Methodology for calibration of ionization chambers for X-ray of low energy in absorbed dose to water

C T Oliveira[1], V. Vivolo[1], M P A Potiens[1]

[1] Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN – USP

E-mail: camila_fmedica@hotmail.com

Abstract: The beams of low energy X-ray (10 to 150 kV) are used in several places in the world to treat a wide variety of surface disorders, and between these malignancies. As in Brazil, at this moment, there is no calibration laboratory providing the control service or calibration of parallel plate ionization chambers, the aim of this project was to establish a methodology for calibration of this kind of ionization chambers at low energy X-ray beams in terms of absorbed dose to water using simulators in the LCI.

Keywords: X-rays; radiotherapy; calibration; ionization chamber; absorbed dose.

1. INTRODUCTION

The X-ray beams of low energy (10 - 150 kV) are used in several places in the world to treat a wide variety of surface disorders, and among these malignancies [1]. In addition, low X-ray energies are used in intraoperative radiotherapy [2].

One of the main factors for X-ray used in radiotherapy is its rapid attenuation by tissues and ease of radiation drive access within an operating room [3].

Most national and international recommendations point advantage in the use of parallel plate ionization chambers (IC) in dosimetry of therapeutic beams mainly for low-energy beams. This is mainly for their construction characteristics [4].

As in Brazil, until now, there is no calibration laboratory providing the control service or calibration of parallel plates ionization chamber, the objective was to establish a methodology for calibration of these kind of ionization chamber in low-energy X-ray beams in terms of absorbed dose to water to be applied at the Laboratório de Calibração de Instrumentos (LCI) of Instituto de Pesquisas Energéticas e Nucleares (IPEN).

2. MATERIALS AND METHODS

Initially were performed quality control tests and characterization of ionization chambers. All tests were performed to two ionization chambers model PTW 23344, with serial numbers 0708 (CA) and 0709 (CB). The analysis procedures and the experimental arrangement were made following the recommendations of *International Electrotechnical Commission* IEC 60731 [5].

The previously established radiation qualities T-10 to T-50 were confirmed following the recommendations of the *Bureau International des Poides et Mesures* (BIPM) [6], and qualities T-70 and T-100 were established according to DIN [7] and TRS 398 [8] recommendations.

The absorbed dose to water was determined using the chambers, CA calibrated in terms of absorbed dose and CB in terms of air kerma according to equation (1) and (2) respectively.

$$D_w = M\ N_w\ K_Q \qquad \text{Equation 1}$$

$$D_w = f_w \, k_{a \to w} \, N_s \;\; K \, M \qquad \text{Equation 2}$$

where N_w is the calibration factor for the absorbed dose in water, K_Q is a specific factor of the CI which corrects differences between the quality of the reference beam and the quality that is being used, M is the measurement, K is the product of factors k_i for influence quantities, f_w is the conversion factor $\frac{w}{e}\, t w^{en}/_{a}$, $K_{a \to w}$ is the correction factor for transitional measures carried out in the air for measurements in the water or water equivalent phantom and N_s is the calibration factor for the default on exhibit in the air.

It was subsequently determined for all qualities the calibration factor, N_{DwQ}, for the chamber CB relative to chamber CA to equalize doses obtained for both ionization chambers.

3. RESULTS AND DISCUSSION

For the test of repeatability and stability in the short term, the greatest deviation obtained was 0.44 % for the chamber CA and 0.22 % for CB, been less than IEC 60731 recommended values of 0.5 % [5]. For long-term stability it is recommended that the measurement of the variation generated by irradiation is less than 1 % by 1 month. The result obtained for CA was 0.41 % and 0.31 % for CB.

For the leakage current test, it is recommended that it should not exceed 0,5 % of the lowest measurement obtained during an interval of at least 1 min. For ionization chambers in the study the results were 0.011 % and 0.010 % for CA and CB, respectively. For post irradiation leakage current, it is recommended that the leakage current measured at 5 s after an irradiation of 10 min should decrease ± 1 % of measurement obtained during irradiation. For CA and CB no change was observed in reading 5 s after irradiation.

For the stabilization time test according to IEC 60731 [5] the response variation limits of the chamber under irradiation conditions for a period between 15 min and 2 h after applying the bias voltage must not be greater than 0.5 % of value obtained 1 h after applying the bias voltage. For both ionization chambers, CA and CB, the measurements were always below than 5 %.

The minimum effective dose rate determination was the first characterization test performed. Following the methodology established by the IEC 60731 [5] the acceptable leakage currents for medium charge encountered in chambers CA and CB were 4.023 pC and 3.801 pC, respectively.

For the saturation curve determination the IC were irradiated applying the voltages of ± 100 V, ± 200 V, ± 300 V e ± 400 V and the readings obtained were used to plot a graph load versus bias voltage. From the graph it was observed that the saturation region for both IC starts at voltage of ± 100 V. In this work, the voltage + 400 were used as the standard in the measurements.

The ion collection efficiency was determined by using data obtained from the saturation curve for the CA and CB chambers. According to recommendations, the efficiency in the ion collection must be greater than or equal to 99 % and should also be found in both polarizations. The largest ion recombination found for all voltages analyzed was 0.44 % for ionization chamber CA and – 0.57 for chamber CB.

It is recommended that the variation of the ionization chamber response to the polarity inversion is lower than 1 %. The effect was measured for polarity voltages of ± 100 V, ± 200 V, ± 300 V e ± 400 V and for all voltages analyzed the results were above the recommended. However, the TRS 398 [8] provides that in parallel plate ionization chambers used in beams of low energy X-ray the change of the polarity distorts the IC window that accounts for the difference between the measured currents with voltages of reverse polarities.

For study the response linearity of the ionization chambers varying the dose rate, it was plotted a graph with the collected charge versus current and obtaining the linear correlation factor. For ionization chamber CA the correlation factor was 0.999 and for ionization chamber CB was 1.000.

The radiation qualities previously established at the LCI were re-established using a smaller field size, 34 mm in order to reduce scattering effects [9]. Comparing the results, the maximum variation found for the air kerma rate was less than 5 %. New radiation qualities (T-70 and T-100) were established. The half-value layer (HVL) found diverged reference values. However, these differences are foreseen, as the DIN [7] states that the recommended values for thicknesses of aluminum used in determining the HVL are standards and may vary depending on the X-ray equipment used.

The absorbed doses determined for both IC were approximately equal considering the obtained uncertainties as shown in table 1. The calibration coefficient ($N_{DW,Q_{CB}}$) obtained for T-10 to T-100 radiation qualities are show in table 2.

Table 1. Absorbed Doses Rates obtained using the ionization chambers CA and CB.

Radiation Quality	$D_{W_{CA}}\left(\frac{mGy}{min}\right)$	$D_{W_{CA}}\left(\frac{mGy}{min}\right)$
T- 10	165.9 ± 9.5	170.8 ± 8.6
T- 25	164.9 ± 9.5	168.5 ± 8.9
T- 30	557.9 ± 32.2	572.1 ± 30.2
T- 50 (a)	54.4 ± 3.1	55.8 ± 3.0
T- 50 (b)	255.0 ± 14.6	261.5 ± 14.0
T- 70	31.5 ± 1.8	32.2 ± 1.8
T- 100	62.8 ± 3.6	64.8 ± 3.6

Table 2. Calibration coefficient calculated for the ionization chamber CB ($N_{DW,Q_{CB}}$).

Radiation Quality	$N_{DW,Q_{CB}}$ (10^9 Gy/C)
T- 10	9.22 ± 0.045
T- 25	9.27 ± 0.047
T- 30	9.24 ± 0.047
T- 50 (a)	9.27 ± 0.048
T- 50 (b)	9.28 ± 0.048
T- 70	9.53 ± 0.050
T- 100	9.37 ± 0.050

4. CONCLUSÕES

Stability and characterization tests showed the excellent performance of the IC and the proper functioning of the assembly and electrometer. All tests were within the recommended limits except for polarization test as expected. Since, for parallel plate IC used in low energy X-ray beam, the electrostatic distortion of the ionization chamber window influences in measurements.

The reestablishment of the T-10 to T-50 radiation qualities enabled a lower contribution from scattered radiation in measurements and therefore more accurate and precise measurements. The results showed concordance with the results presented by BIPM [6] and moreover, the results obtained at deployment time of the qualities in LCI despite the variation in field size.

Because of the correlation between the results obtained with the reestablishment of the reference was possible to establish the qualities of T- 70 and T- 100 with confidence. Furthermore, the low uncertainties relating to the measurements and the comparisons with results obtained in BIPM and DIN indicate that the X-radiation qualities have been correctly established.

With the absorbed dose measurements it was found that an IC calibrated using the formalism of N_{DW} (CA) and with N_k formalism (CB) can yield about the same absorbed dose to water. Therefore, it was possible to determine the calibration coefficients for the ionization chamber CB in terms of absorbed dose to water for all qualities set out in the LCI.

5. REFERENCES

[1] Malinverni G, Stasi M, Baiotto B, Giordana C, Scielzo G e Gabriele P. Clinical application and dosimetric calibration procedure of the superficial and orthovoltage therapy unit Therapax DXT300. ***Tumori.*** v. 88(4), pp. 331–337, 2002.

[2] Wenz F, Blank E, Welzel G, Hofmann F, Astor D, Neumaier C Herskind C Gerhardt A Suetterlin M e Kraus-Tiefenbacher U. Intraoperative radiotherapy during breast-conserving surgery using a miniature Xray generator (Intrabeam): theoretical and experimental background and clinical experience. ***Women's Health***, v. 8(1), pp. 39–47, 2012.

[3] Ma C -M. X-ray therapy equipment, low and medium energy. ***Encyclopedia of Medical Devices and Instrumentation***. 2nd ed. New Jersey: John Wiley & Sons, pp. 580– 590, 2006.

[4] IAEA, International Atomic Energy Agency. ***The Use of Plane-Parallel Ionization Chambers in High-Energy Electron and Photon Beams. An International Code of Practice for Dosimetry.*** Vienna, Austria, 1995. (TRS 381).

[5] IEC, International Electrotechnical Commission. ***Medical Electrical Equipment – Dosimeters with Ionization Chamber and/or Semi-Conductor Detectors as Used in X-ray Diagnosis Imaging.*** Geneva, 2012. (IEC 60731).

[6] BIPM. Bureau International Des Poids Et Measures. ***Measuring Conditions Used For The Calibration Of Ionization Chambers At The BIPM.*** France**,** 1991 (Rapport BIPM – 91/5).

[7] DIN. Deutsches Institut Für Normung. ***Clinical dosimetry.*** Part 4: application of X-radiation with tube voltages of 10 to 100 kV in radiotherapy and soft tissue diagnostics**.** Germany, 1988. (DIN 6809 Part 4).

[8] IAEA, International Atomic Energy Agency. ***Absorbed Dose Determination in External Beam Radiotherapy, An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water***. Vienna, Austria, 2000 (a). (IAEA TRS-398).

[9] Davis A T, Safi H and Maddison S M. **The reduction of dose in paediatric panoramic radiography: the impact of collimator height and programme selection.** Department of Medical Physics, Portsmouth Hospitals NHS Trust, Queen Alexandra Hospital, Portsmouth, UK. A Journal of Head & Neck Imaging. November 20, 2014. DOI: http://dx.doi.org/10.1259/dmfr.20140223.

ACKNOWLEDGEMENTS

The authors acknowledge the partial financial support of the FINEP/MCTI project number 01.10.0650.01; Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, project #2008/57863-2); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Ministério da Ciência e Tecnologia (MCT, Project: Instituto Nacional de Ciência e Tecnologia (INCT) em Metrologia das Radiações na Medicina), Brazil.