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Characterization of a homemade ionization chamber for radiotherapy beams

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ABSTRACT

A homemade cylindrical ionization chamber was studied for routine use in therapy beams of ^{60}Co and X-rays. Several characterization tests were performed: leakage current, saturation, ion collection efficiency, polarity effect, stability, stabilization time, chamber orientation and energy dependence. All results obtained were within international recommendations. Therefore the homemade ionization chamber presents usefulness for routine dosimetric procedures in radiotherapy beams.

1. Introduction

Radiotherapy is well known and widely used in oncological treatment practice. Nowadays, a lot of research has been done in order to improve the treatments involving radiotherapy. These improvements include organ-sparing treatments and local control of the dose delivery, resulting in a reduction of the patient dose and improvement in the treatment results (Russel and Bartelink, 1999). These improvements in the cancer treatments are related to developments in radiobiology, technology and dosimetry.

In order to preserve the patient life quality, there are several types of dosimeters for accurate measurements in radiotherapy beams. These dosimeters may be ionization chambers, diodes, thermoluminescent dosimeters, calorimeters and Fricke gel detectors. Even with the advance of these dosimeters, the ionization chambers still are the most practical and widely used types of dosimeters for dose measurements in radiotherapy. This is mainly due to the fact that ionization chambers are simple, precise, robust and, depending on the circumstances, they may be used as absolute or as relative dosimeters (IAEA, 2003).

The development of new ionizing radiation detectors, for clinical and metrological standard applications, is one of the aims of standard laboratories worldwide. At the Calibration Laboratory (LCI) of IPEN, several ionization chambers were developed, with metrological purposes. The interest in developing these types of ionization chambers relies on the acquisition of knowledge and on the possibility to obtain accurate measurements of radiation doses (Costa and Caldas, 2003; Maia and Caldas, 2005; Oliveira and Caldas, 2007).

In order to contribute with the calibration procedures at LCI, in this work a homemade ionization chamber, designed and developed at LCI, for calibration procedures in ^{60}Co beams was characterized.

The operational tests were: leakage current, saturation, ion collection efficiency, polarity effect, stability, stabilization time, chamber orientation and energy dependence. Moreover, the ionization chamber was also used to verify the behavior of the gamma radiation field as a function of distance. After the characterization tests, this homemade ionization chamber was calibrated against the secondary standard system of LCI.

2. Materials and methods

The special cylindrical ionization chamber developed at LCI was made using Polyvinyl chloride (PVC) and Poly(methyl methacrylate) (PMMA) materials. The wall material of the ionization chamber is made of PVC coated with graphite, and its collecting electrode material is made of aluminum. A scheme of this ionization chamber is shown in Fig. 1.

The internal diameter has 6.70 mm, and its wall thickness and sensitive length are 0.26 mm and 30.00 mm, respectively. The collecting electrode has a thickness of 1.20 mm. The build-up cap is made of PMMA, with a thickness of 4.0 mm.

The ionization chamber developed in this work has three major characteristics that differ from commercial ionization chamber: the sensitive volume, the geometry and the constituent materials. The sensitive volume is 1.06 cm^3, while the ionization chambers available for routine use normally are less than 0.9 cm^3 in volume. Besides that, the sensitive volume of this ionization chamber is located at its center, with the geometry of a pencil type ionization chamber. This configuration proved to be simpler, and with a lower cost, to be developed.

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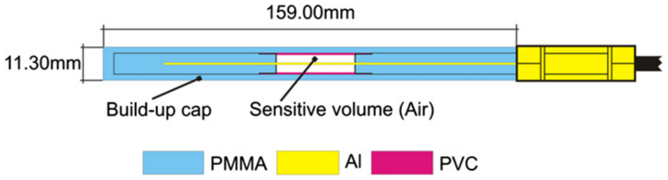

Fig. 1. Ionization chamber developed at LCI, with a 4.0 mm thick build-up cap.

Table 1
Low energy X-ray beam qualities for radiotherapy, established in the Pantak equipment at LCI for calibration procedures, based on BIPM (BIPM, 2004).

Radiation quality	Voltage (kV)	Additional filtration (mmAl)	Half-value layer (mmAl)	Air kerma rate (mGy s^{-1})
T-10	10	-	0.043	3.130 ± 0.013
T-25	25	0.372	0.279	2.762 ± 0.011
T-30	30	0.208	0.185	9.638 ± 0.042
T-50(a)	50	3.989	2.411	0.8208 ± 0.0036
T-50(b)	50	1.008	1.079	4.027 ± 0.016

The constituent material of the sensitive volume is also different from the commercially available ionization chambers. In this work, the sensitive volume was made of PVC coated with graphite, sprayed on its surface. The reason of using PVC is that this material presents mechanical resistance, and it is suitable for coating processes. Due to the small thickness of the material used to delimit the sensitive volume, the PMMA presented a corrosive deterioration, after the application of the graphite spray layer, but this effect was not presented at the PVC cylinder. For thicker PMMA pieces, this problem was not observed. Aluminum was used as the collecting electrode due to its conducting characteristic and its mechanical resistance.

Besides that, it is important to note that all materials used in the construction of this ionization chamber are of low cost, and available at the Brazilian market, which make them a good choice for the LCI.

The ionization chamber was connected to an electrometer, model UNIDOS E Physikalisch-Technische Werkstätten (PTW) Freiburg, Germany, during all tests.

In the response stability tests, a ^{90}Sr+^{90}Y check source device, PTW, model 8921 (33 MBq, 1994), was utilized. Some operational tests were made using a Gammatron equipment, with a ^{60}Co gamma radiation source; and following international recommendations [IEC 61674], some tests were conducted at an X-ray unit, Pantak/Seifert, model ISOVOLT 160HS.

The Gammatron equipment air kerma rate was (0.76 ± 0.01) mGy/s. This air kerma rate was measured using a secondary standard ionization chamber, PTW model TN30002, with traceability to the Bureau International des Poids et Mesures (BIPM). This reference chamber was also used to calibrate the ionization chamber tested in this work. The irradiation conditions, for the tests with the ^{60}Co source, were fixed at a reference field of 10×10 cm^2, with a 1.0 m source-detector distance. For the chamber orientation test, this setup was utilized, but the ionization chamber was positioned at a goniometer, OPTRON, model GN1 200.

During the tests using the X-ray unit, the T radiation quality beams were utilized (BIPM, 2004), as shown in Table 1. These qualities are standard X-ray beams for radiotherapy, with low energies. According to international recommendations (BIPM, 2004), the ionization chambers have to be at a distance of 50.0 cm from the focal spot. An ionization chamber PTW, model 23344, with traceability to BIPM, was utilized to establish these qualities at LCI.

The results obtained during the energy dependence test, for the homemade ionization chamber, were compared with the results obtained with a commercial ionization chamber, PTW Farmer, model TN30011-1, calibrated at LCI.

All readings obtained were corrected for standard environmental conditions (Attix, 1986). To determine whether or not the results obtained with this ionization chamber were acceptable, the IEC 60731 (IEC, 1997) recommendations, specific for ionization chambers used in radiotherapy, were utilized as reference.

3. Results and discussion

3.1. Leakage current

The leakage current was obtained from measurements of charge taken in time intervals of 20 min, before and after the irradiations, and conducted in all tests presented in this work. The maximum value observed was 0.06% of the ionization current produced at the minimum air kerma rate utilized. This value satisfies the IEC 60731 standard requirements (0.5%) (IEC, 1997).

3.2. Saturation, ion collection efficiency and polarity effect

A saturation curve test is responsible for determining the optimal voltage for the chamber operation. This curve was obtained varying the voltage from −400 to +400 V, in steps of 50 V, using the charge collecting time of 15 s. The tests were made using a ^{60}Co gamma source (Fig. 2) and an X-ray unit, with the T-30 radiation quality beam (Fig. 3). For all applied voltages, there were no observed significant changes in the collected charge, indicating that the chamber saturation was achieved in the whole tested voltage interval. Observing the results obtained in the saturation test, it is possible to evaluate two more tests: the polarity effect and ion collection efficiency.

The polarity effect was determined by comparing the collected charges at similar voltages of opposite signals. The highest value obtained in this test was 0.48% using the ^{60}Co source and 0.25% for the T-30 radiation quality beam. According to international recommendations (IEC, 1997), the values shall not exceed the recommended limit of 1%.

The ion collection efficiency in a continuous radiation beam can be calculated by the two voltage method (IAEA, 2001),

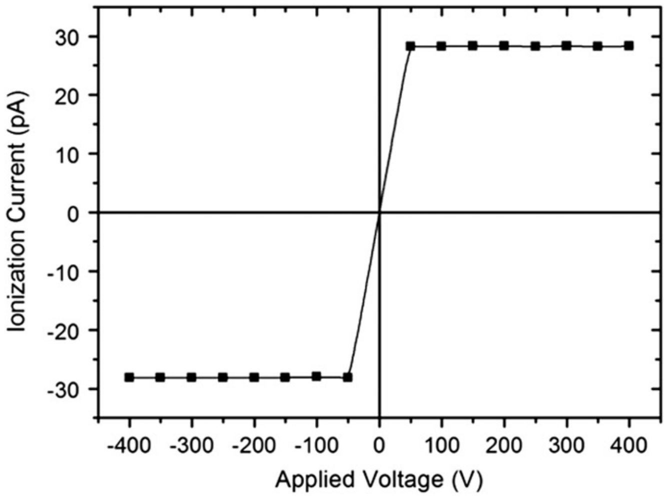

Fig. 2. Saturation curve of the homemade ionization chamber using a ^{60}Co gamma radiation source. The maximum uncertainty was 0.1%, and therefore not visible in the figure.

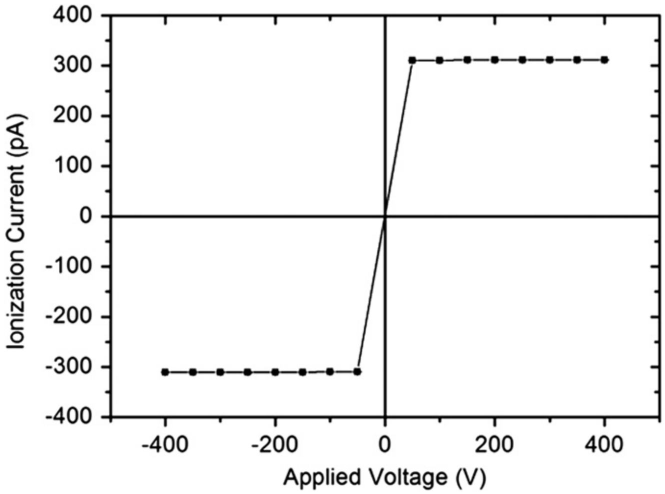

Fig. 3. Saturation curve of the homemade ionization chamber using the T-30 radiation quality beam. The maximum uncertainty was 0.1%, and therefore not visible in the figure.

according to:

$$K_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \tag{1}$$

where M_x is the collected charge at a V_x voltage, and $V_1/V_2 = 2$.

For $V_1 = 100$ V and $V_2 = 200$ V, the ion collection efficiency was better than 99.9% for both sources. This value is within the international recommended limit of 1% (IEC, 1997), and therefore the operational voltage chosen for this ionization chamber was +100 V.

3.3. Short- and medium-term stabilities

The stability tests are useful for determining the constancy in the measurements of an ionization chamber. During the testes, it is very important to ensure the reproducible geometrical positioning of the ionization chamber in relation to the source. In this work, an acrylic holder (Maia and Caldas, 2003) and a ^{90}Sr+^{90}Y check source, were utilized to obtain reproducible measurements.

The stability measurements were taken during 6 months. The short-term stability test was obtained by ten readings of charge, during time intervals of 60 s and using a voltage of +100 V. The highest coefficient of variation obtained was only 0.04%. According to the international recommendations (IEC, 1997), the maximum acceptable coefficient of variation is 0.3% for ionization chambers used in radiotherapy.

The medium-term stability test was obtained by taking the medium value of the ten measurements of the short-term stability tests during a period of six months (Fig. 4). According to IEC 60731 (IEC, 1997), the value obtained in each test must not differ from the reference value by more than 0.5%. As Fig. 4 demonstrates, all deviations obtained in the tested time were within the acceptable range.

3.4. Stabilization time

The ionization chamber was, during this test, continuously irradiated in a ^{60}Co beam, using the operational voltage of +100 V, during 120 min. The ionization current was measured after 0.5, 1.0, 5.0, 10.0, 15.0, 60.0 and 120.0 min. The ionization current obtained 15 and 120 min after switching on the measuring system is 99.9% of the 1 h stabilization current. This result is within the recommended limits of ±0.5% of response variation (IEC, 1997).

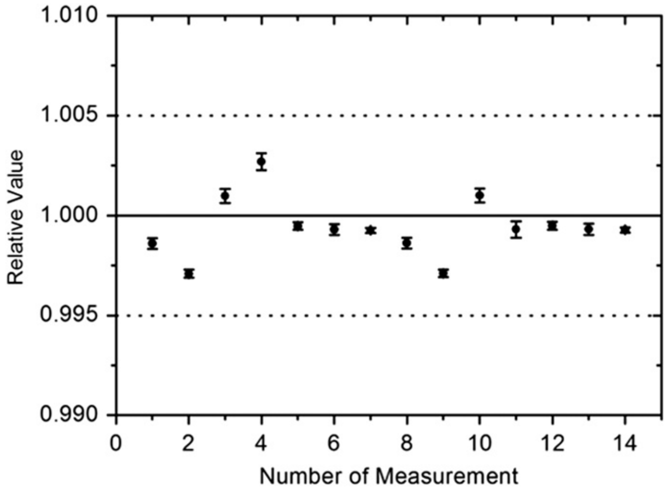

Fig. 4. Medium-term stability test for the homemade ionization chamber using a ^{90}Sr+^{90}Y check source device. The dashed lines represent the recommended limits (0.5%) according to the international recommendations [IEC, 1997].

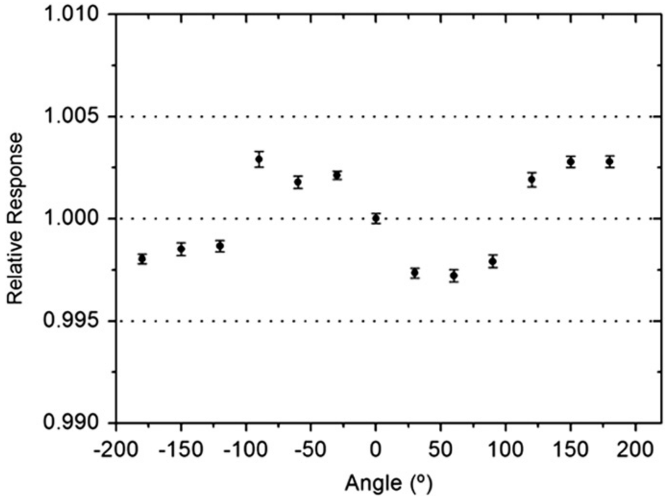

Fig. 5. Ionization chamber rotational test. The results were normalized to a 0° position.

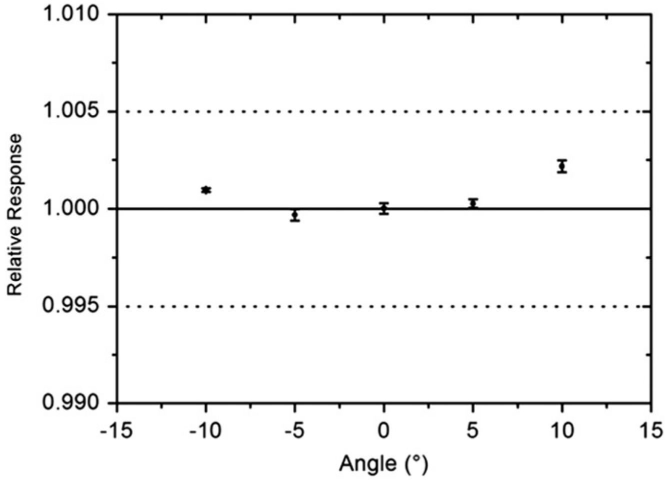

Fig. 6. Ionization chamber tilt test. The results were normalized to a 0° position.

Table 2
Calibration coefficients for the radiotherapy quality beams.

Radiation quality	Half-value layer (mmAl)	Homemade chamber		PTW chamber	
		Calibration coefficients (mGy/nC)	Correction factors	Calibration coefficients (mGy/nC)	Correction factors
T-10	0.043	34.94 ± 0.16	1.126 ± 0.012	4.02 ± 0.05	1.156 ± 0.020
T-25	0.28	33.96 ± 0.14	1.095 ± 0.010	4.29 ± 0.02	1.234 ± 0.012
T-30	0.19	31.02 ± 0.13	1.000 ± 0.009	3.48 ± 0.02	1.000 ± 0.009
T-50(a)	1.08	26.99 ± 0.17	0.870 ± 0.012	4.34 ± 0.14	1.249 ± 0.048
T-50(b)	2.41	28.35 ± 0.12	0.914 ± 0.009	4.04 ± 0.03	1.161 ± 0.014

3.5. *Chamber orientation*

The response of the ionization chamber was observed for different incident radiation angles, in relation to its rotation and tilt, according to (IEC, 1997). During the chamber rotation test, the minimum rated range must be a complete rotation of the ionization chamber, and the value obtained in each angle must not differ from 0° by more than ±0.5%. For the chamber tilt test, the chamber shall be rotated by at least ±5° in relation to its reference measurement position. The values obtained in each angle must not differ from 0° by more than ±1.0% (IEC, 1997).

The results for the chamber rotation test may be observed in Fig. 5. The chamber was rotated around its axis of rotation, and the responses were normalized to a 0° position. In this test, the maximum variation obtained was 0.29%.

For the ionization chamber tilt test, the ionization chamber was tilted about its reference position by 10°. The maximum variation obtained was 0.22%, as can be observed in Fig. 6. All results were within the international recommendations (IEC, 1997).

3.6. *Calibration and energy dependence*

The homemade ionization chamber was initially calibrated against the reference ionization chamber in the radiation qualities described in Table 1. The results obtained are presented in Table 2.

For the energy dependence test, the correction factors were obtained by dividing the calibration coefficients obtained in each radiation quality by the calibration coefficients of the T-30 radiotherapy quality beam utilized as reference beam. The energy dependence obtained in those radiotherapy quality beams was 29%.

The result obtained with the homemade ionization chamber was compared to that of a Farmer type PTW ionization chamber (TN30011-1). The results are also presented in Table 2; the maximum energy dependence was 25%, similar to that obtained with the homemade ionization chamber.

The homemade ionization chamber was also calibrated, with the built-up cap, using the substitution method, in a standard ^{60}Co field against the secondary standard ionization chamber PTW model TN30002 with traceability to BIPM. The calibration coefficient, N_k is (27.05 ± 0.67) mGy/nC.

3.7. *Response variation with the source-detector distance*

To study the response variation of the ionization chamber with the source-detector distance, the chamber position was varied from 80.0 to 120.0 cm, in 2.0 cm steps, and 10 measurements were taken for each position.

The results obtained in this test were compared with theoretical results, as shown in Fig. 7. This comparison shows good agreement, with a maximum difference of 1.4%, and a R^2 factor of 0.9993. Therefore, it is possible to utilize this homemade ionization chamber to evaluate the behavior of ^{60}Co beams.

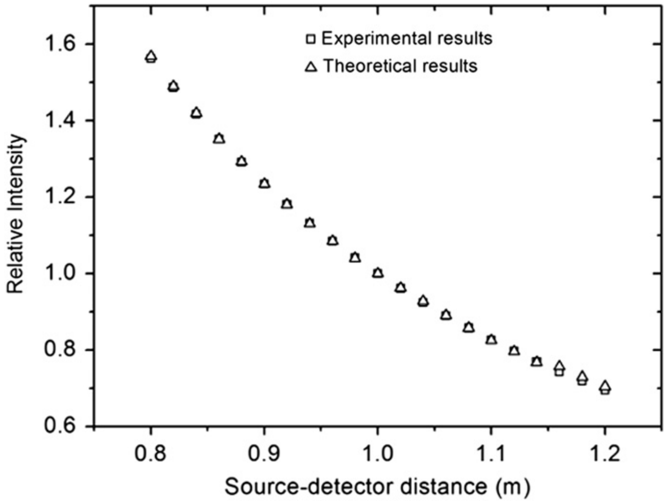

Fig. 7. Response variation of the homemade ionization chamber with the source-detector distance, in a ^{60}Co beam. The highest uncertainty associated with the measurements was 0.1%.

4. Conclusions

The homemade ionization chamber tested in this work presents good performance. The results obtained show agreement with the IEC recommendations. Observing these results, it is possible to use this homemade chamber in clinical and metrological standard applications. Therefore, the good performance of the tested ionization chamber corroborates the possibility of producing radiation detectors using the Brazilian low cost materials.

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