INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **50** (2005) 2929–2936 doi:10.1088/0031-9155/50/12/013

A special mini-extrapolation chamber for calibration of ^{90}Sr+^{90}Y sources

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Received 2 February 2005, in final form 30 March 2005
Published 1 June 2005
Online at stacks.iop.org/PMB/50/2929

Abstract

^{90}Sr+^{90}Y applicators are commonly utilized in brachytherapy, including ophthalmic procedures. The recommended instruments for the calibration of these applicators are extrapolation chambers, which are ionization chambers that allow the variation of their sensitive volume. Using the extrapolation method, the absorbed dose rate at the applicator surface can be determined. The aim of the present work was to develop a mini-extrapolation chamber for the calibration of ^{90}Sr+^{90}Y beta ray applicators. The developed mini-chamber has a 3.0 cm outer diameter and is 11.3 cm in length. An aluminized polyester foil is used as the entrance window while the collecting electrode is made of graphited polymethylmethacrylate. This mini-chamber was tested in ^{90}Sr+^{90}Y radiation beams from a beta particle check source and with a plane ophthalmic applicator, showing adequate results.

Introduction

Beta radiation sources are widely utilized in brachytherapy, including ophthalmic, dermatological, intracranial and intravascular procedures. Because of the low penetration of beta particles in matter, sources of ^{90}Sr+^{90}Y are utilized in the treatment of superficial lesions of the eyes and skin. Since the 1950s, ^{90}Sr+^{90}Y sources have been utilized in the postoperative treatment of pterigya, fibrovascular proliferative tissues that can cover the cornea, causing visual disturbances, and may result in blindness (Monteiro-Grillo *et al* 2000). The applicators used in brachytherapy consist of silver cups, plane or concave, containing the radioisotopes incorporated onto them. Each silver cup has a thin metallic covering to remove low-energy beta particles emitted by ^{90}Sr, so the emitted spectrum resembles pure ^{90}Y. Plane sources are typically about 10–12 mm in diameter while concave sources range from 9 to 23 mm in diameter and 10 or 15 mm of curvature radius. The applicators have a special plastic shield to protect the operator. Usually the total dose to be delivered to the surface is fractioned in

several radiation therapy sessions, less than 1 min each; during the session, the applicator is put manually in contact with the area where the pterygium was removed from (ICRU 2005).

The recommended instruments for the calibration of these applicators are special ionization chambers, called extrapolation chambers. The first extrapolation chamber was proposed by Failla (1937), but since then many modifications have been made. Extrapolation chambers were developed for orthovoltage (Genna *et al* 1956) and megavoltage (Klevenhagen 1991, Manson *et al* 1975) therapy machines; low-energy x radiation beams (Böhm and Schneider 1986, Dias and Caldas 2001) and for radiotherapy beams (Genna and Laughlin 1955). These chambers allow the variation of their sensitive volume through a change of the distance between the chamber electrodes (collecting electrode and chamber entrance window). This distance, and consequently the air volume inside the chamber, should be sufficiently small to not disturb the beta particle flux, satisfying the Bragg–Gray conditions. The ionization current produced is measured as a function of the distance between the electrodes and by extrapolating this function to null distance, it is possible to determine the absorbed dose rate to water.

According to international recommendations (ICRU 2005, IAEA 2002), the ^{90}Sr+^{90}Y applicators should be specified in terms of the reference absorbed dose rate to water at a reference point (1 mm from the source surface, along its symmetry axis). The materials constituting the chamber should be water equivalent, such as polymethylmethacrylate and carbon (ICRU 1984) to simulate appropriately the transmission and backscattering properties of beta particles in water. For clinical applications, the source uniformity and the dose distribution shall be provided as additional specifications for these sources (ICRU 2005, Soares *et al* 2001, De Almeida *et al* 2000). Only a few laboratories perform this kind of calibration: the National Institute of Standards and Technology (NIST), since 1977; the Accredited Dosimetry Calibration Laboratory (ADCL) of the University of Wisconsin, since 1996 and, more recently, the Physikalisch-Technische Bundesanstalt (PTB). In Brazil, no laboratory offers the calibration of these sources.

In previous works, Dias and Caldas (1999) developed an extrapolation chamber for beta ray protection level measurements. This chamber was also tested in low-energy x radiation standard beams (Dias and Caldas 2001). As opposed to these previous designs, an extrapolation chamber for the calibration of ^{90}Sr+^{90}Y applicators should have a very small collecting electrode area to perform true maximum absorbed dose measurements and to guarantee that this area is smaller than the radiation field measured (Soares 1991). The aim of the present work was to develop a mini-extrapolation chamber with adequate geometry for the calibration of ^{90}Sr+^{90}Y plane applicators.

Theoretical background

To measure the absorbed dose in a specific medium, the introduction of a radiation detector is necessary. This detector consists basically of a gas-filled cavity. The theory enunciated independently by Bragg and Gray, known as cavity theory, relates the absorbed dose in the cavity to the absorbed dose in the adjacent medium (cavity wall). According to this theory, the absorbed dose in the reference material (water) is related to the absorbed dose in a filled air cavity by the relationship (ICRU 2005)

$$D_w = \frac{\left(\frac{W}{e}\right) \times S_{\text{air}}^{\text{water}}}{\rho_0 a} \left(\frac{\Delta I}{\Delta d}\right)_{d\to 0} k_{\text{back}}, \tag{1}$$

where $\left(\frac{W}{e}\right)$ is the average energy (in joules) necessary to produce 1 C of charge of either sign in dry air, $S_{\text{air}}^{\text{water}}$ is the ratio of the mean mass collision stopping power of water to the air, ρ_0

is the density of air at the reference temperature and pressure, a is the effective area of the collecting electrode, $\left(\frac{\Delta I}{\Delta d}\right)_{d\to 0}$ is the rate of change of current with the distance, d, between the extrapolation chamber electrodes as it approaches zero and k_{back} is the correction factor for the difference in backscatter between the reference medium (water) and the material of the chamber-collecting electrode.

The backscattering factor, k_{back}, in equation (1), can be determined by the expression given by Tabata *et al* (1971), which is a function of the maximum energy of the beta particles emitted by the source and the effective atomic number of the chamber-collecting electrode.

The ionization current in equation (1) represents the mean value between the absolute values of the currents measured at the positive and negative voltage polarities; this value should be corrected considering the following factors:

1. Recombination factor, k_{recom}, defined by Loevinger and Trott (1966) as

$$k_{\text{recom}} = \left(1 - \frac{0.045\,54}{\sqrt{(Ed^2)}}\right)^{-1}, \tag{2}$$

   where E is the electric field (in V mm^{-1}), d is the distance between the chamber electrodes (in mm) and the constant 0.045 54 carries the units to make the quantity dimensionless.
2. Divergence factor, k_{div}, corrects the ionization current measured due to the curvature that the function of ionization current versus distance between electrodes exhibits, especially for large electrode separations, small area sources and small collecting electrode area (Soares 1991). For large source-detector distances, this factor is defined as

$$k_{\text{div}} = 1 + \frac{d}{y_0} \tag{3}$$

   where d is the distance between the chamber electrodes (in mm) and y_0 is the source-detector distance. For very small chamber depths, k_{div} can be taken as equal to 1 (Soares 1991), with some additional uncertainty.
3. Temperature and pressure factor, $k_{T,p}$, takes into consideration the difference in air density from ambient conditions at the time of measurement to reference conditions. This factor is given by

$$k_{T,p} = \frac{T + 273.15}{T_0 + 273.15} \times \frac{p_0}{p}, \tag{4}$$

   where T (°C) and p (kPa) are the ambient temperature and pressure, respectively, and T_0 (°C) and p_0 (kPa) are the reference temperature and the reference air pressure, respectively.

Materials and methods

A special mini-extrapolation chamber was designed and constructed. This chamber presents geometrical characteristics needed for the calibration of ^{90}Sr+^{90}Y plane applicators: a very small collecting area, which allows the calibration of small area sources and the determination of dose distribution on source surfaces. The developed mini-extrapolation chamber is shown in figure 1. This chamber has an aluminium body with a micrometer screw coupled to it, which allows varying the chamber depth from 0 to 25 mm with an uncertainty of less than 10 μm. The entrance window is made of a double aluminized polyester foil, with an areal density equal to $(111.4 \pm 2.6) \times 10^{-5}$ g cm^{-2}; an acrylic ring is used to stretch it. This material was selected because it combines a good electrical conduction with a high

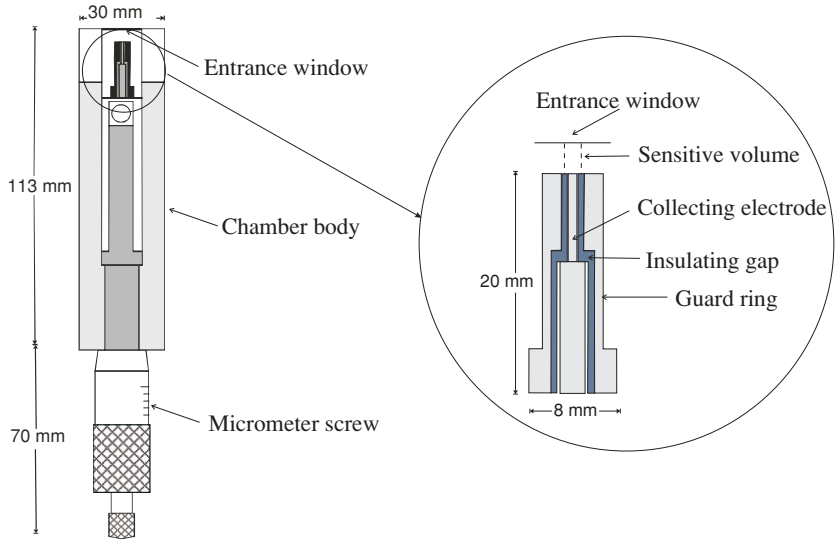

Figure 1. Schematic diagram of the mini-extrapolation chamber developed at the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares (IPEN), Brazil.

mechanical resistance. A polarizing voltage is applied to the chamber body; therefore, the entrance window is polarized. The collecting electrode is isolated from the body chamber; thus a voltage difference is established between the entrance window and the collecting electrode.

The collecting electrode is made of acrylic coated with graphite and surrounded by a polytetrafluoroethylene (PTFE) insulating gap. A graphited guard ring surrounds the collecting electrode and the insulating gap. For the determination of the effective area of the collecting electrode (1.68 mm^2), the collecting electrode diameter (0.95 mm) and the insulating gap diameter (1.98 mm), measured with a micrometer (accuracy of 0.05 mm), were taken into account.

An Amersham $^{90}Sr+^{90}Y$ plane applicator (nominal activity of 633 MBq, 2004) was utilized to verify the feasibility of the developed chamber for the calibration of this kind of source. All measurements were performed in a special acrylic box, designed to guarantee the appropriate protection to the operator and the adequate positioning between the source and the mini-extrapolation chamber. All measurements were performed with a constant polarizing voltage (50 V) applied to the chamber. The distance between the chamber entrance window and the source surface remained constant and equal to 1.0 mm.

Some quality control tests were also performed: short- and medium-term chamber response stability and leakage current before measurements. For the short- and medium-term stability tests, a $^{90}Sr+^{90}Y$ check source (nominal activity of 33.3 MBq, 1988), PTW, type 8921, was utilized. A special polymethylmethacrylate (acrylic) cap was designed to allow a reproducible positioning of the source and the chamber. This cap was utilized to protect the chamber entrance window as well. The leakage current was estimated before each measurement series. In this case, the charge was collected during 20 min without using any radiation source.

The ionization currents were measured using an electrometer from PTW (Physikalisch-Technische Werkstätten), model UNIDOS 10001. All measurements were corrected to the reference conditions of temperature and pressure (20 °C and 101.3 kPa).

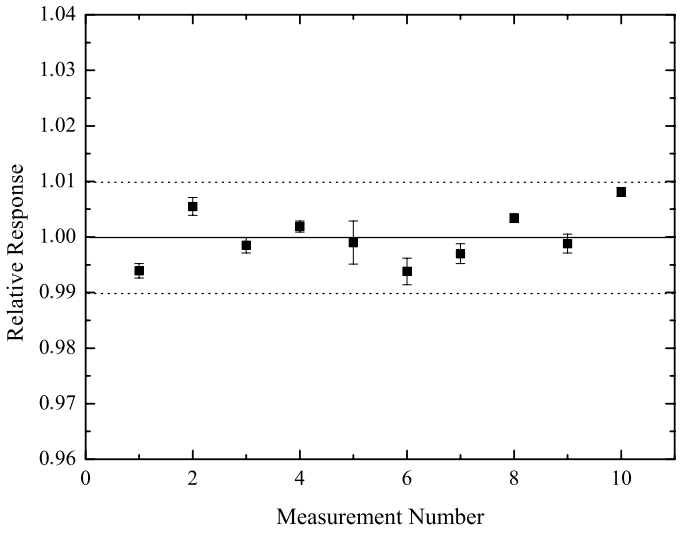

Figure 2. Medium-term stability test of the mini-extrapolation chamber.

Results and discussion

Leakage current

Because of the small chamber sensitive volumes (smaller than 0.002 cm^3), the measured currents are very small, of the order of pA. Even with such small signals, the leakage currents measured before each irradiation were always less than 0.5% of the current measured with the check source for the same chamber depth (1.0 mm).

Short- and medium-term stability tests

For the short-term stability test (repetitivity test) of the extrapolation chamber, ten successive measurements were taken under reproducible conditions. The variation of the chamber response was less than 0.24%. Taking measurements over 10 days, the medium-term stability test (reproducibility test) showed very good results: a maximum variation of 0.81%. The results are shown in figure 2.

Measurements performed with a plane ^{90}Sr+^{90}Y applicator

The occurrence of a negative current due to the beta particles that are stopped in the chamber-collecting electrode reveals the necessity of the measurement of the ionization currents at both voltage polarities. This parasitic current is suppressed by taking the mean value between the ionization currents measured at positive and negative voltage polarities. Therefore, the ionization currents were obtained by collecting charge for 2 min, for each chamber depth and voltage polarity, and repeated 10 times; the maximum standard deviation for these measurements was 0.40%. Extrapolation curves were obtained by plotting the mean value of the measured ionization current as a function of the chamber depth. One extrapolation curve was obtained for chamber depths from 0.4 mm up to 3.0 mm. This curve shows a linear behaviour (determined by a linear fitting) for chamber depths between 0.4 mm and 1.5 mm, as shown in figure 3. All further extrapolation curves were obtained for chamber depths from

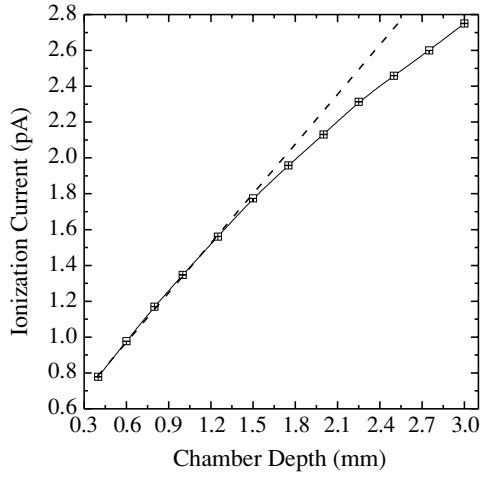

Figure 3. Extrapolation curve for mini-extrapolation chamber depths varying from 0.4 mm up to 3.0 mm.

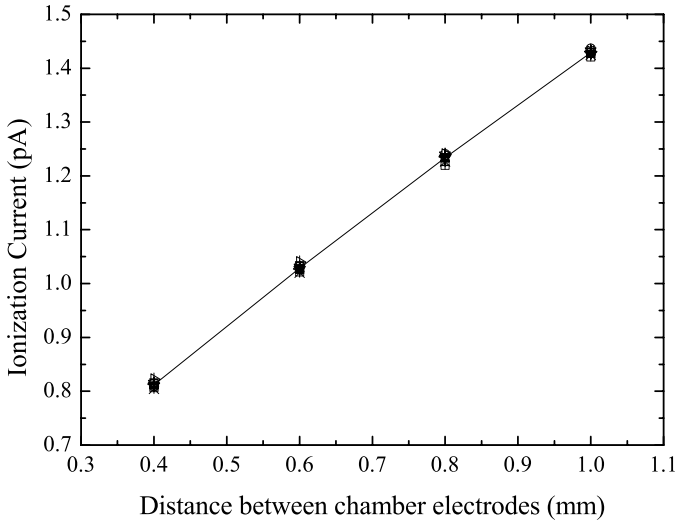

Figure 4. Extrapolation curves of the mini-extrapolation chamber with a plane ^{90}Sr+^{90}Y applicator. The line represents the average data.

0.4 mm up to 1.0 mm. The results are shown in figure 4. For these measurements, the worst correlation coefficient obtained was equal to 0.9997. Measurements performed on consecutive days showed a maximum variation in the chamber response of 2.3%, obtained by positioning and repositioning the chamber and the source in the measurement set-up.

From the obtained extrapolation curves, it was possible to determine the absorbed dose rate of the plane ^{90}Sr+^{90}Y applicator; therefore, the rate of current change as the distance between the extrapolation chamber electrodes approaches zero was determined for each measurement series. The values of the constants in equation (1) utilized in the determination of the absorbed dose rate to water are: $\frac{W}{e} = 33.97 \pm 0.05$ J C^{-1}; $S_{\text{air}}^{\text{water}} = 1.12$ and $\rho_0 = 1.197$ kg m^{-3}. The measured ionization current was corrected by applying all those correction factors already

Table 1. Estimate of uncertainties to determine the absorbed dose rate to water of a plane ^{90}Sr+^{90}Y applicator with the mini-extrapolation chamber.

	Relative uncertainty (%)	
Component	Type A	Type B
Rate of change of current	0.24	0.33
Average energy per ion pair		0.15
Stopping power ratio		0.60
Collecting electrode area	0.46	2.27
Backscatter correction		0.02
Integration time		0.42
Recombination correction		0.01
Divergence correction		0.30
Air density correction		0.01
Combined uncertainty ($k = 2$)		4.97

described: k_{recom}, k_{div} and $k_{T,p}$. The obtained absorbed dose rate in water was equal to 19.85 mGy s^{-1}, at the reference point (1 mm from the source surface in its central symmetry axis).

Uncertainties

The relative combined uncertainty (ABNT 2003) of the determined absorbed dose rate in water was estimated to be 5.0% (coverage factor, k, equal to 2). The combined uncertainty was calculated as the square root of the quadratic sum of type A (standard deviations of the mean of replicate readings) and type B standard uncertainties (see table 1). The major component of this estimated uncertainty was the uncertainty of the effective collecting electrode area; this uncertainty results from the combined uncertainties from the measurement of the collecting electrode area and the insulating gap thickness.

Conclusions

A special mini-extrapolation chamber was designed and constructed for the calibration of ^{90}Sr+^{90}Y plane applicators. This chamber was tested with a ^{90}Sr+^{90}Y check source and a ^{90}Sr+^{90}Y plane applicator. All results obtained show the usefulness of this chamber as a primary standard for the calibration of ^{90}Sr+^{90}Y applicators: the previous calibration of the mini-chamber in relation to a standard ionization chamber or to a standard beta source is unnecessary.

The small collecting electrode area and the small chamber dimensions make the mini-extrapolation chamber a very versatile instrument, which can be used to calibrate very small sources and to determine dose distributions of extended beta sources.

Acknowledgments

The authors are grateful to Mr M Xavier for technical assistance, to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil, for partial financial support of this work.

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