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Gamma Ray Shielding Studies on (100 – x) TeO_2 – x $ZnCl_2$ Glasses

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Abstract: Gamma – ray shielding parameters for (100 – x) TeO_2 – x $ZnCl_2$ (where x = 10, 20, 30, 40 and 60 mol %) glasses were investigated. The mass attenuation coefficients (μ_m) have been calculated using Win XCOM software at 0.122, 0.356, 0.511, 0.662, 0.840, 1.17, 1.275, 1.33 Me V respectively. These coefficients were then used to calculate the other shielding parameters such as linear attenuation coefficient (μ), effective atomic number (Z_{eff}), electron density (N_e) and mean free path (MFP) values. The variation of these shielding parameters with energy has also been discussed. It has been observed that the sample containing higher percentage composition of TeO_2 should be considered as best shielding material due to the higher value of Z_{eff} and lower values of MFP. The shielding efficiencies of these samples have also been compared to the standard shielding concretes in terms of MFP.

I. INTRODUCTION

Many radioactive waste materials acquire highly penetrating radiations such as gamma rays affects human body or receivers [1]. The exposure of gamma rays and neutron is controlled by using shielding materials [2]. Therefore, many researchers have great interest to develop the radiation shielding materials. These materials are used in different fields such as nuclear reactors, nuclear waste storage sites, outer space exploration, agriculture and industries to attenuate the gamma radiations and neutrons [3]. Concrete is used mostly for radiation shielding because it is inexpensive and adaptable for any construction design [4]. But concrete has many disadvantages such as variation in its composition and water content [5]. Water content decreases the density and structural strength of concrete [6]. Heavy metal oxide glasses can be used as a shielding material because glasses are transparent to visible light and its properties can be modified with composition and preparation techniques [7].Nowadays, there has been a great interest among researchers to study the shielding properties of tellurite glasses due to their extraordinary properties such as high infrared transparency, high refractive index, low melting temperature, low glass transition temperature, low phonon energy and high dielectric constant [8]. These glasses are used in nonlinear optical micro devices and solid state batteries [9]. The shielding parameters such as effective atomic number and electron density are required to study the penetration of gamma rays [10]. In our present work, we study tellurite based glasses of composition (100 – x) TeO_2 – x $ZnCl_2$ (where x = 10, 20, 30, 40 and 60 mol %). The shielding parameters such as mass attenuation coefficient, effective atomic number, electron density, mean free path was calculated using Win XCOM program.

A. *Theory*

The mass attenuation coefficient values were determined by using mixture rule [11]:

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

where $(\mu_m)_i$ is the mass attenuation coefficient for single element in glass sample and w_i is the fractional weight of that element in the sample.

The value of linear attenuation coefficient was calculated by multiplying mass attenuation coefficient with density [12]:

$$\mu = \mu_m \times \rho$$

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

Mean free path was calculated using linear attenuation coefficient [13]:

$$MFP = \frac{1}{\mu}$$

The total atomic cross-section, $\sigma_{t,a}$ (barn/atom) and total electronic cross-section, $\sigma_{t,el}$ (barn/atom) was used to determine the Z_{eff} using the following relation [14]:

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}}$$

where $\sigma_{t,a} = \frac{\mu_m M}{N_A \sum_i n_i}$ and $\sigma_{t,el} = \frac{1}{N_A}\sum_i \frac{f_i}{Z_i} A_i (\mu_m)_i$

where M is the molar mass, N_A is the Avogadro's constant n_i is the number of atoms of the element i having atomic weight A_i ,where f_i is the number of atoms of the element relative to the total number of atoms and Z_i is the atomic number of the element i.The electron density of the glass sample can be derived from following formula [15 - 16]:

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

II. RESULTS AND DISCUSSION

The chemical composition, density and weight fraction of each element of the present five glasses are represented in Table1.

Table 1. Chemical composition and density of the selected glass samples

Sample	Mole fraction			Weight fraction of elements present in the sample				Density (g/cm^3)
	TeO_2	ZnO	$ZnCl_2$	Te	Zn	Cl	O	
S1	90	0	10	0.73022	0.04158	0.04509	0.18312	5.30
S2	80	0	20	0.65884	0.08441	0.09153	0.16522	5.21
S3	70	0	30	0.58529	0.12855	0.13939	0.14678	5.15
S4	60	0	40	0.50946	0.17405	0.18873	0.12776	5.06
S5	40	0	60	0.35051	0.26943	0.29216	0.08790	4.91

The mass attenuation coefficient have been determined using Win XCOM software at 0.122, 0.356, 0.511, 0.662, 0.840, 1.17, 1.275, 1.33 MeV respectively and presented in Table2.

Table 2: Mass attenuation coefficient of the selected glasses

Energy (MeV)	Mass attenuation coefficient (cm^2/g)				
	S1	S2	S3	S4	S5
0.122	0.836	0.778	0.719	0.658	0.53
0.356	0.124	0.122	0.119	0.117	0.112
0.511	0.0899	0.0893	0.0887	0.0880	0.0866
0.662	0.0750	0.0749	0.0748	0.0746	0.0744
0.84	0.0646	0.0648	0.0649	0.0650	0.0653
1.17	0.0533	0.0535	0.0538	0.0540	0.0546
1.275	0.0508	0.0511	0.0513	0.0516	0.0521
1.33	0.0497	0.0499	0.0502	0.0505	0.0510

The variation of mass attenuation coefficient of the selected samples with incident photon energy has been shown in Fig1. The values of mass attenuation coefficient decreases gradually as the photon energy increases from 0.122 – 1.17 MeV region. As shown in Table1. the μ_m values of the present glasses decreases from 0.836 - 0.0497, 0.778 – 0.0499, 0.719 – 0.0502, 0.658 – 0.0505 and 0.53 – 0.051 (cm^2/g) for S1, S2, S3, S4 and S5 respectively. This is attributed to the Compton absorption cross-section which is inversely proportional to the photon energy.

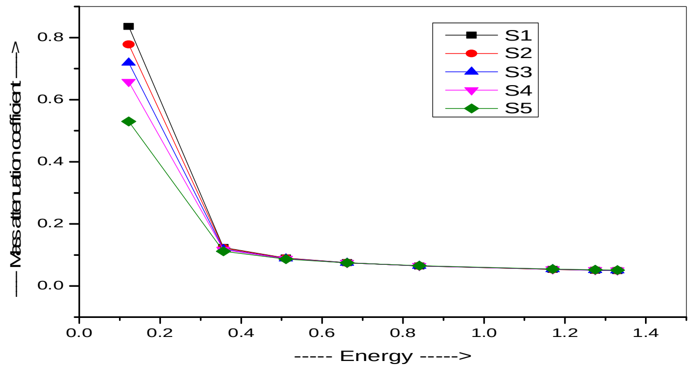

Fig.1. Variation of mass attenuation coefficient with energy

The value of μ_m is maximum for S1 and minimum for S5 for 0.122, 0.356, 0.511 and 0.662 energy ranges. This is due to decrease in percentage composition of TeO_2 as we go from S1 to S5. But for higher energy region (0.840, 1.17, 1.275, 1.33 MeV) the value of μ_m increases as we go from S1 to S5.The variation of effective atomic number (Z_{eff}) of the present glasses with photon energy is shown in Fig.2 and the values of $Z_{eff}$of these glasses are presenting in Table 3.

Table 3: Effective atomic number of the selected glasses

Energy (MeV)	Effective atomic number				
	S1	S2	S3	S4	S5
0.122	43.10	41.97	40.75	39.35	35.82
0.356	27.20	26.72	26.03	25.55	24.38
0.511	24.95	24.58	24.22	23.83	23.05
0.662	24.08	23.79	23.51	23.19	22.62
0.84	23.56	23.35	23.10	22.85	22.38
1.17	23.18	22.96	22.79	22.57	22.19
1.275	23.12	22.95	22.73	22.55	22.14
1.33	23.12	22.90	22.73	22.55	22.14

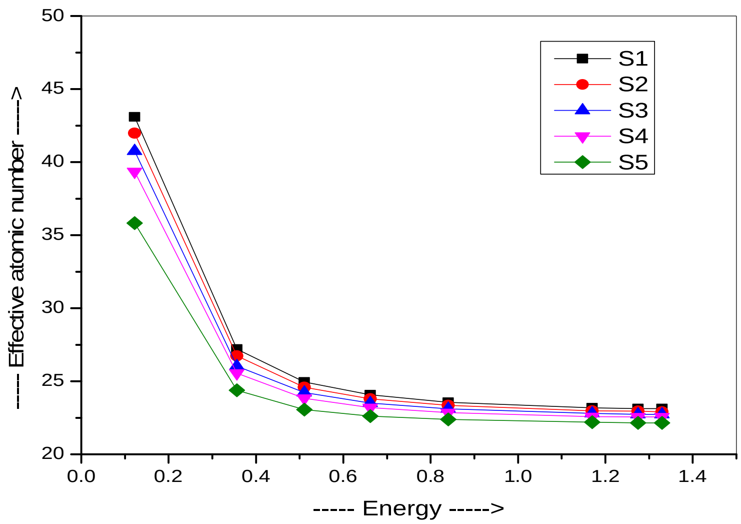

Fig.2. Variation of effective atomic number with energy

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The values of Z_{eff} ranges from 43.09 – 23.12, 41.97 – 22.90, 40.75 – 22.73, 39.35 – 22.55 and 35.82- 22.14 for S1, S2, S3, S4 and S5 respectively. The values of Z_{eff} decreases as photon energy increases which is due to the dominance of Compton scattering process in the given energy region. S1 have highest value of Z_{eff} due to the presence of higher concentration of TeO_2 present in the sample. The variation of MFP of the present glasses with photon energy are shown in Fig 3. The values of MFP are determined from mass attenuation coefficient and are presenting in Table 4. It is clear that the MFP increases as photon energy increases from 0.122 – 1.33 MeV. Fig 3 shows that MFP posses maxima for S5 and minima for S1. Lower is the value of MFP, better is the shielding material. Therefore, we can say that S1 should be considered as best shielding material among all the present samples. This is due to the fact that the Z_{eff} is maximum for S1 and minimum for S5. The comparison of the MFP of the glasses with standard concretes are shown in Fig. 4. The present glasses are having lower values of the MFP compared to the MFP of the standard shielding concretes. The selected glasses are having better shielding efficiencies.

Table 4: Mean free path of the selected glasses

Energy (MeV)	Mean free path (cm)				
	S1	S2	S3	S4	S5
0.122	0.2257	0.2467	0.2701	0.3003	0.3842
0.356	1.5216	1.5732	1.6317	1.6891	1.8184
0.511	2.0987	2.1493	2.1891	2.2457	2.3518
0.662	2.5157	2.5625	2.5959	2.6491	2.7374
0.84	2.9207	2.9620	2.9919	3.0404	3.1189
1.17	3.5399	3.5876	3.6091	3.6597	3.7301
1.275	3.7141	3.7561	3.7850	3.830	3.9091
1.33	3.7963	3.8464	3.8680	3.9134	3.9934

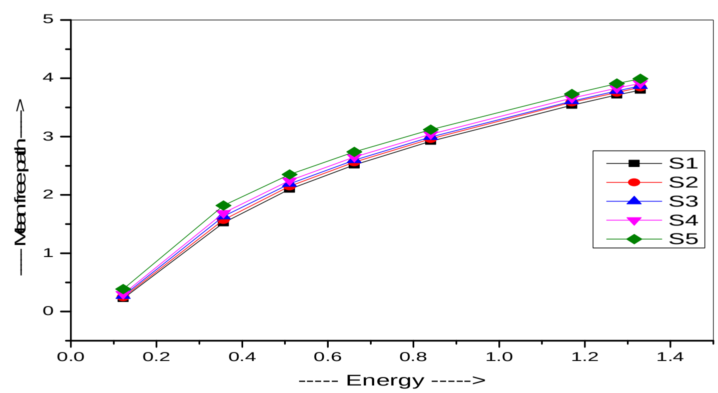

Fig.3. Variation of mean free path with energy

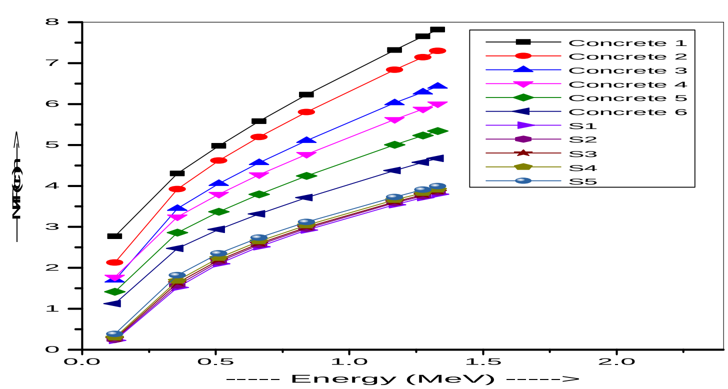

Fig. 4. Comparison of MFP of glasses and standard shielding concretes

The behavior of electron density with incident photon energy is shown in Fig.5 and their values are presenting in Table 6.

Table 5: Electron density of the selected lasses

Energy (MeV)	Electron density (electrons/g)				
	S1	S2	S3	S4	S5
0.122	4.95	4.89	4.82	4.73	4.44
0.356	3.12	3.12	3.08	3.07	3.02
0.511	2.86	2.86	2.87	2.86	2.86
0.662	2.76	2.77	2.78	2.79	2.80
0.84	2.70	2.72	2.73	2.75	2.77
1.17	2.66	2.68	2.69	2.71	2.75
1.275	2.65	2.67	2.69	2.71	2.74
1.33	2.65	2.67	2.69	2.71	2.74

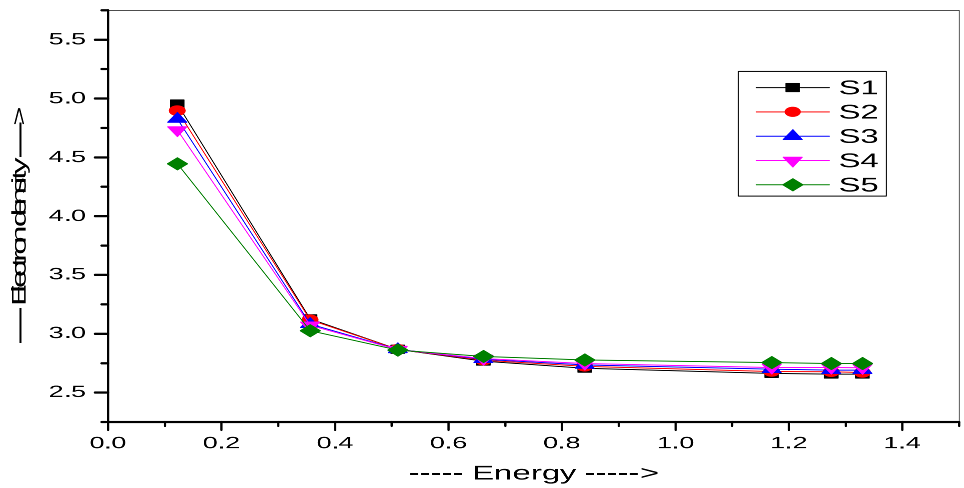

Fig.5. Variation of electron density with energy of the selected glass samples

The value of N_e increases with photon energy as we go from S1 to S5. The number of electrons present in the S1 is maximum due to the higher value of Z_{eff}. S1 is having the highest value of N_e due to the presence of higher concentration of TeO_2 present in it.

III. CONCLUSION

In this work, gamma ray shielding features for different compositions of (100 – x) TeO_2 – x $ZnCl_2$ glasses were investigated at 0.122, 0.356, 0.511, 0.662, 0.840, 1.17, 1.275, 1.33 Me V energies respectively. From investigation, it has been observed that the values of μ_m, ,Z_{eff} and $N_e$of the prepared glass samples decreases with increase in incident photon energy of gamma rays whereas the values of MFP increases with energy. The present glasses are having lower values of the MFP compared to the MFP of the standard shielding concretes. The selected glasses are having better shielding efficiencies. Among the samples, S1 is the best shielding material due to presence of higher percentage composition of TeO_2.Thus the present glasses are useful to control the exposure of radiations.

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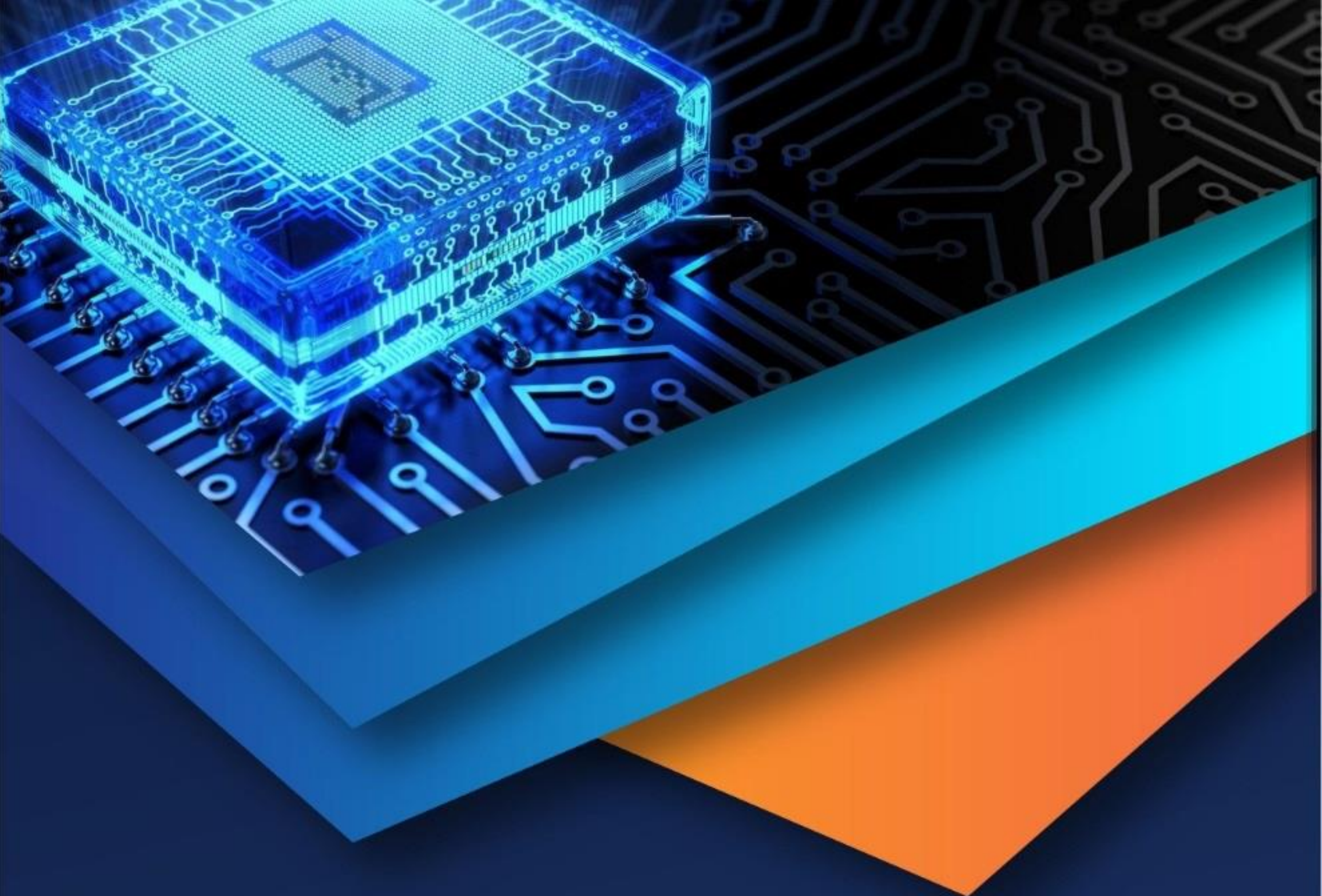

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