Characteristics of an extrapolation chamber for β-ray protection level measurements

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An absolute determination of the absorbed dose rates to tissue from a $^{90}Sr+^{90}Y$ β-ray secondary standard source was attempted using an extrapolation chamber developed at the Calibration Laboratory of São Paulo. The performance of this chamber and its main characteristics are presented in this work. A comparison of the results obtained with those of the calibration certificate indicates an absorbed dose rate agreement within 1.0%. © *1999 American Institute of Physics.* [S0021-8979(99)01313-4]

I. INTRODUCTION

The Calibration Laboratory of IPEN offers calibration services with β radiation since 1982. All protection level monitors are first calibrated in standard γ radiation fields and afterwards tested in the β beams characterized by Caldas.[1] The monitoring instruments and dosimeters have been calibrated using the Amersham–Buchler β particle calibration setup, standardized by Physikalisch-Technische Bundesanstalt (PTB, Germany). The radiation beams of these sources are characterized in terms of absorbed dose rates to air and to tissue at reference distances.

According to the recommendations of the ISO Standard 6980,[2] the series II sources can be used without the flattening filters and closer to the instruments if the achievement of high doses is necessary for the calibration. In this case, the characteristics of the radiation fields have to be defined for different source-detector distances.[3] For this purpose, the extrapolation chamber is the most appropriate instrument.

An extrapolation chamber was designed and constructed at the Calibration Laboratory of São Paulo for the calibration of β-ray dermatological applicators.[4] In the present work, the performance of this extrapolation chamber, also intended to be used as a routine reference instrument, for protection level measurements, was studied at the calibration conditions of a beta secondary standard system.

II. MATERIALS AND METHODS

The extrapolation chamber used has a 10 mm diam collecting electrode and a guard ring, both of graphite. It has two interchangeable entrance windows: aluminized Hostaphan (0.84 mg cm^{-2}) and aluminized Mylar (6.42 mg cm^{-2}). In this work, depending on the entrance window, the chamber will be called C1 (Hostaphan) and C2 (Mylar). Lucite was used as insulating material between the collecting electrode and the guard ring.

The chamber depth was varied between 0.5 and 2.5 mm and the voltage gradient across the chambers was kept at 10 V/mm for the measurements. The ionization currents were measured using a Keithley 617 electrometer. The $^{90}Sr+^{90}Y$ (1850 MBq) source of the beta secondary standard system, with a calibration certificate from PTB, Germany, was used for all experiments.

Details of the measurements techniques were previously published.[5]

III. RESULTS

A. Short and medium term stabilities

For the short term stability ten consecutive readings, corrected for ambient conditions, were taken with the chambers positioned in a reproducible manner in relation to the β source. The standard deviation was 0.3%. For the medium term stability test 12 daily measurements series were realized. Figure 1 shows the response variation of the mean value of measurement series of the chamber C1 response as a function of the day of measurement. Similar results were verified for chamber C2. The mean values were within $\pm 1.0\%$ of the reference value, which is in agreement with the IEC recommendations.[6]

B. Transmission factors

Absorbed dose rates to tissue at a depth of 7 mg cm^{-2} of tissue was obtained by applying experimentally determined correction factors. Depth–dose curves were obtained increasing the entrance window thickness by using additional Hostaphan and Lucite foils of known tissue equivalent areal density. Table I shows the transmission factors obtained with chamber C1 and C2 positioned at a 11 cm distance from the source, and those showed in the source calibration certificate.

A comparison of the results obtained with those presented in the source calibration certificate indicates an agreement within 1.0%.

C. Absorbed dose rates

Extrapolation curves were obtained at calibration distances of 11 and 30 cm. In this study ten consecutive measurements were taken for each chamber depth, for the positive and negative polarities. The mean value obtained in each

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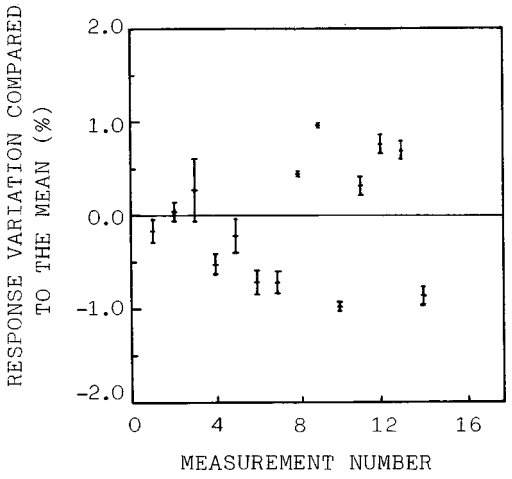

FIG. 1. Medium term stability test of the extrapolation chamber C1. Each measurement number represents a different measurement day.

case was presented as a function of the chamber depth, and linearity was observed in all cases. In Fig. 2 the curves obtained with chambers C1 and C2 at 11 and 30 cm distances from the sources are presented.

The absorbed dose rate to tissue in tissue at a reference date is calculated[7] from the slope of the extrapolation curve by the following equation (in Gy/s):

$$\dot{D}_z = \frac{(\overline{W}/e).S_{\text{air}}^{\text{tissue}}}{\rho_0 A}\left(\frac{\Delta I_c}{\Delta d}\right),$$

where $\dot{D}_z$ is the absorbed dose rate in tissue at depth z, $\overline{W}/e$ is the average energy required to produce an ion pair in dry air (33.97 J/C), $S_{\text{air}}^{\text{tissue}}$ is the ratio of the average mass stopping power of tissue to air (1.12), ρ_0 is the density of dry air at reference conditions of 22 °C, and 101.3 kPa (1.197 kg/m^3), A is the area of the collecting electrode, and $(\Delta I_e/\Delta d)$ is the fitted slope of the corrected current versus air gap function. The transmission factors were applied to determine the absorbed dose rate to tissue at a depth of 7 mg cm^{-2} in tissue. In Table II the results obtained with chambers C1 and C2 at the calibration distances (11 and 30 cm) from the ^{90}Sr+^{90}Y are shown.

Comparing the absorbed dose rates to tissue determined using the two chambers with those given in the source calibration certificate, corrected for the already presented current values[7] of $\overline{W}/e$ and $S_{\text{air}}^{\text{tissue}}$, an agreement within 1.0% was verified.

The overall uncertainty of the absorbed dose rate determination was estimated to be 3.7% for an expanded uncertainty with a coverage factor of 2.

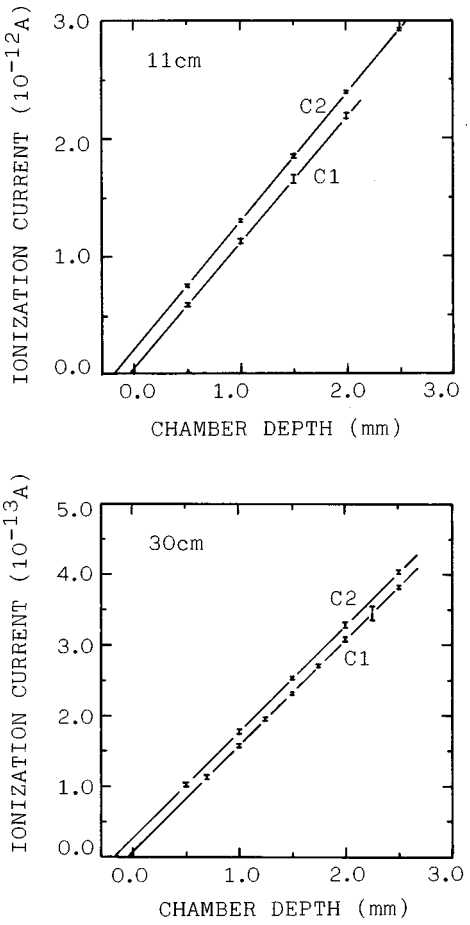

FIG. 2. Extrapolation curves obtained with the chambers C1 and C2 at 11 and 30 cm distances from the ^{90}Sr+^{90}Y source.

TABLE I. Transmission factors for β radiation of ^{90}Sr+^{90}Y.

Tissue thickness (mm)	Transmission Factor: Chamber C1	Transmission Factor: Chamber C2	Certificate PTB
0	1.000	1.000	1.000
0.02	1.034	1.025	1.028
0.04	1.054	1.045	1.049
0.05	1.062	1.055	1.058
0.07	1.080	1.075	1.070
0.10	1.098	1.095	1.095
0.20	1.148	1.150	1.158
0.50	1.200	1.200	1.201
1.00	1.140	1.155	1.157

TABLE II. Absorbed dose rates to tissue at the depth of 7 mg cm^{-2} (μGy s^{-1}) in tissue at calibration distances of 11 and 30 cm from the ^{90}Sr+^{90}Y source.

Chamber	11 cm: $\dot{D}_m$ [a]	11 cm: $\dot{D}_c$ [b]	Δ_{11} [c] (%)	30 cm: $\dot{D}_m$ [a]	30 cm: $\dot{D}_c$ [b]	Δ_{30} [d] (%)
C1	449.1	448.2	0.20	61.5	60.9	0.98
C2	443.9	448.2	0.96	61.3	60.9	0.66

[a] Absorbed dose rate in tissue at 7 mg cm^{-2} obtained experimentally in this work.

[b] Absorbed dose rate in tissue at 7 mg cm^{-2} presented in the PTB source calibration certificate, corrected for the present values of $\overline{W}/e$ and $S_{\text{air}}^{\text{tissue}}$.

[c] Percentage difference between $\dot{D}_m$ and $\dot{D}_c$ for the chamber at 11 cm from the source.

[d] Percentage difference between $\dot{D}_m$ and $\dot{D}_c$ for the chamber at 30 cm from the source.

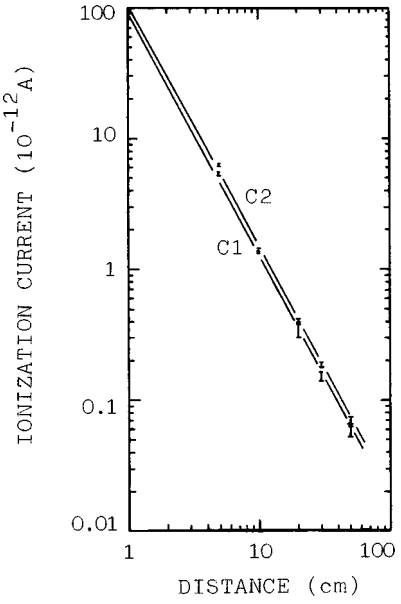

FIG. 3. Response variation of the extrapolation chambers with the $^{90}Sr+^{90}Y$ source–detector distance.

D. Response variation with the source–detector distance

Ionization current measurements were taken varying the source–detector distance between 5 and 80 cm, in order to verify the possibility of establishing alternative calibration conditions for β monitoring survey instruments.

The ionization current values varied between 5.6×10^{-12} and 6.5×10^{-14} A (Fig. 3). The square root distance law was verified between 10 and 50 cm. This result is similar to that presented in the secondary standard source certificate for 11, 30, and 50 cm source–detector distances.

IV. CONCLUSION

The tests performed indicate that the extrapolation chamber used in this work is suitable for protection level β dosimetry and suggest the possibility of using it for the characterization of alternative standard fields. The chamber is simple, of low cost, and presents good metrological characteristics. The short and medium term stability test showed values within the international recommendations. The absorbed dose rates to tissue and the transmission factors obtained experimentally are in very good agreement with those quoted by PTB, within the associated uncertainties.

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