Photon Dose Enhancement Ratio at the Transition Region of Dissimilar Media

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***Abstract*—Accurate measurement was carried out for the dose gradient in Teflon irradiated with filtered X-ray spectra having effective energies of 40 keV and 55 keV when in contact with aluminum, titanium, copper, and tin. At low photon energies, the interface region is only extended for about 10 microns from the interface, therefore, ultra-thin LiF/Teflon discs of the order of 3 microns thick was developed and used to measure directly the dose gradient in Teflon. Due to the relatively large slope of the depth dose curves near the interfaces, a displacement correction factor was introduced to determine the effective measuring point of the detector. A fitting exponential formula is suggested and used to estimate the dose gradient for Bone-Teflon interface. The interface dose for Bone-Teflon is 3.8 times the equilibrium dose at 70 KV, while it is about 3.1 at 100 KV.**

***Index Terms*—Buildup dose, effective energy, radiation, transition region.**

I. Introduction

Radiation dose distribution at interfaces region between dissimilar media are of wide interest in for example, the application of X-ray and gamma rays in the treatment where the presence of air cavity disturb the photon field in a region between tissue-air inside the lungs (Shiu and Hogstrom, 1991; Li XA and Holmes, 2000; Joshi, et al., 2010; Chandra, et al., 2010), in radiotherapy treatment of head and neck (Kinhikar, et al., 2014), in diagnostic radiology where tissue are in contact with high atomic number medium (Nicopoulou-Karayianni, et al., 2003), in radiological protection and nuclear shielding engineering problems, and in the induced of hard and soft errors in VLSI solid state circuitry (Das, et al., 2001). For biophysical application, the effects of low energy photon field are of special importance for several reasons:

1- The biophysical effectiveness of secondary electrons reaches a maximum at energies between 250 eV and 50 keV.
2- The dose in soft tissue near an interface with material of higher atomic number can exceed the equilibrium dose because of the contributions from back scattering and photoelectrons.
3- Attempts to correlate the sparse experimental data with theories had indicated the need for more detailed experimental information.

II. Material and Method

Accurate measurements were made to assess the dose gradient in Teflon taken as a typical example of low atomic number material, in contact with aluminum, titanium, copper, and tin irradiated with filtered X-ray spectra having effective energies of 40 keV (70 KV) and 55 keV (100 KV). For simplicity, plane interface geometry was used in the measurements. Since the transition region extended only for a distance of about 10 microns from the interface, ultra-thin, 30% by weight, LiF/Teflon TLD of 3 micron thick was developed in our laboratory. The ultra-thin discs were first soft and difficult to handle. This problem was overcome by sandwiching the soft discs between two micro-slides glass in an oven at a temperature of 280 $^{\circ}$C for two hours. The micro-discs become rigid and more easily to be handled by vacuum tweezers. The average weight of the discs determined immediately after cutting was $0.18\,mg$ with accuracy not worse than $\pm 0.015\,mg$. Direct measurement of the disc thickness with a standard digital micrometer yield values of the order of 3 ± 0.5 microns. The thickness was also checked by a Mercer digital metric gauge unit type 122D. An average value of $3 \pm 0.5\,microns$ was assumed for all discs. Measurements of the dose gradient, the build-up factor, were carried-out by increasing the separation distance between the detector and the high atomic number media, see Fig. 1.

The radiation beam was directed perpendicularly to the surface of an approximately cylindrical phantom of Teflon plastic. The entrance field, symmetrically situated on the phantom surface, was 1.0 cm diameter defined by means of a special mask made of, lead, copper, aluminum, and Perspex (Al-Arif, 2013b). The mask was arranged so that the material nearest to the detector was the material with the lowest k-edge.

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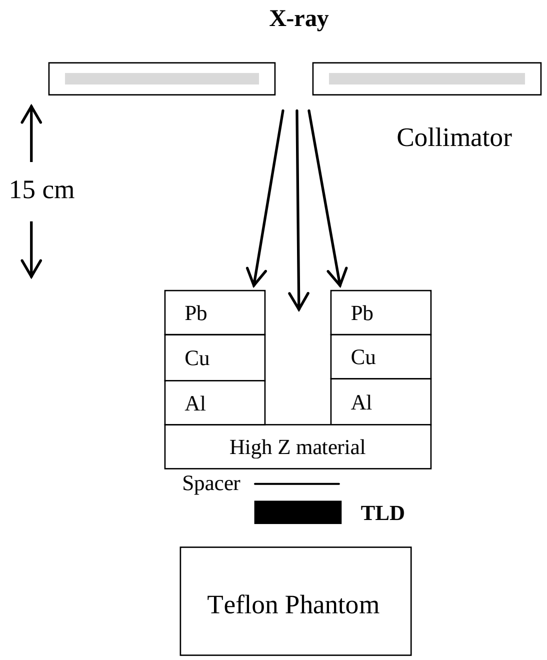

Fig.1. Experimental setup for dose gradient measurement.

The materials with progressively higher k-edges were mounted on the top of this. Thus, the incident spectrum progressively degenerated to negligible proportions in the graded absorber.

The ultra-thin discs were placed in between the high and the low atomic number media. In practice, it is desirable to know to what degree the dose to a low atomic number medium has been increased by the presence of higher atomic number medium. Thus rather than measure the absolute dose values, the dose build up ratio were determined. Each measurement for the dose gradient was repeated five times. The standard deviations of the mean were calculated, see Table I and Table II. The light outputs from the TLD detectors were normalized to unit weight and recorded as TL/mg. The thickness of each high atomic number material was chosen to be greater than the maximum electron range generated to ensure that the electronic equilibrium was established but sufficiently thin so that attenuation of the X-ray beam did not cause a significant quality change. The thicknesses chosen were 60, 50, 25, and 30 microns respectively. Due to the relative sharp dose gradient near to the interface, theoretical displacement correction factor were calculated and used to specify the effective measuring point of the 3 micron TLD discs at the transition region (Al-Arif, 2013a).

III. Results and Discussion

Tables I and II show the displacement correction factor, the measured dose buildup ratio and the effective measuring point of the TLD's at the transition region for the two effective X-ray energies used in this study.

The displacement correction factors shown in the above tables vary with the dose stress ranging from maximum value at the interface to a zero at the equilibrium region. Accordingly the effective measuring point of the TLD shifted toward the radiation stress near to the interface and gradually decreases toward the equilibrium region.

TABLE I
THE MEASURED DOSE BUILD-UP RATIO AT 40 KEV X-RAY EFFECTIVE ENERGY

Interface	Spacer Thickness (microns)	Effective Measuring Point (microns)	Dose Build-up Ratio ± SD
Al - Teflon	0.0	1.46	2.03±0.09
	1.0	2.48	1.70±0.07
	2.0	3.48	1.42±0.09
	4.0	5.49	1.21±0.06
	6.0	7.49	1.04±0.06
Ti-Teflon	0.0	1.39	7.09±0.17
	1.0	2.44	4.50±0.07
	2.0	3.46	3.01±0.07
	3.0	4.46	2.42±0.06
	4.0	5.47	1.42±0.07
	5.0	6.47	1.05±0.05
	6.0	7.48	1.00±0.03
Cu-Teflon	0.0	1.36	11.56±0.15
	1.0	2.42	6.10±0.05
	2.0	3.45	4.20±0.05
	3.0	4.46	2.65±0.02
	6.0	7.47	1.04±0.02
Sn-Teflon	0.0	1.34	18.2±0.42
	1.0	2.41	8.30±0.11
	3.0	4.45	3.92±0.10
	4.0	5.46	1.75±0.03
	6.0	7.47	1.02±0.02

TABLE II
THE MEASURED DOSE BUILD-UP RATION AT 55 KEV X-RAY EFFECTIVE ENERGY

Interface	Spacer Thickness (microns)	Effective Measuring Point (microns)	Dose Build-up ratio± SD
Al - Teflon	0.0	1.47	1.75±0.12
	1.0	2.48	1.59±0.10
	2.0	3.48	1.42±0.04
	3.0	4.49	1.31±0.04
	4.0	5.49	1.09±0.07
	6.0	7.49	1.02±0.07
Ti-Teflon	0.0	1.41	5.54±0.33
	1.0	2.45	3.90±0.23
	2.0	3.46	3.20±0.20
	3.0	4.47	2.38±0.15
	5.0	6.47	1.15±0.15
	6.0	7.48	1.02±0.12
Cu-Teflon	0.0	1.37	9.10±0.19
	1.0	2.43	6.80±0.13
	3.0	4.46	3.30±0.08
	4.0	5.47	2.60±0.09
	5.0	6.47	1.25±0.04
Sn-Teflon	0.0	1.36	14.0±0.36
	1.0	2.43	7.20±0.19
	2.0	3.46	4.10±0.10
	4.0	5.46	3.00±0.06
	6.0	7.47	1.03±0.06

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Since the normalized dose build-up ratio, D, varies between 1.0 at the equilibrium region and a high value at the transition region, the formula suggested for the normalized dose build-up ratio is;

$$D = 1 + K \quad (1)$$

where; K is the increase in the normalized dose build-up ratio at the interface region above the equilibrium dose. The K-factor can be fitted very well by an exponential function of the following form.

$$K = \alpha\, e^{-\beta x} \quad (2)$$

where; α, β are constants for specific energy and material type, and x refer to the distance from the interface. The K-factor, for both X-ray qualities are shown in Figs. 2, 3, 4 and 5.

The constants, α, and β varies linearly with the atomic number as can be seen in Fig. 6 and Fig. 7. We can see that both, α, and β are increases with photon energy.

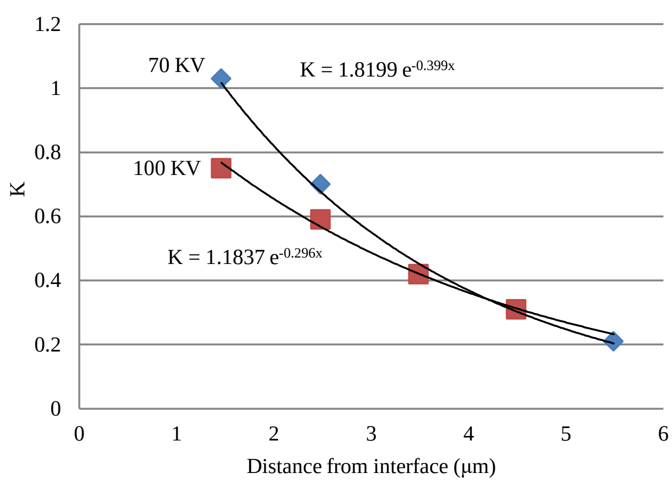

Fig. 2. The K-factor of Al-Teflon interface for 70 KV and 100 KV X-ray potentials.

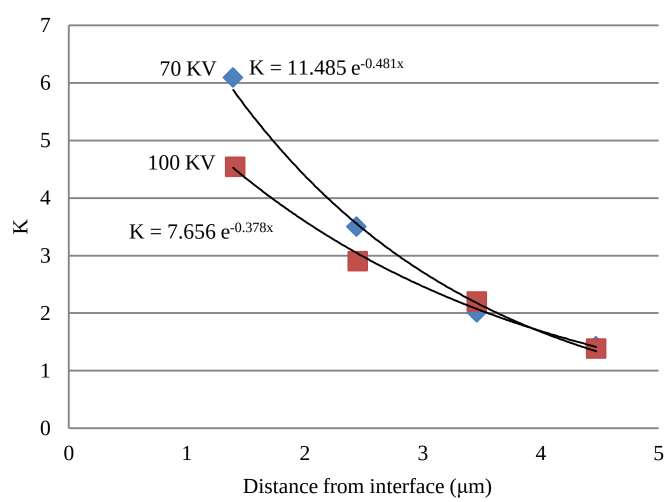

Fig. 3. The K-factor of Ti-Teflon interface for 70 KV and 100 KV X-ray potentials.

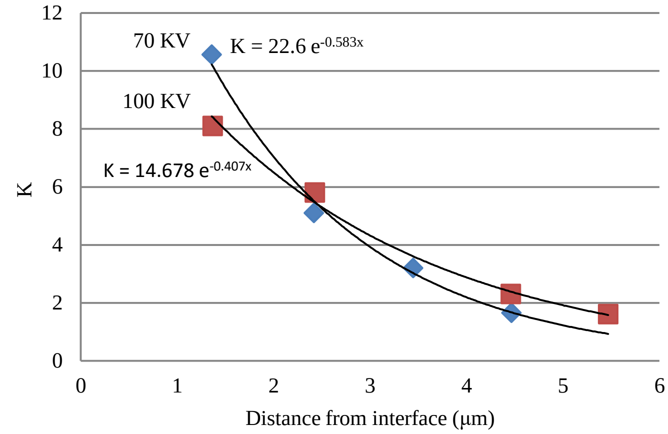

Fig. 4. The K-factor of Cu-Teflon interface for 70 KV and 100 KV X-ray potentials.

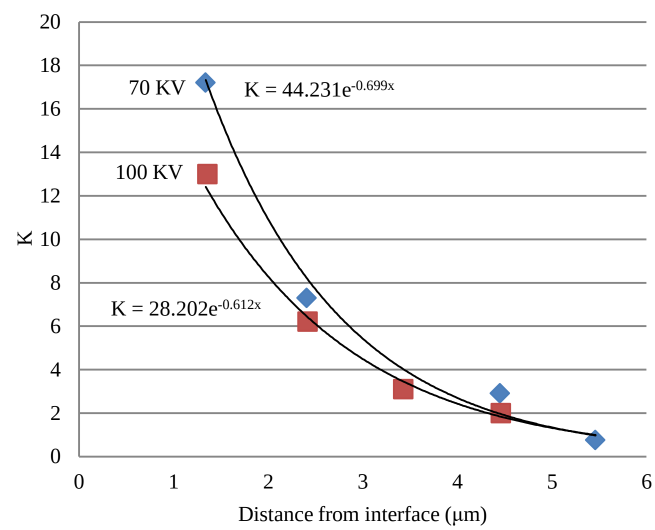

Fig. 5. The K-factor of Sn-Teflon interface for 70 KV and 100 KV X-ray potentials.

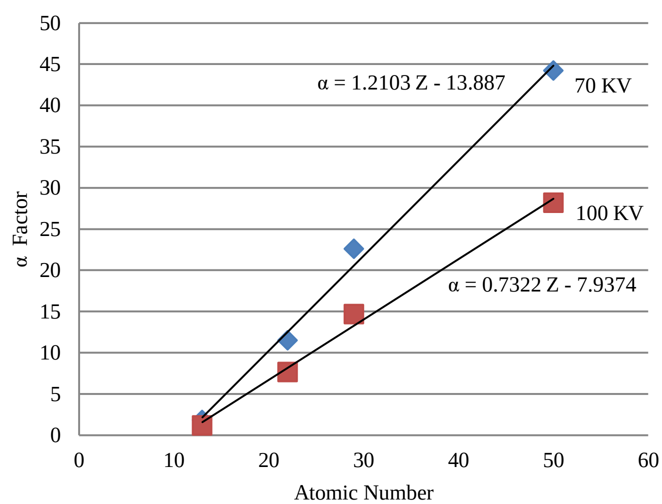

Fig. 6. Variation of α-factor with atomic number.

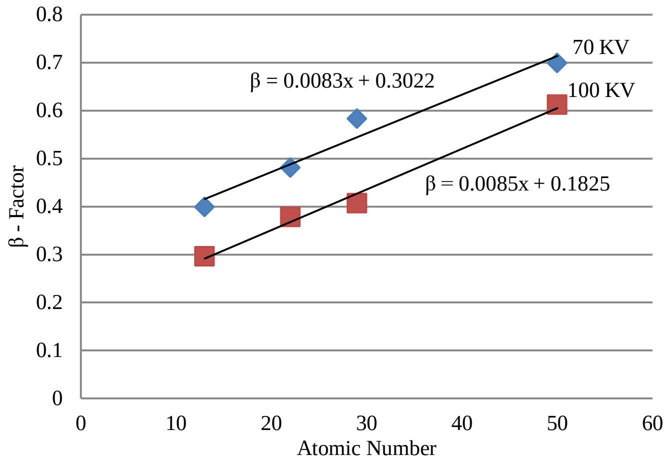

Fig. 7. Variation of *β*-factor with atomic number.

The formula of (1) is used to estimate the normalized build-up factor for Bone-Teflon interface for both X-ray qualities.

For bone, $Z \approx 14$, in contact with Teflon, $\alpha = 3.0572$, $\beta = 0.3015$, at 100 KV, while $\alpha = 2.3134$, $\beta = 0.4148$ at 70 KV. The calculated dose build-up, *D*, at the interface is 3.8 times the equilibrium dose 70 KV, while it is about 3.1 at 100 KV, see Fig. 8.

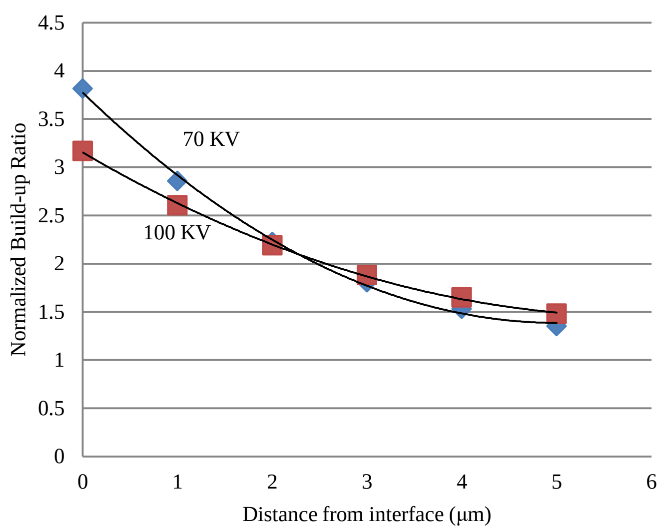

Fig. 8. Estimated normalized dose build-up ratio for Bone-Teflon interface at 70 KV and 100 KV X-ray potentials.

IV. Conclusion

Since the experimental data for the dose build-up ratio at low photon energies are very rare due to the technical problems concerning the need of a very thin dosimeter which is unavailable commercially. The ultra-thin TLD developed in our laboratory are excellently used to have 4 to 5 experimental dose readings at the transition region which is only extended for about 10 microns. The present experiment results become valuable source of data at the transition region at low photon energies. The increases in the normalized dose build-up ratio, *K*-factor, are smoothly fitted by an exponential formula, (2). The formula is used to estimate the normalized dose buildup ratio in Teflon when in contact with Bone. Since the physical absorption and scattering properties of Teflon are close to that for soft tissue, the calculated dose build-up ratio for Bone-Teflon interface indicates that extra care must be considered in determining the dose to Bone Marrow, and soft tissue in contact with Bone at the diagnostic energy range.

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