Characterization of an Extrapolation Chamber for Dosimetry of Low Energy X-Ray Beams

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***Abstract*—**Extrapolation chambers were designed to be used as primary standard dosimeter for measuring absorbed dose in a medium in beta radiation and low energy x-rays. The International Organization for Standardization established series of reference x-radiation for calibrating and determining the energy dependence of dosimeters that are to be reproduced in metrology laboratories. Standardization of the low energy x-ray beams with tube potential lower than 30 kV may be affected by the instrument used for dosimetry. In this work, parameters of a 23392 model PTW extrapolation chamber were determined aiming its use in low energy x-ray beams as a reference instrument.

***Keywords*—**Extrapolation chamber, low energy x-rays, standardization, x-ray dosimetry.

I. Introduction

EXTRAPOLATION ionization chamber has unique characteristics for performing absolute absorbed dose measurements in a medium for both beta radiation and low energy photon beams [1]. The possibility to move one of the two parallel electrodes allows changes in the sensitive volume of detection and, consequently, its ionization current can be extrapolated to an infinitely small volume to determine the absorbed dose in thin tissue.

The use of extrapolation chamber requires the quantitative knowledge of factors for correcting the influence and interference caused by the presence of the detector in the radiation field. Some correction factors can be determined experimentally, but others require the use of the Monte Carlo technique in computer simulations. The determination of the absorbed dose rate in tissue, $\dot{D}_T$ (0.07), is given by (1), adapted from [2]:

$$\dot{D}_T(0.07) = \bar{s}_{T,air} . \frac{\bar{W}_o}{e} . \frac{1}{\rho_o} . \frac{1}{a} . k' . \left(\frac{d(kI)}{dl} \right)_{BG} \quad (1)$$

where: $\bar{s}_{T,air}$ is the quotient of the average mass collision stopping powers of ICRU tissue and air; $\overline{W_o}$ is the quotient of the mean energy required to produce an ion pair in air under reference conditions; e is the elementary charge of electron; ρ_o is the air density in the collecting volume under reference conditions; a is the effective area of the collecting electrode; k' is the product of correction factors that are independent of the chamber depth, k is the product of correction factors that are dependent of the chamber depth, I is the measured ionization current; $\left(\frac{d(kI)}{dl} \right)_{BG}$ is the slope obtained under Bragg-Gray conditions, of the corrected ionization current vs. cavity depth, l, equal to the value of the experimental slope extrapolated to zero thickness.

Extrapolation chambers have been designed and built for specific applications; in all cases, their metrological characteristics should be determined before use [3], [4].

The International Organization for Standardization, ISO, established series of gamma and x-radiations for calibrating and determining the energy dependence of dosimeters. It is expected that the ionizing radiation metrology laboratories to reproduce the ISO reference radiations by establishing the tube voltage and additional filtration, and determining the half value layer, mean energy and spectral resolution of the beam that should comply with specific requirements [5].

The characterization of x-ray beams with tube potential below 30 kV, herein called "low energy beams", is critical as far as the determination of the beam parameters since the presence of the instrument used may affect the measurements. The aim of this work was to study the reliability of using a 23392 model PTW extrapolation chamber for measurements in ISO low energy x-ray reference beams. Polarizing voltage, the true-null depth, repeatability and reproducibility of the chamber were determined; a study of the response of the chamber as a function of the photon energy and estimation of the uncertainties was also done.

II. Materials and Methods

This work was carried out in the Dosimeter Calibration Laboratory of the Centro de Desenvolvimento da Tecnologia Nuclear (LCD/CDTN), where the 23392 Böhm model PTW extrapolation chamber was available. The chamber is composed of one fixed parallel plate electrode and another electrode adjustable by an external micrometer. The distance between its electrodes varies from 0.05 up to 10.5 mm, with parallelism accuracy of ± 1 µm, which corresponds to a change in chamber volume of 0.353 to 7.422 cm^3. Its collecting electrode is made of PMMA with graphite-coated surface with a 30 mm diameter and surrounded by a 14.8 mm width guard ring. The chamber window is graphite coated Hostaphan (mylar), with thickness of 0.75 $mg.cm^{-2}$, and

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diameter is of 60.5 mm.

N series ISO low energy reference radiations were reproduced in a constant potential Seifert-Pantak x-ray machine. Fig. 1 shows the x-ray set-up for measurement with the extrapolation chamber. The characteristics of the low energy beams implemented in LCD/CDTN are presented in Table I.

Fig. 1 X-ray set-up for measurements with the 23392 PTW extrapolation chamber

TABLE I
CHARACTERISTICS OF LCD/CDTN LOW ENERGY REFERENCE RADIATIONS

Code	Tube Voltage (kV)	Mean energy (keV)	Additional Filtration (mm)			Half-Value Layer (mm Al)	
			Al	Cu	air	1st	2nd
N10	10.0	8.2	0.04	-	1000	0.048	0.05
N15	15.0	12.0	0.52	-	1000	0.145	0.16
N20	20.0	15.8	0.85	-	1000	0.32	0.36
N25	25.0	19.9	2.00	-	1000	0.65	0.75
N30	30.0	23.9	4.00	-	1000	1.15	1.30

III. Results and Discussion

A. Polarizing Voltage

The saturation curves of the 23392 PTW extrapolation chamber were determined with 1 and 4.0 mm electrode distances for all low energy reference radiations. An example of the results is shown in Fig. 2, for N30.

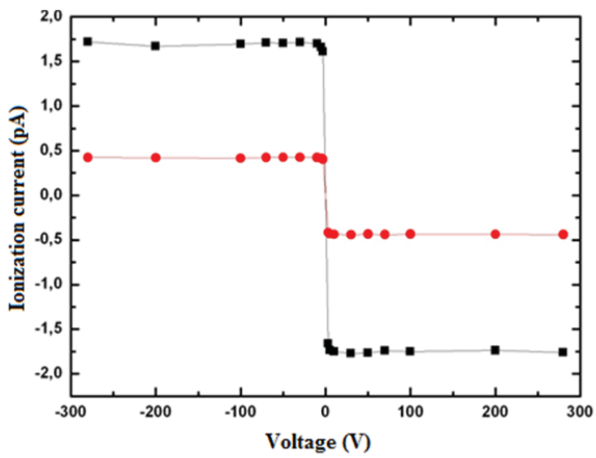

Fig. 2 Saturation curves for 1 (■) and 4 (●) mm electrode distance of the 23392 PTW extrapolation chamber, in N30 reference radiation

Results from saturation curves indicated that the optimum polarization voltage of the chamber was between 30 and 70 V.mm^{-1}.

B. The True-Null Depth

The true sensitive volume of the extrapolation chamber can be calculated by determining the true-null distance between its electrodes. Measurements were done from 1.0 up to 5.0 mm in both polarities and the mean value was adopted to correct differences. Extrapolation to zero was determined as it is shown in Fig. 3 for N15 reference radiation as an example.

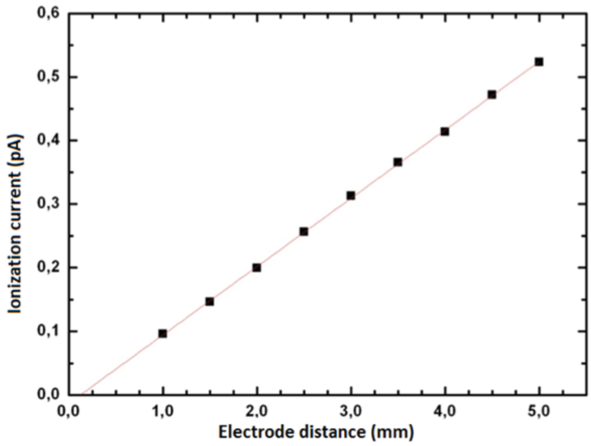

Fig. 3 Variation of the ionization chamber as a function of the electrode distance to calculate the true null distance in N15 radiation

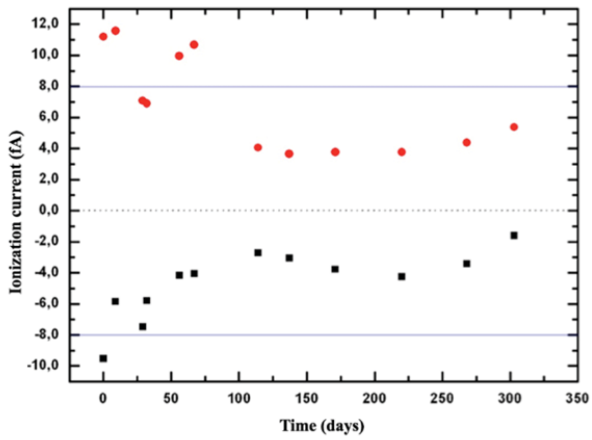

Fig. 4 Leakage current for positive (■) and negative (●) polarities of the 23392 PTW extrapolation chamber

The true null distance values obtained for N15, N25 and N30 were (0.121±0.002), (0.214±0.003) and (0.065±0.001) mm, respectively. The uncertainty is expressed as the expanded value for the coverage factor, k, equal to 2. Large variation of the results suggested that extrapolation method failed or measurements were influenced by the methodology since the true null electrode distance is a geometric parametric due to the chamber design.

C. Leakage Current

Leakage current is the electrical current that appears in the ionization chamber without being irradiated; it is due to the presence of humidity in the chamber or another causes. Results of the leakage current measured for both polarities in the period of 300 days are shown in Fig. 4. For the sake of reliability of any measurement with the extrapolation chamber, it was chosen the maximum acceptable value of 8.0 fA for the leakage current.

D. Repeatability and Reproducibility

The study of the repeatability and reproducibility of the 23392 PTW extrapolation chamber was done based on measurements of the ionization current in a fixed geometry between the chamber and $^{90}Sr/^{90}Y$ check source (Fig. 5).

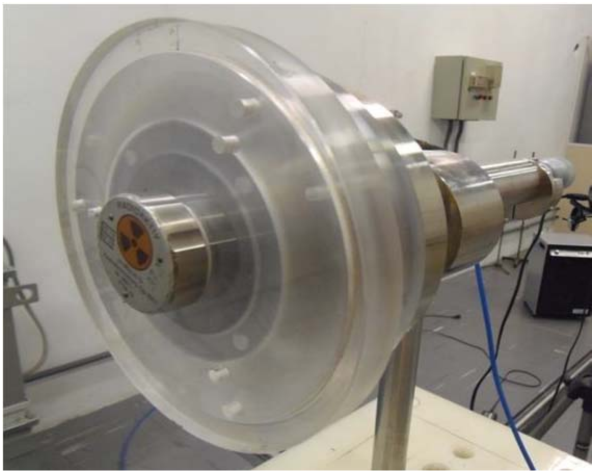

Fig. 5 Fixed geometry $^{90}Sr/^{90}Y$ check source and extrapolation chamber for repeatability and reproducibility measurements

Repeatability represents the dispersion of a set of measurements during a short time with fixed conditions; it is given by the standard deviation. Results of repeatability is shown in Fig. 6 for the first twelve measurements; the value of 0.02 pA was chosen as the maximum acceptable value.

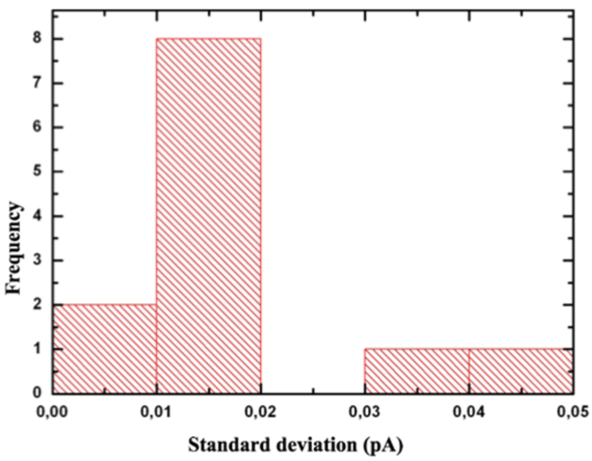

Fig. 6 Repeatability of the 23392 PTW extrapolation chamber given by the standard deviation

Reproducibility represents the stability of the chamber response in a long term in a fixed $^{90}Sr/^{90}Y$ radiation source geometry. Results of reproducibility of the 23392 PTW extrapolation chamber are shown in Fig. 7 for 300 days; the maximum variation in the corrected ionization chamber was 0.8% and 1.0% for positive and negative polarities, respectively. A typical value for a standard dosimeter is 2%.

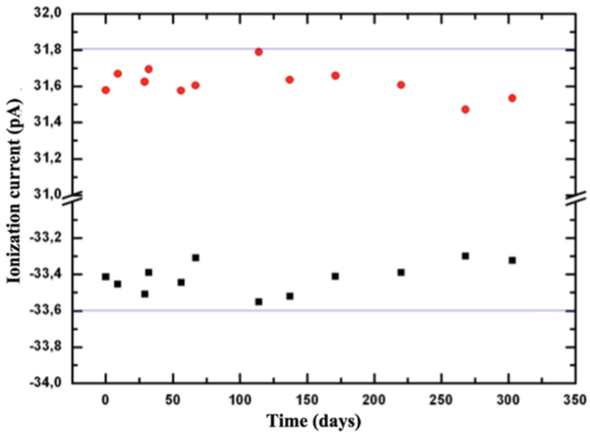

Fig. 7 Reproducibility of the 23392 PTW extrapolation chamber

E. Energy Dependence

The study of the response of the 23392 PTW extrapolation chamber was done by determining its calibration coefficient against a 2575 NE ionizing chamber calibrated and traceable to the National Metrology Laboratory.

Energy correction factors were determined for the low energy radiations and they were normalized to N20. For the sake of comparison, a very thin window Radcal RC-6M ionization chamber used for mammography dosimetry was also calibrated in similar procedure. Fig. 8 shows the experimental set-up used for calibrating the ionization chambers and study their response as a function of the photon energy.

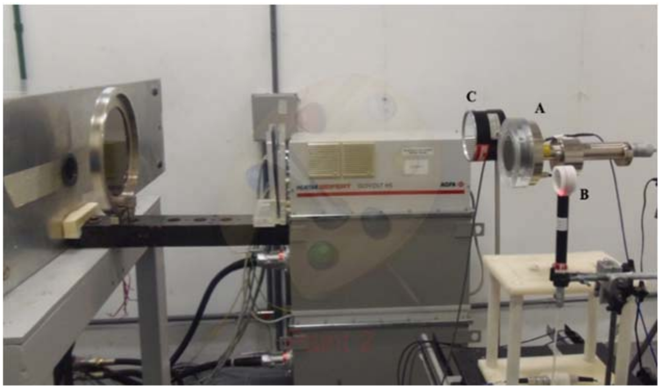

Fig. 8 Experimental set-up for determining and comparing the energy dependence of the PTW extrapolation chamber (*A*) and the RC-6M (*B*) against the 2575 NE standard chamber (*C*)

Results of the energy dependence of the 23392 PTW extrapolation chamber and the RC-6M, normalized to the N20 radiation (15.8 keV) are shown in Fig. 9. They showed that both chambers have an energy dependence lower than 2% in the energy range from N15 (12.0 keV) to N30 (23.9 keV); only at N10 (8.2 keV) the correction factor is about 8%.

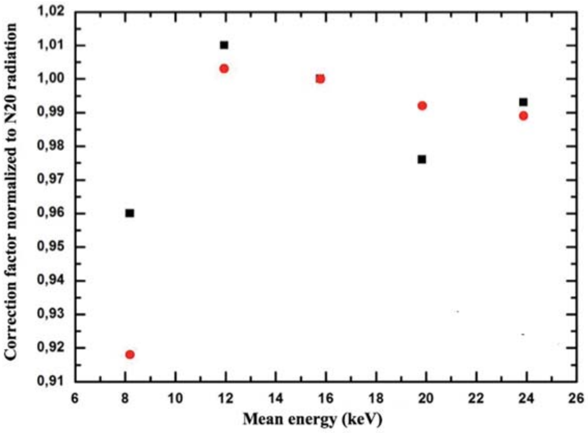

Fig. 9 Energy dependence of the PTW extrapolation (■) and the RC-6M (●) chambers

IV. Conclusion

The 23392 PTW extrapolation chamber has shown reliable characteristics to be used for dosimetry in low energy photon beams. Although the results of the true-null depth were not conclusive, it does not invalidate the conclusion that the chamber can be used as a reference dosimeter.

Acknowledgment

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