Comparison of Four Parallel Plate Ionization Chambers in Standard X-Ray Beams, Therapy Level

Fernanda B. C. Nonato, Jonas O. Silva, Vitor Vivolo and Linda V. E. Caldas

***Abstract*— The performance of four ionization chambers (designed for electron beams) were compared in standard X-ray beams: Advanced Markus chamber, Roos chamber and two homemade parallel-plate ionization chambers. These homemade chambers are made of acrylic material (PMMA), and they have collecting electrodes made of graphite and aluminum. Several characterization tests were undertaken following the international recommendations: short-term stability, polarity effects, determination of the ion collection efficiencies, saturation curves and linearity of their response. All results obtained were within the international recommendations, but the ionization chambers presented some differences among them. The homemade ionization chamber with collecting electrode of graphite presented a very good performance, and may substitute commercial ionization chambers for therapy level beam dosimetry of X-rays.**

***Index Terms*—Ionization chamber, radiation metrology, therapy level, X-ray.**

I. Introduction

LINEAR accelerators with electron beams are used in several Brazilian hospitals. These electron beams emit radiations and high dose rates. The dose needs to vary less than 5% [1]-[5] inside the tumor volume. Consequently, there is an increasing demand for parallel-plate ionization chambers for the calibration of electron beams. In Brazil, the ionization chambers utilized are imported. Therefore, there is a need to study and develop this kind of instrument with national technology. The ionization chambers have usually a simple construction, using different materials and geometries; furthermore, they are easy to use and less expensive than other radiation detectors as the Fricke dosimeter and calorimeters.

At the Calibration Laboratory of IPEN, several ionization chambers of different types were designed and built for diagnostic radiology, mammography, radiotherapy and radiation protection levels to be applied in different radiation beams [6]-[11]. As an example, there is a special double-faced parallel-plate ionization chamber used as a tandem system [8]. It has different collecting electrode materials, presenting different energy dependence of its response. The main advantage of this kind of tandem ionization chamber is the possibility of its use for the determination of the effective energy of unknown radiation beams. This ionization chamber was tested in a therapeutic X-ray equipment, and its operational characteristics were satisfactory. Another parallel-plate ionization chamber with collecting electrode made of graphite was developed at IPEN [7] for use in electron beams, and it was tested in the present work in standard X-ray beams.

The objective of this work was to compare the response of four parallel-plate ionization chambers, *two commercial and two homemade,* in standard X-ray beams, radiotherapy level.

Manuscript received May 29, 2012. This work was supported in part by CNPq, FAPESP, CAPES and MCT (INCT for Radiation Metrology in Medicine).

The authors are with the Instituto de Pesquisas Energéticas e Nucleares, Avenida Professor Lineu Prestes, 2242, Cidade Universiária, 05508-000, São Paulo, Brazil (fbnonato@ipen.br, Jonas.silva@ipen.br , vivolo@ipen.br , lcaldas@ipen.br).

II. Materials and Methods

Four parallel-plate ionization chambers, Fig. 1, designed for dosimetry in electron beams, were tested in standard X-ray beams. Two of them are commercial: Advanced Markus chamber (0.02 m^3) and PTW; Roos chamber (0.35 m^3), PTW; and two are homemade parallel-plate ionization chambers. Both homemade chambers are made of acrylic material (PMMA), and one has a collecting electrode made of graphite [7] and the other of aluminum. The volume of both ionization chambers is 0.056 m^3.

Initially, the short-term stability was obtained using a $^{90}Sr+^{90}Y$ PTW check device presented in Fig. 2 (33 MBq, 1994). Charge measurements were taken during 30s. The leakage current was measured without the radioactive source during 20min.

The saturation curve was obtained varying the voltage applied to the ionization chamber from 0 to ± 400 V, in steps of 50V. A Pantak Seifert Isovolt 160HS X-ray equipment was utilized. It has a tungsten target, and operates from 5 to 160 kV. The tube current can vary from 0.1 to 45 mA; the measurements were taken with a current of 10mA. The radiation quality utilized was T-30 [12], radiotherapy level, low energies, and its characteristics are presented in Table I.

The polarity effect P is determined by [3]:

$$P = \frac{Q_+ - Q_-}{Q_+ + Q_-}$$

where Q± is the collected charge, in module, for the ionization chambers by the positive and negative applied voltages.

The ion collection efficiency K_s is determined by [4]:

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

where V_1 = 300, V_1/V_2=2 and M_x is the collected charge at V_x.

The ionization chambers were connected to a PTW UNIDOS E electrometer for the measurements. This electrometer has traceability to the Brazilian SSDL/IAEA: Brazilian Laboratory of Ionizing Radiation Metrology, Rio de Janeiro. During each test, all four ionization chambers were polarized with +300 V, and a correction factor ($T_{T,p}$) for standard conditions of temperature (T) and pressure (p) was applied to the measurements [4]:

$$F_{T,p} = \frac{273.2 + T}{273.2 + T_0} \cdot \frac{p_0}{p}$$

where T_0 = 20°C, p_0= 101.3 kPa.

III. Results

The short-term stability test of the ionization chambers was obtained taking 10 consecutive readings, Table II. The results showed agreement with the international recommendations [3]-[5]. The leakage current of all four ionization chambers was less than 0.5%, according to the international recommendation (IEC 60731) [3].

The saturation curves were determined, taking 10 measurements for each voltage. The curves are presented in Fig.3.

Through the saturation curves the operating voltage of the four ionization chambers was determined. All ionization chambers showed saturation since ± 50V, except the homemade ionization chamber with collecting electrode of aluminum: ± 100V.

Three ionization chambers presented polarity effects lower than 1.0%, and the ionization chamber with aluminum collecting electrode presented 1.3% for the voltage of ±50 V. At the other voltages, this chamber presented polarity effects lower than 1.0%, as the other three ionization chambers. The results of the ion collection efficiency were satisfactory, with 99.9% for the Advanced Marcus, Ross and Homemade (Graphite electrode) chambers and 99.8% for the homemade (Aluminum electrode) chamber, according to Table III.

For the linearity of response test, the ionizations chambers were exposed to different air kerma rates, obtained through different nominal tube currents (from 1 mA to 40 mA), and 5 measurements were taken for each current. The curves are presented in Fig. 4. All four ionization chambers show linearity of response, and the minimum correlation coefficient R^2 was 0.999.

IV. Conclusions

Four parallel-plate ionization chambers were tested in relation to their main operational characteristics. They showed good results, according to the international recommendations, except in the case of the polarity effects of the homemade ionization chamber with collecting electrode of aluminum, but only for the applied voltages of ± 50V. As the chosen applied tension was 300 V, this fact does not affect the performance of this ionization chamber. The homemade ionization chamber with graphite collecting electrode may substitute the commercial ionization chambers in beam dosimetry of X-rays, therapy level.

References

[1] ICRU, “Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures”, International Commission on Radiation Units and Measurements, ICRU-24:1976, Maryland (1976).

[2] ICRU, “Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV”, International Commission on Radiation Units and Measurements, ICRU-35:1984 Maryland (1984).

[3] IEC, “Dosimeters with Ionization Chambers as Used in Radiotherapy”, International Electrotechinical Commission, IEC 60731, Geneva (2011).

[4] IAEA, “Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water”, International Atomic Energy Agency, IAEA-TRS-398, Vienna, v.12 (2006).

[5] IAEA, “Calibration of Reference Dosimeters for External Beam Radiotherapy”, International Atomic Energy Agency, IAEA-TRS-469, Vienna (2009).

[6] M. P. P. Albuquerque, L. V. E. Caldas, “New Ionization Chambers for Beta and X-Radiation”, Nuclear Instruments and Methods in Physics Research, v. A280, pp. 310-313 (1989).

[7] C. N. Souza, L. V. E. Caldas, C. H. Sibata, A. K. Ho, K. H. Shin, “Two New Parallel-Plate Ionization Chambers for Electron Beam Dosimetry”, Radiation Measurements, v. 26, n. 1, pp. 65-74 (1996).

[8] A. M. Costa, L. V. E. Caldas, “Response Characteristics of a Tandem Ionization Chamber in Standard X-Ray Beams”, Applied Radiation and Isotopes, v. 58, n. 4, pp. 495-500 (2003).

[9] A. F. Maia, L. V. E. Caldas, “A New Extended-Length Parallel-Plate Ionization Chamber”, Physicsi in Medicine and Biology, v. 50, pp. 3837-3847 (2005).

[10] M. T. Yoshizumi, V. Vivolo, L. V. E. Caldas, “Preliminary Studies of a New Monitor Ionization Chamber”, Applied Radiation and Isotopes, v. 68, pp. 620-622 (2010).

[11] J. O. Silva, L. V. E. Caldas, “Establishment of a Tandem Ionization Chamber System in Standard Mammography Beams”, International Joint Conference - II Congresso de Proteção Contra Radiações da Comunidade dos Países de Língua Portuguesa, II Congresso Brasileiro de Proteção Radiológica e V Congresso Internacional de Radioproteção Industrial, Recife (2011).

[12] A. C. M. Bessa, L. V. E. Caldas, “Intercomparison of Ionization Chambers in Standard X-Ray Beams, Radioprotection Level”, First American IRPA Congress, Proceedings of the First American IRPA Congress, Acapulco (2006).

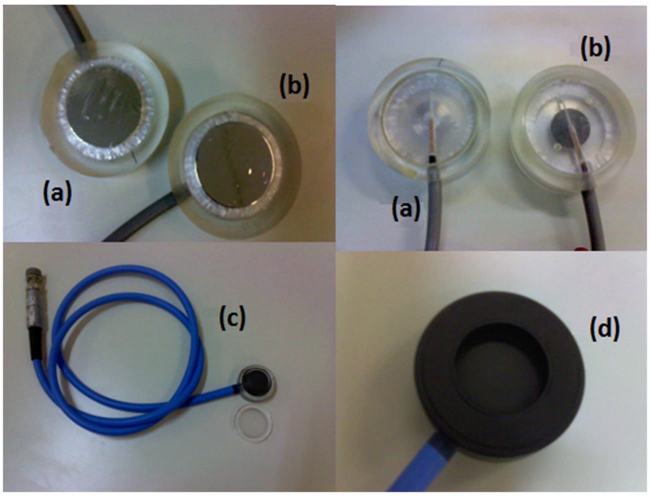


Fig.1. Ionization chambers tested: Homemade parallel-plate chambers with aluminum (a) and graphite (b) collecting electrodes; Advanced Markus chamber(c) and Ross chamber (d).

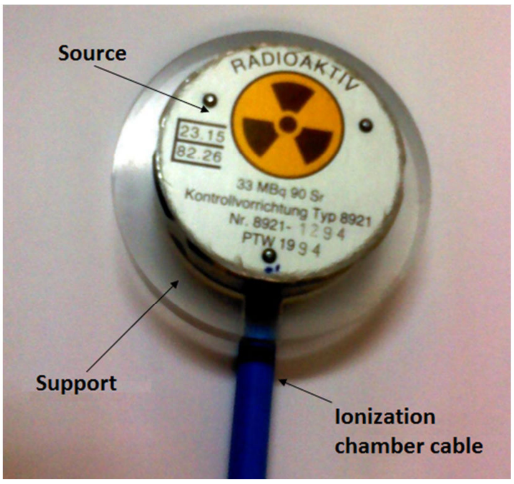
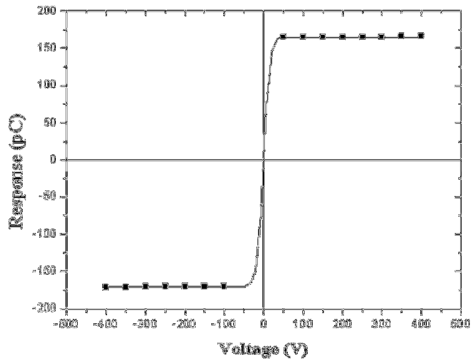
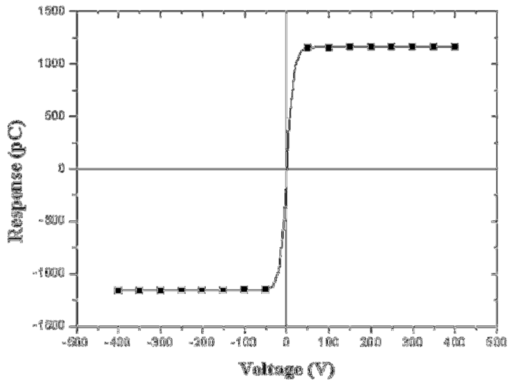


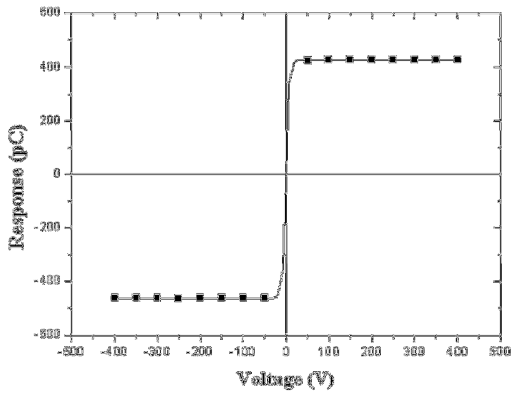
Fig. 2. $^{90}Sr+^{90}Y$ PTW check device at the acrylic support, on the ionization chamber.



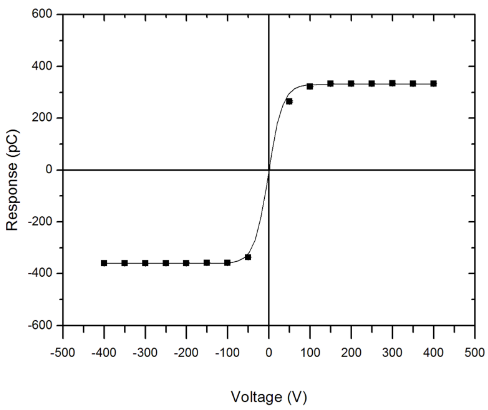
(a)



(b)

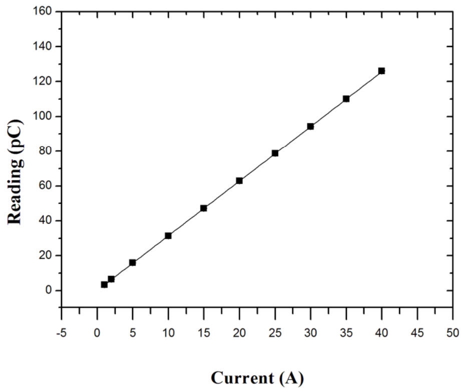


(c)

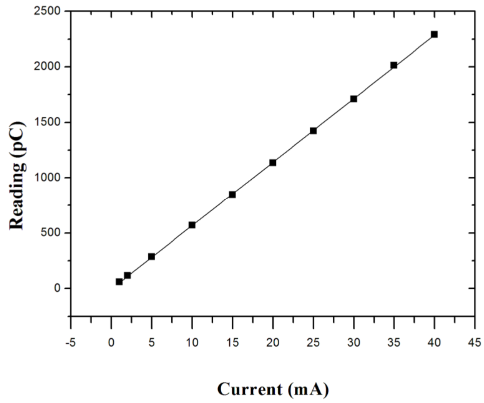


(d)

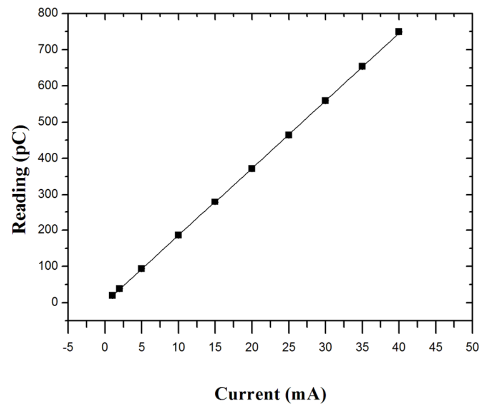
Fig.3 Saturation curves of: Advanced Markus chamber (a), Ross chamber (b), homemade ionization chambers with graphite collecting electrode (c) and with aluminum collecting electrode (d). The uncertainties were lower than 0.15% for all four ionization chambers, not visible in the graphs.



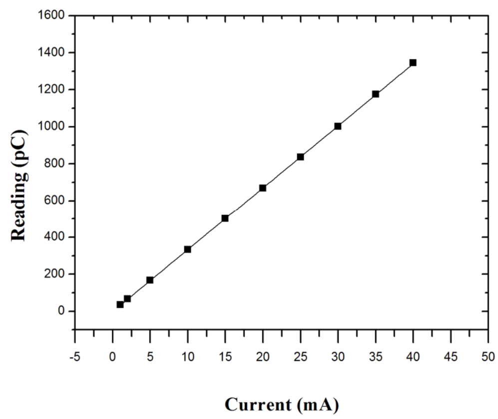
(a)



(b)



(c)



(d)

Fig. 4. Linearity of response curves of: Advanced Markus chamber (a), Ross chamber (b), homemade ionization chambers with graphite collecting electrode (c) and with aluminum collecting electrode (d). The uncertainties were lower than 0.1% for all four ionization chambers, not visible in the graphs.

TABLE I
CHARACTERISTICS OF THE T-30 QUALITY ESTABLISHED AT THE CALIBRATION LABORATORY OF IPEN.

Radiation quality	Voltage (kV)	Additional filtration (mm Al)	Half-value layer (mm Al)	Air kerma rate ($mGy.s^{-1}$)
T-30	30	0.2	0.185	9.638 ±0.042

TABLE II
STABILITY TESTES AND LEAKAGE CURRENTS OF THE TESTED IONIZATION CHAMBERS

Ionization chamber	Short-term stability (%)	Leakage current (+300V) (%)	(-300V) (%)
Advanced Marcus	0.07	0.08	0.08
Ross	0.03	0.05	0.05
Homemade (Graphite electrode)	0.02	0.04	0.04
Homemade (Aluminum electrode)	0.02	0.12	0.11

TABLE III
POLARITY EFFECTS AND LEAKAGE CURRENTS OF THE TESTED IONIZATION CHAMBERS

Ionization chamber	P (%)	k_s (%)
Advanced Marcus	0.19	99.9
Ross	0.19	99.9
Homemade (Graphite electrode)	0.40	99.9
Homemade (Aluminum electrode)	1.30	99.8