SAKARYA ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ
SAKARYA UNIVERSITY JOURNAL OF SCIENCE
e-ISSN: 2147-835X
Dergi sayfası: http://dergipark.gov.tr/saufenbilder

Geliş/Received
19.10.2016
Kabul/Accepted
15.02.2017

Doi
10.16984/saufenbilder.298942

Gamma-ray spectrometry for linear attenuation coefficients and self-attenuation correction factors of the skimmed milk powder

Yusuf AĞUŞ*

ABSTRACT

In this study, gamma-ray linear attenuation coefficients (μ), self-attenuation correction factors (F_{att}) and transmission factors (I/I_0) for the skimmed milk powder were determined experimentally. For this purpose, n-type 20% HPGe detector was used. Linear attenuation coefficients (μ) and self-attenuation correction factors (F_{att}) were obtained for the 30.9, 59.5, 80.9, 276.4, 302.9, 356.0, 661.6, 1173.2 and 1332.5 keV gamma-ray energies. Measured linear attenuation coefficients were 0.335, 0.150, 0.137, 0.084, 0.080, 0.078, 0.073, 0.052 and 0.049 cm^{-1}. Measured self-attenuation correction factors were 2.04, 1.41, 1.37, 1.22, 1.21, 1.20, 1.19, 1.13 and 1.12.

Keywords: Linear attenuation coefficient, gamma-ray spectrometry, self-attenuation correction factor, skimmed milk powder.

Yağsız süt tozunun gama ışını lineer inceltme katsayıları ve inceltme düzeltme faktörleri için gama spektrometri

ÖZ

Bu çalışmada, yağsız süttozu için geçirgenlik faktörleri, dahili inceltme düzeltme faktörleri ve gama ışını lineer inceltme katsayıları deneysel olarak bulunmuştur. Bu amaçla, n-tipi % 20 HPGe dedektör kullanılmıştır. 30.9, 59.5, 80.9, 276.4, 302.9, 356.0, 661.6, 1173.2 ve 1332.5 keV gama enerjileri için lineer inceltme katsayıları(μ) ve dahili inceltme düzeltme faktörleri(F_{att}) elde edilmiştir. Ölçülen lineer inceltme katsayıları 0.335, 0.150, 0.137, 0.084, 0.080, 0.078, 0.073, 0.052 ve 0.049 cm^{-1} dir. Ölçülen dahili inceltme düzeltme katsayıları 2.04, 1.41, 1.37, 1.22, 1.21, 1.20, 1.19, 1.13 ve 1.12 dir.

Anahtar Kelimeler lineer inceltme katsayıları, gama-ışını spektrometri, dahili inceltme düzeltme faktörü, yağsız süt tozu.

* Sorumlu Yazar / Corresponding Author
* Sarayköy Nuclear Reasearch and Training Center , TAEK, 06983, Kahramankazan, Saray, Ankara, Turkey - yusufagus06@gmail.com

1. INTRODUCTION

Gamma-ray spectrometry is a primary radioanalytical spectroscopy technique. Gamma-ray spectrometry is non-destructive method used to identify and quantify gamma emitting radionuclides in a variety of matrices. Gamma-ray spectrometry is widely used for the environmental monitoring, assessing pollution levels and the radioactivity level measurements [1]. Generally the activity concentrations of these environmental samples are at low levels and have wide variety of the density and composition [2]. Due to the variety of the density and composition, at low gamma-ray energies self-attenuation corrections are attracts special interest [3,4,5,6].

Accuracy and precision of the radioactivity concentrations of the environmental samples are important. Therefore radioactivity concentration measurements must be done properly and relevant correction factors (correction factors for dead time, decay time, true coincidence and self-attenuation) must be applied correctly [7]. Especially, self-attenuation correction factors must be applied gamma-ray emitting radionuclide at the low energy region radioactivity determinations in different matrix. Important gamma-ray emitting radionuclides at the low energy region are ^{241}Am, ^{57}Co, ^{210}Pb, ^{238}U and ^{234}Th. Activity concentration is calculated by [7]

$$A = \frac{N}{\varepsilon f t m C_i} \quad (1)$$

where

N: net count rate of the gamma-ray energy
ε : detector efficiency of the gamma-ray energy
f : gamma-ray line intensity (%)
m : mass of the sample
t : counting time in second.
C_i : correction factors for decay time (sample collection - measurement)(C_1), decay during counting period(C_2), self-attenuation(C_3), true coincidence(C_4), random summing(C_5).

Measurement of the activity concentration requires the determination of the efficiency calibration. Some correction factors must be applied for efficiency calculation. One of the correction factors is self-attenuation correction factor (C_3). Gamma-ray emitted by radioisotope in sample has a probability of various interactions within sample. These interactions are compton scattering, photoelectric effect and pair production [8]. As a result of these interactions, gamma-rays attenuate in the sample. Gamma-ray attenuation is directly related with sample geometry and linear attenuation coefficient. Sample density, composition and gamma-ray energy are primary reason of the linear attenuation in the sample. The attenuation of the narrow beam of the gamma-ray passing through in material can be expressed as follows

$$I = I_0 \, e^{-\mu x} \quad (2)$$

where x is the path length(cm). μ is the linear attenuation coefficient(μ *(cm^{-1})*) of the material. μ is not known therefore must be determined [9]. μ may be calculated by measurements or computational techniques using composition and density. Using eq. (2) we obtain

$$\mu = -\frac{\ln\left(I/I_0\right)}{x} \quad (3)$$

where I is the gamma-ray radiation intensity transmitted through an absorber of thickness x, I_0 is the gamma-ray radiation intensity at zero absorber thickness.

Transmission measurements which were proposed by Cutshall et al. can be used to determine self-attenuation correction factor [10]. In this method, the number of counts of full energy peak is measured. For this purpose, a point source is positioned above the sample and empty sample container. Then the number of counts in the full energy peak of the standard air (I_o) and sample (I) are measured. For the calculation of the self-attenuation correction factor(F_{att}), empty container is used as reference and F_{att} is expressed as[5]:

$$F_{att} = -\frac{\ln\ (I/I_0)}{1-(I/I_0)} \quad (4)$$

where I is the peak count rates for the sample. I_0 is the peak count rates for air.

In this study, self-attenuation correction factor (F_{att}), linear attenuation coefficient (μ) and transmission factor values (I/I_0) were determined for 30.9, 59.5, 80.9, 276.4, 302.9, 356.0, 661.0, 1173.2 and 1332.5 keV gamma-ray energies.

2. MATERIALS AND METHODS

2.1. SAMPLING AND SAMPLE PREPARATION

Commercially available skimmed milk powder sample was collected in local market and brought in to the laboratory. Skimmed milk powder sample was dried at temperature of 100 °C until constant mass was obtained. Polypropylene cylindrical containers were used for sample preparation. Container had inner diameter 59 mm, height 49 mm and 1 mm wall thickness.

2.2. MEASUREMENT

Measurements were performed by using a gamma-ray spectrometer. The detector was n-type high-purity germanium (HPGe) detector. The detector had 20% relative efficiency and 46:1 Peak-to-Compton

ratio(P/C). The energy resolution of the detector was 1.80 keV for ^{60}Co (1332.5 keV) and 0.97 keV for ^{57}Co (122 keV) energies. ^{241}Am(46.5 keV), ^{137}Cs(661.6 keV) and ^{60}Co (1173.2 and 1332.5 keV) certified radioactive standard point sources were used for energy calibration of the detector.

The direct transmission method was used to calculate gamma-ray linear attenuation coefficients, self-attenuation correction factors and transmission factors. Point sources were placed on the sample container and the spectrum was collected. The counting time was 1000 s. Then same procedure were applied identical empty sample container. ^{241}Am (59.5 keV), ^{133}Ba (30.9, 80.9, 276.4, 302.9, 356.0 keV),^{137}Cs(661.6 keV) and ^{60}Co (1173.2, 1332.5 keV) certified radioactive standard point sources were used to obtain the photon energies. Radionuclide energies, half-lives and intensities are shown at Table 1.

Table 1. Radionuclide energies, half-lives and intensities [11]

Radionuclide	Energy(KeV)	Half-life (year)	Intensity (%)
^{133}Ba	30.9	10.539(6)	62.4 (7)
^{241}Am	59.5	432.6(6)	35.92 (17)
^{133}Ba	80.9	10.539(6)	33.31 (30)
^{133}Ba	276.4	10.539(6)	7.13 (6)
^{133}Ba	302.9	10.539(6)	18.31 (11)
^{133}Ba	356.0	10.539(6)	62.05 (19)
^{137}Cs	661.6	30.05 (8)	84.99 (20)
^{60}Co	1173.2	5.2711(8)	99.85 (3)
^{60}Co	1332.5	5.2711(8)	99.9826

3. RESULTS AND DISCUSSION

Experimentally obtained gamma-ray linear attenuation coefficients (μ (cm^{-1})), self-attenuation correction factors (F_{att}) and transmission factors (I/I_o) are represented in Table 2. Chemical and physical differences between the sample and the standard are one of the efficiency uncertainty sources and radioactivity measurement error in the gamma-ray spectrometry.

Table 2. Experimentally obtained gamma-ray linear attenuation coefficients (μ (cm^{-1})), self-attenuation correction factors (F_{att}) and transmission factors (I/I_o).

	Energy (keV)								
	30.9	59.5	80.9	276.4	302.9	356.0	661.6	1173.2	1332.5
I/I_o	0.19	0.48	0.51	0.66	0.67	0.68	0.69	0.77	0.78
μ (cm^{-1})	0.335	0.150	0.137	0.083	0.080	0.078	0.073	0.052	0.049
F_{att}	2.04	1.41	1.37	1.21	1.21	1.20	1.19	1.13	1.12

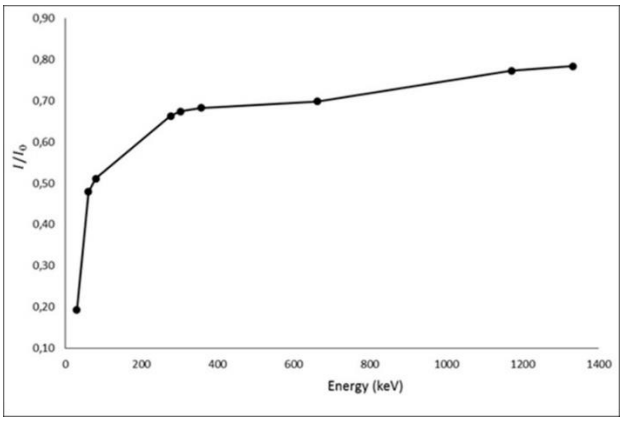

Figure 1. Transmission factor (I/Io) – Gamma-ray energy diagram.

At the low energy region (< 100–200 keV), efficiency uncertainty and radioactivity measurement error increases as the densities and *Z* of the samples increases. Therefore self-attenuation correction factors and transmission factors of the standard and the sample must be calculated.

The transmission factor defined as the ratios between the count-rate in a peak of the sample to the count-rate in the peak obtained with the empty container. As a function of the energy and transmission factors (I/I_o) diagram is shown in Figure 1. As can be seen from Figure 1., transmission factor increases as gamma-ray energy increases.

Using Eq. (3) linear attenuation coefficients for each gamma-ray energies were calculated. Relationship between linear attenuation coefficients and relevant gamma-ray energies was demonstrated. Linear attenuation coefficients and gamma-ray energy relations are shown in Figure 2. As can be seen from Figure 2., at low energies linear attenuation coefficients are high.

Therefore self-attenuation factor should be in to account in low energy region when the standard had different matrix from that of the sample. As the gamma-ray energy increases linear attenuation coefficients decreases.

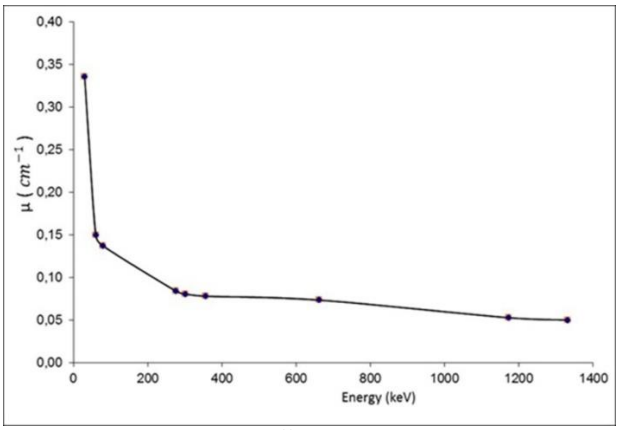

Figure 2. Linear attenuation coefficients – Gamma-ray energy diagram.

4. CONCLUSION

In this study, self-attenuation correction factors (F_{att}), gamma-ray linear attenuation coefficient (μ) and transmission factor values (I/I_0) for the skimmed milk powder were determined experimentally. Determination of the self-attenuation correction factor and linear attenuation coefficients are important for accurate radioactivity concentration measurements. Therefore gamma-ray energy dependence of the linear attenuation coefficients, self-attenuation correction factors and transmission ratios were evaluated.

Difference between matrix of the sample and standard must be accounted in the determination of the efficiency curve. Therefore self-attenuation coefficient (C_3) must be applied to the activity calculation for the accuracy and precision of the radioactivity concentration measurements. Neglecting this factor will give result in the underestimation or overestimation of the activity of a sample.

ACKNOWLEDGEMENT

This study was carried out within the routine activities of Radioactivity and Analytic Measurement Department of TAEK-SANAEM.

REFERENCES

[1] IAEA-International Atomic Energy Agency. "Naturally occurring radioactive materials (NORM IV)", IAEA-TECDOC-1472, Vienna, 2005.

[2] UNSCEAR. "United Nations Scientific Committee on the Effect of Atomic Radiation, Exposures from natural sources", Vol. 1., Annex B.,United Nations, 2000.

[3] S. Dziri , A. Nachab , A. Nourreddine , A. Sellam , A. Pape, "Elemental composition effects on self-absorption for photons below 100 keV in gamma-ray spectrometry", Nuclear Instruments and Methods in Physics Research B, 330, 1–6, 2014.

[4] A.E.M. Khater,Y.Y. Ebaid, "A simplified gamma-ray self-attenuation correction in bulk samples", Applied Radiation and Isotopes, 66, 407–413, 2008.

[5] E. Robu, C. Giovani, "Gamma-ray Self-Attenuatıon Correctıons In Envıronmental Samples", Romanian Reports in Physics, Vol. 61, No. 2, P. 295–300, 2009.

[6] M. Hasan, D. Biodizs, Sz. Czifrus,"A simplified technique to determine the self-absorption correction for sediment samples" , Applied Radiation and Isotopes, 57, 915–918, 2002.

[7] IAEA- International Atomic Energy Agency, "Guide Quantifying Uncertainty in Nuclear Analytical Measurements" , IAEA-TECDOC-1401, Vienna, 2004.

[8] R. Gilmore Gordon, "Practical Gamma-ray Spectrometry", 2nd ed., Sussex, ENGLAND:Wiley, 2008.

[9] K. Debertin and R.G. Helmer, "Gamma-ray and X-ray spectrometry with semiconductor detectors", New York, USA:Elsevier, 1988.

[10] N. Cutshall, IL. Larsen, CR. Olsen, " Direct analysis of Pb-210 in sediment samples: a self-absorption corrections", Nucl Instrum Methods Phys Res,206, 309−312, 1983.

[11]Nucleide-Lara, Library for gamma and alpha emissions, http://www.nucleide.org/Laraweb