The effect of low energy X-rays on the measurement of absorbed dose using TLD-100 dosimeters in radiological studies

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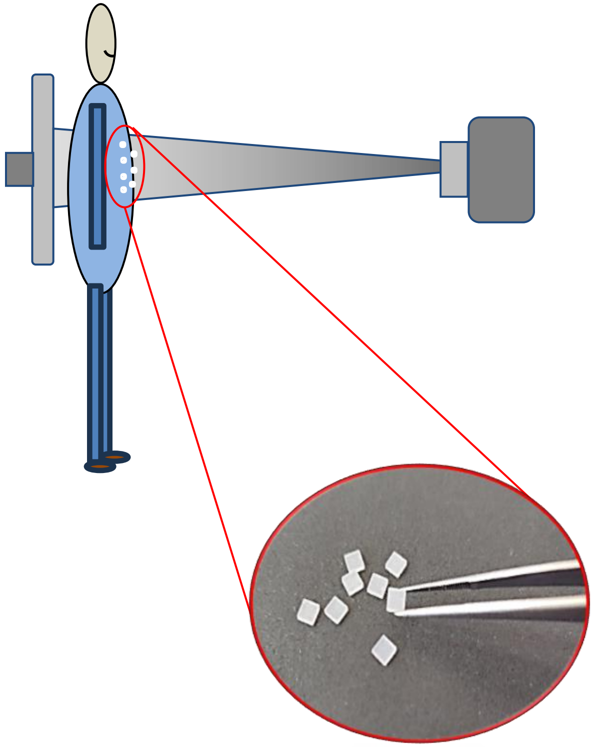
Introduction



- Radiation risk calculation of patients in diagnostic and therapeutic radiology, it is very important to measure the absorbed dose at the exposed region. Radiation detectors such as ionization chambers, solid state detectors, luminescence dosimeters are the most routinary method to measure the radiation dose.

- As a conventional method, Thermoluminescence dosimeters (TLD) are preferred as well as passive dosimeters due to their **small size** and the ability to be **placed in exposed areas simultaneously** without creating a shadow effect or artifact on the image.

- TLD 100 (LiF:Mg,Ti). is the most commonly used dosimeter for dose measurements in the medical field. The effective atomic number of TLD-100 dosimeter (Z_{eff} = 8.2) is very close to soft tissue (, its energy dependence is low (at the energies above 100 keV), it can be produced in millimetric geometries, its linear dose-response range is quite wide (from µGy to Gy orders).

Aim

In diagnostic and interventional radiology where low-energy X-rays (<100 keV) are used, the dosimeter used to determine the absorbed dose by the Thermoluminescence (TL) method must be calibrated according to a known radiation dose. Photon sources such as ^{137}C and ^{60}Co are preferred in dose calibration due to their monoenergetic spectrum. However, while the energy dependence of most dosimeters is quite low at high energies, the energy dependence of the response of TLD is high in low energy regions (Fig. 1). This causes the luminescence signal intensity of TLDs to be observed to be higher in irradiation at low energies. In low energy radiological studies, in this case, the energy dependence of the dosimeter irradiated at low energies must be taken into account.

The aim of this study is to examine the effect of energy dependence on the response of TLDs (energy response) in the calibration to be used in determining the radiation dose in radiological irradiations using low energy X-rays (<100 keV).

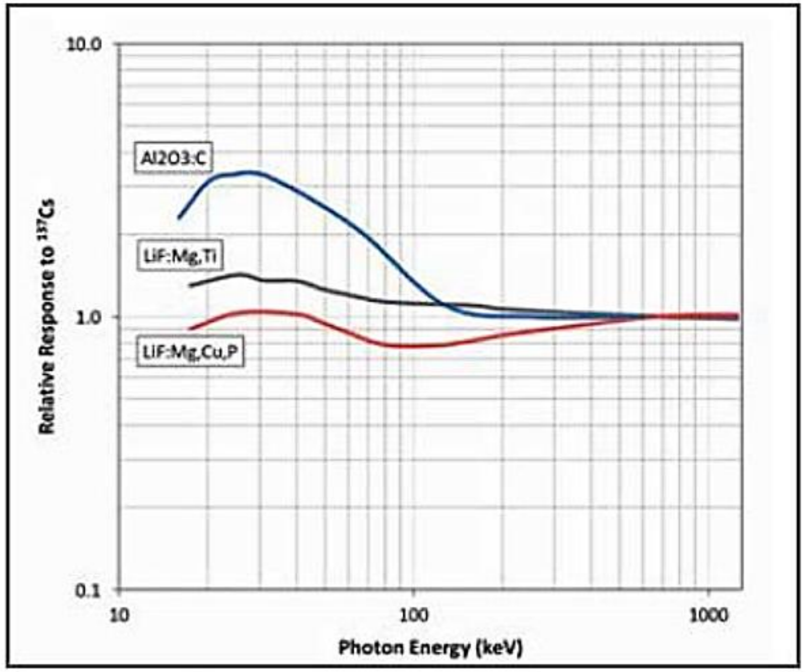


Fig.1 Photon energy response of some different materials (Ref.: https://www.admnucleartechnologies.com.au/blog/tld-badges-and-monitoring-materials)

Materials and Methods

- **TLD-100 chips** (LiF:Mg,Ti), Thermo Scientific Co., USA, 3.2 x 3.2 x 0.89 mm (Fig. 2)
- Dosimeters were annealed at 400 °C for 1 hour followed by fast cooling to 100 °C and then kept at 100 °C for 2 hours. After irradiations, dosimeters were heated up to 100 °C for 30 minutes to erase the shallow traps. Glow curves of dosimeters were obtained by heating up to 300 °C by a heating rate of 10 °C using Harshaw 3500 model TL Reader.
- **5 mGy was used as the test dose** to calibrate dosimeters
- Given radiation doses were measured with a 6 cc ion chamber (Radcal Corporation, calibrated at SSDL) (Fig.3).
- **X-ray irradiations** were performed in a conventional X-ray system (General Electric Silhouette VR) at different peak voltages (V_i (kVp) = 40, 60, 80, 100, 120) (Fig. 4)

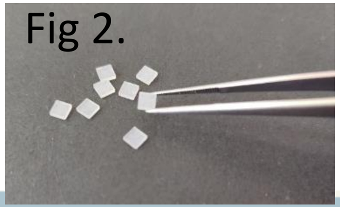


Fig 2.

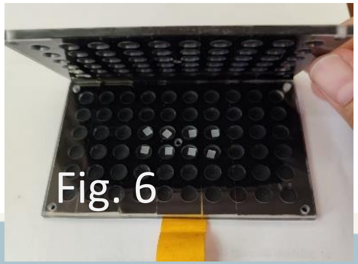


Fig. 6

X-ray irradiations


Fig. 3


Fig. 4

γ irradiation (^{137}Cs)


Fig. 5

Dosimeters were irradiated with a **^{137}Cs photon source** ($E\gamma$ = 661.7 keV) to compare the TL intensities obtained as a result of low and high energy irradiation and also to obtain whether the change in sensitivity depending on the energy (Fig. 5).

During irradiations, dosimeters were placed in a **3 mm thick holder made of plexiglass**. Additionally, dosimeters were placed at a height of 10 cm from the table in order to reduce the effect of backscatter on the absorbed dose when irradiating with X-rays (Fig. 6).

The energy spectra of irradiations at different tube voltages were simulated using **XCOMP5R** software (Nowotny and Höfer 1985) and the mean energy of the beams were determined from the software.

Ref. :Nowotny, R. and Hofer, A. (1985) Ein program fur die berechnung von diagnostischen Rontgenspektren. Fortschr Rontgenstr, 142, 685-689. http://dx.doi.org/10.1055/s-2008-1052738

Calculation of X-ray spectra - XCOMP5R v. 3.5

Nowotny and Höfer 1985

Inputs:

Tube voltage (kVp) = V_i
Anode angle (°)= 12
Focal to detector distance (cm) = 100
HVL (mmAl) = HVL_i

Output:

E_{mean} (i) (keV)
Energy spectrum data (Fig. 7)

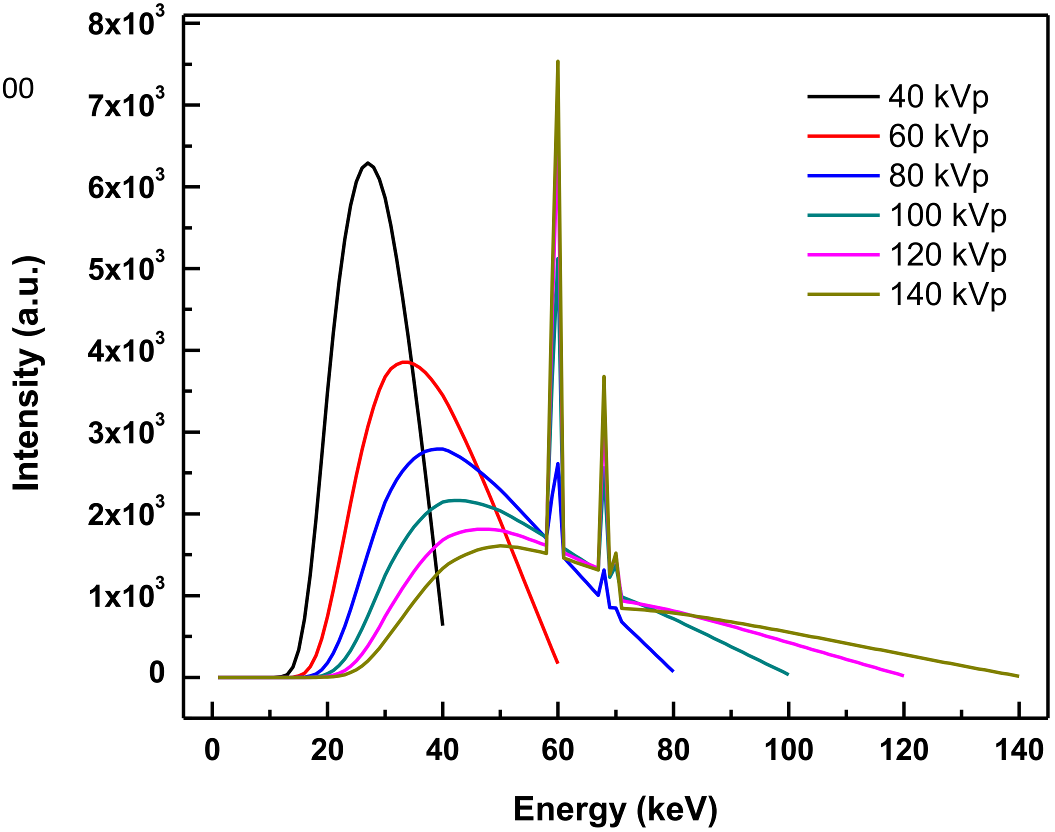


Fig. 7 Some examples of energy spectra simulated by XCOMP5R

V_i (kVp)	HVL_i* (mmAl)	E_{mean}(i) (keV)
30	1.313	20.3
40	1.811	24.7
50	2.499	28.6
60	2.987	32.4
70	3.405	36.1
80	3.903	40.3
90	4.401	44.4
100	4.899	48.5
110	5.397	52.5
120	5.895	56.6
130	6.493	60.6
140	6.991	64.8

**HVL*: Half Value Layer, *HVL* is defined as the thickness of Aluminum required to halve the initial intensity.

Results and Discussion

Irradiation source	Tube Voltage (kVp)	*HVL*[a] (mmAl)	E_{mean}[b] (keV)	TL Intensity (a.u.)	Normalized TL Intensity[c] (a.u.)	μ_{en}/ρ[d] (cm^2/g)
X-ray	30	1.313	20.3	-	-	0.6354
	40	1.811	24.7	236 ± 17	1.53 ± 0.11	0.4300
	50	2.499	28.6	-	-	0.2480
	60	2.987	32.4	243 ± 14	1.58 ± 0.09	0.1577
	70	3.405	36.1	-	-	0.1193
	80	3.903	40.3	252 ± 16	1.64 ± 0.10	0.0779
	90	4.401	44.4	-	-	0.0612
	100	4.899	48.5	259 ± 18	1.68 ± 0.12	0.0504
	110	5.397	52.5	-	-	0.0421
	120	5.895	56.6	261 ± 17	1.69 ± 0.11	0.0367
	130	6.493	60.6	-	-	0.0320
	140	6.991	64.8	-	-	0.0302
^{137}Cs photon	-	-	661.7	154 ± 29	1 ± 0.19	0.0027

[a] *HVL* was determined experimentally

[b] Mean beam energy (E_{mean}) was obtained from XCOMP5R software.

[c] TL intensities obtained as a result of X-ray irradiation were normalized according to the TL intensity of the dosimeters irradiated with ^{137}Cs photon source.

[d] The mass energy absorption coefficients (μ_{en}/ρ) were obtained by linear interpolation according to the E_{mean} values using the $\mu_{en}/\rho_{(NIST)}$ given by NIST for discrete photon energies of LiF (Ref.: https://physics.nist.gov/PhyRefData/XrayMassCoef/ComTab/lithiumflu.html).

Results and Discussion

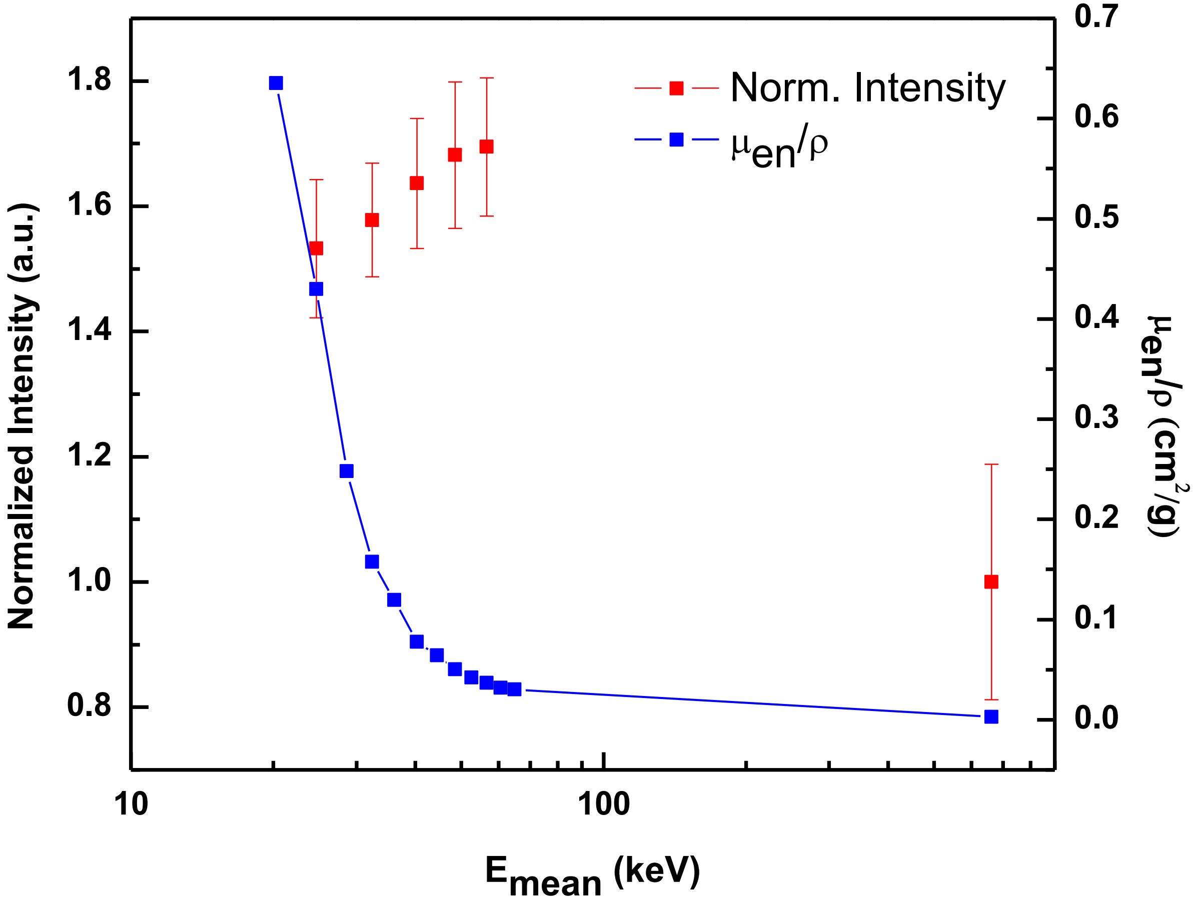


Fig. 8 Variation in TL intensity and mass energy absorption coefficients as a function of the mean energy of X-rays and ^{137}Cs gamma source used for irradiation

Although the same calibration dose was given at different beam energies, higher TL intensity was obtained in irradiation with low energy X-rays (<100 keV) compared to the TL intensity obtained from dosimeters irradiated with ^{137}Cs (661.7 keV).

As observed in Fig. 8, it is observed that there is an energy dependence in the mass absorption coefficients for irradiations below 100 keV, according to the photon energies calculated from NIST data.

The TL intensities obtained as a result of irradiation of dosimeters varies depending on the absorbed dose. However, in this study, dosimeters were irradiated with the same radiation dose at different energies. In this case, while the TL intensity was expected to remain unchanged, it was observed that the intensity changed during irradiation at energies up to 100 keV. This shows the effect of beam energy on the interaction of matter with radiation and therefore on the absorbed dose.

Conclusion

The emitted TL intensity (I) is proportional to the absorbed dose (D) and, once calibrated to a known dose, can be used to evaluate the applied dose in the radiation field.

$$I \propto D$$

With this study, it is observed that if the dosimeters to be used in radiological studies where irradiation is performed at low energies are calibrated at high energies, *the dose results will be overestimated and may cause incorrect dose results*.

Therefore, it has been observed that TLD-100 dosimeters irradiated with a high energy photon source have an increase in TL sensitivity when irradiated with the same dose with low-energy X-rays at 40-120 kVp. This result shows that if TLD-100 dosimeters are used for radiation dose measurement in radiological studies performed with low-energy X-rays, dose-response calibration should be performed with the same tube voltage/energy spectrum planned in the study. Only then the absorption of radiation in the relevant tissue can be measured or compared with the TLD-100 dosimeter. **TL dosimeters can be used to measure the absorbed dose after calibration performed at the same energy as the energy used during treatment.**

I would like to thank Prof. Dr. Turan OLĞAR for providing the opportunity to use the facilities of Ankara University, Institute of Nuclear Sciences, Imaging and Diagnostic Radiology Laboratory

Thank you for the attention!