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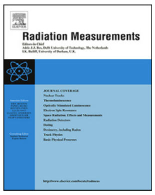

The use of the TL and OSL phenomena for determination of absorbed dose rates of $^{90}Sr + ^{90}Y$ sources by a postal method

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HIGHLIGHTS

- A postal dosimetric system was developed to calibrate clinical applicators.
- Al_2O_3:C samples were characterized in relation to their TL and OSL response.
- The clinical applicators from UFS were calibrated.
- The absorbed dose rates were compared with those provided on the certificates.

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ABSTRACT

International recommendations establish that $^{90}Sr + ^{90}Y$ clinical applicators have to be calibrated in order to determine the absorbed dose rates in the case of the sources that do not have original calibration certificates, or to update the absorbed dose rates presented in the source certificates. Following these recommendations, a postal dosimetric system was developed to calibrate clinical applicators using two luminescent techniques: thermoluminescence (TL) and optically stimulated luminescence (OSL). In this work, Al_2O_3:C commercial detectors were characterized and their TL and OSL responses were analyzed. The results showed the efficiency and the optimal behavior of this material in beta radiation beams. After characterization, the system was sent to the Federal University of Sergipe (UFS), Brazil, for calibration of five $^{90}Sr + ^{90}Y$ clinical applicators, where the detectors were irradiated and returned to IPEN, for their evaluation and determination of the absorbed dose rates. A comparison between these absorbed dose rates and those adopted by the UFS as original was made; the differences obtained were within those of other studies, and they demonstrated the usefulness of the system.

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1. Introduction

Lesions of the skin and eyes can be treated with specialized $^{90}Sr+^{90}Y$ sources (positioned in contact with the injured surface). These sources (clinical applicators) are still used in Brazil for medical and aesthetical treatments, and in research, and they need to be periodically calibrated (IAEA, 2002; ICRU, 2004).

In order to address the calibration requirements for these kinds of sources, the Calibration Laboratory (LCI) at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) developed a postal dosimetric system with thermoluminescent (TL) dosimeters of $CaSO_4$:Dy, which has already been tested initially in some hospitals of São Paulo city by Antonio and Caldas (2011), to observe its effectiveness. The main advantage of this system is that there is no need anymore for the clinical or research laboratory to send their clinical applicators to the LCI, because the irradiations can be made at the place where these sources are used, avoiding the absence problem of the sources at the radiotherapy clinics, hospitals or institutes.

To improve the dosimetric system, and ensure greater reliability, another system to calibrate the clinical applicators was developed,

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including the optically stimulated luminescence (OSL) technique. The addition of this technique to the system occurred because the OSL, as the TL, is a luminescent phenomenom well known for its different applications (Bøtter-Jensen et al., 2003; Pinto et al., 2011; Yukihara and McKeever, 2011; Ding and Malcolm, 2013; Fiore et al., 2013).

To improve the efficiency of the dosimetric system, Al_2O_3:C commercial detectors (Rexon, 2009) were incorporated into the system, in order to be analyzed in relation to their TL and OSL responses. The Al_2O_3:C pellets, first developed to be used as TL dosimeters, consist of a widely-studied OSL material that has excellent OSL dosimetric properties (Akselrod and McKeever, 1999; Yukihara and McKeever, 2008).

Therefore, the main objective of this work was to expand the TL dosimetric system to include OSL detectors (as a new proposal to calibrate clinical applicators). The inclusion of the OSL technique was based on its faster readout, important to the calibration program. This idea was also taken into account as an alternative calibration method. Another objective was to exchange $CaSO_4$:Dy TL detectors to Al_2O_3:C TL detectors, to send them to a research laboratory at the Federal University of Sergipe (UFS), Brazil, where clinical applicators are still utilized in research programs, and to verify this dosimetric system usefulness. Furthermore, another objective was to verify the possibility to use Al_2O_3:C pellets to determine the absorbed dose rates of the clinical applicators, and to compare the responses obtained by both TL and OSL techniques, in order to the quality of the system.

2. Materials and methods

The TL dosimetric material chosen to compose the postal dosimetric system was the aluminum oxide doped with carbon (Al_2O_3:C), commercial (TLD-500), sold by Rexon TLD Systems: pellets with a 5.0 mm diameter and a 1.0 mm thickness.

The detectors were characterized in relation to their responses in beta standard beams. For these tests, three beta sources (at the conditions specified in Table 1) were used: a $^{90}Sr+^{90}Y$ source of the beta secondary standard system BSS1, Buchler GmbH & Co., Germany, and the $^{90}Sr + ^{90}Y$ and ^{85}Kr sources of BSS2, Isotrak, Germany. Both beta secondary standard systems are from LCI. For the determination of the TL and OSL responses in function of absorbed dose, the dosimeters were irradiated with a $^{90}Sr + ^{90}Y$ clinical applicator from LCI, manufactured by Atlantic Research Corporation, model B-1 S/N 233 (0.40 Gy/s, 2003), calibrated at the primary standard laboratory of the National Institute of Standards and Technology (NIST), and will be referred to as the NIST applicator.

The TL/OSL postal dosimetric system is composed of Al_2O_3:C detectors (20 TL pellets and 20 OSL pellets), a clamp, a polymethymethacrylate (PMMA) support (with dimensions of 5.0 cm in diameter and 1.0 cm in thickness) to fix the pellets involved by a plastic film (superficial density of 1.095 mg/cm^2), two dark small boxes for detectors (one for TL and the other for OSL), a dark small box to store the dosimeters, two pairs of gloves, a chronometer, and a pen. An irradiation procedure for the detectors, a form to be completed with the data of each source to be calibrated, and a system component revision sheet were sent with the system.

The clinical applicators of the UFS have original calibration certificates issued by Amersham International Ltd., England, which was also the manufacturer of these sources. The information about the clinical applicators of UFS is shown in Table 2. These clinical applicators were received from clinics that did not want to use them anymore or because the applicators were already too old for medical use (with an activity that was too low).

The calibration methodology consisted of the determination of absorbed dose rates at the clinical applicator surface and their comparison with the original certificate values (taken into account the radioactive decay through the application of a correction factor).

The TL response was obtained using a Harshaw TLD Reader, model 3500, and the OSL measurements were taken using an OSL system, model DOIN-L001, manufactured by the Federal University of Pernambuco (UFPE), Brazil, and a data acquisition system Logan, model SAD-2000.

After each cycle of irradiation and TL/OSL measurement, the Al_2O_3:C samples were thermally treated at 400 °C for 1 h, for subsequent reuse.

The uncertainties in this work were only those of type A (experimental measurements).

3. Results

The Al_2O_3:C detectors were studied in relation to their TL and OSL responses. Initially, the dosimeters were characterized in order to verify the reproducibility of their response, the lower detection limit (minimum detectable dose), energy dependence, and TL and OSL responses in function of absorbed dose. After the characterization process, the absorbed dose rates of the clinical applicators were determined.

3.1. Reproducibility study of TL and OSL responses

Initially, the stability of the TL and OSL systems was verified in relation to the variation of the TL reader, the thermal treatment, the irradiation procedures, and the TL dosimeters, as recommended by Pagonis et al. (2006). In this work, 40 Al_2O_3:C pellets were used (20 as TL and 20 as OSL detectors).

The reproducibility study of the TL and OSL responses was determined by irradiating the pellets with an absorbed dose of 100 mGy, with the $^{90}Sr + ^{90}Y$ source from the BSS1 system (source–detector distance of 11 cm). This procedure was undertaken for both luminescent techniques in five cycles of irradiation, measurement and thermal treatment.

For both TL and OSL response, the total reproducibility of the system including reader, thermal treatment, irradiation steps and detectors (system variability index, SVI); the reproducibility only of the TL and OSL reader systems (reader variability index, RVI); and the signal stability of the detectors (detector variability index, DVI) were obtained according to Pagonis et al. (2006); these results can be observed in Table 3.

The SVI was determined as the covariance (CV) mean value of all CV obtained (standard deviation as a function of the mean value of the five TL or OSL readings) for each TL and OSL dosimeter in the

Table 1
Characteristics of the beta standard sources and experimental conditions used for the irradiation of the Al_2O_3:C dosimeters.

Beta secondary standard system	Radiation source	Field flattening filter	Absorbed dose rate (μGy/s)	Calibration distance (cm)	Reference date
BSS1	$^{90}Sr + ^{90}Y$	No	518 ± 5	11	04.02.81
BSS2	$^{90}Sr + ^{90}Y$	No	16.5 ± 0.2	30	12.01.05
	^{85}Kr	Yes	39.7 ± 0.5	30	30.11.04

Table 2
Description of the $^{90}Sr+^{90}Y$ clinical applicators calibrated in this work.

Source number	Clinical applicator	Model	Nominal activity (MBq)	Absorbed dose rate (mGy/s)	Calibration date
1	Dermatological	2167–SIQ7	370	14.6 ± 2.9	27.11.1973
2	Dermatological	1520–SIA5	74	44.0 ± 8.8	27.11.1973
3	Ophthalmic	9737–SIQ6	740	15.0 ± 4.5	14.01.1992
4	Ophthalmic	1522–SIA6	370	55.0 ± 16.5	27.11.1973
5	Ophthalmic	928–SIA6	370	43.8 ± 13.1	07.01.1992

Table 3
Reproducibility study performed with Al_2O_3:C detectors: system variability index (SVI), reader variability index (RVI), and detector variability index (DVI).

Luminescent technique	SVI (%)	RVI (%)	DVI (%)
TL	3.56	0.06	3.56
OSL	4.31	0.00	4.31

five measurement series. The RVI was calculated as the CV mean (system variability index) as a function of the average of mean readings (the total mean of the TL and OSL readings in the five cycles of irradiation, measurement and thermal treatment). The DVI was obtained by means of the square root of the difference between the SVI and RVI square values (Pagonis et al., 2006).

The results obtained for the SVI, in both TL and OSL techniques, demonstrated the good performance of the whole system involved in this study, as the reader, thermal treatment, irradiation and detectors. The DVI values can be considered the same as the SVI, and this demonstrates that the RVI is not affecting the DVI results, in both cases of TL and OSL techniques. Therefore, the material studied in this work presents good stability in its TL and OSL response.

3.2. Lower detection limit

The lower detection limit (also called minimum detectable dose) was determined by studying the variation among the TL and OSL readings of the non-irradiated detectors (zero-dose reading). As this limit is a dosimetric property of the material, its determination is important to characterize the samples.

The lower detection limit was obtained for the Al_2O_3:C detectors using the method of three times the standard deviation of non-irradiated pellets (Pagonis et al., 2006), and the results were 0.20 mGy for the TL detectors, and 2.85 mGy for the OSL detectors.

As these pellets were designed for use in beta dosimetry of the $^{90}Sr+^{90}Y$ clinical applicators, and the doses are relatively high (from 1 Gy to 15 Gy), the lower detection limits can be considered acceptable.

3.3. Dependence of the TL and OSL response with the radiation energy

The study of the dependence of TL and OSL response with the source energy was performed irradiating the detectors with the beta sources of the BSS2 system, according to the conditions specified in Table 4. The maximum standard deviation obtained at the TL readings was 8.6% (^{85}Kr source). In the case of the OSL measurements, the deviation was 7.8% (^{85}Kr source). The results are presented in Table 4.

The results obtained show the high-energy dependence of both TL and OSL responses in beta radiation beams, and present the similarity of the normalized values for both techniques.

3.4. TL and OSL responses in function of the absorbed dose

The TL and OSL responses in function of the absorbed dose were obtained for both TL and OSL responses, using the same conditions. For this characterization test, the Al_2O_3:C detectors were irradiated in the dose interval from 1 Gy to 15 Gy, in increments of 1 Gy, from 1Gy to 5 Gy, and in increments of 2.5 Gy, from 5 Gy to 15 Gy. The dosimeters were exposed to the $^{90}Sr+^{90}Y$ source from the BSS1 system, at the source–detector distance of 11 cm. In the case of TL response, the maximum standard deviation obtained in all measurements (for all detectors and the 9 absorbed doses) was 8.3% (dose of 10 Gy). For the OSL response, the maximum standard deviation was 7.0% (dose of 10 Gy). TL and OSL responses in function of the absorbed dose obtained are presented in Fig. 1.

The results obtained in this kind of representation for the TL dosimeters in the whole dose interval (from 1 Gy to 15 Gy) was similar to that presented by Chithambo (2004), that studied the same material and irradiated it with the same source (in a dose interval of 1 Gy–50 Gy).

The results obtained for the OSL dosimeters agree from 2Gy to 7.5 Gy with those presented by Pinto et al. (2008), that used samples of another manufacturer (Dot detectors, Landauer), but they also are Al_2O_3:C, which were also irradiated with $^{90}Sr+^{90}Y$ in a dose interval from 1 Gy to 10 Gy. The results obtained by Pinto et al. (2008) presented linearity in the whole studied dose interval, and in this work, the results for the OSL response presented linearity from 2 Gy to 7.5 Gy, considering the uncertainties.

3.5. The postal dosimetric system

The dosimetric system, initially developed as a TL system, was applied in hospitals of São Paulo city to train the future users of the system in the irradiation procedures and its utilization. These results were presented by Antonio and Caldas (2011). Then, this system was improved as a postal TL/OSL system, using Al_2O_3:C detectors.

An irradiation procedure was elaborated step by step for the TL and OSL detector groups, emphasizing important factors, as the

Table 4
Irradiation conditions (BSS2 system) and results obtained for the energy dependence study of the Al_2O_3:C.

Radiation source	Field flattening filter	Absorbed dose (mGy)	Source–detector distance (cm)	Beta mean energy (MeV)	Normalized response in relation to the $^{90}Sr+^{90}Y$ source	
					TL	OSL
$^{90}Sr+^{90}Y$	No	10	30	0.80	1.0000 ± 0.1419	1.0000 ± 0.0379
^{85}Kr	Yes	10	30	0.14	0.3360 ± 0.0002	0.8608 ± 0.0002

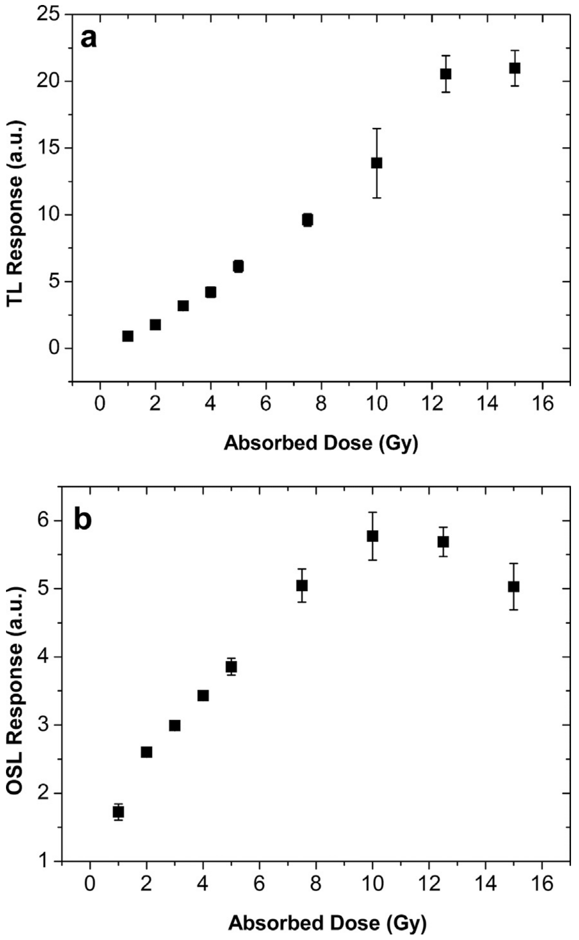

Fig. 1. TL and OSL responses in function of the absorbed dose of the Al_2O_3:C detectors, exposed to the $^{90}Sr + ^{90}Y$ source (1850 MBq): (a) TL, and (b) OSL.

recommendations about the protection of the source operators and the calibration steps of the clinical applicators, including the calculation of the irradiation time of the detectors. A data collection form was also developed with the information related for each applicator (to the calibration certificates to be emitted by IPEN for each calibrated source). Furthermore, an item revision sheet of the dosimetric system was sent as well.

The irradiation procedure, the data collection form, and the item revision sheet were sent to the UFS together with all components of the TL/OSL dosimetric system, described in item 2; they were properly organized in a plastic box.

3.6. *Determination of the absorbed dose rates*

The irradiation of the TL and OSL Al_2O_3:C detectors was completed at the Physics Department at UFS, according to the procedure of the postal system, including different irradiation times at each source (from 3 min to 9 min, depending on the source activity). During the irradiations, there was no separation between source and detector. From the 20 TL pellets, 18 were irradiated (3 with each source), and 2 were maintained as control dosimeters; the same occurred in the case of the 20 OSL pellets.

The postal system was then sent back to the IPEN, where the TL and OSL responses were evaluated, and a new absorbed dose rate was determined for each $^{90}Sr + ^{90}Y$ clinical applicator (using the study of TL and OSL responses in function of absorbed dose obtained with the NIST applicator), and calibration certificates were elaborated. The absorbed dose rates obtained can be seen in Table 5.

In all of the TL measurements, the maximum standard deviation was 7.9% (applicator 4); in the case of the OSL measurements, this result was 5.7% (applicator 4).

The absorbed dose rates obtained in this work were compared to the ones described by the original calibration certificates of the clinical applicators. A comparison was also made for both TL and OSL technique, as seen in Table 5.

Due to the fact that the clinical applicators need to be cleaned after their use (to eliminate disease contamination risks), it is known that this action may sometimes remove part of the source cup material. For this reason, the source surface is not homogenous, which can cause alteration and differences in the measurements and absorbed dose rates.

The results obtained presented acceptable differences in relation to the absorbed dose rates of the certificates, taking into account the uncertainties given in the source calibration certificates, for both TL and OSL techniques. All compared values, in percentage, can be considered relatively high, but this fact could have occurred due to several factors. These clinical applicators present high uncertainties associated with the absorbed dose rates at their original calibration certificates (20% for dermatological applicators, and 30% for ophthalmic applicators, from Amersham). The NIST applicator (reference system in this work) presents also a relatively high uncertainty in its certificate, of 12%. As the irradiation procedures are not simple, small errors may also have occurred during the irradiation, such as, for example, in the irradiation time or in the positioning of the source on each sample.

Thus, taking into account all of these factors, it can be concluded that the results obtained were within the expected range, because they agree with those presented by Antonio and Caldas (2011), where the differences obtained among the absorbed dose rates determined in this work and those provided by the original calibration certificates varied from −36% to 8%. Furthermore, differences between absorbed dose rates from the original certificates of the manufacturer (Amersham) and those determined by Soares (1995) at the primary standard laboratory NIST were from −12% to −27%.

The absorbed dose rates informed by IPEN in the calibration certificates, that will be used at UFS in their research activities, were the absorbed dose rate mean values obtained by using the TL and OSL techniques, as seen in Table 6.

4. Conclusions

The characterization tests of the TL and OSL Al_2O_3:C commercial detectors were performed to evaluate the dosimetric characteristics of the dosimeters, and to analyze the possibility of their use in a dosimetric postal system to calibrate $^{90}Sr + ^{90}Y$ clinical applicators. The results obtained in the tests demonstrated that the TL and OSL detectors can be integrated into the system.

The dosimetric postal system was sent to the Federal University of Sergipe (UFS), which has five clinical applicators. The detectors were irradiated at UFS and sent back to the IPEN, for evaluation of the TL and OSL responses. It was possible to determine new absorbed dose rates for the clinical applicators, and they were compared with those provided in their original calibration certificates.

The results obtained in this work led to several conclusions. The first is that the dosimetric system can be applied, because the differences obtained among the absorbed dose rates in this work, and those presented at the calibration certificates, were within the expected ones (based in a previous study). It can also be concluded that both TL and OSL techniques can be used to calibrate clinical applicators in a postal manner (which is an innovation in the case of OSL). Based on the high uncertainties of the clinical applicators, and

Table 5
Absorbed dose rates obtained for the $^{90}Sr + ^{90}Y$ clinical applicators (UFS), using the TL/OSL dosimetric postal system.

Source number	Time irradiation (min)	Absorbed dose rate (mGy/s)			Difference between A and B (%)	Difference between certificate and TL value (%)	Difference between certificate and OSL value (%)
		Certificate	This work (A) (TL technique)	This work (B) (OSL technique)			
1	9	5.61 ± 1.12	7.47 ± 1.50	7.51 ± 1.51	0.5	33.2	33.9
2	8	16.89 ± 3.38	13.53 ± 2.89	9.99 ± 2.07	−26.2	−19.9	−40.8
3	6	8.91 ± 2.67	6.98 ± 2.16	5.27 ± 1.58	−24.5	−21.7	−40.8
4	6	21.12 ± 6.34	13.64 ± 4.34	15.59 ± 4.76	14.3	−35.6	−26.2
5	3	26.01 ± 7.80	23.90 ± 7.17	27.74 ± 8.34	16.1	−8.1	−6.6

Table 6
Absorbed dose rates of the $^{90}Sr + ^{90}Y$ clinical applicators, to be used by the UFS.

Source number	Absorbed dose rate (mGy/s)
1	7.49 ± 2.13
2	11.76 ± 3.55
3	6.12 ± 2.68
4	14.62 ± 6.44
5	25.82 ± 10.99

on the differences among absorbed dose rates from original certificates and those obtained, which can also be observed in previous works, as for example, the results obtained at NIST, the differences in this work can be considered acceptable because they are within the expected interval.

The results of this work are important to the LCI, because they show the possibility to calibrate beta sources when they cannot be sent to the IPEN. The usefulness of the system is also important with regard to the point of view to users which do not possess original calibration certificates; with the absorbed dose rates determined in this work, the users of these sources can adopt them in their calibration procedures.

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