QA Programme of the TLD Laboratory of the University of Costa Rica: IEC 61066 testing

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Abstract. The Thermoluminescence Personal Dosimetry Laboratory of the University of Costa Rica provides dose measurements for around 90% of occupational radiation workers in the country. The assessment of doses to workers routinely exposed to external sources of radiation constitutes an integral part of any radiation protection programme and helps national authorities to ensure acceptably safe and satisfactory radiological conditions in workplaces. Harshaw Readers Model 4000 and 4500, dosimeter holders Type 8814 with TLD-100 in 0110 cards and loose TLD-100 chips are used to monitor personal dose equivalent, Hp(10) and Hp(0.07). In order to provide a reliable measurement of the operational quantities, a study was undertaken to verify the fulfillment of international requirements in our system (Model 4500 with cards) against the *Thermoluminescence dosimetry systems for personal and environmental monitoring CEI IEC 61066 (1991 -2012)*. The type tests performed were nine in total: batch homogeneity, reproducibility, linearity, detection threshold, effect of climate conditions on reader, effect of light exposure on dosimeters, isotropy, transient voltage and dropping on dosimeters. A Cesium-137 source was used to irradiate the dosimeters and all procedures follow the indications given on the standard. Results showed that all IEC criteria were met by our Laboratory. Acceptable uncertainties were also studied under the ICRP recommendations; the analysis of the Trumpet Curve was done with satisfactory results (for doses above 0.5 mSv; quotient of measure to real dose less than 3%). For purposes of accreditation (ISO/IEC 17025:2005) and performance testing this work is very relevant since the University of Costa Rica wants to establish a solid individual monitoring programme for external radiation exposure that will provide users, registrants, licensees and regulatory bodies with information that can be used for the optimization of protection and dose limitation of Costa Rican workers.

KEYWORDS: TLD, personal monitoring programme, IEC 61066, type testing, radiation protection, optimization.

1. Introduction

In Costa Rica occupational exposure to radiation comes primarily from medical, industry and research applications. Adequate radiation protection of workers is an essential component of our radiation legislation. Requirements for the protection of workers exposed to sources of radiation are based on the effective dose concept.[1-2] International radiation experts have identified the personal dose equivalent as the operational quantity to use for assessing and controlling radiation exposure.[3-4] ICRU has defined the Hp(10) as the quantity for individual monitoring, this is the dose equivalent in soft tissue below a specified point on the body, at an appropriate depth d (in this case d is 10 mm). The personal dose equivalent represents a practical quantity to substitute for the effective dose, an unmeasurable concept based on probabilistic estimates of adverse health consequences that may occur following exposure to radiation .[5]

The University of Costa Rica is the only institution in the country with a dosimetry system in place to determine the personal dose equivalent for occupational conditions. The TLD Laboratory has been approved by the National Regulatory Authority since 1999. Its initial objective was to provide dosimetry services only to university personnel, but after a few years external private and governmental institutions were using it and it has been growing ever since and now it is responsible for the assessment of 90% of the occupational radiation workers in the country.

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In order to estimate the ability of our dosimetry system to evaluate the personal dose equivalent at depth of 10 mm, a series of tests under type testing guidelines have been followed to establish the influence of a large number of factors potentially affecting the ability of our dosimetry system to measure personal dose equivalent with an acceptable amount of uncertainty. [6,7,8] This work is very relevant since the TLD Laboratory has currently undertaken all necessary steps to obtain the ISO/IEC 17025:2005 accreditation [9] and national regulatory bodies need to rely on a solid dosimetry system as part of the radiological protection assessment of radiation workers.

2. Methodology

The Personal Dosimetry Laboratory of the University of Costa Rica has a Harshaw 4500 Reader, the dosimeter holders are model 8814 and the cards are type 0110 with TLD-100 chips (3.1 x 3.1 x 0.89 mm) in positions 2 and 3. The Cesium source used to irradiate was a Shepard Model 28 with 44.4 GBq (1997) that belongs to the Centro de Investigación en Ciencias Atómicas, Nucleares y Moleculares (CICANUM); the spherical ionization chambers used for the dosimetry are PTW TW32002-0256 and TW32003-0087 of volumes 1 and 10 liters respectively. Irradiations were carried out on the ICRU slab water phantom at 2 meters for the magnitude Hp(10) in mSv. [10, 11, 12]

2.1 Reproducibility

A group of 14 dosimeters were annealed and irradiated to 10 mSv; this procedure was repeated 10 times.

For each of the 10 irradiations, the requirement is: [6]

$$\frac{s_{\overline{E_i}} + I_i}{\sum_{i=1}^{10} \frac{\overline{E_i}}{10}} \leq 0.075 \tag{1}$$

where $\overline{E_i}$ is the average evaluated dose equivalent for each irradiation and $s_{\overline{E_i}}$ is its standard deviation. The value I_i is obtained using the following equation:

$$I_s(n_s) = \sqrt{\frac{0.5}{n_s - 1}} \times s \tag{2}$$

For each of the *n* dosimeters, the requirement is: [6]

$$\frac{s_{\overline{Ej}} + I_j}{\sum_{i=1}^{10} \frac{\overline{E_j}}{10}} \leq 0.075 \tag{3}$$

where $\overline{E_j}$ is the average for each dosemeter and $s_{\overline{E_j}}$ is its standard deviation; the value of I_j uses the same above formula.

2.2 Linearity

A group of 20 dosimeters were annealed and irradiated to 0.1, 1, 10 and 100 mSv. The requirement is: [6]

$$0.90 \leq \frac{\overline{E_i} \pm I_i}{C_i} \leq 1.10 \tag{4}$$

where E_i is the average evaluated dose equivalent, C_i is the irradiated dose equivalent and I_i is:

$$I_i = \frac{t_{ni} \times s}{\sqrt{n_i}} \tag{5}$$

2.3 Detection threshold

A group of 20 unirradiated dosimeters were read, the requirement is: [6]

$$t_n \times s_{\overline{E}} \leq 0.1 mSv \tag{6}$$

where t_n is the Student´s t for n-1 degrees of freedom and $s_{\overline{E_j}}$ is the standard deviation for all n dosimeters. This procedure was repeated 10 times.

2.4 Effects of light exposure on the dosimeters

A group of 40 dosimeters were divided into two groups (1 and 2)

For the effect on zero point: group 1 was placed under a daylight fluorescent lamp and group 2 was placed on a dark environment for 24 hours (both groups were unirradiated). The requirement is: [6]

$$\left[\overline{E}(1) - \overline{E}(2)\right] \pm I \leq 0.1 mSv \tag{7}$$

where I, is given by $I = \sqrt{I_1^2 + I_2^2}$, with $I_i = \frac{t_{ni} \times s}{\sqrt{n_i}}$ (8)

For the effect on response: group 1 was placed under a daylight fluorescent lamp and group 2 was placed on a dark environment for one week (both groups were irradiated to 10 mSv). The requirement is: [6]

$$0.90 \leq \frac{\overline{E}(1)}{\overline{E}(2)} \pm I \leq 1.10 \tag{9}$$

$$\text{where } I = \frac{\overline{x_1}}{x_2}\sqrt{\left(\frac{I_1}{x_1}\right)^2 + \left(\frac{I_2}{x_2}\right)^2} \text{ and } I_i = \frac{t_{ni} \times s}{\sqrt{n_i}} \tag{10}$$

2.5 Isotropy

A group of 20 dosimeters were irradiated to 10 mSv with angles of incidence 0^0, 20^0, 40^0 and 60^0.

The requirement is: [6]

$$0.85 \leq \frac{\sum_{i=1}^{4} \overline{E_i}}{4\overline{E_i}} \pm I \leq 1.15 \tag{11}$$

$$\text{where } I = \frac{\overline{x_1}}{x_2}\sqrt{\left(\frac{I_1}{x_1}\right)^2 + \left(\frac{I_2}{x_2}\right)^2} \text{ and } I_i = \frac{t_{ni} \times s}{\sqrt{n_i}} \tag{12}$$

2.6 Power Supply Voltage

A group of 20 dosimeters were irradiated to 10 mSv three times, the first time they were read under normal reader operation conditions (group 1), the second time they were read with a voltage 12% lower (group 2) and the third time they were read with a voltage 10% higher (group 3). Variation of the frequency was not possible. The requirement is: [6]

$$0.95 \leq \frac{\overline{E}(\text{group x})}{\overline{E}(\text{group 1})} \pm I \leq 1.05 \quad (x = 2, 3) \tag{13}$$

$$\text{where } I = \frac{\overline{x_1}}{x_2}\sqrt{\left(\frac{I_1}{x_1}\right)^2 + \left(\frac{I_2}{x_2}\right)^2} \text{ and } I_i = \frac{t_{ni} \times s}{\sqrt{n_i}} \tag{14}$$

2.7 Effects of climatic conditions on the reader

Due to the fact that the CICANUM does not have a climatic chamber to put the reader in it, this test was modified and on a daily basis the temperature is recorded and any effect on the reader is studied.

2.8 Dropping effect on the dosimeter

A group of 20 dosimeters were irradiated to 10 mSv two times, the first time they were read under normal reader operation conditions (group 1), the second time before reading the dosimeters they were dropped from a height of 1 m onto a concrete surface. The requirement is: [6]

$$0.90 \leq \frac{\overline{E}(\text{group 2})}{\overline{E}(\text{group 1})} \pm I \leq 1.10 \tag{15}$$

$$\text{where } I = \frac{\overline{x_1}}{x_2}\sqrt{\left(\frac{I_1}{x_1}\right)^2 + \left(\frac{I_2}{x_2}\right)^2} \text{ and } I_i = \frac{t_{ni} \times s}{\sqrt{n_i}} \tag{16}$$

2.9 Batch homogeneity

A batch of 75 dosimeters was irradiated to 2 mSv. The requirement is: [6]

$$\frac{E_{\max} - E_{\min}}{E_{\min}} \leq 0.3 \tag{17}$$

where E_{max} and E_{min} are the maximum and minimum doses.

2.10 Analysis of the Trumpet Curve

In addition to the previous test contemplated on the IEC document, an analysis of the trumpet curve described in the ICRP was carried out. [10,12] For it, the reference doses where the ones given by a Secondary Standard Calibration Laboratory when our system was calibrated, the points for 0.5 and 0.25 mSv were given at the CICANUM. The requirement is: [6]

$$\left(\frac{1}{1.5}\right)\left[1 - \frac{2H_0}{H_o + H_r}\right] \leq \frac{H_m}{H_r} \leq 1.5\left[1 + \frac{H_0}{2H_0 + H_r}\right] \tag{18}$$

where H_r is the reference dose, H_m is the measured dose and H_o is the detection limit (0.2mSv)

3. Results

3.1 Reproducibility

For each of the 10 irradiations, the values obtained were in the range of 0.035 to 0.041. For each individual chip the values obtained were in the range of 0.021 to 0.037. Both results are Ò7.5%.

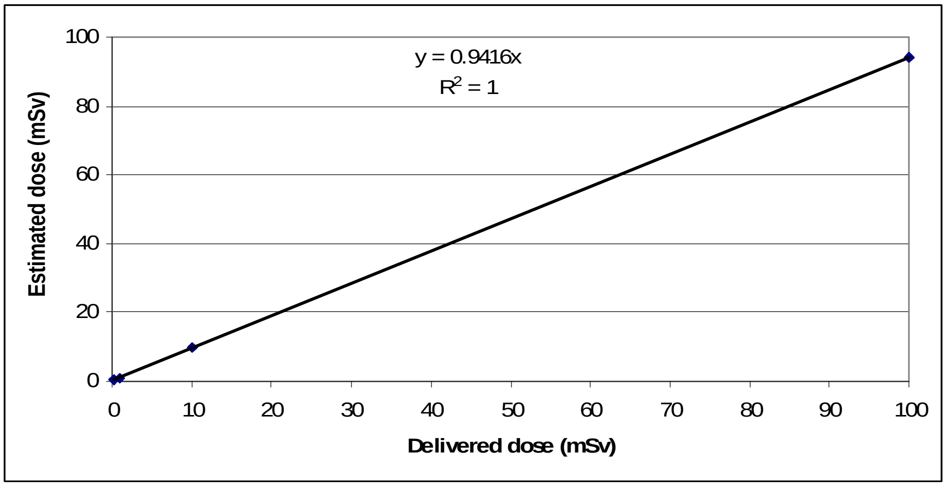
3.2 Linearity

The results for the different dose levels all pass as shown in Table 1. In Figure 1 the linearity of the system is displayed.

Table 1. Linearity results

Dose (mSv)	$\frac{\overline{E_i} + I_i}{C_i}$	$\frac{\overline{E_i} - I_i}{C_i}$
0.1	1.09	0.97
1	1.06	1.04
10	0.99	0.98
100	0.95	0.93

Figure 1. Linearity of the TLD system



3.3 Detection threshold
For each of the 10 irradiations, the values obtained were in the range of 0.027 to 0.059 mSv. For each individual chip the values obtained were in the range of 0.029 to 0.083 mSv. Both results are Ò 0.1 mSv.

3.4 Effects of light exposure on the dosimeters
The results for the effect on zero point ranged from -1.82 µSv to 5.74 µSv, both well below the required 100 µSv. The results for the effect on response range from 0.97 to 1.07, both are less than the ± 10% required.

3.5 Isotropy
The results for the different incidence angles are showed on Table 2, all passing the ±15%.

Table 2. Results for Isotropy

Incidence Angle	$\frac{\sum_{i=1}^{4}\overline{E_i}}{4\overline{E_i}} + I$	$\frac{\sum_{i=1}^{4}\overline{E_i}}{4\overline{E_i}} - I$
0^0	0.95	1.04
20^0	0.94	1.06
40^0	0.94	1.06
60^0	0.96	1.06

3.6 Power Supply Voltage
The results obtained for the -12% voltage variation ranged from 0.97 to 1.07, and for the +10% voltage variation ranged from 0.96 to 1.06. In both cases the upper limit was outside the required limit 0.95 to 1.05.

3.7 Effects of climatic conditions on the reader
Temperature variation inside the reader room varies from 20^0C to 25^0C all year round; no significant variation on our daily quality control cards has been noticed over the years related to room temperature.

3.8 Dropping effect on the dosimeter

The values obtained were in the range 0.93 ï 1.03, well within the required ranged of 0.9 to 1.10.

3.9 Batch homogeneity

The result for one of the batches that the CICANUM has was 0.27, a value below the 0.3 requirement.

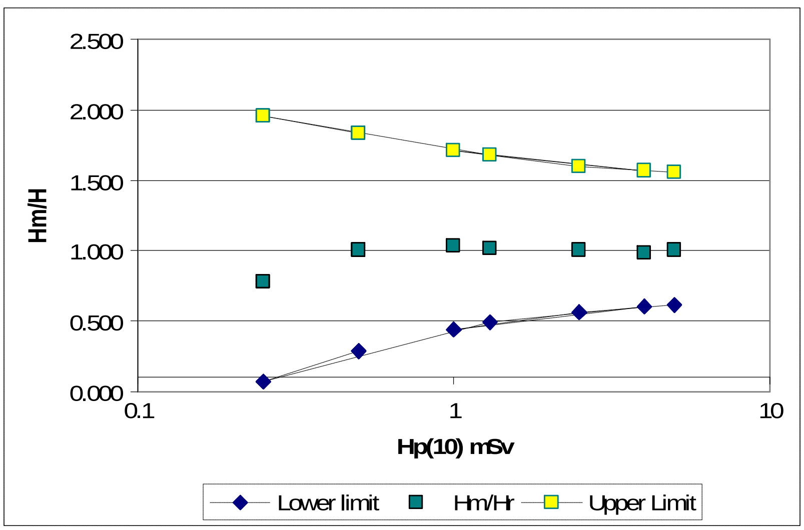
3.10 Analysis of the Trumpet Curve

The results of the analysis of the ICRP Trumpet are showed on Table 3 and on Figure 2.

Table 3. Values of H_m/H_r for the reference doses

H_r	H_m/H_r
0.25	0.08
0.50	1.01
1.00	1.03
1.30	1.01
2.50	1.01
4.00	0.99
5.00	1.01

Figure 2. Trumpet Curve



4. Conclusions

The TLD Dosimetry Laboratory of the University of Costa Rica is used by the majority of radiation workers to determine personal dose equivalent for occupational conditions. National regulations require the use of Hp(10) to demonstrate compliance with the permissible limits of exposure to radiation (20 mSv annually). [13] Type testing is usually a lengthy and costly exercise. This was the first experience in following such international guidelines and the individual results for the entire set of tests performed are very satisfactory. This exercise documents the ability of the dosimetry system implemented at the University to assess with a high degree of confidence the radiation received by radiation workers, enabling national authorities to use this data to optimize their protection and implement dose limitation procedures. With the new acquisition of a Harshaw 6600Plus Reader [14], future type testing at our facility will be done easier, in a shorter time and hopefully with even better results.

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