

# Development and Characterization of a New Cylindrical Ionization Chamber for Dosimetry of $^{60}\text{Co}$ Beams

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**Abstract**—A cavity ionization chamber, made of PVC coated with graphite, was developed and tested to verify its applicability as a reference dosimeter for  $^{60}\text{Co}$  beams. In order to characterize this new ionization chamber, several tests were made, following international recommendations, as saturation, ion collection efficiency, polarity effect, short- and medium-term stabilities, linearity of response, angular dependence and leakage current. All results obtained were within those recommended internationally, showing that this prototype may be used as a dosimetric standard system at the Calibration Laboratory of IPEN.

**Index Terms**—Gamma beam dosimetry, ionization chamber, radiotherapy.

## I. INTRODUCTION

**I**N calibration procedures involving radiation dosimetry, the ionization chambers are the dosimeters most commonly utilized, because they present some advantages such as long-term stability, high precision, direct measurements, and they are relatively easy to use. Despite the development of absorbed dose reference radiation detectors for  $^{60}\text{Co}$ , air kerma standards have still an important role to play in reference dosimetry. Free air chambers are not feasible for x-rays beams generated with tube voltages above 400 kV, and the standard instruments are cavity ionization chambers of various sizes and shapes [1]. The primary air kerma standards for  $^{60}\text{Co}$  beams are mainly ionization chambers, developed by primary standard laboratories. Furthermore, the most common geometry for a primary cavity standard is the cylindrical type [2]. The design and construction of these dosimeters allow the complete understanding of their characteristics, as materials and dimensions. In hospitals, the dosimetry of external radiotherapy beams is carried out by the use of ionization chambers, that must be calibrated at a standard dosimetry laboratory prior to their use.

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In Brazil the Secondary Standard Dosimetry Laboratory (SSDL) is located at the Radioprotection and Dosimetry Institute (IRD/CNEN) in Rio de Janeiro. This institute is part of the SSDL/IAEA network, and it is also responsible for the national program of metrological intercomparisons. The Calibration Laboratory of IPEN (LCI) participates in these intercomparisons as part of its quality control program. Although the LCI is not a SSDL, some of the ionization chambers used to implement radiation quality standards and to calibrate dosimeters used routinely were calibrated at primary standard laboratories, such as the Bureau International des Poids et Mesures (BIPM) and the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB). It occurs mainly because in Brazil, as in whole Latin America, there is no primary standard dosimetry laboratory yet.

The LCI offers calibration services for radiation detectors, as ionization chambers used in radiotherapy centers in Brazil, and has recently developed some ionization chambers used for routine dosimetry in x-rays [3]–[5]. The main objective in the development of this kind of ionization chambers is to produce new radiation detectors of low-cost, that may be fully characterized by any calibration laboratory, following international recommendations [6].

The objective of the present work was to verify the possibility to use a cavity ionization chamber, recently designed and constructed at LCI, as a reference dosimeter. The ionization chamber presented in this work has some differences in relation to the dosimeters previously developed by LCI [3]–[5]. The works of Neves *et al.* [3] and Perini *et al.* [4] present two pencil ionization chambers, with sensitive volume lengths of 3.0 cm (sensitive volume of  $1.06\text{ cm}^3$ ) and 1.0 cm (sensitive volume of  $0.34\text{ cm}^3$ ), respectively. These sensitive volumes are located in the middle of the ionization chambers, and the wall has a thickness of 0.26 mm. Furthermore, the BNC connector is directly connected to the dosimeter. The ionization chamber characterized in the work of Neves *et al.* [5] is a plane-parallel extrapolation chamber, suitable for beta and low energy x-rays dosimetry, and not for gamma-radiation dosimetry. The main differences of the new ionization chamber developed and characterized in this work, and those previously described [3]–[5] were the constituent materials, the use of the same material for the wall and collecting electrode and the design (this is a cylindrical type and the other ones were pencil and extrapolation types).

The walls and collecting electrode of the prototype developed in this work were assembled with an alternative material, polyvinyl chloride (PVC) coated with graphite, in contrast

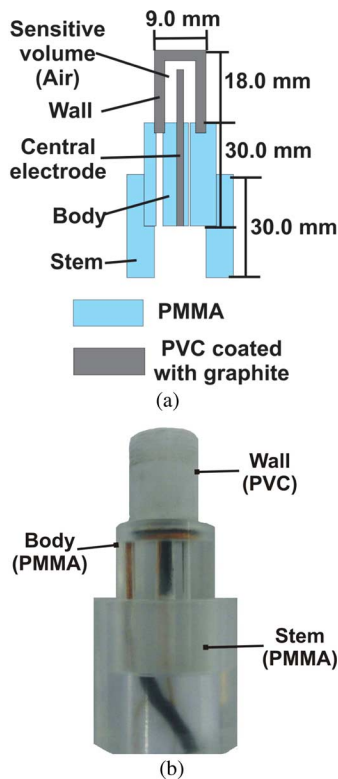


Fig. 1. (a) Schematic diagram and (b) photo of the ionization chamber developed at LCI.

with the normally available materials, polymethylmethacrylate (PMMA) coated with graphite or just graphite, of the commercial ionization chambers. This eliminates the use of aluminum in the central electrode, which may have a large influence in the energy deposited at the sensitive volume due to the recoil Compton electrons. Moreover, the use of the same material in the composition of the wall and collecting electrode may lead to a reduction in the perturbation in the medium. Furthermore, the ionization chamber stem is made of PMMA, which may also reduce the scattered radiation.

This prototype was submitted to several tests in order to characterize it as a standard. The tests suggested by the International Electrotechnical Commission standard IEC 60731 [6] undertaken in this work were: saturation, ion collection efficiency, polarity effect, short- and medium-term stabilities, linearity of response, angular dependence and leakage current.

## II. MATERIALS AND METHODS

The new ionization chamber developed and tested in this work is presented in Fig. 1. This ionization chamber has walls made of PVC coated with graphite, and the technical specifications are shown in Table I.

In order to characterize this ionization chamber, several tests were undertaken, according to the IEC 60731 standard [6]. A PTW electrometer, model UNIDOS E, was utilized for the ionization current measurements. A Gammatron II S 80  $^{60}\text{Co}$  source unit was used to irradiate the ionization chamber, with the exception of the linearity of response test, for which the

TABLE I  
TECHNICAL SPECIFICATIONS OF THE NEW IONIZATION CHAMBER DEVELOPED IN THIS WORK

Characteristics	Specifications
Electrode material	PVC coated with graphite
Electrode diameter (mm)	2.0
Wall material	PVC coated with graphite
Chamber wall thickness (mm)	3.0
Chamber outer diameter (mm)	9.0
Chamber outer length (mm)	18.0
Chamber sensitive volume ( $\text{cm}^3$ )	1.0

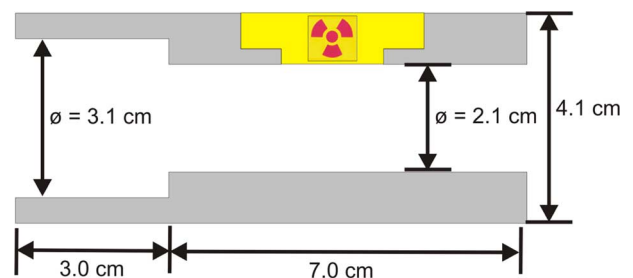


Fig. 2. Schematic diagram of the special PMMA support and check source for the stability tests.

standard therapy radiation quality T-50(b) was utilized [7]. This radiation quality was already established at LCI, at an industrial x-ray unit, Pantak Seifert, model ISOVOLT 160 HS, with a tube voltage of 50 V, 1.008 mmAl of additional filtration, half-value layer of 1.079 mmAl, and an air kerma rate of  $(4.027 \pm 0.016)$  mGy/min at a distance of 50 cm from the x-ray tube focus.

During the measurements realized with the  $^{60}\text{Co}$  source, the ionization chamber, with its build-up cap, was positioned free in air. The distance from the source to the reference point of the chamber was 100 cm, and the radiation field was  $10 \text{ cm} \times 10 \text{ cm}$ . In the measurements obtained with the Pantak industrial x-ray unit, the chamber was positioned at 50 cm from the x-ray tube focus. For the stability tests, a  $^{90}\text{Sr} + ^{90}\text{Y}$  check source, with nominal activity of 33 MBq (1994), was utilized.

To ensure the geometrical reproducibility of the source and ionization chamber set-up, a special support of PMMA was developed (Fig. 2).

The saturation curve was obtained varying the voltage from  $-400 \text{ V}$  to  $+400 \text{ V}$ , in steps of 50 V, which is the minimum possible variation allowed by the electrometer.

In order to obtain the measurements for the angular dependence test, a commercial goniometer, OPTRON, model GN1 200, was utilized. The ionization chamber was positioned at the center of the goniometer, and completely rotated around its central axis. The measurements were taken in  $30^\circ$  intervals. During all tests described in this work, the charge collecting time was 15 s, except for the leakage current test, for which the collecting time was 20 min.

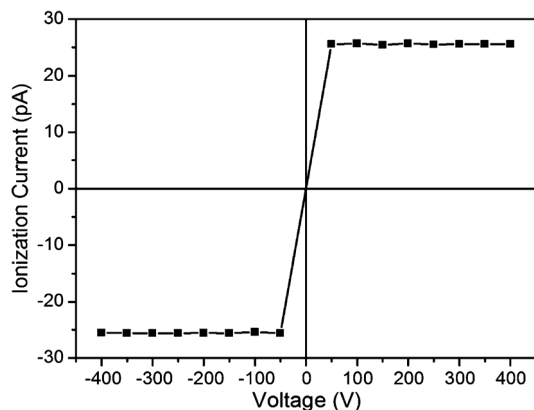


Fig. 3. Saturation curve of the new ionization chamber. The maximum uncertainty was 0.2%, and therefore not visible in the figure.

### III. RESULTS AND DISCUSSION

#### A. Saturation, Ion Collection Efficiency and Polarity Effect

The saturation test determines the optimal voltage for the chamber operation, and the saturation curve is shown in Fig. 3. The ionization chamber achieved saturation in the whole tested interval, and the chosen voltage for all tests was set to +100 V. From the saturation curve, the ion collection efficiency and polarity effect may be determined.

The polarity effect was evaluated utilizing the following relation [8], [9]:

$$k_{pol} = \frac{M^+ + M^-}{2M} \quad (1)$$

where  $M^+$  is the reading with positive polarity;  $M^-$  is the reading with negative polarity; and  $M$  is the polarity chosen from the saturation test. For all polarities evaluated, the maximum polarity effect obtained was 0.7%, which is in accordance with the recommended limit of 1.0% [6].

The ion collection efficiency in a continuous radiation beam may be determined by the two voltage method [10], according to:

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

where  $M_x$  is the collected charge at a  $V_x$  voltage, and  $V_1/V_2 = 2$ . For all tested polarities, the ion collection efficiency was better than 99.99%.

#### B. Short-and Medium-Term Stabilities

The stability tests were conducted utilizing the  $^{90}\text{Sr} + ^{90}\text{Y}$  check source and the PMMA support (to provide reproducible readings).

The mean value of the ionization chamber readings for 10 runs, with ten consecutive readings in each run, was utilized to study the short-term stability of measurement. The maximum variation obtained was 0.1%, within the international recommended limit of 0.3% [6]. The medium-term stability tests were

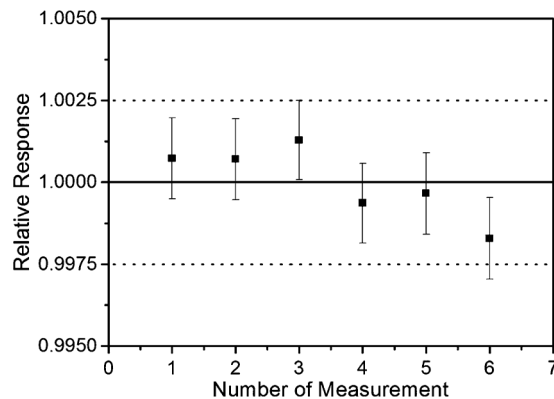


Fig. 4. Medium-term stability test of the new ionization chamber. The dotted lines represent a variation of  $\pm 0.25\%$ , within the recommended limit ( $\pm 0.5\%$ ) [6].

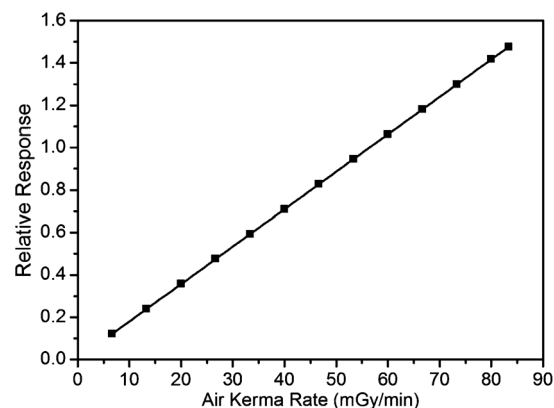


Fig. 5. Linearity of response test of the homemade ionization chamber. The maximum uncertainty was 1.3%, and therefore not visible in the figure.

undertaken for a period of 6 weeks, and the results are shown in Fig. 4. The ionization chamber response is also within the recommended limit of 0.5% for reference field-class ionization chambers.

#### C. Linearity of Response

The linearity of response test of the ionization chamber was undertaken utilizing the T-50(b) radiation quality for radiotherapy, established at the industrial x-ray unit. In this case, the air kerma rate was varied through the variation of the tube current, from 2 mA to 25 mA. The results are shown in Fig. 5.

A linear fit was obtained, and the uncertainty in the angular coefficient was only 0.01%, with a correlation coefficient  $R^2$  of 1.000. There are no limits established for this test, but the results indicate that the response of this ionization chamber is linear in relation to the air kerma rate.

#### D. Angular Dependence

The angular dependence has the objective to determine the ionization chamber response as a function of the incident radiation angle of the  $^{60}\text{Co}$  source, at the source-detector distance of 100 cm. In this case, a complete rotation of the ionization chamber around its axis was made. The ionization chamber was moved in an angle interval from  $0^\circ$  to  $+360^\circ$ , in steps of  $30^\circ$ , as shown in Fig. 6. The variation of response obtained in this test,

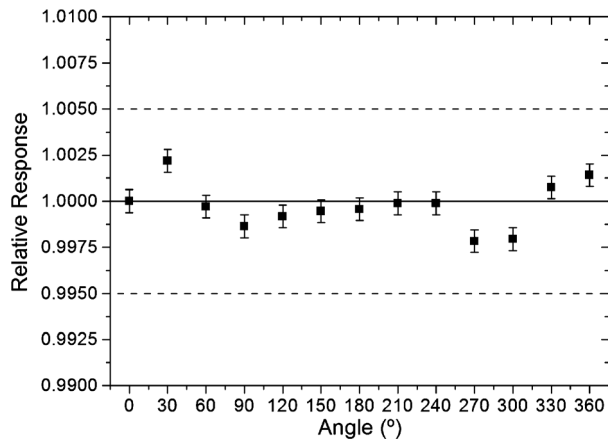


Fig. 6. Angular dependence test. All responses were normalized to that of  $0^\circ$ . The dashed lines represent the recommended limits of  $\pm 0.5\%$  [6].

when compared to that at  $0^\circ$  position, was only 0.2%, therefore, within the recommended limit of 0.5% [6].

#### E. Leakage Current

The leakage current was measured before and immediately after each irradiation of the ionization chamber. During all measurements before and after the irradiations, the current measured was less than 0.05% of the ionization current produced in the chamber sensitive volume during irradiation. This result is better than the 0.5% recommended limit for reference ionization chambers [6].

#### IV. CONCLUSIONS

A new cylindrical ionization chamber was designed and developed using PVC coated with graphite to be a reference dosimeter. The results for the tests of saturation, ion collection

efficiency, polarity effect, short- and medium-term stabilities, linearity of response, angular dependence and leakage current presented results that fulfill the requirements for a reference dosimeter. Thus the alternative material used in this work, PVC coated with graphite, may be used as composition material for both the wall and collecting electrode, leading to a more homogeneous dosimeter. The new ionization chamber, developed and characterized in this work, presents usefulness as a reference dosimeter at the Calibration Laboratory of IPEN.

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