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ScienceDirect

Radiation Measurements 43 (2008) 459–462

Radiation Measurements

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Study of $CaSO_4$: Dy and LiF:Mg,Ti detectors TL response to electron radiation using a SW Solid Water phantom

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Abstract

The TL response to electron-radiation is known to be dependent on the electron energy and the dosimeter thickness, justifying the present study of LiF:Mg,Ti (TLD-100, Harshaw) and $CaSO_4$: Dy (developed and produced at the Dosimetric Materials Laboratory of the Radiation Metrology Centre) TL responses to electron radiation using a SW Solid Water phantom. Dosimeters were previously divided in groups according to their individual sensitivities to ^{60}Co gamma-radiation in air and electronic equilibrium conditions. The electron beams of different energies were provided by a Varian Clinac 2100C linear accelerator and the dosimeters were set at the depth of maximum dose of each beam over $5\,g/cm^2$ of the SW Solid Water phantom made of $30 \times 30\,cm^2$ plates of different thickness. The irradiations with doses ranging from 0.01 to 3.25 Gy delivered at 4 Gy/min were carried out with the electron focus at 100 cm of the phantom surface in a $10 \times 10\,cm^2$ field. The TLD signal was always read in a Harshaw 3500-QS reader 36 h after the irradiation and each value is the average of five readings. The dose–response of both materials presented a linear behavior for doses ranging from 0.05 to 1.25 Gy in all studied energies; however, the $CaSO_4$: Dy TL sensitivities are 17.8–21.5 times greater than the ones presented by the LiF:Mg,Ti. The lower detection limit calculated for the LiF:Mg,Ti is 8.49–11.84 times greater than the ones obtained for the $CaSO_4$: Dy. Due to these facts, $CaSO_4$: Dy dosimeters may constitute one more option for applications in the radiation therapy area in the studied energies and doses, even considering that both $CaSO_4$: Dy and LiF:Mg,Ti TL responses were altered by the electron-radiation energy.

Keywords: Electron dosimetry; $CaSO_4$: Dy TL detector; LiF:Mg,Ti TL detector

1. Introduction

High energy electron beams have been largely applied in the radiation therapy area, where their application demands a great precision and a high accuracy in the delivered dose because a variance of 5% in the dose absorbed by the tumor is determining for the recurrence or sequelae risks. Therefore, the rigorous measurement and control of the dose through dosimeters presenting a high degree of exactitude and precision in their measurements are imperative (Duscombe et al., 1996). Ionization chambers, Fricke dosimeters and thermoluminescent dosimeters (TLD) are the most commonly applied in the medical area (Kase et al., 1982).

TLD play a crucial role in the radiation therapy area for the ionizing radiation dosimetry, the majority of the measures being done with lithium fluoride, a widely and long-term chosen material for these applications (Gooden and Brickner, 1972; Rudén, 1976). However, another phosphor, the $CaSO_4$: Dy, has been intensively applied in dose measurements at the radiation protection levels due to its high sensitivity.

Besides the outstanding linearity of the $CaSO_4$: Dy TL response to gamma-radiation for a wide dose range, from mGy to Gy (Campos and Lima, 1986), this material has not been sufficiently explored in applications related to the radiation therapy.

The high sensitivity of the TLD allows the production of small dosimeters, suitable to be used in regions where acute dose gradients can be expected as well as for "in vivo" dosimetry. The dosimeters are also resistant and applicable in various sizes and shapes (Campos and Lima, 1986, 1987). The $CaSO_4$: Dy had been poorly studied for applications in this area.

IPEN produces $CaSO_4$: Dy as powder and pellets for gamma and X-radiation monitoring. Special pellets, of reduced thickness, are also produced for beta-radiation dosimetry

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doi:10.1016/j.radmeas.2007.11.008

applications (Campos and Lima, 1987). New dosimeters for beta-radiation detection, using graphite to reduce the energy dependence of the TL response, have been recently developed.

The possible application of the $CaSO_4$: Dy in radiation therapy would constitute another dosimeter option due to its sensitivity and the linearity of its response to radiation. The use of the $CaSO_4$: Dy in radiation therapy related applications would be specially worthwhile in Brazil due to easiness of its acquisition, considering that the Laboratory of Dosimetric Materials/IPEN has developed and produces this thermoluminescent dosimeter in commercial scale (Campos and Lima, 1987).

In order to make the use of the $CaSO_4$: Dy in radiation therapy viable, an issue to be considered is the comparison of the TL responses of this material and of the LiF:Mg,Ti, already used in these applications, to the electron energies provided by a Varian Clinac 2100C linear accelerator at the depth of maximum dose for each considered energy in different phantoms. The measurements carried out using the SW Solid Water phantom presented in this study constitute part of the effort to understand the response of the $CaSO_4$: Dy pellets to electron-radiation and therefore establish the conditions to the use of these dosimeters in radiation therapy applications.

2. Materials and methods

$CaSO_4$: Dy and LiF:Mg,Ti TLD pellets were separately annealed and irradiated in electronic equilibrium conditions with a 4π ^{60}Co gamma source to an absorbed dose in air of 25 mGy. This process was repeated three times to define, through the mean value, the individual sensitivities of the pellets, that agree in 10% with $CaSO_4$: Dy (860 nC/Gy) and LiF:Mg,Ti (64 nC/Gy) average sensitivities, and 21 groups of five dosimeters were formed, based on descending individual sensitivities, for both materials.

The groups were ordered from the most to the less sensitive and the irradiation sets were formed by the two groups of the same order, one of each phosphor.

Before every electron irradiation, the dosimeters of each material were separately annealed and the irradiation sets were wrapped together in wrapping paper.

The three most sensitive irradiation sets were not irradiated to make the assessment of the natural background radiation levels possible. The other irradiation sets were irradiated, from the most to the least sensitive, with doses ranging from 0.01 to 3.25 Gy at the dose rate of 4 Gy/min.

The electron irradiations were carried out, respectively, in the 16, 12, 9, 6 and 4 MeV electron beams provided by a Varian Clinac 2100C linear accelerator. A SW Solid Water phantom, made of $30 \times 30\,\text{cm}^2$ plates of different thickness was used and a field of $10 \times 10\,\text{cm}^2$ was formed in its surface, that was at 100 cm of the electron focus.

The irradiation sets were positioned, one at its time, in the geometric center of the field over $5\,\text{g/cm}^2$ of the phantom material, to provide the adequate backscattering, and at the depth of maximum dose, $d_{\max}$, given on Table 1 for each studied electron energy in SW Solid Water.

Table 1
Depths of maximum dose, $d_{\max}$, of 4, 6, 9, 12 and 16 MeV electron beams provided by Varian Clinac 2100C in SW Solid Water phantoms

Energy (MeV)	$d_{\max}$ in SW (cm)
4	0.80
6	1.20
9	2.00
12	2.70
16	2.00

TL responses were read between 36 and 44 h after the end of the irradiations and each data point is the average obtained from the 5 TL readouts of the LiF:Mg,Ti or the $CaSO_4$: Dy dosimeters of the same sensitivity group.

The sensitivities of the groups to the doses delivered to them were calculated and the dose–response curves were considered to be linear for doses ranging from 5 to 125 cGy, where the sensitivities of the groups vary in less than 10%.

By fitting a linear curve whose slope is equal to one to the dose-response curves in the dose range from 5 to 125 cGy, the calibration factor, F_{cal}, is obtained and thus, the lower detection limit, LDL, is calculated through Eq. (1):

$$\text{LDL} = (\overline{\text{TL}(0)} + 3 \cdot \sigma_{\overline{\text{TL}(0)}}) \cdot F_{\text{cal}}, \tag{1}$$

where $\overline{\text{TL}(0)}$ is the mean value for the TL readouts of the non-irradiated dosimeters and $\sigma_{\overline{\text{TL}(0)}}$ is its corresponding mean standard deviation.

The mean TL response for all the studied doses relative to the 16 MeV beam, energy chosen as the reference, was calculated and used to study the behavior of the dosimeters as a function of the electron energy by fitting a polynomial to the experimental points.

All the calculations were done with the Microsoft Excel 97 software and all the graphics were plotted, without showing the experimental errors when they are smaller than the data points, by the Microcal Origin 7.5 software, that also provided the fits to the curves and the parameters of these fits.

3. Results

$CaSO_4$: Dy and LiF:Mg,Ti sensitivities to 16 MeV electrons in SW Solid Water at the depth of maximum dose over 5 cm (about $5\,\text{g/cm}^2$ of SW Solid Water) are plotted in Fig. 1. This graphic allows to define the range, from 0.05 to 1.25 Gy, in which the dose-response curve presents a linear behavior. The sensitivity of both materials are plotted together so that it is easy to notice that the $CaSO_4$: Dy presents a higher sensitivity when compared to the LiF:Mg,Ti. The sensitivity as a function of the dose shows the same pattern for all the other energies considered, in such a way that the doses of 0.05 and 1.25 Gy define the range in which the dose-response curves present a linear behavior.

The dose-response curves of $CaSO_4$: Dy and LiF:Mg,Ti to electrons of 4, 6, 9, 12 and 16 MeV of nominal energies at the depth of maximum dose in a SW Solid Water phantom over 5 cm are presented in Figs. 2–6, respectively.

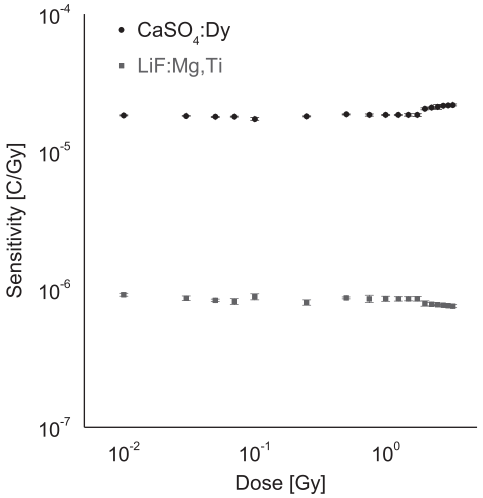

Fig. 1. CaSO$_4$: Dy and LiF:Mg,Ti sensitivities to a 16 MeV electron beam at its depth of maximum dose in SW Solid Water over 5 cm (about 5 g/cm^2).

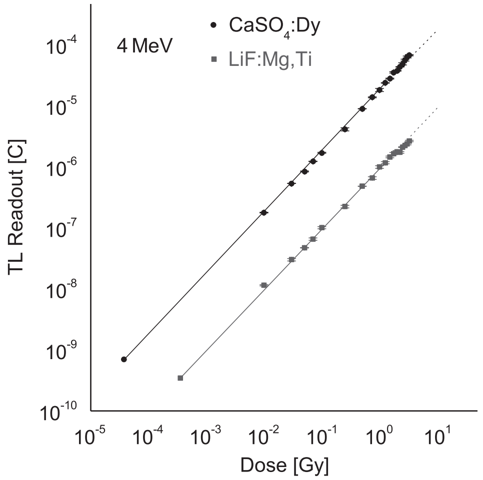

Fig. 2. CaSO$_4$: Dy and LiF:Mg,Ti dose–response curves to a 4 MeV electron beam at its depth of maximum dose (0.60 cm) in SW Solid Water.

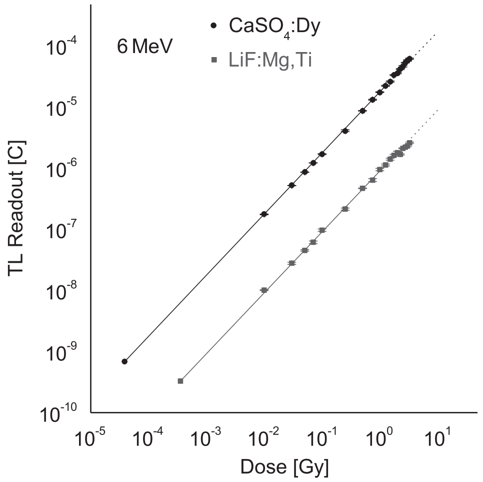

Fig. 3. CaSO$_4$: Dy and LiF:Mg,Ti dose–response curves to a 6 MeV electron beam at its depth of maximum dose (1.20 cm) in SW Solid Water.

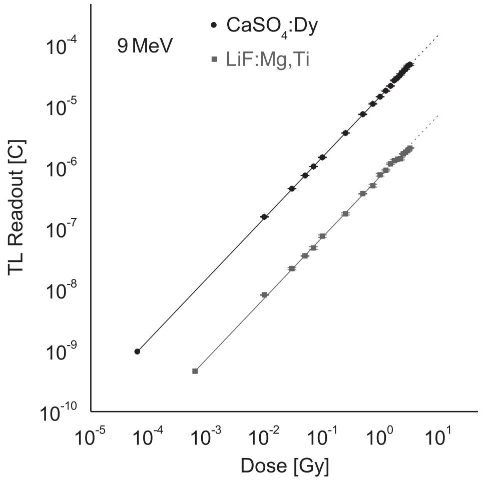

Fig. 4. CaSO$_4$: Dy and LiF:Mg,Ti dose–response curves to a 9 MeV electron beam at its depth of maximum dose (2.00 cm) in SW Solid Water.

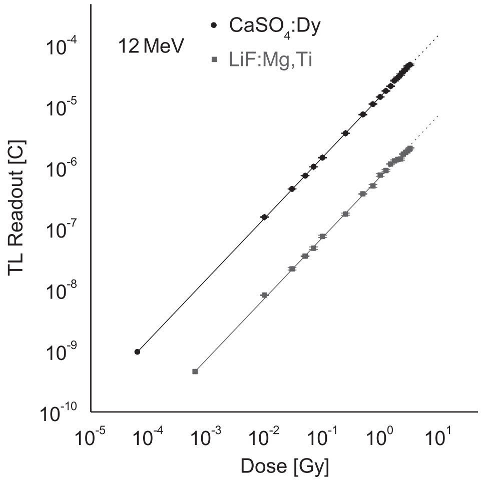

Fig. 5. CaSO$_4$: Dy and LiF:Mg,Ti dose–response curves to a 12 MeV electron beam at its depth of maximum dose (2.80 cm) in SW Solid Water.

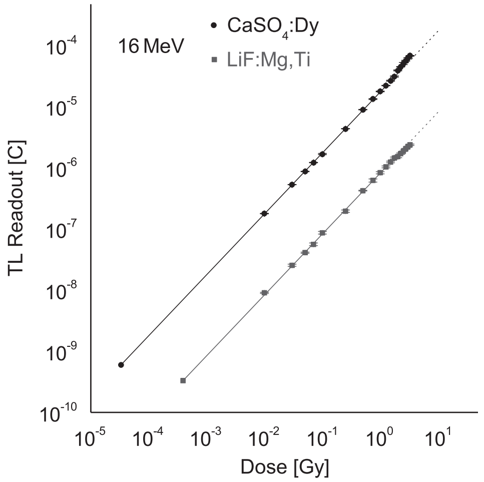

Fig. 6. CaSO$_4$: Dy and LiF:Mg,Ti dose–response curves to a 16 MeV electron beam at its depth of maximum dose (3.30 cm) in SW Solid Water.

Table 2
Lower detection limits, LDL, as a function of the beam energy calculated for the $CaSO_4$: Dy and for the LiF:Mg,Ti

Energy (MeV)	Lower detection limit (μGy)	
	$CaSO_4$: Dy	LiF:Mg,Ti
4	37.8 ± 1.2	356.6 ± 2.4
6	38.6 ± 0.7	355.0 ± 2.4
9	44.9 ± 0.9	450 ± 18
12	38.9 ± 0.8	350 ± 8
16	33.1 ± 0.6	391 ± 3

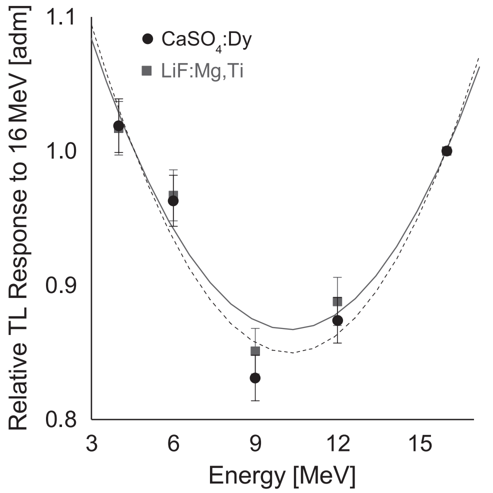

Fig. 7. TL energy dependence responses of $CaSO_4$: Dy and LiF:Mg,Ti detectors relative to 16 MeV electrons using a SW Solid Water phantom.

Only the experimental points of the dose-response curves in the range between 0.05 and 1.25 Gy were considered in the fit of the straight lines whose slopes were determined in order to calculate the LDL's. The results for the studied electron energies are listed in Table 2.

For both dosimetric materials, the slopes of the dose–response curves to 4 and 9 MeV differed the most from each other, in such a way that the sensitivities of the $CaSO_4$: Dy and the LiF:Mg,Ti to the studied energies vary in a maximum of 15.63% and 25.76%. The $CaSO_4$: Dy presents sensitivities that are 17.8 (12 MeV) to 21.5 (16 MeV) times greater than the LiF:Mg,Ti sensitivities, implying in LDL's of the $CaSO_4$: Dy that are smaller than the ones of the LiF:Mg,Ti.

The LDL of the LiF:Mg,Ti vary from 8.49 to 11.84 times the LDL of the $CaSO_4$: Dy, for 12 and 16 MeV electron beams, respectively. These values are inside the limits established for the applications related to the radiation therapy area, in such a way that this characteristic constitutes one advantage of the use of the $CaSO_4$: Dy with dosimetric purposes by allowing the accurate and precise detection of doses smaller than the ones that the LiF:Mg,Ti detects.

The energy dependence of the TL response relative to 16 MeV electrons is presented in Fig. 7. The parameters of the polynomials fitted to the data sets are given by Table 3.

Table 3
Parameters of the $y = A + Bx + Cx^2$ fits to the TL responses relative to 16 MeV of the $CaSO_4$: Dy and of the LiF:Mg,Ti

Parameter	$CaSO_4$: Dy	LiF:Mg,Ti
A	1.34 ± 0.08	1.30 ± 0.07
B	-0.095 ± 0.018	-0.084 ± 0.016
C	0.0046 ± 0.0009	0.0041 ± 0.0008

4. Conclusions

The apparent supra-linear behavior observed below 0.05 Gy is caused by the overestimation of the treatment time demanded to deliver doses that are considered very small in the scope of the radiation therapy. This conclusion is reinforced by the data obtained during the routine dosimetry of the linear accelerator made with ionization chambers by the medical physicists of the hospital.

$CaSO_4$: Dy and LiF:Mg,Ti dosimeters may be used with dosimetric purposes for doses ranging from 1.25 to 3.25 Gy as far as the supra-linear shown by doses of more than 1.25 Gy can be mathematically modeled.

The responses of LiF:Mg,Ti, currently used in applications in the radiation therapy area with dosimetric purposes, and $CaSO_4$: Dy TL dosimeters to electrons of different nominal energies using a SW Solid Water phantom are linear for doses ranging from 0.05 to 1.25 Gy. $CaSO_4$: Dy sensitivities vary in 15.63% with the electron energy and are 17.8–21.5 times greater than LiF:Mg,Ti sensitivities, that vary in 25.76% with the electron energy. LiF:Mg,Ti show lower detection limits that are 8.49–11.84 times greater than the limits shown by $CaSO_4$: Dy, depending on the energy, but the energy dependence of $CaSO_4$: Dy and LiF:Mg,Ti lower detection limits show similar behaviors. Considering these facts, it is possible to conclude that $CaSO_4$: Dy may constitute one more option of dosimeter in radiation therapy applications.

Acknowledgments

The authors are grateful to CNPq and CNEN for the financial support and to the radiation therapy staff of the Hospital Israelita Albert Einstein by making the electron irradiations possible.

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