Calculation of Mass Attenuation Coefficients of Composite Tin Cans Using XCOM: A Computer Simulation Study

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Abstracts: Radiation shielding capability of a material depends on the parameters such as mean-free path (mfp), half value layer (HVL), and tenth value layer (TVL) which can be derived from the mass attenuation coefficients (μ_m) of the materials. Measurement of the mass attenuation coefficients (μ_m) of tin cans and tin can alloys is important for gamma-ray shielding. Steel can, Aluminum can and the alloy of the two at concentrations of 50%-50%, 67%-33%, 33%-67% were fabricated and their weight fractions were measured. The mass attenuation coefficients at an energy range of 1 keV-100 GeV for the prepared samples were evaluated. The mean-free path (mfp), half value layer (HVL), and tenth value layer (TVL) of the Tin can were evaluated using XCOM application at an energy of 1 MeV. Result indicates that lead and steel can have the lowest values of mfp, HVL, and TVL which implies that Steel can, like lead can be used as shielding for gamma rays. In addition, the trend of mass attenuation coefficients varies accordingly to the atomic numbers of elements with higher weight fraction in every sample. Further, Steel can which contains of mostly iron has the highest μ_m values compared to the Aluminum can. Finally, the results are compared to lead (Pb) which is a standard material for radiation shielding. This study shows promising result cost wise and in shielding capability.

Keywords: Computer simulation, XCOM, Mass attenuation coefficients, Tin can alloy, Weight fractions, Radiation shielding, Half value layer, Mean free path, Tenth value layer.

1. INTRODUCTION

Ionizing radiations such as gamma rays are widely used in sterilizing medical equipment, food processing, medical diagnostics, and clinical therapy. However, spontaneous exposure to these radiations may cause several health risks, e.g., tissue damage that leads to mutation, cancer, and other related health effects. Radiation shielding materials varies, from metals to concretes and as such, lead is considered as a standard material for radiation shielding.

One of the basic parameters in determining the penetration of x-ray and gamma rays in matter is the mass attenuation coefficient (μ_m) [1]. This measures how strongly a substance absorbs or scatters light at a given wavelength per unit mass [2]. The mass attenuation coefficient of a material depends on the attenuation coefficient of different photon processes such as: photoelectric absorption, coherent scattering, and pair production at different energy. The precision cross-section data is openly published as tabulated list by the National Institute of Standards and Technology (NIST) for all naturally occurring periodic table elements to an atomic number of 92 (Uranium) [3].

Using the XCOM application, we can calculate the mean free path, half-value layer and tenth-value layer which are factors of mass attenuation coefficients [1], [2]. The aim of this study is to calculate the mean free paths, half-value and tenth-value layers of composite tin cans and lead at an energy range of 1 keV – 100 GeV evaluated at 1 MeV energy using the mass attenuation coefficient.

2. METHODOLOGY

The XCOM software was utilized to evaluate the mass attenuation coefficients of composite tin cans. There are five samples considered in this study which include Steel can, Aluminum can, and three alloy compositions derived from various combinations of the two cans at different concentrations.

The elemental compositions of the cans used are the average compositions typically found in can manufacturing. These compositions typically include elements such as iron, aluminum, and other trace elements. Using ratio and proportion, the weight fractions of the elements present in the can were calculated. These calculations will help determine the relative proportion of each element within the composite Tin cans. The information on the elemental compositions and corresponding weight fractions were used to calculate the mass attenuation coefficients for various energies using XCOM. Based on the input data, the XCOM software is used to perform Monte Carlo simulations.

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The mean free paths (mfp), half-value layers (HVL) and tenth-value layers (TVL) are calculated using the following expressions $mfp = \frac{1}{\rho \mu_m}$, $HVL = \frac{0.693}{\rho \mu_m}$ and $TVL = \frac{2.303}{\rho \mu_m}$. The results are illustrated using a line graph whereas the mass attenuation coefficients (μ_m) of the constituent elements are determined using the XCOM software as shown in Table 1.

Table 1. Weight Fractions of Composite Tin Cans at Different Compositions.

Alloy Compositions	Steel Can	Aluminum Can	Alloy 1	Alloy 2	Alloy 3
Iron	0.996	0.0114	0.738	0.847	0.588
Carbon	$4.35x10^{-3}$	-	$3.21x10^{-3}$	$3.70x10^{-3}$	$2.54x1^{-3}$
Aluminum	-	0.949	0.249	0.143	0.394
Magnesium	-	$6.28x10^{-3}$	$1.65x10^{-3}$	$9.47x1^{-4}$	$2.61x10^{-3}$
Manganese	-	0.0270	$7.076x10^{-3}$	$4.0715x10^{-3}$	0.0112
Silicon	-	$1.68x10^{-3}$	$4.41x10^{-4}$	$2.540x10^{-4}$	$6.99x10^{-4}$
Copper	-	$4.86x10^{-3}$	$1.27x10^{-3}$	$7.33x10^{-4}$	$2.017X10^{-3}$

3. RESULTS AND DISCUSSIONS

Figure 1 provides a graphical representation of mass attenuation coefficient values at an energy range of 1 keV - 100 GeV. There is an abrupt decrease in μ_m values at below 1 MeV before it tends to saturate. Also in this energy range, certain peaks were observed, especially in the lower energy regions.

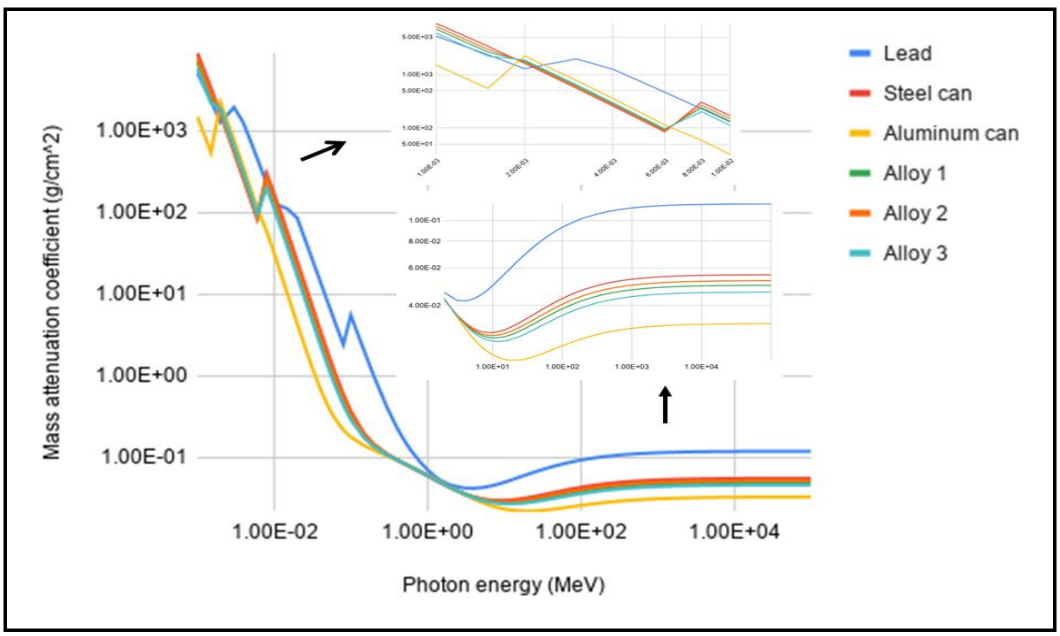

Figure 1. Mass attenuation coefficient at energy range of 1keV-100GeV.

These graphical variations of peaks can be attributed to the cross-sectional dependence of the photon interaction processes at different energy regions to the photon energy, where the total cross-section and the mass attenuation coefficient are directly proportional [4].

At lower energies below 1 MeV the dominant photon interaction is the photoelectric absorption. In this process its cross-section is inversely proportional to the cube of its energy [4], [5]. This explains the abrupt decrease of μ_m values in this energy region.

Photoelectric absorption occurs when the incident photon energy is enough to eject the atoms bound electron usually in the K or L shell. These free electrons (photoelectrons) recombine with free ions and radiate with a characteristic spectra of the material's constituent atoms (recombinational spectral lines). This radiation is emitted in all directions in the form of an X-Ray fluorescence (whose energy increases with atomic number). If the inbound radiation energy is below shell's binding energy, photoelectrons are not formed from that shell and an abrupt decrease in the material's attenuation coefficient is noted [3].

The ejected electron is then replaced by its nearby outer electron, which creates another vacancy, and the process continues [20]. Aside from the radiation that is created by the ejected electron (which may counter the incident photon beams), the outer electrons which fills the vacancies also emits radiation since it decreases its energy level. By this manner, there is a significant difference if the photon's energy is less than the electrons bound energy so this can explain the peaks seen in Figure 1.

In the intermediate energy regions, roughly in the range of 1 MeV - 5 MeV, the Compton scattering dominates, where its cross-section varies linearly with the energy. At high energy regions (above 5 MeV - 100 GeV) the pair-production process now dominates where its energy varies to the log of the photon energy [4], [5].

The difference in mass attenuation coefficients in all the samples is due to the atomic number (Z) dependence of the elements. High Z elements attenuate more radiation than the lower ones [4]. When it comes to mixtures, it turns out that in this study, samples with higher weight fractions of elements with higher atomic number (Z) also possess higher μ_m values especially at high energies.

4. CONCLUSION

Samples with higher atomic number and μ_m values have better absorption property. Steel can, which contains a higher proportion of Iron (atomic number of 26) demonstrated the highest μ_m values (excluding lead), in contrast to the Aluminum can. It follows that the order of highest μ_m values coincides with the samples that contains a higher concentration of Iron. It can be observed that the other component elements with atomic numbers higher than that of Iron do not appear to have significant effect, given their relatively small weight fractions.

Consequently, it is concluded that in an alloy or mixture, samples that contain a higher proportion of elements with higher atomic numbers exhibit higher mass attenuation coefficients, indicating better attenuating ability.

REFERENCES

1. J. Kaewkhao, J. Laipaiboon, W. Chewpradiltkul, "Determination of effective atomic numbers and effective electron densities for Cu/Zn alloy," Journal of Quantitative Spectroscopy & Radiative Transfer, vol. 12, p. 1260–1265, October 6, 2007.
2. Mohammed J.R. Aldhuhaibat, Maitham S. Amana, Najwa J. Jubier, A.A. Salim, Improved gamma radiation shielding traits of epoxy composites: Evaluation of mass attenuation coefficient, effective atomic and electron number, Radiation Physics and Chemistry, Volume 179, 2021, 109183, ISSN 0969-806X, https://doi.org/10.1016/j.radphyschem.2020.109183
3. M. E. Zifp, Radiation Transmission-based Thickness Measurement Systems - Theory and Applications to Flat Rolled Strip Products, University Campus SteP Ri SlavkaKrautzeka 83/A 51000 Rijeka, Croatia: In Tech Europe, April 1, 2010.
4. H. Hirayama, "Lecture Note on Photon Interactions and Cross Sections," in International Conference on the Monte Carlo 2000, Lisbon Portugal, November 2000.
5. Taranjot Kaur, Jeewan Sharma and Tejbir Singh, "Gamma Rays Shielding Parameters for White Metal Alloys," in AIP Conference Proceedings, May 2018.

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