Instrumentation for measure Equivalent Ambient dose in urban buildings using TLDs

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Abstract
Thermoluminescent dosimeters are solid materials used as an instrument to determine environment equivalent dose H*(10). To be applied, they must be properly calibrated at specific energies. Thermoluminescence dosimetry (TLDs) systems are widely used to measure ionizing radiation exposure, as environmental monitoring. The environment is exposed to natural radiation from radionuclide in soil, rocks and air. In the last decade, was noticed the people pass a significant time inside close environment as houses, workplaces, schools and stores. Therefore, it is import to study the exposure, internal and external, by ionizing radiation in close environment. For it, TLDs is a device widely use to monitoring natural radiation in the environment. Thus, the objective of this work was to present the calibration methodology for TLDs dosimeters and their application to measure H*(10) in internal environments occupied by inhabitants of an urban area in the state of Minas Gerais/Brazil. The LiF:Mg,Cu,P (MCP) dosimeters have high sensitivity for environmental monitoring and were used in this work. The conversion of air kerma (Kₐ) to H*(10) was 1.20 (S-CS), according to ISO 4037-3. The irradiation H*(10) were 700, 500, 300, 200 and 100 μSv, respectively. The calibration coefficients Nₖ₀ for determine H*(10) was 0.66156 ± 0.03374 μSv.cm⁻¹. C.I. 95.45% (k=2), reliability of the TL measurements was assured by selecting TL detectors with 3.2% homogeneity and 4.1% repeatability. Energy dependence was rated at ± 11.8% when irradiated with S-Cs (661 keV) source and N-100 X Ray radiation quality (83 keV). In this way, the dosimeters are able to be applied to evaluate H*(10).

Keywords: TLD; Environment; Dosimetry.
1.- INTRODUCTION

Thermoluminescence is a phenomenon of light emission released through fluorescence or phosphorescence. Determined materials, previously excited, are capable to absorb radiation and retain part of the energy absorbed in metastable states. Such states return to fundamental levels with increasing material temperature and consequently the release energy in form of light [Lucca et al., 2019; Abaza, 2018]. Among the types of Luminescence Dosimetry are the Thermoluminescent Dosimeter systems (TLDs) [Abaza, 2018].

TLDs are solid materials with dopants or impurities, as LiF:Mg,Cu,P; LiF:Mg,Ti and CaSO₄:Dy. According to dosimetric requirement, TLD are available at different shapes and sizes (chip, ribbon, disc, powder and rods) [Mallick, Rath & Benson, 2020]. TLDs principle consists of in the transition of electrons in crystal. Electrons can be secondary particles originated from the primary interaction of photons with matter, which are the main responsible for the deposition of energy from photons in matter. Secondary charged particles release low-energy free electrons and holes through ionizations of atoms and ions [Abaza, 2018; Mallick, Rath & Benson, 2020].

Free electrons will recombine or get trapped in traps, these can be intrinsic or introduced into the crystal, which are known as impurities. Exist two types of traps: storage traps and recombination centers [Abaza et al., 2018]. The electrons will come out of the traps by gaining energy in the form of heat thus occur light emission [Mallick, Rath & Benson, 2020].

The light emitted by the material TL is proportional to the energy absorbed by it. TL reader system consists of a device for heating the dosimeter and an electronic system, photomultiplier, to capture the light emitted [Lucca et al., 2019]. The TLD heating gives a
glow curve, a graph of intensity as a function of temperature. For reuse of TLD annealing has to be done, until which traps are emptied [Mallick, Rath & Benson 2020]. Thermoluminescence dosimetry systems are widely used to measure ionizing radiation exposure, as environmental monitoring [IAEA 2000; Abaza 2018]. The ambient dose equivalent is given the symbol $H^*(10)$ in Sievert (Sv) [Röttger, 2021].

The environment is exposed to natural radiation. According to UNSCEAR (2000), worldwide average annual effective dose (mSv) due to natural radiation sources is 2.4 mSv. External exposure is from cosmic rays (0.4 mSv) and terrestrial gamma rays (0.5 mSv) and internal exposure is from inhalation (mainly radon) (1.2 mSv) and ingestion (0.3 mSv) [UNSCEAR, 2000].

The important radionuclide to natural radiation exposure belongs to one of three natural radioactive series: uranium ($^{238}\text{U}$), actinium ($^{235}\text{U}$) and thorium ($^{232}\text{Th}$) (Bonotto, 2004). In this series, radon is the only decay product on gas state and has three radioisotopes from $^{238}\text{U}$, $^{232}\text{Th}$ and $^{235}\text{U}$ which are radon-222 ($^{222}\text{Rn}$), radon-220 ($^{220}\text{Rn}$) and radon-219 ($^{219}\text{Rn}$) respectively [Turner, 1995].

Natural radiation sources are present everywhere, human action like urbanization may result in the increase of human exposure by it. At buildings as houses, schools, stores and workplaces, the major source of natural radiation is from the soil and construction materials. On this place can be found natural radionuclides in different concentrations. Therefore, it is important to monitoring these places and identifies sites with concentrations above the reference levels [Santos, 2010].

Some anthropological factors contribute to the increase of human exposure by natural sources. Along the years was noted that humans pass most of their time in closed environmental, if these aren’t properly ventilated may have a radon accumulation [UNSCEAR, 2006]. Plus increase the time of gamma exposure. All these exposures are
directly correlated to people health due ionizing radiation can cause biological effects to human beings, as cancer [UNSCEAR, 2020].

The objective of this work was to present the calibration methodology for TLDs dosimeters and their application to measure H*(10) in internal environments occupied by inhabitants of an urban area in the state of Minas Gerais/Brazil.

2.- MATERIALS AND METHODS

2.1. Gamma dosimetry systems

The dosimetry system consists of MCP-N type ultra-sensitive thermoluminescent TL LiF doped with magnesium, copper and phosphorus (LiF:Mg,Cu,P). The standard TLD dosimeter card consists of a coded slide placed in a holder without filters. In this work, the dosimetry system used was developed to evaluate H*(10) using two MCP-N TL detectors at the RADOS ME-2000 reader (Mirion Technologies), show Figure 1.
The dosimetry system used in this study is described in Table 1. Before use, TL detectors were annealed and assembled in badges and stored in the laboratory until deployment (installed at sites).

Table 1.- TL dosimetry systems technical specification (RadPro, 2022)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TL detector – (MCP-N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>LiF:Mg,Cu,P</td>
</tr>
<tr>
<td>Isotopes</td>
<td>Natural</td>
</tr>
<tr>
<td>Thermal fading (room temp.)</td>
<td>&lt; 5% / year</td>
</tr>
<tr>
<td>Temperature reading</td>
<td>240°C</td>
</tr>
<tr>
<td>Annealing – before irradiation</td>
<td>240°C – 10 min</td>
</tr>
<tr>
<td>Annealing – after irradiation</td>
<td>100°C – 15 min</td>
</tr>
</tbody>
</table>

The TLD system used in this study are calibrated at CDTN/CNEN Calibration Laboratory using a Cs-137 source, 661 keV energy, at a source/detector distance of 1.5 m. The conversion of air kerma (Kar) to H*(10) was 1.20 (S-CS), according to ISO 4037-3. To
calibration 9 set of 3 TLDs was irradiated. The source calibration is traceable to the primary standards at the PTB (Germany) and has an uncertainty (coverage factor \( k = 2 \)) of the irradiated dose values lower than 2.5%. The irradiation processes were carried out according to international standard procedures [ISO 4037, 1999]. Irradiation times in seconds were 171.6, 122.6, 73.53, 49.02 and 24.51 s for \( H^{*}(10) \) 700, 500, 300, 200 and 100 µSv, respectively.

The main sources of uncertainties in the TL dosimeter calibration procedure were identified for estimating the expanded uncertainty in the calibration coefficient. The overall uncertainties were estimated according to the ISO GUM recommendations [BIPM, 2008].

The international recommendation for adopting radiation protection operational quantities, ambient dose equivalent \( H^{*}(10) \), for environmental and area monitoring by TLDs requires that dosimetric systems must be upgraded to comply with metrological characteristics [ISO 61066, 2006]. The metrological characteristics evaluated were threshold, linearity, energy and angular dependence.

2.1. Environmental monitoring

To study urban buildings in Belo Horizonte, Minas Gerais – Brazil, 1000 TLDs LIF: MCP from the calibrated amount was used. Before TLDs be applied to environmental monitoring, they were annealed. Of these, 15 TLDs was separate to regular control and 21 TLDs made part of the background belonging to detector set. Totally, in the first monitoring, 321 detector set was assembled, with 3 TLD each and 1 CR-39 detector to measure radon, both was placed inside a diffusion chamber, showed in Figure 2. The sampling points were choosing according to squares of 1.2 x 1.2 km of Belo Horizonte’s territory was used as a reference to ensure the geographical distribution [Takahashi et al., 2022].
At each point a building (house, workplace, school, store and other) was placed the device inside, in room widely used by the inhabitant, generally the bedroom. The device didn’t need special cares to install or maintain. They stay at least three months in the same place. After this time, TLDs were submitted to RADOS RE2000 reader to be analyzed.

Figure 3. Environmental monitoring device.

Legend: A) Assembled of the environmental monitoring device:
(1) TLDs; (2) Alpha Track type CR-39; (3) Paper filter quantitative and (4) diffusion chamber.
B) Environmental monitoring device exposed in a regular workplace.

3.- RESULTS

Reliability of TL measurements was assured by selecting TL detectors with 3.2% homogeneity and 4.1% repeatability. The result of calibration coefficients $N_{K,Q}$ for determine $H^*(10)$ was $(0.66156 \pm 0.03374) \mu$Sv.cont$^{-1}$ for C.I. 95.45% (k=2), as shown in Figure 3 and Table 2. Energy dependence was rated at ± 11.8% when irradiated with S-Cs (661 keV) source and N-100 X Ray radiation quality (83 keV).
Figure 3.- Environmental TLD system calibration for H*(10) measurements.

Table 2.- Environmental TLD system calibration for H*(10) uncertainties.

<table>
<thead>
<tr>
<th>Uncertainties source (N_{K,Q})</th>
<th>Value (%)</th>
<th>Distribution</th>
<th>Coverage factor</th>
<th>Type</th>
<th>Relative uncertainty (%)</th>
<th>Degrees of freedom (ν)</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformity TL detector</td>
<td>3.20</td>
<td>Normal</td>
<td>√10</td>
<td>A</td>
<td>1.01</td>
<td>9</td>
<td>2.26</td>
</tr>
<tr>
<td>Repeatability TL detector</td>
<td>4.10</td>
<td>Normal</td>
<td>√10</td>
<td>A</td>
<td>1.30</td>
<td>9</td>
<td>2.26</td>
</tr>
<tr>
<td>Linear Fit - Value</td>
<td>1.46</td>
<td>Rectangular</td>
<td>√3</td>
<td>A</td>
<td>0.84</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Irradiation (K_{a,i})</td>
<td>2.50</td>
<td>Rectangular</td>
<td>√3</td>
<td>B</td>
<td>1.44</td>
<td>Infinite</td>
<td>2.00</td>
</tr>
<tr>
<td>Measurements deviation</td>
<td>6.00</td>
<td>t-student</td>
<td>√36</td>
<td>A</td>
<td>1.00</td>
<td>35</td>
<td>2.04</td>
</tr>
<tr>
<td>Combined</td>
<td>2.5</td>
<td>$\nu_{eff}$ = 91</td>
<td>CI (%)</td>
<td>68.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanded</td>
<td>5.1</td>
<td>k = 2.01</td>
<td>CI (%)</td>
<td>95.45</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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The application of TLDs (MCP) for environmental monitoring showed up as great tool to measure natural exposure. The correct application of the instrumentation and the execution procedure in a reference laboratory ensure the reliability of the results.

4.- DISCUSSION

The angular dependence not evaluated. However, the environmental radiation is typically non-directional and characterized by a broad photon energy spectrum. Therefore, the angle dependence investigated in laboratory with directional irradiation at low energies may not be relevant for practical environmental and area monitoring, except in the case of an unexpected low energy irradiation at angles close to 90° [Yukihara, 2021].

5.- CONCLUSIONS

The work presented the calibration methodology for TLDs dosimeters and their application to measure $H^{*}(10)$ in internal environments occupied by inhabitants of an urban area in the state of Minas Gerais/Brazil. The calibration coefficients $N_{K,Q}$ for determine $H^{*}(10)$ was $0.66156 \pm 0.03374 \, \mu Sv \cdot cm^{-1}$ for C.I. 95.45% (k=2), reliability of the TL measurements was assured by selecting TL detectors with 3.2% homogeneity and 4.1% repeatability. Energy dependence was rated at $\pm 11.8\%$ when irradiated with $\text{S-Cs}$ (661 keV) source and $\text{N-100}$ X Ray radiation quality (83 keV). Natural sources can be found everywhere and people are constantly receiving dose. Gamma monitoring inside places allows identifying the daily exposure by measure $H^{*}(10)$. Knowing dose above the limit levels, the radioactive sources can be studied and concentrations reduce actions can be applied. Due the high sensibility of TLDs MCP, the natural ionizing radiation can be measure, further this device are important instruments to environmental studies.
Acknowledgments

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