*Arab J. Nucl. Sci. Appl., Vol. 55, 1, 53-61 (2022)*

**Arab Journal of Nuclear Sciences and Applications**

Web site: ajnsa.journals.ekb.eg

ISSN 1110-0451

(E S N S A)

# Electromagnetic-Ray Absorption Using $B_2O_3$-PbO-$Na_2O$ Glass Mixtures as Radiation Protection Shields

**Ali H. Taqi*, Ali I. Salih and Azeldeen H. Ibrahim**

*Department of Physics, College of Science, Kirkuk University, Kirkuk, Iraq*

ARTICLE INFO

*Article history:*

Received: 2nd May 2021

Accepted: 15th Aug. 2021

*Keywords:*

Shielding properties,

Glass,

mass attenuation coefficient,

WinXCom,

Phy-X/PSD.

ABSTRACT

**In this work, Lead Borate glass system doped with sodium is prepared and fabricated using the melt-quenching technique. The glasses are prepared based on the empirical formula of xPbO, (80-x) $B_2O_3$, 20$Na_2O$ (where x=0, 10, 20, 30, 40, and 50). The densities of the samples are measured based on the Archimedes method by using Benzene as an immersion liquid. The radiation shielding parameters of the prepared glass samples have been measured experimentally and calculated theoretically. The experimental mass attenuation coefficients are obtained using a shielded NaI(Tl) detector at photon energies of 511, 662, and 1173 keV of the radioactive sources $^{22}$Na, $^{137}$Cs, and $^{60}$Co respectively, where collimators of an aperture diameter 3 mm are used to ensure that the detector absorbs a narrow beam of gamma rays. The calculated mass attenuation coefficients ($\mu_m$), half-value layer (HVL), mean free path (MFP), effective atomic number ($Z_{eff}$), effective electron density ($N_{eff}$), atomic cross-section ($\sigma_a$), electron cross-section ($\sigma_e$) radiation protection efficiency (RPE) are performed theoretically by using WinXCom and Phy-X/PSD computer programs in the energy range from 1 keV to 1 GeV. The calculated parameters of the investigated glasses have been compared with the measured experimental values.**

## 1.1 INTRODUCTION

Generally, ionizing radiation can be classified into two groups, the first group contains all charged particles such as a protons, electrons, alpha particles, and heavy ions interacting primarily with the matter by Columbic forces. This type of radiation is called directly ionizing radiation and it is relatively simple to shield due to the low penetration power associated with charged particles. The second group of ionizing radiation consists of neutron and high-energy photons which are electrically neutral. Neutrons may undergo elastic and inelastic scattering, while photons interact with matter through various electromagnetic mechanisms that produce indirect atomic ionization. Indirectly ionizing radiation passes through most materials easily and thus they are relatively difficult to shield when compared to charged particles [1].

Since radiation is used in large areas and all people should live together with the radiation, shielding is the most important method for protection from radiation [2]. Concrete is opaque to the visible light range but glass can replace concretes because of their transparency in a visible light range and they can work as successful gamma-ray shielding transparent materials [3]. Gamma-ray absorbance can be better by using an element of higher Z. Therefore, the addition of heavy metals such as Pb and Bi in the network of glass will increase γ-rays absorption.

Many experimental and theoretical studies of glass shielding parameters have been investigated for different glass systems, such as $Bi_2O_3$-$SiO_2$ [4], PbO-$SiO_2$ [5], xPbO:(100-x)-$B_2O_3$ [6], $Bi_2O_3$-PbO-BaO [7], $Bi_2O_3$-BaO-PbO [8], ZnO-PbO-$B_2O_3$ [9], x$Bi_2O_3$-(1-x)$B_2O_3$ [10], PbO-$Li_2O$-$B_2O_3$ [11], PbO-$B_2O_3$, PbO-$SiO_2$, PbO-$GeO_2$ and PbO-$WO_3$-$TeO_2$ [12], xPbO-(100-x) $P_2O_5$ [13] and PbO-$Na_2O$-$B_2O_3$-CaO-$Al_2O_3$-$SiO_2$ [14]. A good review on the properties of radiation shielding of heavy metal oxide glasses is presented in a previous study [15].

Corresponding author: alitaqi@uokirkuk.edu.iq
DOI: 10.21608/ajnsa.2021.74814.1469

The purpose of this study is to prepare Borate glass samples of the formula xPbO, (80-x) $B_2O_3$, 20$Na_2O$ (where x=0, 10, 20, 30, 40, and 50). Borate is the most commonly used glass for radiation shielding applications due to its low cost and easy availability. Due to their acceptable characteristic properties, they are used in a variety of fields for glass production. $B_2O_3$ has the highest glass-forming ability because it does not crystallize by itself in the molten form even when cooled at a very slow rate. Moreover, boron can change its oxidation state very easily from three to four. It is therefore a good host for accommodating metal ions [15].

Gamma-ray absorption is represented by shielding parameters including the linear and mass attenuation coefficients ($\mu_L$, $\mu_m$), mean free path (MFP), half and tenth value layers (HVL, TVL), effective atomic number and electron density ($Z_{eff}$, $N_{eff}$), atomic and electronic cross-section ($\sigma_a$, $\sigma_e$).

In this work, the shielding parameters of the prepared samples are measured experimentally using a gamma spectrometer containing shielded NaI(Tl) detector at the energies 511, 662, and 1173 keV of the radioactive sources $^{22}$Na, $^{137}$Cs, and $^{60}$Co respectively. It is also calculated theoretically using the WinXCom and Phy-X/PSD [16] programs in the energy range of 1 keV-100 GeV. The calculated results to be compared with the experimental values.

## 2. Theoretical Background

The linear attenuation coefficient ($\mu_L$) is the decrease in photon beam intensity crossing an absorber material and can be determined by the Lambert-Beer rule [17],

$$I = I_0 e^{-\mu_L x} \quad (1)$$

where $I_0$ is the photon beam intensity just before it enters the material and $I$ the intensity at depth $x$. It is possible to determine $\mu_L$ experimentally, and hence, it is just required to measure the incoming and outgoing photon beam intensity that passes through a slap of $x$. The mass attenuation coefficient ($\mu_m = \mu_L/\rho$) is more fundamental, where ρ is the density of the absorbent sample. [18],

The mean free path (MFP), which is described as the average distance between two successive photon interactions in an absorber, is calculated by using the following formula.

$$\text{MFP (cm)} = \frac{1}{\mu_L} \quad \textbf{(2)}$$

The Half Value Layer (HVL) is the thickness of the material at which the intensity of radiation entering is reduced by one-half which is given as.

$$\text{HVL (cm)} = \frac{0.693}{\mu_L} \quad \textbf{(3)}$$

The effective atomic number ($Z_{eff}$) can be expressed in terms of the total atomic effective cross-section ($\sigma_a$) and the total electronic effective cross section ($\sigma_e$) [19, 20].

$$Z_{\text{eff}} = \frac{\sigma_a}{\sigma_e}$$

where the $\sigma_a$ and $\sigma_e$ are evaluated by the following equations,

$$\sigma_a = \frac{1}{N_A}\sum_i f_i A_i\, (\mu_m)_i$$

$$\sigma_e = \frac{1}{N_A}\sum_i \frac{f_i A_i}{Z_i}(\mu_m)_i$$

where $f_i$ , $Z_i$ and $A_i$ are the mole fraction, atomic number, and atomic weight of the i$^{th}$ constituent element, respectively.

The $Z_{eff}$ is closely related to the effective number of electrons per unit mass $N_{\text{eff}}$ [21],

$$N_{\text{eff}} = \frac{\mu_m}{\sigma_e}$$

## 3. MATERIALS AND METHODS

In this study, $H_3BO_3$ (M.W= 61.83 g/mol), $Na_2CO_3$ (M.W= 105.98 g/mol) and $P_2O_5$ (M.W = 223.2 g/mol) are used as the source materials of $B_2O_3$, $Na_2O$ and PbO, respectively.

### 3.1 Sample Preparation

Six borate glass samples were prepared using the melt quenching technique by mixing a suitable amount of raw materials for the chemical formula: xPbO, (80-x) $B_2O_3$, 20$Na_2O$ (where x=0, 10, 20, 30, 40, and 50). Samples composition with their labels is given in Table (1). The chemicals were thoroughly mixed, then the powder was transferred into a clean and dry porcelain crucible, then it was placed in an electrical furnace and the mixture was preheated at 250$^o$C for one hour in a box electric furnace, then the electric furnace was set up to increase the temperature up to (450$^o$C-490$^o$C) for 1/2 hour and again held at 1000$^o$C for 1/2 hour. The density of the investigated samples was obtained using Archimedes' rule [22], where the Benzene was used as the immersion liquid at room temperature.

**Table (1): Chemical compositions of the prepared samples**

| Sample | Composition | Density(g $cm^{-3}$) |
|---|---|---|
| B1 | 80 B2O3+20 Na2O | 2.175 |
| B2 | $70B_2O_3$+10PbO+$20Na_2O$ | 2.870 |
| B3 | $60B_2O_3$+20PbO+$20Na_2O$ | 3.558 |
| B4 | $50B_2O_3$+30PbO+$20Na_2O$ | 4.112 |
| B5 | $40B_2O_3$+40PbO+$20Na_2O$ | 4.561 |
| B6 | $30B_2O_3$+50PbO+$20Na_2O$ | 5.213 |

### 3.2 Radiation Shielding Properties

The experimental mass attenuation coefficients are obtained by using a shielded NaI(Tl) detector at photon energies 511, 662, and 1173 keV of the radioactive sources $^{22}$Na, $^{137}$Cs, and $^{60}$Co respectively, where collimators of an aperture diameter 3 mm are used to ensure that the detector absorbs a narrow beam of gamma rays. The experimental arrangement is shown in Fig. (1). To reduce the background radiation, the whole system was shielded with 5 cm lead, 0.5 cm copper, and 0.5 cm steel walls. The background of the system is taken for 900s, the number of counts $I_o$ of gamma particles was measured for each path length, and then by inserting the glass sample the number of gamma counts I was recorded.

The calculated mass attenuation coefficients ($\mu_m$), half-value layer (HVL), mean free path (MFP), effective atomic number ($Z_{eff}$), effective electron density ($N_{eff}$), atomic cross-section ($\sigma_a$), electron cross-section ($\sigma_e$) and radiation protection efficiency (RPE) are performed theoretically by using WinXCom and Phy-X/PSD computer programs in the energy range from 1 keV to 1 GeV.

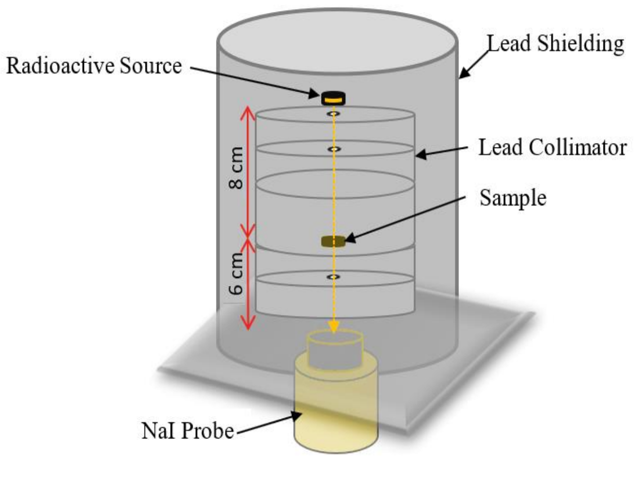


**Fig. (1): Experimental arrangement to obtain the gamma attenuation coefficients**

### 4. RESULTS AND DISCUSSION

The mass attenuation coefficient ($\mu_m$) measures the number of photons that interact with the interacting material. The $\mu_m$ values have been measured and calculated for all the prepared glass samples. The experimentally measured $\mu_m$ of the prepared glass samples values are decreasing with increases in gamma-ray energy from 551 keV to1173 keV. This is because of the dominance of the photoelectric effect at lower energy as compared to the Compton effect which is dominant at higher energies [23].

The $\mu_m$ values of WinXCom, Phy-X/PSD, and experiment for the prepared glass samples at 511, 662, and 1173 photon energies are illustrated in Table 1, while Figs.( 2 and 3) present the theoretical values of $\mu_m$ in the energy range 1 keV to 100 GeV in comparison with the measured values. The $\mu_m$ of the glass samples decreases with the increase in photon energies, this is due to the difference in the interaction of radiation with a matter with energy [24]. These variations can be explained by the dominancy of the photoelectric effect at low energy, the Compton scattering at intermediates energy, and pair production at high energy.

It has been found that the $\mu_m$ values are in the order of $10^3$ at 1 keV, then they dropped quickly at a low energy range 0.001 MeV < E < 0.1 MeV, where the maximum value is found. Above 100 keV, the value of $\mu_m$ of all glass samples becomes in the range (1 – 0.05) $cm^2/g$, hence the $\mu_m$ value decreases rapidly in a low energy region, where Compton scattering dominates. More than 10 MeV, it was found that the $\mu_m$ values tend to increase and become constant around 500 MeV.

Many peaks are observed in the low photon energy region (< 100 keV) due to the *K*- edge absorption of Na and Pb at 1.07 and 88 keV, respectively, *L*- edge absorption of Pb at 15.86, 15.20, and 13.04 keV, and *M*-edge absorption of Pb at 3.85, 3.70, 3.55, 2.59 and 2.484 keV. The borate glass sample containing maximum PbO composition B6 shows multiple peaks to *K*, *L*, and *M* absorption edges.

In this study, the effect of PbO concentration on the shielding properties of the $B_2O_3$-PbO-$Na_2O$ glass system has been investigated. The measured and calculated $\mu_m$ value as a function of PbO% concentration is shown in Figs. (3 and 4). It has been found that the mass attenuation coefficient is increased by increasing of PbO concentration and it should be noted that $\mu_m$ of $B_2O_3$-PbO-$Na_2O$ glass system increases from 0.074 $cm^2/g$ to 0.121 $cm^2/g$ at 511 keV, and 0.073 $cm^2/g$ to 0.107 $cm^2/g$ at 662 keV, and 0.057 $cm^2/g$ to 0.060 $cm^2/g$ at 1173 keV. Good agreements between the calculated and measured values are obtained.

**Table (2): $\mu_m$ values of WinXCom, Phy-X/PSD and experiment of the prepared glass samples at 511, 662 and 1173 photon energies**

| Energy | 511 MeV | | | 662 MeV | | | 1173 MeV | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample | Exp. | XCOM | Phy-x | Exp. | XCOM | Phy-x | Exp. | XCOM | Phy-x |
| B1 | 0.074 | 0.084 | 0.084 | 0.073 | 0.075 | 0.075 | 0.057 | 0.057 | 0.057 |
| B2 | 0.089 | 0.091 | 0.102 | 0.077 | 0.078 | 0.084 | 0.056 | 0.057 | 0.058 |
| B3 | 0.092 | 0.097 | 0.115 | 0.083 | 0.081 | 0.090 | 0.058 | 0.058 | 0.059 |
| B4 | 0.102 | 0.101 | 0.124 | 0.093 | 0.085 | 0.094 | 0.059 | 0.058 | 0.060 |
| B5 | 0.119 | 0.111 | 0.130 | 0.094 | 0.088 | 0.098 | 0.057 | 0.059 | 0.060 |
| B6 | 0.121 | 0.117 | 0.136 | 0.107 | 0.091 | 0.100 | 0.060 | 0.059 | 0.061 |

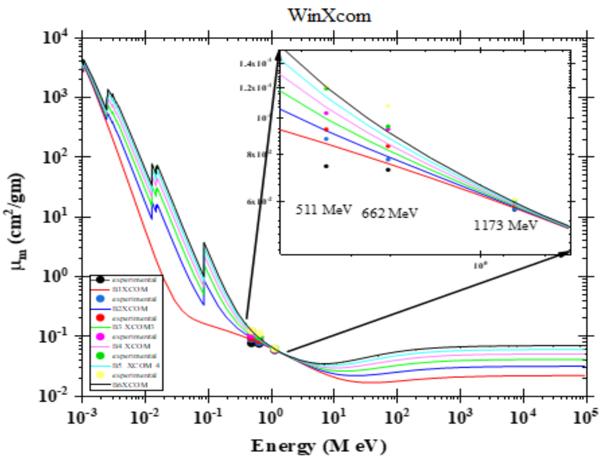


**Fig. (2): WinXCOM values of the total $\mu_m$ for the prepared glass sample in comparison with the measured experimental values.**

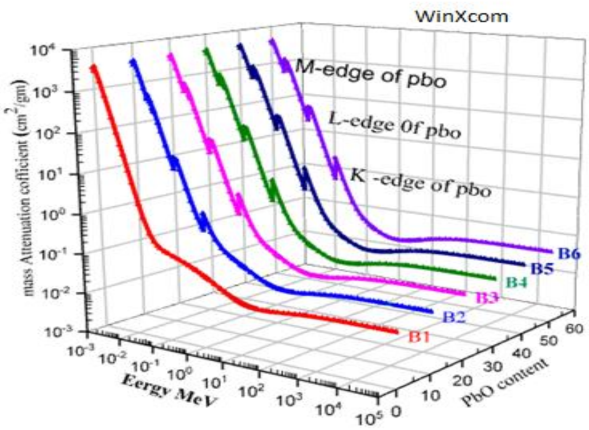


**Fig. (4): The calculated mass attenuation coefficients by WinXCom mass attenuation coefficients values as a function of energy (1 keV to 100 GeV) and PbO concentration (0 to 50%) of the prepared glass samples**

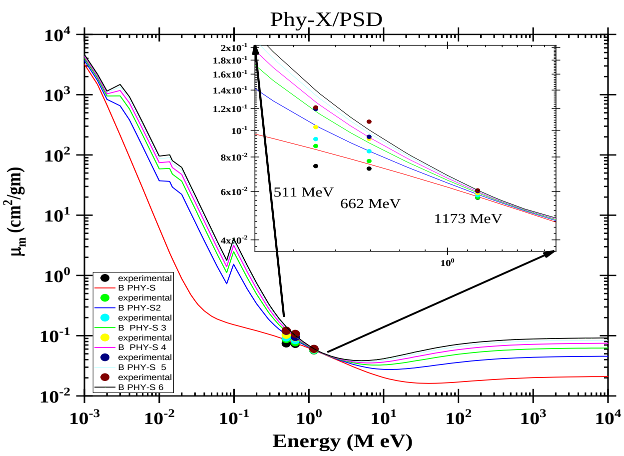


**Fig. (3): Phy-X/PSD values of the total μm for the prepared glass sample in comparison with the measured experimental values**

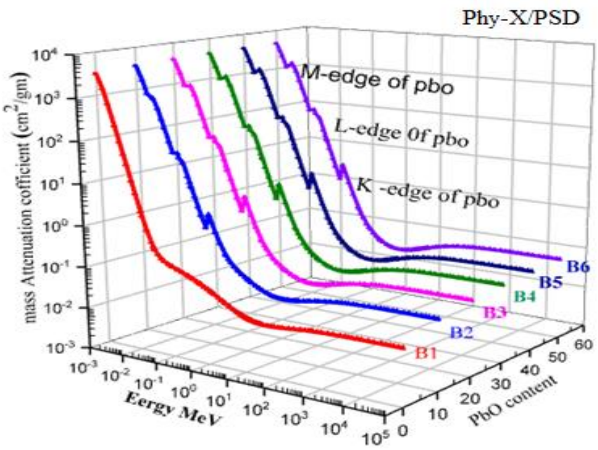


**Fig. (5): The calculated mass attenuation coefficients by Phy-X/PSD as a function of energy (1 keV to 100 GeV) and PbO concentration (0 to 50%) of the prepared glass samples**

**Table (3): Half value layer for different concentrations of all studies borate and silicate glass samples at energies 511, 662, and 1173 keV**

| Energy | 511 MeV | | | 662 MeV | | | 1173 MeV | | |
|---|---|---|---|---|---|---|---|---|---|
| samples | Exp. | XCOM | Phy-x | Exp. | XCOM | Phy-x | Exp. | XCOM | Phy-x |
| B1 | 9.352 | 8.220 | 8.250 | 9.560 | 9.200 | 9.240 | 12.200 | 12.100 | 12.160 |
| B2 | 7.902 | 7.615 | 6.794 | 8.965 | 8.821 | 8.250 | 12.160 | 11.994 | 11.948 |
| B3 | 7.460 | 7.095 | 6.026 | 8.260 | 8.471 | 7.700 | 11.928 | 11.911 | 11.746 |
| B4 | 6.748 | 6.855 | 5.589 | 7.444 | 8.150 | 7.372 | 11.723 | 11.828 | 11.550 |
| B5 | 5.799 | 6.243 | 5.330 | 7.318 | 7.851 | 7.071 | 11.534 | 11.746 | 11.550 |
| B6 | 5.727 | 5.888 | 5.096 | 6.447 | 7.570 | 6.930 | 11.460 | 11.665 | 11.361 |

The Half Value Layer (HVL) of the investigated glass samples at energies 511, 662, and 1173 keV are presented in Table 3. The HVL values tend to decrease with an increase in the amount of PbO. In addition, HVL tends to decrease with the increase of the material density as also obtained in Ref. [25]

It should be noted that sample B6 indicates a more superior shielding capacity than the other samples due to the lower HVL values of 5.727 cm, 6.446 cm, and 11.46 cm at 511, 662, and 1173 keV, respectively which are consistent with the calculated values.

The calculated HVL and mean free path (MFP) values in the energy range from 1 keV to 100 GeV for the prepared borate glass samples are depicted in Figs. (5, 6, 7, and 8) respectively. It has been found that the HVL, and MFP values are initially low and increase gradually with an increase in an incident photon energy up to 5 MeV. Above 5 MeV, the rate of a decrease of HVL, and MFP is weak with the incident energies.

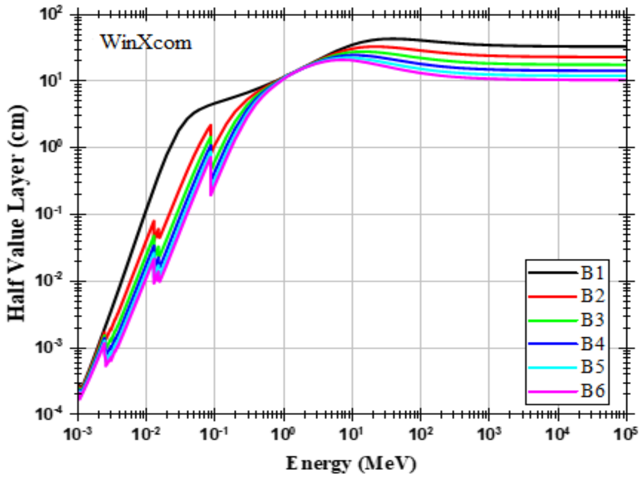


**Fig. (6): WinXCom values of the HVL as a function with photons energies (from 1 keV to 100 GeV) for the prepared glass samples**

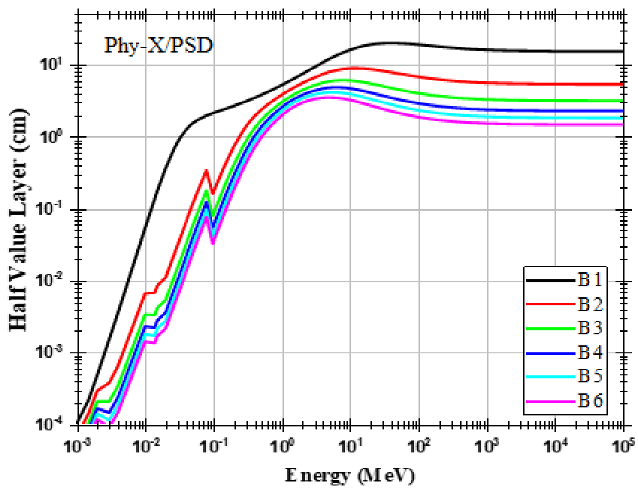


**Fig. (7): Phy-X/PSD values of the HVL as a function with photons energies (from 1 keV to 100 GeV) for the prepared glass samples**

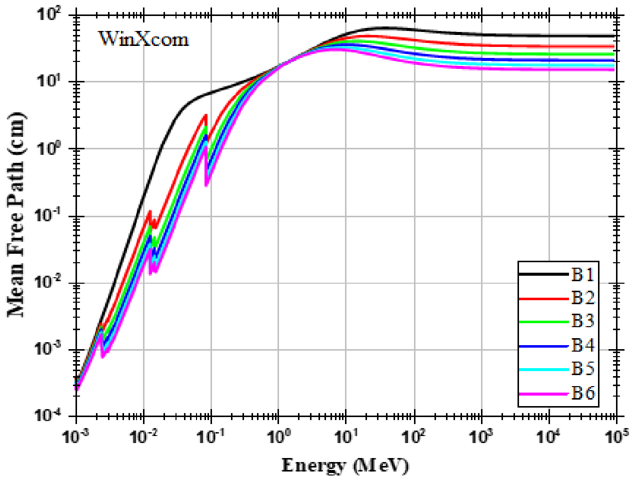


**Fig. (8): WinXCom of the MFP as a function with photons energies (from 1 keV to 100 GeV) for the prepared glass samples**

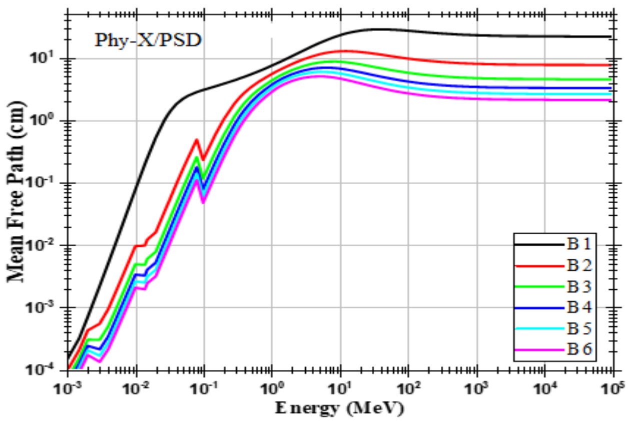


**Fig. (9): Phy-X/PSD values of the MFP as a function with photons energies (from 1 keV to 100 GeV) for the prepared glass samples**

The WinXCom and Phy-X/PSD calculations of the electronic and atomic cross-sections ($\sigma_e$ and $\sigma_a$) in the photon energy range (1 keV-100 GeV) are presented in Figs. (10, 11, 12, and 13) respectively. The results show that the cross-sections decrease with the energy of the incident photon for all the investigated samples, and the cross-sections improved by increasing the PbO concentration over the energy range, due to high *A*. The photoelectric and pair production effect are dominant by high *A* of samples at low and high energy regions. The Compton Effect predominates gradually and almost independent of the *A* of the constituent elements at the intermediate energy region.

The calculated effective atomic numbers ($Z_{eff}$) and effective electron number ($N_{eff}$) by using WinXCom an) d Phy-X/PSD in the photon energy range (1 keV-100 GeV) are depicted in Figs. (14, 15, 16, and 17) respectively. The higher $Z_{eff}$ and $N_{eff}$ for any absorbing material means that an increased amount of energy photon is absorbed by the material. The $Z_{eff}$ and $N_{eff}$ values for all the investigated samples appear with a wide peak and a maximum value of 0.05 MeV, and sudden jumps occur at 0.075MeV. A minimum value of $Z_{eff}$ and $N_{eff}$ occurs at 1 MeV, and above that, the values tend to be increased slowly and end to be constant beyond 3 MeV. However, the addition of PbO leads to an increase in the $Z_{eff}$ value and we can see that the samples B1 and B6 have the lowest and highest $Z_{eff}$, respectively.

## 5. CONCLUSIONS

The shielding properties of prepared $B_2O_3$-PbO-$Na_2O$ glasses were studied at 1 keV-100 GeV photon energies using XCOM and Phy-X/PSD. The calculated results are compared with the experimental data at 511, 662, and 1173 keV using the Na (Tl) detector. The $\mu_m$ values decreased with the increase in photon energies, and it is increased with the increase in the PbO concentration. The HVL values tend to decrease with an increase in the density and the amount of PbO. Electronic and atomic cross-sections ($\sigma_e$ and $\sigma_a$) values decreased as the energy of the incident photon increased, while they increased when the PbO concentration increased. The addition of PbO leads to an increase in the $Z_{eff}$ value and we can see that B1 and B6 have the lowest and highest $Z_{eff}$.

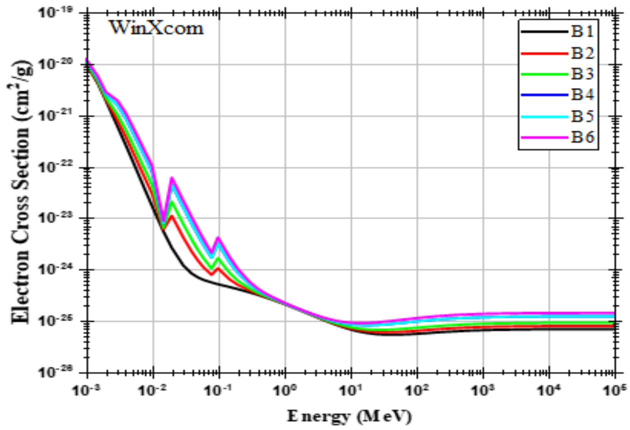


**Fig. (10): WinXCom values of the electron cross-section as a function with photons energies for the prepared glass samples**

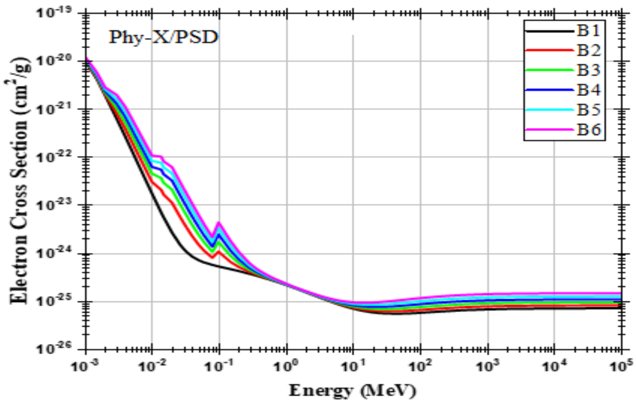


**Fig. (11): Phy-X/PSD values of the electronic cross-section as a function with photons energies for the prepared glass samples**

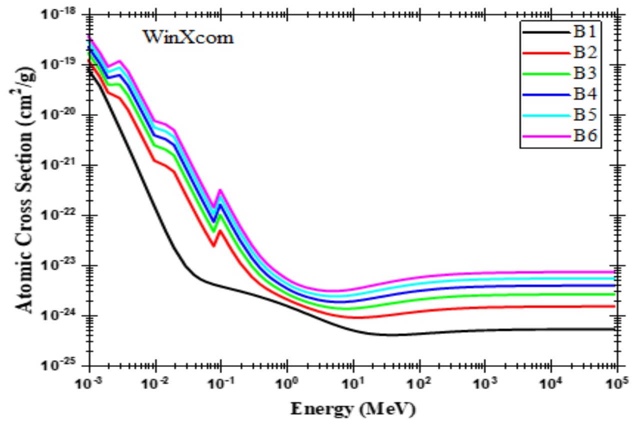


**Fig. (12): WinXCom values of the atomic cross-section as a function with photons energies for the prepared glass samples**

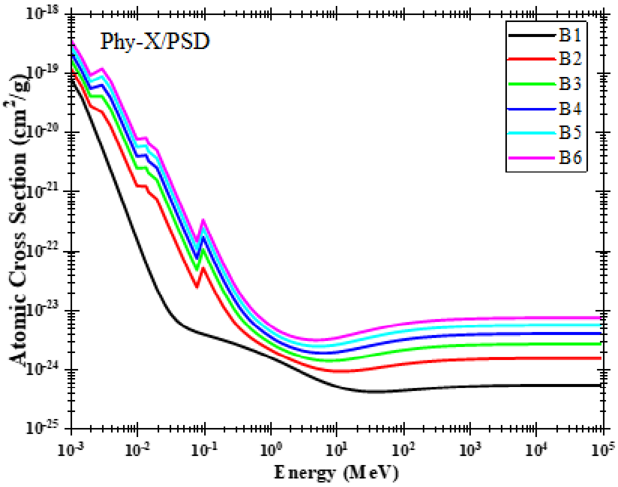


**Fig. (13): Phy-X/PSD of the atomic cross-section as a function with photons energies for the prepared glass samples**

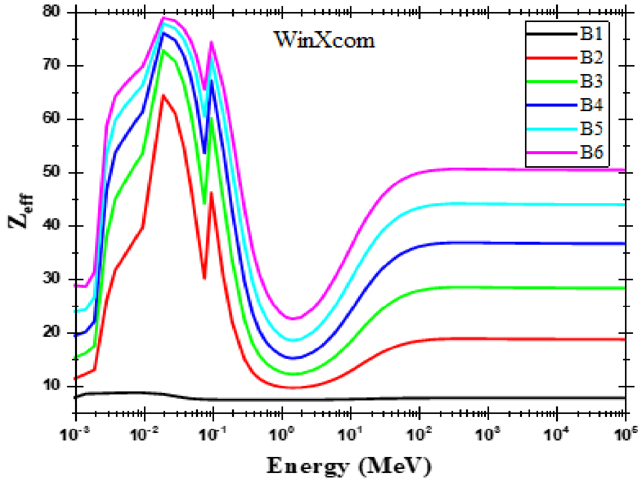


**Fig. (14): the calculated $Z_{eff}$ by WinXCom as a function with photons energies for the prepared glass samples**

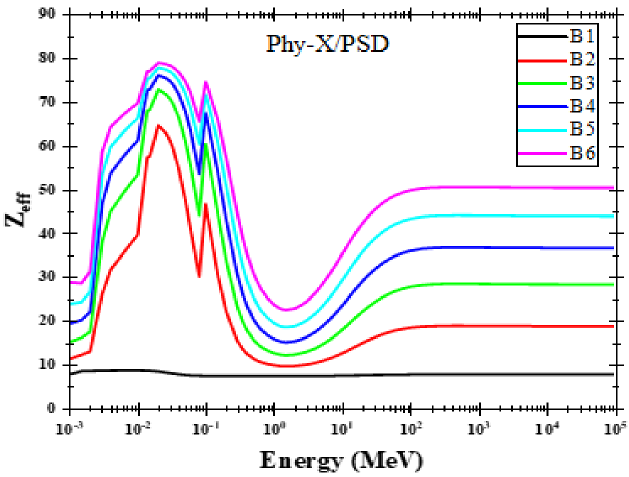


**Fig. (15): the calculated $Z_{eff}$ by Phy-X/PSD as a function with photons energies for the prepared glass samples**

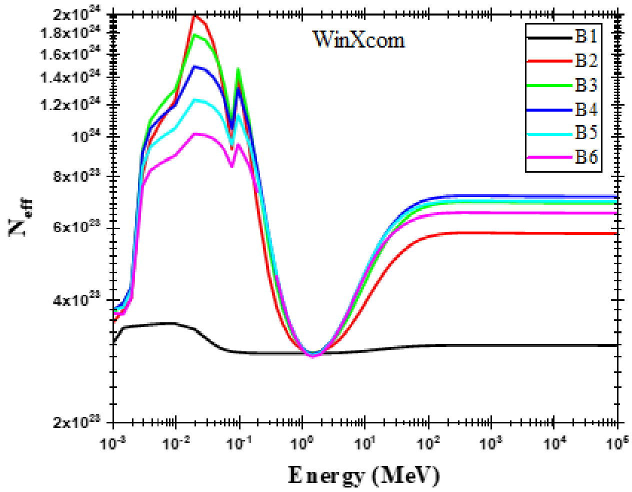


**Fig. (16): the calculated $N_{eff}$ by WinXCom as a function with photons energies for the prepared glass samples**

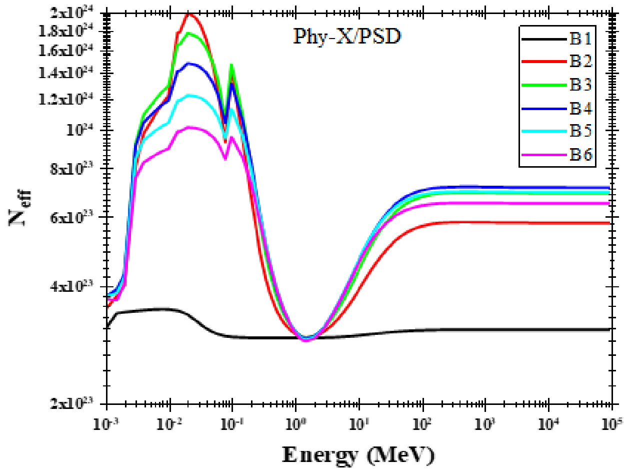


**Fig. (17): the calculated $N_{eff}$ by Phy-X/PSD as a function with photons energies for the prepared glass samples**

## REFERENCES

[1] R. F. F. Meza "Attenuation Properties of Cement Composites: Experimental Measurement Measurements and Monte Carlo Calculations" MSc. Thesis, Missouri University of Science and Technology (2016).

[2] E. Al Sarray "Investigation of Radiation Shielding Properties of Some Composition Materials" MSc. Thesis, Suleyman Demirel Unviersity (2016).

[3] K. Siengsano, W. Hongtong, W. Chaiphaksa, P. Limkitjaroeporn, and J. Kaewkhao "Physical, optical and gamma-ray shielding properties of $BaO$-$La_2O_3$-$B_2O_3$ and $BaO$-$Na_2O$-$B_2O_3$ glass system at 662 keV" Journal of Physics: Conference Series 1250, 1-9, (2019).

[4] J. Kaewkhao, "Interaction of 662keV Gamma-rays with Bismuth-based glass matrices" Journal of the Korean Physical Society, 59(2), 661-665, (2011).

[5] K. J. Singh, N. Singh, R.S. Kaundal and K. Singh, "Gamma-ray shielding and structural properties of $PbO–SiO_2$ glasses", Nuclear Instruments and Methods in Physics Research B, 266: 944–948, (2008).

[6] K. Kirdsiri, J. Kaewkhao, A. Pokaipisit, W. Chewpraditkul and P. Limsuwan, "Gamma-rays shielding properties of $xPbO:(100 - x)B_2O_3$ glasses system at 662 keV", Annals of Nuclear Energy, 36: 1360–1365, (2009).

[7] J. Kaewkhao, P. Limsuwan, "Mass attenuation coefficients and effective atomic numbers in phosphate glass containing $Bi_2O_3$, PbO and BaO at 662 keV", Nuclear Instruments and Methods in Physics Research A, 619:295–297, (2010).

[8] N. Chanthima, J. Kaewkhao and P. Limsuwan, "Study of photon interactions and shielding properties of silicate glasses containing $Bi_2O_3$, BaO and PbO in the energy region of 1 keV to 100 GeV", Annals of Nuclear Energy, 41:119–124, (2012).

[9] Samir Yousha El-Kameesy, Sahar Abd El-Ghany, Moenis Abd El-Hakam Azooz and Yaser Abd Allah El-Gammam, " Shielding Properties of Lead Zinc Borate Glasses", World Journal of Condensed Matter Physics, 3:198-202, (2013).

[10] R. S. Kaundal, "Comparative study of radiation shielding parameters of Bismuth Borate glasses" Materials Research, 19(4), 776-780, (2016).

[11] Ashok Kumar, "Gamma ray shielding properties of $PbO-Li_2O-B_2O_3$ glasses", Radiation Physics and chemistry, 136:50–53, (2017).

[12] R. El-Mallawany, M. I. Sayyed, M. G. Dong, Y. S. Rammah, "Simulation of Radiation Shielding Properties of Glasses Contain PbO", Radiation Physics and chemistry, 151, 239-252 (2018).

[13] A. M. Issa Shams, H. O. Tekin, T. T. Erguzel, G. Susoy, " The effective contribution of PbO on nuclear shielding properties of $xPbO-(100 - x)P_2O_5$ glass system: a broad range investigation", Applied Physics A Materials Science and Processing, 125:640, (2019).

[14] Shams A.M. Issaa, Yasser B. Saddeek, M.I. Sayyed, H.O. Tekin and Ozge Kilicoglu, "Radiation shielding features using MCNPX code and mechanical properties of the $PbO-Na_2O-B_2O_3-CaO-Al_2O_3-SiO_2$ glass systems", Composites Part B, 167:231-240, (2019).

[15] P. Kaur, D. Singh and T. Singh," Heavy metal oxide glasses as gamma rays shielding material", Nuclear Engineering and Design, 307: 364–376, (2016).

[16] E. Sakar, O. F. Ozpolat, 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" Radiation Physics and Chemistry, 166, 108496, (2020).

[17] Ali H. Taqi, Qahtan A. M. Al Nuaimy, Gulalla, A. Karem, “Study of the properties of soil in Kirkuk, Iraq”. Journal of Radiation Research and Applied Sciences, 9, 256-265 (2016).

[18] Ali H. Taqi and Hero J. Khalil, "An investigation on gamma attenuation of soil and oil – soil samples", Journal of Radiation Research and Applied Sciences, 252- 261, 10, (2017).

[19] Ali H. Taqi, Abdulahdi M. Ghalib, Hilala N. Mohammed, “Shielding properties of Cu-Sn-Pb alloy by Geant4, XCOM and experimental data”. Materials Today Communications 26, 101996 (2021).

[20] S. R. Manohara, S. M. Hanagodimath, K. S Thind, L. Gerward,”On the effective atomic number and electron density: a comprehensive set of formulas for all types of materials and energies above 1 keV”. Nucl. Instrum. Methods Phys. Res. B 266,388–402 (2008).

[21] S. R. Manohara, S. M. Hanagodimath, “Studies on effective atomic numbers and electron densities of essential amino acids in the energy range 1 keV – 100 GeV”. Nucl. Instrum. Methods Phys. Res. B 258, 321–328 (2007).

[22] Marián Kireš,”Archimedes' principle in action”. Physics education 42(5), 484–4487 (2007).

[23] M. Dogra, K. J. Singh, k. Kaur, V. Anand, and P. Kaur, "Gamma Ray Shielding and Structural Properties of $Bi_2O_3-B_2O_3-Na_2WO_4$ Glass System ",Universal Journal of Physics and Application 11(5), 190-195, (2017).

[24] Amal. A. EL-Sawy, A. M. Madbouly, "Comparative Study of Gamma Radiation Shielding Parameters for Different Oxide Glasses", European Academic Research, Vol. VI (2), 824 (2018).

[25] Y. Al-Hadethi, M. I. Sayyed, S. A. Tijani "Gamma Radiation Attenuation Properties of Tellurite Glass : A comparative study" Nuclear Engineering and Technology, 51(8), 2005 (2019).