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# Results of type testing of MTS-N dosimeters with IEC 62387:2012 standard at the laboratory of external dosimetry in Nicaragua

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## ABSTRACT

**This study presents the results of the performance of the Laboratory of External Dosimetry (LDE) located at the Laboratory of Radiation Physics and Metrology (LAF-RAM), according to the ISO/IEC 62387:2012. The LAF-RAM is the only External Dosimetry service provider in Nicaragua. The test is considered a validation of the method for the LDE and the Quality Management System of LAF-RAM. The chosen performance testing according to IEC 62387:2012 are Coefficient of variation, Non linearity, Radiation energy and angle of incidence, Dosimeter drop, Light exposure (reader), Over response of radiation incidence and dose build-up, fading, self-irradiation and natural radiation response. The results in general show that all tests are in compliance with the requirements except for some temporal conditions in dose build-up, fading, self-irradiation test.**

***Keywords:*** **dose response, requirement, type testing.**

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# 1. INTRODUCTION

According to the Quality Management System (QMS) the External Dosimetry Laboratory (LDE) has documented the validation of its method in the procedure LDE-PT-02 named Method Verification [1] based on the IEC 62387: 2012 standard and applicable for all quantities of the LDE service. Previously, the LDE had performed the type testing following IEC 1066:1991 and were not within the quality management system, although, the IEC 62387:2012 was the current dosimetry standard, at the time of writing the LDE-PT-02 it was included the test detection threshold described in IEC 1066: 1991, since the result of this test is used in our dosimetric system as the minimum detectable limit [2].

The purpose of this study is to present the results of the verification of the method of the dosimetry system for Hp (10) of the Laboratory of External Dosimetry (LDE) located at the Laboratory of Radiation Physics and Metrology (LAF-RAM). The tests verified according to the IEC 62387:2012 standard are: Coefficient of variation, Non linearity, Dosimeter drop, light exposure (reader), Dosimeter side, Radiation incidence over response, Radiation energy and angle of incidence and dose build-up, fading, self-irradiation and natural radiation response [3].

# 2. MATERIALS AND METHODS

The tests were performed using 86 Thermoluminiscent detectors or dosimeters TLD model RADCARD MTS-N (LiF:Mg,Ti); this means one detector or crystal for each dosimeter configuration (detector + holders), a dosimetry system consisting of Rados RE-2000 TLD-reader, a Rados IR-2000 local irradiator of $^{90}$Sr/$^{90}$Y. Most irradiations were performed at the Laboratory of Dosimetry Calibration (LCD) of LAF-RAM, which has a $^{137}$Cs source and standard chambers traceable to the IAEA Seibersdorf Laboratory in Austria. In case of the tests of the angle of incidence and radiation energy of the beam, the dosimeters were irradiated at the Laboratory of Metrology of Ionizing Radiations of LMRI of DEN-UFPE in Brazil [4].

During the irradiations, the conditions described in ISO 4037-3 [5] were used, with the 30 cm x 30 cm x 15 cm PMMA phantom. For each irradiation, 1 to 2 rows of dosimeters with a maximum of 5 dosimeters were placed on the phantom.

All crystals were read at a constant temperature of 300° C with 2 seconds of preheating, 11 seconds of reading and 2 seconds of post-heating, then the glow curve is constructed by the photon counts as function of the time. The same procedure was applied for annealing after readout [1].

The dosimetry system was calibrated according to the procedures established in the RADOS Win TLD PRO manual. At the time of type testing, the system was calibrated with dosimeters irradiated at IAEA Seibersdorf Laboratory and the calibration factor used was 333 μSv/turn. This is the value referred to the local source $^{90}Sr/^{90}Y$ which performs the exposures to the dosimeters as a function of the number of turns.

The following clauses of IEC 62387:2012 [3] were verified:

Clause 11.2: Coefficient of variation CV, according to IEC 62387:2012; this test verifies that the statistical fluctuations of the indicated value must meet the following requirements for CV:

$$15\% \text{ for } H < 0{,}1 \text{ mSv} \tag{1}$$
$$(16 - H/0{,}1\text{mSv})\ \% \text{ for } 0{,}1 \leq H < 1{,}1 \text{ mSv} \tag{2}$$
$$5\% \text{ for } H \geq 1{,}1 \text{ mSv}, \tag{3}$$

Where H is the evaluated Hp (10) quantity.

A group of dosimeters irradiated at 6 different dose values 0,1 mSv, 0,3 mSv, 1 mSv, 3 mSv, 10 mSv and 30 mSv was used. It was decided to perform this test up to the dose value of 30 mSv, because it is not viable to perform on the LCD irradiations times for doses of 100 mSv, 300 mSv and 1 Sv.

Clause 11.3 Non-linearity, for this test the same dose information as indicated in CV was used. The requirement states that the variation of response due to equivalent dose changes shall not exceed the range between -9 % to 11% described in Equation 4 in the whole measurement range (in this case it was verified until 30 mSv).

$$0{,}1 \text{ mSv} \leq H \leq 1\text{Sv} \tag{4}$$

This test requires satisfying Equations 5 and 6 shown below with respect to a reference dosimeter group in this case the group of 3 mSv. The Equations 5 and 6 were then found to be satisfied.

$$r_{min} - U_{C,com} \leq (G_i / G_{r,0} + U_{com}) C_{r,0}/C_i \quad (5)$$

$$(G_i / G_{r,0} + U_{com}) C_{r,0}/C_i \leq r_{max} + U_{C,com} \quad (6)$$

Here $r_{min}$ is *0,91* and $r_{max}$ is *1,11,* where $G_{r,0}$ is the mean value of the readings of the 3 mSv group, $C_{r,0}$ is the conventional dose reference value 3 mSv, $C_i$ is the conventional dose value for each evaluated group, $U_{com}$ is the expanded uncertainty of $G_i$ and $U_{c,com}$, the expanded uncertainty of $C_{r,0}$ and $C_i$

Clause 11.5 Radiation energy and angle of incidence was performed for 0° and 60° with dosemeters irradiated to 5 mSv at N-80, N-60, N-40 and N-30 beam qualities. The reference dosimeters were irradiated to 5 mSv at 0° to $^{137}Cs$. The requirements according to type of energy are described in Equations 7, 8 and 9.

$$\text{for } 12\ keV \leq Ephoton < 33\ keV: r_{min} = 0{,}67 \text{ to } r_{max} = 2{,}00 \quad (7)$$

$$\text{for } 33\ keV \leq Ephoton < 65\ keV: r_{min} = 0{,}69 \text{ to } r_{max} = 1{,}82 \quad (8)$$

$$\text{for } Ephoton \geq 65\ keV: r_{min} = 0{,}71 \text{ to } r_{max} = 1{,}67 \quad (9)$$

For this test, the dosimeters were sent to the LMRI DEN-UFPE laboratory in Brazil for irradiation. A total of 3 dosimeters were available for each beam quality.

Additionally, the response of the dosimeter when used incorrectly, with its back facing the radiation source, was verified. In this case 16 dosimeters were irradiated in the LCD, checking compliance with the requirements shown in Equation 9.

Clause 11.8 Over response to radiation incidence from the side, this test requires using groups of five dosimeters, which were irradiated free in air (H*(10)) at a dose of 3 mSv on the LCD. The Figure 1 shows the irradiation set up using a 2 mm thick PMMA to place the dosimeters and simulate free-in-air irradiations and a 3 mm thick PMMA as buildup layer.

The irradiation angles were 0° as the reference angle and five groups were irradiated to different angles from 70° to 110°. For this test it was not possible to change angles during irradiation automatically. For this reason, it was chosen to irradiate each group to a selected angle. The test result should be in compliance with Equation 10.

$$(G_{\alpha max} \text{ to } G_{180°\text{-}\alpha max}))/G_0 + U_{com} \leq 1{,}5 \qquad (10)$$

Here $G_{\alpha max}$ is the mean indicated value of dosimeters irradiated to the maximum angle of 70° $G_{180°\text{-}\alpha max}$ is the mean value of the mean indicated value of dosimeters irradiated at the other angles of incidence; $G_0$ is the mean indicated value of the reference dosimeters.

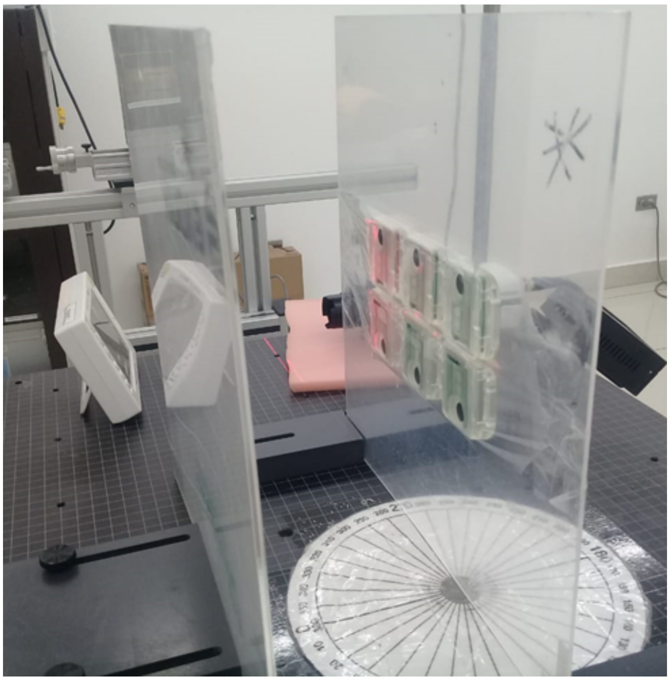

**Figure 1:** *Photo of Irradiations conditions for over response and angle of incidence test*

Clause 13.4 Dose build-up, fading, self-irradiation, and response to natural radiation (dosimeter), here a total of 84 dosimeters distributed in eight groups were used according to quantity and irradiation conditions described in the 62387: 2012.

The quantity of influence (time) in this test is considered as both type F and type S. On the other hand, a time span of two months was set to evaluate the relative response and deviation due to build up and fading, since in general this is the monitoring period of most institutions registered in the dosimetry service.

The criteria of compliance of this clause are: for type F: $r_{min}$ = 0,91; $r_{max}$ = 1,11 and for type S: $D_{max}$ = 0,7 $H_{low}$ at a dose of 7 $H_{low}$. Here $r_{min}$ is the minimum response, $r_{max}$ is the maximum response, $D_{max}$ is the maximum deviation and $H_{low}$ was considered as 0,1 mSv.

When the requirements are type F, and the readout waiting is 1 day and two months, Equation 11 is applied.

$$r_{min} \leq (G'_i / G'_2 \pm U_{com}) \leq r_{max} \tag{11}$$

Then $G'_i$ is the mean indicated value for groups 1 and 3, for $G'_2$ is the mean indicated value for group 2 however $U_{com}$ in Equation 11 applies for $G'_i$. With the group 4 of dosimeters irradiated at 0,1 mSv and read out two months after, Equation 12 shall be applied.

$$r_{min} \leq (7G'_4 / G'_2 \pm U_{com}) \leq r_{max} \tag{12}$$

Where $G'_4$ is the mean indicated value for group 4, both $G'_2$ and $U_{com}$ were described before. The mean values of groups 5, 6, 7 and 8 (Not irradiated groups) was subtracted to results of groups 1, 2, 3 and 4 (irradiated groups) respectively to generate the net dose.

The Equations 13 and 14 are applied when the readout waiting is 1 week and two months respectively and this considered as assessment for type S. For both equations the parameters were described before.

$$| G'_i - G'_2 \pm U_{com} | \leq D_{max} \tag{13}$$

$$| 7 G'_4 - G'_2 \pm U_{com} | \leq D_{max} \tag{14}$$

Equation 15 shall be applied for evaluation of response to natural radiation after two months

$$- H_{low} \leq G_8 \pm U_m - C_{nat} \leq + H_{low} \tag{15}$$

The value suggested by IEC 62387: 2012 for $C_{nat}$ was followed, a value of 2 μSv/d multiplied by 2 months.

Clause 13.8 Light exposure (reader), this test was performed following the methodology described in IEC:62387:2012 but using two different light bulbs one of 100 W and one of 20 W for the first and the second measurement respectively. The light bulbs are shown in Figure 2. Two sets of dosimeters were irradiated at 0,7 mSv. The minimum and maximum responses are required to follow the ones stated for the non-linearity test, therefore they have to satisfy the conditions of Equations 5 and 6 as well as the following Equation 16.

$$|G_2 - G_1 \pm U_{com}| \leq D_{max} \tag{16}$$

Here $D_{max}$ is 0,7 mSv, $G_2$ and $G_1$ are the mean indicated values of the groups affected by light and the reference group. The group 1 of dosimeters were used as reference therefore, they were not exposed to an additional light source, except the usual daylight, neither after irradiations nor after readout. The group 2 of dosimeters were read out under different light conditions, as shown on Figure 2. In this figure it can be seen that a light bulb was positioned as close as possible to the input position of the reader, i.e. where the dosimeters are placed for readout, this is the part that is closest to the photomultiplier. By having this presence of light, the reader system detects the dark counts out of the adjusted range for readings, because of this, the measurements of this test were performed disabling the alarms.

Following clause 13.8, the dosimeters of group 2 were read first using a 100 W light bulb, and the results did not meet the requirements. It is important to mention that these are not the normal conditions of the test method procedure; for this reason, the procedure was repeated by changing the light bulb to one of 20 W, both light bulbs are shown in Figure 2.

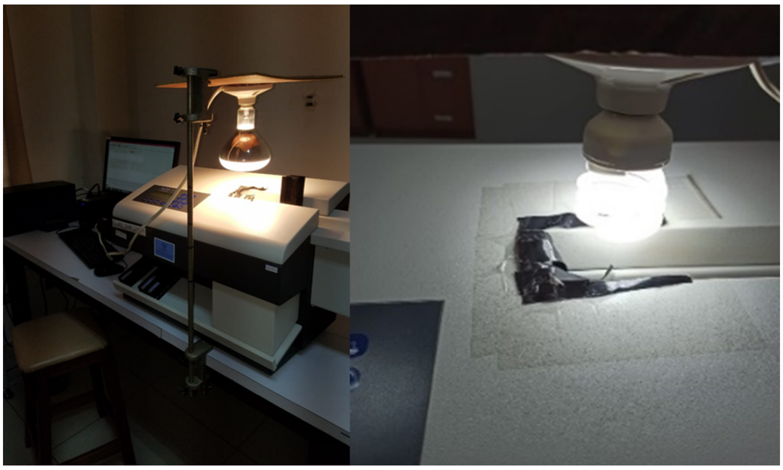

**Figure 2:** *Photo of the measuring conditions using the two types of light bulbs (left side of figure 100 W light bulb and right side 20 W light bulb)*
Source: Prepared by authors

Clause 15.2 Drop (dosimeter), according to IEC 62387: 2012 the complete dosimeters should be strong enough to resist drops from a height of 1 m, and their results should not deviate from ± 0,7 $H_{low}$ (as described before); hence results of the test must fulfill the Equation 17.

$$| G2- G1 \pm Ucom | \leq 0,07\ Hlow \qquad (17)$$

Here $G_2$ and $G_1$ are the indicated value of the groups affected by drops and the reference group respectively. The thermoluminescent crystals were irradiated in the local IR-200 source and prepared in their respective holders or dosimeter holders. The requirement was verified with two groups at two different moments, dropping the 10 dosimeters first on the pavement and then another 10 dosimeters on a smooth surface such as the laboratory floor. The results were compared to 10 reference dosimeters that were not dropped. The Figure 3 shows the moment previous to dropping the dosimeters in the 2 different surfaces.

**Figure 3:** *Photo on the left shows one dosimeter before drop on pavement surface. The photo on the right shows one dosimeter before drop on floor of the laboratory.*

## 3. RESULTS AND DISCUSSION

Clause 11.2 and 11.3 Coefficient of variation CV and Non-linearity

The evaluation of data was used for both coefficient of variation and non-linearity, the measurements were carried out using between 7 and 10 dosimeters and w = 6 different dose values used for the measurement range. The results for coefficient of variation are shown in Table 1.

**Table 1**. Results of coefficient of variation for 6 dose values and verification of compliance with the requirement.

| **Hp(10) [mSv]** | **CV** | **n** | **$c_1$** | **$c_1$*Lim** | **CV <$c_1$*limit** |
|---|---|---|---|---|---|
| 0,1 | 7,9 | 10 | 1,046 | 15,69 | Yes |
| 0,3 | 1,6 | 10 | 1,046 | 13,598 | Yes |
| 1 | 1,8 | 10 | 1,046 | 6,276 | Yes |
| 3 | 2,9 | 10 | 1,046 | 5,23 | Yes |
| 10 | 2,22 | 7 | 1,051 | 5,255 | Yes |
| 30 | 2,31 | 7 | 1,051 | 5,255 | Yes |

Two graphs were generated, showing that the coefficients of variation in all dose values do not exceed the limits according to the clause in line 6 Table 8 of ICE 62387:2012 [3]. The Figure 4 shows the coefficient of variation of the dosimeters as a function of dose. The continuous curve corresponds to the reference curve according to the limits described in Equations 1 to 3. No outliers in this measurement range are observed, since all the mean indicated values fit under the reference curve.

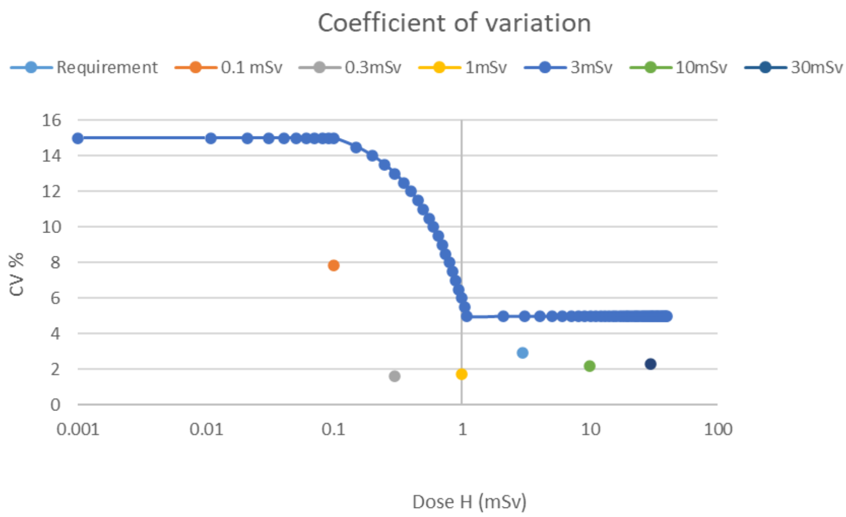


**Figure 4:** *Coefficient of variation for 6 dose values*

The Figure 5 was generated according to the Brunzendorf and Behrens [6] methodology for the new way of evaluating the data, where outliers (up to 2 outliers of non-adjacent values) are allowed, but no outliers were present in this case.

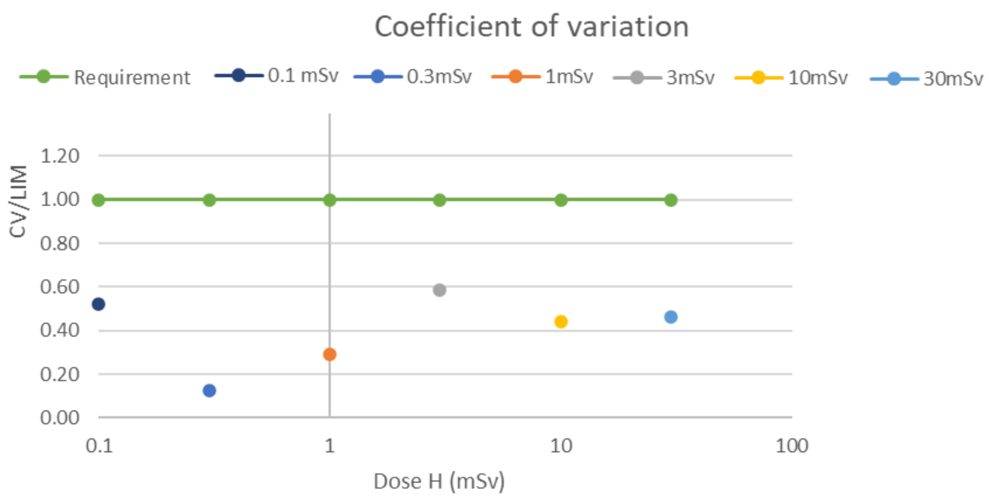


**Figure 5:** *Re-discussion of the interpretation of figure 1 with the CV/LIM notation as a function of dose.*

Table 2 shows the results of the experimental data, it is observed that the variation coefficients are below 10% for all ranges, and only for the dose value of 0,1 mSv the variation coefficient exceeds 5%; however, it complies with the requirements.

**Table 2:** Response range for non-linearity

| Hp(10) [mSv] | COV % | Compliance of Eq. 5 | Compliance of Eq. 6 |
|---|---|---|---|
| 0,1 | 7,9 | $0{,}85 \leq 1{,}07$ | $1{,}11 \leq 1{,}16$ |
| 0,3 | 1,6 | $0{,}86 \leq 0{,}97$ | $1{,}09 \leq 1{,}17$ |
| 1 | 1,8 | $1{,}00 \leq 1{,}07$ | $1{,}12 \leq 1{,}17$ |
| 3 | 2,9 | Reference | Reference |
| 10 | 2,2 | $0{,}85 \leq 0{,}99$ | $1{,}05 \leq 1{,}17$ |
| 30 | 2,3 | $0{,}85 \leq 0{,}98$ | $1{,}04 \leq 1{,}17$ |

According to Brunzendorf and Behrens [6] a test procedure is proposed for standard deviation. (s) is tested if $(s/s_{max}) \leq c$ where $s_{max}$ is the standard deviation of the requirement and c is a parameter calculated from $\chi^2$. The IEC 62387:2012 adopts this requirement for coefficient of variation using the dose values and values of $c_1$ and $c_2$ proposed in the work by Brunzendorf and Behrens.

Clause 11.5 Radiation Energy and angle of incidence

When applying Equations from 7 to 9 in correspondence to the beam quality and angle, the results generated are shown in Table 3 and meet the requirements for $r_{min}$ and $r_{max}$. In the case of the test of wrong position of dosimeter, these were irradiated on LCD to 1 mSv, and the results indicate a mean response of 1,08. The compliance with Equation 9 is also shown in Table 3.

**Table 3:** Results of Radiation energy and angle of incidence

| **Beam Quality and angle** | **Energy [keV]** | **Compliance of requirement** | **Compliance of requirement** |
|---|---|---|---|
| N-80,0° | 62,5 | 0,498 ≤ 1,117 | 1,328 ≤ 1,882 |
| N-60,0° | 47,9 | 0,478 ≤ 1,1025 | 1,648 ≤ 2,032 |
| N-40,0° | 33,3 | 0,478 ≤ 1,038 | 1,665 ≤ 2,032 |
| N-30,0° | 24,6 | 0,458 ≤ 1,240 | 1,603 ≤ 2,212 |
| N-80,60° | 62,5 | 0,498 ≤ 1,166 | 1,428 ≤ 1,882 |
| N-60,60° | 47,9 | 0,478 ≤ 1,275 | 1,564 ≤ 2,032 |
| N-40,60° | 33,3 | 0,478 ≤ 1,539 | 1,815 ≤ 2,032 |
| N-30,60° | 24,6 | 0,458 ≤ 1,491 | 1,952 ≤ 2,212 |
| $^{137}Cs$, back to radiation source | 661,7 | 0,653 ≤ 0,958 | 0,992 ≤ 2,027 |

The energy responses were evaluated by plotting the graph response as a function of beam quality; with the energy response for $^{137}Cs$ as a reference and for normal incidence angle. The results are shown in Figure 6 exhibiting a general behavior of the curve as expected.

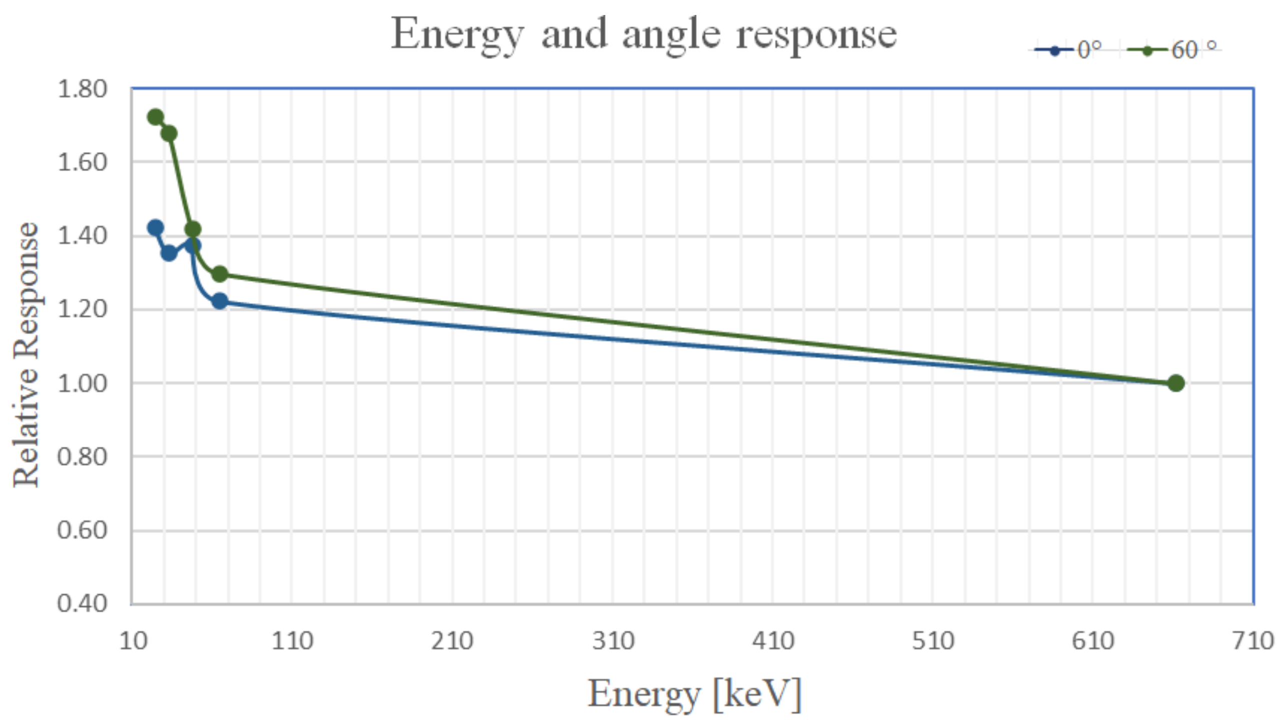


**Figure 6:** *Radiation response to energy and angle*

Clause 11.8 Over response to radiation incidence from the side.

Following Equation 10 the result is 1,004 ≤ 1,5 which indicate compliance with requirement.

Clause 13.4 Dose build-up, fading, self-irradiation, and response to natural radiation

The compliance and non-compliance with the requirements are shown below in Table 4. In general, the system is in compliance, except for F-type when time variable of the two months test fails and for S-type one week after irradiation the test fails as well. The test is also in compliance for the natural radiation conditions.

**Table 4:** Results of Radiation energy and angle of incidence

| Time of readout | Column spanner | | | | |
|---|---|---|---|---|---|
| | **Tipo F** | **Compliance of requirement** | **Tipo S** | **Compliance of requirement** | **Natural Radiation** |
| 1 day after irradiation to 0,7 mSv | 0,91 ≤ 1,12 ≤ 1,11<br>0,91 ≤ 1,06 ≤ 1,11 | No<br>Yes | 0,09 ≤ 0,07<br>0,03 ≤ 0,07 | No<br>Yes | - |
| 2 months after irradiation to 0,7 mSv | 0,91 ≤ 1,00 ≤ 1,11<br>0,91 ≤ 0,93 ≤ 1,11 | Yes<br>Yes | - | - | - |
| 2 months after irradiation to 0,1 mSv | 0,91 ≤ 1,31 ≤ 1,11<br>0,91 ≤ 1,25 ≤ 1,11 | No<br>No | 0,16 ≤ 0,07<br>0,22 ≤ 0,07 | No<br>No | - |
| One week after irradiation to 0,7mSv | - | - | 0,01 ≤ 0,07<br>0,01 ≤ 0,07 | Yes<br>Yes | - |
| 2 months no exposure | - | - | - | - | -0,1 ≤ -0,037 ≤ 0,1<br>-0,1 ≤ -0,064 ≤ 0,1 |

Clause 13.8 Light exposure (reader)

According to Equations 5,6 this test is in compliance with requirement, since for $r_{min}$ is 0,91 ≤ 0,99 ≤ 1,11 and for $r_{max}$ is 0,91 ≤ 1,08 ≤ 1,11. When applying Equation 16 the results are 0,07 ≤ 0,7 and 0,01 ≤ 0,7 indicating compliance. When the dosimeters were exposed to light from a 100 W lamp, the heat generated by this light source was very intense, affecting the results of the reading and the analysis of compliance with the requirements of this clause were not met under these extreme conditions. However, the results were analyzed with respect to the data obtained from the dosimeters exposed during their reading under the light of a 20 W lamp.

Clause 15.2 Drop (dosimeter):

When dosimeters are dropped on the laboratory floor surface, it was obtained as a result 0,038 mSv $\leq$ 0,07 mSv and when dosimeters are dropped on pavement the results indicate 0,023 mSv $\leq$ 0,07 mSv either case applying Equation 17. In both cases the requirement of the standard is met.

It was found that there was a detachment of the metallic filter in 3 of the dosimeters evaluated when dropped in pavement, however, the crystals did not show observable damage. It is worth mentioning that the detachment of the filter (black material in rectangular shape in Figure 1) is effective until the dosimeter holder/holder is disassembled.

Detection threshold

For this test, the procedure described in IEC 1066:1991 was used, using a batch of 20 non-irradiated dosimeters, applying the Student's t-statistics and the standard deviation [2]. It resulted in minimum detectable of 0,04 mSv, i.e. in the service all doses read below this value are considered zero.

## 4. CONCLUSIONS

The LDE dosimetry system for Hp(10) was evaluated and verified to be in compliance with IEC 62387:2012 and shown to be suitable for whole body dosimetry service. The selected performance tests included the thermoluminescent detectors, covers, as well as the readers, all of which in general, meet the requirements.

Apart from a temporary condition of clause 13.4 of IEC 62387:2012 where the dosimeters are irradiated at 0,1 mSv and stored for 2 months, the selected type tests meet the requirements. It was found that the statistical fluctuations and the linearity of the TLDs are acceptable, moreover when evaluating the over response due to side irradiation it was verified that the dosimeter plus cover set responds adequately to side irradiation at high energies even when its shielding is not sufficient as the one provided from the front side. Furthermore, it was found that the response of the dosimeter is adequate when assuming an incorrect positioning of the dosimeter by the user, i.e. turned 180º.

It was observed that in case of drops of at least 1 m some of the dosimeters covers are damaged, however the dosimetric information in terms of response is within the requirements and tolerances, this is considered very positive because during the use of the dosimeters by occupationally exposed workers they might suffer falls on different work surfaces.

Under non-normal conditions of high light intensity, it was observed that extreme heat is transmitted to the reading system, altering the signal in the photomultiplier tube and altering the response of the thermoluminescent detectors. The test procedure of this standard is far from the reality within the working methodology of the laboratory.

The calculated detection threshold is below the minimum detectable dose required for personal dosimetry and is considered acceptable to be used in the laboratory for the service.

The performance tests of the dosimeters used in the LDE service of the LAF-RAM provide the validation of the test method as supporting evidence for the quality management system requirements, an important achievement that gives confidence and recognition to this service at a national level.

## ACKNOWLEDGMENT

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