# Experimental and Monte Carlo evaluation of an ionization chamber in a $^{60}$Co beam



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# Experimental and Monte Carlo evaluation of an ionization chamber in a $^{60}$Co beam

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**Abstract.** Recently a special parallel-plate ionization chamber was developed and characterized at the Instituto de Pesquisas Energéticas e Nucleares. The operational tests presented results within the recommended limits. In order to determine the influence of some components of the ionization chamber on its response, Monte Carlo simulations were carried out. The experimental and simulation results pointed out that the dosimeter evaluated in the present work has favorable properties to be applied to $^{60}$Co dosimetry at calibration laboratories.

## 1. Introduction

Radiotherapy demands high precision and accuracy in the absorbed dose delivered to the tumor and a good protection to the surrounding healthy tissues. There are three main risks for inaccuracy in the dose delivered to patients: dosimetry, treatment planning and patient treatment [1]. The dosimetry area involves the following issues: commissioning of treatment systems and sources; dose calibration and dose calculation of treatment systems and sources; and problems related to equipments.

At the Calibration Laboratory of the IPEN (LCI) some dosimeters were developed to be used in diagnostic radiology [2], radiotherapy [3] and quality control of X-ray facilities [4]. Recently, an ionization chamber prototype was developed to be used in diagnostic radiology dosimetry [5]. As many hospitals and calibration laboratories worldwide still use $^{60}$Co sources for radiation therapy treatments and for calibration of dosimeters, in this work this prototype was also evaluated and characterized to verify its applicability for the dosimetry of $^{60}$Co beams.

The undertaken experiments followed the recommendations of the IEC 60731 standard [6]. As the ionization chamber, evaluated in this work, presents differences in relation to the dosimeters usually employed for $^{60}$Co dosimetry (cylindrical type), Monte Carlo simulations were adopted to study the chamber configuration (design and materials).

## 2. Materials and Methods

### 2.1. Experimental Evaluation

The ionization chamber studied in this work is presented in figure 1. It was manufactured using the following materials: PMMA coated with graphite for the walls and collecting electrode,

**Table 1.** Ionization chamber technical specifications

| Characteristics | Specifications |
|---|---|
| External height (mm) | 16.97±0.02 |
| Wall thickness (mm) | 2.00±0.02 |
| Electrode diameter (mm) | 42.00±0.02 |
| Sensitive volume ($cm^3$) | 6.3±0.1 |

PMMA for the insulators, and co-axial cables. Details of the ionization chamber are given in table 1.

The ionization chamber was tested in the $^{60}$Co teletherapy unit, Gammatron II S80, used to calibrate clinical dosimeters (radiotherapy). The irradiation conditions for all measurements in the $^{60}$Co unit were a field size of 10×10 $cm^2$ and a source-detector distance of 100 cm. The measurements were taken utilizing an electrometer, model UNIDOS E, Physikalisch-Technische Werkstätten (PTW), Germany. All readings were corrected for standard environmental conditions of pressure and temperature.

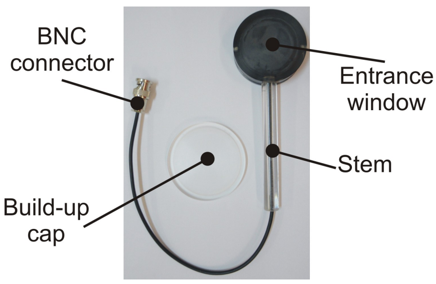


**Figure 1.** Photo of the ionization chamber tested in this work with its PMMA build-up cap

### *2.2. Monte Carlo evaluation*

As this dosimeter was designed at the LCI, all dimensions and composite materials are well known. This information is very important in order to correctly simulate the dosimeter. The simulations were undertaken utilizing the PENELOPE/penEasy Monte Carlo code [7, 8]. The simulated ionization chamber is shown in figure 2.

As input parameter to the PENELOPE/penEasy code, all dimensions and materials were used. The configuration adopted in the present paper is given in table 2.

The $^{60}$Co spectrum utilized in the simulations was provided by Tedgren *et al.* [9], which was obtained for the $^{60}$Co therapy machine, model Gammatron I. The radioactive source of this machine is similar to the one available at the LCI. This spectrum was already utilized in a work of Neves *et al.* [3], and it is very suitable to represent our $^{60}$Co source.

In order to better understand the influences of the components of the chamber response, the sensitive volume was studied as three different parts in relation to the collecting electrode: above, below and around its side. This scheme is also shown in figure 2.

The experimental uncertainties, calculated for all measurements, are expanded uncertainties, obtained by the combination of type A and B uncertainties, using a coverage factor of 2. The type A uncertainties were adopted for Monte Carlo Simulation, also with a coverage factor of 2.

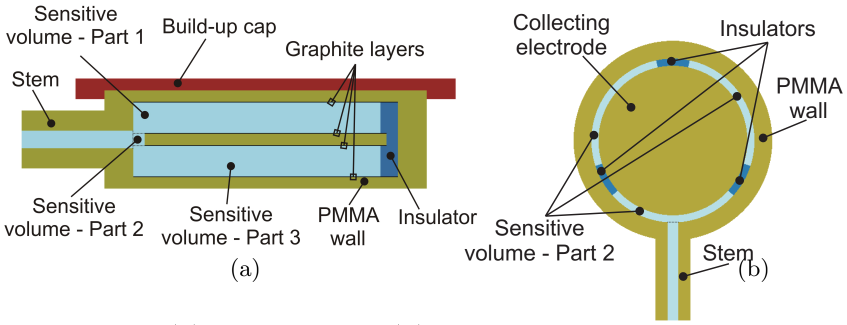


**Figure 2.** Axial view (a) and top view (b) of the geometry used as input for the Monte Carlo simulations. It is also possible to observe the sensitive volume separated in three distinct parts. The stem was reduced in this figure, for better visualization of all components of the ionization chamber.

**Table 2.** Simulation parameters used on the PENELOPE/penEasy code [7]

| Parameters | Values |
|---|---|
| Cutoff energy for photons | 1 keV |
| Cutoff energy for $e^+$ and $e^-$ | 1 keV |
| Average angular deflection ($C_1$) | 0.05 |
| Maximum average fractional energy loss between consecutive hard elastic events ($C_2$) | 0.05 |
| Cutoff energy loss for hard inelastic collisions ($W_{CC}$) | 0.1 keV |
| Cutoff energy loss for hard Bremsstrahlung ($W_{CR}$) | 1 keV |
| External electron step-length control ($S_{max}$) | $10^{30}$ cm |
| Number of histories | $10^{10}$ |

## 3. Results and Discussions

### *3.1. Saturation, ion collection efficiency and polarity effect*

The saturation test was the first evaluation undertaken with the ionization chamber in order to determine the most appropriate voltage that shall be applied to it. The saturation curve is shown in figure 3. It can be seen that for all applied voltage values, no significant changes in the collected charge were observed. To reduce any possible leakage current, the chosen applied voltage to be used in all tests was set as +100 V.

From the results obtained in the saturation curve, two other tests were conducted: ion collection efficiency and polarity effect. The ion collection efficiency was determined by equation (1) [10].

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

Where $M_x$ is the collected charge at a $V_x$ voltage, and $V_1$=$V_2$ = 2, for $V_1 = \pm 200$ V and $V_2 = \pm 100$ V. The ion collection efficiency was better than 99.99%.

The polarity effect was obtained comparing the collected charges at similar voltages of opposite signs. The maximum polarity effect observed was 0.4%, therefore within the maximum limit of 1% recommended by the IEC 60731 standard [6].

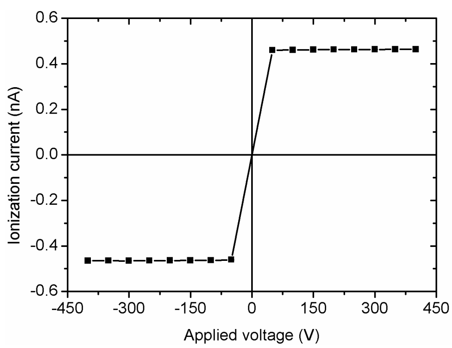


**Figure 3.** Saturation curve of the ionization chamber. The maximum uncertainty was 0.1%, and is therefore not visible in the figure.

*3.2. Short- and medium-term stabilities*

The stability test was undertaken for a period of 12 months, as part of the quality control program of this dosimeter. During the short-term stability test, ten consecutive readings were taken. The maximum variation obtained was 0.17%, which is in accordance with the limit of 0.25% [6].

The medium-term stability was obtained by taking the mean value of ten measurements of the short-term stability tests during a period of 12 months under the same reproducible conditions. The maximum variation coefficient (0.3%) is well within the recommended limit of 0.5% [6].

*3.3. Leakage current*

The leakage current was determined following the instructions of the IEC 60731 standard [6]. Within 5 s after the end of a 10 min irradiation, the leakage current shall have decreased to ±0.5% of the ionization current produced in the measuring volume during the irradiation. For the ionization chamber developed and characterized in this work, this behavior was observed.

*3.4. Monte Carlo evaluation*

To evaluate the new chamber design for the dosimetry of $^{60}$Co beams, some components of the ionization chamber were chosen: collecting electrode, insulators and stem, in order to determine their influence on the chamber response.

The effect of each studied component was obtained as the ratio of the dose to the gas in the ionization chamber (atmospheric air) without the studied component to that with the whole chamber. The influences are listed in table 3. From the results it is possible to observe a small influence of the collecting electrode.

Furthermore, the energy deposited in Parts 1 and 3 of the sensitive volume presented a difference of just 0.06%, which is well within the uncertainties (0.2%). This result indicates that the chamber design of the collecting electrode position, in the middle of the sensitive volume, and material (PMMA coated with graphite) does not alter significantly the energy deposited. This may even improve the dosimeter response, because the electric field becomes more homogeneous in the sensitive volume.

The insulators are very small, and no significant contribution was expected. As the stem presents a considerable size in relation to the sensitive volume of the chamber, its influence is higher. It is important to notice, however, that in this study the whole chamber, including the stem, was in the primary beam.

**Table 3.** Influence of the chamber components on its response, at the three distinct parts of the sensitive volume.

| Studied Component | Influence (%) | | |
|---|---|---|---|
| | Part 1 | Part 2 | Part 3 |
| Collecting electrode | 2.5 | 2.7 | 2.2 |
| Insulators | 0.1 | 0.7 | 0.2 |
| Stem | 6.3 | 4.9 | 7.0 |

## 4. Conclusions

The ionization chamber characterized in this work presented results within the limits recommended by international standards. Furthermore, due to the knowledge of all dimensions, materials and geometrical arrangement, the Monte Carlo analyses were undertaken to study this ion chamber configuration for $^{60}$Co beams. These results point out a small effect of the studied components on the chamber response, and it presented several advantages: low-cost, easy assembling, robustness, good performance in the characterization tests and a configuration with low influence on the chamber response.

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## References

[1] IAEA TECDOC 1040, 1998. Design and implementation of a radiotherapy programme: Clinical, medical physics, radiation protection and safety aspects.

[2] Afonso L C, Vivolo V and Caldas L V E 2010 Characteristics of a tandem system of ionization chambers in X-ray beams, mammography level. *Appl. Radiat. Isot.* **68** 610–3

[3] Neves L P, Perini A P, Fernández-Varea J M and Caldas L V E 2013 Application of a Pencil Ionization Chamber (0.34 cm$^3$ Volume) for $^{60}$Co Beams: Experimental and Monte Carlo Results *IEEE Trans. Nucl. Sci.* **60** 746–50

[4] Maia A F and Caldas L V E 2006 A simple method for evaluation of HVL variation in CT equipment. *Phys. Med. Biol.* **51** 1595–601

[5] Perini A P, Neves, L P and Caldas L V E 2013 Investigation of the applicability of a special parallel-plate ionization chamber for x-ray beam dosimetry *Radiat. Phys. Chem.* **95** 94–97

[6] IEC 60731 2011. International Electrotechnical Commission: Medical electrical equipment Dosimeters with ionization chambers as used in radiotherapy.

[7] Salvat F, Fernández-Varea J M and Sempau J 2008 PENELOPE – A Code System for Monte Carlo Simulation of Electron and Photon Transport, OECD/NEA, Issy-les-Moulineaux.

[8] Sempau J, Badal A, Brualla L, 2011 A PENELOPE – based system for the automated Monte Carlo simulation of clinacs and voxelized geometries – application to far-from-axis fields *Med. Phys.* **38** 5887–95

[9] Tedgren A C, Luelmo S and Grindborg J E 2010 Characterization of a $^{60}$Co unit at a secondary standard dosimetry laboratory: Monte Carlo simulations compared to measurements and results from the literature *Med. Phys.* **37** 2777–86

[10] IAEA TRS 398 2001. Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water.