DETEMINING ATTENUATION COEFFICIENTS OF GAMMA RAYS IN RANGE OF ENERGY FROM 81.0 keV TO 1764.5 keV FOR SOME MATERIALS

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ABSTRACT

In this work, we determine the linear attenuation coefficients of different samples by using the HPGe detector with the gamma rays in the energy range from 81.0 keV to 1764.5 keV emitted from point sources, including ^{133}Ba, ^{226}Ra, and their progenies, ^{214}Pb, ^{214}Bi. The results show that the linear relationship between energy to the densities of the samples. This investigation aims at establishing a database for further studies.

Keywords: attenuation, HPGe detector.

TÓM TẮT

Xác định hệ số suy giảm của tia gamma đối với một số vật liệu trong vùng năng lượng 81,0keV – 1764,5keV

Trong công trình này, hệ số suy giảm tuyến tính của một số mẫu được đo bằng đầu dò HPGe với vùng năng lượng quan tâm từ 81,0keV đến 1764,5keV được phát ra từ nguồn điểm ^{133}Ba, ^{226}Ra và con cháu ^{214}Pb and ^{214}Bi. Kết quả cho thấy sự phụ thuộc tuyến tính của năng lượng vào mật độ của mẫu. Hiện nay, công việc nghiên cứu này được thực hiện với mục đích cập nhật cơ sở dữ liệu cho những nghiên cứu tiếp theo.

Từ khóa: sự suy giảm, đầu dò HPGe.

1. Introduction

Gamma ray spectrometry using hyper pure germanium (HPGe) detectors [1] has been demonstrated as an essential and principal spectroscopy technique for radioactive measurement at many laboratories in the world. Its major advantages are non-destructive testing, multi-elements analysis, no chemical process for samples, analysis for various types of samples, etc.

Jodlowski [2] compared many different methods for self-absorption correction in gamma-ray spectrometry of environmental samples and concluded as follows.

- The experimental method is time consuming and inconvenient. It requires that the curves are fitted to a small number of measurement data, which increases a relatively high uncertainty.

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- Monte Carlo method is not so widely adopted in the laboratory conditions, as they require considerable skill and experience in computer simulations.[4]

- The exact analytical description of self-absorption is a complex task. Another widely applied analytical formula providing a simplified description of self-absorption in cylindrical samples is involving the integration of photons of the specified energy coming from subsequent sample layers and reaching the detector. [3]

2. Experimental arrangement

2.1. Principle

This study suggests a simple measurement of relative photon transmission through unknown samples where the variations of photon transmissions are assumed to be linearly correlated to the samples' density. Specific correction coefficients would be produced for each analyzed sample to be considered when their activities are calculated.

According to Beer – Lambert's law, a parallel photon beam with energy E and intensity $I_0(E)$, arriving upon normal incidence on a material of thickness x, is attenuated according to :

$$I(E) = I_0(E).e^{-\mu(E).x} \quad (1)$$

For any E energy, $I_0(E)$ is the intensity of the parallel beam of incident photons while I(E) is the intensity of transmitted photons, $\mu(E)$ is linear attenuation coefficients (m^{-1}).

In gamma spectrum, we received counts per channel, so formula (1) becomes:

$$N(E) = N_0(E).e^{-\mu(E).x} \quad (2)$$

Where $N(E)$ and $N_0(E)$ are the net peak counts corresponding to energy E in the spectra obtained with the empty and filled containers, respectively.

For each radioisotope, two of series of spectra are taken: one with a void container and the other with the container filled by the sample. (See Fig. 1)

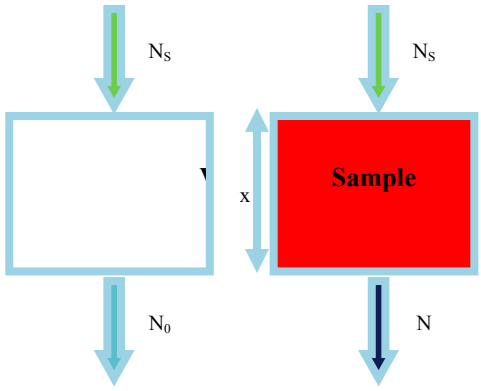


Fig. 1. *Experimental arrangement for measuring the linear attenuation coefficients*

The linear attenuation coefficient correspond to each energy is derived from the ratio of the net peak areas of both spectra as follows

$$\mu(E) = \frac{1}{x} \cdot \ln\left(\frac{N_0(E)}{N(E)}\right) \quad (3)$$

where $N_0(E)$ and $N(E)$ are the net peak counts corresponding to energy E in the spectra obtained with the empty and filled containers, respectively.

The radioisotopes gamma-ray emitter sources that we used in these experiments are point sources, namely ^{133}Ba, ^{226}Ra and their progenies, ^{214}Pb, ^{214}Bi. Each sample was placed on the top of the detector, and then the several point sources were put above the sample. Enough distance was left between the detector and the point sources to maintain acceptable dead time.

The relative combined standard uncertainty is computed according to the law of propagation of uncertainty as follows

$$\frac{u^2(\mu)}{\mu^2} = \frac{u^2(x)}{x^2} + \frac{1}{\ln^2\left(\frac{N_0(E)}{N(E)}\right)} \cdot \left(\frac{u^2(N_0(E))}{N_0^2(E)} + \frac{u^2(N(E))}{N^2(E)}\right) \quad (4)$$

2.2. Sample preparation

In this work, the samples of IAEA434 (photphogysum), IAEA330 (spinach powder), IAEA447 (moss-soil) and IAEA444 (spiked soil) were investigated. These samples are sent to the laboratory of Department of Nuclear Physics by international comparison of the IAEA (International Atomic Energy Agency). Samples were packed in the box of cylindrical geometry with diameter 7.5 cm, height 4.7 cm and thick 0.2 cm. Thickness of the sample was 3.3 cm. Mass and density of the samples are presented in Table 1.

Table 1. *Mass and density of samples*

Sample	Mass (g)	Density (g/cm^3)
IAEA434	97.19	0.74
IAEA330	113.47	0.87
IAEA447	148.88	1.14
IAEA444	166.66	1.28

2.3. Gamma spectrometry

The gamma-ray spectra were measured with a spectrometer, based on a p-type coaxial HPGe semiconductor detector. The performance and geometry of the detector are shown in Table 2.

Table 2. *Characteristics of the semiconductor HPGe detector*

Relative efficiency		20%
Energy resolution (FWHM) at 1332 keV (^{60}Co)		1.8 keV
Peak-to-Compton ratio (^{60}Co)		50:1
Geometrical parameters of the detector	Window thickness	1.5 mm
	Crystal-window distance	5 mm
	Crystal dead layer thickness	0.86mm
	Crystal thickness	49.5 mm
	Crystal diameter	52 mm
	Crystal hole depth	35 mm
	Crystal hole diameter	7 mm
	Side cap thickness	1.5 mm
	Side cap diameter (external)	76.2 mm

3. Results and discussion

In this experiment, acquisitions with HPGe detector are driven using Genie-2K software that is also used for spectra display and processing. The peak areas are generally computed according to Genie-2K processing software. Fig 2 shows comparison gamma spectra of the IAEA-447 and void container for radionuclides of ^{133}Ba and ^{226}Ra.

Measurements of the attenuation coefficients for four samples obtained from 16 most intense emissions were shown in Table 3.

Table 3. *Measured linear attenuation coefficients for samples*

Linear attenuation coefficients (cm^{-1})				
E (keV)	IAEA434	IAEA330	IAEA447	IAEA444
81.0	$1.4\times10^{-1}\pm1.0\%$	$1.3\times10^{-1}\pm1.3\%$	$2.1\times10^{-1}\pm0.7\%$	$2.2\times10^{-1}\pm0.7\%$
186.2	$8.7\times10^{-2}\pm6.0\%$	$9.8\times10^{-2}\pm5.4\%$	$1.3\times10^{-1}\pm4.3\%$	$1.5\times10^{-1}\pm3.8\%$
241.9	$7.8\times10^{-2}\pm3.8\%$	$1.0\times10^{-1}\pm3.1\%$	$1.3\times10^{-1}\pm2.5\%$	$1.3\times10^{-1}\pm2.4\%$
276.4	$7.7\times10^{-2}\pm4.0\%$	$9.7\times10^{-2}\pm3.9\%$	$1.1\times10^{-1}\pm1.8\%$	$1.3\times10^{-1}\pm2.4\%$
295.2	$7.0\times10^{-2}\pm2.2\%$	$8.9\times10^{-2}\pm1.7\%$	$1.2\times10^{-1}\pm1.4\%$	$1.2\times10^{-1}\pm1.4\%$
302.9	$7.6\times10^{-2}\pm2.4\%$	$9.4\times10^{-2}\pm2.4\%$	$1.1\times10^{-1}\pm1.1\%$	$1.3\times10^{-1}\pm1.5\%$

351.9	$6.5\times10^{-2}\pm1.6\%$	$8.2\times10^{-2}\pm1.3\%$	$1.1\times10^{-1}\pm1.0\%$	$1.1\times10^{-1}\pm1.0\%$
356.0	$7.6\times10^{-2}\pm1.4\%$	$9.3\times10^{-2}\pm1.4\%$	$1.1\times10^{-1}\pm0.6\%$	$1.2\times10^{-1}\pm0.9\%$
383.8	$6.5\times10^{-2}\pm4.3\%$	$8.0\times10^{-2}\pm4.3\%$	$1.0\times10^{-1}\pm1.8\%$	$1.1\times10^{-1}\pm2.6\%$
609.3	$5.1\times10^{-2}\pm1.9\%$	$6.5\times10^{-2}\pm1.5\%$	$8.5\times10^{-2}\pm1.2\%$	$8.8\times10^{-2}\pm1.1\%$
768.4	$4.9\times10^{-2}\pm8.5\%$	$5.2\times10^{-2}\pm8.0\%$	$7.2\times10^{-2}\pm5.9\%$	$8.3\times10^{-2}\pm5.2\%$
1120.3	$3.8\times10^{-2}\pm4.6\%$	$4.8\times10^{-2}\pm3.6\%$	$6.6\times10^{-2}\pm2.7\%$	$6.7\times10^{-2}\pm2.7\%$
1238.1	$4.0\times10^{-2}\pm7.9\%$	$4.8\times10^{-2}\pm6.6\%$	$6.1\times10^{-2}\pm5.3\%$	$5.8\times10^{-2}\pm5.5\%$
1377.7	$3.5\times10^{-2}\pm11.7\%$	$4.6\times10^{-2}\pm9.0\%$	$5.6\times10^{-2}\pm7.4\%$	$6.5\times10^{-2}\pm6.5\%$
1729.6	$3.3\times10^{-2}\pm13.6\%$	$4.0\times10^{-2}\pm11.2\%$	$6.0\times10^{-2}\pm7.7\%$	$5.7\times10^{-2}\pm7.9\%$
1764.5	$2.9\times10^{-2}\pm5.6\%$	$3.6\times10^{-2}\pm4.7\%$	$4.8\times10^{-2}\pm3.5\%$	$4.8\times10^{-2}\pm3.5\%$

When the energy transition of interest is not available as point source, it is recommended to produce a fitted correction curve using energies as near as possible to that needed. Using this curve, a correction factor could be easily obtained for most of the required energy transitions. The results are presented at Fig 3.

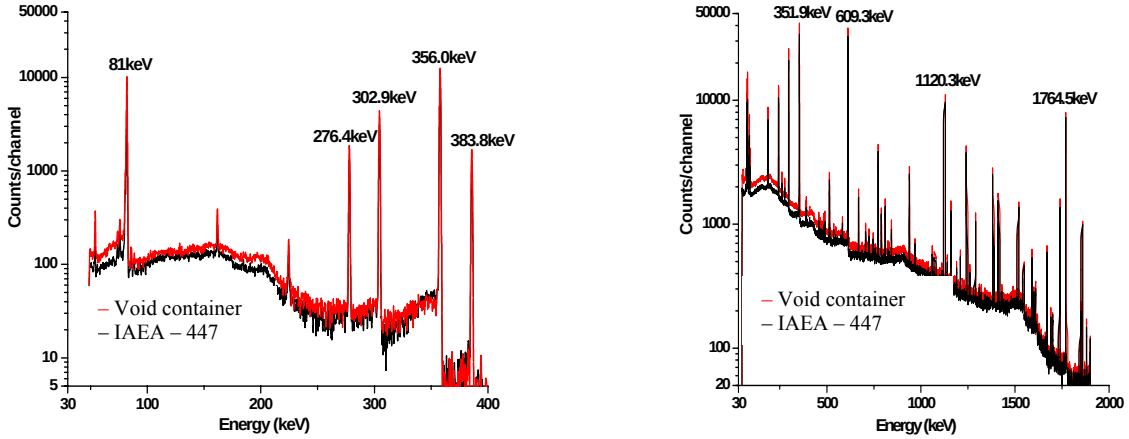
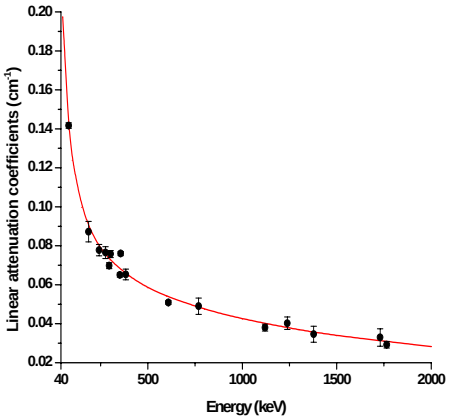
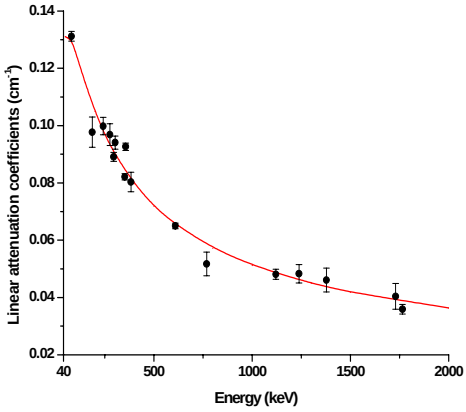


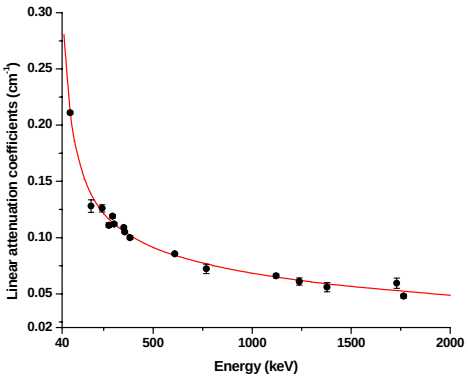
Fig 2. *Gamma spectra of ^{133}Ba and ^{226}Ra, back line and red line are filled sample, container void respectively*



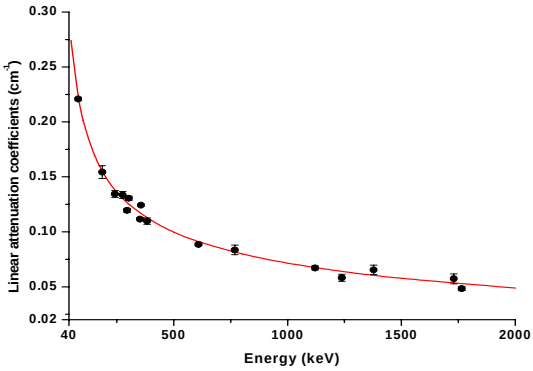
IAEA 434



IAEA 330



IAEA 447



IAEA 444

Fig 3. *Linear attenuation coefficients of IAEA samples*

4. Conclusion

The suggested procedure introduced in this work is an innovative, reliable and straightforward method to overcome the uncertainties produced due to the difference in samples matrices and densities. It also minimizes the measurement uncertainties.

This method could be adopted within the laboratories encountering wide varieties of samples for analysis if unknown material clearly.

Finally, the applicability of this method is almost unlimited as long as the sample is homogenous.

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