PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 27 (5) 985-988 May 2023

Accuracy of Phy-X/PSD Software Compared to XCOM in the Determination of Mass Attenuation Coefficient of Glass Systems

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ABSTRACT: Phy-X/PSD and XCOM are two software programs used for computations in radiation shielding and nuclear energy research. This study aims to compare the accuracy of Phy-X/PSD with that of XCOM in the determination of mass attenuation coefficient (MAC) of glass systems. The MAC values of $60B_2O_3$-(40-x)BaO-xBi_2O_3, 50BaO-xBi_2O_3-(50-x)borosilicate glasses, and $xTeO_2$-(70-x)ZnF_2-25AsO_3-5Sm_2O_3 glass systems at 0.662 MeV, 1.172 MeV and 1.332 MeV were determined using Phy-X/PSD. The mean absolute error (MAE) was determined and compared with MAE from experimental data and from XCOM. The results showed no significant difference between the MAC means obtained from the three data sets. However, single factor ANOVA test shows that the p-values for the MAC means are 0.344, 0.918 and 0.239 approximated to 3 d.p at 0.662 MeV, 1.172 MeV, and 1.332 MeV respectively and the variance was highest in the experimental result, followed by Phy-X/PSD, and least in the XCOM results. It could be concluded that both software programs can be used for radiation shielding computations, although result from Phy-X/PSD may have relatively more outliers compared to XCOM.

DOI: **https://dx.doi.org/10.4314/jasem.v27i5.15**

Cite this paper as: ALHASSAN, M; BARAYA, J. T; GARBA, A. S. (2023). Accuracy of Phy-X/PSD Software Compared to XCOM in the Determination of Mass Attenuation Coefficient of Glass Systems. *J. Appl. Sci. Environ. Manage.* 27 (5) 985-988

Dates: Received: 17 February 2023; Revised: 08 April 2023; Accepted: 16 April 2023
Published: 31 May 2023

Keywords: attenuation coefficient; radiation shielding; radiation protection; glass system

Experimental research involving high-energy gamma rays and other forms of radiation is challenging, expensive, and carries health hazards. To overcome these limitations, alternative models such as simulation and computation are developed to mimic experimental procedures and accurately predict results (Alhassan *et al*., 2023a; Rammah *et al*., 2020; Sayyed *et al*., 2018). The recently developed Phy-X/PSD software by (Şakar et al., 2020) had been used by several authors for this purpose (Alkallas et al., 2022; Lacomme et al., 2021). Furthermore, the software had been used for other purposes, such as conversion of weight percentages (wt%) of the glass compositions into molarity percentages (mol%) and vice versa for easier computations (Alhassan et al., 2023b). Similarly, XCOM and its window version (WinXCOM) had been used by several researchers (Akyildirim et al., 2020; Mahmoud and Rammah, 2020; Sayyed et al., 2018) to find accurate results. Other models that serve the same purpose are the prominent Monte Carlo N-Particle Transport Code (MCNP) with its different versions such as MCNP4, MCNP5, MCNP6, MCNPX, DOSXYZnrc, Geant4, FLUKA, SRIM codes (Ashfaq *et al*., 2020; Kaur *et al*., 2019; Sayyed *et al*., 2020) and MicroShield code (Zaid *et a*l., 2021).

Hence, the objective of this work is to evaluate the accuracy of Phy-X/PSD compared to XCOM in the

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determination of Mass Attenuation Coefficient (MAC) of glass systems.

MATERIALS AND METHODS

Mass Attenuation Coefficient (MAC) is a feature of materials which indicates the probability of radiation interacting with their mass per unit area. Higher MAC of a material at a particular radiation energy indicates its higher protection ability (Isa et al., 2023). MAC can be computed using (Equation 1).

$$\mu_m = \frac{\mu_L}{\rho} \ldots\ldots\ldots\ldots (1)$$

Where ρ is the density and μ_L is the linear attenuation coefficient (LAC) of the material.

Three glass systems were selected for this study: $60B_2O_3$-(40-x)BaO-xBi_2O_3, (where; x = 0, 2.5 and 5 wt%), prepared by (Tashlykov et al., 2021), 50BaO-xBi_2O_3-(50-x)borosilicate glasses, (where ; x= 0, 5, and 10 mol%), prepared by (Bagheri et al., 2016) and xTeO_2-(70-x)ZnF_2-25AsO_3-5Sm_2O_3 (where; x = 35, 40, and 45 mol%), prepared by (Gaikwad et al., 2018). Simulation of the glasses' irradiation by Cobalt-60 at three energy levels (0.662 MeV, 1.173 MeV, and 1.332 MeV) was performed using Phy-X/PSD software. The MAC values for each sample were determined. An experimental and an XCOM MAC values were obtained from previous studies (Bagheri et al., 2016; Gaikwad et al., 2018; Tashlykov et al., 2021). The errors, absolute errors (AE), and mean absolute errors (MAE) of the MAC values were calculated for each case and a single factor analysis of variance (ANOVA) test was performed to study the differences in MAC means obtained from the three data sets.

It was earlier hypothesized for all the three energy levels with null hypotheses that there is no difference in the three MAC means and alternative hypotheses that there is a difference in the MAC means obtained from the experiment, from the Phy-X/PSD and from the XCOM software programs. The p-value for each case was chosen to be p = 0.05. The F (statistics) and the F (critical) were finally compared.

RESULTS AND DISCUSSION

The comparison between the MAE of the MAC values obtained from experiment, Phy-X/PSD and XCOM at 0.662, 1.173, and 1.332 MeV is shown in (Figure 1, 2, and 3) for $60B_2O_3$-(40-x)BaO-xBi_2O_3, 50BaO-xBi_2O_3-(50-x)borosilicate glasses, and xTeO_2-(70-x)ZnF_2-25AsO_3-5Sm_2O_3 glass systems respectively. The MAE for $60B_2O_3$-(40-x)BaO-xBi_2O_3 glass system at 0.662 MeV and 1.332 MeV are seen to be equal from (Figure 1).

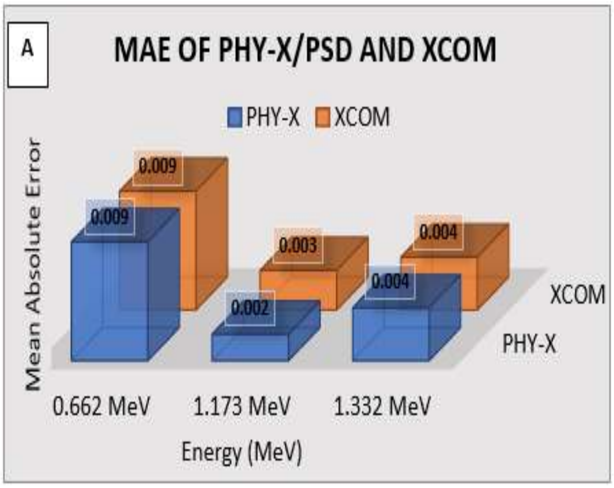

Fig 1: Comparison between MAE of Phy-X/PSD and that of XCOM for $60B_2O_3$-(40-x) BaO-xBi_2O_3 glass system.

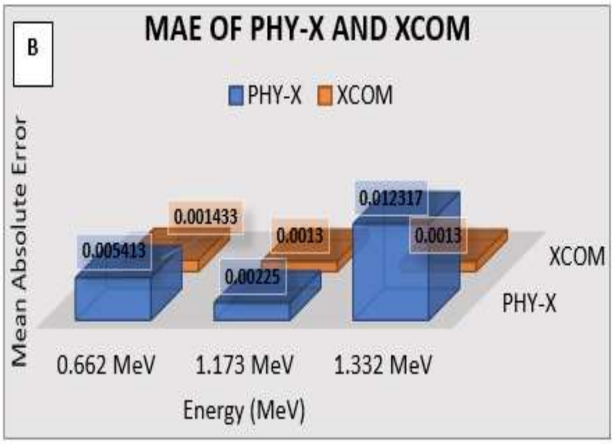

Fig 2: Comparison between MAE of Phy-X/PSD and that of XCOM for 50BaO-xBi_2O_3-(50-x) borosilicate glasses, glass system

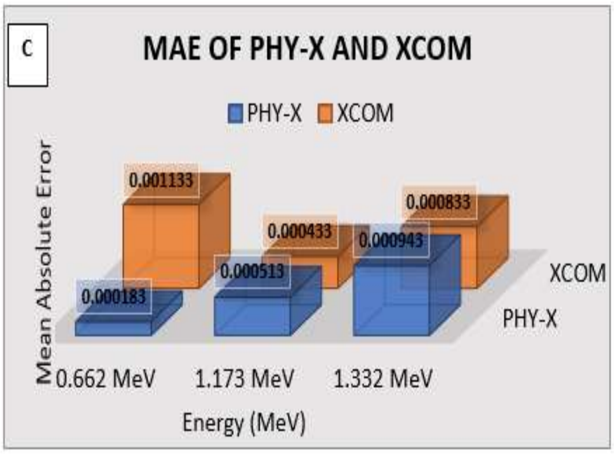

Fig 3: Comparison between MAE of Phy-X/PSD and that of XCOM for xTeO_2-(70-x) ZnF2-25AsO_3-5Sm_2O_3 glass system.

There is also a significant difference between the MAEs of Phy-X/PSD and that of XCOM at 1.332 MeV for 50BaO-xBi2O3-(50-x)borosilicate glasses, glass system as seen in (Figure 2), and at 0.662 MeV for $xTeO_2$-(70-x)ZnF_2-25AsO_3-5Sm_2O_3 glass system as seen in (Figure 3), and there is somehow insignificant differences at other energies in the three glass systems. However, statistical analysis using single factor ANOVA test, shown in (Table 1 - 3) shows that the p-values for the MAC means are 0.344, 0.918 and 0.239 approximated to 3 d.p, at 0.662, 1.173 and 1.332 MeV respectively. It can also be seen that all these p-values are greater than the presumed level of significance, which is p = 0.05 for all the three energy levels. This suggests the acceptance of the null hypotheses that there is no difference between the means of the three data sets; the experimental, the one from Phy-X/PSD and the other from XCOM, and also suggests the rejection of the alternative hypotheses.

Table 1: The ANOVA single factor test result for MAC at 0.662 MeV.

Source of Variation	SS	Df	MS	F	P-value	F(crit)
Between Groups	5.12×10^{-5}	2	2.56×10^{-5}	1.117205	0.343621	3.402826
Within Groups	5.5×10^{-4}	24	2.29×10^{-5}			
Total	6.01×10^{-4}	26				

Table 2: The ANOVA single factor test result for MAC at 1.173 MeV.

Source of Variation	SS	Df	MS	F	P-value	F(crit)
Between Groups	6.43×10^{-7}	2	3.21×10^{-7}	0.085509	0.918323	3.402826
Within Groups	9.02×10^{-5}	24	3.76×10^{-6}			
Total	9.08×10^{-5}	26				

Table 3: The ANOVA single factor test result for MAC at 1.332 MeV.

Source of Variation	SS	Df	MS	F	P-value	F(crit)
Between Groups	1.25×10^{-4}	2	6.24×10^{-5}	1.518712	0.239305	3.402826
Within Groups	9.86×10^{-4}	24	4.11×10^{-5}			
Total	1.11×10^{-3}	26				

The ANOVA test also reveals that the variance of Phy-X/PSD, that of XCOM and that from experimental data are 2.23×10^{-5}, 9.96×10^{-6}, and 3.64×10^{-5} respectively at 0.662 MeV. In a similar order, the variances are 1.19×10^{-6}, 8.51×10^{-7}, and 9.23×10^{-6} at 1.173 MeV and are 1.20×10^{-4}, 4.68×10^{-7}, and 2.31×10^{-6} at 1.332 MeV. This means the variance is highest within the experimental result, followed by Phy-X/PSD and is least in XCOM result at 0.662 MeV and 1.173 MeV. Whereas, at 1.332 MeV, the variance is highest in Phy-X/PSD result, followed by experimental result and then least in XCOM result. This suggests that outliers are expected to be highest in the experimental data and least in XCOM, while Phy-X/PSD lies in between them. Earlier before this work, Phy-X/PSD was used to validate results obtained from MCNP-5 (Abouhaswa et al., 2020; Kurtulus et al., 2021). Also the accuracy of XCOM compared to experimental result was confirmed by some authors (Gaikwad et al., 2018; Mostafa et al., 2017) and disagreement of less than 10% between XCOM and result from MCNP5 was reported by (Sayyed et al., 2020).

Conclusion: MAC values from three glass systems were determined at three energy levels 0.662 MeV, 1.173 MeV, and 1.33 Mev using Phy-X/PSD software. The MAEs of the MAC values were compared with that of XCOM software. There were no significant differences between the MAC means obtained from Phy-X/PSD, XCOM, and experimental data for the three glass systems. However, it is expected that there may be relatively more outliers in the experimental and Phy-X/PSD results than at XCOM result.

Acknowledgement: The Authors acknowledge the contribution of the first research groups who fabricated the glass systems used for this comparative study.

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