ICMP 2011
April 17-20 · Porto Alegre - RS - Brazil

Study of sensitivity and lower detection limit of TL dosimeters in 4 MeV and 9 MeV clinical electron beams using liquid water phantom

A.Bravim[1], R.K.Sakuraba[1,2], J.C.Cruz[2] and L.L.Campos[1]

[1] Instituto de Pesquisas Energéticas e Nucleares/Center of Radiation Metrology, Sao Paulo, Brazil
[2] Hospital Israelita Albert Einstein/Radiotherapy Departament, Sao Paulo, Brazil

Abstract— **The major purpose of clinical dosimetry is to establish a quality control of the radiation beam in order to obtain an improvement in the quality of radiotherapy. This paper aimed to evaluated the sensitivity of thermoluminescent (TL) dosimeters comparing the performance of detectors produced by *IPEN*, $CaSO_4$:Dy, with dosimeters already used in radiotherapy dosimetry, LiF:Mg,Ti (TLD-100) and micro LiF:Mg,Ti (TLD-100) produced by *Harshaw*. The dosimeters were previously separated in groups, each with 5 detectors, according to their TL individual sensitivities to ^{60}Co gamma-radiation in air and electronic equilibrium conditions. The selected dosimeters were irradiated with 4 MeV and 9 Mev clinical electron beams, positioned at depth of maximum dose: 4 MeV – 1.0 cm and 9 MeV – 2.0 cm, with absorbed doses of 0.5, 1.0 and 5 Gy using a linear accelerator Clinac 2100C *Varian*. The field size used was 10x10 cm^2 with 100 cm of source-phantom surface distance according to recommended by the Technical Reports Series nº398 (TRS 398) of IAEA (International Atomic of Energy Agency). The $CaSO_4$:Dy dosimeters are approximately 26 and 318 times more sensitive than LiF:Mg,Ti and microLiF:Mg,Ti for 4 MeV electrons and 24 and 259 times and microLiF:Mg,Ti for 9 MeV electrons. For both energies studied the dose-response of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters presented linear behavior on the electron dose range from 0.5 to 5 Gy and the LDL of the $CaSO_4$:Dy dosimeter is 20 and 25 times lower than LiF:Mg,Ti and microLiF:Mg,Ti for 4 MeV and 18 and 20 times lower than LiF:Mg,Ti and microLiF:Mg,Ti for 9 MeV electron beam respectively. $CaSO_4$:Dy presents similar TL response behavior than LiF:Mg,Ti and microLiF:Mg,Ti dosimeters with higher sensitivity and lower LDL. This results indicates that $CaSO_4$:Dy can be used successfully in radiotherapy dosimetry**.

Keywords— **Thermoluminescence, electron dosimetry, calcium sulfate, lithium fluoride.**

I. Introduction

Thermoluminescence is a phenomenon of the visible photons released by thermal means. In 1950's, Daniels and his co-works made the first applications of TL to dosimetry when they used lithium fluoride (LiF) to made radiation measurements after bomb test (Cameron, 1968). With the advancements in the use of nuclear technology for medical purpose, there was a major concern related to the detection and evaluation of radiation dose for control (Oberhofer e Scharmann, 1979).

Several organizations recommended the verification of patient dose for quality improvement in radiotherapy and the International Committee of Radiation Units and Measurements (ICRU) establish, in 1976, that "*all procedures involved in planning and execution of radiotherapy may contribute to a significant uncertainty in the dose administered to the patient"*. The recommended maximum values for the uncertainty in the dose range of ± 5% (ICRU, 1976).

The application of electron beams in therapy requires great accuracy in the absorbed dose delivered to the tumor, because a small variation is highly determinant in the risk of recurrence or sequel (ICRU, 1976). This fact requires stringent control measures in the doses absorbed by the patients in treatment by dosimeters that have great accuracy and precision in the measurement provided.

The thermoluminescent dosimeters have a long history of ionizing radiation dosimetry in radiotherapy, area where most measurements have been made with LiF (Eggermont et al, 1971; Hufton, 1984, Kalmykov, 1994; Robar et al, 1996) due to its tissue equivalence and the fact that the dependence of the response to the incident radiation energy and dose-rate are small in the rage of doses used in radiotherapy (Rúden, 1976). Other thermoluminescent material, calcium sulfate doped with dysprosium ($CaSO_4$:Dy), has been extensively used in measurements of dose radiation protection due to its high sensitivity (Campos and Lima, 1987; Lakshmanan, 1991). Although this material presents good linearity of response to beta radiation and photons for a wide range of doses (Campos and Lima, 1987; Campos e Nunes, 2008) and preliminary studies (Campos and Souza, 1990; Nunes, 2008) show the feasibility of its application in electron beams, it has been insufficiently explored in radiotherapy dosimetry. The $CaSO_4$:Dy is manufactured and marketed by Instituto de Pesquisas Energéticas e Nucleares (*IPEN*). This work aims to compare the performance of the detectors produced by *IPEN*, $CaSO_4$:Dy, with dosimeters already used in radiotherapy dosimetry, LiF:Mg,Ti (TLD-100) and micro LiF:Mg,Ti (TLD-100) produced by *Harshaw.*

II. Materials And Methods

A. Dosimetric Material

- 160 TL dosimeters LiF:Mg,Ti;
- 85 TL microdosimeters LiF:Mg,Ti;
- 200 TL dosimeters $CaSO_4$:Dy.

B. Irradiation System

- ^{60}Co gamma source (656,4 MBq at 09/12/2008);
- Linear accelerator *Varian*, model Clinac 2100C from Hospital Israelita Albert Einstein.

C. Equipments

- Furnace *VULCAN* model 3-550 PD;
- Surgical sterilizer *FANEN* model 315-IEA 11200;
- TL reader *Harshaw* model QS 3500.
- Liquid water phantom (cubic simulator 40x40x40 cm^3 filled with distilled water).

D. Thermal Treatment before irradiation.

LiF:Mg,Ti dosimeters: 400ºC/1h in the furnace plus 100ºC/2h in the surgical sterilizer*;*
$CaSO_4$:Dy dosimeters: 300ºC/3h in the furnace.

E. ^{60}Co gamma irradiation

Three cycles of thermal treatment, ^{60}Co gamma irradiation in air and electronic equilibrium conditions and TL reading were performed, the individual and average TL responses were evaluated and the dosimeters were separated into groups of 5 detectors according to their sensitivity.

F. Clinical Electrom Beams Irradiations

To irradiations with 4 MeV and 9 MeV clinical electron beams the selected dosimeters were positioned at the liquid water phantom at the depth of maximum dose ($d_{\max}$): 4 MeV electrons – 1.0 cm; 9 MeV electrons - 2.0cm. To ensure the backscatter of the electron beam 5 cm of the same phantom material was used under the dosimeters. The irradiation parameters followed were that recommended by the Technical Reports Series nº398 (TRS 398) of IAEA (International Atomic of Energy Agency): field size – 10x10 cm^2, source-detector distance – 100 cm.

TL readings were carried out between 24 and 32 h after irradiation. Each presented data is the average of 5 TL readings of the dosimeters of the same selected group and the error bars the standard deviation of the mean (1σ).

The Lower Detection Limit (LDL) was calculated through EQ1:

$$LDL = (RT_0 + 3\sigma_{RT_0}) \cdot f_{cal}, \qquad (1)$$

where RT_0 is the average TL readout of non-irradiated dosimeters, σ_{RT_0} the corresponding standard deviation of the mean and f_{cal} the calibration factor for each radiation type and energies, given by the inverse of the slope of the curve fitting dose-response (through *Program Origin 7.0*).

III. Results

The dose-response curves obtained to the different dosimeters and electrons beams are presented in Figures 1 and 2.

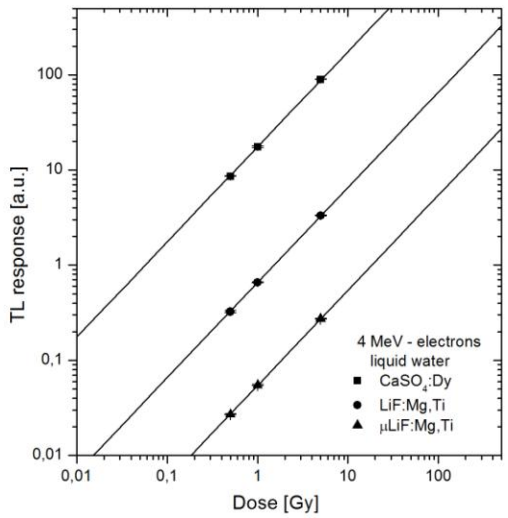

Fig. 1. Dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to 4 MeV electron beams using liquid water phantom.

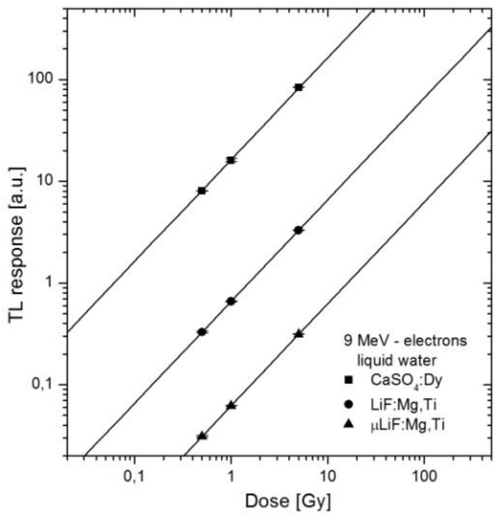

Fig. 2. Dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to 9 MeV electron beams using liquid water phantom.

The dose-response curves show a linear behavior in the electron dose range from 0.5 to 5 Gy.

The average TL sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters for liquid water phantom and doses from 0.1 to10 Gy are presented in the Table 1 and Figures 3 and 4.

Table 1: Average TL sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti for liquid water phantom.

	Dose [Gy]	TL Sensitivity [μC.Gy^{-1}] 4 MeV	9 MeV
$CaSO_4$:Dy	1,0	17.5 (±0.4)	16.1 (±0.6)
LiF:Mg,Ti	1.0	0.659 (±0.007)	0.658 (±0.007)
Micro LiF	1.0	0.0549 (±0.0006)	0.0623 (±0.0005)

Table 2: LDL of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti for liquid water phantom.

	LDL [μC] 4 MeV	9 MeV
$CaSO_4$:Dy	33,2 (±0.9)	36,3 (±1.1)
LiF:Mg,Ti	673 (±7)	675 (±7)
Micro LiF	839 (±27)	731 (±24)

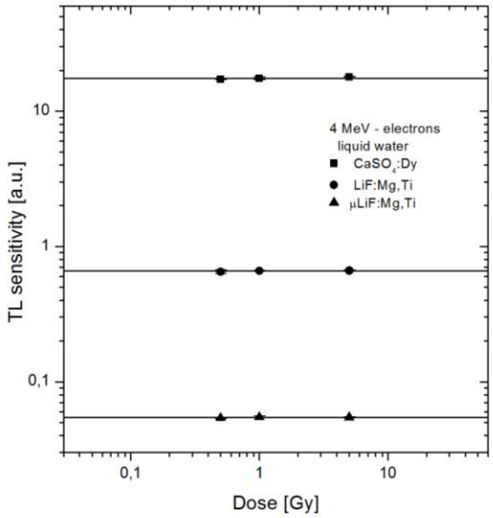

Fig 3. Average TL sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters for 4 MeV electron beams using liquid water phantom.

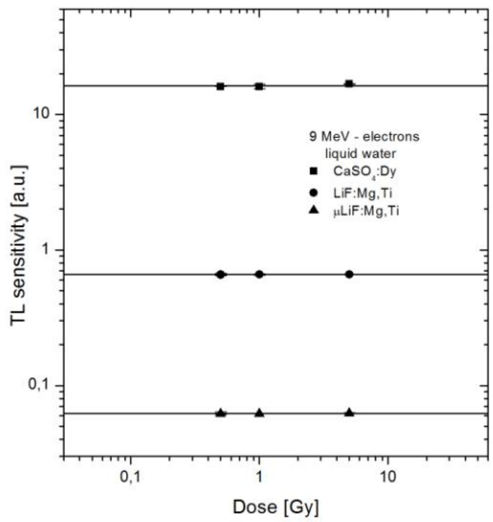

Fig 4. Average TL sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters for 9 MeV electron beams using liquid water phantom.

The LDL calculated as a function of the electron beam energy for the three dosimeters is showed in Table 2.

The TL sensitivity of $CaSO_4$:Dy dosimeters is 26 and 318 times higher than LiF:Mg,Ti and microLiF:Mg,Ti depending the dosimeter and the energy used.

The LDL of the $CaSO_4$:Dy dosimeters is 20 and 25 times smaller than LDL of the LiF:Mg,Ti and microLiF:Mg,Ti for 4 MeV and 18 and 20 times smaller and microLiF:Mg,Ti when the detectors were exposed at 9 MeV electrons beam.

Conclusions

For both clinical electron beams energies evaluated $CaSO_4$:Dy and LiF:Mg,Ti dosimeters presented the same linear behavior to the TL dose-response.

$CaSO_4$:Dy dosimeters showed TL sensitivity 26 and 318 times greater than LiF:Mg,Ti TL and microLiF:Mg,Ti dosimeter for 4MeV and 24 times and 259 times greater than LiF:Mg,Ti and microLiF:Ti TL dosimeter for 9 MeV, respectively.

The LDL of the $CaSO_4$:Dy dosimeters is an advantage in use this dosimeter for clinical dosimetry, allowing more precision and accuracy in the dose evaluation if compared with LiF:Mg,Ti and microLiF:Mg,Ti dosimeters

The obtained results indicate that $CaSO_4$: Dy TL dosimeter produced by Instituto de Pesquisas Energéticas e Nucleares/IPEN can be a new tool to be applied in clinical electron beams dosimetry.

Acknowledgment

The authors are thankful to CNPq and CAPES for the financial support and to the radiation therapy staff of the Hospital Israelita Albert Einstein for the electron irradiations.

References

1. Cameron, J.R.; Suntharalingam, N.; Kenney, G.N. (1968) Thermoluminescent dosimetry.: The Colonial Press, Londres .
2. Oberhofer, M.; Scharmann, A. (1979) Applied Thermoluminescence dosimetry. Adam Hilger Ltd, Ispra, Itália (Commission of the European Communities).
3. International Commission On Radiation Units And Measurements (1976) Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures, ICRU Report 24, ICRU Publications, Bethesda ND.

4. Eggermont, G. Jacobs, R.; Janssesns, A.; Segaert, O.; Thielens, G. (1971) Dose relationship energy response and rate dependence of LiF-100, LiF-7 and $CaSO_4$-Mn from 8 keV to 30 MeV. In: 3rd International Conference On Luminescence Dosimetry, October 11-14, Riso: Danish AEC Research Stablishment, 1971, p. 444-460
5. Hufton, A. P. (1984) Practical Aspects of Thermoluminescence Dosimetry. HPA, London.
6. Kalmykov, L.Z. Materials for thermoluminescent dose detectors and photon radiation energy detectors intendend for intercomparison procedures of radiation therapy units. v. 21 Med. Phys. 1994, n.11 p. 1715-1719.
7. Robar, V.; Zankowski, C.; Olivares, M.P.; Podgorsak, E.B.(1996) Thermoluminescence dosimetry in electron beams: Energy dependence. v. 23 Med. Phy. 1996, n. 5 p. 667-673.
8. Rudén, B. (1976) Evaluation of the clinical use of TLD. v. 15 Acta Radiol. Ther. Phys. Biol., 1976, p. 447-467.
9. Campos. L.L.; Lima, M.F. (1987) Thermoluminescent $CaSO_4$:Dy + Teflon pellets for beta radiation detection. v. 18 Rad. Prot. Dosim., 1987, n. 2, p. 95.
10. Lakshmanan, A.R.; Kher, R.K.; Supe, S.J. (1991) Estimation of effective dose equivalent using individual dosimeters. v. 35 Rad. Prot. Dosimetry. 1991, p. 247-253.
11. Nunes, M.G.; Campos, L.L. (2008) Study of $CaSO_4$:Dy and LiF:Mg,Ti detectors TL response to electron radiation using a SW solid water phantom. Rad. Measur. DOI:10.1016/j.radmeas.2007.11.008
12. Campos, L.L.; Souza, C.N. Aplicação dos dosímetros termoluminescentes de $CaSO_4$:Dy na dosimetria de elétrons de energia alta. Proc. In: 5th Latin American Conference On Medical Physics, Ribeirao Preto, Brazil October 7-12, 1990.
13. Nunes, M.G. Avaliação do desempenho dos detectores termoluminescentes de $CaSO_4$:Dy e LiF:Mg,Ti na dosimetria de feixes clínicos de elétrons. 2008. Dissertação (Mestrado) – Instituto de Pesquisas Energéticas e Nucleares, São Paulo, 2008.

CORRESPONDING AUTHOR:

Author: Amanda Bravim
Institute: Instituto de Pesquisas Energéticas e Nucleares
Street: Av. Professor Lineu Prestes, 2242
City: Sao Paulo
Country: Brazil
Email: abravin@ipen.br