DOSIMETRIC EVALUATION OF FABRICATED *RHIZOPHORA* SPP. PARTICLEBOARD PHANTOMS AT HIGH EENRGY PHOTONS, ELECTRONS AND BRACHYTHERAPY USING TREATMENT PLANNING SYSTEM (TPS) SOFTWARE

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ABSTRACT

Particleboards made of Rhizophora spp. were fabricated with target density of 1.0g/cm^3 and dimension of 30 cm × 30 cm based on the commonly used solid water phantoms. The particleboards were scanned and acquired by the treatment planning system (TPS) software regularly used in radiotherapy and brachytherapy. The CT numbers of the particleboards were determined and the percentage depth dose (PDD) of the particleboards was determined at 6 and 10 MV photons and 6 and 9 MeV electrons using the TPS simulation. The dose profile and depth dose of brachytherapy were also simulated using the TPS based on the ^{192}Ir high dose rate (HDR) brachytherapy. The PDD of Rhizophora spp. particleboards showed good agreement to solid water phantoms at all simulated photon and electron energies with percentage of discrepancies within 7.43 and 7.52% respectively. The dose profile and depth dose of the particleboards in brachytherapy simulation showed an excellent agreement within 2% to solid water phantoms. The results had indicated the potential use of Rhizophora spp. particleboards as phantom for radiotherapy and brachytherapy using TPS simulation.

ABSTRAK

Papan partikel difabrikasi daripada Rhizophora spp. dengan ketumpatan 1.0g/cm^3 dan dimensi luaran 30 cm × 30 cm berdasarkan fantom lazim 'solid water'. Papan-papan partikel diimbas dengan pengimbas CT dan imejnya dihantar ke perisian 'treatment planning' (TPS) untuk radioterapi dan brakiterapi. Nombor CT papan partikel didapatkan dan peratusan dos kedalaman (PDD) dihitung pada foton bertenaga 6 and 10 MV and elektron bertenaga 6 dan 9 MeV menggunakan simulasi TPS. Profil dos dan dos kedalaman bagi brakiterapi juga disimulasi menggunakan TPS berdasarkan brakiterapi HDR bagi ^{192}Ir. PDD bagi papan partikel Rhizophora spp. menyerupai fantom 'solid water' untuk foton dan elektron dengan peratus perbezaan masing-masing 7.43 dan 7.52%. Dos profil dan dos kedalaman papan partikel juga menyerupai fantom 'solid water' dengan peratusan perbezaan sebanyak 2%. Keputusan ujian ini telah menunjukkan potensi papan serpai Rhizophora spp. sebagai bahan fantom bagi radioterapi dan brakiterapi menggunakan simulasi TPS.

Keywords: ***Rhizophora*** **spp. particleboards, phantom, treatment planning system (TPS), photons, electrons, brachytherapy.**

INTRODUCTION

Phantom is the material that simulates the absorption and scattering properties of human soft tissues [1]. Phantom material is an important tool for dosimetric studies and quality assurance in medical physics works including radiotherapy and brachytherapy. Water had been commonly used as phantom in radiotherapy due to its density near to the human soft tissues [1]. Several solid-type phantom materials such as Perspex® and solid water had been introduced to substitute water to overcome the limitations of water as phantom to be used with various types of dosimeters. The use of these water equivalent materials however still failed to provide accurate dosimetric readings due to variation of densities and dissimilarities of elemental compositions to water and soft tissues.

Previous studies had suggested the suitability of *Rhizophora* spp. particleboards to be used as water equivalent phantom in various applications in medical physics [2,3]. The physical properties of *Rhizophora* spp. wood including density and elemental compositions near to the values of soft tissue and water made *Rhizophora* spp. woods to be potentially developed as an alternative phantom material for imaging and dosimetric studies [3,4,5]. The use of *Rhizophora* spp. wood as phantom however has several limitations including non-uniform density of the trunk, and limited size to be constructed at full-size phantoms. The fabrication of particleboards made of *Rhizophora* spp. having the advantages over the untreated wood including better density uniformity and able to be fabricated at various sizes and shapes [5,6]. The biological-based adhesives were introduced into the *Rhizophora* spp. particleboards to increase the physical and mechanical properties of the particleboards [7,8,9]. The biological-based adhesives were preferred over the synthetic-based adhesives commonly used in industry in order to retain the elemental compositions of the *Rhizophora* spp. particleboards. Besides, the use of synthetic-based adhesives such as urea-formaldehyde (UF) had significantly modified the density and attenuation properties of *Rhizophora* spp. particleboards [10,11].

The treatment planning system (TPS) software had been widely used in radiotherapy and brachytherapy treatments. The TPS uses the diagnostic images such as computed tomography (CT) images to determine the best method of beam delivery based on the calculated dose to the target volume and the surrounding tissues. The densities of various tissues were translated as CT numbers and the absorbed dose to the tissues is calculated between the prescribed beam and the density of the tissues. This study determined the dosimetric properties of *Rhizophora* spp. particleboards as phantoms at high energy photon and electron beams and brachytherapy based on the TPS and CT images.

METHODOLOGY

Fabrication of Rhizophora spp. Particleboards

The particleboards were fabricated by using the wood particles obtained from the planning and grinding of *Rhizophora* spp. trunk. The wood particles were mixed with tannin adhesive with percentage of 10% based on the dry weight of the wood particles based on the study by Mohd Yusof et al., [9]. The particleboards were fabricated by using hot pressing method with target density similar to water ($1.0 g/cm^3$) and external dimension of 30 cm × 30 cm × 1 cm similar to the typical solid water phantoms commonly used in radiotherapy and brachytherapy as shown in Figure 1. A total of 30 units of particleboards were fabricated to simulate the typical thickness of abdomen. The density of the particleboards was measured using gravimetric method based on its external dimensions given by the equation

$$\rho = \frac{length \times width \times thickness}{mass} \quad (1)$$

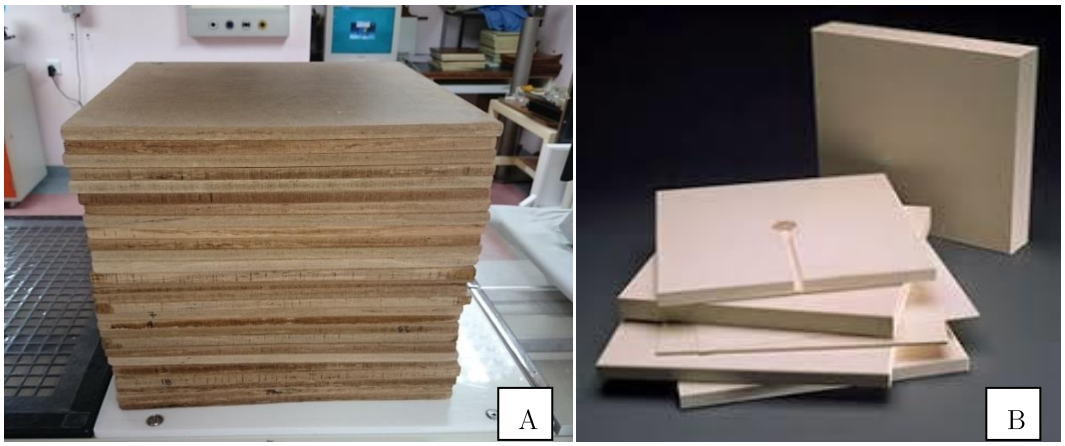

FIGURE 1. (a) The fabricated *Rhizophora* spp. particleboards and (b) the solid water phantoms.

Determination of percentage depth dose in high energy photons and electrons

The phantom set was scanned using Siemens Somatom Definition AS CT scanner at 250 kVp and 250 mAs exposure factors based on the abdominal scanning protocols and the CT images were exported to the TPS software. Photon beams with 6 and 10 MV energies and electron beams with 6 and 9 MeV energies were inserted at midline perpendicular to the particleboard surface as shown in Figure 2. The maximum dose d_{max} were determined based on the isodose lines resulted by the beam insertion. The percentage depth dose (PDD) at depths were calculated based on the equation

$$PDD = \frac{D}{D_{max}} \times 100\% \quad (2)$$

With D and D_{max} is the dose at depths and maximum dose respectively. The PDD curve were plotted between the PDD values and depths and compared to that in solid water phantoms.

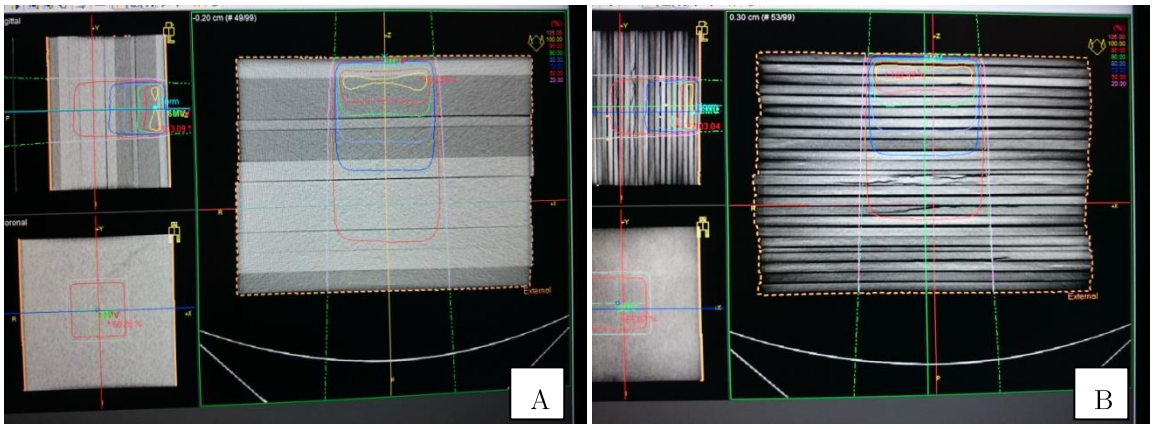

FIGURE 2. Beam simulation using treatment planning system (TPS) at (a) solid water phantoms and (b) *Rhizophora* spp. particleboards.

Determination of depth dose in brachytherapy

An applicator array for brachytherapy was placed at the midline of the particleboards to simulate the positioning of brachytherapy sealed source before being scanned using the CT scanner. The CT images were exported and acquiesced from the TPS software. A ^{192}Ir gamma source was simulated through the applicator array and the isodose lines were obtained as shown in Figure 3. The maximum dose was determined at approximate distance of 1 cm from the source applicator array and the dose profiles at perpendicular distance from the source applicator array were plotted. The depth dose curve was plotted using similar equation as in Equation 2 and compared to that in the solid water phantoms.

RESULTS

The measured density and average CT number of *Rhizophora* spp. particleboards is presented in Table 1. The results showed that the average density of *Rhizophora* spp. particleboards was close to water with low density variations shown by the standard deviation of the density values. The result was in good agreement to the previous study of density of raw *Rhizophora* spp. wood by Bradley et al., (19991) and binderless *Rhizophora* spp. particleboards by Marashdeh et al., (2012). The average CT number of *Rhizophora* spp. particleboards was also close to the value of solid water and water suggesting the water equivalent property of the particleboard. The resuts was consistent on the previous work on the determination of CT number of *Rhizophora* sp. particleboards by Abuaraa et al., [7] and Ababneh et al., [8].

TABLE 1. The average density and CT number of *Rhizophora* spp. particleboards

Physical property	**Description**
Average density ± standard deviation	1.003 ± 0.014[a]
CT number (HU)	-18.43 [a] (solid water = -11.60 [b])

Percentage depth dose on high energy photons and electrons

The PDD curve of the *Rhizophora* spp. particleboards at 6 and 10 MV photons in comparison to solid water phantoms using TPS software is illustrated in Figure 3(a) and 2(b) respectively. The PDD of *Rhizophora* spp. particleboards at 6 MV photons showed good agreement to that in solid water phantoms within 7.43% percentage of discrepancy at all measured depths. The percentages of discrepancies were lower at depths beyond the d_{max} compared to that in the buildup region. The PDD of *Rhizophora* spp. particleboards at 10 MV photons on the other hand showed good agreement to that in solid water phantoms within lower percentage of discrepancy of 5.02% at all measured depths. The surface dose of the particleboards were lower than that in the solid water phantoms with percentage difference of 16.47 and 15.24% for 6 and 10 MV photons respectively. The results were in good agreement to the previous work on the measurement od PDD in solid raw *Rhizophora* spp. wood at high energy photons by Banjade et al., [4].

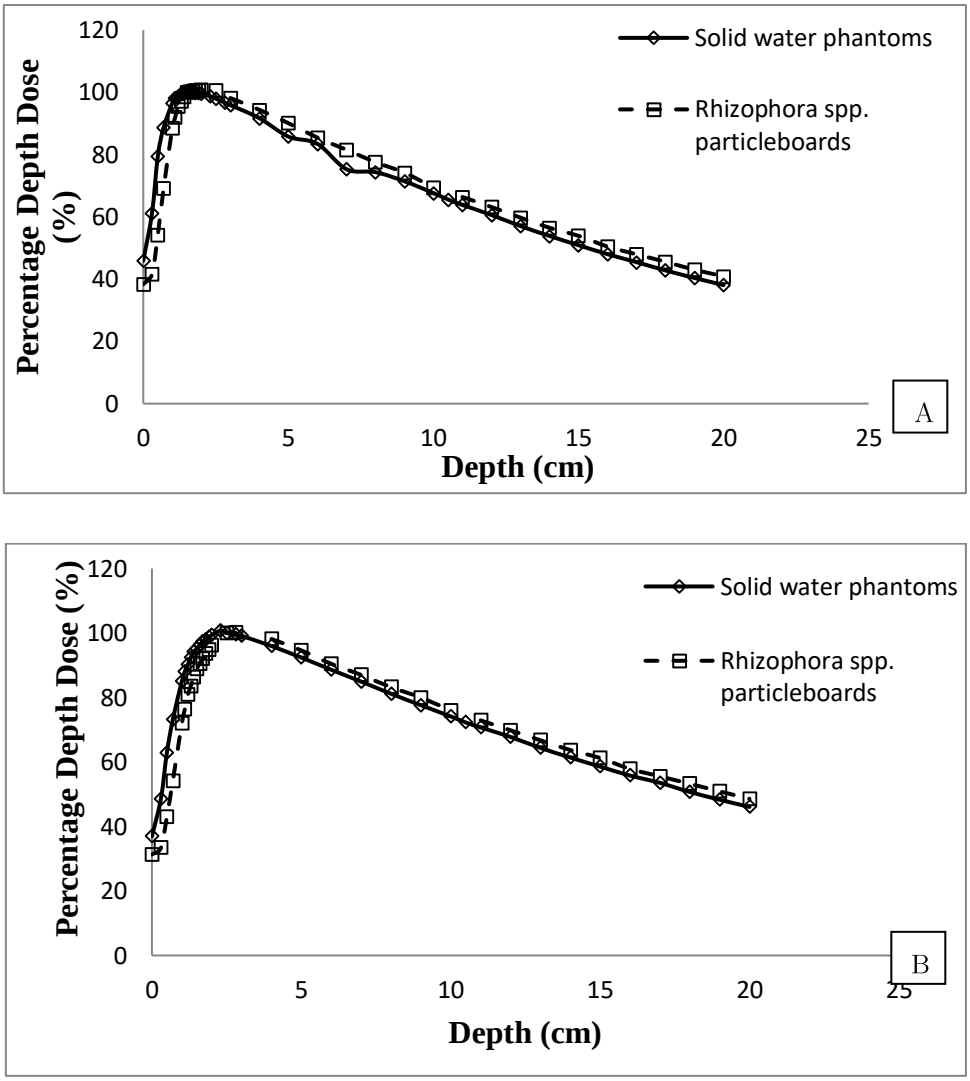

FIGURE 3. The percentage depth dose curve of *Rhizophora* spp. particleboards in comparison to solid water phantoms at (a) 6 MV and (b) 10 MV photons measured using TPS software.

The PDD of *Rhizophora* spp. particleboards at 6 and 9 MeV electrons in comparison to solid water phantoms are illustrated in Figure 4(a) and 3(b) respectively. The PDD of the particleboards at 6 MeV electrons showed remarkable agreement to that in solid water phantoms with maximum percentage of discrepancy of 4.12% at all measured depths. The PDD of the particleboards at 9 MeV electrons however showed larger percentage of discrepancies within 7.52% at all measured depths. The percentages of discrepancies were significantly high at the buildup region compared to that in the depths beyond the d_{max}. The results were in good agreement to Banjade et al., [4] who measured the PDD in solid raw *Rhizophora* spp. wood at high energy electrons.

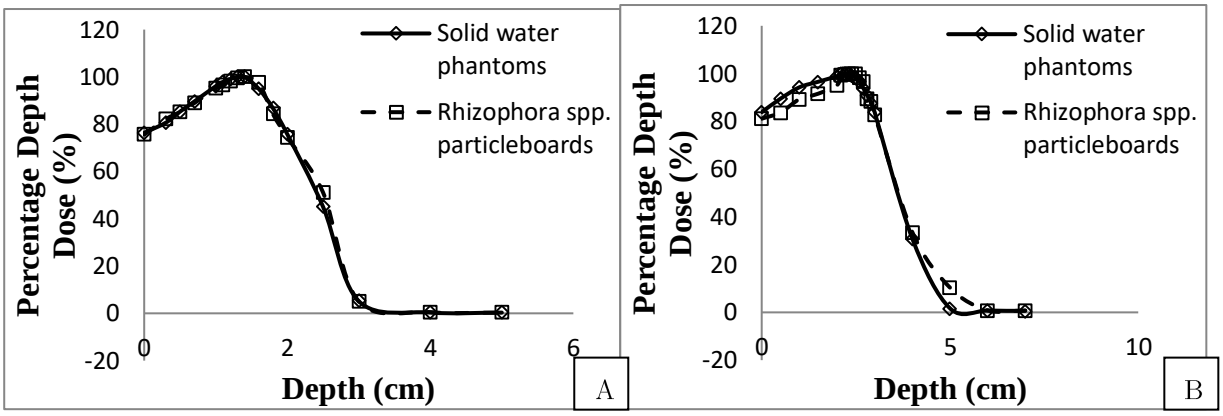

FIGURE 4. The percentage depth dose curve of *Rhizophora* spp. particleboards in comparison to solid water phantoms at (a) 6 MeV and (b) 9 MeV electrons measured using TPS software.

The dose profile and depth dose in brachytherapy

The dose profile at depths measured in the *Rhizophora* spp. particleboards using ^{192}Ir brachytherapy source in comparison to the solid water phantoms is shown in Figure 5(a) and 4(b) respectively. The percentage depth dose of *Rhizophora* spp. particleboards in comparison to the solid water measured at the centre of the applicator array is illustrated in Figure 6. The results showed that the dose profiles measured at various depths in *Rhizophora* spp. particleboards were in good agreement to that in solid water phantoms within 3.5% percentage of discrepancy. Several siodose distortions were observed in the peripherals of the *Rhizophora* spp. particleboards indicating slight density inhomogeneity of the particleboards. The measured percentage depth dose in *Rhizophora* spp. was in excellent agreement to that in solid water phantoms with maximum percentage of discrepancy of 2%. The results are in good agreement to the previous studies on the depth dose of solid *Rhizophora* spp. raw wood using 192Ir brachytherapy source by Bradley et al., [3]. The overall results had indicated the suitability of *Rhizophora* spp. particleboards as phantom material for quality control and dosimetry works in radiotherapy and brachytherapy.

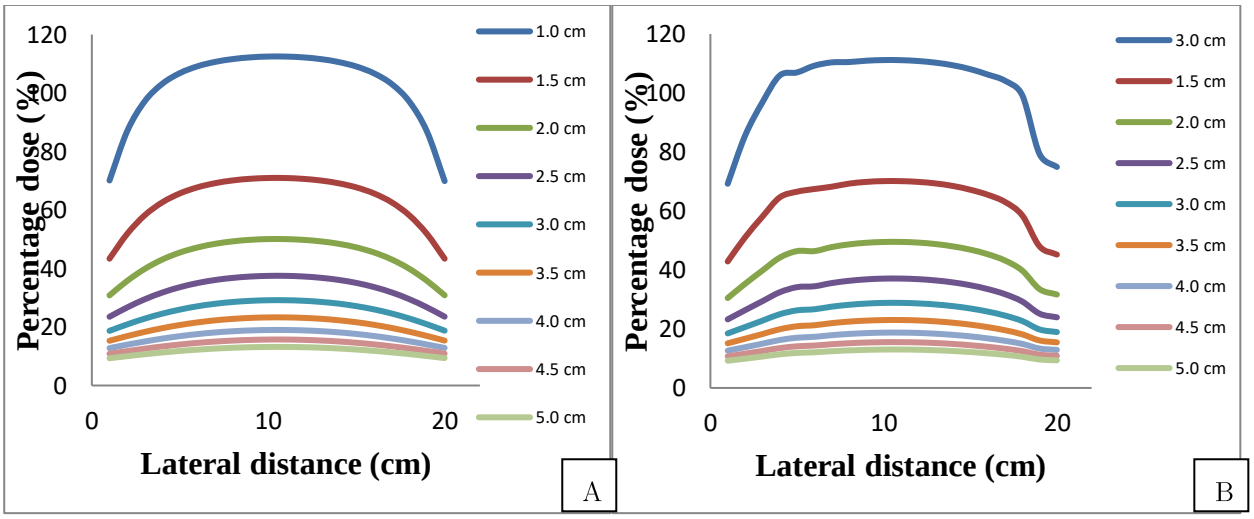

FIGURE 5. The dose profile of (a) solid water and (b) *Rhizophora* spp. particleboards measured at different depths from the applicator array using TPS software.

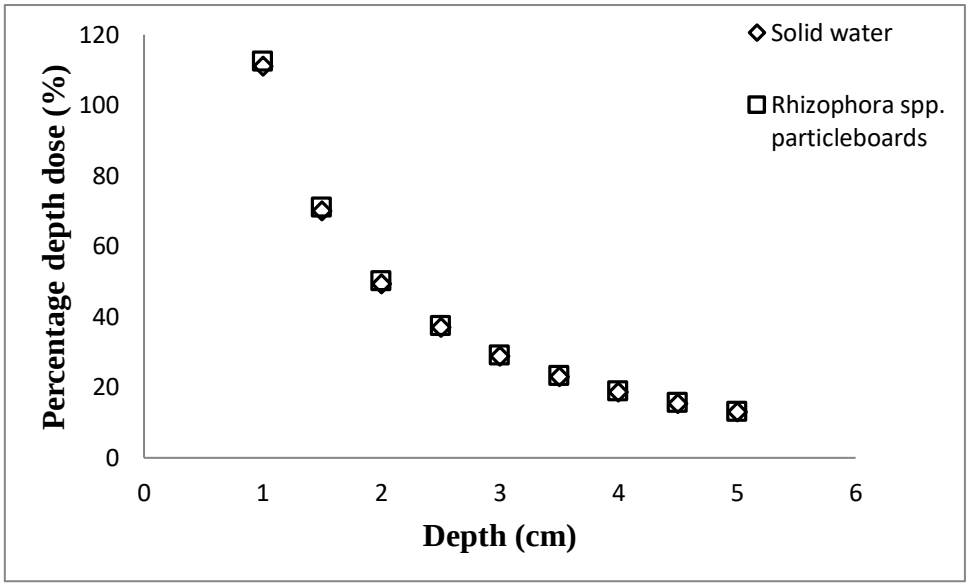

FIGURE 6. The percentage depth dose (PDD) of *Rhizophora* spp. particleboards in comparison to solid water measured using brachytherapy treatment planning system (TPS).

CONCLUSION

The fabricated *Rhizophora* spp. particleboards had achieved density close to water commonly used as phantom in radiotherapy. The measured CT number also indicated the water equivalent property of *Rhizophora* spp. particleboard shown by the CT number. The measured PDD of *Rhizophora* spp. particleboards showed good agreement to solid water phantoms at high energy photons and electrons measured using the TPS simulation based on the CT number of the particleboards. The dose profile and PDD of *Rhizophora* spp. particleboards also showed an excellent agreement to that in solid water phantoms measured using TPS simulation. Several improvements on the density uniformity of the particleboards are required to give better accuracy of dosimetry. The results had indicated the potential use of *Rhizophora* spp. particleboards as phantom for high energy photons, electrons and brachytrherapy.

REFERENCES

[1] F. M. KHAN, "The Physics of Radiation Therapy," Lippincott Williams & Wilkins, 4th Edition (2010).

[2] C. W. A. CHE WAN SUDIN, "Kayu Tropika Sebagai Bahantara Setaraan Tisu Untuk Kajian Dosimetri," M. Sc. Thesis, Universiti Sains Malaysia (1993).

[3] D.A. BRADLEY, A. A. TAJUDDIN, C. W. A. CHE WAN SUDIN, S. BAUK, "Photon Attenuation Studies on Tropical Hardwoods,". Applied Radiation and Isotopes, 42:771-773 (1991).

[4] D. P. BANJADE, Study on Dose Measurements in Different Phantoms Using Different Protocols and the Applicability of Thermoluminescent Dosimetry in Radiotherapy," Ph.D. Thesis, Universiti Sains Malaysia (2002).

[5] B. Z. SHAKHREET, S. BAUK, A. A. TAJUDDIN, A. SHUKRI, "Mass Attenuation Coefficients of Natural *Rhizophora spp.* Wood for X-rays in the 15.77 to 25.27 keV Range, Radiation Protection and Dosimetry, 135:47-53 (2009).

[6] M. W. MARASHDEH, S. BAUK, A. A. TAJUDDIN, R. HASHIM, "Measurement of Mass Attenuation Coefficients of *Rhizophora spp.* Binderless Particleboards in the 16.59–25.26 keV Photon Energy Range and Their Density Profile Using X-ray Computed Tomography," Applied Radiation and Isotopes,70:656-662 (2012).

[7] A. ABUARRA, R. HASIM, S. BAUK, S. KANDAIYA, E. T. TOUSI, "Fabrication and Characterization of Gum Arabic Bonded *Rhizophora spp.* Particleboards," Materials and Design, 60:108-115 (2014).

[8] B. ABABNEH, "Characterization of Solid Wood and Almond Gum Bonded *Rhizophora* spp. Particleboard as Breast Phantom for MRI and CT," Ph.D. Thesis, Universiti Sains Malaysia (2016).

[9] M. F. M. YUSOF, R. HASHIM, A. A. TAJUDDIN, S. BAUK, O. SULAIMAN, "Characterization of tannin-added *Rhizophora* spp. as phantom materials for photon beams," Industrial Crops and Products, 95:467-474 (2017).

[10] K. T. NGU, R. HASHIM, A. A. TAJUDDIN, A. SHUKRI, "Fabrication of Formaldehyde-Based *Rhizophora spp.* Particleboards and Their Mass Attenuation Coefficients at 15.77, 17.48, 21.18, and 25.27 keV Photon Energies," Journal of Physical Sciences, 26(1);27-33 (2015).

[11] B. T. SURANI, "The Suitability of PF, UF and PRF Resins in Term of Structure and Attenuation Properties to be Used in *Rhizophora spp.* Particleboard Phantoms," M.Sc. Thesis, Universiti Sains Malaysia (2008).