2007 International Nuclear Atlantic Conference - INAC 2007
Santos, SP, Brazil, September 30 to October 5, 2007
Associação Brasileira de Energia Nuclear - ABEN
ISBN: 978-85-99141-02-1

LOWER DETECTION LIMIT OF $CaSO_4$:Dy AND LiF:MgTi TL DOSIMETERS TO RADIOTHERAPY ELECTRON BEAMS

Maíra G. Nunes and Letícia L. de Campos

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
mgnunes@ipen.br; lcrodri@ipen.br

ABSTRACT

The aim of this work is to compare the lower detection limit (LDL) of the $CaSO_4$:Dy to the LDL of the LiF:Mg,Ti, widely and long-term used in radiation therapy applications and more recently in radiation therapy modalities involving the irradiation with electrons, in view to investigate the $CaSO_4$:Dy dosimeter, developed and produced in commercial scale by the Laboratory of Dosimetric Materials / IPEN, as a cheaper alternative to the imported TLD-100 pellets. The LDL of both dosimeters showed to be highly dependent on the nominal electron energy, varying in 95% for the same phantom and dosimeter, and on the phantom material, varying in up to 68% for the same dosimeter and electron energy. Although the LDL of the $CaSO_4$:Dy is about 10 times smaller than the LDL of the LiF:Mg,Ti, that is still smaller than the minimum dose delivered by the linear accelerator in the conditions of the irradiation, so that this parameter is inside the limits established for radiotherapy applications and do not constitute an obstacle to the change of the imported pellets by the Brazilian dosimeters, however, further study of other characteristics relevant to the use of this dosimeter in medical applications are required before assuring its efficiency for the ionizing radiation dosimetry in applications related to the radiation therapy.

1. INTRODUCTION

High energy electron beams have been largely applied in the radiation therapy area, were 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, [1] the ionization chambers, Fricke and thermoluminescent dosimeters being the most commonly applied in the medical area. [2]

Thermoluminescent dosimeters (TLD) play a crucial role in the radiation therapy area for the ionizing radiation dosimetry and the majority of the measurements were carried out with lithium fluoride, a widely and long-term chosen material in the applications related to this area, dosimeters. [3, 4]

IPEN produces dosimeters made of another phosphor, the $CaSO_4$:Dy, as powder, pellets for gamma and X-radiation monitoring and special pellets, of reduced thickness, with the recent developed of new pellets that use graphite to reduce the energy dependence of the thermoluminescent (TL) response, for beta-radiation dosimetry applications. [5]

Besides the outstanding linearity of the $CaSO_4$:Dy TL response to gamma-radiation for a wide dose range, from μGy to Gy, and its high sensitivity, which allows the construction of small and resistant dosimeters to be applied in acute gradient regions and to "*in vivo*" dosimetry, characteristics that lead to the intense application of this phosphor in dose measurements at the radiation protection levels, [6] it has not been sufficiently explored in applications related to the radiation therapy.

The possible use of the $CaSO_4$:Dy pellets in applications related to the radiation therapy area would constitute another dosimeter option that would be specially worthwhile in Brazil due to the easy and cheap acquisition of the pellets, considering that the Laboratory of Dosimetric Materials / IPEN has developed and produces this thermoluminescent dosimeter in commercial scale.

It is known that the TL response, and thus the TL dose-response curve, and so the lower detection limit (LDL), is dependent on the phantom material, its dimensions and on the energies of the electron beans, [7] in such a way that evaluating the characteristics of the dose-response curves obtained in different phantoms for different nominal electron energies with the $CaSO_4$:Dy is demanding to propose this new dosimeter as an alternative to the imported TLD-100 pellets.

In this scenario, in view to make the use of the $CaSO_4$:Dy pellets in radiation therapy viable, an issue to be considered is the comparison of the lower detection limits of this material and of the LiF:Mg,Ti (TLD-100), already used in this area, at the depth of dose maximum for different electron energies in different phantoms presented in this work.

2. MATERIALS AND METHODS

$CaSO_4$:Dy (IPEN) and LiF:Mg,Ti (Harshaw) TLD pellets were separately annealed 26h before every irradiation, in the worst case, in a MAS 7000 (CEM) microwave furnace to avoid spurious signals and two different kinds of irradiations, one with ^{60}Co gamma and other with electron radiation, were performed. For all the irradiations, TL readouts were performed with a QS 3500 (Harshaw) reader, the calculations were done with the Microsoft Excel 97 software and the graphics were plotted with the aid of the Microcal Origin 7.5 software.

In the scope of the present study, type B uncertainties, such as the variations in the reference light and in the photo-multiplier tube noise, were not evaluated and type A uncertainties, such as the reproducibility of the pellets readout and the variation in the values read for the different pellets belonging to the same group, were calculated and used to define the mean values and the standard deviations shown throughout the Results section.

2.1. ^{60}Co Gamma Radiation

A 4π ^{60}Co gamma source was used to deliver a dose of 25 mGy to the $CaSO_4$:Dy and LiF:Mg,Ti dosimeters in air and in electronic equilibrium condition, with the TL readouts being performed between 24 h and 32 h after the end of the irradiation.

To form dosimeter sets, 200 pellets of each phosphor were irradiated, their sensitivities, or the ratio between the TL readout and the delivered dose, were calculated and a histogram of these results was plotted, so that the pellets whose individual sensitivities agree in 10% with the most probable sensitivity for the batch could be defined. This process was repeated 3 times and the mean individual sensitivities, as well as a batch based on these mean values, were defined.

The pellets selected for the batches based on each one of the irradiations and on the mean individual sensitivity were ordered according to their decreasingly mean individual sensitivities and separated into groups of 5, with the less sensitive pellets that could not be grouped being excluded from this final batch.

In the case of the $CaSO_4$:Dy, whose most probable sensitivity is 860 nC/Gy (mean values), 107 pellets were previously selected and the final $CaSO_4$:Dy batch is composed by 21 groups of 5 dosimeters, designated by A, B, C and 1 to 18, from the most to the least sensitive group. LiF:Mg,Ti most probable sensitivity is 64 nC/Gy and 109 pellets presented individual mean sensitivities agreeing in 10% with this value, so that the final LiF:Mg,Ti batch is also composed by groups A, B, C and from 1 to 18, each one with 5 dosimeters. The groups with the same designation of both phosphors were then joined to form a dosimeter set.

In order to assure that the individual sensitivities are not altered, the 21 dosimeter sets were irradiated together after each electron irradiation and the individual sensitivities were calculated and compared to the mean individual sensitivities that were previously defined. If the value found for the individual sensitivity agrees, within the standard deviation, with this mean individual sensitivity, it is then used to redefine the mean value.

On the other hand, if these values do not agree, the dosimeter must be excluded from the batch and so must its last TL readout be excluded from the data set corresponding to the electron irradiation performed right before the assurance, because the dosimeter is no longer trustworthy after its sensitivity changes. Fortunately, no dosimeter had its sensitivity changed while the data analyzed in the present work was being collected.

2.2. Electron radiation

The dosimeter sets were wrapped together in wrapping paper, the 3 most sensitive sets (A, B, and C) were not irradiated to assess the natural background radiation levels and a linear accelerator Clinac 2100–C (Varian) was the source of the 4, 6, 9, 12 and 16 MeV electron beams of nominal energies used to deliver doses ranging from 0.01 Gy to 3.25 Gy at the dose rate of 4 Gy/min to the dosimeter sets 1 to 18, in order to plot the dose-response curves.

TL readouts were performed between 36 h and 44 h after the end of the irradiation, that was held with the source-surface distance of 100 cm, the filed size of 10 x 10 cm^2 and the dosimeter sets positioned in the geometric center of the filed, over 7 g/cm^2 of the phantom material, to provide the adequate backscattering, and at the depth of dose maximum, d_{max}, corrected by the scalling factor whenever it is not a water phantom. [8]

A lucite, a SW solid water, both made of 30 x 30 cm^2 plates of different thickness, so that d_{max}, given on Table 1 for each electron energy and phantom material, can be reached for all the studied electron energies, and a 35.5 x 35.5 35.5 cm^3 water phantom, that demanded the construction of an special holder to prevent the contact of the dosimeters with the water without the introduction of scattering.

Table 1. Depths of dose maximum, d_{max}, for 4, 6, 9, 12 and 16 MeV electrons in lucite, SW solid water and water.

	d_{max} [cm]		
Energy [MeV]	lucite	SW	water
4	0.70	0.80	0.80
6	1.10	1.20	1.20
9	0.20	0.20	0.20
12	2.40	2.70	2.70
16	1.80	2.00	2.00

2.3. Lower Detection Limit (LDL) Calculation

The sensitivities to each electron energy and phantom material and the ratio between these sensitivities and the sensitivities to the ^{60}Co gamma radiation were calculated for each dosimeter and the dose-response curves were considered to be linear in the dose range corresponding to the doses delivered to the groups whose mean sensitivity ratios accorded in a maximum of 10% with each other, the mean TL readouts of these groups being used to plot the dose-response curves for each electron energy and phantom material. By fitting a linear curve whose linear coefficient is equal to zero to the experimental points, the calibration factor, c_f, defined as the inverse of the angular coefficient, b, of the linear fit, is obtained.

Calculating the mean TL readout for the 15 non-irradiated dosimeters of groups A, B and C, that were dedicated to the assessment of the natural background radiation levels, $\overline{BG}$, and its standard deviation, $\sigma_{\overline{BG}}$, the LDL to each electron energy and phantom material can be easily calculated through the equation 1 bellow:

$$LDL = \left(\overline{BG} + 3 \cdot \sigma_{\overline{BG}}\right) \cdot c_f \qquad (1)$$

3. RESULTS

The mean sensitivity as a function of the group order show that the dose-response curves obtained under the experimental conditions are linear for doses ranging from 0.03 to 1.75 Gy, regardless the dosimeter, the electron energy and the phantom material. The values obtained for the angular coefficient, b, and the mean natural background radiation and its standard deviation, $\overline{BG} \pm \sigma_{\overline{BG}}$, are given in Table 2 for each dosimeter, phantom and electron energy, while Table 3 shows the values obtained for the LDL under each experimental condition for $CaSO_4$:Dy and LiF:Mg,Ti dosimeters.

Table 2. Mean natural background radiation, $\overline{BG}$, and angular coefficients, b.

		$CaSO_4$:Dy		LiF:Mg,Ti	
	E [MeV]	$\overline{BG}$ [nC]	b [nC/cGy]	$\overline{BG}$ [nC]	b [nC/cGy]
Lucite	4	0.703 ± 0.008	159.2 ± 1.1	0.387 ± 0.010	11.176 ± 0.020
	6	0.708 ± 0.029	147 ± 3	0.2206 ± 0.013	10.69 ± 0.14
	9	0.708 ± 0.029	120.5 ± 2.2	0.2206 ± 0.013	8.59 ± 0.12
	12	0.708 ± 0.029	132.2 ± 2.3	0.2200 ± 0.013	10.89 ± 0.14
	16	0.708 ± 0.029	145.6 ± 2.6	0.2206 ± 0.013	9.67 ± 0.16
SW solid water	4	0.902 ± 0.005	166 ± 3	0.369 ± 0.006	10.784 ± 0.029
	6	0.670 ± 0.012	154 ± 4	0.316 ± 0.003	10.32 ± 0.13
	9	0.670 ± 0.012	126 ± 3	0.316 ± 0.003	8.29 ± 0.12
	12	0.670 ± 0.012	138 ± 3	0.316 ± 0.003	10.51 ± 0.14
	16	0.670 ± 0.012	152 ± 4	0.316 ± 0.003	9.33 ± 0.16
Water	4	0.641 ± 0.020	202.3 ± 2.9	0.3408 ± 0.0022	9.90 ± 0.09
	6	0.650 ± 0.013	187.3 ± 2.5	0.3213 ± 0.0021	9.48 ± 0.08
	9	0.930 ± 0.013	153.1 ± 1.3	0.425 ± 0.012	7.61 ± 0.08
	12	0.851 ± 0.013	167.9 ± 1.2	0.403 ± 0.007	9.65 ± 0.08
	16	0.570 ± 0.010	185.0 ± 1.5	0.324 ± 0.003	8.57 ± 0.12

Table 3. Lower detection limits of the CaSO4:Dy and of the LiF:Mg,Ti.

		Lucite	SW solid water	water
	E [MeV]	LLD [μGy]	LLD [μGy]	LLD [μGy]
$CaSO_4$:Dy	4	45.6 ± 0.6	55.2 ± 1.1	34.6 ± 1.2
	6	53.9 ± 2.5	45.9 ± 1.5	36.7 ± 0.9
	9	66 ± 3	56.1 ± 1.7	63.4 ± 1.1
	12	60.2 ± 2.7	51.2 ± 1.6	53.0 ± 0.9
	16	54.6 ± 2.4	46.4 ± 1.4	32.5 ± 0.6
LiF:Mg,Ti	4	372 ± 9	359 ± 6	351 ± 4
	6	210 ± 3	315 ± 5	346 ± 4
	9	261 ± 4	393 ± 7	606 ± 19
	12	206 ± 3	310 ± 5	439 ± 8
	16	232 ± 4	349 ± 7	386 ± 6

Although the LDL of the $CaSO_4$:Dy is almost 10 times smaller than the LDL of the LiF:Mg,Ti, both dosimeters present values of LDL highly dependent on the energy of the electron radiation, differing in up to 95% from one energy to another, and on the phantom material, differing in up to 68% from one phantom to another.

4. CONCLUSIONS

The dose-response curves are linear for the studied electron dose range, from 0.03 to 1.75 Gy, and the angular coefficient obtained through a linear fit results in a LDL of the $CaSO_4$:Dy that is about 10 times smaller than the LDL of the LiF:Mg,Ti, that is still much smaller than the minimum dose delivered by the linear accelerator in the conditions of the irradiation, so that this parameter is inside the limits established for radiotherapy applications and do not constitute an obstacle to the replacement of the imported pellets by the Brazilian dosimeters, although further study of other characteristics relevant to the use of the $CaSO_4$:Dy in medical applications is required.

For both dosimeters, the LDL is highly dependent on the electron energy, varying in 95% for the same phantom and dosimeter, and on the phantom material, with up to 68% of variation for the same dosimeter and electron energy.

ACKNOWLEDGMENTS

The authors are grateful to CNPq, IPEN and CNEN for the financial support and to the radiation therapy staffs of the Hospital A. C. Camargo and of the Hospital Israelita Albert Einstein by making the electron irradiations possible.

REFERENCES

1. Duscombe, P. et al, “Anthropomorphic phantom measurements for the validation of a treatment planning system.” *Phys. Med. Biol.* **41**, pp.399-411 (1996).
2. Kase, K. R. et al, “Comparisons of electron beam dose measurements in water and polystyrene using various dosimeters.” *Med. Phys.* **9**, pp.13-19 (1982).
3. Gooden, D. S., Brickner, T. J., “The routine use of thermoluminescence dosimetry for radiation therapy.” *Radiology* **102**, pp.685-689 (1972).
4. Rudén, B., “Evaluation of the clinical use of TLD.” *Acta Radiol. Ther. Phys. Biol.* **15**, pp.447-464 (1976).
5. Campos, L. L., Lima, M. F., “Thermoluminescent $CaSO_4$:Dy + Teflon Pellets for Beta Radiation Detection.” *Rad. Prot. Dosim.* **18(2)**, pp.95-97 (1987).
6. Campos, L. L., Lima, M. F., “Dosimetric Properties of $CaSO_4$:Dy + Teflon Pellets Produced at IPEN.” *Rad. Prot. Dosim.* **14(4)**, pp.333-335 (1986).
7. Robar, V. et al., “Thermoluminescent dosimetry in electron beams: energy dependence,” *Med. Phys.* **23**, pp.667-673 (1996).
8. IAEA Technical Reports Series No. 398, *Absorbed Dose Determination in External Beam Radiotherapy.* International Atomic Energy Agency, Vienna, Austria (2000).