Determination of transmission factors for ^{90}Sr+^{90}Y sources with $CaSO_4$:Dy pellets

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Abstract. To determine absorbed doses to skin it is necessary to take into account the tissue backscattering, the mass stopping power ratio of tissue to air, and the tissue transmission of radiation through the matter. The determination of the transmission factors is very important, especially in the case of ^{90}Sr+^{90}Y radiation. To this kind of sources, for very low values of thickness, an increase of the absorbed dose rate is observed, despite the expected decreasing behavior. These factors may be determined using thermoluminescent dosimeters, and covering them with appropriated tissue equivalent plastic foils. In the present work, the transmission factors were determined for a ^{90}Sr+^{90}Y standard source with thermoluminescent dosimeters of $CaSO_4$:Dy, produced at IPEN. Three kinds of pellets were utilized: conventional pellets (0.8 mm in thickness), thin pellets (0.2 mm in thickness) and thin pellets doped with graphite (0.2 mm in thickness). The results were compared with those obtained with different thermoluminescent materials and ionization chamber measurements.

1. Introduction

With the increase of the use of beta radiation sources in the areas of medicine, industry and research, the development of accurate procedures for their calibration is necessary. In this case, an important quantity to be measured is the absorbed dose rate in tissue. The International Commission on Radiological Protection (ICRP) suggests that the absorbed dose rate in tissue shall be determined at the depth of 0.07 mm for the skin and at 3 mm for the eyes [1,2].

The usual instrument utilized for beta calibration and dosimetry is the ionization chamber. Due to the weak penetration of beta particles in matter, a special kind of chamber, the extrapolation chamber, is recommended. The extrapolation chamber allows the variation of its sensitive volume by changing the distance between the electrodes. Using the extrapolation method, the absorbed dose rate in air at the surface can be determined [3].

To convert the absorbed dose rate in air measured with the ionization chamber to absorbed dose in tissue, as required, three factors should be taken into account: the tissue backscattering, the mass stopping power ratio of tissue to air, and the tissue transmission factor. The last one is the correcting factor due to transmission of the radiation through the specified skin thickness [4].

Beta attenuation in matter is usually described approximately by an exponential function. Therefore, in very thin absorbers, the absorbed dose rate can increase despite the expected decreasing behavior. This occurs, for example, for the ^{90}Sr+^{90}Y sources. This "build-up" behavior occurs due to the scattering of the secondary electrons in the detector interior [4,5].

Transmission factors are determined placing sheets of tissue equivalent material between the source and the detector, such as an extrapolation chamber [6,7]. These sheets have to be positioned as close as possible to the chamber. The transmission factors are defined as the ratios between the ionization currents measured with an attenuator (thickness *a*) and the ionization currents extrapolated to absorber null thickness [6]. These factors can also be determined using thermoluminescent dosimeters. In this case, the samples are placed on a suitable phantom and covered by sheets of tissue equivalent material with different thickness [8,9].

There is a variety of available thermoluminescent (TL) materials utilized for radiation detection, but the most popular is lithium fluoride (LiF), because of its radiation absorption characteristics close to water and of its easy reutilization [10]. Natural calcium fluoride (CaF_2) was the most important material on the early days of TL dosimetry; presently, doped forms are most widespread, such as CaF_2-manganese and -dysprosium activated [11]. At the Instituto de Pesquisas Energéticas e Nucleares

(IPEN), Brazil, $CaSO_4$:Dy pellets are produced for radiation dosimetry. Pure and doped samples with different thickness and doping percentage are routinely produced. The most indicated materials for beta radiation detection are thin pellets and pellets doped with graphite [12-14].

The aim of the present work was to determine the transmission factors for a $^{90}Sr+^{90}Y$ standard source using $CaSO_4$:Dy thermoluminescent dosimeters produced at IPEN, and to compare them with former work performed by Caldas [5].

2. Materials and Methods

In this work three kinds of thermoluminescent dosimeters were utilized: conventional $CaSO_4$:Dy (6 mm in diameter and 0.8 mm in thickness), thin $CaSO_4$:Dy (6 mm in diameter and 0.2 mm in thickness) and thin $CaSO_4$:Dy doped with 10% of graphite (6 mm in diameter and 0.2 mm in thickness). The pellets were produced at the Laboratory of Production of Dosimetric Materials at IPEN.

The irradiation system consists of a $^{90}Sr+^{90}Y$ standard source (109 MBq, 2003), Amersham Buchler, calibrated at the German primary dosimetry laboratory, Physikalisch-Technische Bundesanstalt (PTB), at the distances of 11, 30 and 50 cm.

The pellets were always irradiated on a polymethyl methacrylate (acrylic) phantom with 16 mm in thickness. The distance between the source and the phantom was kept constant and equal to 11 cm.

The pellets were thermally treated for 3 h at 300°C before each irradiation. A Harshaw Nuclear System, model 2000 A/B, with a linear heating rate of 6.5°C/s, was utilized as a TL reader. The TL readouts were performed within 45 s, with a constant flow of high purity nitrogen at the rate of 5.0 L/min. Integration areas between 50 and 300°C were utilized. The readings were always taken immediately after irradiation.

Initially, the reproducibility of the TL response of pellets was determined from 5 replicate measurements in repeated cycles of the $^{90}Sr+^{90}Y$ standard source and the standard annealing. The calibration curves of all pellets were determined in the absorbed dose interval from 1 up to 70 Gy.

To determine the transmission factors, polyethylene terephthalate (Hostaphan) foils and acrylic plates with superficial density, respectively, from 1.04 mg/cm^2 to 38.5 mg/cm^2 and from 114.73 mg/cm^2 to 174.84 mg/cm^2 were utilized as absorber materials. The Hostaphan and acrylic transmission factors were converted to transmission factors for tissue by using the relations [4,5]:

10.8 mg/cm^2 Hostaphan ≡ 10.0 mg/cm^2 soft tissue; (1)
10.4 mg/cm2 acrylic ≡ 10.0 mg/cm2 soft tissue. (2)

3. Results and Discussion

The reproducibility of the TL response was adequate for both thin $CaSO_4$:Dy and $CaSO_4$:Dy +10%C. The maximum percentual deviations were 2.8% for thin pellets, 2.3% for doped pellets and 8.9% for conventional pellets. The worst behavior for the conventional $CaSO_4$:Dy pellets was expected because of the beta particle weak penetration in matter.

The TL response of the pellets was plotted as a function of the absorbed dose in air of the beta standard source. The calibration curves for the tested pellets, determined in the dose interval from 1 to 70 Gy, present a similar behavior: they show a linear behavior up to 10 Gy, and after then the curves become supralinear, as shown in Figure 1. This result demonstrates the usefulness of all pellets in the whole tested dose interval to $^{90}Sr+^{90}Y$ radiation detection.

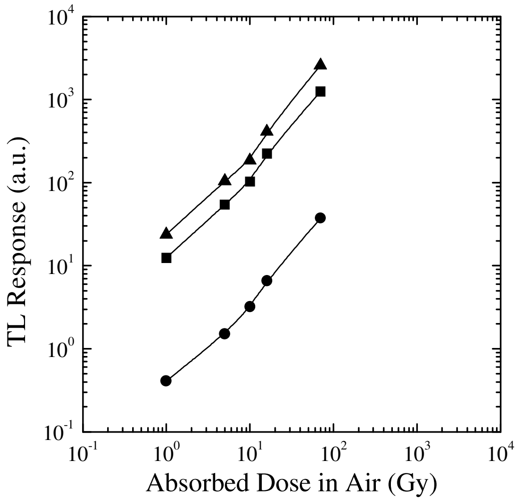

FIG. 1. *Calibration curves for conventional $CaSO_4$:Dy pellets (▲), thin $CaSO_4$:Dy pellets (■), and $CaSO_4$:Dy + 10%C pellets (●). Measurement uncertainties are lower than 12%, 10.0% and 5.7%, respectively.*

The TL response of the $CaSO_4$:Dy pellets as a function of the absorber thickness was determined, and it is shown in Figure 2. An initial increase can be observed, following a decreasing behavior in the TL response. For the determination of transmission factors, the curves were extrapolated to null thickness. The transmission factors are given by:

$$T = \frac{I(a)}{I(0)}, \qquad (3)$$

where I(0) is the TL response of the pellets with null absorber thickness and I(a) is the TL response of the pellets with absorber thickness a. The results are shown in Table 1.

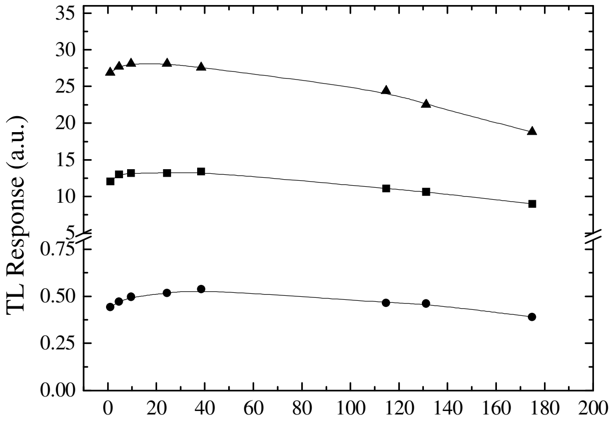

FIG. 2. TL response of the pellets as a function of tissue thickness for conventional $CaSO_4$:Dy pellets (▲), thin $CaSO_4$:Dy pellets (■), and $CaSO_4$:Dy + 10%C pellets (●). Measurement uncertainties are lower than 12%, 9.0% and 3.6%, respectively.

Table I. Transmission factors in tissue for $CaSO_4$:Dy pellets produced at IPEN in $^{90}Sr+^{90}Y$ standard beams.

Tissue thickness		Conventional $CaSO_4$:Dy	Thin $CaSO_4$:Dy	$CaSO_4$:Dy +10%C
(mm)	(mg/cm^2)			
0	0	1.000	1.000	1.000
0.02	2	1.020	1.070	1.038
0.04	4	1.038	1.094	1.074
0.05	5	1.042	1.100	1.090
0.07	7	1.051	1.112	1.114
0.10	10	1.062	1.123	1.142
0.20	20	1.061	1.140	1.194
0.50	50	1.004	1.122	1.214
1.00	100	0.908	1.000	1.074

They present an initial increase in function of tissue thickness, and about 10 mg/cm^2 to 50 mg/cm^2 of tissue thickness they initiate to decrease.

The transmission factors determined by Caldas [5] for different TL materials were summarized in Table II. These factors were determined according to the same experimental procedure utilized in the present work.

Table II. Transmission factors for a $^{90}Sr+^{90}Y$ standard source, adapted from ref [5].

Tissue thickness		LiF (TLD-100)	CaF_2:Dy (TLD-200)	CaF_2:Mn (TLD-400)	$CaSO_4$:Tm (60 µm)	$CaSO_4$:Tm (70 µm)
(mm)	(mg/cm^2)					
0	0	1.000	1.000	1.000	1.000	1.000
0.02	2	1.010	1.000	1.065	1.020	1.035
0.04	4	1.015	1.000	1.115	1.033	1.055
0.05	5	1.020	1.000	1.140	1.040	1.063
0.07	7	1.023	1.000	1.185	1.050	1.080
0.10	10	1.027	1.000	1.247	1.064	1.100
0.20	20	1.030	0.990	1.367	1.100	1.142
0.50	50	0.965	0.932	1.485	1.085	1.145
1.00	100	0.820	0.788	1.327	0.990	1.067

The transmission factors, as shown in Tables I and II, present different values depending on the TL material utilized. Despite that, all materials exhibit the same behavior: the initial increase of the TL response of the samples for thin absorbers. This behavior is the same even when an ionization chamber is utilized as measurement instrument. Table III presents the transmission factors provided in the calibration certificate of the utilized ^{90}Sr+^{90}Y standard source [15].

Table III. Transmission factors for the ^{90}Sr+^{90}Y standard source, ref [15].

Thickness (mm)	Transmission Factor
0.00	1.000
0.02	1.028
0.04	1.049
0.05	1.058
0.07	1.070
0.10	1.095
0.20	1.158
0.50	1.201
1.00	1.157

4. Conclusions

The $CaSO_4$:Dy pellets produced at IPEN are adequate for the dosimetry of ^{90}Sr+^{90}Y radiation. These samples present suitable reproducibility (except for the conventional pellets) and adequate calibration curves. As expected, thinner pellets present the best characteristics for beta detection. The procedure utilized for the determination of the transmission factors is adequate. The transmission factors determined with the $CaSO_4$:Dy radiation detectors are compatible with results from literature.

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