TLD and RPL Dosemeter Performance Criteria for Environmental Monitoring based on Type Tests and Long-Term Experience

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1. INTRODUCTION

Since 1966, solid state dosemeters have been applied for the monitoring of the environment at more than 250 field sites at the Karlsruhe Nuclear Research Center [1]. After exposure periods up to 6 years, the reproducibility of measurement (2σ value) for the background level of 60 mR/a was found to be in the order of ± 4 mR/a with phosphate glasses, ± 4 mR/a for a 4 weeks period with CaF_2:Dy and ± 6 mR/a for a dose rate measurement [2].

Although dosemeter systems with higher accuracy may be applied now, the properties of different TLD readers even of one type is not comparable because of variations either in the PM dark current or in the reproducibility, which may vary by more than a factor 100 and a factor 4, respectively. Accuracy in the low dose range is mainly affected by the zero reading of unexposed detectors, the uniformity and constancy of the detector response after repeated measurements, the post-exposure treatment, the annealing method applied as well as by the period of exposure and the fading.

Therefore, a well founded type test programme has been performed to collect data about the actual state of the art in TL and RPL dosimetry focussing on the problem of selection and application of a suitable dosemeter system. The quality of a system is mainly based on the properties of the individual reader to such an extent that results of other laboratories with the same type of reader or the application of evaluation techniques of the current literature cannot replace an extended performance test with each reader or dosemeter system.

2. REPRODUCIBILITY

For an application in environmental monitoring, measurements are made during exposure periods of several days up to a year which requires accuracy over the mR dose range. The reproducibility found for measurements using only a single dosemeter are presented in Fig. 1 as a function of exposure for four of the seven different dosemeter systems investigated (s.Table 1), based on the maximal deviation within a batch of 10 dosemeters after individual detector calibration. The lower detection limit D_{LDL} defined here as the equivalent exposure for the 3σ value of the dark current deviation was found to be 0.2, 2 and 8 mR for LiF:Mg,Ti detectors and 10 mR for phosphate glasses. For exposures higher than 100 x D_{LDL} a sufficient

	TLD SYSTEM					GLASS	
	1	2	3	4	5	6	7
DOSEMETER SYSTEM							
READER	PITMAN	HARSHAW				TOSHIBA	
TYP		2000				3b	6
YEAR	1975	1972	1968	1972	1972	1961	1967
DETEKTOR	TLD 700				PTL717	FD-1	
SIZE mm^3	3 x 3 x 0.9				4.2ø x 0.9	8 x 8 x 4.7	
EVALUATION T_{max} °C	240	240	240	250	250		
PREHEATING 100°C	E X T E R N A L						
REGENERATION 400°C	YES	YES	YES	NO	NO	YES	YES
DARK CURRENT σ %	16.9	6.6	4.6	7.8	7.5	-	-
MAX. mR	±0.13	±1	±3	±0.8	±0.55	-	-
ZERO-DOSE READING σ %	19.7	48	55	58	55	7.8	1.8
MAX. mR	1.3	1.3	2.7	6.1	12.4	±6.5 [1]	±9 [1]
READER STABILITY σ %	0.02	4.3	0.8	3.0	2.8	0.15	2.3
MAX. %	±0.001	±6.7	±1.5	±5	±5	±0.25	±4.2
LONG-TERM STABILITY σ %	3.3	3.8	5.2	3.4	4.8	0.73	2.2
MAX. %	±6.1	±6.7	±10	±6.5	±6.9	±1	±4.2
REPRODUCIBILITY ± σ % 10xD_{LDL}	15	2.7	4.2	-	-	2.0	3.5
100xD_{LDL}	4.1	1.9	2.3	1.0	2.5	1.2	1.0
±MAX. % 10xD_{LDL}	25	5.2	7.1	-	-	2.5	4.9
100xD_{LDL}	7.5	2.6	3.4	4.2	8.4	1.7	1.7
READER LINEARITY MAX. %	±6.5	±2	±5	-	-	±0.4	±4
BATCH UNIFORMITY σ %	9.4	2.9	7.7	2.4	2.9	0.8	1.9
LOWER DETECTION LIMIT D_{LDL} mR	0.2	2	8	4.5	7.5	10	40
D_{MIN} mR	0.04	0.4	1.8	0.26	0.17	10	20
FADING AT 70°C/10d	26%	26%	23%	-	5 %	1.5%	2.4%

[1]) max. deviation of pre-dose due to washing treatment

Table 1: Dosimetric Properties of TLD and RPL Systems

short-time reproducibilty has been found between 1.5 % and 7 %.

On the other hand, the degree of conformity among 10 repeated measurements or annealing treatments found with a single detector represents the long-term reproducibility under practical conditions (Fig. 2). For a dosemeter system the 1σ values vary from 1 % to 5 % showing relatively low deviations within a batch of 10 dosemeters. For the different dosemeter systems (Fig. 3), however, a significant scattering of the 3σ values has been found depending on the reader (system No. 1,2,3), on the annealing treatment (system No. 2,4) or on the detector material (system 4,5).

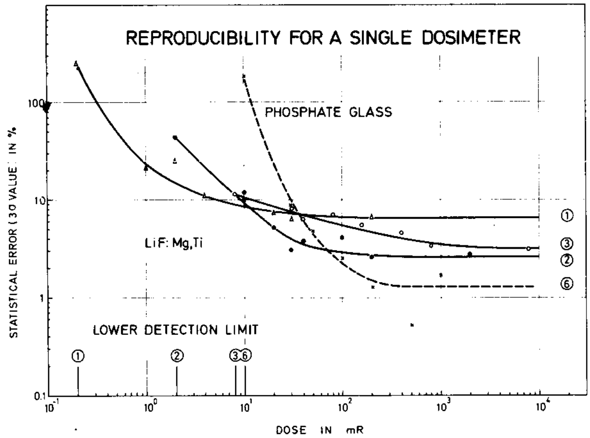

Fig. 1: Reproducibility vs. exposure

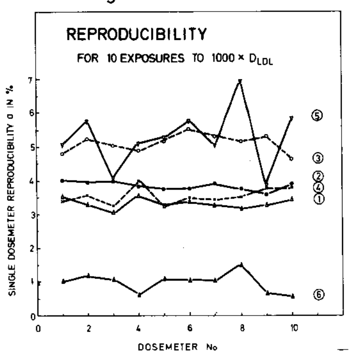

Fig. 2: Long-term reproducibility

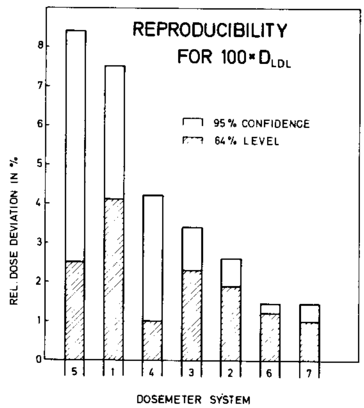

Fig. 3: Short-term reproducibility

3. SENSITIVITY

To investigate the effect of the sensitivity of detector material and reader on the long-term stability in the lower dose range, the 3σ deviation of the dark current as well as the zero reading of unexposed dosemeters after repeated measurements and annealing, respectively, are of interest (Fig. 4). Especially for high sensitive TLD readers, for which the zero reading may be extremely higher than the dark current, both values must be subtracted from the dosemeter reading. Annealing

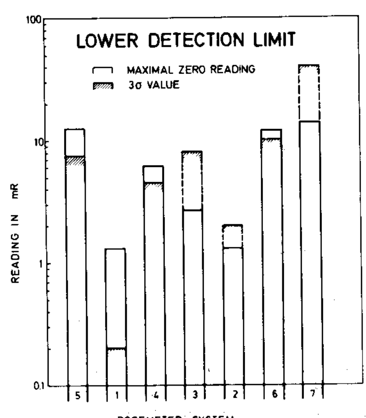

Fig. 4: Lower detection limit

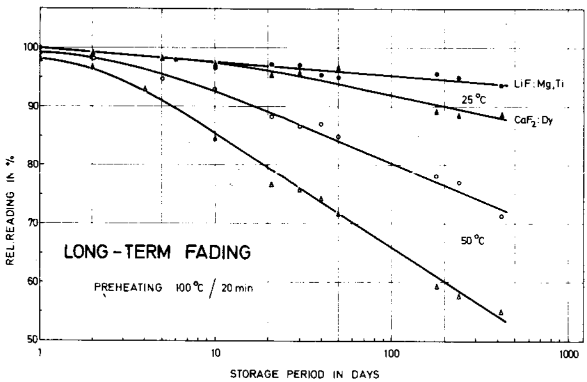

Fig. 5: Fading related to 1 day storage at 25°C

treatments must be applied for system 4 and 5 to yield zero readings below 3 mR, otherwise apparent doses up to 10 mR will be indicated. In phosphate glass dosimetry, on the other hand, the maximal error due to pre-dose subtraction is in the order of 10 mR mainly arising from the washing treatment.

4. FADING

During long-term field exposures, variations with both temperature and humidity in the environment may influence the stability of the dose reading. The dependence of fading on storage time and temperature is presented in Fig. 5 for LiF:Mg,Ti and CaF_2:Dy ribbons [3]. Improvements in the temperature and period of post-irradiation treatment before evaluation may reduce the fading, for instance after 50 days at 50°C practically to zero for LiF:Na,Mg (see Fig. 6) or for LiF:Mg,Ti and even for CaF_2:Dy [4] to values in the order of 5 %. On the basis of such preheating treatment, additional calibration exposures for the correction of the field fading may be avoided and errors minimized.

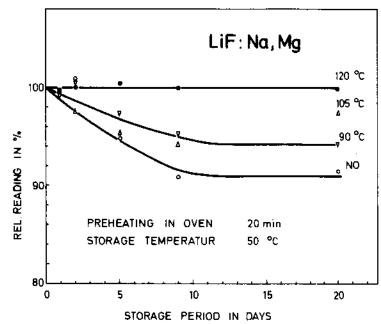

Fig. 6: Reduction of fading of LiF:Na,Mg pellets

5. DOSIMETRIC PROPERTIES

The properties of the dosemeter systems investigated are presented in Table 1 based on the results of 10 dosemeters or exposures. The maximal statistical error of the measurement with a single dosemeter (reproducibility) is found to be in the order of 2.5 % to 25 % for 10 x D_{LDL} or between 3 % and 9 % for the measurement of 30 mR depending mainly on the individual reader. Further errors arise from the uncertainty for the individual dosemeter calibration of 1 % to 4 % (1σ value), the subtraction of the zero dose in the order of 1.2 mR to 20 mR and the non-linearity of the reader (s. Fig. 7).

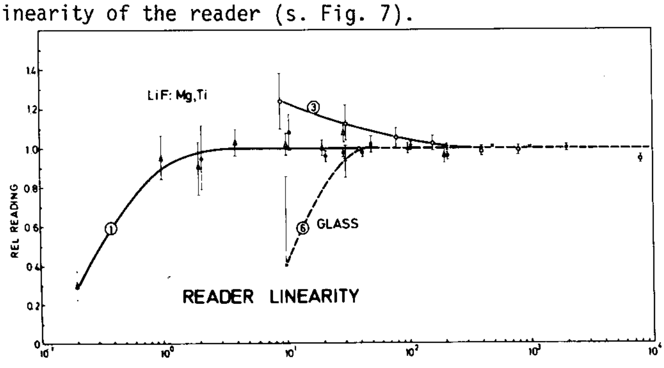

Fig. 7: Reader linearity vs. dose

In addition, appropriate methods of calibration and interpretation must be applied to reduce systematical errors due to additional non-field exposures or environmental effects. For instance field exposures behind a Pb shielding or laboratory exposures with similar dose rates of 10 μR/h may be used to correct for flight doses or for the individual fading during the field exposure [5].

6. CONCLUSION

The paper discusses difficulties concerning the selection of appropriate dosemeter systems for an application in environmental monitoring among others, variations found in the reproducibility and sensitivity even of TLD readers of the same type.

But even with the best system, there is a principal uncertainty of measurement, if an increase in the natural background dose must be estimated. This uncertainty is primarily given by the amount of background dose and the remaining statistical errors of the dosemeter system [6]. For the measurement of low exposures with a single dosemeter an overall uncertainty of at least 10 % should be considered. Variation with both time and space of the natural background dose in the order of 15 % may increase the measuring errors and thus the smallest detectable dose contribution due to the release of radionuclides from nuclear plants. The sensitivity of the dosemeter system does not improve the uncertainty but affects the exposure period which may be at least 1 week for CaF_2:Dy, but more than 3 months or 1 year for LiF:Mg,Ti and phosphate glasses.

7. REFERENCES

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