

Development of an Extrapolation Chamber for the Calibration of Beta-Ray Applicators

Simone K. Dias and Linda V. E. Caldas

Abstract—An extrapolation chamber was designed and constructed, and its performance was studied in beta radiation fields. The characteristics of this chamber and the measurement procedures used for the calibration of beta-ray applicators are discussed in this work. The surface dose rate of a planar $^{90}\text{Sr} + ^{90}\text{Y}$ applicator was also obtained using the extrapolation chamber, and the results were compared with the Amersham calibration certificate. An agreement within 2.7% was verified.

Index Terms—Beta dosimetry, calibration, extrapolation chamber.

I. INTRODUCTION

$^{90}\text{Sr} + ^{90}\text{Y}$ ophthalmic applicators have been in clinical use for many years. In the treatment of pterygium, the prophylactic postoperative irradiation has been proven successful in most of the cases [1], [2]. However, only few applicators in routine use have been calibrated since the manufacturing date. Since 1977, the National Institute of Standards and Technology (NIST) has offered a standard calibration service. In 1989, after an international comparison of surface absorbed dose rates, the calibration procedure of NIST was revised [3], and afterwards the results of the first five years of NIST calibrations of ophthalmic applicators using the revised technique were presented [4]. The NIST and Amersham calibration procedures are well established. They use different techniques and apply slightly different factors to the dose-rate determinations of beta-ray applicators, as pointed out by Soares [4]. Although the final results show a difference of 13%, it may not be significant within the associated uncertainties of the measurements.

Many old applicators, still in use, were calibrated by the manufacturers in archaic terms, inappropriate for beta dosimetry [4]. Few hospitals have adequate instrumentation or protocols to verify the current dose-rate estimate. None of the manufacturers offer recalibration of old applicators [2]. To ensure confidence in the treatment of superficial lesions with beta radiation, it is necessary to verify the source integrity and to know the applicator dose rate with great accuracy and precision. Therefore, the periodic recalibration of such applicators is very important.

The measurements of absorbed dose rates produced by beta radiation are very difficult to obtain with accuracy. The recommended instruments for these measurements are the

extrapolation chambers. They have been chosen as standard measuring devices. Standardized beta particle fields have been established in Primary Standard Laboratories. These laboratories utilize an extrapolation chamber for the calibration of protection-level beta-particle sources and instrumentation. These chambers also have been recommended for calibration of clinical applicators.

The main problems concerning beta rays are their limited penetrating power, strong energy gradient, and angular distribution as functions of spatial position. The dose-rate calibration is difficult because of the fall-off dose with distance, and in the case of the calibration of an ophthalmic applicator it is further complicated due to its curvature.

In this work, the surface dose rate from a planar $^{90}\text{Sr} + ^{90}\text{Y}$ applicator was obtained using an extrapolation chamber developed at Instituto de Pesquisas Energéticas e Nucleares (IPEN). This chamber can be constructed easily for a nominal cost, and it presents simple operation and maintenance. The interchangeable electrodes allow its utilization for different applications. The influence of the collecting electrode size and of the entrance window density on the estimated absorbed dose rate was also investigated. The results were compared with those presented on the Amersham calibration certificate of the source.

II. MATERIALS AND METHODS

The extrapolation chamber developed in this work has interchangeable electrodes. The chamber body is made of Lucite, and the collecting electrodes of graphite (Fig. 1). The influence of the collector electrode size and the entrance window thickness on the absorbed dose rate in tissue was studied using electrodes of 3 and 10 mm in diameter and foils of aluminized polyethylene with areal densities of 0.84 and 6.42 mg/cm⁻². At each modification, a new chamber was defined and submitted to all characterization tests. The main characteristics of these chambers are presented in Table I.

A Keithley 617 electrometer was used to measure ionization currents. An Amersham applicator of $^{90}\text{Sr} + ^{90}\text{Y}$ with nominal activity of 1480 MBq (1968) was utilized in this work.

III. RESULTS

A. Extrapolation Curves

Extrapolation curves were obtained measuring the ionization current for both polarities applied to the chamber electrodes. A constant potential gradient of 100 V/mm was used in all

Manuscript received October 28, 1997; revised February 16, 1998. This work was supported in part by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil.

The authors are with Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear-SP, São Paulo, Brazil.
Publisher Item Identifier S 0018-9499(98)04317-2.

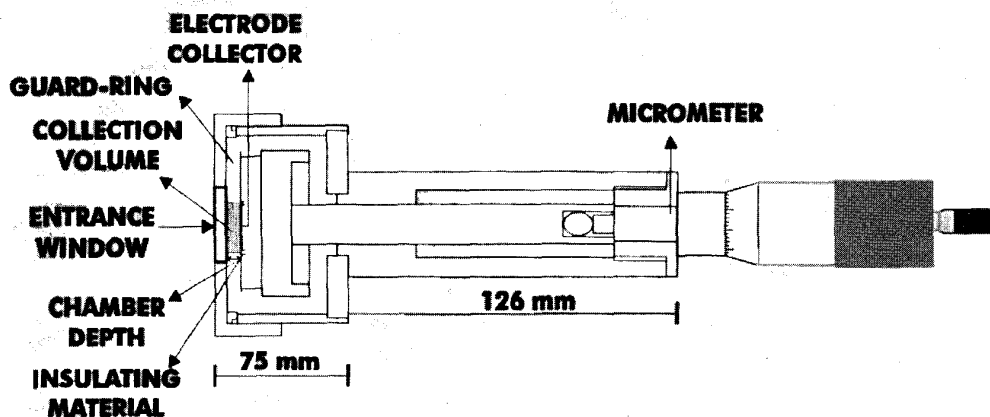


Fig. 1. Extrapolar chamber developed at IPEN.

TABLE I
CHARACTERISTICS OF THE IPEN EXTRAPOLATION CHAMBERS

Chamber	Collecting Electrode Diameter (mm)	Entrance Window Areal Density ($\text{mg}\cdot\text{cm}^{-2}$)	Effective Area (mm)
C1	10	0.84	78.5
C2	10	6.42	78.5
C3	3	6.42	8.30
C4	3	0.84	8.30

cases. The ionization currents were corrected for the ambient conditions and for recombination effects. In the case of the ambient conditions, the correction factor (M) was defined as

$$M = \frac{P_o(273.2 + T)}{P(273.2 + T_o)}$$

where P and T are the pressure and temperature during the experiment and P_o and T_o are the standard conditions (101.3 kPa and 22 °C). The recombination factors were determined experimentally. The measurements of the collected currents were taken, increasing the applied voltage for different air gaps. The saturation current (I_s) was determined by plotting the current values versus the inverse of the square root of the applied voltage and extrapolating the obtained curve (straight line) to zero (infinite voltage). The recombination correction factors (R) were obtained by taking the ratio of the saturation current and the measured current (I_s) for each air gap and applied voltage

$$R = \frac{I_s}{I}$$

The corrected ionization currents is given by

$$I_c = I.M.R.$$

Linear functions were fitted to the current-versus-air-gap curves of chambers C1 and C2 (Fig. 2). Similar results were obtained for the C3 and C4 chambers.

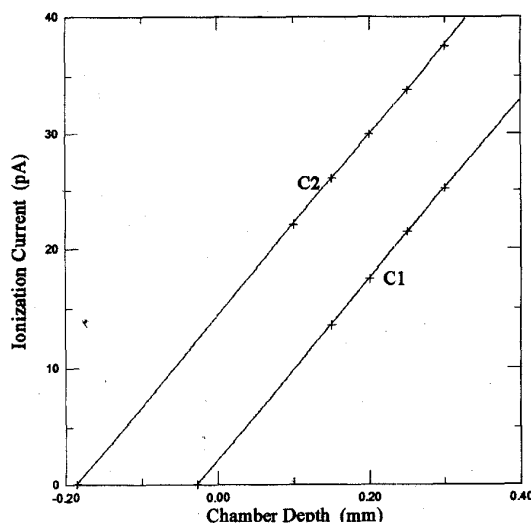


Fig. 2. Extrapolar curves obtained with the chambers C1 and C2 for a null source-chamber distance.

B. Response Variation with the Source-Chamber Distance

Ionization current measurements were taken varying the source-chamber distance between 0 and 20 mm. The results obtained with the chambers C1 and C2 are presented in Fig. 3. A response decrease is observed when the source is positioned at different distances from the chambers. Similar results were obtained for the C3 and C4 chambers.

C. Transmission Factors

The transmission factors were obtained covering the chambers with polyethylene terephthalate (PTP) foils and polymethylmethacrylate (PMMA) plates with different thicknesses. The measurements of the ionization currents were realized with the $^{90}\text{Sr} + ^{90}\text{Y}$ applicator placed as near as possible to the chambers and also at a distance of 1.0 cm in air. The obtained current values were plotted versus the material areal density, taking the chamber window thickness into account. The initial part of these curves was extrapolated to zero attenuator thickness to obtain the ionization current (I_o) for

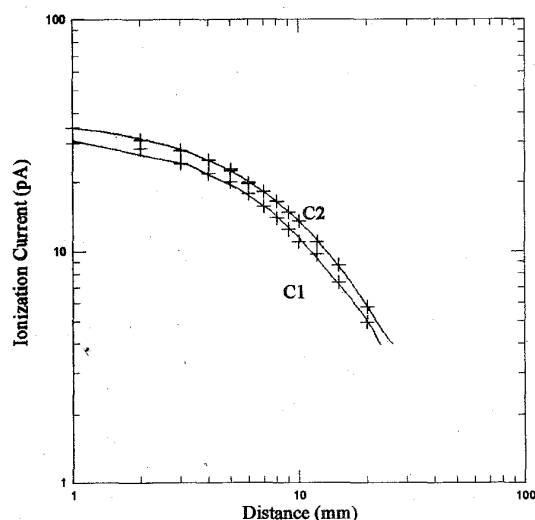


Fig. 3. Response variation with the distance between the planar $^{90}\text{Sr} + ^{90}\text{Y}$ applicator and the surface of the extrapolation chamber window.

TABLE II
TRANSMISSION FACTORS FOR BETA RADIATION
($^{90}\text{Sr} + ^{90}\text{Y}$) a: CHAMBER C4-SOURCE DISTANCE

Tissue Thickness (mm)	Areal Density ($\text{mg}\cdot\text{cm}^{-2}$)	a = 0	a = 1cm
0	0	1.000	1.000
0.02	2	0.984	1.002
0.04	4	0.972	1.008
0.05	5	0.968	1.010
0.07	7	0.956	1.012
0.10	10	0.936	1.016
0.20	20	0.888	1.020
0.50	50	0.748	0.992
1.00	100	0.554	0.816

no absorbing material. The transmission factors were taken to be the ratio of the mean values of the ionization current readings (corrected for the chamber-source distances) and of the I_0 value for each chamber. The maximum relative standard deviation in these measurements was 1%.

The transmission factors obtained with PTP and PMMA materials were converted to transmission factors for soft tissue, taking their densities into account (1.38 and $1.19 \text{ g}\cdot\text{cm}^{-3}$, respectively).

The determined transmission factors for typical values of the tissue-equivalent material with the chamber C4 are presented in Table II. Similar results were verified for the other chambers; a comparison between the obtained transmission factors showed a difference lower than 1%. The results of Table II also indicate that, for a null source-detector distance ($a = 0$), the effect of adding $7 \text{ mg}\cdot\text{cm}^{-2}$ of plastic to the extrapolation chambers has been found to lower the measured dose rate by about 5%.

TABLE III
ABSORBED DOSE RATE IN TISSUE AT $7 \text{ mg}\cdot\text{cm}^{-2}$: \dot{D}_m : ABSORBED DOSE RATE OBTAINED EXPERIMENTALLY; Δ : PERCENTAGE DIFFERENCE BETWEEN \dot{D}_m AND \dot{D}_c FOR THE NULL DISTANCE; \dot{D}_c : ABSORBED DOSE RATE OF THE CALIBRATION CERTIFICATE

Chamber	\dot{D}_m ($\text{mGy}\cdot\text{s}^{-1}$)	Δ (%)
C1	30.91	0.3
C2	30.85	0.5
C3	30.18	2.7
C4	30.98	0.1

The observed increase of the transmission factors with increasing tissue thickness (Table II, $a = 1$) is probably due to the high-energy beta radiation scattering in the air gap between the applicator surface and the chamber.

D. Absorbed Dose Rates in Tissue

The absorbed dose rates in tissue were determined from the current measurements at chamber depths (air gaps) between 0.10 and 0.30 mm. The measurements were realized with the applicator positioned as near as possible to the chambers. The extrapolation curves were obtained measuring the ionization current for both potential polarities applied to the chambers and plotting the average of these values as a function of the chamber depth. A linear function was fitted to the current-versus-air-gap data and the slope was used to determine the average surface absorbed dose rate over the source central area. A constant potential gradient of 100 V/mm was used for all air gaps.

The absorbed dose rate in tissue in Gy/s is given by Soares [3]

$$\dot{D}_Z = \frac{(\bar{W}/e) \cdot S_{\text{air}}^{\text{tissue}}}{\rho_0 \cdot A} \left(\frac{\Delta I_c}{\Delta d} \right) \quad (1)$$

where \dot{D}_Z is the absorbed dose rate in tissue at depth z , \bar{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, A is the area of the collecting electrode, and $(\Delta I_c/\Delta d)$ is the fitted slope of the corrected current versus air-gap function. The transmission factors were applied to the determination of the absorbed dose rates at $7 \text{ mg}\cdot\text{cm}^{-2}$.

The uncertainties in this procedure include the measured $(\Delta I_c/\Delta d)$ ratio (2%) as well as the uncertainties in the chosen values for the average energy per ion pair (0.4%), the stopping power ratios (3%), electrode area (5%), and other correction factors (2%). The overall uncertainties of the absorbed dose rates were estimated to be approximately 13%, defined as two times the square root of the quadratic sum of all component uncertainties of the calibration procedure, with the approximate significance of a 95% confidence limit. Table III presents the obtained results of the four chambers. The absorbed dose rate in tissue ($7 \text{ mg}\cdot\text{cm}^{-2}$) of the calibration certificate, \dot{D}_c , quoted by the manufacturer on 8.11.68 and

corrected for the decay time to the measurement day and for the already cited recent values of \bar{W}/e and $S_{\text{air}}^{\text{tissue}}$, is $31.01 \text{ mGy}\cdot\text{s}^{-1}$.

Comparing the absorbed dose rates in tissue, determined using the four chambers, with those of the source calibration certificate, a maximum percentage difference (Δ) of 2.7% was verified.

IV. CONCLUSION

In this work, a simple and easily constructed extrapolation chamber was developed, and its application for beta dosimetry was described.

The results show that the dose-rate determinations using the developed extrapolation chamber are in agreement with the Amersham evaluations (corrected for the recent constants), within the overall uncertainties. In this study, the influence of the collecting electrode size of the chambers was negligible. However, in all cases an electrode smaller than the source size was used. The comparison between the results obtained with the C1–C4 chambers indicates a percentage difference lower than 3%, showing a good agreement too. From the experiments, it was also verified that the dose rate in tissue irradiation falls by approximately 5% between the surface and

a depth of $7 \text{ mg}/\text{cm}^{-2}$. The response variation with the source-chamber distance showed how critical the positioning of the applicator can be during the calibration procedure.

The developed extrapolation chamber showed its usefulness for calibration of planar beta-ray applicators with the required accuracy.

ACKNOWLEDGMENT

The authors acknowledge the valuable technical assistance of M. Xavier.

REFERENCES

- [1] J. A. Sayeg and R. C. Gregory, "A new method for characterizing beta-ray ophthalmic applicator sources," *Med. Phys.*, vol. 18, no. 3, pp. 453–461, 1991.
- [2] S. J. Goetsch and K. S. Sunderland, "Surface dose rate calibration of ^{90}Sr plane ophthalmic applicators," *Med. Phys.*, vol. 18, pp. 161–166, 1991.
- [3] C. G. Soares, "Calibration of ophthalmic applicators at NIST: A revised approach," *Med. Phys.*, vol. 18, no. 4, pp. 787–793, 1991.
- [4] ———, "Comparison of NIST and manufacturer calibrations of ^{90}Sr + ^{90}Y ophthalmic applicators," *Med. Phys.*, vol. 22, no. 9, pp. 1487–1493, 1995.
- [5] ISO, "Reference beta radiations for calibrating dosimeters and dose-ratemeters and for determining their response as a function of beta radiation energy," International Standard 6980-1984 (E), Geneva, Switzerland, 1984.