Performance of Brazilian Thermoluminescent $CaSO_4$:Dy Pellets in Standard Diagnostic Radiology Beams

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Abstract

The high sensitivity of $CaSO_4$:Dy as a thermoluminescent material is a great advantage when dealing with low dose levels, as in diagnostic radiology procedures. However, these kinds of dosemeters present a high energy dependence that must be precisely determined in the energy range of interest. Dosimetric pellets of $CaSO_4$:Dy are produced at IPEN since the end of the 80's decade. These pellets are produced in three forms: conventional $CaSO_4$:Dy (50mg); thin $CaSO_4$:Dy (20mg) and $CaSO_4$:Dy + 10%C (20mg). The main applications of these dosemeters are in personal and environmental dosimetry. In this study, $CaSO_4$:Dy pellets produced at IPEN were evaluated in diagnostic radiology standard beams. These qualities are based on the IEC 61267 standard, and they were established at an industrial X-ray system Pantak/Seifert, model ISOVOLT 160HS. Former studies evaluated $CaSO_4$:Dy of different origins in diagnostic beams. In this study, a large energy interval was used to include computed tomography energy beams. The results obtained show the behavior of the IPEN $CaSO_4$:Dy pellets in diagnostic standard beams. All results confirm that these pellets may be used for dosimetric procedures in diagnostic radiology beams.

1. INTRODUCTION

Since medical applications of ionizing radiation are the most important sources of irradiation of the population, it is necessary to look for the optimization of these practices. Therefore, an important tool is the Diagnostic Reference Levels (DRLs) concept [1,2]. The DRLs are typical dose values obtained from a dosimetric survey, usually defined as the third quartile of the measurements. To determine the DRLs, it is necessary to choose a dosimetric quantity, which often is based on TL measurements.

Several types of dosimetric materials are commercially available, for a wide range of application. In diagnostic radiology, TL materials are widely used for dosimetric purposes in clinical beams. Because of their small size, these dosimeters are very useful for local measurements on the patient, during the examination procedures [3-7].

As in the case of other TL materials, $CaSO_4$:Dy pellets were already studied in the diagnostic radiology range [8,9]. Although, even having high sensitivity, their utilization in diagnostic radiology beams are not so frequent, because of the high energy dependence. The most used TL materials in diagnostic radiology beams are the LiF based materials, which are nearly energy independent. In this study, three types of $CaSO_4$:Dy pellets produced at Instituto de Pesquisas Energéticas e Nucleares (IPEN) were studied in diagnostic radiology qualities.

2. MATERIALS AND METHODS

In this study, three types of $CaSO_4$:Dy pellets, produced at IPEN, were used: the conventional $CaSO_4$:Dy pellets, the thin $CaSO_4$:Dy pellets, and the thin $CaSO_4$:Dy+10%C pellets. The conventional $CaSO_4$:Dy pellet has 6.0mm in diameter and 0.8mm in thickness, and the thin $CaSO_4$:Dy types have the same diameter of 0.6mm and 0.2mm in thickness [10-13].

The pellets were evaluated in diagnostic radiology standard beams established at an industrial X-ray system Pantak/Seifert, model ISOVOLT 160HS. These qualities are based on the IEC 61267 standard, and the parameters are listed in Table I. The reference system for these qualities was a parallel-plate ionization chamber with 1 cm^3 of sensitive volume, PTW, model 77334, coupled to a PTW electrometer, model UNIDOS 10001. The ionization chamber was calibrated by the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB).

Table I. Diagnostic radiology qualities, direct beams, with 2.5 mmAl total filtration, at the *Pantak/Seifert* X-ray equipment.

Radiation Quality	Voltage (kV)	Half-Value Layer (mmAl)	Effective Energy (keV)	Air Kerma Rate (mGy/min)
Direct Beams				
RQR2	40	1.44	25.10	13.79
RQR3	50	1.79	27.15	24.06
RQR4	60	2.09	28.80	35.35
RQR5	70	2.35	30.15	47.17
RQR6	80	2.65	31.65	60.39
RQR7	90	2.95	33.05	74.51
RQR8	100	3.24	34.40	89.81
RQR9	120	3.84	37.05	121.80
RQR10	150	4.73	40.75	175.19
Attenuated Beams				
RQA2	40	2.22	29.50	5.39
RQA3	50	3.91	37.30	3.39
RQA4	60	5.34	43.25	3.03
RQA5	70	6.86	49.40	3.40
RQA6	80	8.13	54.75	3.99
RQA7	90	9.22	59.70	4.87
RQA8	100	10.09	63.95	5.76
RQA9	120	11.39	71.15	7.93
RQA10	150	13.02	82.10	13.28

For the TL measurements, a Harshaw Nuclear System, model 2000A/B, was utilized. All pellets were evaluated using a linear heating rate of 10°C/s, and a constant flow of high pure nitrogen of 5.0 l/min. The thermal treatment applied to all pellets, prior irradiation, was 300°C for 3 hours.

3. RESULTS AND DISCUSSION

Tests were performed with the three types of $CaSO_4$:Dy, produced at IPEN. The tests were realized in the diagnostic radiology range, although it is not the prior application of these pellets. During the irradiations, all pellets were positioned simultaneously in the beam. For each pellet, the irradiation position was maintained during all irradiations.

3.1 Response Reproducibility

The response reproducibility of the materials was analyzed by exposing the materials ten times to the same absorbed dose (12 mGy), in a specific quality (RQA6 – 80kV, CSR of 8.13 mmAl), with a fixed geometry. The maximum percentage standard deviation obtained for each type of pellet is presented in Table II. The values obtained in this study were somewhat higher than the values presented by L.L. Campos (3-4%) [10,13], using beta and gamma radiations. Typical TL reproducibility values are between 2% and 10% [10,13-15], and they depend on several factors, such as dosemeter type, TL reader quality and stability, radiation type, dose range, among others. Therefore, the results obtained in this work are within the expected range.

3.2 Lower Dose Limits

The lower dose limit was set as equal to three times the standard deviation of the signal from the unexposed dosemeters (zero-dose) of each type of material. The values, in units of absorbed dose, are presented also in Table II. These values were very similar to the values obtained by L.L. Campos (9-23μGy) [10,13].

Table II. Reproducibility and lower dose limit of the $CaSO_4$:Dy pellets produced at IPEN, in a diagnostic standard beam.

TL Pellets	Reproducibility Maximum Variation (%) (Percentage Standard Deviation)	Lower Dose Limit (μGy)
$CaSO_4$:Dy	5.8	10
Thin $CaSO_4$:Dy	3.3	10
Thin $CaSO_4$:Dy + 10% C	4.3	15

3.3 Calibration Curves

Two calibration curves were obtained for each material, using two diagnostic radiology standard beams – RQR6 and RQA6 (see Table I). For the direct beam, the dose range was 5 to 200mGy, and the air kerma rate was 60.4 mGy/min. For the attenuated beam, the dose range was 1 to 50mGy, and the air kerma rate was 4.0 mGy/min. A calibration curve was obtained for each pellet individually. Figures 1 and 2 present examples of the calibration curves obtained. In these dose ranges, all TL materials evaluated presented linear behaviors. Each set of data were fitted and the lowest correlation coefficients obtained are presented in Table III. The results of the calibration curves showed that the sensitivity of the $CaSO_4$:Dy pellets varies significantly, being the thin $CaSO_4$:Dy + 10% C the least sensitive.

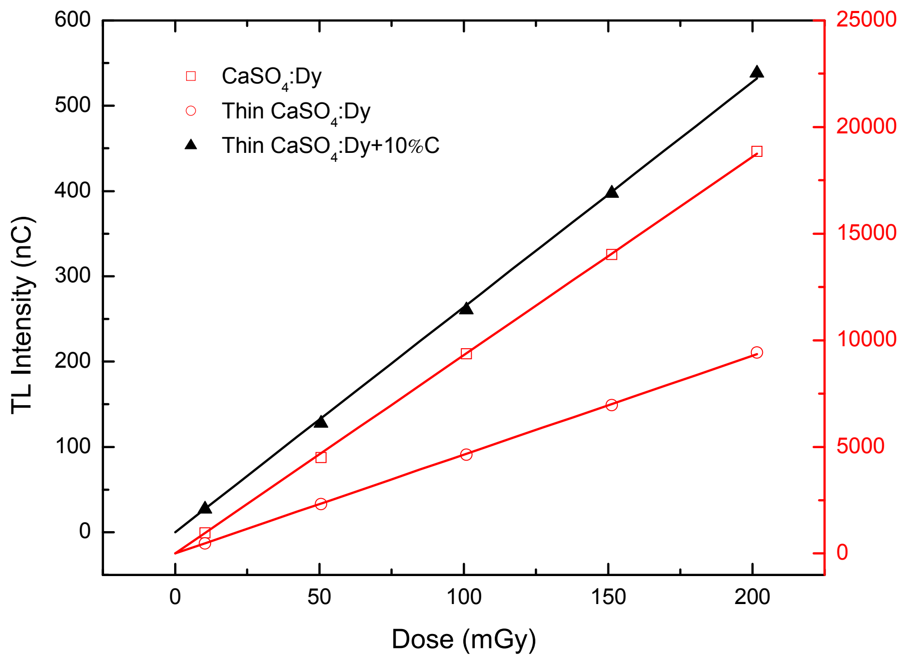

Figure 1. Calibration curves of the $CaSO_4$:Dy pellets produced at IPEN, for diagnostic radiology quality, direct beam (RQR6). The left axis is related to the thin $CaSO_4$:Dy+10%C pellets, and the right axis is related to the $CaSO_4$:Dy and thin $CaSO_4$:Dy pellets.

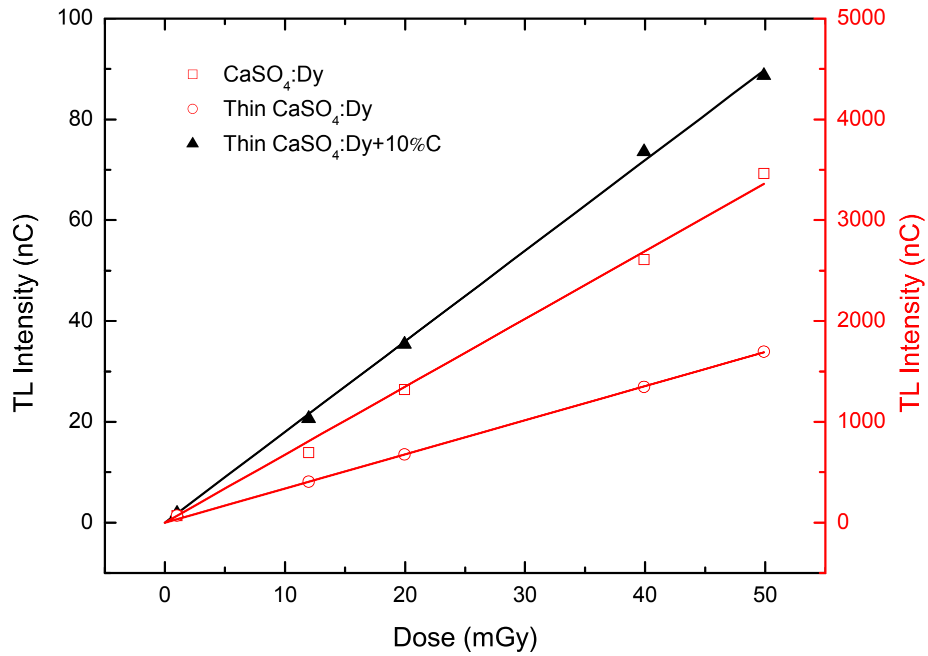

Figure 2. Calibration curves of the $CaSO_4$:Dy pellets produced at IPEN, for diagnostic radiology quality, attenuated beam (RQA6). The left axis is related to the thin $CaSO_4$:Dy+10%C pellets, and the right axis is related to the $CaSO_4$:Dy and thin $CaSO_4$:Dy pellets.

Table III. Lowest correlation coefficients obtained for the linear fits of the calibration curves of the $CaSO_4$:Dy pellets.

TL Pellets	Lowest Correlation Coefficient	
	Direct Beam	Attenuated Beam
$CaSO_4$:Dy	0.999	0.998
Thin $CaSO_4$:Dy	0.999	0.996
Thin $CaSO_4$:Dy + 10% C	0.998	0.998

3.4 Energy Dependence

The energy dependency of the dosemeters was evaluated also for direct and attenuated beams. The mean energy dependence curves, obtained for each type of $CaSO_4$:Dy pellet, are presented in Figure 3. The behavior of all three types of $CaSO_4$:Dy pellets were similar, and the values of energy dependence were very high, mainly for the attenuated beams, as can be seen in Table IV. The results presented agree with those of former studies. Niroomand-Rad and DeWerd [8] reported an energy dependence about 10% for radiation beams with HVL lower than 6mmAl, and Pradhan *et al.* [9] reported an energy dependence about 20% for direct beams of tube potentials below 117 kV_p. For higher tube potentials and for attenuated beams, the results obtained by Pradhan *et al.*[9] were strongly dependent on energy, as obtained in this work.

It can also be observed from these results that the energy response is strongly dependent of the beam characteristics, such as total filtration, since there are significant response variations for direct and attenuated beams in the same energy range, vide the rectangular area in emphasis. So, the calibration curves should always be obtained in radiations qualities similar in most aspects to the clinical beams. The selection of the calibration beam only by energy aspects is not adequate enough.

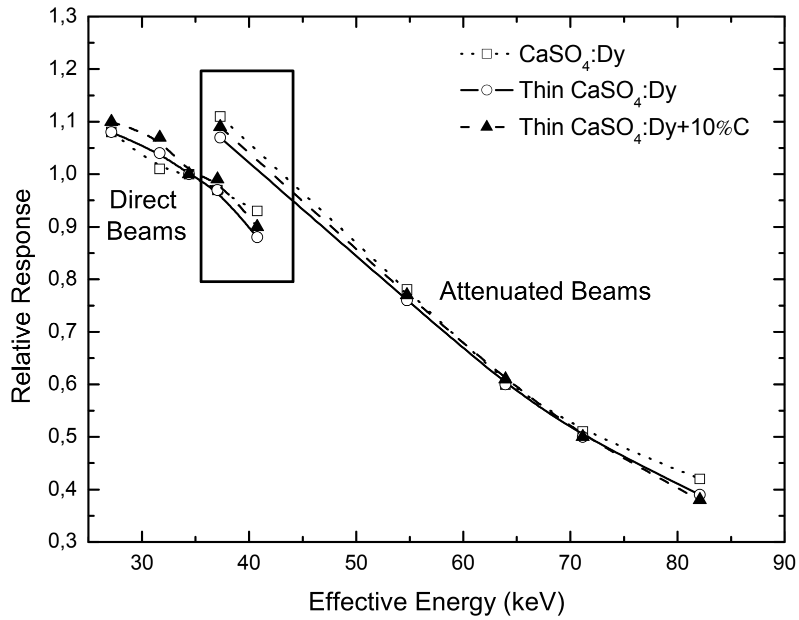

Figure 3. Energy dependence curves for the $CaSO_4$:Dy pellets produced at IPEN, in diagnostic radiology qualities, attenuated and direct beams.

Table IV. Energy dependence of the $CaSO_4$:Dy pellets in diagnostic radiology qualities, attenuated and direct beams.

TL Pellets	Energy Dependence (%)	
	Direct Beam	Attenuated Beam
$CaSO_4$:Dy	15.8	164.7
Thin $CaSO_4$:Dy	21.8	173.1
Thin $CaSO_4$:Dy + 10% C	22.8	184.6

3.5 Uncertainties Measurements

For all tests evaluated, the overall uncertainties were estimated following the ISO-GUM recommendations [16]. The factors considered in the uncertainty determination are presented in

Table V, with their respective estimated values. The expanded uncertainties obtained, considering a coverage factor of 2, are presented in Table VI.

Table V. Parameters considered in the uncertainty estimative for the tests performed with different types of $CaSO_4$:Dy pellets, in diagnostic radiology qualities.

TL Pellets	Parameters Considered in the Uncertainty Estimative	
	Reproducibility	Calibration and Energy Dependence
TL Measurements	2.12	2.12
Irradiation Time	0.10	1.77
Pellet Positioning during Irradiation	0.06	0.06
TL Reader Stability	0.17	0.17
Air Kerma Rate Stability	0.50	0.50
TL Pellet Reproducibility	-	2.33 – 4.10

Table VI. Expanded uncertainties obtained for the tests performed with different types of $CaSO_4$:Dy pellets, in diagnostic radiology qualities.

TL Pellets	Uncertainties Measurements (%)	
	Reproducibility	Calibration and Energy Dependence
$CaSO_4$:Dy	4.4	10.0
Thin $CaSO_4$:Dy	4.4	7.3
Thin $CaSO_4$:Dy + 10% C	4.4	8.3

4. CONCLUSIONS

The performance of three types of Brazilian thermoluminescent $CaSO_4$:Dy pellets was evaluated in the diagnostic radiology energy range, using IEC standard beams. The results obtained in the tests were similar to the typical values for TL materials, proving that the pellets evaluated are adequate for dosimetric purpose in diagnostic radiology.

However, it is necessary to be specially careful with the high energy dependence of the materials. The calibration curves must be obtained in radiation beams really similar to the clinical beams, not only in energy, but also in total filtration.

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