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CHARACTERIZATION TESTS AND APPLICATION OF SPECIAL IONIZATION CHAMBERS IN STANDARD MAMMOGRAPHY BEAMS

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ABSTRACT

The most used instrument for quality assurance programs in mammography beams is the ionization chamber. At the Calibration Laboratory of IPEN three different ionization chambers were recently designed and assembled for dosimetry in standard mammography beams. These ionization chambers are parallel plate chambers, with different geometries. The objective of this work was to study the performance of all three ionization chambers in relation to a commercial one. The established standard beams at an industrial X-ray system Pantak-Seifert were used for the characterization tests of the ionization chambers as short- and medium-term stability, saturation curves, polarity effect, ion collection efficiency, response linearity and angular dependence. All of the results obtained were within the limits recommended by the international standards IEC 61674 and IEC 60731.

1. INTRODUCTION

Breast cancer is the second type of disease that affects women more often in the world, contributing significantly to raising the female mortality rate. For this reason, various public health actions have been developed since the 80s with the aim of reducing the mortality rate for the disease (INCA, 2013), such as mammography which is currently the method that has proven more reliable and with relatively low cost in the early detection of breast cancer, requiring a good quality image. Thus, it was necessary to implement an effective quality control program for calibration equipment to meet the radiation protection recommendations. Concerning image quality standardization in mammography, the Ministry of Health created through Ordinance 531/2012, the National Quality Program in Mammography (PNQM) where quality control monitoring mechanisms in public and private institutions all around the country were established. The most used instrument for quality assurance programs in mammography beams is the ionization chamber.

The characteristics of the radiation detectors used to perform beam dosimetry in quality control procedures used in X-ray mammography, follow the recommendations of IEC 61674 (IEC 1997). The document of the American Association of Physicists in Medicine - AAPM

(Wagner et al , 1992) and the TRS 457 document of the International Atomic Energy Agency (IAEA, 2007) recommend calibration procedures for both the ionization chamber and X-ray beams, and dosimetric measurements of interest within the commonly used energy range for clinical practice in mammography .

There are some ionization chamber models commercially available for applications in mammography. An ionization chamber used as a standard system is the Radcal 10X5-6M, with nominal sensitive volume of 6.0 cm^3 (Radcal, 2008). It is recommended as a reference for the Calibration Laboratory of the International Atomic Energy Agency (IAEA) in attenuated and non-attenuated X-ray beams (IAEA, 2008), showing that its response is not influenced by the material of the pipe or filtration system X-ray (Radcal, 2008).

Three specific ionization chambers have recently been developed at the Calibration Laboratory of IPEN. They are parallel plate ionization chambers with sensitive volumes of 6.0 cm^3 for use in mammography quality control programs: one double-sided ionization chamber, with graphite and aluminum collecting electrodes in a Tandem system (Silva and Caldas, 2011); the other ionization chamber has a thickness of 2 cm, suitable for measurements of small breasts in radiation fields; and the third chamber has a double sensitive volume for ion collection, thus avoiding the polarity effects in the response stability tests.

The objective of this work was to study the performance of all three ionization chambers in relation to a commercial one. The established standard beams at an industrial X-ray system Pantak-Seifert were used for the characterization tests of the ionization chambers as short- and medium-term stabilities, saturation curves, polarity effect, ion collection efficiency, response linearity and angular dependence. All of the results obtained were within the limits recommended by the international standards IEC 61674 and IEC 60731.

2. MATERIALS AND METHODS

In this work, an industrial X-ray equipment, a beta radiation control source, ionization chambers, electrometers and some accessories were utilized.

2.1. Calibration Laboratory of IPEN

The following radiation systems were utilized:

- $^{90}Sr+^{90}Y$ control source, Physikalisch-Technische Werkstätten (PTW), type 8921 (activity of 21 MBq, 2012).

- X-ray equipment, Pantak/Seifert, model 160 HS ISOVOLT, which operates up to 160kV, with stardard mammography radiation qualities (Tables 1 and 2).

Table 1. Radiation qualities of mammography beams established at LCI, with additional molybdenum filtration (PTB , 2014)

Quality Radiation	Tube Tension (kV)	Tube Current (mA)	Additional Filtration (mmMo)	(mmAl)	Half-value Layer (mmAl)	Air Kerma Rate (mGy/min)
			Direct Beams			
WMV 25	25	10	0.07	-----	0.36	9.71 $\pm$ 0.01
WMV 28	28	10	0.07	-----	0.37	12.14 $\pm$ 0.01
WMV 30	30	10	0.07	-----	0.38	13.74 $\pm$ 0.02
WMV 35	35	10	0.07	-----	0.41	17.86 $\pm$ 0.01
			Attenuated Beams			
WMH 25	25	10	0.07	2.0	0.56	0.47 $\pm$ 0.01
WMH 28	28	10	0.07	2.0	0.61	0.67 $\pm$ 0.01
WMH 30	30	10	0.07	2.0	0.68	0.85 $\pm$ 0.01
WMH 35	35	10	0.07	2.0	0.93	1.47 $\pm$ 0.02

Table 2. Radiation qualities of mammography beams established at LCI, with additional aluminum filtration (PTB , 2014)

Quality Radiation	Tube Tension (kV)	Tube Current (mA)	Additional Filtration (mmMo)	(mmAl)	Half-value Layer (mmAl)	Air Kerma Rate (mGy/min)
			Direct Beams			
WAV 25	25	10	0.57	-----	0.35	22.72 $\pm$ 0.02
WAV 28	28	10	0.57	-----	0.40	30.40 $\pm$ 0.01
WAV 30	30	10	0.58	-----	0.43	34.79 $\pm$ 0.02
WAV 35	35	10	0.62	-----	0.51	44.56 $\pm$ 0.02
			Attenuated Beams			
WAH 25	25	10	0.57	2.0	0.73	1.66 $\pm$ 0.02
WAH 28	28	10	0.57	2.0	0.88	3.00 $\pm$ 0.01
WAH 30	30	10	0.58	2.0	0.97	4.05 $\pm$ 0.02
WAH 35	35	10	0.62	2.0	1.21	7.14 $\pm$ 0.02

2.2 Measuring systems

The following ionization chambers were utilized:

- Ionization chamber (parallel plate) Radcal, model RC6M, with is the secondary standard system for mammography beams at the LCI;
- Double-sided ionization chamber, comprising two chambers, one with aluminum collecting electrode and the other with graphite collecting electrode, both with entry windows of aluminized polyester with a surface density of 1.87 mg.cm^{-2}. This ionization chamber constitutes a Tandem system. The total sensitive volume is 6.0 cm^3 and the distance between the collecting electrode and entrance window is 2.72 mm, developed by

Silva (2012a, 2012b, 2013). In this work, these ionization chambers will be identified as Chambers 1A (aluminum collecting electrode) and 1G (graphite collecting electrode).

- Ionization chamber (parallel plate) with a thickness of 2 cm, developed to measure doses in X-ray beams for small breasts without the need for corrections in the height of the ionizaton chamber; it has basic thread and its sensitive volume is 6.0 cm^3, developed by Silva (2013), identified as Chamber 2.

- Ionization chamber (parallel plate) with a double volume and unique face, with a thin layer collecting electrode to prevent polarity effects during the stability testing with the control source of ^{90}Sr + ^{90}Y; the distance between the entrance window / high voltage and the collector electrode is smaller to check for ion recombination. The sensitive volume of this chamber is 6.0 cm^3 and has a distance between the entrance window / high voltage and the collecting electrode of 4.0 mm, developed by Silva (2013), identified as Chamber 3.

- Electrometer PTW UNIDOS.

- Barometers, thermometers, hygrometers, dehumidifiers and room air conditioners, etc.

3. RESULTS AND DISCUSSION

In this item the results obtained about the characterization tests of the ionization chambers will be presented.

The ionization chambers used in this work were subjected to characterization tests based on international standards and protocols to determine their best operating conditions: response repeatability, response stability, saturation curves, ion collection efficiency, polarity effect, linearity of response and angular dependence.

3.1 - Response Repeatability

To perform this test, INMETRO (2012) states that the measurement conditions should be the same (operator, operating conditions, place, procedure) to ensure the test repeatability. To verify the repeatability of the response of the chambers, 10 successive measurements were taken and the values shall not present a higher variation than 3 %. As shown in Table 3, all three ionization chambers presented results within the recommended limits.

Table 3 - Repeatability of the response of ionization chambers 1A, 1G, 2 and 3 (%)

Ionization Chambers			
1A	1G	2	3
1.00	1.01	1.00	1.00

3.2 – Response Stability

This test consists to perform the repeatability test along the time. Figure 1 shows the mean values obtained in the measurements that must not exceed ± 2 %, according to the IEC 61674 recommendations (1997). As can be observed, in all cases the limits were not reached.

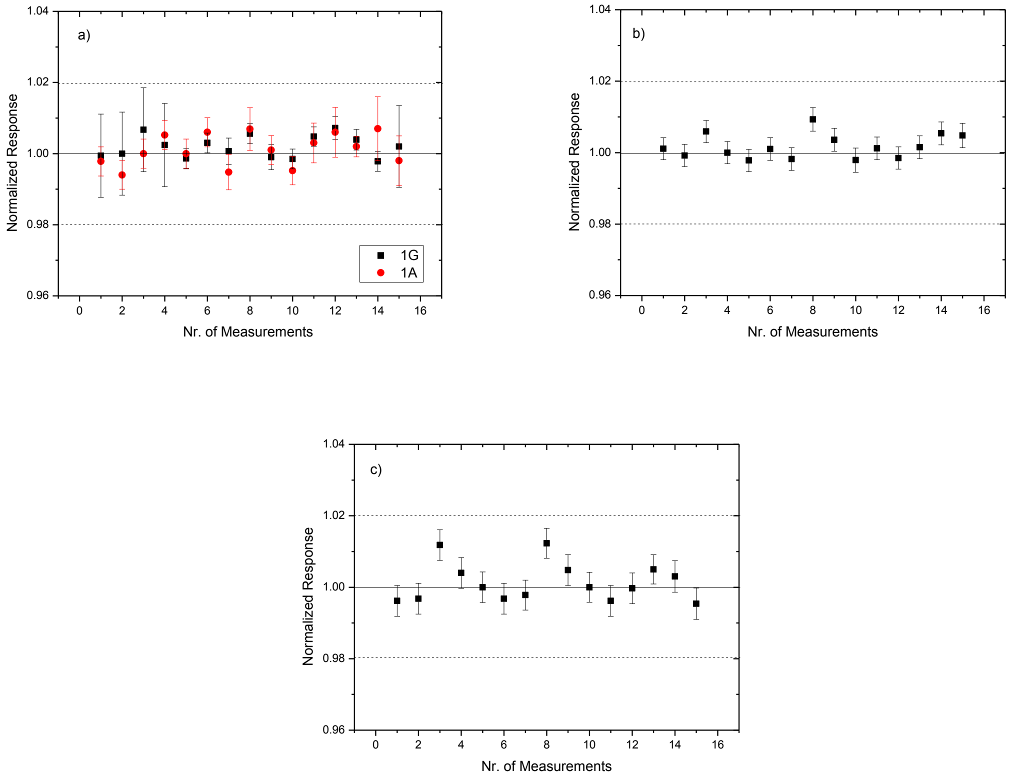

Figure 1 – Response stability results of chambers 1G, 1A (a); 2 (b) and 3 (c).

3.3 - Saturation Curves

To determine the saturation curves, the Chambers 1, 2 and 3 were subjected to the bias voltage ranging from -400 V to +400 V at intervals of 50 V, and X-ray beams (WMV28), using the source-detector distance of 100 cm. Results were by taking the average of ten measurements for each voltage value.

Uncertainties were always lower than 0.75 % (Chamber 3) for all cases, not visible in the graphs. In Figure 2 it can be seen that saturation occurs from + 50 V; thus, any voltage above + 50 V can be used to polarize the ionization chambers. However, the + 300 V voltage was chosen for the measurements taken with the ionization chambers, for to avoid ion recombination effects.

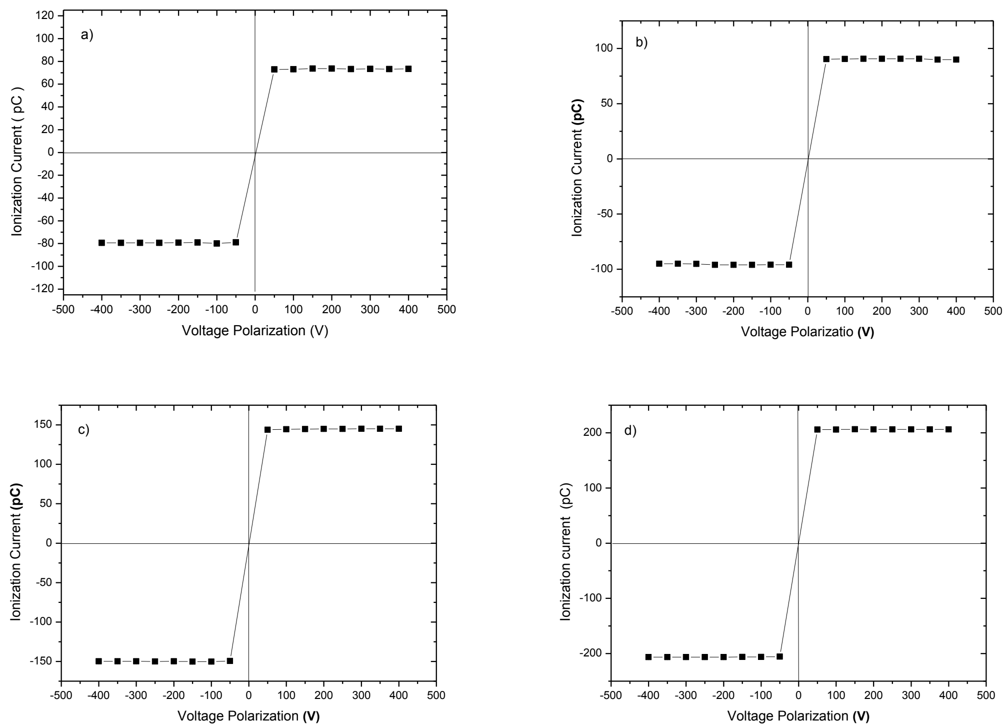

Figure 2 - Saturation curves of chambers 1A (a), 1G (b), 2 (c) and 3 (d). The maximum uncertainty of the measurements was 0.75 % (Chamber 3), not visible in the graphs.

3.4 - Ion Collection Efficiency

The ion collection efficiency is determined from the saturation test using the method of two voltages. The voltage used was + 300 V, which is the usual value for ionization chambers. The ion collection efficiency for mammography beams for the Chambers 1A, 1G, 2 and 3 of this study (Table 4) shows values higher than 99.9 %, which meets the international standard (IEC, 2011), which recommends values equal to or above 95 %.

Table 4 - Ion collection efficiency of Chambers 1A, 1G, 2 and 3 (%)

Ionization Chambers			
1A	1G	2	3
99.95	99.96	99.93	99.98

3.5 – Polarity Effects

To check the influence of the change in the bias voltage in the response of the ionization chambers, they were subjected to the polarity effect test. Using the results obtained from the saturation curve for the same absolute value with opposite signs, and in accordance with the international standard (IEC, 2011), the difference between them shall not be greater than 1.0 %. Table 5 shows that values obtained are within the recommended limit.

Table 5 – Polarity effect values polarity of the ionization chambers 1A and 1G, 2 and 3 of this work

Voltage Polarization (V)	Ratio $(I_+/I_-)^a$ Chambers			
	1A	**1G**	**2**	**3**
+50/-50	0.925	0.943	0.964	0.999
+100/-100	0.925	0.944	0.964	0.998
+150/-150	0.926	0.944	0.965	0.998
+200/-200	0.925	0.945	0.967	0.998
+250/-250	0.927	0,945	0.968	0.998
+300/-300	0.925	0.944	0.969	0.997
+350/-350	0.926	0.944	0.970	0.997
+400/-400	0.926	0.945	0.971	0.998

[a]I_+ is the ionization current with positive voltage and I_- is the ionization current with negative voltage

3.6 - Linearity of Response

For the linearity of response test, the ionization chambers were subjected to the X-ray beam with the mammography quality (WMV28) at a distance of 100 cm and voltage + 300 V, with tube current between 1 mA and 40 mA . It can be seen from Figure 3 that the response behavior of all ionization chambers is linear as a function of X-ray tube current X.

Each point shown on the graph represents the average of 5 measurements and the calculated uncertainty was always less than 1.75% (Chamber 1G), not being visible in the figures. The correlation coefficient (R^2) was always greater than 0.999, showing a linear response.

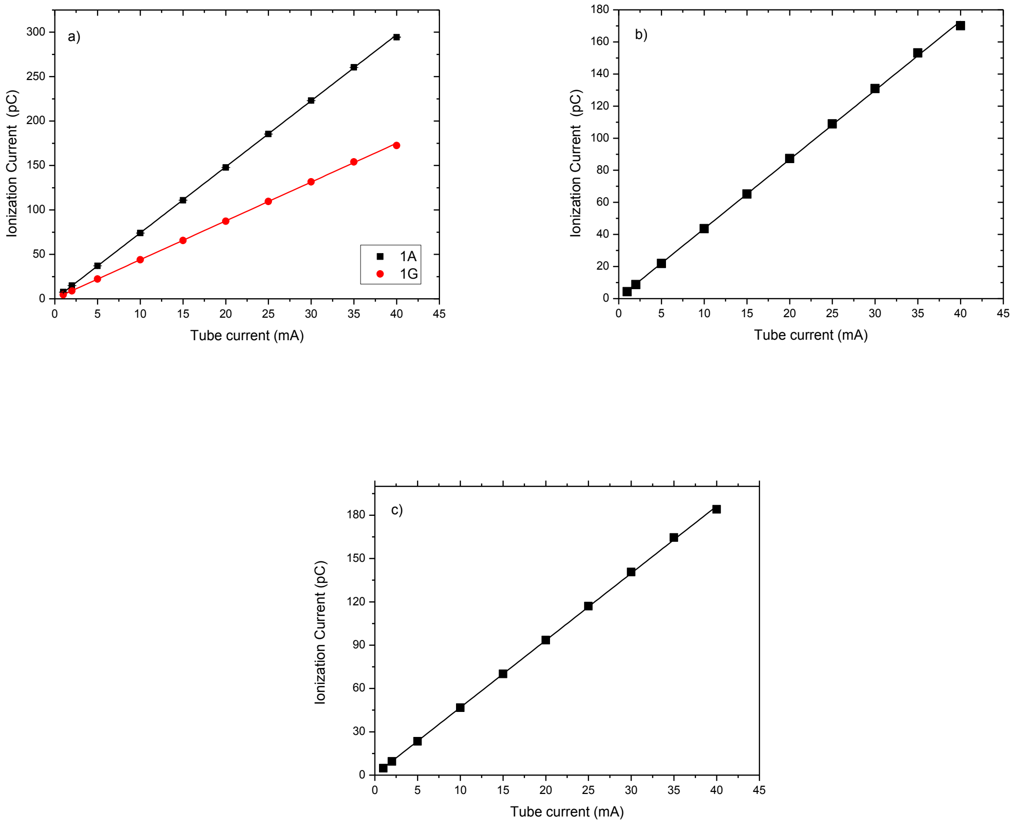

Figure 3 - Linearity of response of ionization chambers involved in this work: 1A, and 1G(a), 2 (b) and 3 (c) in X-ray beams with the mammography quality WMV28

3.7 - Angular Dependence

To determine the angular dependence of the response of the ionization chambers, they were subjected to the X-ray beam, of mammography quality WMV28, positioned each one on the goniometer with the entrance window centered at 100 cm from the focal point, with angles from -10° to + 10°, around the central axis, with intervals of 2°. The clockwise direction was considered negative and counter clockwise direction was considered positive. The results presented in Figure 4 show that the Chambers meet the recommendations of the standard IEC 61674 (1997), not presenting more than a variation of ± 3.0 % with respect to the measurement of the null angle of incidence.

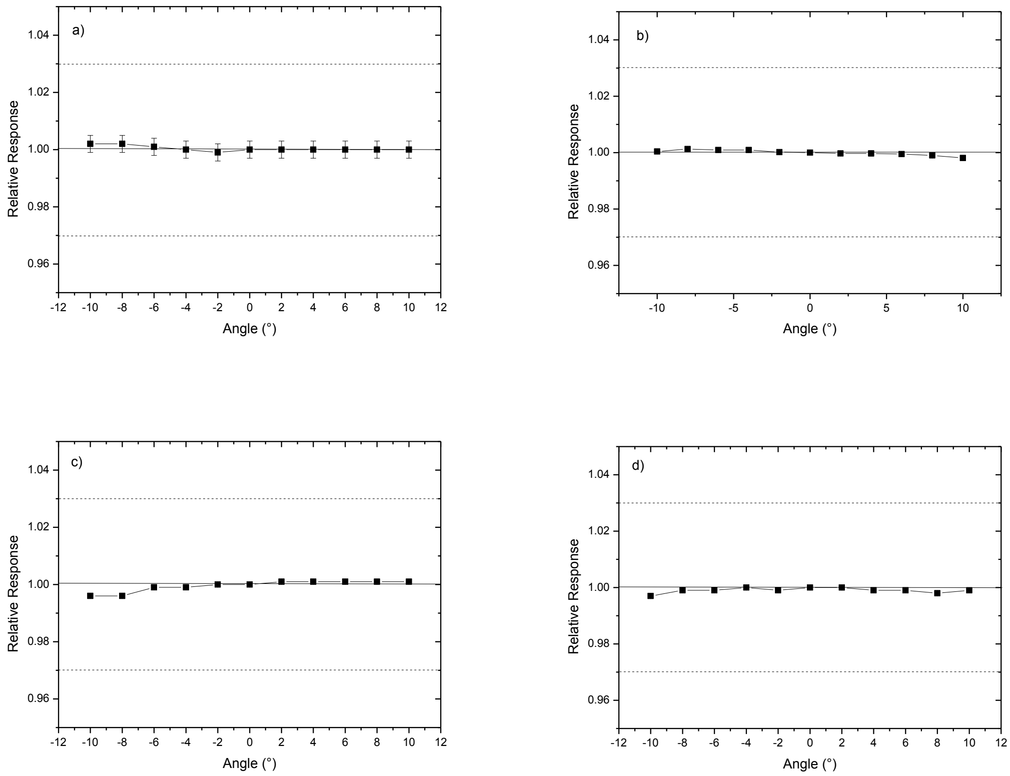

Figure 4 - Angle dependence of the response of Chambers 1A (a), 1G (b), 2 (c) and 3 (d) in X-ray beams with the WMV28 the quality of mammography. In Figures b, c and d, the uncertainties were always lower than 0.84 %, not visible in the graphs.

4. CONCLUSIONS

The ionization chambers were tested in standard mammography radiation fields established at the Calibration Laboratory of IPEN. The ionization chambers showed adequate response in all characterization tests, as response repeatability, response stability, saturation curves, polarity effect, ion collection efficiency, response linearity and angular dependence as specified in international standards. Therefore, the ionization chambers can be used as working standards for quality control programs of mammography beams.

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