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# PRELIMINARY RESULTS ON CHARACTERIZATION TESTS OF A FREE-AIR CHAMBER

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## ABSTRACT

Free-air chambers are widely used in radiation metrology laboratories as primary standards for air kerma in the range of low and medium x-ray energies. There are two types of free-air ionization chambers: the parallel-plate type and the cylindrical type. The first one is used as primary standard at laboratories as the NIST, BIPM and NPL. The cylindrical type, on the other hand, is used in the standard calibration laboratories of Germany, Italy and Taiwan**.** In 1961, Attix proposed a design of a cylindrical free-air ionization chamber with a variable length presenting some advantages over the fixed-length design. The Instituto de Pesquisas Energéticas e Nucleares (IPEN) has a Victoreen chamber, model 481, based on this design for x-ray energies up 50 keV. The objective of this study is to investigate the possibility of using this chamber as a primary standard of air kerma in the Calibration Laboratory of IPEN. In this work are presented the preliminary results of the characterization tests of the free-air ionization chamber: leakage current, stability of response, saturation curve, collection efficiency, response linearity and response linearity with the cylinder displacement.

## 1. INTRODUCTION

The primary standard dosimetry laboratories use free-air ionization chambers for the realization of the units of air kerma and exposure in low and medium energy X-ray beams. [1] Two different types of free-air chamber are employed in these laboratories: parallel-plate type and cylindrical type. The parallel-plate type is used at the National Institute of Standards and Technology (NIST, USA), the Bureau International des Poids et Mesures (BIPM, France) and the National Physical Laboratory (NPL, UK)[2]. The cylindrical l type is used at the Physikalisch-Technische Bundesanstalt (PTB, Germany), the Ente per le Nuove Tecnologiel'Ambiente (ENEA, Italy)[3] and the Institute of Nuclear Energy Research (INER, Taiwan)[4].

The cylindrical free-air ionization chamber with a variable length design was proposed by Attix in 1961[5,6]. This type of ionization chamber has significant advantages over fixed-length free-air chambers. The main advantages are [2,7,8]:

(a) Since the collection rod extends the entire length of the cylinders, the collecting region is the entire volume inside the cylinders. Therefore, there is no need of guard electrodes and plate alignment to confine the collection volume.
(b) There is no need of a correction factor for electric field distortion since this effect does not interfere with the operating principle of the chamber.

(c) The movement of the cylinders is made with precision equipment. Thus, the air mass can be more accurately defined.

The cylindrical free-air ionization chamber proposed by Attix is based upon a subtraction method in which two readings of the ionization are taken and the difference is used to determine the air kerma quantity. The principle is simplified and shown in Fig. 1 and Fig. 2.

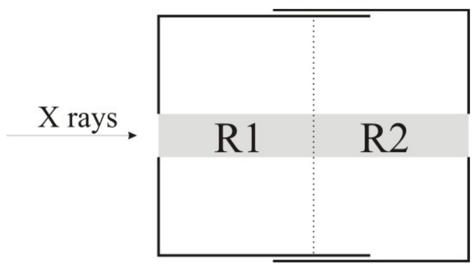


**Figure 1: Simplified diagram of the cylindrical free-air chamber in collapsed position. The interaction of photons with air occurs at regions R1 and R2.**

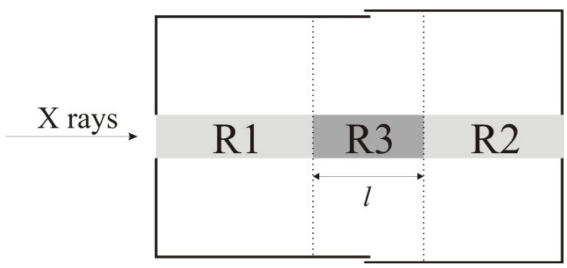


**Figure 2: Simplified diagram of the cylindrical free-air chamber in expanded position. The interaction of photons with air occurs at regions R1, R2 and R3.**

The two readings made with the chamber on the collapsed and expanded positions, are realized with a fixed center point. The charge collected on the first reading arises from the interaction of photons on the regions R1 e R2 (Fig.1).When the chamber is expanded by a length *l*, a third region (R3) is created on the sensitive volume (Fig. 2). The subtraction of the charges obtained gives the charge produced at R3, since R1 and R2 remain constant. The increase on the photon interactions at R1, when the cylinders are displaced, is compensated by a proportional reduction at R2.

The Instituto de Pesquisas Energéticas e Nucleares (IPEN), São Paulo, Brazil, has the Calibration Laboratory of Instruments (LCI) that performs calibration of radiation dosimeters used on radiotherapy, diagnostic radiology and nuclear medicine. In order of improve the calibration service, several research projects are constantly in progress. There is, at this laboratory, a Victoreen cylindrical chamber, model 481, with a variable length. This chamber can be used for X-ray beams up 50 kV. A study has been made for the implementation of this chamber as a primary standard of the air kerma quantity for beams qualities used on mammography and radiotherapy calibration. This paper presents the preliminary results on the characterization tests of the free-air ionization chamber.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The environmental conditions were controlled utilizing a thermometer, an hygrometer, a barometer and dehumidifiers.

The radiation system used at the Calibration Laboratory of Instruments is a Pantak-Seifert, Isovolt 160HS, with a tungsten target. The high tension varies between 5 kV and 160 kV. At this system were established diagnostic radiology, radiotherapy and mammography standard qualities.[9]

The Victoreen free-air ionization chamber, model 481, used in this study is a cylindrical type based on the Attix design with a variable length and a center fixed point. Because of its dimensions, the chamber can be only used for X-ray beams up 50 kV. Figure 3 shows the chamber without its shield.

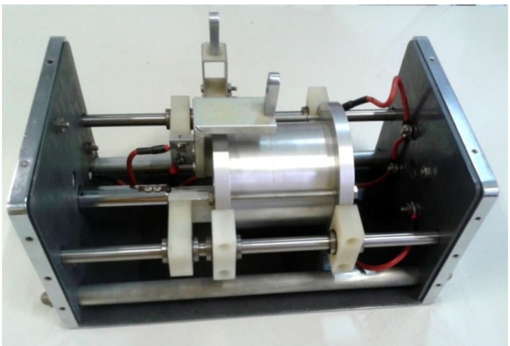

**Figure 3: Free-air ionization chamber Victoreen, model 481, without the shield**

The high voltage power supply is from Victoreen and accompanies the free-air chamber (Fig. 4). The voltage varies from 0 to 5000 V. For the charge collection an electrometer Keithley, model 6517A (Fig. 5), was utilized.

**Figure 4: High voltage power supply Victoreen**

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**Figure 5: Electrometer Keithley, model 6517A**

## 2.2. Methods

This section presents the methods used on the characterization tests. All tests were made with the standard mammography quality WAV28 [9,10], at the distance of 1 m of the focal spot of the X-ray tube and using the beam collimator with 50.8 mm of diameter. The chamber was maintained in its collapsed position. Table 1 presents the technical parameters of the standard quality WAV28.

**Table 1: Technical parameters of the standard mammography quality WAV 28**

| | |
|---|---|
| X-ray tube voltage | 28 kV |
| X-ray tube current | 10 mA |
| Added filtration | 0.57 mmAl |

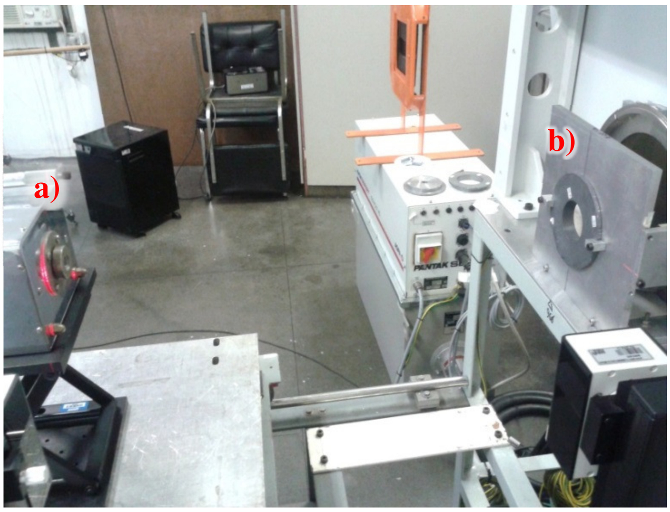


**Figure 6: Free-air ionization chamber positioned at 1 m from the focal spot of the X-ray tube. a) Free-air ionization chamber; b) Collimator**

### 2.2.1. Leakage current

The leakage current test evaluates the influence of this effect on the free-air chamber response. The test was made observing the variation on the measurements during 20 min. The leakage current was obtained through Equation 1.

$$I_l = \frac{\Delta Q}{t}, \qquad (1)$$

where $\Delta Q$ is the charge variation and $t$ is the time in seconds.
According the IEC 61674 (1997) [11], the leakage current shall not exceed 5.0% of the minimum measurement obtained during an irradiation time of at least 1 minute.

### 2.2.2. Stability of response

The stability tests were made observing the repeatability of the measurements. Ten measurements of 30s each were taken, at different days. A voltage of 1 kV was applied to the free-air chamber.

According to IEC 61674 (1997), the coefficient of variation of the measurements shall not exceed 3.0%.

### 2.2.3. Saturation curve

From the saturation curve the voltage that minimizes the recombination effects is determined. For this test 3 measurements were taken for each voltage applied to the chamber cylinders.

The voltage was varied between 100 V and 1000 V in steps of 100 V. This test was made with the chamber on its collapsed and expanded positions.

### 2.2.4.Ion recombination factor

The ion recombination factor was determined utilizing the saturation curve data by means of the two voltage method [12], defined by the Equation 2:

$$k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)}, \qquad (2)$$

where $V_1$ is the voltage usually applied to the chamber, $V_2 = V_1/2$ , $M_1$ and $M_2$ are the charges measured with $V_1$ and $V_2$, respectively.

### 2.2.5. Response linearity

The response linearity test is used to verify if the response of a dosimeter is linear with the variation of the dose rate. For this test, the tube current was varied between 2 mA and 35 mA. The filtration and the tube voltage were maintained constant. Three measurements were taken for each current.

### 2.2.5. Response linearity with the volume displacement

Since the air kerma is calculated by means of the variation of the sensitive volume, it is important to know if the response is linear with the cylinder displacement. Each measurement was taken increasing 1 cm on the cylinder length, 0.5 cm per cylinder. The charge collected at each volume was normalized for the collapsed position.

## 3. RESULTS

### 3.1. Leakage current and stability tests

The highest leakage current obtained was 0.2% of the measurement obtained during 1 min of irradiation. The repeatability test presented a maximum coefficient variation of 1.9%. The results obtained at both tests are in accordance with IEC 61674 (1997).

### 3.2. Saturation curve

The saturation curves of the expanded and collapsed chamber (Fig. 7 and Fig. 8) show that the saturation occurs at 300 V. Thus, any voltage greater than 300 V can be used for the chamber operation at both positions, collapsed and expanded. The voltage chosen for the tests was 1000 V.

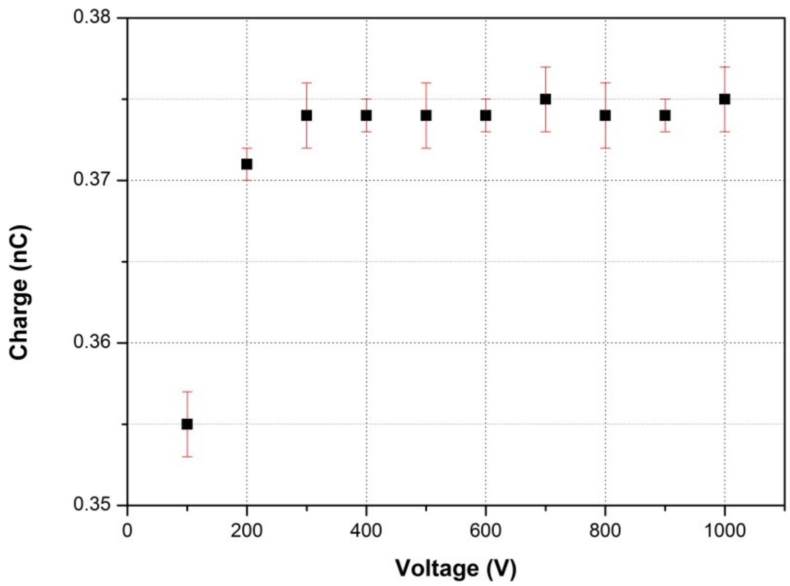


**Figure 7: Saturation curve of the free-air ionization chamber on its collapsed position**

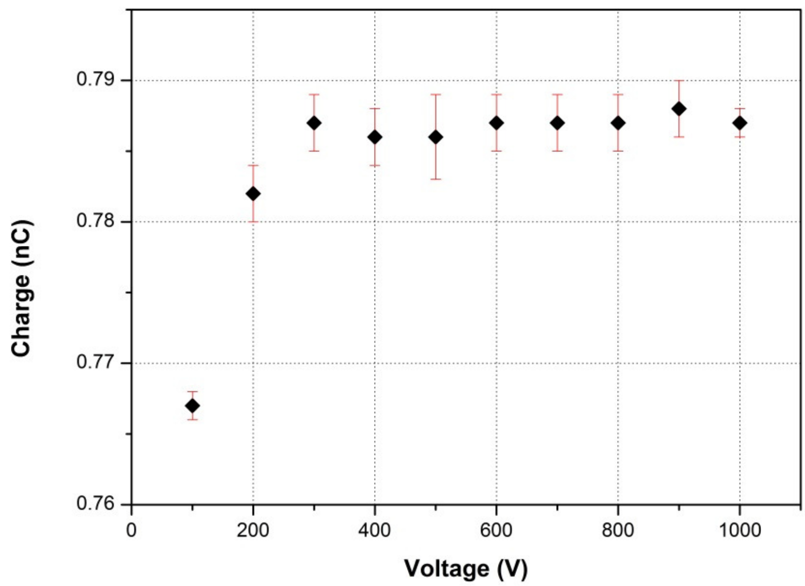


**Figure 8: Saturation curve of the free-air ionization chamber on its expanded position**

### 3.3. Ion recombination factor

Table 2 shows the recombination factors of the free-air ionization chamber for 600 V, 800 V and 1000 V. The collection efficiency obtained was 99,9 % for the studied voltage range.

**Table 2: Ion recombination factors**

| Voltage | $k_s$ |
|---|---|
| 600 V | 1.001 ± 0.007 |
| 800 V | 1.001 ± 0.006 |
| 1000 V | 1.000 ± 0.007 |

### 3.4. Response linearity

The response linearity is presented in Fig. 9. The linear correlation coefficient ($R^2$) for the curve was 0.999, demonstrating a satisfactory behavior of the ionization chamber with the increase of the dose rate.

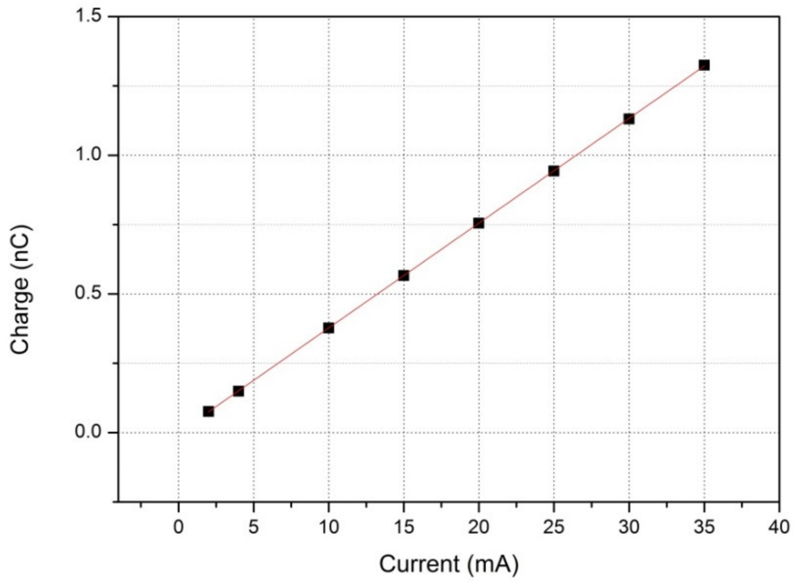


**Figure 9: Response linearity of the free-air ionization chamber. The uncertainties were lower than 2%, not visible in the figure.**

### 3.4. Response linearity with the cylinder displacement

The linearity with the volume displacement was verified in Fig. 10, where $Q_0$ is the charge collected at the collapsed position and Q is the increment due to the variation on volume. Thus, any volumes can be used to determine the air kerma quantity.

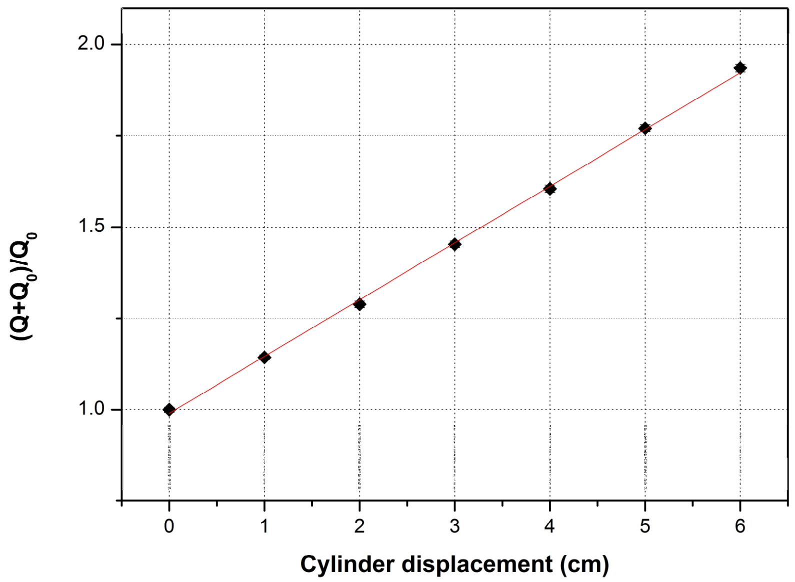


**Figure 10: Response linearity with the cylinder displacement. Q is the charge increment due to the variation volume and $Q_0$ is the charge collected at the collapsed position. The uncertainties were lower than 1%, not visible in the figure.**

## 4. CONCLUSION

The results obtained show a satisfactory performance of the free-air ionization chamber when utilized in the standard X-ray beams of mammography. The study of the long term stability is in progress, and is not shown, because it needs a period of at least six months. The saturation curve and the ion recombination test show that any operational voltage greater than 300 V can be applied at the collapsed and expanded chamber positions for a good efficiency on charge collection. The voltage chosen for the tests was 1000 V. The response linearity with the cylinder displacement demonstrates the ability of utilizing any cylinder displacement for the air kerma determination. All results are in agreement with international reports.

## ACKNOWLEDGMENTS

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