Response of TL materials in diagnostic radiology X radiation beams

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Abstract

The main objective of this study was to carry out a direct performance comparison among some known types of TLDs – three types of $CaSO_4$:Dy pellets, sintered Al_2O_3 pellets, LiF:Mg,Ti (Harshaw TLD-100), CaF_2:Dy (Harshaw TLD-200) and CaF_2:Mn (Harshaw TLD-400) – in the energy and dose ranges of diagnostic radiology beams. Several dosimetric characteristics were evaluated, such as reproducibility, sensitivity, calibration curves, lower dose limits and energy dependence.

Keywords: TLDs, diagnostic radiology, energy dependence

1. INTRODUCTION

Medical applications of ionizing radiations are the most important sources of irradiation of the population. Even being their benefits indubitable, the continuous growth in the number of procedures and equipments is warning the specialists for the need of a specific care in the optimization of these practices. Therefore, dosimetric investigations in diagnostic radiology have been increasing in importance in the last two decades, frequently with the purpose of the determination of Diagnostic Reference Levels (DRLs) (Drexler, 1998; ICRP 73, 1996). 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 thermoluminescent measurements.

Several types of thermoluminescent dosemeters (TLD) are commercially available, for a wide range of applications. In diagnostic radiology, TL materials are widely used for dosimetric purposes in clinical beams. Because of their small size, these dosemeters are very useful for local measurements on the patient, during the examination procedures (Bull, 1986; Portal, 1986; Rangajec-Komor et al., 1993; DeWerd and Chiu, 1993; Kron, 1999; Yu and Luxton, 1999; Berni et al., 2002).

LiF:Mg,Ti, usually named TLD-100, is one of the first materials used in diagnostic radiology, and, even nowadays, it is one of the most utilized. However, some other materials have also been used in this energy range (Niroomand-Rad and DeWerd, 1983; Pradhan et al., 1993; Miljanie et al., 1999).

Even though the general characteristics of most materials are well documented in literature (McKeever et al., 1995), the parameters cannot easily be compared, because they derive from different studies, each one with its particularities. Studies comparing directly their performance, in particular energy and dose ranges, may be specially useful in a process of choosing materials, because they allow a quantitative evaluation of the TLD behavior. Therefore, the main purpose of this study was to compare the performance of different types of TLDs in diagnostic radiology energy range, using standard beams. The studied materials were always irradiated simultaneously and read in sequence, at the same TL reader, to allow a direct comparison.

The results presented in this paper may be useful for any one having to decide among TLD materials for diagnostic radiology dosimetry, particularly for those with access to other materials than LiF:Mg,Ti. Moreover, the results can also be very helpful for the establishment of a tandem system for energy determination in diagnostic radiology beams.

2. MATERIALS AND METHODS

Seven types of TL materials were used in this study: three types of $CaSO_4$:Dy pellets (conventional $CaSO_4$:Dy pellets, thin $CaSO_4$:Dy pellets, and thin $CaSO_4$:Dy+10%C pellets), sintered Al_2O_3 pellets (also called Alumina), LiF:Mg,Ti (Harshaw TLD-100), CaF_2:Dy (Harshaw TLD-200) and CaF_2:Mn (Harshaw TLD-400). Both the sintered Al_2O_3 pellets and the three types of $CaSO_4$:Dy pellets were produced at IPEN. The conventional $CaSO_4$:Dy pellets have 6.0 mm in diameter and 0.8 mm in thickness, and the thin $CaSO_4$:Dy types have the same diameter and 0.2 mm in thickness (Campos, 1983, 1988, 1993; Campos and Lima, 1986). The sintered Al_2O_3 pellets have 8.5 mm in diameter and 0.8mm in thickness. The Harshaw pellets have the dimensions of 3 mm x 3 mm x 0.9 mm.

For the TL measurements a Harshaw Nuclear System, model 2000A/B, was utilized. All TLDs were evaluated with a linear heating rate of 10°C/s, using a constant flow of high purity nitrogen of 5.0 liters/min.

The thermal treatment applied to $CaSO_4$:Dy pellets, prior irradiation, was 300°C for 3 hours. For the sintered Al_2O_3 pellets and for all the Harshaw TLDs, the thermal treatment, prior irradiation, was 400°C for 1 hour (Muniz et al., 1996). In the case of TLD-200, a post-irradiation thermal treatment at 115°C for 10 minutes was also applied.

The TLDs were evaluated in diagnostic radiology standard beams (International Electrotechnical Commission-IEC), established at an industrial X-ray system Pantak/Seifert, model ISOVOLT 160HS. Their parameters are listed in Table 1. Two kinds of beams were utilized: direct beams, which are helpful for entrance dose measurements, and attenuated beams, which are helpful for measurements behind the patient or inside anthropometrical phantoms. The reference system for these qualities was a parallel-plate ionization chamber with 1 cm^3 of sensitive volume, PTW, model 77334, with a PTW electrometer, model UNIDOS 10001. This chamber was calibrated by the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB).

3. RESULTS AND DISCUSSION

Several tests were performed using the TLDs. In all cases, the TLDs were irradiated simultaneously, and the irradiation position of each pellet was maintained fixed during all irradiations. The similar conditions of irradiation and reading (same radiation beams, same TL reader, same furnace for thermal treatments, and same irradiation holder) allowed a direct performance comparison.

3.1 Response Reproducibility

The response reproducibility of the materials was analyzed by exposing them ten times to the same radiation dose (12 mGy), in a specific radiation quality (RQA6 – 80 kV, HVL of 8.13 mmAl), with a fixed geometry. The response reproducibility was determined for each pellet individually. The maximum percentage standard deviation obtained for each type of TLD is presented in Table 2.

Typical TL reproducibility values are between 2 and 10% (Campos, 1983, 1993; Oliveira and Caldas, 2004; Oberhofer and Scharmann, 1981), and they depend on several factors, such as dosemeter type, TL reader quality and stability, radiation type, dose range, among others. The results of this study were all within the expected range. Moreover, some materials, such as TLD-100, TLD-200, TLD-400 and thin $CaSO_4$:Dy, presented a very good performance, with reproducibility values below 3.5%.

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). The values obtained, in units of absorbed dose, are presented also in Table 2. Although most materials presented results in accordance with the needs of the diagnostic radiology dose range, the alumina pellets presented a high lower dose limit, becoming inadequate for patient dosimetry studies.

3.3 Relative Sensitivity

The relative sensitivity of each material was determinated by comparing the mean values obtained in the reproducibility tests, considering TLD-100 as reference. The results obtained are also listed in Table 2. The least sensitive material is Alumina. Among all other materials, the TLD-100 presented the lowest TL sensitivity, and the TLD-200 the highest TL sensitivity. The second most sensitive materials are the conventional $CaSO_4$:Dy pellets. The variations of TL response among the different types of $CaSO_4$:Dy pellets are considerable, being the conventional $CaSO_4$:Dy pellets almost twice more sensitive than the thin $CaSO_4$:Dy pellets, and more than 40 times more sensitive than the thin $CaSO_4$:Dy + 10% C pellets.

It is not easy to compare the sensitivity values obtained in this study with those from literature, because this parameter varies significantly with the beam energy. Most frequently, the sensitivity values are presented for the ^{60}Co energy, which are not useful for dosimetry purposes in low energy beams. The results obtained showed that, in the diagnostic radiology energy range, the differences in sensitivity among the materials are even more accentuated than for the high energy beam of ^{60}Co.

3.4 Calibration Curves

For each material, two calibration curves were obtained, using two diagnostic radiology standard beams – RQR6 and RQA6 (see Table 1). For the direct beam, the dose range was from 5 to 200 mGy, and the air kerma rate was 60.4 mGy/min. For the attenuated beam, the dose range was from 1 to 50 mGy, and the air kerma rate was 4.0 mGy/min. A calibration curve was obtained for each pellet individually. In these dose ranges, all TL materials evaluated presented a linear behavior. Since the calibration curves are specific for the dosimetric system utilized, they are not useful for other users and, therefore, they are not presented here. However, the curve linearities were quantified by the correlation coefficients of the linear fit applied to each curve and all values obtained were better than 0.991.

3.5 Energy Dependence of Response

The energy dependence of the TL materials response was studied for direct and attenuated X-ray beams. The mean dependence energy curves, obtained for each type of TLD, are presented in Figures 1 to 3. The maximum energy dependence obtained in each case is presented in Table 3.

The TLD-100 dosemeters presented the flattest energy dependence of response. All other materials presented a very high energy dependence of response for the attenuated beams. The behavior of the three types of $CaSO_4$:Dy pellets was similar, and the values of energy dependence of response were high, even for the direct beams. The good behavior of the TLD-100 dosemeters in the energy dependence of response test is the main reason for its great popularity in dosimetry. The other materials, which are also useful for this purpose, must be used carefully, once the energy dependence of their responses is high enough to misunderstand the dose results. In specific circumstances, where the beam energy is known, those TLDs can be used associated to well-constructed calibration curves. In others circumstances, those TLDs should be used associated to a device that allows the estimative of the effective energy of the beam. A simple device for energy discrimination is a tandem system, which can easily be composed by different types of TLD materials (Gorbics and Attix; 1968; Spurny et al., 1973; Miljanie et al., 1999). The accentuated differences in the energy dependence curves obtained in this study, mainly between the TLD-100 and the other dosemeters, show the potentiality of those materials to be combined in tandem systems.

The energy response is strongly dependent on the beam characteristics, such as total filtration, since there is a significant response variation for direct and attenuated beams in the same energy range, as can be seen in the rectangular areas in emphasis in Figures 1 to 3. Therefore, the calibration curves should always be obtained in radiation qualities as similar as possible, in most aspects, to the clinical beams.

3.6 Uncertainties of Measurements

The overall uncertainties in all realized tests were estimated following the ISO-GUM recommendations (ISO-GUM, 1995). Most of the considered parameters in the uncertainty determination are related to the irradiator system or to the TL reader precision, and do not vary among the different materials once all materials were irradiated and read in similar conditions. The expanded uncertainties obtained, considering a coverage factor of 2, varied from 7 to 10%.

4. CONCLUSIONS

Seven different types of TLDs were evaluated in relation to their performance in the diagnostic radiology energy range, using IEC standard beams. The tests were performed simultaneously with all materials to allow a direct comparison. The results show that the sintered Al_2O_3 pellets, produced at IPEN, do not have the adequate sensitivity to be used in this dose range. All other materials presented a sensitivity higher than the TLD-100 dosemeters. However, none of the materials, except TLD-100, presented flat energy dependence of response, which is in accordance with literature data. The utilization of those materials for dosimetric purposes should be associated to devices for the determination of the beam effective energy, as, for example, a TLD tandem system. It is essential also to obtain precise calibration curves, in radiation beams really similar to the clinical beams.

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Figure Captions:

Figure 1. Energy dependence of response curves for the three types of $CaSO_4$:Dy pellets produced at IPEN, in diagnostic radiology qualities, direct and attenuated beams.

Figure 2. Energy dependence of response curves for sintered alumina and TLD-100 pellets, in diagnostic radiology qualities, direct and attenuated beams.

Figure 3. Energy dependence of response curves for TLD-200 and TLD-400 pellets, in diagnostic radiology qualities, direct and attenuated beams.

Table 1. Characteristics of diagnostic radiology qualities, direct beams, with 2.5 mmAl total filtration, at the *Pantak/Seifert* X-ray equipment, model ISOVOLT 160HS.

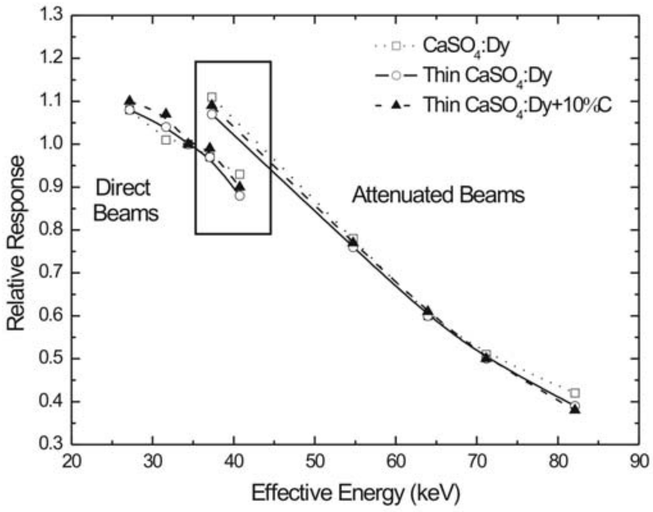
Radiation Quality	Voltage (kV)	Half-Value Layer (mmAl)	Effective Energy (keV)	Air Kerma Rate (mGy/min)
Direct Beams				
RQR3	50	1.79	27.15	24.06
RQR6	80	2.65	31.65	60.39
RQR8	100	3.24	34.40	89.81
RQR9	120	3.84	37.05	121.80
RQR10	150	4.73	40.75	175.19
Attenuated Beams				
RQA3	50	3.91	37.30	3.39
RQA6	80	8.13	54.75	3.99
RQA8	100	10.09	63.95	5.76
RQA9	120	11.39	71.15	7.93
RQA10	150	13.02	82.10	13.28

Table 2. Reproducibility, lower dose limits and relative sensitivity of different TLDs, in a diagnostic standard beam (RQA6).

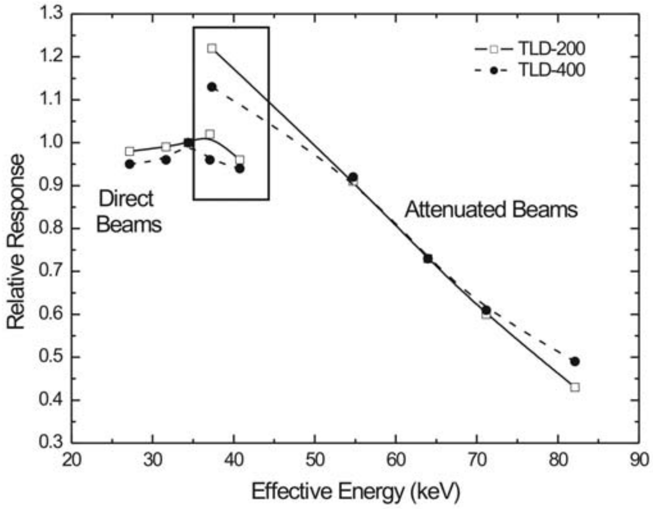
TL Pellets	Reproducibility Maximum Variation (%) (Percentage Standard Deviation)	Lower Dose Limit (μGy)	Relative Sensitivity
$CaSO_4$:Dy	5.8	10	61.8
Thin $CaSO_4$:Dy	3.3	10	32.3
Thin $CaSO_4$:Dy + 10% C	4.3	15	1.5
Sintered Alumina	4.2	130	0.2
TLD-100	3.2	15	1.0
TLD-200	3.0	10	179.7
TLD-400	2.9	10	42.4

Table 3. Energy dependence of response values for the different types of TLDs in diagnostic radiology qualities, direct (RQR3-10) and attenuated beams (RQA3-10).

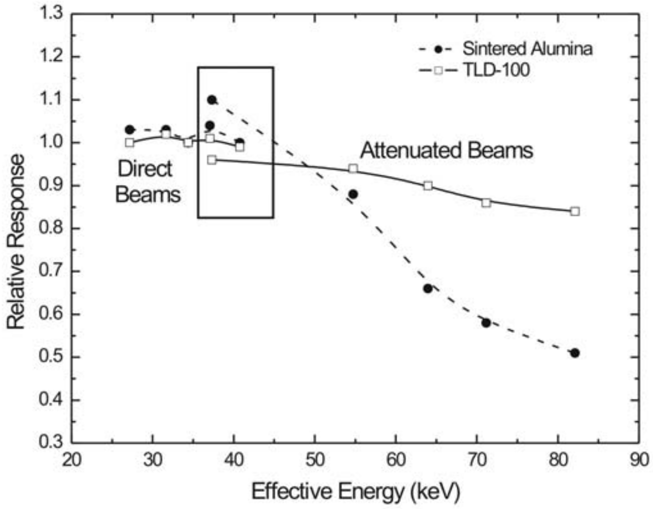
TL Pellets	Energy dependence of response (%)	
	Direct Beams	Attenuated Beams
$CaSO_4$:Dy	15.8	164.7
Thin $CaSO_4$:Dy	21.8	173.1
Thin $CaSO_4$:Dy + 10% C	22.8	184.6
Sintered Alumina	4.1	117.4
TLD-100	2.5	14.4
TLD-200	5.9	183.9
TLD-400	6.4	128.4



CaSO4:Dy
Thin CaSO4:Dy
Thin CaSO4:Dy+10%C
Direct Beams
Attenuated Beams
Relative Response
Effective Energy (keV)



Relative Response
Effective Energy (keV)
TLD-200
TLD-400
Direct Beams
Attenuated Beams



Sintered Alumina
TLD-100
Direct Beams
Attenuated Beams
Relative Response
Effective Energy (keV)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
20
30
40
50
60
70
80
90