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Application of extrapolation chambers in low-energy X-rays as reference systems

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ABSTRACT

Extrapolation chambers are instruments designed to measure doses of low-energy radiations, mainly beta radiation. In this work, a commercial extrapolation chamber and a homemade extrapolation chamber were applied in measurements using standard radiotherapy X-ray beams. Saturation curves and polarity effect as well as short- and medium-term stabilities were obtained, and these results are within the recommendations of the International Electrotechnical Commission (IEC). The response linearity and the extrapolation curves were also obtained, and they presented good behavior. The results show the usefulness of these extrapolation chambers in low-energy X-ray beams.

1. Introduction

Ionizing radiations are widely used in medicine in areas including diagnostic radiology and radiotherapy. In this regard, high accuracy and precision measurement of quantities related to ionizing radiations are of considerable importance to ensure high quality of delivery. The development of new instruments that provide for such measurements is supported by knowledge of the uncertainties, based on a program of quality assurance and traceability. In particular, the ionization chamber is an instrument developed for such purposes (Albuquerque and Caldas, 1989; Soares et al., 2009; Yoshizumi et al., 2010). The most suitable ionization chamber for detecting low-penetrating radiations is the extrapolation chamber (Böhm and Schneider, 1986). This chamber offers a sensitive variable volume and is used mainly for measurements of beta radiation (Dias and Caldas, 1998, 1999; Oliveira and Caldas, 2005, 2007). In the present work, two extrapolation chambers were tested in standard radiotherapy X-ray beams as defined by the Bureau des Poids et Mesures (BIPM). These were a commercial Physikalisch-Technische Werkstätten (PTW) extrapolation chamber and an extrapolation chamber designed and constructed at IPEN for use with beta radiation.

2. Materials and methodology

Use was made of the IPEN extrapolation chamber, with a Mylar entrance window (thickness 0.025 mm) and an aluminum collecting electrode of 30 mm diameter, and a PTW extrapolation chamber, model M23391T-055, with a Mylar entrance window (thickness 0.025 mm) and an aluminum collecting electrode of 40 mm diameter. A Keithley electrometer, model 6517a, completed the measurement system. The extrapolation chambers were exposed to X-ray beams provided by a Pantak/Seifert Isovolt X-ray system, model 160HS. The radiation qualities used were those based on BIPM (2011) radiation qualities, and they are presented in Table 1. The extrapolation chambers were positioned at 50.0 cm from the X-ray tube focus. The tube current was typically kept fixed at 10 mA, although, for the linearity test, the tube current was varied from 10 to 35 mA. The ionization currents were measured for positive and negative polarities, and the mean values were recorded. For determination of the air kerma rates, use was made of a PTW ionization chamber, model RC6, calibrated at the German primary laboratory Physikalisch-Technische Bundesanstalt (PTB).

3. Results and discussion

As detailed below, comparison has been made of the main characteristics determined for both extrapolation chambers, specifically saturation curves, ion collection efficiency, polarity effect, repeatability to provide for short- and medium-term stabilities, linearity of response, extrapolation curves and energy dependency. The study was carried out for the three radiation qualities of radiotherapy level: T-25, T-30 and T-50. However, the short- and medium-term stability tests were performed only for one radiation quality, T-25.

3.1. Saturation

In determining the saturation curve, the applied voltage was varied between −100 V and +100 V, for electrode separations of 0.75 mm, 1.00 mm and 1.25 mm. Figs. 1–6 show the saturation

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curves and saturation currents obtained for both extrapolation chambers using the standard X-ray beam T-30. As can be seen, saturation of the ionization currents occurs at ± 10 V.

3.2. Ion collection efficiency

From the saturation curves, the ion collection efficiencies and the recombination factors can be determined. The ratio of the ionization current to the saturation current obtained at each value of applied voltage provides the ion collection efficiency. The recombination ion factor is obtained by the inverse of the ion collection efficiency. In Tables 2 and 3 are presented the values of ion collection efficiencies for three radiation qualities, for the IPEN and PTW extrapolation chambers, respectively. The IEC 60731 standard (IEC, 1997) recommends that the ion collection efficiencies should not be less than 99% for radiotherapy qualities. It can be observed that, for the applied voltage of 40 V, the ion collection efficiency reaches 99.0% for the IPEN chamber, and, at 100 V in the case of the PTW chamber, it reaches 98.7%, a value routinely used for this device.

Table 1
Characteristics of the standard X-ray beams used in this work.

Radiation quality	Tube voltage (kV)	Additional filtration (mmAl)	Half value layer (mmAl)	Air kerma rate (mGy/min)
T-25	25	0.4	0.279	176.54 ± 0.09
T-30	30	0.2	0.185	588.06 ± 0.52
T-50	50	1.0	1.079	264.34 ± 0.07

3.3. Polarity effect

The polarity effect is to be observed when the voltage polarity is reversed while it maintains its same absolute value, the amount of charge collected by the electrodes potentially being different. Tables 4 and 5 show the IPEN and PTW chamber responses obtained at the radiation qualities of T-25, T-30 and T-50, expressed as the ratio of the charges collected, $Q+$ and $Q-$, at positive and negative polarity, respectively. In this test, the applied voltage was varied from 10 V to 100 V. The IEC 60731 standard (IEC, 1997) recommends that the polarity effect should be a maximum of 1.0%; thus, for both chambers, the polarity effect was maintained within the international recommendations.

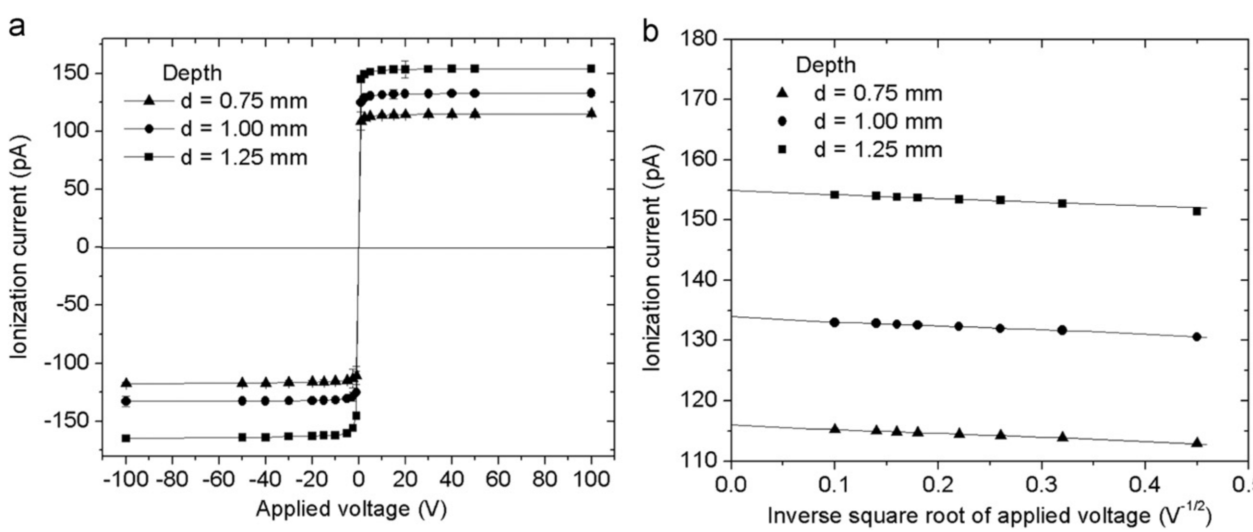

Fig. 1. (a) Saturation curves of the IPEN chamber in the radiotherapy beam T-25 and (b) saturation currents obtained from the saturation curves for the IPEN chamber.

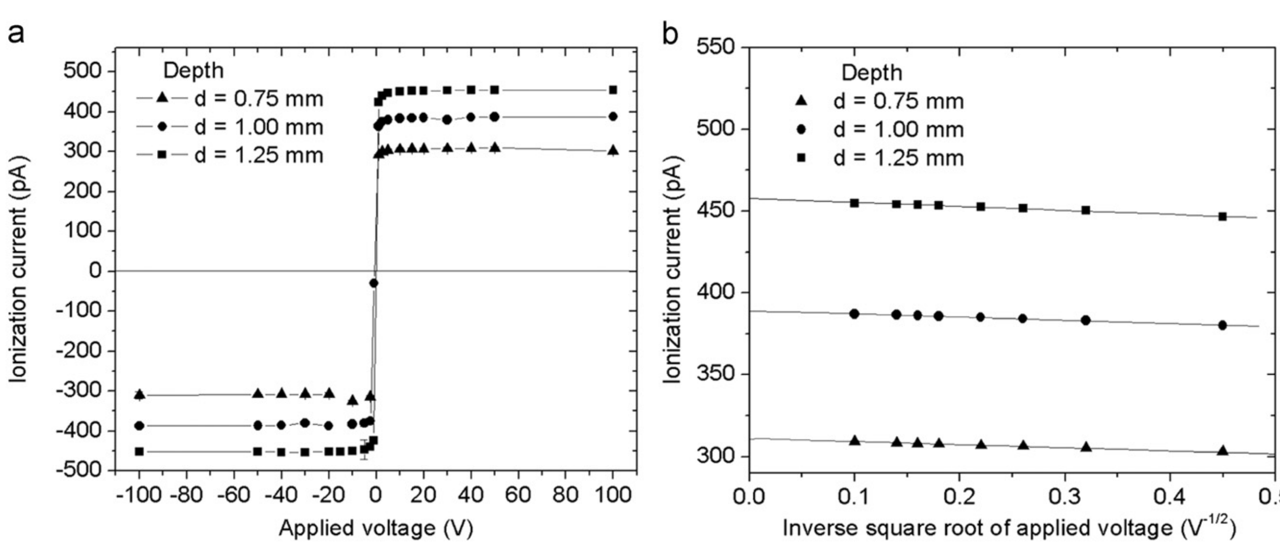

Fig. 2. (a) Saturation curves of the IPEN chamber in the radiotherapy beam T-30 and (b) saturation currents obtained from the saturation curves for the IPEN chamber.