

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

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ARTICLE INFO

Available online 3 April 2012

Keywords:
Extrapolation chamber
X-radiation
Characterization test
Reference systems

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.

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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.

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.

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

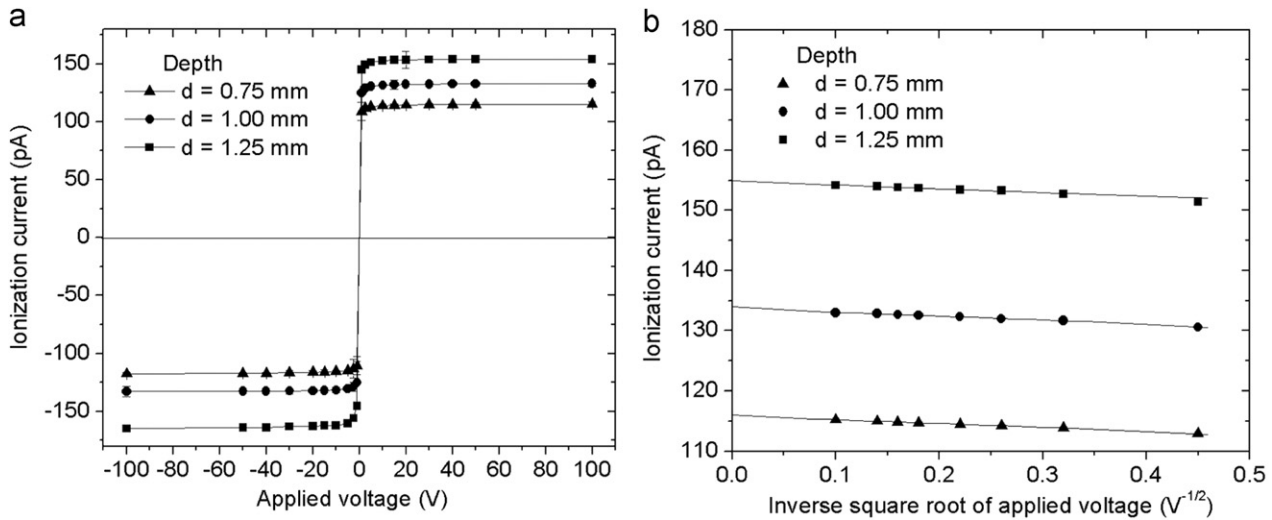


Fig. 1. (a) Saturation curves of the IPEN chamber in the radiotherapy beam T-25 and (b) saturation currents obtained from the saturation curves for the IPEN chamber.

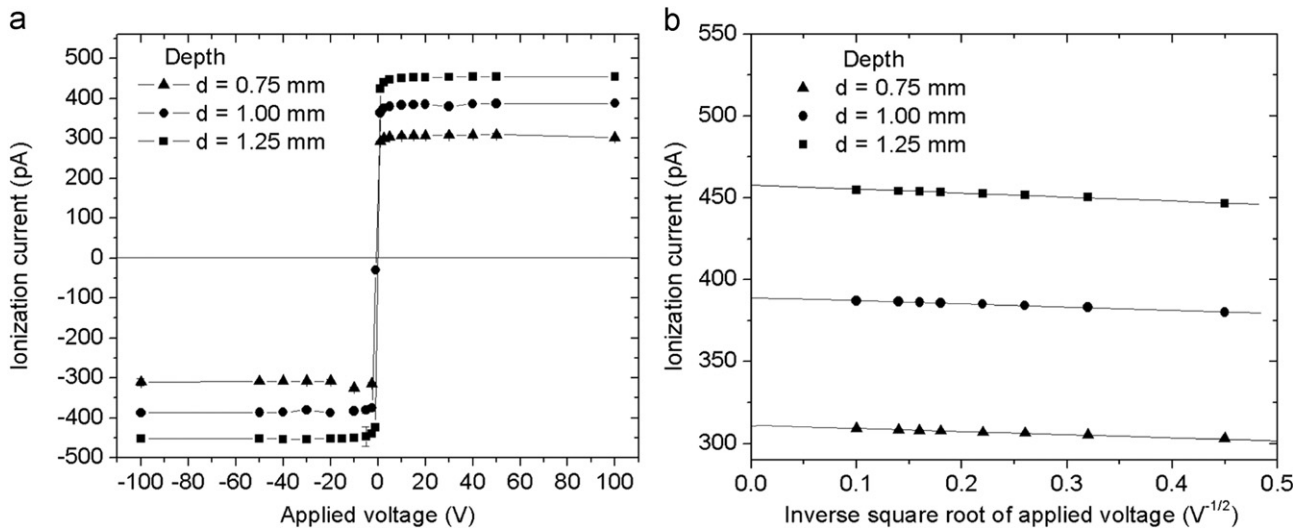


Fig. 2. (a) Saturation curves of the IPEN chamber in the radiotherapy beam T-30 and (b) saturation currents obtained from the saturation curves for the IPEN chamber.

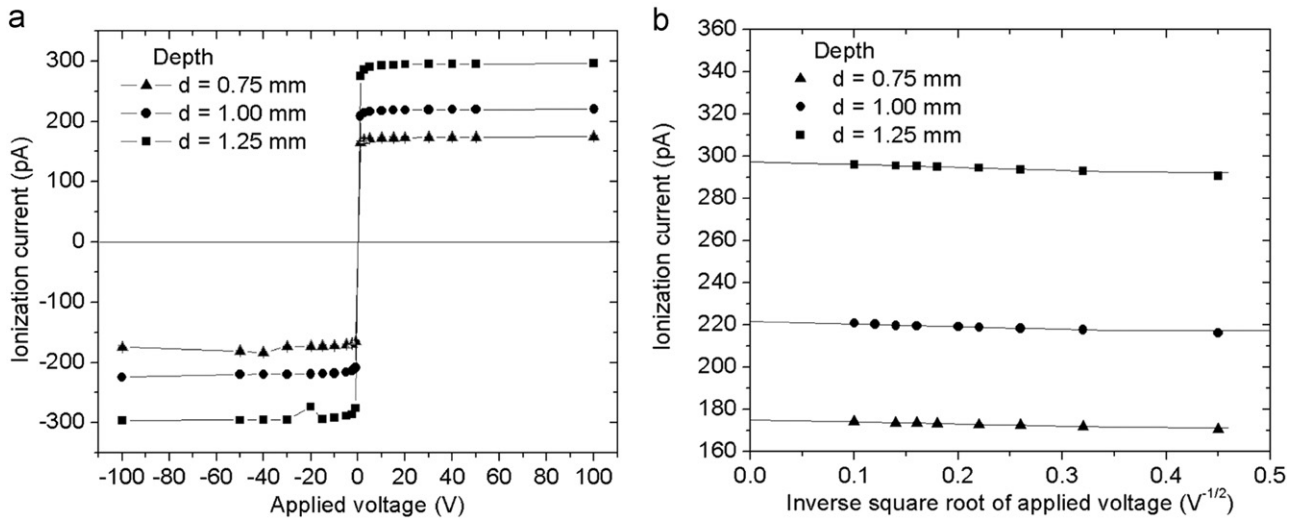


Fig. 3. (a) Saturation curves of the IPEN chamber in the radiotherapy beam T-50 and (b) saturation currents obtained from the saturation curves for the IPEN chamber.

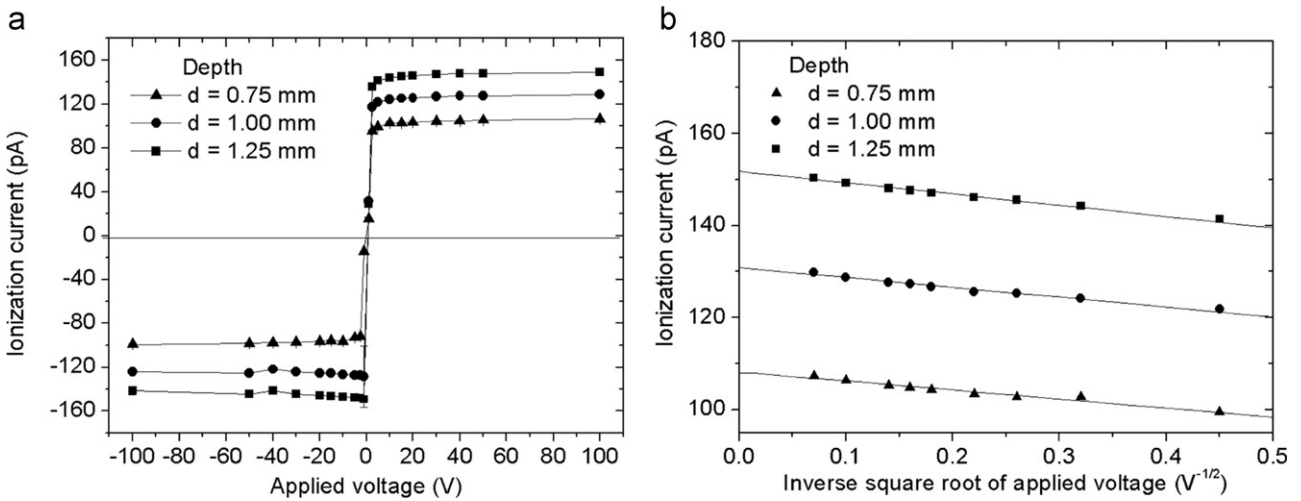


Fig. 4. (a) Saturation curves of the PTW chamber in the radiotherapy beam T-25 and (b) saturation currents obtained from the saturation curves for the PTW chamber.

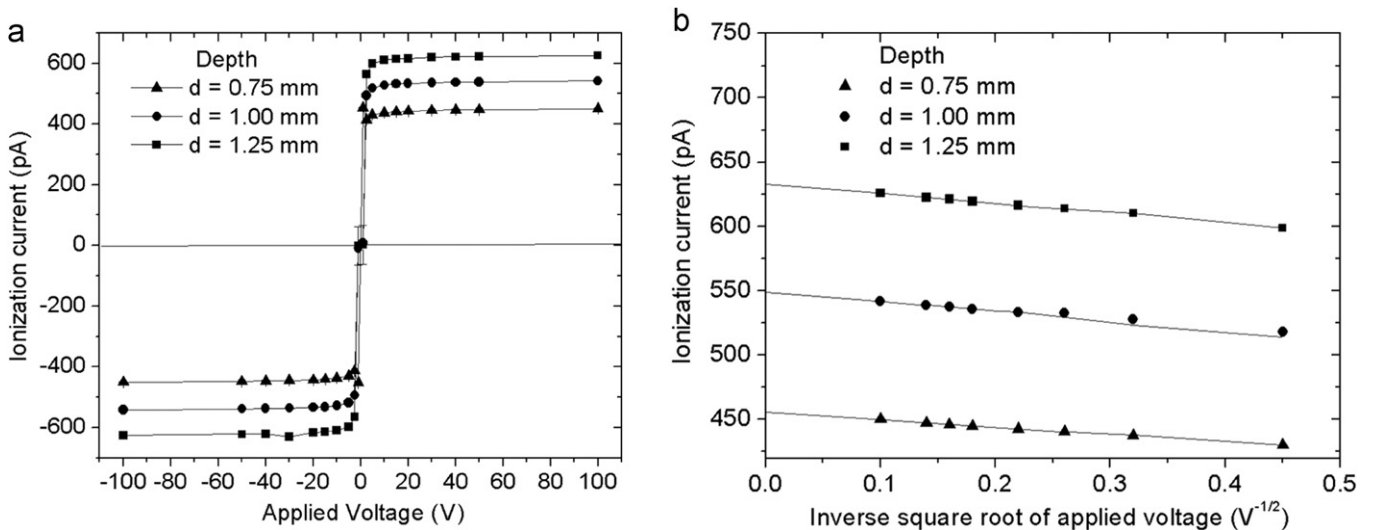


Fig. 5. (a) Saturation curves of the PTW chamber in the radiotherapy beam T-30 and (b) saturation currents obtained from the saturation curves for the PTW chamber.

3.4. Short- and medium-term stabilities

In a repeatability test or short-term stability test, the chamber depth was fixed at 1.25 mm, and a series of 10 measurements was taken every 15 s. The extrapolation chamber response was obtained only for the standard radiation quality T-25. A reproducibility test for medium-term stability was also performed, obtaining measurements in a similar manner to the repeatability

test, but over a more prolonged time period, 6 months, keeping the same geometric configuration between the radiation source and the measuring instrument. In the short-term stability test, the standard deviation was consistently below 0.5%, being within the IEC 60731 recommendations (IEC, 1997). In the medium-term stability test, it was again observed that the chamber responses were within the recommendations, this time of 1.0%.

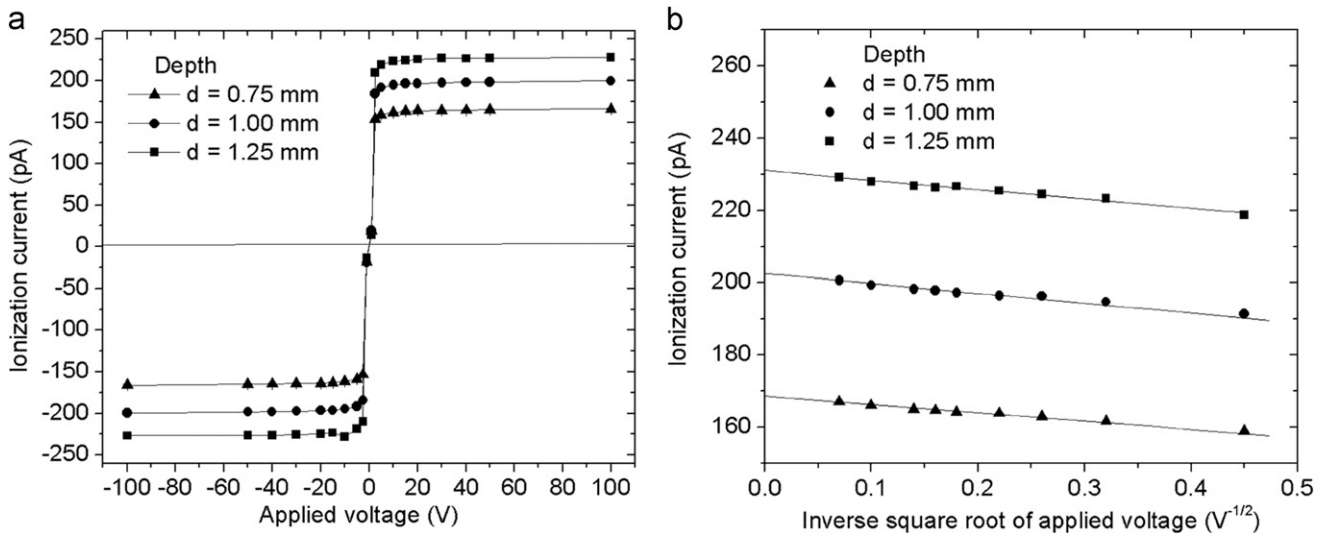


Fig. 6. (a) Saturation curves of the PTW chamber in the radiotherapy beam T-50 and (b) saturation currents obtained from the saturation curves for the PTW chamber.

Table 2
Ion collection efficiency values of the IPEN extrapolation chamber.

Quality	T-25			T-30			T-50		
	Distance between electrodes (mm)								
	0.75	1.00	1.25	0.75	1.00	1.25	0.75	1.00	1.25
1.0	0.939	0.935	0.937	0.938	0.936	0.925	0.943	0.941	0.927
2.5	0.964	0.964	0.964	0.964	0.964	0.960	0.964	0.964	0.963
5.0	0.975	0.977	0.978	0.975	0.977	0.976	0.975	0.975	0.977
10.0	0.983	0.985	0.987	0.983	0.985	0.984	0.982	0.982	0.985
15.0	0.986	0.987	0.990	0.986	0.988	0.987	0.985	0.985	0.987
20.0	0.988	0.990	0.991	0.987	0.990	0.989	0.986	0.987	0.990
30.0	0.990	0.991	0.993	0.990	0.992	0.991	0.989	0.989	0.992
40.0	0.991	0.993	0.993	0.991	0.993	0.992	0.991	0.990	0.993
50.0	0.992	0.994	0.994	0.993	0.994	0.992	0.992	0.991	0.993
100.0	0.996	0.997	0.998	0.996	0.996	0.995	0.996	0.995	0.996

Table 3
Ion collection efficiency values of the PTW extrapolation chamber.

Quality	T-25			T-30			T-50		
	Distance between electrodes (mm)								
	0.75	1.00	1.25	0.75	1.00	1.25	0.75	1.00	1.25
1.0	0.050	0.015	0.003	0.110	0.095	0.060	0.143	0.241	0.192
2.5	0.906	0.901	0.892	0.909	0.910	0.907	0.886	0.895	0.895
5.0	0.944	0.944	0.946	0.943	0.946	0.946	0.921	0.931	0.932
10.0	0.960	0.962	0.964	0.959	0.963	0.966	0.952	0.949	0.950
15.0	0.967	0.970	0.971	0.966	0.970	0.971	0.952	0.957	0.959
20.0	0.972	0.971	0.974	0.972	0.971	0.975	0.957	0.960	0.963
30.0	0.976	0.976	0.979	0.973	0.975	0.980	0.966	0.968	0.969
40.0	0.980	0.979	0.982	0.979	0.979	0.980	0.978	0.975	0.979
50.0	0.985	0.984	0.988	0.981	0.983	0.985	0.980	0.982	0.983
100.0	0.991	0.990	0.989	0.990	0.992	0.992	0.991	0.990	0.987

Table 4

Polarity effects of the IPEN chamber for the radiotherapy qualities T-25, T-30 and T-50; Q+ and Q− are the charges collected at positive and negative polarities respectively.

Quality	T-25		T-30		T-50	
	Charge Q (nC)	Ratio Q+ / Q−	Charge Q (nC)	Ratio Q+ / Q−	Charge Q (nC)	Ratio Q+ / Q−
+10/−10	+2.0036/−2.0177	0.993	+2.074/−2.0637	1.005	+2.0152/−2.0172	0.999
+25/−25	+2.0332/−2.0393	0.997	+2.0934/−2.0807	1.006	+2.0528/−2.0487	1.002
+50/−50	+2.0346/−2.0366	0.999	+2.0934/−2.0887	1.002	+2.0544/−2.0523	1.001
+100/−100	+2.0537/−2.0640	0.995	+2.1011/−2.1007	1.001	+2.0841/−2.0820	1.001

Table 5

Polarity effects of the PTW chamber for the radiotherapy qualities T-25, T-30 and T-50; Q+ and Q− are the charges collected at positive and negative polarities respectively.

Quality	T-25		T-30		T-50	
	Charge Q (nC)	Ratio Q+ / Q−	Charge Q (nC)	Ratio Q+ / Q−	Charge Q (nC)	Ratio Q+ / Q−
+10/−10	+2.6487/−2.6485	1.000	+2.9868/−2.9715	1.005	+2.8413/−2.8469	0.998
+25/−25	+2.6490/−2.6543	0.998	+3.0119/−2.9968	1.005	+2.8466/−2.8450	1.001
+50/−50	+2.6506/−2.6520	0.999	+3.0148/−3.0117	1.001	+2.8508/−2.8479	1.001
+100/−100	+2.6516/−2.6528	0.999	+3.0219/−3.0277	0.998	+2.8578/−2.8549	1.001

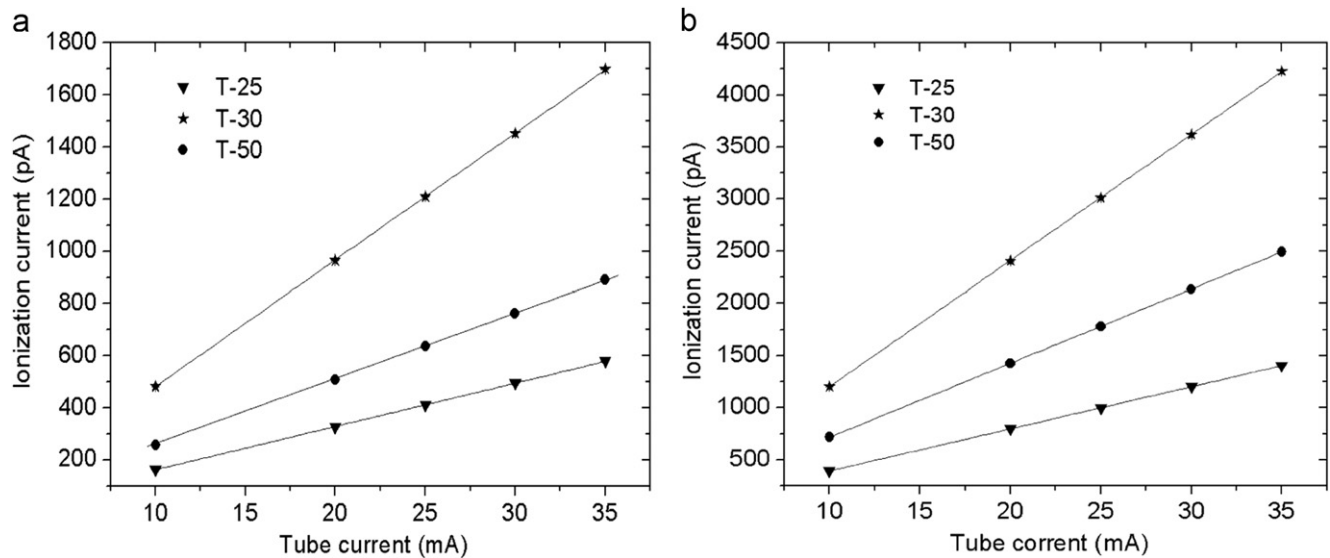


Fig. 7. Linearity of response of (a) the IPEN chamber and (b) the PTW extrapolation chamber, as a function of X-ray tube current, for radiation qualities of T-25, T-30 and T-50.

3.5. Linearity of response

In the linearity test, the ionization currents were obtained by varying the X-ray tube current for the standard radiation qualities while the air kerma rate was varied. The extrapolation chambers were positioned at a distance of 50 cm from the focal spot, keeping the chamber fixed at a depth of 1.25 mm. The X-ray tube current was varied from 10 to 35 mA. Fig. 7(a) and (b) shows the extent of linearity of the extrapolation chambers as a function of tube current, i.e., the chamber response is proportional to the tube current, showing good behavior.

3.6. Extrapolation curves

The extrapolation curves are obtained by plotting the ionization currents as a function of the electrode separation. The main

advantage of the extrapolation chamber is the possibility of changes in its sensitive volume by varying the electrode separation. The charge was collected in each of a series of 15 s exposures, one at each distance between the electrodes. The slope of this curve is related to the air kerma rate of the incident radiation. Fig. 8(a) and (b) shows the extrapolation curves for the IPEN and PTW extrapolation chambers for all radiotherapy qualities. Although there are no specific IEC recommendations about this test, extrapolation curves with linear response are essential for the absorbed dose determinations. All curves showed linear response.

The maximum coefficient of variation in Fig. 8(a) and (b) was 0.35%. Dividing the air kerma rate by the slope for each radiation quality, the calibration factor can be determined; this enables the extrapolation chamber to be used as a reference instrument for calibration of other radiation detectors.

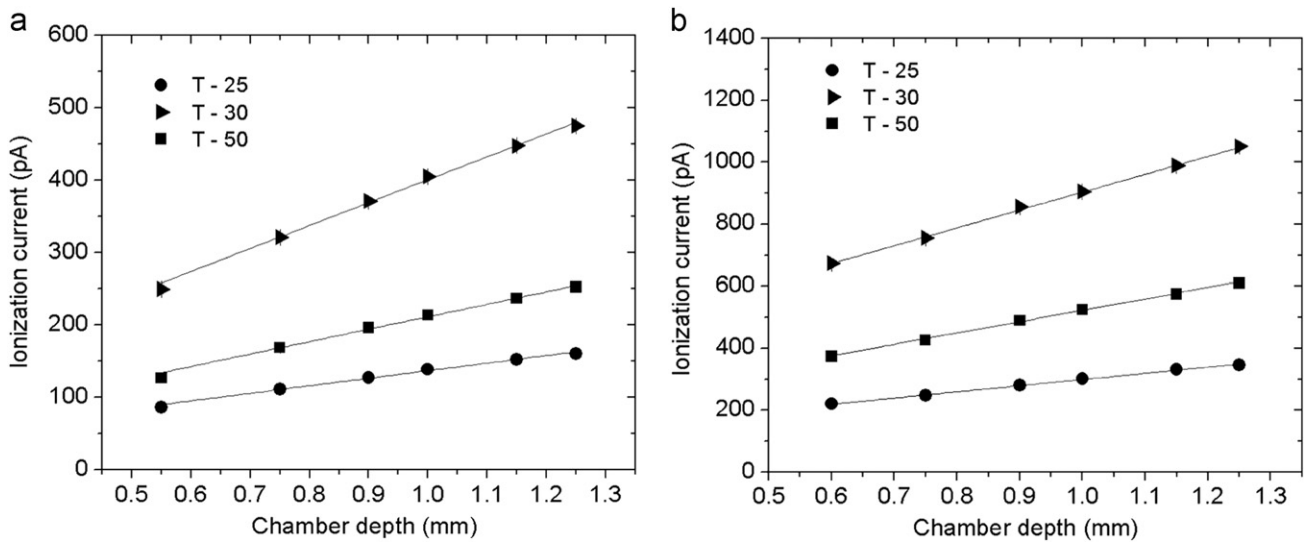


Fig. 8. Extrapolation curves of (a) the IPEN chamber and (b) the PTW extrapolation chamber, for radiation qualities of T-25, T-30 and T-50.

4. Conclusions

Two extrapolation chambers were tested in low-energy X-rays. The ion collection efficiencies and recombination factors were determined from the saturation curves; the results satisfied the recommendations of the IEC 60731 standard (IEC, 1997). The polarity effects were determined for all radiation qualities T-25, T-30 and T-50, and were again within the IEC recommendations. For the short- and medium-term stability studies, the extrapolation chambers showed excellent results. The chamber responses were found to be linear with tube current. These results indicate that the two extrapolation chambers, IPEN and PTW, may be useful as reference systems for X-ray radiotherapy beams.

Acknowledgments

The authors are thankful to CNPq, CAPES, FAPESP and MCT (Project INCT for Radiation Metrology in Medicine) for partial financial supports.

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