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Constancy of the Half Value Layer of Cobalt-doped borate glasses with Lanthanum Oxide Additive at Extremely High Radiation Energy

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ABSTRACT: Radiation shielding is essential for protecting workers, patients, and the environment from harmful effects of radiation. To achieve effective and non-toxic shielding, scientists are interested in developing lead-free materials with low thickness that can still attenuate radiation. This is where the concept of Half Value Layer (HVL) comes in. The aim of this study is to investigate the nature of the HVL of Cobalt-doped borate glasses with five different concentrations of Lanthanum oxide (La_2O_3) additive at various energy levels. Phy-X/PSD software was used to simulate radiation exposure and determined the HVL values for energies within the order of 0-10 keV, 10 – 100 keV, 100 keV – 1 MeV, 1 – 10, 10 – 100, 100 – 1,000, 1,000 – 10,000, and 10,000 - 100,000 MeV. The results showed that the HVL values fluctuated depending on the energy range of the incident radiation, but they remained constant within a mean value at extremely high energies. These findings can help manufacturers to determine the appropriate thicknesses and the amounts of (La_2O_3) additive for different applications of this glass system.

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Key words: glass system; half value layer; radiation energy; radiation shielding.

Ionizing radiation is a valuable tool in several fields, including radiotherapy, radiology, nuclear medicine, nuclear research, agriculture, and power generation (Al-Buriahi et al., 2021). However, its harmful effects require the use of three key principles: minimizing exposure time, maximizing distance from the source, and using shielding barriers. These principles have helped in optimizing radiation doses (Lacomme et al., 2021). One approach to achieving effective shielding is to choose appropriate materials with the right chemical compositions and thickness. Glass systems are a promising option for radiation shielding due to their transparency, temperature stability, and mechanical durability (Al-Buriahi et al., 2021; Boonin et al., 2020). Researchers are studying the interaction of radiation with glass materials to determine appropriate thicknesses that limit the amount of radiation that reaches people and the environment (Mahmoud and Rammah, 2020). The Half Value Layer (HVL) is therefore a term used to assess a material's ability to attenuate half of the radiation energy before it transmits across its length, so that appropriate thickness would be chosen for proper limitation of radiation dose that reaches the people around and the surrounding environment. For radiation shielding materials which occupy less space (low HVL) and at the same time serve the required purpose are given more priority than others which occupy more space (high HVL).

The HVL of material is not the same for all energies. This was reported in earlier publications by (Aladailah et al., 2022; Mahmoud and Rammah, 2020; Sayyed et al., 2020). Some authors (Abul-Magd et al., 2021) explored the mechanical, structural, and optical properties of glass system with different concentrations of (La_2O_3) added to Cobalt-doped borate glasses, and also its radiation shielding features were investigated by (Alhassan et al., 2023), but the extent to which its HVL varies with energy is not well-known. Therefore, this study aims to determine that extent by adjusting the energy from low to extremely high values.

MATERIALS AND METHODS

The set up for HVL determination is shown in Figure 1.

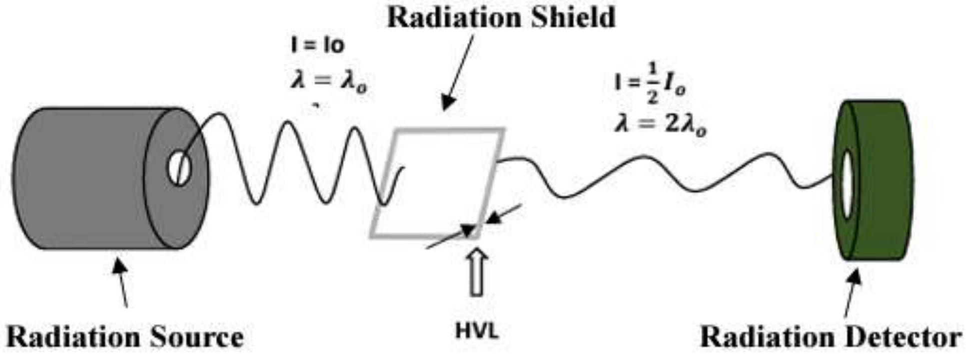

Fig 1: Demonstration of HVL of shielding material

The HVL of a particular material is calculated using (Equation 1).

$$\mathbf{HVL} = \frac{0.693}{\mu_L} \quad (1)$$

Where μ_L is the linear attenuation coefficient (LAC).

We used Phy-X/PSD online software to simulate the radiation exposure of five glasses (G0, G1, G2, G3, and G4) with varying La_2O_3 concentrations listed in (Table 1). The simulation covered a range of exposure energies, including (A) 0 - 10 keV, (B) 10 - 100 keV, (C) 100 keV – 1 MeV, (D) 1 - 10 MeV, (E) 10 - 100 MeV, (F) 100 – 1,000 MeV (G) 1,000 – 10,000 MeV and (H) 10,000 – 100,000 MeV.

Table 1: The compositions of the glasses based on percentage weight (wt%.).

Sample	CoO (wt%)	B2O3	La2O3	PbO
G0	0.20	55.80	0.00	44.00
G1	0.20	54.70	1.60	43.50
G2	0.10	12.90	76.70	10.30
G3	0.20	52.70	4.70	42.40
G4	0.20	51.70	6.20	41.90

The HVL values were recorded in Microsoft Excel file, they were plotted against energy and then the result was analysed and discussed.

RESULT AND DISCUSSION

The HVL of G1 – G5 glasses at energies within (A) 0 - 10 keV, (B) 10 - 100 keV, (C) 100 keV – 1 MeV, (D) 1 - 10 MeV, (E) 10 - 100 MeV, (F) 100 – 1,000 MeV and (G) 1,000 – 10,000 MeV, and (H) 10,000 – 100,000 MeV are shown in (Figure 2 – 9) respectively.

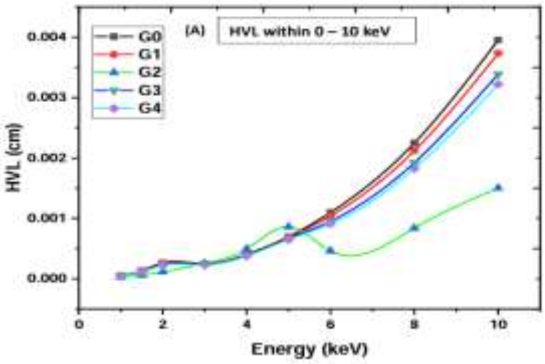

Fig 2: Variation of HVL with energy within 0 - 10 keV.

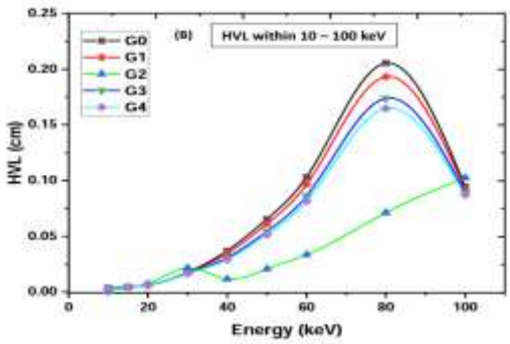

Fig 3: Variation of HVL with energy within 10 - 100 keV.

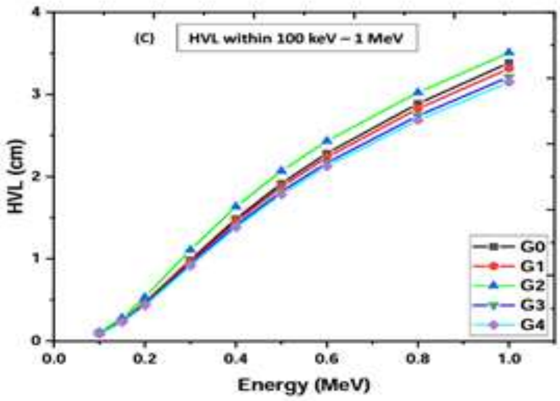

Fig 4: Variation of HVL with energy within 0.1 - 1 MeV.

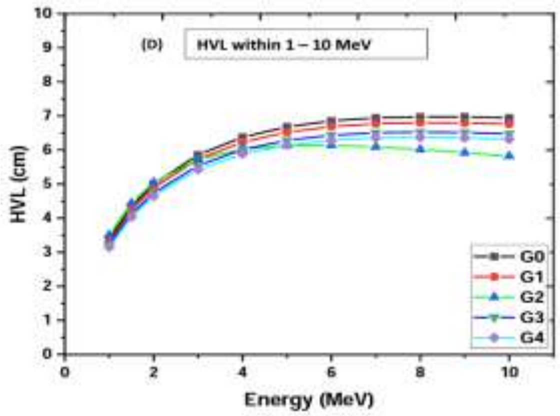

Fig 5: Variation of HVL with energy within 1 - 10 MeV.

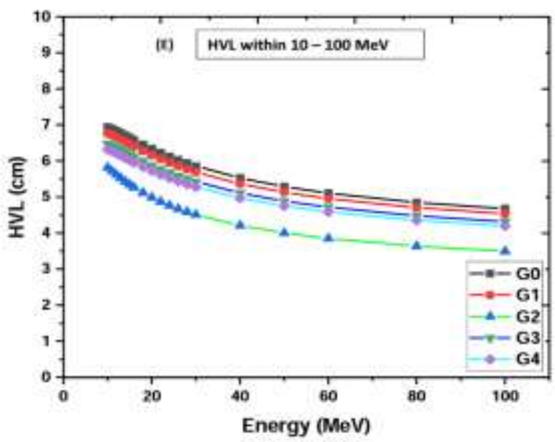

Fig 6: Variation of HVL with energy within 10 - 100 MeV.

The HVL values for all the glasses were observed to increase with an increase in radiation energy (Figure 2), except for energies where edge absorption of the glasses' compositions occurs, similar effect for other glass systems were reported in previous studies (Mahmoud and Rammah, 2020; Wagh et al., 2019). The required thicknesses to attenuate half of the incident radiation for glasses G1 to G5 were found to increase until they reached their maximum values at 80 keV (Figure 3). However, the needed thickness decreased with increasing energy until 100 keV, after which it started to increase again until 9 MeV (Figure 4 & 5).

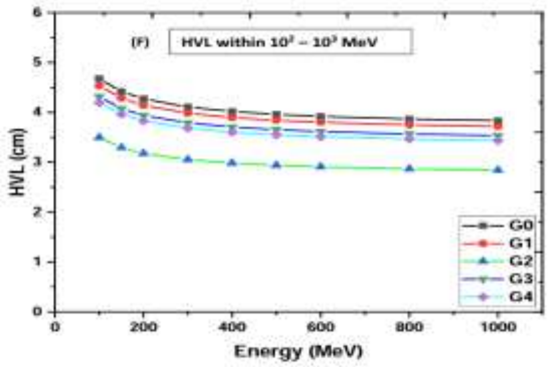

Fig 7: Variation of HVL with energy within 10^2 - 10^3 MeV.

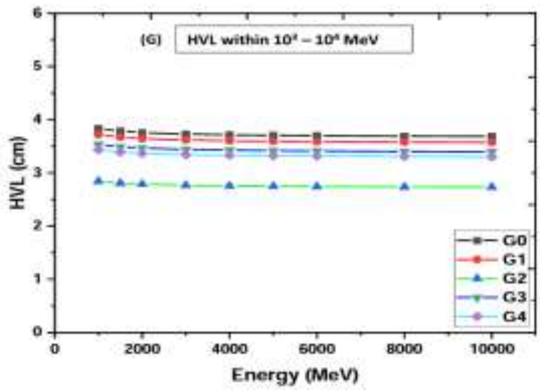

Fig 8: Variation of HVL with energy within 10^3 - 10^4 MeV

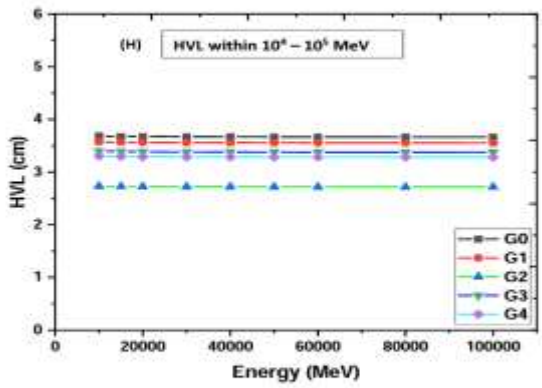

Fig 9: Variation of HVL with energy within 10^4 - 10^5 MeV.

At 9 MeV, the HVL values required were observed to reduce continuously as the energy increases (Figure 6 - 8). The HVL values were found to remain constant around the mean values of 3.665, 3.554, 2.710, 3.381, and 3.285 cm and standard deviations of 1.09 x 10^{-8}, 4.45 x 10^{-6}, 1.94 x 10^{-6}, 4.17 x 10^{-6}, and 3.81 x 10^{-6} for G1, G2, G3, G4, and G5, respectively, when the energy was in the order of 10^4 - 10^5 MeV and above (Figure 9). This indicates that the HVL is dependent on the energy range, not just the magnitude of the energy. The effect of an increase in La_2O_3 concentration on the variation of HVL at any given energy was also observed in (Figure 2-9), which was previously discussed in Alhassan et al. (2020).

Conclusion: The HVL values of Cobalt-doped borate glasses with Lanthanum oxide additive were determined and studied over a wide range of energies using Phy-X/PSD software. The results showed that the HVL values varied with the change in energy. However, at extremely high energies, the HVL remained constant despite the increase in energy. This finding could assist manufacturers in selecting an appropriate shielding thickness based on the energy range being dealt with.

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REFERENCES

Abul-Magd, AA; Abu-Khadra, AS; Abdel-Ghany, AM (2021). Influence of La2O3 on the structural, mechanical and optical features of cobalt doped heavy metal borate glasses. *Ceram Int*. *47*(14): 19886–19894.

Aladailah, MW; Tashlykov, OL; Shirmanov, IA; Strugov, ED; Sayyed, MI; Marashdeh, MW; Elsafi, M; Al-Maaitah, AF (2022). Radiation attenuation properties of novel glass system using experimental and Geant4 simulation. *Radiat. Phys. Chem*. *199*: 110404.

Al-Buriahi, MS; Alomairy, S; Mutuwong, C; Boukhris, I; Olarinoye, OI; Tonguç, BT (2021). Effect of Nd3+ ions on radiation attenuation properties of PbF2-TeO2-WO3 glass system for shielding applications. *Boletin de La Sociedad Espanola de Ceramica y Vidri*. 03: 005.

Alhassan, M; Ibrahim, HA; Muazu, SI (2023). Effect of La2O3 Additive on the Radiation Shielding Properties of Cobalt-doped Borate Glasses. *J. Appl. Sci. Environ. Manage. 27*(2): 343–348.

Alhassan, M; Khan, B; Baraya, JT (2020). Evaluation of 1.5mm Lead Shield for Radiological Protection and Comparison of Calculated and Measured Results of Equivalent Dose. *J. Appl. Sci. Environ. Manage. 23*(12): 2195 - 2199.

Boonin, K; Yasaka, P; Limkitjaroenporn, P; Rajaramakrishna, R; Askin, A; Sayyed, MI; Kothan, S; Kaewkhao, J (2020). Effect of BaO on lead free zinc barium tellurite glass for radiation shielding materials in nuclear application. *J Non Cryst Solids*. *550*: 120386.

Lacomme, E; Sayyed, MI; Sidek, HAA; Matori, KA; Zaid, MHM (2021). Effect of bismuth and lithium substitution on radiation shielding properties of zinc borate glass system using Phy-X/PSD simulation. *Res. Phys*. *20*: 103768.

Mahmoud, KM; Rammah, YS (2020). Investigation of gamma-ray shielding capability of glasses doped with Y, Gd, Nd, Pr and Dy rare earth using MCNP-5 code. *Physica B: Condensed Matter*. *577*: 411756.

Şakar, E; Özpolat, ÖF; Alım, B; Sayyed, MI; Kurudirek, M (2020). Phy-X / PSD: Development of a user friendly online software for calculation of parameters relevant to radiation shielding and dosimetry. *Radiat. Phys. Chem. 166*: 108496.

Sayyed, MI; Laariedh, F; Kumr, A; Al-Buriahi, MS (2020). Experimental studies on the gamma photons-shielding competence of TeO2–PbO–BaO–Na2O–B2O3 glasses. *Applied Physics A: Mat. Sci. Processing.* 126(1). 3182-3188.

Wagh, A; Sayyed, MI; Askin, A; Özpolat, ÖF; Sakar, E; Lakshminarayana, G; Kamath, SD (2019). Influence of RE oxides (Eu3+, Sm3+, Nd3+) on gamma radiation shielding properties of lead fluoroborate glasses. *Solid State Sci. 96*: 105959.