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Technical note

Skin beta-dose assessment with ultra-thin thermoluminescent detectors

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1. Introduction

Recommended maximum skin doses are larger than those for the whole body. The ICRP (1977) imposes an annual maximum of 0.5 Gy to skin and 0.05 Gy to the whole body. Thus when only penetrating or penetrating plus small amounts of low-penetration radiation are involved, high quality dosimetry for low-penetration radiation is not particularly important.

Control of the skin dose does become specially important when working in environments with a large component of soft or low-penetration radiation. In these situations, particularly when the skin dose may be the limiting factor, accurate dosimetry for the skin is essential.

The recommendations of the ICRP (1977) indicate that the skin dose should be averaged between 5 and 10 mg cm^{-2}. For practical dose assessment purposes they recommend the determination of the skin dose at a depth of 7 mg cm^{-2}.

Low-energy beta rays may contribute significantly to the skin dose. For skin beta-dose assessment thermoluminescence (TL) dosemeters may be used and have been, with this aim, intensively investigated recently (Caldas 1980, Regulla and Caldas 1980, Heinzelmann *et al* 1982, Murthy and Böhm 1982, Christensen 1983, da Rosa *et et al* 1984, Caldas *ét al* 1986, da Rosa *et al* 1985). For beta energies below 1 MeV the TL response changes appreciably with the energy distribution, dependent upon the thickness of the detector and the shielding. For a detector with an actual thickness of about 150 mg cm^{-2} or 200 mg cm^{-2}, the energy threshold achieved in practice is about 0.6 or 0.8 MeV (Piesch 1981). Since the skin dose should be averaged between 5 and 10 mg cm^{-2} (ICRP 1977), a 5 mg cm^{-2} tissue-equivalent detector beneath a 5 mg cm^{-2} tissue-equivalent material appears appropriate for skin dose assessment (Driscoll *et al* 1984). Usually somewhat thicker detectors are used which underestimate the dose of low-energy beta rays by up to 50% (Piesch 1981). Therefore the skin dose due to low-energy beta rays should be assessed using TL detectors of small thickness.

Caldas (1980) investigated several TL detectors for beta dose measurements. The materials studied were TLD-100, TLD-200, TLD-400, TLD-600 and TLD-700 from Harshaw Chemical Co. and $Li_2B_4O_7$: Ag, Cu and BeO and $CaSO_4$: Tm from Matsushita Electric Industry Co. Ltd. Among them, $CaSO_4$: Tm with a thickness of 60 μm presented the best properties for beta dosimetry, mainly with respect to energy dependence. Its TL response energy dependence in air was found to be better than 30% over the range of average beta-particle energies from 0.06 to 0.80 MeV. When determining the beta

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absorbed dose at a tissue-equivalent depth of 7 mg cm^{-2} using $CaSO_4$:Tm detectors, it was possible to obtain energy independence, within the experimental errors, in the region between ^{147}Pm and ^{90}Sr-^{90}Y irradiations. $CaSO_4$:Tm TL response properties are very similar to those of $CaSO_4$:Dy (Portal 1981). Dosemeters in the form of ultra-thin discs (6 mm in diameter and 20 μm thick) made of $CaSO_4$:Dy Teflon (Type UT-$CaSO_4$; Dy) are commercially available from Teledyne Isotopes Inc. Murthy and Böhm (1982) showed that such detectors are suitable for measuring backscatter and transmission factors for beta radiation. Da Rosa *et al* (1983) investigated the applicability of UT-$CaSO_4$:Dy for beta radiation detection. These detectors presented a linear response for values greater than or equal to 0.5 mGy for ^{90}Sr-^{90}Y irradiations. In the case of ^{204}Tl, the linear behaviour was observed for values greater than or equal to 1 mGy, while for ^{147}Pm a linear response was obtained for values greater than or equal to 2 mGy. No dependence on the beta absorbed dose rate was found. The detector presented optical fading and an angular dependence in the most unfavourable case (90° in relation to a frontal irradiation) of about 70% for ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm radiation fields. The energy dependence in air of the detector TL response was found to be better than 65% for detectors irradiated under 0.32 mg cm^{-2} tissue-equivalent material.

In the present work the reproducibility of the UT-$CaSO_4$:Dy TL response as a function of the beta absorbed dose in air was investigated. The detector's lower detection limit was determined. Transmission factors for different thicknesses of tissue-equivalent material were obtained for UT-$CaSO_4$:Dy using ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm beta sources. The energy dependence of the detector TL response per unit absorbed dose in air was also determined. Based on the results obtained, a dosemeter for shallow dose assessment is proposed.

2. Experimental procedures

The UT-$CaSO_4$:Dy detectors were irradiated, using the Beta Secondary Standard System of the Calibration Laboratory at the Instituto de Pesquisas Energéticas e Nucleares, with ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm sources. This system consists of a source stand, a control unit with timer and different interchangeable sources. Compensation filters of plastic foils provide for field homogeneity within a diameter of 11 cm at the calibration distances. The sources were calibrated in terms of absorbed dose rates to air, in air, at Physikalisch-Technische Bundesanstalt (PTB), FRG, with a Primary Standard System using an extrapolation chamber. The detectors were always placed on a 12 mm thick phantom (Lucite) during the irradiations. The standard thermal treatment used for UT-$CaSO_4$:Dy consisted of a pre-irradiation annealing at 300 °C for 3 h and a post-irradiation annealing at 100 °C for 15 min. The detectors were evaluated in a Teledyne 7300C thermoluminescence reader with a special planchet to avoid triboluminescence effects.

The reproducibility of the detector TL response was initially investigated. Groups of ten detectors were irradiated with 1.5, 7, 35 and 75 mGy (^{90}Sr-^{90}Y) three times. Batch non-uniformity corrections were applied. The detector's lower detection limit, which may be defined as three times the standard deviation of its zero-dose reading (Piesch 1981), was also determined.

Transmission factors for different thicknesses of tissue-equivalent material were obtained for UT-$CaSO_4$:Dy using the three available beta sources. Hostaphan foils with thicknesses of tissue-equivalent material varying from 0.32 up to 4.6 mg cm^{-2} and from 0.32 up to 25.9 mg cm^{-2} were used in the case of the ^{147}Pm and ^{204}Tl irradiations respectively. For the ^{90}Sr-^{90}Y irradiations, Hostaphan foils and Plexiglas plates were used as absorber materials. The maximum thickness obtained with the Hostaphan foils was 38.9 mg cm^{-2}. With Plexiglas plates it was possible to vary the thickness from 163.5 up to 326.9 mg cm^{-2}. The source-detector distance was 30, 15 and 15 cm respectively for ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm sources. The transmission factors for Hostaphan foils and Plexiglas plates were converted to transmission factors for soft tissue by assuming relative attenuation factors to tissue equal to 0.92 and 1.01 respectively (Owen 1973).

The energy dependence of the UT-$CaSO_4$: Dy TL response per unit beta absorbed dose in air was also determined for ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm radiation fields.

3. Results and discussion

For beta absorbed dose values greater than 1 mGy, UT-$CaSO_4$: Dy presented a reproducibility of better than 3%. Figure 1 shows the reproducibility curve for UT-$CaSO_4$: Dy. This curve can be described by a two-parameter fit (Burgkhardt and Piesch 1980, Piesch 1981):

$$S = \left(\frac{A^2}{D^2} + B^2\right)^{1/2}$$

where S is the reproducibility of the TL response for an absorbed dose value D in mGy, B is the relative standard deviation at high doses (1.3% for UT-$CaSO_4$: Dy) and A is the absolute standard deviation for the detector zero-dose reading (29 μGy for UT-$CaSO_4$: Dy). The value 1.3% is the mean relative standard deviation obtained from detectors irradiated with 75 mGy. The value 29 μGy is the mean absolute standard deviation obtained from three zero-dose readings of a group of ten detectors. For this case the calibration factor obtained from the 75 mGy irradiations was used. Linearity corrections from the results of da Rosa *et al* (1986) were applied. The lower detection limit determined was 87 μGy. The energy dependence of the detector TL response per

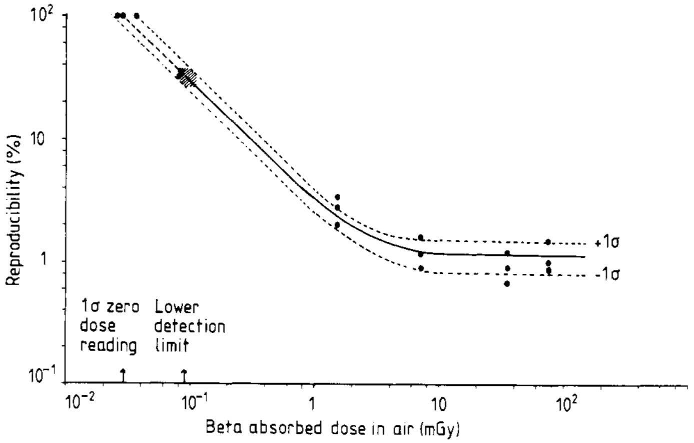

Figure 1. Reproducibility curve of UT-$CaSO_4$: Dy.

unit beta absorbed dose in air is shown in figure 2 (curve a). It can be observed that the detector underestimates by 60% the beta absorbed dose in air for a ^{147}Pm irradiation. This causes a greater lower detection limit approximately equal to 139 μGy for low-energy beta radiation. For beta absorbed dose values below 2 mGy (^{147}Pm irradiation) the UT-$CaSO_4$: Dy TL response is not linear (da Rosa *et al* 1983). Therefore a calibration curve must be used if the detector is intended to be used for the assessment of such low doses.

Table 1 presents the transmission factors obtained for different thicknesses of tissue-equivalent material for UT-$CaSO_4$: Dy. These results showed an agreement of better than 10% with those reported by Murthy and Böhm (1982) for the same sources. The results cannot be directly compared because the experimental conditions were different.

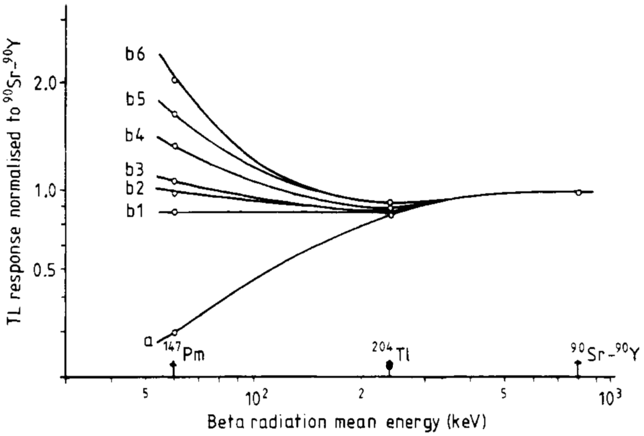

Figure 2. Energy dependence of UT-$CaSO_4$: Dy TL response per unit absorbed dose. Curves: a, in air; b, at a depth of 7 mg cm^{-2} to soft tissue with the following thicknesses of tissue-equivalent material overlying the detector: b1, 4 mg cm^{-2}; b2, 3.4 mg cm^{-2}; b3, 3 mg cm^{-2}; b4, 2 mg cm^{-2}; b5, 1 mg cm^{-2}; b6, 0 mg cm^{-2}.

Table 1. Transmission factors for beta radiation sources using UT-$CaSO_4$: Dy detectors.

Tissue thickness		Source		
(mm)	(mg cm^{-2})	^{147}Pm	^{204}Tl	^{90}Sr-^{90}Y
0	0	1.000	1.000	1.000
0.01	1	0.820	0.988	1.008
0.02	2	0.670	0.973	1.014
0.04	4	0.435	0.948	1.022
0.05	5	0.345	0.933	1.028
0.07	7		0.908	1.034
0.10	10		0.868	1.044
0.20	20		0.740	1.072
0.50	50			1.100
1.00	100			1.083
2.00	200			0.872
3.00	300			0.702

4. Proposal for a dosemeter

For practical purposes, the ICRP (1977) recommends that the skin dose due to beta radiation should be determined at a depth of 7 mg cm^{-2}. It is therefore necessary to calibrate the dosemeter for beta absorbed dose values at this depth. The beta absorbed dose at a depth of 7 mg cm^{-2} tissue-equivalent material can be determined from the beta absorbed dose to air, in air, using conversion factors equal to 1.111, 1.139 and 1.15 respectively for ^{90}Sr-^{90}Y, ^{204}Tl and ^{147}Pm sources, and transmission factors respectively equal to 1.068, 0.955 and 0.20 for the same sources (Böhm 1975, PTB 1981). The TL response (R_t) of the UT-CaSO$_4$:Dy dosemeters irradiated under different thicknesses (t) of tissue-equivalent material can be computed, for a certain beta mean energy value, using the transmission factors (T_t) obtained for the detector beneath different layers of tissue-equivalent material (table 1). Thus,

$$R_t = R_0 T_t$$

where R_0 is the TL response of the dosemeters irradiated without a tissue-equivalent layer for the beta mean energy considered.

The TL response beneath an absorber thickness t (R_t) per unit absorbed dose to tissue at a depth of 7 mg cm^{-2} (D_7) is

$$F = R_t / D_7.$$

The resulting energy dependence curves for different absorber thicknesses are shown in figure 2, curves b (1–6). It can be observed that for a tissue-equivalent material layer of 3.4 mg cm^{-2}, the UT-CaSO$_4$:Dy TL response per unit absorbed dose to tissue at a 7 mg cm^{-2} depth presents an energy independence of better than 12% in the beta radiation mean energy range in question.

This procedure is general and may be applied to different detectors, in order to select a suitable absorber thickness which could improve the energy dependence of their TL response per unit absorbed dose to tissue at a depth of 7 mg cm^{-2}.

A dosemeter is proposed consisting of two UT-CaSO$_4$:Dy detectors. One detector is placed under a layer of 3.4 mg cm^{-2} tissue-equivalent material and is used to assess the skin dose at a depth of 7 mg cm^{-2} with an energy independence of better than 12%. It is necessary to use an opaque material, aluminised Mylar for instance, since the detector presents optical fading (da Rosa *et al* 1983). The other detector is placed under a 10 mm Lucite layer (made opaque) and is used to evaluate the high-energy gamma radiation contribution after a proper calibration. Both dosemeters are placed on a 12 mm thick Lucite base, as in the calibration conditions.

5. Conclusions

The UT-CaSO$_4$:Dy detector showed its usefulness for skin beta dose assessment. It has a good lower detection limit (87 μGy) and its TL response presents a reproducibility of better than 3% for absorbed dose in air values greater than 1 mGy. Under a layer of 3.4 mg cm^{-2} tissue-equivalent material the detector can be used to determine the skin beta dose at a depth of 7 mg cm^{-2} with an uncertainty, due to its energy dependence, of better than 12%. It is necessary to emphasise that the usefulness of the proposed beta dosemeter is potential. Tests under routine conditions are necessary to prove the good performance of such a dosemeter.

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