EVALUATION OF UNCERTAINTY SOURCES IN A THERMOLUMINESCENT DOSIMETRIC SYSTEM

Peterson L. Squair¹,², Paulo Márcio C. Oliveira¹,², Maria do S. Nogueira¹, Teógenes A. da Silva¹,²

¹Centro de Desenvolvimento da Tecnologia Nuclear (CDTN / CNEN - MG) 
R. Prof. Mário Werneck, snº, Cidade Universitária 
Pampulha, Caixa Postal 941 
30123-970 Belo Horizonte, MG 
pls@cdtn.br; pmco@cdtn.br; mnogue@cdtn.br; silvata@cdtn.br.

²Universidade Federal de Minas Gerais – UFMG 
Programa de Pós Graduação em Ciências e Técnicas Nucleares – PCTN 
Av. Antônio Carlos, 6627 – Campus UFMG 
31270-090 Belo Horizonte/MG

ABSTRACT

The adoption and dissemination of a metrological culture is usually a permanent approach of many institutions; they seek for innovations in their products, high quality provided services, cost reduction, besides giving support to preventive, educational or punitive actions. The accurate dosimetry of radiation fields requires specific characteristics that the instruments must comply with as far as national and international metrological standards. The identification of the uncertainty sources in a measurement procedure with their respective quantitative influence is the first step for improving the metrological quality standard at dosimetry laboratories. Aiming at the reduction of the expanded uncertainty, each relevant source of uncertainty of the dosimetry procedure with thermoluminescent dosimeters LiF:Mg,Ti (TLD 100) was evaluated for different confidence levels. Both theoretical and experimental approaches were used to quantify the effect of each influence quantity in the measured dose value. For doses close to 0.1 mGy results showed that the relevant sources of uncertainties were TL reader electronic noises and detector residual signals with 11.5% and 28.9%, respectively. For doses higher than 1 mGy those uncertainties become negligible when compared to the energy dependence and fading, for example.

1. INTRODUCTION

One of the prerequisite to have an accurate dosimetry of a radiation field is the use of reliable measuring instruments that follow some international performance standard requirements. It is also necessary that measurement values should have their uncertainties stated, which are inherent in a measurement process, so as to have the reliability of the metrological system established.

Performance requirements and test conditions are described by standards produced by national and international institutions and Committees like CASMIE – Brazilian Committee for Evaluating External Individual Monitoring Systems [1], ISO-International Organization for Standardization [2] and IEC-International Electrotechnical Commission [3].

This paper identifies and estimates the values for the many sources of uncertainties inherent to a specific thermoluminescent dosimetry system, as far as different confidence intervals and dose levels.
2. MATERIALS

Tests were performed with a Thermo Electron model 4500 thermoluminescent reader, a Thermo Electron model 2210 $^{90}\text{Sr}/^{90}\text{Y}$ Beta Irradiator source; Steuerungstechnik & Strahlenschutz Gmbh STS model OB85 $^{137}\text{Cs}$ irradiator, a Büchler $^{137}\text{Cs}$ irradiator, 100 dosimetric cards with two LiF:Mg,Ti detectors from Thermo Electron and a Minipa model MTH 1380 thermohigrometer.

3. METHODOLOGY AND RESULTS

The values for each identified source of uncertainty in the thermoluminescent measurement system were determined through the following tests:

3.1. Performance Tests of the Thermoluminescent Dosimeters

3.1.1. Homogeneity and Reproducibility

The batch homogeneity of the thermoluminescent detectors represents the variation of each individual detector reading in relation to the mean reading value of the whole batch; the detector reproducibility represents the ability of each detector to maintain stable readings after successive use.

Tests were performed by irradiating the dosimeters 10 times with 5 mGy air kerma, free-in-air, in $^{137}\text{Cs}$ radiation field; the ISO 12794, IEC 1066 and CASMIE standards were applied to the calculation and determination of the most restrictive limits.

All the used dosimeters showed satisfactory results in accordance to the performance test standards. The detector reproducibility was found below the maximum acceptable limit of 7.5%. The batch homogeneity showed a value below of 15% that is not to be considered a source of uncertainty if sensitivity correction factor of each detector is used.

3.1.2. Fading

Fading is the process in which there is an unintentional loss of the latent information. Many are the causes of the fading process, but the thermal influence is the main one.

In order to reduce the fading effect without the need of an additional pre-reading heat treatment, it was adopted a charge acquisition method, which was related to a single peak region of the thermoluminescent glow curve emission. Peaks 4 and 5 region of the LiF:Mg,Ti (TLD-100) emission was selected through the WimRem software for charge integration purpose between channels 110 and 190. This region was identified as ROI 1.

Figure 1 shows the variation of the thermoluminescent signal of the TLD-100 in the elapsed time of 30 days. In the worst measurement condition, the influence of the fading effect to the reading would not exceed 7.3%.
3.1.3 Residual Signal

The residual signal is the value of the residual charge found during the second reading of the thermoluminescent detectors that were not exposed to any radiation type.

For the accomplishment of this test two readouts of the batch of 100 LiF:Mg,Ti thermoluminescent detectors were realized. It was found an average value of 40 µGy with a standard deviation of 10 µGy.

The most restrictive value established for the residual signal of the LiF:Mg,Ti (TLD-100) thermoluminescent detector was of 50 µGy. However, the uncertainty value of this source depends on the air kerma given to the TLD; low air kerma values show high uncertainties (e.g.: 50% for air kerma of 0.1 mGy and 5% to 1 mGy).

3.1.4. Energy Dependence

The energy dependence test determines the response of the dosimeters in relation to the energy of the incident radiation.

The uncertainty value considered to the energy dependence of the TLD-100 was 10% in all energy range relatively to the $^{60}\text{Co}$ (1250 keV) radiation energy. However, if there is the possibility of correcting the energy dependence or if the dosimeter is irradiated with the same
energy spectrum with which the system was calibrated, this uncertainty source will have a reduced influence.

3.2. Performance of the thermoluminescent reader

3.2.1. Reader Calibration

The calibration of the thermoluminescent reader was realized by the Dosimeter Calibration Laboratory of CDTN/CNEN. In this process, dosimeters were irradiated with 5 mGy air kerma with an expanded uncertainty of 3.5% (k=2) that corresponds to a 95.45% confidence level interval.

3.2.2. Electronic noise

The noise is a false signal inherent in the reading electronic system, and which is still present during the measurements. To reduce the influence of the electronic noise in the readings, it established that its value must not exceed the maximum limit of 1 nC, which represents a 20 µGy (Kerma), as stated by the quality control plan. The uncertainty source, just as the influence of the uncertainty in the residual signal, depends on the air kerma given to the TLD, the less the air kerma, the higher the uncertainty (e.g.: 20% for air kerma of 0.1 mGy and 2% to 1 mGy).

3.2.3. Stability of the thermoluminescent reader

Measurements of the variation of the TL reader response to an stable reference light and to the absorbed dose were taken, in order to test the thermoluminescent reader stability (Figure 2). To verify the reader response variation to the absorbed dose, four selected dosimeters were exposed in a beta radiation field to fixed times that corresponds to 5 mGy absorbed dose; simultaneously four measurements with reference light were done. The mean value of 256 readings was taken as reference for comparison purpose.

The value obtained for the uncertainty related to thermoluminescent reader stability was given by the standard deviation of all readings, that is 5.5%.

This study showed that there is no correlation between the reader responses to the absorbed dose values to the reference light variations, on the contrary of what could be expected. There were cases in which the reader response to the reference light increases but it decreases in terms of absorbed dose, and vice-versa.
3.3. Expanded uncertainty of the measurement system

After the determination of the values related to all relevant sources of uncertainties, the expanded uncertainties for 68.27%, 95.45%, 99.00% and 99.75% were determined, as required in the ISO standard [4]. The uncertainty values related to the air kerma range from 0.1 to 1000 mGy are shown in Figure 3. They represent the uncertainty for just one set of measurements; it may increases depending on the number and the quality of measurements to be performed.

For the final expanded uncertainty calculation, it was used a spreadsheet that identifies all the relevant sources of uncertainties in the system and their respective influence values in the measurement results. Tables 1 and 2 explain how the uncertainty values can vary in relation to the air kerma or absorbed dose values given to the detector.
Values of Expanded Uncertainty in Relation to Kerma

Coverage Interval of 99.73%
Coverage Interval of 99.00%
Coverage Interval of 95.45%
Coverage Interval of 68.27%

Figure 3 – Variation of the uncertainty values in relation to the coverage interval and the received doses.

Table 1 – Information considered in the calculation of the uncertainty for a 0.1 mGy air kerma.

<table>
<thead>
<tr>
<th>Uncertainty Source</th>
<th>Source Value (%)</th>
<th>Probability Distribution</th>
<th>Divisor</th>
<th>Uncertainty Type</th>
<th>Relative Uncertainty (%)</th>
<th>Degree of Freedom (v)</th>
<th>Coverage Factor (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration - Reader</td>
<td>3.5</td>
<td>Supposed Normal</td>
<td>k = 2</td>
<td>B</td>
<td>1.8</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Dosimeter Calibration - Reader</td>
<td>7.5</td>
<td>Normal</td>
<td>Square 10</td>
<td>A</td>
<td>2.4</td>
<td>9</td>
<td>2.32</td>
</tr>
<tr>
<td>Resolution - Reader</td>
<td>0.1</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>0.1</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Stability - Reader</td>
<td>5.5</td>
<td>Normal</td>
<td>Square 256</td>
<td>A</td>
<td>0.3</td>
<td>255</td>
<td>2.00</td>
</tr>
<tr>
<td>Noise - Reader</td>
<td>20.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>11.8</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Residual Sign - TLD</td>
<td>50.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>28.9</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Fading - TLD</td>
<td>7.3</td>
<td>Normal</td>
<td>Square 8</td>
<td>A</td>
<td>2.6</td>
<td>7</td>
<td>2.43</td>
</tr>
<tr>
<td>Reproducibility - TLD</td>
<td>7.5</td>
<td>Normal</td>
<td>Square 16</td>
<td>A</td>
<td>2.4</td>
<td>9</td>
<td>2.32</td>
</tr>
<tr>
<td>Energy Dependence - TLD</td>
<td>10.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>5.8</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Calculated k = 2.00

Table 2 – Information considered in the calculation of the uncertainty for a 1000 mGy air kerma.

<table>
<thead>
<tr>
<th>Uncertainty Source</th>
<th>Source Value (%)</th>
<th>Probability Distribution</th>
<th>Divisor</th>
<th>Uncertainty Type</th>
<th>Relative Uncertainty (%)</th>
<th>Degree of Freedom (v)</th>
<th>Coverage Factor (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration - Reader</td>
<td>3.5</td>
<td>Supposed Normal</td>
<td>k = 2</td>
<td>B</td>
<td>1.8</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Dosimeter Calibration - Reader</td>
<td>7.5</td>
<td>Normal</td>
<td>Square 10</td>
<td>A</td>
<td>2.4</td>
<td>9</td>
<td>2.32</td>
</tr>
<tr>
<td>Resolution - Reader</td>
<td>0.1</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>0.1</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Stability - Reader</td>
<td>5.5</td>
<td>Normal</td>
<td>Square 256</td>
<td>A</td>
<td>0.3</td>
<td>255</td>
<td>2.00</td>
</tr>
<tr>
<td>Noise - Reader</td>
<td>0.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>0.0</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Residual Sign - TLD</td>
<td>0.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>0.0</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Fading - TLD</td>
<td>7.5</td>
<td>Normal</td>
<td>Square 8</td>
<td>A</td>
<td>2.6</td>
<td>7</td>
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<td>Reproducibility - TLD</td>
<td>7.5</td>
<td>Normal</td>
<td>Square 16</td>
<td>A</td>
<td>2.4</td>
<td>9</td>
<td>2.32</td>
</tr>
<tr>
<td>Energy Dependence - TLD</td>
<td>10.0</td>
<td>Rectangular</td>
<td>Square 3</td>
<td>B</td>
<td>5.8</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Combined Standard Uncertainty - $u_c$: 32.0
Effective v = 77862.1
Calculated k = 2.00

Expanded Uncertainty - $U$: 99.45
Expanded Uncertainty - $U_c$: 63.9

INAC 2007, Santos, SP, Brazil.
Results from tables 1 and 2 showed that the uncertainties due to the reader noise and the residual signal of the thermoluminescent detector had different influence on the measurements. It depends on the air kerma or absorbed dose values provided to the TL detectors; for low dose values the uncertainties increases considerably.

4. CONCLUSIONS

Among many sources of uncertainties that can be found in the measurement procedure with a thermoluminescent dosimetric system, some of them did not contribute effectively to the expanded uncertainty. However, relevant sources of uncertainties like the energy dependence of the thermoluminescent detector must be studied and well defined. Procedures to reduce the influence of significant sources of uncertainties should always be searched for.

When concepts of metrology are proper introduced in the measurement system they provide high quality information and show precisely what should be improved in the measurement system to get accurate results.

REFERENCES


