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Characterization of a free air ionization chamber for low energy X-rays

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Abstract. Free air ionization chambers are used by most primary metrology laboratories as primary standards of the quantities air kerma and exposure in X-ray beams. The free air ionization chamber for low energies of the Calibration Laboratory (LCI) of IPEN showed in a characterization test a problem in the set responsible for the variation of its sensitive volume. After a modification in the support of the micrometers used for the movement of the internal cylinder and the establishment of a new alignment system protocol, the tests were redone. The objective of this work was to present the results obtained in the new condition.

1. Introduction

Most of the primary standard calibration laboratories use the free air ionization chambers as primary standards of the quantities air kerma and exposure to X-ray beams of low and medium energies [1].

The free air ionization chambers do not possess a material in the chamber entry window as in other ionization chambers, thus the primary photons and secondary electrons interact only with the air in the sensitive volume [2]. There are different types of free air ionization chambers; the model most used is the free air ionization chamber with parallel plates (called also conventional model) and the free air ionization chamber with concentric cylinders [3].

The ionization chamber with cylinders, proposed by Attix in 1961, allows the variation of the sensitive volume lenght. The movement of the cylinders is performed with a high precision equipment that allows a precise determination of the air mass and consequently of the exposure and air kerma values. In this case, the independence of the response to the uniformity of the electric field within the sensitive volume eliminates the need for guard rings, required in the case of the parallel plate model. Once the collecting electrode extends throughout the sensitive volume, the collection region is across the internal volume of the cylinder [4].

The Calibration Laboratory (LCI) of the Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP) has a free air ionization chamber of the cylindrical type for low energies. A first characterization of this ionization chamber was already performed and reported in a previous study. These tests showed good results for the chamber, except in the volumetric response linearity test [6]. After a modification in the support of the micrometers used for the movement of the internal cylinder devices, the tests were redone using a new alignment protocol described in a previous report [7]. The objective of this work is to present the new results of characterization tests in the new condition.

2. Materials

The free air ionization chamber utilized was of the cylindrical type, Victoreen, model 481.

An X-ray equipment, Pantak/Seifert, model ISO - VOLT 160 HS, operating between 5 kV and 160 kV, was utilized in this work. The standard radiation quality of the mammography beam used in the tests was RQR-2M, with the following characteristics: additional filtration of 0.07mmMo, half value layer of 0.37mmAl, 28kV and 10 mA. Formatting the title

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3. Results and Discussion

3.1. Stability Tests

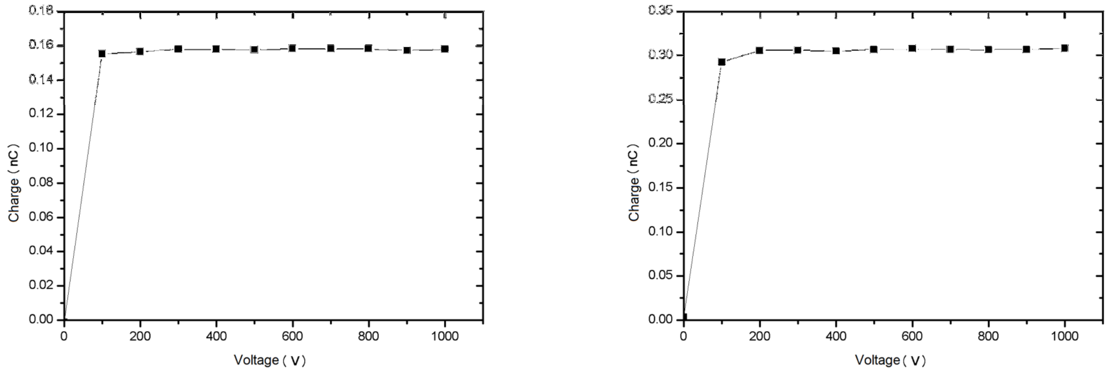
The results on the repeatability tests were within the limit recommended, by the standard IEC 61674 [8], which is 1.0%; the highest value obtained was 0.7 %. Long-term stability was observed with the results obtained in the repeatability tests over a period of three months. According to the IEC 61674 [8], the maximum variation on the measurements results should be 2.0%; the highest value obtained was only 0.5 %.

3.2. Characterization Tests

The results obtained for the characterization tests include: saturation curve, ion collection efficiency, polarity effect, the linearity response with the X ray tube current and linearity of response to the volume variation.

3.3. Saturation curve

As the free air ionization chamber of cylindrical type requires two measurements to obtain the air kerma, two saturation curves must be obtained: one with the smallest possible length of the sensitive volume (collapsed position) and the other with the greatest possible length of the sensitive volume (expanded position). Figure 1 shows the curves obtained in these cases.



(a) (b)

Figure 1. Saturation curves of the free air ionization chamber in the (a) collapsed position; (b) expanded position.

3.4. Ion collection efficiency

The ion collection efficiency was determined through data obtained from the saturation curve in the extended position for the voltages of 400V, 600V, 800V and 1000V, using the equation (1) [9].

$$k_s = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \quad (1)$$

where k_s is the correction factor for ion recombination, V_1 is the voltage used in measurement M_1 and $V_2 = V_1/2$ with its measurement M_2. Table 1 shows the values obtained.

The IEC 61674 [8] states that the ion collection efficiency should be greater than or equal to 95% and the IEC 60731 standard [10] recommends a minimum of 99.0%. Observing the table 1, it can be concluded that the results obtained are in accordance with both standards.

Table 1. Ion collection efficiency and the correction factors for ion recombination at different voltages.

Voltage (V)	Efficiency (%)	ks
400	99.67	1.0033
600	99.95	1.0005
800	99.98	1.0002
1000	99.95	1.0005

3.5. Polarity effect

For the polarity effect, measurements for the saturation curve were taken by varying the voltage from + 1000V to -1000V, with intervals of 100V. The curve obtained is presented in Figure 2.

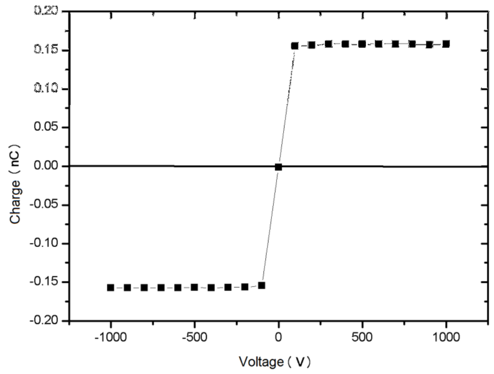


Figure 2. Saturation curve obtained of the free air ionization chamber in the collapsed position for the voltage in both polarities. The maximum uncertainty of the measurements was 0.5%, not visible in the graph.

According to IEC 60731 [10], the variation of the responses obtained by the ratio between the charge collected by the positive polarity and the charge collected by the negative polarity should not be higher than 1.0%. All values were obtained according to this recommendation: the maximum variation was 0.74%.

3.6. *Linearity of response with the current variation in the tube*

In this test the current in the X-ray tube was varied between 5 mA and 35 mA, keeping constant the voltage and the additional filtration of the RQR-2M quality. In figure 3 the resulting curve can be observed. The measured ionization charge was normalized for the result obtained at 5 mA of tube current.

The linear correlation coefficient (R^2) was obtained equal to 0.9999, showing the linearity of the response with the X ray tube current.

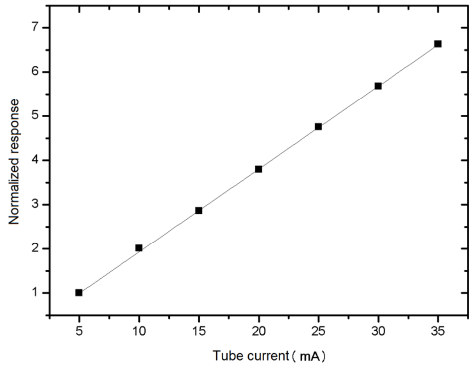


Figure 3. Linearity of response with the X ray tube current variation. The maximum uncertainty of the measurements was 0.4%, not visible in the graph.

3.7. Linearity of response with the volumetric variation

This test was performed by increasing the length of the sensitive volume of 1 cm each time, until 6 cm. This test allows the verification of another volumetric variation to be used for determining the air kerma, since this quantity shall be estimated by means of two measurements from different volumes. Figure 4 shows the results.

The linear correlation coefficient (R^2) was obtained equal to 0.9999, showing the linearity of the response to the variation in the sensitive volume length.

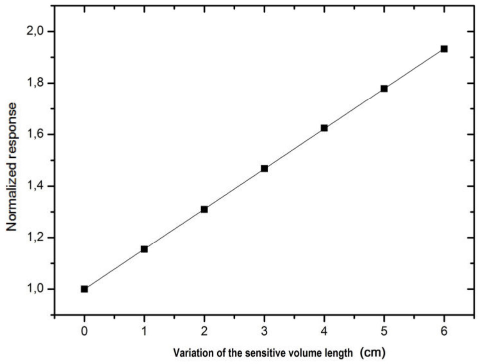


Figure 4. Linearity of response to the variation of the sensitive volume length of the ionization chamber.

4. Conclusions

In this work the characterization test results of a free air ionization chamber are presented using standard mammography X-ray beams of low energy. These results correspond to the expected ones, showing a proper functioning of the ionization chamber. Therefore, the modification of the micrometer set and the new alignment protocol have corrected the problem obtained in the response linearity test with the volumetric variation.

From the results of the ion collection efficiency test, it was also possible to determine the correction factors for ion recombination at voltages of 400V, 600V, 800V and 1000V.

5. Acknowledgments

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