Novel Strategy for Hazardous Cement Bypass Dust Removal: Structural, Optical and Nuclear Radiation Shielding Properties of CBD-Bismuth Borate Glass

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Abstract
Herein, this study introduced a novel strategy for hazardous cement bypass dust (CBD) removal via incorporated it into glassy system having the chemical formula 10Li₂O–10Bi₂O₃–(80 − x)B₂O₃–xCBD, where x = 0, 10, 20 and 30%. The doped glass samples with the CBD were used as a radiation shielding material. The structural, optical and nuclear radiation shielding properties of CBD-lithium bismuth borate (LBB) glass were investigated. The optical energy gap increases from 2.22 eV for LBB + 0% CBD glass sample to 2.66 eV for LBB + 30% CBD glass sample. Also, a comparative study between the experimental data and theoretical interpretation for the attenuation coefficients was addressed via the Phy-X software database. The outcomes unveiled that the shielding parameters such as the linear attenuation coefficient, mass attenuation coefficient, and the effective atomic number were enhanced as CBD content increases. In the same time, the half-value layer, the tenth value layer, and the mean free path are reduced with the enrichment in the CBD content. Furthermore, the exposure build-up factor is inversely related to equivalent atomic numbers. Based on these findings, it was determined that the manufactured bismuth lithium-borate glass system doped cement bypass dust can be used for radiation shielding purposes.

Keywords Cement bypass dust removal · Lithium bismuth borate glass · Optical properties · Radiation shielding properties

1 Introduction
With the perspective increase of population growth in the middle east and north Africa countries and the increase in cement production, it is expected to increase other wastes produced by the cement industry, such as dust dispersed by clinker. Egypt produced almost 30 million tonnes of various types of cement, with 3 million tonnes of cement bypass dust (CBD)/year in dry lines. It has been employed in a variety of cost-effective and helpful applications in various parts of the world. Its contamination has been discovered to be an issue in the vicinity of cement plants. It could have toxic substances in it that are damaging to the environment [1, 2]. The amount of energy released per individual in the developing world could represent its stage of progress. Cement manufacturing is another factor that should be taken into account.

Radiation has a wide range of applications, but an excessive exposure can have major long-term consequences for human health [5]. As a result, appropriate radiation shielding material has been the most significant topic of research. The conventional materials can shield gamma rays and neutrons. However, it has many disadvantages like toxic, opaque, coast, inflexible, and unsuitable at high...
temperatures. Additionally, another feature is harmful to human health and the surrounding environment. In search of alternative radiation shielding materials, glasses without lead doped by high and low Z elements are being recommended because of its transparency, easy manufacturing, non-toxicity, favorable durability, structural stability, cost-effective, lighter in weight and attenuation coefficients [6]. Numerous studies have been conducted to investigate a variety of radiation shielding glass technologies. The glasses PbO–Li2O–B2O3, BaO–Bi2O3–B2O3, ZnO–Bi2O3–B2O3, Bi2O3–Li2O–Sb2O3–B2O3, B2O3–Bi2O3–Li2O have been studied [6–10]. The rare-earth ions doped borate glasses, for example, erbium oxide (Er2O3), cerium oxide (CeO2) and tellurium oxide (TeO2) have various proposes. Their significance is due to chemical stability, corrosion resistance, and low glass transition temperatures, superior mechanical properties, low melting temperatures, high refractive indices and high optical transmittance and had an important role in areas of medical and industrial radiation shielding potential [11, 12]. Different researches have been investigated the incorporation of CBD into glass systems for various applications. Elazaka et al. [13], have incorporated the CBD into Na2O–BaCl2–B2O3 glass system as a nuclear radiation shielding material.

This research aimed to produce a gamma radiation shielding material based on cement bypass dust (CBD) doped with lithium bismuth borate (LBB) glass with composition 10Li2O–10Bi2O3–(80 – x) B2O3–xCBD, where (x = 0, 10, 20, and 30%). The LBB + x% CBD (x = 0, 10, 20, and 30) glass samples were characterized via EDX, XRD, FTIR and UV–Vis spectroscopy. Also, the experimental results along with theoretical estimations such as the mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), mean free path (MFP), effective atomic number (Zeff), half value layer (HVL), tenth value layer (TVL) and effective electron density (Neff) were resolved to study the gamma-ray attenuation properties. The exposure build up factor (EBF) and equivalent atomic numbers (Zeq) were also computed. The current examination results would be suitable for special applications on removing hazardous cement bypass dust (CBD) through incorporated it with a glass system to build novel material for gamma radiation shielding.

### 2 Materials and Methods

#### 2.1 Sample Preparation

In this study, CBD was incorporated with a glass system with composition 10Li2O–10Bi2O3–(80 – x) B2O3–xCBD, (LBB + xCBD) where (x = 0, 10, 20 and 30%) (Table 1). The chemical composition of CBD are analyzed by EDX technique that consists of silicon dioxide (SiO2), aluminium oxide (Al2O3), ferric oxide (Fe2O3), calcium oxide (CaO), potassium oxide (K2O), sodium oxide (Na2O), sulfur trioxide (SO3), titanium dioxide (TiO2), manganese oxide (Mn2O3) and magnesium oxide (MgO) at (0.0%, 1.09% and 1.02%), respectively. Proper amounts of Li2O, Bi2O3, B2O3, and CBD were used in the glass synthesis as previously described in [14, 15]. The thickness of LBB + xCBD where (x = 0, 10, 20 and 30%) samples was found of 2 ± 0.4 mm.

#### 2.2 Characterization Techniques Employed

The traditional Archimedes rule has been utilized to calculate the density of LBB + x% CBD samples at the room temperature as the subsequent equation [16]:

$$\rho = \frac{M_a}{(M_{air} - M_{Liqui})} \rho_L$$  \hspace{1cm} (1)

where: $M_a$ is the weight of the sample in the air, $M_L$ is the weight of the sample in the distilled water. The molar volume ($V_m$) of the LBB + x%CBD samples was computed by the following relation,

$$V_m = \frac{X_i M_i}{\rho}$$  \hspace{1cm} (2)

where $M_i$ is the molecular weight of the ith component and $X_i$ is the molar fraction of the ith component.

The LBB + x%CBD samples were characterized for their structural properties using X-ray powder diffraction (XRD; Shimadzu XRD-6000) [17–22]. Fourier Transform Infrared (FT-IR) spectroscopy was used to investigate the groups that initiated the LBB + x% CBD samples in range of (4000–400 cm$^{-1}$). The optical properties of

### Table 1

| Sample code | Mole fraction | Density (ρ) (cm$^3$/g) | Molar Volume V$_m$ (cm$^3$) |
|-------------|---------------|------------------------|-----------------------------|
| LBB +0%CBD  | 10 10 80 0    | 2.965                  | 35.528                      |
| LBB +10%CBD | 10 10 70 10   | 2.988                  | 35.124                      |
| LBB +20%CBD | 10 10 60 20   | 3.046                  | 34.298                      |
| LBB +30%CBD | 10 10 50 30   | 3.169                  | 32.838                      |
LBB + x% CBD samples were illustrated in the wavelength range 300–1100 nm via UV–Vis spectrophotometer [15, 23].

### 2.3 Shielding Parameters Simulation

A fine beam transmission scheme has been applied to measure the gamma ray effectiveness parameters for LBB + x% CBD samples as represented in Fig. 1. The $^{137}$Cs (1 µCi) and $^{60}$Co (1 µCi) gamma ray point sources were utilized in this study as well as a NaI (Tl) scintillation detector with a 3”x3” powerful crystal location. The gamma-ray detector held attached to Canberra Genie-2000 software for the data interpretation. Furthermore, the Phy-X /PSD software was accepted in order to calculate the gamma-ray shielding characteristics of LBB + x% CBD samples at different energies from 0.001 to 15 MeV [24, 25].

### 3 Results and Discussion

#### 3.1 Structural Analyses

Figure 2 shows the XRD patterns of LBB + x% CBD glass samples. The figure reveals that the samples displayed a broad amorphous hump at 20 = 20°–28° and there is non-attendance of sharp peaks [26, 27]. This gives confirmation of the glassy state of the prepared samples. Besides, there a small peak appeared in the range (2$\theta$ = 10°–20°) for LBB + 30% CBD sample, which may be related to the presence of a second phase (ceramic/glass) due to increasing the CBD doping ratio [28–30].

Figure 3 exhibited the FTIR spectra of LBB + x% CBD glass samples. The figure tells a clear explanation about the chemical structure of the prepared cement-glass samples, and the changes that occurred upon increasing CBD concentration in the wavenumber range from 400 to 4000 cm$^{-1}$. In case of base glass (LBB + 0% CBD); the spectra admit four main absorption peaks at 520, 690, 955 and 1300 cm$^{-1}$. In general, boron atoms are found inside the glass network as tetraborate units (BO$_4$) and boroxol rings. The tetraborate units can be broken to give NBO (non-bridging oxygen) upon addition any cation which results from other additives to the structure as former or modifiers [31]. Bi$^{3+}$ can be settled inside the glass network by ionic bond between Bi$^{3+}$ ion and oxygen atoms bonded to borate network as a result of the previous rupture occurred from borate units so bismuth borate glasses can show two bands; one at 850 cm$^{-1}$ for BiO$_3$ units and another one at 540 cm$^{-1}$ for BiO$_6$ (octahedron) [32, 33].

Figure 3 gives four broad regions due to the amorphous nature and the well homogenous distribution of the component inside the glass matrix. The first three regions can be decovoluted to illustrate the overlap peaks under these regions as given by Fig. 4a and b. All observed peaks are shown at Table 2.

Upon introducing and increment of CBD concentration by (x = 10, 20 and 30%) in bismuth-borate glass; some observations are detected as follow:

(a) relative area for bands in the ranges from 1245 to 1450 cm$^{-1}$ decreased by increased cement dust concentration due to the formation of BO$_3$ from BO$_4$
Peak at 520 cm$^{-1}$ give higher intensity for 30% cement dust

(c) Lowering in borate group intensity due to the breaking in borate bonds and formation of NBO and at the same time decreasing of OH and H$_2$O groups inside the network as CaO introduced.

(d) Position of some bonds show shift to higher values of wavenumber

The first three regions can be deconvoluted to illustrate the overlap peaks under these regions as given by Figs. 3 and 4 with their relative area (A) and band center (C) in wavenumber range from 400 to 1800 cm$^{-1}$ as shown in Table 3. These parameters help in calculating (N4) values for each sample where:

$$N_4 = \frac{BO_4}{(BO_3 + BO_4)}$$

N$_4$ value can confirm how the transformation from BO$_3$ into BO$_4$ units is; only one oxygen atom for each transformation is needed to finish this process. Upon the addition of cement bypass dust, N$_4$ values increase due to the decrease of the area and shifted of most of the peaks to higher wavenumbers due to the formation of (SiO$_4$ and CaO$_4$) units and the tendency of conversion from BO$_3$ to BO$_4$ by creating calcium silicate covalent bonds inside the borate glassy network which raise the yield of non-bridging oxygen [31] by filling the positions between boron-oxygen linkage with Ca$^{2+}$ and Si$^{4+}$ that meaning the glass network become more lose. N$_4$ results are confirmed by density values as by adding more cement dust to bismuth borate glass, the density increase gradually, so the compactness of the glass network increases. This behavior suggested that our samples can be used for many purposes, including radiation shielding.

3.2 Optical Behavior

Figure 5 presents the transmittance (T) of LBB + x% CBD glass samples. In Fig. 5, the transmittance edges in the visible region were showed a shift to a higher wavelength ($\lambda$) as the CBD’ concentration was increased [42–44]. Besides, it is clear that in IR region, the transmittance was increased with the increase in CBD’ concentration except for the decrease that occurred at $x = 20\%$. This behavior can be attributable to the defects variation and the localized electronic states in the glass lattice between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) band edges [45]. These parameters lead to appearing the changing in the energy transitions available as a result of CBD’ addition [23, 46]. This behavior was previously seen in [14]. Radiation-shielded windows are commonly employed to give total protection while providing visibility into the protected room’s operations. As a result, it should be transparent rather than opaque.

Also, Fig. 6 illustrates the extinction coefficient k of LBB + x% CBD glass samples [47]. The extinction coefficient k is represented the light lost ascribing to scattering and absorption by unit volume. Therefore, great values of k in the lower wavelength area confirm that these materials are opaque in this area [48]. The addition of CBD to LBB glass shifted the absorption edge for the higher wavelength in the visible area [14, 49, 50].

The indirect bandgap can be obtained via plotting ($\alpha$hv)$^{1/2}$ vs (hv) for LBB + x% CBD glass samples (Fig. 7). The optical energy gap increases from 2.22 eV for LBB + 0% CBD glass sample to 2.66 eV for LBB + 30% CBD glass sample due to the addition of CBD to LBB glass [51]. The increase in Eg values can be ascribed to a change in LBB glass structure and the generation of defects in charge distribution as a result of the addition of CBD concentration through enhancing the energy state of the oxygen ions and the degree of localization. It should be highlighted that all
### Table 2 FTIR peaks and their assignment for LBB + x% CBD glass samples

| Peak (cm\(^{-1}\)) | Assignment |
|---------------------|------------|
| 430                 | Vib. of Fe\(^{3+}\) cations\[^{34}\] |
| 450                 | Vib. of Li\(^{2+}\) cations \[^{31}\] |
| 520                 | Vib. of Ca\(^{2+}\) cations \[^{34, 35}\] |
| 540                 | Bi–O–Bi and Bi–O in BiO\(_6\) octahedral group \[^{32, 36}\] |
| 590                 | Bend. Vib. O–Si–O and Si–O–Si in SiO\(_4\) unit (tetrahedral) \[^{35, 37}\] |
| 620                 | Vib. of BO\(_4\) group |
| 690                 | Bend. Vib. of B–O–B of BO\(_4\) groups |

#### Area (I) 400–800 cm\(^{-1}\) (Cation region)

| Peak (cm\(^{-1}\)) | Assignment |
|---------------------|------------|
| 430                 | Vib. of Fe\(^{3+}\) cations\[^{34}\] |
| 450                 | Vib. of Li\(^{2+}\) cations \[^{31}\] |
| 520                 | Vib. of Ca\(^{2+}\) cations \[^{34, 35}\] |
| 540                 | Bi–O–Bi and Bi–O in BiO\(_6\) octahedral group \[^{32, 36}\] |
| 590                 | Bend. Vib. O–Si–O and Si–O–Si in SiO\(_4\) unit (tetrahedral) \[^{35, 37}\] |
| 620                 | Vib. of BO\(_4\) group |
| 690                 | Bend. Vib. of B–O–B of BO\(_4\) groups |

#### Area (II) 800–1155 cm\(^{-1}\) (Tetragonal Units) (BO\(_4\) units)

| Peak (cm\(^{-1}\)) | Assignment |
|---------------------|------------|
| 820                 | Bend. Vib. of Si–O–Si of (SiO\(_4\)) groups \[^{38}\] |
| 865                 | For BiO\(_3\) groups \[^{32}\] |
| 950                 | Str. Vib. of B–O in diborate BO\(_4\) groups \[^{32}\] |
| 1050                | Str. Vib. of B–O in triborate BO\(_4\) groups and may be for Si–O–B linkage \[^{39}\] |
| 1100                | Str. Vib. of B–O in tetraborate BO\(_4\) groups \[^{31}\] |
| 1150                | Str. Vib. of B–O in pentaborate BO\(_4\) groups \[^{31}\] |
| 1155                | Str. Vib. of CaO\(_6\) units |

#### Area (III) 1155–1640 cm\(^{-1}\) (Triangular Units) (BO\(_3\) units)

| Peak (cm\(^{-1}\)) | Assignment |
|---------------------|------------|
| 1245                | Vib. of BO\(_3\) groups (meta, ortho, pyro) |
| 1345                | Vib. of BO\(_3\) groups (meta, ortho, pyro) |
| 1450                | Antisym. Str. Vib. of 3 NBO of B–O–B of BO\(_3\) units \[^{31}\] |
| 1650                | Str. B–O of BO\(_3\) |

#### Area (IV) Above 1640 cm\(^{-1}\) (near IR region)

| Peak (cm\(^{-1}\)) | Assignment |
|---------------------|------------|
| 1980                | (SiOH) silanol units \[^{40}\] |
| 2160, 2975 and 3370 | Str. vib. of OH and hydroxyl units beside the bending vib. from H–O–H bonds \[^{41}\] |

### Table 3 De-convolution parameter of the infrared spectra of studied glasses, (C) is the component band center and (A) is the relative area (%) of the samples bands (0, 10, 20, 30% CBD)

| Sample | x% CBD | C  | A  |
|--------|--------|----|----|
|        | 0%     | 10%| 20%| 30%|
| Peak 1 | 411    | 0.258 | 401 | 0.454 | 401 | 0.185 | 401 | 0.061 |
| Peak 2 | 503    | 0.141 | 431 | 0.145 | 436 | 0.099 | 444 | 0.100 |
| Peak 3 | 599    | 0.109 | 469 | 0.148 | 470 | 0.085 | 502 | 0.150 |
| Peak 4 | –      | –     | 525 | 0.016 | 512 | 0.034 | 532 | 0.096 |
| Peak 5 | –      | –     | 550 | 0.063 | 555 | 0.060 | 577 | 0.092 |
| Peak 6 | 620    | 0.459 | 614 | 0.131 | 611 | 0.209 | 617 | 0.518 |
| Peak 7 | 688    | 1.092 | 697 | 0.627 | 704 | 0.824 | 711 | 0.825 |
| Peak 8 | –      | –     | 850 | 1.172 | 846 | 0.698 | 829 | 0.161 |
| Peak 9 | 868    | 2.272 | 914 | 1.539 | 902 | 0.578 | 888 | 0.836 |
| Peak 10| 955    | 2.160 | 978 | 1.324 | 960 | 1.058 | 949 | 0.384 |
| Peak 11| 1017   | 0.679 | 1050| 1.024 | 1038| 0.747 | 996 | 0.779 |
| Peak 12| 1058   | 0.539 | 1098| 0.119 | 1106| 0.383 | 1129| 0.137 |
| Peak 13| 1110   | 1.000 | 1211| 0.156 | 1176| 0.310 | 1163| 0.164 |
| Peak 14| –      | –     | 1248| 0.184 | 1239| 0.395 | 1204| 0.476 |
| Peak 15| 1237   | 1.489 | 1287| 0.612 | 1297| 0.618 | 1328| 0.638 |
| Peak 16| 1317   | 1.795 | 1343| 1.683 | 1340| 0.598 | 1385| 0.341 |
| Peak 17| 1383   | 1.438 | 1429| 0.198 | 1389| 0.954 | 1424| 0.181 |
| Peak 18| 1455   | 1.331 | 1475| 0.103 | 1455| 0.585 | 1468| 0.157 |
| N\(_4\) value | 0.459 | 0.469 | 0.475 | 0.499 |
data show an increase in NBO in the glass matrix, which causes an increase in $O^{2-}$ ions [52].

### 3.3 Radiation Shielding Properties

By analyzing the spectrum of emitted gamma rays across an absorber of a specific thickness, the gamma-ray attenuation capabilities were investigated for the glass barriers under study. Lambert-law Beer's law was utilized to get linear attenuation coefficient (LAC) parameter for the investigated glass samples using gamma rays narrow beam system of $^{60}$Co and $^{137}$Cs that can be computed by the following equation.

\[
I_d = I_0 e^{LAC \cdot d}
\]

where (d) is the thickness of sample, $I_0$ is the intensity of incident gamma rays without absorber, and $I_d$ is the intensity of incident gamma rays with absorber thickness (d).

The gamma-ray effectiveness relations did apply to assess the attenuation parameters LAC, MAC, HVL, TVL, MFP, Neff and Zeff of the LBB + x% CBD samples according to equations as presented in [14, 16, 24].

Along with all specified photon energies, Fig. 8 displays the LAC values in a relationship to CBD content. That shows LAC increases as CBD content increase due to adding more elements have gamma-ray absorption effect, which increases the molecular weight of the sample as well as density increase (such as, $Fe_2O_3$, $TiO_2$, $Al_2O_3$, $SiO_2$, $Mn_2O_3$, $MgO$ and $CaO$) [9, 13, 14].

By comparing the gamma-ray mass attenuation coefficient of the prepared samples with ordinary concrete (OC) and barite concrete (BC) at 662 keV, it was found of 0.07889, 0.084 and 0.0857 cm$^2$/g, respectively. In addition, it is observed that the sample 30% CBD has the lowest...
values of the mean free path compared to the mean free path for ordinary concrete, hematite-serpentine concrete and ilmenite-limonite concrete at the 662 keV energy are 5.5957, 5.2219 and 4.6038 cm respectively. Therefore, the substitution of the ordinary gamma-ray shielding materials by low weight, reusing hazardous by-products, transparent shield, relatively efficient attenuator and low coast manufactured material was much gained [53–55].

Figure 9 illustrates the MAC values as a relationship of CBD content for all particular photon energies. Table 4 shows a contrast of computed MAC values LBB + x% CBD glass samples and gamma ray energy. It can be observed that the experimental data obtained and the numerical simulations are in reasonable conformity.

The HVL, MFP, and TVL are depicted in Figs. 10, 11, and 12. The HVL, MFP, and TVL values decreases as the CBD content in the LBB glass increasing, as shown in those graphs. As well as the gamma rays energies increases these values increase [6, 54]. Therefore, it may be confirmed that addition of CBD to the LBB glass increases the system’s shielding properties.

Figures 13 and 14 illustrated the Z\text{eff} and N\text{eff} values for LBB + x% CBD glass samples at given gamma rays energies (662, 1.173 and 1.332 MeV) were increased with increasing CBD concentration (Table 5). Conversely, when photon energy increase, both Z_{\text{eff}} and N_{\text{eff}} values reduced for LBB + x% CBD samples. In addition, Table 5 shows that the total atomic cross section (\sigma_t) and the total electronic cross

### Table 4

| CBD mol% | Phy-X | EXP | Diff |
|----------|-------|-----|------|
| 662 MeV  |       |     |      |
| 0        | 0.0785 | 0.07858 | 0.105732 |
| 10       | 0.07867 | 0.07865 | 0.027965 |
| 20       | 0.07884 | 0.07879 | 0.060883 |
| 30       | 0.07901 | 0.07889 | 0.153145 |
| 1.173 MeV|       |     |      |
| 0        | 0.0577 | 0.05734 | 0.630849 |
| 10       | 0.05781 | 0.05756 | 0.425532 |
| 20       | 0.05792 | 0.05778 | 0.239986 |
| 30       | 0.05803 | 0.05806 | 0.055144 |
| 1.332 MeV|       |     |      |
| 0        | 0.0539 | 0.05363 | 0.508349 |
| 10       | 0.054 | 0.05388 | 0.218519 |
| 20       | 0.05411 | 0.05417 | 0.109037 |
| 30       | 0.05421 | 0.05427 | 0.11437 |

\[ \text{Diff} = \frac{\left| \text{Phy-X} - \text{EXP} \right|}{\text{Phy-X}} \times 100 \]
section ($\sigma_e$) values for LBB + x% CBD glass samples. All of these variables exhibit nearly identical response to that of MAC as energy dependence and CBD content.

Figure 15 shows the EBF against gamma rays energy charts for LBB + x% CBD samples at different penetration depths of 1, 5, 10, 15, 20, 25, 30, 35 and 40 mfp. The steep peaks in the graphs are caused by bismuth absorption edges. The EBF grows with a depth and reaches extreme value at 40 mfp. Several scattering reactions result in the creation of secondary gamma rays at deeper penetration depths [54, 56, 57].

The fluctuation of EBF with penetration depth (mfp) for the glass samples has been estimated and can be seen in Fig. 16 for gamma rays energies of 0.015, 0.15, 1.5, 3, 8, 15 MeV. The EBF values are mfp independent at the low energy range (0.015, 0.15 MeV) and lowest values. The gamma rays photons are fully cancelled out due to the photoelectric effect in this energy band. In the intermediate energy area, EBF has a linear relationship with mfp. The EBF improved within repeated Compton scattering at higher gamma-ray energies [6]. Furthermore, in the low and intermediate energy zones, an inverse relation between EBF and the equivalent atomic number ($Z_{eq}$), whereas in the higher energy region, it is roughly related to $Z_{eq}$ (Fig. 17). This occurs due to the pair production phenomenon is the most important interacting activity in the higher energy area.

At middle photon energy region the EBF is lowest for LBB + 30% CBD (30 mol% CBD) and in dissimilarity, the EBF is lowest for LBB + 0% CBD (0 mol% CBD) in higher photon energy area (Fig. 16). Hence, the choice of appropriate radiation shielding material be influenced by the incident radiation energy in a specific application [9, 58].

4 Conclusions

This study displayed a novel strategy for removing hazardous cement bypass dust (CBD) by incorporating it into a glassy system with the chemical formula 10Li$_2$O–10Bi$_2$O$_3$–(80 − x)B$_2$O$_3$–xCBD, where x = 0, 10, 20, and 30%. Further, the LBB + x% CBD glass samples possess an additional function as a candidate material for radiation shielding applications. Also, the structural, optical, and attenuation properties of the LBB + x% CBD glass samples have studied. The optical energy gap increases from 2.22 eV for LBB + 0% CBD glass sample to 2.66 eV for LBB + 30% CBD glass sample. The increase in $E_g$ values can be ascribed to a change in LBB glass structure and the generation of defects in charge distribution due to the addition of CBD concentration. The MAC values were
Table 5  The total atomic cross section ($\sigma_a$), the total electronic cross section ($\sigma_e$), the effective atomic number ($Z_{\text{eff}}$), and the electron density ($N_{\text{eff}}$) for LBB $+ x\%$ CBD glass samples

| CBD mol% | $\sigma_a \times 10^{-24}$ (cm$^2$/g) | $\sigma_e \times 10^{-25}$ (cm$^2$/g) | $Z_{\text{eff}}$ | $N_{\text{eff}} \times 10^{23}$ (e$^-$/g) |
|----------|----------------------------------|----------------------------------|-----------------|----------------------------------|
|          |                                  |                                  |                 |                                  |
| 662 MeV  |                                  |                                  |                 |                                  |
| 0        | 1.9035                           | 2.6555                           | 7.17            | 2.9592                           |
| 10       | 1.9995                           | 2.5959                           | 7.70            | 3.0297                           |
| 20       | 2.1076                           | 2.5296                           | 8.33            | 3.1148                           |
| 30       | 2.2263                           | 2.4553                           | 9.07            | 3.2131                           |
| 1.173 MeV|                                  |                                  |                 |                                  |
| 0        | 1.3888                           | 1.9818                           | 7.01            | 2.8931                           |
| 10       | 1.4634                           | 1.9343                           | 7.57            | 2.9760                           |
| 20       | 1.5456                           | 1.8813                           | 8.22            | 3.0713                           |
| 30       | 1.6386                           | 1.8220                           | 8.99            | 3.1867                           |
| 1.332 MeV|                                  |                                  |                 |                                  |
| 0        | 1.2989                           | 1.8535                           | 7.01            | 2.8932                           |
| 10       | 1.3698                           | 1.8088                           | 7.57            | 2.9788                           |
| 20       | 1.4490                           | 1.7591                           | 8.24            | 3.0794                           |
| 30       | 1.5316                           | 1.7033                           | 8.99            | 3.1863                           |

Fig. 15  The EBF versus photon energy for LBB $+ x\%$ CBD glass samples at various penetration depths

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Fig. 16  The EBF versus the penetration depth for LBB + x% CBD glass samples at various photon energies
calculated using the Phy-X database code, and experiments. The LAC and MAC values are enhanced as the CBD substituent ratio increases. The MFP and HVL values declined as the CBD substituent ratio increased in the same context. By comparing the gamma-ray mass attenuation coefficient of the prepared samples with ordinary concrete (OC) and barite concrete (BC), it was found to be promising. Furthermore, a good matching between the experimental results and theoretical calculations was observed, indicating the Phy-X code’s efficiency. Besides, it is noticed that the best sample for gamma-ray shielding is LBB + 30% CBD. Choosing a suitable shield material with the best thickness for radiation shielding could be accomplished using data from the tenth value layer, considering the exposure build-up factor, the energy of incident radiation, and the particular applications. Overall, the structural, optical, and attenuation properties of the LBB + x%CBD glass samples make them candidate materials for radiation shielding applications.

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**Declarations**

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