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Comparative shielding properties of some tellurite glasses: Part 2

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ABSTRACT

This article focuses on the shielding properties among 21 tellurite glass samples in the form of TeO_2-V_2O_5, TeO_2-V_2O_5-TiO_2, TeO_2-V_2O_5-CeO_2 and TeO_2-V_2O_5-ZnO. The shielding properties are:

1. Mass attenuation coefficient, μ/ρ (10 keV–10 MeV),
2. Effective atomic number Z_{eff},
3. Half value layer, HVL,
4. Macroscopic effective removal cross-section for fast neutron (Σ_R).

Also, variation of the shielding parameters is compared with other tellurite, borate and silicate glasses to explore the superior shielding properties of tellurite glasses from gamma rays than other glasses.

1. Introduction

Now, neutrons, gamma and X rays are used widely in the world in many applications, for example, food irradiation, environmental protection, manufacture, elemental analysis, medical therapy, etc. However, the exposure for long times to the high penetrating radiation such as gamma rays may cause genetic mutations, cancer and death. So, it is necessary to choose suitable shielding materials to protect people from these harmful radiations [1–6]. Concrete shields are used widely for shielding harmful radiations [7–10]. However, during the period of using the concrete, the water contained in concrete would be lost. This would be harmful for the structural of concrete. Further, concrete is utterly opaque to visible light and so, it is quite impossible to look through a concrete-based radiation shield [11]. Due to their optical transparency for visible light, cheap cost, easily to shape, glasses recently are attracted several investigators to study them as promising materials for gamma-rays shielding. A number of researches have been reported on structural and physical properties of tellurite-glasses with different transition metal oxides TMO and rare earth oxides REO composition [12–25] for:

(i) the high refractive index of tellurite glasses rather than other silicate, borate, phosphate and germinate glasses,
(ii) modifying tellurite glasses with oxides like vanadium, titanium and cerium increase its semiconductivity.

The aim of this work is to calculate the shielding parameters in tellurite glasses: TeO_2-V_2O_5, TeO_2-V_2O_5-TiO_2, TeO_2-V_2O_5-CeO_2 and TeO_2-V_2O_5-ZnO, while part 1 of this work focused on the shielding parameters among tellurite glasses in the form: TeO_2-A_nO_m, TeO_2-WO_3-B_nO_m and TeO_2-WO_3-Er_2O_3-PbO where A_nO_m = La_2O_3, CeO_2, Sm_2O_3, MnO_2, CoO_3, Nb_2O_5, B_nO_m = Er_2O_3, La_2O_3, Sm_2O_3, CeO_2 mol% [26]. The glass samples and densities used in this investigation are given in Table 1.

2. Calculation method

Mass attenuation coefficient (μ/ρ) is a measure of the decrement in intensity of gamma-ray when passing through a material and can be calculated from the equation [27]:

$$\mu/\rho = \sum_i w_i (\mu/\rho)_i \qquad (1)$$

here w_i represents the fractional weight of the ith constituent in the glass sample and $(\mu/\rho)_i$ is the mass attenuation coefficient of the ith element that have been taken from XCOM software [28]. Effective atomic number (Z_{eff}) is parameter which describes the properties of the composite materials in terms of equivalent elements, and it changes with photon energy. The Z_{eff} can be evaluated from the value of μ/ρ, and is given by the relation [29]

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Table 1
Density and molar volume of binary and ternary tellurite glasses.

No.	Sample code	Sample	Reference	Density gm/cm^3	Molar volume cm^3
1	T90V10	90TeO2-10V2O5	A	5.213	31.04
2	T80V20	80TeO2-20V2O5		4.900	33.48
3	T75V25	75TeO2-25V2O5		4.620	35.75
4	T70V30	70TeO2-30V2O5		4.564	36.43
5	T65V35	65TeO2-35V2O5		4.330	38.66
6	T60V40	60TeO2-40V2O5		4.225	39.88
7	T55V45	55TeO2-45V2O5		4.100	41.37
8	T50V50	50TeO2-50V2O5		3.996	42.73
9	T50V48Ti2	50TeO2-48V2O5-2TiO2	B	3.988	42.30
10	T50V45Ti5	50TeO2-45V2O5-5TiO2		4.018	41.22
11	T50V40Ti10	50TeO2-40V2O5-10TiO2		4.062	39.52
12	T50V37.5Ti12.5	50TeO2-37.5V2O5-12.5TiO2		4.131	38.24
12	T50V35Ti15	50TeO2-35V2O5-15TiO2		4.182	37.17
14	T70V27C3	70TeO2-27V2O5-3CeO2	C	6.0882	27.3
15	T70V25C5	70TeO2-25V2O5-5CeO2		6.1327	28.0
16	T70V23C7	70TeO2-23V2O5-7CeO2		6.5384	26.2
17	T70V20C10	70TeO2-20V2O5-10CeO2		6.7610	24.5
18	T70V27Z3	70TeO2-27V2O5-3ZnO		5.0769	32.2
19	T70V25Z5	70TeO2-25V2O5-5ZnO		5.1169	31.5
20	T70V23Z7	70TeO2-23V2O5-7ZnO		5.1919	30.7
21	T70V20Z10	70TeO2-20V2O5-10ZnO		5.2585	29.7

$$Z_{eff} = \frac{\sum_i f_i A_i \left(\frac{\mu}{\rho}\right)_i}{\sum_j f_j \frac{A_j}{Z_j} \left(\frac{\mu}{\rho}\right)_j} \quad (2)$$

Half value layer (HVL) is the thickness of material which will decrease radiation intensity to 50% of the initial value. It is calculated according to the equation [30]

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

where: μ is the linear attenuation coefficient (μ = mass attenuation coefficient × density). It worth noting that, materials with the highest value of density, μ/ρ and Z_{eff} and lowest value of HVL are best suitable for gamma-ray shielding applications. On the other hand, the macroscopic effective removal cross sections for fast neutrons Σ_R is the probability of a neutron undergoing specific reaction per unit length of moving through the shielding material [27]. The Σ_R values for the present glasses can be evaluated by utilizing following equation [31]

$$\sum_R = \sum_i W_i \left(\sum_{R/\rho} \right)_i \quad (4)$$

where $\Sigma_{R/\rho}$ (cm^2/g) and W_i represent the mass removal cross-section of the ith constituent and the partial density (g/cm^3) respectively.

3. Results and discussion

Fig. 1 shows the obtained results of the μ/ρ of the binary glass system $(TeO_2)_{1-x}$-$(V_2O_5)_x$, (x = 10, 20, 25, 30, 35, 40, 45 and 50 mol %) calculated using XCOM and MCNP5 and their variations over V_2O_5 concentrations and gamma ray energies in the energy range 10 keV–10 MeV. There are good agreements on the μ/ρ obtained by XCOM and MCNP5 code as shown in Fig. 1. It is observed that μ/ρ values are influenced by V_2O_5 concentration and photon energy and for all V_2O_5 concentration, the μ/ρ values were decreased exponentially with the increasing of energy. In addition, it is clear that at lower energies the total interaction of photons with all glasses is high while at higher energies it decreases which indicates that the transmission of photon increases thorough the glass samples. Also, it can be observed that the μ/ρ values are decreased with the increase of V_2O_5 content for all energies. From this figure it is clearly that the μ/ρ of all glasses reduce very sharply as the photon energy decreases from 0.01 MeV to 0.02 MeV, for example the μ/ρ of tellurite glass with 10 mol% V_2O_5

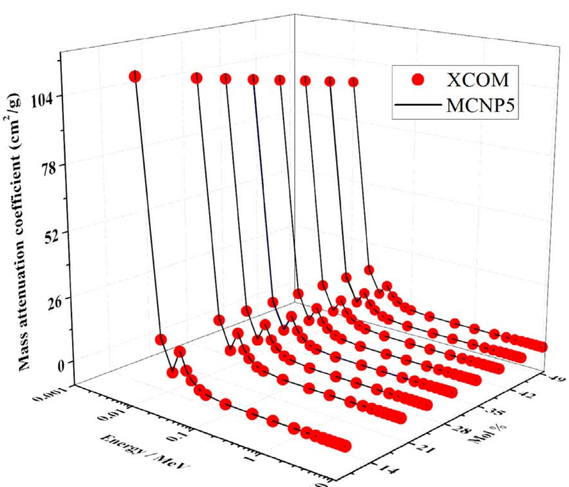

Fig. 1. Comparison of MCNP5 and XCOM calculated values of mass attenuation coefficients versus photon energy for the binary glass system $(TeO_2)_{1-x}$-$(V_2O_5)_x$ in the energy range 10 keV to 10 MeV.

found to be decreasing from 114.11 cm^2/g to 17.08 cm^2/g, while in tellurite glass with 50 mol% V_2O_5 it decreases from 96.01 cm^2/g to 14.55 cm^2/g. In the low energy region (E < 0.01 MeV), the μ/ρ values decrease very sharply due to photoelectric effect. Photoelectric effect predominates at low photon energy as its cross section changes with atomic number ($\sim Z^{4-5}$) and energy ($\sim 1/E^3$). Hence, glasses have highest μ/ρ values in this energy region where photoelectric effect dominates and the values of μ/ρ decrease as energy increases. Additionally, it is also noted a peak in the μ/ρ happens at 40 keV corresponding to k-edge absorption of Te (i.e. 31.18 keV). In order to compare the μ/ρ of the binary glass system TeO_2-V_2O_5 with other glass systems, μ/ρ values of 80TeO_2-20K_2O [31], 60ZnO-40P2O_5 and 10PbO-50ZnO-40P2O_5 [32] glasses are collected and given in Table 2. From Table 2, it can be observed that 80TeO_2-20V_2O_5 has about the same values of μ/ρ with 80TeO_2-20K_2O, and all tellurite glasses with V_2O_5 modifier have higher values of μ/ρ than those reported for 60ZnO-40P2O_5 and 10PbO-50ZnO-40P2O_5 glasses.

Fig. 2 shows the μ/ρ values of $(TeO2)_{50}$–$(V_2O_5)_{50-x}$$(TiO_2)_x$ (x = 2, 5, 10, 12.5 and 15 mol% TiO_2) glasses calculated using XCOM software and MCNP5 code and their variations over photon energies and TiO_2