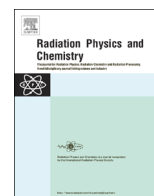




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A new parallel-plate graphite ionization chamber as a ^{60}Co gamma radiation reference instrument



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HIGHLIGHTS

- ▶ A new ionization chamber was characterized as a reference dosimeter for ^{60}Co beams.
- ▶ The EGSnrc code was used to determine the influence of the chamber components.
- ▶ The characterization test results were within the recommended limits.
- ▶ The results showed that this dosimeter may be used as a reference dosimeter.

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ABSTRACT

The calibration procedure in radiotherapy treatments is very important and a sensitive task due to the high doses delivered to the patients. Generally, the air-kerma cavity standards for ^{60}Co gamma rays are graphite cavity ionization chambers. In this work a new parallel-plate graphite ionization chamber was studied to analyze its potential use as a reference instrument. In order to evaluate its performance in ^{60}Co beams, it was submitted to several characterization tests. Moreover, Monte Carlo simulations were undertaken using the EGSnrc code to study the influence of the chamber components on its response. The results obtained showed that this new ionization chamber presented a satisfactory performance in all evaluated tests.

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1. Introduction

The accuracy and traceability of dosimeter calibrations is of great interest to those involved in dose delivery in radiotherapy. The International Commission on Radiation Units and Measurements (ICRU) has recommended an overall accuracy in tumor dose delivery of $\pm 5\%$ (Podgorsak, 2005). To maintain the uncertainties lower than 5% it is important to employ precise detectors in order to ensure an appropriate dosimetry procedure. The most utilized radiation detector for accurate measurements in radiotherapy dosimetry is the ionization chamber (Podgorsak, 2005).

Free-air ionization chambers are well suited to measure air kerma in X-ray beams produced with tube voltages up to around 400 kV (Büermann and Burns, 2009). For higher photon energies other types of ionization chambers, such as cavity ionization chambers, are necessary. The impossibility of utilization of free-

air ionization chambers for dosimetry of higher energy beams is explained because the air column surrounding the sensitive volume (to establish the electronic equilibrium condition in air) would become very long.

The air-kerma standards for ^{60}Co and ^{137}Cs beams of several primary standard laboratories, such as PTB, NIST and BIPM, are graphite cavity ionization chambers (Büermann and Burns, 2009; Minniti and Czap, 2011; Burns et al., 2007). These ionization chambers may have different designs and sensitive volumes because each calibration laboratory is responsible for the development, characterization and maintenance of its own reference dosimeters.

At the Calibration Laboratory of the IPEN (LCI) some ionization chambers were developed and characterized for diagnostic radiology (Perini et al., 2012) and radiotherapy (Neves et al., 2012). The ionization chambers studied in those works were made with graphite-coated PMMA or PVC, and they presented metrological quality to be used at calibration laboratories. In the present work, a parallel-plate graphite ionization chamber was assembled and evaluated to be utilized as a reference instrument in gamma beams (^{60}Co) at the LCI. Several characterization tests were carried out, and a Monte Carlo simulations were also undertaken

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to evaluate the influence of some components of the ionization chamber (wall, collecting electrode and stem) on its response.

2. Materials and methods

The new graphite-walled, air-filled cavity chamber was machined from a homogeneous block of graphite, and it consists of an annular ring and two end plates, that form a circular cylinder enclosing a cylindrical graphite disc. The electrical connection passes through an insulating stem made of Teflon. The picture and scheme of the Monte Carlo simulation of this ionization chamber are shown in Fig. 1, and the technical specifications are presented in Table 1.

The measurements were taken at LCI, utilizing a ^{60}Co source (Gammatron II S80) and an electrometer (PTW, model UNIDOS E). The ionization chamber was positioned at a distance of 100.0 cm from the ^{60}Co source. All measurements were corrected to the standard environmental conditions of temperature (20 °C) and pressure (101.3 kPa) because the ionization chamber is unsealed.

All simulations were done using the EGSnrc Monte Carlo system for the coupled electron/photon transport (Kawrakow et al., 2011). The photon spectrum of the ^{60}Co source adopted in the simulations pertains to a ^{60}Co therapy machine (Gammatron I) (Tedgren et al., 2010), which is similar to the ^{60}Co unit available at LCI. In a previous work (Neves et al., accepted for publication), this spectrum was evaluated, and the results indicated that it may suitably represent the equipment present at LCI.

To determine the influence of the stem and collecting electrode on the chamber response, the C++ user code cavity was employed, and to evaluate the influence of the wall the CAVRZnrc user code was chosen. The number of histories was 10^9 in all simulations.

The uncertainties of all reported results are expanded uncertainties utilizing a coverage factor of 2 (95% of confidence level).

3. Results and discussion

The performance of the graphite ionization chamber was assessed by the following characterization tests: saturation curve,

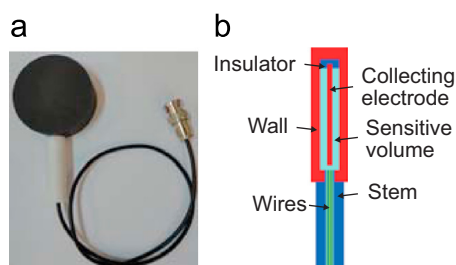


Fig. 1. (Color online) (a) Picture of the graphite ionization chamber developed at LCI and (b) scheme of the simulation geometry adopted in the cavity user code.

Table 1
Technical specifications of the graphite ionization chamber.

Characteristics	Specifications
Graphite density (g/cm ³)	1.77
Wall thickness (mm)	4.0
Internal diameter (mm)	46.0
Outer diameter (mm)	56.0
Collecting electrode diameter (mm)	42.0
Collecting electrode thickness (mm)	2.0
Sensitive volume of air (cm ³)	9.4

stability, ion collection efficiency, polarity effect, leakage current, and linearity of response. Furthermore, the determination of the influence of the chamber components was carried out with Monte Carlo simulations.

3.1. Saturation, ion collection efficiency and polarity effect

The ionization chamber achieved the saturation in the whole tested interval of voltage, as shown in Fig. 2. Thus the chosen voltage was +100 V.

From the saturation curve, two other parameters were also determined: polarity effect and ion collection efficiency. The polarity effect was obtained comparing the charge measurements using voltages of same values but of opposite signs. For all tested voltage pairs in the saturation test (± 50 V to ± 400 V, in steps of 50 V), the maximum value obtained for the polarity effect was 0.3%, in agreement with the international limit of 1% (IEC 60731, 2011).

The values for the ion collection efficiency were obtained by the two-voltage method (IAEA, 2001), given by

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

where M_x is the collected charge at a voltage equal to V_x , and $V_1/V_2 = 2$. For $V_1 = 300$ V (or -300 V) and $V_2 = 150$ V (or -150 V), the ion collection efficiency was better than 99.9% for both polarities.

3.2. Short- and medium-term stabilities

The stability of the graphite ionization chamber response was monitored during two months with the chamber exposed to the ^{60}Co beam under reproducible conditions. Ten charge readings were done in order to obtain the short-term stability. The maximum variation observed was 0.1%; this value is within the limits recommended internationally (0.3%) (IEC 60731, 2011). The medium-term stability is shown in Fig. 3, and it was undertaken by plotting the results of the short-term stability test as a function of time. According to the IEC 60731 standard (2011), the maximum variation for this evaluation test must be inferior to 0.5% for reference dosimeters. As observed in Fig. 3, the graphite ionization chamber response is within this recommended limit.

3.3. Leakage current

This test was carried out every time the ionization chamber was utilized. According to the IEC 60731 standard (2011), within 5 s after a 10 min irradiation, the leakage current shall have decreased to $\pm 1\%$ of the ionization current produced in the measuring volume during the irradiation. For the ionization

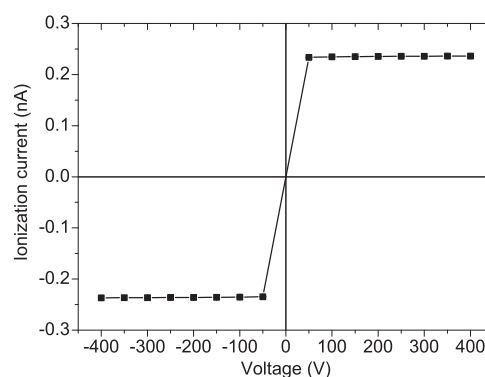


Fig. 2. Saturation curve of the graphite ionization chamber using a ^{60}Co source. The uncertainties were lower than 0.2%, and therefore not visible in the figure.

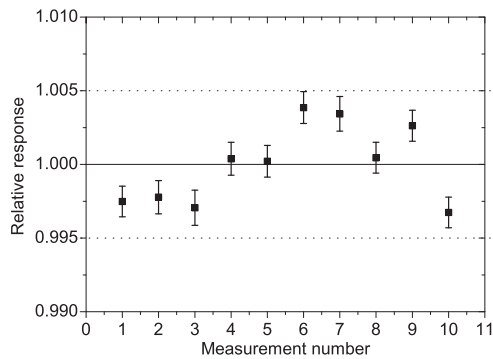


Fig. 3. Medium-term stability of the graphite ionization chamber using a ^{60}Co source. The dotted lines represent the maximum limit allowed by IEC 60731 standard (2011).

Table 2

Influence of some components on the chamber response for ^{60}Co beams.

Studied component	Influence (%)
Wall	0.5
Stem	0.13
Collecting electrode	0.15

chamber developed and characterized in this work, the leakage current was smaller than 0.5%.

3.4. Linearity of response

The response of the new graphite ionization chamber was studied in relation to its collected charge as a function of the gamma irradiation time. The chamber presented a linear response, with a coefficient of correlation (R^2) of 1.000.

3.5. Determination of the influence of the chamber components

The studied chamber components were: wall, stem and collecting electrode. The wall influence was obtained directly with the CAVRZnrc user code. The stem and electrode influences were obtained as a ratio of the dose to the gas in the ionization chamber without the studied component (stem and collecting electrode) to that with the studied component. The results obtained are listed in Table 2.

The values obtained for the wall and stem influences are in accordance with results presented in the literature (Büermann and Burns, 2009). According to that work, the influence of the wall and stem on the ionization chamber response, utilized by the PTB (parallel-plate graphite cavity ionization chamber) as reference for ^{60}Co beams, is of the order of 0.1%. The collecting electrode presented an influence of 0.15% (Table 2), showing a small effect on the studied ionization chamber measurements. This is expected because the collecting electrode and wall are composed by the same material (Muir and Rogers, 2011).

This type of analysis is important to evaluate the design (materials and dimensions) of the ionization chamber. In the case of the ionization chamber characterized in this work it was designed to have a wall thick enough to exclude the highest

energy secondary particles produced by the interaction of the radiation with other media, and this thickness is more than sufficient to achieve secondary-particle transient equilibrium. According to Table 2, the graphite and thickness chosen for assembling the wall of the ionization chamber has no significant influence on the ionization chamber measurements.

4. Conclusion

A parallel-plate graphite ionization chamber was evaluated to be used as a reference dosimeter in ^{60}Co beams. The results showed that it attended the recommended limits in all undertaken tests. The Monte Carlo simulations were very useful for the determination of the influence of some components on the chamber response. The maximum influence obtained of 0.5% was for the chamber wall. Since the influences of the studied components were all small, the material chosen for the chamber wall (graphite) is sufficiently like air, with respect to its interaction with the radiation of ^{60}Co . Therefore, this work presented the characterization of an ionization chamber, assembled in a simple and low-cost way, with a good performance to be utilized in calibration laboratories such as the LCI.

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