JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 4, August 2006, p. 1545 - 1551

A new passive dosimetric system with thermoluminescent LiF: Mg, Cu, P detectors applied in individual radiation monitoring

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The paper presents the results of measuring the main parameters and characteristics of a new passive dosimetric system outfitted with thermo luminescent (TL) LiF Mg Cu P detectors for individual radiation monitoring, constructed in IFIN - HH. The presented dosimetric system is employed for measuring the equivalent absorbed dose of X, γ and β radiations within the energy range of 30 KeV – 3 MeV for a 1 to 90 days monitoring period. Among the parameters and characteristics of the new dosimetric system note: the homogeneity of the dosimetric response for a batch of 30 dosimeters is max. 10%; the dosimetric response repeatability is max. 3%; the measurement uncertainty within 7.5 μSv – 100 mSv range is max. 8%; the minimum traceable equivalent dose 70 nSv; loss of dosimetric response information in time is max. 2% per month and the variation of the dosimetric response with the incident radiation energy is max. 8%. The measurements and the system characterization were developed according to CEI 1066 standards previsions. The obtained values fall in the standard provisions. The paper also presents some constructive elements of the dosimetric system.

(Received March 14, 2006; accepted July 20, 2006)

Keywords: Dosimetry, Thermoluminescent detectors, Biological protection, Radioactivity monitoring

1. Introduction

The variety of the activities in the nuclear field requires that such activities should develop under maximum safety conditions. Such a requirement implies the monitoring of the environment radiation and of the operation personnel and generally of all the population [1-5].

The systems employed for such activities are classified as active and passive systems. The dosimetric systems with LiF:Mg, Cu, P, TL detectors of GR-200 A type for individual monitoring fall in passive system category. Such a system is of integrator type with the possibility to integrate the information through one day period – 90 days period. The reading and the upgrading of the detectors is rather fast so that the system may be used in emergency cases as well.

The high accuracy measurement, the low detection limit (threshold), the re-use of the TL detectors for several times, their high sensitivity, make this system recommendable for measuring the equivalent dose for personnel developing its activity in nuclear units.

In a previous paper [6] we have shown how a thermoluminescent detector based on LIF crystal is manufactured.

2. Dosimetric system components and technical-functional characteristics

The individual monitoring dosimetric system (IMDS) consists of:
I) TL reader "Analyzer TL 770A type",
II) TL dosimeter.

The TL dosimeter is including a dosimetric box and LiF:Mg, Cu, P detectors, type GR – 200 A.

The TL reader-analyzer 770 A type for such type of detectors is calibrated for a temperature cycle of 20 – 240 ^{o}C and a heating-up speed of 20 ^{o}C/sec. The value of the test source is 1000 ± 50 pulses for HV=800 V and 200 ± 10 pulses for HV = 700 V and the reader background is 20 ± 5 pulses. The multiplier optimum operation temperature control is provided by a water circuit.

The system is aimed to determine the equivalent absorbed dose value in case of X, γ and β radiation exposure of the personnel. That is why the dosimetric box is provided with several housings in which the detectors are inserted. The housings are provided with filters to disseminate the radiation type. The TL detectors are made of LiF microcrystal with natural Li, activated by Mg, Cu, P and sizing: Ø = 5 ± 0.2 mm and h = 0.8 ± 0.02 mm. In the nuclear domain, such type of detectors are very much used due to the easy reading and fast upgrading. The main technical-functional characteristics of the TL dosimetric system are according to the perceptions in the International Standard ICE 1066 / 91 [1]. The system characterization is satisfying the requirements of the above standards, i.e.:

1. The homogeneity of the dosimetric response for a 30 dosimeter batch is max 11% as to 30%;
2. The dosimetric response for γ and β radiations is 40000 ± 10% pulses/mSv for HV = 800V at the reader and 8000 ± 10% pulses/nSv for HV = 700 V;
3. The repeatability of the dosimetric response is max. 3% as to 7.5%;
4. The measurement uncertainty within the 7.5 μSv - 100 mSv range is max. 8% as to 10%;

5. The minimum traceable equivalent dose is 70 nSv as to 30 μSv;

6. The loss of dosimetric response information in time is max. 2% / month;

7. The variation of the dosimetric response with the incident radiation energy is max. 8% as to 30%

LiF: Mg, Cu, P TL detectors employed in a system, represent the main parts which determine the obtained parameter values and make it recommendable for measuring doses within very small ranges.

3. Calculation method and results of experimental measurements

In order to set the performances of the dosimetric system with GR-200A TL detectors, irradiations with ICRU phantom have been conducted. The ICRU phantom size, were 30 cm x 30 cm x 12 cm.

The equivalent dose value, conventionally true, was determined by a UNIDOS 1001 type dosimeter with Hp (10) ion chamber, for the equivalent dose of 2 μSv/h…1Sv/h, 3% uncertainty and a Baleyline type radiation flow meter for 0…1Gy/h, class I.

The radiation sources were: ^{137}Cs with activity range between 216 - 224Bq, ^{241}Am with 43,7 TBq activity and ^{90}(Sr→Y) with activity between 50mCi…50Ci.

Dosimeters with GR-200A type TL detectors were irradiated at distances varying between 25…50 cm away from the source.

3.1 Homogeneity of the dosimeter batch

In view of that, 20 dosimeters were irradiated at the equivalent dose value, conventionally true, of 1 mSv. Each dosimeter included 3 detectors. The equivalent value of homogeneity results from the relation (1):

$$\omega = \frac{E_{\max} - E_{\min}}{E_{\min}} \cdot 100 \ , \qquad (1)$$

E_{max} – maximum value of V (pulses)
E_{min} – maximum value of Z (pulses)

Table 1. Evaluated values, E, for the TL dosimeters at equivalent dose values, conventionally true, H_{Ca} = 1mSv.

Nr Dos	Nr Measure	Evaluate values E (pulses)	Mediate values of E (pulses)	Nr Dos	Nr. Measure	Evaluate values E (pulses)	Average values of E (pulses)
	1	48 700	43 866 ±		1	47 600	45 466 ±
1	2	41 700	4 193	11	2	43 800	1 943
	3	41 200	(9,5 %)		3	45 000	(4,3 %)
	1	49 400	46 233 ±		1	48 300	46 066 ±
2	2	47 100	3 677	12	2	44 800	1 940
	3	42 200	(7,9 %)		3	45 100	(4,2 %)
	1	48 100	44 500 ±		1	42 900	41 633 ±
3	2	43 800	3 306	13	2	40 500	1 205
	3	41 600	(7,4 %)		3	41 500	(2,9 %)
	1	41 700	41 950 ±		1	48 300	44 900 ±
4	2	-	353	14	2	44 500	3 218
	3	42 200	(0,8 %)		3	41 900	(7,2 %)
	1	45 000	43 633 ±		1	45 900	43 900 ±
5	2	45 700	2 993	15	2	43 000	1 735
	3	40 200	(6,8 %)		3	42 800	(3,9 %)
	1	48 200	46 000 ±		1	44 900	42 933 ±
6	2	45 900	2 151	16	2	41 200	1 861
	3	43 900	(4,6 %)		3	42 700	(4,3 %)
	1	48 100	45 866 ±		1	47 600	45 233 ±
7	2	45 200	2 250	17	2	45 100	2 301
	3	43 600	(4,9 %)		3	43 000	(5,1 %)
	1	45 300	43 400 ±		1	45 300	43 600 ±
8	2	41 500	1 900	18	2	44 000	1 931
	3	43 400	(4,3 %)		3	41 500	(4,4 %)
	1	44 700	44 162 ±		1	47 100	44 866 ±
9	2	47 100	3 233	19	2	44 900	2 250
	3	40 700	(7,3 %)		3	42 600	(5,0 %)
	1	42 500	42 066 ±		1	46 300	45 200 ±
10	2	41 800	378,5	20	2	45 100	1 054
	3	41 900	(1,3 %)		3	44 200	(3 %)

The data presented in Table 1 show that the variation of the dosimetric response for all the 20 dosimeters, for the same value of the equivalent dose, conventionally true, i.e. about 10.2%.

3.2 Dosimetric response

Dosimetric response for the dosimeters for γ and β radiations is 40000 ± 10% pulses/mSv for HV = 800 V (reader) and 8000 ± 10% for HV = 700 V.

Such a dosimetric response was obtained by the irradiation of a representative number of dosimeters at an equivalent dose value, conventionally true, of 10 - 25mSv.

3.3 Dosimetric response repeatability

Ten (10) dosimeters were irradiated 10 times in the same geometrical arrangement and at same equivalent dose value, conventionally true, of H_{Ca}= 6.5 mSv. The experimental results are shown in Table 2.

Table 2. Dosimetric response, R, of the dosimeters irradiated at an equivalent dose value conventionally true, H_{Ca} = 6.5 mSv.

No Dos	Irradiation number										Average value [mSv]	tΔn [%], p=95%
	1	2	3	4	5	6	7	8	9	10		
1	6.10	6.41	656	6.47	6.37	6.44	5.96	6.03	6.04	6.52	6.29	2.6
2	6.79	6.5	6.57	6.67	6.36	6.32	6.29	6.25	6.25	6.47	6.45	2.0
3	6.50	6.46	6.56	6.57	6.30	6.23	6.07	6.23	6.11	6.31	6.3	2.0
4	6.55	6.39	6.59	6.46	6.21	6.19	6.14	6.13	6.15	.30	6.31	2.0
5	6.69	6.62	6.57	6.65	6.28	6.31	6.16	6.10	6.12	6.31	6.38	2.5
6	6.22	6.28	6.35	6.29	5.97	5.99	5.85	5.85	5.84	6.06	6.07	2.3
7	6.64	6.51	6.54	6.56	6.30	6.27	6.23	6.09	6.18	6.30	6.37	2.2
8	6.52	6.46	6.59	6.34	6.26	6.31	6.25	6.19	6.29	6.42	6.36	1.4
9	6.80	6.31	6.29	6.32	6.31	6.19	6.12	5.95	6.08	6.25	6.26	2.5
10	6.24	6.31	6.43	6.36	6.14	6.24	6.15	6.08	6.16	6.28	6.24	1.2
Average value [mS]												
Average value [mSv]	6.51	6.43	6.51	6.47	6.25	6.25	6.12	6.06	6.12	6.32		
tΔn [%], p=95%												
	2.7	1.2	1.2	1.5	1.9	1.3	1.5	2.2	1.4	1.4		

Max values for tΔn is 2.7% for a 95% certainty level.

3.4 The linearity of the dosimetric response within the measurement dose

The dosimetric system with GR-200A type TL detector was tested for γ radiations in the 10 μSv -100 mSv range and for β radiations in the 25 μSv -100 mSv range. The measured equivalent dose was determined by the ratio between the evaluated value and the dosimetric response (calibration factor):

$$H_{mas} = \frac{\overline{E_i}}{F} \quad \text{[mSv]} \qquad (2)$$

H_{mas} - measured equivalent dose value [mSv]

$\overline{E_i}$ - weighted evaluate value [pulses]

F -calibration factor [pulses/mSv]

For HV_{read} = 800 V, F = 40080 pulses/mSv and for HV_{read} = 700 V, F=7959 pulses/mSv.

$$\varepsilon[\%] = \frac{H_{c.a.} - H_{mas}}{H_{c.a.}} \quad , \qquad (3)$$

- ε - measured error

$H_{c.a.}$-value, conventionally true, of measured equivalent dose [mSv]

H_{mas} - measured equivalent dose value [mSv]

Other relation use for linearity verify is:

$$0.90 \le \frac{H_{masi} \pm I_i}{H_{c.a.i}} \le 1.10 \qquad (4)$$

The obtained values are shown in Table 3 and Table 4 and the graph presentation is given in Figs. 1-4.

Table 3. Values of the measurement uncertainties for the γ radiation equivalent dose.

HV (read) (V)	Equivalent dose, conventionally true $D_{c.a.}$	Mediate value of indication ± s_{n-1} (pulses)	Measure equivalent dose H_{mas}	Relative error (%)
800	7,5 μ Sv	350,0 ± 14 %	7,9 μ Sv	
	10 μ Sv	403,7 ± 10 %	10,1 μ Sv	+ 1,0
	16,7 μ Sv	722,3 ± 5 %	18,1 μ Sv	+ 8,4
	50 μ Sv	2 046,2 ± 5 %	51,2 μ Sv	+ 2,4
	100 μ Sv	4 089,3 ± 5 %	102,2 μ Sv	+ 2,2
	500 μ Sv	20 300 ± 8 %	507,5 μ Sv	+ 1,5
	783 μ Sv	31 167 ± 6 %	779,2 μ Sv	- 0,5
	1,0 m Sv	38 600 ± 9 %	0,965 m Sv	- 3,5
	5,0 m Sv	192 300 ± 10 %	4,8 m Sv	- 4,0
	10,0 m Sv	370 300 ± 4 %	9,3 m Sv	- 7,0
700	24,5 m Sv	197 500 ± 10 %	24,7 m Sv	+ 0,8
	29,9 m Sv	233 000 ± 10 %	29,1 m Sv	- 2,7
	55,9 m Sv	474 500 ± 13 %	59,3 m Sv	+ 6,1
	474 500 ± 13 %	59,3 m Sv	+ 6,1	474 500 ± 13 %

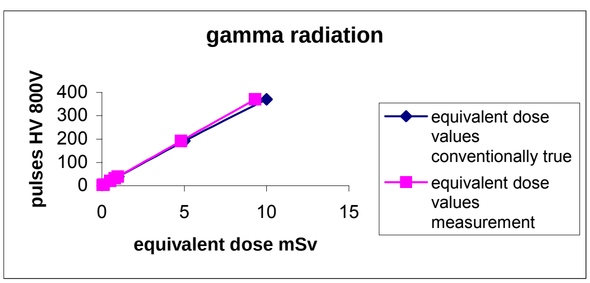

Fig. 1. Graphic representation of conventionally true dose and measured dose, (mSv), function of number of pulses, for gamma radiation; HV 800 V.

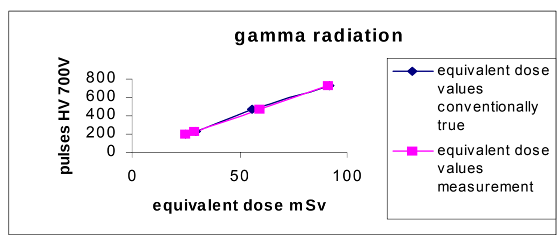

Fig. 2. Graphic representation of conventionally true dose and measured dose, (mSv), function of number of pulses, for gamma radiation; HV 700 V.

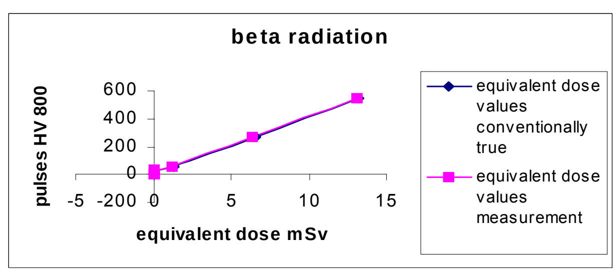

Fig. 3. Graphic representation of conventionally true dose and measured dose, (mSv), function of number of pulses, for beta radiation; HV 800 V.

Table 4. Values of the measurement uncertainties for the β radiation equivalent dose.

HV Reader (V)	Conventionally true dose equivalent $H_{c.a}$	Average indication value $E_i + \Delta_{n-1}$ (impulses)	Radiation equivalent Measurement dose H_{mas}	Relative error %
800	10 µ Sv	397 ± 10 %	9,6 µ Sv	- 4,0
	25 µ Sv	1 027 ± 13 %	24,8 µ Sv	- 0,8
	50 µ Sv	2 066 ± 20 %	49,9 µ Sv	- 0,2
	75 µ Sv	2 985 ± 6 %	72,1 µ Sv	- 3,9
	100 µ Sv	38 543 ± 3 %	93,1 µ Sv	- 6,9
	1,3 m Sv	50 800 ± 1 %	1,2 m Sv	- 8,3
	6,6 m Sv	267 800 ± 3 %	6,4 m Sv	- 3,0
	13,2 m Sv	546 520 ± 4 %	13,1 m Sv	- 0,8
700	25,0 m Sv	197 890 ± 4 %	24,9 m Sv	- 0,05
	75,0 m Sv	630 000 ± 5 %	79,2 m Sv	+ 5,6
	92,9 m Sv	795 400 ± 3 %	99,9 m Sv	+ 7,5

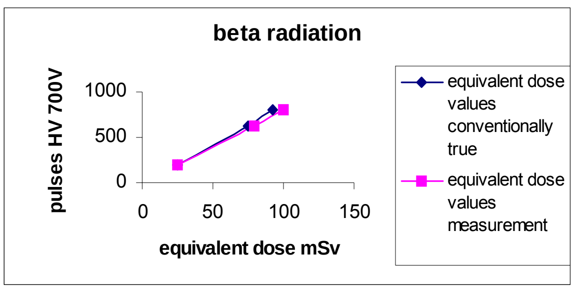

Fig. 4. Graphic representation of conventionally true dose and measured dose, (mSv), function of number of pulses, for beta radiation; HV 700.

Analyzing the graph presentation for the two values of HV and types of radiation, one can observe that the variation of the equivalent dose values measured by the new TL system is comparable with the variation of the equivalent dose values, conventionally true, with the measurement uncertainties presented in Tables 1 and 2.

In Romania, there are 2 TL automatic systems for individual monitoring: one in the Institute of Hygiene-Bucharest and the other in Cernavoda-Nuclear Power Plant.

The SD-TL Model System is a half-automatic system certified by CNCAN (Rumanian Authority for the Nuclear Activity Control)

By means of such a system one can supply extended services of individual monitoring for the operation personnel in the nuclear field.

Analyzing the two tables one may see that the measurement error is 8.4% as to 10% (as required by the international standards).

3.5 Dosimeter detection limit (Threshold)

According to the international standards, the minimum detection limit of the dosimeter employed in the individual monitoring must be 0.1 mSv. In order to determine the detection limit, the detectors in 6 non-irradiate dosimeter were read. The standard experimental deviation was calculated for a 95% level of certainty (trust) and the minimum traceable equivalent dose, $\overline{H}_{MD}$, was established by relation (5).

$$\overline{H}_{MD} = tS_n / R \tag{5}$$

t_n - student factor for n-1 liberty degree;
n –number of dosimeters used for test;
R-answer in pulses/mSv;
S_n –the standard experimental deviation.

Following to the experimental measurements and calculations developed for the γ radiation response value for 800V, the results were:

- average value of readings (in pulses): 38.7
- average value of measured equivalent dose 0.97 (µSv):;
- S_{n-1}(µSv)=0.091 and S_n(µSv) = 0.032

So, the resulted minimum traceable value is 0.08 µSv.

3.6 Dosimetric stability in time

The relative variation of the measured equivalent dose for irradiated dosimeters has the following values:

- at the beginning or the end of a shelf-life period, the value must not differ from the equivalent dose, conventionally true, by more than 5% for 30 day shelf-life under normal test conditions; by -10% for 90 day shelf-life under normal test conditions; by -20% for a 30 day shelf-life at 55˚C and 60% relative humidity and by -20% for a 30 day shelf-life at 90% relative humidity.

For that purpose 2 groups of 2 dosimeters each, were prepared. The two groups were conditioned for 24 h at 20˚C.

One group was irradiated at a conventionally true value of the equivalent of 20 mSv. The two groups were conditioned at 20˚C for a continuous period of 30 days. The second group was irradiated at the same conventionally true value of the equivalent dose like 1st group. The two groups were again conditioned for 24 h under normal test conditions. The average of the measured values and the experimental standard deviation of the equivalent dose for each of the two groups, H_1 and H_2, were calculated and the same tests were repeated for each of the conditioning periods established above.

The obtained experimental data are presented in Table 5.

Table 5. Dosimetric stability in time.

T (days)	T˚C	Humidity [%]	H (mSv)	H_1 (mSv)	H_2 (mSv)	H_1/H	H_2/H
30	20˚C	65	10	9.55	9.63	0.95	0.96
90	20˚C	65	10	9.35	9.43	0.94	0.94
30	55˚C±2˚C	65	10	8.95	9.13	0.90	0.91
30	20˚C±2˚C	90	10	8.88	9.02	0.89	0.90

Following to the experimental measurements, it was found that the relative variation of the equivalent dose value measured for the irradiated dosimeter and stored under the temperature and humidity conditions mentioned above, fall in the allowable variation limit requirements.

4. Comparison of performances with the standard performances and conclusions

Comparison of the performance values obtained with the new IFIN dosimetric system, with the CEI values, is presented in Table 6.

Table 6. Performance values of IFIN dosimetric system versus CEI requirements.

CEI requirement		CEI values	IFIN HH values
1	Catch homogeneity The evaluated value for any one dosimeter in a catch shell not differ from the evaluated value for any other dosimeter in the catch by more then 30 % for a dose equal to 10 times the required detection three hold limits.	max 30%	10.2%
2	Dosimetric answer – ratio between evaluate value and conventionally true value: 40000 ± 10% pulses/mSv for γ radiation (HV = 800V); 8000 ± 10% pulses / mSv for γ radiation (HV = 700)		
3	Reproductibility – the coefficient of variation of the evaluated value shall not exceed 7,5 % for each dosimeter separately and all dosimeters collectively, for a dose 50 μ Sv and 200 μ Sv.	max 7.5%	max 2.7%
4	Linearity – the response shall not vary by more then 10 % over the range declarated.	max 10%	max 8.6%
5	Detection limit (detection threshold) – minimum evaluated value for which the readout value of a dosimeter is significantly different (at the 95 % confidence level) from the readout value of an unirradiated dosimeter. The detection threshold shall not exceed 0,1 m Sv.	max 0.1 mSv	0.08 μSv
6	Stability of dosimeter under various climatic conditions – the evaluated value of dosimeters irradiated at the beginning or at the end of a storage period shall not differ from the conventional true value by more than 5 % for 30 d storage under standard test conditions	5% for 30 days, in normal conditions; 10% for 80 days in normal conditions	4% 6%
7	Energy response (photons) – when irradiated with photons in the range 15 keV – 30 MeV, the evaluated value shall not differ from the conventional true value by more than 30 %.	max 30%	8.2%

The results presented above lead to the following conclusions:

- Since the new linearity error is max 8.4%, actually all dosimeters may be used in measurements,
- The value obtained for the repeatability error is much lower than the value imposed by standards and consequently the 2.70 uncertainly is representing 8.4% maximum,
- The dependence of the dosimetric response is small, leading to the determination of the equivalent dose for each type of radiation, with small uncertainties,
- The measurements developed for the two high-voltage values of the TL reader, allow the performance of the calculation in the low value range (μSv) of the equivalent dose,
- The dosimetric box allows the determination of the doses for the two types of radiation: γ and β.
- The performances obtained with the dosimetric system certified in IFIN, allow its application in the determination of the equivalent dose with very good results in any location where radiation sources are handled along a 1day -90 day period.

  In Romania, there are 2 automatic TL individual assambly systems: one at the Institute of Hygiene-Bucharest and the other at Cernavoda NPP.

The SD-TL Model System is a half-automatic system certified by CNCAN. By means of such a system, extended services of individual radiation monitoring can be provided for the operation personnel in the nuclear field.

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