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COMPREHENSIVE STUDY OF HEAVY METAL OXIDES AS GAMMA RAY SHIELDING GLASSES

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ABSTRACT

The goal of present work is to analyze gamma ray shielding properties of various metal oxides as reported by different research groups. Fundamental properties required for suitable shielding materials in the form of glasses are measured in terms of mass attenuation coefficient, half value layer, mean free path and effective atomic number. Six glass systems have been selected for investigation of gamma ray shielding properties.
Keywords:

INTRODUCTION

Due to highly ionizing and penetrating nature of gamma radiations, these can travel long distances and produce undesirable results on our lives. Gamma radiation exposure produces hazardous effects on medical, engineering, technology applications, radiation treatment rooms, agriculture, screening rooms in which radiations are used. Several measures are taken to protect our hostile environment from these harmful radiations in the form of shields. Different types of concretes are used for shielding against gamma radiations. Barite concrete is one of the concretes commonly used for shielding purposes with high mass attenuation coefficient for γ-rays (Singh et al, 2002). This concrete is also considered to be unfit for shielding gamma rays due to some drawbacks such as its non transparent nature, transportation difficulties or existence of cracks (Lee et al, 2007). Therefore, concretes are replaced by glasses which overcome the drawbacks of concretes and are transparent in nature as well as absorb gamma radiations to a large extent. Silicon and boron based glasses are used in preparing shielding materials but due to their low refractive index and poor optical properties, heavy metal oxides are replacing these glasses (Qi et al, 2010). The purpose of this study is to analyze different types of glass compositions and compare their shielding parameters in terms of mass attenuation coefficients ((μ/ρ), half value layer (HVL), mean free path (MFP) and effective atomic number (Z_{eff}).

MATERIAL AND METHODS

Glass compositions as studied by research groups A (Kirdsiri et al. 2011), B (Kumar et al. 2017), C (Kaur et al.2016), D (Tekin et al.2022) [8], E (Dogra et al. 2018) and F (Kaur et al.2015) have been analyzed in terms of their shielding properties. All samples are prepared by melt quenching technique. XRD study of samples has been done for identification of amorphous nature of samples. Density of these glass samples have been determined by Archimedes' principle as per the following relation:

$$\rho = \left(\frac{W_a}{W_a - W_b}\right)\rho_b \qquad (1)$$

Where W_a= weight of sample in air, W_b= weight of sample in benzene and ρ_b = density of benzene.

Density is measured in gcm^{-3} and can be used to extract the information regarding molar excess volume which is related to information regarding softness of the glass network.

Molar volume (V_m) is given by

$$V_m = \frac{M}{\rho} \quad (2)$$

Where ρ is density of the glass samples obtained by Archimedes' principle and M is molar mass of the prepared samples. It is measured in $cm^3 mole^{-1}$.

Mass attenuation coefficient is the fundamental property on which other parameters such as linear attenuation coefficient, half value layer, tenth value layer, mean free path , effective atomic number etc. are measured.

Mass attenuation coefficient is calculated by using following equation [11].

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

where ρ is the density of material (gcm^{-3}), I_o and I are the incident and transmitted intensities and x is the thickness of absorber in cm.

Theoretical values of mass attenuation coefficients have been calculated by using NIST XCOM software [4].

$$\text{Mass Attenuation Coefficient} = \Sigma_i w_i \left(\frac{\mu}{\rho}\right)_i \quad (4)$$

Where w_i is the weight fraction of i^{th} constituent elements and $(\mu/\rho)_i$ is the mass attenuation coefficients of i^{th} constituent elements.

The mass attenuation coefficient relates half value layer to linear attenuation coefficient (μ) by the formula

$$HVL = \frac{0.693}{\mu} \quad (5)$$

RESULTS AND DISCUSSIONS

Gamma ray shielding properties

Various glass systems as reported by different research groups have been given in Table 1.

Kirdsiri et al. 2011 investigated various systems and analyzed that mass attenuation coefficient at 662 keV was improved by adding Bi_2O_3 and PbO to the glass systems. Addition of heavy metal oxides raised the photoelectric absorption in glasses and Compton scattering interaction decrease with increase of Bi_2O_3 and PbO. Addition of BaO produces no significant change in attenuation of radiations. Bi_2O_3 and PbO shows better shielding properties than commercial window, barite and ferrite concrete whereas BaO does not exhibit better shielding properties in comparison with ferrite and barite concretes but better than ordinary concrete and commercial window only.

Kumar et al. 2017 measured attenuation coefficients at 356, 662, 1173 and 1332 keV and compared shielding properties with steel - magnetite concrete. Authors also measured radiation protection efficiency of glass materials. As reported by authors, the prepared glass system showed better properties due to lower values of mean free path as compared to steel-magnetite concrete. Mass attenuation coefficient and radiation protection efficiency increases with increase in incident energy of incident photons.

Kaur et al. 2016 studied the prepared glass system at 662 keV and compared shielding properties with barite concrete.

Addition of Bi_2O_3 increases the mass attenuation values and is found to be better than standard barite concrete. In this research, authors analyzed brittleness of the prepared glass system. It has been reported that increase of Bi_2O_3 increases brittleness of glasses due to increase in density and molar volume.

Tekin et al. 2022 examined glass system from 0.015 to 15MeV gamma ray energies.

Decrease in mass attenuation coefficient has been observed with increase in gamma ray energies. The glass system ZnO- BaO- PbO-Bi_2O shows better shielding properties as compared to PbO-Bi_2O-Tl_2O-GeO_2. These systems are also compared with concrete shields and commercial schott glass shields. ZnO- BaO- PbO- Bi_2O shows superior qualities in terms of radiation shielding parameters in comparison to standard concretes.

Table 1: Various glass systems as reported by different research groups

Research group	Glass composition
A	xBi_2O_3-(100-x)SiO_2 xPbO--(100-x)SiO_2 xBaO-(100-x)SiO_2
B	(0.6-x)PbO-xLi_2O-0.40B_2O_3
C	xBi_2O_3-(0.70-x)B_2O_3-0.15SiO_2-0.15 Na_2O
D	PbO-Bi_2O-Tl_2O-GeO_2 ZnO-BaO-PbO- Bi_2O
E	(0.45+x) Bi_2O_3-(0.25-x) BaO-0.15 B_2O_3-0.15 Na_2O
F	55PbO_x-BaO-(45-x)P_2O_5

Dogra et al. 2018 studied (0.45+x) Bi_2O_3-(0.25-x) BaO-0.15 B_2O_3-0.15 Na_2O system and measured mass attenuation coefficient and half value layer parameter at 662 keV. Besides this, dissolution rate of samples has also been evaluated to measure the durability of prepared samples. The system shows better durability and cost effective in preparing suitable shields. Kaur et al. 2015 has evaluated the BaO doped with Pbo-P_2O_5 glass system by measuring shielding parameters at 662, 1173 and 1332 keV. Increase of BaO increases mass attenuation values and decreases HVL parameter which is related to low production cost of glass samples. Decrease in the values of effective atomic number has been measured from 662 to 1332 keV which is attributed to photoelectric absorption.

CONCLUSION

The motive of this research was to analyze radiation shielding parameters of different oxides at various photon energies. It has been inferred from above study that incorporation of heavy metal oxides increases the attenuation coefficient and durability of samples.

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