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Interlaboratory comparison of two homemade pencil type ionization chambers

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Astract: Computed tomography (CT) is a diagnostic exam responsible for the highest dose values received by the patients during the procedure. Over the years, this kind of equipment has been improved to ensure that the patients do not receive unnecessary doses. For this reason it is important to keep a quality control program for the CT equipment. To perform the dosimetry in CT beams, the instrument used is usually a pencil type ionization chamber with a sensitive volume length of 10 cm. However, this kind of detector is available with different sensitive volume lengths. The aim of this study was to compare the response of two homemade pencil type ionization chambers with sensitive volume lengths of 10 cm and 30 cm in the laboratories of Instituto de Pesquisas Energéticas e Nucleares (IPEN, Brazil) and National Physical Laboratory (NPL, UK). The characterization tests were performed, and the results obtained are within the international recommended limits. The only difference observed in the response of the two chambers in both laboratories is the fact that the ionization current obtained in all the tests at the IPEN is higher than at the NPL, because of the beam characteristics.

Keywords: pencil type ionization chamber, radiation dosimetry, computed tomography beams.

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Comparação interlaboratorial de dois protótipos de câmaras de ionização do tipo lápis

Resumo: A tomografia computadorizada (TC) é um exame diagnóstico responsável pelos maiores valores de dose recebidos pelos pacientes durante o procedimento. Ao longo dos anos, esse tipo de equipamento foi aprimorado para garantir que os pacientes não recebam doses desnecessárias. Por esta razão é importante manter um programa de controle de qualidade dos equipamentos de TC. Para realizar a dosimetria em feixes de TC, o instrumento utilizado geralmente é uma câmara de ionização tipo lápis com comprimento de volume sensível de 10 cm. No entanto, este tipo de detector está disponível com diferentes comprimentos de volume sensível. O objetivo deste estudo foi comparar a resposta de dois protótipos de câmaras de ionização do tipo lápis com comprimentos de volume sensível de 10 cm e 30 cm nos laboratórios do Instituto de Pesquisas Energéticas e Nucleares (IPEN, Brasil) e do National Physical Laboratory (NPL, Reino Unido). Os testes de caracterização foram realizados e os resultados obtidos estão dentro dos limites recomendados internacionalmente. A única diferença observada na resposta das duas câmaras nos dois laboratórios é o fato da corrente de ionização obtida em todos os testes no IPEN ser maior que no NPL, devido às características do feixe.

Palavras-chave: câmara de ionização do tipo lápis, dosimetria da radiação, feixes de tomografia computadorizada.

1. INTRODUCTION

The use of Computed Tomography (CT) for diagnostic images has shown a growing use, due to technological advances of this equipment [1-3]. This type of equipment has undergone many improvements [4] with the aim to reduce the doses received by the patients during the procedure, because this kind of imaging procedure uses higher radiation doses, in comparison to other procedures of conventional radiology. Therefore, it is important to perform radiation dosimetry using appropriate and reliable detectors.

The dosimetry of CT beams is usually made using a pencil type ionization chamber with a sensitive volume length of 10 cm, but there are also other sizes available in the market. This detector presents a uniform response to the incident radiation beam from all angles, which makes it appropriate once the X-ray tube executes rotation movement around the patient table during irradiation [5].

The metrological reliability of a dosimetric detector is maintained through its calibration and performance tests. For this reason, it is very important that the equipment to be calibrated is traced to a reference instrument.

Traceability refers to how the response of a given detector is related to a given reference system. Therefore, there must be a chain in which all comparisons ensure the results of the measurements obtained, leading to the highest standard reference system, which in this case is the absolute detector of each type of radiation from the primary standard laboratory [6].

The Instrument Calibration Laboratory (LCI) from Instituto de Pesquisas Energéticas e Nucleares (IPEN) has standard systems traceable to the Brazilian National Ionizing Radiation Metrology Laboratory (LNMRI) that is a secondary standard laboratory, and to the primary standard laboratories of the Physikalisch-Technische Bundesanstalt (PTB, Germany), the National Institute of Standards and Technology (NIST, USA) and to the National Physical Laboratory (NPL, UK).

The research group of the LCI has developed over the last ten years some prototypes of ionization chambers, including a pencil type [7-10]. These homemade chambers were made with low cost material, and they present some small differences in relation to the commercial models. The aim of this work was to compare the response of two homemade pencil type ionization chambers with sensitive volume lengths of 10 cm and 30 cm at the LCI/IPEN and at the NPL, and as a consequence their calibration.

2. MATERIALS AND METHODS

2.1. Equipment

The following equipment were utilized:

- A secondary standard pencil type ionization chamber, Radcal, model RC3CT, with sensitive volume length of 10 cm and volume of 3 cm³, called C_{IPEN}, of LCI. This chamber was calibrated at the Physikalisch-Technische Bundesanstalt (PTB) laboratory (Certificate n. 5889, 14/07/2009).
- A primary standard free air chamber utilized in the energy range of the laboratory radiation beams from 40 kV to 300 kV, called C_{NPL}, of NPL.
- Two homemade pencil type ionization chambers, with sensitive volume lengths of 10 cm (called C10) and 30 cm (called C30) manufactured at IPEN. Figure 1 shows the design of the ionization chambers and Table 1 shows their specifications.

Figure 1. Design of a pencil type ionization chamber showing the components.

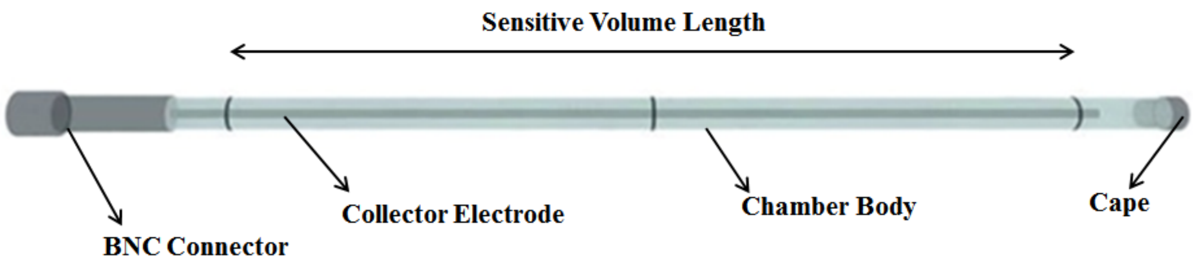


Table 1. Characteristics and specifications of the pencil type ionization chambers C10 and C30. The material of the collector electrode is aluminum with a layer of graphite, the chamber body material is PMMA with a layer of graphite and the cape material is Teflon.

CHARACTERISTICS	SPECIFICATIONS	
	C10	C30
Diameter of the central collector electrode (mm)	3.20	3.20
Inside diameter of the ionization chamber (mm)	7.40	7.40
Wall thickness (mm)	0.26	0.26
Sensitive volume length (mm)	100	300
Sensitive volume (cm^3)	3.50	10.5

For all of the measurements, both ionization chambers were connected to an electrometer, model UNIDOS E, Physikalisch-Technische Werkstatten (PTW), Germany. The measurements obtained were corrected to the standard values of environmental temperature and pressure. The uncertainties of type A and type B were determined, with the combined uncertainty of factor k = 2.

The X-ray equipment, Pantak / Seifert, model ISOVOLT 160 HS, operating between 5 kV and 160 kV, was utilized at the LCI. In the National Physical Laboratory (NPL) the X-ray equipment, Comet, model MXR-321, operating up to 320 kV was used. The characteristics of the CT standard X radiation qualities are presented in Table 2 (LCI) and Table 3 (NPL).

Table 2. Characteristics of the CT standard X radiation qualities at the LCI (IEC, 2005).

RADIATION QUALITY	TUBE VOLTAGE (KV)	TUBE CURRENT (MA)	ADDITIONAL FILTRATION (MM)	HALF-VALUE LAYER (MM AL)	AIR KERMA RATE (MGY/MIN)
RQT 8	100	10	3.2 Al + 0.30 Cu	6.9	22.0
RQT 9†	120	10	3.5 Al + 0.35 Cu	8.4	34.0
RQT 10	150	10	4.2 Al + 0.35 Cu	10.1	57.0

† LCI Reference CT radiation quality

Table 3. Characteristics of the CT standard X radiation qualities at the NPL (IEC, 2005).

RADIATION QUALITY	TUBE VOLTAGE (KV)	TUBE CURRENT (MA)	ADDITIONAL FILTRATION (MM CU)	AIR KERMA RATE (MGY/MIN)
RQT 8	100	10	0.20	22.7
RQT 9†	120	10	0.25	31.5
RQT 10	150	10	0.30	48.1

† NPL Reference CT radiation quality

2.2 Characterization tests

The tests performed in both laboratories were: stabilization time, saturation curve, polarity effect, ion collection efficiency and linearity of response.

For the stabilization time test of the ionization chambers, the measurement standard deviation must not exceed ± 2 % when comparing the response ionization current obtained in 15 min and 60 min [12].

The polarity effect and the ion collection efficiency were obtained through the saturation curve. For the polarity effect test, the ratio of the ionization currents obtained for positive and negative polarities must not exceed ± 1 % [12]; therefore, the results should be in the range 0.99 - 1.01. Using Equation 1 [6], it was possible to calculate the ion collection efficiency of each ionization chamber, where the standard deviation must not exceed ± 5 % [12].

$$K_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \quad (1)$$

where: M_1 and M_2 are the values obtained with the voltages V_1 = + 200 V and V_2 = + 100 V, respectively.

The linearity of response of both pencil type ionization chambers must present a linear curve, so the correlation factor needs to be close of 1.00 (R^2= 1.00).

The two pencil type ionization chambers were calibrated in relation to the standard chambers (C_{IPEN} and C_{NPL}) using the replacement method. Through the results obtained, it was possible to determine the energy dependence, where the standard deviation must not exceed ± 5 % [12].

3. RESULTS AND DISCUSSIONS

For all tests each of the pencil type ionization chambers was positioned in a specific setup, at the distance of 1 m from the focus of the X-rays equipment used for calibration of radiation detectors. At the distance of 5 cm in front of the chamber there is a collimator with a central window with dimensions of 2 cm x 5 cm. For the tests, 5 measurements during 30 s were taken in the three radiation qualities.

Initially are presented the results obtained for the stabilization time test. After irradiation, the current was measured 15 min and 60 min after switching on the dosimetric system. The difference between results obtained in 15 min and 60 min was calculated and compared with the limits established by IEC (IEC, 1997), and they can be seen in Table 4.

Table 4. Stabilization time test for the pencil type ionization chambers (C10 e C30) in the CT radiation qualities in both laboratories (LCI and NPL). Δ: Difference between the ionization current values measured in 15 min and 60 min.

RADIATION QUALITY	LCI Δ (%)	NPL Δ (%)
	C10	
RQT 8	0.02	0.11
RQT 9	0.09	0.23
RQT 10	0.29	0.16
	C30	
RQT 8	0.01	0.10
RQT 9	0.18	0.78
RQT 10	0.02	0.21

As can be observed in Table 4, the results obtained for the stabilization time test are within the recommended limit (± 2 %) in the three radiation qualities in both laboratories [12].

To determine the optimal voltage for the operation of the ionizing chambers, saturation curves were obtained varying the applied voltage to both ionization chambers from - 400 V to + 400 V, in steps of 50 V. The results are shown in Figures 2 and 3 for the C10 and C30 chambers in both laboratories.

Figure 2. Saturation curves for the pencil type ionization chamber C10 in the three CT radiation qualities at (a) LCI and (b) NPL. The maximum measurement uncertainty was 0.05 %.

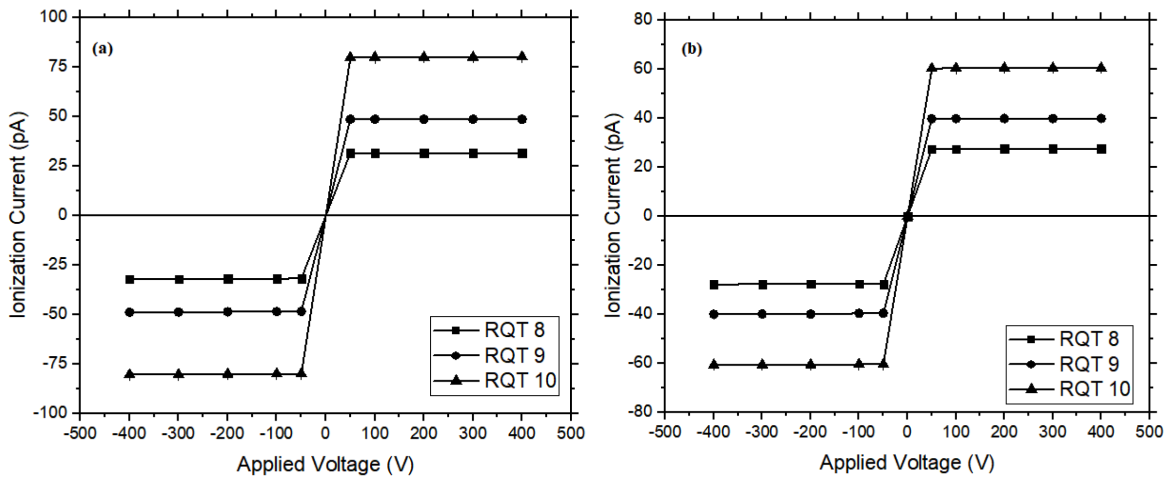
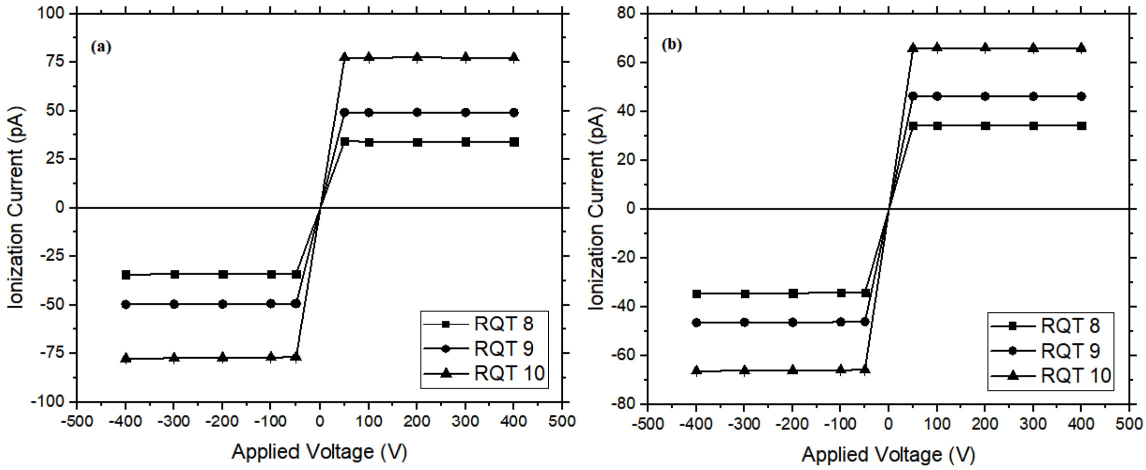


Figure 3. Saturation curves for the pencil type ionization chamber C30 in the three CT radiation qualities at (a) LCI and (b) NPL. The maximum measurement uncertainty was 0.04 %.



As observed in Figures 2 and 3, the saturation curves present the same behavior for both polarities applied to the chambers C10 and C30 in all three CT radiation qualities in both laboratories. Comparing the chamber results obtained in the two laboratories, the only difference is the current ionization values, which is higher at the LCI, due to the higher air kerma rate.

The polarity effect was estimated by the calculation of the ratio between the ionization current values obtained for the positive and negative polarities, for each applied voltage utilized in the saturation curves. Tables 5 and 6 show the results obtained for the polarity effect at LCI and NPL for both ionization chambers.

Table 5. Polarity effect for the pencil type ionization chambers C10 and C30 in the CT radiation qualities at LCI.

APPLIED VOLTAGE (V)	C10			C30		
	RQT 8	RQT 9	RQT 10	RQT 8	RQT 9	RQT 10
50	0.999	1.007	1.000	1.005	1.007	1.006
100	0.997	1.005	1.000	1.003	1.005	1.004
200	0.996	1.003	1.000	1.000	1.002	1.003
300	0.994	1.000	0.998	1.000	1.000	1.000
400	0.994	0.997	0.999	0.993	0.997	0.996

Table 6. Polarity effect for the pencil type ionization chambers C10 and C30 in the CT radiation qualities at NPL.

APPLIED VOLTAGE (V)	C10			C30		
	RQT 8	RQT 9	RQT 10	RQT 8	RQT 9	RQT 10
50	0.993	1.007	0.999	1.004	1.008	1.005
100	1.000	1.006	1.002	1.006	1.005	1.004
200	0.999	1.000	1.000	1.002	1.001	1.002
300	0.998	1.001	0.998	0.998	1.000	0.999
400	0.996	0.999	0.998	0.998	0.996	0.997

The results obtained for the polarity effect are within the recommended limits (± 1 %) [12] for both ionization chambers at the two laboratories, in the three CT radiation qualities.

As in the case of the polarity effect obtained from the saturation curve, the ion collection efficiency used the values obtained for the + 200 V and + 100 V in each radiation quality for both ionization chambers at LCI and NPL. The results are shown in Table 7.

Table 7. Ion collection efficiency (%) for the ionization chambers (C10 and C30) in the CT radiation qualities at the LCI and NPL.

IONIZATION CHAMBER	RADIATION QUALITY		
	RQT 8	RQT 9	RQT 10
	LCI		
C10	98.99	99.00	98.99
C30	98.99	98.99	98.99
	NPL		
C10	98.99	98.99	98.99
C30	99.00	99.90	99.99

As observed in Table 7, the ion collection efficiency obtained of the chambers C10 and C30 in all three CT radiation qualities in both laboratories are within the recommended limits (± 95 %).

The linearity of response was obtained varying the applied current (tube current) to both ionization chambers from 2 mA to 20 mA at LCI and from 1 mA to 15 mA at NPL. The results are shown in Figures 4 and 5 for the C10 and C30 chambers in both laboratories.

Figure 4. Linearity of response for the pencil type ionization chamber C10 in the three CT radiation qualities at (a) LCI and (b) NPL. The maximum measurement uncertainty was 0.03 %.

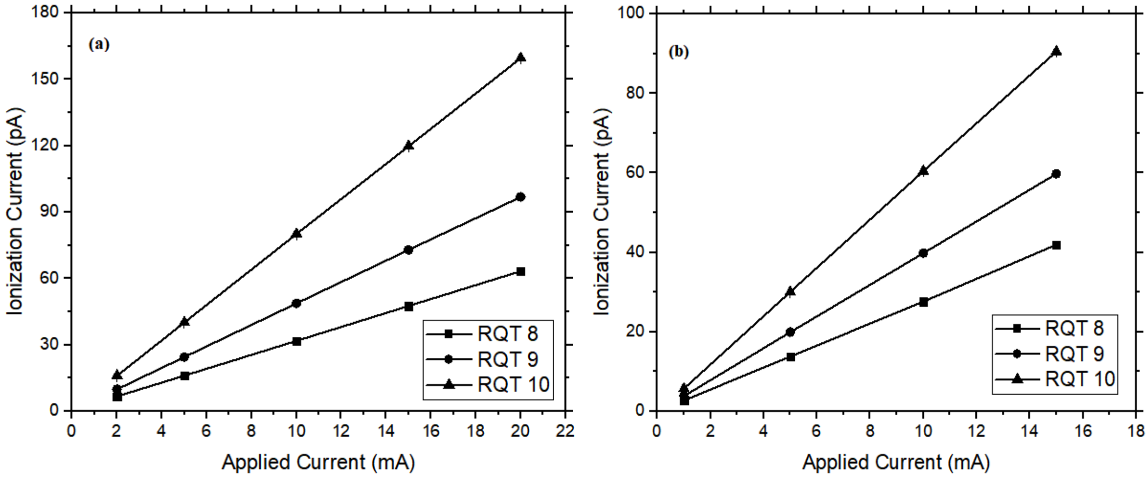
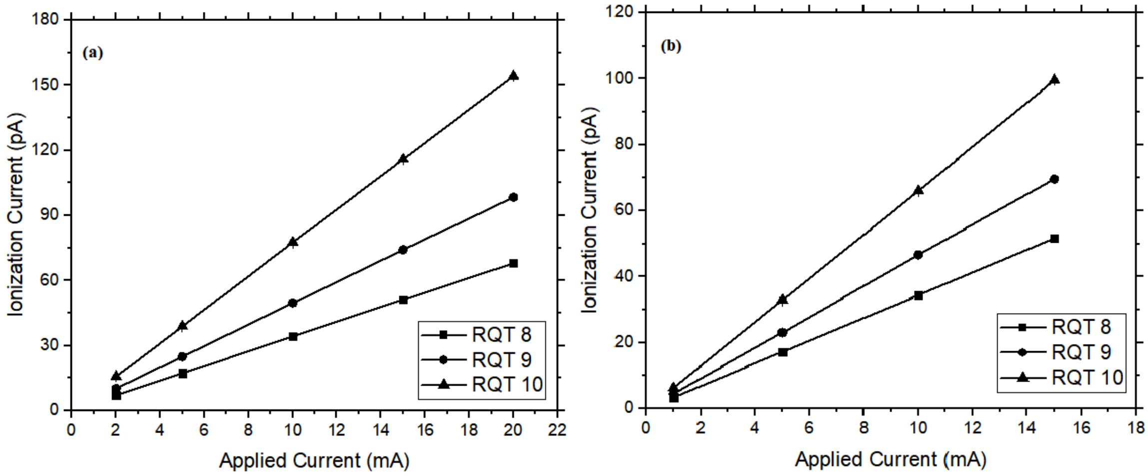


Figure 5. Linearity of response for the pencil type ionization chamber C30 in the three CT radiation qualities at (a) LCI and (b) NPL. The maximum measurement uncertainty was 0.03 %.



As can be observed in Figures 4 and 5, each curve obtained for the linearity of response is linear; the correlation coefficients (R^2) are shown in Table 8.

Table 8. Correlation coefficients (R^2) obtained for the linearity of the response for both pencil type chambers (C10 and C30) in the three CT radiation qualities at LCI and NPL.

RADIATION QUALITY	R^2			
	LCI		NPL	
	C10	C30	C10	C30
RQT 8	1.0000	0.9999	0.9998	1.0000
RQT 9	0.9999	0.9999	0.9999	0.9999
RQT 10	0.9999	0.9999	0.9999	0.9999

All of the correlation coefficients obtained for the two pencil type ionization chambers in the three CT radiation qualities in both laboratories (LCI/IPEN and NPL) are very close to 1.000. Therefore, it is possible to confirm the linearity of the response.

The energy dependence was determined for the two ionization chambers in both laboratories. It was obtained by the maximum deviation of the calibration factor for each radiation quality in relation to the correction factor obtained for the reference radiation quality (RQT 9). Tables 9 and 10 show the results obtained at LCI and Tables 11 and 12, at NPL laboratory.

Table 9. Calibration coefficient, correction factor and energy dependence of the CT radiation qualities for the pencil type ionization chamber C10 at LCI.

RADIATION QUALITY	CALIBRATION COEFFICIENT (10^7 GY/C)	CORRECTION FACTOR	ENERGY DEPENDENCE (%)
RQT 8	5.78 ± 0.06	0.990	1.0
RQT 9	5.84 ± 0.06	1.000	--
RQT 10	5.94 ± 0.06	1.017	1.7

Table 10. Calibration coefficient, correction factor and energy dependence of the CT radiation qualities for the pencil type ionization chamber C30 at LCI.

Radiation Quality	Calibration Coefficient (10^7 Gy/C)	Correction Factor	Energy Dependence (%)
RQT 8	5.36 ± 0.06	0.938	6.2
RQT 9	5.71 ± 0.06	1.000	--
RQT 10	6.12 ± 0.06	1.072	7.2

Table 11. Calibration coefficient, correction factor and energy dependence of the CT radiation qualities for the pencil type ionization chamber C10 at NPL.

RADIATION QUALITY	CALIBRATION COEFFICIENT (10^7 GY/C)	CORRECTION FACTOR	ENERGY DEPENDENCE (%)
RQT 8	6.82 ± 0.01	1.016	1.6
RQT 9	6.71 ± 0.01	1.000	--
RQT 10	6.77 ± 0.01	1.009	0.9

Table 12. Calibration coefficient, correction factor and energy dependence of the CT radiation qualities for the pencil type ionization chamber C30 at NPL.

RADIATION QUALITY	CALIBRATION COEFFICIENT (10^7 GY/C)	CORRECTION FACTOR	ENERGY DEPENDENCE (%)
RQT 8	5.36 ± 0.01	0.947	5.3
RQT 9	5.66 ± 0.01	1.000	--
RQT 10	6.06 ± 0.01	1.070	7.0

As can be observed, the energy dependence obtained for the ionization chamber C10 at LCI/IPEN and at NPL is within the international recommended limit of ± 5 % (IEC, 1997). The results obtained for the pencil type ionization chamber C30 in both laboratories are not in agreement with the international recommendations IEC 61674 [12]. Table 13 shows the percentual difference between the calibration coefficients of chambers C10 and C30 in both laboratories.

Table 13. Percentual difference on calibration coefficients for C10 and C30 in both laboratories.

RADIATION QUALITY	DIFFERENCE (%) C10	DIFFERENCE (%) C30
RQT 8	15.2	0.0
RQT 9	13.0	0.9
RQT 10	12.3	1.0

As can be seen in Table 13 for the C30 chamber the maximum deviation was less than 1%. However, for chamber C10 the highest difference was 15.2% for RQR 8; this difference may be due to the chamber design of the reference systems used for the calibration and the setup of the chamber during the measurements.

4. CONCLUSIONS

Is this study two homemade pencil type ionization chambers with sensitive volume lengths of 10 cm (C10) and 30 cm (C30), manufactured with low cost material, were tested in two laboratories (LCI and NPL) in the CT radiation qualities. The results obtained for the characterization tests (stabilization time, saturation curve, polarity effect, ion colleting efficiency and linearity of response) are all within the recommended limits.

Both chambers were calibrated at LCI and NPL laboratories, and the energy dependence of their responses was obtained. In the case of the C10 chamber, the results were within the recommended limit, but for the C30 chamber it was not the case, probably because of its extended chamber length.

The behavior of the two pencil ionization chambers showed to be similar in both laboratories; the only difference is that the ionization current obtained for each test is higher at the LCI/IPEN than at the NPL, due to the established radiation quality characteristics in each laboratory.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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