Quality Control Tests in a Mammographic Unit Using a Homemade Ionization Chamber

Jonas O. Silva, Eduardo L. Corrêa, Vitor Vivolo, Maria da Penha A. Potiens, and Linda V. E. Caldas

***Abstract*—An important modality of radiation diagnosis is the mammography that is a diagnostic tool to detect breast cancer in an initial stage as well as the tumor localization for treatment. It is essential that the mammographic unit follows an accurate quality control program to assure the image quality, and patient and staff radiation protection. The ionization chambers play an important role in the quality control of mammographic units, because they are the reference detectors for calibration purposes. In this work a homemade double faced ionization chamber developed at IPEN, Brazil, was used to perform some quality control tests in a mammographic unit. All results obtained were within international recommendations.**

***Index Terms*—Ionization chamber, mammography, quality control, X-ray detection.**

I. INTRODUCTION

THE most common source of human radiation exposures comes from diagnostic radiology [1], but it brings benefits to patients undergoing these procedures. The examinations with ionizing radiations may show various characteristics of the disease for a correct medical procedure. An important modality of radiation diagnosis is the mammography that is a tool to detect breast cancer in an initial stage as well as the tumor localization for treatment [2]. In Brazil, the breast cancer is the second most incident cancer disease in women, and around 53,000 new cases are expected to happen in 2012/2013 period [3].

Mammography screening is performed on large numbers of predominantly asymptomatic women. It is essential that the mammographic unit follows an accurate quality control program to assure the image quality, patient and staff radiation protection. According to the most recent reports about global cancer control, a well-organized programme with a good compliance should lead to a reduction in breast cancer mortality of at least 20% in women aged over 50 [4]. In a mammography screening quality control program the dosimetry is essential for optimization purposes and should follow international protocols [5]. The interest quantity is the mean glandular dose, and it has been used to check the balance between the high image quality and the patient dose, obtained from the product of the measured incident air kerma and appropriate correction factors radiation spectra dependents [6], [7].

The ionization chambers play an important role in the quality control of mammographic units, because they are the reference detectors for calibration purposes [8]. Commercial available ionization chambers represent sometimes high cost for medium mammographic clinics in developing countries as Brazil. So, some Brazilian research centers as IPEN (Instituto de Pesquisas Energéticas e Nucleares) have assembled ionization chambers with low cost materials with no need of importation procedures for initial use in their metrology/calibration laboratories, in radiation protection, diagnostic radiology and radiotherapy energy ranges [9]–[11], within international requirements. These ionization chambers have been calibrated both for clinical and laboratory utilizations, presenting high metrological behaviour. In this work, a homemade double faced ionization chamber developed at IPEN, Brazil, was used to perform some quality control tests in a clinical mammographic unit and to compare its performance with that of a commercial ionization chamber. The advantage of the double faced chamber is that it presents different energy dependence behavior depending on the collecting electrode material, and this fact allows the determination of a tandem curve. This technique can be used to check routinely the beam quality specification without adding absorbers for the half-value layer determinations. In a previous work [12], the homemade double faced ionization chamber has already been tested in standard X-ray beams, and the tandem curve for diagnostic radiology beams was presented.

II. MATERIAL AND METHODS

The homemade double faced ionization chamber has two faces with different collecting electrode materials: aluminum and graphite. Each face of the chamber has a distinct energy dependence [12] that is important for beam quality verification/confirmation. Each side has an electrode separation of 2.7 mm and a collecting electrode radius of 2.67 cm resulting in a cavity sensitive volume of 6.0 cm^3. The distance between the sensitive volumes is around 5.1 cm, and as each sensitive volume is polarized separately, this distance does not cause any interference in the readings. This plane-parallel ionization chamber is a vented type, according to international recommendations [13]. The entrance windows of both faces are made of aluminized polyester with 1.87 $\mathrm{mg.cm^{-2}}$ of superficial density. The collecting electrodes are made of Poly(methyl methacrylate) (PMMA) with a layer of approximately 1.0 $\mu\mathrm{m}$ of aluminum and a thin graphite coating of approximately 0.35 $\mu\mathrm{m}$. To guarantee a uniform electric field in the sensitive volume, a guard ring made of PMMA with graphite coating was placed around the collecting electrode. This ionization

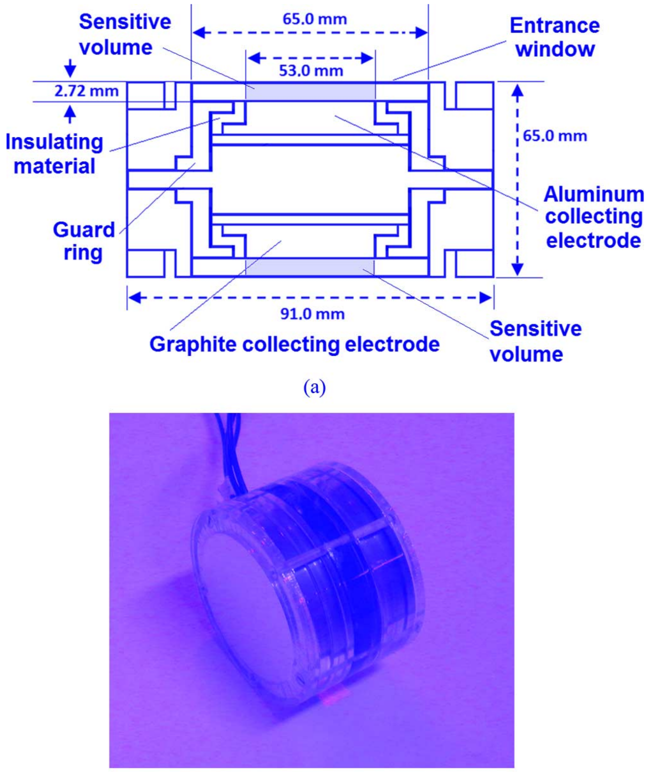
---

Manuscript received May 23, 2012; revised August 07, 2012; accepted August 24, 2012. Date of publication October 11, 2012; date of current version April 10, 2013. This work was supported in part by CNPq, CAPES, FAPESP and MCT (INCT for Radiation Metrology in Medicine).

The authors are with the Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear—IPEN—CNEN/SP, 05508-000 São Paulo, Brazil (e-mail: jonas.silva@ipen.br; educorrea1905@gmail.com; vivolo@ipen.br; mppalbu@ipen.br; lcaldas@ipen.br).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TNS.2012.2216548



(a)

(b)

Fig. 1. The homemade double faced ionization chamber presented (a) as a drawing and (b) as a photo.

(a) (b)

Fig. 2. (a) The reference ionization chamber and (b) the homemade double faced ionization chamber positioned at the irradiation system.

TABLE I
X-RAY OUTPUT REPEATABILITY MEASUREMENTS (%) USING THE IONIZATION CHAMBERS OF THIS WORK AT THE RADIATION QUALITY RQR-M2 (28 kVP AND MO/MO TARGET/FILTER COMBINATION)

Tube loading (mAs)	Ionization chamber Radcal 10X5-6M	Homemade ionization chamber with Aluminum electrode	Homemade ionization chamber with Graphite electrode
20	0.5	0.3	0.1
40	0.2	0.6	0.4
80	0.1	0.3	0.2

chamber is presented in Fig. 1. To perform the readings, each face of the double faced ionization chamber was connected to a PTW UNIDOS E electrometer sequentially, which provided the chamber face polarization too. During all experiments each face of the double faced ionization chamber was polarized independently with $+300\ \mathrm{V}$, and the charge from each sensitive volume was collected.

All results obtained with the double faced ionization chamber were compared with those from a Radcal 10X5-6M dedicated mammography ionization chamber, with a sensitive volume of $6.0\ \mathrm{cm}^3$. This ionization chamber was connected to a Radcal 9015 electrometer, and it was used as reference dosimeter. Both ionization chamber and electrometer were calibrated at the Calibration Laboratory at IPEN (LCI-IPEN).

The irradiations were undertaken using a Philips VMI Graph Mammo AF system with a molybdenum target and molybdenum/rhodium filters with thicknesses of 0.035 mmMo and 0.025 mmRh. This mammography unit has a kVp variation from 10 kVp to 35 kVp and a focus to breast support distance of 64.5 cm. Fig. 2 presents the irradiation system and the homemade double faced ionization chamber. The experimental setups for the quality control tests performed followed the IAEA report HHS No 2 [7], which recommends for all tests that the device should be centered in the X-ray field and aligned with the chest-wall edge of the breast support. This recommendation states that the center of the device sensitive volume should be at 40 mm from the chest wall, but it was noted previously at LCI that the highest incidence of radiation was around 50 mm from the chest wall; therefore this distance was utilized instead of 40 mm.

For the repeatability measurements of the beam output and its linearity the double faced ionization chamber was positioned 100 mm from the breast support in the radiation field. The compression paddle was removed for this test. The Mo/Mo target filter combination and 28 kVp in the manual mode were utilized. Three mAs values usually applied in clinical practice (20 mAs, 40 mAs and 80 mAs) were utilized. Five consecutive measurements were taken to obtain the mean values of the air kerma for each combination of tube voltage and loading. The beam output Y was determined by [7]

$$Y = \frac{\bar{K}_a}{\mathrm{mAs}} \tag{1}$$

where $\bar{K}_a$ is the mean air kerma value obtained for the corresponding mAs value. Using the output values obtained the beam output linearity was determined by [7]

$$L = 100\frac{(Y_1 - Y_2)}{(Y_1 + Y_2)} \tag{2}$$

where Y_1 and Y_2 are the output values at the respective mAs values. The normalized output was calculated from the product of the mean value of the output for the different mAs values and the distance correction factor for 1 m.

The half-value layers of the X-ray beams used in this work were determined with the compression plate localized around halfway between the X-ray tube focus and the ionization chamber, with its sensitive volume entirely into the radiation field. Several sheets of 0.1 mm of pure aluminum (99.99%) were utilized to estimate the HVL values; these sheets were placed on the compression paddle. The ionization chamber was

TABLE II
OUTPUT VALUES AND NORMALIZED OUTPUT VALUES OF RQR-M2 RADIATION BEAM QUALITY

Ionization chamber		Y [a] (µGy/mAs) Y_1	Y_2	Y_3	Normalized output (µGy/mAs at 1 m)
Radcal 10X5-6M		112.44 ± 6.41	114.05 ± 3.20	115.15 ± 1.60	41.00 ± 3.74
Chamber with	Aluminum electrode	145.80 ± 1.46	145.56 ± 1.45	146.22 ± 1.42	43.32 ± 1.44
	Graphite electrode	147.07 ± 1.47	148.19 ± 1.49	149.15 ± 1.45	44.00 ± 1.47

[a] Y_1, Y_2 and Y_3 are related to 20, 40 and 80 mAs, respectively.

positioned at different heights, corresponding to intermediary and thick breasts. The filter target combination used in this test was Mo/Rh, because the rhodium filter is suitable for thick breast examinations. Five measurements were taken for each filtration, and the mean values were considered. The HVLs were determined by [7]

$$HVL = \frac{t_2 ln\left[\frac{2\mathrm{M}_1}{\mathrm{M}_0}\right] - t_1 ln\left[\frac{2\mathrm{M}_2}{\mathrm{M}_0}\right]}{ln\left[\frac{2\mathrm{M}_1}{\mathrm{M}_2}\right]} \tag{3}$$

where M_0 is the mean value of readings obtained without any added filter, M_1 and M_2 are the readings respectively just above and just below 50% of M_0, and t_1 and t_2 are the thicknesses of the utilized filters. The HVL tolerance interval, in mm Al, was obtained by [7]:

$$\left(\frac{\mathrm{kVp}}{100}\right) + 0.03 \leq \mathrm{HVL} \leq \left(\frac{\mathrm{kVp}}{100}\right) + C$$

where $\mathrm{C} = 0.19$ for Mo/Rh [7] and kVp is the measured value for the selected nominal kVp.

III. RESULTS

A. *Beam Output Repeatability and Linearity*

The results for beam output repeatability, the normalized output value and the beam output linearity are presented in Tables I–III.

The beam output repeatability should be lower than 5% at 28 kVp and Mo/Mo [7]. In Table I it can be observed that the maximum value of the output repeatability is 0.6% for the homemade ionization chamber with aluminum collecting electrode. This value is within the requirement in the IAEA HHS No 2 report [7]. Although the sensitive volumes of both faces are identical, the repeatability data of the homemade ionization chamber with aluminum collecting electrode are significantly different from the data of the ionization chamber with graphite collecting electrode, due to the different energy dependence caused by the different materials [12].

In Table II are presented the results for the output values for each ionization chamber studied in this work. It can be seen that the output values of the homemade double faced ionization chamber with graphite collecting electrode follow the same behavior of the reference chamber, and that they are higher than the ones from the ionization chamber with aluminum collecting electrode. This occurs due to the difference between the collecting electrode materials. The results for the homemade ionization chamber were higher than the ones of the reference chamber, probably due to the geometrical difference (distance between collecting electrodes, radius of collecting electrodes) between the reference ionization chamber and the homemade ionization chamber that it is still under study. The normalized output should be higher than 30 $\mu\mathrm{Gy/mAs}$ at 1 m [7]. It can be seen in Table II that the normalized output obtained for the homemade ionization chamber fulfills the requirements given in [7]. All the uncertainties presented are the overall uncertainties with $k = 2$.

TABLE III
BEAM OUTPUT LINEARITY (L). L_1 IS RELATED TO Y_1 AND Y_2 AND L_2 IS RELATED TO Y_2 AND Y_3

Ionization chamber		L (%) L_1	L_2
Radcal 10X5-6M		0.71	0.48
Chamber with	Aluminum electrode	0.08	0.23
	Graphite electrode	0.38	0.32

It can be seen in Table III that the beam output linearity values were within the limit of 10% as recommended at the IAEA HHS No 2 report [7]. The values obtained using the homemade ionization chamber were similar to those obtained with the reference ionization chamber.

B. *Half-Value Layer (HVL) Measurements*

The HVL measurements results are presented in Table IV. As it can be seen, all HVL values determined for the ionization chambers used in this work are within the HVL tolerance interval [7]. The HVL values obtained increase with the tube voltage.

The energy dependence of the double faced ionization chamber studied in this work is presented in Table V in terms of calibration coefficients. These values were obtained by the calibration at the Pantak X-ray system at IPEN in mammography energy range.

As can be seen in Table V, the values for the aluminum collecting electrode are different from ones of graphite collecting electrode, because of their different energy dependence [12].

The homemade double faced ionization chamber was tested in terms of the leakage current. For both tests, pre- and post-irradiation, the leakage current was collected during an interval time of 20 minutes. The maximum values for the leakage current

TABLE IV
HVL MEASUREMENTS RESULTS USING THE REFERENCE CHAMBER AND THE HOMEMADE IONIZATION CHAMBER

Tube voltage (kVp)	HVL (mmAl) Radcal 10X5-6M	Aluminum electrode	Graphite electrode	HVL tolerance interval (mmAl)
29	0.446	0.476	0.438	0.32 ≤ HVL ≤ 0.48
30	0.457	0.487	0.444	0.33 ≤ HVL ≤ 0.49
31	0.465	0.497	0.452	0.34 ≤ HVL ≤ 0.50

TABLE V
CALIBRATION COEFFICIENTS AND CORRECTION FACTORS OF THE REFERENCE AND THE HOMEMADE IONIZATION CHAMBER IN MAMMOGRAPHY ENERGY RANGE

	Calibration coefficient (Gy/μC)		
Radiation quality	Radcal 10X5-6M	Aluminum electrode	Graphite electrode
WMV 25	4.770 ± 0.013	2.606 ± 0.025	4.444 ± 0.043
WMV 28	4.722 ± 0.012	2.587 ± 0.025	4.446 ± 0.043
WMV 30	4.753 ± 0.009	2.573 ± 0.025	4.427 ± 0.043
WMV 35	4.760 ± 0.012	2.504 ± 0.024	4.480 ± 0.043

TABLE VI
LEAKAGE CURRENT TEST FOR THE HOMEMADE DOUBLE FACED IONIZATION CHAMBER

Chamber collecting electrode	Pre-irradiation leakage current index (%)	Post-irradiation leakage current index (%)
Aluminum	0.10	0.28
Graphite	0.11	0.33

are presented in Table VI and do not exceed the recommended limit of 5% as stated in IEC 61674 standard [14].

IV. CONCLUSIONS

The homemade ionization chamber was tested in clinical mammographic radiation fields. These results were compared with those from a commercial ionization chamber. The new ionization chamber presented in this paper is made with low cost materials and all results obtained were within the IAEA specifications [7]. This ionization chamber may be used for routine verification of the quantities studied in this work. It may be applied in a quality control program at hospitals and calibration laboratories.

REFERENCES

[1] A. Meghzifene, D. R. Dance, D. McLean, and H.-M. Kramer, “Dosimetry in diagnostic radiology,” *Eur. J. Radiol.*, vol. 76, pp. 11–14, Oct. 2010.

[2] International Commission on Radiation Units and Measurements (ICRU), Mammography—Assessment of Image Quality, ICRU no. 82, 2009.

[3] Instituto Nacional de Câncer José Alencar Gomes da Silva (INCA), Estimativa 2012 Incidência de Câncer, Brasil, 2012.

[4] International Agency for Research on Cancer (IARC), World Cancer Report, 2008.

[5] D. R. Dance, K. C. Young, and R. E. Engen, “Further factors for the estimation of mean glandular dose using the United Kingdom, European and IAEA breast dosimetry protocols,” *Phys. Med. Biol.*, vol. 54, pp. 4361–4372, Jul. 2009.

[6] D. R. Dance, C. L. Skinner, K. C. Young, J. R. Beckett, and C. J. Kotre, “Additional factors for the estimation of mean glandular breast dose using the UK mammography dosimetry protocol,” *Phys. Med. Biol.*, vol. 45, pp. 3225–3240, Nov. 2000.

[7] International Atomic Energy Agency (IAEA), IAEA Human Health Series No 2—Quality Assurance Programme for Screen Film Mammography, IAEA HHS No. 2, 2009.

[8] International Commission on Radiation Units and Measurements (ICRU), Patient Dosimetry for X-rays Used in Medical Imaging, ICRU no. 74, 2005.

[9] V. Vivolo, “Development of a reference system for the determination of personal dose equivalent and the constancy of X-ray beams,” (in Portuguese) Ph.D. dissertation, Instituto de Pesquisas Energéticas e Nucleares, Universidade de São Paulo, São Paulo, Brazil, 2006.

[10] A. M. Costa and L. V. E. Caldas, “A special ionisation chamber for quality control of diagnostic and mammography X-ray equipment,” *Radiat. Prot. Dosim.*, vol. 104, no. 1, pp. 41–45, Apr. 2003.

[11] L. P. Neves, A. P. Perini, G. P. dos Santos, M. Xavier, H. J. Khoury, and L. V. E. Caldas, “Characterization of a homemade ionization chamber for radiotherapy beams,” *Appl. Radiat. Isotop.*, vol. 70, pp. 1291–1295, Jul. 2012.

[12] J. O. Silva and L. V. E. Caldas, “A double faced ionization chamber for quality control in diagnostic radiology beams,” *Appl. Radiat. Isot.*, vol. 70, pp. 1424–1428, Jul. 2012.

[13] International Atomic Energy Agency (IAEA), Dosimetry in Diagnostic Radiology: An International Code of Practice, IAEA TRS no. 457, 2007.

[14] International Electrotechnical Commission (IEC), Medical Diagnostic X-ray Equipment. Medical Electrical Equipment—Dosimeters with Ionization Chambers and/or Semi-Conductor Detectors as Used in X-ray Diagnostic Imaging (Standards Style), IEC 61674, 1997.