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Determination of the optimal cylindrical geometry heights for gamma-ray spectrometric analysis

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HIGHLIGHTS

- Optimal sample thickness for γ spectrometry was determined.
- Estimation and experimental study for sample thickness and count rate was done.
- Optimal thickness was found to be 10 cm for $E > 100$ keV regardless the type of HPGe.
- For N-type HPGe, thicknesses 3.5 cm for 46.5 keV and 5 cm for 59.5 keV were found.
- Very good agreement between estimation and experimental results were found.

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ABSTRACT

The optimal heights (sample thickness) for samples of cylindrical geometry analyzed by gamma-spectrometry with HPGe detectors have been determined by studying the correlation between the sample thickness and the sample mass multiplied by the efficiency. For energies higher than 100 keV, the optimal thickness for a cylindrical sample with a diameter of 6.8 cm was determined to be 10 cm, regardless of the type of HPGe detector. A strong relationship was observed between the optimal sample thickness and the gamma energy line (when $E < 100$ keV) and the density of the sample for N-type HPGe (R.eff. 60%) detectors. For a sample density 2 g cm^{-3}, the optimal thickness was determined to be 3.5 cm at 46.5 keV and 5 cm at 59.5 keV.

1. Introduction:

Gamma spectrometry is one of the most widely used techniques for the determination of natural and artificial radionuclide in environmental samples (L' Annunziata, 2004). The activity concentration (A) of the sample is usually calculated using the following equation (Debertin and Helmer, 1988):

$$A = \frac{N}{t \cdot \varepsilon \cdot I_\gamma \cdot w} C_1\, C_2\, C_3 \ldots C_j \qquad (1)$$

where A: activity concentration of measured isotope (Bq kg^{-1}).

N: net count at gamma line E_i for the isotope (i).
ε: detector efficiency for gamma line E_i.
I_γ: gamma line intensity (%).
C_j: correction factors for self-attenuation, decay time, dead time, etc.
t: counting time (sec).
w: sample weight (g).

To analysis the environmental samples with low radioactivity concentrations, a large sample mass is required to obtain accurate and precise results. Various geometries, commonly Marinelli beakers and cylindrical containers, may be used in the analysis of such samples.

To decrease the cost of gamma-spectrometric analysis, the various measurement parameters should be optimally balanced. For example, a large volume of sample, long counting time, and the choice of a good shielding method can be used to increase the net count N. However, any of these solutions has its limitations, and overextending a given parameter provides no additional benefit.

Barrera et al. (1999) have developed a model using Monte Carlo methods to determine the optimal thickness for cylindrical sample geometries in the energy range of 100–1700 keV. Their results show that for a sample thickness of 5.5 cm, detection efficiencies

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Table 1
Comparison between the calculated (EFFTRAN code) and measured efficiencies, for the 27 cm^3 cylindrical sample container (diameter 5.4 cm and height 1.1 cm).

Energy (keV)	Efficiency %		Bias %
	Measured value	Calculated value	
59.5	4.85	4.62	−5%
88.0	11.42	11.19	−2%
122.0	14.26	14.00	−2%
661.6	5.54	5.63	2%
834.0	4.68	4.73	1%
1115.6	3.73	3.78	2%
1173.2	3.63	3.61	−1%
1332.4	3.31	3.27	−1%

greater than 75% of the theoretical maximum can be achieved for all sediment samples with densities between 1 and 2 g cm^{-3} over the energy range considered.

In this work, the optimal sample thickness (cylinder height) h_{opt} was determined by calculating the minimum value of the thickness that makes the first derivative of the sample mass multiplied by the detector efficiency ($|(\varepsilon \cdot w)'|$) nearly zero for two energy ranges (<100 keV and >100 keV).

2. Materials and methods:

Two gamma spectrometry systems were used in this study:

1. Eurisys, P-type HPGe detector model EGPC 80-205-R (R. eff., 80%) for gamma energies higher than 100 keV.

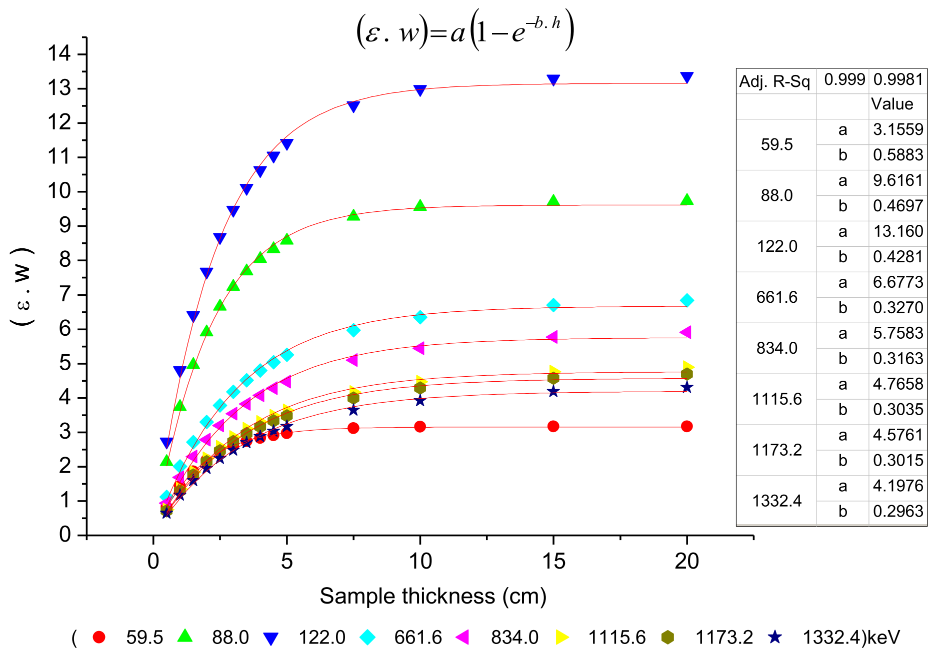

Fig. 1. An example of interpolating the relationship between (ε.w) and the sample thickness.

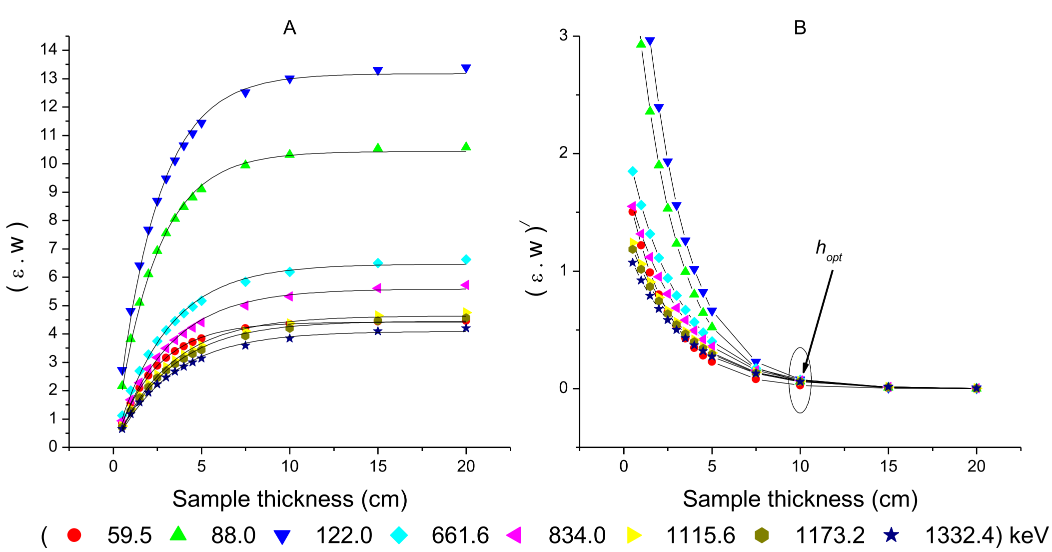

Fig. 2. Correlation between (A) the sample thickness and (ε.w) and (B) the sample thickness and (ε.w)′ using a P-type HPGe detector (R. eff. 80%) and a cylindrical sample geometry. The sample matrix is water (density 1.02 g cm^{-3}) and the diameter of the sample is 6.8 cm.