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Determination of transmission factors in tissue using a standard extrapolation chamber

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HIGHLIGHTS

- Böhm extrapolation chamber was tested to be used as a primary standard system.
- The chamber was exposed to the three $^{90}Sr+^{90}Y$ secondary standard sources.
- Transmission factors were obtained.
- Absorbed dose rates were determined using the sources at certificate conditions.
- The results showed the good performance of the extrapolation chamber.

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ABSTRACT

A commercial ionization chamber, Böhm extrapolation chamber, PTW, model 23392, recommended for measurements in low energy X-rays and beta radiation fields, was tested in three different $^{90}Sr+^{90}Y$ beams to verify its performance as a primary standard system for the calibration and dosimetry of beta radiation sources and detectors. Characterization tests were performed, as determination of the chamber null depth using two methods (the results presented a difference of only 0.9%), transmission factors in tissue, in comparison with those of the certificate (the maximum difference was 2.1%), and absorbed dose rates of the $^{90}Sr+^{90}Y$ sources, in comparison with the values provided by the calibration certificates (the maximum difference was 4.90%). The results obtained confirmed that this extrapolation chamber presents a very good behavior in beta radiation fields as a primary standard system.

1. Introduction

Beta radiation is usually specified in terms of absorbed dose rates, and the adequate and designed instrument for this purpose is the extrapolation chamber (Böhm, 1986; ISO, 2004).

Böhm (1986) tested an extrapolation chamber, and established it as the German primary standard at the Physikalisch-Technische Bundesanstalt (PTB), Germany, for the determination of the absorbed dose rate in tissue. Afterward, this chamber was manufactured and commercialized by Physikalish-Technische Werkstätten (PTW), and named Böhm extrapolation chamber. It was manufactured to be used as a primary or secondary standard system for calibration of beta radiation detectors and sources (PTW, 2002).

In beta radiation dosimetry, and in the calibration of beta radiation sources and detectors, two of the characteristics to be determined are the transmission factors in tissue, and absorbed dose rates in air (Caldas, 1986), or in tissue (water) (ISO, 2004).

The Calibration Laboratory (LCI) at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) received a Böhm extrapolation chamber to establish as a primary standard system for calibration of beta radiation sources and detectors.

This work has the purpose to determine transmission factors in tissue using a Böhm extrapolation chamber, in $^{90}Sr+^{90}Y$ beams. Furthermore, absorbed dose rates in air were also determined using three $^{90}Sr+^{90}Y$ sources, in comparison with those provided in the calibration certificates. With the obtaining of the transmission factors and the absorbed dose rates, it was possible to verify the possibility of application of the Böhm extrapolation chamber as a primary standard system to the dosimetry and calibration of beta radiation detectors and sources. As there is no primary standard laboratory for beta radiation in Brazil yet, these results present a great importance to the LCI (IPEN), since a primary standardization using this extrapolation chamber was established in this work.

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Table 1
Main characteristics of the Böhm extrapolation chamber used in this work (PTW, 2002).

Extrapolation chamber	Characteristics	
Chamber body	Aluminum	
Entrance window	Material	Mylar
	Density superficial (mg/cm^2)	0.71
	Diameter (mm)	60.5
Collecting electrode	Material	Polymethyl methacrylate (PMMA) graphited
	Diameter (mm)	30
	Area (cm^2)	7.16
Insulation ring	Thickness (mm)	0.2
	Width (mm)	0.2
Micrometer screw*	Chamber depth interval (mm)	0.5–10.5

* Distance variation between the entrance window and the collecting electrode (from 0.5 mm to 10.5 mm, corresponding to a variation in the air volume from 0.353 cm^3 to 7.422 cm^3).

2. Experimental

The Böhm extrapolation chamber, PTW, model 23392, was the instrument of study in this work. The main physical characteristics of this chamber are presented in Table 1.

During the data collection, the measurements were always taken in terms of electric charge, using an electrometer from Keithley Instruments Inc., model 6517B. Correction factors were applied to the final ionization current values in order to correct them for the standard environmental conditions of temperature and pressure. In all measurements, the electric field applied to the chamber was always kept constant at 10 V/mm (Caldas, 1986; ISO, 2004).

The LCI has two beta secondary standard systems: BSS1, Buchler GmbH, & Co., Germany, and BSS2, Isotrak, Germany. During the determination of the chamber null depth, the transmission factors and absorbed dose rates, all three ^{90}Sr+^{90}Y sources of these systems were used. In Table 2 the characteristics of the ^{90}Sr+^{90}Y sources can be observed (PTB, 1981a, 1981b, 2005), emphasizing that the absorbed dose rates of the calibration certificates of the BSS1 sources are given at null tissue depth ($\dot{D}_t$ $(d=0)$), and the BSS2 sources are provided in 0.07 mm of tissue depth ($\dot{D}_t$ $(d=0.07)$).

2.1. Chamber null depth

The chamber null depth, d_0, is an important factor to be determined, because it represents the minimum distance between the electrodes. Furthermore, this value is necessary for correction of the chamber depth.

The determination of the chamber null depth was obtained using a method described by Caldas (1986), exposing the chamber to the ^{90}Sr+^{90}Y source (1850 MBq), at the calibration distance of 11 cm (source-detector). The chamber depth varied in the interval of 0.5–3.0 mm, in steps of 0.5 mm; therefore, the voltage applied to the extrapolation chamber varied from 5 V to 30 V, in both polarities.

2.2. Transmission factors

In relation to the determination of the transmission factors, the measurements were taken using the ^{90}Sr+^{90}Y source (1850 MBq), and with the chamber at the calibration source-detector distance of 30 cm, and chamber depth fixed at 1.0 mm (voltage applied of $\pm$10 V). Eight absorbers of Hostaphan were used, RN 8–RN 300 (corresponding of 8–300 μm), and two absorbers of Plexiglas of 1.0 mm and 2.0 mm. The measurements were also taken without any absorber. The absorbers were positioned as near as possible of the chamber entrance window.

Table 2
Characteristics of the ^{90}Sr+^{90}Y beta radiation sources used in this work, according to their calibration certificates.

Beta system	Nominal activity (MBq)	Filter presence	Absorbed dose rate (μGy/s)	Calibration date
BSS1	74	Yes	1.70 ± 0.02	Jan 12, 1981
	1850	No	7.60 ± 0.71	Feb 4, 1981
BSS2	460	Yes	10.6 ± 0.14	Dec 8, 2004
	460	No	16.5 ± 0.22	Jan 12, 2005

To determine the transmission factor in tissue, it is necessary to use an equivalence relating the absorber materials with tissue. The equivalence between Hostaphan and tissue is 10.8 mg/cm^2 Hostaphan to10.0 mg/cm^2 tissue (Owen, 1973); the relation to Plexiglas and tissue is 10.4 mg/cm^2 Plexiglas to 10.0 mg/cm^2 tissue (Caldas, 1980). Using these relations, the superficial density to Hostaphan in tissue varied between 0.660 mg/cm^2 (without absorber) and 39.55 mg/cm^2 (RN 300). In the case of the Plexiglas material, the superficial density in tissue was 114.12 mg/cm^2 for only 1.0 mm absorber, and 227.58 mg/cm^2 for 2.0 mm. It is also necessary to convert the superficial density of the entrance window material, Mylar, in tissue; the following relation was used: 10.8 mg/cm^2 Hostaphan to 10.0 mg/cm^2 tissue (Pinto, 2010).

For the determination of the transmission factors, T', it is necessary to relate the ionization currents, $I(d_0)$, and the superficial densities in tissue; from this relation, the ionization current extrapolated to a null superficial density, $I(0)$, can be determined, and the transmission factors can be obtained by means of Eq. (1) (Caldas, 1980)

$$T' = I(d_0)/I(0) \tag{1}$$

However, to these transmission factors a correction factor, k_d, has to be incorporated, relating the source-detector distance (30 cm) a, and the absorber thickness a_1, due to the use of different absorbers. This correction factor can be calculated by Eq. (2) (Caldas, 1980)

$$k_d = (a - a_1)^2/a^2 \tag{2}$$

Thus, the final transmission factors, T, can be obtained by Eq. (3) (Caldas, 1980)

$$T = T'k_d \tag{3}$$