Characterization of an extrapolation chamber as a primary standard dosimeter for beta radiation

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Inbeta or electron radiation fields, operational dose equivalent quantities, based on absorbed dose in tissue, are used for radiation protection of the workers. Low penetration and high scattering in matter are characteristics of beta radiation that make its dosimetry more complex. Reliable measurements of absorbed dose in tissue must be traceable to an extrapolation chamber, which is the only primary standard dosimeter available for beta radiation. This ionization chamber uses the extrapolation to zero volume as the method of measurement of absorbed doses in 0.07 mm of tissue, $D_T(0.07)$;its requires the determination of correction factorsrelated to influences from the detector itself and from the radiation field geometry. In this work, a 23392 model PTW extrapolation chamber was characterized by determining its collector electrode area, its true-null depth and the influence in its response of temperature, humidity and chamber depth. Values of the true-null depth were 0.46±0.04 mm and 0.40±0.04 mm for $^{90}Sr/^{90}Y$ and ^{85}Kr beta field sources, respectively. Corrections of the chamber ionization current, according to the ideal gas law significantly reduced the high influence of temperature; air humidity influence showed to be negligible within the 50% to 70% range. The high dependence of the chamber response with its volume addressed the need to determine accurately its true-null depth. These results are to be used as appropriate corrections for accurate absorbed dose in tissue determination.

Keywords: extrapolation chamber, beta radiation dosimetry, primary standard dosimeter.

1. INTRODUCTION

The ionization chamber that uses extrapolation to zero volume as a method of measurement is the only existing primary standard for measuring absorbed doses in 0.07 mm depth of tissue, $D_T(0.07)$, in beta radiation fields. The extrapolation chamber requires quantitative determination of various influence factors caused by the presence of the detector (i.e. scattering of the beam at the chamber entrance window, beam divergence, attenuation in bulk collector), the difference between the detector material and the human tissue and its response properties in beta radiation fields. Some correction factors can be experimentally determined [1] but others have to be calculated by computational methods [2].

The Böhmtype extrapolation chamber is a high precision device which may be used to determine absorbed dose for X-rays generated at potentials higher than 7.5 kV and for electrons of average energy higher than 5 keV [3]. The absorbed dose rate in extrapolation chamber measurements is calculated from the slope $\Delta I_c/\Delta d$ of the extrapolation curve by Bragg-Gray cavity theory as Equation 1.

$$D_T = s_{T,air}\frac{W}{e}\left(\frac{\Delta I_c}{\Delta d}\right)\frac{1}{(\rho_0 \cdot A)} \qquad (1)$$

where,W/eistheenergy required to produce an ion pair in air;
$s_{T,air}$is theratio of the average mass stopping power of tissue and dry air;
ρ_0 is the density of dry air at reference ambient conditions;
A isthe area of the collecting electrode;
$I_c$is the corrected ionization measured by the chamber;
d is the depth of the extrapolation chamber volume.

The corrected ionization current, I_c, is given by Equation 2.

$$I_c = I \prod_i C_i \quad \prod_j k_j \quad (2)$$

where I is the measured ionization current, C_i are correction factors related to the use of specific chamber with a particular beta-particle spectrum, and k_j are correction factors relate to environmental conditions and source properties [4].

The main objective of this work was to characterize the 23392 model PTW extrapolation chamber by determining its collector electrode area, the true-null depth and the influence factor of temperature and humidity for different chamber depths.

2. METHODS AND RESULTS

In this work, the 23392 Böhm model PTW extrapolation chamber was used (Fig.1). It is composed of one fixed parallel plate electrode and one adjustable by an external micrometer. The distance between the electrodes varies from 0.05 to 10.5 mm, with parallelism accuracy of ± 1μm, which corresponds to a change in chamber volume of 0.353 to 7.422 cm^3. The 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 diameter is of 60.5 mm [5].

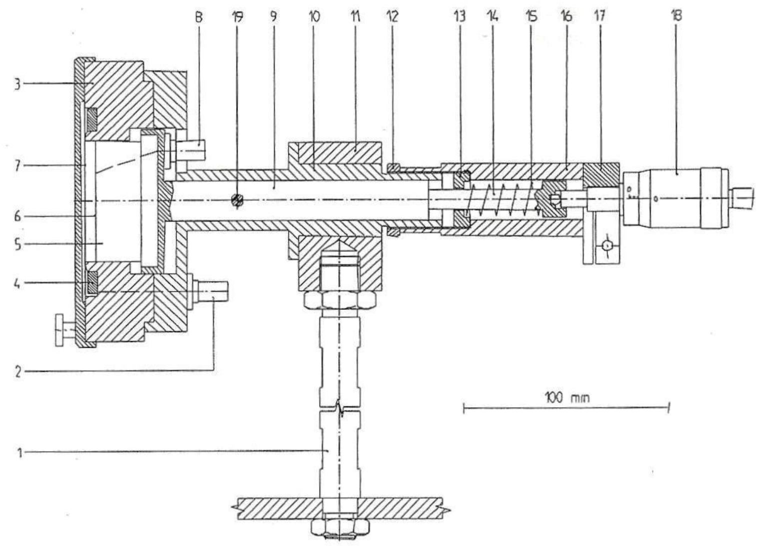

Figura 1: Cross section of the Böhm type extrapolation chamber. 1: stand, 2: polarizing voltage socket, 3: acrylic housing, 4: tension ring, 5: acrylic block, 6: graphite coated surface, divided into collecting electrode and guard ring, 7: entrance foil, 8: collecting electrode socket, 9: sliding-fit rod, 10: central guide for rod, 11: holder, 12: nut, 13: threaded ring, 14: bolt, 15: spring, 16: tube, 17: clamp, 18: micrometer screw, 19: pistonlocking screw.
Source: [5]

2.1 Choice of the electrical field

The choice of the electrical field to be applied to the extrapolation chamber was done based on two procedures: a 30 V/mm voltage was used according to the chamber manual [5] and 10 V/mm according to Caldas [6]. The $^{90}Sr+^{90}Y$ beta radiation field was used without a flattening filter; measurements were done with the chamber at 30 cm from the reference point of the radiation source. The chamber depth was varied from 1.0 to 9.0 mm in increments of 0.5 mm. All ionization current values were normalized for reference temperature and pressure (20°C and 101.3 kPa) and they were repeated 10 times for each depth and polarity of the chamber.

Figure 2 shows the results of the ionization current for different chamber depths under the two voltages and for positive and negative polarities.Since no significant difference in the ionization currents within the range from 1 to 9 mm depth was observed, it was chosen to adopt the 30 V/mm electrical fieldfor the $^{90}Sr+^{90}Y$ beam.

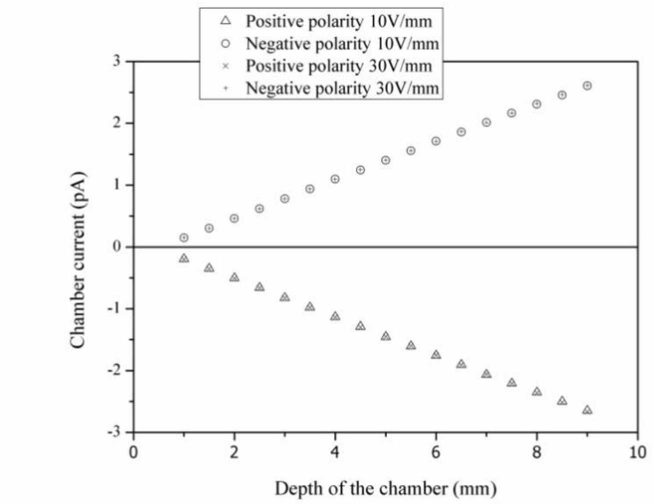

Figura 2: Response of the 23392 PTW extrapolation chamber for 10 and 30 V/mm with different depths and polarities in$^{90}Sr+^{90}Y$ betaradiationbeam.

2.2 Area of the collecting electrode

The effective area of the collecting electrode of the extrapolation chamber was analytically calculated according to the geometrical dimensions and permissiveness of the medium. In the case of a parallel plate capacitor, filled by only one dielectric medium, the capacitance C is given by Equation 3.

$$C = \varepsilon_0 \varepsilon \frac{a_{ef}}{d} \tag{3}$$

where, ε_o is the vacuum permissiveness equals to 8,85419 x 10^{-12} F/m;

ε is the relative permissiveness of the air, at 20ºC and 101.3kPa, equals to 1.000594;

a_{ef} is the effective area of the parallel plate electrode;

*d*is the distance between the capacitor plates.

The effective area of the parallel plate electrode, a_{ef}, is given by Equation 4, where *b* is the angular coefficient of the extrapolation line of the response of the chamber for different depths.

$$a_{ef} = \frac{1}{\varepsilon_0 \cdot \varepsilon \cdot b} \tag{4}$$

The extrapolation line showed in Fig.3 was obtained with the chamber in the$^{90}Sr/^{90}Y$ radiation beam without flattening filter, at 30 cm distance from the radiation source, with depths from 1.0 to 2.5 mm in steps of 0.5 mm and with 30 V/mm.Based on Equation 4 and parameters of the extrapolation line, the area of the collecting electrode was calculated as 0.072 cm^2.

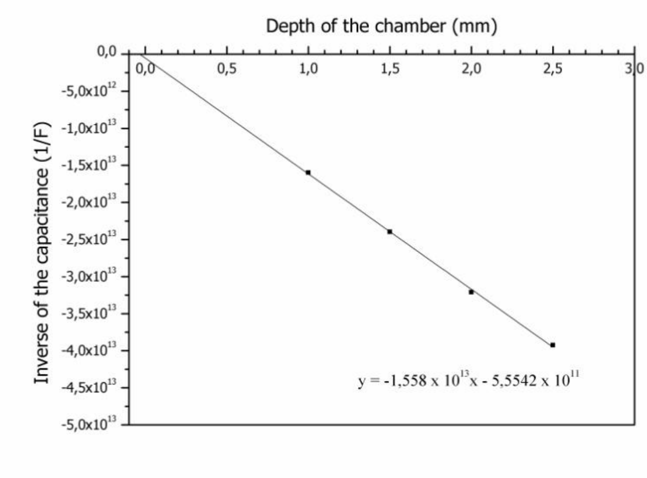

Figura 3: Extrapolation line of the 23392 PTW chamber in $^{90}Sr/^{90}Y$ beta radiation beam.

2.3 True-null depth

The true-null depthof the extrapolation chamber isthe minimum distance betweenthe electrodes in which they do not touch each otheravoiding any damagetothe window of the chamber. It was determined by a graphical method of the measured ionization currents in both voltage polarities at different depths that were given by the nominal readingsin the chamber micrometer [4].

Fig. 3 shows the results of the extrapolation line for both 30 V/mm polarities, in the ^{90}Sr/^{90}Y and the^{85}Kr without and radiation beams, respectively; all measurements were done at 30 cm chamber to radiation source distance.Results showed that up to 4 mm depth the ionization current had a linear behaviour; the true-null depth of the chamber was determined as (0.46± 0.04) mm and (0.40± 0.04)mm for ^{90}Sr/^{90}Y and ^{85}Kr beta radiation beams, respectively.

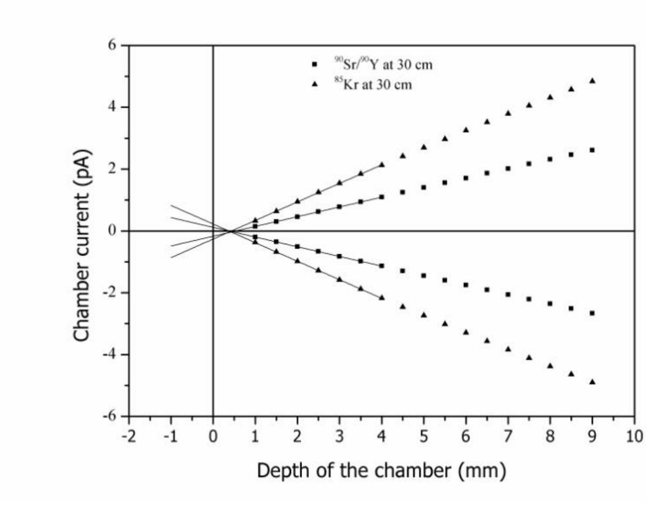

Figura 4: Truenull depth the 23392 PTW extrapolation chamber in the without filter $^{90}Sr/^{90}Y$ and with filter^{85}Kr radiation beams.

2.4 Evaluation of the influence of temperature, humidity and volume of the chamber

The influence of the temperature, humidity and the size volume of the chamber in the response of the chamber were investigated using a climatic chamber and according to international recommendations [7]. Standard conditions of test were within 18ºC to 22ºC and 50% to 75% relative humidity. Measurements were done for thecollector electrodedistances of the chamber equal to 2.0; 5.0and10.0mm and anelectric fieldof30V/mm. A ^{90}Sr/^{90}Y radiation source was placedin a fixed geometry close to the entrancewindow of thechamber. Ten measurementswere performedfor each set oftemperature-humidity-depth combinations. Statisticalanalysis was performedin two set of measurements using a factorial design 2^3, by means of the array (Tab. 1),to study theeffect in the ionization currentof temperature,humidityand chamber depthvariations [8].

Table 1 – Array of the influence study of the temperature, humidity and depth of the chamber in the ionization current measured by the 23392PTW extrapolationchamber.

Factors		(-)	(+)
1	Temperature (ºC)	18	22
2	Humidity (%)	50	75
3	Depth of the chamber (mm)	2	5

Test	**1**	**2**	**3**	**Ionization current (nA)**		**Mean value (nA)**	**Variance $(nA)^2$**
				set 1	**set 2**		
1	-	-	-	0.341	0.341	0.341	1.744E-08
2	+	-	-	0.411	0.411	0.411	8.215E-08
3	-	+	-	0.341	0.341	0.341	4.489E-08
4	+	+	-	0.414	0.414	0.414	9.526E-08
5	-	-	+	0.866	0.866	0.866	5.549E-08
6	+	-	+	1.021	1.021	1.021	9.420E-10
7	-	+	+	0.858	0.858	0.858	2.516E-08
8	+	+	+	1.033	1.032	1.033	1.478E-07

Effects were considered statistically significant if the effect influence is higher than standard error of 0.171 pA, which is the product of the square root of aggregated variance by the t-Student at95% confidence level for eight freedom degrees. In case of values without the correction to reference temperature the effect influence is 0.395pA and 0.025 pA for corrected measurements.

The results of the main and interaction effects of the influence quantities (temperature, humidity and depth of the chamber) are shown in Tab. 2; it is the product of the influence quantity matrix by the mean ionization current matrix with and without normalization to the reference temperature.

Table 2 – Results of main and interaction effectsof the influence quantities in the measured ionization current in the 23392PTW extrapolationchamber – factorial designs 2^3.

	Ionization current (pA)	
	Without temperature correction	**With temperature correction**
Main effects		
Temperature	118.21±0.39	0.10±0.025
Humidity	1.72±0.39	-0.18±0.025
Depth of the chamber	567.85±0.39	28.17±0.025
Interaction effects		
Temperature/Humidity	5.46±0.39	0.14±0.025
Temperature/Depth	46.76±0.39	-0.11±0.025
Humidity/Depth	-0.01±0.39	-0.19±0.025
Temperature/Humidity/Depth	4.08±0.39	0.16±0.025

A comparison between the values of Tab. 2 with the uncertainty values of the effects of the influence quantities (0.395 pA and 0.025 pA)showed that the temperature effect has higher significance than the humidity influence when no correction to the reference temperature is done.Results also showed that ionization current values are highly dependent on the depth of the chamber. On the other hand, humidity has shown no significant effect on measurements.

3. CONCLUSION

Characterization of the 23392PTW extrapolationchamberwas done and it resulted in establishing the 30 V/mm electrical field to be used and the true-null depth of thechamber of(0.46± 0.04)and (0.40± 0.04)mm for $^{90}Sr/^{90}Y$ and^{85}Kr, respectively. Corrections of the ionization current to the reference temperature based on the ideal gas law are mandatory to reduce its influence effect. Humidity is less significant and it is enough to keep it within the 50% to 75% range. Direct dependence of the ionization current with the depth of the chamber was demonstrated and corrections due to the true-null depth must be considered.

4. ACKNOWLEDGMENTS

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