Development and Characterization Tests of a PMMA Ionization Chamber with Silver Collecting Electrode for Use in Electron Beams

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Highlights

An ionization chamber with silver collecting electrode was developed.
A developed ionization chamber was tested in radiotherapy electron beams.
The characterization tests showed results within the international standard limits.

Abstract

Ionization chambers are dosimeters used to calibrate radiation beams in hospitals. In this work, a PMMA parallel-plate ionization chamber was designed and built for use in electron beams of linear accelerators. This ionization chamber has a PMMA collecting electrode covered with silver paint. Several characterization tests were undertaken following international recommendations. The ionization chamber showed good performance in the characterization tests of its electrical properties and in most of the tests performed in the linear accelerators beams.

Key words: ionization chamber, linear accelerator, electron beam radiation, dosimetry.

Introduction

Teletherapy is a radiotherapy modality that uses external beams directed to a target volume. Nowadays the modern teletherapy equipment is the linear accelerator that can emit X-rays or electron beams. Superficial lesions can be treated with electron beams. In this case or in any treatment, the dose delivered to the target needs to be very well defined. Radiation dosimetry is an important process that assures a treatment with an efficient quality control. Ionization chambers are dosimeters used to calibrate radiation beams in hospitals. A research group at the Calibration Laboratory of the Nuclear and Energy Research Institute (IPEN) developed different kinds of ionization chambers for use at 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). A research group of the Medical Physics Department of the University of Wisconsin, School of Medicine and Public Health, studied the behavior of the mammographic ionization chamber (DeWerd et al, 2002); Snow et al (2013), investigated the applicability of a wide range of microionizarion chambers; and DeWerd and Mackie (2003) compared the behaviour of ionization chambers with various volumes for IMRT absolute dose verification.

In this work, a PMMA parallel-plate ionization chamber was designed, built and characterized for use in electron beams of linear accelerators.

Material and Methods

The parallel-plate ionization chamber, with a PMMA collecting electrode covered with silver paint, was developed at the Calibration Laboratory of IPEN. The characterization tests of this ionization chamber were performed, following international recommendations. Some tests were undertaken at the Israelita Albert Einstein Hospital and other testes at the São Paulo State Cancer Institute, both in São Paulo city.

The materials utilized for this work were: a polystyrene buld-up cap for the ionization chamber, with a width of 4 cm; a polystyrene solid phantom in slab form to hold the ionization chamber; a solid water phantom in slab form and a goniometer.

The sources utilized for this work were: a ^{90}Sr+^{90}Y PTW check device, with nominal activity of 33 MBq (1994); a ^{90}Sr+^{90}Y source of the beta secondary standard system BSS1, with nominal activity of 1.85 GBq (1981). This beta irradiation source has a certificate from the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB). The linear accelerator Varian, model 2100C of the Israelita Albert Einstein Hospital (IAEH), with energies of 4, 6, 9, 12, 16 and 18 MeV for electron beams and the linear accelerator Elekta Synergy, of the São Paulo State Cancer Institute (ICESP), with energies of 4, 6, 9, 12, 15 and 18 MeV for electron beams were utilized. For the measurements, PTW Unidos E electrometers, of IPEN and of ICESP; and a Keithley electrometer, model 35617EBS, of the Israelita Albert Einstein Hospital were utilized.

All measurements were corrected for the reference environmental conditions of temperature and pressure.

Results and Discussion

The ionization chamber, with silver collecting electrode, was developed and tested according to the international recommendations.

1. Characteristics of the homemade ionization chamber for electron beams .

A scheme of the ionization chamber can be observed in Figure 1.

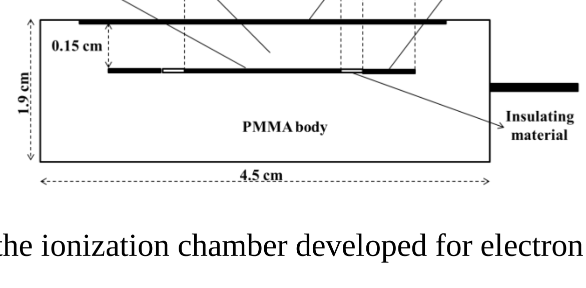

Figure 1. Scheme of the ionization chamber developed for electron beams

In Table 1, the characteristics and dimensions of the developed ionization chamber are presented.

Table 1. Technical specifications of the developed ionization chamber, silver collecting electrode

Characteristics	Dimensions and specifications
Wall material	PMMA, Acrylic
Electrode material	PMMA covered with silver paint
Entrance window	Aluminized polyester
Electrode diameter	1.70 cm
Electrode separation	0.15 cm
Guard ring width	0.30 cm
Nominal volume	0.34 cm^3

2. Short-term stability test

For this test, ten measurements were taken, using the $^{90}Sr+^{90}Y$ PTW check device, during 30s for each measurement, for positive and negative polarities. The limit of the standard deviation is ± 0.5% (IEC, 2011). The maximum standard deviation of this test, repeating eight times the test, was not greater than ± 0.02% for both the positive and negative polarizing voltages, and therefore within the recommended limit.

3. Medium-term stability test

The medium-term stability test is part of the permanent study of the constancy of the chamber response. The stability test was repeated eight times and a relative response of the ionization chamber was obtained and presented in Figure 2. The maximum variation obtained was 0.05% and agrees with the IEC 60731 recommendations (IEC, 2011); the limit of the medium-term stability test is 1%.

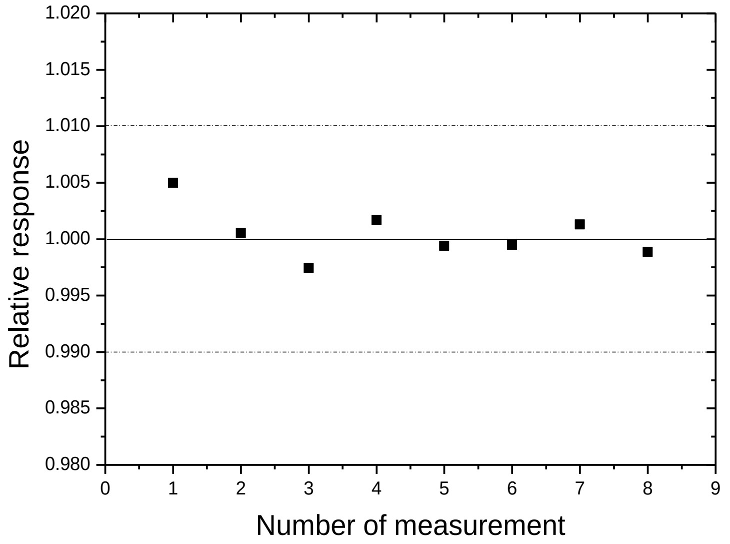

Figure 2. Medium-term stability of the ionization chamber response.

4. Leakage current test

The leakage currents for this ionization chamber were 0.01% and 0.02% for respectively the positive and negative polarities. These results are within the recommended limit of the IEC 60731 (IEC, 2011) standard (0.5%).

5. Saturation curve and ion collection efficiency

The voltage applied to the ionization chamber was varied from 0 to ± 400 V, in steps of 50 V, using the $^{90}Sr+^{90}Y$ check device. The polarizing voltage chosen to be used in this ionization chamber was + 300 V. The saturation curve is presented in Figure 3. It presents a symmetrical behavior to the positive and negative polarities.

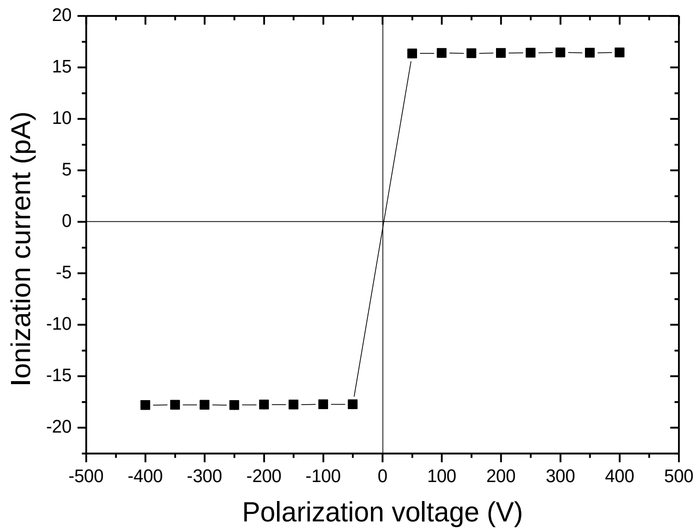

Figure 3. Saturation curve of the developed ionization chamber. The uncertainties were all lower than 0.03%, not visible in the figure.

The collection efficiency K_s was calculated by (IAEA, 2009):

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

The ion collection efficiency K_s was determined using the saturation curve data. The result was 1.00 to the positive and negative polarities. The result agrees with the international recommendation of K_s to be less than 1% (IEC, 2011). The uncertainties were lower than 0.03%.

6. Linearity of response

The linearity of response curve was obtained using the $^{90}Sr+^{90}Y$ source of the BSS1 system, taking 5 measurements at different irradiation times: 15, 30, 60, 120 and 240 s, at the reference source-chamber distance of 11 cm. The linearity of response was obtained, and can be observed in Figure 4 where the correlation coefficient was obtained as exactly 1.000.

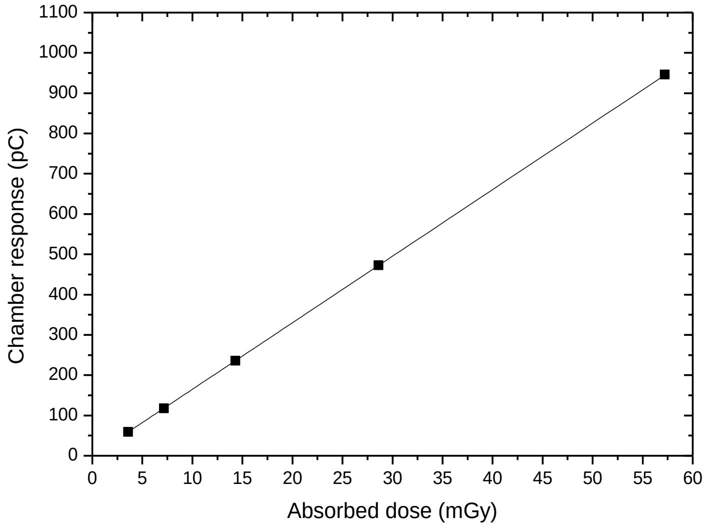

Figure 4. Linearity of response of the ionization chamber. The maximum uncertainty was 0.17%, not visible in the figure.

The linearity of response was also obtained using the electron beams of the linear accelerator Elekta Synergy, with energies of 6 MeV and 9 MeV, and taking 3 measurements at different monitor units: 100, 200, 400, 600, 800 e 1000 cGy, at the reference source-chamber distance: 100 cm. The linearity curves are presented in Figure 5 where the correlation coefficients for the curves were obtained as exactly 1.000.

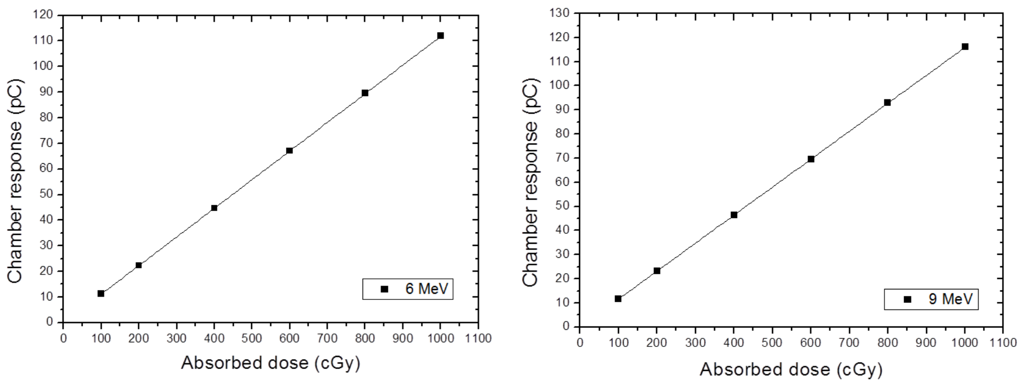

Figure 5. Linearity of response of the ionization chamber, for electron energies of 6 MeV and 9 MeV. The maximum uncertainty was 0.22%, not visible in the figure.

8. Polarity effect

8.1 Polarity effect in relation to the practical range

The polarity effect in relation to the practical range was determined in electron beams of the linear accelerator 2100C using two energies, 6 MeV and 12 MeV, and of the linear accelerator Elekta Synergy with energies of 6 MeV and 9 MeV. The ionization chamber was tested in approximate depths of 0.1Rp; 0.3Rp; 0.5Rp; 0.7Rp; where Rp is the practical range of the electron beam. A solid water phantom in slab form was used to determine the practical range depth.

The measurements were taken for each depth for both positive and negative polarizing voltages, 100 MU in each measurement. The field size was 15x15 cm^2 for the linear accelerator 2100C and 14x14 cm^2 for the linear accelerator Elekta Synergy. The polarity effect curves are presented in Figures 6 and 7.

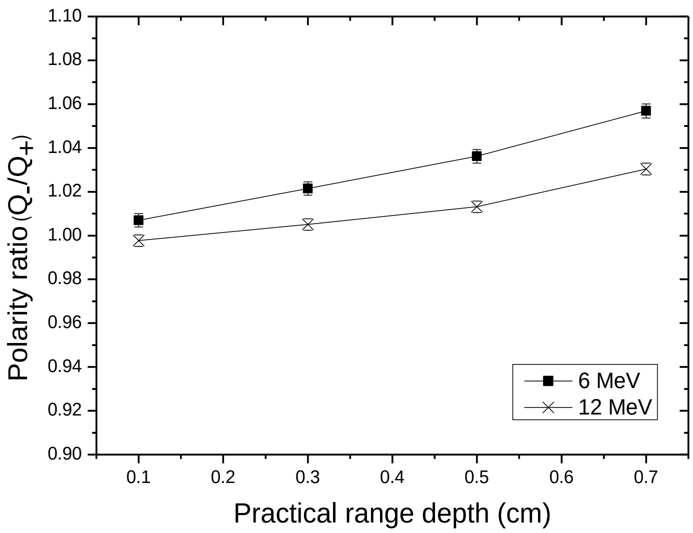

Figure 6. Polarity effect of the ionization chamber response in relation to the the ionization chamber dephts, for two energies (6 MeV and 12 MeV) of the linear accelerator 2100C. The maximum uncertainty was 0.3%

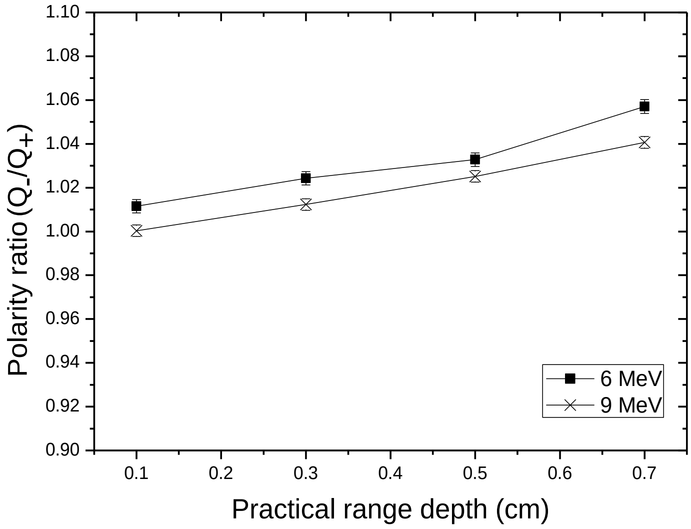

Figure 7. Polarity effect of the ionization chamber response in relation to the ionization chamber depth, for two energies (6 MeV and 9 MeV) of the linear accelerator Elekta Synergy. The maximum uncertainty was 0.3%.

The behaviour of the ionization chamber response in Figures 6 and 7 is similar to that of the Capintec and the Memorial Chamber responses of another work (Gerbi and Khan, 1987). A small polarity effect was observed near to d_{max} (0.1 Rp), and it grows while the depth is below d_{max}. The value obtained at 0.7 Rp is lower than the values obtained at other practical ranges; therefore the polarity effect is greater in relation to the polarity effects obtained by others, because the ratio of the lower values tend to exhibit great variations.

For the energies of 9 MeV and 12 MeV, Figures 6 and 7, the polarity effect was lower than for 6 MeV, and just to the 0.7Rp the polarity effect it was higher than 1%. This behavior is similar to the Calcam chamber data presented by Havercroft and Klevenhagen (1994).

The recommended limit of the IEC 60731 (IEC, 2011) for the polarity effect is less than 1%, or a correction factors has to be applied.

According to the international standard TRS 398 (IAEA, 2009), a correction factor K_{pol} for the polarity effect can be obtained as:

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

8.2 Polarity effect in relation to the field size

The polarity effect in relation to the field size was determined in electron beams of the linear accelerator Elekta Synergy with energies of 6 MeV and 9 MeV. The ionization chamber was tested in field sizes of 6 x 6 cm^2, 10 x 10 cm^2, 14 x 14 cm^2, 20 x 20 cm^2. The measurements were taken for each field size for both positive and negative polarizing voltages, during 100 MU in each measurement. The 1 MU equates to 1cGy of the absorbed dose. The polarity effect in relation to the field size is presented in Figure8.

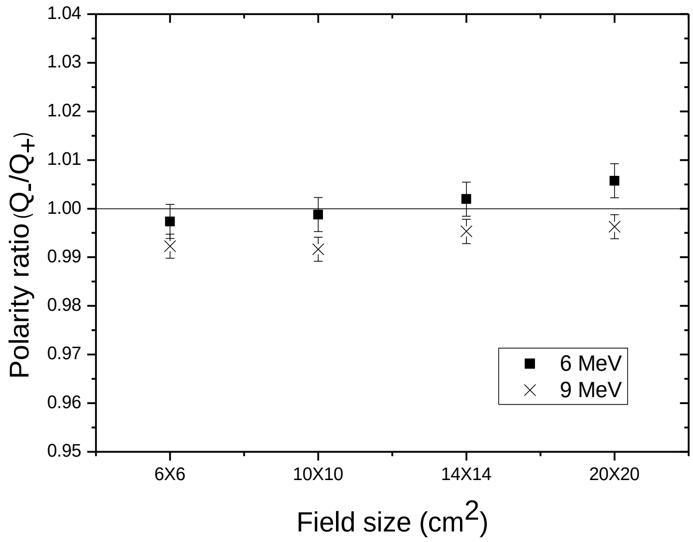

Figure 8. Polarity effect of the ionization chamber depth in relation to the field size of the ionization chamber, for two energies (6 MeV and 9 MeV) of the linear accelerator Elekta Synergy. The maximum uncertainty was 0.28%.

The polarity effect tends to grow due to the increase of the backscattering when the radiation field size increases.

It is noted that the polarity ratio in relation to the radiation field, in Figure 8, is lower than the polarity ratio in relation to the practical range, in Figures 7 and 6. In Figure 8, the solid water phantom, that attenuates the radiation beams, was not used in this case.

9. Angular dependence

The study of the angular dependence was performed varying the incident radiation angle from 0˚ to 360˚, in steps of 45˚, using the goniometer. The measurements were taken in the electron beams of the linear accelerator Elekta Synerg with energies of 6 MeV and 9 MeV. Each measurement was obtained with 100 MU. The reference source-chamber distance was 100 cm.

The results obtained show that the ionization chamber do not present angular dependence, comparing the response of the ionization chamber in angles from 45° of to 360° in relation to the angle 0°.

10. Cable effect

The cable effect was studied comparing the measurements obtained when the cable was exposed to an electron beam and when the cable was protected in relation to the electron beam of the linear accelerator Elekta Synergy. The measurements were taken with 100 MU. The reference source-chamber distance was 100 cm. The cable factor (N_{cable}) was determined using the ratio of the measurements with the cable protected and without protection.

The N_{cable} was (1.000 ± 0.004) for both energies of 6 MeV and 9 MeV.

Conclusions

The homemade ionization chamber, with silver collecting electrode, showed good performance in its characterization tests of the electrical properties, as the short-term and medium-term stabilities; leakage current; saturation curve; collection efficiency; linearity of response. Other tests in linear accelerators were undertaken and the ionization chamber presents a good performance, as the linearity of response; polarity effect in relation to the field size; angular dependence and cable effect, except for the polarity effect test in relation to the depth, but a polarity effect is not a problem if the chamber is always used at the same polarity and potential as usually happens.

Acknowledgments

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