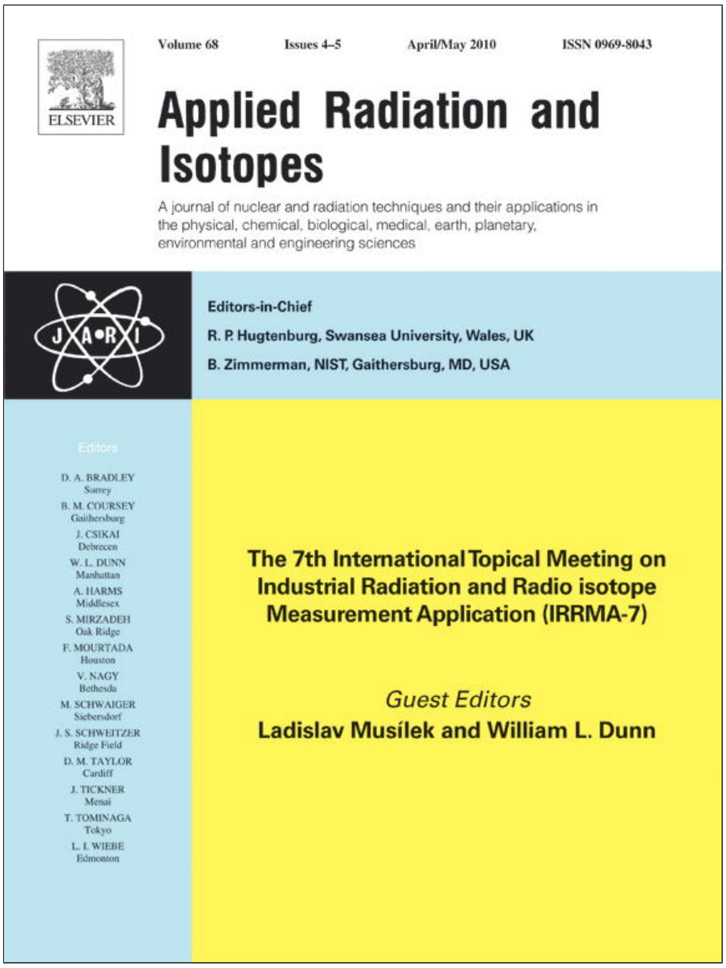
Volume 68
Issues 4–5
April/May 2010
ISSN 0969-8043
ELSEVIER
Applied Radiation and Isotopes
A journal of nuclear and radiation techniques and their applications in the physical, chemical, biological, medical, earth, planetary, environmental and engineering sciences
JARI
Editors-in-Chief
R. P. Hugtenburg, Swansea University, Wales, UK
B. Zimmerman, NIST, Gaithersburg, MD, USA
Editors
D. A. BRADLEY Surrey
B. M. COURSEY Gaithersburg
J. CSIKAI Debrecen
W. L. DUNN Manhattan
A. HARMS Middlesex
S. MIRZADEH Oak Ridge
F. MOURTADA Houston
V. NAGY Bethesda
M. SCHWAIGER Siebersdorf
J. S. SCHWEITZER Ridge Field
D. M. TAYLOR Cardiff
J. TICKNER Menai
T. TOMINAGA Tokyo
L. I. WIEBE Edmonton
The 7th International Topical Meeting on Industrial Radiation and Radio isotope Measurement Application (IRRMA-7)
Guest Editors
Ladislav Musílek and William L. Dunn

Applied Radiation and Isotopes 68 (2010) 610–613

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

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

Characteristics of a tandem system of ionization chambers in X-ray beams, mammography level

L.C. Afonso *, V. Vivolo, L.V.E. Caldas

Instituto de Pesquisas Energéticas e Nucleares (IPEN–CNEN), Comissão Nacional de Energia Nuclear, Av. Prof. Lineu Prestes 2242, 05508-000 São Paulo, SP, Brazil

A R T I C L E I N F O

Keywords:
Ionization chamber
Calibration
Tandem system

A B S T R A C T

Two parallel plate ionization chambers (inserted in slab phantoms) recently assembled at IPEN were studied in relation to their operational characteristics for use in quality control of X-ray beams, mammography level. The chambers present only one difference: one has an inner collecting electrode made of graphite and the other, of aluminum. These chambers make up a tandem system, which may be employed to verify X-ray beams energy constancy, by the confirmation of half-value layers and effective energies, and to determinate air kerma rates. The chambers presented good results for the operational tests, as recommended internationally.

1. Introduction

To avoid health damage for workers, patients and the general public that are submitted to diagnostic radiology procedures and radiotherapy treatments is achieved by keeping radiation use under acceptable (and/or controllable) limits.

For this reason, it is advisable to know very well the beams characteristics before their utilization at radiotherapy and radiation diagnostic clinics, and laboratories for radiation detectors calibration. A quality control program for diagnostic radiology and radiotherapy procedures may optimize the dose application to the patient and improve the accuracy in determining the related absorbed doses.

Regarding this subject, the International Atomic Energy Agency has published some recommendations and procedures related to the calibration of both radiation beams and radiation detectors (IAEA, 2000a, b), and the determination of absorbed doses using different types of instruments and radiations.

Some papers have been published on the design and the construction of ionization chambers depending on each application (Ankerhold et al., 1999; Albuquerque and Caldas, 1989; Costa and Caldas, 2003b; Maia and Caldas, 2005). These authors have taken into account the international recommendations related to the ionization chambers performance, and they also aim easy procedures for routine data acquisition.

At the radiation metrology group of IPEN some parallel plate ionization chambers were developed for detection of X-rays (Albuquerque and Caldas, 1989; Costa and Caldas, 2003 a,b; Maia and Caldas, 2005).

Ankerhold et al. (1999) developed the first prototype of a parallel plate ionization chamber as a secondary standard system, optimized to achieve a nearly constant response for personal dose equivalent measurements in a phantom. Vivolo (2006) extended this work by assembling two similar ionization chambers, however, with one difference: one ionization chamber has the inner collecting electrode made of graphite and the other has the inner collecting electrode made of aluminum.

The similar ionization chambers with different inner collecting electrode materials make up a tandem system, which consists of two dosimetric systems with different energy dependence that allows the determination of characteristics as the effective energy and air kerma rates of X-ray beams. The tandem system also allows the confirmation of the half-value layers or effective energies in X radiation beams, previously determined by the conventional method using well known absorber layers. The tandem system is a very simple measurement system: it is only necessary to study the ratio of the dosimeter responses obtained in X-ray beams to verify their effective energy constancy.

These ionization chambers were initially assembled to be used as work standard systems for calibration at radioprotection level, and this objective has been achieved successfully (Vivolo, 2006). In this work, the main objective was to verify the operational characteristics of those ionization chambers to establish a control quality program to be applied in X-ray beams, mammography level used in calibration procedures of ionization chambers.

2. Materials and methods

Two parallel plate ionization chambers inserted in slab phantoms (with dimensions of $30 \times 30 \times 15\,cm^3$), assembled at IPEN, with different inner collecting electrode materials (graphite

* Corresponding author. Tel./fax: +55 11 31339716
E-mail address: lafonso@ipen.br (L.C. Afonso).

0969-8043/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apradiso.2009.10.045

and aluminum), both with sensitive volumes of 10 cm^3, were coupled to a PTW electrometer (model Unidos) that allows the variation of the polarization voltage from −400 to +400 V. Mammography systems use X-ray tubes with different kinds and combination of targets and additional filtration, as: Mo/Mo; Mo/Rh; Rh/Rh and W/Rh. The use of each kind of combination (target plus filter) depends on the application, imaging system used and the structure and dimensions and each kind of breast (size, shape, etc.). In this paper an X-ray system, with a Rigaku Denki generator, coupled to a Philips tube (W target), model PW 2184/00, with 1 mm of beryllium window, and a filter of Mo (0.06 mm), was added for direct beams measurements, and an Al (2 mm) filter was added for attenuated beams. The characteristics of the standard beams (direct and attenuated) are presented in Table 1. A Radcal measuring system, model 9015; with ionization chamber, model 10 × 5–6 M, with sensitive volume of 6 cm^3, was the reference detector system in this study.

3. Results and discussion

The ionization chamber behaviors were studied in relation to their saturation curves, ion collection efficiencies, polarity effects and linearity of response due to air kerma variation, following international recommendations (IEC, 1997a; IEC, 1997b; IAEA, 2000a).

3.1. Saturation curves

The ionization chambers assembled at IPEN were positioned successively, with the ionization chambers sensitive volume centers as reference, perpendicularly to the incident radiation beam, at 1 m from the X-rays tube focal spot. Varying the polarization voltage in steps of 50 V (from −400 to +400 V), the ionization chambers were irradiated in the mammography X-rays beams produced with the tube potential of 35 kV and current of 30 mA. Sets of ten consecutive ionizing current readings were taken at each polarization voltage value. The uncertainties presented by the reading sets did not exceed ±0.15% for both chambers. Afterwards, the saturation curves were plotted for both ionization chambers, shown in Fig. 1. They show an adequate behavior, with the saturation achieved immediately above 50 V. This result shows that these ionization chambers can be used with the most common electrometers, with polarization voltages above 50 V.

3.2. Ion collection efficiency

From the data obtained from saturation tests, the ion collection efficiency was determined for each ionization chamber. The polarization voltages of 200 and 400 V (positive and negative) were used for the calculation (method of two voltages, IEC, 1997a; IAEA, 2000a) by the equation

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

where M_1 and M_2 are the ionization currents measured at the polarization voltages V_1 and V_2=V_1/2. The ion collection efficiency determined by this method was better than 99.9% for both ionization chambers, for negative and positive polarization voltages, as shown in Table 2. This result demonstrates that the losses by ionic recombination are below 1%, as recommended by IEC, 1997a and IAEA, 2000a.

3.3. Polarity effects

Sometimes the charge collected by an ionization chamber changes when the polarity voltage is inverted. The polarity effect shall be lower than 1% (IEC, 1997a; IEC, 1997b). It means that the ratio between the charges collected with maximum voltage values (positive and negative) may vary from 0.99 to 1.01. The ionization chamber with graphite collecting electrode presented polarity effect results within the recommended range for all polarization voltage values (Table 3). The ionization chamber with aluminum electrode presented polarity effect results within this range for most polarization voltage values; the polarity effect for 50 and 100 V presented results slightly out of the recommended range, not resulting in a problem, once the operational polarization

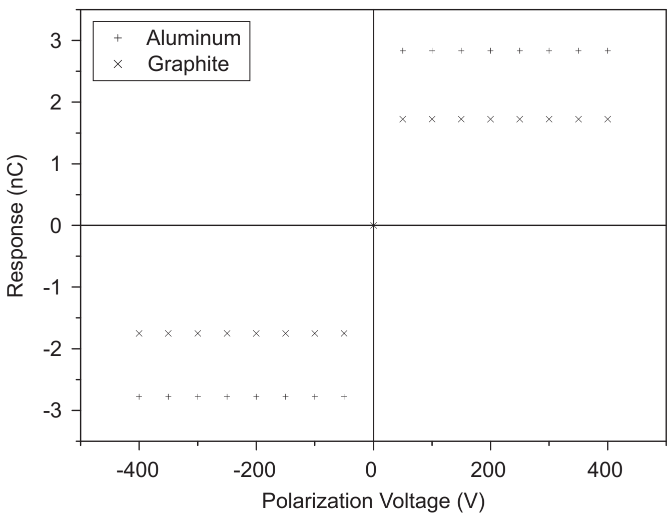

Fig. 1. Saturation curve for the ionization chambers with inner collecting electrode made of aluminum, and collecting electrode made of graphite.

Table 1
Characteristics of the Rigaku–Denki X-rays system at mammography level.

Radiation quality	Tube potential (kV)	Half-value layer (mmAl)	Air kerma rate (mGy min^{-1})	Calibration coefficient (aluminum) × 10^5 (Gy/C)	Calibration coefficient (graphite) × 10^5 (Gy/C)
M 25	25	0.33	32.9 ± 1.9	57.8 ± 3.4	87.4 ± 5.3
M 28	27.5	0.34	39.3 ± 2.3	56.3 ± 3.3	84.6 ± 5.1
M 30	30	0.35	45.1 ± 2.7	54.3 ± 3.2	82.1 ± 4.9
M 35	35	0.38	59.5 ± 3.6	49.2 ± 2.9	75.8 ± 4.6
M 25 ×	25	0.58	1.46 ± 0.08	35.4 ± 2.1	58.0 ± 3.5
M 28 ×	27.5	0.61	2.02 ± 0.12	32.1 ± 1.9	52.4 ± 3.1
M 30 ×	30	0.67	2.78 ± 0.16	29.2 ± 1.7	49.5 ± 3.0
M 35 ×	35	0.85	4.70 ± 0.33	21.9 ± 1.3	42.5 ± 2.6

The tube current was 30 mA, and the radiation qualities with suffix " × " represent attenuated beams.

Table 2
Ion collection efficiency of both ionization chambers for mammography level beam (35 kV).

Ionization chamber with inner collecting electrode made of	Ion collection efficiency	
	Positive polarization voltage	Negative polarization voltage
Aluminum	1.0004	1.000 06
Graphite	0.9996	0.9994

Table 3
Polarity effect of the ionization chambers response with inner collector electrodes made of graphite or aluminum.

Polarization voltage (V)	Ratio (Q+/Q−) (graphite inner electrode)	Ratio (Q+/Q−) (aluminum inner electrode)
+50/−50	1.009	1.0124
+100/−100	1.006	1.0108
+150/−150	1.005	1.0097
+200/−200	1.005	1.0095
+250/−250	1.005	1.0093
+300/−300	1.006	1.0093
+350/−350	1.005	1.0104
+400/−400	1.005	1.0108

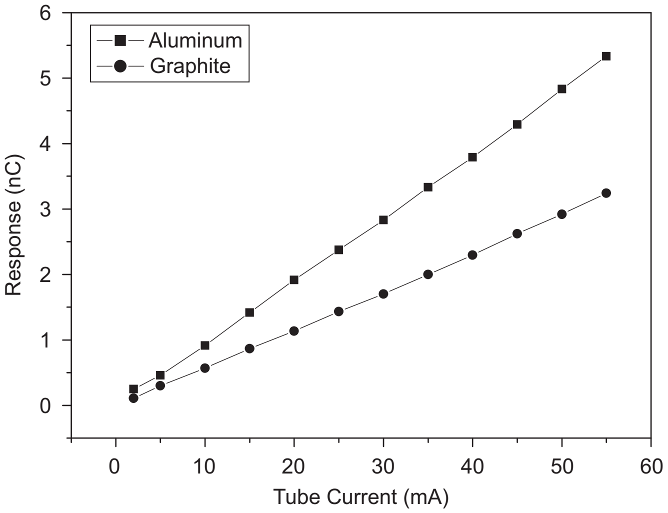

Fig. 2. Linearity of the response of the ionization chamber with inner collecting electrode made of aluminum, and collecting electrode made of graphite versus X-rays tube current. Tube potential: 35 kV (M35).

voltages are usually higher than 200 V (Table 3). The operational voltage was chosen to be 400 V for both ionization chambers.

3.4. *Linearity of the ionization chamber response*

The ionization chamber response due to air kerma rate change was studied by varying the current at the X-rays tube between 2 and 55 mA, at the tube potential of 35 kV. The polarization voltage of 400 V was utilized. Sets of ten consecutive readings were taken at each current value. Both ionization chambers showed the expected results, presenting a linear behavior in function of the tube current, as shown in Fig. 2. The uncertainties presented by the reading sets did not exceed ±1.5% for both chambers. It means also that the X-ray generator system presented a stable behavior.

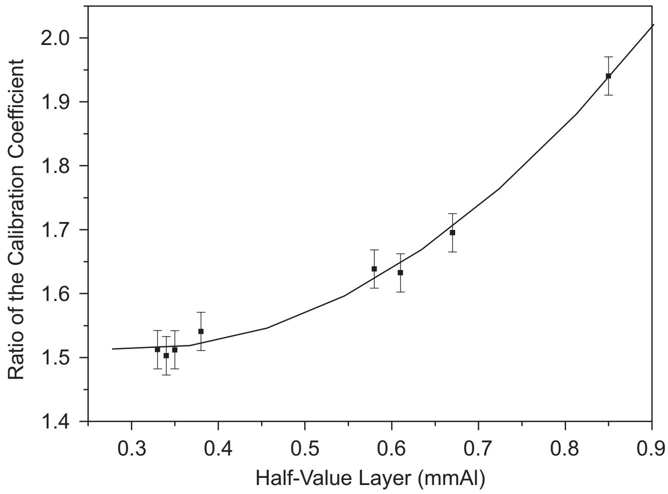

Fig. 3. Tandem curve for X-ray beams, mammography level, direct and attenuated beams, of the ionization chambers with inner collecting electrodes of aluminum and graphite.

3.5. *Energy dependence*

The ionization chambers were irradiated at 1 m from the focal spot of the X-rays tube. The air kerma calibration coefficients were determined using the measurements obtained with the secondary standard ionization chamber, Radcal 9015, model 10 × 5–6 M. The obtained calibration coefficients are listed in Table 1.

3.6. *Tandem system formation*

The tandem system was formed by determining the ratio of the responses of the ionization chambers. The tandem curve for the direct and attenuated beams (radiation qualities from M25 to M35, and from M25 × to M35 ×, respectively), mammography level, obtained by the ratio of the ionization chambers with inner collecting electrodes of aluminum and graphite is shown in Fig. 3.

4. Conclusions

The results obtained show an adequate behavior of the ionization chambers, with the saturation achieved immediately above 50 V; or better, they can be used with the most common electrometers (bias voltages above 50 V). The results for ion collection efficiency demonstrate that the losses by ionic recombination are below 1%, for both ionization chambers as recommended (IEC, 1997a; IAEA, 2000a). In the case of the polarity effect tests shall be lower than 1% such as recommended (IEC, 1997a; IEC, 1997b). The ionization chambers response due to air kerma rate change was studied by varying the current at the X-rays tube between 2 and 55 mA, and it showed good linearity in this range.

The ionization chambers can be used as a work reference system at the Calibration Laboratory of IPEN, including in intercomparison programs among laboratories. The main advantage of this type of tandem system is no need of use of expensive measurement systems. Using only two ionization chambers, it is possible to verify the X-ray beam constancy of the calibration set-up in calibration laboratories, clinics, in a very simple and quick verification.

Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil, for partial financial support of this work.

References

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

Ankerhold, U., Behrens, R., Ambrosi, P., 1999. A prototype ionisation chamber as a secondary standard for the measurement of personal dose equivalent, Hp(10), on a slab phantom. Radiat. Prot. Dosim. 86 (3), 167–173.

Costa, A.M., Caldas, L.V.E., 2003a. Response characteristics of a tandem ionization chamber in standard X-ray beams. Appl. Radiat. Isot. 58, 495–500.

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

IAEA, 2000a. Absorbed dose determination in external beam radiotherapy: implementation of the international code of practice on dosimetry in radiotherapy. IAEA-Technical Reports Series—398. Vienna: International Atomic Energy Agency.

IAEA, 2000b. Calibration of radiation protection monitoring instruments. IAEA-Safety Reports Series—16. Vienna: International Atomic Energy Agency.

IEC, 1997a. Medical electrical equipment. Dosimeters with ionization chambers as used in radiotherapy. IEC 60731. Geneva: International Electrotechnical Commission.

IEC, 1997b. Medical electrical equipment. Dosimeters with ionization chambers and/or semi-conductor detectors as used in X-ray diagnostic imaging. IEC 61674. Geneva: International Electrotechnical Commission.

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

Vivolo, V, 2006. Development of a reference system for the determination of personal dose equivalent and the constancy of X-ray beams. São Paulo: PhD thesis-Instituto de Pesquisas Energéticas e Nucleares, Universidade de São Paulo. (In Portuguese).