Performance of a parallel plate ionization chamber in beta radiation dosimetry

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Abstract. A homemade parallel plate ionization chamber with graphite collecting electrode, and developed for use in mammography beams, was tested in relation to its usefullness in beta radiation dosimetry at the Calibration Laboratory of IPEN. Characterization tests of this ionization chamber were performed, using the $^{90}Sr+^{90}Y$, ^{85}Kr and ^{147}Pm sources of a beta secondary standard system. The results of saturation, leakage current, stabilization time, response stability, linearity, angular dependence, and calibration coefficients are within the recommended limits of international recommendations that indicate that this chamber may be used for beta radiation dosimetry.

1 Introduction

Parallel plate ionization chambers are, depending on their sensitive volume and characteristics, often used in metrology and dosimetry of low energy X radiation, as well for electron radiation detection. These instruments are also called surface ionization chambers, and they are used in routine procedures of calibration laboratories, as secondary standard systems [1,2]. Furthermore, they can have different geometries, with fixed or variable sensible volumes, as the extrapolation chambers.

Some parallel plate ionization chambers were developed at the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares (LCI), for use in low energy X radiation and beta radiation, radiotheraphy and diagnostic radiology beam dosimetry, and for calibration of beta sources [2-6]. One of the developed chambers designed for use in mammography beams was studied in relation to its Tandem system application, and it was tested in X rays beams [7].

The determination of the accurate absorbed dose in a medium, according to international protocols and recommendations is fundamental [8-10].

The Calibration Laboratory of IPEN (LCI) offers calibration services of clinical applicators and different beta radiation detectors (among many other types of detectors), and for this reason, it became interesting to verify the possibility of utilization of this chamber in beta radiation detection and dosimetry.

In this work, the objective was to evaluate the performance of a parallel plate ionization chamber for mammography beams developed at IPEN and its possible application in beta dosimetry, by studying its main dosimetric characteristics.

2 Materials and Methods

The parallel plate ionization chamber studied and characterized in this work has Lucite walls, a graphite collecting electrode and an entrance window of aluminized Mylar. This chamber has an active volume of 6.0 cm^3. It can be observed in Figure 1.

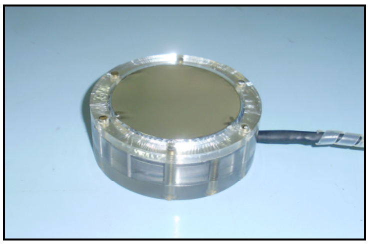


Fig. 1. Parallel plate ionization chamber studied in this work in beta radiation standard fields.

All measurements obtained in this work were taken in terms of electric charge, and the analysis was performed with the values in terms of ionization current. An electrometer UNIDOS E, from Physikalish-Technische Werkstätten (PTW), Freiburg, was utilized.

For the stability, linearity and stabilization time tests of the chamber response, a $^{90}Sr+^{90}Y$ check source (33 MBq, 1988), PTW, model 8921, and an acrylic holder for positioning of the source were utilized. For the angular dependence test, a goniometer was necessary for the angle variations.

Four different beta radiation sources were utilized for the tests. The LCI has two beta radiation secondary standard systems. The first system is the model BSS1, from Buchler GmbH & Co., Germany, and the second system is the BSS2, from Isotrak, Germany. Table 1 shows the characteristics of the sources of both systems utilized in this work.

Table 1. Characteristics of the beta radiation sources from BSS1 and BSS2 systems, utilized in this work.

Standard System	Source	Nominal Activity (MBq)	Mean Beta Energy (MeV)	Absorbed Dose Rate in the Air (µGy/s)	Calibration Date
BSS1	$^{90}Sr+^{90}Y$	1850	0.80	70.60 ± 0.71	04.02.1981
BSS2	$^{90}Sr+^{90}Y$	460	0.80	10.56 ± 0.14	08.12.2004
	^{85}Kr	3700	0.14	39.70 ± 0.50	30.11.2004
	^{147}Pm	3700	0.06	2.35 ± 0.05	19.11.2004

Only the BSS1 $^{90}Sr+^{90}Y$ source was used without field flattening filter, according to its calibration certificate.

Different methods were utilized to verify the response of the ionization chamber. The leakage current was measured without exposure of the source and during a time interval of 20 min.

The saturation curve was obtained for the determination of the best operation voltage of the ionization chamber. In this test, the polarity voltage applied to the ionization chamber was varied from -300 V to + 300V, in steps of 50 V, and the distance used between source and detector was 30 cm. In this case, the charge collection time was 10 s. The polarity effect of the ionization chamber was determined taking the mean values of the ionization current obtained for the positive and negative polarity voltages. This effect shows the variation in the measured current when the polarity is changed. The ion collection efficiency was obtained taking into consideration the collected charges for both polarity voltages and the minimum and maximum values of voltage [11].

The stabilization time of the ionization chamber response was determined in the interval time of 0.5 min to 2 h. The voltage used in this test was 300 V in both positive and negative polarities, and the mean values of the ionization currents were considered.

The ionization chamber response was studied when it was exposed to the $^{90}Sr+^{90}Y$ check source. For the repetitivity test, or short-term stability test, ten charge readings for 300 V, in both polarities, were taken during a time interval of 60. The response reproducibility, or medium-term stability, was studied through successive repetitivity tests.

For the study of the linearity of ionization chamber response, the charge collecting time was 30 s in each measurement, and the voltage used was 300 V, in both polarities. This test was performed using the $^{90}Sr+^{90}Y$ check source.

The angular dependence has as objective to determine the ionization chamber response as a function of the incident radiation angle of the BSS1 $^{90}Sr+^{90}Y$ source, at the source-detector distance of 11 cm. In this case, the angle was varied around the central axis of the chamber sensitive volume. In this work, the chamber was moved in angle intervals from – 40º to + 40º. From 0º to ± 10º, the angles were varied in steps of 2º, and the remained angle interval was studied in steps of 5º.

The ionization chamber was calibrated using the $^{90}Sr+^{90}Y$, ^{85}Kr and ^{147}Pm sources of the BSS2 system, at the calibration distances of 30 cm, 30 cm and 20 cm between source and chamber, respectively, and using flattening filters. For the $^{90}Sr+^{90}Y$ source, the collecting charge time was 60 s, and for the ^{85}Kr and ^{147}Pm sources it was 30 s and 300 s, respectively.

The variation of the chamber response was studied using the BSS1 $^{90}Sr+^{90}Y$ source positioned at 16 different distances close to the calibration distances, from 10 cm to 55 cm. The charge collecting time was 10 s for the 10 initial distances, and 30 s for the 6 other distances.

3 Results

The performance of the parallel plate ionization chamber in beta radiation beams was verified by the characterization tests of: leakage current without irradiation, saturation, polarity effect, ion collection efficiency, stabilization time, stability, linearity, angular dependence and calibration factors of the chamber response, and variation of the response as a function of distance.

3.1 Leakage Current without Irradiation

The maximum result obtained in these measurements was 0.01%. Considering that IEC 60731 [12] recommends for the leakage current test a limit of 0.5% of the highest measured value during an irradiation, the result obtained in this work was within the expected limit.

3.2 Saturation Curve

In Figure 2, the saturation curve obtained in this work can be observed. The value of the ionization current obtained for the positive polarity was 1.32 pA, and for the negative polarity it was 1.48 pA (mean value 1.40 pA), and the maximum variation coefficient was 1.8%. The results obtained demonstrate that the ionization chamber achieved saturation in the whole polarity voltage interval, and therefore, it is able to collect all generated ions inside its sensitive volume.

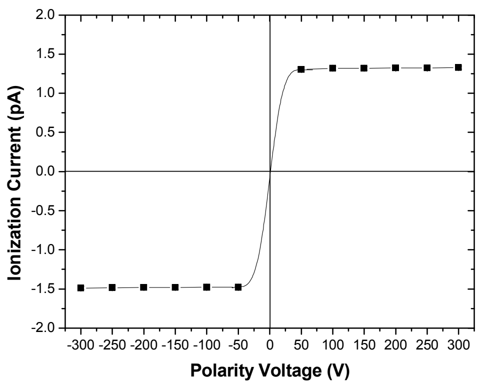


Fig. 2. Saturation curve of the chamber response, using the BSS1 $^{90}Sr+^{90}Y$ source (1850 MBq, 1981).

The maximum polarity effect was 6.3%, as can be observed in Table 2. The recommended value for this test by IEC 60731 [12] is 1.0%; however, the value obtained is acceptable because it is related to beta radiation. In this kind of radiation, there is the presence of an ionization current which is originated when beta particles interact with the entrance window of the chamber. Antonio and Caldas [11] obtained a similar result for the same conditions and another ionization chamber.

Table 2. Results of the polarity effect of the parallel plate ionization chamber.

Voltage (V)	Ionization current (pA)		Value (%)
	Polarity		
	Positive	Negative	
50	35.92	40.76	6.3
100	36.35	40.79	5.8
150	36.34	40.84	5.8
200	36.42	40.85	5.7
250	36.45	40.95	5.8
300	36.64	41.04	5.7

The result for the ion collection efficiency in this work was better than 99.97%, and it is within the recommended limit established by IEC 60731 [12], which is 99.0%. Therefore, the losses by ion recombination were less than 0.03%.

3.3 Stabilization Time

The results obtained in the stabilization time can be observed in Table 3.

Table 3. Stabilization time test of the parallel plate ionization chamber, results normalized for 1 h.

Time (min)	Polarity	
	Positive	Negative
0.5	1.0010	1.0015
1	1.0008	1.0016
5	1.0007	1.0011
10	1.0008	1.0010
15	1.0006	1.0005
60	1.0000	1.0000
120	0.9990	1.0003

The maximum variation observed in the measurements was 0.002 % for 0.5 min and 1 min and in the negative polarity. According to IEC 60731 [12], the stabilization time test should be studied during two time periods, of 15 min and 2 h, and the variation of response shall not exceed 0.5%. Therefore, the result of this test was within the recommended limit.

3.4 Stability Test

In the repetitivity test, the maximum variation coefficient obtained was 0.07%, and the recommended limit by the IEC 60731 [12] is 0.3%. In relation to reproducibility test, the maximum variation coefficient recommended by IEC 60731 [12] is 0.5%, and the result obtained in this work was 0.26%, which can be observed in Fig. 3.

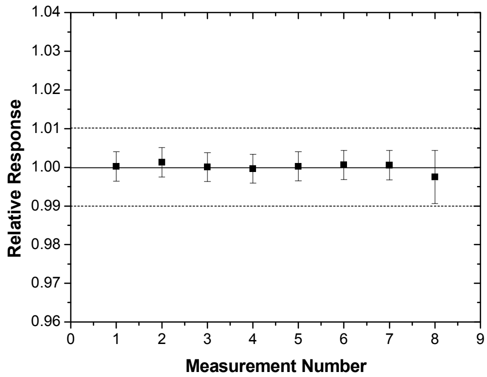


Fig. 3. Medium-term stability test of the parallel plate ionization chamber, using the ^{90}Sr+^{90}Y check source.

3.5 Linearity of Ionization Chamber Response

The linearity test of the parallel plate ionization chamber was studied.

A linear behavior was observed (Figure 4), with a correlation factor, r^2, of 1.000. The maximum variation coefficient of all measurements was 0.07%.

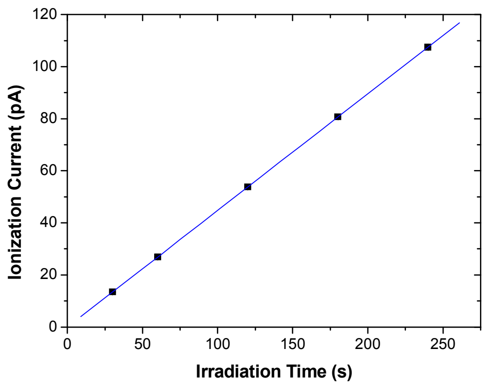
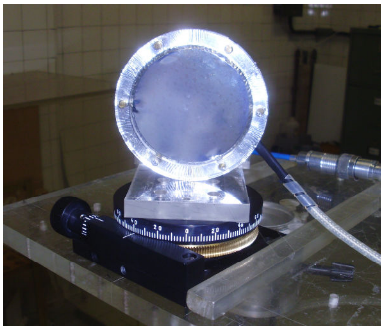
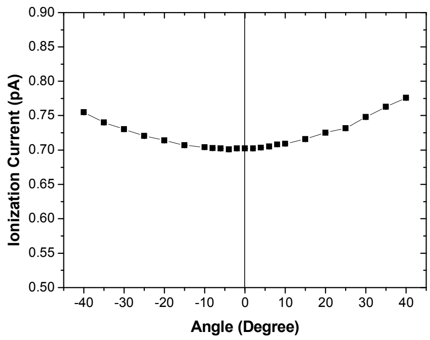


Fig. 4. Linearity test of the parallel plate ionization chamber response, using the ^{90}Sr+^{90}Y check source.

3.6 Angular Dependence

In Figure 5a can be observed the experimental set-up used in the angular dependence test. The results are shown in Fig. 5b. The maximum variation coefficient of the measurements was 0.38%.





(a) (b)

Fig. 5. Angular dependence test: a) Parallel plate ionization chamber on the goniometer, during the measurements, and b) Results obtained in this test, using the BSS1 ^{90}Sr+^{90}Y source.

3.7 Calibration Coefficients

Calibration coefficients were obtained for all sources. In the case of the ^{147}Pm source, a correction factor for air density was also considered, as recommended in its calibration certificate. The results obtained can be observed in Table 4. The maximum variation coefficient of the measurements was 3.04%. As can be observed, this ionization chamber presents high energy dependence. In Figure 6 the experimental set-up used during these measurements, can be observed.

Fig. 6. Parallel plate ionization chamber positioned at the BSS2 system during the calibration procedure.

Table 4. Calibration coefficients of the ionization chamber for the BSS2 system sources.

Sources	**Beta Mean Energy (MeV)**	**Absorbed Dose Rate (µGy/s)**	**Calibration Coefficient (µGy.s^{-1}/pA)**
^{90}Sr+^{90}Y	0.800	9.081 ± 0.140	16.481 ± 0.155
^{85}Kr	0.150	26.483 ± 0.500	17.178 ± 0.504
^{147}Pm	0.060	0.697 ± 0.050	49.786 ± 0.083

3.8 Variation of the Chamber Response as a Function of Distance

The results of the variation of the ionization chamber response are presented in Figure 7. The maximum variation coefficient obtained in the measurements was 0.31%.

The results show that the ionization chamber response follows the inverse square law in relation to the source-detector distance.

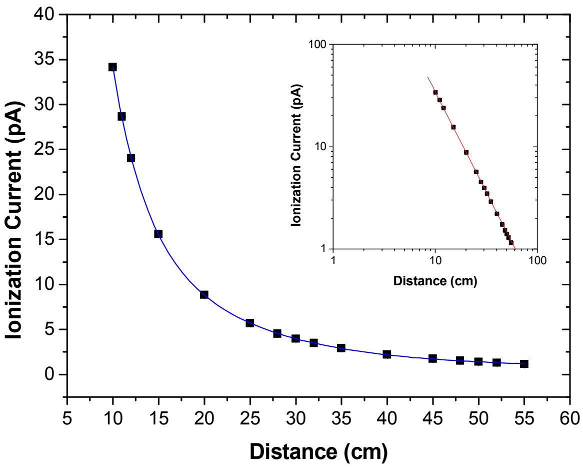


Fig. 7. Variation of the ionization chamber response in function of the source-detector distance, using the BSS1 ^{90}Sr+^{90}Y source.

4 Conclusion

A parallel plate ionization chamber with collecting electrode of graphite developed at IPEN was tested in relation to its use in beta radiation dosimetry. Different tests were performed to characterize this chamber in beta radiation standard beams. The tests presented satisfactory results, showing the good performance of the ionization chamber to beta radiation. Thus, it may be used with efficiency for beta beam dosimetry at the Calibration Laboratory of IPEN, because it presents some advantages, as: considerably large active volume, allowing the beta radiation dosimetry of sources of different energies; graphite collecting electrode, recommended for beta radiation detection; and adequate dimensions for easy positioning in radiation beams.

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