Determination of Mass Attenuation Coefficients for Some Building Materials

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Abstract

The mass attenuation coefficients for some building materials such as cement, lime, marble, PVC, Plaster of Paris (POP) have been measured at 22.16 and 24.94 keV (Ag X-rays) using Si-PIN semi-conductor detector. The mass attenuation coefficient values for the same materials were also computed in the wide energy range of 1 keV - 100 GeV using WinXCom database, so as to compare the experimental values with the theoretical ones. It has been observed that among the selected building materials, POP offers better gamma ray shielding in the low energy range.

1. Introduction

When X-ray photons interact with matter, the intensity of photons is reduced from original photon beam. Attenuation is the result of interaction between photons and matter that includes absorption & scattering. Mass attenuation coefficient is a measurement of how strongly a substance absorbs and/or scatters photons at a particular energy. Lambert Beer law can be mathematically written as:

$$I_x = I_o e^{-\mu x} \qquad \dots (1)$$

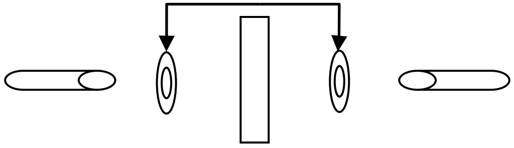
Where x is the thickness-density (cm^2/g) of interacting matter, I_0 is the intensity of un-attenuated photon beam (without matter) and μ is mass attenuation coefficient (g/cm^2) of the interacting matter. Attenuation coefficients are used to quantify different media according to how strongly the transmitted amplitude decreases as a function of photon energy. The values of mass attenuation coefficient depends upon various absorption & scattering processes such as Rayleigh scattering, Compton scattering, photoelectric effect and pair production.

The attenuation of X-rays & gamma rays depends on atomic number and density of material. The material with higher atomic number and higher density provides better attenuation of X-ray photons. In the design of a shielding system, one of the key factors is preventing the penetration of the rays. The increasing use of gamma active isotopes in various fields such as non-destructive testing, agriculture, space technology as well as medical fields draw the attention of nuclear engineers, radiologists & radiation physicists to focus on radiation interaction with different typed of materials for different purpose.

The present work has been carried out in order to visualize the shielding effectiveness of the building materials. In case of nuclear accident (as recently happened in Japan), the results of present work will be very useful for estimating the effective dose. Although, the selected materials were not having high atomic number or density, but these materials were readily available, hence cheaper than lead, mercury, steel or concrete (commonly used shielding materials). The present work is carried out with the consideration that the thick slabs of these building materials will definitely provide shielding from highly penetrating photons [1].

2. Experimental Details

The experimental setup used in the present measurements has been shown in Fig. 1. It consists of Mini-X (X-ray tube with Ag target), a Si-PIN (5 mm^2 × 500 μm) semi-conductor detector, collimators (2 mm diameter × 1 cm thickness) and different samples of building materials. Mini-X was procured from Amptek Inc. (USA), which generates x-ray photons of 22.16 keV and 24.94 keV (K_α and K_β of Ag respectively). It is self contained compact X-Ray tube system which includes the x-ray tube, high voltage power supply & USB controller. During the experiment, it has been operated at 35 KV high potential and at fixed current of 50 μA. Si-PIN semi-conductor detector has been used due to its better resolution (170 eV at 5.9 keV) and good efficiency at lower photon energy (ignoring attenuation in the diode window and/or package), the detection efficiency is nearly 100% at 10 KeV which falls to nearly 1% at 150 KeV. The detector system includes PX4, a digital interface system and multi-channel analyzer (MCA). The PX4 works at 5V DC power supply. The distance between X-ray tube and Si-PIN detector was kept fixed (10 cm). The samples of different building material were always kept at the centre of the X-ray tube and detector. The samples of different thickness were used so as to maintain the condition of $\mu x < 1$. The transmitted photon spectra were recorded for the time span of 600 second, which provides more than 10,000 counts under the photo-peak. This condition has been satisfied for keeping the statistical error below 1 %.



Mini - X Si-PIN detector

Sample

Fig. 1 Experimental Setup (not to scale)

WinXCom [2] computer software provides mass attenuation coefficient for partial as well as total photon interaction processes in the wide energy range from 1 keV to 100 GeV. The mass attenuation coefficient of a compound or mixture can be obtained from the mass attenuation coefficients of its constituent elements using the following mixture rule:

$$\left(\frac{\mu}{\rho}\right)_{Compound} = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i \qquad \dots (2)$$

3. Results and Discussion

In Fig. 2, the variation of mass attenuation coefficients versus for partial as well as total photon interaction processes with incident photon energy in the range from 1 keV to 100 GeV has been shown for PVC. It has been observed that the mass attenuation coefficient (μ_m) for PVC decreases rapidly upto 100 keV. The rapid decrease in mass attenuation coefficient (μ_m) values below 100 keV can be explained on the basis of the dominance of the photoelectric effect in the lower energy region, whose cross-section can be given by the formula $\sigma_{Photo} \propto Z^{4-5}/E^{3.5}$. Here, the cross-section for photoelectric effect depends on atomic number as Z^4 for low photon energy and Z^5 for high photon energy. Further, it is inversely proportional to the photon energy as $E^{3.5}$. In the limited energy region from 100 keV to 10 MeV, the mass attenuation coefficient values decreases slowly. It can be explained on the basis of dominance of Compton scattering in the intermediate energy region. The cross-section for Compton scattering absorption varies linearly with Z and it is inversely proportional to incident photon energy.

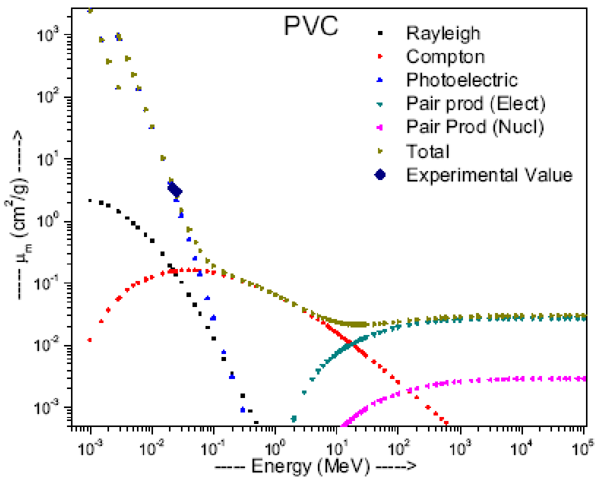


Fig. 2. Variation of mass attenuation coefficient with photon energy for PVC

With the further increase in the incident photon energy up to 100 MeV, the mass attenuation coefficient increases slowly and become almost constant beyond 100 MeV. The slowly increasing behaviour can be explained on the basis of dominance of pair production in the higher energy region. According to the cross-section formula for pair production $\sigma_{Pair} \propto Z^2$ (log E). Its logarithmic behaviour with photon energy results in almost constant values for mass attenuation coefficients beyond 100 MeV.

Moreover, a sharp edge has observed for PVC at the photon energy of about 3 keV, which is an K-absorption edge (2.82 keV) of chlorine, one of the constituent element of PVC. Similarly, sharp edges were also observed for other materials, which are absorption edges of one of the constituent elements (Ca in case of lime and marble). Similar trend has been observed for other building materials as shown in Fig. 3-4 for marble and lime. Further, good agreement has been observed between theoretical and experimentally measured mass attenuation coefficient values.

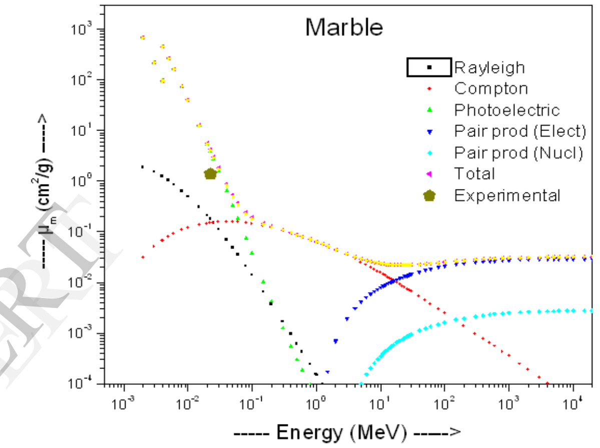


Fig. 3. Variation of mass attenuation coefficient with energy for marble

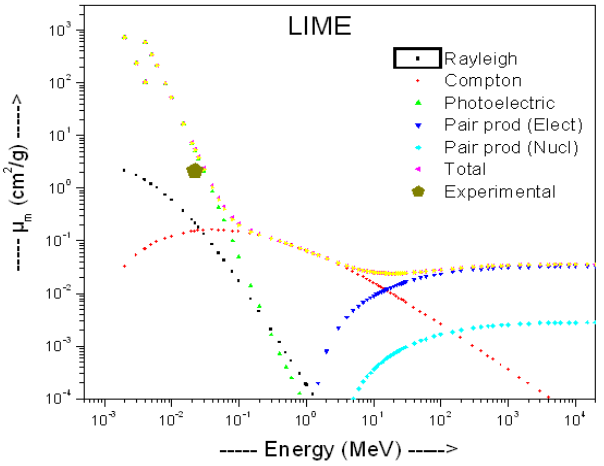


Fig. 4. Variation of mass attenuation coefficient with energy for lime

References

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[2] L. Gerward, N. Guilbert, K. Bjorn Jensen and H. Levring (2001) X-ray absorption in matter. Reengineering XCom. Radiat. Phys. Chem.60: 23.