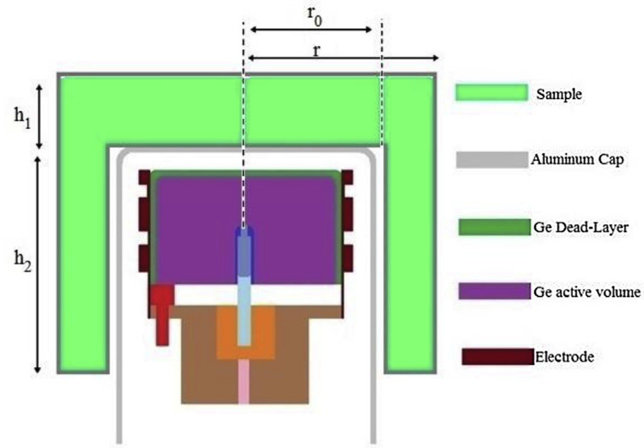

Fig. 1. The HPGe detector and marinelli beaker.

Table 1
Specifications of the Canberra GC1518 HPGe detector (after Huy et al., 2007).

Parameter	Dimension (cm)
Aluminum Cap thickness	0.15
Aluminum Cap diameter	7.62
Germanium dead-layer thickness	0.116
End cap to crystal distance	0.5
Germanium crystal height	3.2
Germanium crystal diameter	5.4
Core hole height	1.7
Core hole diameter	0.7

at a distance of 15 cm from detector surface. The peak absolute efficiencies of the detector with specifications given in Table 1, was extracted by running MCNPX for each energy, ranging from 60 to 1332 keV. Only the bare detector as illustrated in Fig. 1 without any shielding was simulated. Since the normalized count under full energy peak area for mono-energetic sources was considered as output of the MCNPX, definition of the surrounding materials (shield) were not included in the simulation results. The simulation results in the present study together with the results reported by

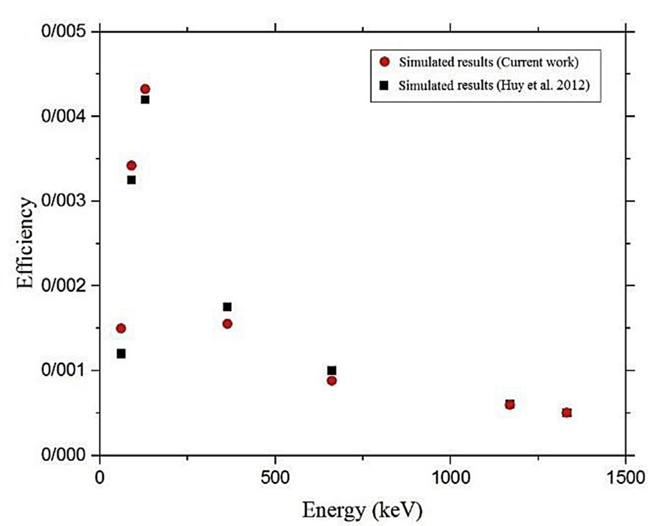

Fig. 2. Energy-dependent detector efficiencies; comparison between the simulated results obtained in this study with those reported by Huy et al. (2012).