Applied Radiation and Isotopes 70 (2012) 1300–1303

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

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

Characterization of a CT ionization chamber for radiation field mapping

Ana P. Perini [a], Lucio P. Neves [a], Vitor Vivolo [a], Marcos Xavier [a], Helen J. Khoury [b,1], Linda V.E. Caldas [a,*]

[a] Instituto de Pesquisas Energéticas e Nucleares (IPEN-CNEN), Comissão Nacional de Energia Nuclear, Av. Prof. Lineu Prestes 2242, 05508-000, São Paulo, SP, Brazil
[b] Universidade Federal de Pernambuco, Departamento de Energia Nuclear, Av. Prof. Luiz Freire 1000, 50740-540, Recife, PE, Brazil

ARTICLE INFO

Available online 30 November 2011

Keywords:
Pencil ionization chamber
Standard X-rays beams
Radiation field mapping

ABSTRACT

A pencil-type ionization chamber, developed at Instituto de Pesquisas Energéticas e Nucleares (IPEN), was characterized with the objective to verify the possibility of its application in radiation field mapping procedures. The characterization tests were evaluated, and the results were satisfactory. The results obtained for the X radiation field mapping with the homemade chamber were compared with those of a PTW Farmer-type chamber (TN 30011-1). The maximum difference observed in this comparison was only 1.25%, showing good agreement.

1. Introduction

Ionization chambers are dosimeters widely used for measurements of air kerma and absorbed dose at hospitals and radiation metrology laboratories. There are several types of ionization chambers for different applications. For example, one type of chamber commonly used in computed tomography (CT) dosimetric measurements is the pencil-type ionization chamber. This chamber presents a special design and some particular properties. It has a cylindrical geometric shape with a sensitive length of 10 cm and a sensitive volume of approximately 3 cm^3 in most cases (Suzuki and Suzuki, 1978).

In Brazil, there is an increasing interest in the development of ionization chambers and other radiation detectors, because there are difficulties in importing and servicing them. In order to construct low cost ionization chambers as an alternative for use at laboratories for calibration and dosimetric measurements, some ionization chambers were developed at the Calibration Laboratory of IPEN (LCI) for use in diagnostic radiology and radiotherapy energy ranges (Albuquerque and Caldas, 1989; Costa and Caldas, 2003; Oliveira and Caldas, 2007; Yoshizumi and Caldas, 2010).

In this work a pencil ionization chamber was developed for a different application than the dosimetry in CT; the pencil ionization chamber was tested for diagnostic radiology calibration beam mapping. This ionization chamber differs from other commercial pencil ionization chambers mainly due to its volume and constituent materials. The sensitive volume of this chamber is only 1.0 cm length instead of the usual 10.0 cm of commercial pencil ionization chambers, and only Brazilian low cost materials were used for its construction.

The beam mapping is an important step to assure a reliable calibration procedure. This test is required, because it allows the verification of the homogeneity level in the radiation field, and therefore, it will indicate if there is any irregularity in the radiation field caused, for example, by setup changes of the radiation system.

Several services are offered at the LCI, such as calibration services of radiation detectors for X radiation, using an industrial X-ray unit. In order to offer reliable services to customer, measurements are periodically taken to evaluate the radiation beam homogeneity. Observing this need, a small ionization chamber of sensitive volume of 0.34 cm^3 was studied to evaluate the field homogeneity of standard diagnostic radiology beam qualities established in the industrial X-ray unit at LCI. The main quality control tests to characterize this ionization chamber were: saturation curve, polarity effects, ion collection efficiency, stabilization time, short- and medium-term stabilities, leakage current, linearity of response, angular dependence and energy dependence in standard diagnostic radiology calibration beams.

2. Materials and methods

A new pencil ionization chamber, developed at IPEN, was manufactured using polymethyl methacrylate (PMMA), polyvinyl chloride (PVC) coated with graphite, aluminum electrode and coaxial cables. The sensitive volume is delimited by the PVC cylinder, coated with a thin layer of graphite, connected with two other cylinders of PMMA. Since this is a vented ionization chamber, a small hole was made in the PVC cylinder. To attach the

* Corresponding author. Tel.: +55 11 3133 9716; fax: +55 11 3133 9671.
E-mail addresses: aperini@ipen.br (A.P. Perini), lpneves@ipen.br (L.P. Neves), vivolo@ipen.br (V. Vivolo), mxavier@ipen.br (M. Xavier), hjkhoury@gmail.com (H.J. Khoury), lcaldas@ipen.br (L.V.E. Caldas).
[1] Tel./fax: +55 81 21 268708.

0969-8043/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apradiso.2011.11.051

PVC and PMMA, a small quantity of special glue, made with silver, was used. This glue was also used as electrical contact. The photo and the detail of the sensitive volume of the homemade ionization chamber manufactured in this work are shown in Fig. 1.

The aluminum electrode is connected directly to the BNC connector, at the extremity of the ionization chamber, and it is maintained at the center of the sensitive volume due to the PMMA cylinders. Aluminum was utilized as collecting electrode material due to its high electrical conductivity and mechanical resistance. The sensitive volume of this ionization chamber has 10.00 mm length and 6.78 mm internal diameter. The thickness of the PVC cylinder and aluminum electrode is 0.26 mm and 1.20 mm, respectively.

The PVC material was used in the sensitive volume due to its chemical resistance during the graphite coating process. The PMMA cylinders with the same thickness presented some cracks, after the deposition of the graphite layer, which was not seen at the PVC cylinder. All these materials are easy to obtain at the Brazilian market, and they present low cost. Besides that, the PVC, PMMA and aluminum are easy to obtain in various sizes and shapes commercially, and they are simple for machining, requiring no special apparatus or techniques.

During all measurements the ionization chamber was connected to an electrometer, model UNIDOS E, Physikalisch-Technische Werkstätten (PTW) Freiburg, Germany, and all measurements were corrected to the standard values of environmental temperature and pressure.

For the characterization tests, an industrial X-ray unit, Pantak Seifert, model ISOVOLT 160HS, that operates from 5 to 160 kV, was utilized. The tests were performed using the standard diagnostic radiology beam qualities defined by the International Electrotechnical Commission, IEC 61267 (IEC, 2005). The parameters of those qualities are listed in Tables 1 and 2. The reference system for the established diagnostic radiology qualities in this equipment was a PTW parallel plate ionization chamber, model 77334. The reference system used for the standard computed tomography qualities was a RADCAL pencil ionization chamber, model RC3CT. Both reference systems described above have traceability to the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB).

A $^{90}Sr+^{90}Y$ check source device, PTW, model 8921, with nominal activity of 33 MBq, 1994, was utilized for the stability tests. For the angular dependence test a goniometer, OPTRON, model GN1 200 was also utilized.

In order to compare the results obtained in the radiation field mapping, a commercial ionization chamber, PTW Farmer-type (TN 30011-1), was also utilized. The sensitive volume of this ion chamber was 0.6 cm^3.

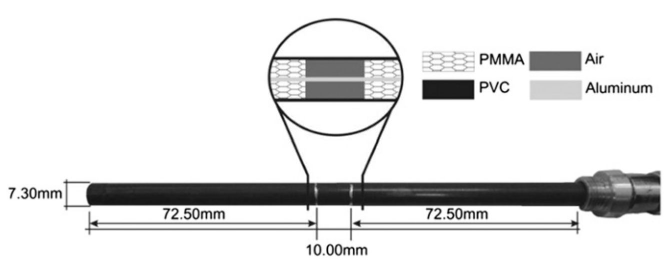

Fig. 1. Photo and detail of the sensitive volume of the homemade ionization chamber developed.

Table 1
Standard diagnostic radiology qualities at the Pantak/Seifert X-ray equipment, using a constant tube current of 10 mA.

Radiation Quality	Voltage (kV)	Additional filtration (mmAl)	Half-value layer (mmAl)	Air kerma rate (mGy/min)
RQR 3	50	2.40	1.78	21.60 ± 0.18
RQR 5	70	2.80	2.58	37.88 ± 0.32
RQR 8	100	3.20	3.97	67.45 ± 0.54
RQR 10	150	4.20	6.57	120.01 ± 1.02

Table 2
Standard computed tomography qualities at the Pantak/Seifert X-ray equipment, using a constant tube current of 10 mA.

Radiation Quality	Voltage (kV)	Additional filtration	Half-value layer (mmAl)	Air kerma rate (mGy/min)
RQT 8	100	3.2Al+0.30Cu	6.90	22.0 ± 0.33
RQT 9	120	3.5Al+0.35Cu	8.40	34.0 ± 0.51
RQT 10	150	4.2Al+0.35Cu	10.1	57.0 ± 0.86

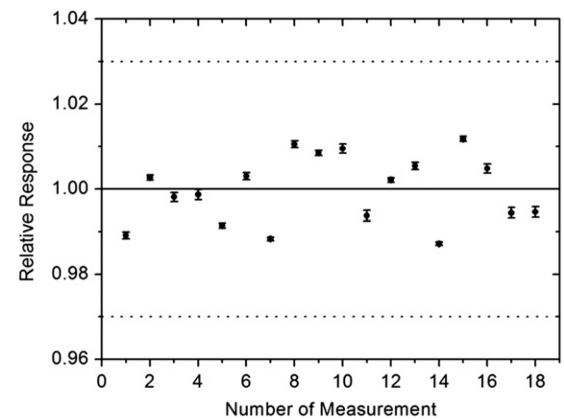

Fig. 2. Medium-term stability of the homemade ionization chamber developed during a period of two months. The dotted lines represent the recommended limits.

3. Results and discussion

The operational characterization tests of the homemade ion chamber studied were: short- and medium-term stabilities (measurements taken over a period of two months), saturation curve, ion collection efficiency, polarity effect, stabilization time, leakage current, linearity of response, and angular and energy dependence.

3.1. Short- and medium-term stabilities

The chamber response was tested in relation to its stability (short- and medium-term stabilities). The homemade chamber was repeatedly exposed to a check source under reproducible geometric conditions. A $^{90}Sr+^{90}Y$ check source was utilized, and it was positioned at an acrylic support described by Maia and Caldas (2003).

The short-term stability test was obtained by ten readings of charge, during time intervals of 60 s and using a voltage of +100 V. The highest variation coefficient obtained was 0.7%. According to the international recommendations IEC (1997a), the maximum acceptable coefficient of variation is 1% for CT specific chambers.

The medium-term stability test was obtained by taking the medium value of ten measurements of the short-term stability tests during a period of two months (Fig. 2). In Fig. 2, the relative response on the *y*-axis represents the ratio between the ionizing current measurements and the mean value of the eighteen measurements. According to IEC (1997a), the value obtained in each test must not differ from the reference value by more than 3%. As shown in Fig. 2, all deviations were within the acceptable range.

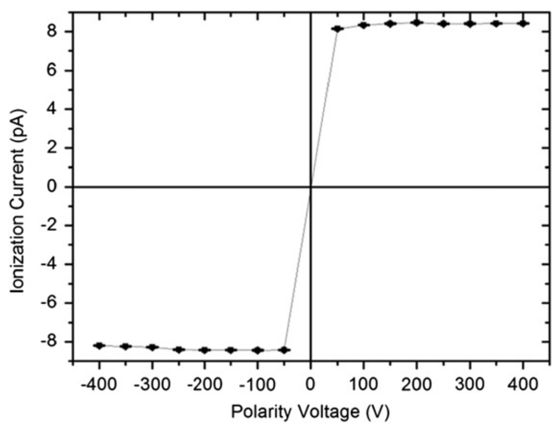

Fig. 3. Saturation curve of the homemade ionization chamber developed, for the RQT 9 diagnostic radiology quality beam.

3.2. Saturation, ion collection efficiency and polarity effect

The saturation curve test determines the optimal voltage for the ionization chamber operation. A saturation curve (Fig. 3) was obtained varying the voltage from −400 V to +400 V, in steps of 50 V, using the charge collecting time of 15 s. This test was performed using the diagnostic quality beam RQT 9. For all applied voltage values, no significant changes in the collected charge were observed. The chosen applied voltage for the homemade ion chamber was +100 V.

From the saturation curve two other characteristics were analyzed: the polarity effect and ion collection efficiency.

The polarity effect should be determined by comparing the collected charges at similar voltages of opposite signal. For all pair of voltage values in the saturation test, the polarity effect did not exceed the recommended limit of 1% by IEC (1997b). The highest value obtained in this test was 0.87%.

The ion collection efficiency was obtained taking into consideration the collected charges and the two polarity voltages method, given by the following equation (IAEA, 2001):

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

where M_x is the collected charge at a V_x voltage, 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. This result presents agreement with the value of 5% of ionic recombination losses, recommended by IEC (1997a).

3.3. Stabilization time test

For the stabilization time test, the check source was positioned at the same acrylic support utilized in the stability tests, and the ionization chamber was connected to the electrometer, in the operating voltage of +100 V. The ionization current was measured after 15, 30, 60 and 120.0 min.

The ionization current obtained 15 min after switching on the measuring system is 99.7% of the stabilization current obtained after 60 min. This result is within the recommended limits of ±2% of response variation (IEC, 1997a).

3.4. Leakage current

The leakage current of the ionization chamber was measured in time intervals of 20 min, after its irradiation at the RQT 9 radiology quality beam, and the maximum value obtained was 0.07% of the ionization current produced at the minimum air kerma rate produced in this work. This value is within the limit recommended internationally (IEC, 1997a).

3.5. Linearity of response

In the linearity of response test, the homemade ion chamber was exposed to several different air kerma rates. The nominal current was varied between 2 and 25 mA, at the constant voltage of 120 kV, to provide different air kerma rates that were determined using the reference system calibrated for the RQT 9 quality beam. A linear fit of the chamber response versus air kerma rate was obtained, and the uncertainty in the angular coefficient was only 0.01%, with a correlation coefficient R^2 of 0.9999%.

3.6. Angular dependence

In the angular dependence test, the ionization chamber was rotated around its central axis from −180° to +180°, in steps of 30°. This test was performed using the diagnostic radiology quality beam RQT 9. By the IEC 61674 recommendations (IEC, 1997a), the value obtained in each angle must not differ from the 0° position by more than 3%. The maximum variation obtained was only 0.9%. These results show that the homemade ionization chamber presents results within the recommended international limits (IEC, 1997a).

3.7. Calibration and energy dependence

The energy variation in response of the homemade ion chamber of standard computed tomography and conventional radiology X ray ranges (direct beams) was studied using the radiation qualities given in Tables 1 and 2. The ionization chamber was calibrated against the reference systems, a PTW parallel plate ionization chamber, model 77334, for diagnostic radiology beams and a RADCAL pencil ionization chamber, model RC3CT, for computed tomography beams. Table 3 shows the calibration coefficients and the correction factors obtained. The energy dependence obtained in the direct beams was 3.0%. For the tomography beams, the energy dependence obtained was 1.2%.

3.8. Radiation field mapping

The radiation field mapping was obtained using the diagnostic quality beam RQT 9. Steps of 1.00 cm for both vertical and horizontal directions were utilized, and 10 measurements were taken for each position. The results for the horizontal and vertical directions are shown in Figs. 4 and 5, respectively. In these Figures the relative response on the *y*-axis represents the ionizing current measurements normalized by the current measured at the 0° position (radiation field center).

Table 3
Calibration coefficients and correction factors of the homemade ionization chamber in conventional radiology (RQR qualities) X-ray and standard computed tomography (RQT qualities) beams.

Radiation Quality	Half-value layer (mmAl)	Calibration coefficients (mGy/pC)	Correction factors
RQR 3	1.78	0.0706 ± 0.0006	0.9967 ± 0.0118
RQR 5	2.58	0.0709 ± 0.0006	1.0000 ± 0.0119
RQR 8	3.97	0.0696 ± 0.0005	0.9814 ± 0.0114
RQR 10	6.57	0.0717 ± 0.0006	1.0108 ± 0.0121
RQT 8	6.90	0.0759 ± 0.0011	0.9899 ± 0.0209
RQT 9	8.40	0.0767 ± 0.0011	1.0000 ± 0.0212
RQT 10	10.1	0.0768 ± 0.0011	1.0016 ± 0.0213

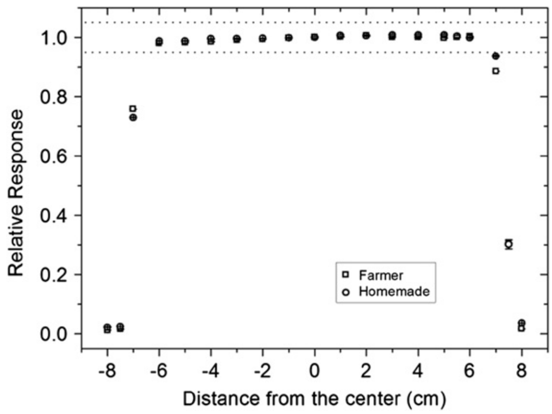

Fig. 4. Mapping of the standard X-ray radiation field in the horizontal direction with the homemade and PTW Farmer-type ionization chambers. The dotted lines represent the limits of the radiation field definition.

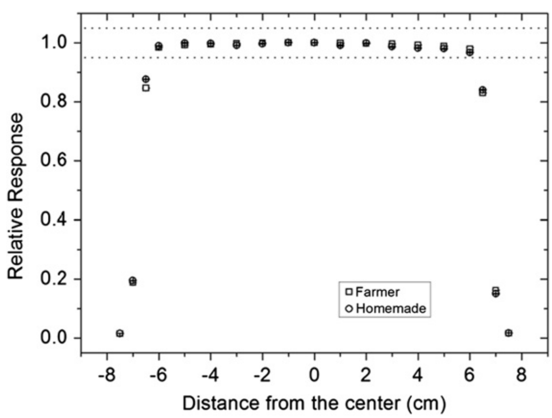

Fig. 5. Mapping of the standard X-ray radiation field in the vertical direction with the homemade and PTW Farmer-type ionization chambers. The dotted lines represent the limits of the radiation field definition.

The radiation field is defined by the position where the radiation detector response is approximately 95% of the measured value in the radiation field center (ISO 4037-1, 1996). Observing the results obtained, the radiation field was defined with the following dimensions: 12.0 cm in the horizontal direction and 12.0 cm in the vertical direction. It is possible to observe that in both directions the field maintains approximately the same behavior in the positive and negative directions.

Comparing the homemade and the PTW Farmer-type ion chambers in terms of the field mapping of the standard X-ray radiation beam, the maximum difference obtained, in a homogeneous radiation field, was 0.98% in the horizontal direction and 1.25% in the vertical direction, as shown in Figs. 4 and 5, respectively. These satisfactory results show that the ion chamber developed presents an excellent performance for radiation field mapping.

4. Conclusions

In this work, a new pencil ionization chamber was designed, assembled and tested. The main motivations for the development of this chamber were its low cost construction and the possibility of its application at calibration laboratories. Several operational characteristics of this chamber were evaluated and compared to international recommended limits. The pre-operational tests realized: saturation, polarity effects, ion collection efficiency, stabilization time, short- and medium-term stability, leakage current, linearity of response, angular and energy dependence achieved the expected results. The results obtained in the radiation field mapping with the homemade ion chamber were also satisfactory, when compared with those of a commercial ionization chamber. Therefore, the ionization chamber constructed and characterized in this work presents an excellent potential use in quality control programs and for assuring reliability in calibration procedures.

Acknowledgments

The authors acknowledge the Brazilian agencies CNEN, CAPES, CNPq, FAPESP, MCT: Project INCT for Radiation Metrology in Medicine, and MRA Electronic Equipment Industry for their partial financial support.

References

Albuquerque, M.P.P., Caldas, L.V.E., 1989. New ionization chambers for beta and X radiation. Nucl. Instrum. Methods Phys. Res. A 280, 310–313.

Costa, A.M., Caldas, L.V.E., 2003. A special ionization chamber for quality control of diagnostic and mammography X -ray equipment. Radiat. Prot. Dosim. 104, 41–45.

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. International Atomic Energy Agency, Vienna.

IEC, 1997a. Medical Electrical Equipment-Dosimeters With Ionization Chambers and/or Semi-Conductor Detectors as Used in X-ray Diagnostic Imaging. IEC 61674. International Electrotechnical Commission, Genève.

IEC, 1997b. Medical Electrical Equipment-Dosimeters with Ionization Chambers as Used in Radiotherapy. IEC 60731. International Electrotechnical Commission, Genève.

IEC, 2005. Medical Diagnostic X-ray Equipment—Radiation Conditions for Use in the Determination of Characteristics. IEC 61267. International Electrotechnical Commission, Genève.

ISO 4037-1, 1996. X and Gamma Reference Radiation for Calibrating Dosimeters and Doserate Meters and for Determining Their Response as a Function of Photon Energy—Part 1: Radiation Characteristics and Production Methods, Genève.

Maia, A.F., Caldas, L.V.E., 2003. Performance of a pencil ionization chamber in various radiation beams. Appl. Radiat. Isot. 58, 595–601.

Oliveira, M.L., Caldas, L.V.E., 2007. Performance of a prototype of na extrapolation minichamber in various radiation beams. Appl. Radiat. Isot. 65, 975–979.

Suzuki, A., Suzuki, M.N., 1978. Use of a pencil-shaped ionization chamber for measurement of exposure resulting from a computed tomography scan. Med. Phys. 5 (6), 536–539.

Yoshizumi, M.T., Caldas, L.V.E., 2010. A new ring-shaped graphite ionization chamber. Nucl. Instrum. Methods Phys. Res. A 619, 210.