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# Assessment of energy and angular dependence of LiF:Mg,Ti dosimeters irradiated in the quantity Hp(0.07)

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## ABSTRACT

**Radiation dosimetry has the purpose of quantifying the dose received by the occupationally exposed individual. The device used in this process is called a dosimeter, the dosimeter can be used in different situations, for example, the dosimeter used to quantify the dose received in the fingers is the ring model dosimeter, for the extremity, which is the focus of this work. In Brazil, we still do not have standards for the calibration of extremity dosimeters, therefore, in this work, the CASEC recommendations were used, adapted for extremity dosimetry. For a dosimeter to be used in its respective routine, it must present results within some pre-established limits in reference standards. For this purpose, energy dependence and angular dependence tests were carried out. To calibrate the LiF:Mg,Ti thermoluminescent dosimeters, a phantom rod was used. The phantom rod has the function of simulating the region of interest, in the case of this work, the fingers. The dosimeters were irradiated in the magnitude Hp(0.07), with the doses and energies recommended by the CASEC standard. The aim of this work is to characterize end dosimeters in the ring model with LiF:Mg,Ti detectors.**

*Keywords:* **Dosimetry, extremity, Hp(0.07)**

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# 1. INTRODUCTION

Radiation metrology is the basis for achieving credibility metrology in dose measurements in several areas, it is also part of a structure to ensure radiological protection procedures, so as to avoid or minimize the possible biological effects induced by exposure to ionizing radiation [1]. The metrological reliability of the measurements performed in the dosimetry of patients or materials is achieved by establishing a metrological basis that must include: calibration and evaluation procedures using performance tests of experimental dosimetric systems [2].

For practices involving exposure to ionizing radiation, workers must use individual monitors capable of quantifying the effective dose received during the period of use [2].

Dosimeters are devices that have the purpose of quantifying the dose that the worker received in a certain region of the body during his period of activities involving ionizing radiation [1, 3]. The use of the dosimeter is necessary to quantify the dose that the occupationally exposed individual received in a certain region of the body, using specific calculations for each region [1]. For the extremity, the dosimeter is used in the ring model, which has the purpose of quantifying the dose received in the region of the extremity [3].

A dosimeter must have, at least, one physical property that varies as a function of the measured dosimetric quantity [1, 4], in addition to the physical properties, the dosimeter must pass the calibration tests; the energy dependence and angular dependence tests are essential tests for the dosimeter calibration process [1, 2, 4]. Dosimeter calibration is essential both in the medical area (technicians, technologists, nurses, and doctors) and in the research area (production of radiopharmaceuticals and performance in different stages of the fuel cycle). In Brazil, so far, there are no standards for extremity dosimeters, therefore, in this work the recommendations of the Evaluation Committee of Testing and Calibration Services (CASEC) for whole-body dosimeters adapted for extremity dosimeters were used [1, 3, 5]. The objective of this work is to evaluate the dependence of the dose evaluated in thermoluminescent dosimeters as a function of the energy and incidence angle of radiation.

## 2. MATERIALS AND METHODS

In this section, all the characteristics, definitions and relevant information of the materials, methods and equipment used in this work will be presented.

The equations used in this session are recommended by the CASEC standard for whole-body dosimetry, however, in this work, adapted for extremity dosimetry.

The irradiations were performed in the quantity $H_P(0.07)$ using a phantom rod in (Figure 1) a Cs-137 (Figure 2) source and an irradiator Pantak/Seifert model Isovolt 160 HS in the clinical radiodiagnostic range (50 kVp - 150 kVp) (Figure 3) with energies of 48, 65, 83 and 118 keV and dose of 10 mSv. The voltages of the X-ray tube used in the irradiations were 60, 80, 100 and 150 kVp. The radiator system uses an electrical current of 20 mA. The filters (mmAl) for qualities N-60, N-80, N-100 and N-150 are composed by the presence of the following materials 0.6 Cu + 4.0 Al, 2.0 Cu + 4.0 Al and 5.0 Cu + 4.0 Al. The irradiations using the Pantak/Seifert system were carried out at a distance of 250 cm. As shown in Table 1.

**Figure 1:**
*LCI-IPEN Phantom Rod*

**Figure 2:**
*Caesa-gammatron radiator system*

Source: Adapted from Iremar, 2012

**Figure 3:**
*Pantak/Seifert Isovolt 60 HS Irradiator System*

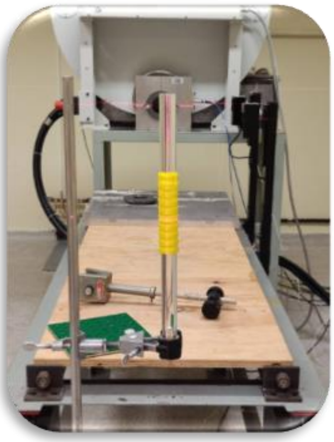


**Table 1:** Parameters used

| Quantity | Voltage (kV) | Energy (keV) | Filtration (mmAl) | Distance (cm) |
|---|---|---|---|---|
| N-60 | 60 | 48 | 0.6 Cu + 4.0 Al | 250 |
| N-80 | 80 | 65 | 2.0 Cu + 4.0 Al | 250 |
| N-100 | 100 | 83 | 5.0 Cu + 4.0 Al | 250 |
| N-150 | 150 | 118 | 2.5 Sn + 4.0 Al | 250 |

In the angular dependence test angles of 0, 20, 40 and 60° were evaluated using energy of 118 keV and dose of 10 mSv [4]. The Harshaw model 4500 reader (Figure 4) was used for dosimeter readings and in the heat treatment process [6]

**Figure 4:** *Harshaw model 4500 thermoluminescent reader*


### 2.1. Energy Dependence

For the energy dependence test, 10 TLDs were selected. Initially, the batch started with the quantity of 43 dosimeters, which was reduced to 23 after a batch homogeneity test, the dosimeters were irradiated in different quantitys of energies in an X-ray irradiation system (48, 65, 83 and 118 keV) and a source of gamma radiation with a source of Cesium- 137, used as a reference.

The dosimeters were irradiated at a focus-object distance of 2.5 meters in the X-ray tests and 1 meter in the tests with the Cs-137 source.

The evaluation of the dosimeters was performed 60 minutes after the irradiations. Irradiations were performed at room temperature, with doses of 10 mSv, and the irradiation and reading process was repeated 5 times with each dosimeter at each energy used.

The variation of the TL response as a function of the incident radiation energy and the dose of each group must not exceed the limits presented in equation (1), where A is the value evaluated for each dosimeter, $\bar{A}_i$ is the average of the values evaluated, *C* is the conventional true value, $s_i$ is the standard deviation of the samples and $l_i$ is the confidence interval of $s_i$.

$$0.7 \geq \frac{\bar{A}_i}{\bar{A}_5} \pm l_i \leq 1.3$$

Equation (1)

To perform the energy dependence test, 10 thermoluminescent dosimeters were used, irradiated at energies of 48, 65, 83 and 118 keV and Cs-137 with energy of 662 keV. The average of the TL readings ($\bar{A}_i$) as a function of the energy used and the standard deviation ($s_i$) were obtained and compared with the values recommended by CASEC, where the results cannot exceed 30% (0.7> <1.3).

Group 1 to 48 keV;

Group 2 to 65 keV;

Group 3 to 83 keV;

Group 4 to 118 keV; and

Group 5 (Cs-137).

### 2.2. Angular Dependence

For the angular dependence test, the same 10 TLDs of the energy dependence test were used. The dosimeters were irradiated with X-ray voltage at 150 kVp and a dose of 10 mSv. The detector was positioned at different angles to the source (0°, 20°, 40° and 60°) with clockwise rotation. Irradiations were performed with a focus-object distance of 2.5 meters with readings after 60 minutes of irradiation. The process was repeated 5 times. The variation of the TL response as a function of the radiation incidence angle of each group must not exceed the limits presented in equation (2), where *C* is the conventional true value, *A* is the evaluated value for each dosimeter, $\bar{A}_i$ is the average of the evaluated values, $s_i$ is the standard deviation of the samples and $l_i$ is the confidence interval of $s_i$.

$$0.85 \geq \frac{\sum_{i=1}^{4} \bar{A}_i}{4_{\bar{A}_i}} \pm l_i \leq 1.15$$

Equation (2)

Group 1: normal incidence (zero degree);

Group 2: 20° compared to normal;

Group 3: 40° compared to normal; and

Group 4: 60° compared to normal.

## 3. RESULTS AND DISCUSSION

Tables 2, 3, 4, 5 and 6 present the values of the readings of each energy evaluated, 48, 65, 83, 118 keV and Cs-137, respectively. Table 7 presents the results of the TL response energy dependence test using the recommended equation, where $\bar{A}_i$ is the mean of the evaluated values and $l_i$ is the confidence interval of the standard deviation. Figure 5 presents the mean of the results of the energy dependence test in graph format.

**Table 2:** Values obtained in the energy dependence test for X-ray energy of 48 keV with doses of 10 mSv

| **Group 1 – 48 keV – Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 8.83 | 8.62 | 8.65 | 9.29 | 9.07 | 8.67 | 8.75 | 10.89 | 11.10 | 10.69 |
| 10.60 | 9.38 | 9.23 | 9.43 | 8.48 | 8.13 | 8.82 | 11.00 | 10.98 | 10.84 |
| 9.71 | 9.94 | 10.42 | 9.36 | 9.69 | 9.87 | 9.96 | 8.91 | 9.47 | 9.11 |
| 9.15 | 10.25 | 10.54 | 10.02 | 9.45 | 9.60 | 9.32 | 8.86 | 9.36 | 9.08 |
| 9.02 | 10.11 | 9.80 | 10.04 | 9.39 | 10.00 | 9.50 | 8.93 | 9.09 | 9.35 |
| **$\bar{A}_i$ mSv** | | | **$s_i$** | | | **$l_i$** | | | |
| 9.58 | | | 0.265 | | | 0.19 | | | |

**Table 3:** Values obtained in the energy dependence test for X-ray energy of 65 keV with doses of 10 mSv

| **Group 2 – 65 keV – Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 9.47 | 10.38 | 11.48 | 10.48 | 11.00 | 10.48 | 10.48 | 9.60 | 10.04 | 9.84 |
| 10.00 | 11.45 | 10.57 | 10.51 | 10.13 | 9.86 | 10.42 | 9.78 | 9.78 | 9.59 |
| 9.59 | 9.78 | 10.53 | 9.91 | 10.13 | 9.63 | 10.51 | 10.42 | 10.14 | 9.07 |
| 9.96 | 10.69 | 10.35 | 10.48 | 10.87 | 10.36 | 9.88 | 10.79 | 10.08 | 9.32 |
| 9.33 | 10.55 | 10.36 | 9.96 | 9.87 | 10.08 | 10.16 | 10.75 | 10.04 | 9.42 |
| **$\bar{A}_i$ mSv** | | | **$s_i$** | | | **$l_i$** | | | |
| 10.17 | | | 0.378 | | | 0.27 | | | |

**Table 4:** Values obtained in the energy dependence test for X-ray energy of 83 keV with doses of 10 mSv

| **Group 3 – 83 keV – Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 10.45 | 11.46 | 11.37 | 10.2 | 10.56 | 11.10 | 11.01 | 9.05 | 10.31 | 10.82 |
| 10.31 | 11.05 | 11.33 | 10.3 | 10.51 | 11.46 | 10.69 | 11.19 | 10.50 | 9.78 |
| 10.34 | 10.75 | 10.63 | 10.5 | 10.89 | 10.29 | 10.12 | 11.15 | 9.90 | 9.83 |
| 10.36 | 11.09 | 11.11 | 10.4 | 10.65 | 10.95 | 10.61 | 10.46 | 10.24 | 10.15 |
| 10.33 | 9.64 | 11.12 | 10.35 | 10.78 | 10.61 | 10.79 | 11.46 | 10.00 | 9.33 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.57 | | | 0.341 | | | 0.24 | | | |

**Table 5:** Values obtained in the energy dependence test for X-ray energy of 118 keV with doses of 10 mSv

| **Group 4 – 118 keV – Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 11.01 | 11.51 | 11.27 | 11.32 | 11.01 | 10.81 | 10.79 | 10.77 | 10.44 | 10.62 |
| 10.31 | 10.94 | 11.41 | 11.09 | 11.18 | 10.28 | 10.49 | 10.55 | 10.48 | 10.62 |
| 10.65 | 11.5 | 11.33 | 11.34 | 10.61 | 10.66 | 11.11 | 10.58 | 10.43 | 10.4 |
| 10.39 | 10.87 | 11.5 | 11.03 | 10.69 | 11.06 | 10.88 | 10.65 | 10.47 | 10.41 |
| 10.46 | 10.91 | 11.23 | 11.55 | 11.08 | 10.39 | 10.98 | 10.47 | 10.56 | 10.66 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.83 | | | 0.322 | | | 0.23 | | | |

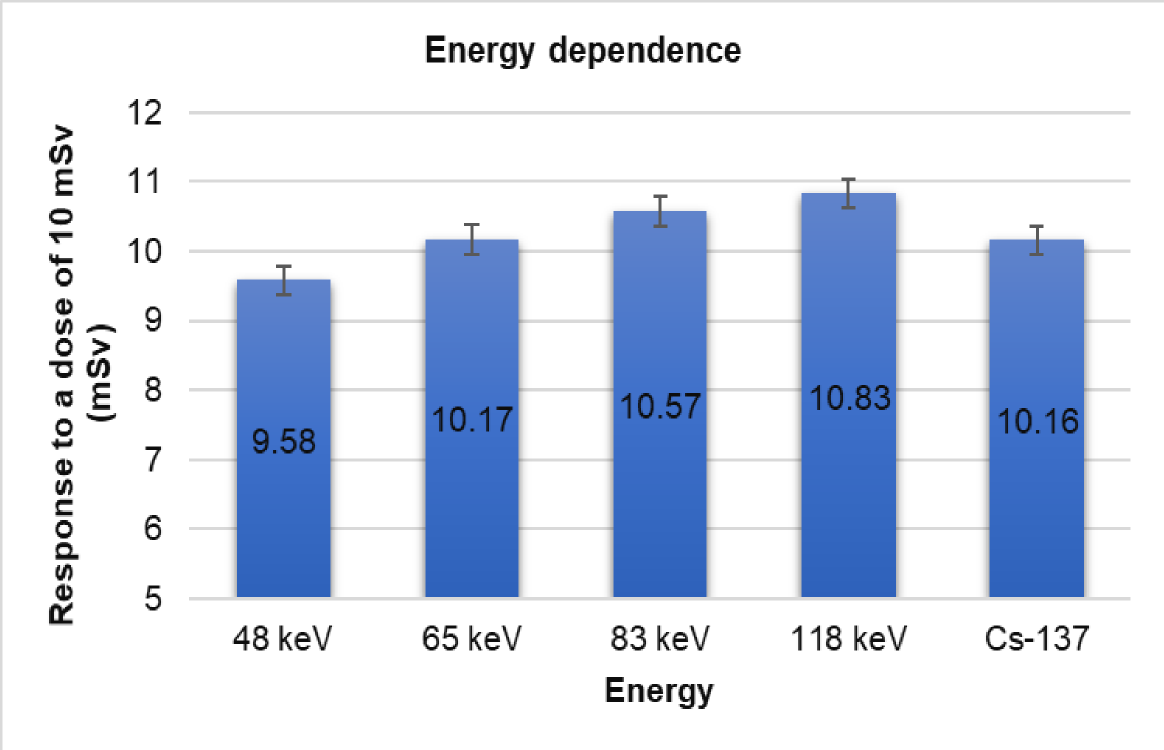
**Table 6:** Values obtained in the energy dependence test for cesium-137 energy with doses of 10 mSv

| **Group 5 – Cs-137 – Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 9.91 | 11.04 | 11.17 | 10.23 | 10.89 | 9.58 | 11.10 | 10.46 | 9.76 | 9.74 |
| 9.96 | 10.32 | 11.01 | 10.29 | 9.94 | 9.60 | 9.83 | 9.97 | 9.74 | 9.69 |
| 9.82 | 10.12 | 10.49 | 10.93 | 9.67 | 9.68 | 9.99 | 9.74 | 9.91 | 9.61 |
| 9.91 | 10.49 | 10.93 | 10.48 | 10.24 | 9.62 | 10.59 | 10.06 | 9.84 | 9.68 |
| 9.90 | 10.84 | 10.89 | 10.56 | 10.17 | 9.67 | 10.31 | 9.91 | 9.80 | 9.69 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.16 | | | 0.419 | | | 0.30 | | | |

**Table 7:** Results of the TL response energy dependence test applying the reference equation

| | **Group 01** | **Group 02** | **Group 03** | **Group 04** | **Group 05** |
|---|---|---|---|---|---|
| $\bar{A}_i$ **mSv** | 9.58 | 10.17 | 10.57 | 10.83 | 10.16 |
| $I_i$ | 0.19 | 0.27 | 0.24 | 0.23 | 0.30 |
| **C** | 10 | 10 | 10 | 10 | 10 |
| **Criterion** | $0.7 \geq \frac{\bar{A}_i}{\bar{A}_5} \pm I_i \leq 1.3$ | | | | |
| $\frac{\bar{A}_i}{\bar{A}_5} \pm I_i$ | 1.1 | 1.2 | 1.2 | 1.3 | 1.3 |
| **Condition** | Accepted | Accepted | Accepted | Accepted | Accepted |

**Figure 5:** Graphical presentation of the average of the results of the energy dependence test




Source: author of the work

Tables 8, 9, 10 and 11 present the values of each view evaluated (0°, 20°, 40° and 60°) respectively. Table 12 presents the results of the TL response angular dependence test using the equation recommended by CASEC. Figure 6 presents the mean of the angular dependence test results in graph format.

**Table 8:** Results obtained as a function of the irradiations in 0° angle

| **Group 1 – 0° - Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 9.99 | 10.95 | 10.30 | 10.24 | 10.43 | 10.28 | 10.92 | 10.09 | 9.98 | 10.06 |
| 10.43 | 10.89 | 10.37 | 10.02 | 10.89 | 10.73 | 10.93 | 10.56 | 10.52 | 10.54 |
| 10.57 | 11.02 | 10.39 | 10.15 | 10.96 | 10.72 | 10.72 | 10.66 | 10.46 | 10.55 |
| 10.28 | 10.41 | 10.27 | 10.04 | 10.78 | 10.48 | 10.83 | 10.43 | 10.16 | 10.39 |
| 10.47 | 11.02 | 10.32 | 11.03 | 10.96 | 10.44 | 10.86 | 10.53 | 10.49 | 10.56 |
| **$\bar{A}_i$ mSv** | | | **$s_i$** | | | **$I_i$** | | | |
| 10.52 | | | 0.229 | | | 0.16 | | | |

**Table 9:** Results obtained as a function of the irradiations in 20° angle

| **Group 2 – 20° - Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 10.35 | 10.31 | 10.29 | 10.33 | 10.51 | 10.15 | 10.72 | 9.971 | 9.90 | 10.10 |
| 10.22 | 10.48 | 10.37 | 10.46 | 10.55 | 10.33 | 10.66 | 10.05 | 9.96 | 10.14 |
| 10.31 | 10.45 | 10.48 | 10.27 | 10.25 | 10.39 | 10.68 | 10.29 | 9.88 | 10.41 |
| 10.29 | 10.44 | 10.41 | 10.34 | 10.39 | 10.33 | 10.68 | 10.16 | 9.91 | 10.27 |
| 10.33 | 10.38 | 10.39 | 10.30 | 10.38 | 10.27 | 10.70 | 10.13 | 9.89 | 10.26 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.31 | | | 0.205 | | | 0.15 | | | |

**Table 10:** Results obtained as a function of the irradiations in 40° angle

| **Group 3 – 40° - Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 10.25 | 10.41 | 10.26 | 10.44 | 10.37 | 10.44 | 10.56 | 9.95 | 10.25 | 10.34 |
| 9.79 | 10.67 | 10.34 | 10.58 | 10.22 | 10.20 | 10.59 | 10.17 | 9.83 | 10.05 |
| 10.06 | 10.52 | 10.29 | 10.50 | 10.31 | 10.34 | 10.57 | 10.04 | 10.08 | 10.22 |
| 10.02 | 10.54 | 10.30 | 10.51 | 10.30 | 10.32 | 10.58 | 10.06 | 10.04 | 10.20 |
| 10.14 | 10.48 | 10.28 | 10.48 | 10.33 | 10.38 | 10.57 | 10.01 | 10.15 | 10.27 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.29 | | | 0.198 | | | 0.14 | | | |

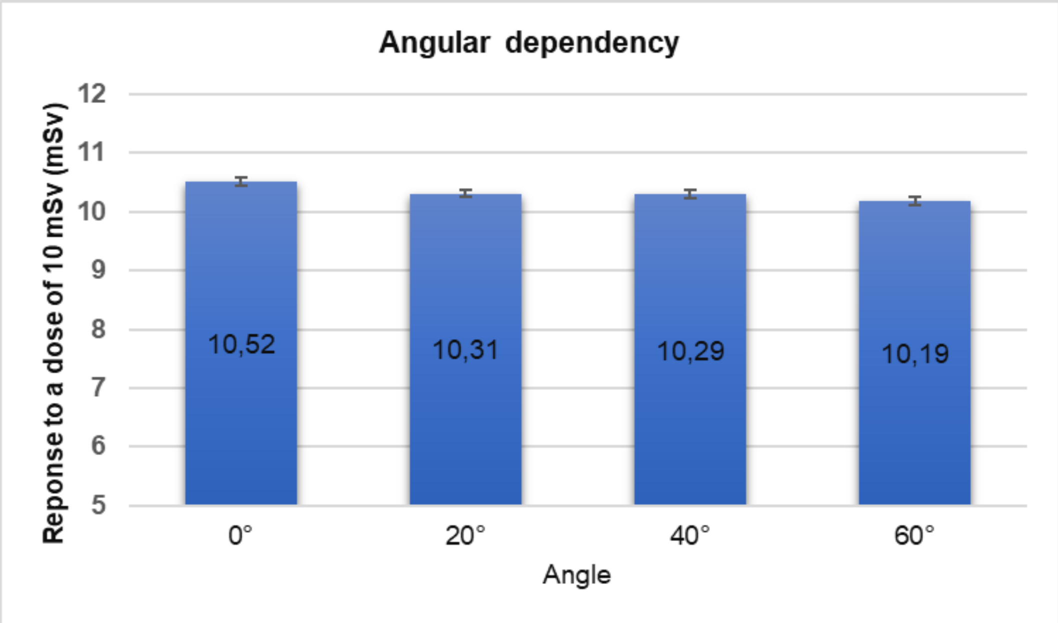
**Table 11:** Results obtained as a function of the irradiations in 60° angle

| **Group 4 – 60° - Dose 10 mSv** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **01** | **02** | **03** | **04** | **05** | **06** | **07** | **08** | **09** | **10** |
| 10.17 | 10.42 | 10.49 | 10.39 | 10.49 | 9.794 | 10.41 | 9.96 | 10.41 | 10.2 |
| 10.00 | 10.43 | 10.27 | 10.42 | 10.26 | 10.03 | 10.28 | 9.93 | 9.93 | 9.88 |
| 9.98 | 10.47 | 10.19 | 10.38 | 10.26 | 9.95 | 10.56 | 9.96 | 9.93 | 9.92 |
| 9.89 | 10.37 | 10.28 | 10.29 | 10.18 | 10.52 | 10.33 | 9.92 | 9.90 | 9.95 |
| 10.01 | 10.42 | 10.32 | 10.35 | 10.31 | 10.09 | 10.43 | 9.95 | 10.08 | 10.02 |
| $\bar{A}_i$ **mSv** | | | $s_i$ | | | $I_i$ | | | |
| 10.19 | | | 0.189 | | | 0.14 | | | |

**Table 12:** TL Response Angular Dependency Assay Results

| **Angle** | **0°** | **20°** | **40°** | **60°** |
|---|---|---|---|---|
| $\bar{A}_i$ **mSv** | 10.52 | 10.31 | 10.29 | 10.19 |
| $I_i$ | 0.16 | 0.15 | 0.14 | 0.14 |
| **C** | 10 | 10 | 10 | 10 |
| **Critério** | $0{,}85 \geq \frac{\sum_{i=1}^{4} \bar{A}_i}{4_{\bar{A}_1}} \mp I_i \leq 1{,}15$ | | | |
| $\frac{\sum_{i=1}^{4} \bar{A}_i}{4_{\bar{A}_1}} \mp I_i$ | 1.146 | 1.148 | 1.145 | 1.149 |

**Figure 6:** Graphical presentation of the average of the angle dependence test results




## 4. CONCLUSION

The results obtained in the energy and angular dependence tests present a small range of variation +0,5% for energy dependence and +0,001% for angular dependence, according to the CASEC recommendations.

In the energy dependence test, the average of the energies evaluated using the reference equation was 1.26. None of the samples exceeded the limits established by the reference equation in the values of 0.70> <1.30.

In the angular dependence test, the average of the TL responses as a function of the evaluated angle had a value of 1.147. None of the samples exceeded the limits established by the reference equation in the values of 0.85> <1.15.

The results indicate that the dosimetry system studied meets the calibration requirements in the quantity Hp(0.07), using a phantom rod recommended by ICRU in Report 47 [7] in gamma radiation field (Cs-137) and X radiation at energies of 48, 65, 83 and 118 keV recommended by CASEC and adapted to the equipment used.

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## REFERENCES

[1] NASCIMENTO, G. et al. **Characterization and calibration of thermoluminescent dosimters of LiF: Mg, Ti in the quantity Hp (0.07)**, INAC, 2021.

[2] ICRP, International Commission on Radiological Protection. **The recommendations of the Internation Commission on Radiological Protecion**. Publication 103, 2007.

[3] SQUAIR, P. L., NOGUEIRA, M. S., OLIVEIRA, P. M. C. **Calibração e Caracterização de Dosímetros de Extremidade**. Santos, INAC, 2005.

[4] CASEC, Comitê de Avaliação de Serviços de Ensaio e Calibração, **Desempenho de Monitoração Individual – Critérios e Condições**, 2013.

[5] OKUNO, Emico; YOSHIMURA, Elisabeth Mateus**. Física das radiações**. Oficina de Textos, 2016.

[6] Harshaw-Bicron, **model 4500 TLD Workstation Operators Manual**, Publication N°4500-0-0-0598-002, 1998.

[7] ICRU, International Commission on Radiation Units and Measurements, **Measurement of Dose Equivalent from External Photon and Electron Radiation**, Report 47, 1992.