DETERMINATION OF THE TRUE NULL ELECTRODE SPACING OF AN EXTRAPOLATION CHAMBER FOR X-RAY DOSIMETRY

M.T.T. Figueiredo[1]; F.M.Bastos;[1] T.A. da Silva[1,2]

[1] Post graduation Course on Science and Technology of Radiation, Minerals and Materials, CDTN/CNEN, Av.Pres. Antônio Carlos, 6.627 - Campus UFMG, Caixa Postal 941, CEP 30161-970 Belo Horizonte, Minas Gerais Brazil

mttf@cdtn.br

[1] Post graduation Course on Science and Technology of Radiation, Minerals and Materials, CDTN/CNEN, Av.Pres. Antônio Carlos, 6.627 - Campus UFMG, Caixa Postal 941, CEP 30161-970 Belo Horizonte, Minas Gerais Brazil

fmb@cdtn.br

[2]Development Center of Nuclear Technology, CDTN/CNEN, Av.Pres. Antônio Carlos, 6.627 - Campus UFMG, CEP 31270-901 - Caixa Postal 941, CEP 30161-970 Belo Horizonte, Minas Gerais Brazil

silvata@cdtn.br

ABSTRACT

An accurate determination of the actual null distance is critical for the establishment of primary measurement method for absorbed dose in tissue, since the concept of the true null electrode spacing is used to define the sensitive volume of an extrapolation chamber. In this paper, a critical analysis of two methodologies for determining the true null electrode spacing of an extrapolation chamber was done. Firstly, the ionization current as a function of electrode spacing was measured in ISO 4037 low energy X-ray beams. In the second procedure, a LC Bridge was used to measure the capacitance between the electrodes of a 23392 Böhm model PTW ionization chamber and a reliable relationship between capacitance and relative distance was established. Results showed that the true null spacing values varied from 0.0015 to 0.38 mm. Since capacitance meters with high resolution are not always available in calibration laboratories, the second method showed values with large uncertainties. The first method proved to be highly sensitive to the quality of the X-ray beams used.

Keywords: true null spacing; extrapolation chamber; dosimetry

1. INTRODUCTION

The characterization of an extrapolation chamber to be used as a primary standard dosimeter for measuring the absorbed dose to tissue requires determining the true null spacing and effective volume, besides additional tests including the determination of the saturation current, the collection ions efficiency, the polarity effects, the repeatability and the reproducibility of the chamber response. Except the first two, a prior knowledge of the absolute distance between the chamber electrodes is required.[1]

Electrode plates spacing exists because manufacturers keep a safety distance between them considering that it cannot be so short that would make the electric field to exceed the dielectric rigidity of the medium; besides there are doubts regarding the parallelism between the plates and the material roughness. The relative distance indicated by the micrometer cursor is given with high resolution and low uncertainties, however, the absolute distance that is defined as the relative distance added to the true null spacing, obviously depends on the true null spacing value, which is not provided by the manufacturer. [2]

Traditionally, for extrapolation chamber, the true spacing is determined by analyzing the experimental relationship between the ionization current and the electrodes relative distance. The curve that defines this relation is a line that intersects the horizontal axis at the correspondent true null spacing. It is quite reasonable to assume that, for constant intensity electric field and homogeneous radiation beam, the ionization current measured by the extrapolation chamber will be proportional to the sensitive volume, and therefore for the absolute distance between the electrodes, since the overlapping area of the electrodes is constant.

The adjustment of the electric field intensity value, which is a proportionality condition, depends on the prior knowledge of the absolute distance between the electrodes. The relative distance given by the micrometer cursor has been used as a reference for adjusting the intensity of the electric field, which may introduce significant errors for smaller electrode spacing values. Assuming the constancy of electric field strength and uniformity of the radiation beam are necessary and sufficient conditions of proportionality, the use of relative distance, instead of the absolute distance for adjusting the electric field intensity, will produce inevitable loss of proportionality.

Considering that an inherent capacitance is associated with any parallel-plate ionization chamber, there should be a well-defined relationship among the capacitance, the effective colleting area and the electrode spacing of an extrapolation chamber. The knowledge of the capacitance allows the effective electrode spacing of the extrapolation chamber, to be calculated within reasonable uncertainties.

The aim of this paper is analyze and compare the measurement of the 23392 Böhm Type PTW true null spacing by two different procedures: one based on ionization current and the other on the capacitance measurements.

2. MATERIALS AND METHODOLOGY

The international organization for standardization ISO in order to promote international standardization and metrological coherency established four series of reference radiations for dosimeters calibrating and typing-test; Low (L), Narrow (N), Wide (W) and High (H): Call respectively of low Kerma rate series, narrow spectrum series, wide spectrum series and high kerma rate series[3]. The ISO low energy series N characterized by parameters shown in table 1 were used to determine the true null spacing for the PTW 23392 extrapolation chamber in the facilities shows in Figure 1.

To determine the relationship between the extrapolation chamber PTW 23392 ionization current and the distance between the electrodes, measurements of the 60 s accumulated charge were done by varying the distance between 1:00 and 5:00 mm at regular intervals of 0.5 mm. This procedure was performed for each of the ISO low energy qualities-series N.

Table 1 Characterization parameters of ISO low energy x-ray beams - series N

Quality	Spectral Resolution	Mean Energy (keV)	Voltage (kV)	Additional Filtration (mmAl)	1ª Hvl (mmAl)	2ªHvl (mmAl)
N 10	28	8	10	0.1	0.047	0.052
N 15	33	12	15	0.5	0.14	0.16
N 20	34	16	20	1.0	0.32	0.37
N 25	33	20	25	2.0	0.66	0.73
N 30	32	24	30	4.0	1.15	1.30

Figure 1 Experimental facility for determining the true null spacing of PTW 23392 extrapolation chamber for ISO series **N**.

By the other hand, an extrapolation chamber can be viewed as a parallel plate capacitor, which the distance between its plates can vary continuously and accurately.

Capacitance is the ability of a body to store electrical charge. The parallel-plate capacitor is the most common device of energy storage. The capacitance of a parallel plate capacitor, which is defined as the ratio of the charge stored and the voltage applied to the plates, is directly proportional to the area of the conductive plates and inversely to the distance between them, as given by Equation 1.

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} \quad (1)$$

where:

C is the capacitance, in Farads;
A is the area of overlap of the two plates, in square meters;
ε_r is the relative static permittivity or dielectric constant of the material between the plates (it depends on the dielectric material and it varies within wide limits)

ε_0 is the vacuum permittivity ($\varepsilon_0 \approx 8.854 \times 10^{-12}$ F m^{-1});
d is the separation between the plates, in meters;

In this work, capacitance measurements of a 23392 PTW extrapolation chamber were done in absence of the radiation field using an L-C Bridge. The L-C meter operates by measuring the change in frequency when an unknown capacitance is added to an oscillator tank circuit. These capacitance measurements were obtained keeping the relative distance cursor, setting to zero.

The results were compared with measurements performed in LCD/CDTN with the same extrapolation chamber and identical conditions, however obtained by analysis of the ionizing current versus electrodes distance function [4].

3. RESULTS AND DISCUSSIONS

The true null spacing of a 23392 PTW extrapolation chamber was measured in ISO low energy reference X-ray beams. Figures 2, 3 and 4 shows the ionization current versus electrodes distance in the range between 1.0 mm and 5.0 mm [4]

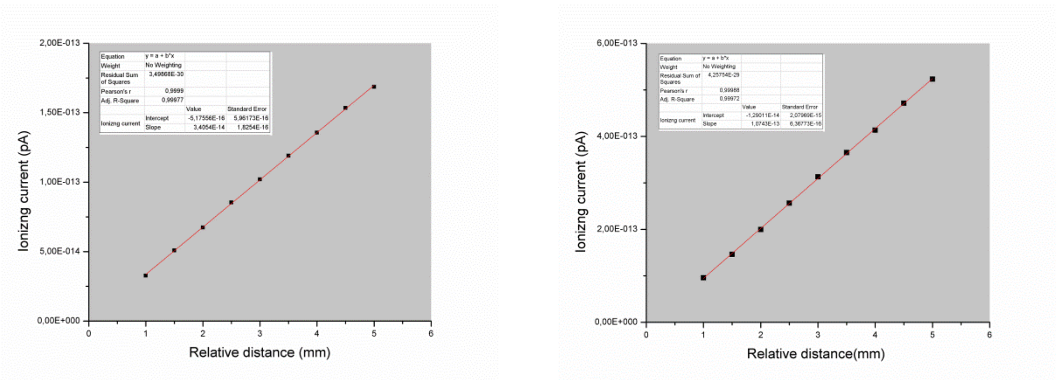

Figure 2 Extrapolation line to determine the true null spacing. ISO reference radiation N 10 (Left side) and N15 (Right side) Source: BASTOS, 2015

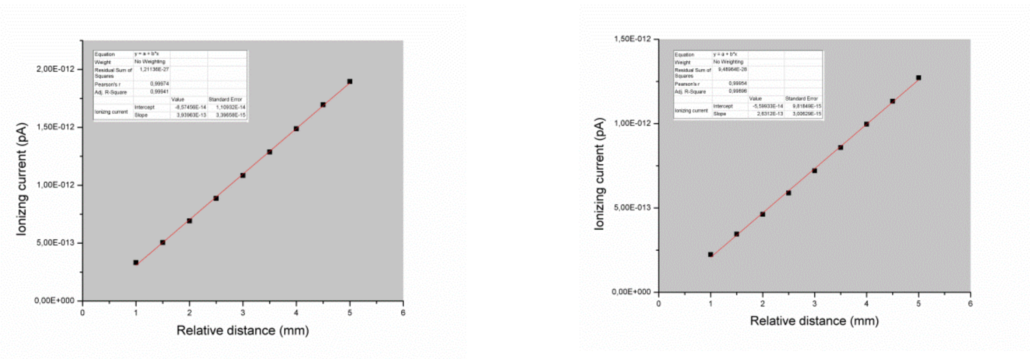

Figure 3 Extrapolation line to determine the true null spacing. ISO reference radiation N 20 (Left side) and N25 (Right side) Source : BASTOS, 2015

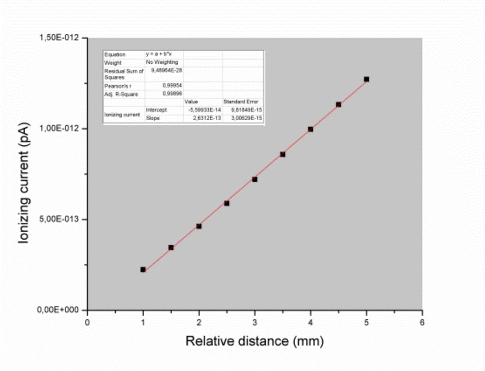

Figure 4 Extrapolation line to determine the true null spacing ISO reference radiation N 30 Source : BASTOS, 2015

Linear fits were done to obtain the fitting equation and determine the true null spacing for each X-ray quality

Table 2 True null spacing of a 23392 PTW extrapolation chamber for ISO low energy X ray reference radiation- series N.

ISO Qualities	Linear Fit Equation	True null spacing (mm)	Relative Expanding Uncertainty (%) (*)
N 10	I=0.034d-0.0005	0.015	1.6
N 15	I=0.108d-0.013	0.121	1.6
N 20	I=0.394d-0.086	0.218	1.6
N 25	I=0.263d-0.056	0.213	1.6
N 30	I=0.394d-0.086	0.065	1,6

* 95% confidence level.

The uncertainties were evaluated by techniques according to the Guide to the Expression of Uncertainty in Measurement. The following sources of uncertainty were considered: standard deviation, thermo-hygrometer resolution, thermo-hygrometer calibration, barometer calibration positioning extrapolation chamber [5]

The second method is based on direct measurement of the capacitance between the electrodes, with the slider set at zero by means of a LC bridge. In this work it was carried out ten measures in identical conditions. Table 3 shows the mean capacitance and the standard deviation.

Table 3 Capacitance of a 23392 PTW extrapolation chamber measured by an LC bridge with the adjustment cursor setting to zero

Mean capacitance (pF)	Standard deviation (pF)
16.5	0.311

From equation (1), explaining *d*,

$$d_{(0)} = \varepsilon_0 \varepsilon_r \frac{A}{C} \qquad (2)$$

Where:

$d_{(0)}$ Is setting zero electrode distance or true null spacing.

In the absence of the radiation field it is assumed that the effective area of the plates is defined by the diameter. According to the manufacturer the diameter is 3.00 mm [2] consequently the overlap area of the two plates is 7.068 cm^2. According to equation (2)

$d_{(0)} = 0{,}3800$

The uncertainties were evaluated by techniques according to in Guide to the Expression of Uncertainty in Measurement and the following sources were considered: capacimeter resolution, standard deviation, capacimeter calibration certified, and micrometer resolution with a 95%, confidence level. Were obtained a 0.3800 mm true null spacing and a 5.56%, relative expanding uncertainty. Thus,

$d_{(0)} = 0{,}3800 \mp 0{,}0211\, mm$

4. CONCLUSIONS

Comparing the results of true null spacing that were determined by the traditional methodology, i.e., by analyzing the experimental relationship between the ionization current and the electrodes relative distance - were observed high sensitivity to the radiation quality which could be partly explained by the loss of proportionality caused by the nonlinear electric field intensity adjustment. Moreover, the use of an LC bridge to capacitance measurement, although it may be considered a more direct method, uses an unusual equipment in calibration laboratories producing results with high uncertainty.

For primary standardization purpose, the accurate determination of true null spacing is very important because it directly impacts the calculation of the sensitive volume of a extrapolation chamber. The radiation quality dependence of the results obtained by the traditional method can be considered as weakness since by definition the true null spacing is just the distance between the electrodes necessary to prevent damage to the measurement procedure and therefore should not be dependent on the quality of ionizing radiation.

ACKNOWLEDGMENTS

Marcus Tadeu Tanuri de Figueiredo is thankful to CNEN for his doctorate fellowship. This work was supported by FAPEMIG (PPM) and CNPQ (PQ); it is part of the project INCT Radiation Metrology in Medicine.

REFERENCES

[1]REYNALDO, S.R. BENAVENTE, J.A. DA SILVA, T.A 2013 Characterization of an extrapolation chamber as a primary standard dosimeter for beta dosimetry. *Scientia Plena 2013* vol 9 pp 081002-6

[*2*]PTW-FREIBURG, 2002. Instruction Manual Extrapolation Chamber according to Böhm Type 23392 Freiburg Germany : s.n. 2002

[3]ISO, INTERNATIONAL ORAGANIZATION FOR STANDARDIZATION .1996. *ISO 4037. X and gamma reference radiation for calibrating dosemeters and dose rate meters and for determining their response as a function of photon energy. Geneva:* International Organization for Standardization 1996.

[4]BASTOS, F.M. Caracterização de feixes de raios X de baixa energia com uma câmara de extrapolação. *Dissertação de Mestrado*. Belo Horizonte: Centro de Desenvolvimento da Tecnologia Nuclear CNEN 2015

[5] INSTITUTO NACIONAL DE METROLOGIA, QUALIDADE E TECNOLOGIA Avaliação de dados de mediçã**o**: Guia para a expressão de incerteza de medição – GUM 2008. Rio de Janeiro: INMETRO/CICMA/SEPIN, 2012. 141p. (Traduzido de: Evaluation of measurement data: guide to the expression. Of uncertainty in measurement – GUM 2008)