technical note

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Performance Characteristics of an Extrapolation Chamber for Beta Radiation Detection

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The performance of an extrapolation chamber was evaluated in β radiation fields. The main characteristics such as calibration factors, energy and angular dependence, transmission factors in tissue and source–detector distance dependence have been determined. The influence of the collecting electrode area on the calibration factors was also investigated.

1. Introduction

A special system for β radiation calibration and dosimetry using a commercial extrapolation chamber has been tested in different β radiation fields. Such chambers have been used to measure the β dose rate in tissue and for calibration of survey instruments. They have been chosen as standard measuring devices, since they allow the absorbed dose rates in a solid medium to be deduced from the ionization in small gas-filled volumes within the medium by extrapolation to zero volume. The problems concerning β radiation calibration and dosimetry using extrapolation chambers have been studied by Böhm.[1–3] Backscatter and transmission factors for β rays were obtained by Murthy and Böhm[4] using thermoluminescent dosimeters and the results were compared with extrapolation chamber measurements, showing a very good agreement. Different kinds of detectors have been tested for β dosimetry and calibration.[5]

2. Experimental Procedure

The β radiation secondary standard system of the Instituto de Pesquisas Energéticas e Nucleares (IPEN) Calibration Laboratory was utilized for these experiments.[6] This system was developed by the Physikalisch-Technische Bundesanstalt (PTB, Brunswick, Germany), manufactured by Amersham Buchler & Co. (Germany) and delivered with a PTB Calibration Certificate. It consists of a source stand, a control unit with timer and three interchangeable β sources of ^{147}Pm, ^{204}Tl and ^{90}Sr + ^{90}Y, whose specifications have been summarized in Table 1. Sources 1 and 2 are only used with beam flattening filters, which serve for the provision of an absorbed dose rate that is as uniform as possible over a circular area, about 10 cm in diameter at the calibration distance. These filters consist of thin plastic foils and are mounted vertically on the axis of the radiation field at a fixed distance from the source. The uniformity of the dose rate due to the beam flattening filters is effective mainly at the calibration distances so that calibrations should be carried out only at these distances. Source 3 has been calibrated at distances of 11, 30 and 50 cm and is used without a beam flattening filter. The radiation field of this source is less uniform than that of sources 1 and 2 and may, for instance, be used for the calibration of dosimeters with small sensitive measuring volumes. For the control of the calibration distance from the sources there are special spacers of 20 and 30 cm.

Table 1. Beta sources

Source	1	2	3
Radionuclide	^{147}Pm	^{204}Tl	^{90}Sr + ^{90}Y
Nominal activity (MBq)	518	18.5	1850
Beam flattening filter	yes	yes	no
Mean beta energy (MeV)	0.06	0.24	0.80
Distance between source and entrance window (cm)	20	30	30

A commercial extrapolation chamber (PTW, Germany) was used as radiation detector, with electrodes and guard rings made of tissue equivalent material. The movable collecting electrode is surrounded by a guard ring which has the same potential as the collecting electrode. Five electrodes with different diameters varying between 10 and 40 mm are also available. The chamber is provided with Mylar entrance windows of different thicknesses, so that it is possible to extrapolate to an entrance window of zero thickness. The distance between the chamber electrodes can be changed between 0.5 and 25.0 mm with the help of the micrometer. The electric field was always maintained constant at 10 V/mm. A digital Keithley 616 electrometer was used for the ionization current detection. Due to the fact that the involved currents are very low, the integrated electric charge was measured about 20 consecutive times, in intervals of 10 s, determining the ionization current in question. A Fluke 405B high voltage power supply and a digital Keithley 160 multimeter were also necessary. Alongside the electrometer, a system was adapted to make possible a periodic display blocking during time intervals necessary for the charge measurements, without altering the continuity of charge accumulation.

Extrapolation curves were obtained for each source measuring the ionization current for both potential polarities applied to the chamber electrodes and plotting the average of these values as a function of the chamber depth between 0.70 and 2.50 mm. When not specified, the 0.025 mm Mylar entrance window and the 40 mm diameter collecting electrode were used for all experiments.

Transmission factors were determined covering the chamber with polyethylene therephthalate (Hostaphan) foils and Plexiglas plates with different thicknesses. These factors were converted to transmission factors for soft tissue by assuming a relative attenuation factor to tissue of 0.92 and 1.01 respectively, for Hostaphan and Plexiglas materials, as shown by Owen.[7] For these experiments the chamber depth was maintained constant at 1.15 mm and the detector was positioned at 15, 20 and 30 cm from the ^{147}Pm, ^{204}Tl and ^{90}Sr + ^{90}Y sources, respectively. In the case of angular dependence determination, the beam flattening filters were exceptionally not utilized for the ^{204}Tl and ^{147}Pm sources, because as the involved currents were very low, it was necessary to take measurements at a source chamber distance of only 10 cm. The ^{90}Sr + ^{90}Y source was used at the calibration distance of 30 cm. The chamber depth was kept constant at 1.15 mm. The rotation axis was chosen at the chamber window surface, which is the reference point for all experiments in the present work.

The maximum relative standard deviation in the measurements using ^{147}Pm, ^{204}Tl and ^{90}Sr + ^{90}Y radiation was 5.5, 3.5 and 0.80% respectively in the most unfavorable cases. These values are mainly due to the technical restrictions of the employed electrometer in these kind of measurements of very low currents.

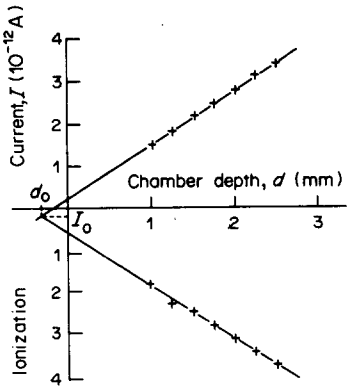

Fig. 1. Extrapolation chamber null depth determination: $^{90}Sr + ^{90}Y$ radiation.

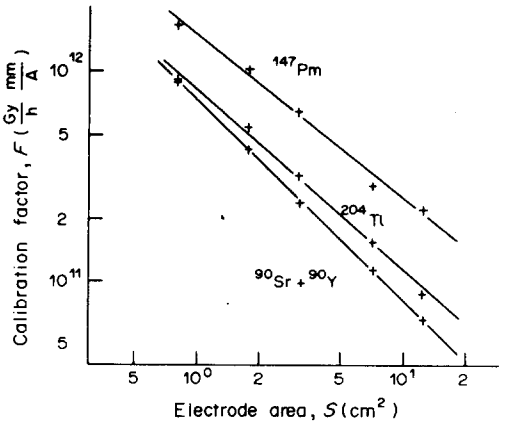

Fig. 3. Collecting electrode area influence on calibration factors.

3. Results

By plotting the ionization current for both potential polarities applied to the chamber electrodes as a function of the chamber depth, two straight lines are obtained which serve to determine the chamber null depth which is defined as the minimum distance between the electrodes. In Fig. 1, d_0 represents the chamber null depth: -0.32 mm. $^{90}Sr + ^{90}Y$ radiation was used. I_0 is the ionization current, always negative, proceeding from the primary beam charged particles (β particles and very energetic δ rays), which lose part or all of their energy at the collector electrode. The I_0 value depends mainly on the electrode thickness.

The chamber depth was varied up to 25.0 mm, using $^{90}Sr + ^{90}Y$ radiation, in order to determine the linearity limit of an extrapolation curve; as it can be seen in Fig. 2, it took place around 3.0 mm chamber depth. The lack of linearity behaviour above this value, for a certain irradiation geometry, is due to the fact that the measuring volume can not be treated as an ideal cavity because the chamber dimensions are not negligible.

Through measurements for extrapolation curves (for each source) and their angular coefficients (which are proportional to the absorbed dose rates in air), the energy dependence of the extrapolation chamber was determined. Table 2 shows its calibration factors. Considering the different entrance window thicknesses, these results agree with those obtained at Institut für Strahlenschutz, GSF, Germany, in similar conditions.[8] A maximum energy dependence of only 42% is achieved after an extrapolation to zero entrance window thickness, by interchanging these windows for each source and taking measurements for extrapolation curves.

Changing the available chamber collecting electrodes with the respective guard rings, measurements for extrapolation curves were taken using all β sources. The determined calibration factors were plotted as a function of the electrode area, as shown in Fig. 3. These results permit the user to choose the electrode according to the necessity, for high and low dose rate determinations.

Keeping the chamber depth at a constant value of 1.15 mm, the ionization current was determined for different chamber–source distances. In the case of $^{90}Sr + ^{90}Y$ and ^{204}Tl radiation the response obeyed the inverse square law respectively in the regions 11–80 cm and 20–40 cm. For ^{147}Pm radiation, the power function relationship presented a power of -4.85 between 11 and 25 cm.

In order to verify the influence of the beam flattening filters on the chamber calibration factor, extrapolation curves were obtained with and without the use of filters. The relative variation of the angular coefficients of the extrapo-

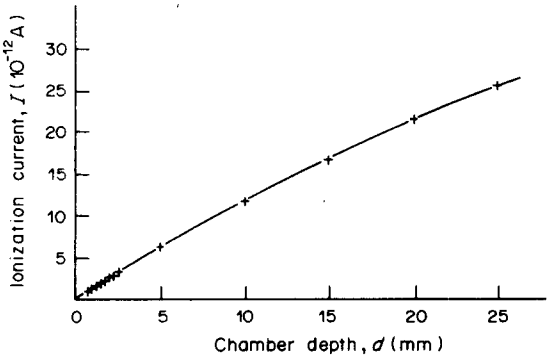

Fig. 2. Extrapolation curve until maximum depth limit: $^{90}Sr + ^{90}Y$ radiation.

Table 2. Energy dependence of the extrapolation chamber. Collecting electrode: 40 mm diameter. Chamber entrance window thickness: 0.025 mm

Source	Mean energy, E (MeV)	Calibration factor F (10^{10} Gy mm h^{-1} A^{-1})
$^{90}Sr + ^{90}Y$	0.80	7.477
^{204}Tl	0.24	8.387
^{147}Pm	0.06	18.52

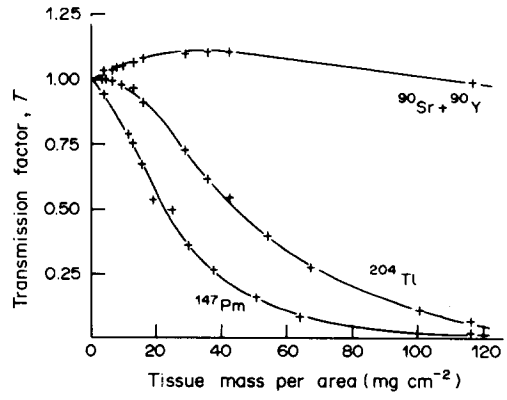

Fig. 4. Transmission factor behaviour as a function of tissue equivalent material thickness. Chamber depth constant at 1.15 mm.

Table 3. Transmission factors for β radiation

Tissue thickness (mm)	^{147}Pm	^{204}Tl	$^{90}Sr + ^{90}Y$
0	1.000	1.000	1.000
0.01	0.937	1.000	1.005
0.02	0.865	0.998	1.013
0.03	0.757	0.996	1.018
0.04	0.650	0.995	1.024
0.05	0.550	0.993	1.030
0.07	0.390	0.988	1.040
0.10	0.235	0.975	1.055
0.20		0.870	1.088
0.50			1.098
1.00			1.024
1.50			0.910

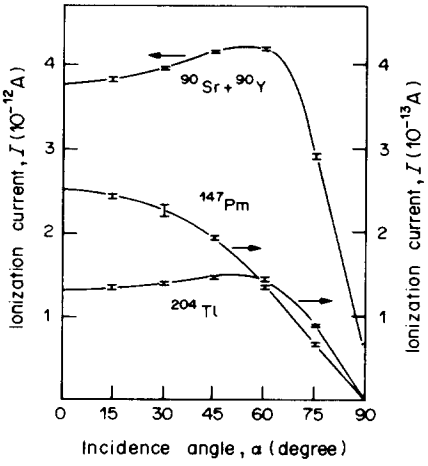

Fig. 5. Angular dependence of the extrapolation chamber. All β sources without beam flattening filters. Chamber depth constant at 1.15 mm

lation curves was 58, 67 and 387% respectively for $^{90}Sr + ^{90}Y$, ^{204}Tl and ^{147}Pm radiation.

The transmission factor behaviour for the three β sources is represented in Fig. 4 as a function of tissue equivalent material thickness expressed in terms of tissue mass per unit area. Table 3 presents the transmission factors from Fig. 4 for typical values of the thickness of tissue equivalent material. These results can not be compared directly with those of Murthy and Böhm,[4] because the experimental conditions were different. The knowledge of transmission factors in tissue is specially important in β dosimetry.

Finally the angular dependence of the extrapolation chamber was investigated. Figure 5 shows its behaviour for all three β sources. The 0 incidence angle corresponds to perpendicular irradiation. The data in this figure are not normalized to the same value of absorbed dose rate, because of the special conditions (without the use of the beam flattening filters). Therefore the curves in this figure are independent of each other. For instance, the energy dependence of the chamber can not be deduced from them. The main objective of this study was to observe how critical a small deviation in the chamber orientation could be in β radiation fields during, for instance, a calibration procedure.

In conclusion, these results demonstrate the utility of a system consisting of the PTW extrapolation chamber and the digital Keithley electrometer for β radiation calibration and dosimetry. The whole set has been largely used at IPEN for calibration of survey monitors, photographic and thermoluminescent dosimeters among others, and for activity determination of $^{90}Sr + ^{90}Y$ clinical small plane sources.

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