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Evaluation of TeO2-WO3-Bi2O3 glasses for their potential in radiation shielding with the utilization of the Phy-X software program

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Abstract

This study investigates the radiation shielding potentiality of [(78-x) TeO_2-22WO_3-xBi_2O_3; where x=2, 5, 8] glasses within the 0.284 MeV to 1.333 MeV energy range utilizing a novel computer program, Phy-X. The linear attenuation coefficient (LAC), half value layer (HVL), tenth value layer (TVL), mean free path (MFP), and effective atomic number (Z_{eff}) were assessed to gauge the efficacy of these glasses as radiation shields. The variations in these parameters were analyzed for different compositions of Bi_2O_3 (x = 2, 5, 8) within the glass matrix. The utilization of the Phy-X software enabled a comprehensive evaluation, offering insights into the shielding capabilities of the glasses across a broad energy spectrum. This study contributes to advancing the understanding of material properties relevant to radiation shielding applications, facilitating informed decisions in the design and selection of suitable shielding materials for diverse radiation environments. After conducting this study, it was found that with the enhancement of the ratio of Bi_2O in the composition of TeO_2-WO_3-Bi_2O_3 glasses, the density, LAC, and Z_{eff} values were higher, while the HVL, TVL, and MFP values were lower. Considering the HVL of the studied glasses, the following declining trend was found: TWB-2>TWB-5>TWB-8. Through analyzing the composition of these glasses, it was found that the addition of increasing amounts of Bi_2O_3 instead of TeO_2 decreased the HVL. Therefore, it can be concluded that Bi_2O_3 is a more suitable additive than TeO_2.

1. Introduction:

Human beings are not only exposed to natural radiation—as from the crust to the environment, the existence of natural radiation has been found everywhere—but also artificial radiation because of its use in diagnostic centers, nuclear power plants, aerospace, etc. [1]. In the medical sector, 98% of radiation comes from artificial radiation sources. Every year, all over the world in the medical sector, 7.5 million radiotherapy treatments are provided with 3,600 million radiological diagnoses, as well as 37 million nuclear medicines being manufactured [2].

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It is well known that radiation has negative effects on life, yet it is not possible to lead a modern life without the use of radiation. Therefore, to mitigate the effects of radiation, radiation shielding is required [3]. Radiation effects do not only impact human beings, since they also destroy equipment such as electrical devices [4]. Due to the cost-efficiency, environment friendliness, transparency, and non-toxicity features, glasses

represent a good shielding material [5]. Among numerous HMO, high density and great attenuation ability have made Bi_2O_3 popular as a glass modifier, considering the composition of the glass matrix [6]. To make a comparison, tellurite glass shows better radiation shielding efficiency than Pb glass and concrete [7]. Good thermal and chemical stability, low phonon energy, high refractive index, good devitrification resistance, and low melting temperature are some good characteristic of TeO_2 glasses [8].

PbO, Bi_2O_3, and W_2O_3 are familiar heavy metal oxides for radiation shielding because of their high density and large atomic number [9]. In 2019, Tijani et al. discovered that enhancement through Bi_2O_3 and TeO_2 addition helps to increase the MAC and HVL at the energies of 20-30 keV and 40-60 keV, respectively [10].

The purpose of this study is to analyze the radiation shielding efficiency of the glass composition [(78-x) TeO_2-22WO_3-xBi_2O_3; where x=2, 5, 8] by including a new ratio of TeO_2, WO_3, and Bi_2O_3. The aim is to identify a suitable radiation protection shield that is lighter and less toxic, which can then be made available in the commercial market. To the best of our knowledge, no prior research has examined the glass system with the ratio of the composites (TeO_2, WO_3, and Bi_2O_3) used in this research.

2. Materials and Methods:

Importance of Phy-X/PSD software:

To calculate numerous radiation shielding parameters, such as the linear attenuation coefficient (LAC), half value layer (HVL), tenth value layer (TVL), mean free path (MFP), effective atomic number (Z_{eff}), and so on for an element, compound, or mixture without being exposed to experimental hazard, the online software Phy-X/PSD has been developed [11].

When any *y*-ray is passed through an absorber, then a few incident photons are absorbed by it and others are transmitted due to the photoelectric effect, Compton scattering, pair production, and so on. The Beer-Lambert equation is a well-established formula for evaluating the value of the LAC [12] as follows:

$$I = I_0 e^{-\mu x} \quad (1)$$

where, I and I_0 represent the incident and transmitted photon intensity, respectively, t is the penetration depth (cm) for a specific photon energy, and μ shows the attenuation coefficient of the absorber.

HVL, TVL, and MFP are LAC-dependent parameters.

HVL is the absorber's thickness that has the ability to reduce one half of the intensity of the incident photon energy [13]:

$$HVL = \frac{0\ 693}{LAC} \quad (2)$$

The TVL is nothing but a similar parameter of HVL. Here, it indicates that the thickness value of a shield or an absorber can diminish the radiation level by a factor of one-tenth of the initial level instead of one-half [14].

With the help of the LAC (μ), the TVL can be evaluated by the following equation:

$$TVL = \frac{2\ 303}{LAC} \quad (3)$$

The average distance between two interactions of a photon is represented by the MFP. The unit of the MFP is cm^{-1}. The following formula is used to determine the value of the absorber's MFP:

$$MFP = \frac{1}{LAC} \quad (4)$$

The Z_{eff} is defined as the ratio of the atomic and electronic cross-sections [15]:

$$Z_{eff} = \frac{a_a}{a_b} \quad (5)$$

2. Results and Discussion:

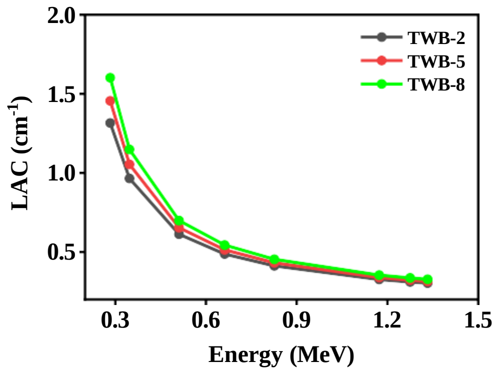

Fig. 1. Diagram of the studied glass samples' LAC values.

The LAC values regarding the glasses studied herein were investigated utilizing the MCNP6-code. Fig. 1 presents the inconsistency of the LAC values (cm^{-1}) of the TWB-2, TWB-5, and TWB-8 glasses for the 0.284 MeV to 1.333 MeV energy region. This figure displays a decreasing trend of the value of LAC with the increase of energy from 0.284 MeV to 1.333 MeV. At 0.284 MeV, the LAC values of the regarded glasses were 1.32 cm^{-1} (TWB-2), 1.46 cm^{-1} (TWB-5), and 1.6 cm^{-1} (TWB-8).

However, at the energy region of 1.333 MeV, the LAC values among the regarded glasses were 0.30 cm^{-1} (TWB-2), 0.32 cm^{-1} (TWB-5), and 0.33 cm^{-1} (TWB-8). The sample glasses TWB-2, TWB-5, and TWB-8 were shown to have 4.3-, 4.6-, and 4.89-times higher LAC values at 0.284 MeV compared to 1.333 MeV.

Besides, sample TWB-8 showed the highest LAC values among the regarded glasses. As an example, at the energy of 0.284 MeV, the LAC values among the regarded glasses were 0.30 cm^{-1} (TWB-2), 0.32 cm^{-1} (TWB-5), and 0.33 cm^{-1} (TWB-8). Hence, sample glasses TWB-5 and TWB-8 showed 1.1- and 1.2-times greater LAC values compared with the TWB-2 glass sample.

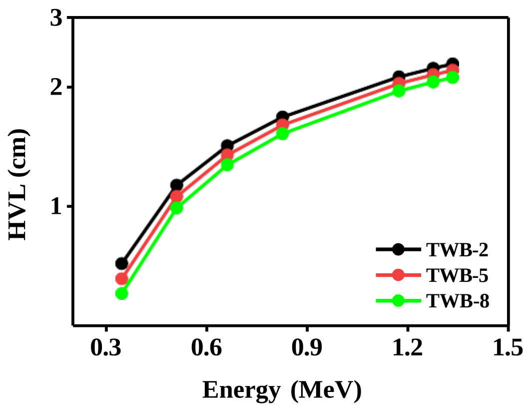

Fig. 2. Diagram of the studied glass samples' HVL.

According to the Beer-Lambert law, when the lower thickness's absorber can reduce a greater amount of incident radiation, that means it contains higher radiation shielding ability. The HVL indicates the required thickness of that absorber, which can emit half of its incident photon. Fig. 2 demonstrates the HVL of the TWB-2, TWB-5, and TWB-8 glasses from the energy of 0.284 MeV to 1.333 MeV. For any insufficient room, the lowest value of the half value layered absorber is needed to provide proper radiation protection.

Considering the HVL of these studied glasses, the following decreasing trend was found: TWB-2>TWB-5>TWB-8. For instance, at 0.284 MeV, the LAC values among the regarded glasses were 0.53 cm^{-1} (TWB-2), 0.48 cm^{-1} (TWB-5), and 0.43 cm^{-1} (TWB-8), again at the energy of 1.33 MeV, while the HVL values were 2.3 cm^{-1} (TWB-2), 2.2 cm^{-1} (TWB-5), and 2.1 cm^{-1} (TWB-8). Hence, the sample glasses TWB-5 and TWB-8 showed 1.1- and 1.2- times greater LAC values compared with glass sample TWB-2. Sample glasses TWB-2, TWB-5, and TWB-8 were shown to have 4.3-, 4.6-, and 4.9-times higher LAC values at the energy of 0.284 MeV compared to 1.333 MeV.

At 1.333 MeV, the HVL values were 2.3 cm^{-1} (TWB-2), 2.2 cm^{-1} (TWB-5), and 2.1 cm^{-1} (TWB-8), which indicates that glass sample TWB-8 had a 0.9-times lower value than sample TWB-2. Therefore, sample TWB-8 represents the highest shielding ability considering the HVL. Hence, it is clear that TWB-8 showed the lowest value of HVL. Through analyzing the composition of these glasses, it was found that the addition of increasing amounts of Bi_2O_3 instead of TeO_2 decreased the HVL.

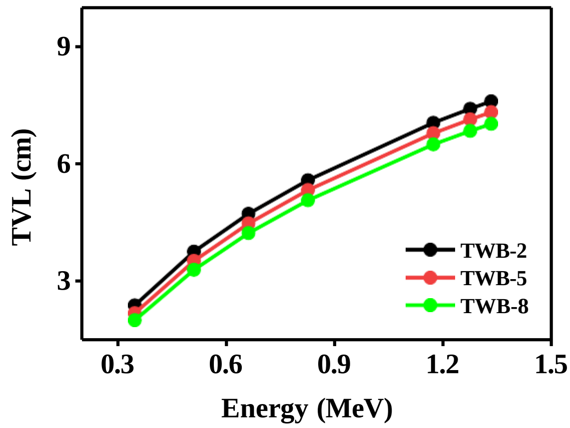

Fig. 3. Diagram of the studied glass samples' TVL.

Fig. 3 portrays the TVL of the studied glasses TWB-2, TWB-5, and TWB-8 from 0.284 MeV to 1.333 MeV. Here, glass sample TWB-8 gave the lowest TVL compared to the other studied glasses. According to the TVL of these studied glasses, they followed a decreasing trend: TWB-2>TWB-5>TWB-8. For example, at the energy of 0.662 MeV, the TVL of the studied glass samples were 4.7 cm (TWB-2), 4.5 cm (TWB-5), and 4.2 cm (TWB-8). Hence, it can be said that among the studied glasses samples, TWB-8 showed the lowest value of TVL.

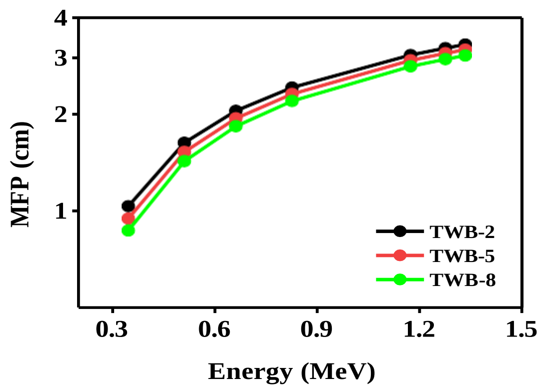

Fig. 4. Diagram of the studied glass samples' MFP.

MFP is another prominent parameter to judge the radiation shielding capability of any absorber. Not only for HVL but also for MFP, a short half value layered absorber is obligatory for any kind of good radiation shield. Fig. 4 presents the MFP of the studied glasses TWB-2, TWB-5, and TWB-8 from the energy of 0.284 MeV to 1.333 MeV. Within two successive collisions, the distance travelled by photons inside the absorber is called the MFP of that absorber. For example, at 1.17 MeV, the MFP of the studied glass samples were 3.06 cm (TWB-2), 2.95 cm (TWB-5), and 2.82 cm (TWB-8). This indicates that among the studied glasses samples, TWB-8 exhibited the lowest value of MFP.

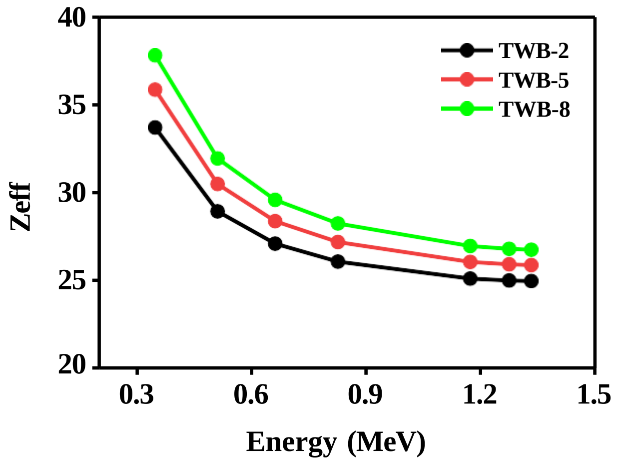

Fig. 5. Diagram of the studied glass samples' Z_{eff}.

To analyze the radiation shielding ability of any compound matrix, the Z_{eff} parameter plays a significant role. Fig. 5 shows the obtained Z_{eff} values of the glasses studied herein in terms of the photon energy upon on it from the energy of 0.284 MeV to 1.333 MeV. The figure presents a declining movement of the Z_{eff} with the increase of incident photon energy from 0.284 MeV to 1.333 MeV. The obtained Z_{eff} values of the regarded glasses showed the following increasing trend: TWB-2<TWB-5<TWB-8. At the energy of 0.284 MeV, the Z_{eff} of the regarded glasses were 37.4 (TWB-2), 39.9 (TWB-5), and 42.1 (TWB-8). However, at the energy region of 1.333 MeV, the Z_{eff} among the regarded glasses were 24.95 (TWB-2), 25.86 (TWB-5), and 26.74 (TWB-8). The sample glasses TWB-2, TWB-5, and TWB-8 were shown to have 1.50-, 1.54-, and 1.58 -times higher Z_{eff} values at the energy of 0.284 MeV compared to 1.333 MeV. Therefore, for higher incident photon energy, the Z_{eff} was greater. However, sample TWB-8 showed the maximum Z_{eff} among these studied glasses. Studied sample TWB-8 had a Z_{eff} of 42.12 and 26.74 for the energy of 0.284 MeV and 1.333 MeV, respectively. At 0.284 MeV, the value of Z_{eff} was 1.6-times higher than the value at 1.333 MeV. To scrutinize the composition of the studied glasses, it was found that the addition of the same amount of Bi_2O_3 instead of TeO_2 enhanced the Z_{eff} values of the glasses studied herein. This happens because the atomic weight of Bi_2O_3 (465.96 g/mol) is higher than TeO_2 (159.6 g/mol). Therefore, the glass composition $70TeO_2$-$22WO_3$-$8Bi_2O_3$ showed the highest value of Z_{eff}, and hence it can be concluded that as an additive Bi_2O_3 is more suitable than TeO_2.

4. Conclusion:

With the enhancement of the ratio of Bi_2O in the composition of TeO_2-WO_3-Bi_2O_3 glasses, the values of the density, LAC, and Z_{eff} increased, while the HVL, TVL, and MFP decreased. Considering the HVL of these studied glasses, the following decreasing trend was found: TWB-2>TWB-5>TWB-8. The results of the [(78-x) TeO_2-$22WO_3$-xBi_2O_3; where x=2, 5, 8] glasses showed that the composition of $70TeO_2$-$22WO_3$-$8Bi_2O_3$ having density (6.32 g/cm^3) provided the best shielding ability. Through analyzing the composition of these glasses, it was found that the addition of an increasing amount of Bi_2O_3 instead of TeO_2 decreased the value of HVL. Therefore, it can be concluded that as an additive, Bi_2O_3 is more suitable than TeO_2.

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