Radiation shielding competence of TeO_2 and Eu_2O_3 incorporated borosilicate glasses

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Introduction

Apart from being a major source of energy in various technological fields, nuclear radiation has harmful effect on human health and poses a possible threat to the surrounding environment. This has raised an urgent demand for developing different shielding agents to avoid radiation exposure. Borosilicate glasses containing heavy metal oxides (HMOs) such as Bi_2O_3, BaO and ZnO exhibiting dual property of excellent transparency and radiation absorption, can function as radiation shields for scientists and observers working in these fields [1, 2]. Though HMOs contribute to greater density and effective atomic number, the combined effect of TeO_2 and Eu_2O_3 in improving the quality of radiation shields is yet to be explored.

Experiment and methods

Traditional melt-quench technique [1] was utilized to fabricate five glasses of two compositions (50-x)B_2O_3- 17.5SiO_2 -0.5CeO_2-xTeO_2-12Bi_2O_3- 12ZnO- 8BaO and 12B_2O_3-16SiO_2 - yEu_2O_3- (40-y) TeO_2-12Bi_2O_3- 12ZnO-8BaO with x= 0, 20, 40 mol% and y= 2, 4 mol%, later coded as Te-0,20,40 and Eu-2,4. Glasses were polished to 0.3 cm thickness. Density of these glasses was measured using Archimides principle with a weighing balance using water as immersion liquid. Further, the attenuation measurements for these glasses were done by exposing them to ϒ-rays from three radioisotopes namely, ^{137}Cs, and ^{60}Co. Canberra High Pure Germanium (HPGe) Detector: CS20-A31CL with relative efficiency = 24.5% was used for these measurements [3]. The results were then compared and validated with the values computed from Photon Shielding and Dosimetry (Phy-X/PSD) software [4].

Results and Discussion

The density values obtained for the selected are listed in Table 1. We see that on adding 20 and 40 mol% of TeO_2 to the host HMO borosilicate glass, density has increased considerably from 3.9084 to 5.0875 g/cm^3. Then again for Eu-2 and Eu-4, density soars to still higher value of 5.4377 g/cm^3. Such increase in density is clearly attributed to higher molecular weight of TeO_2 and Eu_2O_3 which are replacing compounds of low molecular weight.

Table 1: Density of selected glass samples

Sample code	**Density, ρ (g/cm^3)**
Te-0	3.9084
Te-20	4.3262
Te-40	5.0875
Eu-2	5.3403
Eu-4	5.4377

Linear attenuation coefficient (LAC or μ) values were determined experimentally with the help of Lambert- Beer law [3] for 0.662 (**^{137}Cs)** and 1.173 (**^{60}Co)** MeV energies. The initial intensity (I_o)and intensity of ϒ- rays after passing through the glasses (I) were obtained using HPGe detector set up. The calculated LAC values are represented in Table 2. Meanwhile, when these LAC values were compared with theoretical values obtained from Phy-X/PSD software, they were in close agreement with each other with deviation < 5%.

Table 1. LAC values (cm^{-1}) determined experimentally and from Phy-X/PSD software

Glass	0.662 MeV (^{137}Cs)		1.173 MeV (^{60}Co)	
	Exp	**Phy-X**	**Exp**	**Phy-X**
Te-0	0.350	0.356	0.227	0.232
Te-20	0.385	0.390	0.257	0.254
Te-40	0.467	0.462	0.299	0.302
Eu-2	0.459	0.466	0.301	0.304
Eu-4	0.458	0.475	0.309	0.310

The graph in Fig. 1 represents the variation of LAC values obtained from Phy-X software with gamma energy in 0.015-15 MeV range. The dramatic fall of LAC values at lower photon energies can be justified by occurrence of photoelectric absorption of photons by glass material. LAC in intermediate energy area acquire constancy because of the predominance of Compton scattering process. Further at energy above 10 MeV, the interaction of radiation photons by pair production process leads to slight rise in LAC values [1].

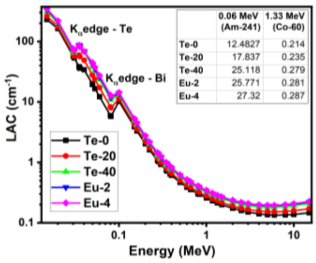

Fig. 1. LAC values in 0.015-15MeV range

Half value layer (HVL) calculated from the LAC values using HVL=ln2/μ relation for 0.662 MeV energy is compared with the values of commercial radiation shields such as ordinary concrete, steel-magnetite concrete [5], RS-323 and RS-360 glasses[6] in Fig.2. Eu-4 glass produced lowest HVL of 1.458 cm among other investigated glasses which is even lower than the commercial shields.

Radiation protection efficiency (RPE) is an indicator of number of photons attenuated by the material. RPE (%) and transmission factor TF (%) for t=0.3 cm thick glasses are determined using the relations [3]: RPE%= $(1-I_o/I).100$ and TF %= $e^{-\mu t}.100$

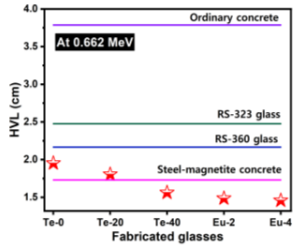

Fig. 2. HVL values compared with commercial radiation shields

Glasses with low TF values are ideal to stop more photons from penetrating the glasses. Results shown in bar graph (Fig.3) imply that though RPE% of Eu-4 glass is the highest, the Eu-2 glass exhibits minimum TF. Therefore, using Eu-4 glass of greater thickness would help in achieving lower photon transmission.

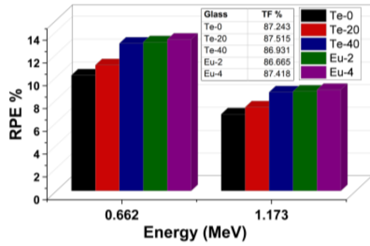

Fig. 3. RPE and TF (%) values of selected glasses at 0.662 and 1.173 MeV energies

Conclusions

The experimental and theoretical LAC values were close match to each other which proved the reliability of theoretical approach for determining shielding parameters. Eu-4 glass has minimum HVL and maximum RPE. Overall results showed improvement in shielding efficiency of HMO borosilicate glasses on adding TeO_2. Then again, by doping Eu^{3+}, we were able to enhance the radiation shielding performance of these tellurite glasses.

References

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