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STUDY ON THE LINEAR ATTENUATION COEFFICIENT OF SOIL AND CONSTRUCTION MATERIALS IN BANGLADESH USING HPGe DETECTOR

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Abstract

The linear attenuation coefficient (μ) of some soil samples and construction materials has been investigated for eight gamma ray energies in the energy range from 80 keV to 1400 keV using a narrow beam collimator. It was observed that as the energy increases the linear attenuation coefficient (μ) of soil samples and construction materials decreases. The uncertainties of the measured values for the investigated materials are less than 4%.

Keywords: Linear Attenuation coefficient, Gamma radiation, Germanium detector, Construction materials, Soil

Introduction

The study of interaction of radiations with the materials of common and industrial use, as well as of chemical, biological, agricultural, medicinal and commercial importance has become major area of interest in the field of radiation science (Chaudhari, 1996, 2012). The uses of radioactive materials are increasing day-by-day and thus the risk of radiation hazard increasing. Protection from the radiation, shielding is the one of the basic method. Therefore, attenuation coefficient is very important research area for selecting of shielding materials. For finding out the suitability of soil samples and construction materials at different areas, knowledge of attenuating capacity of these samples used in Bangladesh is important. This is especially important for the radioactive waste management and the protection of human health from possible radiological hazards. Cesareo *et al.* (Cesareo, 1994) measured attenuation coefficients for soil in energy range 10-300 keV. Jahandirdar et al., also measured attenuation coefficients for narrow beam using broad beam geometrical configuration for 320 keV (Jahagirdar, 1992) and 145.5 keV photons (Jahagirdar, 1993). Midgley (Midgley, 2005) measured linear attenuation coefficient, μ of X-ray for low atomic number materials up to 140 keV. The gamma-ray attenuation coefficients for bismuth borate glasses were measured (Tamura, 2002). Khanna et al. had measured γ-ray attenuation coefficients in some heavy metal oxide borate glasses at 662 keV (Khanna, 1996). The attenuation coefficient of ammonium chloride for 662 keV gamma radiations measured for dilute solutions (Teli, 1996). Many authors have also used the NaI detector to measure the attenuation coefficients for diverse materials in their works. The NaI detector has comparatively a poorer resolution. Alam et al. also measured linear attenuation coefficient for soil samples from Cox's bazaar and Chittagong and building materials like concrete, Gypsum, mortor, mosaic stone, rutile and zircon in the energy range of 276–1332 keV (Alam, 2001) using HPGe detector of relative efficiency of 35% and resolution of 1.8 keV. So we are interested to study the linear attenuation coefficient (μ) of soils from several districts in Bangladesh and several types of building materials that regularly used all over the countries. The present work has been performed using high purity germanium (HPGe) detector of higher relative efficiency (40%) and resolution (2.0 keV).

Materials and Methods

Seven types of soil samples (Cultivated soil, Low land soil, High land soil, Red soil, Hilly soil, River soil and Pond soil) were collected from several districts (Dhaka, Gazipur and Banderban) in Bangladesh and also seven types of samples (two types of Sands, Brick, Portland cement, Limestone, Lime powder and Zinc oxide) which are frequently used as construction materials in Bangladesh were studied in this work. One of the sands was local and the other was collected from Sylhet and the rest of the construction materials were collected from the local market. All the samples were individually cleaned and dried at 105°C in an oven for about 72 hours to remove moisture and finally were crushed with mortar to get fine powder. The samples having thickness of 5.0 cm were stored into a cylindrical plastic container. A collimator was used to produce in a narrow beam geometry with the standard γ-point sources placed one after the other at a distance of 14 cm from the end cap of the detector the number of counts reaching the detector with and without the samples under study were recorded for a counting time of 10000 sec. High Purity Germanium (HPGe) detector was used in the experiment, which have effective efficiency 40% and resolution 2.0 keV at full-width at half-maximum (FWHM) at 1.33 MeV.

The linear attenuation coefficient of these materials was measured experimentally using the application of Lambert−Beer's law with standard transmission method by adopting narrow beam geometry. This process is described by the following equation:

$$I(x) = I_0 e^{-\mu x} \tag{1}$$

Where, I_0 and I are the incident and measured photon intensities, μ (cm^{-1}) is the linear attenuation coefficient and x is the thickness of the materials. The total uncertainty associated with the estimation of μ was less than 4%.

Results and Discussion

Before measuring the attenuation coefficient, one sample (Portland cement) was used for finding out the relation between the count rate and the sample thickness. The counts of each peak energy from 1 cm to 6 cm are given in Fig. 1. The slope of lines is not same for all energies. The dependency of count with sample thickness is different for diverse energies of γ-radiation. In Fig. 1 it is observed that the slope of the lines decreases with energies. The linear attenuation coefficient (μ) for different soil samples and construction materials are measured for eight energies in the range of 80 to1400 keV. Linear attenuation coefficients were measured at different types of energy levels that are shown in Table 1 and Table 2 for soil samples and construction materials respectively. It is observed that the coefficient value decreases with the raise of energies for both soils and construction materials. The measured uncertainties for soil samples and construction materials are less than 4%. Fig. 2 represents the variation of linear attenuation coefficient (μ) with energies for soil samples and Fig. 3 also represents it for construction materials. An interesting feature of Zinc Oxide has been observed that at the energy of 81 keV, the count of photon in the detector is totally absent. It means that zinc oxide absorbed all the energy of lower range, like 81 keV. Zinc oxide has the wurtzite hexagonal crystal structure.

Table 1: Linear Attenuation coefficient (μ_s) of soil materials

Energy (keV)	Cultivated Soil	Low Land Soil	High Land Soil	Red Soil	Hilly Soil	River Soil	Pond Soil
81	0.282219	0.381003	0.343024	0.449166	0.461118	0.477772	0.413304
276	0.121707	0.185374	0.160271	0.214804	0.213856	0.222101	0.189858
302	0.110613	0.167900	0.142090	0.195153	0.197730	0.197593	0.167936
356	0.097322	0.153714	0.131798	0.178224	0.178336	0.181185	0.150427
382	0.095769	0.146159	0.131905	0.167499	0.172084	0.17615	0.154282
662	0.070837	0.113550	0.099607	0.123285	0.136199	0.141411	0.119781
1173	0.055027	0.080139	0.074224	0.096176	0.101973	0.100485	0.086084
1332	0.047677	0.076422	0.065040	0.092613	0.097447	0.090707	0.082717

keV means kilo-electron volt

Table 2: Linear Attenuation coefficient (μ_{cm}) of construction materials

Energy (keV)	Normal Sand	Sylhet Sand	Brick	Portland Cement	Lime Stone	Lime Powder	Zinc Oxide
81	0.439641	0.413501	0.394738	0.440635	0.477078	0.273879	---
276	0.221248	0.214519	0.199216	0.208367	0.222101	0.138712	0.167155
302	0.207209	0.197586	0.173562	0.182015	0.188923	0.11916	0.154706
356	0.190711	0.185831	0.164346	0.172364	0.173533	0.111973	0.139927
382	0.18204	0.17616	0.153722	0.154531	0.156878	0.107146	0.131603
662	0.141579	0.142067	0.119795	0.115302	0.110773	0.081917	0.101391
1173	0.114866	0.113906	0.093132	0.089994	0.083074	0.061796	0.081092
1332	0.104555	0.101404	0.09081	0.084986	0.07973	0.059071	0.076413

keV means kilo-electron volt

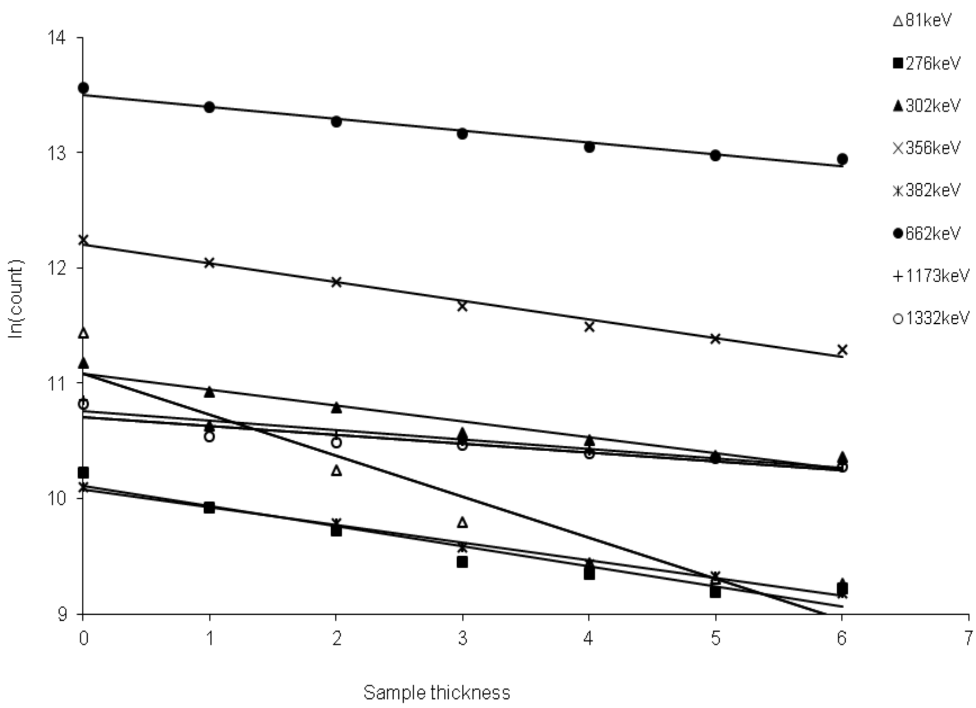

Fig. 1: Variation of counts with thickness

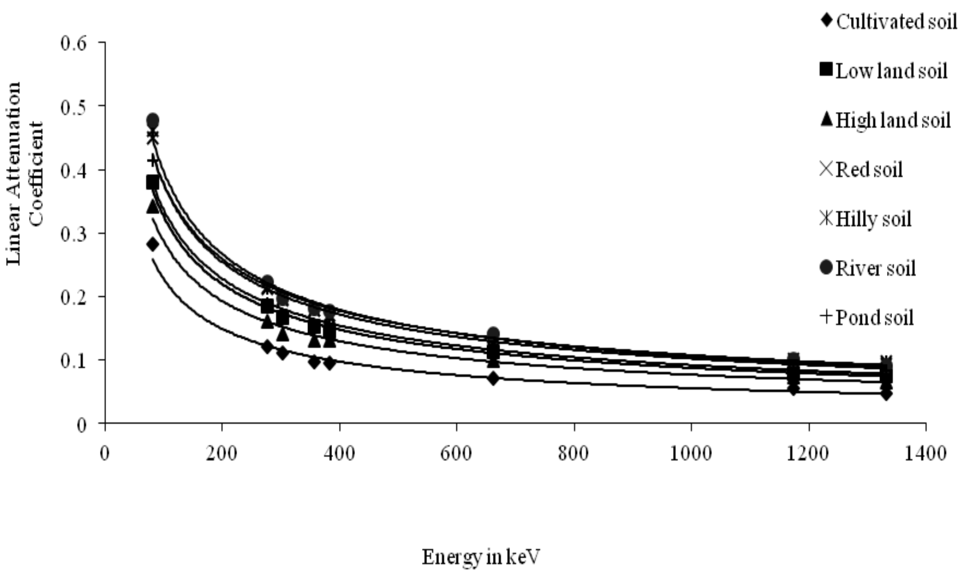

Fig. 2: Variation of Linear attenuation coefficient (μ_s) with energy for soil samples

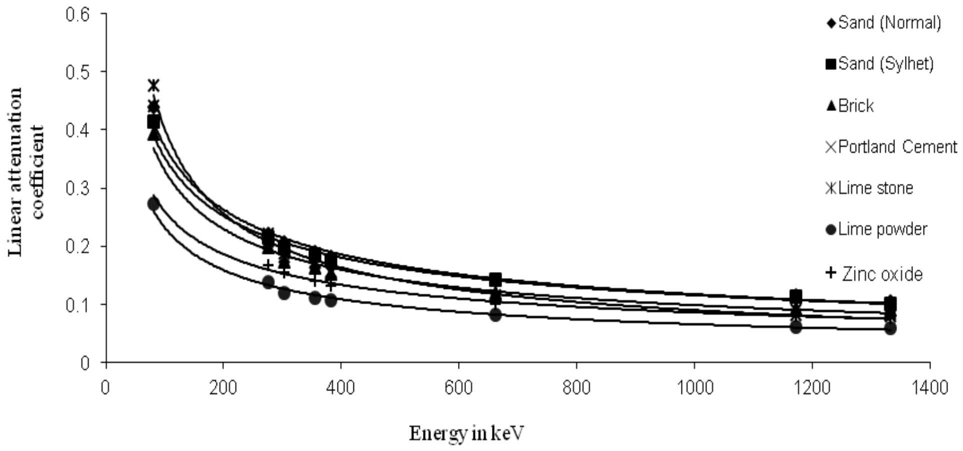

Fig. 3: Variation of linear attenuation coefficient (μ_{cm}) with energy for construction materials

It is composed of stoichiometric excess of zinc ions which occupy interstitial locations in the crystal lattice. Due to the structural effects, zinc oxide is transparent to visible light but strongly absorbs high frequency electromagnetic wave like γ-radiation, X-ray and ultra violet light below 3655 Å.

All the fitted curves for soil samples and building materials can be described by a power series of equation.

$$y = A\,x^{-B} \tag{2}$$

Where, y = Attenuation coefficient of this curve, x = Energy in keV and, A and B are constants. The constant values of A and B and square regression coefficient R^2 are given in Table 3 and Table 4 for soil samples and construction materials respectively. On examination of the measured photon linear attenuation coefficient μ for soil samples and construction materials across the energy range 80 keV to 1400 keV, it is observed that the results in soil samples and construction materials are slightly different. These may be due to the compositional variation among the different types of soil and construction materials.

Table 3: Value of A, B and R^2 for soil samples

Sample Name	Value of A	Value of B	Value of R^2
Cultivated soil	3.817	0.612	0.988
Low land soil	4.527	0.571	0.997
High land soil	3.986	0.572	0.992
Red soil	5.097	0.566	0.992
Hilly soil	4.653	0.545	0.988
River soil	5.565	0.573	0.991
Pond soil	4.505	0.563	0.986

A and B are constants in Eq. (2)

R^2 is square regression coefficient in Fig. 2

Table 4: Value of A, B and R^2 for construction materials

Sample Name	Value of A	Value of B	Value of R^2
Sand (Normal)	3.715	0.499	0.991
Sand (Sylhet)	3.262	0.483	0.991
Brick	3.691	0.524	0.987
Portland cement	5.469	0.587	0.989
Lime stone	7.952	0.648	0.991
Lime powder	2.869	0.546	0.992
Zinc oxide	2.359	0.479	0.990

A and B are constants in Eq. (2)

R^2 is square regression coefficient in Fig. 3

Conclusion

Attenuation is an important parameter to know how much energy is absorbed by various components in the soil samples and construction materials. This data is useful for deposition of radioactive waste and radiation protection. One can calculate attenuation coefficient of these sample using power series of Eq. 2 within or beyond the energy range of 80 to 1400 keV. One can also measure the mass attenuation coefficient (μ_m) using the formula, $\mu_m = \frac{\mu}{\rho}$; where ρ is the density of the material. Our result gives the validity of the experimental absorption law, $I(x) = I_o e^{-\mu x}$. Alternatively one can also determine the theoretical attenuation coefficient values from this equation in any range. So further experimental is needed to establish these theoretical values which will help in future for the selection of soil and materials to the modern construction.

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