



# Photon Shielding Characterization of SiO<sub>2</sub>-PbO-CdO-TiO<sub>2</sub> Glasses for Radiotherapy Shielding Application

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## Authors' contributions

*This work was carried out in collaboration among all authors. Author IMM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author ABJ managed the literature searches and organize the study design. Author SMB managed the analyses of the study. All authors read and approved the final manuscript.*

## Article Information

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## ABSTRACT

In this study, photon attenuation parameters of (30-x) SiO<sub>2</sub>-15PbO-10CdO-xTiO<sub>2</sub>, with x = 0, 2, 4, 6, 8 and 10% mol, were determined and their application as shielding material were discussed. The WinXCOM software was used to determine the mass attenuation coefficient of the studied glasses for the energy range (0.015-15MeV). The mass attenuation coefficient of the glass samples first decline up to 0.09 MeV and slightly increase abruptly and then declined uniformly for all the glasses to approximately zero after about 10 MeV. The effective atomic number ( $Z_{\text{eff}}$ ) was also calculated for the glass samples and were observe to raise from 0.015 to 0.02 MeV and then decreased between 0.02-5 MeV. On account of the dominance of the photoelectric effect in the low energy region, there was a sudden increase in  $Z_{\text{eff}}$  at about 0.08 MeV close to the absorption edge of the Pb (0.088 MeV). The rapid increment was observed at 0.1-1.5 MeV by transcending typical Compton scattering interaction at intermediate energies for  $Z_{\text{eff}}$ 's and began to decrease in the same form again. The lower  $Z_{\text{eff}}$  values were found in low and high energy region for all SPCT

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glasses. The calculated mean free path, half value layer and tenth value layer values were observed to decline as the TiO<sub>2</sub> doping of the glasses increased which accounts for the three photon interaction mechanisms effectiveness in the variation of MFP and HVL values with energy. It can be concluded that SPCT glasses may be considered an alternative material for radiation shielding practices.

**Keywords:** Photon attenuation parameter; SPCT glass; mass attenuation coefficient and WinXCOM software.

## 1. INTRODUCTION

The increased demand of ionizing radiation in many areas of endeavor such as radiotherapy is one of the most concerning subjects in regard to use of medical radiation [1,2]. In the medical radiation facilities, technicians, doctors, and nurses are experiencing radiation exposure every day which could potentially lead to effects that are detrimental. The evaluation of the radiation exposure of the clinical personnel is important and numerous publications have been analyzed this subject with common target the safe application of the exposure [2,3,4]. Several protection procedures are currently implemented in everyday practice, including radiation protection apparels, personalized radiation monitoring devices and exposure-decreasing operational techniques [1,3]. However, the basic protection of the medical radiation fields is the correct and complete shielding of the room which is capable of ensuring the safety of the personnel and population [5,6]. The term of ionizing radiation transmission through matter is basic of the shielding studies for medical radiation fields. The selection of the shielding material requires some pre-decided parameters such as attenuation performance, structural properties and thermal properties considering the radiation type, energy and source type [1,7]. Radiation shielding serves a number of functions. Foremost among these is reducing the radiation exposure to persons in the vicinity of radiation sources. Shielding used for this purpose is named biological shielding [8,9].

In different areas of ionising radiation application photons (gamma rays) are of major concern to medical physicist and engineers when designing radiation shield. This is due to their abilities to penetrate deeper into any given medium. Traditionally, materials for photon attenuation are required to be of high density. Obviously, effective shielding of photons is very important because it is the primary product of a radiotherapy unit [10]. One of the parameters than can be used to describe the photon

shielding effectiveness of a medium is the mass attenuation coefficient. The mass attenuation coefficient is a quantity that describes how much photon is absorbed or transmitted by a medium [2,4,11]. Therefore, this study aimed to determine the gamma shielding parameters Tin oxide added glasses.

## 2. MATERIALS AND METHODS

In this study, gamma attenuation parameters of (30-x) SiO<sub>2</sub>-15PbO-10CdO-xTiO<sub>2</sub>, with x = 0, 2, 4, 6, 8 and 10% mol, were determined and their application as shielding material were discussed.

Theoretical mass attenuation coefficients  $\mu_m$  of the glass mixtures were calculated for the chemical composition of the glass mixtures (S1 to S6) using winXCOM software. The XCOM code is a database for calculating mass attenuation coefficients at different photon energies [1,2,12]. Theoretical linear attenuation coefficients were calculated by multiplying the obtained theoretical mass attenuation coefficients by the density of the mortar mixtures. The linear attenuation coefficients ( $\mu$ ) which are a measure of the shielding capacity of the material against radiation is investigated for many materials both theoretically and experimentally. The linear attenuation coefficient ( $\mu$ ) is related to the mass attenuation coefficient ( $\mu_m$ ) as [1,10]:

$$\mu_m = \frac{\mu}{\rho} \quad (1)$$

where  $\rho$  represents the density of the absorbing medium. It has the dimensions of area per unit mass (cm<sup>2</sup>/g).

The other important related shielding parameters were calculated by applying the linear attenuation coefficient ( $\mu$ ) results of each glass mixtures. The HVL and MFP reflect the necessary thickness that should be used to attenuate gamma rays or x-rays by half and a factor of e, respectively. They were calculated using [1,2,12]:

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

and

$$MFP = \frac{1}{\mu} \quad (3)$$

The  $Z_{eff}$  values of materials have a strong energy dependence, which differs from the  $Z$  (atomic number) of individual elements (for example,  $Z$  is constant with changing  $E$ ). In this study, the equations 4 was used to calculate the  $Z_{eff}$  of the investigated glasses mixtures [2,10,12]:

$$Z_{eff} = \frac{\sum f_i A_i \left(\frac{\mu}{\rho}\right)_i}{\sum f_j A_j \left(\frac{\mu}{\rho}\right)_j} \quad (4)$$

where  $Z_i$ ,  $f_i$ , and  $A_i$ , are the atomic number, molar fraction, and atomic mass of the elements inside the glass specimens, respectively.

### 3. RESULTS AND DISCURSIONS

The mass attenuation coefficient ( $\mu_m$ ) values obtained in the 0.015–15 MeV range using the WinXCOM program is shown in Fig. 1. The chemical compositions and densities of the investigated glasses are summarized in Table 1.

Firstly, there is a decline of  $\mu_m$  of the glasses up to 0.09 MeV. After 0.09 MeV, a slight abrupt increase is observed. The presence of PbO in the content of the studied glass informed the reason for this sudden increase. Then, the  $\mu_m$  values are declined constantly for all the glasses and approximately zero after about 10 MeV. The different photon interaction processes in these energy range (0.015-15 MeV) is the reason for these changes of  $\mu_m$  values. For low energies (< 0.2 MeV), the photoelectric cross section is direct and inversely proportional with  $Z^{4-5}$  and  $E^{3.5}$  respectively. Therefore, the  $\mu_m$  indicates the

maximum values at low energies for the glasses and quickly drops as the energy of photons is raised. The  $\mu_m$  values are almost constant and close to zero in the middle and high energy regions where Compton scattering and pair production which possess cross-section proportional to  $Z$  and  $Z^2$  respectively are effective [2,10]. With the increase of TiO<sub>2</sub> percentage, the enhancement of SiO<sub>2</sub> reduction in the glasses increases the radiation attenuation efficiency of the glasses.

The linear attenuation coefficient ( $\mu$ ) was calculated from  $\mu_m$  and the density ( $\rho$ ) of the glass sample as a function of energy as depicted in Fig. 2. The  $\mu$  vary with energy in similar way as  $\mu_m$ . The increase in density of the glass mixture (S1-S6) greatly affect the attenuation capability.

A vital parameter to consider a material to be substituted for radiation shielding is the effective atomic number ( $Z_{eff}$ ). The fluctuation of  $Z_{eff}$  with respect to photon energy is depicted in Fig. 3. Initially,  $Z_{eff}$  values were raised from 0.015 to 0.02 MeV and then decreased between 0.02-5 MeV. On account of the dominance of the photoelectric effect in the low energy region, there was a sudden increase at about 0.08 MeV close to the absorption edge of the Pb (0.088 MeV). The rapid increment was observed at 0.1–1.5 MeV by transcending typical Compton scattering interaction at intermediate energies for  $Z_{eff}$ 's and began to decrease in the same form again. The lower  $Z_{eff}$  values were found in low and high energy region for all SPCT glasses. Observation of the larger  $Z_{eff}$  values in the high energy region compared to the lower energies is due to the fact that the cross-section of pair production mechanism is less dependent on the energy and atomic number [1]. The addition of TiO<sub>2</sub> to the SPCT glass systems has also increased the  $Z_{eff}$  values.

**Table 1. Codes, chemical compositions and densities of the glasses**

Glass Mixture code	Weight fraction					Density
	O	Si	Cd	Pb	Ti	
S1	0.33269	0.25496	0.15916	0.25318	0.00000	5.230
S2	0.32789	0.23797	0.15916	0.25318	0.02180	5.611
S3	0.32310	0.22097	0.15916	0.25318	0.04359	5.813
S4	0.31830	0.20397	0.15916	0.25318	0.06539	6.022
S5	0.31350	0.18697	0.15916	0.25318	0.08719	6.124
S6	0.30870	0.16998	0.15916	0.25318	0.10898	6.197

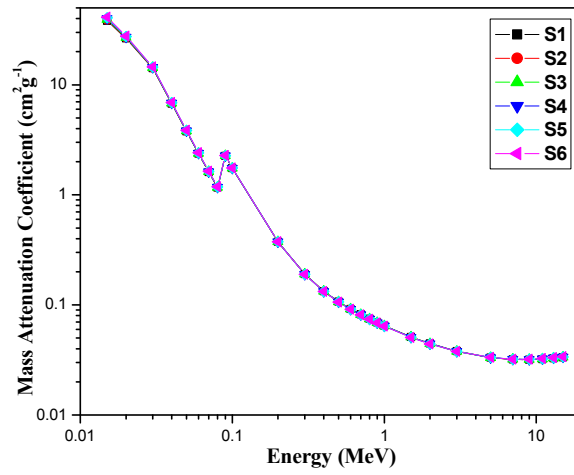


Fig. 1. Mass attenuation coefficient spectra of the S1-S6 SPCT glasses

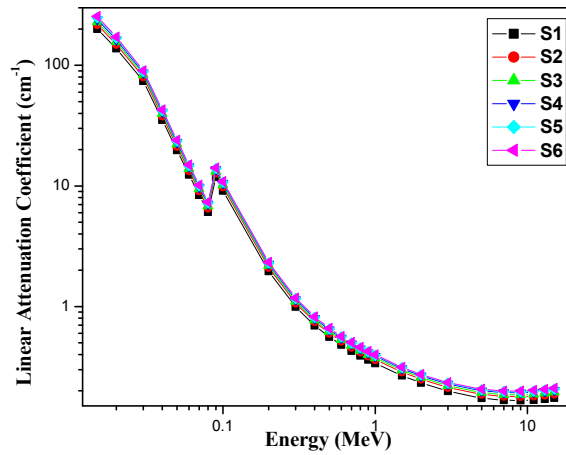


Fig. 2. Linear attenuation coefficient spectra of the S1-S6 SPCT glasses

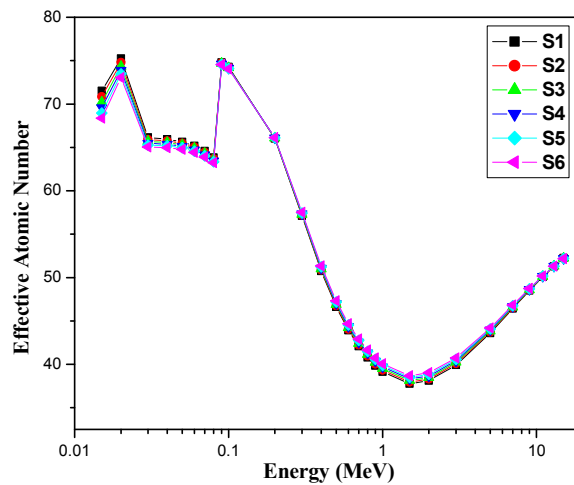


Fig. 3. Effective atomic number spectra of the S1-S6 SPCT glasses

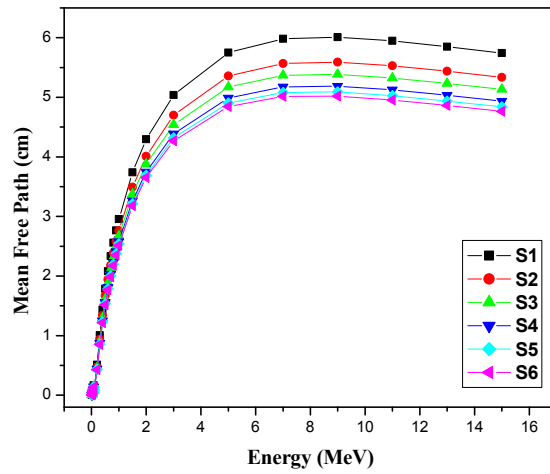


Fig. 4. Mean free path spectra of the S1-S6 SPCT glasses

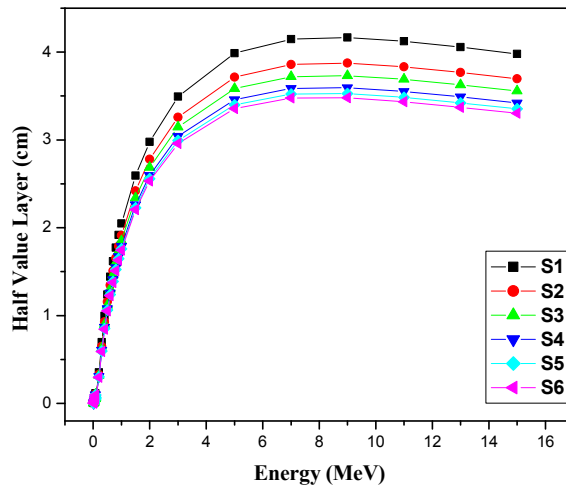


Fig. 5. Half value layer spectra of the S1-S6 SPCT glasses

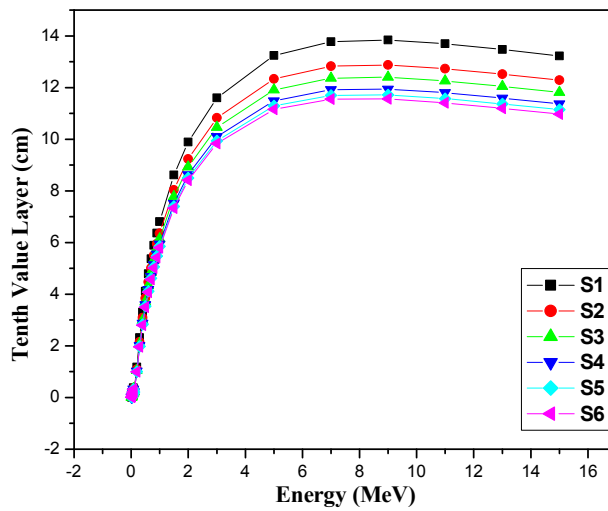


Fig. 6. Tenth value layer spectra of the S1-S6 SPCT glasses

The mean free path (MFP), half value layer (HVL) and tenth value layer (TVL) which are the most commonly used transmission thickness for gamma rays [1,10,11], are given in Fig. 4, 5, and 6 respectively. The MFP, HVL and TVL values were declined as the TiO<sub>2</sub> doping of the glasses increased. As we explained for  $\mu_m$  values, it is seen that the three photon interaction mechanisms is effective in the variation of MFP and HVL values with energy.

#### 4. CONCLUSION

This study investigates the gamma attenuation parameters of (30-x) SiO<sub>2</sub>-15PbO-10CdO-xTiO<sub>2</sub> glass, with x = 0, 2, 4, 6, 8 and 10% mol. Mass attenuation coefficient of the glass exposed to gamma radiation decline up to a certain value and increases abruptly within a short energy range and decreases thereafter as the photon energy increases. The mean free path, half value layer and tenth value layer were observed to decline as the TiO<sub>2</sub> doping of the glasses increased. The addition of TiO<sub>2</sub> and enhancement of SiO<sub>2</sub> reduction in the glasses increases the radiation attenuation capability of the glasses. The fluctuation of these parameters with energy is due to the three photon interaction mechanisms (photoelectric effect, Compton scattering and pair production). The addition of TiO<sub>2</sub> to the glass mixture has a significant effect to evolve the gamma shielding properties of the studied glass.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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