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Measurement of mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards at high energy photons by using Compton scattering method

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Measurement of mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards at high energy photons by using Compton scattering method

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Abstract. The mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards were measured by using the Compton scattering technique and Ludlum configurations. The mass attenuation coefficients of the particleboards were measured at scattered gamma energies of ¹³⁷Cs between 337.72 and 564.09 keV and compared to its theoretical values and the values of water by using XCOM calculation. The results showed that the measured mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards were in good agreement to its theoretical values and water (XCOM) within 3.8 and 5.9% discrepancies. The results showed the near attenuation properties of the fabricated *Rhizophora* spp. particleboards to water at scattered gamma energies and the suitability of the Ludlum configuration for the measurement of mass attenuation coefficients of materials.

1. Introduction

The potential of *Rhizophora* spp. particleboards as phantom had been studied by many researchers in the previous works [1-5]. The *Rhizophora* spp. particleboards showed good attenuation and dosimetric properties in comparison to water and other phantom materials such Perspex® and solid water phantoms at photons of the various energy ranges [6]. The mass attenuation coefficient is one of the most important parameter to determine attenuation properties of materials towards the ionizing radiations. The mass attenuation coefficient is determined based on the linear attenuation coefficients of a material when a line source passing through the material taking into considerations of the mass density of the material [7]. The measurement of mass attenuation coefficient shall be made in photons of various energy ranges to determine its proportionality at different photon [8].

The measurement of mass attenuation coefficient of materials with known elemental compositions can be determined theoretically by using computer program of photon cross-section database named XCOM [9][10]. This program enables the calculation of mass attenuation coefficient at various ranges of photon energies and has been used by many researchers. The mass attenuation coefficient of substances that consists of more than one element can also be calculated by inserting the molecular formula of the respective elements into the calculation program.

Several studies had been conducted for the measurements of mass attenuation coefficients of *Rhizophora* spp. particleboards based on the transmission of photons by using the X-ray fluorescent (XRF) and sealed sources [1-4][11]. A previous study suggested that the measurement of mass



attenuation coefficient at high energy photons can be measured using the Compton scattering method by using ^{137}Cs gamma energy [12]. 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. This study measures the mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards at scattered gamma energies from the ^{137}Cs sealed source

2. Methodology

2.1. *Rhizophora* spp. Particleboard Phantoms

The fabricated *Rhizophora* spp. particleboards used in this study was based on the previous work by Mohd Yusof *et al.* [5] and Mohd Yusof *et al.* [11] as shown in Figure 1. The *Rhizophora* spp. particleboards were fabricated with the addition of tannin as adhesive material to increase their physical and mechanical properties [5]. Several evaluations on their physical properties including the percentage of elemental compositions, calculated effective density and effective atomic number were investigated and presented in Table 1. A previous work indicated the close values of mass attenuation coefficients of the particleboards to the values of water at ^{137}Cs and ^{60}Co gamma energies by using the transmission method [6]. Therefore, this study focused on the measurement of mass attenuation coefficients of the particleboards at scattered gamma energies of ^{137}Cs by using the Compton scattering method.



Figure 1. The fabricated *Rhizophora* spp. particleboards used in the study.

Table 1. The physical properties of the fabricated *Rhizophora* spp. particleboards

| Physical properties | Descriptions |
|--|--|
| Elemental compositions | C (51.25%), O (43.11%), F (5.64%) ^a |
| Density (g/cm ³) | 1.03 ^a |
| Effective atomic number, Z_{eff} | 7.22 ^a |
| Electron density ($\times 10^{23}/\text{g}$) | 3.33 ^a |

^aMohd Yusof *et al.* [5]

2.2. Experimental Set Up

The Ludlum configuration was used in this study to provide the scattered gamma energies as shown in Figure 2. It consists of the gas type Ludlum detector connected to a computer analysis. A ^{137}Cs sealed source with gamma peak energy of 662 keV was used to provide the incident gamma energies. The ^{137}Cs sealed source was encapsulated in a lead container with collimation size of 0.1 cm to simulate the line source projection. An aluminum (Al) plate with approximate thickness of 0.1 cm was used as an attenuator to produce the scattered photons. The Al plate was placed between the detector and the source at 20 cm distances from both the detector and the source as shown in Figure 3. The Ludlum detector was placed at angles of 30° , 45° , 60° and 75° to measure the scattered gamma energies. The scattered gamma energies was calculated based on the previous work by Limkitjaroenporn *et al.* [12] by using the equation of,

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

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 [12]. This equation easily derived by assuming a relativistic collision between gamma ray and an electron initially at rest [6]. The calculated scattered gamma energies of the ^{137}Cs is presented in Table 2.



Figure 2. The Ludlum configuration used for the measurement of mass attenuation coefficient in the study.

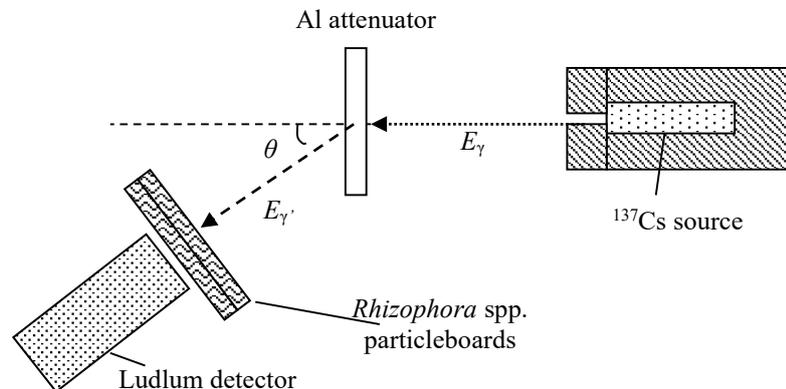


Figure 3. The experimental set up of the Ludlum configuration for the measurement of mass attenuation coefficients by using Compton scattering method.

Table 2. The scattered gamma energies at different angles of measurements.

| Scattering angle, θ | Incident gamma energy, E_γ (keV) | Scattered gamma energy, $E_{\gamma'}$ (keV) |
|----------------------------|---|---|
| 0 | 662 | 662.00 |
| 30 | | 564.09 |
| 45 | | 479.90 |
| 60 | | 401.76 |
| 75 | | 337.72 |

2.3 Measurement of Linear and Mass Attenuation Coefficients

The linear attenuation coefficient of the phantom samples was measured based on the transmission of photon through the samples based on the Beer-Lambert equation of,

$$I = I_0 e^{-\mu x} \quad (2)$$

with I_0 and I is the initial and transmitted photon respectively, μ is the linear attenuation coefficient of the sample medium and x is the thickness of the sample medium. The linear attenuation coefficient can be calculated by rearranging Equation 2 into the equation,

$$\mu = \frac{\ln I_0/I}{x} \quad (3)$$

The mass attenuation coefficient, μ/ρ of the phantom materials can be calculated by dividing the value of linear attenuation coefficient with the density of the phantom material. The measured mass attenuation coefficients of the particleboards were compared to the theoretical values of water by using the XCOM software calculation at similar photon energies [4]. The percentage differences of between the mass attenuation coefficients of the particleboards and water were calculated at all scattered gamma energies to determine the discrepancies between the materials.

3. Results and Discussions

The values of mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards at all experimented scattered gamma energies is shown in Table 3. The comparison of mass attenuation coefficients between the particleboards and the XCOM values of water is illustrated in Figure 4. The results showed that the mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards

decreased exponentially when the scattered gamma energy increased [12]. The results also showed that the mass attenuation coefficients of the particleboards were in good agreement to the values of water (XCOM) at all experimented gamma energies. This indicated the similarities of attenuation properties of the fabricated *Rhizophora* spp. particleboards to water suggesting its potential to be used as water equivalent phantom material for high energy photons. The measured mass attenuation coefficients of the particleboards measured at transmitted and unattenuated ^{137}Cs gamma energies also showed good agreement to the scattered gamma energies [6]. This indicated that the scattered gamma energies can be used to determine the mass attenuation coefficients of a material.

The mass attenuation coefficients of the *Rhizophora* spp. particleboards in this study were measured based on the transmission of scattered gamma energies compared to the transmitted $\text{K}_{\alpha 1}$ photons used from the X-ray fluorescent (XRF) configuration on the previous works [1-5]. This study also measured the mass attenuation coefficients of lower density material compared to the high density material in the previous work [12]. The overall results indicated the suitability of the Compton scattering method for the measurement of mass attenuation coefficients of materials at high photons energies.

Table 3. The measured mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards at transmitted and scattered ^{137}Cs gamma energies.

| Energy (keV) | Mass attenuation coefficients, μ/ρ (cm^2/g) | | Percentage Difference (%) |
|--------------|--|---------------------------------------|---------------------------|
| | Water (XCOM) | <i>Rhizophora</i> spp. particleboards | |
| 662 | 0.086 ^a | 0.080 ^a | 8.13 |
| 564.09 | 0.097 | 0.090 ^b | 7.21 |
| 479.90 | 0.105 | 0.095 ^b | 8.04 |
| 401.76 | 0.115 | 0.105 ^b | 8.69 |
| 337.72 | 0.118 | 0.115 ^b | 2.54 |

^aMohd Yusof et al., [11], ^bCurrent study

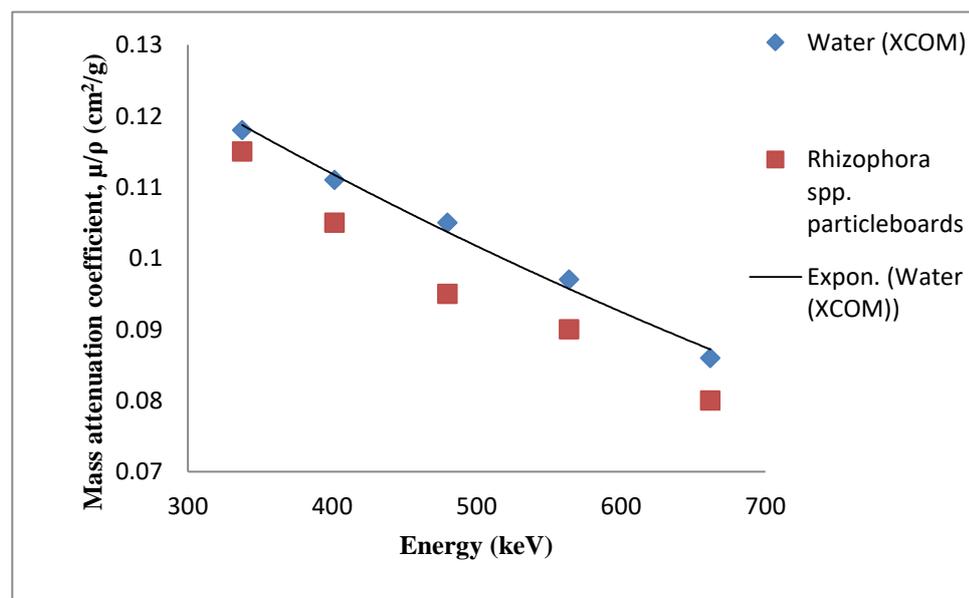


Figure 4. The mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards in comparison to water (XCOM) at scattered gamma energies.

4. Conclusion

The mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards decreased at higher scattered gamma energies. The values of mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboards also showed good agreement to the theoretical values of water at all scattered gamma energies. The study also indicated the suitability of the Ludlum configuration for the measurement of mass attenuation coefficients by using the Compton scattering method.

5. References

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