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Characterization tests of a new parallel plate ionization chamber for use in electron beams

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HIGHLIGHTS

- An ionization chamber was developed to be used in radiotherapy electron beams.
- The ionization chamber was submitted to several characterization tests.
- The test results showed values within the international standard limits.

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ABSTRACT

Linear accelerators with electron beams are used in several Brazilian hospitals. Consequently, there is an increasing demand for parallel-plate ionization chambers, to be utilized for dosimetry of electron beams. In Brazil, the commercial ionization chambers utilized are imported. The ionization chambers have usually a simple construction, using different materials and geometries. A homemade ionization chamber was developed to be used in electron beams of linear accelerator. The ionization chamber body is made of acrylic and the collecting electrode is painted with graphite powder mixed with nail polish. Several tests were applied, and the results showed values better than the limits established by the international recommendations, except for the polarity effect test, but the response of the developed ionization chamber, for this test, is similar in relation to the response of other commercial ionization chambers from the literature.

1. Introduction

In Brazil, most of the linear accelerators are localized in big cities. Therefore, the government is buying more 80 linear accelerators to attend the needs of the radiotherapy services of the whole country in the next years.

Linear accelerators emit radiations with high dose rates, and the doses need to vary less than 5% inside the target volume (IAEA, 2009a). The dosimetry of electron beams is very important, and ionization chambers are the dosimeters used in the hospital routine for dosimetry of electron and photon beams. Therefore, there is an increasing demand for parallel-plate ionization chambers.

Some types of ionization chambers have been developed at the Calibration Laboratory group of the Nuclear and Energy Research Institute (IPEN) for diagnostic radiology, mammography, radiation protection, radiotherapy and computed tomography beams (Yoshizumi and Caldas, 2010; Silva and Caldas, 2012; Neves et al., 2012; Perini et al., 2013).

In radiotherapy, the cylindrical ionization chamber type is used for the dosimetry of electron beams with energies above 10 MeV, whereas the plane-parallel ionization chambers are applicable at all electron energies, and below 10 MeV their use is mandatory. The scattering perturbation effects are minimized when the parallel-plate ionization chamber is utilized for electron beam dosimetry (IAEA, 2009a).

The objective of this project was to develop a parallel-plate ionization chamber with a simple construction, using commercially and available low cost materials, with a volume of 0.4 cm^3, to be used in the dosimetry routine of electron beams of linacs.

2. Material and methods

An ionization chamber was developed to be used in electron beams according to the TRS 398 and TRS 381 specifications (IAEA, 1995, 2009a).

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Several characterization tests were undertaken using different radiation sources:

A $^{90}Sr+^{90}Y$ PTW check device, with nominal activity of 33 MBq (1994), was utilized for the leakage current test, the short-term stability (or repeatability) test, and saturation curve of the ionization chamber.

A Gammatron II S 80 ^{60}Co source, with activity of 0,34 TBq (1999), was utilized for the stabilization time test according to the international IEC 60731 standard (IEC, 2011). A polystyrene build-up cap, with a width of 4 cm was developed to be used during the test.

The $^{90}Sr+^{90}Y$ source of the beta secondary standard system BSS1, with nominal activity of 1.85 GBq (1981) was used to obtain the linearity curve and to study the behavior of the ionization chamber response in relation to the distance variation. This source has a certificate from German Primary Standard Laboratory Physikalisch-Technische Bundesanstalt (PTB).

The linear accelerator Varian, model 2100C at the Israelita Albert Einstein Hospital, São Paulo, with energies of 6, 9, 12, and 16 MeV, was used to investigate the polarity effect of the ionization chamber. A phantom of PMMA was developed to be used together with the solid water phantom from the hospital. A Keithley electrometer, model 35617EBS, from the hospital, was utilized.

For the other measurements with the developed ionization chamber, a PTW Unidos E electrometer was utilized. The measurements were corrected for the standard conditions of temperature and pressure.

3. Results

The ionization chamber was developed and tested according to the international recommendations.

3.1. Characteristics of the homemade ionization chamber for electron beams

A scheme of the ionization chamber can be observed in Fig. 1. Its characteristics and dimensions are in agreement according to the recommendations of the TRS 381 (IAEA, 1995) and are presented in Table 1. The effective point of the ionization chamber is the centre of the front surface of the air cavity, on the entrance foil.

The collecting electrode material was different from the collecting electrodes of other developed ionization chambers at IPEN, that were coated with a special graphite spray.

In Fig. 2 the ionization chamber may be observed inside an acrylic phantom.

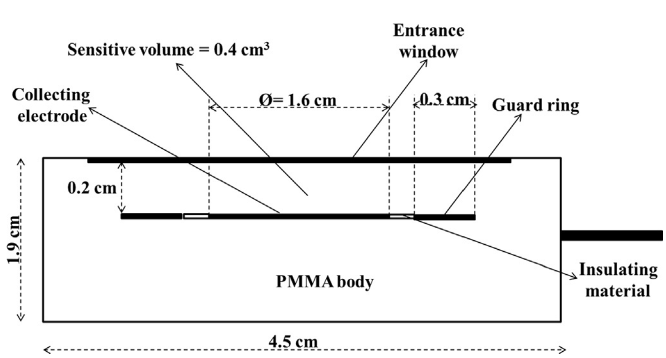

Fig. 1. Scheme of the ionization chamber developed for electron beams.

3.2. Leakage current test

For the leakage current test, the measurements were taken with the ionization chamber without exposure to the radioactive source, during 20 min. This current was compared with the current obtained in the repeatability test, and the maximum variation of the currents was only 0.05%. This result is within the recommended limit of the IEC 60731 (IEC, 2011) standard that presents a limit of 0.5%.

The leakage current may also be obtained, without irradiation, using a maximum polarizing voltage applied to the chamber assembly of 300 V, and taking measurements after 15 min, 1 h and 6 h. The average current was obtained as (0.024 ± 0.001) pA. This current should be less than 0.5% of the ionization current produced by the minimum effective dose rate obtained in the electron beams for the energy of the 6 MeV (IEC, 2011). The result of the current measured in electron beams has nA of magnitude. The variation between the currents was 0.003%.

3.3. Short-term stability

The short-term stability test was carried out taking ten measurements, using a $^{90}Sr+^{90}Y$ PTW check device, during 30 s in each measurement, for positive and negative polarities. The limit of the repeatability is $\pm$ 0.5% (IEC, 2011). The result of this test was not greater than 0.03% for the positive and negative polarizing voltages, with the uncertainty lower than 0.04%.

3.4. Stabilization time test

The stabilization time was determined irradiating the ionization chamber using the polystyrene build-up cap, with a width of 4 cm, at a distance of 100 cm in relation to the cobalt-60 source, and keeping the ionization chamber continuously irradiated; the measurements were taken after 15 min, 1 h and 2 h.

The response of the ionization chamber for its stabilization time was within the recommended limit of the IEC 60731 (IEC, 2011). The measurements after 15 min and 2 h of the application of the polarizing voltage, and irradiation of the cobalt-60 source should not show a variation greater than $\pm$0.5% of the measurement taken after 1 h. In this test, the measurement procedure taken after 15 min showed 0.37% of variation in relation to the measurement taken after 1 h, and the measurement taken after 2 h showed 0.25% of variation in relation to the measurement taken after 1 h. The uncertainty was lower than 0.5%. For this ionization chamber, the stabilization time was established in 1 h.

3.5. Saturation curve and ion collection efficiency

The saturation curve was obtained varying the voltage applied to the ionization chamber from 0 to $\pm$400 V, in steps of 50 V, using the same check device. The objective of this test was to determinate the polarizing voltage that the ionization chamber will be used. With these results, it was possible to choose the voltage to be used during the tests and to calculate the ion collection efficiency K_s by:

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

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

The ionization current, observed in Fig. 3, is constant from $\pm$50 to $\pm$400 V, and it presents a symmetrical behavior to the positive and negative polarities. The polarizing voltage chosen to be used in this ionization chamber was +300 V.

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

Chamber characteristics	Developed ionization chamber	Memorial Pipe / Retangular	Capintec PS-033	Calcam
Material body	PMMA	Polystyrene	Polystyrene	Rexolite housing
Electrode material	PMMA painted with graphite powder mixed with nail polish	Graphite layer on polystyrene	Shonka C-553 impregnated carbon	Graphite body (back wall)
Entrance window	Aluminized polyester film	Mylar	Aluminized polyester film	
Electrode diameter	1.6 cm	1.13 × 0.25 cm	1.62 cm	
Electrode separation	0.2 cm	0.25 cm	0.24 cm	
Nominal volume	0.4 cm^3	0.07 cm^3	0.5 cm^3	

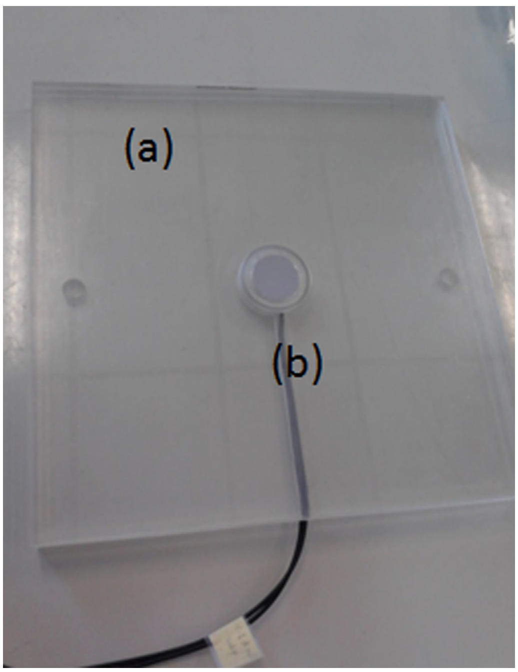

Fig. 2. (a) PMMA phantom, (b) the developed ionization chamber.

The ion collection efficiency K_s was determined using these data. The result was 1.00 to the positive and negative polarities. It was a very good result for the homemade ionization chamber, and it attends the international recommendation of: K_s less than 1% (IEC, 2011). The uncertainties were lower than 0.05%.

3.6. Linearity curve

The linearity curve was obtained taking 5 measurements at different times: 15, 30, 60, 120 and 240 s, using the $^{90}Sr+^{90}Y$ source of the BSS1system, without filter; the reference source-chamber distance was 11 cm. The linearity curve is presented in Fig. 4 where the correlation coefficient for the curve could be obtained, and it was exactly 1.000.

3.7. Ionization chamber response in relation to the distance variation

The ionization chamber was irradiated with different source-chamber distances: 11, 20, 30, 40 and 50 cm, during 1200 s in each measurement, using the $^{90}Sr+^{90}Y$ source of the BSS1 system, without filter. The behavior of the ionization chamber response in relation to the distance variation obeyed the law of the inverse square of the distance, with a maximum variation of 2.3% between the ionization chamber response and the response of the distance inverse square.

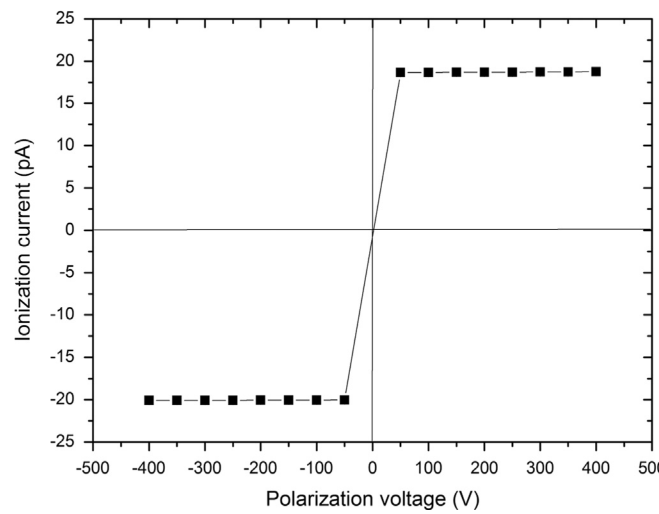

Fig. 3. Saturation curve of the developed ionization chamber, using a $^{90}Sr+^{90}Y$ PTW check device; the uncertainties were all lower than 0.06%, not visible in the figure.

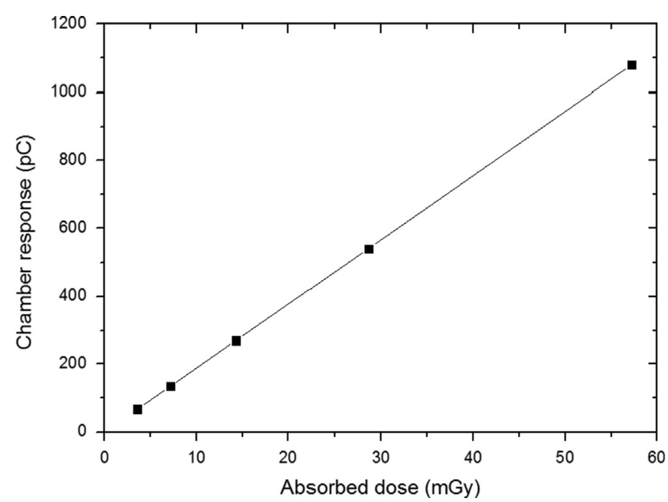

Fig. 4. Linearity curve of the ionization chamber in relation to the irradiation time, using the $^{90}Sr+^{90}Y$ source of the beta secondary standard system BSS1. The maximum uncertainty was 0.07%, not visible in the figure.

3.8. Polarity effect

The polarity effect was determined in electron beams of the linear accelerator 2100C using just two energies: the first one is the minimum energy normally used in the routine: 6 MeV, and the other energy was 12 MeV. The ionization chamber was tested in approximate depths of $0.1R_p$; $0.3R_p$; $0.5R_p$; $0.7R_p$; where R_p is the practical range of the electron beam.

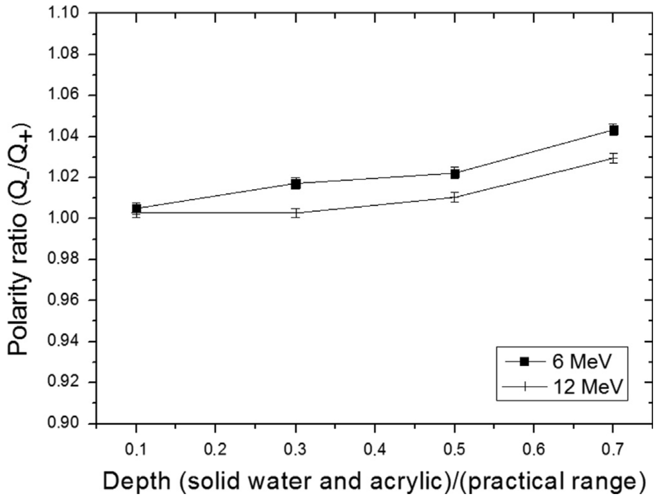

Fig. 5. Curve representing the polarity effect in relation to the depth of the ionization chamber for two energies (6 and 12 MeV), with 15×15 cm^2 of the field. The maximum uncertainty was 1.2%.

The dose rate used was 400 mU/min, and 5 measurements were taken for each depth for both positive and negative polarizing voltages, during 100 mU in each measurement. The field size was 15×15 cm^2.

The polarity effect for both energies is presented in Fig. 5.

For the energy of 6 MeV the polarity effect reached 4% to the $0.7R_p$. This behavior is similar to the Capintec and the Memorial Chambers response in Gerbi and Khan work (Gerbi and Khan, 1987). A small polarity effect was observed near to the practical range depth $0.1R_p$, and it grows in function of the practical range depth. The field in this work is larger than the field of Gerbi and Khan's work (10×10 cm^2). The polarity effect tends to grow due to increase of the radiation field.

The polarity effects obtained with the energy of 12 MeV were lower than that obtained with the energy of 6 MeV, and just to the $0.7R_p$ the polarity effect was greater than 1%. This behavior is similar to the Calcam chamber data presented by Havercroft and Klevenhagen (1994).

A significant polarity effect is not a problem if the chamber is always used at the same polarity and potential. (IAEA, 2009b). A correction factor K_{pol} for the polarity effect can be applied, according to the international standard TRS 398 (IAEA, 2009a):

$$K_{pol} = \frac{|M_+| + |M_-|}{2M}$$

where M_+ and M_- are the electrometer readings (positive and negative polarities, respectively), and M is the measurement obtained with the polarity chosen in the routine use of the ionization chamber.

3.9. Cross-calibration of the calibration factor for the developed ionization chamber in ^{60}Co beam

The calibration of the developed ionization chamber was performed against a calibrated reference chamber, PTW TN 30013 Famer, in a Gammatron II S 80 ^{60}Co source. The chambers are compared by alternately placing each chamber in a water phantom of size 30×30 cm^2, with size field of gamma irradiation of 10×10 cm^2 with its reference point at 5 g/cm^2 in accordance with the reference conditions. The reference point of the Farmer chamber was on the central of the cavity volume and for the developed ionization chamber it was on the inner surface of the window at its central position.

The calibration factor in terms of absorbed dose to water for the developed ionization chambers was obtained as 76.77 ± 1.5 (mGy/nC). And the Farmer calibration factor is 53.59 ± 1.5 (mGy/nC).

3.10. Beam quality correction factor $k_{Q,Qo}$

The beam quality correction factor for the ionization chamber was obtained to correct the effects of the difference between the ^{60}Co gamma radiation reference beam quality, Q_0, and the qualities of the electron beams of the linear accelerator, Q, used in this work for the energies 6, 9, 12 and 16 MeV. According to the TRS 398 (IAEA, 2009a), the factors were obtained calculating the ratio of the water/air stopping-power in the ^{60}Co and the electron beams and considering the perturbation factors = 1 for the parallel ionization chamber. The beam quality correction factors calculated for the developed ionization chamber are 0,03; 0.05; 0.15; 0.28, respectively for the energies 6, 9, 12 and 16 MeV.

4. Conclusions

The homemade ionization chamber showed good performance in the tests of leakage current, repeatability, stabilization time, saturation curve and linearity curve; all results showed values better than the limits established by the international recommendations. Except for the polarity effect test, using the energy of 6 MeV, with depth $0.7R_p$, the polarity effect was 4%. But a significant polarity effect is not a problem if the chamber is always used at the same polarity and potential. The ionization chamber developed in this work shows possibility of use in electron beams of linear accelerators.

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