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Gamma Ray Shielding Properties of $(90 – x)TeO_2 – xBaO$ Glasses

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Abstract: **Gamma ray shielding properties of tellurite based glasses of composition $(90 – x)TeO_2 – xBaO$ (where x = 10, 15, 20 mol%) have been determined. The important shielding parameter such as mass attenuation coefficient (μ_m) was determined by using XCOM computer program based on mixture rule at photon energies 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV respectively. The value of mass attenuation coefficient was used to calculate other shielding parameters such as effective atomic number (Z_{eff}), electron density (N_e) and mean free path (MFP). It has been observed that all the shielding parameters decreases with increase in energy. The MFP of the present glasses have been compared to the standard shielding concretes. The lower values of MFP proves that the present glasses have better gamma shielding efficiencies.**

Keywords —Mass attenuation coefficient, effective atomic number, electron density, glass.

I. INTRODUCTION

Though concretes are commonly used for the gamma ray shielding because of their cheap cost and easy to fabricate in different shapesand large sizes, but they exhibit cracks with extended radiation exposure and loss of water causes the density and compositional variations; further concretes are opaque to visible light, which makes them impossible for the on-lookers to monitor the situation inside the radiation source [1]. In this situation, recently, glasses have attracted much attention as substitute for concretes for potential gamma and neutron radiation shielding applications due to their relatively low production cost, preparation simplicity, ease in making various shapes and in large quantities, and optical transparency [2], and different glass systems are studied in this regard [1-8]. Tellurite oxide are most promising oxides used as a network former in various glasses due to its various extraordinary properties such as high refractive index, low melting temperature, good mechanical strength and chemical durability, high thermal stability, high dielectric constant, important transmission coefficient and good resistance towards moisture and corrosion and low phonon energy [9]. These oxides also have ability to form a glass through melt quenching technique [7]. These glasses have many applications in the field of fuel cells, solid state batteries, in nonlinear optical micro devices and optical amplifiers [10].The absorbance of gamma rays can be increased by using high atomic number elements such as inclusion of heavy metals in the glass network which can lead to increase in absorption of gamma rays. This feature makes these materials as effective shielding material rather than concrete [11]. Many researchers reported that barium oxides are promising material for radiation shielding rather than lead oxide due to toxic nature of lead and protectionism in world economy [12].

In the present work, we deal with the tellurite glasses of composition $(90 – x)TeO_2 – xBaO$ (where x = 10, 15, 20 mol%) and investigated the shielding parameter of these glasses such as mass attenuation coefficient (μ_m) using XCOM computer program at photon energies 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV respectively. The value of mass attenuation coefficient further used to calculate the other shielding parameters such as effective atomic number (Z_{eff}) and electron density (N_e).

II. THEORY

A narrow beam of monoenergetic photons having an initial intensity I_0 is attenuated to an intensity 'I' after passing through a layer of material with mass-per-unit-area 'x', according to the exponential law:

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

where μ/ρ is the mass attenuation coefficient. Above can be rewritten as:

$$\mu_m = \frac{\ln\left(I_0/I\right)}{x} \quad (2)$$

The mass attenuation coefficients of the prepared glass samples were derived from XCOM software for photon energies of 0.122-1.33 MeV range using following equation [13 - 14]:

$$\mu_m = \sum_i W_i \left(\mu_m\right)_i \quad (3)$$

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where $(\mu_m)_i$ is the mass attenuation coefficient for ith element and w_i is the weight fraction of the ith element in the mixture.

The effective atomic number (Z_{eff}) was derived from total atomic crossection ($\sigma_{t,a}$) and total electronic crossection ($\sigma_{t,el}$) and these two parameters derived from the following mixture formulas [6, 15]:

$$\sigma_{t,a} = \frac{\mu_m M}{N_A \sum_i n_i} \quad (4)$$

where M is the molecular mass, N_A is the Avogadro's constant, n_i is the number of atoms in the molecule and A_i is the atomic weight of ith element.

$$\sigma_{t,el} = \frac{1}{N_A} \sum_i \frac{f_i}{Z_i} A_i (\mu_m)_i \quad (5)$$

where $f_i = \frac{n_i}{\sum n_i}$ is the fractional abundance of atoms of ith element and Z_i is the atomic number of the element i.

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad (6)$$

The electron density (number of electrons per unit mass) (N_e) can be found by following formula [16 - 17]:

$$N_e = \frac{\mu_m}{\sigma_{t,el}} = \frac{Z_{eff}}{M} N_A \sum_i n_i \quad (7)$$

The linear attenuation coefficient was determined using following relation [18]:

$$\mu = \mu_m \times \rho \quad (8)$$

where μ is the linear attenuation coefficient of the present glass sample and ρ is the density of the sample.

The linear attenuation coefficient was used to calculate the mean free path [6]:

$$MFP = 1/\mu \quad (9)$$

III. Results and Discussion

The values of mass attenuation coefficients, μ_m (cm^2/g) for tellurite based glasses were obtained using XCOM computer program at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV photon energies and these values are displayed in Table 1.

Table 1. Mass attenuation coefficient of the selected glasses

Energy (MeV)	Mass attenuation coefficient		
	S1	S2	S3
0.122	0.920	0.935	0.949
0.356	0.128	0.129	0.130
0.511	0.091	0.091	0.092
0.662	0.075	0.075	0.076
0.84	0.065	0.065	0.065
1.17	0.053	0.053	0.053
1.275	0.051	0.051	0.051
1.33	0.049	0.049	0.049

Fig 1. shows the variation of μ_m with incident photon energy for given glass samples. It has been observed that the value of μ_m decreases as photon energy increases. This is due to the dominance of Compton scattering cross-section. From Table 1, it is clear that S1 has minimum value of mass attenuation coefficient and S3 has maximum value. The values of μ_m ranges from 0.920 – 0.049 for S1, 0.935 – 0.049 for S2 and 0.949 – 0.049 for S3.

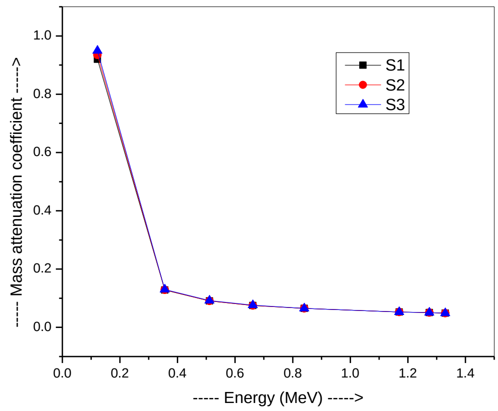

Fig 1: Variation of mass attenuation coefficient with photon energy

Table 2.shows the values of effective atomic number (Z_{eff}) at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV energies respectively.

Table 2: Effective atomic number of the selected glasses

Energy (MeV)	Effective atomic number		
	S1	S2	S3
0.122	44.93	45.35	45.77
0.356	28.65	29.09	29.56
0.511	26.09	26.50	26.92
0.662	25.09	25.47	25.87
0.84	24.51	24.88	25.27
1.17	24.05	24.41	24.78
1.275	24.00	24.36	24.73
1.33	23.99	24.35	24.72

Fig 2. shows the variation of Z_{eff} with incident photon energy for present glass samples.. The value of Z_{eff} increases with increase in BaO as we go from S1 to S3. We observed in Table 2 that S1 has low value of Z_{eff} and S3 has maximum value for all photon energies. But the value of Z_{eff} decreases as photon energy increases for the present glass samples. This is due to the dominance of Compton scattering process. The value of Z_{eff} ranges from 44.93 – 23.99 for S1, 45.35 – 24.35 for S2 and 45.77 – 24.72 for S3.

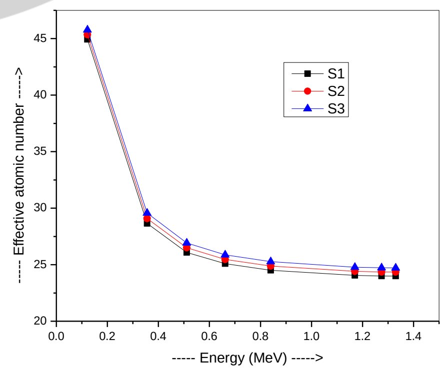

Fig 2. Variation of effective atomic number with energy

The electron density values have been obtained using Eq. (5) and are shown in Table 3.

Table 3: Electron density of the selected glasses

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Energy (MeV)	Electron density		
	S1	S2	S3
0.122	4.94	4.91	4.87
0.356	3.15	3.15	3.15
0.511	2.87	2.87	2.87
0.662	2.76	2.76	2.75
0.84	2.69	2.69	2.69
1.17	2.64	2.64	2.64
1.275	2.64	2.64	2.63
1.33	2.64	2.63	2.63

Fig 3. shows the variation of electron density with incident photon energy. It is clear that the electron density decreases as energy of incident photon increases. The value N_e ranges from 4.94 – 2.64 for S1, 4.91 – 2.63 for S2 and 4.87 – 2.63 for S3. The number of electrons present in S1 is maximum for all photon energies; therefore value of N_e is maximum for S1. This is due to the higher concentration of TeO_2.

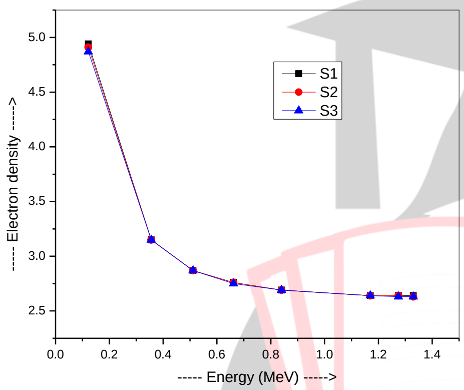

Fig 3: Variation of electron density with energy

Fig 4. shows the variation of mean free path with incident photon energy and values are given in Table 4.

Table 4: Mean free path of the selected glasses

Energy (MeV)	Mean free path		
	S1	S2	S3
0.122	0.19	0.19	0.19
0.356	1.40	1.39	1.39
0.511	1.96	1.96	1.97
0.662	2.37	2.38	2.39
0.84	2.77	2.78	2.79
1.17	3.37	3.38	3.41
1.275	3.54	3.55	3.57
1.33	3.62	3.63	3.66

We observed that the mean free path increases as the photon energy increases from 0.122 – 1.33 MeV for all three samples. From Table 4 it is clear that S1 has minimum value of MFP while S3 has maximum value for all energies. For better shielding material, the value of MFP should be minimum. So, we can say that S1 should be considered as better shielding material among all the glass samples. The value of mean free path ranges from 0.19 – 3.62 for S1, 0.19 – 3.63 for S2 and 0.19 – 3.66 for S3. Fig.5 shows the comparison of mean free path of present glass samples with the standard shielding concretes. We observed that the standard shielding concretes have greater values of mean free path rather than present glass samples. Therefore, we can say that the present glasses can be considered as promising shielding material.

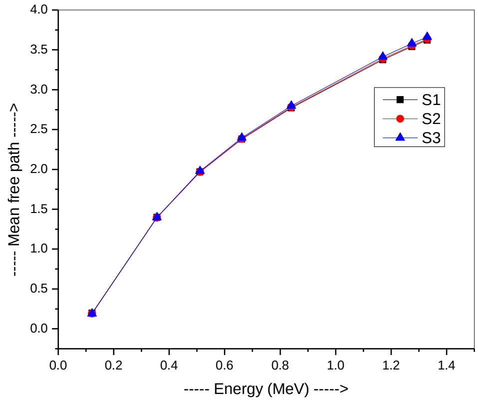

Fig 4: Variation of mean free path with incident photon energy

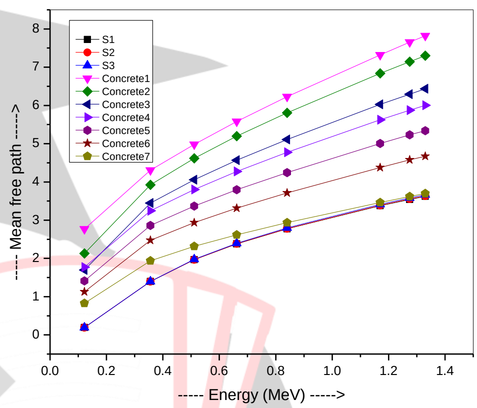

Fig 5. Comparison of MFP of glasses and standard shielding concrete

IV. Conclusion

In the present work, shielding parameters such as mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}) and electron density (N_e) have been computed for TeO_2 – BaO glasses at photon energies 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV respectively. We observed that all the shielding parameters decreases with increase in incident photon energy. So, we can say that the tellurite based glasses have been used as a shielding material. The present glasses compared with the standard shielding concretes in terms of mean free path. S1 is the best shielding material.

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