Radiation Physics and Chemistry 95 (2014) 98–100

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Dosimetric application of a special pencil ionization chamber in radiotherapy X-ray beams

Lucio P. Neves [a,*], Ana P. Perini [a], José M. Fernández-Varea [b], Vagner F. Cassola [c], Richard Kramer [c], Helen J. Khoury [c], Linda V.E. Caldas [a]

[a] Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear (IPEN-CNEN/SP), Av. Prof. Lineu Prestes, 2242, 05508-000 SP, Brazil
[b] Facultat de Física (ECM and ICC), Universitat de Barcelona, Diagonal 645, E-08028 Barcelona, Spain
[c] Universidade Federal de Pernambuco, Departamento de Energia Nuclear, Av. Prof. Luiz Freire 1000, 50740-540 Recife, Brazil

HIGHLIGHTS

- A special pencil-type ionization chamber was characterized for radiotherapy X-ray beams.
- The results of the characterization tests were within the recommended limits.
- The EGSnrc code was employed to evaluate the components of the dosimeter.
- The simulations showed that this novel configuration is suitable for this application.
- This dosimeter may be used for quality control programs at laboratories and clinics.

ARTICLE INFO

Article history:
Received 29 September 2012
Accepted 25 December 2012
Available online 31 December 2012

Keywords:
Very low-energy radiotherapy beams
Radiation dosimetry
Monte Carlo simulation
Ionization chamber

ABSTRACT

The aim of this work was to study the performance of a pencil ionization chamber with a sensitive volume of only 1.06 cm^3 and a length of 3.0 cm, developed at the Calibration Laboratory of the IPEN, in very low-energy radiotherapy X-ray beams. These beams are still used for certain skin cancer treatments due to their rapid attenuation in tissue. The dosimeter performance was evaluated in some tests proposed by the IEC 60731 standard: short- and long-term stability and linearity of response. For a complete analysis of the dosimeter response, the EGSnrc Monte Carlo simulation was utilized to investigate the influence of its different parts on the ionization chamber response. All results of the tests were in accordance with the recommended limits, and this work shows that it is possible to extend the application of this pencil-type ionization chamber developed at the LCI.

1. Introduction

According to the IPEMB code of practice (Klevenhagen et al., 1996), X-rays of half-value layers in the range 0.035–1.0 mm Al, covering approximately those generated at tube voltages of 8–50 kV are defined as very low-energy X-rays. They may deliver a relatively high dose rate with a limited penetration, which makes them a good choice for the treatment of some skin disorders and superficial lesions. Besides these uses in medicine, radiobiology research laboratories may also use them in irradiations of small animals or cells in culture media.

Although there is a limited number of centers employing these radiation qualities, as compared to other techniques based on the use of linear accelerators, it is very important to maintain a quality control program for these equipments. The quality control programs must include the periodic dosimetric measurements of their equipment. The most common ionization chamber types employed for this task are the cylindrical and parallel-plate ionization chambers, as recommended by the TG-61 protocol (Ma et al., 2001) and the IAEA TRS-398 report (IAEA TRS-398, 2000).

The calibration laboratory of the IPEN (LCI) offers calibration services of dosimeters utilized in diagnostic radiology, radiotherapy, including the T radiation qualities (BIPM, 2004) and beta applicators. In addition to these services, the LCI also develops and maintains some ionization chambers for dosimetry in radiotherapy and diagnostic radiology. Recently, a new pencil-type ionization chamber was developed to be used in dosimetry procedures of ^{60}Co beams (Neves, 2012). Although some tests were already made for the T-radiation qualities (Neves, 2012), such as saturation curve, ion collection efficiency and polarity effect, further analyses are needed in this energy range, as well as a more comprehensive understanding of the chamber components. This dosimeter has the

* Corresponding author. Tel.: +55 11 31339716; fax: +55 11 31339678.
E-mail addresses: lpneves@ipen.br, pereiraneves@gmail.com (L.P. Neves), aperini@ipen.br (A.P. Perini), jose@ecm.ub.edu (J.M. Fernández-Varea), vagner.cassola@gmail.com (V.F. Cassola), rkramer@uol.com.br (R. Kramer), hjkhoury@gmail.com (H.J. Khoury), lcaldas@ipen.br (L.V.E. Caldas).

0969-806X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radphyschem.2012.12.042

advantage of a small sensitive volume (with a diameter of approximately 7.2 mm), which is suitable for radiation dosimetry in radiotherapy. Moreover, this dosimeter presents a novel chamber design for this energy interval, and a new wall material—polyvinyl chloride (PVC).

In this work, the new dosimeter was submitted to a preliminary evaluation, following the IEC 60731 (2011) recommendations, utilizing very low-energy radiation fields. Furthermore, Monte Carlo simulations were carried out to evaluate the influence of some components of the ionization chamber in the addressed energy range. The main reason to undertake these simulations was to understand how this geometry would influence the energy deposition in the sensitive volume of the dosimeter. The influence of the collecting electrode, PMMA body, and wall (thickness and material) of the ionization chamber were studied using the Monte Carlo code EGSnrc (Kawrakow et al., 2011).

2. Materials and methods

The ionization chamber characterized in this work is shown in Fig. 1, with the scheme utilized during the simulations with the EGSnrc code. The technical specifications of the dosimeter are listed in Table 1.

The measurements have been carried out in air, and the majority of them were made with a Pantak/Seifert industrial X-ray unit, model ISOVOLT 160HS utilizing the radiation qualities established for radiotherapy (Table 2). These radiation qualities were established at the X-ray system employing a parallel-plate ionization chamber, PTW, model M2344, with traceability to the German primary standards laboratory Physikalisch-Technische Bundesanstalt (PTB). On the other hand, the stability test was made with a $^{90}Sr+^{90}Y$ check source and a special PMMA holder developed by Maia and Caldas (2003). The charge readings were taken with an electrometer (PTW, model UNIDOS E), and corrected to the standard environmental conditions of temperature and pressure because the ionization chamber is unsealed.

The EGSnrc user code (Kawrakow et al., 2011) has been used to evaluate the influence of the collecting electrode and the PMMA body on the ionization chamber readings. It was also employed for the calculations of the response of the ionization chambers with a wall of different thickness and different material (PVC was replaced by PMMA). The number of simulated histories was 10^9. The X-ray photon spectra were obtained from the PTB (Büermann, 2012), acquired in a 450 kV Yxlon-facility with a tube of type "MB450-1H450" from Thales, at a distance of 50.0 cm from the X-ray focus.

The uncertainties of all measurements obtained in this work are expanded uncertainties (combination of type A and B uncertainties for the experimental data, and type A for the simulations), using a coverage factor of 2.

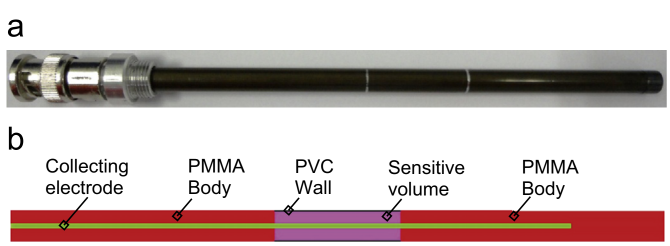

Fig. 1. (a) Pencil ionization chamber characterized in this work and (b) geometry adopted in the Monte Carlo simulations.

Table 1
Technical specifications of the pencil ionization chamber investigated in this work.

Characteristics	Specifications
Electrode material	Aluminum
Wall material	Graphite-coated PVC
Electrode thickness	1.2 mm
Chamber inner diameter	6.7 mm
Chamber wall thickness	0.26 mm
Chamber sensitive length	30.0 mm
Chamber sensitive volume	1.06 cm^3
Connector type	BNC

Table 2
BIPM based X-ray beam qualities for radiotherapy (BIPM, 2004) established at the LCI.

Radiation quality	Voltage (kV)	HVL (mm Al)[a]	$\dot{K}_{air}$ (mGy/s)[b]
T-25	25	0.279	2.76 ± 0.01
T-30	30	0.185	9.64 ± 0.04
T-50(a)	50	2.411	0.82 ± 0.01
T-50(b)	50	1.079	4.03 ± 0.02

[a] Half-value layer.
[b] Air kerma rate.

3. Results and discussion

To complete the performance tests of this ionization chamber, it was submitted to the stability and linearity of response tests. Moreover, a study of the influence of the chamber components on its measurements was carried out using Monte Carlo simulations.

3.1. Short- and long-term stability

This test was done having recourse to a special PMMA support and the radioactive check source. To assess the short-term stability, ten successive measurements were taken. The maximum variation obtained was 0.2%, within the recommended limit of 0.3% (IEC 60731, 2011). The long-term stability test was evaluated plotting the short-term stability test as a function of time (see Fig. 2(a)). As may be observed, the maximum variation was within the standard recommendation of 0.5% (IEC 60731, 2011).

3.2. Linearity of response

This test was performed varying the ionization current (2–25 mA) of the X-ray system to obtain different $\dot{K}_{air}$ values. The T-30 beam quality for radiotherapy (Table 2) was employed, and the ionization chamber was positioned at 50 cm from the X-ray tube focus. As expected, a linear fit of the chamber response versus $\dot{K}_{air}$ was obtained (Fig. 2(b)), and the uncertainty in the slope was only 0.01%, with a coefficient of correlation $R^2 = 0.999$.

3.3. Monte Carlo simulations

The Monte Carlo results were reported as the ratio between the absorbed dose calculated in the air cavity without the studied component and the absorbed dose calculated with the whole ionization chamber. The simulation results completed the characterization study of the ionization chamber evaluated in this work, as the influence of some components (collecting electrode, PMMA body and wall-material and thickness) may only be determined by Monte Carlo simulations.

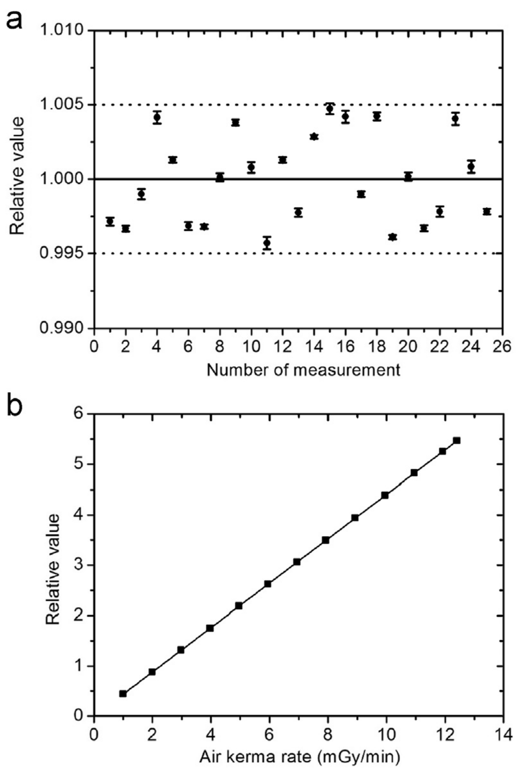

Fig. 2. (a) Stability test of the ionization chamber during a time period of 12 months. The dashed lines represent the maximum recommended aeration (IEC 60731, 2011) and (b) Linearity of response of the ionization chamber. The maximum uncertainty was 1% and therefore not visible in the figure.

Table 3
Influence of the collecting electrode and the PMMA body on the chamber response.

Radiation quality	Influence	
	Collecting electrode	PMMA body
T-25	0.4921 ± 0.0007	0.001 ± 0.001
T-30	0.4899 ± 0.0007	0.001 ± 0.001
T-50(a)	0.2845 ± 0.0011	0.004 ± 0.002
T-50(b)	0.4032 ± 0.0010	0.004 ± 0.001

These analyses were undertaken for the T radiation qualities listed in Table 2. The chamber parts evaluated were: collecting electrode, PMMA body and the thickness and material of the wall. The influences obtained are presented in Table 3 for the collecting electrode and PMMA body.

From the data listed in Table 3, it is possible to observe a large influence of the collecting electrode on the chamber response. This is due to the strong dependence of the photoelectric cross-section on the atomic number in the examined X-ray energy interval. As shown in the literature (Muir and Rogers , 2011), some dosimeters presented also an electrode effect of up to 50% for X-ray beams generated by tube potential of 200 kVp. The influence of the PMMA body is small, mainly because the only contribution to the sensitive volume is from the scattered radiation. This fact was also verified for other energy ranges using similar ionization chambers (Neves et al., accepted for publication; Perini et al., accepted for publication).

The wall was studied considering its thickness and material. The PVC wall thickness was varied between 0.2 mm and 0.36 mm (with the standard T radiation quality T-30). The maximum variation on the dose in the cavity was 15%. This is mainly due to the attenuation of the beam in the wall. It is very important to note that a thinner layer could make the dosimeter less robust, since it would have a very fragile wall. Furthermore, the substitution of the PVC wall by a PMMA wall, normally used in ionization chambers developed for diagnostic radiology dosimetry, would present a difference of only 1.4%. This small difference shows that this new wall material is also suitable to be used in this energy range.

4. Conclusion

The special pencil ionization chamber developed at the LCI was submitted to various tests in order to evaluate it as a dosimeter in very low-energy radiotherapy X-ray beams. The results were all within the recommended limits. The Monte Carlo analyses showed that the influences of the chamber components are all in accordance with data available in the literature, indicating that this new chamber design may be another option for dosimetry of very low energy X-rays at calibration laboratories. These laboratories normally use parallel plate ionization chambers, with entrance windows made of Mylar. It is also important to note that the tests undertaken in this work followed IEC 60731 (2011) and that further tests are still needed, as recommended by the TG-61 protocol (Ma et al., 2001) and by the IAEA TRS-398 report (IAEA TRS-398, 2000).

Acknowledgments

The authors would like to thank Dr. L. Büermann (PTB, Germany) for kindly providing the spectra of the X-ray machine used in this work. The authors also thank the Brazilian agencies FAPESP, CNEN, CNPq, CAPES and MCT: Project INCT for Radiation Metrology in Medicine for the partial financial support.

References

BIPM, 2004. Measuring conditions used for the calibration of ionization chambers at the BIPM, BIPM-04/17, Sèvres.
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.
IAEA TRS-398, 2000. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water, TRS-398, Vienna.
IEC 60731, 2011. Medical electrical equipment—dosimeters with ionization chambers as used in radiotherapy, IEC 60731, Geneva.
Kawrakow, I., Mainegra-Hing, E., Rogers, D.W.O., Tessier, F., Walters, B.R.B., 2011. The EGSnrc code system: Monte Carlo simulation of electron and photon transport, NRCC Report PIRS-701, Ottawa.
Klevenhagen, S.C., Aukett, R.J., Harrison, R.M., Moretti, C.J., Nahum, A.E., Rosser, K.E., 1996. IPEMB code of practice for the determination of absorbed dose for X-rays below 300 kV generating potential (0.035 mm Al–4 mm Cu HVL; 10–300 kV generating potential). Phys. Med. Biol. 41, 2605–2625.
Ma, C.-M., Coffey, C.W., Dewerd, L.A., Liu, C., Nath, R., Seltzer, S.M., Seuntjens, J.P., 2001. AAPM protocol for 40–300 kV X-ray beam dosimetry in radiotherapy and radiobiology. Med. Phys. 28 (6), 868–892.
Maia, A.F., Caldas, L.V.E., 2003. Performance of a pencil ionization chamber in various radiation beams. Appl. Radiat. Isot. 58 (5), 595–601.
Muir, B.R., Rogers, D.W.O., 2011. The central electrode correction factor for high-Z electrodes in small ionization chambers. Med. Phys. 38 (2), 1081–1088.
Neves, L.P., 2012. Characterization of a homemade ionization chamber for radiotherapy beams. Appl. Radiat. Isot. 70 (7), 1291–1295.
Neves, L.P., Perini, A.P., Fernández-Varea, J.M., Caldas, L.V.E. Application of a pencil ionization chamber (0.34 cm^3 volume) for ^{60}Co beams: experimental and Monte Carlo results. IEEE Trans. Nucl. Sci. http://dx.doi.org/10.1109/TNS.2012.2229294, in press.
Perini, A.P., Neves, L.P., Fernández-Varea, J.M., Büermann, L., Caldas, L.V.E. Evaluation and simulation of a new ionization chamber design for use in computed tomography beams. IEEE Trans. Nucl. Sci. http://dx.doi.org/10.1109/TNS.2012.2233752, in press.