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Thin $CaSO_4$:Dy thermoluminescent dosimeters for calibration of $^{90}Sr+^{90}Y$ applicators

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ABSTRACT

Clinical applicators are used in brachytherapy to treat superficial lesions of skin and eye. They should be periodically calibrated according to quality control programs and international recommendations. Thin $CaSO_4$:Dy thermoluminescent dosimeters were used to calibrate various applicators with a dermatological applicator as a reference. The obtained absorbed dose rates were compared with those quoted in their calibration certificates. Depth-dose curves were constructed for all the applicators. A mail dosimetry system was developed for calibration of clinical applicators.

1. Introduction

Calibration of $^{90}Sr+^{90}Y$ clinical applicators and dosimetry in their use have become important procedures. These beta-ray sources developed by Friedell et al. (1950) have been utilized in brachytherapy to treat superficial lesions of skin and eye. Dermatological applicators can be used to treat keloids (scars on skin), and ophthalmic applicators are used in post-surgery treatments of pterigiums. The flat dermatological and curved ophthalmic applicators should be periodically calibrated according to requirements of quality control programs and international recommendations (IAEA, 2002; ICRU, 2004), and references in the papers by De Almeida et al. (2000) and Soares et al. (2001).

Thermoluminescent materials are extensively used in environmental, personal, medical, and industrial dosimetry (Soares, 2002). In particular, they are recommended for calibration of brachytherapy sources and dosimetry in their applications (Soares et al., 2009). TLDs are especially appropriate for the geometry of such sources. Oliveira and Caldas (2004) tested performance of several thermoluminescent materials in the standard beta radiation fields of the Calibration Laboratory (LCI) of Instituto de Pesquisas Energéticas e Nucleares in Sao Paulo, Brazil (IPEN). They found that thin $CaSO_4$:Dy pellets, thin CaF_2:Mn pellets, and thin $CaSO_4$:Dy pellets with graphite showed better responses to beta radiation than other materials, such as LiF, CaF_2:Dy, CaF_2:Mn, and 0.2 mm-thick $CaSO_4$:Dy pellets. That study focused, in particular, on reproducibility and transmission factors.

In another paper, Oliveira and Caldas (2007) reported that thin $CaSO_4$:Dy pellets proved to be useful in beta radiation dosimetry of a $^{90}Sr+^{90}Y$ source.

2. Materials and methods

Various $^{90}Sr+^{90}Y$ sources were used: a secondary standard system Buchler GmbH (Braunschweig, Germany, 1850 MBq, 1981), dubbed BSS1, and seven clinical applicators, five of which were dermatological (designated as NIST, A, B, D, and E, all flat), one ophthalmic (F, concave) and one dermatological/ophthalmic (C, slightly concave). Applicators C, D, E and F were certified by Amersham (Buckinghamshire, UK). Table 1 lists characteristics of these applicators. Three dermatological applicators were from LCI: the NIST applicator calibrated at the primary standards laboratory of the National Institute of Standards and Technology (Gaithersburg, MD, USA), Applicator A with a calibration certificate from Amersham, and uncertified Applicator B. Applicators C, D, E and F were kindly provided by clinics and research institutes for this study.

$CaSO_4$:Dy samples (0.2 mm thick and 6.0 mm in diameter) were irradiated on a PMMA base at a distance of 11.0 cm from the source of the BSS1 system. The dosimeters were also exposed to each of the clinical applicators. Each pellet was positioned on a phantom, and thus, the dosimeter and the applicator were in contact. Irradiated $CaSO_4$:Dy pellets were recycled by heating at 300 °C for 3 h with a subsequent quick cooling down to room temperature.

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Table 1
Characteristics of the $^{90}Sr+^{90}Y$ clinical applicators used in this study.

Clinical applicator	Manufacturer and model	Nominal absorbed dose rate (Gy/s)	Calibration date
NIST	Atlantic research corporation/B-1 S/N 233	0.40 ± 0.02	28.01.2003
A	Amersham/SIQ 18	0.056 ± 0.011	08.11.1968
B	no certificate		
C	Amersham/SAI 20	0.438[a]	31.07.1996
D	Amersham/SIQ 21	0.053[a]	17.09.1986
E	Amersham/Sr 5072 2096	0.0401[a]	14.05.2003
F	Amersham/SAI 6/1418	0.0296[a]	14.05.2003

[a] No uncertainties provided in the calibration certificates.

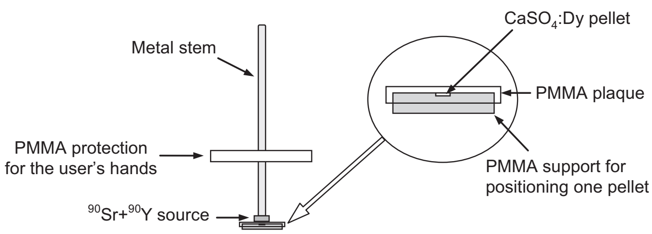

Fig. 1. Setup for irradiation of the $CaSO_4$:Dy pellets with the $^{90}Sr+^{90}Y$ clinical applicators. The plaque was used only in depth-dose-curve measurements.

Harshaw Nuclear System, Model 2000A/B with a linear heating rate of 10 °C/s was used; the readings were performed within 30 s. The light emission was integrated in the temperature interval from 180 to 350 °C, as suggested by Campos and Lima (1987).

Also, five PMMA supports (5.0 cm in diameter and 1.0 cm thick) were manufactured for the mail dosimetry system. One of such supports can be seen in Fig. 1. The figure shows the experimental setup for irradiation of the thermoluminescent dosimeters with $^{90}Sr+^{90}Y$ clinical applicators. PMMA plaques of various thicknesses, one of which is shown in the figure, were used only in depth-dose-curve experiments.

3. Results

3.1. Reproducibility of the TL response

Reproducibility of the TL response of $CaSO_4$:Dy dosimeters was measured with 14 pellets in a series of five cycles, each of which consisted of irradiation to 1 Gy (BSS1 system), TL measurements and subsequent thermal treatment (300 °C for 3 h). The relative standard deviation of the results of all the TL measurements was found to be 4.1%. The calculated overall standard uncertainty of 10.4% comprises the standard uncertainty of the dose rate of the source calibration (1.0%) and the maximal standard uncertainty of the response measurements.

3.2. Dose-response curve for the NIST applicator

The $CaSO_4$:Dy samples were irradiated with the NIST applicator used as a reference source to doses between 5 and 20 Gy. The TL response of the dosimeters was related to the absorbed dose in air at zero source-detector distance. The response is linear in the whole tested dose interval (Fig. 2).

3.3. Calibration of the clinical applicators

The $CaSO_4$:Dy pellets were irradiated in contact with Applicators A, B, C, D, E and F for 330, 330, 25, 300, 240 and 360 s,

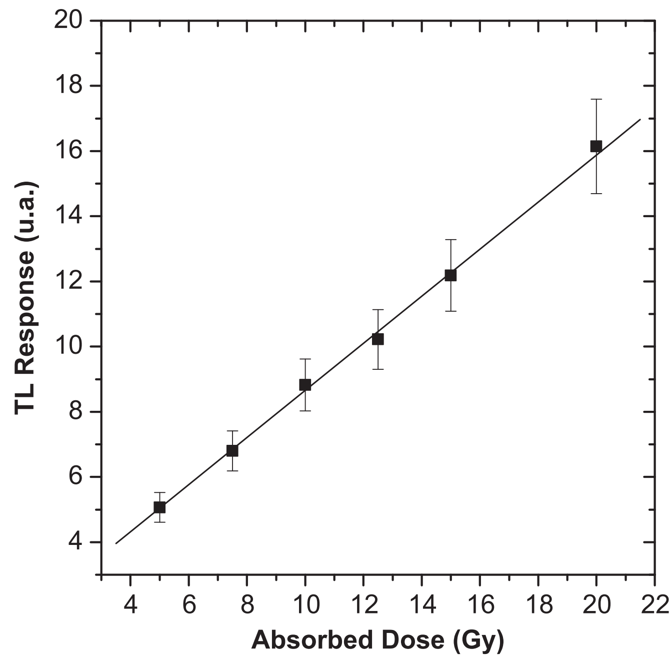

Fig. 2. Dose response curve for the $CaSO_4$:Dy thin pellets irradiated with NIST Applicator ($^{90}Sr+^{90}Y$).

Table 2
Absorbed dose rates measured with the $CaSO_4$:Dy dosimeters in contact with the applicators.

Clinical applicator	Absorbed dose rate (Gy/s)	
	Certificate	This work
A	0.0213 ± 0.0043	0.0281 ± 0.0058
B	–	0.0322 ± 0.0027
C	0.3245	0.5364 ± 0.0646
D	0.0299	0.0397 ± 0.0056
E	0.0349	0.0420 ± 0.0031
F	0.0257	0.0307 ± 0.0027

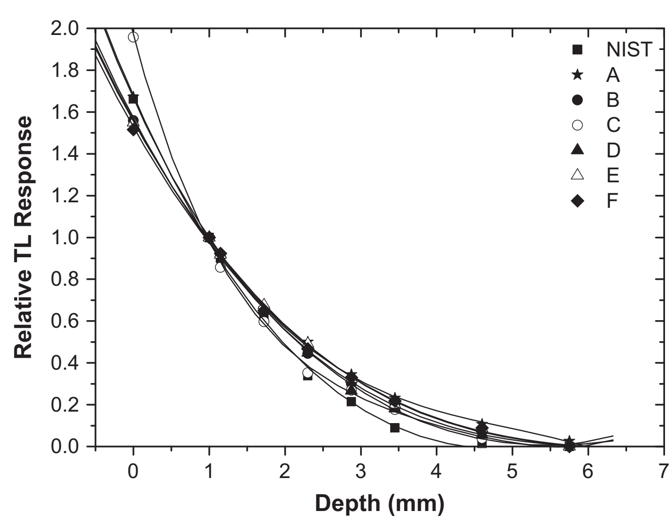

Fig. 3. Depth-dose curves for the applicators obtained with the $CaSO_4$:Dy dosimeters (normalized to 1.0 mm water-equivalent thickness).

Table 3
Depth doses for the clinical applicators normalized to the values for 1.0 mm of water.

Depth in water(mm)	IAEA Report (2002)	Relative TL response						
		NIST	**A**	**B**	**C**	**D**	**E**	**F**
0	1.752	1.662 ± 0483	1.670 ± 0183	1.562 ± 0192	1.960 ± 0360	1.550 ± 0159	1.554 ± 0250	1.518 ± 0207
0.5	1.342	1.334 ± 0388	1.287 ± 0141	1.260 ± 0155	1.383 ± 0254	1.264 ± 0130	1.250 ± 0201	1.243 ± 0169
1.0	1.000	0.999 ± 0290	0.979 ± 0107	0.988 ± 0121	0.976 ± 0179	0.996 ± 0102	0.989 ± 0159	0.988 ± 0135
1.5	0.734	0.705 ± 0205	0.732 ± 0080	0.751 ± 0092	0.687 ± 0126	0.755 ± 0078	0.767 ± 0123	0.762 ± 0104
2.0	0.533	0.469 ± 0136	0.532 ± 0058	0.552 ± 0068	0.481 ± 0088	0.549 ± 0056	0.581 ± 0093	0.570 ± 0078
3.0	0.272	0.171 ± 0049	0.230 ± 0025	0.269 ± 0033	0.229 ± 0042	0.253 ± 0026	0.304 ± 0049	0.293 ± 0039
4.0	0.127	0.043 ± 0012	0.005 ± 0000	0.121 ± 0015	0.098 ± 0018	0.103 ± 0010	0.132 ± 0021	0.144 ± 0020
5.0	0.052	0.016 ± 0005	−0.183 ± 0.000	0.051 ± 0006	0.028 ± 0005	0.045 ± 0005	0.040 ± 0006	0.067 ± 0009
6.0	0.018	0.001 ± 0000	−0.343 ± 0.000	−0.032 ± 0.000	−0.010 ± 0.000	−0.020 ± 0.000	0.000 ± 0000	−0.037 ± 0.000

respectively. The absorbed dose rates determined with the dose-response curve were compared with the absorbed dose rates quoted in the calibration certificates of the applicators corrected for the decay (Table 2).

A significant difference between the two values was observed for Applicator C, probably because the applicator was concave (ophthalmic), which made the contact between the dosimeters and the source imperfect, and also because the source surface was inhomogeneous. Soares (1995) reported that results of calibrations of Amersham applicators by NIST and by the manufacturer differed approximately by 20%. In view of this observation, the agreement between the dose rates measured in this work and those reported in the calibration certificates can be regarded as satisfactory.

3.4. Lower detection limit

The lower detection limit was calculated from the variability of the TL response of unirradiated pellets. The value for the $CaSO_4$:Dy samples is 77.2 μGy, which is of the same order of magnitude as the result reported by Campos and Lima (1987).

3.5. Depth-dose curves

The $CaSO_4$:Dy pellets were used to obtain depth-dose curves in water for the studied applicators. Seven PMMA plaques (1.0, 1.5, 2.0, 2.5, 3.0, 4.0 and 5.0 mm thick, 5.4 cm in diameter) were used. As shown in Fig. 1, a pellet rested on the acrylic phantom, and the plaque of the selected thickness was on top of it, between the pellet and the applicator.

The results thus obtained were normalized to water-equivalent thickness and to 1.0 mm depth, as recommended by the IAEA standard (2002). Fig. 3 shows the depth-dose curves obtained for all the applicators. Each PMMA thickness was converted to equivalent water thickness using the equation:

$$\rho_{water} \times d_{water} = \rho_{acrylic} \times d_{acrylic} \quad (1)$$

where ρ_{water} is the volumetric density of water (1.0 g/cm^3), d_{water} is the thickness of water-equivalent material, $\rho_{acrylic}$ is the volumetric density of PMMA (1.15 g/cm^3) and $d_{acrylic}$ is the thickness of the used PMMA absorber. The measured TL responses were then normalized to the response corresponding to 1 cm of water and plotted vs. water thickness.

The values at null depth for the applicators obtained in this study and the values quoted in the IAEA standard (2002) were similar: the differences were only 4.7% for NIST Applicator and 11.0% for Applicator B (Table 3). The maximal difference was 22.3%.

3.6. Mail dosimetry system

A mail dosimetry system was developed with these TL pellets. The pellets, already in special supports, are sent to clinics and hospitals for calibration of their clinical applicators.

Users irradiate the dosimeters with their applicators and then send the dosimeters back to LCI/IPEN for dose measurements to get a calibration certificate. Detailed instructions for irradiation are provided. This system makes it possible to avoid shipping radioactive applicators to the Calibration Laboratory (LCI).

4. Conclusions

Reproducibility of the TL response of the $CaSO_4$:Dy thin dosimeters was found to be satisfactory. The measured absorbed dose rates for the six clinical applicators were satisfactory in view of the uncertainties and non-uniformity of the distribution of the radioactive material in the applicators.

Depth-dose curves were obtained for all applicators, and the results were similar to the data presented in the recommendations by IAEA (2002). Therefore, the $CaSO_4$:Dy thin dosimeters are adequate for calibration of $^{90}Sr+^{90}Y$ clinical applicators and dosimetry in their applications.

A mail dosimetry system was developed for calibration of clinical applicators at clinics and hospitals.

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