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EVALUATION OF THE PERFORMANCE OF TWO LiF:Mg,Ti AND LiF:Mg,Cu,P DOSEMETERS FOR EXTREMITY MONITORING

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In this paper, the results aimed at assessing the performance of two varieties of LiF detectors (LiF:Mg,Ti and LiF:Mg,Cu,P) in photon fields relatively to reproducibility, detection threshold and angular dependence as defined in the ISO 12794 standard are presented. The fading properties and the limit of detection were also investigated for both materials. The results suggest that both LiF varieties are well suited for extremity monitoring. However, better fading properties of LiF:Mg,Cu,P when compared with LiF:Mg,Ti, combined with previous results relatively to energy dependence suggests that LiF:Mg,Cu,P dosemeters are better suited for extremity monitoring.

INTRODUCTION

The Radiological Safety and Protection Unit of ITN (ITN-UPSR) is implementing the necessary tasks in order to provide extremity monitoring to exposed workers, mainly in the fields of Nuclear Medicine and Interventional Radiology. Presently, ITN provides whole-body monitoring to around 2500 workers in Portugal.

The aforementioned tasks include the characterisation of two LiF detectors for routine use in extremity monitoring and of the reading system. In this paper, additional results aimed at assessing the performance of two varieties of LiF detectors LiF:Mg,Ti (TLD-100) and LiF:Mg,Cu,P (TLD-100H) in photon fields are presented. The dosemeters tested are of the EXT-RAD type and consist of a polyamide strap with a TLD chip and a five-digit barcode, in a sealed vinyl pouch (7 mg cm^{-2}), which is then inserted in a ring strap[(1)].

The tests included reproducibility, detection threshold and angular dependence, as defined in the ISO 12794:2000 standard[(2)], the characterisation of fading properties according to established methods[(3,4)] and criteria established in National Legislation[(5)], and the evaluation of the limits of detection according to the method proposed by Hirning[(6)].

This work complements a previous one[(7)] in which the same varieties of LiF detectors were assessed relatively to several tests defined in the same standard, e.g. residual signal, batch homogeneity, linearity and energy dependence. In the same work, results concerning the stability of the reading system were also presented.

Combined together, these two papers present a comprehensive characterisation of an extremity monitoring system based on LiF detectors.

MATERIALS AND METHODS

The dosimetry system for individual monitoring at ITN-UPSR is based on two Harshaw 6600 readers. One of the readers incorporates a ^{90}Sr/^{90}Y irradiator that is used for the determination of individual element correction coefficients (ECCs), for the irradiation of quality control cards to be read interspaced with field cards during readouts and for experiments that do not require special irradiation conditions. In all experiment sets of 5, 12 or 20 dosemeters of each LiF variety were randomly selected out of the respective batches, which comprise one hundred dosemeters each. All detectors in each batch received initialisation cycles followed by individual ECC determination. The sets of both LiF varieties were always simultaneously prepared and submitted to the same steps (pre-irradiation treatment, irradiation and readout) in order to ensure the direct comparison of the results. Readouts were performed using reading cycles specific for each detector as described elsewhere[(7)]. All irradiations were performed in terms of $H_p(0,07)$ In this study, the following tests were considered.

Reproducibility

The reproducibility test[(2)] requires N dosemeters to be prepared, irradiated and read out for M consecutive times, with a conventional true dose value of 10 mSv or less. After calculating the mean, E_i, and the standard deviation, S_i, values for each dosemeter (i=1,..,N), the reproducibility acceptance criterion is attained if one gets a reproducibility coefficient, r_i, such that:

$$r_i = 100\frac{S_i + I_i}{E_i} \leq 10\,\% \quad (1)$$

with,

$$I_i(M) = t_M\, S_i(2M-2)^{-1/2}, \quad (2)$$

where t_M corresponds to the Student's t-value for a 95 % confidence interval (for M measurements) and I_i represents the half-width of the confidence interval of S_i, calculated from the M measurements.

For this test five dosemeters (N=5) of each LiF variety were irradiated to 5 mSv 10 times (M=10), using the ^{90}Sr-^{90}Y irradiator built-in one the Harshaw 6600 readers.

Detection threshold

The assessment of the detection threshold[2] requires preparing and reading out N unirradiated dosemeters. After the evaluation of each dosemeter, E_i (i=1,...,N), the test is verified if $E_i \leq 1$ mSv. This was performed with a set of five dosemeters (N=5) used in the experiment aimed at assessing the highest dose in the linearity test[7], namely the ones irradiated with a conventional true dose of 100 mSv.

Detection limit

The detection limit L_D, of the measurement system was also investigated, based on the methodology proposed by Hirning[6], for *Levels I* and *III*. The detection limit is defined as a function of the standard deviation of unirradiated dosemeters, s_b, and the relative standard deviation of irradiated dosemeters, s_μ, as in the following equation:

$$L_D = \frac{2(t_n s_b + t_m^2 s_\mu^2 \bar{K}_b)}{1 - t_m^2 s_\mu^2}, \tag{3}$$

where K_b is the background dose, t_m and t_n are the *t-Student* factors for a confidence level of 95 % of the m irradiated and the n unirradiated dosemeter set, respectively.

For both *Levels I* and *III*, 20 dosemeters of each LiF variety were used, which were split into m=10 irradiated and n=10 unirradiated dosemeters. In *Level I* the dosemeters were irradiated to 5 mSv using the aforementioned ^{90}Sr-^{90}Y irradiator. In *Level III* the dosemeters were always irradiated in a ^{137}Cs beam to 100 mSv in terms of $H_p(0,07)$. Ten control periods of 45 d were considered, corresponding to the total time elapsed between shipment to users and readout in routine monitoring.

Isotropy

The isotropy test[2] requires the irradiation of four groups of dosemeters in a photon beam with an energy of 60 $\pm$ 5 keV, at different angles of incidence, e.g. 0°, $\pm$20°, $\pm$40° and $\pm$60° with normal[8]. The isotropy acceptance criterion is verified if the measurement from any irradiated group does not differ from the corresponding response from normal incidence by more than 15 %. Mathematically, the following condition should be verified:

$$0.85 \leq \sum \frac{E_i}{4E_1} \pm I \leq 1.15 \tag{4}$$

in which E_i is the mean of the evaluated values of the dosemeters in group i, E_1 is the mean of the evaluated values corresponding to an incidence of 0° and I, the half-width of the confidence interval of the combined quantity, is given by:

$$I = \sum \left(\frac{\partial \bar{x}}{dx_i}\right)^2 I_i^2, \tag{5}$$

where I_i is the half-width of the confidence interval of the ith mean.

Groups of five dosemeters of each variety were used in this experiment irradiated in a N80 beam (mean energy of 65 keV)[8]. The evaluated values, E, were reported relatively to the ^{137}Cs calibration factors.

Fading

Finally, the fading properties of the two LiF varieties of dosemeters were evaluated. It is required by law that the fading effect shall be <10 % per month[5]; however, no experimental procedure is provided for its evaluation. The experimental setup currently used at ITN for the evaluation of the fading properties of whole-body dosemeters was followed[4] also based on previous work[3]. The experiments covered 2, 4, 6 and 8 week periods so that enough time was given to simulate issuing, integrating and receiving times and respective delays. The dosemeters were organised in subsets of 12. In each subset, four dosemeters were irradiated and stored at room temperature (SA, storage after irradiation group), four were not irradiated at all (M measurement group) and the last four were irradiated after storage (SB, storage before irradiation group). The reference irradiation dose was chosen so that the natural radiation dose is negligible (<1 %). The 12 dosemeters of each subset were readout at the same time, covering the 8 week period.

The results from the sets irradiated and stored at different periods allowed for the evaluation of the fading and sensitivity changes experienced over the whole monitoring period and respective preparation time and readout delay. A fading coefficient f, was defined as (SB−SA)/SA×100 (%), and used to estimate the fading effect.

RESULTS AND DISCUSSION

The results will be presented and discussed in the same order.

Reproducibility

The results were analysed according to the acceptance criteria given by equations 1 and 2 and are presented in Table 1.

From Table 1 the reproducibility coefficients yielded values <2.01 and 1.65 % for LiF:Mg,Ti and LiF:Mg,Cu,P, respectively, which are well below the 10 % acceptance criterion defined in ref. (2), and comparable to previously published results[9].

Detection threshold

The results corresponding to the detection threshold test are presented in Table 2 showing the evaluated values E_i, their mean, standard deviation and coefficient of variation for each set of five unirradiated LiF:Mg,Ti and LiF:Mg,Cu,P. It can be observed in Table 2 that the evaluated values of each LiF variety are between 0.08 and 0.17 mSv for LiF:Mg,Ti (similar to previously published data[10]) and between 0.53 and 0.85 mSv for LiF:Mg,Cu,P, <1 mSv established for this test.

The detection threshold has often been defined as a multiple of the standard deviation of unirradiated detectors[11–13] enabling a fast way to estimate this value. Frequently found values in the literature are 3σ[11], although other values have been used, such as 2σ[12] and 3.29σ[13]. Had the highest of these values been used the detection threshold would be 0.10 mSv and 0.46 mSv, respectively for LiF:Mg,Ti and for LiF:Mg,Cu,P still well <1 mSv value.

Table 1. Reproducibility coefficient values, r_i, for the five pairs of LiF:Mg,Ti and LiF:Mg,Cu,P dosemeters.

Dosemeter	r_i (%) $\leq$ 10 %, N=5, M=10	
	LiF:Mg,Ti	LiF:Mg,Cu,P
TLD 1	1.88	1.39
TLD 2	1.54	1.56
TLD 3	0.99	0.60
TLD 4	2.01	1.65
TLD 5	1.31	1.62

Table 2. Values of E_i, respective mean, standard deviation and coefficient of variation for the five pairs of unirradiated LiF:Mg,Ti and LiF:Mg,Cu,P dosemeters.

Dosemeter	E (mSv) $\leq$ 1 mSv	
	LiF:Mg,Ti	LiF:Mg,Cu,P
TLD 1	0.14	0.85
TLD 2	0.17	0.66
TLD 3	0.12	0.85
TLD 4	0.08	0.69
TLD 5	0.12	0.53
Mean ± standard deviation	0.12 ± 0.03	0.72 ± 0.14
Coefficient of variation (%)	25	19

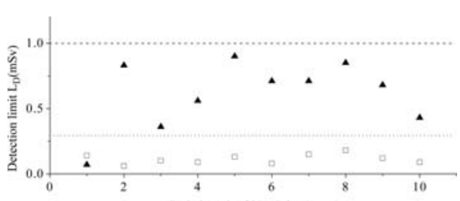

Figure 1. Calculation of the detection limit performed in 10 periods of 45 d: TLD-100H (closed triangles) and TLD-100 (open squares). The dotted line (at 0.3 mSv) and the dashed line (at 1 mSv) represent upper bounds for each set of data.

Detection limit

The detection limits determined according to equation 3 and corresponding to *Level I* are 0.09 and 0.07 mSv for LiF:Mg,Ti and LiF:Mg,Cu,P, respectively.

For *Level III*, the 10 evaluations of the detection limit for each LiF variety were calculated according to equation 3 and considering the time elapsed in routine monitoring on a monthly basis, taken as 45 d. The results obtained are represented in Figure 1. Upper bounds for each set were fixed at 0.30 mSv for LiF:Mg,Ti and at 1.00 mSv for LiF:Mg,Cu,P detectors. These values are in agreement with the 1 mSv value defined for the detection threshold test[2]. For each LiF set, the average was 0.11 ± 0.04 mSv for LiF:Mg,Ti and 0.61 ± 0.26 mSv for LiF:Mg,Cu,P dosemeters. However, the respective upper bounds seem to better represent the actual limit of detection of the reading system based on each LiF detector.

Isotropy

The results corresponding to the isotropy test are presented in Figures 2 and 3, where the dashed lines are the acceptance criteria ±15 % established in the ISO 12794 standard[2].

Figures 2 and 3 show that the differences in the evaluated value between different angles of incidence are well below the 15 % mentioned before. This is confirmed by the isotropy coefficients, calculated according to equations 4 and 5, which are presented in Table 3.

From Table 3 the isotropy coefficients are between 0.96 and 0.99 for LiF:Mg,Ti and between 0.94 and 0.98 for LiF:Mg,Cu,P. These values are well within the acceptance criterion defined in the ISO 12794[2].

Fading

The results for the fading evaluation of both LiF varieties obtained in the 2, 4, 6, and 8 week experiments are shown in Figure 4 and in Table 4. The dots represent the average of SA and SB sets for each LiF detector and the dashed lines ±10 % per month variation allowed by law[5]. The dashed lines should only concern the 4 week experiment but were left in the figure.

In the case of LiF:Mg,Ti, the results in Figure 4 suggest that the integration period should be higher than 2 weeks. For the other integration periods, the dosemeter provided acceptable fading characteristics fitting in the established values.

The results obtained for LiF:Mg,Cu,P detectors show a negligible fading effect as had already been anticipated in similar studies at higher temperatures[3].

In all experiments, the variation in the signal was always less than 10 % per month for all storage periods higher than 2 weeks for LiF:Mg,Cu,P and higher than 4 weeks for LiF.Mg,Ti. The fading effect for LiF:Mg,Cu,P is systematically lower than for LiF:Mg,Ti.

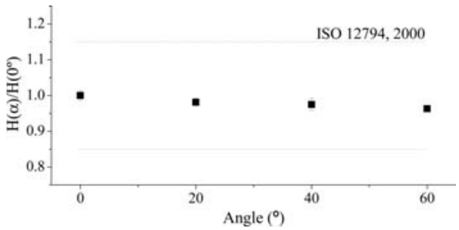

Figure 2. Angular dependence of the LiF:Mg,Ti dosemeter. The angles of incidence correspond to 0°, ±20°, ±40° and ±60°.

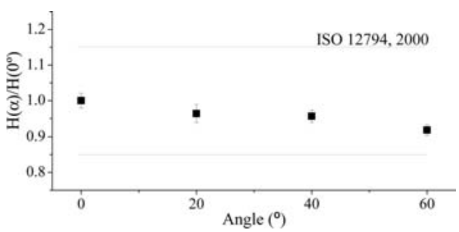

Figure 3. Angular dependence of the LiF:Mg,Cu,P dosemeter. The angles of incidence correspond to 0°, ±20°, ±40° and ±60°.

Table 3. Isotropy coefficient for both dosemeter varieties.

	LiF:Mg,Ti	LiF:Mg,Cu,P
Isotropy coefficient	0.96–0.99	0.94–0.98
Acceptance interval[2]	0.85–1.15	0.85–1.15

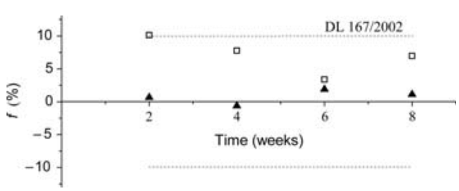

Figure 4. Fading effect for storage periods of 2, 4, 6 and 8 weeks for LiF:Mg,Ti (open squares) and LiF:Mg,Cu,P (closed triangles). The dashed lines represent an allowed variation of ±10 % per month[5].

Table 4. Fading effect *f* (%).

Storage period (weeks)	LiF:Mg,Ti	LiF:Mg,Cu,P
2	10.14±0.04	0.66±0.03
4	7.81±0.03	−0.62±0.04
6	3.39±0.02	1.88±0.02
8	6.98±0.03	1.11±0.04

CONCLUSION

The results described herein complemented with others presented elsewhere[7] suggest that both LiF varieties are well suited for extremity monitoring. However, the best fading properties of LiF:Mg,Cu,P dosemeters, when compared with LiF:Mg,Ti, combined with previous results on energy dependence[7], reenforce the idea that LiF:Mg,Cu,P dosemeters are better suited for this type of application. The results for reproducibility and detection threshold obtained are comparable with previously published results[12, 13].

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