

Photon Shielding Performance of TeO₂-Doped Calcium-Phosphosilicate Glass for Brachytherapy Applications

*Abdulaziz Marafa, Idris M. Mustapha, Umar Ibrahim, Mohammed Musa

Physics Department, Nasarawa State University, Keffi.

*Corresponding authors' email: abdulaziz.marafa.am@gmail.com Phone: +2349038688998

ABSTRACT

In this research work, the radiation shielding performance of calcium-phosphosilicate bioactive glass system doped with tellurium dioxide at different mole concentration was investigated. A theoretical investigation was carried out using WinXcom software and Phy-x/PSD online software at the energy range of 0.1 to 10MeV to study the shielding properties of the bioactive glass. The mass attenuation coefficient (MAC) at 1.3 cm²/g shows a smooth reduction as energy increases with a sudden spike at 0.07 MeV for all samples except for sample CPST1 which showed no peak. The sudden increase in MAC value indicate an absorption edge due to the presence of TeO₂ in sample CPST2-CPST6. The values of linear attenuation coefficient (LAC), halve-value layer (HVL), tenth value layer (TVL), mean free path (MFP) and effective atomic number (Z_{eff}) were calculated by substituting the results obtained for MAC into their relations. The trend of linear attenuation coefficient follow a similar trend to that of mass attenuation coefficient. The trend of mean-free path increases linearly with increasing energy. Similar to mean-free path, the half-value layer and tenth-value layer increases linearly with increasing energy. The effective atomic number decreased drastically from 0.010 to 0.500 MeV photon energy, and increases gently afterward. The results obtained for the bioactive glass samples were compared with experiment results of previous studies and were found to be in good agreement at all energies. As a result of the glass shielding competency, it can be employed in thyroid and cervical cancer treatment for organs protection against radiation.

Received: 02 Dec. 2026

Accepted: 22 Dec. 2026

Published: 05 Oct. 2026

Keywords: Radiation shielding, calcium-phosphosilicate, Software

INTRODUCTION

Radiation originates from different processes in form of particles or waves with different properties and characteristics such as penetration power, detection, and measurement (Almuqrin *et al.*, 2022). These properties make radiation possible for application in different fields of human endeavor. These include medical field (for diagnosis and treatment purposes), agricultural practices as well as in industrial practices (Kaundal & Bharol, 2022). Radiation is therefore very essential to the modern life of humans. However, unnecessary exposure to this radiation can cause different abnormalities and diseases (especially cancer). This necessitates the establishment of protection and safety measures regarding exposure to radiation. Therefore these protective measures involve the use of many different specialized materials to reduce (absorb and attenuate) the radiation reaching a given target (Khazaalah *et al.*, 2022).

In medical practices, shielding materials are employed to absorb and attenuate radiation in order to avoid unnecessary exposure of patients, staffs and some equipment to the harmful effects of radiation within the medical facility. Similarly, in brachytherapy, shielding materials are equally employed for the purpose of protecting healthy surrounding tissues and organs from unnecessary exposure to high doses of radiation during medical treatment with radiation. Some shielding materials include lead, glass, borated polyethylene, bismuth, plastic scintillators, barium-sulfate and tungsten etc (Nazrin *et al.*, 2021).

Other materials used for photon shielding include silicate glasses and bioactive glasses. These bioactive glasses consist of high Z-elements, enabling them to exhibit radiation shielding properties. The properties can be enhanced by

doping the glass system with a different compound that consist of high Z-element. This is done by taking shielding parameters in to consideration such as MAC, LAC, HVL, TVL, MFP and Z_{eff} (Sayyed *et al.*, 2021).

Among the various high-Z additives reported for glass shielding (PbO, Bi₂O₃, WO₃, Gd₂O₃, Sb₂O₃), tellurium dioxide (TeO₂) was selected as the dopant in this study for several reasons. First, tellurium (Z = 52) has its K-absorption edge at 31.8 keV, which lies within the energy range of low-energy brachytherapy photon sources such as palladium-103 (~21 keV), iodine-125 (~28 keV) and caesium-131 (~30 keV). In contrast, the K-edges of heavier dopants such as bismuth (90.5 keV) and tungsten (69.5 keV) lie well above this window, making them less efficient per atom in the low-energy brachytherapy range. Unlike lead oxide, TeO₂ is not a restricted hazardous substance, and its use supports the development of environmentally acceptable, lead-free shielding materials. Additionally, TeO₂ is a conditional glass former that substantially increases the density of silicate and phosphate glass matrices while preserving glass stability, chemical durability and optical transmission; in the present system the density rises from 3.64 to 5.50 g/cm³ as TeO₂ is introduced. Finally, tellurite-based glasses have repeatedly demonstrated excellent gamma-ray attenuation in previous investigations (Agar *et al.*, 2019; Sayyed *et al.*, 2021; Yin *et al.*, 2022), providing a well-established benchmark against which the present bioactive glass system can be assessed. It is also noteworthy that the host calcium-phosphosilicate glass is a bioactive system, so a modest TeO₂ addition offers the prospect of a single material that combines radiation shielding with biological compatibility for patient-contact shielding

components such as eye shields, vaginal/rectal applicator inserts and surface moulds used in brachytherapy.

Objectively, this research work tends to theoretically determine the photon shielding parameters (MAC, LAC, HVL, TVL, MFP, and Z_{eff}) of 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ bioactive glass system over the photon energy range 0.01–10 MeV using WinXcom and Phy-X/PSD by establishing the influence of progressive TeO₂ substitution (x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 mol%) on such shielding parameters, thereby interpreting the observed trends in terms of the photon–matter interaction mechanisms and the Tellurium K-absorption edge.

MATERIALS AND METHODS

Phy-X /PSD Online Computer Software Program

Phy-X (Photon Shielding and Dosimetry) is an online computer software program that is used commonly for radiation transport simulation. Phy-X/PSD is therefore employed in simulating the influence of radiation exposure on certain materials. This is achieved by analyzing radiation-matter interactions and energy deposition to calculate the radiation shielding parameters of different specialized materials in order to determine the radiation shielding capabilities of the materials. The radiation shielding parameters that can be determined by Phy-X/PSD include mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), half-value layer (HVL), tenth-value layer (TVL), mean free path (MFP), and effective atomic number (Z_{eff}) (Alhassan *et al.*, 2023). Therefore, in this research work, Phy-X/PSD online software was used to determine the radiation shielding parameters of calcium-phosphosilicate bioactive glass doped with different mole concentration (mol%) of tellurium-dioxide (TeO₂) at varying energy range. This process was conducted to determine the radiation shielding performance of calcium-phosphosilicate bioactive glass system for photon shielding in brachytherapy procedure. Employing Phy-X/PSD in this research was deliberate. Phy-X/PSD is a freely accessible online platform that directly computes the complete set of shielding parameters (MAC, LAC, HVL, TVL, MFP, Z_{eff} , effective electron density, and exposure buildup factors) from only the elemental composition and density of the material. Phy-X/PSD has been validated against Monte Carlo simulations (MCNP) and experimental data (Alhadeethi *et al.*, 2020).

WinXcom Computer Software Program

WinXcom computer software program is a computer software that is designed for simulating the effects of different

radiation shielding materials. This computer software program is employed in the field of radiation shielding in order to determine the mass attenuation coefficient (MAC) of certain specialized materials. Additionally, the data obtained from WinXcom computer software program as the mass attenuation coefficient (MAC) can be used to obtain the other radiation shielding parameters, such as linear attenuation coefficient (LAC), half-value layer (HVL), tenth-value layer (TVL) and so on. This is done manually by substituting MAC values obtained from the WinXcom computer software program into the formulas of other radiation shielding parameters. These processes are therefore done in order to find the best materials that can provide effective radiation shielding performance for different applications (Mishra *et al.*, 2023).

The choice of WinXcom over alternative computational tools was deliberate. WinXcom is built upon the XCOM photon cross-section database (Berger & Hubbell, National Institute of Standards and Technology), which contains theoretically evaluated total interaction cross-sections widely regarded as the reference standard for mass attenuation coefficients, and the program has been extensively validated against experimental measurements over broad energy and compositional ranges.

Chemical Composition of the Glass System

The TeO₂ concentration was restricted to the range 0.0–1.0 mol% in steps of 0.2 mol% for the following reasons. Firstly, tellurium oxide is relatively costly, and a systematic low-doping study is required to identify the minimum dopant level at which a meaningful improvement in shielding performance is obtained. Secondly, the parent calcium-phosphosilicate matrix is a bioactive system whose network connectivity, chemical durability and biological response depend on the phosphate content; replacing P₂O₅ (a network former) with large quantities of TeO₂ would progressively degrade these properties, so the dopant level must remain modest for the material to remain a credible candidate for patient-contact shielding components. Thirdly, the small, regular increments allow the specific effect of TeO₂ to be isolated from other compositional variables. Based on these considerations, and on the densities measured for the series (as shown in Table 1), the expected influence of TeO₂ is: an increase in density (from 3.64 to 5.50 g/cm³) and in the average atomic number of the glass, which should increase the MAC, LAC and Z_{eff} and decrease the HVL, TVL and MFP of the system.

Table 1: Chemical Composition and Density of 40CaO- (10-x) P₂O₅-50SiO₂-xTeO₂ Bioactive Glass System

Bioactive Glass Samples	CaO (mol%)	P ₂ O ₅ (mol%)	SiO ₂ (mol%)	TeO ₂ (mol%)	Density (g/cm ³)
CPST1	40	10	50	0.0	3.64
CPST2	40	9.8	50	0.2	3.74
CPST3	40	9.6	50	0.4	4.40
CPST4	40	9.4	50	0.6	4.90
CPST5	40	9.2	50	0.8	5.22
CPST6	40	9.0	50	1.0	5.50

Radiation Shielding Parameters

Mass Attenuation Coefficient

The mass attenuation coefficient (MAC) represents the attenuation ability of a material (the glass) per unit mass. The MAC is related to LAC and density by equation 1.

$$\mu_m = \frac{\mu}{\rho} \quad (\text{cm}^2/\text{g}) \quad (1)$$

Where; $\mu = \text{LAC}$ = Linear attenuation coefficient.

ρ = Density of the material (glass).

$\mu_m = \text{MAC}$ = Mass attenuation coefficient.

S.I unit = cm²/g

Linear Attenuation Coefficient

Linear Attenuation Coefficient (LAC) represents the fraction of photons attenuated per unit distance traveled through a material (the glass). The LAC was calculated using equation 2.

$$LAC = \mu = \mu_m \times \rho \quad (2)$$

Where; μ_m = Mass attenuation coefficient (MAC)

ρ = Density of the glass

S.I unit is: cm^{-1} .

Half-Value Layer

Half-Value Layer (HVL) is the thickness of a shielding material (the glass) that is required to reduce the radiation intensity by half. The HVL was calculated using equation 3.

$$HVL = \frac{\ln(2)}{\mu} \quad (3)$$

Where; μ = linear attenuation coefficient.

S.I unit is: m (meters).

Tenth-Value Layer

Tenth-Value Layer (TVL) is the thickness of a shielding material (the glass) which is required in reducing the intensity of the radiation to one-tenth (10%) of its original value.

The TVL was calculated using equation 4.

$$TVL = \frac{\ln(10)}{\mu} \quad (4)$$

Where; μ = linear attenuation coefficient.

S.I unit is: m (meters).

Mean-Free Path

Mean Free Path (MFP) is the average distance a photon travels in a material before undergoing an interaction. The MFP was calculated using equation 5.

$$MFP = \frac{1}{\mu} \quad (5)$$

Where; μ = linear attenuation coefficient.

S.I unit is: m (meters).

Effective Atomic Number

Effective Atomic Number (Z_{eff}) is a parameter that represents the average atomic number of a material, taking into account the contributions from different elements present.

The Z_{eff} was calculated using equation 6.

$$Z_{eff} = \frac{\sum_i w_i A_i (\mu_m)_i}{\sum_i w_i \frac{A_i}{Z_i} (\mu_m)_i} \quad (6)$$

Where; W_i = the weight fraction of each element in the composition.

A_i = Atomic weight of each element in the composition.

Z_i = Atomic number of each element in the composition

μ_m = Mass attenuation coefficient of each element in the composition

RESULTS AND DISCUSSION

Mass Attenuation Coefficient (MAC) of the Glass Samples

Table 2 and Figure 1 shows a plot of MAC versus photon energy (MeV) for all the bioactive glass samples determined using WinXcom software. This plot shows a smooth reduction in MAC values as energy increases and a sudden spike at 0.07 MeV for all glass samples except for sample CPST1 which showed no peak. This increase in MAC value is attributed to the k- absorption edge of Tellurium atom. The decrease in MAC values from 0.01 – 0.04 MeV was drastic when compared with the other MAC values. This drastic decrease in MAC values is therefore due to the dominance of photoelectric interaction cross section. The photoelectric effect varies inversely with the fourth power of the photon energy (0.04 MeV) which is responsible for the sharp decrease. Therefore, the MAC values that are above 0.04 MeV decreases relatively slower due to the dominance of incoherent photon scattering process. The probability of incoherent photon scattering depends on the number of electrons per unit mass of an absorbing medium. Except for Hydrogen, most elements has number of electrons per unit mass varying between 0.40 and 0.50 with a decrease as atomic number increases. Furthermore, incoherent photon scattering slowly decreases with energy. For the glass samples, the minimum and maximum MAC values were obtained at photon energies of 10 and 0.010 MeV. The relative MAC values of the glass samples marked an absorption edge with an increment from sample CPST2 to CPST6. This increment can be attributed to the density of the glass system as a result of introducing TeO₂ to the glass composition resulting to an increase in the mass attenuation coefficient (MAC) of the glass samples.

From a clinical standpoint, the most relevant feature of Figure 1 is the behavior of the MAC in the 0.02–0.05 MeV interval, which corresponds to the mean photon energies of the low-energy brachytherapy sources palladium-103 (~0.021 MeV), iodine-125 (~0.028 MeV) and caesium-131 (~0.030 MeV). In this window CPST6 exhibits the highest MAC of the series (24.985 cm²/g at 0.01 MeV and 16.971 cm²/g at 0.05 MeV), reflecting both the high density of the TeO₂-doped glass and the proximity of the Tellurium K-absorption edge (31.8 keV), which selectively enhances photoelectric absorption of low-energy brachytherapy photons. Because the photoelectric interaction cross-section varies approximately as Z^4 – Z^5 per atom and as $\sim E^{-3.5}$, even the modest 1.0 mol% TeO₂ addition produces a measurable gain in attenuation per unit mass precisely in the energy range in which permanent-implant brachytherapy sources emit.

Table 2: MAC of 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ Bioactive Glass Samples

Energy (MeV)	Mass Attenuation Coefficient (cm ² /g)					
	CPST1	CPST2	CPST3	CPST4	CPST5	CPST6
0.01	23.005	23.529	23.9378	24.242	24.784	24.985
0.02	19.388	19.9038	20.452	20.915	21.516	21.891
0.03	17.433	17.751	18.562	18.773	19.007	19.228
0.05	15.099	15.526	15.908	16.561	16.363	16.971
0.08	11.910	12.244	12.962	13.254	13.954	14.644

Energy (MeV)	Mass Attenuation Coefficient (cm ² /g)					
	CPST1	CPST2	CPST3	CPST4	CPST5	CPST6
0.12	9.994	10.169	10.709	10.954	11.409	11.764
0.15	7.576	7.982	8.232	8.888	9.109	9.676
0.20	5.343	5.638	5.931	6.129	6.467	6.936
0.50	3.212	3.359	3.916	4.529	4.904	5.015
0.80	0.819	0.952	0.993	1.567	1.919	2.732
1.00	0.559	0.590	0.641	0.785	0.808	0.837
2.00	0.323	0.372	0.398	0.444	0.497	0.521
3.00	0.194	0.198	0.222	0.239	0.258	0.295
4.00	0.180	0.183	0.186	0.188	0.189	0.191
5.00	0.163	0.166	0.167	0.171	0.175	0.177
6.00	0.106	0.109	0.129	0.144	0.153	0.162
7.00	0.100	0.102	0.105	0.109	0.113	0.116
8.00	0.099	0.101	0.103	0.104	0.111	0.114
9.00	0.087	0.089	0.092	0.098	0.106	0.109
10.00	0.085	0.088	0.090	0.094	0.095	0.097

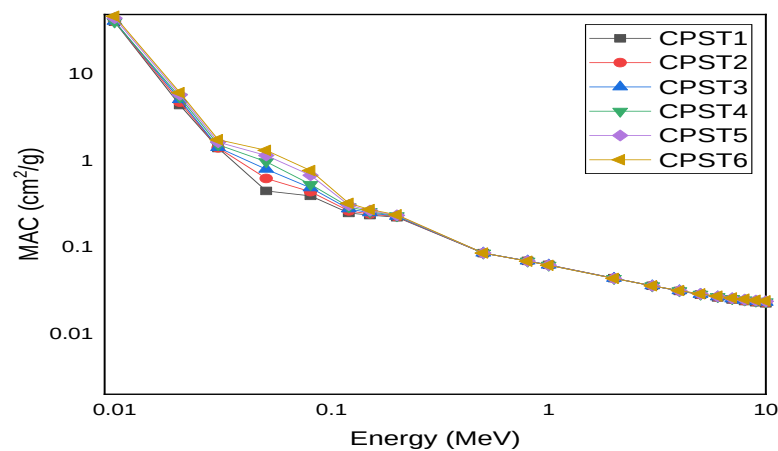


Figure 1: Mass Attenuation Coefficient Spectra of 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ Bioactive Glass Samples at Various Photon Energies

Linear Attenuation Coefficient (LAC) of the Glass Samples

Figure 2 shows the plot of linear attenuation coefficient (LAC) versus photon energy (MeV) obtained using WinXcom respectively. The plots for LAC values obtained as a function of energy follows a similar trend as the MAC plot. These plots shows a spike for the absorption edge by sudden peak at 0.07 MeV, except for CPST1 that shows no peak. This sudden rise in the LAC value is as a result of the presence of tellurium dioxide in the bioactive glass system. This shows that the presence of tellurium dioxide in 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ bioactive glass samples has enhanced the attenuation rate of the glass samples.

However, linear attenuation coefficient (LAC) has a higher relative difference when compared with mass attenuation coefficient (MAC). These changes are as a result of the relative difference in mass density of 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ bioactive glass samples. The minimum and

maximum LAC values obtained using WinXcom software are 0.087cm⁻¹ (as minimum at 10MeV) and 33.998cm⁻¹ (as maximum at 0.01MeV).

The clinical implication of the LAC trend is best illustrated by converting it into shielding thickness. For CPST6 at 0.05 MeV, LAC $\approx$ 93.3 cm⁻¹, which corresponds to a half-value layer of only $\sim$ 0.007 cm ($\sim$ 70 μ m); a glass layer of about 0.25 mm would therefore transmit less than 10% of incident 0.05 MeV photons. Even at 0.662 MeV (caesium-137) and around 0.38 MeV (mean energy of iridium-192), where attenuation is intrinsically weaker, the LAC rises systematically with TeO₂ content, so that thinner applicator walls, eye shields or surface-mould inserts can achieve the same attenuation as thicker undoped glass. This inverse relationship between LAC and the required shielding thickness is directly relevant to patient comfort, ease of applicator insertion and reproducibility of source positioning during brachytherapy procedures.

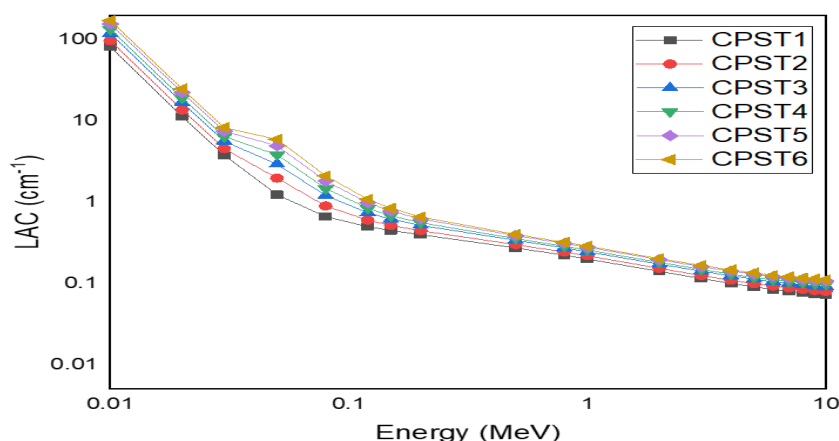


Figure 2: Linear Attenuation Coefficient Spectra of $40\text{CaO}-(10-x)\text{P}_2\text{O}_5-50\text{SiO}_2-x\text{TeO}_2$ Bioactive Glass Samples at Various Photon Energies Obtained using Winxcom

Half-Value Layer (HVL) of the Glass Samples

Figure 3 shows the plot of HVL versus photon energy (MeV) obtained using WinXcom software. The trend increases linearly with increase in photon energy (MeV) for all the bioactive glass samples (CPST1 to CPST6). These trends clearly indicates that at lower energies, there is a very high

penetration of photons. As such, thicker absorbing materials are required for higher absorption rate. It also indicate that the HVL values of sample CPST1, CPST2, CPST3, CPST4, CPST5 and CPST6 is an inverse of the LAC value. The half-value HVL of a material is the thickness required to reduce the intensity of radiation to half (50%) of its original value.

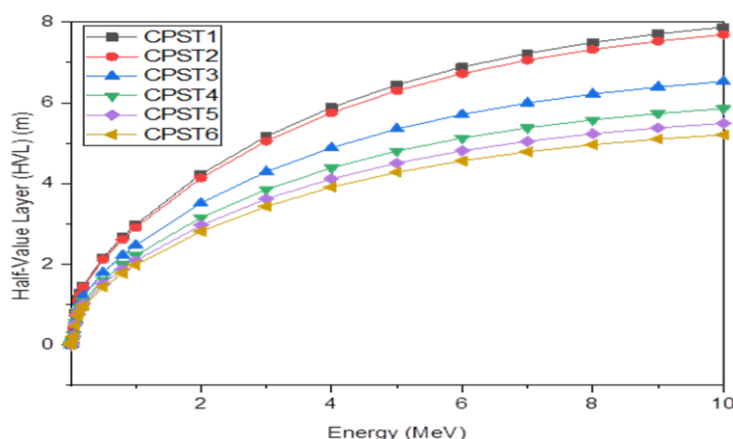


Figure 3: Half-value Layer Spectra of $40\text{CaO}-(10-x)\text{P}_2\text{O}_5-50\text{SiO}_2-x\text{TeO}_2$ Bioactive Glass Samples at Various Photon Energies obtained using WinXcom

Tenth-Value Layer (TVL) of the Glass Samples

Figure 4 shows the plot of tenth-value layer (TVL) versus photon energy (MeV) obtained using WinXcom. The trends of the tenth-value layer (TVL) obtained using WinXcom increases linearly with increase in photon energy (MeV) for all the glass samples (CPST1 to CPST6). These Figure clearly follow a similar trend as half-value layer (HVL) (Figure 4). Generally, TVL

is directly proportional to the photon energy and this implies that the values of TVL for the glass samples increase with increase in photon energy (MeV). This simply means that

higher photon penetration rate decrease in the glass samples due to reduced interaction cross section of the process leading to photon absorption. Therefore, the reduction in the values of the tenth-value layer (TVL) of the glass samples as TeO_2 content increase simply means that, it enhances the photon shielding performance of the glass system. As such, it also indicate that the thickness of the glass system required to reduce the intensity of the photon energy to one-tenth (10%) of its original value, should be as low as possible for effective attenuation properties.

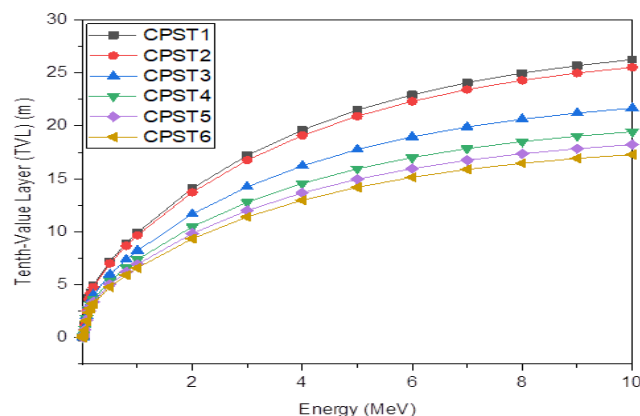


Figure 4: Tenth-value Layer Spectra of $40\text{CaO}-(10-x)\text{P}_2\text{O}_5-50\text{SiO}_2-x\text{TeO}_2$ Bioactive Glass Samples at Various Photon Energies Obtained using WinXcom Software

The minimum and maximum values of TVL obtained from WinXCom, the minimum values were obtained at 1 MeV and the maximum values were obtained at 10 MeV. Therefore, these photon energy values corresponds to 6.599m, 6.950m, 7.402m, 8.240m, 9.690m, 9.953m with 6.574m, 6.926m, 7.377m, 8.214m, 9.662m, 9.926m (WinXcom) as minimum values of the TVL. 18.289m, 19.339m, 20.676m, 23.108m, 27.284m, 28.135m with 17.288m, 18.234m, 19.445m, 21.678m, 25.530m, 26.258m (WinXcom) as maximum values of the TVL for the bioactive glass samples (CPST1, CPST2, CPST3, CPST4, CPST5, and CPST6, respectively).

Mean-Free Path (MFP) of the Glass Samples

Figure 5 shows the plot of mean-free path (MFP) versus photon energy (MeV) obtained using WinXcom. This Figure clearly follows a similar trend to the trend of HVL and TVL. The trends of the MFP value obtained increases linearly with increase in photon energy (MeV) for all the glass samples (CPST1 to CPST6). This indicates that higher photon energies travels further in the glass samples due to reduced interaction cross section of the process leading to photon absorption. This is attributed to the high attenuation rate that took place after the photon (MeV) covered a very short distance (MFP) before

interacting with the glass system. This implies that lower MFP value is attributed to more effective photon shielding performance of a material. As such, CPST2, CPST3, CPST4, CPST5 and CPST6 shows high shielding performance because of their low MFP value, except for CPST1 which shows a higher MFP value. The reduction in MFP of the glass samples as TeO_2 content increase shows that the presence of the TeO_2 in the glass system enhances the shielding performance of the glass samples.

The shielding performance of the optimally doped glass (CPST6) is compared with values reported for other tellurite- and heavy-metal-oxide-containing glass systems for radiation shielding. Although direct comparison is limited by differences in composition and density, it is evident that the addition of only 1.0 mol% TeO_2 raises the calcium-phosphosilicate glass into the same shielding class as glasses containing much larger fractions (typically 10–30 mol%) of Bi_2O_3 or other high-Z oxides. On a per-mole basis, TeO_2 is therefore a highly efficient dopant for this glass system, delivering a large density and attenuation gain at very low concentration while avoiding the toxicity concerns associated with PbO and the high cost of large Bi_2O_3 loadings.

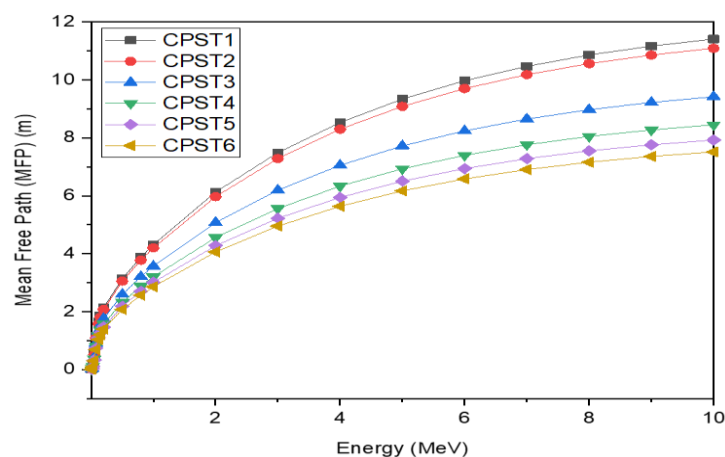


Figure 5: Mean-free path Spectra of $40\text{CaO}-(10-x)\text{P}_2\text{O}_5-\text{SiO}_2-x\text{TeO}_2$ Bioactive Glass Samples at Various Energies Obtained using WinXcom Software

Effective Atomic Number (Z_{eff}) of the Glass Samples

Figure 6 clearly shows the plot of effective atomic number (Z_{eff}) as a function of photon energy (MeV) obtained using WinXcom for all the glass samples. The variation pattern in the trends of the Z_{eff} from the first sample (CPST1) to the sixth sample (CPST6) is similar due to their common chemical composition. The trends shows that the Z_{eff} decreases drastically from 0.01 MeV to 0.05 MeV photon energy and increases gently forward. This simply indicates that the trend of the Z_{eff} increases at different energy range for all the glass

samples similar to MAC and LAC. This gradual increase after a sharp drop is simply due to the presence of TeO₂ in the glass system. As such, it shows that the presence of TeO₂ in the composition of the glass enhances the shielding performance of the glass. Therefore, the variation of the effective atomic number (Z_{eff}) of the glass samples for all photon energy varies individually, which implies that the absorption capacity of the glass samples (CPST1 to CPST6) differs at different photon energies (MeV).

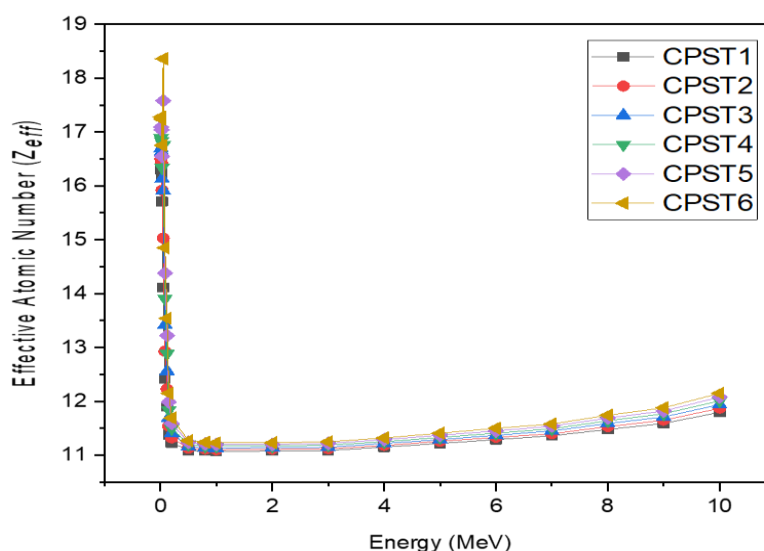


Figure 6: Effective Atomic Number Spectra of 40CaO-(10-x)P₂O₅-SiO₂-xTeO₂ Bioactive Glass Samples at Various Energies Obtained using WinXcom Software

Mean Value of the Computed Shielding Parameters

Table 3: Mean-Value of the Radiation Shielding Parameters Obtained Using WinXcom

Radiation Shielding Parameters	Bioactive Glass Samples					
	CPST1	CPST2	CPST3	CPST4	CPST5	CPST6
MAC (cm ² /g)	5.869	5.944	6.177	6.399	6.587	6.814
LAC (cm ⁻¹)	5.273	5.526	5.749	6.042	6.263	6.556
HVL (m)	3.597	3.512	2.982	2.675	2.508	2.378
TVL (m)	11.991	11.657	9.898	8.878	8.325	7.892
MFP (m)	5.214	5.068	4.303	3.860	3.619	3.431
Z_{eff}	11.371	11.434	11.555	11.652	11.747	11.844

CONCLUSION

The photon shielding performance of the 40CaO-(10-x)P₂O₅-50SiO₂-xTeO₂ bioactive glass system (x = 0.0–1.0 mol%) was investigated over 0.01–10 MeV using WinXcom and Phy-X/PSD. The mass attenuation coefficient decreases smoothly with photon energy and shows a pronounced spike at 0.07 MeV for all TeO₂-containing samples, which is attributed to the K-absorption edge of tellurium (31.8 keV). No such peak occurs in the undoped CPST1 glass, confirming that the feature originates from the dopant. The MAC of the glasses follows the order CPST6 > CPST5 > CPST4 > CPST3 > CPST2 > CPST1 at every energy level. From the result, at 0.01 MeV the MAC rises from 23.005 cm²/g (CPST1) to 24.985 cm²/g (CPST6), and at 0.05 MeV from 15.099 to 16.971 cm²/g. This monotonic improvement is a direct consequence of the density increase from 3.64 to 5.50 g/cm³ produced by TeO₂ doping.

The linear attenuation coefficient mirrors the MAC trend, and because LAC is the product of MAC with density, the practical consequence is a sharp reduction in the shielding thickness required, where the mean HVL falls from 3.597 m (CPST1) to 2.378 m (CPST6), and the mean TVL from 11.991 m to 7.892 m. At brachytherapy-relevant low energies the effect is even more pronounced, where at 0.05 MeV a CPST6 layer only ~70 μ m thick is sufficient to halve the transmitted intensity.

The MFP, HVL and TVL all increase approximately linearly with photon energy for every sample, confirming that attenuation is strongest at low energy. Since the energies of low-energy brachytherapy sources (Pd-103, I-125, Cs-131) fall within the high-attenuation region of these glasses, thin TeO₂-doped glass shields are highly effective for protecting organs at risk (e.g., the eyes, rectum and bladder) during permanent-implant and intracavitary brachytherapy, while the

rise in LAC with TeO₂ content also benefits high-dose-rate treatments using Ir-192.

REFERENCES

- Abdelwahab, E. A., El-Maaref, A. A., Shaaban, K. H. S., Borcsok, J. & Abdelawwad, M. (2020). Lithium cadmium phosphate glasses doped Sm³⁺ as a host material for near-IR laser applications. *Journal of Radiation Science*, 101(55), 3435-3467. <https://doi.org/10.1016/j.optmat.2020.110638>.
- Agar, O., Kavaz, E., Altunsoy, O., Kilicoglud, E. E., Tekin, H. O., Sayyed, M. I., Erguzel, T. T. & Tarhan, N. (2019). Er²O₃ effects on photon and neutron shielding properties of TeO₂-Li₂O-ZnONb₂O₅ glass system. *Journal of Radiation Science*, 22(9), 1277-1247. <https://doi.org/10.1016/j.rinp.2019.102277>.
- Alajerami, Y. S., Drabold, D., Mhareb, M. H. A., Cimat, K. L. A., Chena, G. & Kurudirek, M. (2020). Radiation shielding properties of bismuth borate glasses doped with different concentrations of cadmium oxides. *Journal of Materials*, 12(9), 8822-8842. <https://doi.org/10.1016/j.ceramint.2020.02.039>.
- Alhadeethi, Y., Alburiahi, M. S. & Sayyed, M. I. (2019). Bioactive glasses and the impact of Si₃N₄ doping on the photon attenuation up to radiotherapy energies. *Journal of Applied Science*, 12(7), 1222-1201. <https://doi.org/10.1016/j.ceramint.2019.10.281>.
- Alhadeethi, Y., Sayyed, M. I. & Alburiahi, M. S. (2020). Bioactive glasses doped with TiO₂ and their potential use in radiation shielding applications. *Journal of Material Science*, 78(67), 1189-1201. <https://doi.org/10.1016/j.ceramint.2020.02.276>.
- Alhassan, M., Ibrahim, H. A. & Muazu, S. I. (2023). Effect of La₂O₃ additive on the radiation shielding properties of cobalt-doped borate glasses. *Journal of Applied Science*, 27(2), 343-378. <https://dx.doi.org/10.4314/jasem.v27i2.23>.
- Almuqrin, A. H., Sayyed, M. I., Prabhu, N. S. & Kamath, S. D. (2022). Influence of Bi₂O₃ on mechanical properties and radiation-shielding performance of lithium zinc bismuth silicate glass system using Phys-X software. *Journal of Materials*, 15(1), 1315-1327. <https://doi.org/10.3390/ma15041327>.
- Atkinson, I. (2020). Effect of Sr, Zn, and Ce substitution on the properties of bioactive glass systems. *Journal of Biomedical Sciences and Research*, 756(26), 2642-2665. <https://doi.org/10.34297/AJBSR.2020.10.001467>.
- Baino, F., Montazerian, M. & Verne, E. (2023). Cobalt-doped bioactive glasses for biomedical applications. *Journal of Radiation and Materials Science*, 16(4), 4981-4994. <https://doi.org/10.3390/ma16144994>.
- Chavez, M. C. P., Angel, J. A. E., Gomezsolis, C., EdaPriego, R. C., Carrillo, H. R. V., Aquino, M. A. S. & Hernandez, M. A. V. (2022). Lead glass shielding capabilities. *Journal of Materials*, 9(5), 3166-3175. <https://doi.org/10.1016/j.bsecv.2022.06.002>.
- Hussein, K. I., Alqahtani, M. S., Alzahrani, K. J., Alqahtani, F. F., Zahran, H. Y., Alshehri, A. M., Yahia, I. S., Reben, M. & Yousef, E. S. The effect of ZnO, MgO, TiO₂, and Na₂O. (2022). Modifiers on the physical, optical, and radiation shielding properties of a TeTaNb glass system. *Journal of Materials*, 15(10), 1844-1834.
- Kargozar, S., Mozafari, M., Ghodrat, S., Fiume, E. & Baino, F. (2020). Copper-containing bioactive glasses and glass-ceramics from tissue regeneration to cancer therapeutic strategies. *Journal of Materials*, 9(1), 901-931. <https://doi.org/10.1016/j.msec.2020.111741>.
- Kaundal, R. S. & Bharol, R. (2022). Radiation shielding parameters for zinc borate and zinc silicate glasses doped with oxides of Bismuth-a comparative study. *Journal of Physics: Conference Series*, 226(7), 90-99. <https://doi.org/10.1088/1742-6596/2267/1/012093>.
- Khazaalah, T. H., Mustafa, I. S., Al-Ghamdi, H., Abdulrahman, A., Sayyed, M. I., Almuqrin, A. H., Zaid, M. H. M., Hisam, R., Abdul Malik, M. F. I., Ezra, S. N. & Shariff, H. M. (2022). The effect of WO₃-doped soda lime silica SLS waste glass to develop lead-free glass as a shielding material against radiation. *Journal of Sustainability*, 14(4), 2413-2400. <https://doi.org/10.3390/su14042413>.
- Kilicoglu, O. & Tekin, H. O. (2019). Bioactive glasses and direct effect of increased K₂O additive for nuclear shielding performance. *Journal of Radiation Science*, 222(95), 4372-4389. <https://doi.org/10.1016/j.ceramint.2019.09.095>.
- Kumar, A., Jain, A., Sayyed, M. I., Laariedh, F., Mahmoud, K. A., Nebhen, J., Khandaker, M. U. & Faruque, M. R. I. (2021). Tailoring bismuth borate glasses by incorporating PbO/GeO₂ for protection against nuclear radiation. *Scientific Report*, 11(23), 8567-8594. <https://doi.org/10.1038/s41598-021-87256-1>.
- Mishra, R. K., Avinashi, S. K., Kumari, S. & Gautam, C. (2023). Synergistic effect of Fe₂O₃ doping on physical, structural, optical, and radiation shielding characteristics of the glasses in a system for optoelectronic applications. *Journal of Inorganic Polymers*, 34(425), 2213-4334. <https://doi.org/10.1007/s10904-023-02897-1>.
- Nazrin, S. N., Amandeep, S., Jufa, M. S., Izzatym, M. K. & Boukhris, I. (2021). Mechanical and radiation shielding properties of CuO doped TeO₂-B₂O₃ glass system. *Journal of Research Square*, 81(4), 121-15. <https://doi.org/10.21203/rs.3.rs-1036115/v1>.
- Sallam, O. I., Madbouly, A. M., Moussa, N. L. & Abdel-Galil, A. (2022). Impact of radiation on CoO-doped borate glass: lead-free radiation shielding. *Journal of Applied Physics*, 70(128), 674-650. <https://doi.org/10.1007/s00339-021-05190-5>.
- Saudi, H. A. & Elkameesy, S. U. (2018). Investigation of modified zinc borate glasses doped with BaO as a nuclear radiation-shielding material. *Journal of Radiation Detection Technology and Methods*, 2(44), 679-650. <https://doi.org/10.1007/s41605-018-0075-x>.
- Sayyed, M. I., Albarzan, B., Almuqrin, A. H., El-Khatib, A. M., Kumar, A., Tishkevich, D. I., Trukhanov, A. V. & Elsafi, M. (2021). Experimental and theoretical study of radiation shielding features of CaO-K₂O-Na₂O-P₂O₅ glass systems. *Journal of Materials*, 14(11), 3772-3755. <https://doi.org/10.3390/ma14143772>.

- Sayyed, M. I., Hamad, M. K., Mhareb, M. H., Naseer, K. A., Mahmoud, K. A., Khandaker, M. U., Osman, H. & Elesawy, B. H. (2021). Impact of modifier oxides on mechanical and radiation shielding properties of B₂O₃-SrO-TeO₂-RO glasses. *Journal of Applied Science*, 88(11), 10891-10904. <https://doi.org/10.3390/app112210904>.
- Sayyed, M. I., Mahmoud, K. A., Tashlykov, O. L., Khandaker, M. U. & Faruque, M. R. I. (2020). Enhancement of the shielding capability of soda–lime glasses with Sb₂O₃ dopant: A potential material for radiation safety in nuclear installations. *Journal of Applied Sciences*, 67(5), 5642-5610. <https://doi.org/10.3390/app11010326>.
- Shams, A. M. I., Mahmoud, A., Tekin, H. O., Yasser, B. S. & Sayyed, M. I. (2019). Effect of Bi₂O₃ content on mechanical and nuclear radiation shielding properties of Bi₂O₃-MoO₃-B₂O₃-SiO₂-Na₂O-Fe₂O₃ glass system. *Journal of Material Science*, 56(12), 2211-2200. <https://doi.org/10.1016/j.rinp.2019.102165>.
- Shams, A. M. I., Ahmad M., Tekin, H. O., Saddeek, Y. B. & Sayyed, M. I. (2019). Effect of Bi₂O₃ content on mechanical and nuclear radiation shielding properties of Bi₂O₃-MoO₃-B₂O₃-SiO₂-Na₂O-Fe₂O₃ glass system. *Journal of Applied Sciences*, 89(54), 3761-3797. <https://doi.org/10.1016/j.rinp.2019.102165>.
- Takai, Z. I., Kaundal, R. S., Mustafa, M. K., Asman, S., Idris, A., Shehu, Y., Mohammad, J., Idris, M. G. & Said, M. (2018). Gamma ray and FTIR studies in zinc doped lead borate glasses for radiation shielding application. *Journal of Materials Research*, 22(1), 1244-1282. <http://dx.doi.org/10.1590/1980-5373-MR-2018-0404>.
- Vani, P., Vinitha, G., Sayyed, M. I., Elbashir, B. O. & Manikandan, N. (2019). Investigation on structural, optical, thermal and gamma photon shielding properties of zinc and barium doped fluorotellurite glasses. *Journal of Material Science*, 43(11), 3065-3093. <https://doi.org/10.1016/j.jnoncrysol.2019.02.005>.
- Yin, S., Wang, H., Li, A., Ma, Z. & He, Y. (2022). Study on radiation shielding properties of new barium-doped zinc tellurite glass. *Journal of Materials*, 15(2), 11-17.
- Yin, S., Wang, H., Wang, S., Zhang J. & Zhu, Y. (2022). Effect of B₂O₃ on the radiation shielding performance of telluride lead glass system. *Journal of Crystals*, 12(178), 1365-1345. <https://doi.org/10.3390/cryst12020178>.



©2026 This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International license viewed via <https://creativecommons.org/licenses/by/4.0/> which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is cited appropriately.