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DEVELOPMENT AND CHARACTERIZATION OF A NEW GRAPHITE IONIZATION CHAMBER FOR DOSIMETRY OF ^{60}Co BEAMS

Lucio Pereira Neves, Ana Paula Perini, William de Souza Santos and Linda V. E. Caldas

Instituto de Pesquisas Energéticas e Nucleares (IPEN)
Comissão Nacional de Energia Nuclear (CNEN)
Av. Professor Lineu Prestes, nº 2242
05508-000 São Paulo, SP
lpneves@ipen.br
aperini@ipen.br
wssantos@ipen.br
lcaldas@ipen.br

ABSTRACT

Ionization chambers are the most employed dosimeters for precise measurements, as those required in radiotherapy. In this work, a new graphite ionization chamber was developed and characterized in order to compose a primary standard system for the beam dosimetry of the ^{60}Co sources. This dosimeter is a cylindrical type ionization chamber, with walls and collecting electrode made of high-purity graphite, and the insulators and stem made of Teflon®. The walls are 3.0 mm thick, and it has a sensitive volume of 1.40 cm^3. The characterization was divided in two steps: experimental and Monte Carlo evaluations. This new dosimeter was evaluated in relation to its saturation curve, ion collection efficiency, polarity effect, short- and medium-term stabilities, leakage current, stabilization time, linearity of response and angular dependence. All results presented values within the established limits. The second part of the characterization process involved the determination of the correction factors, obtained by Monte Carlo simulations. Comparing these correction factors values with those from other primary standard laboratories, the highest differences were those for the wall and stem correction factors. The air-kerma rate of the ^{60}Co source was determined with this new dosimeter and with the IPEN standard system, presenting a difference of 1.7%. These results indicate that this new dosimeter may be used as a primary standard system for ^{60}Co gamma beams.

1. INTRODUCTION

Primary air-kerma standards for ^{60}Co beams are based on graphite-walled cavity ion chambers. These ionization chambers generally present cylindrical or plane-parallel design. Free-air ionization chambers are commonly utilized to measure air-kerma in X-ray beams produced with tube voltages of up to around 400 kV [1]. At higher photon energies, it is not possible to use free-air chambers, and cavity ionization chambers or calorimeters are employed.

In order to measure the air-kerma at higher photon energies, some cavity ionization chambers were developed. These ionization chambers present some advantages in relation to free-air chambers such as: small size, easy to use, and they could measure multidirectional irradiation fields.

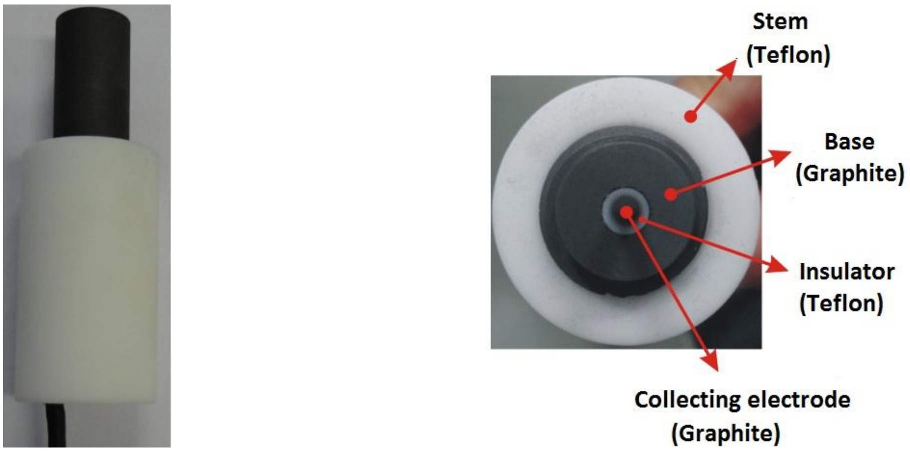
In the characterization process of the cavity ionization chambers, some experiments and Monte Carlo simulations need to be undertaken. The experimental characterization tests are based on international standards. The Monte Carlo simulations are undertaken in order to determine the correction factors of the ionization chamber.

The Monte Carlo method has proven to be invaluable for radiation transport simulations, especially to determine the correction factors of the ionization chambers characterized as primary standards. Besides that, it is widely considered that a reliable computational measure may substitute a physical experiment when direct measurements are not possible [2].

In this work, a new graphite-cavity ionization chamber was developed and characterized. This new ionization chamber is part of a system of ionization chambers, intended to compose a primary standard system for the ^{60}Co source available at the Calibration Laboratory of the Instituto de Pesquisas Energéticas e Nucleares (IPEN) [3,4]. The experimental characterization was carried out using internationally accepted standard limits. The Monte Carlo simulations were undertaken in order to determine the correction factors of this ionization chamber.

2. MATERIALS AND METHODS

The graphite ionization chamber developed and characterized in this work is showed in Fig. 1. The details of this ionization chamber are presented in Table 1.



(a) (b)

Figure 1. (a) External view of the ionization chamber developed at the IPEN and (b) ionization chamber without the wall, presenting inner details.

Table 1. Ionization chamber technical specifications

Characteristics	Dimensions
External height	26.0 mm
External diameter	16.0 mm
Internal diameter	10.0 mm
Wall thickness	3.0 mm
Electrode diameter	2.0 mm
Sensitive volume	1.40 cm^3

In the experimental measurements, the ionization chamber was attached to an electrometer, model UNIDOS E, PTW, Germany. As the chambers used in this work are unsealed, all measurements were corrected to the reference environmental conditions of temperature (20°C) and pressure (101.3 kPa).

The irradiation conditions for the characterization tests were fixed at a reference field of 10×10 cm^2 using a Gammatron II S80 irradiator unit.

The experimental uncertainties of all measurements obtained in this work are expanded uncertainties, obtained by the combination of types A and B uncertainties, using a coverage factor of 2.

The Monte Carlo simulations were carried out using the EGSnrc code [5] for radiation transport, in order to obtain the correction factors of the graphite ionization chamber. The spectrum utilized in the simulations was provided by the Secondary Standard Dosimetry Laboratory of Sweden [6]. The source spectrum of the Swedish laboratory was previously tested in the work of Neves et al. [7], and the results showed that it may be used to represent the equipment available at the IPEN.

The number of histories utilized in each simulation was 10^9. The uncertainties of all simulated results are Type A uncertainties utilizing a coverage factor of 2.

3. RESULTS AND DISCUSSION

3.1. Saturation, Ion Collection Efficiency and Polarity Effect

The saturation curve was obtained with a ^{60}Co gamma irradiator Gammatron II S80. This test was carried out by varying the applied voltage on the ionization chamber from -400 V to +400 V, in 50 V steps, and taking ten measurements for each voltage. No significant changes were observed in the collected charge, and therefore, the saturation was achieved at ±50 V (Fig. 2).

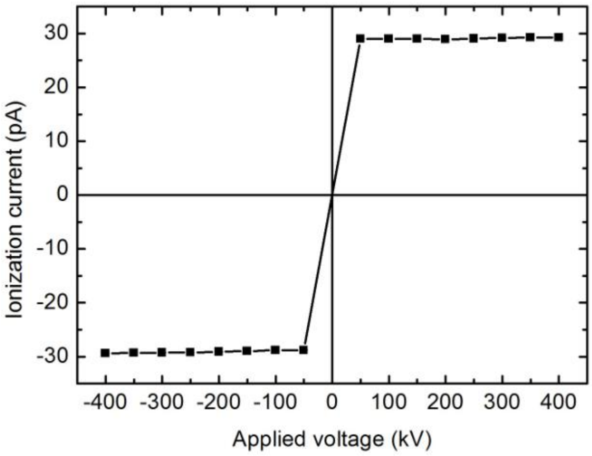


Figure 2. Saturation curves of the new graphite ionization chamber for ^{60}Co beams. The maximum uncertainty was 0.1%, and therefore not visible in the figure.

The ion collection efficiency was better than 99.9%, for all tested applied voltages. The maximum value for the polarity effect was 0.4%, within the recommended limit of 1.0% [8]. Considering these results, the chosen applied voltage was +100 V for all further testes.

3.2. Short- and Medium-term Stabilities

The highest variation in the short-term stability test was 0.05%, which is in agreement with the 0.3% limit [8]. For the medium-term stability test, the mean value of ten consecutive measurements was obtained, for a time period of three months, as presented in Fig. 3. These values should not differ by more than 0.5% [8], which was observed.

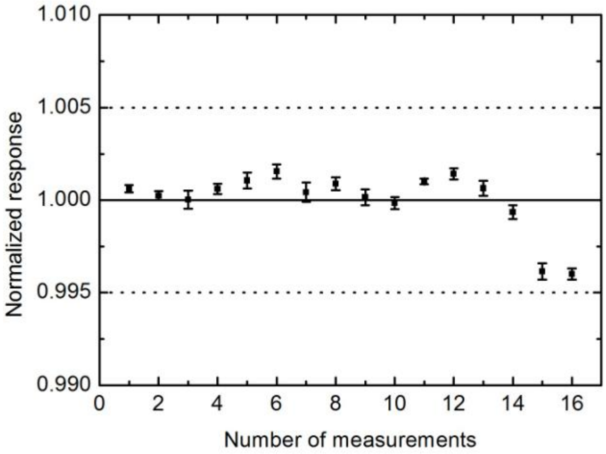


Figure 3. Medium-term stability test of the new graphite ionization chamber. The dashed lines represent the recommended limit of ±0.5% [8].

3.3. Linearity of Response

During this test, the absorbed doses were varied from 12 mGy to 150 mGy, and ten measurements were undertaken for each absorbed dose. The ionization chamber responses as a function of the absorbed doses were than analyzed, and the results are presented in Fig. 4. The correlation coefficient was 1.000, showing that the response of the ionization chamber characterized in this work is linear in ^{60}Co beams.

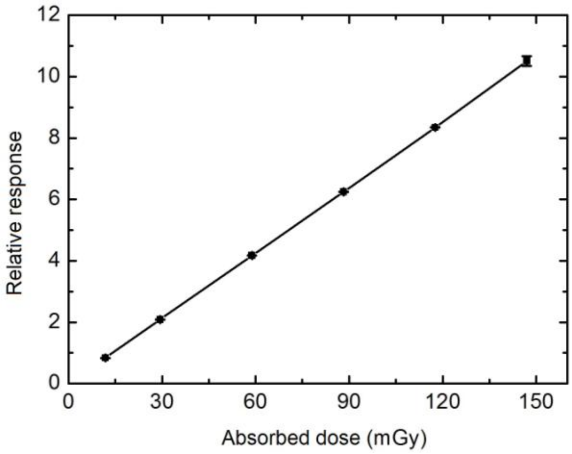


Figure 4. Linearity of response of the new graphite ionization chamber. The responses are all relative to that of an absorbed dose of 12 mGy.

3.4. Leakage Current

The maximum value for the leakage current was 0.10% of the ionization currents measured during all tests presented in this work. This value satisfies the recommended limit of 0.5% [8].

3.5. Stabilization Time

In this test the ionization current was measured 15 min and 120 min after the connection of the dosimeter to the electrometer. These values were 99.9% of the value measured 60 min after the connection, which is in agreement with the recommended ±0.5% variation [8].

3.6. Angular Dependence

In this test, the ionization chamber was rotated around its central axis, and ten measurements were taken for each position. The results are presented in Fig. 5, and it is possible to observe that all variations are within the recommended limits of 0.5% [8].

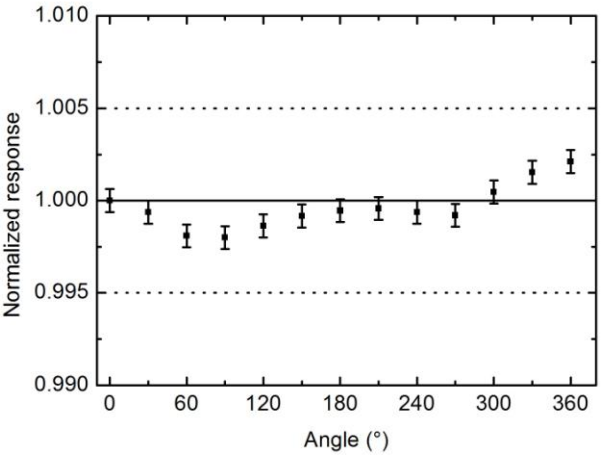


Figure 5. Angular dependence test of the new graphite ionization chamber. The dashed lines represent the recommended limits of ±0.5% [8].

3.5. Corrections Factors

The correction factors were determined employing the EGSnrc Monte Carlo code [5]. This code presents some specific libraries, for the determination of some correction factors, as wall (P_{wall}) and nonaxial uniformity (P_{an}). Other correction factors such as stem (P_{stem}) and central collecting electrode (P_{elec}) were determined as the ratio between the responses of the ionization chamber without the studied component to that of the complete ionization chamber.

For the Monte Carlo simulations, the radioactive source has to be represented by its spectrum. In this work, the source is a ^{60}Co Gammatron II S80 system. Since this spectrum and its blueprints were not available, the ^{60}Co source at the Swedish SSDL was utilized [6]. This spectrum was already applied to simulate this irradiation system, as presented elsewhere [7], and also to determine some correction factors for some graphite ionization chambers, with different sensitive volumes and shapes [3,4]. The results showed that it is very suitable for this application, and therefore, it was also employed in this work. The correction factors calculated for this new radiation detector are presented in Table 2.

Table 2. Correction factors for the new graphite ionization chamber

Correction factor	Value
P_{wall}	1,0112±0,0002
P_{stem}	0,9910±0,0057
P_{elec}	1,0017±0,0011
P_{an}	1,0019±0,0023

3.6. Air-kerma Rate Determination

The air-kerma rate ($\dot{K}_{air}$) was determined with the use of Equation (1) [9]:

$$\dot{K}_{air} = \frac{I_{gas}}{m_{air}(1-\bar{g}_{air})}\left(\frac{W}{e}\right)_{air}\left(\frac{\bar{L}}{\rho}\right)_{air}^{wall}\left(\frac{\bar{\mu}_{en}}{\rho}\right)_{wall}^{air} \times \prod P_{cf} \tag{1}$$

where I_{gas} is the electric current measured in the ionization chamber cavity, with air mass m_{air}; $\bar{g}_{air}$ is the fraction of energy dissipated outside the cavity due to Bremsstrahlung effect produced inside the cavity; W is the mean energy spent by an electron of charge e to produce a pair of ions in dry air; $\left(\bar{L}/\rho\right)_{air}^{wall}$ is the stopping power ratio between the wall and air; $\left(\bar{\mu}_{en}/\rho\right)_{wall}^{air}$ is the mass-energy absorption coefficient ratio of wall to air. All these values are well established, and may be found elsewhere [3]. P_{cf} represents the correction factors P_{wall}, P_{stem}, P_{elec} and P_{an}, listed in Table 2. A complete description of the types A and B uncertainties may be found in the literature, for a similar ionization chamber, developed at the LCI by Neves *et al.*, 2014 [3].

The value of $\dot{K}_{air}$ determined with the IPEN reference dosimeter and with the new ionization chamber developed in this work, are listed in Table 3. The IPEN standard is a PTW TN 30002 ionization chamber with traceability to the BIPM, through the Brazilian SSDL (IRD/CNEN-RJ).

Table 3. Comparison of the air-kerma rates determined with the new ionization chamber and the IPEN standard (PTW TN 30002)

Ionization chamber	$\dot{K}_{air}$ (mGy/s)
New graphite ionization chamber	0.591±0.014
IPEN standard (PTW TN 30002)	0.581±0.018

Comparing the data presented in Table 3 it is possible to observe that the difference between the two dosimeters is only 1.7%. This difference is acceptable, because the IPEN standard is not a primary standard, but calibrated against a secondary standard dosimeter. Comparing this result with that of another graphite ionization chamber, previously developed [3], the difference between the $\dot{K}_{air}$ values is just 0.17%.

4. CONCLUSIONS

The new ionization chamber developed and characterized in this work is intended to be a primary standard system for ^{60}Co gamma beams. It presented results within international recommended limits. The air-kerma rate was determined, and presented acceptable differences in relation to other dosimeters. Therefore, this new graphite ionization chamber presents potential for use as a primary standard dosimeter at calibration laboratories.

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