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Counting Efficiency in Gamma-Ray Spectrometry with Different Volumes for the Same Geometry

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1. Introduction

The technique of gamma-ray spectrometry is a powerful tool for determining the contents of gamma-ray emitter radionuclides in environmental samples (soil, sediment, water, and biological samples). As the result of applying this technique, a count vs. energy spectrum is obtained [1]. To ensure that high-quality spectra are obtained, good practices for their acquisition must be established, including physical setup (detector, shielding and appropriate laboratory), electronic settings (associated electronics), counting conditions, correction for the background radiation in the laboratory (corrections for unwanted sources of radiation) [2] and methodology validation by proficiency tests. The fundamental step in gamma-ray spectrometry technique is obtaining a correct efficiency curve, which basically depends on the counting geometry (geometric configuration of the container used for conditioning samples), solid angle (position of the counting geometry relative to the detector), quantity (volume of sample used in the counting geometry) and density of the sample [3]. For the gamma-ray spectrometry technique, it is necessary to know very well the efficiency of the measurement system, usually obtained through calibrated standards prepared in the same geometry used in the samples counting. Widely used standards for the efficiency curve are certified reference materials for soil, sediment, vegetation, among others standards. Another option for the laboratory is the preparation of the standard calibration solution, which consists of diluting a certified radioactive solution with radionuclides, in the appropriate volume of the sample counting geometry [4]. Monte Carlo code can also be used to obtain calibration efficiency in the gamma spectrometry technique. Depending on the condition of the sample to be analyzed, it is necessary to reduce the volume of samples for the counting geometry. The conditions are: high density, sample activity, insufficient amount of sample, among other factors. Samples with high density makes it difficult to determine self-absorption, resulting in an inappropriate quantity of counts; high activity in the sample increases the dead time of the detection system, impairing the resolution of the spectrum peaks and increasing the uncertainty in determining the activity; the insufficient amount of sample would be for specific cases that do not have enough available quantity to complete the count geometry. For these conditions described, it is necessary to determine the efficiency curve for each quantity of sample to be analyzed. Different density and composition of the sample analyzed in relation to the certified reference materials used in the efficiency curve, it becomes necessary the self-absorption correction to obtain the correct result [5]. The dependence on efficiency is directly related to the volume, density and composition of the sample, which can be easily and quickly corrected with the self-absorption test [4].

The aim of this study is to determine an easy and fast method to calculate efficiencies for different volumes in the same geometry.

2. Methodology

The geometry used was a polyethylene flask with a volume capacity of 100 mL (F100), a geometry well known and tested in several intercomparisons, also evaluating the secular radioactive equilibrium obtained in the F100. Reference Material Soil IAEA 326 was packed in a polyethylene bottle of 100 ml, different masses, ranging from 25g to 128g, to obtain different sample volumes from 19.5mL to 100 mL and sealed for about four weeks prior to measurement in order to ensure that radioactive equilibrium had been reached between ^{226}Ra and its progeny. After this time it was measured by gamma-ray spectrometry with a hyper-pure germanium detector Canberra model XtRa, 25% relative efficiency with associated electronics and coupled to a microcomputer. Multichannel Maestro A65-I model software [6] was employed for spectrum acquisition. Interwinner 6.0 from Eurisys Measurements Incorporation [7] software was used for personal computer analysis of gamma-ray spectra from HPGe detectors and for making the efficiency curve. The blank samples for background determination were prepared with deionized water.

3. Results and Discussion

The efficiency was measured for a hyper-pure germanium detector using reference material soil IAEA 326. The energies of gamma-rays used in this paper are recommended by taking into account: gamma intensity value, peak quality, and spectral region without interference [9]. Selected gamma-ray energies were: 46.5 keV from ^{210}Pb, 295.2 and 35.9 keV from ^{214}Pb and 609.3 keV from ^{214}Bi of the ^{238}U series; for the ^{232}Th series gamma-ray emissions were: 238.6 keV from ^{212}Pb and 911.1 keV from ^{228}Ac. Fig. 1 shows fitting equations using linear regression on the counting efficiencies, with mass ranging from 25 to 128 grams for each energy studied.

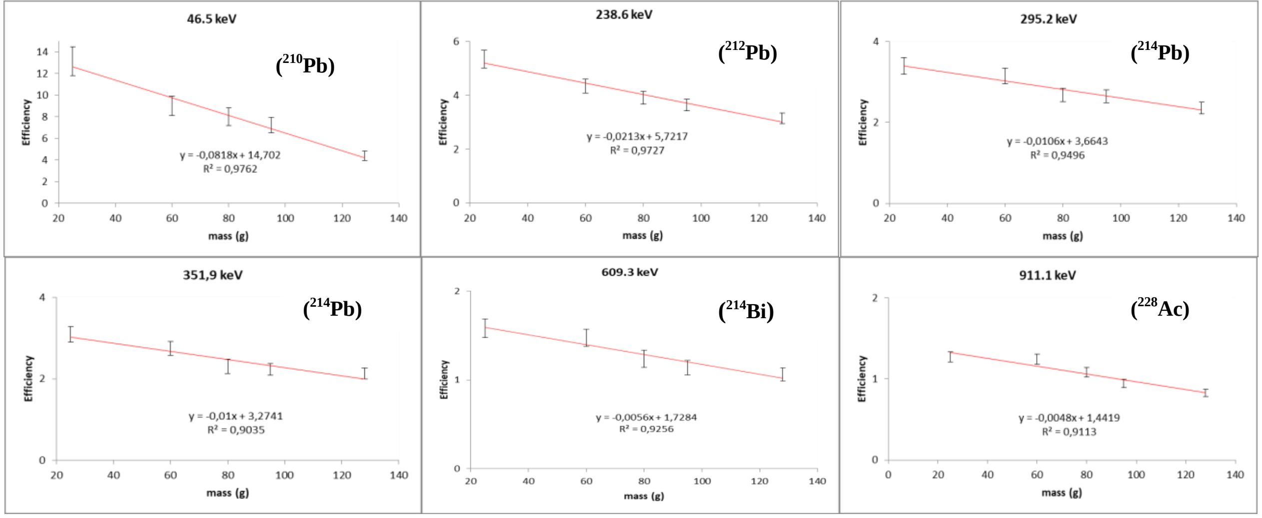
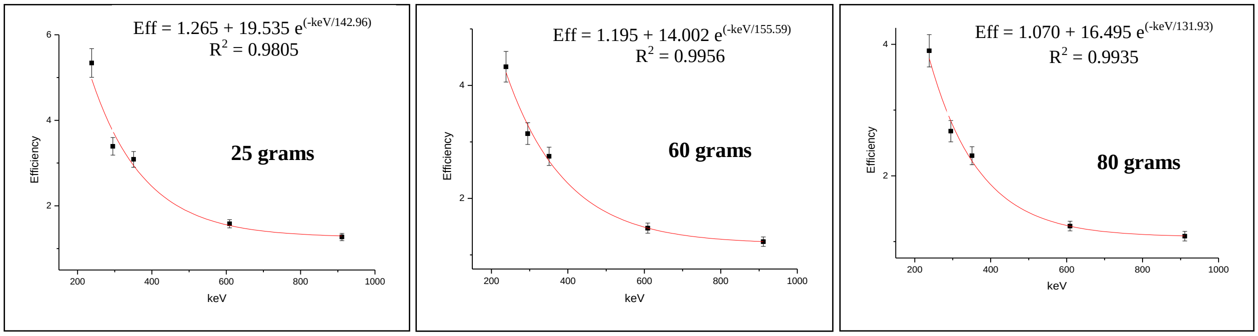


Figure 1: Linear regression considering the efficiencies with range of mass from 25 to 128 grams.

Fig. 2 shows adjustment used by the exponential decay (first order) equation considering the efficiency with range of 238.6 to 911.2 keV for each mass.



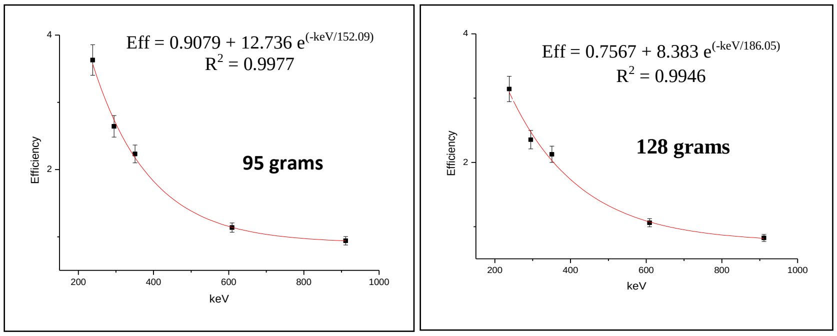


Figure 2: Exponential decay (first order) equation with range of 238.6 to 911.2 keV.

The blank sample was used to determine the minimum detectable activity (MDA) "a priori" and was calculated by the model proposed by Currie [11]. The counting time of 24 h was used to determine MDA "a priori" for each sample mass and energies of interest are shown in Fig. 3.

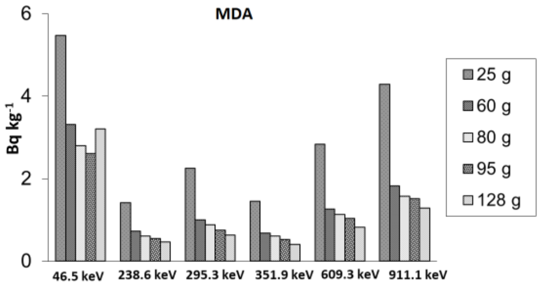


Figure 3: MDA "a priori" for the energies of interest, calculated from the blank samples spectra

When the MDA is higher than desired, it is necessary to increase the counting time with optimization properly. Counting time optimization is the fastest, economical alternative and with a good accuracy to resolve the problem [3,12,13,14,15].

The performance (precision, accuracy and normalized deviation) of the method was verified using the ^{137}Cs (661.6 keV) and comparing the presented value in the intercomparison report [16].

4. Conclusions

This paper aimed to propose an easy and fast method for determining efficiencies with different volumes for the same geometry; it becomes important when the samples have high density, sample activity, insufficient amount of sample, among other factors.

The energies of gamma-rays used in this paper are recommended considering proper gamma intensity value, peak quality, spectral region without interference and gamma-ray energies from the natural radioactive ^{238}U and ^{232}Th decay series, that are very important for determining natural radioactivity in samples.

The efficiency values obtained, when compared to the adjusted efficiency values, were similar and the plots showed a good correlation coefficient.

The performance was acceptable for all different masses studied, indicating consistent results for the method.

The proposed method could be useful as a tool for laboratories, dealing with samples on a routine basis, by reducing the costs on the purchase of additional counting geometry and optimizing the use of the detection system, thus improving their performance.

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