Determination of Attenuation Coefficients of Some Selected Soil Samples by Using Gamma Energy at 0.360 Mev

Abdu Hamoud Al-khawlany[*1, 2], J. M. Pathan[3], Ifra Fatema[3]

[1]Department of Physics, Dr. Babasaheb Ambedkar University, Aurangabad-431001, India

[2]Department of Physics, Faculty of Education & Languages, Amran University, Amran, Yemen

[3]Department of Physics, Maulana Azad College, Dr. Babasaheb Ambedkar University, Aurangabad-431001, India

abdu.alkhawlany@gmail.com

Abstract

The study of attenuation coefficients of various materials is an important part of research in radiation physics, chemistry, human health, and agriculture. In addition, the linear and mass absorption coefficients have a major role in the estimation of absorbed dose use in the medical and radiation dosimetry. In this paper, the liner and mass absorption coefficients, half-value layer, tenth value layer, and mean free path have been determined by performing the experiment of gamma irradiation on soil samples for gamma energy 0.360 MeV using NaI(Tl) detector. Furthermore, the physicochemical properties of the investigated soil samples were measured using standard methods to assess soil quality. Samples of soil were collected from different sites of Aurangabad-India and prepared using standard techniques. The mass attenuation coefficient decreases exponentially with increasing density and confirms the interaction of gamma-ray with different soil samples of various components. The mass absorption coefficient depends on sample density, gamma energy, the chemical composition of the soil, and its physical properties. The experimentally measured values are in good agreement which validates the gamma absorption law. Generally, the absorption coefficients of gamma-ray measured in this study can be used for the determination of gamma-ray interaction with any soil samples. The study has practical importance to know the nature of the soil to be used in agriculture and construction purposes.

Keywords: Gamma-Ray, Attenuation Coefficient, Multichannel Analyzer, Density, Soil.

Introduction

The study of the interaction of nuclear radiations with materials is an important research field for the development of materials that may be utilized for high environmental radiation [1]. These radiation shielding materials have great importance for several scientific, engineering, and medical applications. The data based on linear and mass attenuation coefficients, half-value layer, tenth value layer and mean free path is extremely useful for the purpose to identify the various radiation shielding materials. The mass attenuation coefficient (μ_m) is a measure of the probability of interaction that occurs between incident gamma-ray and matter per unit mass per unit area. The knowledge of μ_m of X-rays and gamma-ray in chemical, biological, and other important materials is of significant practical interest for industrial, biological, agricultural, and medical applications [2, 3]. Accurate data of attenuation coefficients of photons are required to provide fundamental data in many fields such as nuclear medicine, radiation protection, nuclear diagnostics, radiation dosimetry, shielding, and radiation physics. Determination of the chemical composition of soil such as P, K, N, Ca, Mg, Na, Fe, Mn, etc., as well as the physical properties such as density, porosity, organic matter, particle size distribution (sand, silt, clay) and moisture, are the most important parameters to evaluate soil quality. Gamma-ray interaction with the soil depends on chemical and physical properties [4, 5]. Several studies discussed the physical effects of a gamma-ray beam passing through matter as a basis for soil density, moisture, porosity, and field capacity determination. Gamma-ray which passes through the material makes either absorbed or scattered. The attenuation coefficient is a very important criterion for describing the transmission of radiation within the soil. The accurate measurement is important to obtain the physical properties of the soil [6, 7]. The degree of attenuation coefficient depends on several factors like the sample density, sample composition, photon energy, and the length of the radiation path within the material. Recently, many studies related to the measurement of the photon shielding parameters such as linear attenuation coefficient, mass attenuation coefficient, half-value layer, tenth value layer, and mean free path for different types of materials have been published [8-10]. The present study aims to determine attenuation coefficients for the selected soil samples using gamma energy at 0.360 MeV. We investigated the linear and mass attenuation coefficients, half-value layer, tenth value layer, and mean free path of soil samples using gamma-ray spectrometry with a source of ^{133}Ba at the energy of 360 KeV. Furthermore, the chemical and physical properties have been examined in soil.

Calculation Method

The linear attenuation coefficient is determined by the following equation:

$$I = I_0 \, exp \, (\mu_m \, \rho L \,) \quad (1)$$

where I_o is the incident γ-ray intensity and I is the transmitted γ-ray energy, L is the thickness and μ_m is the mass absorption coefficient and is related to the linear absorption coefficient as:

$$\mu_m = {}^{\mu}/_{\rho} \quad (2)$$

where ρ is the density of the sample used. Half-value layer (HVL) is the thickness of the shield at which the initial radiation intensity is reduced by one half and it is related to μ; is calculated by the following equation:

$$HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \quad (3)$$

where μ (cm^{-1}) is the linear attenuation coefficient of the sample. Similarly, the Tenth value layer (TVL) is defined as the thickness of shield required for attenuating a radiation beam to one-tenth of its initial intensity and is computed by the following relation:

$$TVL = \frac{ln\ 10}{\mu} = \frac{2.303}{\mu} \quad (4)$$

Mean free path (λ) is defined as the average distance between two successive interactions and is calculated by the following equation:

$$\lambda = \frac{\int_0^{\infty} x \, exp\,(-\mu\, x)\, dx}{\int_0^{\infty} exp\,(-\mu\, x)\, dx} = \frac{1}{\mu} \quad (5)$$

where μ is the linear attenuation coefficient and x is the absorber thickness.

Experimental Details

Samples of soil were collected from various locations of Aurangabad-India and standard initial preparations of the samples were implemented that includes drying, powdering, and sieving. Gamma-ray spectrometry with NaI(Tl) detector was used for measuring the intensity of gamma rays (Fig. 1) and the source used was ^{133}Ba with gamma-ray energy of 360 KeV. It was well shielded using lead bricks. For the narrow beam setup, the gamma-ray beam from the source was collimated by using a cylindrical lead block with a central hole of diameter 1 cm. The transmitted beam was also collimated using a similar lead cylinder. The absorbers used were lead sheets of dimensions 5 cm×5 cm and had a thickness of 0.9 gm/cm^2. The detector was placed in a lead castle with proper shielding and arrangement was provided for placing the sample above the detector and at the top of the sample holder source with γ ray source was mounted at a fixed place. The multichannel analyzer used with the gamma-ray spectrometer had 8192 channels and the channel numbers were set corresponding to the gamma-ray photopeak of 360 KeV radiation from ^{133}Ba. An initial pulse height spectrum was obtained using a multichannel analyzer (MCA) without absorbers for Ba-133 as shown in Fig. 2.

Fig.1. Photograph of experimental set-up of attenuation of gamma-ray

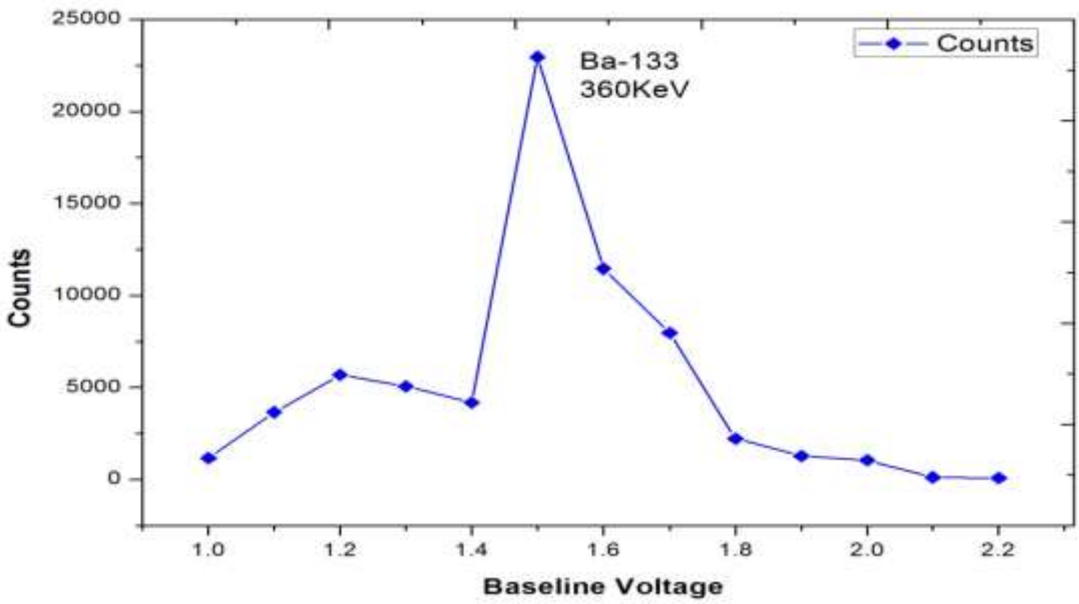

Fig. 2. A typical spectrum of gamma-ray without attenuation for Ba-133

The sample cell was a cylindrical container made of plastic and the powdered soil sample after due preparation was placed in the cell and the sample cell was placed in the sample holder provided in the detector housing. The diameter of the sample cell was 4.2 cm and the height was 5.1 cm thus the available volume is 70.62 cm^3. Once the gamma-ray scintillation counter assembly is ready and set to appropriate channel background count was found taking several readings. The incident gamma-ray intensity I_o was determined using the standard source keeping the channel number at the photo-peak of the gamma radiation used, and no sample in the sample cell. For determination of gamma intensity I at different sample thicknesses the sample cell was filled with a fixed amount of soil sample (say 1, 2,... cm thick layer) and kept between the source and detector in the sample holder present in the lead castle. Counting was done for a suitable time interval and several trials were used and the average count was recorded for each sample thickness used.

From the count representing the gamma-ray intensity, background count was subtracted to find I. A graph is plotted using incident intensity (I_o) divided by transmitted intensity (I) versus the sample thickness for each sample as shown in Fig.3. It is seen from Fig. 3 that all the points lay well along a straight line, the points plotted to represent the actual data i.e. the value of I_o/I corresponding to each thickness of the sample and the straight line joining to those points is the least square fit straight line. The equation shown in the inset of the graph is the equation to the fitting straight line and the slope is used for the calculation of the attenuation constant.

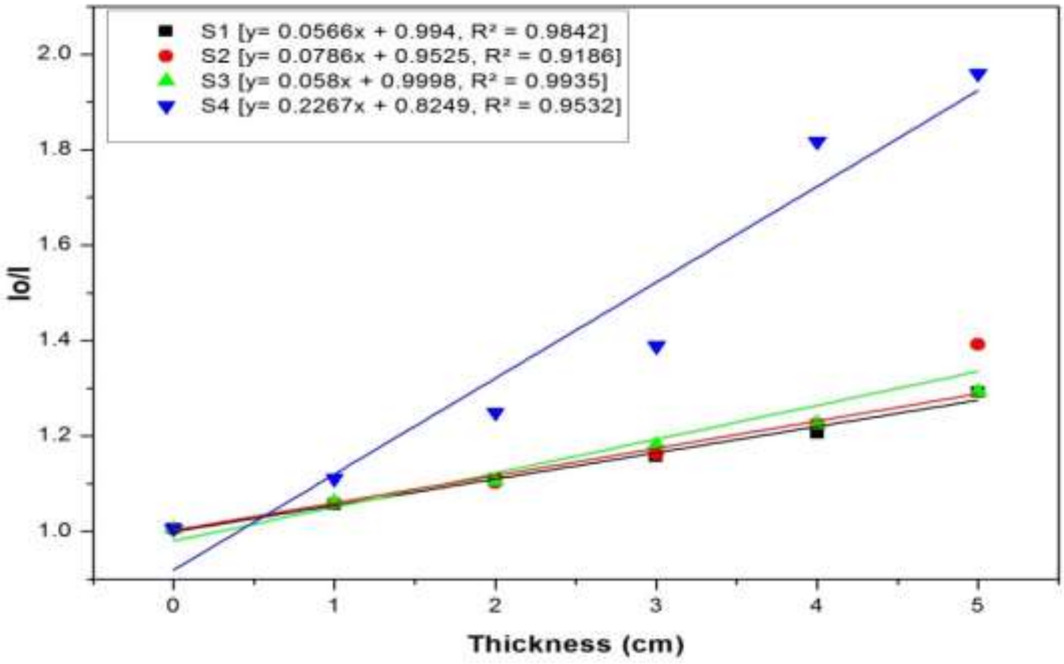

Fig.3. The thickness versus Io/I for the investigated soil samples

Results and Discussion

The linear and mass attenuation coefficients, half-value layer, tenth value layer, and mean free path for the selected soil samples have been determined for gamma radiation from ^{133}Ba with γ ray energy of 360 KeV using gamma-ray spectrometry and presented in Table1. It was noted that the experimental values of the number of particles of radiation counted without absorber (I_0) per the number of particles of radiation counted with an absorber (I) were linearly increased with increasing thickness. Moreover, as the density of soil increases, the mass attenuation coefficient decreases (Fig. 4). This confirms the contribution of photoelectric absorption, Compton scattering, and pair production to the absorption of gamma rays by the soil samples. It was observed that the linear attenuation coefficient ranged from 1.0520 to 1.0813 cm^{-1} and the mass attenuation coefficient ranged from 0.7687 to 0.9562 cm^2/gm in the selected soil samples.

Half-value layer (HVL), tenth value layer (TVL), and mean free path (MFP) are important parameters that reflect the fact that energetic photons have the capability to penetrate a sample with the increment of photon energy. Half value layer (HVL) and tenth value layer (TVL) are two important parameters in designing any radiation shielding since half-value layer and tenth value layer indicates the required thickness of an absorber to reduce the radiation level to half and one-tenth of its initial value respectively. The mean free path of any particular radiation represents the average distance between two successive interactions, the shielding properties of the present samples can be easily compared by studying this parameter for that particular kind of radiation. Three parameters namely, HVL, TVL, and MFP were calculated from linear attenuation coefficient values for each sample at gamma energy 360 KeV. We conclude that the half-value thickness and mean free path are mainly related to the density and then thickness and the atomic number of absorbing medium.

Moreover, the results of μ, HVL, TVL, and MFP parameters are depended on the mass attenuation coefficient. The linear attenuation coefficient μ is inversely proportional to HVL, TVL, and MFP.

Table 1. Attenuation coefficients of soil samples using Ba-133 of energy 360 keV

Sample No	Density (ρ) gm/cc	Slope (m)	Intercept on Y-axis (c)	μ (cm^{-1})	(μ/ρ) (cm^2/gm)	HVL (cm)	TVL (cm)	MFP (cm)
S1	1.3959	0.0566	0.9940	1.0730	0.7687	0.6459	2.1459	0.9320
S2	1.2662	0.0786	0.9525	1.0520	0.8308	0.6587	2.1888	0.9506
S3	1.2322	0.0580	0.9998	1.0713	0.8694	0.6469	2.1497	0.9334
S4	1.1308	0.2267	0.8249	1.0813	0.9562	0.6409	2.1298	0.9248

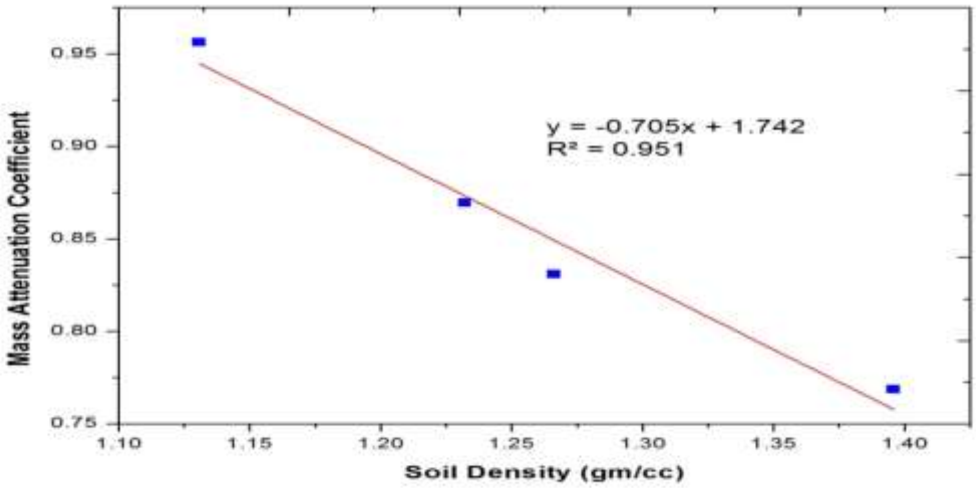

Fig.4. Mass attenuation coefficient versus the soil density at 360 keV

The chemical components and physical properties of the selected soil samples have been measured by using various standard analytical techniques and results are given in Tables 2 & 3. The studied soil samples have a different chemical composition (Fe, Mn, Zn, Cu, P, K, N, Ca, Mg, Na, and $CaCO_3$) with various concentrations. It is important to have in mind that different proportions of sand, silt, and clay will result in different soil textures. Soil texture is an important physical property related to several dynamic phenomena. The particle size analysis was used to measure the percentage of sand, silt, and clay in the soil. From Table 3 soil samples were classified as sandy, sandy loam, and loam sandy based on their different proportions of sand, silt, and clay.

The texture analysis was carried out according to the feel method. Sandy loam has the larger size of its particles, feels gritty. Whereas silt, being moderate in size, has a smooth or floury texture and clay loam has the smaller size of its particles, feels sticky. Sandy, sandy loam, and loam sandy soils demonstrate poor photon energy absorption characteristics (i.e. low μ, μ_m, HVL, TVL, and MFP) comparison to the clay and clay loam soils which have good photon energy absorption characteristics. These results because of the variation of the chemical compositional of the different types of the soils and the effects of the soil grain size on the gamma-ray attenuation. Generally, as the soil is characterized by a broad distribution of particle sizes, soils with different textures can also attenuate the radiation in a different manner. These results are majorly associated with chemical contents such as heavy metals Fe, Mn, Zn, and Cu.

Table 2. Some chemical contents of the investigated soil samples

Sample No	Fe ppm	Mn ppm	Zn ppm	Cu ppm	P Kg/ hect	K Kg/ hect	N Kg/ hect	Ca %	Mg %	Na %	$CaCO_3$ %
S1	24.53	10.34	1.19	0.25	25.16	324.24	425.39	43.04	5.48	79.40	1.25
S2	6.80	68.45	2.89	2.34	58.06	4509	102.49	26.52	7.05	74.20	6.25
S3	3.13	6.87	5.36	0.84	15.24	197.50	28.55	33.91	4.31	88.70	2.63
S4	7.06	15.25	1.56	1.21	12.34	142.58	61.42	30.43	6.66	11.20	2.25

Table 3. Physical properties of the investigated soil samples

Sample ID	Particle density (gm/cc)	Porosity (%)	Organic matter (%)	Moisture (%)	Particle size distribution (%)			Texture Classification (USDA) [11]
					Sand	Silt	Clay	
S1	2.54	50.08	0.67	2.61	87.63	6.49	5.80	Sandy
S2	2.33	45.06	1.45	5.49	71.68	17.41	10.54	Sandy loam
S3	1.91	43.51	1.12	3.66	79.21	6.81	13.10	Loam sandy
S4	1.75	48.25	0.98	4.36	85.19	5.34	9.43	Sandy

Conclusion

The liner and mass attenuation coefficients, half-value layer, tenth value layer, and mean free path for soil samples collected from the study area were measured using gamma-ray spectrometry NaI(Tl) detector for gamma radiation source ^{133}Ba at gamma-ray energy of 360 KeV. Furthermore, the chemical components, as well as physical properties, have been determined for soil. The mass attenuation coefficient values are useful for quantitative assessment of the interaction of gamma radiation with materials. It can be concluded from this work as density increases the mass attenuation coefficient of soil samples decreases, therefore, this conforms of exponential absorption law $I = I_0 e^{-\mu x}$ where x is the thickness of the sample. Generally, we concluded that the attenuation coefficients depend on the soil density, sample composition, and photon energy. This work is useful for the study of properties of the soils in agriculture and construction purposes.

Conflicts of Interest

Authors have declared no competing interests regarding the publication of this article.

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