Reliability of an x-ray system for calibrating and testing personal radiation dosimeters

M C Guimarães¹, C R E Silva¹, P H G Rosado², P G Cunha² and T A Da Silva¹

¹Centro de Desenvolvimento da Tecnologia Nuclear, CDTN, Belo Horizonte, Brazil
²Instituto de Radioproteção e Dosimetria, IRD, Rio de Janeiro, Brazil

E-mail: margaretecristinag@gmail.com, silvata@cdtn.br

Abstract. Metrology laboratories are expected to maintain standardized radiation beams and traceable standard dosimeters to provide reliable calibrations or testing of detectors. Results of the characterization of an x-ray system for performing calibration and testing of radiation dosimeters used for individual monitoring are shown in this work.

1. Introduction

X and gamma reference radiations were internationally established for calibrating and determining the energy dependence of dosimeters that are used for radiation protection purpose [1].

Dosimetry of the reference radiations in terms of air kerma in air requires reliable and traceable standard dosimeters. Reliable dosimetry is the basis of a system to derive the operational quantity for individual monitoring, the personal dose equivalent in 10 mm depth, Hp(10). Calibration and performance testing conditions of personal dosimeters are well established to assure their metrological reliability [2].

Several passive solid-state or direct-reading electronic type dosimeters have been used for individual monitoring in Brazil in compliance with radiation protection legal requirements. All dosimeters are required to be calibrated and have their response to different radiation field conditions well known [3].

The aim of this work was to verify the reliability of the x-ray calibration system of the Dosimeter Calibration Laboratory, Centro de Desenvolvimento da Tecnologia Nuclear, LCD/CDTN, for performing calibration and testing of radiation dosimeters used for individual monitoring in terms of personal dose equivalent, Hp(10).

2. Methods and results

2.1. Repeatability and reproducibility of the 2575 NE standard dosimeter

The stability of a 600cc 2575 NE standard ionization chamber was studied based on its response from a \(^{90}\)Sr/\(^{90}\)Y radiation source-chamber fixed geometry.

Results from 2013 to 2016 showed that its repeatability (the variation coefficient of many cycles of ten measurements) varied from 0.04% to 0.21%. In the same time interval, its reproducibility represented by its relative response varied within ±1.0%. Both results are acceptable values for a standard chamber.
2.2. Traceability of the 2575 NE standard dosimeter
The traceability of the 2575 NE standard ionization chamber was verified by calibrating it against a similar chamber that is the national standard of the Brazilian Laboratory of Ionizing Radiation Metrology, Instituto de Radioproteção e Dosimetria, LNMRI/IRD.

Air kerma rates in air were measured by both chambers by substitution method in N60, N80, N100 and W60, W80 and W110, narrow and wide ISO spectrum series, respectively (Fig. 1).

Figure 1. LCD/CDTN x-ray calibration set-up for calibrating the 2575 NE chamber against the LNMRI/IRD national standard.

Calibration coefficients of the LCD/CDTN 2575 NE ionization chamber (Table 1) showed that its maximum energy dependence was about 2% in the energy range; this is a typical value for a standard chamber.

| Reference radiation | Calibration coefficient \( \times 10^4 \text{ Gy.C}^{-1} \) | Expanded uncertainty, k=2 (%) |
|---------------------|--------------------------------|-------------------------------|
| N60                 | 4.30                          | 2.28                         |
| N80                 | 4.27                          | 2.28                         |
| N100                | 4.22                          | 2.28                         |
| W60                 | 4.34                          | 2.25                         |
| W80                 | 4.31                          | 2.25                         |
| W110                | 4.25                          | 2.25                         |

2.3 Reliability of the LCD/CDTN dosimeter calibration procedure in terms of air kerma
The reliability of the LCD/CDTN calibration procedure in terms of air kerma in air was verified through a cross-comparison with the LNMRI/IRD by calibrating a TK30 model EXRADIN travelling ionization chamber in both laboratories (Fig. 2).

Results were given in terms of the calibration coefficients with their respective expanded uncertainties for k equal to 2 (Table 2).

Analysis was done in terms of the Zeta score that establishes that results are consistent for \(|z| \leq 2.0\), acceptable but investigation is needed for \(2.0 < |z| < 3.0\) and unacceptable for \(|z| \geq 3.0\) [4].
In comparison to the values obtained in the LNMRI/IRD, the calibration coefficients of the TK30 chamber determined in the LCD/CDTN showed a small increase in the uncertainty values due to its calibration procedure. Considering that Zeta score \[4\] were lower than 2.0, the results confirmed the metrological coherence between both laboratories and, consequently, the reliability of the LCD/CDTN calibration procedure in terms of air kerma.

### Table 2. Cross-comparison between the LCD/CDTN and LNMRI/IRD calibration procedures of a TK30 ionization chamber in terms of air kerma in air.

| Reference radiation | Calibration coefficient (10\(^6\) G\(y\).C\(^{-1}\)) | Zeta score [4] |
|---------------------|-----------------------------------------------|--------------|
|                     | LCD/CDTN                                    | LNMRI/IRD    |              |
| N60                 | 1.023 (2.84\%)*                             | 1.022 (2.28\%)* | 0.05        |
| N80                 | 1.035 (2.76\%)                              | 1.039 (2.28\%) | 0.20        |
| N100                | 1.036 (2.92\%)                              | 1.028 (2.28\%) | 0.40        |
| W110                | 1.037 (2.68\%)                              | 1.040 (2.25\%) | 0.15        |

* Expanded uncertainty, \(k=2\).

In comparison to the values obtained in the LNMRI/IRD, the calibration coefficients of the TK30 chamber determined in the LCD/CDTN showed a small increase in the uncertainty values due to its calibration procedure. Considering that Zeta score \[4\] were lower than 2.0, the results confirmed the metrological coherence between both laboratories and, consequently, the reliability of the LCD/CDTN calibration procedure in terms of air kerma.

### 2.4 Reliability of the LCD/CDTN to irradiate dosimeters in terms of Hp(10)

The metrological ability of the LCD/CDTN to irradiate dosimeters in terms of Hp(10) was compared with two others Brazilian metrology laboratories. A set of five thermoluminescent (TL) dosimeters was irradiated by the three laboratories on the ISO standard slab phantom in N60, N80, N100 and W110 radiations with a requested Hp(10) value. Figure 3 shows the LCD/CDTN x-ray set-up where TL dosimeters were irradiated.

![Figure 3. LCD/CDTN x-ray set-up used to irradiate TL dosimeters on the ISO slab phantom.](image)
Dosimeters were provided and evaluated by an independent dosimetry laboratory in terms of Hp(10). Table 3 shows the Hp(10) evaluated values and the analysis in terms of the Zeta score.

Table 3. Comparison between the LCD/CDTN and two other metrology laboratories on the ability to irradiate dosimeters in terms of Hp(10).

| Reference radiation | Personal dose equivalent, Hp(10) (mSv) | Zeta score [4] |
|---------------------|---------------------------------------|----------------|
|                     | CDTN | Lab. 2 | Lab. 3 | CDTN to Lab. 2 | CDTN to Lab. 3 | Lab.3 to Lab.2 |
| N60                 | 2.77 ± 0.14* | 2.94 ± 0.16* | 2.62 ± 0.12* | 1.6 | 1.1 | 2.2 |
| N80                 | 2.39 ± 0.14  | 2.33 ± 0.16  | 2.33 ± 0.15  | 0.6 | 0.4 | 0.0 |
| N100                | 2.11 ± 0.13  | 2.33 ± 0.11  | 2.04 ± 0.09  | 2.6 | 0.6 | 2.7 |
| W110                | 2.18 ± 0.13  | 2.30 ± 0.16  | 2.02 ± 0.10  | 1.2 | 1.3 | 2.2 |

* Expanded uncertainty, k=2.

Results show that the metrological coherence exists between the LCD/CDTN and Lab.3, since Zeta score is lower than 2.0. Related to Lab.2, result for N100 is acceptable but it should be investigated. Investigation should also be done to identify the cause of the differences between Lab.2 and Lab.3.

3. Conclusion

Since the metrological tests showed acceptable results, one can state that the reliability of the LCD/CDTN x-ray system to calibrate and test personal dosimeters in terms of Hp(10) was proved.

References

[1] International Organization for Standardization ISO 1996 X and gamma reference radiations for calibrating dose meters and for determining their response as a function of photon energy - Part 1 - Radiation characteristics and production methods ISO International Standard 4037 Geneva.

[2] International Organization for Standardization ISO 2015 Reference radiation fields for radiation protection — Definitions and fundamental concepts ISO International Standard 29661:2012 +A1:2015 Geneva.

[3] Guimarães M C, Silva C R E, Oliveira P M C and Da Silva T A 2016 On the response of electronic personal dosimeters on constant potential and pulsed x-ray beams J. Phys. Conf. Ser. 733 012094 pp 1-5 doi:10.1088/1742-6596/733/1/012094.

[4] British Standard, BS 2010. Conformity assessment – General requirements for proficiency testing ISO/IEC International Standard 17043 Geneva.

Acknowledgments - M C Guimarães is thankful to CNEN for her doctorate fellowship and to IPEMED for supporting her participation in the CBMRI 2018 congress. We thank C Maurício (IRD) for providing and evaluating the TL dosimeters. This work was supported by METRORADI/SIBRATEC Network, FAPEMIG (Universal 2015) and CNPQ (PQ Fellowship). It is part of the Project INCT Radiation Metrology in Medicine.