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Investigation of radiation shielding properties for Bi_2O_3 - V_2O_5 - TeO_2 glass system using MCNP5 code

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ABSTRACT

In materials engineering design understanding and prediction over the physical properties are essential to develop new class of functionalized materials. The objective of this work is to assess the radiation shielding properties for Bi_2O_3 - V_2O_5 - TeO_2 glass system. For this aim, the MCNP5 Monte Carlo code was used to estimate the mass attenuation coefficients (μ/ρ) for the Bi_2O_3 - V_2O_5 - TeO_2 glasses in the energy range of 0.356-1.33 MeV. The MCNP5 values of μ/ρwere verified by XCOM at the selected energy range.The results showed that BiVTe6 and BiVTe1 glass samples have the highest and lowest values of mass attenuation coefficient respectively. The addition of Bi_2O_3 in the glass samples leads to a reduce in HVL and MFP values at all photon energies. Hence, BiVTe6 glass sample possesses the lowest HVL and MFP values, thus this glass sample has better shielding properties in comparison with the other samples in this work.The exploitation of their useful shielding properties may open many new technological applications in optoelectronics and radiation protection.

1. Introduction

The fundamental principle of electromagnetic radiation protection is to prevent any possible hazardous effects on living organisms cells. Electromagnetic radiation such as gamma ray and x-ray has been involved in many areas including diagnostic radiology, radiotherapy, nuclear medicine, nuclear reactors, industries, food preservation and many other applications which used in human daily activities. Therefore, it is necessary to have prevention measures to reduce the radiation effect on the workers and other people involved [1–5].

The term of shielding is the most important aspect in dealing with ionizing-radiation. Usually, lead (Pb) is the common material used for this purpose. However, lead have some limitations, such as, toxicity, weak mechanical strength and inflexibility, nevertheless the high cost of materials and installation. As a consequence, researchers are trying to find alternative shielding material that can protect from radiation as lead with less limitations [6].

Recently, glass has been introduced by many researchers as a suitable alternative material in the field of radiation safety [7–10]. Lead-free, non-toxic and environmentally friendly properties make glass a better alternative radiation protection material.

For the last decades, tellurite glasses has been widely used for several well known applications such as in fiberoptic, spectroscopy and many other uses. Tellurite glasses have high density, low-phonon energies, good stability and durability, high nonlinear optical properties and low glass transition temperature [11–15]. All this properties derived lots of investigations and researches on tellurite based glasses in order to determine their effectiveness in reducing and attenuating different electromagnetic radiation and to investigate the effect of irradiation on its mechanical and physical properties. For example, Ersundu et al., [13] used the WinXcom program and studied the mass attenuation coefficients and some other parameters of K_2O-WO_3-TeO_2 glasses in the photon energy region of 0.015 to 15 MeV. They reported that these glasses show potentiality to be used as shielding materials. El- Mallawany et al. [16] reported the shielding properties for 21 tellurite glass samples in the form of TeO_2-V_2O_5-ZnO, TeO_2-V_2O_5-CeO_2, TeO_2-V_2O_5-TiO_2 andTeO_2-V_2O_5. Tijani et al. [17] worked on the radiation shielding properties of Er_2O_3-ZnO-TeO_2 glass system at at the medical diagnostic energy range (i.e 20, 30, 40 and 60 keV) and they concluded that all the glass samples showed significantly better shielding performance than ordinary concrete. Lakshminarayana et al. [18] used the Monte Carlo simulation code to study the shielding

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Table 1
Composition (mol%) and density of Bi_2O_3 - V_2O_5 - TeO_2 glass system

Sample code	Bi_2O_3	V_2O_5	TeO_2	Density (g/cm^3)
BiVTe1	0	47	53	3.9956
BiVTe2	2	43	55	4.3764
BiVTe3	4	40	56	4.7969
BiVTe4	6	36	58	5.1884
BiVTe5	8	32	60	5.6240
BiVTe6	11	27	62	6.0314

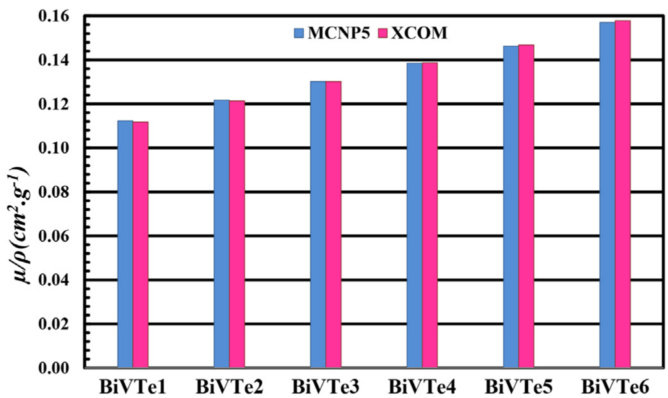

Fig. 1. Comparison between the mass attenuation coefficientof the glass samplescalculated by XCOM and MCNP5 at 0.356MeV.

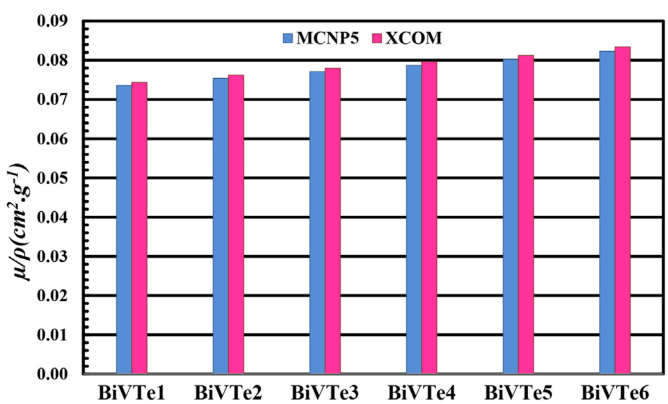

Fig. 2. Comparison between the mass attenuation coefficientof the glass samplescalculated by XCOM and MCNP5 at 0.662 MeV.

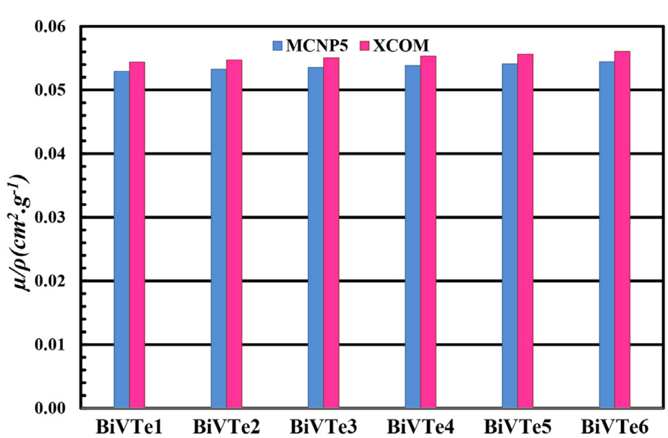

Fig. 3. Comparison between the mass attenuation coefficientof the glass samplescalculated by XCOM and MCNP5 at 1.173 MeV.

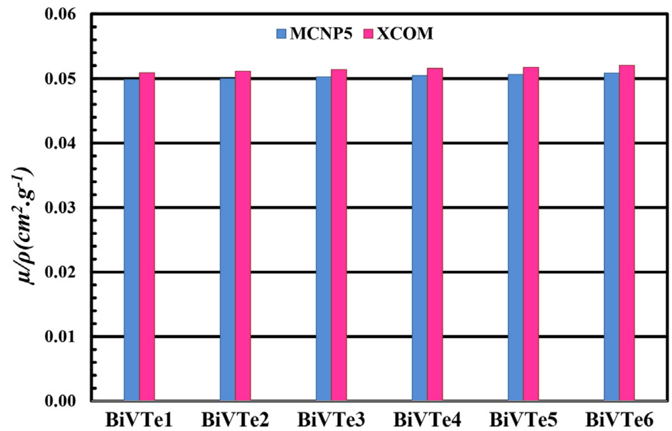

Fig. 4. Comparison between the mass attenuation coefficientof the glass samplescalculated by XCOM and MCNP5 at 1.33 MeV.

effectiveness of titanate bismuth borotellurite glasses in the energy range 0.015–10 MeV. Their results revealed that the titanate bismuth borotellurite glasses showed a better shielding ability than different types of concretes. Besides, Sayyed [19] used the G-P fitting method to evaluate the exposure buid up factor of tellurite glasses with different forming oxides (MgO, PbO, BaO, Ag_2O, Nb_2O_5, and ZnO). Ersundu et al. [20] measured the mass attenuation coefficients for the WO3-MoO3-TeO2 glass system using transmission geometry at 81 keV, 276 keV, 303 keV, 356 keV and 384 keV. From the measured mass attenuation coefficients values, they calculated some relevant parameters such as effective atomic number and half value layer. The authors concluded that $10WO_3$-$10MoO_3$-$80TeO_2$ sample showed superior shielding properties when compared to other smaples.

Accurate values of different parameters such as mass attenuation coefficient (μ/ρ), effective atomic number (Z_{eff}), half value layer (HVL), which determine the scattering and absorption of gamma-rays with matter are necessary to judge a material's practical application in radiation shielding. Usually, gamma-rays interaction is dependent upon photon energy, density and an atomic number of elements present in the materials and high values of density attenuation coefficients are required for best radiation shielding applications 21–23].

This work comes as continuity in the line of research work on the photon attenuation properties of different glass systems. Accurate data on attenuation coefficients for the present glasses are required to use in applications mentioning in above. Table 1 summarizes the density and composition for the investigated V_2O_5-contained tellurite Bi_2O_3 - V_2O_5 - TeO_2 glass system [24]. The present glasses were labelled as 'BiVTe1', 'BiVTe2', 'BiVTe3', 'BiVTe4', 'BiVTe5' and 'BiVTe6' (see Table 1).

2. Theoretical and computational background

2.1. MCNP5 and XCOM Software

MCNP is a general purpose and well known code used to evaluate radiation interaction properties in various materials such as glasses [5,16,25], polymers [26], concrete [27,28] and alloys [29] for radiation shielding studies. In this research work, MCNP5 code [30–31] was used for examination the shielding performance of the present glass samples against gamma radiation. More details about this numerical algorithm and the principles underlying its method of simulation are presented elsewhere [32–33]. Besides, XCOM program [34] is also a suitable software used to calculate the photon interaction cross section for different materials. In the present work, we used the XCOM to evaluate the μ/ρ of the present glass samples. In this program, each glass sample was defined by their elemental fractions, which are given in Table 1.