Preliminary tests of a commercial extrapolation chamber for utilization as a beta radiation standard system

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Abstract. Characterization tests were applied on a Böhm extrapolation chamber, PTW, model 23392. For this purpose, the presence of leakage current was investigated; the response stability, and saturation curves to different chamber depths were obtained. From these curves the polarity effect, the ion collection efficiency and the ion recombination of the extrapolation chamber were determined. A $^{90}Sr+^{90}Y$ radiation source, from the beta secondary standard system (BSS2) of LCI was utilized in all measurements. The objective of this work was to verify the performance of this extrapolation chamber in beta radiation fields, for its later application as a primary standard system in the calibration of beta radiation sources and detectors.

1 Introduction

The extrapolation chamber differs from other parallel plate ionization chambers by the presence of a micrometer screw and, consequently, allowing to vary its active volume (or sensible volume), enabling measurements in different chamber depths (distance between the entrance window and the collecting electrode). The extrapolation chambers are used, since their creation, to measure absorbed dose rates in a solid medium. By means of extrapolating their response to zero volume, it is possible to determine the absorbed dose rate at the skin surface and to different tissue depths [1,2].

The extrapolation chambers are recommended for the detection of beta radiation, besides low energy X-rays. They are primary standard devices for specifying absorbed dose rates in beta radiation reference fields. Therefore, they are used for beta dosimetry in metrology laboratories for the precise and absolute determination of absorbed dose rates to water [3,4].

The Calibration Laboratory at IPEN (LCI) has a Böhm extrapolation chamber, PTW. It is an instrument of high precision, which can be used as a primary or a secondary standard system [5]. This instrument will be established at LCI as a primary standard system for the calibration of beta radiation sources and detectors.

Ionization chambers have to be characterized before their routine application. The determination of these characteristics is important to establish parameters and work conditions.

In this work, the objective was to verify the performance of a Böhm extrapolation chamber during the application of essential characterization tests, analyzing its possible application as a primary standard system in the calibration of beta radiation sources and detectors.

2 Materials and Methods

In this work, a parallel plate ionization chamber, of the extrapolation type, was used. The Böhm extrapolation chamber, from Physikalisch-Technische Werkstätten (PTW), Freiburg, model 23392, was manufactured to be used as a primary or secondary standard system for calibration of beta radiation detectors and sources. The chamber has aluminized Lucite, polymethyl methacrylate (PMMA) graphited collecting electrode (diameter of 30 mm), and entrance window of aluminized Mylar (superficial density of 0.71 mg/cm^2). A micrometer screw coupled to the chamber allows the variation between the electrodes (entrance window and collecting electrode) of 0.5 to 10.5 mm, and consequently a variation in the air volume of 0.353 to 7.422 cm^3 [5]. This chamber can be seen in Figure 1.

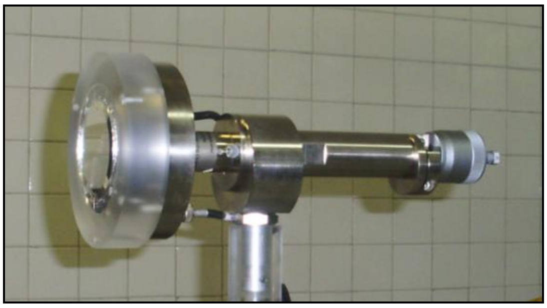

Fig. 1. Böhm extrapolation chamber studied in this work when exposed to the beta radiation secondary standard system ($^{90}Sr+^{90}Y$).

During the characterization tests performed in this work (leakage current, stability of response and saturation curves) the measurements were taken in terms of electric charge using an electrometer from Keithley Instruments Inc., model 6517B (Fig. 2). In all cases, correction factors for the standard environmental conditions of temperature and pressure were applied to the ionization current values.

Fig. 2. Electrometer from Keithley Instruments Inc., model 6517B, used in this work in the characterization tests of the Böhm extrapolation chamber.

For the study of the stability of response of the chamber, and in the saturation curve tests, a $^{90}Sr+^{90}Y$ beta source (1850 MBq, 1981), from the beta secondary standard system of LCI, BSS1, Buchler & GmbH, Germany, was utilized. During the tests, the source was used without its field flattening filter and at the specific distances, according to its calibration certificate. The main characteristics of this source are presented in Table 1.

Table 1. Characteristics of the $^{90}Sr+^{90}Y$ beta radiation source used in this work.

Standard System	**Source**	**Nominal Activity (MBq)**	**Mean Beta Energy (MeV)**	**Absorbed Dose Rate in Air (µGy/s)**	**Calibration Date**
BSS1	$^{90}Sr+^{90}Y$	1850	0.80	70.60 ± 0.71	04.02.1981

3 Results

The characterization tests of the extrapolation chamber were performed, as leakage current without exposing the chamber to radiation, stability of response and saturation curves, in order to verify its performance in standard beta radiation beams.

3.1 Leakage Current

The leakage current test was performed taking measurements of electric charge using the chamber without exposing it to any radiation source, during a time interval of 20 min, with the applied voltage of + 10 V, and maintaining the chamber depth fixed at 1.0 mm.

The maximum leakage current obtained in all measurements was only 0.06%. The IEC 60731 standard [6] recommends for the leakage current test a limit of 0.5% of the highest measured value during an irradiation, in the case of ionization chambers for radiotherapy level. Therefore, the result obtained in this work was within the expected limit.

3.2 Stability of Response

The stability of response of the Böhm extrapolation chamber when exposed to the $^{90}Sr+^{90}Y$ source (1850 MBq, 1981) was verified by means of two tests: repetitivity (short-term stability) and reproducibility (medium-term stability).

The repetitivity test was performed with the chamber at the source-detector distance of 11.0 cm, and in all repetitivity measurements, the extrapolation chamber was studied using a depth of 1.0 mm. In this test, ten electric charge readings were taken applying a voltage of ± 10 V to the chamber, and a constant electric field of 10 V/mm, according to other studies [7,8]. The measurements were taken during a time interval of 60 s. In this test, the maximum variation coefficient obtained was 0.2%, and the IEC 60731 standard [6] recommends a limit of 0.3 % for this test.

The reproducibility test was obtained from the evaluation of the results of successive repetitivity tests. For this study, the IEC 60731 standard [6] recommends a limit of 0.5%, and in the case of this work, the result obtained was 0.4%, agreeing with the recommended value.

The normalized results of the two stability tests can be observed in Fig. 3.

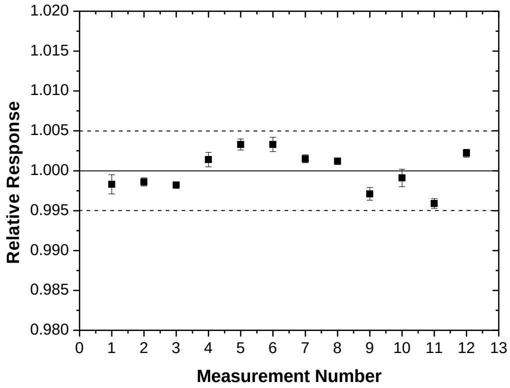

Fig. 3. Medium-term stability test of the Böhm extrapolation chamber, using the $^{90}Sr+^{90}Y$ check source.

3.2 Saturation Curve, Ion Collection Efficiency and Polarity Effect

In this work, saturation curves were obtained for three different chamber depths (0.7, 1.5 and 2.5 mm), in order to compare the performance of the extrapolation chamber in different voltages, and to determine the polarity effect in each case. Furthermore, the saturation curves were obtained and studied for the determination of the more adequate operation voltage to use in the measurements with the extrapolation chamber.

For the experiments, the voltage applied to the electrode of the chamber was varied from ± 2 V to ± 300 V. The source-detector distance used was 11 cm, and the electric charge measurements were collected during 60 s. The values of the mean ionization current obtained for both polarities for each one of the saturation curves can be seen in Table 2. The three saturation curves were plotted in the same Figure 4, as in other studies that reported about saturation curves in different chamber depths [9,10], in order to verify their behavior.

Table 2. Mean ionization current obtained for the positive and negative polarities with the Böhm extrapolation chamber, and for three chamber depths.

Chamber Depth (mm)	Mean Ionization Current (pA)		Maximum Variation Coefficient (%)
	Positive Polarity	Negative Polarity	
0.700	+3.562 ± 0.016	-5.188 ± 0.024	2.33
1.500	+8.573 ± 0.020	-9.222 ± 0.023	2.18
2.500	+14.56 ± 0.029	-14.68 ± 0.032	2.58

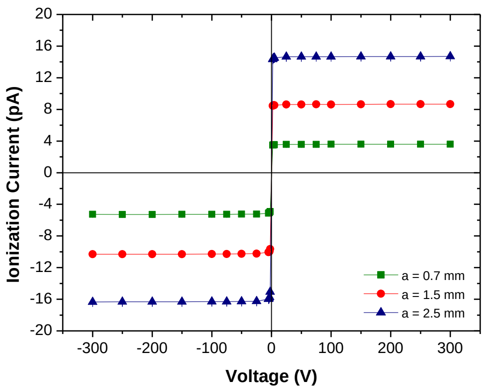

Fig. 4. Saturation curves of the extrapolation chamber, with three different chamber depths (a).

From each saturation curve, it was possible to determine the saturation current for each chamber depth. This current, I_s, can be obtained from the graphic relating the ionization current measured in relation to the inverse square-root of the voltage values applied to the chamber electrode during the measurements of the saturation curve, and extrapolating the values obtained to infinite voltage. The saturation currents, which are shown in Fig. 5, are essential for the calculation of another important characteristic of the extrapolation chamber, the ion collection efficiency.

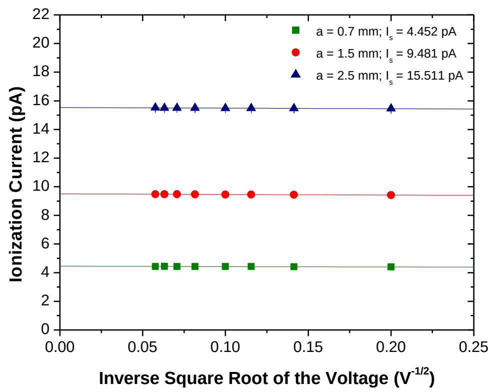

Fig. 5. Saturation currents, I_s, obtained from the saturation curves of the Böhm extrapolation chamber, a = chamber depth.

The ion collection efficiency, *f*, is calculated by the Eq. 1 [7,8,10]:

$$f = \frac{I}{I_s} \tag{1}$$

where:
f = ion collection efficiency;
I = mean ionization current (pA) measured to both polarity voltages;
I_s = ideal saturation current (pA), obtained from the saturation curves (Fig. 5).

The results obtained for the ion collection efficiencies (chamber depths of 0.7, 1.5 and 2.5 mm) showed that the extrapolation chamber only achieved saturation in the case of its depth at 2.5 mm, and for the voltage equal to ± 300 V. However, the results of the chamber in the three chamber depths may be considered satisfactory, because in all three cases the chamber response achieved more than 99.0% of ion collection efficiency at the voltage of 25 V that is the recommended limit by the IEC 60731 standard [6] for this test. These results agree with those obtained by Caldas [7]. The maximum ion collection efficiencies were 99.49%, 99.98% and 100.0%, for the chamber depths of 0.7, 1.5 and 2.5, respectively, and for a voltage of 300 V.

From the ion collection efficiency, the losses by ion recombination that occur within the active volume of the extrapolation chamber can be determined. Considering the ion collection efficiency, the ion recombination was less than 1%, just the limit recommended by the IEC 60731 standard [6].

The polarity effect of the Böhm extrapolation chamber was studied for the three chamber depths. This factor demonstrates the variation that occurs in the values of ionization currents obtained for voltages in positive and negative polarities. The polarity effect was calculated by means of the Eq. 2 [9]:

$$k_{pol} = \frac{(I_- + I_+)}{(I_- - I_+)} \tag{2}$$

where:
k_{pol} = polarity effect;
I_+ = ionization current measured at the positive polarity;
I_- = ionization current measured at the negative polarity.

The results obtained demonstrate that the polarity effect decreases with the increase of the chamber depth. The IEC 60731 standard [6] recommends for this test the value of 1.0% for the polarity effect, but the results of this work are still acceptable, because in the case of beta radiation there is the presence of an ionization current originated at the moment in which the particles interact with the entrance window of the extrapolation chamber. Böhm [9] obtained polarity effects higher than 1.0% in measurements with a Böhm extrapolation chamber. Furthermore, the same behavior was observed in a report of the National Institute of Standards and Technology (NIST), during the calibration procedure of a Böhm extrapolation chamber in standard secondary beta radiation beams [12]. In Table 3 the maximum polarity effect obtained in this work for each chamber depth can be observed. Figure 6 shows the relation between polarity effect and active volume of the chamber obtained in this work, and compared with the NIST results [12].

Table 3. Polarity effects of the Böhm extrapolation chamber to different chamber depths.

Chamber Depth (mm)	Polarity Effect (%)
0.700	19.0
1.500	8.79
2.500	5.33

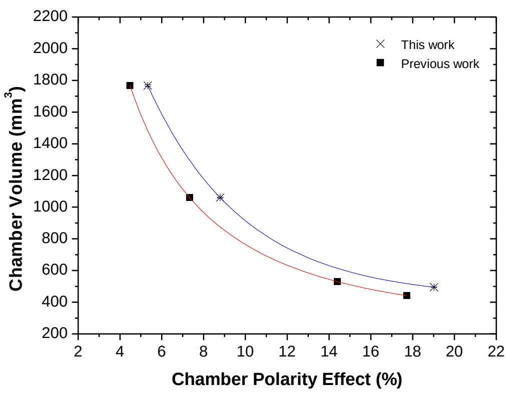

Fig. 6. Polarity effect as a function of the chamber volume, obtained for two Böhm extrapolation chambers: one of this work, and the other calibrated at NIST.

4 Conclusion

A commercial extrapolation chamber, the Böhm extrapolation chamber, was tested in the beams of a $^{90}Sr+^{90}Y$ secondary standard beta radiation. The response of this chamber was verified by means of characterization tests, as leakage current, stability of response and saturation curves, with the objective of analyzing the possibility of its use as a primary system at LCI in the calibration of beta radiation sources and detectors. The results obtained for the leakage current showed the absence of this current that might disturb the measurements; the stability test showed that the chamber response is good and stable. The saturation curves allowed defining the voltage gradient as 25 V/mm, because for this voltage value the ion collection efficiency was higher that 99.0%. These curves were obtained for three different chamber depths, and it was observed that the ion collection efficiency decreases with the increase in the chamber volume, and consequently, the distance between the chamber electrodes.

Therefore, the extrapolation chamber responded in a satisfactory manner to the performed preliminary tests, showing the possibility of its use as a primary standard system, as expected.

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