Jurnal Sains Nuklear Malaysia, 2018, 30(1): 1 – 7
ISSN: 2232-0946

THE EVALUATION OF MASS ATTENUATION COEFFICIENTS OF WATER EQUIVALENT PHANTOM MATERIALS AND *RHIZOPHORA* SPP. PARTICLEBOARDS BY USING COMPTON SCATTERING METHOD

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ABSTRACT

The mass attenuation coefficients of solid water phantoms, Perspex® phantoms and Rhizophora spp. particleboards were determined by using Compton scattering technique measured using Ludlum configuration. The gamma energy of ^{137}Cs sealed source were measured at 30°, 45°, 60° and 75° angles providing scattered gamma energies between 337.72 and 564.09 keV. The mass attenuation coefficients of solid water and fabricated Rhizophora spp. particleboards were the nearest to XCOM values of water with average percentage of discrepancies of 6.8% and 5.9%, respectively. The results indicated similar attenuation properties of solid water and fabricated Rhizophora spp. particleboards and the suitability of the Ludlum configuration to determine the mass attenuation coefficient of materials using Compton scatter technique.

Keywords: Mass attenuation coefficient, phantom materials, *Rhizophora* spp. particleboard

INTRODUCTION

Mass attenuation coefficient is the main parameter to determine absorption and scattering properties of a material towards ionizing radiations (Cevik and Baltas, 2007). This information can be used to understand the attenuation characteristics of a material in comparison to known materials. Phantom material is an important tool for dosimetry and quality control in medical physics. Phantom is the material that simulates absorption and scattering properties of human soft tissues (Khan, 2010). Water has been recommended as a standard phantom material for measurements at high energy photons due to its effective atomic number and mass density close to average human soft tissues. However the liquidity of water has limited the use of various type of dosimeter due to its compatibility. Several solid water equivalent materials have been introduced to replace water such as solid water and Perspex®. The solid water phantom is an epoxy resin-based material that commonly used in dosimetry works involving high energy photons and electrons. Previous studies had suggested the similarity of dosimetric characteristics of solid water to water shown by the calibrated output of high energy X-rays and gamma energies (Constantinou et al., 1982). A Monte Carlo simulation study also indicated good agreement of gamma transmission between solid water and water (Hill et al., 2007). Perspex® phantom on the other hand is commonly used for quality control and image analysis at low energy X-rays.

Mass attenuation coefficients can be measured based on transmission of mono energetic photons through a material according to the Beer-Lambert law. A study by Limkitjaroenporn et al. (2012)

suggested the measurement of based on the scattered photon energy from ^{137}Cs gamma source. This method provided better accuracy of experimented gamma energy range as the scattering of incident gamma to the attenuator is commonly inelastic at specific angles and scattered gamma energies. Therefore this study focused on measurement of several water equivalent phantom materials in comparison to the calculated value of water using XCOM software using Compton scattering method.

Another type of phantom was also experimented in this study. The mass attenuation coefficient of fabricated particleboards made of *Rhizophora* spp. with target density similar to water (1.0 g/cm^3) was evaluated (Mohd Yusof et al., 2017). A previous work suggested the similarity of mass attenuation coefficients of the particleboards to that in water at X-ray Fluorescence (XRF) between 16.59 and 25.26 keV (Mohd Yusof et al., 2015).

MATERIALS AND METHODS

Preparation of Samples

Three types of phantoms were experimented in this study namely the solid water phantoms, Perspex® phantoms and the fabricated *Rhizophora* spp. particleboard phantoms as shown in Figure 1. The solid water phantoms are commonly used to substitute water for quality control and dosimetric studies in radiotherapy. The Perspex® phantoms on the other hand is the common material to simulate the absorption and scattering of human soft tissue for image analysis and quality control in diagnostic imaging. The *Rhizophora* spp. particleboards were fabricated based on the study by Mohd Yusof et al., (2017). An amount of tannin was added as biological adhesive to improve their physical properties while retaining the elemental compositions of the particleboards. The physical properties including the elemental compositions, density and effective atomic number of the phantoms is shown in Table 1.

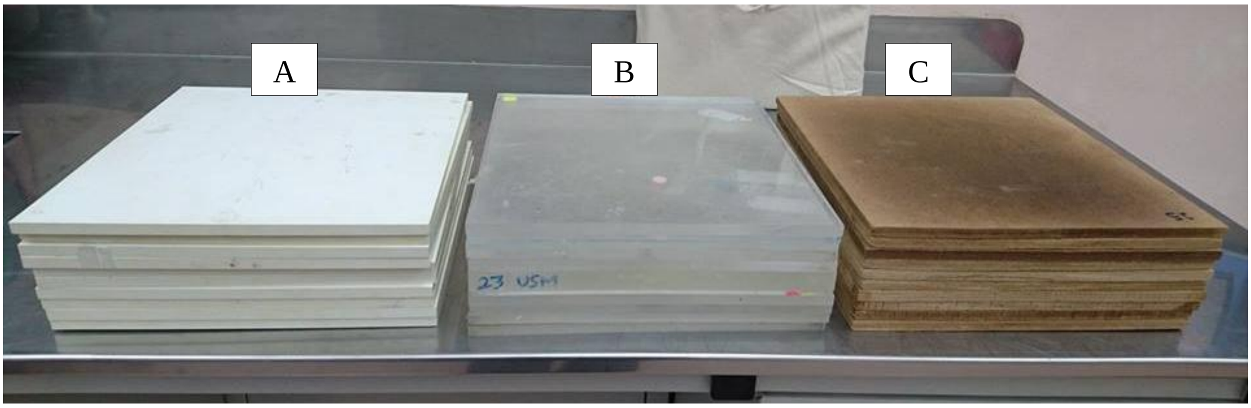

Figure 1: Thephantom materials of (a) solid water, (b) Perspex® and (c) fabricated *Rhizophora* spp. Particleboards

Table 1: The chemical compositions, density and effective atomic number of the phantom materials

Phantom Material	Chemical Composition	Density (g/cm^3)	Effective Atomic Number
Solid water	$(C_5O_2H_8)_n$[1]	1.16[1]	6.48[1]
Perspex	Epoxy resin[1]	1.00[1]	7.35[1]
Rhizophora spp. particleboards	$C_{13}O_8F$[2]	1.03[2]	7.22[2]

[1]Khan, (2010), [2]Mohd Fahmi et al. (2017)

Experimental Set Up

A Ludlum configuration was used to determine the mass attenuation coefficients of materials as shown in Figure 2. This configuration was used in conjunction with ^{137}Cs gamma source that provided gamma peak energy of 0.662 MeV. The sealed source was placed within a shielded container with collimation of 1.0 mm to simulate a line source. An aluminum (Al) plate with approximate thickness of 1.0 mm was used as an attenuator to provide scattering photons. The Ludlum detector was placed at different angles of 30°, 45°, 60° and 75° from the Al attenuator. The phantom materials were placed between attenuator and detector. The distance between the source and attenuator was 20 cm similar to the distance between attenuator and detector. A total of 10 cm of phantom material samples were used to determine the transmission of scattered gamma energies from the attenuator.

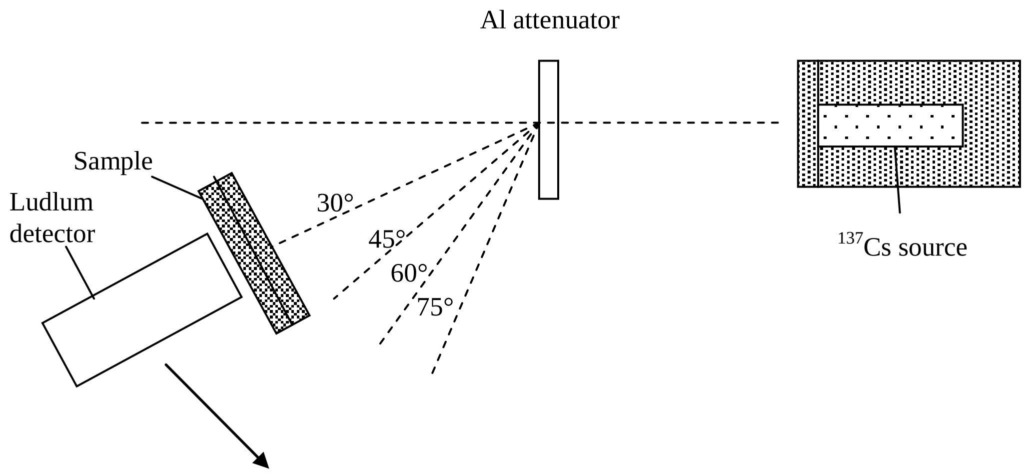

Figure 2: The experimental set up for Ludlum configuration

Determination of Scattered Gamma Energies

The energies of inelastic scattered gamma can be calculated based on the relationship between the incident and scattered gamma energy given by the equation:

$$E_{\gamma'} = \frac{E_\gamma}{1 + (1 - \cos\theta)E_\gamma / mc^2} \quad (1)$$

Where E_{γ} and $E_{\gamma'}$ is the incident and scattered gamma energy respectively, θ is the angle of scattered gamma and m is the electron rest mass (Knoll, 2000; Trousfanidis, 1983). This equation is easily derived by assuming a relativistic collision between gamma ray and an electron initially at rest (Limkitjaroenporn et al., 2012).

Measurement of Mass Attenuation Coefficients

The attenuation properties were determined by using Beer-Lambert law that stated the beam is attenuated exponentially when passing through materials given by the equation:

$$I = I_o e^{-\mu x} \quad (2)$$

Where I is the transmitted photon intensity, I_o is the photon intensity without attenuation, μ is the linear attenuation coefficient and x is the thickness. The linear attenuation coefficients were determined by rearranging Equation 1 into:

$$\mu = \frac{\ln I_o / I}{x} \quad (3)$$

The mass attenuation coefficients (μ/ρ) of the water equivalent phantoms and *Rhizophora* spp. particleboards were measured by dividing the value of linear attenuation coefficients obtained from Equation 3 to their mass density. The results were compared to the mass attenuation coefficients of water calculated using the photon cross-section database (XCOM). The percentage deviations of the experimental values for samples compared to theoretical value for water at all energies were calculated using equation:

$$Discrepancy\ (\%) = \frac{(\mu/\rho)_w - (\mu/\rho)_p}{(\mu/\rho)_w} \times 100\% \quad (4)$$

With $(\mu/\rho)_w$ and $(\mu/\rho)_p$ are the mass attenuation coefficients of samples of water and the water equivalent phantoms, respectively.

RESULTS AND DISCUSSIONS

Calculation of the Scattered Gamma Energies

The calculated scattered gamma energies between 30° and 75° are presented in Table 2. The results showed that the scattered gamma energies decreasing at higher scattering angles. These results are in good agreement to previous work by Limkitjaroenporn et al. (2012) using the mean of scintillation detectors based on the full width half maximum method.

Table 2: The calculated scattered gamma energies of ^{137}Cs gamma at different scattering angles

Scattering Angle, (degree)	Incident Gamma Energy E_{γ}(keV)	Calculated Scattered Gamma Energy, $E_{\gamma'}$ (keV)
30	662	564.09
45		479.90
60		401.76
75		337.72

Mass Attenuation Coefficients of Particleboards

The linear and mass attenuation coefficients of water equivalent phantoms and fabricated *Rhizophora* spp. particleboards are presented in Table 3. The curve of mass attenuation coefficients of samples to the values of water (XCOM) is illustrated in Figure 3. The percentage of discrepancies between phantoms to XCOM values of water is presented in Table 4. The results showed the mass attenuation coefficients of water equivalent phantoms and fabricated *Rhizophora* spp. particleboards were in good agreement to the values of water. The percentage of discrepancies showed the solid water and fabricated *Rhizophora* spp. particleboards having the nearest mass attenuation coefficients to water with of 6.8% and 5.9%, respectively. These results are in good agreement to the previous studies by Constantinou et al. (1982) and Hill et al. (2008). The mass attenuation coefficients of Perspex® however were higher when compared to the values of water with average percentage of discrepancies of 7.2%. This is due to higher mass density of Perspex® (1.16 g/cm^3) in comparison to solid water and fabricated *Rhizophora* spp. particleboards.

Table 3: The mass attenuation coefficients of *Rhizophora* spp. particleboards at 16.59 keV to 25.26 keV photon energies in comparison to water (XCOM)

Gamma Energy (keV)	Water (XCOM)	Solid Water		Perspex®		*Rhizophora* spp. Particleboards	
		μ	μ/ρ	μ	μ/ρ	μ	μ/ρ
564	0.097	0.085	0.085	0.099	0.085	0.09	0.089
480	0.105	0.096	0.096	0.105	0.091	0.095	0.095
401	0.106	0.105	0.105	0.11	0.095	0.105	0.105
337	0.12	0.115	0.115	0.14	0.121	0.115	0.114

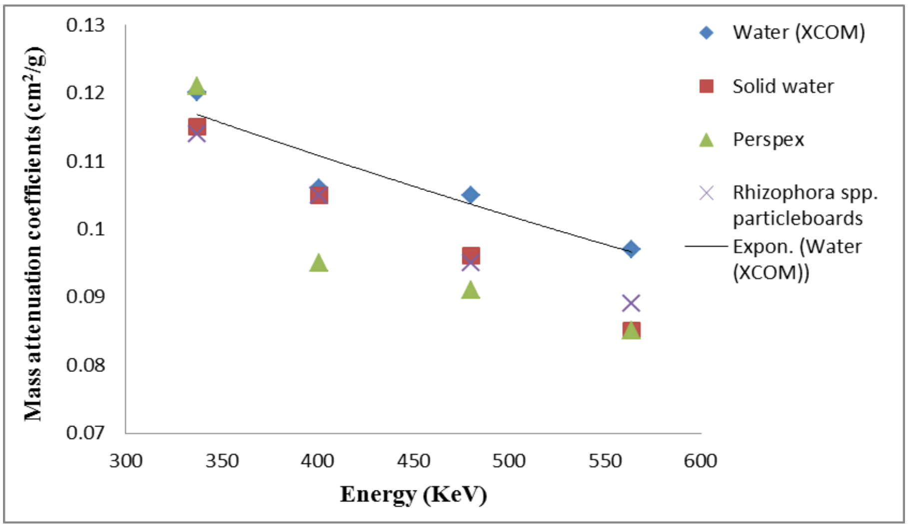

Figure 3: The mass attenuation coefficients of the *Rhizophora* spp. particleboards and raw wood

Table 4: The percentage of discrepancies of mass attenuation coefficients of samples in comparison to the XCOM values of water

Energy (keV)	**Percentage of Discrepancies to Water (%)**		
	Solid Water	**Perspex®**	***Rhizophora* spp. Particleboards**
564	12.37	12.37	8.24
480	9.88	5.21	9.52
401	0.94	10.37	0.94
337	4.17	0.83	5.00
Mean	**6.84**	**7.20**	**5.92**

CONCLUSIONS

The scattered gamma energies can be demonstrated by using the ^{137}Cs gamma and Ludlum configuration. The mass attenuation coefficients of materials therefore can be measured by using the transmission of scattered gamma energies at the respective scattering angles. The mass attenuation coefficients of solid water and fabricated *Rhizophora* spp particleboards were in good agreement to the values of water. This indicated the similar attenuation and dosimetric properties of the materials at high energy photons. The overall results indicated the suitability of Ludlum configuration for the measurement of mass attenuation coefficients using Compton scattering method.

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