ATTENUATION STUDIES ON DRY AND HYDRATED CROSS-LINKED HYDROPHILIC COPOLYMER MATERIALS AT 8.02 TO 28.43 keV USING X-RAY FLUORESCENT SOURCES

Sabar Bauk[1]*, Nicholas M. Spyrou[2] and Michael J. Farquharson[3]

[1]Physical Sciences Programme, School of Distance Education, Universiti Sains Malaysia, 11800 USM Pulau Pinang, Malaysia
[2]Department of Physics, University of Surrey, Guildford GU2 7XH, Surrey, England
[3]Department of Radiography, City University, London EC1M 6PA, England

*Corresponding author: sabar@usm.my

Abstract: *Hydrophilic copolymers which consist of a combination of hydrophobic monomers (methyl methacrylate, MMA) and hydrophilic monomers (vinyl pyrolidone, VP) have all the required major elements such as hydrogen, carbon, nitrogen and oxygen, found in tissues. They have the potential to be used as breast phantom materials since they can be made to have similar elemental composition as that of body soft tissues. Photon attenuation measurements were performed on dry and hydrated hydrophilic copolymers using X-ray fluorescent (XRF) photons. They were obtained by bombarding copper, molybdenum, silver and tin targets to X-rays from an industrial X-ray tube; effectively producing 8.02, 8.89, 17.41, 19.55, 22.08, 24.87, 25.16 and 28.43 keV photons. The measured mass attenuation coefficients of the samples were compared with the calculated breast mass attenuation coefficients.*

Keywords: attenuation, hydrophilic copolymer, X-ray fluorescence

1. INTRODUCTION

Breast cancer is a major health problem as it is the most common cancer in women. It comprises 28% of all female cancers.[1] Mammographic techniques used for screening programmes need to be of the highest quality; hence, the need of a good phantom to mimic breast response to radiation. The phantom must be sensitive to small changes in the mammographic system and provides the means for evaluating the absorbed dose to the breast.

The radiation and physical properties of cross-linked hydrophilic copolymers produced by Highgate[2] have been studied.[3,4] We believe that they have the potential to be good phantom materials for the breast as their elemental compositions are similar to soft tissue. By controlling the hydration level, the type of solution and the physical and chemical properties of the hydrophilic materials, it may be possible to imitate various types and different diseased stages of tissues.

The objective of this experiment was to determine the mass attenuation coefficients of dry and hydrated hydrophilic copolymer materials, in the mammographic energy range.

2. MATERIALS AND METHOD

2.1. Copolymer Samples

The hydrophilic copolymer materials used in this study are made from a combination of vinyl pyrolidone (VP, a hydrophilic monomer) and methyl methacrylate (MMA, a hydrophobic monomer). The elemental compositions of MMA in terms of weight percentage is 9.59% H, 71.4% C and 19.02% O; whilst for VP is 8.16% H, 64.84% C, 12.6% N and 14.39% O. The elemental composition of the cross-linked copolymer can be tailored by changing the composition ratio of the monomers. The two samples which are used in this study are designated as ED1S and ED4C. The MMA to VP monomers composition ratio for ED1S is 1:3 and for ED4C is 1:4. The major elemental composition of the hydrophilic material is comparable to that of tissue and other well-known tissue-equivalent materials (Table 1). The H, C and O contents of our samples were comparable to that of the breast tissue-equivalent BR12. In addition, trace elements may also be introduced into the hydrophilic materials by hydration. Hence, it was suggested that the hydrophilic copolymer materials might be breast tissue-equivalent too.

2.2 Radiation Source

The radiation source at the City University, London was an industrial X-ray machine. It was water-cooled and could produce X-radiation continuously. The tube assembly type was a Comet ceramic X-ray tube assembly MXR-160/0.4–3.0. The tube generator was a Pantak HF160 C.P. unit.

Table 1: The percentage elemental composition of ED1S and ED4C as compared to that of some tissues and other tissue-equivalent materials (ICRU 1989).[10] ED1S and ED4C contain the major elements of real tissues.

Sample	H	C	N	O	Others
Adipose	11.4	59.8	0.7	27.8	0.1 Na, 0.1 S, 0.1 Cl
Soft tissue	10.1	11.1	2.6	76.2	0.1 Na, 0.2 P, 0.3 S, 0.2 Cl, 0.2 K
Muscle	10.2	14.3	3.4	71.0	0.1 Na, 0.2 P, 0.3 S, 0.4 K, 0.1 Cl
Breast (mammary gland)	10.6	33.2	3.0	52.7	0.1 Na, 0.1 P, 0.2 S, 0.1 Cl
Acrylic	8.0	60.0	-	32.0	
BR12	8.7	69.9	2.4	17.9	0.1 Cl, 1.0 Ca
Mix D	13.4	77.8	-	3.5	3.9 Mg, 1.4 Ti
Paraffin wax	15.0	85.0	-	-	
Polyethylene	14.4	85.6	-	-	
P.T.F.E.	-	24.0	-	-	76.0 F
Temex	9.6	87.5	0.1	0.5	1.5 S, 0.3 Ti, 0.5 Zn
Water	11.2	-	-	88.8	
ED1S (dry)	8.52	66.48	9.45	15.55	
ED4C (dry)	8.45	66.15	10.08	15.32	

The typical arrangement of the X-ray fluorescence (XRF) apparatus is as shown in Figure 1. X-ray photons from the tube pass through a 5 mm diameter collimator towards the target. The target atoms are excited causing them to produce XRF photons unique to the element of the target. The XRF beam then passes through four 2 mm diameter collimators before reaching the detector. Samples are placed between the second and the third collimators. Due to laboratory space constraint, the angle between the incident photon beam and the XRF beam travelling to the detector was always maintained at 90^{o}. The grazing angle θ can be varied.

The detector used was an ORTEC High-Purity Germanium GLP Series Pop top cryostat configuration, crystal diameter was 36 mm, crystal length was 13 mm, endcap to crystal distance was 7 mm, window thickness was 0.254 mm and window diameter was 50 mm.

The industrial X-ray tube was used to irradiate copper, molybdenum, silver and tin targets producing K_α fluorescent X-rays with effective energies of 8.02, 17.41, 22.08 and 25.16 keV, respectively. The unattenuated and the attenuated XRF beam from the molybdenum target in ED4C sample (fully hydrated in saline) is shown in Figure 2 showing the K_α and K_β peaks. The K_β peaks were also used for the attenuation study and hence provides additional effective photon energies of 8.89, 19.55, 24.87 and 28.43 keV. However, it should be noted that the signal under the K_β is lower.

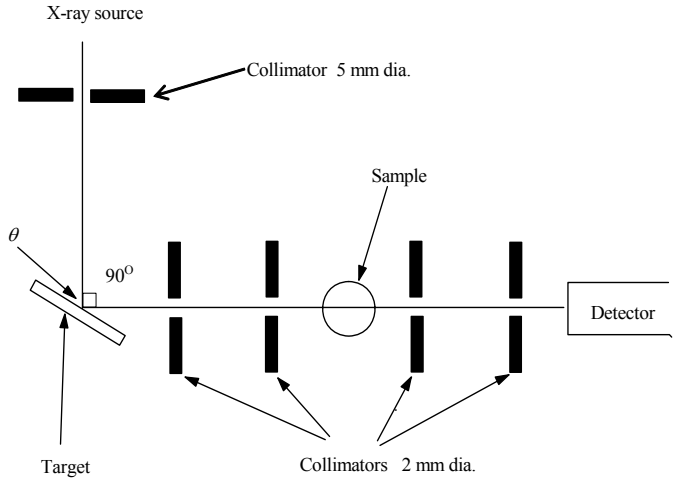


Figure 1: Typical arrangement of the XRF set-up at the City University

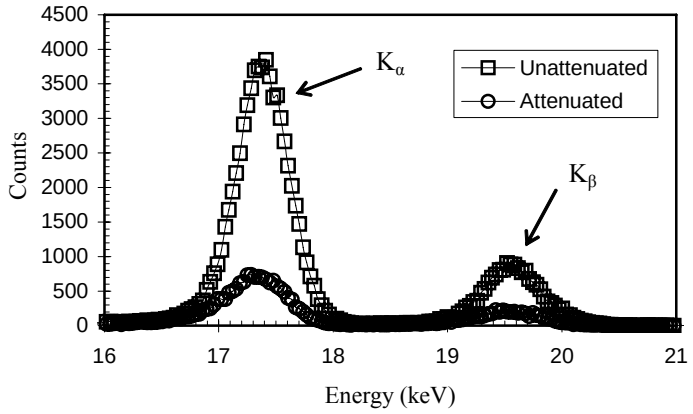


Figure 2: A typical spectrum of unattenuated and attenuated XRF beams from a molybdenum target in ED4C (fully hydrated in saline) sample. K_β peaks too have the potential to be used for attenuation studies.

2.3 Optimum Grazing Angle

With the current being kept constant, we investigated the effects of the grazing angle θ on the intensity of the XRF beam at different tube voltages kVp. The current was fixed at 5 mA and the exposure time was 120 s. For each setting of kVp at a specific grazing angle θ, the counts under the K_α peaks of the target spectra were determined.

2.4 Aluminium Measurements

The ability of the system to determine the mass attenuation coefficient of a sample accurately was tested by measuring the mass attenuation coefficient of aluminium, since it is one of the most tested material in radiation physics. High purity aluminium (>99.9%) samples of varying thicknesses were placed across a beam of collimated XRF photons. This test was done using four XRF photon energies of K_α peaks of copper, molybdenum, silver and tin targets.

2.5 Copolymer Attenuation Measurements

Solid hydrophilic material samples of ED1S and ED4C were used. Three states of the samples were studied: dry, fully hydrated in deionized water (fhw) and fully hydrated in saline (fhs). The surfaces of the hydrated samples were dried using blotting paper and wrapped in cling film before placing them in the XRF beam. Both the K_α and K_β peaks of the XRF photons were utilized. The intensities of the incident and the transmitted beams were recorded and the linear attenuation coefficient μ was determined by using the relationship:

$$\mu = -\frac{1}{x}\ln\left(\frac{I_t}{I_0}\right)$$

where x is the thickness of the samples, I_t is the intensity of the transmitted beam and I_0 is the intensity of the incident beam.

The density of the samples was determined by weighing and measuring the volume of the samples. Subsequently the mass attenuation coefficients (μ/ρ) of the samples were calculated.

The theoretical average breast values were calculated by using XCOM.[5] The average breast elemental compositions used were taken from Constantinou[6] with Breast 1 was designated as young-age (25% fat, 75% muscle), Breast 2 as

middle-age (50% fat, 50% muscle) and Breast 3 as old-age (75% fat, 25% muscle) breasts.

3. RESULTS AND DISCUSSION

The determination of the optimum grazing angle results were plotted as shown in Figure 3. It was found that for all kVps, the grazing angle θ of 70°–75° gives the highest XRF photon intensity. In all cases, the higher the kVp, the higher is the intensity. The targets were then set at a grazing angle of 70° for the rest of the experiments in order to take advantage of the highest XRF yield.

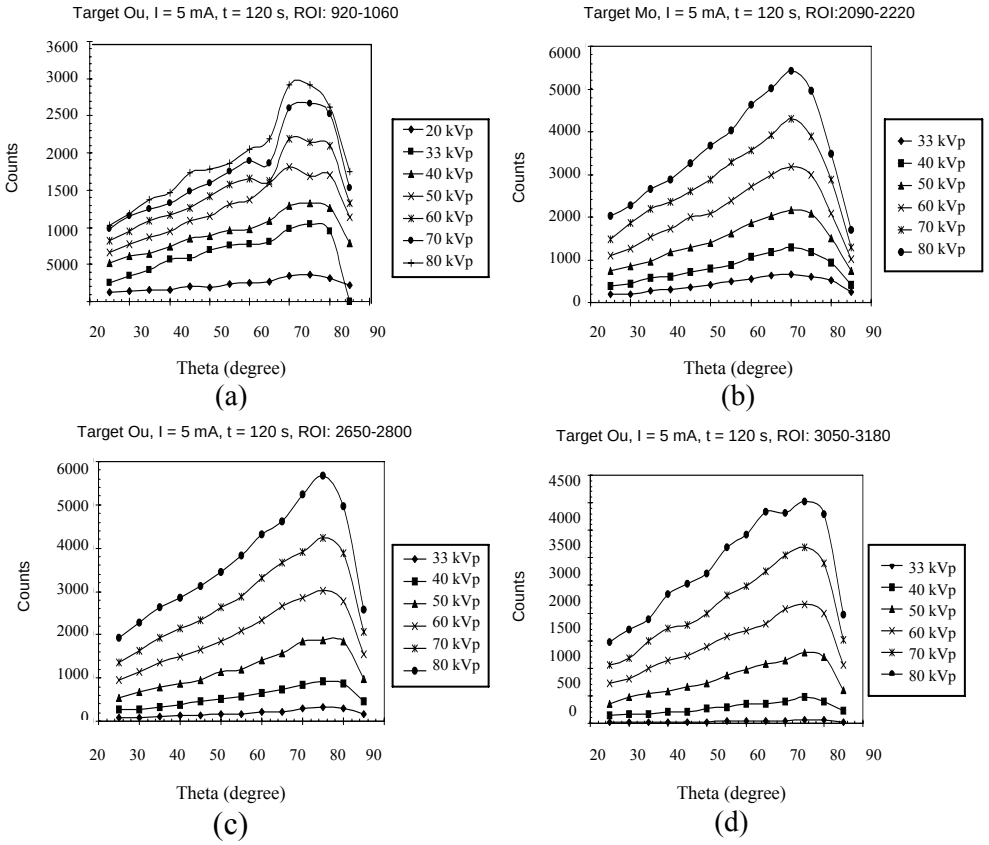


Figure 3: The counts under the K_α peaks of the four target materials at different kVp settings and at different grazing angles θ. Targets: (a) copper, (b) molybdenum, (c) silver, and (d) tin. The optimum grazing angle for all targets is between 70° to 75°.

Figure 4 shows the mass attenuation coefficient of aluminium in the present study compared to the values obtained from the XCOM[5] computer calculation as well as experimental results from Millar and Greening[7] and Al-Haj.[8] The data fitted well with the calculated values with a maximum deviation of 8.1% at 22.16 keV, indicating that the accuracy of the system is reliable.

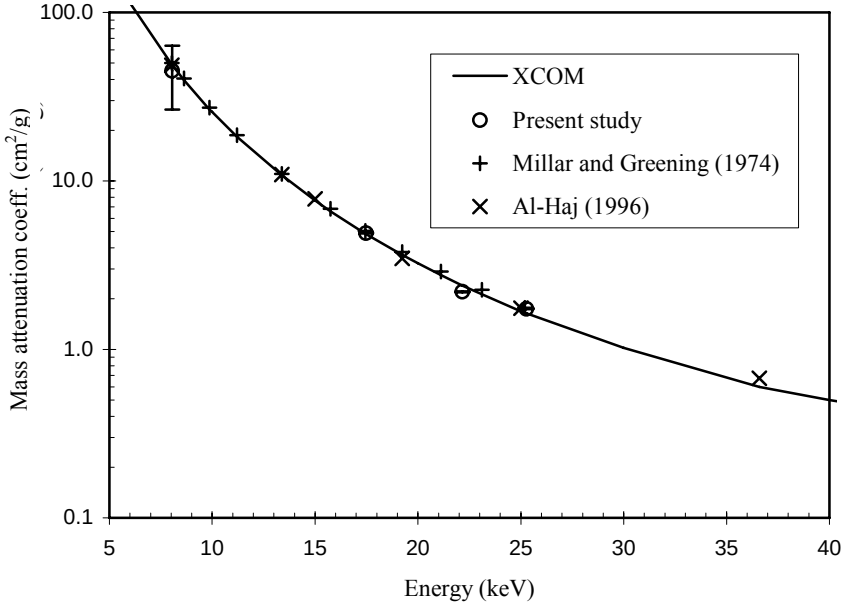
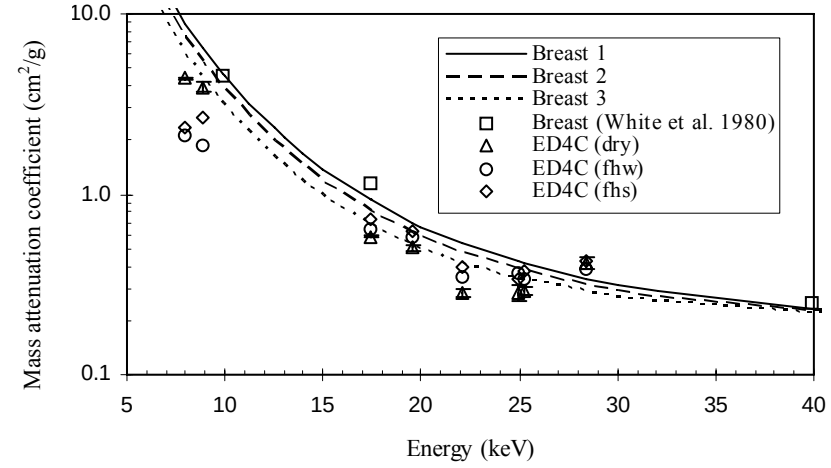
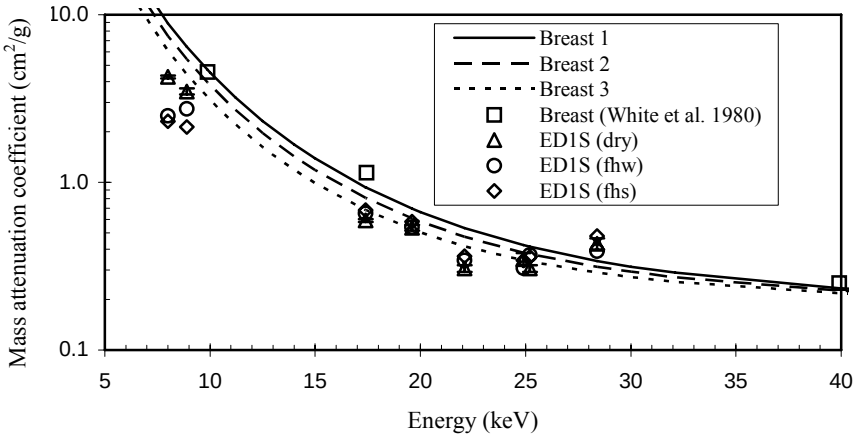


Figure 4: Measurement of the mass attenuation coefficient of aluminium. The error bars for the present study are as indicated in the graph.

The results of the copolymer attenuation measurements obtained were compared with the results of breast tissue measurements by White et al.[9] and theoretical calculated average breast values as shown in Figure 5. Measurements of the breast attenuation coefficient of breast tissues by White et al.[9] were consistently higher than our values. The mass attenuation coefficients of the hydrophilic materials are consistently lower than the calculated Breast 1 values, except at 28.43 keV. In fact, from Figure 5, the data points for all states of the hydrophilic copolymer samples are closer to the calculated Breast 3.



(a)



(b)

Figure 5: Measured and calculated mass attenuation coefficients of hydrophilic copolymer materials: (a) ED1S sample and (b) ED4C sample. Error bars for dry samples are shown (fhw = fully hydrated with water, fhs = fully hydrated with saline).

The percentage deviation of the mass attenuation coefficients of all states of ED1S and ED4C from the calculated Breast 3 values are shown in Figure 6. Dry ED1S and ED4C samples have the least deviation from calculated Breast 3, which

means that they are quite similar to old-age breast. Their mass attenuation coefficients are within 50% of the percentage deviation. Another point to note is that there is no marked or specific difference between the mass attenuation coefficients of ED1S and ED4C against photon energy.

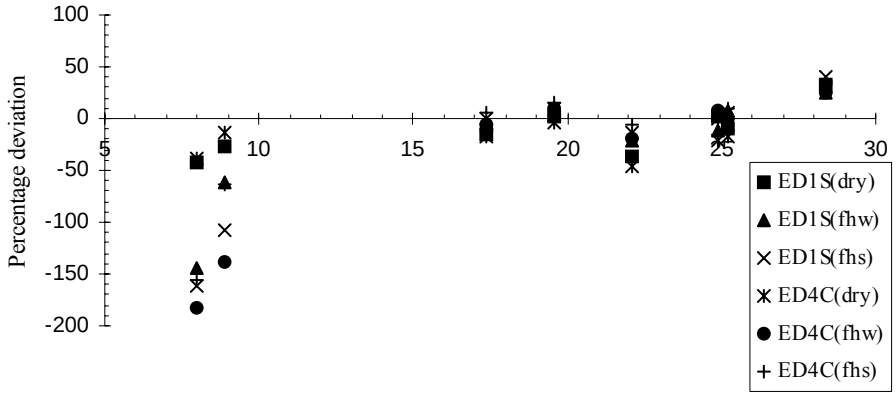


Figure 6: Percentage deviation of the mass attenuation coefficients of the different states of ED1S and ED4C with respect to the calculated Breast 3 values

Hydrated samples too have their mass attenuation coefficients percentage deviation within 50% of the calculated values except at energies below 10 keV where their percentage deviation are more than 50%. The higher percentage deviations are at the copper target XRF energies of 8.02 and 8.89 keV. Since hydrated samples increased in size, more low energy photons were absorbed. Further studies need to be carried out to determine the optimum sample size for each particular photon energy.

4. CONCLUSION

Dry ED1S and ED4C hydrophilic copolymer materials have comparable mass attenuation coefficients as that of the old-age breast tissue.

5. AKNOWLEDGEMENT

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6. REFERENCES

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