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ANALYSIS OF HALF VALUE LAYER (HVL), TENTH VALUE LAYER (TVL) AND MEAN FREE PATH (MFP) OF SOME OXIDES IN THE ENERGY RANGE OF 122KeV to 1330KeV

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ABSTRACT

In the present work half value layer (HVL), tenth value layer (TVL)and mean free path (Mfp) are the most frequently used important parameter for explaining both the penetrating ability of particular radiations and the penetration through specific objects or material. The half value layers (HVL), tenth value layers (TVL) gives the thickness of a shield or an absorber that reduces the radiation level by a factor of one-half and one tenth of the initial level, respectively. The concepts of HVL and TVL are widely used in shielding design. In the present investigation we calculated the values of linear attenuation coefficient, mean free path (MfP), half value layer (HVL) and tenth value layer (TVL) for some oxides such as aluminum oxide, manganese oxide, copper oxide and magnesium oxide in the energy range from 122keV to 1330keV were measured. The transmitted intensity of photons emitted by radioactive isotopes of 133Ba, 22Na, 137Cs, 54Mn and 60Co measured using the NaI(Tl) scintillation detector and results obtained are in good agreement with the values reported in the present study.

KEYWORDS: Linear Attenuation Coefficient; Mean Free Path; Half Value Layer; Tenth Value Layer

In recent years the study of interactions of radiation with different material has become an important in our routine life, especially in medical applications and it gives the increasing use of radioactive isotopes in different fields. Data on the attenuation of gamma-rays with matter is extremely useful for many scientific, agriculture, engineering, shielding and medical applications (Singh *et al.,* 2006). The linear attenuation coefficient is extremely useful for characterizing the penetration and diffusion of gamma rays in the medium through which they passes. This mainly based on the photon energy, the nature of the selected material and the density of medium (Bashter, 1997). The interaction of photon of gamma radiation takes place various kinds of processes in the medium like photoelectric effect, incoherent scattering, coherent scattering and pair production and which is based on the energy of photon (Berger and Hubbell, 1987). The linear attenuation coefficient values of partial photon interaction processes such as photoelectric effect, Compton scattering, pair production and all these are available in the form of software package XCOM from Berger and Hubbell (1987). It is observed that the value of the linear attenuation coefficient depends on the incident photon energy and also depends on density ρ.

Now days the study of photon interaction with different materials has becomes more importance because of extensive use of radioactive sources in different field like medicine, industrial, biological, chemical and other field. The Oxide material covers a wide range of applications almost in every field. The study on the interaction of gamma radiation with selected oxide samples are of great interest from theoretical and experimental point of view. The linear attenuation coefficient of aluminum, manganese, copper, magnesium oxides in the energy range of 122-1330 keV are calculated. These values are calculated and compared with theoretical values calculated using XCOM program (Berger and Hubbell 1987 & 1999) are found to be good agreement between each other. Absorbed radiation can cause biological damage in living tissues and DNA Shielding is the basic very useful method for radiation protection (Akkaş, 2015).

It is not possible to attenuate the radiation completely, the radiation shielding properties should also be known. Half-value layer (HVL), tenth-value layer (TVL), and mean free path (mfp) are very essential theoretical parameters that are measured for gamma-ray shielding (Gundogdu *et al.,* 2016). The HVL represents the thickness of an absorber that will reduce the gamma radiation to half, while the TVL represents the thickness of an absorber that will reduce the gamma radiation to a tenth of its original intensity (Akkurt *et al.,* 2010). In this present investigation the HVL, TVL and mfp values for oxides are calculated for the energy of 122KeV to 1330KeV. HVL and TVL values are very useful parameter for understanding the penetrating ability of particular radiations through specific material.

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CALCULATION METHODS

Mass Attenuation Coefficient

The inverse exponential power law that in the present work we study some theoretical parameters of some oxide that have been used to determine the mass attenuation coefficient μ_m and other related parameters which are based on it. A parallel beam of the measured intensity I of the transmitted mono-energetic X-ray or γ-photons passing through matter is related to the incident intensity I_0 is usually referred to as Beer-Lambert law is given by the relation.

$$I = I_0 e^{-\mu_m X} \tag{1}$$

Where, I_0 and I are incident and transmitted photon intensities respectively,

X is mass per unit area (g/cm^2), μ_m is mass attenuation coefficient (cm^2/g) given by the following equation for a compound or mixture of elements (Jackson and Hawkes, 1981) (Hubbell and Seltzer, 1995): Solving the Eq. (1), we get the following equation for the linear attenuation coefficient (cm^{-1}):

$$\mu = 1/t \ln(I/Io) \tag{2}$$

Half Value Layer (HVL) and Tenth Value Layer (TVL)

The values of HVL and TVL thicknesses are calculated by using Eq.4 and Eq.5, respectively. The HVL and TVL are very important factor for calculations of sheling.

$$HVL = X_h = \ln 2/\mu, \tag{4}$$

$$TVL = X_t = \ln 10/\mu. \tag{5}$$

Mean Free Path

Mean free path Mean free path is the average distance at which a single particle travels through the medium of given sample before interacting it with material and is calculated by the following equation

$$X_m = 1/\mu. \tag{6}$$

EXPERIMENTAL DETAILS

We measured incident and transmitted photon energies by using a narrow-beam good geometry set up. Figure 1 shows the schematic view of experimental set up. In this study we use the radioactive sources, Co^{57} (122 keV), Ba^{133} (356 keV), Na^{22} (511 and 1275 keV), Cs^{137} (662 keV), Mn^{54} (840 keV) and Co^{60} (1170 and 1330 keV) which is obtained from Bhabha Atomic Research Centre, Mumbai, India. The emission of gamma radiation by these radioactive sources were collimated and detected with the help of NaI(Tl) scintillation detector. The Signals from the detector (2"×2") NaI (Tl) crystal having energy resolution of 8.2% at 0.662 MeV gamma rays from the decay of Cs^{137} after suitable amplification were recorded in an EG&G ORTEC 13-bit plug-in-card coupled with a PC/AT. Stability and reproducibility of the arrangement were checked before and after each set of runs. In order to minimize the effects of small-angle scattering and multiple scattering events on the measured intensity, the transmitted intensity was measured by setting the channels at the full-width half-maximum position of the photo-peak.

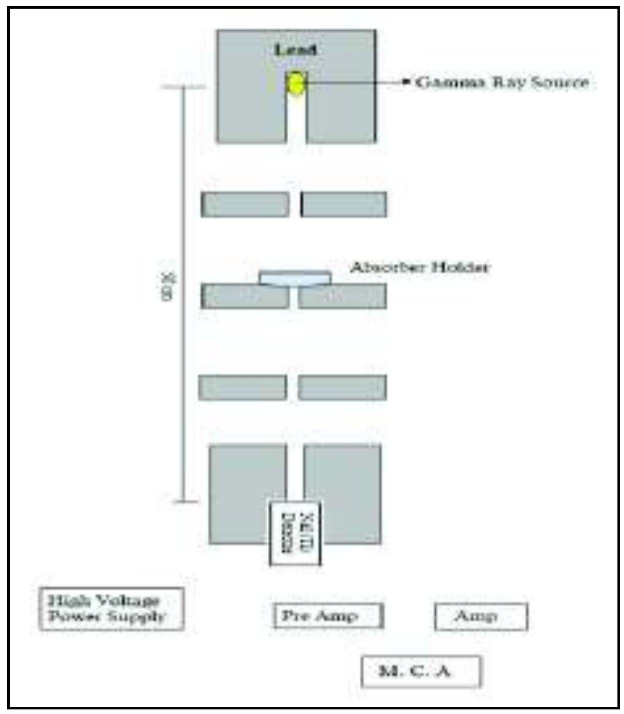

Figure 1: Narrow-beam Good Geometry Set-up

Pellet shaped uniform thickness of chosen oxides such as aluminum oxide (Al_2O_3), manganese oxide (MnO_2), copper oxide (CuO), magnesium oxide (MgO) under investigation were confined in a cylindrical plastic container with diameter similar to that of the sample pellet. The diameters of the sample pellets were determined using a traveling microscope. The attenuation of photons in the empty containers was negligible. Each sample pellet was weighted in a sensitive digital balance with an accuracy of 0.001 mg several times to obtain the average value of the mass. The mass per unit area was determined in each case using the diameter of the pellet and mean value of the mass of the pellet. The sample thickness was selected in order to satisfy the following ideal condition as far as possible (Creagh, 1987):

$$2 \le \ln(\frac{I_o}{I}) \le 4.$$

The Mass attenuation coefficients (μ/ρ) of all the samples of oxides were determined from the measured values of incident photon intensity I_0 (without sample) and transmitted photon intensity I that is with samples and mean values are used for the calculation of linear attenuation coefficients (μ) for all selected oxide sample. The experiments were conducted in an air-conditioned room to avoid possible shifts of the photo-peaks. Room temperature of 26 ± 1°C was maintained throughout the experimental period. Other sources of error, excluding multiple scattering and counting statistics, are small-angle scattering, sample impurity, nonuniformity of the sample, photo built-up effects, dead time of the counting instrument, and pulse pile effect which were evaluated and reduced.

The scattering angle was maintained in this study <30 min by proper adjustment the distance between the detector and source (30cm < d < 50 cm), due to the coherent and incoherent scattering at an angles calculated in the cross sections at intermediate energy range is very less or negligibly small (Hubbell, 1999). Hence, no small-angle scattering corrections were applied to the measured data. All the four oxides samples used in this study were of high quality sigma Aldrich and of high purity (99.9 %) without high-Z impurities. Hence, sample impurity corrections were not applied to the measured data.

In the presented investigation, uncertainty in the mass per unit area and the error due to nonuniformity of the sample are <0.05% for all energies of interest. Optimum values of count rate and counting time were chosen to reduce the effects of photon built-up and pulse piles. The photon built-up effect, which is a consequence of the multiple scattering inside the sample, depends on the atomic number and sample thickness, as well as the incident photon energy. A built-in provision for dead time correction was present in the MCA used during this investigation.

RESULTS AND DISCUSSION

In the present work, the values of linear attenuation coefficient μ of investigated oxides such as aluminum oxide, manganese oxide, copper oxide, magnesium oxide. The variation between experimental and theoretical values of μ (cm^{-1}) for all sample studied at 122, 360, 511, 662, 840, 1170, 1275- and 1330-keV photon energies are shown in Table 1, and those for all oxide samples are plotted in Figure 2. It can be observed from the figure and table that μ decreases with increasing photon energy. It is observed that he experimental values of μ agree with the theoretical values calculated using the XCOM program.

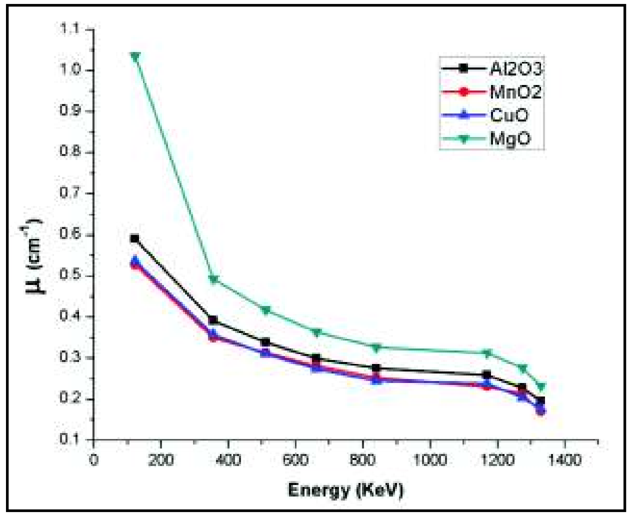

Figure 2: Typical Plot of μ versus Energy for Oxide

The total uncertainties in experimental values of μ depend on the uncertainties of I_0 (without attenuation), I (after attenuation) measurements of mass thickness values, and counting statistics. The estimated total uncertainty in the measured experimental values of μ was found to be in the range of 3-4%. The another important parameter The half-value layers, tenth-value layers and mean free paths of four oxide sample materials for different radiation energies levels from 122KeV to 1330KeV have been obtained and are presented in Table 2, 3 and 4 respectively and those for plotted in figure 3, 4 and 5. The mean free path, half value layer and tenth value layer of oxide increases with increases in energy of photon. It is found that the lower the values of half-value layers and tenth-value layers, the higher are the radiation shielding material in terms of the thickness requirements.

Table 1: Linear Attenuation Coefficient (μ) of Oxides

Energy	Al_2O_3		MnO_2		CuO		MgO	
Kev	Expt.	Theo.	Expt.	Theo.	Expt.	Theo.	Exp.	Theo.
122	0.5821	0.5901	0.522	0.5364	1.7163	1.7415	1.0202	1.0353
356	0.3787	0.3907	0.3492	0.3564	0.6499	0.631	0.4774	0.4925
511	0.3276	0.3388	0.3132	0.3096	0.5363	0.5232	0.4272	0.4171
662	0.291	0.299	0.2808	0.2736	0.448	0.4606	0.3769	0.3638
840	0.2751	0.2751	0.252	0.2448	0.4227	0.4101	0.3166	0.3266
1170	0.2511	0.2591	0.2304	0.2376	0.3849	0.3975	0.3015	0.3116
1275	0.2352	0.2272	0.2166	0.2038	0.347	0.3344	0.2613	0.2764
1330	0.2083	0.1953	0.1692	0.1764	0.2587	0.2776	0.2412	0.2311

Table 2: Half Value Layer (HVL) Thickness X_h (cm) for Oxides

Energy	Al_2O_3		MnO_2		CuO		MgO	
Kev	Expt.	Theo.	Expt.	Theo.	Expt.	Theo.	Exp.	Theo.
122	1.1905	1.1744	1.3276	1.2919	0.4038	0.3979	0.6793	0.6694
356	1.8299	1.7737	1.9845	1.9444	1.0661	1.0983	1.4516	1.4071
511	2.1154	2.0455	2.2126	2.2384	1.2922	1.3245	1.6222	1.6615
662	2.3814	2.3177	2.4679	2.5329	1.5469	1.5046	1.8387	1.9049
840	2.5191	2.5191	2.7511	2.8309	1.6395	1.6898	2.1889	2.1219
1170	2.7599	2.6746	3.0078	2.9167	1.8005	1.7434	2.2985	2.2241
1275	2.9464	3.0502	3.2994	3.4004	1.9971	2.0724	2.5521	2.5072
1330	2.4989	3.5484	4.0057	3.9286	2.5788	2.4964	2.9231	2.9987

Table 3: Tenth Value Layer (TVL) Thickness X_t (cm) for Oxides

Energy	Al_2O_3		MnO_2		CuO		MgO	
Kev	Expt.	Theo.	Expt.	Theo.	Expt.	Theo.	Exp.	Theo.
122	3.9557	3.9021	4.4111	4.2927	1.3416	1.3222	2.2571	2.2241
356	6.0803	5.8935	6.5939	6.4607	3.5431	3.6491	4.8232	4.6753
511	7.0287	6.7963	7.3519	7.4373	4.2935	4.4011	5.39	5.5205
662	7.9127	7.701	8.2001	8.4159	5.1397	4.9991	6.1093	6.3293
840	8.3701	8.3701	9.1373	9.4061	5.4474	5.6147	7.2729	7.0502
1170	9.1701	8.8869	9.9941	9.6911	5.9823	5.7927	7.6371	7.3896
1275	9.7901	10.135	10.9311	11.298	6.6357	6.8858	8.5581	8.3306
1330	11.454	11.791	13.2019	13.053	8.4007	8.2947	9.7464	9.9637

Table 4: Mean Free Path (Mfp) Thickness X_m (cm) for Oxides

Energy	Al_2O_3		MnO_2		CuO		MgO	
Kev	Expt.	Theo.	Expt.	Theo.	Expt.	Theo.	Exp.	Theo.
122	1.7179	1.6946	1.9157	1.8643	0.9802	0.9659	0.5826	0.5742
356	2.6406	2.5595	2.8637	2.8058	2.0947	2.0305	1.5387	1.5848
511	3.0525	2.9516	3.1928	3.2301	2.3408	2.3975	1.8646	1.9113
662	3.4364	3.3445	3.5613	3.6551	2.6532	2.7488	2.2321	2.1711
840	3.6351	3.6351	3.9683	4.0851	3.1586	3.0618	2.3657	2.4384
1170	3.9825	3.8595	4.3403	4.2088	3.3167	3.2092	2.5981	2.5157
1275	4.2517	4.4014	4.8268	4.9068	3.7171	3.6179	2.8818	2.9904
1330	4.9988	5.1203	5.7102	5.6689	4.2459	4.3271	3.7054	3.6023

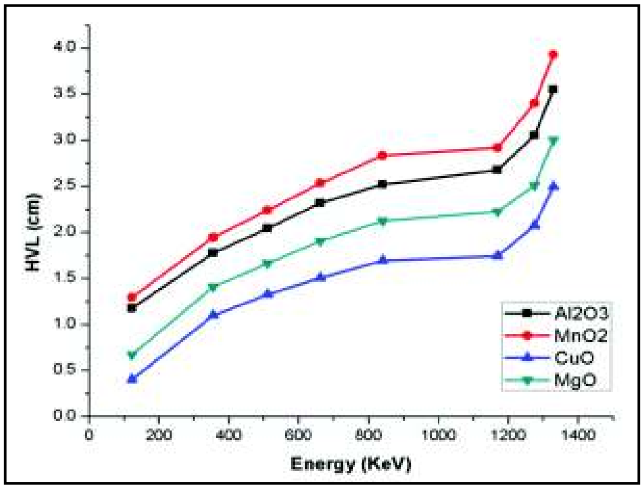

Figure 3: Typical Plot of HVL Thickness versus Energy

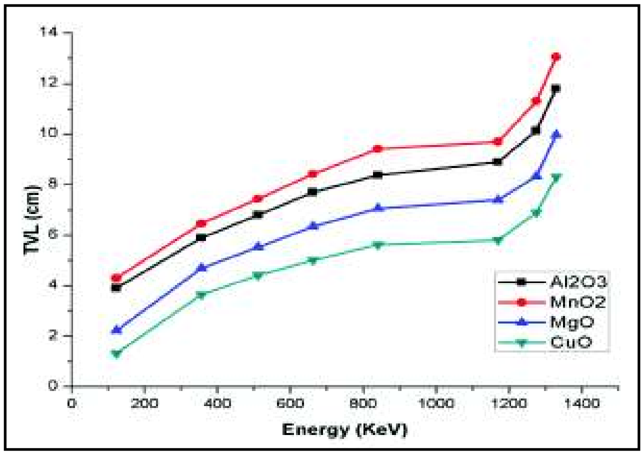

Figure 4: Typical Plot of TVL Thickness versus Energy for Oxide

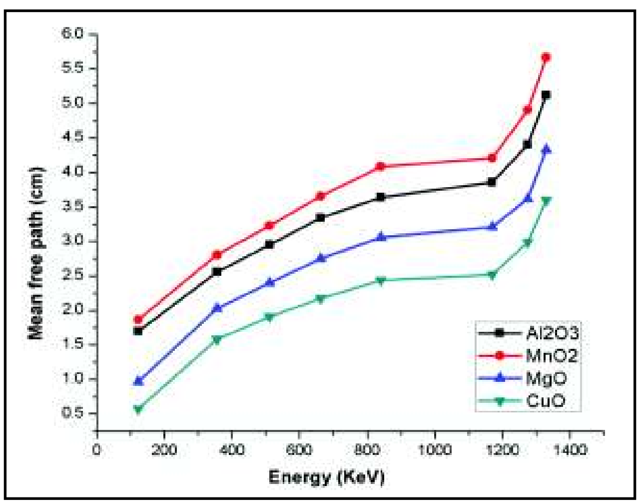

Figure 5: Typical Plot of Mean Free Path versus Energy of Oxide

CONCLUSION

The present experimental study was carried out to obtain information on linear attenuation coefficient, μ and related parameters such as half value layer (HVL), tenth value layer (TVL) and mean free path (mfp) for the selected four oxide samples. It has been found that μ is an extremely useful and sensitive physical quantity for the determination of these parameters for the chosen oxide samples. such as aluminum oxide(Al_2O_3), manganese oxide(MnO_2), copper oxide(CuO), magnesium oxide(MgO), are determined in the chosen energy range (122-1330 keV) which is emitted by the radioisotopes ^{60}Co, ^{57}C$_o$, ^{133}Ba, ^{54}Mn, ^{22}Na, and ^{137}Cs. For the interaction of photons with matter the values of that μ depend on the physical and chemical environments of the samples. It is found that from table and figure these values decrease with increasing photon energies. From the study it is clear that it depends totally on the number and nature of atoms. In the present work, it has been observed that the data on linear attenuation coefficient (μ) and other parameters are HVL, TVL and mfp are very useful in industrial, biological, technological, shielding and other applications, solar cell and recently in sensors field. The measured data were compared against Win-XCOM- based data the agreement within 3-4%.

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