STUDY OF DOSEMETER PARAMETERS FOR THE MEASUREMENT OF $H_s(0.07)$ FOR PERSONAL BETA DOSIMETRY

P. Christensen[1] and V. Vanamo[2]

1) Risø National Laboratory, DK-4000 Roskilde, Denmark
2) Alnor Oy, SF-20101 Turku, Finland

INTRODUCTION

The basic requirement of a dosemeter designed for individual monitoring of beta radiation is the capability of measuring the skin dose (in a few cases also the dose to the lens of the eyes) independently of energy and incident angle of the radiation and with the accuracy prescribed by national and international bodies. Other important design criteria are concerned with cost and such practical aspects as dosemeter size, identification possibilities and fitness for automated processing. According to ICRU the skin dose should be measured at a depth of 0.07 mm below the surface of the skin and a dosemeter with an energy and angular response equal to that of $H'(0.07)$ is considered to satisfy this requirement(1). In nearly all practical situations a dosemeter intended for personal beta dosimetry must also be able to measure the dose contribution to $H_s(0.07)$ from strongly penetrating gamma radiation.

The performance of a dosemeter is determined from a combination of detector characteristics and badge design. If a tissue-equivalent detector is used, $H_s(0.07)$ can be measured with a simple dosemeter design. Where non-tissue-equivalent detectors are used it is necessary to evaluate beta ray and low energy photon doses separately due to the energy dependence of these detectors to low-energy photon radiation, implying the requirement of using different thin filters. The most common non-tissue-equivalent detector type, the film, is wrapped in a light-tight packet, typically about 0.25 mm thick, permitting this dosemeter to be used only for monitoring beta rays with energies above approximately 0.5 MeV.

A thin tissue-equivalent detector of a few $mgcm^{-2}$ and covered with a similar tissue-equivalent filter is an appropriate dosemeter for skin dose measurements. During the last few years different types of tissue-equivalent detectors with a thin effective detector thickness have been developed(2) and this study in addition comprises a new graphite-mixed sintered LiF detector recently developed by the Alnor Oy. For a dosemeter intended for automatic readout it may be difficult to obtain a position of the skin dose detector in the badge exhibiting an optimal dosemeter performance.

In this investigation the importance of different dosemeter parameters, e.g. detector thickness, filter thickness, and detector/filter geometry and material, for obtaining an optimal energy and angular dosemeter response for beta dose measurements has been studied.

EXPERIMENTAL METHODS

Five types of TL detectors were included in this study, namely LiF, $Li_2B_4O_7$:Mn, and LiF with graphite produced by the Alnor Company, LiF TLD-700 produced by the Harshaw Chemical Company and MgB_4O_7:Dy, with graphite produced by the Boris Kidrić Institute, Vinća[3]. Dimensions and dosimetric properties for irradiation with ^{60}Co photons are presented in Table 1. The detectors were read-out in a hot nitrogen stream for 10 s at 270^{0}C. As pre-irradiation annealing was used a second read-out in the reader and all detectors were given a post-irradiation annealing of 15 min. at 100^{o}C.

Table 1. Dimensions and dosimetric characteristics of different types of TL detectors.

Detector	Dimensions (mm)	Relative γ-ray(^{60}Co) sensitivity	Detection threshold (3σ) (eqv. μGy ^{60}Co)
LiF-N, Alnor	4.5(diam.)x0.8	100	8
LiF TLD-700, Harshaw	4.5(diam.)x0.9	86	8
$Li_2B_4O_7$:Mn, Alnor	4.5(diam.)x0.85	21	20
LiF-N, (2% C), Alnor	4.5(diam.)x0.7	9.5	110
LiF-N, (4% C), Alnor	"	4.5	110
LiF-N, (8% C), Alnor	"	2.0	200
MgB_4O_7:Dy(3%C),Vinća	4 (diam.)x0.9	4.5	120

Beta-ray doses from ^{90}Sr-^{90}Y (E_{max} = 2.27 MeV), ^{204}Tl (E_{max} = 0.76 MeV) and ^{147}Pm (E_{max} = 0.225 MeV) were obtained from the PTB-Büchler secondary standard beta calibration unit. Furthermore, two stronger ^{204}Tl- and ^{147}Pm-sources were used: a 42-mm diameter ^{204}Tl source covered with 20 mgcm^{-2} thick silver foil and a 5-mm diameter ^{147}Pm source with a 5-μm titanium face layer. The distances used between source and detector were 30 cm for the ^{204}Tl and ^{90}Sr-^{90}Y sources and 20 cm for the ^{147}Pm source. As calibration quantity for the measurement of $H_s(0.07)$ for beta radiation was used, the dose equivalent at a depth of 0.07 mm in a semi-infinite extended slab of tissue-equivalent material. Values of this quantity for the standard beta sources were obtained from the calibration certificates for normal radiation incidence and from Böhm[4] for other angles of radiation incidence. The values for the two non-standard sources were obtained from measurements with an extrapolation chamber designed by Böhm[5] and purchased from PTW, Freiburg, FRG. A 1-cm thick perspex plate that can be turned to obtain different irradiation angles was used as phantom for the irradiations. ^{60}Co gamma radiation was used as reference radiation with the detectors placed between two 4-mm thick perspex plates during the irradiations.

RESULTS AND DISCUSSION

Detector/filter thickness

The energy and angular response of a dosemeter to beta radiation strongly depends on the thickness of the detector and/or filter as illustrated in Table 2 where responses of dosemeters with different detector and filter thicknesses are given for different angles of radiation incidence and beta particle energies. The standard ^{90}Sr-^{90}Y source and the two non-standard ^{204}Tl and ^{147}Pm sources were used for these measurements. It can be seen from the table that if appropriate, thin filters are used the graphite-mixed detectors, all having a thin effective detector thickness, are well-suited to the measurement of $H_s(0.07)$ for beta radiation with energies above approximately 220 keV. In contrast, the use of a dosemeter with a relatively thick detector, e.g. the normal 0.9 mm thick LiF detector, for beta dosimetry may imply a significant underestimation of the dose, even for a beta dose from a high-energy beta emitter like the ^{90}Sr-^{90}Y source.

Table 2. Beta ray response of TL detectors placed on a perspex phantom. Results are given for measurements with and without the use of a 7 mgcm^{-2} tissue-equivalent filter and for 0° and 45° angle of radiation incidence.

Detector type	Filter (mgcm^{-2})	TL reading per unit beta dose at 0.07 mm tissue and at angle β° / TL reading per R ^{60}Co					
		^{90}Sr-^{90}Y		^{204}Tl		^{147}Pm	
		0°	45°	0°	45°	0°	45°
LiF-N	0	1.05	0.84	0.49	0.38	0.12	0.13
Alnor	7	1.02	0.80	0.42	0.32	0.03	0.03
LiF, TLD-700	0	1.00	0.80	0.29	0.22	0.12	0.13
Harshaw	7	1.00	0.80	0.27	0.22	0.03	0.03
$Li_2B_4O_7$:Mn	0	1.06	0.89	0.62	0.54	0.21	0.27
Alnor	7	1.03	0.83	0.58	0.47	0.04	0.04
LiF-N (2%C)	0	1.01	0.92	0.93	0.96	0.84	1.02
Alnor	7	1.02	0.95	0.87	0.85	0.16	0.16
LiF-N (4%C)	0	1.02	0.94	1.02	1.00	1.10	1.37
Alnor	7	1.02	0.96	0.93	0.90	0.21	0.24
LiF-N (8%C)	0	0.98	0.96	1.02	1.13	1.50	1.94
Alnor	7	1.03	0.96	0.96	0.96	0.30	0.29
MgB_4O_7:Dy(3%C)	0	0.95	0.94	1.05	1.14	2.90	3.80
Vinča	7	1.02	0.98	0.96	0.90	0.70	0.73

Detector/filter geometry

In most personal dosemeters the detector is positioned at a certain distance from the filter beneath a so-called beta window that has a significant influence on the energy and angular response of the dosemeter to beta radiation(2). In the Alnor and Risø badge the skin dose detector is placed behind holes in 1 mm thick plastic and aluminum shields, respectively(6). Beta-ray responses of the two types of badges were measured by use of graphite-mixed LiF and MgB_4O_7:Dy detectors and by use of both cylindrical- and cone-shaped beta windows (see Table 3). By comparing the data of Table 3 with those of Table 2 it can be seen that to obtain an optimal energy and angular response of the dosemeter a detector/filter geometry as close as possible to that of a simple dosemeter design with the detector positioned in contact with the filter and with no disturbing beta windows should be aimed at. The results furthermore show that improvements can be obtained by optimising the shape and size of the beta window as well as the type of construction material.

Table 3. Beta ray response of TL detectors placed in the beta window position of the Alnor and Risø badge. Results are given for a 4.5 $mgcm^{-2}$ tissue-equivalent filter, for 0^o and 45^o angle of radiation incidence, and for different beta window shapes (see text).

Detector type	Badge type	Diam.(mm) and shape of beta window	TL reading per unit beta dose at 0.07 mm tissue and at angle β^o / TL reading per R ^{60}Co					
			^{90}Sr-^{90}Y		^{204}Tl		^{147}Pm	
			0^o	45^o	0^o	45^o	0^o	45^o
LiF-N		3.5 Cyl.	1.08	0.66	0.50	0.34	0.14	0.16
(4% C)	Alnor	3.5 Con.	1.13	0.68	0.55	0.44	0.16	0.17
Alnor		3.5 Cyl.	0.83	0.48	0.44	0.32	0.15	0.15
	Risø	4.0 Con.	1.07	0.65	0.68	0.53	0.20	0.20
MgB_4O_7:Dy		3.5 Cyl.	1.13	0.74	0.72	0.60	0.51	0.50
(3% C)	Alnor	3.5 Con.	1.15	0.81	0.81	0.69	0.62	0.66
Vinča		3.5 Cyl.	0.85	0.50	0.60	0.47	0.48	0.48
	Risø	4.0 Con.	1.14	0.74	0.81	0.85	0.70	0.70

CONCLUSIONS

The results obtained from this study emphasise the importance of using thin detectors for skin dose assessment. Furthermore a badge design with a minimal shadow effect caused by the beta window should be aimed at.

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