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Measuring Thermo-luminescence Efficiency of TLD-2000 Detectors to Different Energy Photons

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ABSTRACT

Background: As an important detecting device, TLD is a widely used in the radiation monitoring. It is essential for us to study the property of detecting element. The aim of this study is to calculate the thermo-luminescence efficiency of TL elements.

Materials and Methods: A batch of thermo-luminescence elements were irradiated by the filtered X-ray beams of average energies in the range 40-200 kVp, 662 keV ^{137}Cs gamma rays and then the amounts of lights were measured by the TL reader. The deposition energies in elements were calculated by theory formula and Monte Carlo simulation. The unit absorbed dose in elements by photons with different energies corresponding to the amounts of lights was calculated, which is called the thermo luminescent efficiency ($\eta(E)$). Because of the amounts of lights can be calculated by the absorbed dose in elements multiply $\eta(E)$, the $\eta(E)$ can be calculated by the experimental data (the amounts of lights) divided by absorbed dose.

Results and Discussion: The deviation of simulation results compared with theoretical calculation results were less than 5%, so the absorbed dose in elements was calculated by simulation results in here. The change range of $\eta(E)$ value, relative to 662 keV ^{137}Cs gamma rays, is about 30% in the energy range of 33 keV to 662 keV, is in accordance by the comparison with relevant foreign literatures.

Conclusion: The $\eta(E)$ values can be used for updating the amounts of lights that are got by the direct ratio assumed relations with deposition energy in TL elements, which can largely reduce the error of calculation results of the amounts of lights. These data can be used for the design of individual dosimeter which used TLD-2000 thermo-luminescence elements, also have a certain reference value for manufacturer to improve the energy-response performance of TL elements by formulation adjustment.

Keywords: Thermo-luminescence efficiency, Monte Carlo model, Personal dosimeter

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1. INTRODUCTION

The thermo-luminescence dosimeter is an important device in the dose monitoring. Though thermo-luminescence dosimeter and related monitoring technology have already developed for decades and is mature relatively, the new thermo-luminescence materials, dosimeters and reading technologies are still continuing to bring out. Monte Carlo method has been widely used in the design of new thermo-luminescence dosimeter [1]. When a batch of thermo-luminescence elements were irradiated by the filtered X-rays and gamma rays with different energies, their thermo luminescence efficiency, which is unit absorbed dose in the elements corresponding to the amounts of lights, tend to be different. The thermo-luminescence efficiency parameter is used to modify the amounts of lights calculated by the direct ratio assumed relations with energy deposition in the TL elements for the different energy of photons. This study designed the experiment, got the range of data that unit deposition energy in elements correspond to the amounts of lights when thermo-luminescence elements, TL-2000 elements, were irradiated by photons with different energies, in order to lay a basis for establishing the more accurate model of thermo-luminescence dosimeter (TLD).

The photon energy response in TL elements usually normalized to the air kerma, which indicated that the TL elements are irradiated by unit air kerma leading to the amounts of lights. The absorbed dose in TL elements and air kerma tend to be different. Founding the equation is shown as the following:

$$\mathrm{S(E)} = \eta(E)\mu'(E) = \eta(E)\frac{(\mu_{en}/\rho)_{\mathrm{TLD}}}{(\mu_{en}/\rho)_{air}} \cdots\cdots\cdots\cdots (1)$$

Where $S(E)$ indicates that unit air kerma lead to the amounts of lights in TL elements, and $\mu'(E)$ is the ratio of the energy-dependent mass energy absorption coefficients of the thermo-luminescence material $(\mu_{en}/\rho)_{LiF}$, and that of air, $(\mu_{en}/\rho)_{air}$, which physical meaning is absorbed dose in TL element normalized to the air kerma. The relative TL efficiency, $\eta(E)$, which responds the range of luminance of the elements in case of the identical absorbed dose of TL materials that are irradiated with the different energy of the filtered X and gamma rays. The phenomenon of the change of $\eta(E)$ values can be explained by the principle of microdosimetry [2], which indicates that the ionization density of the TL materials irradiated by the different energy photons are various, which will make $\eta(E)$ values various. Under conditions of secondary electron equilibrium, the ionization density of the TL materials is intimately related to the energy of photons, but the surrounding materials of TL elements have a negligible effect on the density of ionization. As a result, when constructing Monte Carlo model of individual dosimeter, we can modify the assumed condition that the deposition energy is proportional to luminescent quantity by means of the various rules of $\eta(E)$ values, which will attain the more correct result. The foreign bibliographic data indicate that the amounts of lights given through the deposition energy in TL elements are modified by $\eta(E)$ values, which is a familiar method [3]. The $\eta(E)$ values may depend on many other factors such as the type of dopants, the amounts of dopants, grain size and the materials surrounding the grains and the TL etc. Even if using the identical materials, which produced by the different manufactures can cause $\eta(E)$ values diversely. The $\eta(E)$ values can be measured by the experiment, which may make the using $\eta(E)$ values correct.

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2. Materials and Methods

2.1 Experimental materials

The wafer type TL elements (TLD-2000) are commercially produced at Beijing Conqueror Electronic Co. Ltd (Beijing, China), dimension: Φ4.5×0.8 mm. The dose pill (TLD-2000) described in this article in fact only refers to this dimension, which will not repeat.

2.2 Experimental procedure

The TL elements selected uniformity within ±3%, were annealed at 240℃ for 10 min and cooled rapidly to room temperature. The elements were packed in 80 mg·cm^{-2} thick, white polyethylene plastic bags and irradiated free-in-air. The main purpose of plastic bags met the conditions of secondary electron equilibrium, also can make a supporting role.

The dose pills packed the plastic bags were irradiated by the filtered X-rays (40 kV, 60 kV, 80 kV, 100 kV, 120 kV, 150 kV, and 200 kV) and ^{137}Cs gamma ray which were provided through China Institution for Radiation Protection Radioactive Metrology Station. The air kerma of radiation field was 1 mGy. In the irradiation process, the normal directions of the surface of dose pills were parallel to the incident directions of rays. In order to reduce the

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error, we took five dose pills as a term that was irradiated in the experiment. The experimental results were average. After the irradiation, the elements were measured by the TL reader (TLD-3500).

3. RESULTS AND DISCUSSION

3.1 Calculation of Absorbed Dose in the Dose Pills

The absorbed dose was calculated by two methods: one for according to the principle of dosimetry, using theoretical formula to calculate; the other for using the Monte Carlo method to calculate the deposition energy in the dose pills, then the results were divided by mass (TL element), which got the absorbed dose. Two methods were as follows:

3.1.1 Computational Method of Theoretical Formula

The absorbed dose was calculated by the following formula:

$$D_{\mathrm{LiF}} = D_{\mathrm{air}} \bullet \frac{(\mu_{en}/\rho)_{LiF}}{(\mu_{en}/\rho)_{air}} \cdots\cdots\cdots\cdots(2)$$

The mass absorption energy coefficients for each material (μ_{en}/ρ) was calculated by weighting the corresponding coefficients for elements according to their relative weight content, w_i, in the material, as follows:

$$\left(\frac{\mu_{\mathrm{en}}}{\rho}\right) = \sum_{i=1}^{N} w_i \left(\frac{\mu_{\mathrm{en}}}{\rho}\right)_i, \sum_{i=1}^{N} w_i = 1 \cdots\cdots\cdots\cdots(3)$$

The component elements for TL material (TLD-2000) were Li, F, Mg, Cu, P, H, O, and the w_i coefficients for Li, Mg, Cu, P, H, O were equal to 0.254366, 0.696269, 0.00086, 0.000228, 0.015062, 0.00147, and 0.031745; The assumed component elements for air were H, C, N, O, Ar, and the w_i coefficients for H, C, N, O, Ar were equal to 0.0006, 0.0001, 0.7509, 0.2356, and 0.0128, respectively, the values of μ_{en}/ρ for all these elements and for air, were taken from Hubbell [4]. The computational results were as follows:

Table 1. Computational Results of the μ_{en}/ρ Value in the TL Material

Radiation medium	Corresponding radiation energy*(keV)	The μ_{en}/ρ values of each element in TL material							The μ_{en}/ρ values of TL material
		Li	F	Mg	Cu	P	H	O	
40 kV	33	0.00112	0.01986	0.05562	0.78193	0.11562	0.00200	0.01403	0.01653
60 kV	48	0.00121	0.00655	0.01701	0.25914	0.03507	0.00263	0.00494	0.00563
80 kV	65	0.00142	0.00355	0.00769	0.11073	0.01488	0.00320	0.00299	0.00319
100 kV	83	0.00162	0.00262	0.00445	0.05200	0.00758	0.00369	0.00244	0.00245
120 kV	100	0.00178	0.00239	0.00339	0.02952	0.00504	0.00406	0.00235	0.00228
150 kV	118	0.00189	0.00240	0.00317	0.02260	0.00437	0.00433	0.00240	0.00231
200 kV	164	0.00215	0.00245	0.00276	0.00940	0.00310	0.00494	0.00255	0.00239
^{137}Cs	662	0.00254	0.00278	0.00290	0.00279	0.00285	0.00583	0.00294	0.00273

* For the X-rays, which refer to average energy

Table 2. Computational Results of the μ_{en}/ρ Value for Air

Radiation medium	Corresponding radiation energy* (keV)	The μ_{en}/ρ values of each element in the air					The μ_{en}/ρ values of air
		H	C	N	O	Ar	
40 kV	33	0.00200	0.00547	0.00896	0.01403	0.19416	0.01252
60 kV	48	0.00263	0.00254	0.00352	0.00494	0.05944	0.00457
80 kV	65	0.00320	0.00207	0.00244	0.00299	0.02478	0.00286
100 kV	83	0.00369	0.00205	0.00220	0.00244	0.01190	0.00238
120 kV	100	0.00406	0.00214	0.00223	0.00235	0.00731	0.00232
150 kV	118	0.00433	0.00225	0.00231	0.00240	0.00601	0.00238
200 kV	164	0.00494	0.00251	0.00252	0.00255	0.00350	0.00254
^{137}Cs	662	0.00583	0.00293	0.00293	0.00294	0.00266	0.00293

* For the X-rays, which refer to average energy

Table 3. The Deposition Energy and Absorbed Dose of Pills (TLD-2000) Irradiated by different Energy Rays under the Air Kerma of 1 mGy

Radiation medium	Mean energy of rays (keV)	Deposition energy of mean single particle in the dose pill（MeV）	Absorbed dose of simulation computation in the dose pill (mGy)	Absorbed dose of theoretical computation in the dose pill（mGy）	Deviation of simulation results with the theoretical calculation results
40 kV	33	2.88×10^{-9}	1.32	1.32	0%
60 kV	48	1.54×10^{-9}	1.27	1.23	3.3%
80 kV	65	1.17×10^{-9}	1.17	1.12	4.5%
100 kV	83	1.14×10^{-9}	1.06	1.03	2.9%
120 kV	100	1.25×10^{-9}	0.987	0.983	0.41%
150 kV	118	1.46×10^{-9}	0.962	0.971	-0.93%
200 kV	164	2.03×10^{-9}	0.935	0.941	-0.64%
^{137}Cs	662	9.73×10^{-9}	0.941	0.932	0.97%

* Pill mass: 0.0335 g

Table 4. The Amounts of Lights of Dose Pills (TLD-2000) which was Irradiated by Different Energy Rays under the Air Kerma of 1 mGy

Radiation medium	Mean energy of rays(keV)	$\frac{(\mu_{en}/\rho)_{LiF}}{(\mu_{en}/\rho)_{air}}$	Reading of reader（S(E)）(μC)	Absorbed dose of simulation computation in the dose pill（$\eta(E)$）(mGy)	Unit deposition energy correspond to the amounts of lights（$\eta(E)$）(μC·mGy^{-1})	
					The amounts of lights toward per mGy absorbed dose	The amounts of lights toward per MeV deposition energy*
40 kV	33	1.32	0.677	1.32	0.511	2.44×10^{-6}
60 kV	48	1.23	0.653	1.27	0.513	2.46×10^{-6}
80 kV	65	1.12	0.591	1.17	0.504	2.41×10^{-6}
100 kV	83	1.03	0.499	1.06	0.470	2.25×10^{-6}
120 kV	100	0.983	0.465	0.987	0.472	2.26×10^{-6}
150 kV	118	0.971	0.492	0.962	0.512	2.45×10^{-6}
200 kV	164	0.941	0.497	0.935	0.531	2.54×10^{-6}
^{137}Cs	662	0.932	0.603	0.941	0.641	3.07×10^{-6}

*Dose pill mass: 0.0335 g; the range of energies were 33 keV-662 keV involved in this article, and the thermo luminescence dosimeter used the low atomic number material, the proportion of Bremsstrahlung can be neglected, so the air absorbed dose is equal to air kerma.

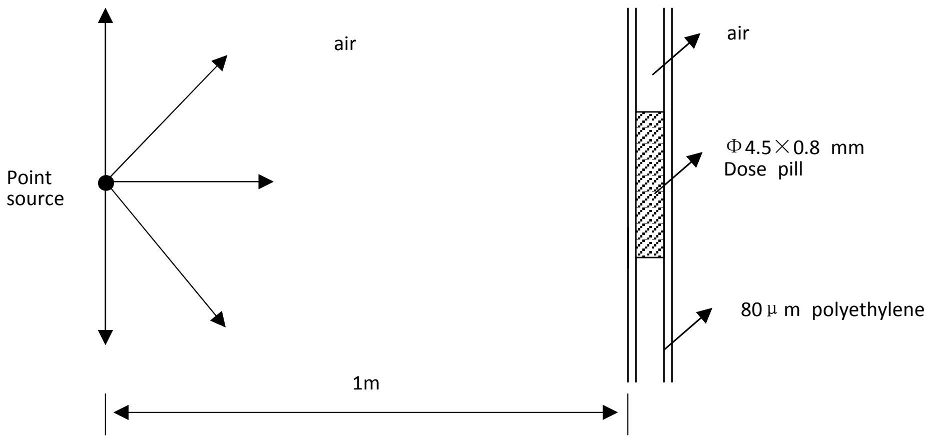

Fig. 1. Schematic diagram of simulation calculation (the dimension of model was not drew according to scale, should be based on mark in the figure).

3.1.2 Computational Method of Monte Carlo

The Monte Carlo model was established by MCNP-5 and calculated. The model is shown in Figure 1. The FCL is forcing collision card, which was added to reduce variance in the simulation. The *F8 card was used to record the simulation results, namely recording the deposition energy in the dose pills.

The simulation results were as follows:

The Table 3 suggested that the deviation of simu-

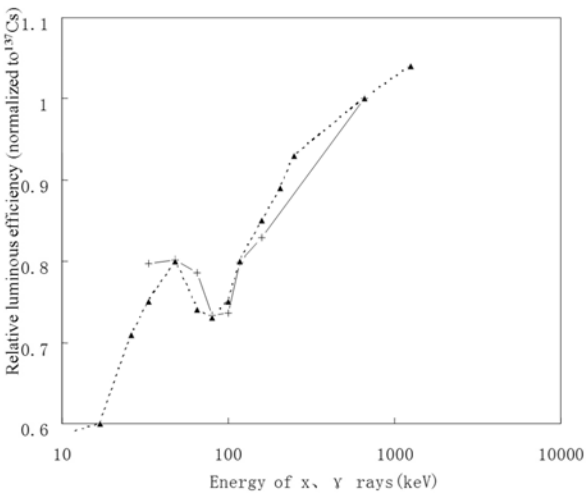

Fig. 2. The relative range values of luminous efficiency. (—+—experimental data，---▲---the data of literature [5])

lation results compared with theoretical calculation results was less than 1% for the 40 kV, 120 kV, 150 kV, 200 kV, 662 keV; the deviation was about 3% for the 60 kV and 100 kV; the deviation was 4.5% for 80 kV, both the results were almost the same.

3.2 Related Results and Analysis

The related analysis results were shown in Table 4:

According to the above calculation，drawing the trend changing of $\eta(E)$ with energy, and comparing to the given data of literature [5], as shown in the following figure（normalized to ^{137}Cs）：

Because of $\eta(E)$ values depend on many other factors such as the type of dopants, the amounts of dopants, grain size and the materials surrounding the grains and the TL etc. Even if using the identical materials, which produced by the different manufactures can cause $\eta(E)$ values diversely. But the given $\eta(E)$ values of this article were close to the changeable range of corresponding data in the literature five.

4. CONCLUSION

The study showed that photon with mean energies between 33 keV and 662 keV, the range of unit deposition energy in TL elements correspond to the amounts of lights was close to 30%. The data of literature [5] suggested that photon with mean energies between 12 keV and 1250 keV, the change range reached 40% or more. In terms of personal dosimeter, according to Chinese national standards[1)], the range of energy should be between 20 keV-1.5 MeV when personal dose equivalence $H_p(10)$ is monitored, between 10 keV-1.5 MeV when $H_p(0.07)$ is monitored, and the deviation caused by energy response and angle response should not exceed 30%. So, when the Monte Carlo model for the designing of personal dosimeters is built, the $\eta(E)$ values can be used to modify the amount of luminescent lights calculated by energy deposition in the TL elements. These data can be used for the design of individual dosimeter which used TLD-2000 thermo-luminescence elements, also have a certain reference value for manufacturer to improve the energy-response performance of dose slice by formulation adjustment. For energies of X-ray is within 10-33 keV, the $\eta(E)$ will be calculated in the future.

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