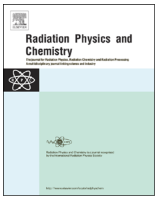
Radiation Physics and Chemistry 95 (2014) 94–97

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem



# Investigation of the applicability of a special parallel-plate ionization chamber for x-ray beam dosimetry

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## HIGHLIGHTS

- An ionization chamber with a novel design was characterized for x-ray beam dosimetry.
- This ionization chamber was evaluated in diagnostic radiology qualities.
- The characterization tests results were within the recommended limits.
- Monte Carlo simulations were employed to evaluate the design of the dosimeter.
- The developed prototype is a good alternative for calibration laboratories and clinics.

## ARTICLE INFO

*Article history:*
Received 28 September 2012
Accepted 3 March 2013
Available online 15 March 2013

*Keywords:*
Ionization chamber
Standard x-rays beams
Monte Carlo simulation

## ABSTRACT

Diagnostic x-rays are the greatest source of exposition to ionizing radiation of the population worldwide. In order to obtain accurate and lower-cost dosimeters for quality control assurance of medical x-ray facilities, a special ionization chamber was designed at the Calibration Laboratory of the IPEN, for dosimetry in diagnostic radiology beams. For the chamber characterization some tests were undertaken. Monte Carlo simulations were proposed to evaluate the distribution of the deposited energy in the sensitive volume of the ionization chamber and the collecting electrode effect on the chamber response. According to the obtained results, this special ionization chamber presents potential use for dosimetry of conventional diagnostic radiology beams.

## 1. Introduction

According to UNSCEAR (2008), there are approximately 3.6 billion diagnostic radiology x-ray examinations (including medical diagnostics and dental examinations) undertaken every year worldwide. This large number of examinations requires a special care in relation to the doses delivered to the patients that can be realized with an effective quality assurance program.

Ionization chambers are usually utilized as reference instruments in diagnostic radiology dosimetry and in quality assurance programs, mainly due to their high sensitivity and relatively constant response within a wide range of energies. The parallel-plate type ionization chamber is the most commonly used radiation detector in diagnostic radiology dosimetry, because it presents a nearly flat energy dependence in low-energy region when compared to the cylindrical ionization chambers (DeWerd and Wagner, 1999).

At the Calibration Laboratory of the IPEN (LCI) some ionization chambers were designed and developed for diagnostic radiology (Perini et al., 2012a) and radiotherapy (Neves et al., 2012). These ionization chambers presented satisfactory results to be applied in calibration laboratories and medical clinics. Recently, a special parallel-plate ionization chamber was projected and assembled to be used in different energy ranges. The main differences between this dosimeter and those used for diagnostic radiology dosimetry are the collecting electrode localization and the materials utilized. The collecting electrode is located in the middle of the sensitive volume, which provides a more homogeneous electric field. The material used in the manufacturing process was PMMA coated with a thin layer of graphite, for the wall and collecting electrode. As graphite interacts with radiation very similarly to air, which is used as the gas and surrounding medium, its influence was expected to be very small in the chamber readings. This dosimeter was already tested in the standard radiotherapy qualities (T qualities) (Perini et al., 2012b), presenting good performance. In order to extend the use of this ionization chamber, in this work, it was evaluated in diagnostic radiology beams with the objective to take part of the quality control program at the LCI.

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0969-806X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radphyschem.2013.03.006

To evaluate the ionization chamber performance, it was submitted to several tests listed by IEC (IEC 61674, 1997). Due to the novel design of the collecting electrode position (in the middle of the ionization chamber) in diagnostic radiology dosimetry, some analyses employing Monte Carlo simulations with the PENELOPE/penEasy code (Salvat et al., 2008) were undertaken. These simulations were very important to evaluate the distribution of the deposited energy within the sensitive volume parts and also the collecting electrode influence on the ionization chamber measurements.

## 2. Materials and methods

The unsealed ionization chamber presented in this work was manufactured utilizing PMMA coated with a thin layer of graphite, coaxial cables and air as gas in the sensitive volume. The chamber collecting electrode has a diameter of 42.0 mm and thickness of 2.0 mm, while the chamber walls present a thickness of 2.0 mm. This ionization chamber has a sensitive volume of 6.3 cm$^3$. The photo and the geometry schemes used for the simulations with the PENELOPE/penEasy code are shown in Fig. 1.

The materials utilized in the assembling of this new dosimeter were chosen mainly because they present low cost, are easily machined, requiring no special apparatus or new techniques, and they are very resistant, which may increase the life cycle of the dosimeter. The wall and collecting electrode were made with the same material (PMMA coated with graphite) to avoid perturbation of the beam due to the presence of the ionization chamber, thus optimizing its readings and leading to a small collecting electrode effect. Also, the position of the collecting electrode in the middle of the chamber establishes a homogeneous electric field, reducing the polarity effects inherent in ionization chambers with this sensitive volume size.

The measurements were undertaken with an electrometer, model UNIDOS E, Physikalisch-Technische Werkstätten (PTW), and all measurements were corrected to the standard environmental conditions of temperature (20 °C) and pressure (101.3 kPa).

For the stability tests, a $^{90}$Sr+$^{90}$Y radioactive check source, PTW, model 8921, with nominal activity of 33 MBq (1994), and a special PMMA support dedicated to this ionization chamber were employed. The other tests were made using an industrial x-ray unit, Pantak Seifert, model ISOVOLT 160HS, that operates from 5 to 160 kV. The reference system utilized for the energy dependence test was a RADCAL RC6 ionization chamber, calibrated at the Physikalisch-Technische Bundesanstalt (PTB). The diagnostic radiology qualities utilized, RQR3, RQR5 and RQR8, were defined by the IEC 61267 (2005). The characteristics of those qualities are listed in Table 1.

The Monte Carlo simulations were carried out with the PENELOPE/penEasy code, and the geometry arrangement is illustrated in Fig. 1. The simulation parameters were: 1 keV for the average deflection ($C_1$), 1 keV for the maximum average fractional energy loss between consecutive hard elastic events ($C_2$), 0.1 keV for cutoff energy loss for hard inelastic collisions ($W_{CC}$) and 1 keV for the cutoff energy loss for hard Bremsstrahlung ($W_{CR}$). The cutoff energy for photons and electrons was set to 1 keV. The spectra utilized in the simulations were measured at the PTB (Büermann, 2012), in the same radiation qualities described in Table 1.

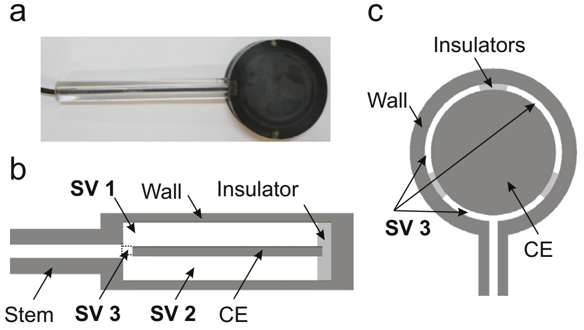

**Fig. 1.** (a) Photo of the ionization chamber developed at LCI, (b) lateral and (c) top views of the geometry used in the PENELOPE/penEasy code. SV stands for sensitive volume and CE for collecting electrode.

**Table 1**
Characteristics of the standard diagnostic radiation qualities utilized in this work.

| Radiation quality | Voltage (kV) | Half-value layer (mmAl) | Air kerma rate (mGy/min) |
|---|---|---|---|
| RQR3 | 50 | 1.78 | 21.60 ± 0.18 |
| RQR5 | 70 | 2.58 | 37.88 ± 0.32 |
| RQR8 | 100 | 3.97 | 67.45 ± 0.54 |

The Monte Carlo analyses were made in order to evaluate the deposited energy in each part of the sensitive volume and also the effect of the collecting electrode on the chamber response. To verify the deposited energy in the sensitive volume, it was divided in three parts, as represented in Fig. 1(b). The results were obtained as the ratio between the deposited energy in each part of the sensitive volume and the deposited energy in the whole sensitive volume.

The influence of the collecting electrode on the chamber readings was evaluated as the ratio between the deposited energy to the gas in the ionization chamber (atmospheric air) without the collecting electrode and to that with the collecting electrode.

The uncertainties calculated in this paper are expanded uncertainties obtained by combining the A and B type uncertainties (or just type A for the simulated results), using a coverage factor of 2.

## 3. Results and discussion

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

The saturation test was undertaken to define the voltage for the ionization chamber operation. It was made varying the voltage applied to ionization chamber, in steps of 50 V, and analyzing the chamber response. The results are shown in Fig. 2a, and for the interval of voltage tested there is no significant difference in the ionization chamber response. The voltage chosen for the tests was +100 V.

From the saturation test it is possible to obtain more two parameters: ion collection efficiency and polarity effect. The ion collection efficiency was determined by the two-voltage method (IAEA, 2001), and it was better than 99.9%. The polarity effect was obtained by comparing the collected charge at similar voltages of opposite signs. For all pairs of voltages, the maximum polarity effect was 0.11% (50 V); this value is in accordance with the limit of 1.0% recommended by the IEC 60731 standard (2011).

### 3.2. *Stability tests*

The stability test is part of the permanent control to evaluate the constancy of the chamber response. In this work, this test was undertaken utilizing a $^{90}$Sr+$^{90}$Y radioactive check source and a PMMA support developed specially for the ionization chamber characterized in this work. The short-term stability was performed by taking 10 measurements with the ionization chamber exposed to the check source in reproducible conditions. The highest

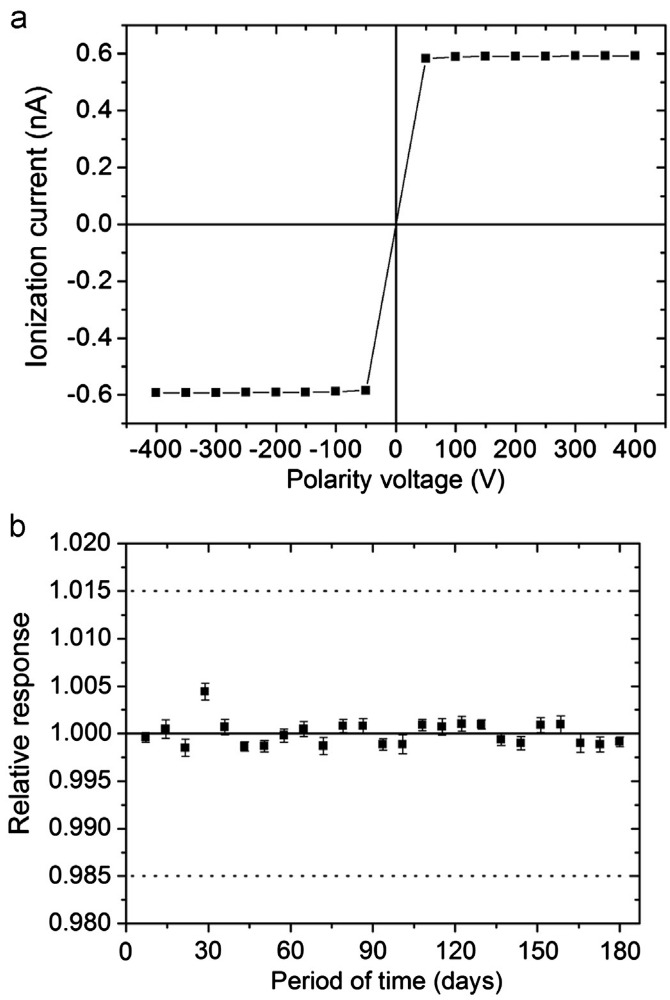

**Fig. 2.** (a) Saturation curve using the RQR5 radiation quality and (b) medium-term stability test. The dotted lines represent half of the recommended limit (3%) (IEC 61674, 1997).

variation observed was only 0.4%, within the recommended limit of 1% (IEC 61674, 1997).

The medium-term stability was made during a time interval of 6 months, and it was carried out by plotting the results of the short-term stability tests as a function of time (Fig. 2b). As represented in Fig. 2b, the maximum variation observed was only 0.4%, thus within the limit of 3% predicted by the IEC 61674 (1997).

### *3.3. Leakage current*

The leakage current of the ionization chamber was measured in time intervals of 20 min, before and after the irradiations. The maximum value obtained was 0.3% of the ionization current produced at the minimum air kerma rate produced in this work. This value is within the limit recommended internationally of 5% (IEC 61674, 1997).

### *3.4. Linearity of response*

In the linearity of response test, the ionization chamber was exposed to several different air kerma rates. The nominal current of the Pantak x-ray unit was varied between 2 and 25 mA, using the RQR5 radiation quality, to provide different air kerma rates. A linear fit of the chamber response versus the air kerma rate was obtained, with a correlation coefficient ($R^2$) of 0.9999. Therefore, the ionization chamber presented a linear behavior.

### *3.5. Calibration and energy dependence*

The calibration coefficients were obtained comparing the measurements with the ionization chamber characterized in this work and the reference ionization chamber (RADCAL, RC6).

The energy dependence of this new dosimeter is 2.8% (between RQR3 and RQR8), within the limit of 5.0% recommended by the IEC 61674 (1997). This value is comparable to results obtained with other ionization chambers developed at the IPEN. In the work of Maia and Caldas (2005), a parallel-plate ionization chamber was evaluated in diagnostic radiology radiation qualities and its energy dependence was 2.6%. In the work of Perini et al. (2012a), a pencil ionization chamber was characterized in the diagnostic radiology qualities, and presented an energy dependence of 3.0%. The correction factors were obtained normalizing the calibration coefficient obtained in each quality to the calibration coefficient of the RQR5 radiation quality. The values for the calibration coefficients and correction factors are listed in Table 2.

### *3.6. Monte Carlo study*

In order to study the design of the ionization chamber characterized in this work, it was simulated to evaluate the energy distribution in its sensitive volume and the effect of the collecting electrode on its response.

The results for the analyses of the sensitive volume are presented in Table 3. It is possible to observe that the maximum difference in the deposited energy in SV 1 and SV 2 is 1.6% (RQR5 and RQR8). This shows that this new design for the collecting electrode position may be applied to diagnostic radiology dosimetry.

The effect of the collecting electrode on the ionization chamber response was only 0.34%, showing that a homogeneous construction of the ionization chamber (wall and collecting electrode of the same material) presents the advantage of no significant influence on the chamber measurements.

## 4. Conclusion

In this work, the performance of a special parallel-plate ionization chamber made with PMMA coated with graphite was evaluated. The tests undertaken showed all results within the recommended limits; therefore this ionization chamber presents potential to be used for diagnostic radiology dosimetry. The Monte Carlo simulations demonstrated that this ionization chamber was

**Table 2**
Calibration coefficients and correction factors for the new parallel-plate ionization chamber in diagnostic radiology beams.

| Radiation quality | Calibration coefficient ( $\times 10^5$ Gy/C) | Correction factor |
|---|---|---|
| RQR3 | 9.930 | 1.018 |
| RQR5 | 9.747 | 1.000 |
| RQR8 | 9.653 | 0.990 |

**Table 3**
Distribution of the deposited energy in the sensitive volume parts.

| Radiation quality | Fraction of the deposited energy (%) | | |
|---|---|---|---|
| | SV 1 | SV 2 | SV 3 |
| RQR3 | 48.8 | 48.6 | 2.6 |
| RQR5 | 49.1 | 48.3 | 2.6 |
| RQR8 | 49.1 | 48.3 | 2.6 |

well designed, with a low collecting electrode effect. Furthermore, the sensitive volume parts (above and below the collecting electrode) presented a maximum difference in the deposited energy of 1.6%. These results show the usefulness of this new detector for the beam dosimetry of diagnostic radiology qualities at calibration laboratories.

## Acknowledgments

The authors would like to thank Dr. L. Büermann (PTB, Germany) for kindly providing the radiation spectra used in this work; and the Brazilian agencies CNEN, FAPESP, CNPq, MCT: Project INCT/MRM, and MRA Industry for their partial financial support.

## References

Büermann, L., 2012. PTB Radiation qualities for calibration of secondary standards. URL ⟨www.ptb.de/en/org/6/62/625/pdf/strhlq.pdf⟩. Access at May 2012.

DeWerd, L.A., Wagner, L.K., 1999. Characteristics of radiation detectors for diagnostic radiology. Appl. Radiat. Isot. 50 (1), 125–136.

IAEA, 2001. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water, IAEA TRS 398, Vienna.

IEC 60731, 2011. Medical electrical equipment—dosimeters with ionization chambers as used in radiotherapy, IEC 60731, Geneva.

IEC 61267, 2005. Medical diagnostic X-ray equipment—radiation conditions for use in the determination of characteristics, IEC 61267, Geneva.

IEC 61674, 1997. Medical electrical equipment—dosimeters with ionization chambers and/or semi-conductor detectors as used in X-ray diagnostic imaging, IEC 61674, Geneva.

Maia, A.F., Caldas, L.V.E., 2005. A new extended length parallel plate ionization chamber. Phys. Med. Biol. 50, 3837–3847.

Neves, L.P., Perini, A.P., dos Santos, G.P., Xavier, M., Khoury, H.J., Caldas, L.V.E., 2012. Characterization of a homemade ionization chamber for radiotherapy beams. Appl. Radiat. Isot. 70 (7), 1291–1295.

Perini, A.P., Neves, L.P., Vivolo, V., Xavier, M., Khoury, H.J., Caldas, L.V.E., 2012a. Characterization of a CT ionization chamber for radiation field mapping. Appl. Radiat. Isot. 70 (7), 1300–1303.

Perini, A.P., Neves, L.P., Caldas, L.V.E, 2012b. Assembling and study of a plane-parallel ionization chamber in low-energy X-ray qualities for radiotherapy. In: SORMA IEEE 2012 Proceedings, Oakland.

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

UNSCEAR, 2008. Sources and effects of ionizing radiation, UN, New York.