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Response of TL materials to 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.

1. Introduction

Medical applications of ionizing radiation are the most important sources of irradiation of the population. Even though their benefits are indubitable, the continuous growth in the number of procedures and equipment is warning specialists for the need of special care in the optimization of these practices. Therefore, dosimetric investigations in diagnostic radiology have been increasing in importance in the last two decades, often with the purpose of determining the 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 is often based on thermoluminescent measurements.

Several types of thermoluminescent dosimeters (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 dosimeters are very useful for local measurements on the patient, during examination procedures (Bull, 1986; Portal, 1986; Ranogajec-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, was 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 the literature (McKeever et al., 1995), the parameters cannot easily be compared because they derive from different studies, each with its own particularities. Studies comparing directly their performance, in particular energy and dose ranges, may be especially useful in the process of choosing materials because they allow a quantitative evaluation of TLD behaviour. Therefore, the main purpose of this study was to compare the performance of different types of TLDs in the energy range of diagnostic radiology, using standard beams. The materials studied were always irradiated simultaneously and read in sequence, on the same TL reader, to allow a direct comparison.

The results presented in this paper may be useful for anyone having to decide among TLD materials for diagnostic radiology dosimetry, particularly for those with access to materials other 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 a diameter of 6.0 mm and a thickness of 0.8 mm, and the thin $CaSO_4$:Dy types have the same diameter and a thickness of 0.2 mm (Campos, 1983, 1988, 1993; Campos and Lima, 1986). The sintered Al_2O_3 pellets have a diameter of 8.5 mm and a thickness of 0.8 mm. The Harshaw pellets have dimensions of 3 mm × 3 mm × 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 l/min.

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Table 1
Characteristics of diagnostic radiology quality direct beams, with 2.5 mmAl total filtration, from 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

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

The TLDs were evaluated in diagnostic radiology standard beams (International Electrotechnical Commission, IEC), established with 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. 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. Reproducibility of response

The reproducibility of response of the materials was analysed by exposing them 10 times to the same radiation dose (12 mGy), at a specific radiation quality (RQA6—80 kV, HVL of 8.13 mmAl), with a fixed geometry. Reproducibility of response 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 depend on several factors, such as dosimeter 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 very good performance, with reproducibility values below 3.5%.

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

3.2. Lower dose limits

The lower dose limit was set equal to three times the standard deviation of the signal from the unexposed dosimeters (zero dose). The values obtained, in units of absorbed dose, are presented in Table 2. Although most materials presented results in accordance with the needs of the diagnostic radiology dose range, the alumina pellets exhibited a high lower dose limit, making it inadequate for patient dosimetry studies. Except for alumina, the lower dose limits were similar for most materials, because of the important influence of the TL reader.

3.3. Relative sensitivity

The relative sensitivity of each material was determined by comparing the mean values obtained in the reproducibility tests, using TLD-100 as a reference. The results obtained are also listed in Table 2. The least sensitive material is alumina. Among all other materials, TLD-100 exhibited the lowest TL sensitivity, and TLD-200 the highest TL sensitivity. The second most sensitive materials are the conventional $CaSO_4$:Dy pellets. The variations of TL response among different types of $CaSO_4$:Dy pellets are considerable, with conventional $CaSO_4$:Dy pellets almost twice as sensitive as 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 sensitivity values obtained in this study with those from the literature, because this parameter varies significantly with beam energy. Most frequently, 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 exhibited a linear behaviour. 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 linearity of the curves was quantified in terms of the correlation coefficients of the linear fit applied to each curve and all values obtained were better than 0.991.

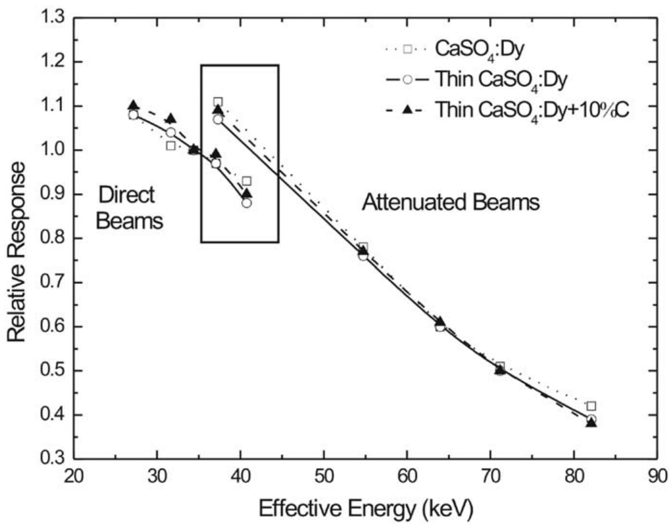

Fig. 1. Energy dependence of response curves for three types of $CaSO_4$:Dy pellets produced at IPEN, in diagnostic radiology qualities, direct and attenuated beams.

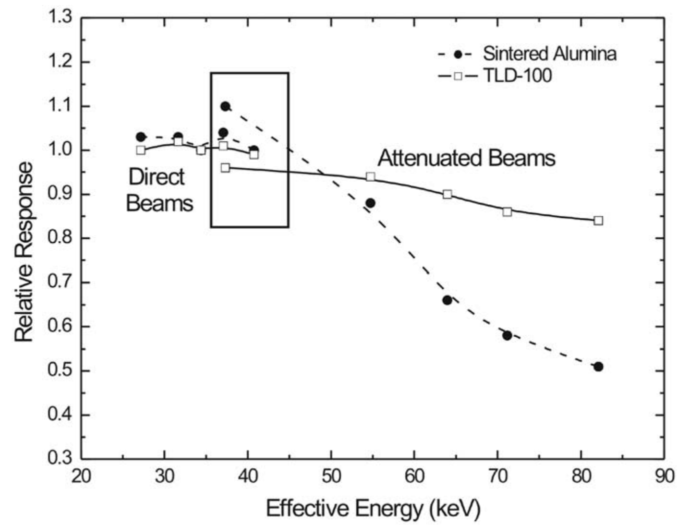

Fig. 3. Energy dependence of response curves for TLD-200 and TLD-400 pellets, in diagnostic radiology qualities, direct and attenuated beams.

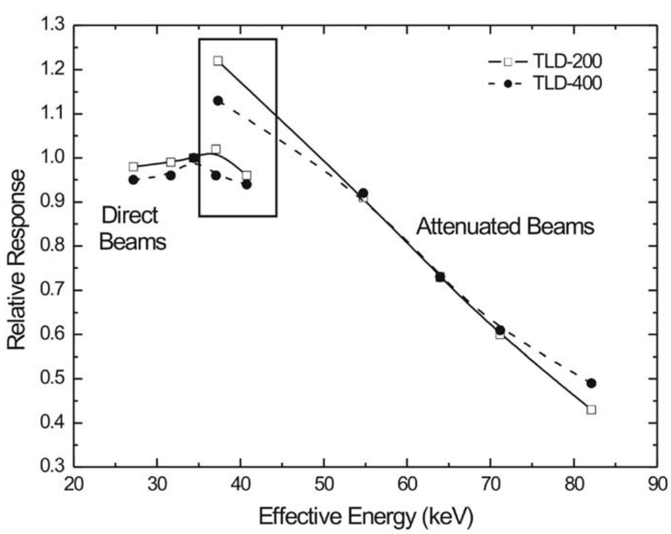

Fig. 2. Energy dependence of response curves for sintered alumina and TLD-100 pellets, in diagnostic radiology qualities, direct and attenuated beams.

Table 3
Energy dependence of response values for the different types of TLDs in diagnostic radiology quality, 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

3.5. Energy dependence of response

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

The TLD-100 dosimeters presented the flattest energy dependent response. All other materials presented a very high energy dependence of response for the attenuated beams. The behaviour of the three types of $CaSO_4$:Dy pellets was similar, and the responses had a very great energy dependence, even for direct beams. The good behaviour of the TLD-100 dosimeters in the energy dependent 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, as the energy dependence of their responses is high enough to distort the dose results. In particular circumstances, where the beam energy is known, these TLDs can be used and associated to well-constructed calibration curves. In others circumstances, these TLDs should be used and associated to a device that allows the effective energy of the beam to be estimated. A simple device for energy discrimination is a tandem system, which can be easily composed of different types of TLD materials (Gorbics and Attix, 1968; Spurny et al., 1973; Miljanie et al., 1999). The accentuated differences among the energy dependence curves obtained in this study, mainly between TLD-100 and the other dosimeters, show the potential for these materials combined in tandem systems.

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

3.6. Uncertainties of measurements

The overall uncertainties in all realized tests were estimated according to the ISO-GUM (1995) recommendations. Most of the parameters considered in the uncertainty determination are related to the irradiator system or TL reader precision, and do not vary among the different materials once all materials are irradiated and read under similar conditions. The expanded uncertainties obtained, based on 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 on all materials to allow a direct comparison. The results show that the sintered Al_2O_3 pellets produced at IPEN do not have adequate sensitivity to be used in this dose range. All other materials exhibited sensitivity higher than TLD-100 dosimeters. However, none of the materials except TLD-100 exhibited a flat energy response, which agrees with data in the literature. Therefore, the utilization of materials other than TLD-100 (or similar) depends on the acquisition of precise calibration curves, in radiation beams closely approximating clinical beams. An important application of these other materials, however, is in tandem systems. A simple way to determine the energy of unknown beams is to use a pair of detectors with different energy dependences. Although TLD-100 exhibited the best characteristics for dosimetric purposes in the diagnostic radiology energy range, the use of other materials is also possible but they should be used in combination with devices for the determination of beam effective energies.

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