Characterization of a parallel plate ionization chamber for the quality control of clinical applicators

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Abstract. A parallel plate ionization chamber, developed at the Calibration Laboratory of IPEN (LCI), was utilized with the objective to verify the possibility of its application in the quality control program of $^{90}Sr+^{90}Y$ clinical applicators at clinics and hospitals that perform betatherapy procedures.The characterization of this ionization chamber was realized using a reference clinical applicator. The results of this work showed that this kind of ionization chamber may be useful in quality control programs of $^{90}Sr+^{90}Y$ sources, including the procedure of calibration of these sources.

1. Introduction

The parallel plate ionization chambers are instruments utilized in electron beam dosimetry because they have some advantages as different geometries, applications and a simple construction. Since long ago the parallel plate ionization chamber have been applied for the determination of absorbed doses [1].

At the Calibration Laboratory of IPEN, several parallel plate ionization chambers were already developed [2□4]. The parallel plate ionization chamber developed by Souza et al [3] was designed for utilization in high energy electron beam dosimetry.

The calibration of clinical applicators is recommended by protocols of calibration and dosimetry of sources used in brachytherapy [5,6]. The extrapolation chambers are the most adequate instruments for the determination of absorbed dose rates of these kinds of sources. Some extrapolation chambers were developed at IPEN [7,8], to calibrate dermatological (plane) and ophthalmic (curve) applicators of beta radiation. However, due to the relative complexity in their construction and utilization, they are not recommended for use in clinics and hospitals where $^{90}Sr+^{90}Y$ clinical applicators are applied, but at calibration laboratories. For the calibration of clinical applicators at radiotherapy clinics, one recommended method is the use of thermoluminescent dosimeters.

At the clinics, three main tests would be recommended for a quality control program of clinical applicators, using a parallel plate ionization chamber (homemade or commercial): leakage current and repeatibility (for the ionization chamber) and measurements of the clinical applicator radiation beam, positioned at, for instance, three different short distances from the chamber. An extrapolation of its response to null distance will allow the determination of the absorbed dose rate at its surface, using a calibration factor previously provided for the ionization chamber at a calibration laboratory.

The objective of this work was to characterize a homemade parallel plate ionization chamber to verify its potential application in a quality control program, and for the calibration of the $^{90}Sr+^{90}Y$ clinical applicators.

2. Materials and methods

Initially, the stability and linearity of the ionization chamber response were determined. For these tests, a $^{90}Sr+^{90}Y$ check source (33 MBq, 1994), PTW, model 8921, was utilized positioned on a PMMA support.

In this work, a $^{90}Sr+^{90}Y$ clinical applicator (called NIST applicator), calibrated at the American Primary Standard Laboratory of the National Institute of Standards and Technology, USA, was utilized in the characterization tests. Three other clinical applicators were calibrated using the NIST applicator as reference. The applicator A2 does not present an original calibration certificate. The characteristics of the applicators can be observed in Table I.

Table I. Characteristics of the $^{90}Sr+^{90}Y$ clinical applicators tested in this work

$^{90}Sr+^{90}Y$ applicator	**Manufacturer and model**	**Nominal absorbed dose rate (Gy/s)**	**Calibrated by**	**Calibration date**
NIST	Atlantic Research Corporation / B-1 S/N 233	0.40 ± 0.02	NIST	28.01.2003
A1	Amersham / SIQ 18	0.056 ± 0.011	Amersham	08.11.1968
A2	No information	—		
A3	Amersham / SIQ 21	0.053*	Amersham	17.09.1986

* No uncertainty provided in its calibration certificate

The measurements were realized with the objective to characterize a parallel plate ionization chamber. It was made of acrylic and in a cylindrical geometry, with an entrance window of aluminized Mylar and collecting electrode of graphite. This chamber has 25.4 mm of diameter and 17.25 mm of thickness. The collecting electrode has 6.0 mm of diameter [3].

PMMA supports were developed to allow the reproducible positioning of the parallel plate ionization chamber (Fig. 1). A goniometer was also utilized, and it can be observed in Fig. 2, for the measurements of the angular dependence of the chamber response.

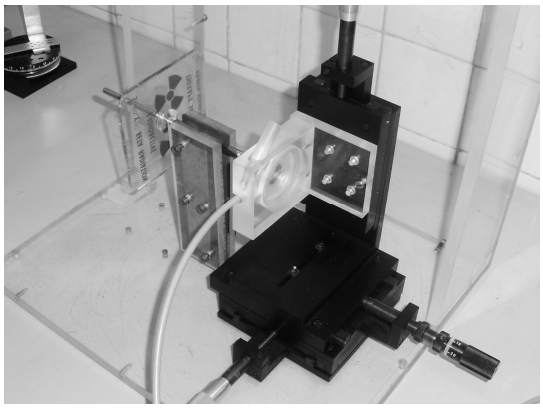

FIG. 1. Set-up utilized in the measurements with the parallel plate ionization chamber and the clinical applicators.

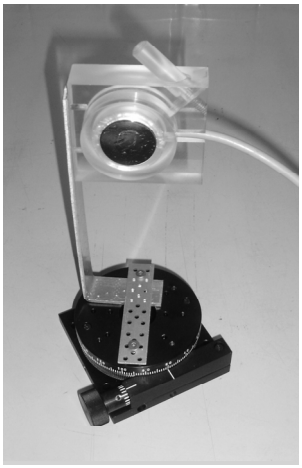

FIG. 2. Goniometer for the angular dependence test.

The ionization currents were obtained using an electrometer PTW, model UNIDOS E, serial number 10475.

3. Results

The ionization chamber was studied in relation to several characterization tests.

3.1. Leakage current without irradiation

The leakage current was measured in a time interval of 20 min, before and after the irradiation, and the maximum value obtained in this work was 0.02%. According to Ref. [9], the recommended limit to the leakage current test before irradiation is 0.5% of the highest value of the measurements. Therefore, the leakage current obtained presented a result within the recommended limit.

3.2. Stability tests

The chamber response was tested in relation to its stability (repeatibility and reproducibility tests). R The repeatibility was obtained by ten readings of charge for each polarity, during a time interval of 60 s and polarity voltage of ± 300 V. The highest variation coefficient obtained was 0.17% According to international recommendations [9], the aceptable limit to the stability test when a check source is utilized is 0.3%.

The reproducibility test was performed with successive repeatibility tests. The maximum variation coefficient obtained was 0.44% and the results are shown in Fig. 3.

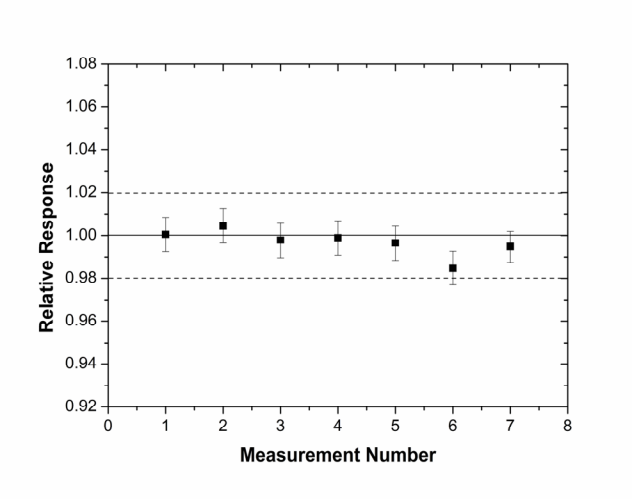

FIG. 3. Stability test of the parallel plate ionization chamber performed with a $^{90}Sr+^{90}Y$ check source.

3.3. Linearity of response

The linearity of the ionization chamber response was studied in relation to the collected charge in function of the irradiation time. In the linearity test the charge collecting time was 30 s, and the polarity voltage used was ± 300 V. Linear behaviour can be observed, with a correlation factor of 1.00. For these measurements, a $^{90}Sr+^{90}Y$ check source was utilized. The Fig. 4 shows the results obtained for the linearity test.

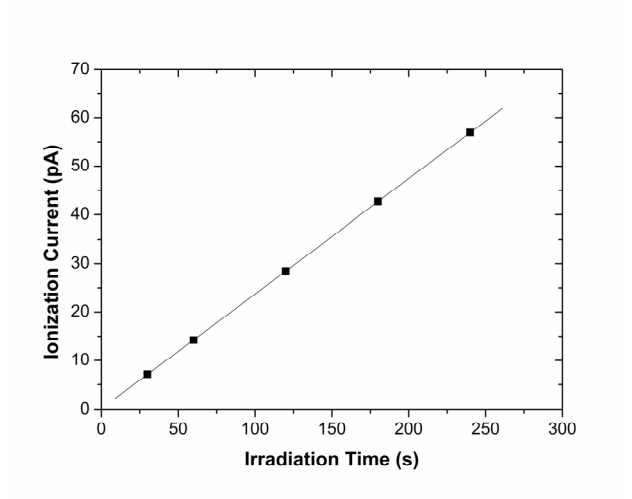

FIG. 4. Linearity of the ionization chamber response in function the irradiation time, using a $^{90}Sr+^{90}Y$ check source. The maximum standard deviation of all measurements was less than 0.5%.

3.4. Stabilization time

According to internacional recommendations [9], the stabilization time of an ionization chamber response should be studied during a time period of 15 min and 2 h, and the variation of response shall not exceed 0.5%. In order to verify the variation of the chamber response, the interval studied in this work was 0.5 min to 2 h. The voltage used in this test was ± 300 V. After the voltage application, the maximum variation obtained was 0.05% in 1 h and for the positive polarity. Table II shows the results obtained for the determination of the stabilization time. The ionization currents were normalized to the measurement realized 1 h after the application of the polarity voltage to ionization chamber.

Table II. Stabilization time test

Time (min)	Polarity	
	Positive	Negative
0.5	1.0030	1.0116
1	1.0475	1.0099
5	1.0022	0.9740
10	1.0018	1.0033
15	1.0014	0.9940
60	1.0000	1.0000
120	0.9980	0.9913

3.5. Saturation curve

The saturation curve is utilized for the determination of the best polarity voltage applied at the ionization chamber. A saturation curve (Fig. 5) was obtained varying the voltage from –300 V to +300 V, in steps of 50 V. A distance equal to 1.0 cm was utilized between the $^{90}Sr+^{90}Y$ NIST applicator and the ionization chamber, and the charge collecting time was 30 s.

The mean value of ionization current obtained was 49.04 pA and the maximum variation coefficient obtained was 0.9%. These results indicate that the ionization chamber achieves the saturation in the whole polarity voltage interval.

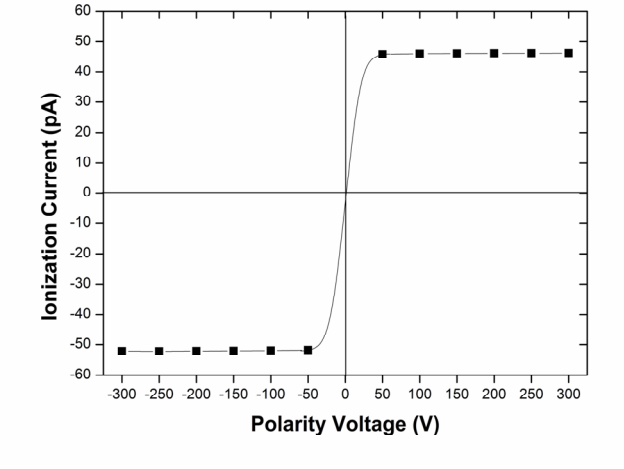

FIG. 5. Saturation curve for the parallel plate ionization chamber, using the NIST applicator. The maximum standard deviation of the measurements was less than 0.5%.

3.5.1. Polarity effect

The saturation curve can be utilized to determine two chamber characteristics: polarity effect and ion collection efficieny.

The polarity effect was determined by comparing the collected charges in the same voltages of opposite signals. This effect was obtained by Eq. (1) [10].

$$p = \frac{|Q_+| - |Q_-|}{|Q_+| + |Q_-|} \tag{1}$$

where

p polarity effect,
Q_+ collected charges of the ionization chamber in the positive polarity,
Q collected charges of the ionization chamber in the negative polarity.

For all pairs of polarity voltage tested during the saturation test, the polarity effect was 6.0%. Although this result is greater than the recommended value of 1% from in Ref. [9], the obtained value in this work was considered acceptable, since these measurements were taken using the ^{90}Sr+^{90}Y beta radiation source. In this case, the effect becomes more pronounced because there is the presence of a different ionization current that is originated by the shock between the beta radiation and the collecting electrode of the ionization chamber.

3.5.2. Ion collection efficiency

The ion collection efficiency was obtained taking into consideration the collected charges and the two polarity voltages [11], according to Eq. (2):

$$k_s = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \tag{2}$$

where

k_s value of ion collection efficiency,
V_1 greatest voltage value,
V_2 lowest voltage value,
M_1 greatest collected charge,
M_2 lowest collected charge.

The ion collection efficiency obtained in this work was better than 99.9%. This means that the losses by ion recombination are lower than 0.1%.

3.6. Angular dependence

The angular dependence angular test was performed to determine the chamber response in function of the incident radiation of small angles. The objective of this study was to verify how small positioning errors influence the ionization chamber response. The chamber was moved around its central axis in a angle interval between from –16º to +16º, in steps of 4º. During the measurements, a distance of 4.0 cm was kept between the source and the chamber center. According to Ref. [9], the value obtained in each angle must not differ from 0º by more than 3%. In this work, the maximum variation obtained was just 3%, as can be observed in Fig. 6.

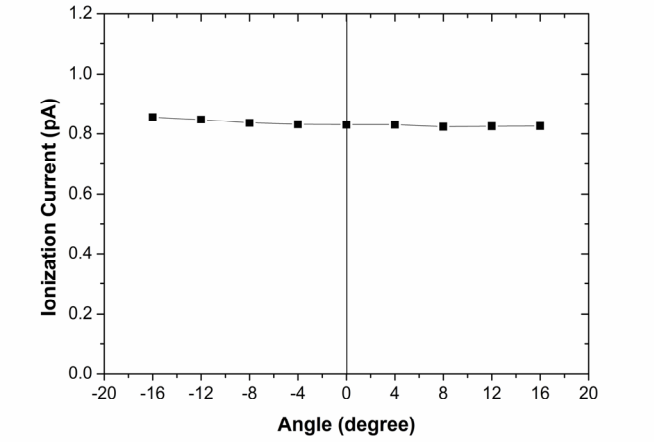

FIG. 6. Angular dependence test of the parallel plate ionization chamber exposed to NIST clinical applicator. The maximum standard deviation of the measurements was less than 1%.

3.7. Variation of the response in function to the distance

Measurements were taken in order to verify the chamber response in relation to the variation of the chamber-source distance.

The variation of the response was studied using the NIST applicator and in a distance interval of 0 to 4.0 cm (Fig. 7). The charge collecting time was 60 s.

This test is very useful in dosimetry of sources used in betatherapy. According to international recommendations [5,6], the magnitude recommended for the specification of beta radiation sources is the absorbed dose rate in water, at a reference distance. In the case of dermatological applicators, this distance is 1.0 mm. However, the dosimetry procedure at this distance is difficult because of the positioning. Therefore these sources are usually calibrated at a null distance between source and detector.

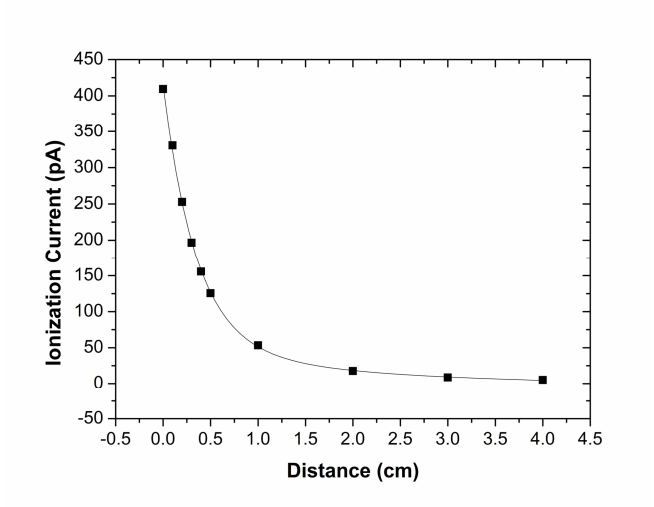

FIG. 7. Variation of the chamber response in function of the distance between NIST applicator and parallel plate ionization chamber.

The variation of the response in function to the distance allows the determination of the difference in the measurements to distances of 0 and 1 mm. A decrease of 23% was observed when the source was 1.0 mm away of the source, in relation to null distance.

3.8. Determination of the absorbed dose rates of dermatological applicators

Three dermatological applicators were calibrated using the NIST applicator as reference. A calibration factor was obtained for the ionization chamber in relation to the NIST applicator, taking the ratio between the absorbed dose rate of the NIST applicator (provided in its calibration certificate and corrected for radioactive decay), and the measured value.

Measurements were taken of the A1, A2 and A3 applicators, at constant null distances between source and detector, and a charge collecting time of 60 s. The original absorbed dose rate of each applicator was corrected for radioactive decay. Applying the calibration factor of the ionization chamber (for the NIST applicator) to the measurements of the A1, A2 and A3 applicators, their absorbed dose rates were determined at null distance. The results obtained can be observed in Table III.

Table III. Absorbed dose rates obtained in this work, at null distance, using the NIST applicator as reference

$^{90}Sr+^{90}Y$ applicator	Absorbed dose rate (Gy/s)	
	Previous study [12]	This work
A1	0.0195 ± 0.0040	0.0154 ± 0.0031
A2	0.0218 ± 0.0045	0.0169 ± 0.0034
A3	0.0297 ± 0.0060	0.0207 ± 0.0041

The values obtained in this work were compared with the results showed in a previous study [12], in which the absorbed dose rates were determined using a mini-extrapolation chamber as a reference instrument. This extrapolation chamber was developed by Oliveira and Caldas [8].

Taking into consideration that the expanded uncertainty of the NIST applicator is 12% and that the uncertainties described in the manufacturer source certificates are equal to 20% in the case of dermatological applicators, the uncertainties and the differences obtained and shown in this work can be considered acceptable.

4. Conclusion

The results show that the parallel plate ionization chamber with a collecting electrode of graphite may be used with efficiency for the quality control programs of clinical applicators.

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