GAMMA-RAY SELF-ATTENUATION CORRECTIONS
IN ENVIRONMENTAL SAMPLES

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Abstract. Gamma-spectrometry is a commonly used technique in environmental radioactivity monitoring. Frequently the bulk samples that should be measured differ with respect to composition and density from the reference sample used for efficiency calibration. Correction factors should be applied in these cases for activity measurement. Linear attenuation coefficients and self-absorption correction factors have been evaluated for soil, grass and liquid sources with different densities and geometries.

Key words: gamma-ray spectrometry, environmental samples, self-absorption, density effects, transmission measurements.

1. INTRODUCTION

Gamma-ray spectrometry is one of the most widely used techniques to determine the concentration of natural and artificial radionuclides in environmental samples. The use of germanium detectors in high-resolution gamma-ray spectrometry allows a precise quantitative determination of the radioactive concentration of any type of sample. In order to obtain correct results the samples should be counted under the same measuring conditions as those under which the system has been calibrated. However, while most laboratories measuring environmental samples by gamma-ray spectrometry can prepare the samples in essentially identical shape and size, they must contend with a large variety of sample densities and compositions. Many gamma spectrometric studies of environmental samples are concerned with low energy photons and the variations from sample to sample and sample to standard could be large enough to require a correction for sample self-attenuation.

A gamma photon that passes through any material, including the sample in which it is generated, undergoes, with a given probability, specific interactions. In these interactions the photon is either absorbed or scattered, losing energy; in any case it cannot contribute to the peak count-rate. The degree of self-attenuation depends on a number of factors such as sample geometry and linear attenuation coefficient μ; the linear attenuation coefficient depends in turn on material density, sample composition, and photon energy E. The attenuation of a gamma-ray flux passing through a path of length x in a sample with linear attenuation coefficient μ can be expressed as:

$$I = I_0 e^{-\mu x}. \tag{1}$$

For most environmental analyses, the value of μ is not known and should be estimated by measurements [1] or using an assumed sample composition and density [2, 3]. The distribution of the path lengths through the sample of the photons contributing to the peak count-rate depends on sample geometry and slightly on detector dimensions and photon energy. For a realistic evaluation of self-attenuation corrections a suitably weighted average of the transmission factor should be computed [4], taking into account the distribution of the path lengths. This type of computation requires the application of Monte Carlo simulation techniques [3].

Simplified procedures affordable in any laboratory, useful in routine measurements, have also been proposed. For example, self-attenuation correction factors F_{att} for cylindrical samples of height x and linear attenuation coefficient μ with respect to a reference air sample ($\mu \approx 0$) can be approximately computed by the following equation:

$$F_{att} = \frac{\mu x}{1 - e^{-\mu x}}. \tag{2}$$

A similar equation was proposed for samples measured in Marinelli beakers [5, 6] with an appropriate value of x that can be analytically computed from the beaker dimensions [7].

A convenient method based on transmission measurements that can be easily done in any laboratory was proposed by Cutshall et al. [8]. In this method a point source is positioned above the sample located on the detector and the number of counts in the full energy peak is measured. By replacing the value of μ from equation (1) in equation (2) the sample self-attenuation correction factor, F_{att}, with respect to the reference air sample is expressed as:

$$F_{att} = -\frac{\ln(I/I_0)}{1 - (I/I_0)}, \tag{3}$$

where I and I_0 are the peak count rates for the actual sample and the standard air sample, respectively.

Frequently the efficiency calibration for volume samples is done using a water standard source. The relative self-attenuation correction factor for a sample (*s*) with respect to a water sample (*w*) is given by:

$$F_{att;s,w} = \frac{F_{att;s}}{F_{att;w}},$$

(4)

where the attenuation factors from the right side of the equation are computed using equation (3).

The aim of our work is to apply a simple practical procedure to correct for self-attenuation effects.

2. MATERIALS AND METHODS

A HPGe detector of 80% relative efficiency coupled to standard electronics and to a multichannel analyzer with 8192 channels was used in the measurements. The main technical features provided by manufacturer are:
1. p-type HPGe detector;
2. crystal diameter – 72.8 mm;
3. crystal length – 79.8 mm;
4. end cap to crystal distance – 4 mm;
5. entrance window – 1 mm Al;
6. inactive Germanium – 0.7 mm;
7. resolution (FWHM) at 1.33 MeV, ^{60}Co – 1.95 keV measured;
8. Amplifier time constant – 6 μs.
9. Gamma-spectrum software – Genie-2000 by Canberra.
The detector and the samples were placed inside of a shielded container.

Three gamma-ray point sources (^{109}Cd, ^{57}Co and ^{137}Cs) were used to perform transmission measurements for air and for several samples.

Four types of environmental samples (water, soil, grass and honey) have been prepared in three different geometries (source height of approximately 11, 22 and 50 mm). The samples were prepared in identical polypropylene cylindrical containers with the inner diameter $D = 55$ mm, height $H = 80$ mm and thickness of the walls $t = 1$ mm. The containers were placed directly on the end cap of the detector.

The mass and the height of the samples were carefully measured for each source. It should be noted that in the case of the grass sample it was difficult to assure identical compactness of all the samples; consequently there are important differences in the densities of grass samples with different heights. Smaller differences are observed in the case of soil samples.

To calculate self-absorption correction factors using the direct transmission method a point source was places on top of each sample container and counted for 1000 s. The source was then placed in the same position on an identical empty container and the spectrum was collected as before.

3. RESULTS AND DISCUSSIONS

The variation of chemical and physical proprieties of the bulk samples with respect to the standard samples used for efficiency calibration could be the main source of uncertainty, especially for samples with high apparent densities and high Z, for photons with low energies (< 100–200 keV). These differences are reflected in the differences in the transmission factors.

The transmission factors, defined as the ratios between the count-rate in a peak in the presence of the sample to the count-rate in the peak obtained with the empty container, have been computed for all the samples and geometries. The results obtained for the honey sample (density ρ = 1.53 g cm^{-3}) are presented in logarithmic scale in Fig. 1 as function of the sample thickness. The three curves correspond to the energies E = 88 keV (triangles), 122 keV (squares) and 662 keV (diamonds). The results are in agreement with equation (1), with the linear attenuation coefficient decreasing with increasing photon energy. The linear attenuation coefficients obtained using equation (1) in the case of grass and soil samples have a less clear pattern, due to the fact that the samples with different height do not have the same density; however the mass attenuation coefficients μ/ρ (in cm^2 g^{-1}) have the expected dependence on photon energy.

Using the values of the transmission factors and the equation (4) the self-attenuation correction factors were computed for all the samples with respect to the water sample. The results are presented in Table 1.
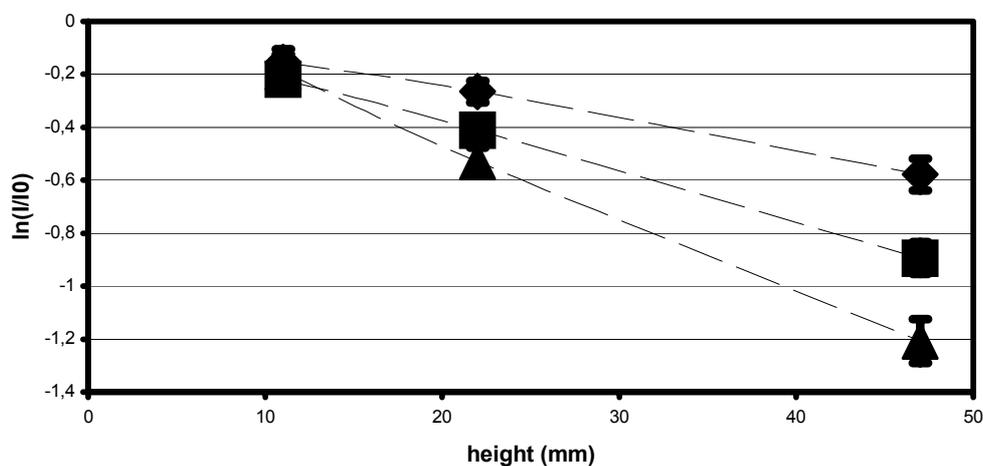

Fig. 1 – The experimental results for the transmission factor in the case of a honey sample (density ρ = 1.53 g cm^{-3}). The measurements have been done at the photon energies E = 88 keV (triangles), 122 keV (squares) and 622 keV (diamonds).

Table 1

Self-attenuation correction factors $F_{at;s,w}$ (equation 4) for environmental samples with different matrices with respect to the water standard

Sample type	Density [g cm^{-3}]	Height [mm]	88 keV	122 keV	662 keV
Honey	1.53	11	1.04	1.03	1.02
	1.53	22	1.06	1.037	1.035
	1.53	47	1.10	1.044	1.040
Grass	0.65	11	1.00	0.98	1.00
	0.34	22	0.87	0.96	0.97
	0.32	50	0.79	0.80	0.87
Soil	0.69	11	0.94	0.98	1.00
	0.71	22	0.95	0.96	0.98
	0.56	50	0.88	0.90	0.92

From Table 1 it is evident that self-attenuation effects are important, especially at the lowest energy. Neglecting these effects and using the efficiency curve measured with a water standard results in the underestimation of the activity of a honey sample by about 10% and in the overestimation of the activity of a grass sample by 20% in the case of samples with a thickness of about 5 cm at around 88 keV. The bias in activity decreases when the thickness of the sample decreases.

4. CONCLUSIONS

The efficiency curve depends on sample composition and density in the case of volume samples. In order to evaluate the activity of a sample with given composition and density on the basis of the efficiency calibration curve measured with a standard source (usually water solution) with a different composition and density it is necessary to apply self-attenuation corrections. In this work a simplified method based on transmission measurements was applied for the computation of self-attenuation correction factors in the case of grass, soil and honey samples measured in cylindrical containers with several filling heights.

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