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Alternative test conditions of beta–gamma monitors in beta radiation fields

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Abstract. An extrapolation chamber and the beta radiation secondary standard system of the Calibration Laboratory of São Paulo, with sources of $^{90}Sr + ^{90}Y$, were used to verify the influence of the beam flattening filter on the radiation field. Extrapolation curves, calibration and transmission factors were obtained with and without the presence of the beam flattening filter, in order to study the possibility of establishing alternative test conditions of beta–gamma instruments.

1. Introduction

The increasing use of radioactive sources in medicine, industry and research has led to a growth in the number of persons exposed to beta radiation. Therefore the importance of accurate beta dosimetry in radiation protection has grown. This type of radiation, which always has a low-penetrating component, is strongly absorbed by the skin. The absorbed dose in tissue is the most important component measuring quantity in this case.

Extrapolation chambers, special plane-parallel ionisation chambers of variable volume, can be used as reference or transfer instruments for beta calibration and dosimetry purposes (Deasy and Soares 1994, Francis 1985, Böhm and Schneider 1986, Pruitt *et al* 1988, Herbaut *et al* 1986a). They allow the absorbed dose in a solid medium to be determined from the ionisation in a small gas-filled cavity inside the medium by extrapolation to zero volume, leading to the determination of the absorbed dose in tissue. Such chambers are present in almost all secondary standard dosimetry laboratories. They are also used to measure the absorbed dose rates in phantoms exposed to beta and low energy x-radiation (Francis 1985). For routine calibration purposes of radiation protection instrumentation the use of calibrated beta sources is more convenient than the use of calibrated ionisation chambers (Herbaut *et al* 1986b, Uray and Heinzelmann 1992). However, in order to characterise the standard radiation fields at the calibration laboratories, extrapolation chambers are very useful.

Table 1. Beta sources: secondary standard system.

Radionuclide	$^{90}Sr + ^{90}Y$	$^{90}Sr + ^{90}Y$
Nominal activity (MBq)	74	1850
Half-life (years)	28.5 ± 0.8	28.5 ± 0.8
Mean beta energy (MeV)	0.80	0.80
Absorbed dose rate in air (μGy s^{-1})	1.701	70.6
Absorbed dose rate in tissue (μGy s^{-1})	1.896	78.4
Beam flattening filter	Yes	No
Calibration distance (cm)	30	30
Reference date	12.01.1981	04.02.1981

The Calibration Laboratory of São Paulo offers calibration services for survey instruments used for monitoring of gamma, beta and alpha radiation. About 1000 instruments are normally calibrated every year. For the calibration of these instruments with beta radiation, the calibration laboratory owns a system developed by the Physikalisch-Technische Bundesanstalt (PTB, Braunschweig, Germany), manufactured by Amersham Buchler and Co. (Germany). It is a secondary standard

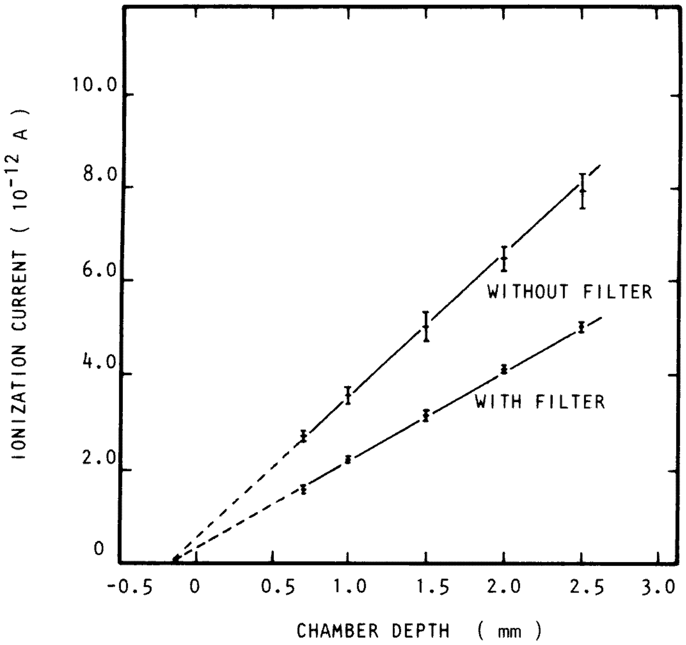

Figure 1. Extrapolation curves. Source: $^{90}Sr + ^{90}Y$ (1850 MBq), with and without the presence of the beam flattening filter.

Table 2. Calibration factors for the extrapolation chamber.

Source	Calibration distance (cm)	Slope B (A mm^{-1})	Calibration factor (10^{10} Gy mm h^{-1} A^{-1})
$^{90}Sr + ^{90}Y$ (74 MBq) with beam flattening filter	30	6.326×10^{-14}	7.363
$^{90}Sr + ^{90}Y$ (1850 MBq) with beam flattening filter	30	2.879×10^{-12}	6.727

and the set-up consists of a source stand, a control unit with timer and interchangeable beta sources of $^{90}Sr+^{90}Y$, ^{204}Tl and ^{147}Pm. Beam flattening filters of plastic foils are used to provide absorbed dose rates that are as uniform as possible over a circular area, about 10 cm in diameter, at the calibration distances. These filters are mounted vertically on the axis of the radiation field, at a fixed distance from the source (103 mm).

The calibration of survey instruments with beta radiation presents some problems. One of these is related to the field uniformity, since it may be difficult to use the specified conditions of the calibrated certificates, sometimes because of the dimensions of the instruments.

Experiments were performed in order to verify the influence of the beam flattening filter on the absorbed dose rates and the measurement of the transmission factors in tissue, using two $^{90}Sr+^{90}Y$ sources of different activities. Specifications of these beta sources are shown in table 1. A study was also made to determine the distance intervals where the chamber response obeys the inverse square distance law.

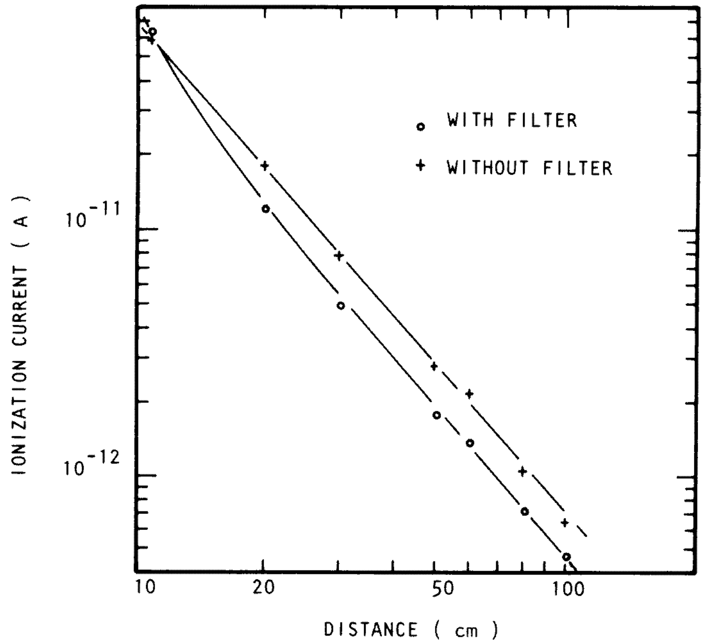

Figure 2. Response variation of the extrapolation chamber as a function of the source–detector distance. $^{90}Sr + ^{90}Y$ (1850 MBq).

2. Materials and methods

A commercial extrapolation chamber (PTW model 23391A) was used in this experiment. This chamber is provided with polyethylene terephthalate (PTP) entrance windows of different thicknesses, and collecting electrodes and guard rings of tissue equivalent material. The collecting electrode is movable and the chamber depth can be changed between 0.50 and 2.50 mm using a micrometer. The electric field in the air gap was always kept constant at 10 V mm^{-1}. A digital electrometer (Keithley 616) was used to measure the ionisation currents. Due to the fact that the involved currents are very low (1×10^{-14}–1×10^{-12} A), the integrated electric charge was measured about 20 consecutive times, in intervals of 10 s, to determine the ionisation current at each polarity and air gap. Measurements were also taken without the presence of radiation, in order to correct the measured ionisation currents for eventual non-constant background leakage currents. The performance characteristics of this extrapolation chamber have been previously reported (Caldas 1986).

Table 3. Effect of the beam flattening filter.

	Slope B (A mm^{-1})	
Source	Source with filter	Source without filter
$^{90}Sr + ^{90}Y$ (1850 MBq)	1.865×10^{-12}	2.879×10^{-12}
$^{90}Sr + ^{90}Y$ (74 MBq)	6.326×10^{-14}	10.346×10^{-14}

Measurements of the ionisation currents were made at chamber depths between 0.70 and 2.50 mm to obtain the extrapolation curves for each source, with and without the use of the beam flattening filter. Through analysis (least-squares fitting) of the extrapolation curves, the slopes of the current versus air-gap functions were determined. The calibration factor, f_c, is given by $f_c = \dot{D}_c B^{-1}$, where $\dot{D}_c$ is the absorbed dose rate in air in μGy s^{-1}, and B is the slope of the current versus air-gap function in A mm^{-1}.

Keeping the chamber depth and the electric field at constant values of 2.50 mm and 10 V mm^{-1}, it was possible to study the response variation with

Table 4. Transmission factors in tissue. Source: $^{90}Sr + ^{90}Y$ (74 MBq).

Tissue thickness (mg cm^{-2})	T with filter	T without filter	T with filter (PTB certificate)
0	1.000	1.000	1.000
2	1.015	1.010	1.017
4	1.031	1.024	1.027
5	1.037	1.028	1.032
7	1.042	1.037	1.041
10	1.057	1.048	1.054
20	1.077	1.070	1.085
50	1.114	1.125	1.118
100	1.023	1.034	1.056

Table 5. Transmission factors in tissue. Source: $^{90}Sr + ^{90}Y$ (1850 MBq).

Tissue thickness (mg cm^{-2})	T with filter	T without filter	T with filter (PTB certificate)
0	1.000	1.000	1.000
2	1.009	1.026	1.029
4	1.018	1.044	1.046
5	1.022	1.051	1.053
7	1.028	1.060	1.068
10	1.034	1.072	1.084
20	1.051	1.098	1.122
50	1.099	1.115	1.175
100	1.007	1.069	1.121

the source–detector distance, with and without the presence of the beam flattening filter. The source–detector distance was varied between 11 and 100 cm.

Transmission factors were determined by covering the chamber with PTP foils and polymethyl methacrylate (PMMA) plates with different thicknesses. The chamber depth and the electric field were kept at constant values of 2.50 mm and 10 V mm^{-1} respectively.

3. Results

The extrapolation curves obtained using the $^{90}Sr + ^{90}Y$ (1850 MBq) source, at the calibration distance of 30 cm, with and without the use of the filter, are presented in figure 1. The measured slopes and calibration factors are shown in table 2 for the beta sources of 74 and 1850 MBq respectively, measured in the same geometries as specified in the calibration certificate. Since the certificate supplies no data for the dose rate of the 1850 MBq source used with filter and the 74 MBq source used without the filter, it was only possible to compare the slopes B, obtained from the extrapolation curves. These slopes are shown in table 3. Differences of 54.4% and 63.5% were found for the 1850 and 74 MBq sources respectively, without and with the filter present in the radiation beam.

In figure 2 the response variation of the extrapolation chamber is presented as a function of the source–detector distance, with and without the presence of the filter (source: 1850 MBq). The response of the extrapolation chamber to the $^{90}Sr + ^{90}Y$ (1850 MBq) source obeys the inverse square distance law in the interval from 11 to 100 cm without the presence of the filter, and between 20 and 100 cm with the presence of the filter. Although the results obtained with the other source (74 MBq) are not shown, they are similar to those with the 1850 MBq source. The standard deviation of the repeated measurements at the same standard calibration conditions was always lower than 3.5%. A prediction of the calibration factors at the different source–detector distances can be made using the data of table 3 and figure 2. The field uniformity was verified at all distances tested between 11 and 100 cm, with and without the presence of the filter, using 18×24 cm Kodak XK-1 (X-OMAT) films. Except for the case of the 11 cm distance using the filter, all radiation fields presented a better uniformity than 99.0% (74 MBq source) and 97.8% (1850 MBq source), as at the calibration distances, over areas with 10 cm diameter. An overall uncertainty of the calibration procedure at the tested source–detector distances was determined as 4.6%.

Finally, in tables 4 and 5 the measured transmission factors for different thicknesses of tissue equivalent material are given for both sources, with and without the use of the filter. In these experiments, the chamber–source distance was kept constant at 30 cm. These data show that the transmission factors increase with the thickness of tissue equivalent material, reaching a maximum value at 50.0 mg cm^{-2} for both sources, and then decrease. The difference between the values of the transmission factors in this study and those from the PTB calibration certificate may be due to the fact that the experimental conditions in the two laboratories were different. In this case, the transmission factors presented differences always smaller than 2.1%, except for the case of 100 mg cm^{-2} tissue thickness (4.9%, 1850 MBq source).

4. Conclusion

The influence of the beam flattening filter in the determination of the calibration and the transmission factors for the chamber–source distance of 30 cm was studied. The intervals where the chamber response obeys the inverse square distance law were also verified for both sources, with and without the presence of the filter, providing alternative test conditions for beta–gamma portable instruments.

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Résumé

Nous avons employé une chambre à extrapolation et l'étalon bêta secondaire du Laboratoire Métrologique de São Paulo, employant des sources de ($^{90}Sr+^{90}Y$), pour vérifier l'influence, sur le champ de rayonnement, du filtre égalisateur du faisceau. Nous avons obtenu les courbes d'extrapolation, les facteurs d'étalonnage et de transmission, avec et sans la présence du filtre égalisateur du faisceau; le but est d'étudier la possibilité d'établir des conditions alternatives de contrôle des instruments bêta-gamma.

Zusammenfassung

Eine Extrapolationskammer und das Beta-Strahlen-Kontrollsystem des Calibration Laboratory in São Paulo mit $^{90}Sr + ^{90}Y$-Strahlern wurden zur Überprüfung des Einflusses des Strahlenglättungsfilters auf das Strahlenfeld eingesetzt. Die Extrapolationskurven, Kalibrier- und Transmissionfaktoren wurden erzielt mit und ohne Benutzung des Strahlenglättungsfilters, um die Möglichkeit zu studieren, alternative Testbedingungen für Beta-Gamma Geräte zu etablieren.

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