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Characterization of a new ionization chamber in radiotherapy beams: Angular dependence and variation of response with distance

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HIGHLIGHTS

- ▶ The new ionization chamber was submitted to ^{60}Co and radiotherapy X-rays beams.
- ▶ We examined the chamber response in two characterization tests.
- ▶ The chamber response variation with distance presented maximum variation of 11%.
- ▶ The angular dependence of this ionization chamber was within 1%.
- ▶ The results showed good agreement with the literature and international standards.

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ABSTRACT

A new double faced ionization chamber was constructed at the Calibration Laboratory of IPEN. It has different collecting electrode materials: aluminum and graphite. It was irradiated in standard radiotherapy beams (^{60}Co and X-rays). The response variation with distance and the angular dependence of this ionization chamber were evaluated. It was verified that the chamber response follows the inverse square law within a maximum variation of 11.2% in relation to the reference value. For the angular dependence it showed good agreement with international standards.

1. Introduction

In radiotherapy procedures, radiation dosimetry is a high source of uncertainty (IAEA, 1998). To keep this uncertainty within acceptable levels, a quality control program for radiotherapy equipment must be carried out. In the case of radiation dosimetry, a radiotherapy radiation detector must be submitted to various tests to verify its level of reliability (IEC(International Eletrotechnical Commission), 2011).

Among those tests, the angular dependence and the response variation with distance tests are important. The first one is important to estimate positioning errors due to small angular variations (Caldas and Albuquerque, 1991). The other one is necessary to check the detector response by varying its position in relation to the radiation source (Samat et al., 2000).

Ionization chambers are the most common type of detectors for dosimetry in radiotherapy, and they can be found in several geometries and dimensions. For medium radiotherapy clinics in developing countries the acquisition of commercial ionization chambers may be a problem because of their cost. So, some research institutes as IPEN have developed ionization chambers with low cost materials and following international standards (Costa and Caldas, 2003; Maia and Caldas, 2005; Yoshizumi et al., 2010). One of these chambers is the double faced ionization chamber that, as TL dosimeters (Gorbics and Attix, 1968; Oliveira and Maia, 2010), allows the formation of a tandem system using the ratio between the responses of ionization chambers with different collecting electrode materials.

The main interest in this kind of radiation detector is due to the fact that it allows the routine verification of the effective energies of X-ray beams after an appropriate pre-calibration (Costa and Caldas, 2003; Silva and Caldas, 2011). This principle can be applied to obtain the beam energy specification in terms of half-value layer without the use of absorbers (aluminum filters) in radiotherapy energy ranges (Sartoris and Caldas, 2001). So, the

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tandem system can be used for confirmation or determination of the radiation qualities in X-ray beams for use mainly in quality control programs. The double faced ionization chamber was constructed with Lucite, and the collecting electrode materials are aluminum and graphite.

The object of this work was to study the angular dependence and the variation with distance from the radiation source of the response of the new double faced ionization chamber.

2. Materials and methods

The double faced ionization chamber has a sensitive volume of 6.0 cm^3 and an electrode separation of 2.7 mm. This ionization chamber was specially developed for dosimetry of diagnostic radiology beams and has presented good performance in this energy range (Silva and Caldas, 2011). A photo of this ionization chamber is presented in Fig. 1. The double faced ionization chamber was connected to a PTW UNIDOS-E electrometer by a triaxial cable to perform the measurements. This electrometer has traceability to the Brazilian SSDL/IAEA: National Laboratory of Ionizing Radiation Metrology, Rio de Janeiro, Brazil.

During each test the double faced ionization chamber was polarized with +300 V with respect to the collecting electrode. The irradiation systems used in this work were a $^{90}Sr+^{90}Y$ PTW check device (33 MBq, 1994), a ^{60}Co Siemens Gammatron irradiator device (0.34 TBq, 1999) and a Pantak Seifert Isovolt 160HS X-ray source with a tungsten target that operates from 5 kV to 160 kV (the tube electric current has a range of 0.1–45 mA). The Pantak system has an inherent filtration of 0.8 mm Be. The radiotherapy radiation quality used in this work was T-30, as described in Table 1. For the tests with the ^{60}Co source a build-up cap of 4.0 mm thickness was utilized. A special apparatus to ensure the geometrical reproducibility between the double faced ionization chamber and the $^{90}Sr+^{90}Y$ check source was developed. As the double faced ionization chamber is unsealed, the measurements were corrected to the standard environmental conditions of temperature and pressure of 20 °C and 101.325 kPa, respectively.

For measurements of the ambient temperature and pressure in the X-ray laboratory, a Hart Scientific thermometer, 1529 model, and a GE Druck barometer, DPI 142 model were utilized. In the ^{60}Co laboratory a Vaisala HM34 Humidity & Temperature Meter and a Negretti & Zambra Croydon Precision Aneroid Barometer MK.2, type M2236 were utilized. The relative humidity varied between 50% and 60%, and it was controlled using dehumidifiers.

Fig. 1. Double faced ionization chamber and the check source positioned on the support apparatus.

Table 1
T-30 radiation quality characteristics as established at the Calibration Laboratory of IPEN.

High voltage (kV)	Additional filtration (mm Al)	Half-value layer (mm Al)	Air kerma rate ($mGy\ s^{-1}$)
30	0.2	0.185	9.638 ± 0.042

3. Results and discussion

The double faced ionization chamber was studied in relation to the system leakage current, chamber short- and medium-term stabilities, variation of response with distance and angular dependence. For the variation of response with distance and angular dependence tests the reference distance of 1.0 m (source to chamber distance) was used for the ^{60}Co measurements and 0.5 m (focal spot to chamber distance) for the X-ray T-30 radiation quality measurements.

3.1. Leakage current

For both chamber faces, the pre-irradiation leakage current was 0.1% in relation to the minimum ionization current measured during the irradiations. The post-irradiation leakage was 0.3% for both chamber faces. These results are in agreement with the IEC 60731 standard recommendations (IEC, 2011).

3.2. Stability tests

The stability tests were performed using the $^{90}Sr+^{90}Y$ check source. For the short term stability test (repeatability test), 10 successive measurements were taken under the same conditions, and the mean value was obtained. In this test the highest variation of the standard deviation was 0.03% for the aluminum collecting electrode face and 0.04% for the graphite collecting electrode face, both for the positive polarity.

The results of the medium term stability test (reproducibility test) are presented in Fig. 2 as a set of measurements for the short term stability.

As can be seen in Fig. 2, the measurements taken with the chamber with the graphite collecting electrode face were within about ±1.0%, in concordance with the IEC 60731 standard for this

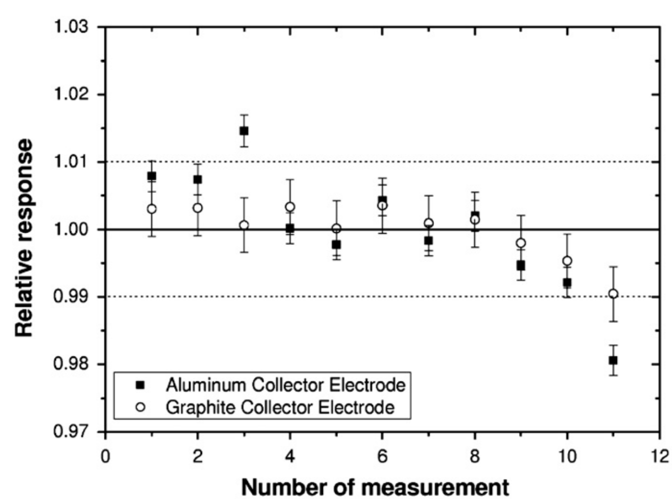

Fig. 2. Double faced ionization chamber: medium term stability test. The uncertainty bars represent the standard deviation.

Table 2
n values for the double faced ionization chamber.

Chamber collecting electrode	n value	
	^{60}Co	T-30
Aluminum	−1.984 ± 0.004	−2.181 ± 0.001
Graphite	−1.986 ± 0.004	−2.224 ± 0.001

test (IEC, 2011). The aluminum collecting electrode face presented some results outside the limits given by the IEC standard. This could be caused by experimental errors of positioning.

3.3. Response variation with distance

The purpose of this test was to determine if the double faced ionization chamber response changes in relation to the distance

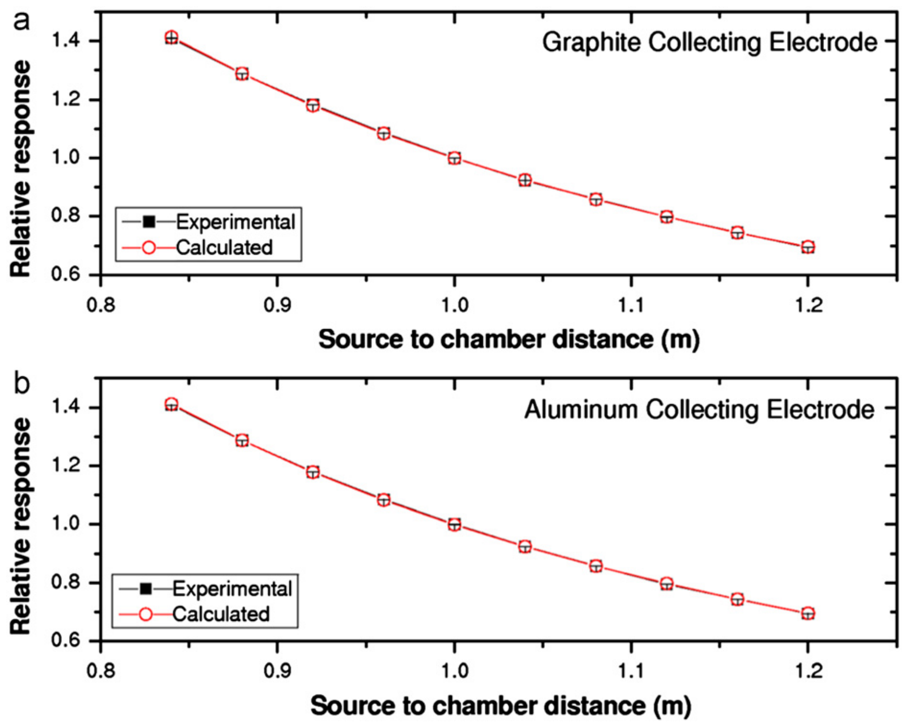

Fig. 3. Variation with distance test for the double faced ionization chamber when exposed to X-ray beams (T-30 radiation quality): (a) graphite collecting electrode and (b) aluminum collecting electrode. The overall uncertainty was lower than ±1.0%, not visible in the graphics.

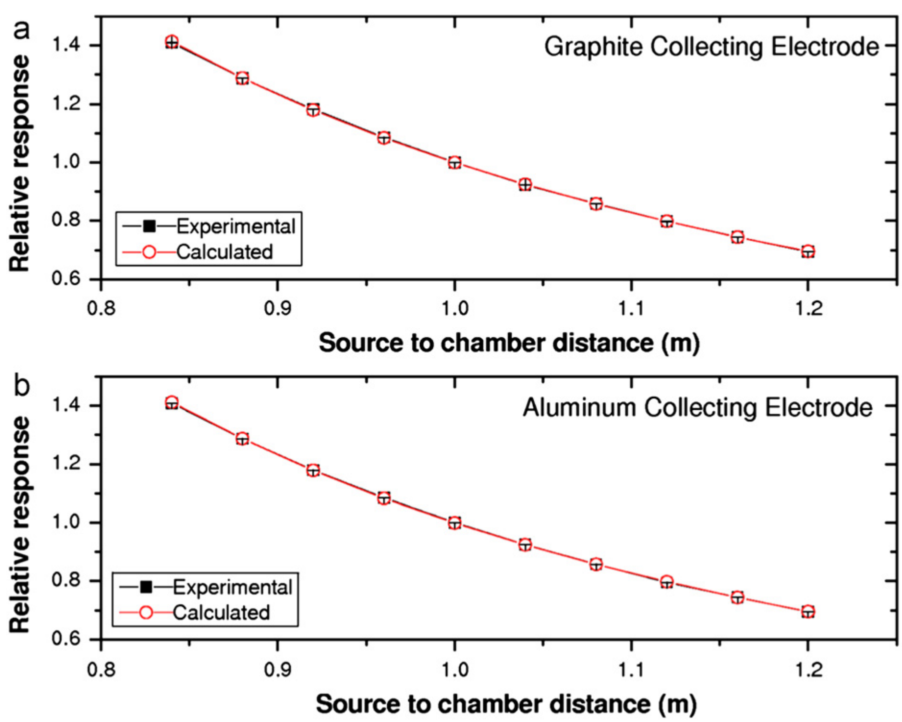

Fig. 4. Variation with distance test for the double faced ionization chamber when exposed to X-ray beams (T-30 radiation quality): (a) graphite collecting electrode and (b) aluminum collecting electrode. The overall uncertainty was lower than ±1.0%, not visible in the graphics.

between the source and the detector, and if its response follows the inverse square law. For each experimental data point, 10 measurements were taken, and the mean value was obtained for each case. For each set of ten measurements, the uncertainty was calculated using the relative uncertainty of the temperature and pressure and the standard deviation of the measurements. To verify the inverse square law the following equation was utilized:

$$y = Ab^n \quad (1)$$

where A and n are determined using the experimental results. To follow the inverse square law n must be 2. The results for the n values are shown in Table 2. With these results it was possible to calculate the theoretical curve for the variation with distance test and compare the results with the experimental ones. In Fig. 3 the results of this test for the ^{60}Co irradiator are presented. Fig. 4 presents the results for the T-30 radiation quality. The measurements were normalized to those at the reference distance of 1.0 m.

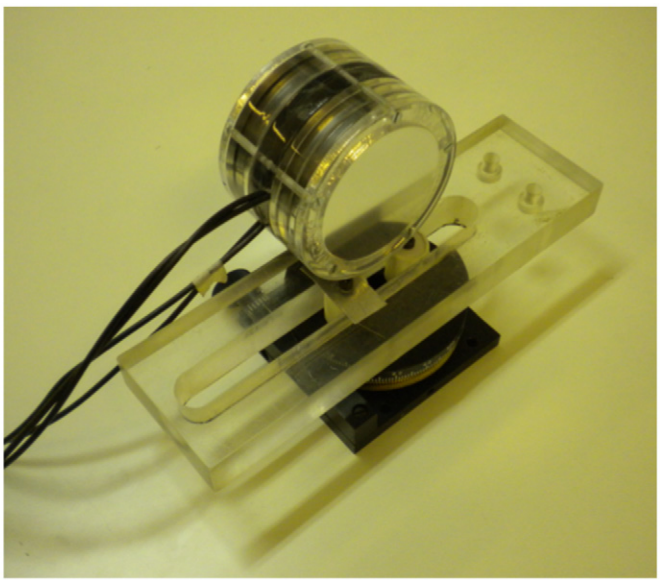

Fig. 5. Double faced ionization chamber mounted on the goniometer.

3.4. Angular dependence test

This test was performed by placing the double faced ionization chamber at a goniometer at the reference distance (1.0 m for ^{60}Co source and 0.5 m for X-ray generator). Both the double faced ionization chamber's sensitive volume and the goniometer centers were made coincident to guarantee the correct angular displacement. The double faced ionization chamber and the goniometer are presented in Fig. 5.

The incident radiation angle was varied in steps of 5° from 0° to 20° and in steps of 10° from 20° to 40°. The angles were changed in clockwise and counter clockwise senses. The counterclockwise was considered as the positive one. Ten measurements were taken for each angle, and the mean values were considered. All results were normalized to the ones for 0°. In Figs. 6 and 7 the results for the angular dependence test are presented. It can be seen that the double faced ionization chamber presents an angular dependence within ±1.0% for all angular variations between 0° and ±40° for ^{60}Co beams.

In case of the T-30 X-ray radiation quality, the ±1.0% variation is in agreement with the IEC 60731 standard (IEC, 2011), for tilted angles of ±20° in any direction from its reference position, perpendicular to the axis of the radiation beam. For angles above +30° for the graphite collecting electrode face and for angles above ±30° for the aluminum collecting electrode face, the variation was higher than ±1.0%.

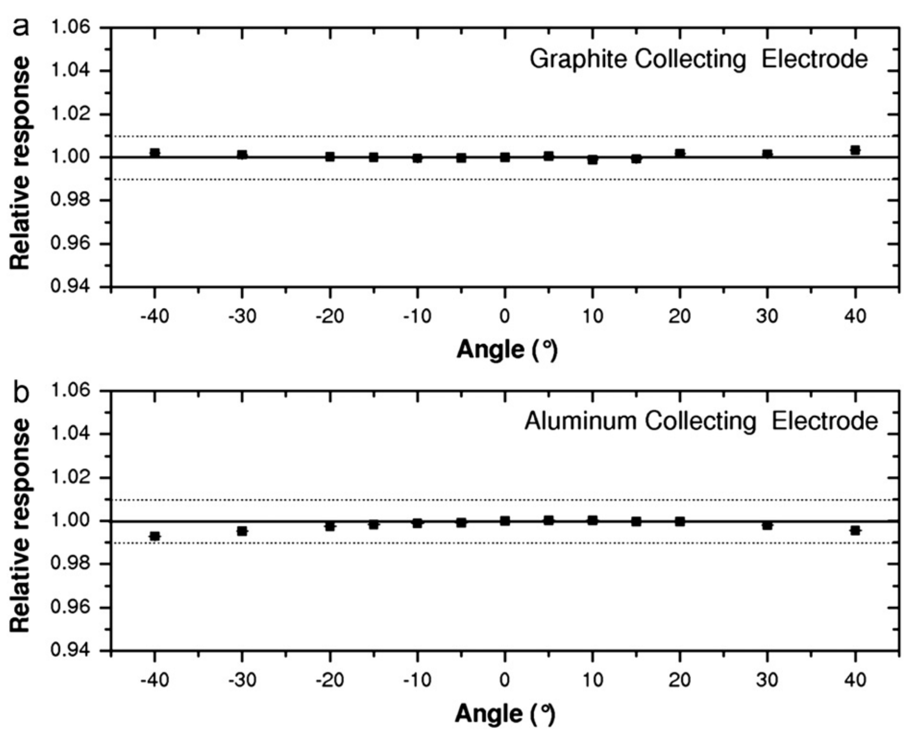

Fig. 6. Angular dependence test for the double faced ionization chamber when exposed to ^{60}Co beams: (a) graphite collecting electrode and (b) aluminum collecting electrode. The overall uncertainty was lower than ±1.0%, not visible in the graphics.

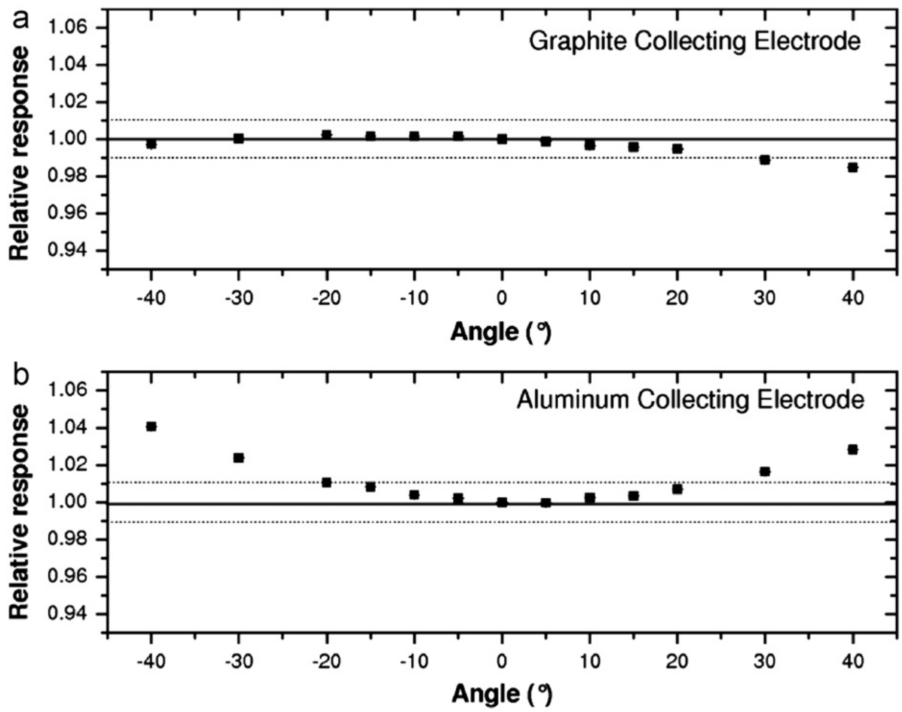

Fig. 7. Angular dependence test for the double faced ionization chamber when exposed to X-ray beams (T-30 radiation quality): (a) graphite collecting electrode and (b) aluminum collecting electrode. The overall uncertainty was lower than $\pm 1.0\%$, not visible in the graphics.

4. Conclusions

A new double faced ionization chamber, developed in-house at the Calibration Laboratory of IPEN, was tested in radiotherapy energy range beams. Even with a higher sensitive volume ($6.0\ cm^3$) than those of common ionization chambers for radiotherapy qualities, this chamber showed results consistent with published standards in the variation of response with distance and angular tests.

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