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Intrinsic Efficiency of $CaSO_4$:Dy to Electron Beams

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Abstract. The intrinsic efficiency of $CaSO_4$:Dy thermoluminescent dosimeters, developed by Instituto de Pesquisas Energéticas e Nucleares – IPEN was calculated for 3.43, 5.48, 8.27, 11.67 and 15.42 MeV clinical electron beams at their depth of maximum ionization in polymethyl methacrylate (PMMA), SW Solid Water and standard water phantoms. The sensitivity, varying from 14.6 ± 0.3 $\mu C.Gy^{-1}$ (11.67 MeV, PMMA) to 19.6 ± 0.5 $\mu C.Gy^{-1}$ (15.42 MeV, water), the reproducibility of the TL response, better than 2.4%, and the TL response as a function of the dose, linear between 0.01 and 3.25 Gy, were also evaluated. The intrinsic efficiency of 0.0342 ± 0.0021 % indicates that $CaSO_4$:Dy dosimeters can be applied to the radiation protection for high energy electron beams generated by linear accelerators.

Introduction

The rising application of linear accelerators in industry and medicine has lead to the usage of calcium sulphate doped with dysprosium ($CaSO_4$:Dy) dosimeters, already intensively applied in gamma, beta, X-ray and mixed beta-gamma ionizing radiation fields dosimetry at radiation protection level, [1–5] as well as in the ultraviolet (UV) and laser non-ionizing radiations monitoring, [6–10] also in the dosimetry of high energy electron beams. [11]

The most widely applied thermoluminescent dosimeter (TLD) for personal, environmental and area dosimetry in Brazil at the radiation protection level is the $CaSO_4$:Dy + Teflon® dosimeter developed and produced at IPEN with 6 mm of diameter, 50 mg of mass and 1 mm of thickness. [12] Despite its high effective atomic number, (15.3) $CaSO_4$:Dy dosimeter present an excellent performance in high energy clinical photon beams dosimetry and were more recently evaluated for clinical electron beams applications, due to their sensitivity and response linearity for a wide dose range, as an alternative to commonly used LiF TLD. [13–15]

Special $CaSO_4$:Dy dosimeters with 20 mg and 0.1 mm of thickness containing graphite were also developed and are being applied to beta radiation dosimetry. [3,5]

As the dose equivalent received by occupationally exposed workers estimation will become more accurate with the determination of the intrinsic efficiency of the TLD used in monitoring, this work aims to determine the intrinsic efficiency of $CaSO_4$;Dy dosimeters for 3.43, 5.48, 8.27, 11.67 and 15.42 MeV clinical electron beams at their depth of maximum ionization in polymethyl methacrylate (PMMA), SW Solid Water and standard water phantoms. To do so, the assessed parameters were the sensitivity, the TL response reproducibility and the TL response as a function of the dose in the range of 0.01 to 3.25 Gy.

Methodology

The selection of $CaSO_4$:Dy + Teflon® pellets with mass of 50 mg and 1 mm of thickness ($CaSO_4$:Dy TLD) used in this study was based on three irradiations of a batch containing 203 dosimeters with a dose of 500.0 ± 0.5 mGy of ^{60}Co gamma radiation in air and electronic equilibrium conditions.

15 TLD whose sensitivities varied from 0.894 ± 0.005 to 0.937 ± 0.005 $\mu C.Gy^{-1}$, with an average sensitivity of 0.9077 ± 0.0018 $\mu C.Gy^{-1}$, were selected to determine the background radiation levels, 17 groups of 5 TLD with individual sensitivities varying in less than 0.7% in each group and average sensitivities varying from 0.844 ± 0.006 to 0.892 ± 0.006 $\mu C.Gy^{-1}$ were selected to determine the reproducibility and the linearity range of the $CaSO_4$:Dy TLD response and 5 TLD with identical individual sensitivities of 0.875 ± 0.011 $\mu C.Gy^{-1}$ were selected to determine the intrinsic efficiency of the TLD to the electron beams.

A furnace with microwave heating model MAS 7000 (CEM) was used to perform the TLD reuse annealing, that consist of maintaining an aluminum tray with the $CaSO_4$:Dy TLD at 300ºC during 3 h with quick cooling the dosimeters down to the environment temperature in order to reestablish the TLD electron traps before each electron beam irradiation.

The irradiations with 3.43, 5.48, 8.27, 11.67 and 15.42 MeV of incident energy electron beams were performed using a linear accelerator model Clinac 2100–C (Varian) which belongs to the Hospital Israelita Albert Einstein.

A polymethyl methacrylate (PMMA), a SW Solid Water or a standard water phantom was used to maintain the TLD positioned at the centre of the 0.10 x 0.10 m^2 radiation field formed at the phantom surface, located at 1.00 m of the electron beam focus, at the depth of maximum ionization, R_{100}, of the electron beam of incident energy E in the phantom material, shown by Table 1 for the studied electron beams and phantoms, and over a thickness equivalent to 80 $kg.m^{-2}$ of the phantom material, thick enough to assure the adequate backscattering of the electron beam.

Table 1. Depth of maximum ionization, R_{100}, of the electron beam of incident energy E relative to the material density, expressed in $kg.m^{-2}$, for PMMA, SW Solid Water and Water

E [MeV]	R_{100} [$kg.m^{-2}$]	R_{100} [mm] PMMA	SW	Water
3.43	8.0	7	8	8.0
5.48	12.0	11	13	12.0
8.27	20.0	18	21	20.0
11.67	28.0	24	28	28.0
15.42	18.0	16	19	18.0

PMMA and SW phantoms are made of 0.300 x 0.300 m^2 plates of different thicknesses that allow the TLD positioning at the different desired depths while the standard water phantom, a tank made of 0,355 x 0,355 x 0,02 m^3 PMMA walls filled with tri-distilled water, uses a screw system to control the position of a special holder with a precision of 0.1 mm without the introduction of detectable radiation scattering.

The thermoluminescent (TL) signal of the $CaSO_4$:Dy TLD was always read 36 h after irradiation at a heating rate of 10ºC.s^{-1} between 50ºC and 350ºC, a temperature that is maintained for 7 s after heating, using a TL reader model QS 3500 (Harshaw) that operates between 15ºC and 20ºC with the relative humidity of the air below 40% associated to the data acquisition software TLDSHELL for DOS.

Due to the good stability of the TL reader, assessed through the average signal/noise and average test light readouts performed before and after the readout of the selected $CaSO_4$:Dy TLD, it was not necessary to correct the TL signals obtained in different days, the sensitivity factor for the differences in the sensitivity of each dosimeter to the ^{60}Co gamma radiation in air and electronic equilibrium conditions being the only correction factor applied to the read TL signals.

The average TL response of the $CaSO_4$:Dy TLD irradiated in the same conditions was obtained by the correction of the average TL signal for each group of dosimeters for the background radiation, the average TL signal of the non-irradiated TLD.

Three groups of dosimeters whose individual sensitivities to the ^{60}Co gamma radiation in air and electronic equilibrium conditions vary in less than 0.25% were irradiated at the depth of maximum ionization of the electron beam in the phantom with a dose of 500,0 ± 1,0 mGy to determine, by the percentile ratio between the average sensitivity standard deviation and the average sensitivity to the electron beam relative to the sensitivity to the ^{60}Co gamma radiation, given by the ratio between the TL responses to the electron beam and to the ^{60}Co gamma radiation, the reproducibility of the $CaSO_4$:Dy TLD response to the electron beam in the phantom.

Each group of 5 five TLD was irradiated with a dose of 0.01, 0.03, 0.05, 0.07, 0.10, 0.25, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00 or 3.25 Gy of ^{60}Co gamma radiation in air and electronic equilibrium conditions and of each incident energy of the electron beam in each phantom. The group of identical individual sensitivities to the ^{60}Co gamma radiation was irradiated with 0.50 Gy in the same conditions of the remaining groups.

If the average sensitivity to the electron beam of incident energy E relative to the ^{60}Co gamma radiation is the same for two groups irradiated with distinct doses, considering their experimental uncertainties, and does not show a trend with the radiation dose, the average relative sensitivity is independent of radiation dose in the considered range, in which the dose-response curve is linear and the $CaSO_4$:Dy TLD is applicable to the electron beam dosimetry.

The intrinsic efficiency of the $CaSO_4$:Dy TLD, defined as the percentile ratio of the TL response by the product of the TLD mass and the absorbed dose by the dosimeter, to the ^{60}Co gamma radiation in air and electronic equilibrium conditions and to the electron beam of incident energy E in each phantom, was calculated through the average TL response of the group with the same sensitivity to the dose of 0.50 Gy of ^{60}Co gamma radiation, whose irradiation was repeated three times.

Results

Table 2 shows the TL response to the ^{60}Co gamma radiation in air and electronic equilibrium conditions and to the electron beam of incident energy E in the PMMA, SW and standard water phantoms, the average sensitivity relative to the ^{60}Co gamma radiation and the reproducibility of the $CaSO_4$:Dy TLD to the electron beams.

Table 2. TL response to the ^{60}Co gamma radiation, L_{Co-60}, and to the electron beams of incident energy E, L_E, average sensitivity relative to the ^{60}Co gamma radiation, $S_{E/Co-60}$, and reproducibility, R_E, of the $CaSO_4$:Dy TLD in PMMA, SW and water phantoms.

Phantom	Characteristic	Incident Energy [MeV]				
		3.43	5.48	8.27	11.67	15.42
Air	L_{Co-60} [nC]	440.0 ± 1.2	436.4 ± 0.9	431.6 ± 1.0	427.0 ± 1.2	423.9 ± 1.1
PMMA	L_E [μC]	7.43 ± 0.17	7.97 ± 0.19	8.88 ± 0.21	7.29 ± 0.17	8.94 ± 0.21
	$S_{E/Co-60}$	16.9 ± 0.4	18.3 ± 0.4	20.9 ± 0.5	17.1 ± 0.4	20.7 ± 0.5
	R_E [%]	2.4	2.4	2.4	2.4	2.4
SW	L_E [μC]	8.19 ± 0.19	8.95 ± 0.21	9.00 ± 0.22	7.77 ± 0.18	9.24 ± 0.22
	$S_{E/Co-60}$	19.2 ± 0.5	20.5 ± 0.5	21.2 ± 0.5	17.6 ± 0.4	21.4 ± 0.5
	R_E [%]	2.4	2.4	2.4	2.4	2.4
Water	L_E [μC]	8.86 ± 0.21	9.24 ± 0.22	9.61 ± 0.23	8.81 ± 0.21	9.82 ± 0.24
	$S_{E/Co-60}$	20.1 ± 0.5	21.4 ± 0.5	22.0 ± 0.5	20.6 ± 0.5	23.2 ± 0.6
	R_E [%]	2.4	2.4	2.4	2.4	2.4

The reproducibility, of 2.4%, is independent of the incident energy of the applied electron radiation and phantom, as it is expected for a characteristic that is more strongly related to the detection system than to the type or the energy of the radiation which is used to irradiate the dosimeter.

The dispersion of the average sensitivities relative to the ^{60}Co gamma radiation for the $CaSO_4$:Dy TLD groups irradiated with the ^{60}Co gamma radiation in air and electronic equilibrium conditions and at the depth of maximum ionization of the electron beam in the PMMA, SW and standard water phantoms with doses varying from 0.01 to 3.25 Gy is very similar for all electron beam energies and phantoms.

As the backscatter of the electron beam is stronger for lower incident energies, the largest dispersions were observed for the electron beam of 3.43 MeV and the average relative sensitivity for each TLD group, presented by Fig. 1 as a function of the group order for a better visualization, is lower for lower delivered doses.

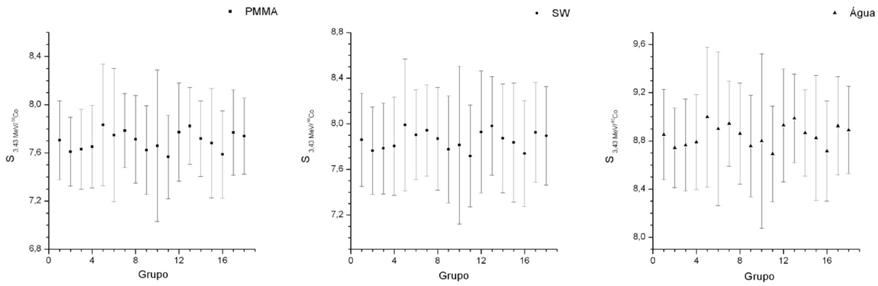

Fig 1. Average sensitivity relative to the ^{60}Co gamma radiation for each TLD group irradiated with 3.43 MeV electrons in the PMMA, SW and water phantoms.

Considering that the average relative sensitivities agree, inside their experimental uncertainties, in the worst observed case, the linearity range of the $CaSO_4$:Dy TLD response as function of the dose is the whole studied range, from 0.01 to 3.25 Gy, regardless electron beam incident energy or phantom, and the $CaSO_4$:Dy TLD the dose-response curve at the depth of the maximum ionization of the 3.43 MeV electron beam in the PMMA, the SW and the water phantoms is presented by Fig. 2.

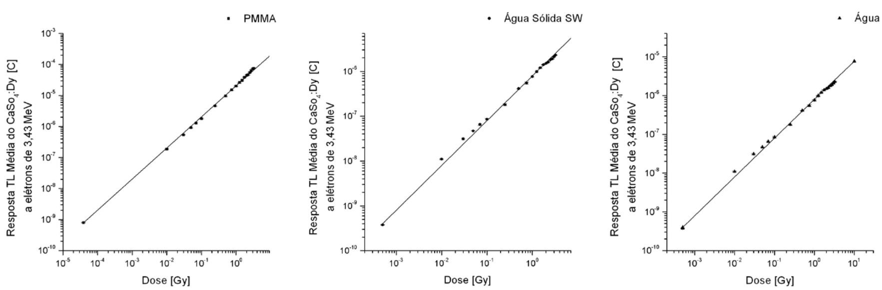

Fig. 2. $CaSO_4$:Dy TLD dose-response curves to the electron radiation of 3.43 MeV of incident energy in PMMA, SW and water phantoms.

The variation of the $CaSO_4$:Dy TLD intrinsic efficiency with the type and the incident energy of the radiation is presented by Fig. 3, that shows the intrinsic efficiency of the $CaSO_4$:Dy TLD irradiated with the ^{60}Co gamma radiation in air and electronic equilibrium conditions and with the electron beams of 3.43, 5.48, 8.27, 11.67 and 15.42 MeV of incident energy in the PMMA, SW solid water and water phantoms. The behavior of the $CaSO_4$:Dy TLD intrinsic efficiency with the electron beam incident energy does not depend on the applied phantom and, considered the experimental uncertainties, $CaSO_4$:Dy TLD intrinsic efficiency of 0.0342 ± 0.0021 % is independent of both the electron beam incident energy and phantom, being twenty times superior to the $CaSO_4$:Dy TLD intrinsic efficiency to the ^{60}Co gamma radiation.

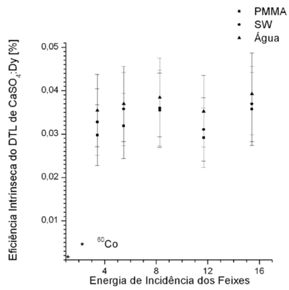

Fig. 3. $CaSO_4$:Dy TLD intrinsic efficiency to the ^{60}Co gamma radiation in air and electronic equilibrium conditions and to the electron beams of 3.43, 5.48, 8.27, 11.67 and 15.42 MeV of incident energy at their depth of maximum ionization in PMMA, SW and water phantoms.

Conclusões

Although the sensitivity of the $CaSO_4$:Dy + Teflon® thermoluminescent dosimeters (TLD) vary with the incident energy of the electron beam and with the applied phantom, from 14.6 ± 0.3 μC.Gy^{-1} for 11,67 MeV in PMMA to 19.6 ± 0.5 μC.Gy^{-1} for 15,42 MeV in water, the uncertainties associated to the mass of the dosimeter and to the absorbed dose, yet very small, are comparable to the uncertainties associated to the dosimeter sensitivities, resulting in an intrinsic efficiency of 0.0342 ± 0.021 % independent of the electron beam incident energy and applied phantom, if the experimental uncertainties are considered.

This value is twenty times superior to the value obtained for the $CaSO_4$:Dy + Teflon® intrinsic efficiency to the ^{60}Co gamma radiation in air and electronic equilibrium conditions, of 0.001696 ± 0.000005 %, and this difference shall be considered in order to avoid the overestimation of the dose equivalent when the $CaSO_4$:Dy + Teflon® TLD are used in the construction of dosimeters to be applied in the radiation protection at facilities dealing with high energy electron beams.

The reproducibility, of 2.4%, and the linearity range of the $CaSO_4$:Dy + Teflon® TLD response as a function of the dose, from 0.01 to 3.25 Gy, were not affected by the electron beam incident energy or by the phantoms studied in this work, in such a way that these factors does not influenced the determination of the $CaSO_4$:Dy + Teflon® intrinsic efficiency to high incident energy electron beams.

References

1. Campos, L. L.; Lima, M. F.: Dosimetric properties of $CaSO_4$:Dy + Teflon® pellets produced at IPEN. Radiation Protection Dosimetry (1986) 333–333
2. Lakshmanan, A. R.; Kher, R. K.; Supe, S. J.: Estimation of effective dose equivalent using individual dosemeters. Radiation Protection Dosimetry (1991) 247–253

3. Campos, L. L.: Graphite Mixed $CaSO_4$:Dy TL Dosemeter for Beta Radiation Dosimetry. Radiation Protection Dosimetry (1993) 205–209
4. Silva, T. A.; Rosa, L. A. R.; Campos, L. L.: Thermoluminescent Individual Dosemeter for Personal Dose Equivalent Assessment in Photon Fields. Radiation Protection Dosimetry (1995) 17–21
5. Daros, K. A. C.; Medeiros, R. B.; Campos, L. L.: TL Response Study of the $CaSO_4$:Dy Pellets with Graphite for Dosimetry in Beta Radiation and Low Energy Photons Fields. Applied Radiation and Isotopes (2001) 957–960
6. Potiens Jr., A. J.; Campos, L. L.: Photostimulated Thermoluminescence Application in Ultraviolet and Laser Radiation Dosimetry. Physics in Medicine and Biology (1994) 802–802
7. Potiens Jr., A. J.; Campos, L. L.: Ultraviolet and Laser Radiation Dosimetry Using Photostimulated Thermoluminescence in $CaSO_4$:Dy. Radiation Protection Dosimetry (1996) 95–97
8. Grossi, F. H..; Campos, L. L.: Studies of UV Induced Phototransfered Thermoluminescence in $CaSO_4$:Dy Pellets. Radiation Protection Dosimetry (2002) 421–424
9. Grossi, F. H..; Schor, P.; Campos, L. L.: Aplicação da Termoluminescência Fotoestimulada na Área Oftalmológica Usando o $CaSO_4$:Dy. Revista Brasileira de Pesquisa e Desenvolvimento (2002) 884–887
10. Grossi, F. H..; de Melo Jr., L. A. S.; Schor, P.; Campos, L. L.: PTTL Method Applied to UV Radiation Detection During Refractive Surgery Using Excimer Laser. Radiation Protection Dosimetry (2005) 185–188
11. Chatterjee, S., Bakshi, A. K, Kinhikar, R. A., Chourasiya, G., Kher, R. K.: Response of $CaSO_4$:Dy Phosphor Based TLD Badge System to High Energy Electron Beams from Medical Linear Accelerator and Estimation of Whole Body Dose and Skin Dose. Radiation Measurements (2009) 257–262
12. Nogueira, M. S.; Campos, L. L.: The Angular Dependence of $CaSO_4$:Dy Pellets for Personal Dose Equivalent Hp (D) Measurements. Physics in Medicine and Biology (1994) 384–384
13. Nunes, M. G.; Campos, L. L.: LiF:Mg,Ti and $CaSO_4$:Dy TL Responses to Radiation Therapy Electron Beams Using Lucite, RW3 Solid Water and Water Phantoms. In: 10th International Symposium on Radiation Physics, Coimbra: 10th International Symposium on Radiation Physics – Book of Abstracts (2006) D-63–D-63
14. Nunes, M. G.; Campos, L. L.: Study of $CaSO_4$:Dy and LiF:Mg,Ti Detectors TL Response to Electron Radiation Using a SW Solid Water Phantom. Radiation Measurements (2008) 459–462
15. Nunes, M. G.; Campos, L. L.: Phantom Influence on $CaSO_4$:Dy and LiF:Mg,Ti TL Responses to Electrons. In: 16th International Conference on Medical Physics, Dubai: 16th International Conference on Medical Physics Programme & Book of Abstracts (2008) 89 – 89

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