Characteristics of a Thermoluminescence Dosimetry System based on LiF:Mg,Cu,P (GR-200) Detectors for Environmental Monitoring

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\textbf{Abstract.} The increasing interest of many environmental dosimetry programmes in the highly sensitive phosphor LiF:Mg,Cu,P is based on the positive results of many basic and laboratory type testing and practical results. Our institute has been completed an environmental dosimetry system based on LiF:Mg,Cu,P detectors. The systems consist of LiF:Mg,Cu,P, model GR-200A, detectors in RADOS dosimetry cards (three TLDs per card), two automatic RADOS-DOSACUS TLD reader and heating ovens. In order to evaluated the performance of the system we were carried out the type test recommended by the International Electrotechnical Commission (IEC) in the IEC 1066 standard. The main dosimetry parameters of the dosimeters such as: homogeneity, reproducibility, linearity, detection threshold, residue, and energy and angular response have been tested. In addition, we were carried out an especial study consisting in the comparison of the response of the TL dosimeters with a reference instrument used for continuously monitoring of environmental external radiation. The results show a good performance of the TL system due to accomplish of the IEC 1066 requirements. Also, the value of kerma rate measured with the TLD dosimeters agree well with that determined with the reference instrument for different measurement period.

\textit{KEYWORDS:} thermoluminescence, environmental monitoring

\section{1. Introduction}

The efforts to know the effects on health of the very low level of radiation dose, at which are exposed the people due to natural radiation, are increasing in the recently years. In this order, there is necessary a dosimetry system that should be able to measure that levels of dose. It is well known that thermoluminescence (TL) dosimetry systems are widely used for environmental monitoring. This method offers considerable advantages due to of its high sensibility, stability under severe climatic conditions, very low zero dose reading and a suitable energy and angular response. The use of the dosimeter requires that these properties should be tested according to the requirements recommended by international standard.

In our country the environmental monitoring is carried out by the National Network of Environmental Radiological Surveillance (RNVRA). The RNVRA had employed TL dosimeters for the evaluation of the integrated gamma dose over an exposure period of about six months. For many years, the measurements were carried out using LiF:Mg,Ti detectors \cite{1}. However, the promising performance of LiF:Mg,Cu,P materials for very low dose measurements, based on its very good performance \cite{2}, had been attracted our interest. In this order, we acquired a batch of LiF:Mg,Cu,P (model GR-200) detectors produced in China.

The aim of the present work was to carried out the test to determined the performance of the TL dosimeter based on LiF:Mg,Cu,P, according to the ISO/IEC 1066 standard \cite{3}. Additionally, we developed an investigation to evaluate the fading of the dosimeter under our climatic conditions and to compare their response with the reference dose value reported by the reference instrument used in RNVRA for the monitoring of gamma dose.

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2. Materials and methods

2.1. Thermoluminescence Dosimetry System

The thermoluminescence detectors based on LiF:Mg,Cu,P, model GR-200, whose dimensions are the following ones: 4.5 mm of diameter and 0.9 mm of thickness, were produce in China. The TL environmental dosimeter is structured by Thermoluminescence RADOS Dosimeter (TLD RADOS) and 3 GR-200 detectors. The TLD RADOS dosimeter is composed by the holder and the slide. The slide is plate-shaped, with 4 circular cavities where TL detectors can be placed and it possesses a number recorded in one of its ends that allows its identification. This number is transformed into a code of holes that allows its identification during its process in the reading equipment. The holder contains positions where three filters of aluminum (compensators of the energy of radiation) of 1 mm of thickness and a window of 3.5 mm of diameters are located. This set is placed inside a polyethylene bag that is sealed to guarantee the protection of the dosimeter.

The readings were carried out with two RADOS-DOSACUS readers. The readout parameters were as follows: heating up to 240 °C (constant temperature) during 30 s. The process of heating is carried out by means of a flow of gassy nitrogen of 4.5 l/min⁻¹.

The irradiations were carried out with an automatic RADOS-DOSACUS irradiator, with the ⁹⁰Sr/⁹⁰Y source built into the irradiator. This irradiator supplies irradiations in relative units of dose denominated exposure, and each exposure in the irradiator corresponds to 0.87 mSv. The set is calibrated with regard to the Secondary Laboratory of Dosimetry Calibration (LSCD). When carrying out some tests, the dosimeters will be irradiated in the LSCD because very small dose are required, with a specific angle and energies.

Keeping in mind that the detectors used were "virgin", all of them were subjected to the following process: realization of two irradiation and reading cycles, firstly, five exposures and later two in the RADOS-DOSACUS irradiator.

2.2. Type tests

With the objective of evaluating the performance of the system, we were carried out the tests recommended in the IEC 1066 standard. Among the properties that were evaluated can be found: homogeneity, reproducibility, linearity, detection threshold, energy dependence and residual signal. For that reason, irradiations were carried out under reference and test conditions which are specified in this standard.

The results of these tests were evaluated according to the established performance criteria, which are based on the fulfillment of the levels of accuracy and precision required for this type of service. Following, these tests are described.

**Batch homogeneity:** Sixty dosimeters (180 detectors) were irradiated with the RADOS-DOSACUS automatic irradiator at two exposure cycle (equivalent of a dose value equal to 1.74 mSv). All dosimeters were read in the same working day. The maximum (Dmax) and minimum (Dmin) reading value were determined and the following expression was evaluated:

\[
\frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{min}}} \leq 0.3
\]  

**Reproducibility:** Ten dosimeters were irradiated to two exposures (1.74 mSv) in the RADOS-DOSACUS automatic irradiator and read. This procedure was repeated 10 times. The coefficients of variation (V) of the evaluated value were determined according to the following expression:
\[ V = \frac{S \pm I_i}{D} \leq 0.075 \]  

(2)

Where:
S: Standard deviation of the mean value of the evaluated dose.
D: Mean value of the doses evaluated by the dosimeter in the 10 cycles.
Ii: Confidence interval by:

\[ I_i = \frac{t_{n_i} \cdot S_i}{\sqrt{n_i}} \]  

(3)

Where:
S_i: Standard deviation
\( t_{n_i} \): The Student’s \( t \) for \( n-1 \) degrees of freedom (\( n \)=number of dosimeters used in the test)

**Linearity:** Four groups of five dosimeters each were irradiated in the automatic RADOS-DOSACUS irradiator at different number of exposure cycle, corresponding to the following values of doses: 0.2, 0.5, 1 and 10 mSv. After irradiation, the four groups of dosimeters were read. The average measured dose of each group is plotted against delivered dose.

**Detection threshold:** Ten dosimeters were prepared and read out. The mean value (D) and the standard deviation (SD) were calculated. The detection threshold was determined by the following expression:

\[ Ho = t_n \cdot S_D \]  

(4)

Where:
t_n: Student-\( t \) for \( n-1 \) degrees of freedom (\( n \)=number of dosimeters used in the test) at 95% confidence level.
S_D: Standard deviation of the mean value of the dose.

**Residue:** The same ten dosimeters used in detection threshold were irradiated to 10 mSv and subsequently, the test of detection threshold was repeated.

**Photon energy response:** Twelve dosimeters were prepared and divided into three groups of four dosimeters each. All the dosimeters were irradiated in the LSCD in free air at 10 mGy of air kerma. Each group was irradiated with different energies of the incident radiation: Group 1: 33 keV X-rays; Group 2: 83 keV X-rays; Group 3: \(^{137}\)Cs gamma rays (662 keV). Subsequently the relative response to \(^{137}\)Cs was plotted against energy.

**Photon angular response:** This test was not carried out exactly like it is recommended in the standard, because the LSCD don't have the conditions to carry out rotational irradiation of the dosimeters. However, we were carried out the test in a similar way like it recommended for personal dosimetry, in order to evaluate the dosimeter response with the angle of incidence. Five groups of five dosimeters each were used. All the irradiations were carried out in LSCD in free air, using gamma rays from \(^{137}\)Cs source (662 keV) to a dose of 10 mGy. Each group was irradiated with the following conditions: Group 1: normal incidence (0 °); Group 2: 30 °; Group 3: 60 °; Group 4: 120 °; Group 5: 150 °. The mean values of the dosimeter response were determined for each group and the relative response to normal incidence was plotted against incidence angle.
2.3. Tests of the dosimeters under field conditions.

There were two parts in this test: (a) fading and (b) relative response of the dosimeter to a reference instrument under field climatic conditions.

**Fading:** The study was conceived to evaluate the stability of the dosimeter response in a more that two months exposure period under two different environmental conditions: (a) indoor (acclimatized room) and (b) outdoor locations (natural climatic conditions). Thirty six dosimeters, divided into 16 groups of two dosimeters, were used. All dosimeters were irradiated at 10 mSv with RADOS-DOSACUS automatic irradiator (equivalent exposure cycle). On chronological day, two groups of dosimeter were irradiated and stored in each condition. During the first two months, each group was storage at two weeks intervals and at the third month at one week intervals. After the last irradiation (day 0), all dosimeters were collected and read. The average readouts of all groups of dosimeters were normalized to that of group irradiated on day 0.

**Relative response of the dosimeter to a reference instrument:** The environmental external radiation is continuously monitored by using a Gamma Tracer instrument, based on two independent channels with a Geiger-Müller counter. This instrument is suitable for gamma radiation with energy range from 45 to 1350 keV and to measured dose rate in the range from 8.7 nGy.h$^{-1}$ to 8.7 mGy.h$^{-1}$. The study was conceived to compare the response of the TL dosimeter and the instrument for different exposure period. Four groups of two dosimeters were used. All groups were prepared and subsequently stored for 24 hour in low background storage. On chronological day during one month, each group of dosimeters was stored near the Gamma Tracer instrument. The first group was placed on day 1, the second group 2 weeks later and the third 3 weeks later. One week later, all the dosimeters were collected and evaluated, including that group of dosimeters that remained in the low background storage. The evaluated dose values by the dosimeters were compared with the registered dose value by the Gamma Tracer instruments for the corresponding dates.

3. Results and discussion

In the **homogeneity** test, the values of maximum and minimum dose evaluated were: 1.96 mSv and 1.62 mSv, respectively. Substituting these values in expression (1), we obtain a factor of 0.2, which is very much less than the value recommended by the standard (0.3). In a general sense, the mean value of the evaluated doses and their standard deviation were 1.79 mSv and 0.09 mSv (5%). These results evidence that GR-200A detectors presents very good homogeneity.

In the **reproducibility** test, the determined coefficient of variation range from 3.1 and 3.5%, with an average value of 3.3% for the whole batch of detectors. These values demonstrate that the requirement of the IEC 1066 standard (7.5%) is met.

For **linearity** test, we used the following Fig. 1, which show the average measured dose against the dose delivered for each group.
Figure 1: Linearity of dosimeter response.

From this figure, it is seen that the dosimeter response is within 10% of delivered dose in the studied range, so the IEC 1066 requirement is met and the dosimeter response is consider linear.

The detection threshold was determined by expression (4). The results show a detection threshold value of 1.1 µSv, which is much smaller than 30 µSv. That means that the IEC 1066 requirements for a monthly monitoring period are met. Also, this result is similar to those that are reported by other authors [4]. It is convenient to make clear that the dosimeters were annealed at 240 °C for 120 s before reading, in the RADOS-DOSACUS reader.

In the residue test, the determined detection threshold was of 1.15 µSv. This value is much smaller than the IEC 1066 recommended value (30 µ Svy) and also is consistent with the value that was obtained in the previous test.

In the energy response test, the photon energy response was determined by the ratio of measured dose to conventionally true value. The energy and relative response (to $^{137}$Cs) is shown Fig. 2.

Figure 2: Photon energy response relative to $^{137}$Cs of the RADOS dosimeters base on LiF:Mg,Cu,P.
From this figure, it is evident that the energy response is very flat. Also, it can be seen that the energy response is within 30%, therefore the IEC 1066 requirements is met.

The photon **angular response** is shown in Fig. 3. This figure shows the relative response of each group (mean value) to normal incidence against incidence angle.

**Figure 3**: Photon angular response of the RADOS dosimeters based on LiF:Mg,Cu,P.

![Photon Angular Response](image)

In general, the normalised angular response is within 10% of unity, it is an indication that the dosimeter follows closely the variation of the conventionally true angular factors. The IEC 1066 standard requires that the isotropy fall between 0.85 and 1.15. This requirement is met.

The results of **fading** test are shown in Fig. 4. The temperature was ranged between 20 and 24°C in the acclimatized room, and between 13.5 and 38°C in the outdoor locations.

**Figure 4**: Readout normalised to that of Day 0 in fading test. Conditions: (▲) indoor, (◊) outdoor.

![Fading Test](image)
From this figure, we can observe that there was any significant fading over the exposure period (more than two months). Normalised readout is within 5% of unity for both exposure conditions. The IEC 1066 requirement, which is 10% for 90 days under standard test conditions, is met.

The results of the study carried out to determine the relative response of the dosimeter to a reference instrument are shown in Table 1.

**Table 1**: Relative response of the TLD dosimeter to reference instrument (Gamma Tracer).

<table>
<thead>
<tr>
<th>Exposure time (days)</th>
<th>Reference Dose (Gamma Tracer) $D_s$ (µSv)</th>
<th>TLD Dose (DTLD) (µSv)</th>
<th>Ratio $D_{TLD}/D_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>11.6</td>
<td>12.8</td>
<td>1.10</td>
</tr>
<tr>
<td>13</td>
<td>21.4</td>
<td>21.2</td>
<td>0.99</td>
</tr>
<tr>
<td>28</td>
<td>46.3</td>
<td>44.9</td>
<td>0.97</td>
</tr>
</tbody>
</table>

In addition, Fig. 5 displays the ratio of TL readout to the reference value as a function of environmental dose.

**Figure 5** Relative response of the RADOS dosimeters based on LiF:Mg,Cu,P and Gamma TRACER

Note that there is a good agreement between the dose evaluated with the TL dosimeter and reference dose reported from Gamma Tracer instrument. The maximum ratio is about 10% for an exposure time of one week. This result is very important, because it means that this dosimeter allows the measurements of environmental dose in a very short time.

**4. Conclusions**

The TL systems based on LiF:Mg,Cu,P (model GR-200) detectors and RADOS holder have been studied. The TL dosimeter has been evaluated against an IEC 1066 standard for environmental monitoring. There were carried out the following test: homogeneity, reproducibility, detection threshold, linearity, residue and energy and angular response. In general, the dosimeter passes the entire test requirement with very good performance.

In addition, the dosimeter performance was evaluated under field conditions in which it will be used. The results show a very low fading for a long exposure period (more than two months) in fields.
conditions. Furthermore, LiF:Mg,Cu,P (model GR-200) dosimeters are able to measure environmental dose in a very short integrating period (about a week), with an accuracy better than 10%.

REFERENCES


