Applied Radiation and Isotopes 70 (2012) 388–391

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Comparison of calibration results for an extrapolation chamber obtained with different $^{90}Sr+^{90}Y$ secondary standard sources

Patrícia L. Antonio, Valdir S. Carvalho, Linda V.E. Caldas *

Instituto de Pesquisas Energéticas e Nucleares, IPEN—CNEN/SP, Av. Prof. Lineu Prestes, 2242, São Paulo, SP, Brazil

ARTICLE INFO

Article history:
Received 15 October 2009
Received in revised form
18 October 2011
Accepted 18 October 2011
Available online 25 October 2011

Keywords:
Extrapolation chamber
Extrapolation curve
Beta radiation
Calibration
$^{90}Sr+^{90}Y$ source

ABSTRACT

Two secondary standard systems of beta radiation were used to calibrate a PTW extrapolation chamber Model 23391. Three $^{90}Sr+^{90}Y$ sources of different activities were used in this calibration procedure. Medium-term stability of the response of the chamber was also studied. The calibration was performed with and without field-flattening filters. The relative standard deviation of the obtained calibration factors was 8.3% for the aluminum collecting electrode and 4.1% for the graphite collecting electrode.

1. Introduction

Absorbed doses can be measured with ionization chambers. Operation of such instruments is based on measuring the charge resulted from interactions of ionizing radiation with the gas in the chamber. In particular, one can use extrapolation chambers with a variable sensitive volume (the space between their electrodes), which is adjustable with a micrometer. A voltage applied to the two electrodes collects the ionization products formed by the radiation passing through this volume.

Extrapolation chambers are recommended for weakly-penetrating types of radiation, such as beta- and low-energy x-rays (Böhm and Schneider, 1986; Pruitt et al., 1988; Dias and Caldas, 1998; Soares et al., 2001; Oliveira and Caldas, 2005; Soares et al., 2009), and they are used for measuring superficial absorbed dose rates. Such dose rates can be measured essentially at the location of the entrance window of the chamber because the ionization current is extrapolated to zero-depth air gap (IAEA, 2002).

Calibration procedures relate the instrument response to the dose rate in a standard radiation field. Because of the low penetration power of beta particles, calibration of beta radiation detectors is difficult and requires well-defined and reproducible radiation fields.

The aim of this work was to compare results of calibration of a commercial PTW extrapolation chamber, which can be used with an aluminum or a graphite collecting electrode, with three $^{90}Sr+^{90}Y$ sources of different activities. The sources belong to two secondary standard systems of the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares in Sao Paulo, Brazil (IPEN). The measurements were performed with and without field-flattening filters.

2. Materials and methods

One of the secondary standard systems of beta radiation used in this work, Buchler GmbH & Co. Model BSS1 (Germany), dubbed "Beta System 1", consists of radiation sources ($^{90}Sr+^{90}Y$, ^{204}Tl and ^{147}Pm), field-flattening filters, a source support system, an irradiation system, and a control unit. The other used beta secondary standard system, Isotrak Model BSS2 (Germany), dubbed in this work "Beta System 2", is composed of radiation sources ($^{90}Sr+^{90}Y$, ^{85}Kr and ^{147}Pm), a source support system, field-flattening filters,

Table 1
Characteristics of the $^{90}Sr+^{90}Y$ sources used in this work. Source–detector distance is 30 cm.

Beta system	Source activity (MBq)	Filter presence	Absorbed dose rate (μGy/s)	Calibration date
BSS1	74	Yes	1.707 ± 0.017	Jan 12, 1981
	1850	No	7.60 ± 0.71	Feb 4, 1981
BSS2	460	Yes	10.56 ± 0.14	Dec 8, 2004
	460	No	16.46 ± 0.22	Jan 12, 2005

* Corresponding author. Tel.: +55 11 3133 9716; fax: +55 11 3133 9671.
E-mail address: lcaldas@ipen.br (L.V.E. Caldas).

0969-8043/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apradiso.2011.10.008

sensors of environmental conditions, a control unit, and special software for irradiation procedures.

Three different $^{90}Sr+^{90}Y$ sources were used in this study, namely, two sources of different activities of Beta System 1 and one source of Beta System 2. These sources had been previously calibrated at the primary standards laboratory of Germany, Physikalisch—Technische Bundesanstalt (PTB). Their calibration certificates quoted the absorbed-dose rates in air and in tissue for various source–detector distances, with and without flattening filters. Table 1 lists the main characteristics of these sources.

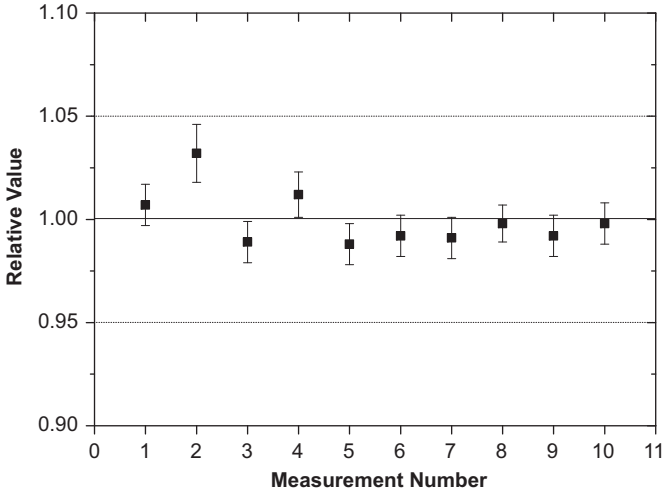

Fig. 1. Reproducibility of the response of the PTW extrapolation chamber with the graphite collecting electrode and the 74-MBq $^{90}Sr+^{90}Y$ source. The source–detector distance is 30 cm.

The PTW extrapolation chamber Model 23391 was connected to a Keithley electrometer Model 167. Both aluminum and graphite collecting electrodes ($D=40$ mm) were tested. The thickness of the chamber entrance window was 0.025 mm. This particular electrometer was chosen because it allowed for variations of the voltage in 0.5-V steps.

In all measurements, the chamber rested on a PMMA support 30 cm far from the source. For the repeatability test, ten sequential measurements of the charge were taken for 60 s each. The ionization current was also measured; these values were read every 10 s, ten measurements in total. In the repeatability and reproducibility tests, the air gap was 1.82 mm. In constructing the extrapolation curves with the aluminum collecting electrode, the interelectrodic distances (air gaps) were 1.02, 1.32, 1.82, 2.32, 2.82, 3.32, 4.32 and 5.32 mm, except in the case of the 460-MBq source with the filter, where distances of 1.02, 1.32, 1.82 and 2.32 mm were used. In constructing extrapolation curves with the graphite collecting electrode, we used the same source–detector distances as for the 460-MBq source with the filter.

The charge and current measurements were taken at both polarities of the voltage, and the mean values were calculated using the equation

$$I=\frac{(I_+ + |I_-|)}{2}, \tag{1}$$

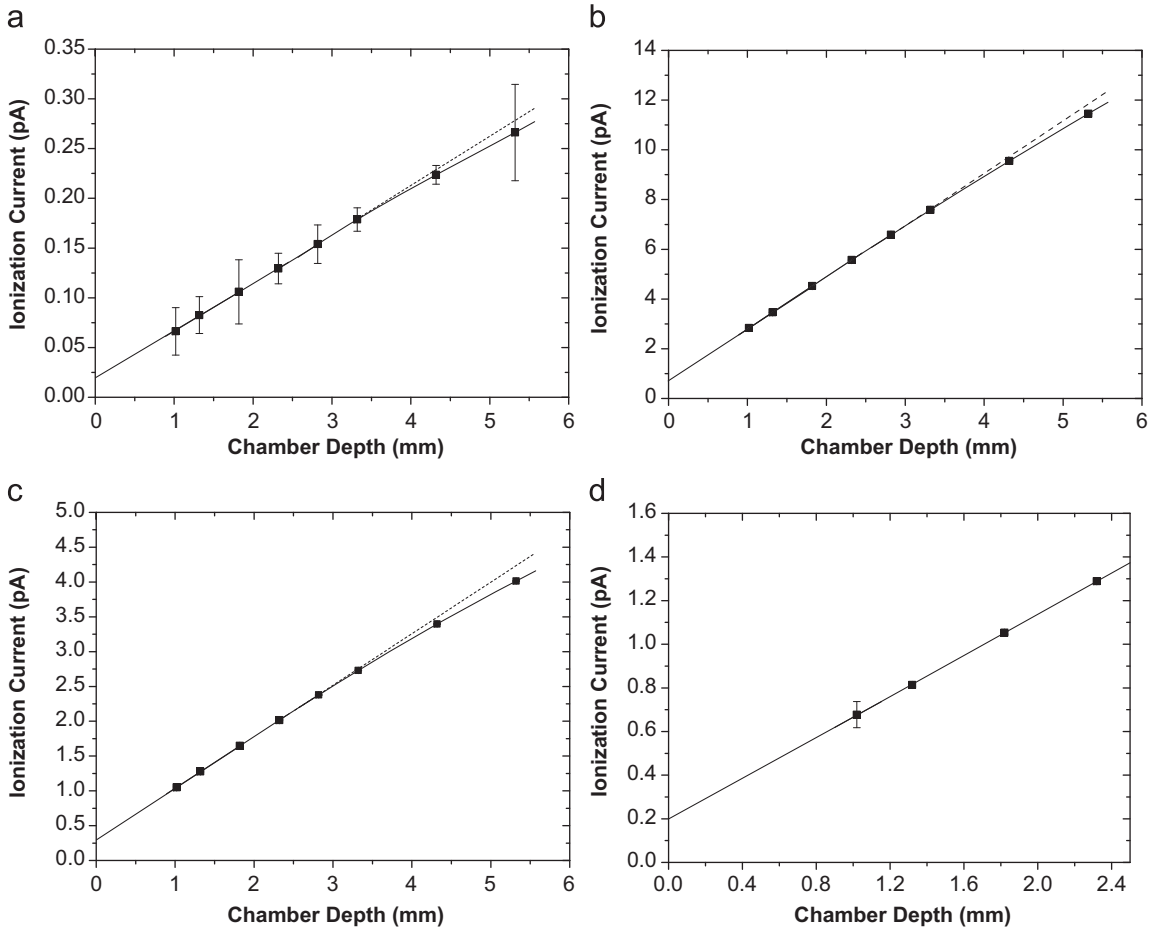

Fig. 2. Extrapolation curves for the PTW extrapolation chamber with the aluminum collecting electrode. $^{90}Sr+^{90}Y$ sources: (a) 74 MBq with the filter; (b) 1850 MBq without a filter; (c) 460 MBq without a filter; and (d) 460 MBq with the filter. The source–detector distance is 30 cm.

where I_+ is the current at the positive polarity, I_- is the current at the negative polarity, and I is the mean ionization current.

Calibration factors of the extrapolation chamber were determined with each of these sources, with and without the beam flattening filters, according to the experimental conditions described in the calibration certificates. For the 74-MBq source, the measurements were taken with the filter; no filter was needed for the 1850-MBq source. For the 460-MBq source, two calibration factors were determined, with and without the filter. To determine each calibration factor, extrapolation curves were constructed (the ionization current vs. the air-gap depth).

The ionization chamber response was always normalized to the standard conditions of temperature and pressure (20 °C and 101.325 kPa).

3. Results

3.1. Repeatability and reproducibility tests

Before the calibrations, it was tested the stability of the chamber response, namely, its repeatability (short-term stability) and reproducibility (medium-term stability). The repeatability test consisted of one series of ten measurements, while reproducibility test consisted of a sequence of several repeatability tests.

The reproducibility test was performed ten times with the graphite collecting electrode and the 74-MBq $^{90}Sr+^{90}Y$ source (Fig. 1).

In the repeatability test, the chamber response varied within 0.8%. The maximal variation in the reproducibility test was 3.2%. Similar performance was observed with the aluminum collecting electrode and the 460-MBq and 1850-MBq sources.

3.2. Calibration of the chamber

Extrapolation curves were initially obtained with the aluminum collecting electrode and a real null depth 0.32 mm determined previously (Caldas, 1986). When the aluminum collecting electrode was replaced with the graphite collecting electrode, the real null depth was found to be 0.18 mm.

Extrapolation curves for the three sources were obtained under the conditions specified in the PTB calibration certificates. Ten readings were taken at each chamber depth and at each polarity. In the case of the 460-MBq source, extrapolation curves were obtained with and without the beam-flattening filter for both the aluminum and the graphite collecting electrodes. Fig. 2 shows extrapolation curves for the aluminum electrode.

With the graphite collecting electrode, the extrapolation curves were obtained at interelectrodic distances (chamber depths) ranging from 0.7 to 2.0 mm. Ten readings were taken for each chamber depth and polarity. Fig. 3 shows the curves obtained in this experiment.

All extrapolation curves in both the experiments are linear, with linear correlation coefficients above 0.9992.

Table 2 lists calibration factors determined for the extrapolation chamber. A calibration factor represents the relation between the absorbed dose rate of the source and the slope of the

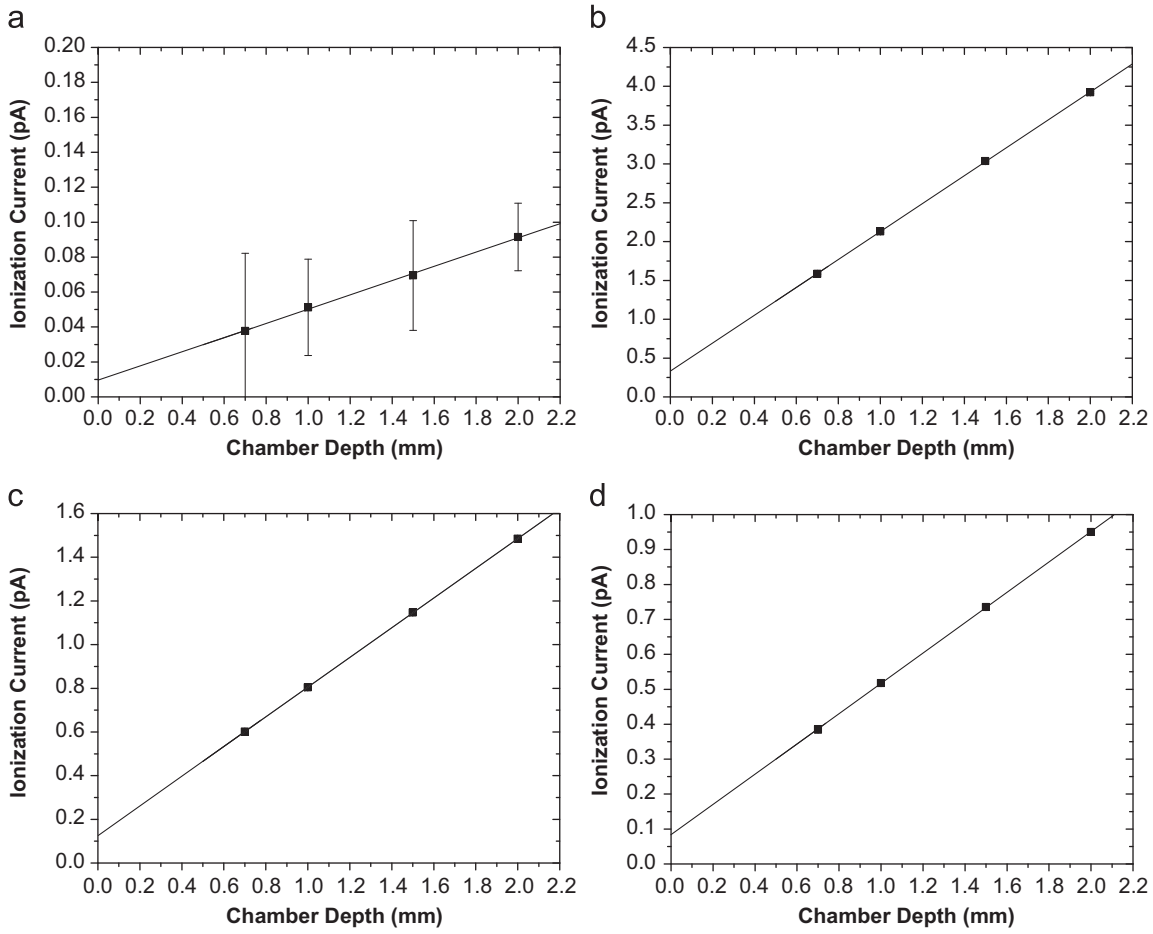

Fig. 3. Extrapolation curves for the PTW extrapolation chamber with the graphite collecting electrode. $^{90}Sr+^{90}Y$ sources: (a) 74 MBq with the filter; (b) 1850 MBq without a filter; (c) 460 MBq without a filter; and (d) 460 MBq with the filter. The source–detector distance is 30 cm.

Table 2
Calibration factors for the extrapolation chamber obtained with different $^{90}Sr+^{90}Y$ sources. Source–detector distance is 30 cm.

Collecting electrode	Source activity (MBq)	Flattening filter presence	Beta system	Angular coefficient (mm pA^{-1})	Calibration factor (μGy s^{-1} mm pA^{-1})
Aluminum	74	Yes	BSS1	0.0472	17.95 ± 0.44
	1850	No	BSS1	2.0075	19.90 ± 0.30
	460	Yes	BSS2	0.4748	20.05 ± 0.43
	460	No	BSS2	0.6929	16.87 ± 0.31
Graphite	74	Yes	BSS1	0.0408	21.66 ± 0.53
	1850	No	BSS1	1.8050	20.30 ± 0.25
	460	Yes	BSS2	0.4327	21.93 ± 0.48
	460	No	BSS2	0.6801	22.33 ± 0.38

extrapolation curve:

$$F_C = \frac{\dot{D}}{B}, \quad (2)$$

where $\dot{D}$ is the absorbed dose rate (μGy/s), B is the inverse of the slope of the extrapolation curve (mm/pA) and F_C is the calibration factor (μGy s^{-1} mm pA^{-1}).

The calibration factors measured in this work with the graphite collecting electrode are comparable with the value 20.77 μGy s^{-1} mm pA^{-1} obtained previously by Caldas (1986).

The calibration factors obtained in this study can be analyzed in two ways: with respect to the flattening filter and with respect to the collecting electrode material.

As for the effect of the filter (Table 2), with the aluminum collecting electrode, the calibration factors obtained with the filter (74-MBq source) and without it (1850-MBq source) differed by 10.8% (both the sources were of Beta System 1). When the same 460-MBq source of Beta System 2 was used, the calibration factor obtained with the filter differed from that obtained without it by 18.9%. The corresponding differences with the graphite collecting electrode were 6.7% for the 74-MBq and 1850-MBq sources, and only 1.8% for the 460-MBq source.

With the aluminum collecting electrode and the filter, the difference between the calibration factors obtained with the 74-MBq and the 460-MBq sources was 11.7%. The difference between the calibration factors for the 460-MBq and 1850-MBq sources obtained with the same collecting electrode, but without a filter was 18%.

In the case of the graphite collecting electrode and the flattening filter present, the difference in the calibration factors obtained with the 74-MBq and the 460-MBq sources was 1.2%. Without the filter, the difference between the calibration factors obtained with the 1850-MBq and the 460-MBq sources was 10%.

As for the effect of the collecting electrode material, the difference between the calibration factors obtained with the aluminum and graphite electrodes was 20.7% for the 74-MBq source and 2% for the 1850-MBq source. In the case of the 460-MBq source, the difference between the values for the two electrodes was 9.4% in the presence of the filter and 32.4% in its absence.

The overall accuracy of measurements with the aluminum collecting electrode was poorer (the relative standard deviation with the aluminum electrode was 8.3%, whereas, with the graphite electrode, it was only 4.1%). It is probably not incidental that aluminum collecting electrodes are not recommended for measurements in beta radiation fields.

4. Conclusions

The stability of the response of the extrapolation chamber was good. The extrapolation curves obtained with the $^{90}Sr+^{90}Y$ sources of the two beta secondary standard systems were linear. The relative standard deviation of the calibration factors obtained with aluminum collecting electrode was bigger than of the factors obtained with the graphite electrode.

The commercial PTW extrapolation chamber was calibrated with aluminum and graphite collecting electrodes using the BSS1 and BSS2 $^{90}Sr+^{90}Y$ sources, with and without filters. All results are acceptable; however, a significant variation of the calibration factors was observed in the case of the aluminum collecting electrode as this material is not adequate for measurements of beta radiation.

Acknowledgments

The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Ministério de Ciência e Tecnologia (MCT, Project: INCT for Radiation Metrology in Medicine) for partial financial support.

References

Böhm, J., Schneider, U., 1986. Review of extrapolation chamber measurements of beta rays and low energy X-rays. Radiat. Prot. Dosim. 14, 193–198.
Caldas, L.V.E., 1986. Performance characteristics of an extrapolation chamber for beta radiation detection. Appl. Radiat. Isot. 37 (9), 988–990.
Dias, S.K., Caldas, L.V.E., 1998. Development of an extrapolation chamber for the calibration of beta-ray applicators. IEEE Trans. Nucl. Sci. 45 (3), 1666–1669.
IAEA, 2002. International Atomic Energy Agency. Calibration of photon and beta ray sources used in brachytherapy. IAEA TECDOC-1274. International Atomic Energy Agency, Vienna, Austria.
Oliveira, M.L., Caldas, L.V.E., 2005. A special mini-extrapolation chamber for calibration of $^{90}Sr+^{90}Y$ sources. Phys. Med. Biol. 50, 2929–2936.
Pruitt, J.S., Soares, C.G., Ehrlich, M., 1988. Calibration of beta-particle radiation instrumentation and sources. National Institute of Standards and Technology Special Publication SP-250-21. NIST, Gaithersburg, MD, USA.
Soares, C.G., Vynckier, S., Järvinen, H., Cross, W.G., Sipilä, P., Flühs, D., Schaeken, B., Mourtada, F.A., Bass, G.A., Williams, T.T., 2001. Dosimetry of beta-ray ophthalmic applicators: Comparison of different measurements methods. Med. Phys. 28, 1373–1384.
Soares, C.G., Douysset, G., Mitch, M.G., 2009. Primary standards and dosimetry protocols for brachytherapy sources. Metrologia 46, 80–98.