Quality control methodology and implementation of X-radiation standards beams, mammography level, following the standard IEC 61267

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ABSTRACT

This study presents the results of the establishment of a quality control program developed and applied for the X-ray system of the Calibration Laboratory of IPEN. The X-ray standard beams, mammography level, using molybdenum and aluminum as additional filtration were established after the application of this quality control and the spectrometry of these qualities was made. The reference ionization chamber has traceability to the PTB. The radiation qualities RQR-M, RQA-M, RQN-M and RQB-M, following the recommendations of the IEC 61267 and the IAEA TRS 457 were established.

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1. Introduction

Mammography is the breast radiography, which allows premature breast cancer detection, by the fact that it is capable to show injuries in its initial stage INCA, 2010. It is made in an appropriate X-ray system, the mammography system. But to obtain premature and reliable diagnosis, it is necessary to guarantee that the mammography system is calibrated and working properly.

For this reason a good quality control of these equipments is very important, especially in terms of the radiation generated by them. This control must be done using a special ionizing chamber which must be calibrated as well as the X-ray equipment. The calibration of these instruments must be done periodically in a laboratory with proper devices.

In Brazil, there are just few laboratories which have mammography qualities established in their systems. One of these laboratories is the Laboratório de Calibração de Instrumentos (LCI) at IPEN, which has calibrated about 40 mammography ionizing chambers from 2009 to 2010. And it is important to highlight that this number means about 80% of this sort of ionizing chambers in Brazil.

With this information in mind, this study has been made to establish mammography qualities at LCI X-rays calibration system which has a tungsten (W) target according to the new international standard IEC 61267, "Medical diagnostic X-ray equipment—Radiation conditions for use in the determination of characteristics", by the IEC (2005), and the International Atomic Energy Agency (IAEA) code of practice, Technical Report Series No. 457, "Dosimetry in Diagnostic Radiology: An International Code of Practice" (IAEA, 2007).

Furthermore, it is expected to provide the necessary knowledge for future studies be developed in this area, since there are only few laboratories in Brazil that have mammography qualities established in their systems.

2. Materials and methods

The X-ray system used was a Pantak/Seifert, with a tungsten (W) target. The tube has an inherent filtration of 0.138 mm of aluminum and a window of 0.8 mm of beryllium. These characteristics have already been determined in previous studies (Franciscatto, 2009; Maia, 2005).

This equipment can generate voltages up to 160 kV. However this study used the voltages to mammography (25 kV, 28 kV, 30 kV and 35 kV). The current used was 10 mA, since this is the value for calibrations in diagnostic radiology.

It was used a 6 cm^3 ionizing chamber, RC6M for mammography from Radcal, with a thin window of Mylar$^®$. The electrometer used was a Keithley 6517A.

For the additional filtration aluminum (Al) and molybdenum (Mo) were used with 99.99% of purity. The aluminum filters have also been used to determine the half-value layer (HVL).

To determine the addition filtration using molybdenum filters, different thicknesses were tested until the correct filtration was found. This is obtained by making a measurement with and without the HVL. The correct thickness is found when the beam intensity is reduced to $(50+1.5)\%$. The same idea was used for the aluminum filters. The HVL used to check the additional filtration

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was presented by the primary standard dosimetry laboratory *Physikalisch-Technische Bundesanstalt* (PTB). Because of this, the same quality codes used by the PTB were also used here: WAV (aluminum as additional filtration) and WMV (molybdenum as additional filtration). The first letter (W) indicates the anode material (in this case, tungsten). The second letter (A or M) indicates the additional filtration material (aluminum or molybdenum, respectively).

To determine the air-kerma rate the Eq. (1) below was used

$$K = L_c \times F_{t,p} \times N_k \times k_Q \qquad (1)$$

In the Eq. (1), L_c is the measurement made using the electrometer, $F_{t,p}$ is the temperature and pressure correction factor, N_k is the chamber calibration coefficient and k_Q is the radiation quality coefficient.

With the WAV and WMV qualities established, the spectrometry was made so the beam behavior and the energy could be analyzed. This procedure was made using a portable Ortec NOMAD Plus spectrometer, Hyperpure Germanium (HPGe) for low energies. The calibration was made using Am-241 and the software used was Maestro®.

The spectrometer has been placed 2.5 m away from the anode. The beam was collimated and the current used was 0.1 mA.

To establish the qualities based on a phantom made up of an aluminum added filter (using the PTB code, WAH for aluminum and WMH for molybdenum) the same filtrations were used from the direct beams, but now, a 2 mmAl filtration was added. The air-kerma rates have been calculated using the same procedure presented previously.

For the narrow beam (WAN and WMN) and broad beam (WAB and WMB) qualities, the ionizing chamber was positioned 600 mm away from the tube and the phantom was used. The charge measurement has been made but it was not possible to determine the air-kerma rate because the chamber does not have traceability for these qualities. An important difference between these two qualities is that, in the first one, the phantom is placed between the anode and the ionizing chamber and the beam is well collimated. In the second case, the phantom is leaning against the chamber and beam is less collimated. The phantom used is presented by the IEC 61267. It consists of five plates with 5 mm of thickness each one, 120 mm of width and 80 mm of length.

3. Results

The thickness found for the additional filtration and air-kerma rate determined are shown in Tables 1 and 2.

Comparing the results it is possible to notice that the air-kerma rate is higher when an aluminum filter is used since

Table 1
Additional filtration (in mmAl and mmMo), k_Q and air-kerma rate found for each direct quality.

Quality	Nominal voltage (kV)	Additional filtration	k_Q	Air-kerma rate (mGy/min)
WAV 25	25	0.57 mmAl	0.999	23.2 ± 0.7
WAV 28	28	0.57 mmAl	1.000	31.0 ± 0.9
WAV 30	30	0.58 mmAl	1.001	35.6 ± 1.0
WAV 35	35	0.62 mmAl	1.002	45.8 ± 1.2
WMV 25	25	0.07 mmMo	0.9998	9.8 ± 0.3
WMV 28	28	0.07 mmMo	1.000	12.2 ± 0.4
WMV 30	30	0.07 mmMo	1.0003	13.8 ± 0.4
WMV 35	35	0.07 mmMo	1.001	18.0 ± 0.5

Table 2
k_Q and air-kerma rate found for attenuated beams with Al and Mo.

Quality	Voltage (kV)	Additional filtration		k_Q	Air-kerma rate (mGy/min)
		(mmMo)	(mmAl)		
WAH 28	28	0	0.57+2	1.000	3.0 ± 0.1
WAH 30	30	0	0.58+2	1.002	4.1 ± 0.1
WAH 35	35	0	0.62+2	1.009	7.2 ± 0.2
WMH 25	25	0.07	2	0.999	0.47 ± 0.01
WMH 28	28	0.07	2	1.000	0.67 ± 0.02
WMH 30	30	0.07	2	1.002	0.85 ± 0.02
WMH 35	35	0.07	2	1.009	1.47 ± 0.04
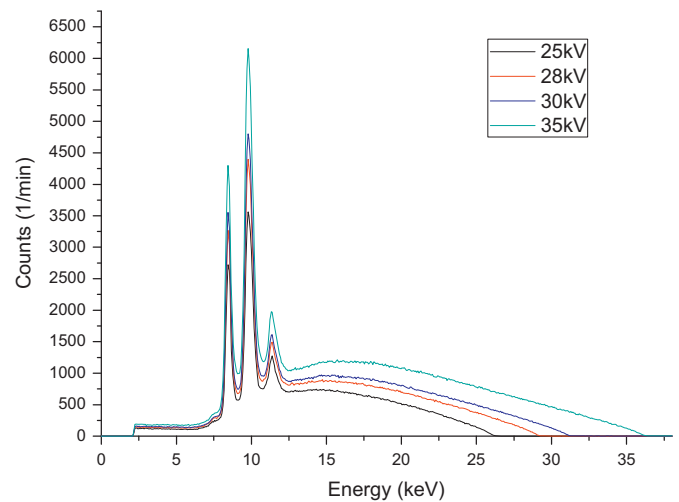
Fig. 1. Spectra of the X-ray system without additional filtration.

the molybdenum is much denser. The uncertainties have been calculated using the type A and type B and the combined and expanded uncertainties.

The spectra of these qualities had a characteristic behavior for the WMV qualities. Fig. 1 presents the spectra of this system without any additional filtration.

Fig. 2 show the spectra of WAV (black) and WMV (red) qualities.

In the qualities WMV a phenomenon identified as the k-edge effect was observed which the photon energy is the same as the k-layer electron binding energy. The photons with this energy are absorbed by the material. This quality is important considering the dose received by the patient. The molybdenum filter absorbs both low and high photon energy reducing patient doses.

For the attenuated beams, the air-kerma rate obtained is showed in Table 3 (for aluminum) and Table 4 (for molybdenum).

Table 3 shows the collected charges in WAN and WAB qualities (using aluminum as additional filtration).

Table 4 shows the collected charges in WMN and WMB (using molybdenum as additional filtration).

It is possible to note that, in both cases, the system collected less charges in the narrow beams qualities. This result was expected because in the broad beam qualities the chamber is also detecting the scattered radiation.
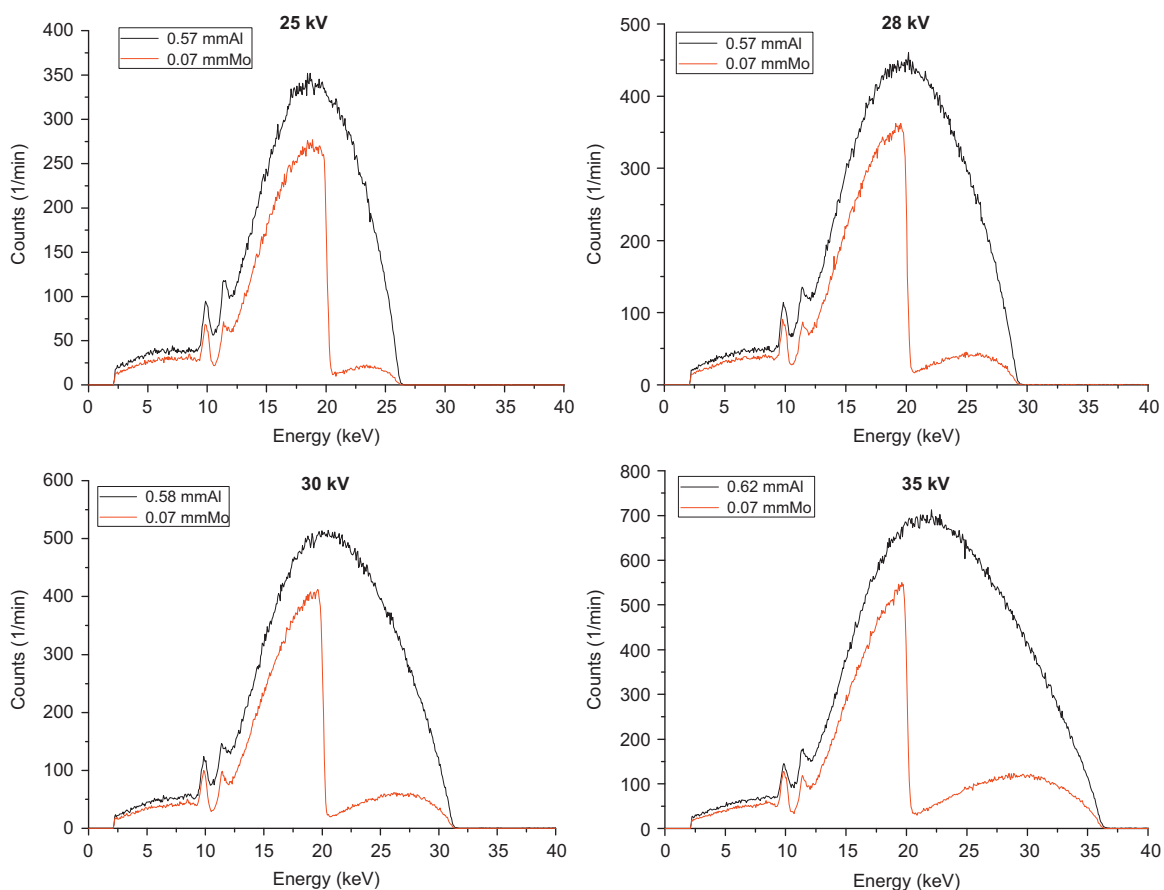
Fig. 2. Spectra of WAV (black) and WMV (red) qualities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Collected charges for WAN and WAB qualities.

Quality	Voltage (kV)	Additional filtration (mmAl)	Collected charges (pC/min)
WAN 25	25	0.57	208.8 ± 1.4
WAN 28	28	0.57	365.8 ± 1.2
WAN 30	30	0.58	487.2 ± 2.4
WAN 35	35	0.62	823.5 ± 5.0
WAB 25	25	0.57	787.5 ± 11.3
WAB 28	28	0.57	1401.3 ± 6.2
WAB 30	30	0.58	1880.7 ± 15.7
WAB 35	35	0.62	3234.9 ± 23.3

Table 4
Collected charges for WMN and WMB qualities.

Quality	Voltage (kV)	Additional filtration (mmMo)	Collected charges (pC/min)
WMN 25	25	0.07	61.2 ± 0.7
WMN 28	28	0.07	86.1 ± 0.6
WMN 30	30	0.07	107.1 ± 0.4
WMN 35	35	0.07	177.3 ± 0.8
WMB 25	25	0.07	229.7 ± 1.2
WMB 28	28	0.07	325.3 ± 2.7
WMB 30	30	0.07	407.8 ± 2.3
WMB 35	35	0.07	693.9 ± 4.9

4. Conclusions

The non-attenuated beams, WAV and WMV, have been established using both aluminum and molybdenum filtration, respectively. It is expected to provide not only more calibration options for the LCI clients and an appropriate calibration service but also knowledge, so new studies can be performed in this area.

Some problems have occurred in establishment of attenuated beams because the beam intensity reduction, after the insertion of the HVL, was close to the maximum edge. Just the WAH 25 quality could not be established.

Tests of the qualities that use the phantom were made. The results were within expectations with more charges being collected in the broad beam qualities. This is because, in this case, the chamber detected both direct and scattered beam.

The air-kerma rates were not calculated because the reference chamber has not been calibrated in these qualities. However, the other characteristics have been determined such as distance, filtration, voltage and collected charges.

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