Characterization of an extrapolation chamber in X ray beams, diagnostic radiology level

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Abstract. A commercial extrapolation chamber designed for beta radiation detector was studied in this work in relation to the possibility of its use in standard X rays beams, diagnostic radiology level. Saturation curves, polarity effects, response linearity, extrapolation curves and calibration factors were obtained.

1 Introduction

In measurements of quantities related to ionizing radiations the term "Quality Assurance" and its concept have significant relevance, because such measurements involve health risks. Thus, the measurements must be accurate; therefore, greater will be the control, safety and reliability of the results.

The measurement of accurate dosimetric quantities with knowledge of their uncertainties, based on a quality assurance program and traceability, is mainly related to the radiological protection of workers, the environment and the general public. Moreover, there is a great need to ensure the correct dose values in radiotherapy and diagnostic radiology procedures. Reducing harmful effects of ionizing radiations and of radioactive substances, allowing meanwhile the human race to enjoy all benefits that can arise from the use of nuclear energy, are some of the radiological protection purposes.

Extrapolation chambers are used to detect low penetrating radiations. These ionization chambers have as main advantage the possibility of determining surface doses. They may be used as primary standards [1,2,3] and for the calibration of dermatologic and ophthalmic applicators [4.5].

In this work the characterization of an extrapolation chamber of Physikalisch-Technische Werkstätten (PTW) was performed in standard X radiation qualities, diagnostic radiology level, to demonstrate the possibility of its application in this energy range.

2 Materials and methodology

A PTW extrapolation chamber, model M23391T-055, named PTW chamber, with a Mylar entrance window (thickness of 0.025 mm) and collecting electrode of aluminum (40 mm in diameter) was utilized. A Keithley electrometer 6517a was used for the measurements. The chamber was positioned at 100.0 cm from the X-ray tube focus. The ionization currents were measured for positive and negative polarities, and the mean values were considered. The tube current was kept fixed at 10 mA, except in the linearity test, in which the tube current was varied from 10 to 35 mA. For determining the air kerma rates of the RQR radiation qualities, Table 1, according to IEC 61267 [6], an ionization chamber PTW, model 23344, calibrated at the German primary laboratory Physikalisch-Technische Bundesanstalt (PTB) was utilized connected to a Keithley 6517a electrometer.

Table 1: Characteristics of standard X-ray beams diagnostic radiology level [6].

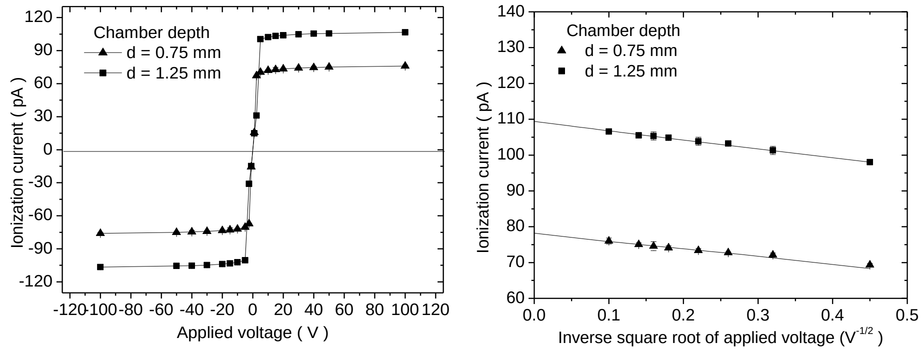
	Radiation quality	Tube voltage (kV)	Additional filtration (mmAl)	Half value layer (mmAl)	Air kerma rate (mGy/min)
Direct beams	RQR2	40	2.3	1.4	11.96 ± 0.08
	RQR3	50	2.4	1.8	21.60 ± 0.18
	RQR4	60	2.7	2.2	28.65 ± 0.32
	RQR5	70	2.8	2.6	37.88 ± 0.32
	RQR6	80	3.0	3.0	46.17 ± 0.35
	RQR7	90	3.1	3.5	54.17 ± 0.42
	RQR8	100	3.2	4.0	67.45 ± 0.54
	RQR9	120	3.5	5.0	89.30 ± 0.59
	RQR10	150	4.2	6.6	120.01 ± 1.02
Attenuated beams	RQA2	40	7.3	2.2	1.13 ± 0.01
	RQA3	50	12.4	3.8	3.46 ± 0.01
	RQA4	60	18.7	5.4	3.11 ± 0.01
	RQA5	70	23.8	6.8	3.45 ± 0.01
	RQA6	80	29.0	8.2	4.04 ± 0.01
	RQA7	90	33.1	9.2	5.00 ± 0.01
	RQA8	100	37.2	10.1	5.93 ± 0.02
	RQA9	120	43.5	11.6	8.06 ± 0.02
	RQA10	150	49.2	13.3	1.48 ± 0.03

The first characterization test was the determination of the saturation curve. It is important to know the saturation region to define the operating region of the ionization chamber. Applying the voltage to levels well above this region may cause an increase in the air ionization due to accelerated electrons resulting from the high values, of the electric field that may cause more ionizations; and applying voltages

well below the region saturation, the negative and positive ions can recombine before being collected.
The saturation curve is obtained by measuring the ionization current as a function of the applied voltage. In this case, the applied voltage was varied between -100 V and +100 V. The chamber depth (interelectrode distance) was fixed at 0.75 mm and 1.25 mm; a saturation curve was obtained for each chamber depth.
Another objective of this study was the determination of the ion collection efficiencies and the recombination factors to be applied to the extrapolation chamber readings. The ion collection efficiency is determined by the ratio of the ionization currents obtained for each value of applied voltage. The recombination ion factor corresponds to the inverse of the ion collection efficiency.
In the polarity test, the response of the extrapolation chamber was compared, when exposed to radiation, with the same voltage applied in module, but with reversed polarity.
In the short-term stability test, or repetitivity test, of the extrapolation chamber response, a series of 10 measurements was taken, keeping the chamber depth fixed at 1.25 mm. The measurements with X radiation (RQR 5) were obtained every 15 seconds.
The extrapolation chamber has as main advantage the possibility of a change in its sensitive volume, by varying the distance between the collector electrode and the input window. By measuring the ionization current for each depth and keeping fixed the electric field, the extrapolation curve can be obtained. The slope of this curve is related to the air kerma rate of the incident radiation.
For the linearity test, the ionization chamber response was investigated by varying the X-ray tube current for the standard radiation qualities, diagnostic radiology level, that is, by varying the air kerma rate. The X-ray tube current was varied from 10 to 35 mA, keeping fixed the chamber depth at 1.25 mm. For tube voltages above 100 kV it was not possible to apply currents greater than 30 mA.

3 Results and discussion

The PTW extrapolation chamber was studied in relation to its main characteristics such as saturation curve, the ion collection efficiency, polarity effect, repeatability of response, linearity of response, extrapolation curves and energy dependence. Figures 1a and 1b show the saturation curves and the saturation currents for the radiation quality of diagnostic radiology RQR 5 for two chamber depths: 0.75 mm and 1.25 mm. As can be seen, saturation of the ionization current occurs from ± 50 V up to ± 100 V.



(a) (b)

Figure 1: (a) Saturation curves of the PTW chamber in the direct beam of the conventional diagnostic radiology RQR5. (b) Saturation currents obtained from the saturation curves for the PTW chamber.

Table 2 shows the values of ion collection efficiency for radiation the qualities of conventional diagnostic radiology.

Table 2: Ion collection efficiency of PTW extrapolation chamber in the radiation qualities of conventional diagnostic radiology.

Quality	RQR 3		RQR 5		RQR 8		RQR 10	
Applied voltage (V)	Distance between electrodes (mm)							
	0.75	1.25	0.75	1.25	0.75	1.25	0.75	1.25
1.0	0.222	0.165	0.198	0.136	0.202	0.035	0.126	0.085
2.5	0.871	0.905	0.856	0.873	0.854	0.871	0.844	0.866
5.0	0.934	0.941	0.935	0.947	0.930	0.929	0.921	0.908
10.0	0.938	0.960	0.958	0.955	0.951	0.933	0.930	0.927
20.0	0.946	0.968	0.966	0.967	0.964	0.953	0.941	0.934
30.0	0.962	0.969	0.973	0.979	0.973	0.969	0.959	0.942
50.0	0.967	0.978	0.983	0.984	0.983	0.976	0.976	0.951
100.0	0.981	0.987	0.983	0.984	0.984	0.988	0.986	0.989

According to the IEC 61674 standard [7], the ion collection efficiencies should not be less than 95% for diagnostic radiology qualities. It can be observed that the ion collection efficiency reaches 95.0 %, as recommended by IEC 61674 when the polarity of 50 V is applied, a value lower than that used in routine.

Table 3 shows the values of the PTW chamber response for the polarity test at the diagnostic radiology quality RQR 5: ratio of the collected positive (Q +) and negative

(Q-) charges in module for the positive and negative polarity voltages respectively. The applied voltages studied ranged from 10 V to 100 V.

Table 3: Polarity effects of the PTW chamber, in diagnostic radiology quality RQR 5.

Polarity voltage (V)	Charge (nC)	Ratio |Q+|/|Q-|
+10 / -10	+0.6487 / -0.6485	0.998
+25 / -25	+0.6490 /-0.6510	0.998
+50 / -50	+ 0.6506 /-0.6520	0.998
+100 / -100	+0.6516 /-0.6528	0.998

According to the recommendations of IEC 6073[8], the polarity effect should be a maximum of 1.0 %; otherwise, correction factors have to be determined for application to the extrapolation chamber response. The polarity effect was maintained within the standard recommendations.

In the short-term stability test, repetitivity test, the standard deviation was always below 0.5%, which is within the recommendations of IEC 60731 [8].

The response linearity of the extrapolation chamber as a function of tube current may be observed in Figure 2 for the conventional diagnostic radiology qualities.

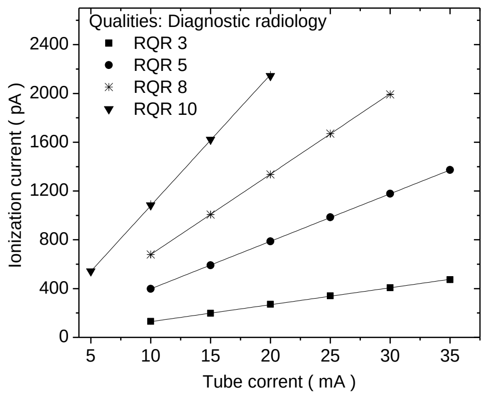


Figure 2: Response linearity of the PTW extrapolation chamber, in the radiation qualities of conventional diagnostic radiology, in relation to the X-ray tube current.

Figure 3 shows the extrapolation curves for the conventional diagnostic radiology qualities of the PTW extrapolation chamber.

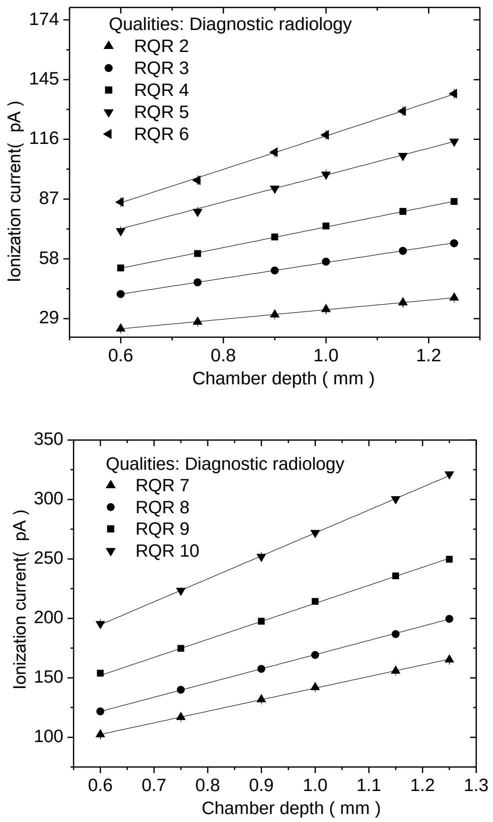


Figure 3: Extrapolation curves of the PTW extrapolation chamber in the standard diagnostic radiology direct beams.

The maximum coefficient of variation for Figure 3 was 0.15%. Dividing the air kerma rate by the slope for each radiation quality, the calibration factor was obtained. The PTW extrapolation chamber can therefore be used as a reference system for the calibration of other instruments such as work standards.

In Tables 4 and 5 are presented the slope values, the air kerma rates and the calibration factors for the qualities of conventional diagnostic radiology, attenuated and direct beams, for the PTW extrapolation chamber.

Table 4: Calibration factors of the PTW extrapolation chamber in diagnostic radiology, direct beams, normalized to the RQR 5 radiation quality.

Radiation Quality	Slope ($x10^{-2}$ pA/mm)	Air kerma rate (mGy/s)	Calibration factor (mGy/s . mm/pA)	Normalization to RQR 5	Variation (%)
RQR2	2.312	0.216	9.343 ± 0.121	0.964	3.24
RQR3	3.820	0.366	9.581 ± 0.155	0.988	1.30
RQR4	5.000	0.478	9.560 ± 0.114	0.986	1.44
RQR5	6.510	0.631	9.693 ± 0.050	1.000	0.00
RQR6	8.108	0.769	9.484 ± 0.189	0.979	2.12
RQR7	9.733	0.966	9.925 ± 0.060	1.024	2.36
RQR8	11.950	1.124	9.406 ± 0.121	0.970	2.94
RQR9	15.150	1.498	9.888 ± 0.095	1.020	1.30
RQR10	19.290	1.961	10.166 ± 0.089	1.049	4.86

Table 5: Calibration factors of the PTW extrapolation chamber in diagnostic radiology attenuated beams, normalized to the RQA 5 radiation quality.

Radiation Quality	Slope ($x10^{-2}$ pA/mm)	Air kerma rate (mGy/s)	Calibration factor (mGy/s . mm/pA)	Normalization to RQR 5	Variation (%)
RQA 2	3.480	0.0434	12.474 ± 0.325	1.010	0.90
RQA 3	2.480	0.0274	11.048 ± 0.553	0.894	10.70
RQA 4	2.060	0.0235	11.408 ± 0.518	0.923	7.80
RQA 5	2.210	0.0273	12.535 ± 0.650	1.000	0.00
RQA 6	2.370	0.0289	12.194 ± 0.388	0.987	1.43
RQA 7	3.140	0.0354	11.274 ± 0.564	0.913	8.82
RQA 8	3.160	0.0443	14.019 ± 0.726	1.135	13.37
RQA 9	4.060	0.0597	14.704 ± 0.745	1.190	18.96
RQA 10	6.310	0.0965	15.293 ± 0.863	1.238	23.73

The recommendation of IEC 61674 [7] on the response variation of the chamber as a function of energy is 5.0% for the diagnostic radiology qualities. In this work, for the diagnostic radiology qualities, direct beams, the calibration factor variation was lower compared to the case of attenuated beams. Therefore, the PTW chamber is more appropriate for dosimetry direct beams than in attenuated beams.

4 Conclusions

From the results, it can be concluded that the PTW extrapolation chamber, despite the recommendation of its use mainly in beta radiation fields, it presents application in dosimetry of diagnostic radiology qualities, direct and attenuated beams.

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