INVESTIGATIONS OF GAMMA RAY SHIELDING PROPERTIES OF MoO_3 MODIFIED P_2O_5-SiO_2-K_2O-MgO-CaO GLASSES

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The aim of this paper is to investigate the gamma radiation shielding properties of P_2O_5-SiO_2-K_2O-MgO-CaO-MoO_3 glasses. The mass attenuation coefficients (μ_m) have been computed via Photon Shielding and Dosimetry (Phy-X/PSD) software in the energy range 0.015-15 MeV. The other shielding factors are also computed as the effective atomic number (Z_{eff}), electron density (N_e), and mean free path (MFP) values, exposure (EBF) and energy absorption (EABF) buildup factors for a penetration depths 20 mfp. The values of the shielding parameters are strongly dependent on energy and chemical composition. The PSKMCM6 possesses the lowest value of MFP and highest value of μ_m and $Z_{eff,}$ among the glasses. The glass sample PSKMCM6 has minimum value of EBF and EABF as compared to other samples.

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1. Introduction

Gamma radiation are finding numerous applications in the medical, industrial, nuclear power, x-ray systems, food sterilization and a number of other fields. Preventing ionizing radiation from causing damage to the human cells and tissues is one of the most important challenges facing scientists in the current century. Maintaining human safety from the negative effects of ionizing radiation is one of the things that must be taken into consideration with the expansion of the use of radiation in various areas of life [1, 2]. Thus, it became necessary to use materials that have the ability to absorb the incident photons and thus mitigate the negative effects of radiation. These materials are called radiation shielding materials [3, 4]. The idea of the radiation shielding is based on the ability of the medium to decrease the effect of the photons by blocking the photons and this is known as attenuation. Practically, high-density mediums such as lead and lead composites are more efficacious for this purpose. Glasses are an example of the materials that possess the previous properties and have many uses in radiation protection applications [5-8]. Recently, there are many studies that have proven the effectiveness of different glass systems in reducing and mitigating ionizing rays. Thus, it can be said that glass is considered one of the most promising materials as a protective radiation [9, 10]. In order to evaluate the effectiveness of certain glassy medium, we need to determine the mass attenuation coefficient of this medium and then from the obtained results we can calculate other shielding factors. The theoretical calculations of the mass attenuation coefficient and related parameters are considered a significant method for the radiation shielding investigators. This method based on the determination of the shielding factors by suitable compute programs such as WinXcom, XMuDat, Auto-Zeff and Py-MLBUF [11-14]. In this work,

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the detailed study of the gamma radiation shielding parameters e.g. mass attenuation coefficients (μ_m), effective atomic numbers (Z_{eff}), electron density (N_e), mean free path (MFP), exposure (EBF) and absorption buildup factors (EABF) have been discussed for the MoO_3 modified P_2O_5-SiO_2-K_2O-MgO-CaO glasses.

2. Materials and methods

Glass samples of MoO_3 modified P_2O_5-SiO_2-K_2O-MgO-CaO glasses under study are as follows:

PSKMCM1: 40.7P_2O_5-5.7K_2O-28.8MgO–6.5SiO_2–18.2CaO
PSKMCM2: 40.8P_2O_5-5.7K_2O-27.8MgO–6.0SiO_2–17.8CaO-1.9MoO_3
PSKMCM3: 41.9P_2O_5-6.9K_2O-25.5MgO–5.2SiO_2–16.6CaO-3.9MoO_3
PSKMCM4: 40.8P_2O_5-6.2K_2O-22.9MgO–5.7SiO_2–16.4CaO-8.0MoO_3
PSKMCM5: 40.6P_2O_5-6.2K_2O-19.1MgO–6.2SiO_2–12.8CaO-15.1MoO_3
PSKMCM6: 41.2P_2O_5-6.3K_2O-10.0MgO–5.8SiO_2–7.2CaO-29.5MoO_3

For the above six glass samples, the composition is given in mol% [15]. The chemical composition and density of the selected glasses as given in Table 1.

Table 1. Chemical Composition and density of the present PSKMCM glass samples.

Sample	**Mole fraction of compounds present in the sample**						**Density g/cm^3**
	P_2O_5	SiO_2	K_2O	MgO	CaO	MoO_3	
PSKMCM1	40.7	6.5	5.7	28.8	18.2	0.0	2.4685
PSKMCM2	40.8	6.0	5.7	27.8	17.8	1.9	2.5294
PSKMCM3	41.9	5.2	6.9	25.5	16.6	3.9	2.6063
PSKMCM4	40.8	5.7	6.2	22.9	16.4	8.0	2.6445
PSKMCM5	40.6	6.2	6.2	19.1	12.8	15.1	2.6597
PSKMCM6	41.2	5.8	6.3	10.0	7.2	29.5	2.6785

The Phy-X/PSD program [16] has been used for the evaluation of the gamma ray shielding properties for the present glasses. The method of calculating shielding quantities using this program can be summarized in three steps as follows: (a) definition of materials: in this step, the user needs to input the composition and the density of the investigated materials. For the first sample in this work, we inputted it in this software as "40.7P_2O_5+5.7K_2O+28.8MgO+6.5SiO_2+18.2CaO". The second step is (b) selection of energies: we selected the energy range between 0.015 and 15 MeV and, finally (c) selection of parameters to be determined: in the last step, the users can select which factors they need to determine according to their work.

3. Results and discussions

The variation of μ_m values with energy the energy range of 0.015-15 MeV are shown in Fig. 1. The μ_m are PSKMCM1 (3.868 cm^2 /g), PSKMCM2 (5.354 cm^2 /g), PSKMCM3 (6.840 cm^2 /g), PSKMCM4 (9.747 cm^2 /g), PSKMCM5 (14.152 cm^2 /g), and PSKMCM6 (21.440 cm^2 /g) respectively for the selected samples at 20 keV. After that value of μ_m decreases with increase in energy upto 0.1 MeV. This is due to the dominance of photoelectric effect (PE) whose interaction cross-section varies with energy as $E^{-3.5}$. The values of the μ_m are different for all the materials in the low energy region due to the Z-dependence of Z^{4-5} for the dominant PE. The values of μ_m are approximately constant for all the materials and decreases with increase in energy in the range of photon energy 0.1 - 6 MeV because of the dominance of Compton scattering (CS) in the medium energy range (0.1 - 6 MeV) whose interaction cross-section varies with Z and E as the Z/E. Thereafter, the values of μ_m are decreases extremely slowly with increase in the photon energy beyond 6 MeV, because there is dominance of pair production (PP) effect which varies with Z^2 [17, 18]. The maximum value of MAC is observed for sample PSKMCM6 whereas, the minimum for sample PSKMCM1.

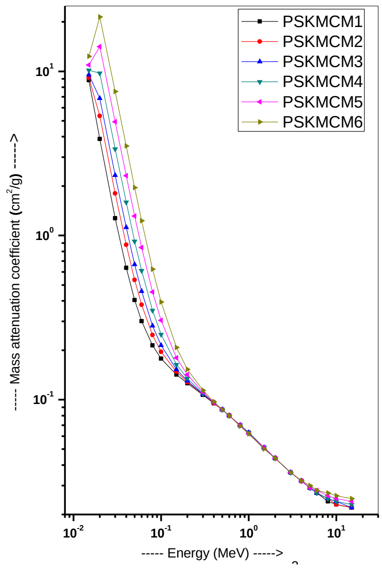

Fig. 1. Variation of mass attenuation coefficient (cm/g) with photon energy.*

Fig. 2 represents the variation of Z_{eff} with energy for the PSKMCM1- PSKMCM6 glasses. The maximum values of Z_{eff} for PSKMCM1 (14.83), PSKMCM2 (18.34), PSKMCM3 (21.11), PSKMCM4 (25.34), PSKMCM5 (29.77), and PSKMCM6 (34.21) respectively for all glasses and this maxima is noted to be at 20 keV. After that value of Z_{eff} decreases with increase in energy upto 0.1 MeV which is due to the dominance of PE effect in lower energy region which has the Z-dependence of Z^{4-5}. In the middle energy range from 0.1-4 MeV, the values of the Z_{eff} are linearly varied with Z which is due to the dominance of CS. The Z_{eff} starts increasing slowly above 4 MeV which is due to pair production in this energy region, which has the Z-dependence of Z^2 [19, 20]. The PSKMCM6 glass possess the highest value of Z_{eff}.

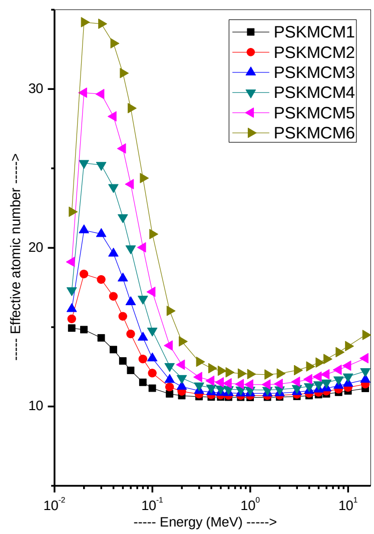

Fig. 2. Variation of effective atomic number with proton energy.

Fig. 3 shows the variation of N_e with energy. The maximum values of N_e for PSKMCM1 (4.18 x 10^{23} electrons/g), PSKMCM2 (5.10 x 10^{23} electrons/g), PSKMCM3 (5.79 x 10^{23} electrons/g), PSKMCM4 (6.79 x 10^{23} electrons/g), PSKMCM5 (7.70 x 10^{23} electrons/g), and PSKMCM6 (8.30 x 10^{23} electrons/g) respectively for all selected glass systems and this maximum value is found at 20 keV. The PSKMCM6 glass possess the maximum value of N_e whereas, the minimum value of N_e for sample PSKMCM1 [21, 22]. The variation of N_e is similar to the variations of Z_{eff} with energy.

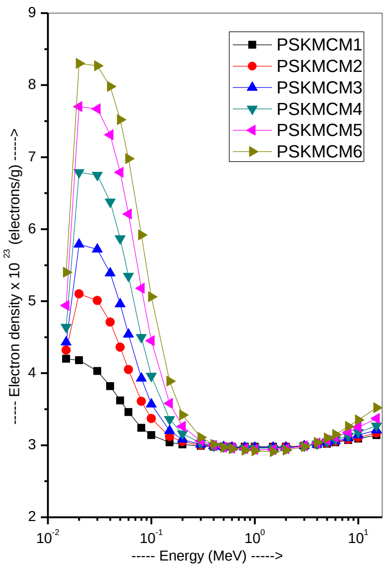

Fig. 3. Variation of electron density with proton energy.

The variation of MFP with energy is shown in Fig. 4. The range of values of MFP for samples are PSKMCM1 (0.046-18.738 cm), PSKMCM2 (0.043-18.012 cm), PSKMCM3 (0.040-17.208 cm), PSKMCM4 (0.037-16.481cm), PSKMCM5 (0.034-15.736 cm), and PSKMCM6 (0.030-14.649 cm) respectively. The MFP is gradually increasing with increase in the energy. Hence, the sample PSKMCM6 has the lowest MFP among all the selected samples due to higher concentration of MoO_3 enabling the sample PSKMCM6 as better gamma radiation shielding properties among all [23, 24].

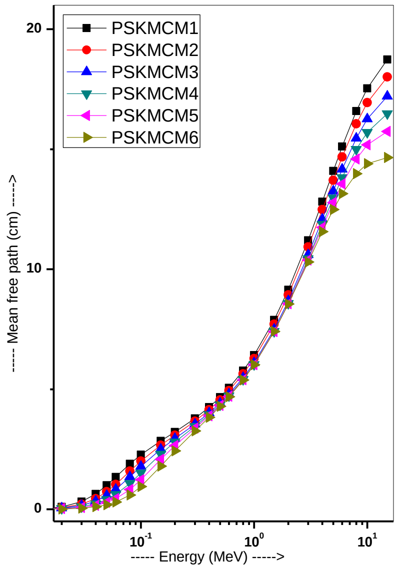

Fig. 4. Variation of mean free path (cm) with photon energy.

Figs. 5 and 6 represent the variation of exposure (EBF) and energy absorption buildup factor (EABF) for all selected samples PSKMCM1- PSKMCM6 for a penetration depth of 20 mfp. The values of EBF and EABF of the selected glasses possess the minimum values in low-energy and high-energy ranges whereas their values are higher in the middle energy range. In the low and high energy range, these photons are completely absorbed or removed by PE and PP effect resulting in the reduction of the number of photons. However, in the middle energy region, there is only degradation of energy of the photon takes place due to the CS process and due to which the number of low energy photon pile up resulting in higher values of BF [25-27]. The glass sample PSKMCM6 has minimum value of EBF and EABF as compared to other samples.

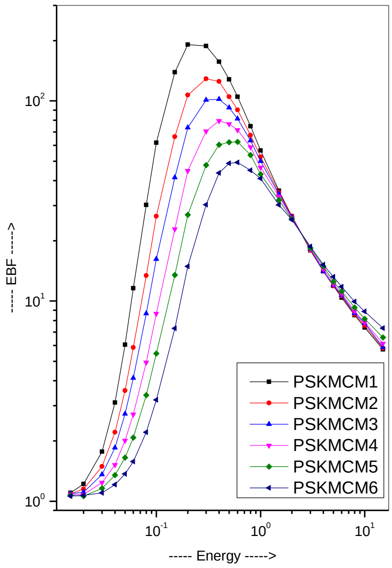

Fig. 5. Variation of EBF with energy at the penetration depth of 20 mfp.

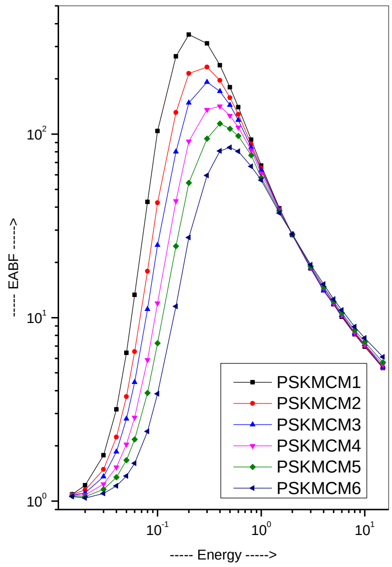

Fig. 6. Variation of EABF with energy at the penetration depth of 20 mfp.

4. Conclusion

In the present work, the mass attenuation coefficients (μ_m), the effective atomic number (Z_{eff}), electron density (N_e), mean free path (MFP), exposure (EBF), and energy absorption (EABF) buildup factors for a penetration depth for 20 mfp have been investigated using the Phy-X / PSD computer program. The value of the effective atomic number (Z_{eff}), and mass attenuation coefficients (μ_m) increases whereas the values of mean free path (MFP) decreases as we move from sample PSKMCM1 towards PSKMCM6.

The glass PSKMCM6 possesses the lowest value of MFP and highest value of μ_m and $Z_{eff,}$ among the glasses. The values of EBF and EABF buildup factors varies with energy such that in the lower and higher energy range, the BF values are lower as compared to the values in the medium energy reange. The glass sample PSKMCM6 has minimum value of EBF and EABF as compared to other samples. Overall it is established that the glass PSKMCM6 possesses the best gamma radiation shielding properties as compared to all the selected glasses.

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