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Determination of Self-absorption Correction Factors of Some Algae Samples: An Experimental Study

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Abstract: The purpose of this study to examine experimentally self-absorption correction factors (SACFs) of some algae samples using gamma-ray spectrometry. Various algae samples were collected from Boğaçay in Antalya, Turkey. Collected algae samples were dried, and masses of the samples were calculated. Then densities of the samples were calculated. Each of algaes was counted with and without point sources which are ^{22}Na, ^{60}Co, ^{133}Ba, and ^{137}Cs about 1000 seconds using high purity germanium detector. The SACFs of algae samples were determined between 80 keV and 1332 keV gamma-ray energies. As a result, SACFs of studied algae samples generally reduce as gamma-ray energy enhances. SACFs of some algae samples are higher at low photon energies because cross section of the photoelectric effect is higher at low photon energies.

Bazı Alg Örneklerinin Öz-soğurma Düzeltme Faktörünün Belirlenmesi: Deneysel Bir Çalışma

Anahtar Kelimeler
Alg,
Öz soğurma düzeltme faktörleri,
Gama-ışını spektrometresi,
HPGe dedektör

Öz: Bu çalışmanın amacı bazı alg örneklerinin öz soğurma faktörünü deneysel olarak gama spektroskopisini kullanarak belirlemektir. İncelenen alg örnekler Antalya ili Boğaçay bölgesinden toplanmıştır. Toplanan alg örnekleri kurutulmuş ve kütleleri hesaplanmıştır. Daha sonra örneklerin özkütleleri hesaplanmıştır. Her bir alg örneği yüksek saflıkta germanium dedektörü kullanılarak ^{22}Na, ^{60}Co, ^{133}Ba, and ^{137}Cs noktasal kaynaklar olmadan ve bu noktasal kaynaklar ile birlikte 1000 s sayılmıştır. Alg örneklerinin öz-soğurma düzeltme faktörü 80 keV ile 1332 keV gama enerji aralığında belirlenmiştir. Sonuç olarak, çalışılan alg örneklerinin öz-soğurma düzeltme faktörü değerleri genellikle gama enerjisi arttıkça azalmaktadır. Ayrıca, alg örneklerinin öz-soğurma düzeltme faktörü değerleri düşük foton enerjilerinde fotoeleketrik olayın tesir kesitinin düşük enerjilerde daha yüksek olmasından dolayı daha büyüktür.

1. INTRODUCTION

Nuclear weapons testing, authorized discharge of radioactive waste to shore, erosion, river transport, dissolution, diffusion, and wind-blown particles, in addition to naturally occurring radionuclides from the atmosphere, have all resulted in worldwide investigations of the radioactivity content of waters and the high seas [1]. When radioactive materials interact aquatic environment for a variety of reasons, they may remain in solution or suspension, precipitate at the bottom, or be consumed by organisms. As a result, they may cause radioactive contamination in the aquatic ecosystem.

Algaes are an important component of the marine ecosystem. Algaes are ubiquitous in the water system and have colonized almost every part of the globe [2]. Since ancient times, they have been used for food, feed, fertilizer, and medicine all over the world, and they are still used in skin care products today. They also contain a high concentration of biofunctional metabolites with potential health benefits [3]. Algaes are biological pointers of contaminants in the sea habitats due to their ability to accumulate radioisotopes, including low-level radionuclides in water [4]. As a result, analyzing marine organisms has become influential method for assessing

the quality of the marine environment. The existence of radionuclides in the sea habitat is the greatest concern because their existence may ascend ecological danger. Various studies have been carried out to investigate the activity concentration of naturally occurring radionuclides found in algaes [4-7].

Using high resolution gamma-ray spectrometry is a simple and influential method for precisely quantifying the natural radionuclide activity concentration of environmental materials like algaes in the scientific literature [8]. High-purity germanium (HPGe) detectors are widely utilized in gamma-ray spectrometry for activity measurements at low radioactivity levels and small sample amounts [9]. The primary superiority of HPGe detector is its high energy resolution, which provides discrimination among near-energy (several keV) emissions [10]. The efficiency curve for a fixed source-sample location is typically optimized in HPGe detector models [11]. The activity concentration of radionuclides connected with a gamma line is calculated by precisely determining its energy peak yield. The total energy peak efficiency of a sample can be calculated experimentally or numerically [12]. Different types of detector efficiency corrections must be applied for each measurement setup to achieve adequate analytical accuracy in gamma-ray spectrometry [13, 14].

Self-attenuation correction factors (SACFs) are of particular interest in sensitive gamma-ray spectrometry. Correction of photon attenuation of studied samples is a critical parameter in volumetric gamma-ray spectrometry [15,16]. The SACF is dependent on the physical properties of studied material. Some information about structure of the studied material can be evaluated by measuring this factor, which is distinguishing feature of the studied material. The self-absorption of gamma rays occurs in gamma spectrometry of environmental samples, reducing counting efficiency [17]. Therefore, determination of SACF of each sample is critical [18]. Furthermore, activity concentrations calculated for radionuclides with gamma emission energies in the small energy range may deviate significantly from expected values if self-absorption effects are not corrected for when the composition and densities of the actual sample differ greatly from those of the reference sample [19, 20]. Especially, at energies lower than 100 keV, the attenuation of gamma rays by the absorber material causes reducing of the photopic intensity in the spectrum [8, 21].

The elemental composition of samples with densities close to that of the reference sample is the primary source of count loss [22]. The bigger gamma-ray absorption is observed at the higher the atomic number of the substance [23].

As photons travel through the material, they interact with material in the form of scattering, absorption, or energy loss. Many factors influence the value of gamma-ray self-absorption. These are the contents of the components of the sample, its atomic density, its weight, and its dependence on gamma emission energy. [17, 24, 22]. Self-attenuation correction can be determined experimentally [13, 23, 24, 26], numerically [14, 27,], or analytically [14,15, 28].
Many researchers investigated the effect of SACF to calculate accurate activity concentration of the samples using gamma-ray spectrometry. [8, 21, 23, 29, 30-33]. The peak count ratio for given energy in a gamma-ray spectrum can easily be used to calculate the intensity of gamma rays at that energy.

The goal of this research is to determine SACFs of eight algae samples collected from Boğaçay in Antalya, Turkey. The SACFs of algae samples will be experimentally determined using the transmission method proposed by Cutshall et al [34].

2. MATERIAL AND METHOD

2.1. Locations of the Collected Algae Samples

Boğaçay is formed by the combination of the Doyran and Çandır Streams from Antalya Province Konyaaltı Region and the Karaman Stream from the North in Turkey. Eight algae samples from Boğaçay were collected. Table 1 and Figure 1 show coordinates of collected algaes and a mapping of the studied region based on the coordinates.

Table 1. Coordinates of the collected algae samples

Sample Name	Latitude	Longitude
A1	36° 52' 01"	30° 37' 07"
A2	36° 51' 58"	30° 37' 06"
A3	36° 51' 56"	30° 37' 06"
A4	36° 51' 49"	30° 37' 07"
A5	36° 51' 43"	30° 37' 04"
A6	36° 51' 28"	30° 37' 06"
A7	36° 51' 27"	30° 37' 16"
A8	36° 51' 20"	30° 37' 25"

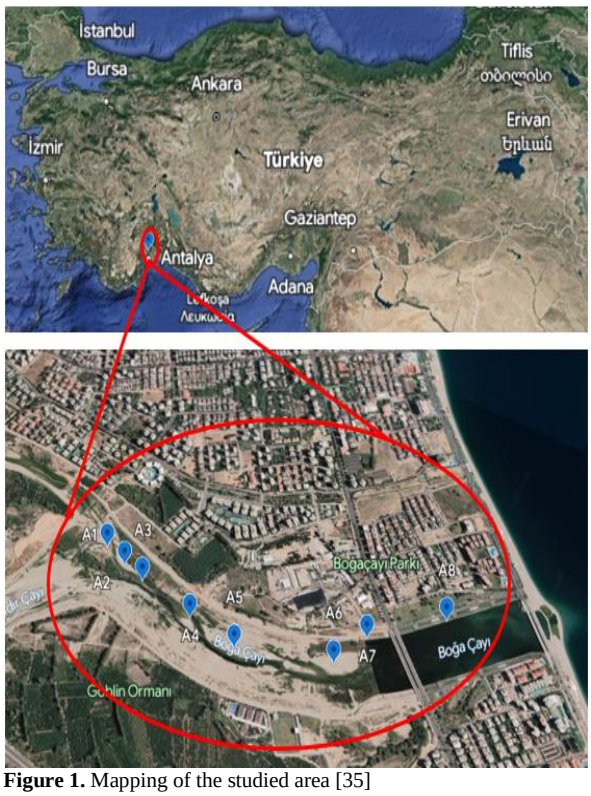

Figure 1. Mapping of the studied area [35]

2.2. Preparation of the Algae Samples

Eight algae samples were dried in environment for a week before being ground separately and passing through a 2 mm sieve. To calculate density of the of the algae samples, they were dried 24 hours at 80°C in vacuum oven. After drying of the algae samples, the samples were placed in 30 ml plastic containers and then the densities of the samples were calculated. Calculated bulk densities of studied algae samples are presented in Table 2. The bulk density or apparent density is calculated as $\rho = {}^{M}/_{V}$ where M is the oven-dry mass of the sample and V is the total volume of the sample [36, 37]. The bulk densities of the algae samples range from 0.154999 g/cm^3 to 0.626192 g/cm^3.

Table 2. Bulk densities of studied algae samples

Sample Name	Density (g/cm^3)
A1	0.487575
A2	0.396929
A3	0.527853
A4	0.626192
A5	0.20778
A6	0.248792
A7	0.154999
A8	0.230077

2.3. Counting of the Algae Samples by the HpGe Dedector

The SACFs of the algae samples were obtained using a HPGe detector by using four-point sources which were ^{22}Na, ^{60}Co, ^{133}Ba, and ^{137}Cs. The point sources were placed on the empty container and algaes samples, respectively to count of the gamma-rays about 1000 s. Schematic view of the experimental setup (see Fig.2) After analyzing of the obtained gamma-ray spectra using the MC^2 Analyzer Program [38].

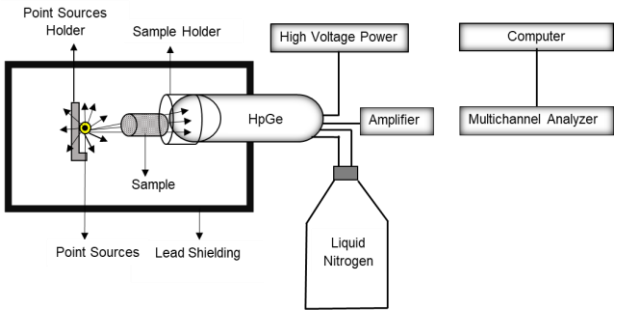

Figure 2. Schematic view of the experimental setup

2.4. Determination of the SACFs for the Algae Samples

The SACFs of algae samples were carried out experimentally using Cutshall's transfer model [34] is base of the SACFs calculations. Radioactive point sources are used to experimentally determine the SACFs using the Cutshall Method [23, 24]. The Cutshall's transmission method presumes that gamma rays disseminated by the sample have a parallel track for both sample and transmission measurements [39]. Therefore, following formula is used for parallel beams to obtain experimentally SACF of the studied samples [9, 25].

$$SACF = \frac{\ln \frac{I}{I_0}}{\frac{I}{I_0} - 1} \quad (1)$$

where I is the number of counts of the point sources with algae samples and I_0 is the number of counts of the point sources with air sample.

3. RESULTS

The SACFs of studied algaes dependent with gamma-ray energies vary as illustrated in Figure 3.

Obtained experimentally SACFs of A1, A2, A3 and A4 samples were fitted using exponential function (see Eq.2) and those of A5, A6 and A7 were fitted using power function (See Eq.3) as following functions (see eqs: 2 and 3):

$$y = a + b\exp^{(-cx)} \quad (2)$$

$$y = a + bx^{(c)} \quad (3)$$

Where a, b and c are fit parameters, x is related gamma-ray energy and y is the SACFs. The fit parameters and R^2 values of algaes (see Table 3).

The R^2 values of A1, A2, A3 and A4 are very high, and this value shows that the exponential fit model is suitable for experimental data of algae samples. The SACFs relative to air versus the energy for the A5, A6, A7 and A8 could not be fitted very well using exponential function therefore A5, A6 and A8 were fitted using power function. As illustrated in Figure 3, the SACFs of the A7 which vary nearly constant is not fitted using exponential or power functions. This situation can be explained that densities and elemental composition of the studied algae samples. Because the SACFs of the algae samples modify with elemental composition and density of the samples [22, 23, 40].

At low photon energies, the SACFs of algae samples are higher and at higher photon energies the SACFs of the algae samples are lower and they tend to be steady. Because the large atomic number of sample is the higher the interaction of the gamma-rays with it gets, and the cross section of the photoelectric effect of the samples is higher in the low photon energies and at middle photon energies, Compton scattering is effective [40, 41]. At higher photon energies, pair production is dominant [42].

Consequently, this study is an experimental study for the application of the Cutshall's transmission method and this method is fundamentally based on the normal incidence radiation hypothesis, which states that all gamma radiation reaching the detector follows a straight line through the source.

Table 3. Fit parameters and R^2 for the SACFs of algae samples relative to air sample

Sample No	*a*	*b*	*c*	R^2
A1	1.04269±0.00285	0.19242±0.01563	0.00509±5.27791E-4	0.97947
A2	1.03083±0.0056	0.12789±0.02312	0.00378±0.00101	0.90138
A3	1.04807±0.00539	0.26541±0.04076	0.00673±0.00124	0.93952
A4	1.04698±0.00459	0.30602±0.04005	0.00751±0.00117	0.95975
A5	1.04239±0.00689	-8.9595E-7±7.04026E-6	1.43857±1.06852	0.86551
A6	1.05113±0.01472	-6.0585E-6±6.23221E-5	1.19927±1.28356	0.72248
A7	Not fitted.			
A8	1.03949±0.01214	-9.11523E-7±1.42105E-5	1.41712±2.1189	0.60941

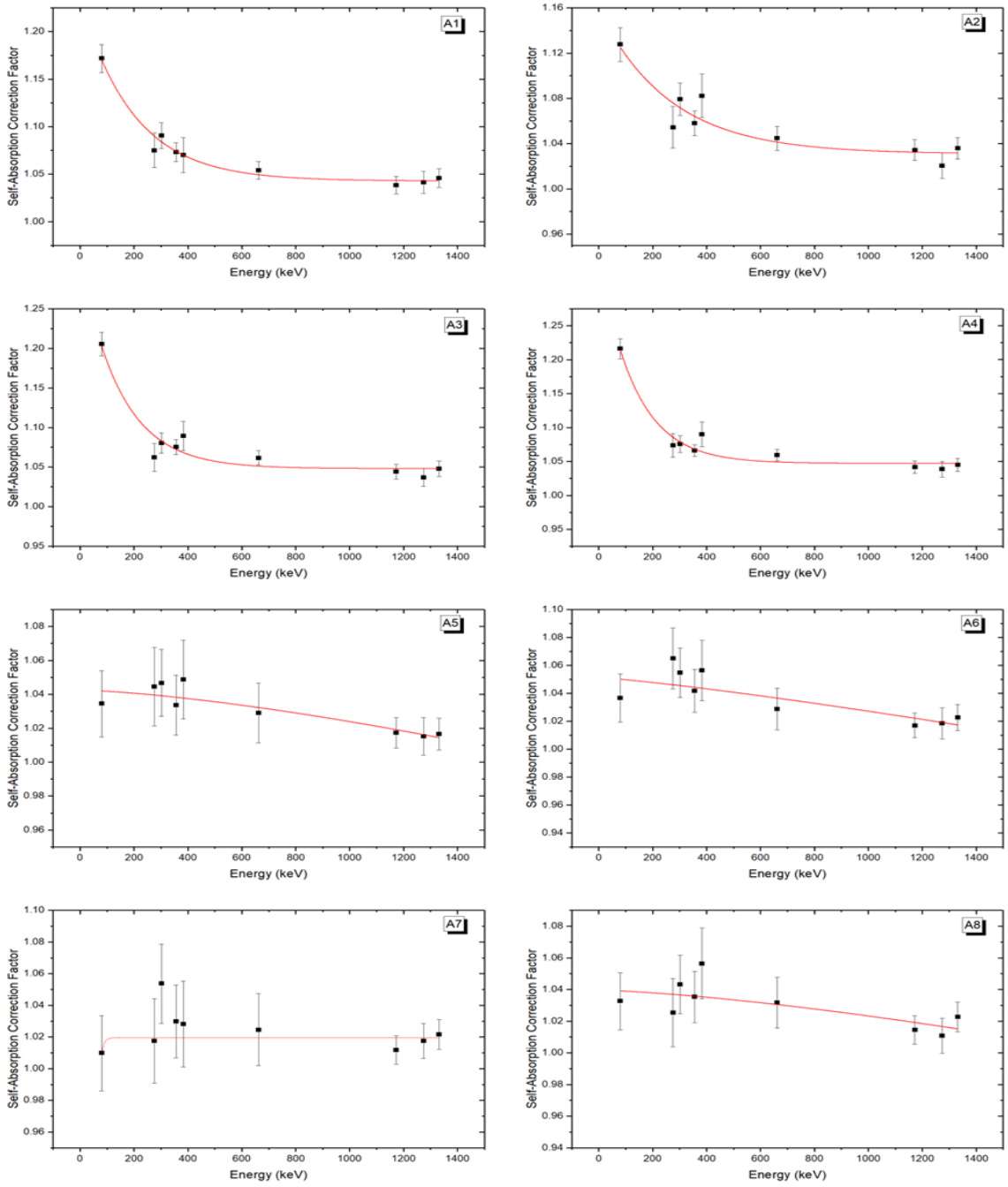

Figure 3. Variation of the SACFs relative to air of studied algae samples with photon energies

The path of gamma radiation within the source is determined by the source's origin and direction of emission [43]. This method determines the attenuated intensity of the source, as well as the difference

between the peak count rate at a given energy and the weldless working sample for a point source placed above the working sample.

4. DISCUSSION AND CONCLUSION

In this study, the SACFs of the algae samples collected from Boğaçay in Antalya, Turkey were determined experimentally using HPGe detector. Determination of the SACFs of the samples are significant to obtain accurate activity concentration of the samples if the geometry of the sample and reference material are different. The SACFs of the A1, A2, A3 and A4 are fitted exponential function and they are fitted power function for A5, A6 and A8 samples. As the density of the samples increase, the SACFs of the samples enhance. The significant differences can be found samples A1-A4 and A5, A6 and A8. These are due to the density of the composition of the studied algae samples. Besides, particularly, the SACFs of the algae samples are significant at low photon energies. At higher photon energies, the SACFs of the algae samples are lower and nearly steady due to the interactions of the gamma-ray with matter as photoelectric effect, Compton scattering and pair production. As a result, this paper is a new experimental example for determination of the SACs of algae samples using Cutshall's transmission method.

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REFERENCES

[1] Linsley G, Sjöblom KL, Cabianca T. Overview of the point sources of anthropogenic radionuclides in the oceans, in: Marine Radioactivity. Radioactiv. Environm. H.D. Livingston (Ed.). 2004;6.

[2] Peng C, Ma Y, Ding Y, He X, Zhang P, Lan T, et al. Influence of Speciation of Thorium on Toxic Effects to Green Algae Chlorella pyrenoidosa. Int. J. Mol. Sci. 2017; 18:795.

[3] Barrow C, Shahidi F. Marine nutraceuticals and functional foods. CRC Press, Boca Raton. 2007; 512.

[4] Tejera A, Pérez-Sánchez L, Guerra G, Arriola-Velásquez A, Alonso H, Arnedo M, et al. Natural radioactivity in algae arrivals on the Canary coast and dosimetry assessment. Sci. Total Environ. 2009; 658:122-131.

[5] Khandaker M, Heffny NAB, Amin YM, Bradley DA. Elevated concentration of radioactive potassium in edible algae cultivated in Malaysian seas and estimation of ingestion dose to humans. Algal Research. 2019; 38:101386.

[6] Uddin S, Bebhehani M, Sajid S, Karam Q. Concentration of 210Po and 210Pb in macroalgae from the northern Gulf, Mar. Pollut. Bull. 2019; 145:474-479.

[7] Shigeoka Y, Myose H, Akiyama S, Matsumoto A, Hirakawa N, Ohashi H, et al. Temporal Variation of Radionuclide Contamination of Marine Plants on the Fukushima Coast after the East Japan Nuclear Disaster. Environ. Sci. Technol. 2019; 53(16):9370-9377.

[8] Robu E, Giovani C. Gamma-ray self-attenuation corrections in environmental samples. Rom. Rep. Phys. 2009;61(2):295.

[9] Gouda MM, Hamzawy A, Badawi MS, El Hatib AM, Thabet AA, Abbas MI. Mathematical method to calculate full-energy peak efficiency of detectors based on transfer technique. Indian J Phys. 2016; 90:201–210.

[10] Guerra JG, Rubiano JG, Winter G, Guerra AG, Alonso H, Arnedo MA. Computational characterization of HPGe detectors usable for a wide variety of source geometries by using Monte Carlo simulation and a multi-objective evolutionary algorithm. Nucl. Instrum. Methods. Phys. Res. A. 2017; 858:113-122.

[11] Subercaze A, Sauzedde T, Domergue C, Destouches C, Philibert H, Fausser C, et al. Effect of the geometrical parameters of an HPGe detector on efficiency calculations using Monte Carlo methods, Nuclear Instruments and Methods in Physics Research Section A: Nucl. Instrum. Methods Phys. Res. A. 2022; 1039:167096.

[12] Mohebian M, Pourimani R, Modarresi SM. Using MCNP Simulation for Self-absorption Correction in HPGe Spectrometry of Soil Samples. Iran J Sci Technol Trans Sci. 2019; 43:3047–3052.

[13] Barba-Lobo A, Bolívar JP. A practical and general methodology for efficiency calibration of coaxial Ge detectors. Measurement. 2022; 197:111295.

[14] Sostaric M, Babic D, Petrinec B, Zgorelec Z. Determination of gamma-ray self-attenuation correction in environmental samples by combining transmission measurements and Monte Carlo simulations. Appl. Radiat. Isot. 2016; 113:110-116.

[15] Jodłowski P. Self-absorption correction in gamma-ray spectrometry of environmental samples - an overview of methods and correction values obtained for the selected geometries. Nukleonika. 2006;51(2): 21–25.

[16] Khater AEM, Ebaid YY. A simplified gamma-ray self-attenuation correction in bulk samples. Appl. Radiat. Isot. 2008; 66:407–413.

[17] Pourimani R, Mohebian M, Modarresi SM. Assessment of the Soil Self-Attenuation Correction Factor to Determine the Efficiency of a High-Purity Germanium Detector. Iran J Sci Technol Trans Sci. 2020; 44:311–317.

[18] Eke C, Boztosun I. Gamma-ray spectrometry for the self-attenuation correction factor of the sand samples from Antalya in Turkey. J Radioanal Nucl Chem. 2014; 301:103–108.

[19] Barba-Lobo A, Mosqueda F, Bolívar JP. A general function for determining mass attenuation

coefficients to correct self-absorption effects in samples measured by gamma spectrometry. Radiat. Phys. Chem. 2021; 179:109247

[20] McMahon CA, Fegan MF, Wong J, Long SC, Ryan TP, Colgan PA. Determination of self-absorption corrections for gamma analysis of environmental samples: comparing gamma-absorption curves and spiked matrix-matched samples. Appl. Radiat. Isot. 2004; 60 (2–4):571-577.

[21] Millsap DW, Landsberger S. Self-attenuation as a function of gamma ray energy in naturally occurring radioactive material in the oil and gas industry. Appl. Radiat. Isot. 2015; 97:21-23.

[22] Dziri S, Nachab A, Nourreddine A, Sellam A, Pape A. Elemental composition effects on self-absorption for photons below 100 keV in gamma-ray spectrometry. Nucl Instrum Methods Phys Res B. 2014: 330:1-6.

[23] Bonczyk M. Determination of 210Pb concentration in NORM waste – An application of the transmission method for self-attenuation corrections for gamma-ray spectrometry. Radiat. Phys. Chem. 2018; 148:1-4.

[24] Barros LF, Pecequilo BRS. Self-attenuation factors in gamma-ray spectrometry of select sand samples from Camburi Beach, Vitória, Espírito Santo, Brazil. Radiat. Phys. Chem. 2014; 95:339-341.

[25] Misiak R, Hajduk R, Stobiński M, Bartyzel M, Szarłowicz K, Kubica B. Self-absorption correction and efficiency calibration for radioactivity measurement of environmental samples by gamma-ray spectrometry. Nukleonika. 2011; 56:23-28.

[26] Bouisset P, Lefèvre O, Cagnat X, Kerlau G, Ugron A, Calmet D. Direct gamma-X spectrometry measurement of 129I in environmental samples using experimental self-absorption corrections. Nucl. Instrum. Methods Phys. Res.,Sect. A. 1999; 437(1):114-127.

[27] Eke C, Yildirim A. Experimental and Simulation Results of the Self-Absorption Correction Factors of Some Chemical Fertilizers in the Energy Range from 80 to 1332 keV. Bull. Russ. Acad. Sci. Phys. 2020; 84:1012–1021.

[28] Pilleyre T, Sanzelle S, Miallier D, Fain D, Courtine F. Theoretical and experimental estimation of self-attenuation corrections in determination of 210Pb by γ-spectrometry with well Ge detector. Radiat. Meas. 2006; 41(3):323-329.

[29] Bolivar JP, García-León M, García-Tenorio R. On self-attenuation corrections in gamma-ray spectrometry. Appl. Radiat. Isot. 1997; 48(8):1125-1126.

[30] Eke C, Agar O, Boztosun I, Aslan A, Emsen B. Determination of self-attenuation correction factor for lichen samples by using gamma-ray spectrometry. Kerntechnik. 2017; 82 (1):136-139.

[31] Cessna JT, Golas DB, Bergeron DE. Source self-attenuation in ionization chamber measurements of 57Co solutions. Appl. Radiat. Isot. 2016; 109:402-404.

[32] Boshkova T, Minev L. Corrections for self-attenuation in gamma-ray spectrometry of bulk samples Appl. Radiat. Isot. 2001; 54:777-783.

[33] Al-Masri MS, Hasan M, Al-Hamwi A, Amin Y, Doubal AW. Mass attenuation coefficients of soil and sediment samples using gamma energies from 46.5 to 1332 keV. J. Environ. Radioact. 2013; 116:28-33.

[34] Cutshall NH, Larsen IL, Olsen CR. Direct analysis of 210Pb in sediment samples: self-absorption corrections. Nucl Instrum Methods Phys Res.1983; 206:309-312.

[35] Google Earth; (2023) [cited 16 March 2023]. Available from: https://www.google.com/intl/tr/earth/

[36] Al-Shammary AAG, Kouzani AZ, Kaynak A, Khoo SY, Norton M, Gates W. Soil Bulk Density Estimation Methods: A Review. Pedosphere. 2018; 28(4): 581-596.

[37] Han Y, Zhang J, Mattson KG, Zhang W, Weber TA. (2016), Sample Sizes to Control Error Estimates in Determining Soil Bulk Density in California Forest Soils. Soil Sci. Soc. Am. J. 2018; 80: 756-764.

[38] MC2 Analyzer; (2022) [cited 2022 October 12]. Available from: https://www.caen.it/products/mc2analyzer/

[39] Lurian AR, Millward GE, Sima O, Taylor A, Blake W. Self-attenuation corrections for Pb-210 in gamma-ray spectrometry using well and coaxial HPGe detectors. Appl. Radiat. Isot. 2018; 134:151-156.

[40] Ba VN, Thien BN, Loan TTH. Effects of element composition in soil samples on the efficiencies of gamma energy peaks evaluated by the MCNP5 code. Nucl. Eng. Technol., (2021); 53: 337-343.

[41] Barba-Lobo A, Mosqueda F, Bolivar JP. A general function for determining mass attenuation coefficients to correct self-absorption effects in samples measured by gamma spectrometry. Radiat. Phys. Chem. 2022; 179: 109247.

[42] Gilmore GR. Practical Gamma-Ray Spectroscopy. 2nd ed. Warrington: Wiley; 2008.

[43] Barrera M, Suarez-Llorens A, Ruiz MC, Alonso JJ, Vidal J. Theoretical determination of gamma spectrometry systems efficiency based on probability functions. Application to self-attenuation correction factors. Nucl. Instrum. Methods. Phys. Res. A. 2017; 854:31-39.