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Evaluation of Reproductibility and Detection Limit of $CaSO_4$:Dy Radiation Detectors

José Eduardo Manzoli[1,2*], Vicente de Paulo de Campos[1] and Mirian Saori Doi[1]
[1]Instituto de Pesquisas Energéticas e Nucleares - IPEN; Av Lineu Prestes, 2242; Cidade Universitária; 05508-000; São Paulo - SP - Brasil. [2]Universidade São Judas Tadeu - USJT; R. Taquari, 546; Mooca; jmanzoli@ipen.br; São Paulo - SP - Brasil

ABSTRACT

Measurement response of thermoluminescent dosimeter, TLD, used by workers or placed at positions where gamma radiation field could be in action affecting biological tissues, should be completely characterized, in order to achieve the radiation quantity with precision and confidence. Among the evaluations concerned to its characterization, the detector reproductibility is of fundamental importance, because detectors present inside the TLD will be used many times in routine. Reproductibility is studied by repeated exposure to the same radiation field. The minimum detection limit is another important characteristics of a TLD. In this work evaluations of reproductibility and minimum detection are presented, for dosimeters produced at IPEN.

Key words: Detector selection, personal dosimetry, environmental dosimetry

INTRODUCTION

Brazilian *Laboratório de Dosimetria Termoluminescente*, LDT at IPEN, uses, for its personal dosimetry (Manzoli and Carvalho, 2002) and environmental dosimetry (Manzoli and Manzoli, 2003), thermoluminescent dosimeters, TLDs, composed by three phosphor detectors. A view of the trunk dosimeter is presented in (Fig. 1). A detector will be used many times in its routine lifetime and its TL response should be precisely known at every utilization, mainly at non predictable radiological emergencies.
Detectors are not selected by the manufacturer, stockist of LDT, then detectors must be selected in batches of sensibility before utilization. For selection and characterization, it was evaluated, in this work, the measurement uncertainty sources *reproductibility* and *detection limit* (minimum). These are the most strength sources of measurement uncertainties, for the $CaSO_4$:Dy detector.

MATERIALS AND METHODS

Detector is a composite whose shape is a disc of 6.0 mm diameter and 1.0 mm thick, composed by Calcium Sulphate and Disprosium doping ($CaSO_4$:Dy) pressed in a matrix of polytetrafluorethilene (PTFE) (Manzoli and Carvalho, 2002). These detectors are re-utilized many times.
Thermoluminescent response of detectors, called "readings", were made in TL reader Harshaw model 5500 and in model 2000.
TL reading is an indirect measurement. The hole measurement method has many uncertainty

* Author for correspondence

sources. Some of them are illustrated in Ishikawa diagram of (Fig. 2).

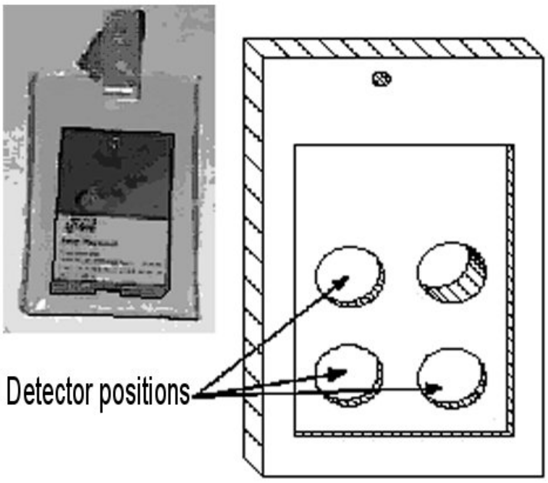

Figure 1 - Trunk dosimeter (6x4 cm) of LDT-IPEN. In the indicated positions of the drawing, three detectors of $CaSO_4$:Dy/PTFE are placed.

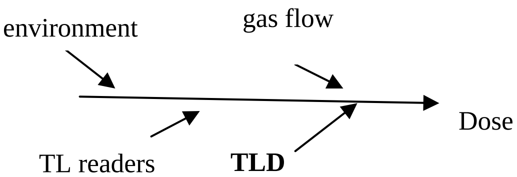

Figure 2 - Ishikawa diagram of some uncertainty sources of the dose measurement using TLD. Each of the sources could be subdivided in many others.

The "branch" TLD, as source of uncertainty in (Fig. 2), presents subdivisions like reproductibility, thermal treatment, homogeneity and detection limit, as represented in diagram of (Fig. 3).
The value of each uncertainty source should be methodically evaluated using whenever possible, the procedure to vary one and leave the other sources unchanged. This is called robustness analysis, in analytical essays. The weight, or importance of each source can be estimated.
It is worth remembering that there is no repeatability in destructive (information) essays, like thermoluminescence ones. It is considered a destructive essay, because the information is lost after TL reading and it is not possible to repeat the measurement at the same conditions. R*eproductibility* is defined here as the detector ability to reproduce its measurement, maintaining the other conditions as unchanged as possible, trying to be closer to the *repeatability* concept. Actually, the technical definition of reproductibility demands to change the essays conditions as much as possible, which will not be the case in this work.

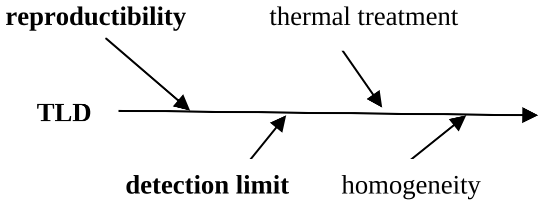

Figure 3 - Ishikawa diagram of subdivisions in TLD itself as source of measurement of radiation dose uncertainty.

RESULTS AND DISCUSSION

Reproductibility
It is extremely difficult to maintain all uncertainty sources as low as desired, like irradiation details, thermal treatment, machine parameters, environmental conditions etc.. Thus, the reproductibility alone, as defined, contains or summarizes important information about the TL response variation that a detector batch could have under the same radiation dose imparted on it.
Determination of the interval of this variation, or the dispersion of TL responses (reproductibility), leads us to state that the same detector, being read at the same conditions, will not have a TL response out of this interval, at a determined confidence level.
The first step after receiving the detectors is to make the selection in batches by theirs sensibility (Manzoli and Campos, 2003). An example of TL response distribution used in such a selection is shown in (Fig. 4). It can be seen that for the hole received set there is a TL response variation higher than 100%, a great non-homogeneity characteristics of the received detectors..
To evaluate the reproductibility is to define the width of each box in that mathematical distribution

histogram, in such a way that these boxes fit precisely the sensibility batches.

A sample set with 189 detectors was chosen. They were irradiated with 5.0 mGy, read after 24 h, thermally treated and irradiated again. This cycle was repeated four times.

These TL responses were analysed by the criteria 10, 15, 20, 25 and 30% as follows: if a detector had its TL response in the next cycle different from the previous, and the modulus of this difference per cent is smaller than the criterion, it is counted in; if not, it is counted out of this criterion.

The difference in successive TL readings is measured by the per cent deviation, $D_{\%}$:

$$D_{\%} = \frac{A_{max} - A_{min}}{A_{min}}.100 \qquad (1)$$

Where $A_{max,min}$ are the higher and the lower values in successive TL readings, respectively.

After four TL readings (three repetitions), and putting each detector response in one or more criteria in successive readings, the per cent number of detectors which are excluded from the previous oddment is counted.

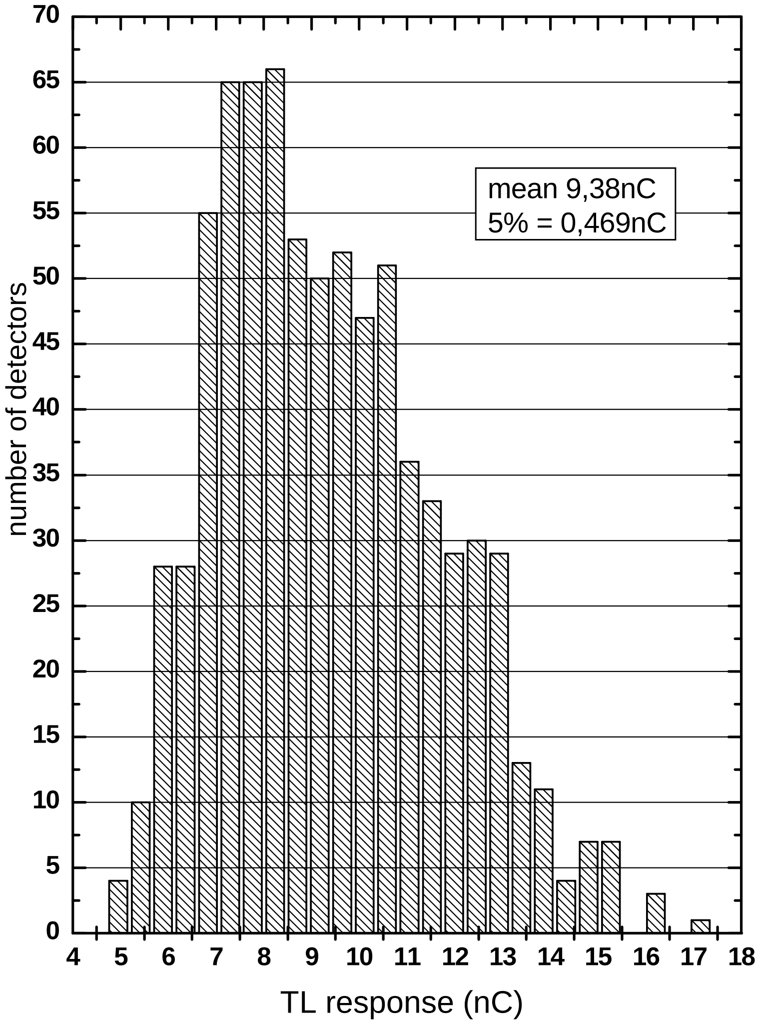

Figure 4 - TL response distribution of 777 detector irradiated by 2.0 mGy of ^{60}Co.

These counting results for each criterion are in (Fig. 5). This procedure permits to establish a reproductibility limit, below which it will not have an acceptable number of detectors. The boundary of 95% confidence level of this uncertainty source could be assumed as the criterion in which the exclusion does not cross the line of 5% of exclusion (Fig. 5).

Then, reproductibility as an uncertainty source, was evaluated as $(15\%)_{95\%}$ for $CaSO_4$:Dy/PTFE detectors used at LDT/IPEN.

Minimum Detection Limit

Minimum detection limit, DL, is the quantity value below which it is not possible to use it for measurements.

The DL calculus for a batch of $CaSO_4$:Dy/PTFE detectors used results of 90 TL readings. Detectors are thermally treated but not irradiated, and read next. Thermal treatment consists of heating detectors at 300°C for 1 h.

Mathematical distribution of TL responses is in (Fig. 6). One detector was excluded by Chauvenet criterion.

DL is:

$$\text{DL} = \text{measurement median} + 2 \times (\text{standard deviation}) \qquad (2)$$

The factor 2 comes from spectroscopy resolution of peaks. The median, instead of mean, is more interesting for these evaluation because it is less liable to individual results and ideal for distributions of small symmetry. For TL response, in the limit, the median is the mean and distribution becomes gaussian.

For the studied batch, DL is 0.094 nC. In the quantity Photon Individual Dose, DL is 4.5 μSv, and in Photon Exposure, DL is 0.12 μC/kg.

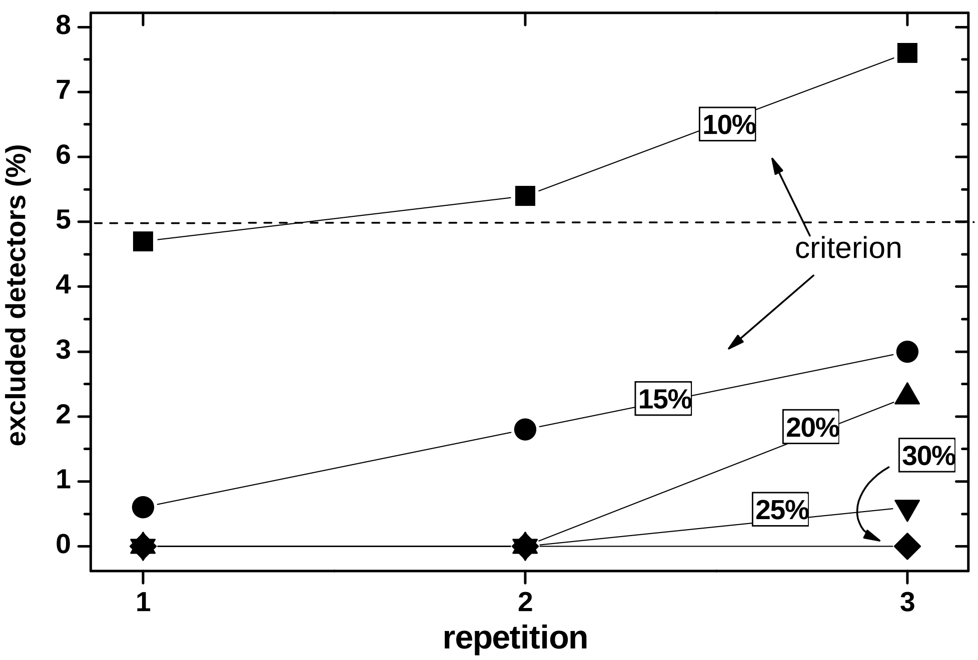

Figure 5 - Per cent number of excluded detectors in each repetition of cycle (thermal treatment - irradiation with 5.0 mGy - TL reading after 24 h). If $D_{\%}$ (Eq. 1) is above the criterion, the detector is excluded and not counted in the next repetition. Dotted line is the 5% of exclusion.

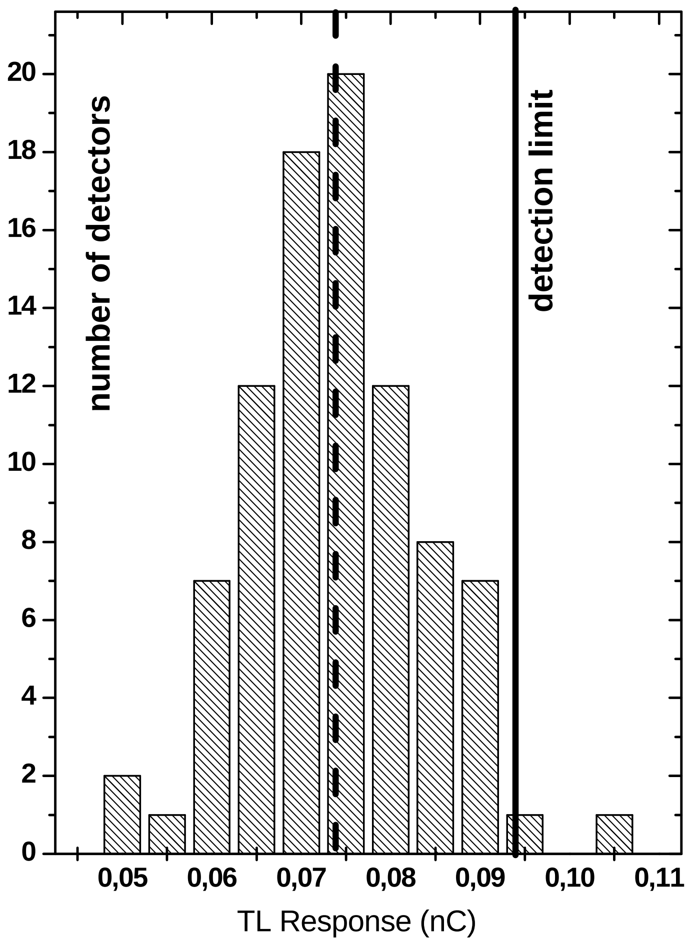

Figure 6 - TL response distribution for non irradiated detectors. Dotted line is the median. Straight line is the DL, not yet converted by the calibration factor.

These values of reproductibility and detection limit permit the utilization of these detectors for Personal and Environmental Dosimetry because they are in accordance with the regulations (C.A.S.M.I.E., 1995; Townsend et al., 1995).

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RESUMO

A resposta de um dosímetro termoluminescente, TLD, utilizado por um trabalhador ou colocado em um local que possa estar sujeito a um campo de radiação gama afetando tecidos biológicos, deve ser muito bem caracterizada afim de se obter o valor da grandeza de medição da radiação desejada, com precisão e confiança. Entre as avaliações envolvidas nesta caracterização encontra-se sua reprodutividade, de fundamental importância pois o detector é re-utilizado várias vezes na rotina de serviços. A reprodutividade é estudada pela exposição do detector a um mesmo campo de radiação repetidas vezes. O seu limite de detecção é outra importante característica. Neste trabalho são apresentadas avaliações da reprodutividade e do limite de detecção dos detectores produzidos no IPEN.

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