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Comparative study of attenuation properties of some ternary borate glass systems

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Some borate-based systems doped with sodium, zinc and lead are chosen to study gamma ray mass attenuation properties. Different parameters like mass attenuation, half value layer and mean free path have been analyzed at different photon energies. The values of molar volume have been estimated from density values to get idea regarding the compactness of the network structure. XCOM computer software has been employed to estimate mass attenuation coefficient at various energies. Further the values of HVL for the studied systems are compared with standard radiation shielding materials like concrete.

Keywords: Glasses; Density; Shielding; Mean free path; Half value layer.

1. INTRODUCTION

Now days, the use of nuclear energy and radiation is necessary in modern society such as nuclear power plants and radiotherapy. Handling radiation sources with safe is essential. The knowledge of gamma-ray interaction parameters such as mass attenuation coefficient, effective atomic number, electron density, total interaction cross-section, half value layer, mean free path, etc. is very important in the designing of radiation shielding materials.[1]

It is worth mentioning that, radioactive sources are hazard to environment and the intensity of radioactive materials varies in proportionality to the factors like time, distance and nature of shielding material. The glasses containing heavy metals are the promising candidates in the field of radiation shielding materials. Samir et.al [2] have studied experimentally the attenuation properties of lead zinc borate glasses at energies at 662 KeV, 1173 KeV, 1332 KeV and 2641 KeV by using Co-60. In his findings the authors have concluded that addition of heavy metal like PbO helps in improving the shielding properties of the glasses. Generally, borate (B_2O_3) and silicates (SiO_2) are used as the glass formers. SiO_2 window glass silica finds many applications and is also used as reflector in electrical appliances.[3] These borate and

silicate glasses when doped with heavy metals find applications in radiation shielding materials [4-5].
Singh et. al [6] have studied the systems lead bismuth borate, lead borate and bismuth borate for gamma ray exposure build up factors. Again improved shielding properties of these materials were concluded by the authors H.Singh et al [7] in the study of radiation shielding properties of lead borate and zinc glasses. Further it was concluded by many authors that increasing the content of PbO in glasses improve its hardness. It was observed by many authors [7] that the glasses containing heavy-metal oxide like barium, lead and bismuth can be used as alternate to conventional shielding materials due to their high effective atomic number and strong absorption coefficient. [8] However one of the most important type of radiation for which shielding is needed in a nuclear reactor are initially neutron and gamma-ray coming-out from the core and then gamma-ray produced by neutron interaction with the material external to the reactor core [9-10]. Therefore, any type of material can be used for radiation shielding once it has capability to absorb the incident radiation to a certain level. In the area shielding material and propose same research works with different glass as new shielding material [11]. In the light of above discussion, the author in the present paper has shown interest in the borate glass system containing oxides of boron, zinc and lead. The density and molar volume values were used to get the idea regarding rigidity of the network structure. Mass attenuation coefficient of the glass systems have been studied in the energy range from 1KeV to 100 GeV. Further the values of mean free path and half value layer are estimated and analyzed.

2. COMPUTATIONAL TECHNIQUE

(I) Linear attenuation coefficients

The mass attenuation coefficients of the selected heavy metal oxide glasses were calculated using the formula as given below

$$\mu_m = \sum_i^n w_{i(\mu/\rho)} \quad (1)$$

Where w_i is the weight and μ/ρ is the mass attenuation coefficient of the sample. The μ/ρ values can be taken from XCOM program or user-friendly Win Xcom software. The linear attenuation coefficient (in cm^{-1}) is multiplication of μ/ρ value and density of the glass.

(II) Mean Free Path and Half Value Layer

The mean free path (MFP) is reciprocal of linear attenuation coefficient. Mean free path (MFP) and half valve layer (HVL) can be found using the following relations

$$\text{MFP } (\lambda) = 1/\mu \quad (2)$$

$$\text{HVL} = 0.693/\mu \quad (3)$$

(5)

The molar volume V_g was evaluated using the relation

$$V_g = M/\rho \quad (4)$$

Here ρ is the density and M is the molar mass

The Computational Technique has proven to be one of the most accurate methods for the computation of the electronic structure of solids [12-15].

3. RESULTS AND DISCUSSION

The chemical composition, molar volume and density of samples S1, S2 and S3 have been taken from literature [2,16-17] are listed in the Table 1. The density increases with increase in heavy metal in the glass system. The density values are helpful in estimating the molar volume of glass samples given in Table 1. The molar volume, which gives idea as the volume occupied by unit mass of the samples. And hence it can be used as a parameter to identify nature of compactness or openness of the glass structure [2].

Table 1 Chemical composition, density (ρ), molar volume (V_m)

Sample Name	PbO	Na_2O	ZnO	B_2O_3	Density (gcm^{-3})	Molar Volume (cm^3mol^{-1})	Reference
S1	0	20	10	70	2.53	28.77	[2]
S2	10	20	0	70	2.9	27.33	[16]
S3	20	0	10	70	3.67	23.78	[17]

It is evident from Table 1 that a composition $20Na_2O10ZnO70B_2O_3$ corresponds to the maximum open structure. At low mole fractions the role of metal oxide is of network modifier and at higher mole fractions the role changes to network former. [10,11] Further mass attenuation coefficients are given in table 2.

A large attenuation coefficient means that the beam is quickly "attenuated" as it passes through the medium, and a small attenuation coefficient means that the medium is relatively transparent to the beam. The theoretical value of the mass attenuation has been calculated using WinXcom program and given in table 2.

Table 2 Mass attenuation coefficients (μ_μ) of glass sample

	Mass Attenuation Coefficient (cm^2/g)								
Sample	1.00E-03	1.00E-02	1.00E-01	1.00E+00	1.00E+01	1.00E+02	1.00E+03	1.00E+04	1.00E+05
S1	3.70E+03	3.71E+01	1.49E+00	6.44E-02	2.76E-02	3.60E-02	4.36E-02	4.54E-02	4.57E-02
S2	3.05E+03	2.76E+01	1.84E-01	6.19E-02	2.13E-02	2.00E-02	2.39E-02	2.49E-02	2.51E-02
S3	4.15E+03	7.08E+01	2.38E+00	6.57E-02	3.29E-02	4.97E-02	6.07E-02	6.31E-02	6.35E-02

The concepts of half-value layers (HVL) are the simplest methods for determining the effectiveness of the shielding materials. One half-value layer is defined as the amount of shielding material required to reduce the radiation intensity to one-half of the unshielded value. The figure 2; show the comparison of HVL value of ordinary concrete (composition listed in table 3) and glass sample S3.

Table 3 Chemical compositions of concretes

oncrete	**Weight Fraction**														**Density (gcm^{-3})**
	H	*B*	*C*	*O*	*Na*	*Mg*	*Al*	*Si*	*S*	*K*	*Ca*	*Cr*	*Fe*	*Ba*	
Ordinary	*0.10*	--	*0.0010*	*0.5291*	*0.0160*	*0.0020*	*0.0338*	*0.3370*	..	*0.0130*	*0.0440*	..	*0.0140*	..	*2.3*

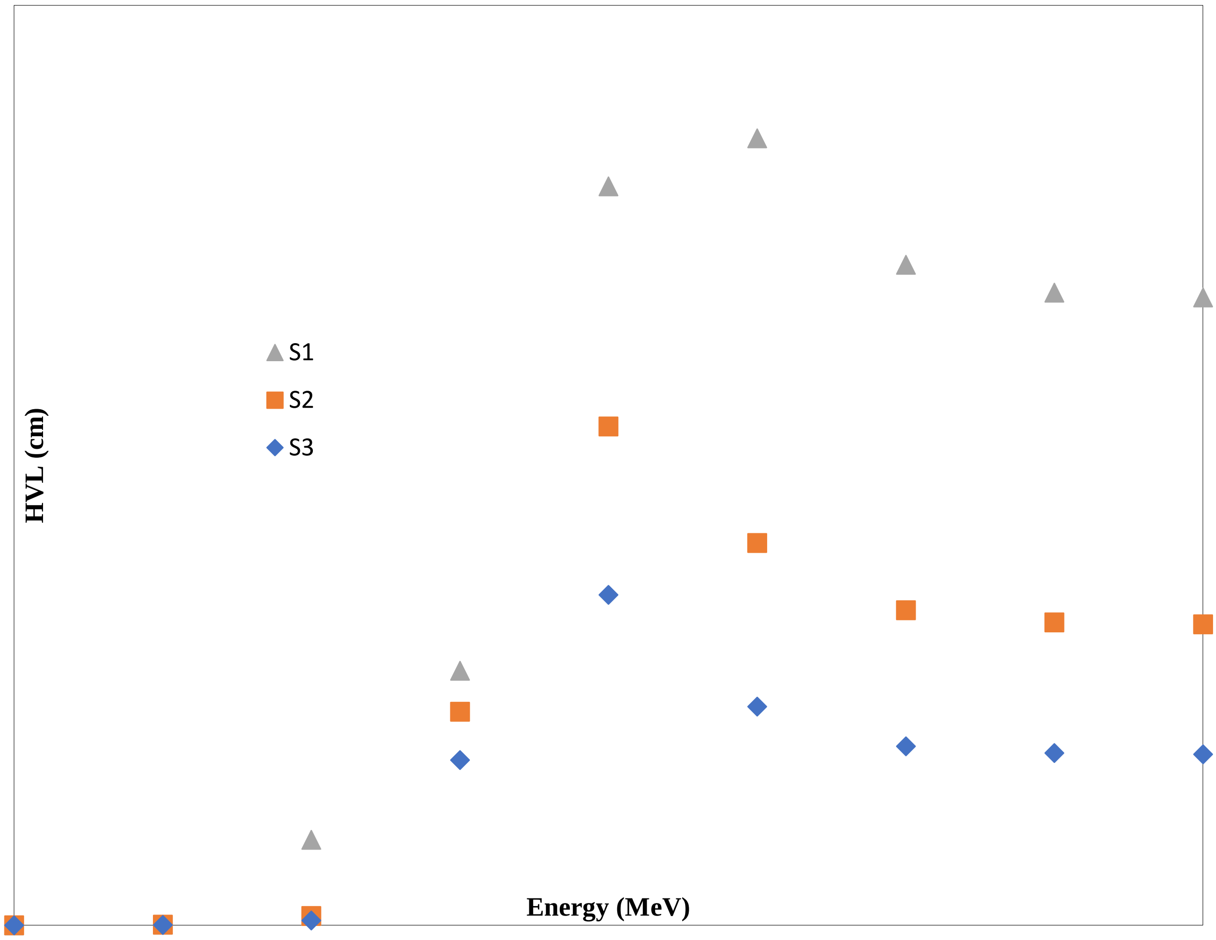

Figure 1 Plot of HVL for various samples as a function of photon energy.

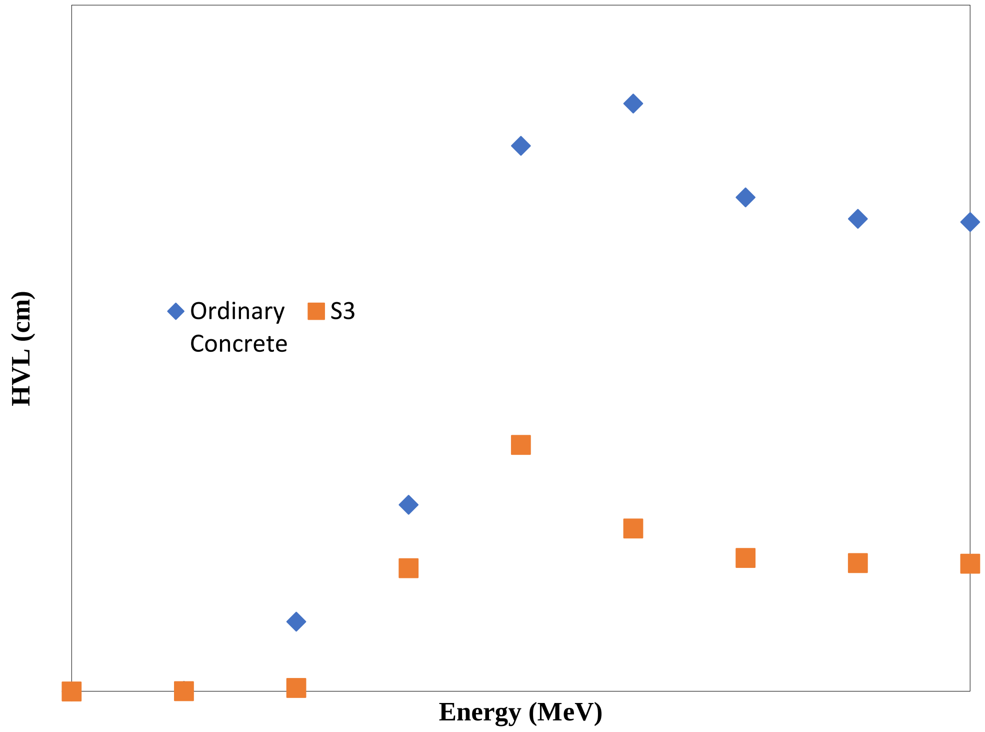

Figure 2 Plot of HVL for sample S3 and ordinary concrete as a function of photon energy.

The values of mean free path are listed in table 4 for the studied samples.

Table 4: Theoretical result of mean free path

	Mean Free Path		
Energy	**S1**	**S2**	**S3**
1.00E-03	0.00013	9.32E-05	6.57E-05
1.00E-02	0.014295	0.00929	0.003849
1.00E-01	2.143476	0.231118	0.114632
1.00E+00	6.385411	5.357793	4.14733
1.00E+01	18.54795	12.52097	8.292135
1.00E+02	19.75297	9.591866	5.484693
1.00E+03	16.57262	7.905263	4.490434
1.00E+04	15.87377	7.595321	4.317534
1.00E+05	15.7598	7.547113	4.291693

5. CONCLUSIONS

It can be concluded from the result that in all the studied glass systems S3 has minimum HVL value and low mean free path. In light of this analysis shown that the glass S3 is suitable for radiation shielding because of high mass attenuation and low HVL value.

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