



Response of TL materials to diagnostic radiology X radiation beams

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ARTICLE INFO

Keywords:

TLDs
Diagnostic radiology
Energy dependence

ABSTRACT

The main objective of this study was to carry out a direct performance comparison among some known types of TLDs—three types of CaSO₄:Dy pellets, sintered Al₂O₃ pellets, LiF:Mg,Ti (Harshaw TLD-100), CaF₂:Dy (Harshaw TLD-200) and CaF₂: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.

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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; Miljanic 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 CaSO₄:Dy pellets (conventional CaSO₄:Dy pellets, thin CaSO₄:Dy pellets, and thin CaSO₄:Dy+10%C pellets), sintered Al₂O₃ pellets (also called Alumina), LiF:Mg,Ti (Harshaw TLD-100), CaF₂:Dy (Harshaw TLD-200) and CaF₂:Mn (Harshaw TLD-400). Both the sintered Al₂O₃ pellets and the three types of CaSO₄:Dy pellets were produced at IPEN. The conventional CaSO₄:Dy pellets have a diameter of 6.0 mm and a thickness of 0.8 mm, and the thin CaSO₄:Dy types have the same diameter and a thickness of 0.2 mm (Campos, 1983, 1988, 1993; Campos and Lima, 1986). The sintered Al₂O₃ 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)
<i>Direct beams</i>				
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
<i>Attenuated beams</i>				
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 CaSO₄:Dy pellets, prior to irradiation, was 300 °C for 3 h. For the sintered Al₂O₃ 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 cm³ 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 CaSO₄: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 CaSO₄:Dy pellets. The variations of TL response among different types of CaSO₄:Dy pellets are considerable, with conventional CaSO₄:Dy pellets almost twice as sensitive as the thin CaSO₄:Dy pellets, and more than 40 times more sensitive than the thin CaSO₄: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 ⁶⁰Co 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 ⁶⁰Co.

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.

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