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Radiation shielding study of tellurite tungsten glasses with different antimony oxide as transparent shielding materials using MCNPX code

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ABSTRACT

The radiation shielding performance of tellurite tungsten glasses with different antimony oxide (Sb_2O_3) content was studied using Monte Carlo simulation MCNPX and WinXCOM software. The mass attenuation coefficients were computed for photon energies of 0.662, 1.173, 1.274 and 1.332 MeV. Moreover, The transmission factor of the selected glasses was calculated at a different thickness from the incident and transmitted photons. It was found that the transmission factor of the investigated glasses lies within 0.11–0.28 range. Also, it was found that the MCNPX and WinXCOM results were matched with each other. It can also be concluded that the high density TSW5 glass sample has the maximum shielding effect over the other samples because of the high weight fraction of the highest atomic numbers (i.e. W, Z = 74) as well as its high density.

1. Introduction

Tellurite based glasses have gained increasing attention from researchers for optical, thermal, structural and radiation shielding studies. This attention of the tellurite glasses is attributed to their unique properties such as high thermal stability, high refractive index, low melting temperature and low photon energy [1–5].

Until now, numerous applications of radiation sources have been found in different fields such as accelerator technologies, nuclear reactors, industries, agriculture, radiotherapy, nuclear medicine …etc. Hence, it is necessary to study some parameters related to shielding against the ionizing radiation. One of the most important parameters to study the interaction between the ionizing radiation and any material is the mass attenuation coefficient (μ/ρ). This important parameter is needed in order to solve different aspects in gamma ray shielding applications [6–11]. Lead is the common material used for the purpose of radiation protection to shield humans from gamma radiation. However, lead is a hazardous material and has disadvantages in both its weight and lack of environmental friendliness. Hence, it is logical that the application of glasses in gamma radiation protection technology is growing steadily [12]. Recently, different researchers have attempted to study tellurite-based glasses for gamma radiation shielding. Issa and Mustafa [13] studied the effects of Bi_2O_3 in borate-tellurite-silicate glass system. The authors measured the μ/ρ of this glass system experimentally at different photon energies using ^{133}Ba, ^{137}Cs and ^{60}Co sources. Ersundu et al. [14] prepared WO_3-MoO_3-TeO_2 glass system and measured the mass attenuation coefficients of this system experimentally at 80.8, 276.4, 302.8, 356 and 383.8 keV photon energies. They found that $10WO_3$-$10MoO_3$-$80TeO_2$ glass sample has superior shielding properties when compared to concrete. Issa et al., [16] measured the shielding performance of TeO_2-ZnO glass system at 0.662, 1.173 and 1.33 MeV photon energies. The authors compared their experimental results with the results obtained from WinXcom and good agreement between the two approaches was reported. El-Mallawany et al. [17] used MCNP5 Monte Carlo simulation code and reported the shielding properties of 21 tellurite glass samples. They compared their results with other glasses such as silicate and borate glasses to investigate the superior shielding properties of tellurite glasses from radiation than other types of glasses. Recently, Ersundu et al. [18] evaluated structural and shielding properties for K_2O-WO_3-TeO_2 glass system. They used WinXcom software to calculate the mass attenuation coefficients and some relevant parameters such as half value layer and discussed the variation of these parameters with the addition of WO_3 in the glass composition. The authors stated that a large WO_3 concentration would be required to improve the shielding performance of the K_2O-WO_3-TeO_2 glass system. Besides, Sayyed [19] used the G-P fitting method and

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Table 1
Chemical composition (in mol%) and density of the TSW glasses.

Code	TeO_2	Sb_2O_3	WO_3	Density (g/cm^3)
TSW5	75	5	20	6.01
TSW10	75	10	15	5.89
TSW15	75	15	10	5.76
TSW20	75	20	5	5.71

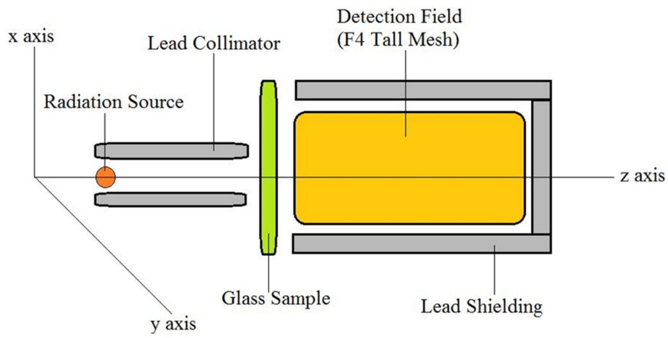

Fig. 1. Total simulation geometry of present investigation.

calculated the exposure buildup factor of tellurite glasses with different oxides (PbO, MgO, ZnO, BaO and Ag_2O). The author found that TeO_2-PbO glasses have superior shielding ability against gamma radiation. The G-P fitting method has allowed Lakshminarayana et al. [20] successfully to calculate the buildup factors for titanate bismuth borotellurite glasses.

This work is devoted to investigating the radiation shielding performance of tellurite tungsten glasses with different antimony oxide (Sb_2O_3) content using Monte Carlo simulation MCNPX. The glass compositions and their density values are summarized in Table 1 [21]. These glasses are termed as TSW5 (5 mol% Sb_2O_3), TSW10 (10 mol% Sb_2O_3), TSW15 (15 mol% Sb_2O_3), and TSW20 (20 mol% Sb_2O_3). The mass attenuation coefficients of the present samples were computed for 0.662, 1.173, 1.274 and 1.332 MeV photon energies.

2. Materials and methods

2.1. MCNPX code

In this work, Monte Carlo N-Particle Transport Code System-extended (MCNPX) version 2.4.0 (Los Alamos national lab, USA) general purpose Monte Carlo code was utilized for the determination of mass attenuation coefficients of various types of tellurite tungsten glasses with different antimony oxide (Sb_2O_3) such as TSW5 (5 mol% Sb_2O_3), TSW10 (10 mol% Sb_2O_3), TSW15 (15 mol% Sb_2O_3), and TSW20 (20 mol% Sb_2O_3). MCNPX is a general purpose Monte Carlo radiation transport code for modeling the physical interactions of radiation with the material environment at large energy range. MCNPX is totally three-dimensional and it operates an extended nuclear cross section libraries using physics models for particle types [22]. In the direction of different objectives, MCNPX Monte Carlo code has been employed for investigation of radiation mass attenuation coefficients and other shielding parameters [23–35].

2.2. MCNPX geometry and input file

In the present investigation, the geometry was employed as a square prism for the modeling of tellurite tungsten glass samples. The edge lengths of this square prism are defined as 5 cm while the axial z-length is defined for each simulation in different sizes due to the thickness of the glass sample. The mass attenuation coefficients of the each studied glass samples were calculated in a narrow beam transmission geometry using a point isotropic radiation source with collimated and monoenergetic beam. The photon energies have been defined at 0.662, 1.173, 1.274 and 1.332 MeV for each calculation. In addition, geometric center of detection cell on central axis was considered for location of point source which emit gamma rays perpendicular to the front face of the glass samples in the direction of z-axis. MCNPX simulation geometry can be seen from Fig.1. On the other hand, another important definition is the material specification considering the atomic number, mass number, elemental mass fraction and density for compounds or mixtures. The compositions and densities of each glass samples were presented in Table 1.To obtain the average photon flux in the detection cell, average flux tally mesh (F4) was utilized. F4 tally mash gives the sum of average flux in cell. The quantity of gamma ray is set as 10^8 particle. The screenshot of modeled MCNPX simulation setup can be seen in Fig.2. The mass attenuation coefficient calculations were done by using Intel® Core™ i7 CPU 2.80 GHz computer hardware. The error rate has been observed < 0.1% in the output file.

2.3. Transmission

The term of tally cards (Fn) are used to define what type of information the user wants to obtain from the MCNPX simulation; that is, current across a surface, average flux at a point, heating, etc. One can say that tally cards are kind of detection tool to obtain required output from the interactions. To obtain tally results in MCNPX Monte Carlo simulation, the definition of Fn card should be required. Further in this section, the conditions of use of the F4 tally mesh for calculation of transmission factor in the recent study will be explained. In addition to calculation of mass attenuation coefficients, transmission factors of each glass samples in used photon energies have been investigated. The transmission factor of an attenuator material is the ratio of the radiation flux (F) passing through the attenuation medium to the flux incident upon the surface of attenuator material. In the present investigation, transmission factor for a glass sample T(E,d) for a certain gamma energy (E), through the thickness x cm of the attenuator glass sample can be obtained by dividing the value of average photon flux in detection field (F4 tally mesh) by average value of photon flux in uniform detection field as shown in Eq. 1 [14].

$$T(E,x) = F(E,x)/F(E,0) \quad (1)$$

To obtain the F (E,O) value, an F4 Tally has been defined just before attenuator glass sample. Thus, the average flux of incoming photon beam before attenuated by glass sample was obtained. Moreover, to obtain the F (E,x) value, another F4 Tally has also been defined behind of the attenuator glass sample. Thus, the transmission factors of investigated glass samples were obtained by dividing those two average fluxes by considering Eq. (1) for each measurement, respectively. The average flux data of F4 Tallies were obtained from MCNPX output file.

3. Results and discussion

The attenuation effects of the TSW glasses were illustrated in Fig. 3as TF versus thickness at 0.662, 1.173, 1.274 and 1.173 and 1.332 MeV photon energies, respectively. The justification of photon energies used in this study can be explained by well-known experimental radioactive isotopes. We chose those energies as they are frequently used in experimental investigations, not only in the industrial field but also in the medical field as well such as in external beam radiotherapy using Cobalt-60. On the other hand, we chose some other energies which are the characteristics gamma energies of different