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Transmission, buildup factors, and photon shielding capacity of vanadium reinforced tellurite glasses

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Abstract

The ionizing radiation shielding parameters of $(90-y)\text{TeO}_2-y\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$ (TVCN): $y= 5-20$ mol% semiconductor glasses were investigated. The average track lengths of photons with different energies (0.015- 15 MeV) in the TVCN-glasses were simulated via MCNP-5 code, then the corresponding LAC were computed. Based on LAC values, the MACs were calculated and compared with values which obtained via XCOM software. The highest LAC achieved for low energy (0.015 MeV) and reduced from 199.549 to 169.891 cm^{-1} , while the lowest values achieved for gamma photon with higher energies and reduced from 0.188 to 0.161 cm^{-1} with replacment of TeO_2 compound by V_2O_5 . The highest (I/I_0) achieved for TVCN20 glasses and decreased from 0.703 to 0.172., while the lowest (I/I_0) performed for TVCN5 glasses and decreased from 0.680 to 0.145 for glasses thickness varied between 1 and 5 cm. The thinner HVL was achieved for TVCN5 and increases from 0.003 to 3.684 cm, while the thicker HVL was achieved for TVCN20 and increases from 0.004 to 4.293 cm. The highest dose rate was recorded in the presence of the TVCN20 glasses and varied between 5.680 and 23.210 $\mu\text{Sv/hr}$, while the lowest dose rate recorded in the presence of the TVCN5 glasses and varied between 4.807 and 22.448 $\mu\text{Sv/hr}$ for glass thickness varied in range between 1-5 cm. The highest values of the Z_{eff} was recorded for glasses TVCN5 and varied between 21.209 and 50.402, while the lowest Z_{eff} achieved for TVCN20 and varied between 18.489 and 40.479. The calculated buildup factors (EBF and EABF) reach

maximum values for glasses TVCN5 while the lowest EBF and EABF achieved for glasses TVCN20. Therefore, the glasses TVCN5 have a higher ability to attenuate the incident gamma photons. Thus, the TVCN-glasses can be applied in various radiation shielding applications in medical area.

Keywords: Radiation shielding; Monte Carlo simulation; Semiconductor glasses; HVL; EABF

1. Introduction

Recently, due to modern technology especially in nuclear medical field, artificial and natural sources of ionizing radiation (i.e., X- and gamma- photons) and their radioisotopes have been used in different applications. Sealed sources of ^{60}Co , ^{123}I , and ^{201}Tl are considered as isotopes applied in medicine for the treatment of health trauma, nuclear medicine, and sterilizing medical equipment. Furthermore, ionizing radiation can be applied preservation industries, food processing, and for material characterization, among others.

The use of shielding as a radiation protection procedure is an essential aim for continuous adoption of radiation in existing and modern applications. Therefore, in nuclear science and technology, research into radiation shielding materials becomes very active. The selection of radiation shielding materials depends on factors such as radiation energy and quality, cost, available space, required physical, thermal, mechanical, and optical features of the shield. The most important factor is that the shielding material must have high absorption cross-section for the radiation energy of interest. Photons (gamma- and X-radiation) and neutrons are of major concern due to their high penetration power. Therefore, shielding parameters for these radiations are essential when evaluating any material for ionizing radiation shielding effectiveness.

Formerly, concrete, lead (Pb), and depleted uranium are traditional shielding material have major disadvantages and have continuously limit application. Pure lead (Pb) and Pb-based composite have toxicity and cost related issues [1,2]; concrete suffers from unstable and cracking features due to thermal changes which leads to changes in its chemical (hydrogen) content [3]; uranium on its own is radioactive. Thus, research into novel

materials such as glasses very attractive to research community to be applied as radiation shields [4-14].

Tellurium oxide (TeO_2) based glasses are one of the most significant considerable attention among other oxide glasses such as phosphate, borate and silicates because of their several unique and attractive physical and chemical properties such as high thermal expansion coefficient in the range of $120 \times 10^{-7} \text{ }^\circ\text{C}^{-1}$ to $170 \times 10^{-7} \text{ }^\circ\text{C}^{-1}$, high index of refraction (1.8–2.3), low glass transition temperature (less than 300°C), dielectric constant in the range of 13–35, low melting temperature (less than 1000°C), and higher optical transmission in the infrared (IR) region from 0.4 to 6 μm) [15-19]. Therefore, TeO_2 -based glasses have been widely applied amplifiers and laser tools [18-20].

Adding V_2O_5 helps to improve their semiconducting, thermal, and optical features [11,14, 21-26]. Vanadia (V_2O_5) is a strong oxidant, it can be applied in several uses in different fields such as industrial utilization, biological and pharmacological [27,28].

This article presents the ionizing radiation shielding capacity of TeO_2 - V_2O_3 - CaO - Na_2O (TVCN) semiconductor glasses. The mass and linear attenuation coefficients (MAC and LAC), half value layer and mean free path (HVL and MFP), effective and equivalent atomic numbers (Z_{eff} and Z_{eq}), and photon energy absorption and exposure buildup factors (EABF and EBF) were evaluated.

2. Materials and methods

2.1 Glasses description

The studied glasses in the present article were samples of vanadate–tellurite glasses with from $(90-y)\text{TeO}_2 - y\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$: $y = 5, 10, 15$, and $20 \text{ mol\%}$ glasses. These glasses were chosen from Ref. [29] and labelled as TVCN-glasses and each glass sample coded as:

TVCN5: $85\text{TeO}_2-5\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$ for $y=5 \text{ mol\%}$,

TVCV10: $80\text{TeO}_2-10\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$ for $y=10 \text{ mol\%}$,

TVCN15: $75\text{TeO}_2-15\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$ for $y=15 \text{ mol\%}$, and

TVCN20: $20\text{TeO}_2-20\text{V}_2\text{O}_5-5\text{CaO}-5\text{Na}_2\text{O}$ for $y=20 \text{ mol\%}$,

Characteristics and some physical properties of TVCN-glasses are listed in Table 1.

3. Results and discussion

The Monte Carlo N-particle transport code (MCNP-5) was used to investigate the average track length of photons with different energies varied in range between 0.015- 15 MeV in the studied TVCN-glasses. Based on the simulated average track length, the linear attenuation coefficient (LAC) was and plotted in Figure 1. The calculated values of the LAC presented in Figure 1 showed that the highest LAC values achieved for photons with lower energy (0.015 MeV). After that, a speedily diminish was observed in the calculated values of the HVL. This speedily diminish is due to the photo-electric interaction (PE) which is the main interaction for gamma photon with low energies. An Unpredicted increase in the calculated values of the HVL was detected around 31.8 keV. This unpredicted increase is due to the x-ray K-absorption edges of the tellerium element (Te). The Compton scattering is the major interaction for photons with intermegiate energy values between 0.15-3 MeV. Thus, a softly decrease in the LAC values was observed. This softly decrease is due to the variation of the Comprton scattering cross section with the E^{-1} . The LAC values for photons with higher energies ($E > 3\text{MeV}$) were observed to be nearly constant. This equiling values for the LAC is due to the Pair production interaction (PP) where the pair production cross section vary with $\log(E)$ [30,31].

Figure 1 depicts that the highest LAC achieved for low energy (0.015 MeV) and reduced from 199.549 to 169.891 cm^{-1} while the lowest values of the LAC achieved for gamma photon with higher energies and reduced from 0.188 to 0.161 cm^{-1} with replacment of TeO_2 compound by V_2O_5 . The results showed that replacment of TeO_2 compound by V_2O_5 compounds has a negative effect in the density and LAC values of the studies glasses. This negative effect is due to the replace met of the TeO_2 compounds with higher density ($\rho = 5.67 \text{ g cm}^{-3}$) and LAC values by V_2O_5 compounds with lower density ($\rho = 3.36 \text{ g cm}^{-3}$).

The mass attenuation coefficient (MAC) was also calculated based on the simulated LAC according to Equation (1) [32,33]:

$$MAC (cm^2 g^{-1}) = \frac{LAC (cm^{-1})}{\rho (g cm^{-3})} \quad (1)$$

The ρ refers to the studied glasses density. The mass attenuation coefficient was estimated theoretically using XCOM program in the same energy range between 0.015 and 15 MeV. The calculated values of the MAC using MCNP and XCOM were listed in Table 2 where agreement was observed for the MAC values calculated using XCOM and MCNP. The difference (%) between the XCOM and MCNP results was calculated and listed in Table 2. It is clear that the diff. (%) was found to be around 1% for all the studied TVCN glasses.

The transmission rate of gamma photons energy 662 keV was calculated for the studied TVCN-glasses at different thicknesses varied between 1 and 5 cm according to Equation (2).

$$Transmission\ rate = \frac{I}{I_0} = \exp(-\mu x) \quad (2)$$

The μ and x refer to the (LAC) and the glass thickness, respectively. The result presented in Figure 2 showed that the highest transmission rate is obtained for 1cm thickness of the studied glasses and varied between 0.680 and 0.703 while the lowest transmission rate achieved at sample thickness 5 cm and varied between 0.145 and 0.172 for glasses TVCN5 and TVCN20. As the thickness of the glass increases, the number of gamma ray interactions with the glass atom increase. Thus, the thicker slides are more effective in absorb of the incident gamma photons. Figure 2 depicts that replacement of TeO_2 by V_2O_5 increase the transmission rate of the incident gamma photons which have a negative effect in the shielding properties of the studied glass. The highest transmission rate achieved for glasses TVCN20 and decreased from 0.703 to 0.172 while the lowest transmission rate performed for glasses TVCN5 and decreased from 0.680 to 0.145 for glasses thickness varied between 1 and 5 cm.

The half value layer (HVL) used to calculate the thickness of the studied TVCN-glasses required to attenuate the incident gamma photons to 50% of its initial values. The HVL was calculated for the studied TVCN-glasses according to Equation (3) [34,35]:

$$HVL (cm) = \frac{\ln(2)}{\mu (cm^{-1})} \quad (3)$$

The calculated HVL for the studied TVCN glasses was presented in Table 3 and Figure 3. The thinner values of the HVL were observed at lower energy (0.015 MeV) and varied in range between 0.003- 0.004 cm while the thicker HVL were observed at high gamma ray energy (for 8 MeV) and varied in 4.072- 4.640 cm range for glasses TVCN5 and TVCN20, respectively. The gamma ray interactions with the studied TVCN glasses can be discussed as the following. Above 15 keV, the HVL values suffered a speedily increase with increment in the incident photon energy due to the PE interaction. The PE cross-section is directly proportional to $\frac{Z^4-5}{E^{3.5}}$. With increase the incident gamma photon energies, the PE interaction decreases while the Compton scattering increase inside the studied glasses. Above 0.3 MeV, the Compton scattering began to be the main interaction. Thus, values of the HVL were observed to increase amiably with increase the incident photon energy. The Compton cross section varies with $\frac{Z}{E}$. After that for high gamma photons energy, the PP interaction is main so values of the HVL were observed to decrease slowly with increase the incident gamma energy. The PP cross-section is proportional to $Z^2 \log(E)$.

The thinner HVL was achieved for TVCN5 glasses with content 5 mol% V_2O_5 and increases from 0.003 to 3.684 cm while the thicker HVL was achieved for TVCN20 with content 20 mol% V_2O_5 and increases from 0.004 to 4.293 cm for gamma-photons with energy between 0.015 and 15 MeV. According the previous discussion we can concluded that the replacement of TeO_2 by V_2O_5 contents reduce the ability of the studied glass to attenuate the incident gamma-rays.

The mean free path (MFP) is the shielding parameter which calculate the average distance between to following collisions inside the studied glasses. The MFP for the studied glasses calculated using Equation (4) [34,35]

$$MFP (cm) = \frac{1}{\mu (cm^{-1})} \quad (4)$$

The computed values for the MFP was plotted in Figure 4 as a function of the gamma photon energy and the V₂O₅ contents. The potted MFP values were found to have the same trend as in the HVL. Results recorded for HVL and MFP reflected the importance of existence of Te with high ratios in glass composition which improves the shielding properties of the studied TVCN- glasses. According the present calculation the lowest MFP achieved for glasses coded TVCN5 and varied between 0.0050 and 5.9270 cm while highest MFP achieved for glasses coded TVCN20 and varied between 0.0058 and 6.702 cm for gamma ray energy between 0.015 and 15 MeV.

The dose rate received by an exposure at a definite distance from the radioactive source without a shielding material can be described by Equation (5).

$$\text{Dose rate} \left(\frac{\text{Sv}}{\text{h}} \right) = \frac{\Gamma A}{d^2} \quad (5)$$

Where Γ , A and d represent the specific gamma ray constant, activity of the radioactive source and the measured distance between the radioactive source and the exposure, respectively. When a shielding material was used to shield the radioactivity outcome from the radioactive source, Equation (5) can be modified and written as the following.

$$\text{Dose rate} = \frac{\Gamma A}{d^2} \exp(-\mu_{\text{glass}} x) \quad (6)$$

Where μ_{glass} and x refer to the LAC of the thickness of the studied TVCN-glass, respectively.

The dose rate received by an exposure at a distance 100 cm from radioactive gamma ray source ¹³⁷Cs with activity 1Ci was computed theoretically according to Equation (6) and the recorded results were plotted in Figure 5. The computed results showed that the dose rate received from the ¹³⁷Cs radioactive source without a shielding material (thickness=0

cm) was found to be 33.2 $\mu\text{Sv/hr}$. After that, with increase the studied glasses thickness, the dose rate received by exposure began to decrease moderately. Among the studied TVCN-glasses, the highest dose rate was recorded in the presence of the TVCN20 glasses with V_2O_5 contents 20 mol % and varied between 5.680 and 23.210 $\mu\text{Sv/hr}$, while the lowest dose rate recorded in the presence of the TVCN5 glasses with V_2O_5 contents 5 mol % and varied between 4.807 and 22.448 $\mu\text{Sv/hr}$ for glass thickness varied in range between 1-5 cm. Increase of the studied glass thickness helps the incident gamma photons to make more collisions with the studied glass atoms which leads to absorb the intensity of the incident gamma photons. Thus, the dose rate decreases with increase the shielding studied glass thickness. The presented results showed that replacement of TeO_2 with V_2O_5 increase the dose rate received by the exposure.

The effective atomic number (Z_{eff}) is used to calculate the effective number of electrons inside the shielding materials. The Z_{eff} is a shielding factor which used to describe the shielding material as its equivalent element. For a glass material consists of i^{th} constituent elements, the Z_{eff} can be calculated using Equation (7).

$$Z_{\text{eff}} = \frac{\sum_i f_i A_i (\text{MAC})_i}{\sum_j \frac{A_j}{Z_j} (\text{MAC})_j} \quad (7)$$

Where f_i , A_i , Z_j and $(\text{MAC})_i$ refer to the fractional abundance, mass number, atomic number, and the mass attenuation coefficient of the i^{th} constituent element respectively.

Additionally, the effective electron density (N_{eff}) can be calculated based on the values of the Z_{eff} as shown in Equation (8):

$$N_{\text{eff}} = \frac{N_A}{M} Z_{\text{eff}} \sum n_i \quad (8)$$

Where N_A and M refer to the Avogadro's number and the atomic mass in unit (g).

The Z_{eff} of the studied TVCN-glasses were estimated using Phy-X/PSD program [36] and the obtained results plotted in Figure 6. The maximum values of the Z_{eff} were observed at the lower energy while the lowest values of the Z_{eff} obtained at higher energies due to the PP interaction. Around 31.8 keV, a raise in the calculated values of the Z_{eff} was

detected. This increase is due to the X-ray and K-absorption edges of the tellurium (Te) element. After that, a rapidly decrease in the Z_{eff} values was detected due to the PE interaction. Due to the Compton scattering interaction is the main for gamma-photons with energy higher than 300 keV, a moderately reduction in the Z_{eff} values was detected. For high gamma ray energy, the values of the Z_{eff} began to increase again with increase the incident photon energy. This increase is due to the pair production cross section which varied with $\log(E)$. The highest values of the Z_{eff} was recorded for glasses TVCN5 and varied between 21.209 and 50.402 while the lowest Z_{eff} achieved for TVCN20 and varied between 18.489 and 40.479.

Figure 7 showed the changing of the N_{eff} versus the incident gamma-ray energy. The potted values of the electron density were found to have the same trend as appeared in Z_{eff} . According to the previous discussion we can concluded that the glasses with the highest values of Z_{eff} and N_{eff} (TVCN5) contains large number of electrons per unit mass than the other glasses (TVCN10, TVCN15 and TVCN20). Thus, the probability of photon interaction in TVCN5 glasses is higher than the other studied glasses. This means that the studied glasses TVCN5 have a higher ability to attenuate the incident gamma photons.

The effective conductivity (C_{eff}) is a factor related to the number of free electrons in the studied material. These free electrons were ejected during the interaction of gamma ray with the material atoms. The effective conductivity (C_{eff}) of the TVCN-glasses were estimated for gamma-photons with energy varied in range between 0.015 – 15 MeV using Phy-X/PSD program The result plotted in Figure 8 showed that the C_{eff} parameter is directly proportional to the effective atomic number and the electron density of the studied TVCN-glasses. The calculated values of the C_{eff} were observed to affect by the major three interactions of the gamma photons (photoelectric effect, Compton scattering and pair production) with the material. Therefore, values of the C_{eff} values can be affected by the changes of photon energy.

Besides, the newly Phy-X/PSD software was used to compute buildup factors exposure buildup factor (EBF) and energy absorption buildup factor (EABF) for the studied glasses

in the energy range between 0.015- 15 MeV and at various penetration depths (PD) starting from 0.5 up to 40 mfp. The calculated EBF and EABF WERE plotted versus the incident gamma-photon energy for some penetration depths as presented in Figures 9 and 10, respectively. The calculated buildup factors showed that the lowest EABF and EBF values were achieved at low gamma-photon energy. For low photon energy, the photoelectric effect is the main interaction in the studied glasses. Thus, the energy of the incident photon was totally removed to eject one boundary electron. As the gamma-photon energy increases, the Compton scattering interaction began to increase inside the TVCN-glasses and become maximum around 1 MeV. At this energy interval ($0.3 < E < 1$ MeV), the EBF and EABF increase gradually with increase the incident gamma-photon energy due to the accumulation of photons resulting from Compton scattering. Compton scattering interaction remove only a part of the photon energy to eject one boundary electron and the gamma photon move with the rest of energy inside the studied glasses searching for another collision. Thus, the photons accumulated inside the studied glasses and causing an increase in the buildup factors. Above 1.5 MeV, values of the buildup factors began to decrease again due to the pair production interaction. The pair production interaction consumed the energy of incident photon to create an electron- positron pair. After that at high gamma ray energy $E > 8$ MeV, a rapid increase in the EBF and EABF values were observed especially for high energy and high penetration depth ($PD > 20$).

The calculated EBF and EABF reach maximum values for glasses TVCN5 with V_2O_5 content 5 mol% while the lowest EBF and EABF achieved for glasses TVCN20 with V_2O_5 contents 20 mol %. The calculated values of EBF and EABF was observed to decrease with the replacement of TeO_2 by V_2O_5 contents. Thus, the addition of V_2O_5 has a positive effect in enhancement of the buildup factors of the studied glasses.

Variation of the EBF and EABF versus the penetration depth (PD) for the studied TVCN glasses was studied as illustrated in Figures 11 and 12. In photoelectric interaction region (for 0.015 and 0.15 MeV), values of EBF and EABF are equaling for the studied glasses at low penetration depth between 0.5 and 15 mfp. After that, values of the EBF and EABF

were speedily progressed with increase the penetration depth especially for high penetration depth ($PD > 20$ mfp). For Compton scattering region (for 1.5 MeV), values of EBF and EABF were observed to increase speedily with the penetration especially for $PD > 15$ MeV.

4. Conclusion

In this study, the ionizing radiation shielding parameters of $\text{TeO}_2\text{-V}_2\text{O}_5\text{-CaO-Na}_2\text{O}$ (TVCN) semiconductor glasses were evaluated. Gamma-photon shielding parameters include the mass and linear attenuation coefficients (MAC and LAC), half value layer and mean free path (HVL and MFP), effective and equivalent atomic numbers (Z_{eff} and Z_{eq}), and photon energy absorption and exposure buildup factors (EABF and EBF) were computed. Results revealed that:

- 1- The highest LAC achieved for low energy (0.015 MeV) and reduced from 199.549 to 169.891 cm^{-1} while the lowest values of the LAC achieved for gamma photon with higher energies and reduced from 0.188 to 0.161 cm^{-1} with replacment of TeO_2 compound by V_2O_5 .
- 2- The highest transmission rate achieved for glasses TVCN20 and decreased from 0.703 to 0.172 while the lowest transmission rate achieved for glasses TVCN5 and decreased from 0.680 to 0.145 for glasses thickness varied between 1 and 5 cm.
- 3- The thinner HVL was achieved for TVCN5 glasses with content 5 mol% V_2O_5 and increases from 0.003 to 3.684 cm while the thicker HVL was achieved for TVCN20 with content 20 mol% V_2O_5 and increases from 0.004 to 4.293 cm for gamma photons with energy between 0.015 and 15 MeV.
- 4- The lowest MFP achieved for glasses coded TVCN5 and varied between 0.0050 and 5.9270 cm while highest MFP achieved for glasses coded TVCN20 and varied between 0.0058 and 6.702 cm for gamma ray energy between 0.015 and 15 MeV.
- 5- The highest dose rate was recorded in the presence of the TVCN20 glasses and varied between 5.680 and 23.210 $\mu\text{Sv/hr}$, while the lowest dose rate recorded in the

presence of the TVCN5 glasses and varied between 4.807 and 22.448 $\mu\text{Sv/hr}$ for glass thickness varied in range between 1-5 cm.

- 6- The highest values of the Z_{eff} was recorded for glasses TVCN5 and varied between 21.209 and 50.402 while the lowest Z_{eff} achieved for TVCN20 and varied between 18.489 and 40.479.
- 7- The calculated buildup factors (EBF and EABF) reach maximum values for glasses TVCN5 while the lowest EBF and EABF achieved for glasses TVCN20.

In general, the results showed that replacment of TeO_2 compound by V_2O_5 compounds has a negative effect in the density and LAC and MAC values of the TVCN-glasses, reduces the ability of the studied glass to attenuate the incident gamma photons, and increases the dose rate received by the exposure. Thus, the probability of photon interaction in TVCN5 glasses is higher than the other studied glasses. This means that the studied glasses TVCN5 have a higher ability to attenuate the incident gamma photons. Therefore, the TVCN-glasses can be applied in various radiation shielding applications in medical area.

References

- [1] K. Kaur, K.J. Singh, V. Anand, Correlation of gamma ray shielding and structural properties of PbO-BaO-P₂O₅ glass system, Nucl. Eng. Des. 285 (2015) 31–38. <https://doi.org/10.1016/j.nucengdes.2014.12.033>.
- [2] M.I. Sayyed, H.O. Tekin, O. Kılıcoglu, O. Agar, M.H.M. Zaid, Shielding features of concrete types containing sepiolite mineral: comprehensive study on experimental, XCOM and MCNPX results. Results Phys. 11 (2018) 40–45. <https://doi.org/10.1016/j.rinp.2018.08.029>.
- [3] V. P. Singh, H.O. Tekin, N.M. Badiger, T. Manici, E.E. Altunsoy, Effect of Heat Treatment on Radiation Shielding Properties of Concretes, Journal of Radiation Protection and Research 43(1) (2018) 20–28. <https://doi.org/10.14407/jrpr.2018.43.1.20>.
- [4] C. Bootjomchai, J. Laopaiboon, C. Yenchai, R. Laopaiboon, Gamma-ray shielding and structural properties of barium-bismuth-borosilicate glasses. Radiat. Phys. Chem. 81 (2012), 785–790 . <https://doi.org/10.1016/j.radphyschem.2012.01.049>
- [5] A.A.A. Darwish, S.A.M. Issa, M.M. El-Nahass, Effect of gamma irradiation on structural, electrical and optical properties of nanostructure thin films of nickel phthalocyanine. Synth. Methods 215 (2016) 200–206. <https://doi.org/10.1016/j.synthmet.2016.03.002>
- [6] B.O. Elbashir, M.G. Dong, M.I. Sayyed, S.A.M. Issa, K.A. Matori, M.H.M. Zaid, Comparison of Monte Carlo simulation of gamma-ray attenuation coefficients of amino acids with XCOM program and experimental data. Results Phys. 9 (2018) 6–11. <https://doi.org/10.1016/j.rinp.2018.01.075>
- [7] S. Issa, M. Sayyed, M. Kurudirek, Investigation of Gamma Radiation Shielding Properties of Some Zinc Tellurite Glasses. J. Phys. Sci. 27 (2016) 97–119. <https://doi.org/10.21315/jps2016.27.3.7>
- [8] S.A.M. Issa, Y.B. Saddeek, H.O. Tekin, M.I. Sayyed, K. Saber Shaaban, Investigations of radiation shielding using Monte Carlo method and elastic properties of PbO-SiO₂-B₂O₃-Na₂O glasses. Curr. Appl. Phys. 18 (2018) 717–727.
- [9] S.A.M. Issa, M.I. Sayyed, M.H.M. Zaid, K.A. Matori, Photon parameters for gamma-rays sensing properties of some oxide of lanthanides. Results Phys. 9 (2018) 206–210. <https://doi.org/10.1016/j.rinp.2018.02.039>
- [10] M.I. Sayyed, S.A.M. Issa, S.H. Auda, Assessment of radio-protective properties of some anti-inflammatory drugs. Prog. Nucl. Energy 100 (2017) 297–308. <https://doi.org/10.1016/j.pnucene.2017.07.003>

- [11] Y. S. Rammah, F. I. El-Agawany, K. A. Mahmoud, R. El-Mallawany, Erkan Ilik, Gokhan Kilic, FTIR, UV–Vis–NIR spectroscopy, and gamma rays shielding competence of novel ZnO-doped vanadium borophosphate glasses, *Journal of Materials Science: Materials in Electronics* (2020), <https://doi.org/10.1007/s10854-020-03440-5>.
- [12] A.A. Ali, Y.S. Rammah, M.H. Shaaban, The influence of TiO₂ on structural, physical and optical properties of B₂O₃ –TeO₂ – Na₂O – CaO glasses. *Journal of Non-Crystalline Solids* 514 (2019) 52–59.
- [13] Y.S Rammah, M. S. Al-Buriahi, A. S. Abouhaswa. "B₂O₃–BaCO₃–Li₂O₃ glass system doped with Co₃O₄: Structure, optical, and radiation shielding properties. *Physica B: Condensed Matter* (2019) 411717.
- [14] Y.S. Rammah, Gökhan Kilic, R. El-Mallawany, U. Gökhan Issever, F.I. El-Agawany, Investigation of optical, physical, and gamma-ray shielding features of novel vanadyl borophosphate glasses. *Journal of Non-Crystalline Solids* 533 (2020) 119905.
- [15] S. Shen, A. Jha, X. Liu, M. Naftaly, K. Bindra, H.J. Bookey, A.K. Kar, Tellurite glasses for broadband amplifiers and integrated optics, *J. Am. Ceram. Soc.* 85 (2002) 1391-1395.
- [16] S.F. Mansour, Y. El Sayed, M.Y. Hassaan, A.M. Emara, The influence of oxides on the optical properties of tellurite glasses, *Phys. Scripta* 89 (2014) 115812.
- [17] Y. El Sayed, Er³⁺ ions doped tellurite glasses with high thermal stability, elasticity, absorption intensity, emission cross section and their optical application, *J. Alloy Compd.* 561 (2013) 234-240.
- [18] A. Jha, B. Richards, G. Jose, T.T. Fernandez, P. Joshi, X. Jiang, J. Lousteau, Rare earth ion doped TeO₂ and GeO₂ glasses as laser materials, *Prog. Mater. Sci.* 57 (2012) 1426-1491.
- [19] S.J. Madden, K.T. Vu, High-performance integrated optics with tellurite glasses: status and prospects, *Int. J. Appl. Glass Sci.* 3 (2012) 289-298.
- [20] R.A.H. El-Mallawany, *Tellurite Glasses Handbook: Physical Properties and Data*, CRC Press, Boca Raton, FL, USA, 2002.
- [21] H. Mori, T. Kitami, H. Sakata, Electrical conductivity of V₂O₅-Sb₂O₃-TeO₂ glasses, *J. Non-Cryst. Solids* 168 (1994) 157-166.

- [22] D. Souri, K. Shomalian, Band gap determination by absorption spectrum fitting method (ASF) and structural properties of different compositions of $(60-x)\text{V}_2\text{O}_5-40\text{TeO}-x\text{Sb}_2\text{O}_3$ glasses, *Journal of Non-Crystalline Solids* 355 (2009) 1597–1601.
- [23] D. Souri, Effect of molybdenum tri-oxide molar ratio on the optical and some physical properties of tellurite–vanadate–molybdate glasses, *Measurement* 44 (2011) 717–721.
- [24] R. El-Mallawany, A. Abdel-Kader, M. El-Hawary, N. El-Khoshkhany, Volume and thermal studies for tellurite glasses, *J Mater Sci* (2010) 45:871–887.
- [25] S.A. Salehizadeh, D. Souri, The glassy state of the amorphous $\text{V}_2\text{O}_5-\text{NiO}-\text{TeO}_2$ samples, *Journal of Physics and Chemistry of Solids* 72 (2011) 1381–1385.
- [26] D. Souri, Crystallization kinetic of $\text{Sb}-\text{V}_2\text{O}_5-\text{TeO}_2$ glasses investigated by DSC and their elastic moduli and Poisson's ratio, *Physica B* 456 (2015) 185–190.
- [27] A.G. Bezerra, A. Barison, V.S. Oliveira, et al. The mechanism of cysteine detection in biological media by means of vanadium oxide nanoparticles. *J Nanopart Res.* 14(9) (2012) 1123.
- [28] D. Rehder, Implications of Vanadium in Technical Applications and Pharmaceutical Issues, *Inorganica Chimica Acta* (2016).
- [29] N. Elkhoshkhany, A. Reda, A. M. Embaby, Preparation and study of optical, Thermal, and Antibacterial Properties of vanadate–tellurite glass, *Ceramics International* 43 (2017) 15635-15644.
- [30] K.A. Mahmoud, E. Lacomme. M.I. Sayyed, Ö.F. Özpolat, O.L. Tashlykov, Investigation of the gamma ray shielding properties for polyvinyl chloride reinforced with chalcocite and hematite minerals *Heliyon*, 6 (2020), Article e03560.
- [31] Y.R. Rammah, K.A.Mahmoud, E. Kavaz, K. Ashok, F.I. El-Agawany, The role of $\text{PbO}/\text{Bi}_2\text{O}_3$ insertion on the shielding characteristics of novel borate glasses. *Ceramics international* (2020), <https://doi.org/10.1016/j.ceramint.2020.04.018>.
- [32] K.A. Mahmoud, O.L. Tashlykov, M.I. Sayyed, E. Kavaz, The role of cadmium oxides in the enhancement of radiation shielding capacities for alkali borate glasses, *Ceram. Int.*, <https://doi.org/10.1016/j.ceramint.2020.02.219>.
- [33] R. Divina, K. Marimuthu, K.A. Mahmoud, M.I. Sayyed, Physical and structural effect of modifiers on dysprosium ions incorporated boro-tellurite glasses for radiation shielding purposes, *Ceram. Int.* (2020), [10.1016/j.ceramint.2020.04.102](https://doi.org/10.1016/j.ceramint.2020.04.102).

- [34] F.I. El-Agawany, K.A. Mahmoud, E. Kavaz, R. El-Mallawany, Y.S. Rammah, Evaluation of nuclear radiation shielding competence for ternary Ge-Sb-S chalcogenide glasses Appl. Phys. A, 126 (2020) 258.
- [35] K.A. Mahmoud, O.L. Tashlykov, A.F. El Wakil, H.M.H. Zakaly, I.E. El Aassy, Investigation of radiation shielding properties for some building materials reinforced by basalt powder AIP Conference Proceedings, (2019) 2174.
- [36] E. Sakar, Ö.F. Özpolat, B. Alim, M.I. Sayyed, M. Kurudirek, Phy-X/PSD: development of a user friendly online software for calculation of parameters relevant to radiation shielding and dosimetry. Radiat. Phys. Chem. 166, 108496 (2020).

Figures

Figure 1

The variation of the linear attenuation coefficient of the TVCN glasses versus the incident gamma photon energies at various V_2O_5 concentrations.

Figure 2

The variation of the transmission versus the glasses thickness for the TVCN glasses.

Figure 3

The variation of the HVL versus the incident gamma photon energy of TVCN glasses.

Figure 4

The variation of the mean free path of the studied glasses versus the incident gamma photon energy of TVCN glasses.

Figure 5

The dose rate at different thicknesses of the TVCN glasses.

Figure 6

Variation of the effective atomic number Z_{eff} versus the gamma photon energy and the V2O5 contents of TVCN glasses.

Figure 7

The variation of the effective electron density versus the gamma photon energy and V₂O₅ contents of TVCN glasses.

Figure 8

Variation of the effective conductivity (C_{eff}) values versus the incident gamma photon energy for the studied TVCN glasses.

Figure 9

Variation of exposure and energy absorption buildup factor (EBF) for the studied glasses with the incident gamma photons

Figure 10

Variation of exposure and energy absorption buildup factor (EABF) for the studied glasses with the incident gamma photons

Figure 11

Variation of the exposure buildup factor (EBF) versus the penetration depth at different photon energy.

Figure 12

Variation of the energy absorption buildup factor (EABF) versus the penetration depth at different photon energy.