Development of a Dosimetric Postal System for Calibration of $^{90}Sr+^{90}Y$ Clinical Applicators

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Abstract. The Calibration Laboratory of IPEN (LCI) offers calibration services of different metrology instruments using various types of ionizing radiations. Recently, the LCI started to offer the calibration service of $^{90}Sr+^{90}Y$ clinical applicators, using a mini-extrapolation chamber, for those sources which can be sent to the laboratory. Several Brazilian clinics and hospitals that offer brachytherapy treatments and still use these applicators, sometimes can not send them to the LCI, to avoid disruption and delays in the patient treatments. To minimize this problem, an alternative calibration method was suggested. The objective of this work was the development of a dosimetric postal system to be sent to clinics and hospitals, for the calibration of these sources.

Keywords. $^{90}Sr+^{90}Y$ clinical applicators, calibration, extrapolation chamber, thermoluminescent dosimetry, dosimetric postal system.

Introduction

Beta radiation sources, and other types of radiation, and all metrological instruments must be calibrated in order to follow quality control programs. According to international recommendations[1,2], and to De Almeida et al.[3] and Soares et al.[4], the dosimetry and calibration of the $^{90}Sr+^{90}Y$ clinical applicators must be performed periodically, to ensure their correct use. The calibration of these sources is realized in terms of absorbed dose rate in water.

The $^{90}Sr+^{90}Y$ clinical applicators are beta radiation sources utilized in brachytherapy for the treatment of superficial lesions of skin and eyes, and can therefore be dermatological (usually planes) or ophthalmic (usually curves). They can be calibrated using different methods, which include the use of extrapolation chambers and thermoluminescent dosimetry[3,4]. Due to the high half-life of the $^{90}Sr+^{90}Y$ sources (28.8 years), many applicators are still in use in Brazilian clinics and hospitals that work with brachytherapy, although since many years these sources are not commercialized anymore.

The Calibration Laboratory of IPEN (LCI) has been providing calibration services of portable detectors with X, gamma and beta radiation, contamination detectors with alpha and beta radiations, clinical dosimeters with gamma radiation, detectors utilized in diagnostic radiology (conventional, tomography and mammography) and activimeters used in Nuclear Medicine for many years. More recently, the LCI began the calibration service of the $^{90}Sr+^{90}Y$ clinical applicators using a mini-extrapolation chamber that was developed exclusively for this purpose[5]. In this case, the clinical applicators are sent to LCI for calibration.

For a long time, these sources were calibrated by the manufacturer or by the primary standard dosimetry laboratory of the National Institute of Standards and Technology (NIST), but not by both laboratories[6]. Soares[7] found differences of approximately 20% between the two calibration procedures. Therefore, it would be important that the calibration of the applicators could be done at the same place where they are used, i.e., at the clinics and hospitals (with brachytherapy services). Another reason for this kind of calibration is that not always the applicators can be sent to the LCI, as, for example, those from clinics and hospitals located far from the calibration laboratory. As the sending of these sources to the calibration laboratory may result in delays in the treatment of patients, the calibration at the place of their use is a relevant alternative.

The objective of this work was to develop a dosimetric postal system for calibration of $^{90}Sr+^{90}Y$ clinical applicators, to be sent to clinics and to radiotherapy services in hospitals as an alternative method, to be used when the clinical applicators can not be sent to the calibration laboratory. The postal system was developed using thermoluminescent dosimeters (TLDs) of $CaSO_4$:Dy, that Oliveira and Caldas[8] showed to be appopriate for the calibration of this type of source.

For the development of the postal system, $^{90}Sr+^{90}Y$ clinical applicators were calibrated using the mini-extrapolation chamber and thermoluminescent dosimeters.

Materials and Methods

In this work, seven $^{90}Sr+^{90}Y$ clinical applicators, five with plane geometry (NIST, A, B, E and E), one curved (F) and one with a softly curved geometry (C) were calibrated. The applicators NIST, A and B are from LCI, while the other four applicators were gently lent by different clinics. The applicator NIST was calibrated in the primary standard laboratory of USA National Institute of Standards and Technology (NIST), and it was utilized in this work as a standard system. Table 1 presents the main characteristics of the clinical applicators utilized in the present work.

The initial calibration of the clinical applicators was performed using a mini-extrapolation chamber of plane window, connected to a PTW electrometer, model UNIDOS, for the measurements. The charge values were measured and corrected to the normal conditions of temperature and pressure. During this procedure, the mini-extrapolation chamber and the clinical applicator were fixed horizontally, in a support developed for this purpose. Figure 1 shows the set-up for the measurements for the calibration of each clinical applicator.

Table 1. Main characteristics of the 90Sr+90Y clinical applicators

Applicator	Type	Manufacturer/ Model	Absorbed Dose Rate (Gy/s)	Original Calibration Date
NIST	Dermatological	Atlantic Research Corporation/ B-1 S/N 233	0.40 ± 0.02	28.01.2003
A	Dermatological	Amersham/ SIQ 18	0.056 ± 0.011	08.11.1968
B	Dermatological	No certificate		
C	Dermatological/ Ophthalmic	Amersham/ SAI 20	0.438*	31.07.1996
D	Dermatological	Amersham/ SIQ 21	0.053*	17.09.1986
E	Dermatological	Amersham/ 5072 2096	0.0401*	14.05.2003
F	Ophthalmic	Amersham/ SAI 6/1418	0.0296*	14.05.2003

* No uncertainties provided in their calibration certificates

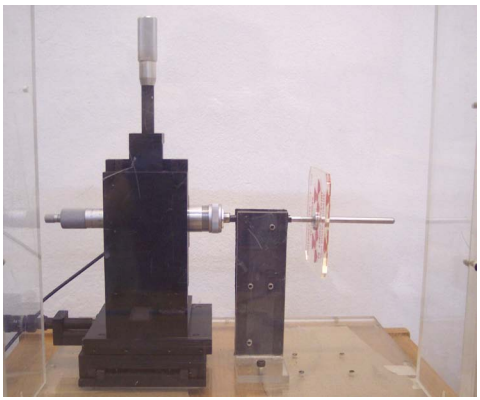


Fig. 1. Experimental set-up utilized during the calibration of the clinical applicators using the mini-extrapolation chamber.

For the second part of the calibration of the clinical applicators, thin pellets of $CaSO_4$:Dy were utilized, with 6.0 mm of diameter and 0.2 mm of thickness, produced at the Dosimetric Materials Laboratory of IPEN. In the reproducibility study, these

pellets were irradiated using a $^{90}Sr+^{90}Y$ source (1850 MBq, 1981) of the Beta Secondary Standard System 1 (BSS1), positioned at 11 cm of distance from the source. Each pellet was positioned on PMMA phantom, and the distance utilized between the source and dosimeter was null, as can be observed in Figure 2.

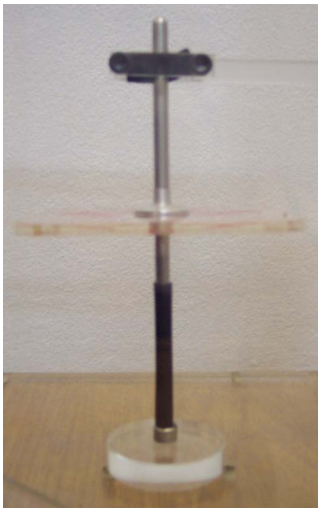


Fig. 2. Experimental set-up for the irradiation of thermoluminescent dosimeters with each clinical applicators.

The $CaSO_4$:Dy samples were thermally treated at 300°C during 3 hours and cooled, for their reutilization. The thermoluminescent evaluation of the dosimeters was realized using a TL reader from Harshaw Nuclear System, model 2000A/B, with a linear heating rate of 10°C/s, reading cycle of 30s, constant flux of N_2 of 5.0 l/min and light emission integrated in the temperature interval of 180°C to 350°C.

Five PMMA plaques of 5.0 cm of diameter and 1.0 cm of thickness, with a hole of same thickness of the pellets and 6.2 mm of diameter, were utilized for the development of the dosimetric postal system.

Results

Calibration of clinical applicators utilizing the applicator NIST as reference (standard system)

Initially, the mini-extrapolation chamber was calibrated in relation to the reference system adopted in this method, applicator NIST. An extrapolation curve was obtained for

the applicator NIST that can be observed in Figure 3. The extrapolation curve represents the variation of the ionization current in function of the distance between the electrodes of the mini-extrapolation chamber (inter-electrodic distance). The calibration coefficient, F, can be obtained as:

$$F = \frac{\dot{D}}{B} \tag{1}$$

where $\dot{D}$ is the absorbed dose rate from the calibration certificate of the applicator and B is the slope of the extrapolation curve.

Extrapolation curves were obtained for the other clinical applicators, and they can be observed in Figures 4 and 5. All curves were obtained for the inter-eletrodic distances of 0.7, 0.8, 0.9 and 1.0 mm and considering a real null depth of 0.40 mm[5] for each applicator. Five charge measurements were taken for each voltage polarity (± 50 V). The charge collecting time interval was 60s.

All extrapolation curves presented linear behavior, with correlation coefficients greater than 0.9995. The uncertainties calculated for these measurements were obtained to the coverage factor, k, of 2. In the case of the extrapolation curves, the uncertainties were lower than 0.1% and, therefore, the error bars became imperceptible.

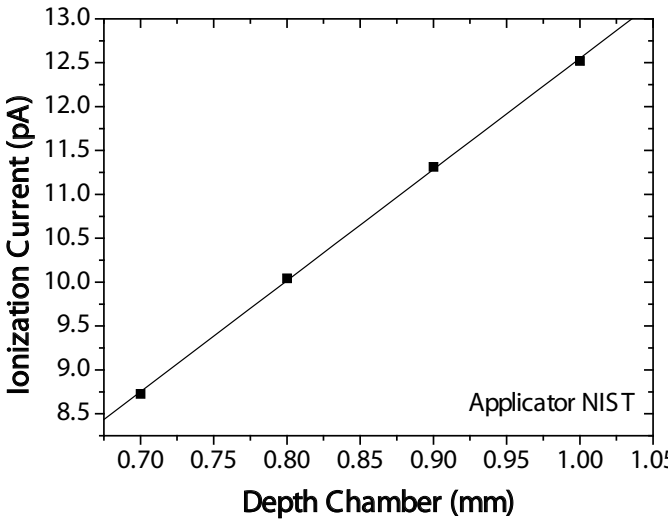
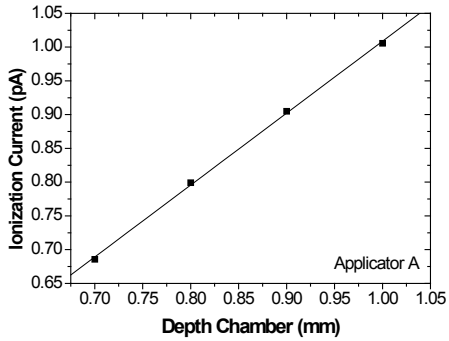
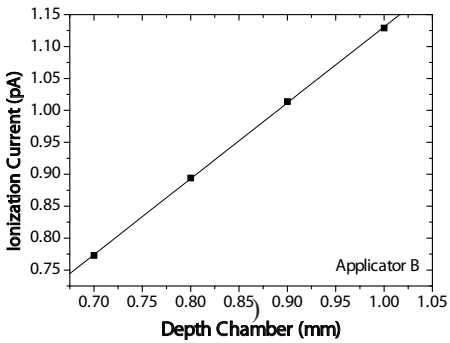


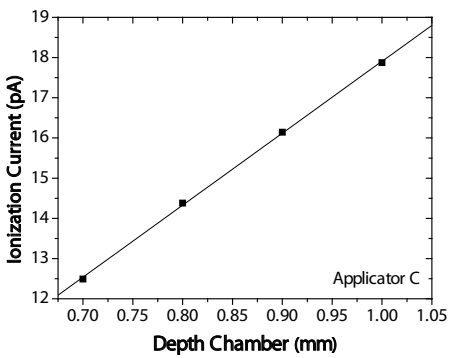
Fig.3. Extrapolation curve obtained with the mini-extrapolation chamber and the $^{90}Sr+^{90}Y$ dermatological applicator NIST.



(a)

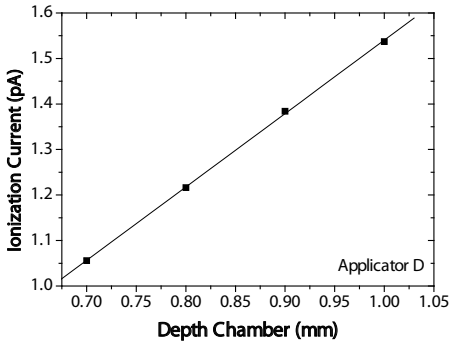


(b)

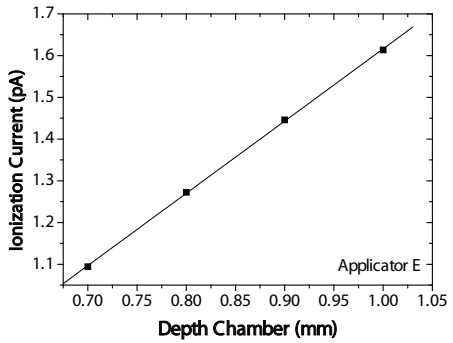


(c)

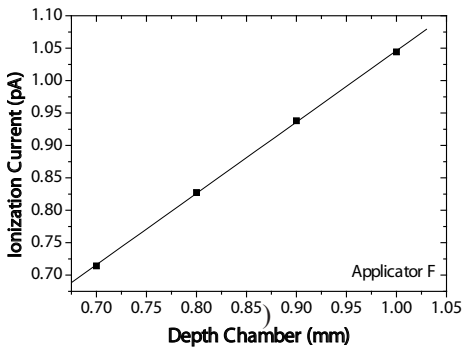
Fig. 4. Extrapolation curves obtained with the mini-extrapolation chamber and the $^{90}Sr+^{90}Y$ clinical applicators: (a) A, (b) B and (c) C.



(a)



(b)



(c)

Fig. 5. Extrapolation curves obtained with the mini-extrapolation chamber and the $^{90}Sr+^{90}Y$ clinical applicators: (a) D, (b) E and (c) F.

Using the slopes of the extrapolation curves obtained for the applicators A, B, C, D, E and F, and the calibration coefficient previously obtained for the applicator NIST, the absorbed dose rates at the surface of these applicators were obtained.

The absorbed dose rates can be observed in Table 2, in comparison with the values provided in the calibration certificates of the clinical applicators, corrected for radioactive decay to the measurement dates.

Table 2. Absorbed dose rates obtained in this work using the mini-extrapolation chamber, in comparison with those from the calibration certificates of the clinical applicators

Applicator	Absorbed dose rate (Gy/s)		Variation (%)
	Certificate	This work	
A	0.0213 ± 0.0043	0.0295 ± 0.0036	-28
B	No certificate	0.0329 ± 0.0040	–
C	0.3245 ± 0.0649	0.4953 ± 0.0587	-34
D	0.0299 ± 0.0060	0.0446 ± 0.0055	-33
E	0.0349 ± 0.0070	0.0511 ± 0.0065	-32
F	0.0257 ± 0.0051	0.0302 ± 0.0037	-15

The comparison among the absorbed dose rates of the clinical applicators presented the minimum percentage variation for the applicator F (-15%) and the maximum percentage variation for the applicator C (-34%). Soares[7] verified, in the case of several applicators from Amersham, the occurrence of variations of -12% to -27% among the values of the absorbed dose rates from the calibration certificates and those obtained in the NIST calibration. Furthermore, according to Soares[9], the clinical applicators present a lack of uniformity of the radioactive material at their surfaces. This fact may cause the differences already discussed.

Calibration of clinical applicators using thermoluminescent dosimeters

Initially, the reproducibility of the pellets of $CaSO_4$:Dy was studied. Five series of measurements and thermal treatments, after the irradiation of the TL samples (1.0 Gy) were performed. The maximum standard deviation obtained was 4.1% and the associated uncertainty was 10.4%.

The lower detection limit was also obtained, analyzing the variability of the thermoluminescent response (TL) of non-irradiated pellets. The lower limit obtained was (77.2 ± 0.2) μGy.

For the calibration of clinical applicators through the thermoluminescent technique, it was necessary to obtain a dose-response curve for the dosimeters. The TL response of the pellets was obtained in function of absorbed dose in air, irradiating the pellets with the applicator NIST at a null distance and with doses between 5.0 Gy and 20.0 Gy. The relative maximum uncertainty obtained in the measurements for the dose-response curve (Figure 6), was 6.7%.

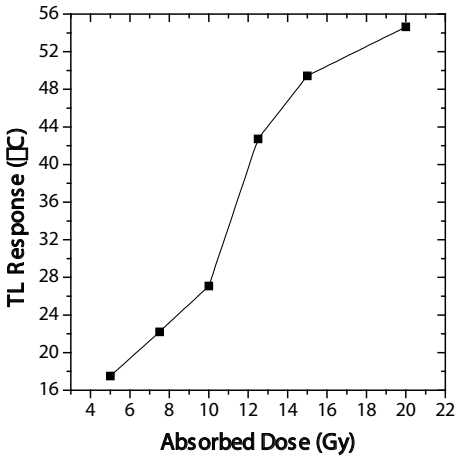


Fig. 6. Dose-response curve of the pellets of $CaSO_4$:Dy exposed to the clinical applicator NIST.

Afterwards, the $CaSO_4$:Dy pellets were irradiated with the applicators A, B, C, D, E and F, during time intervals of 330, 330, 25, 300, 240 and 360 s, respectively, at a null distance.

The absorbed dose rates of the clinical applicators were determined, and they are presented in Table 3, in comparison with the absorbed dose rates provided in the calibration certificates of the applicators.

Table 3. Absorbed dose rates obtained in this work, using thermoluminescent dosimeters, in comparison to the values from their calibration certificates.

Applicator	Absorbed dose rate (Gy/s)		Variation (%)
	Certificate	This work	
A	0.0213 ± 0.0043	0.0281 ± 0.0058	-24
B	No certificate	0.0322 ± 0.0027	–
C	0.3245 ± 0.0649	0.5364 ± 0.0646	-39
D	0.0299 ± 0.0060	0.0397 ± 0.0056	-25
E	0.0349 ± 0.0070	0.0420 ± 0.0031	-17
F	0.0257 ± 0.0051	0.0307 ± 0.0027	-16

It can be observed that the greatest variation percentage between the absorbed dose rate from the source certificate and the dose rate determined in this work occurred for the applicator C (-39%). This fact happened probable because this clinical applicator is used as dermatological and ophthalmic. The lowest percentage difference obtained was -16%, for the applicator F.

On the other hand, comparing the results obtained from both calibration methods of the applicators, using the applicator NIST as reference system, and the TL technique, the values of absorbed dose rate obtained are close, as shown in Table 4.

Table 4. Absorbed dose rates obtained through two calibration methods: the mini-extrapolation chamber and the TL technique, using the applicator NIST as reference

Applicator	Absorbed dose rate (Gy/s)		Variation (%)
	Mini-extrapolation chamber	TL dosimeters	
A	0.0295 ± 0.0036	0.0281 ± 0.0058	+5
B	0.0329 ± 0.0040	0.0322 ± 0.0027	+2
C	0.4953 ± 0.0587	0.5364 ± 0.0646	-8
D	0.0446 ± 0.0055	0.0397 ± 0.0056	+12
E	0.0511 ± 0.0065	0.0420 ± 0.0031	+22
F	0.0302 ± 0.0037	0.0307 ± 0.0027	+2

The two calibration methods presented variations lower than 12% (except in the case of applicator E, that presented a variation of 22%), mainly because the same applicator (NIST) was used as reference.

Considering that the absorbed dose rate at the calibration certificate of applicator NIST presents an uncertainty of 12%, and the Amersham applicators present an uncertainty of 20% in their calibration certificates, and the results obtained by Soares[7] described previously, the values obtained in this work can be considered satisfactory.

Development of the dosimetric postal system

The postal system is to be sent to clinics and hospitals that use $^{90}Sr+^{90}Y$ applicators, for the irradiation of the dosimeters. After this step, the samples will be sent back to the laboratory (LCI) for the TL evaluation and the determination of the absorbed dose rate of the applicator at null distance. A calibration certificate will be emitted and sent to the user.

The dosimetric postal system (Figure 7) is composed by five PMMA supports for irradiation of the samples, five thin dosimeters of $CaSO_4$:Dy and an irradiation

procedure, to inform the correct and safe use of the source and the dosimeters, by the users.

Fig. 7. PMMA supports for $CaSO_4$:Dy pellets of the dosimetric postal system for calibration of $^{90}Sr+^{90}Y$ clinical applicators.

The five pellets of the postal system will be sent packed properly, in a plastic film, with surface density of 1.095 mg/cm^2. It is a measure of precaution and care with the dosimeters, since the samples may be lost or crushed due to incorrect use during their positioning in the PMMA supports.

Two of the five pellets that will be sent to the clinics and hospitals will be the control samples, and they should not be irradiated, because they have the objective to measure the radiation during their transport.

Conclusions

The absorbed dose rates were obtained during the calibration procedure of different $^{90}Sr+^{90}Y$ clinical applicators, using two methods, in which the applicator NIST was the reference: use of a mini-extrapolation chamber and of thermoluminescent dosimeters.

The two calibration methods presented a certain perceptual difference when their results were compared to those from the calibration certificates of the sources. This perceptual difference was predicted, because a previous study revealed a discrepancy between the results of the calibration by a calibration laboratory and that realized by the manufacturer of the source. This difference may be caused in part to the fact that the applicators have a lack of uniformity in the radioactive material on their surfaces. Furthermore, these differences may have relation to the high values of the uncertainties presented in the calibration certificates of the applicator NIST and of the Amersham clinical applicators that are 12% and 20%, respectively.

The results show that the two calibration methods are efficient. As the same applicator (NIST) was utilized as reference system, the results obtained by the two techniques were similar. An alternative calibration method, in the form of a dosimetric postal system, may provide great usefulness and viability.

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References

1. IAEA, INTERNATIONAL ATOMIC ENERGY AGENCY. *Calibration of photon and beta ray sources used in brachytherapy.* Vienna, 2002 (IAEA-TECDOC-1274).
2. ICRU, INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. *Dosimetry of beta rays and low-energy photons for brachytherapy with sealed sources.* v. 4, n. 2, England, 2004 (ICRU Report nº 72).
3. DE ALMEIDA, C.; DeWERD, L.; JÄRVINEN, H.; SOARES, C. Guidelines for the calibration of low energy photon sources and beta-ray brachytherapy sources. *SSDL Newsletter,* n. 43, p. 4-25, 2000.
4. SOARES, C. G.; VYNCKIER, S.; JÄRVINEN, H.; CROSS, W. G.; SIPILÄ, P.; FLÜHS, D.; SCHAEKEN, B.; MOURTADA, F. A.; BASS, G. A.; WILLIAMS, T. T. Dosimetry of beta-ray ophthalmic applicators: Comparison of different measurement methods. *Med. Phys.,* v. 28, n. 7, p. 1373-1384, 2001.
5. OLIVEIRA, M. L.; CALDAS, L. V. E. A special mini-chamber for calibration of ^{90}Sr+^{90}Y sources. *Phys. Med. Biol.,* v. 50, p. 2929-2936, 2005.
6. HOLMES, S. M.; MICKA, J. A.; DeWERD, L. A. Ophthalmic applicators: An overview of calibrations following the change to SI units. *Med. Phys.,* v. 36, n. 5, p. 1473-1477, 2009.
7. SOARES, C. G. Comparison of NIST and manufacturer calibrations of ^{90}Sr+^{90}Y ophthalmic applicators. *Med. Phys.,* v. 22, n. 9, p. 1487-1493, 1995.
8. OLIVEIRA, M. L.; CALDAS, L. V. E. Performance of different thermoluminescence dosimeters in ^{90}Sr+^{90}Y radiation fields. *Radiat. Prot. Dosim.,* v. 111, n. 1, p. 17-20, 2004.
9. SOARES, C. G. Personal communication, 2009.