A new ring-shaped graphite monitor ionization chamber

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Abstract

A ring-shaped monitor ionization chamber was developed at the Instituto de Pesquisas Energéticas e Nucleares. This ionization chamber presents an entrance window of aluminized polyester foil. The guard ring and collecting electrode are made of graphite coated Lucite plates. The main difference between this new ionization chamber and commercial monitor chambers is its ring-shaped design. The new monitor chamber has a central hole, allowing the passage of the direct radiation beam without attenuation; only the penumbra radiation is measured by the sensitive volume. This kind of ionization chamber design has already been tested, but using aluminium electrodes. Changing the electrode material from aluminium to a graphite coating an improvement in the chamber response stability is expected. The pre-operational tests, as saturation curve, recombination loss and polarity effect showed satisfactory results. The repeatability and the long-term stability tests were also evaluated, showing good agreement with international recommendations.

Key words: monitor chamber, X radiation, graphite chamber

1. Introduction

Ionization chambers are the most utilized radiation detectors. They are simple, supply online response and, depending on their material, design or volume, they may be used for a great variety purposes.

One special type of ionization chamber is the monitor chamber. These kinds of chambers are used whenever the X-radiation beam intensity may vary due to power supply instabilities. In radiotherapy treatments as well in diagnostic radiology procedures these ionization chambers are used to assure the correct patient exposure and they are mounted at the X-ray tube exit [1, 2]. In calibration laboratories these chambers are used to correct any variation in the standard radiation beams intensity during the calibration.

At the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares (IPEN), a ring-shaped monitor chamber was already developed and tested, showing good results [3]. This ionization chamber was designed (with aluminium collecting electrodes) to be used as a monitor chamber for diagnostic radiology X-ray beams.

The objective of this work was to assemble a new ring-shaped monitor chamber, with graphite collecting electrodes, to improve the performance of this chamber type. Pre-operational tests were performed to characterize this new monitor chamber.

2. Materials and Methods

The new ring-shaped graphite ionization chamber, developed at IPEN was manufactured using graphite coated PMMA, aluminized polyester foil (for the entrance window) and co-axial cables.

An electrometer, Physikalisch-Technische Werkstätten (PTW), Germany, model UNIDOS was used as an associated measuring assembly.

An X-ray unit, Pantak/Seifert. model ISOVOLT 160HS, was utilized to perform the pre-operational tests. Standard radiation qualities, specified in IEC 1267 [4], were established in this equipment,

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and the diagnostic radiology quality RQR 5 was used in all tests presented in this work.

The response stability tests (repeatability and long-term stability) were performed using a $^{90}Sr+^{90}Y$ check source device, PTW, model 8921, with nominal activity of 33 MBq, 1994. This source was positioned at a PMMA holder, which has 4 different positions for the check source.

3. Results

The ring-shaped graphite monitor chamber developed at IPEN has a thin entrance window of aluminized polyester foil; its electrodes are graphite coated PMMA plates connected to a coaxial cable. The whole chamber body is made of PMMA, which is an easy-handy material. This ionization chamber is to be used as a monitor chamber in X-radiation fields with no interference in the direct beam. Therefore, it presents a 7 cm-diameter central hole. A schematic diagram and a photograph of the chamber can be seen in Figures 1 and 2, respectively.

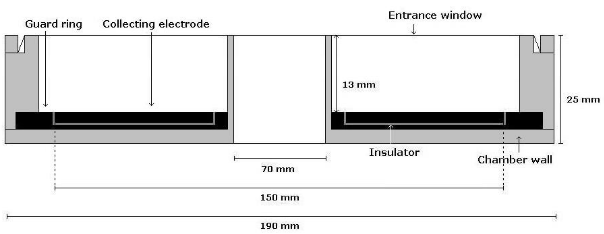

Figure 1: Schematic diagram of the ring-shaped graphite monitor chamber.

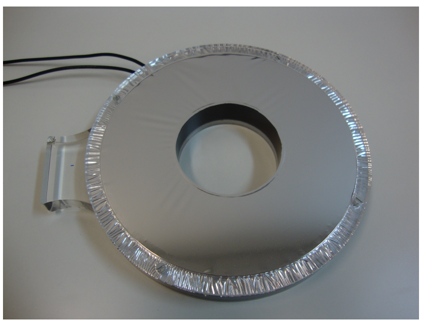

Figure 2: Ring-shaped graphite monitor chamber.

Not only the electrode material was changed (from aluminium to graphite) in this new ring-shaped chamber, but also the diameter of the central hole was increased from 6 to 7 cm.

Several tests were performed to characterize the new ring-shaped ionization chamber: saturation curve, ion collection efficiency, polarity effect, linearity of response, leakage current and the response stability tests (repeatability and long-term stability).

3.1. *Saturation curve, ion collection efficiency and polarity effect*

The saturation curve was obtained by applying different voltages to the ionization chamber. An interval from $-400\,V$ to $+400\,V$ was applied in steps of $\pm 50\,V$. As can be seen in Figure 3, the chamber response achieves saturation in the whole voltage interval.

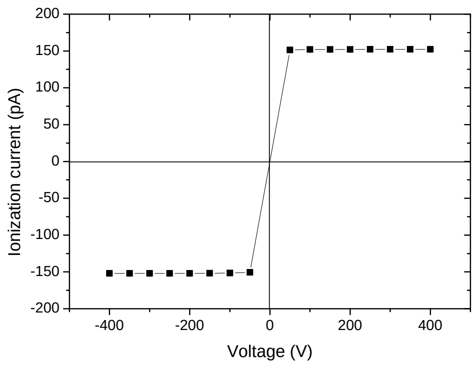

Figure 3: Saturation curve of the ring-shaped ionization chamber.

From the saturation curve, the polarity effect and the ion collection efficiency were determined. The polarity effect comprises the comparison between the measured currents at same voltages of opposite signals. For the voltage interval studied, the polarity effect was less than 0.4%, therefore within the recommended limit of 1% [5]. The two-voltage method [2] was used to determine the ion collection efficiency. For the voltages of $-300\,V$ and $-150\,V$, the efficiency of ion collection was better than 99%; the operational voltage chosen for the ionization chamber was $-300\,V$.

3.2. *Linearity of response*

Using the X-ray unit, the graphite ionization chamber was exposed to several air kerma rates, from

26.0 to 2088.6 $mGy.min^{-1}$. For this test, the voltage was fixed at 70 kV while the nominal current was varied from 0.5 to 40.0 mA. Figure 4 shows that the response is linear for the whole air kerma rate range studied, with a maximum uncertainty of 0.02%.

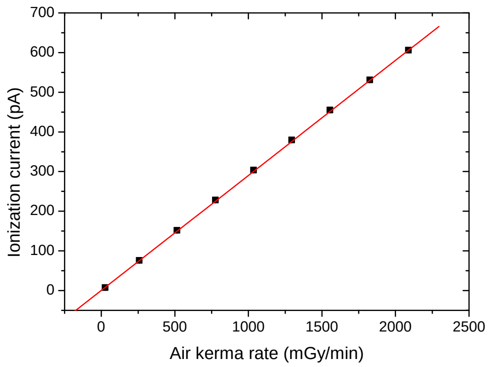

Figure 4: Linearity of the graphite monitor chamber response.

3.3. *Stability tests*

The response stability tests were performed using a $^{90}Sr + ^{90}Y$ check source device. This source was positioned at a PMMA holder, which has 4 different positions for the check source. These positions are regularly arranged on the chamber sensitive volume. The check source holder is showed in Figure 5.

Figure 5: Photography of the check source device positioned at the PMMA holder (position 1) on the monitor chamber.

3.3.1. *Repeatability test*

The repeatability test consists on the analysis of ten consecutive charge collection measurements. The standard deviation of these measurements shall not vary more than 3%, according to international recommendations [5]. In this work, 14 repeatability tests were performed for each of the four positions, during one month, and the maximum deviation was only 0.4%. This same result was obtained for the ring-shaped aluminim chamber [3]

3.3.2. *Long-term stability*

Evaluating the repeatability tests over a time period, the long-term stability of the chamber response can be determined. A baseline can be obtained from the first ten measurements of the repeatability test. The measurements are normalized to the mean value of these first ten measurements to facilitate the analysis. In Figure 6 the long-term stability of the monitor chamber response (taking measurements at position 1) is showed. The chamber response on the other 3 positions were similar to this one, as can be seen in Table 1.

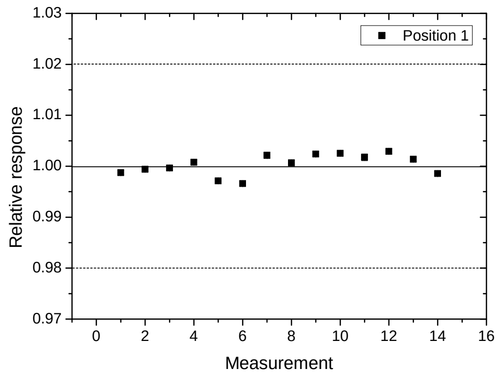

Figure 6: Long-term stability test of the ring-shaped monitor chamber (measurements taken at position 1 of the PMMA holder).

The dashed lines in Figure 6 show the recommended limits of ±2% of response variation in a period of one year [5]. As can be seen, the graphite monitor chamber presented a response variation lower than 0.5%. Comparing to the aluminium chamber response variation (0.7%)[3], the new graphite chamber achieved a better response stability.

3.3.3. *Response stability for X raditaion*

The repeatability and long-term stability tests were also performed utilizing X-radiation beams, during two weeks.

Table 1: Long-term stability test considering the four positions of the PMMA holder.

Position	Mean value (pA)	Standard deviation (%)
1	121.32 ± 0.23	0.25
2	121.67 ± 0.25	0.22
3	123.85 ± 0.21	0.16
4	122.47 ± 0.24	0.13

The maximum deviations obtained were 0.06% and 1.30% for the repeatability and long-term stability tests, respectively. Figure 7 shows the long-term stability test for the beam quality RQR 5.

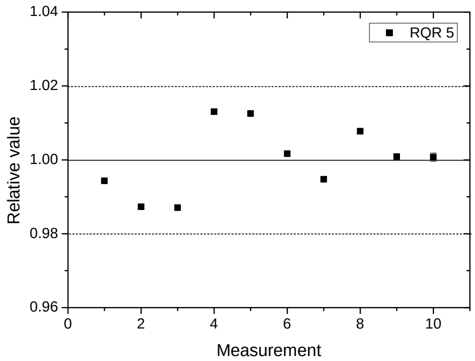

Figure 7: Long-term stability test of the ring-shaped monitor chamber utilizing the radiation beam quality RQR 5.

The results obtained for the graphite monitor chamber were better than the results obtained for the aluminium monitor chamber [6]. In this case, the maximum variation was 4%.

3.4. Leakage current

Two types of leakage currents were measured: pre- and post-irradiation. In both cases, the leakage current was analyzed for 20 minutes. The maximum leakage current was less than 1% of the ionization current produced by the minimum air kerma rate used in this study ($26.0\,mGy.min^{-1}$). The internationally recommended leakage current limit is 5% of the minimum effective air kerma rate [5]. Thus, the leakage current of the new graphite monitor chamber may be considered negligible.

4. Conclusions

In this work, a new ring-shaped graphite ionization chamber was designed, assembled and tested. The motivation for the development of this chamber was mainly its easy and low-cost construction. The graphite chamber presented good responses to all pre-operational tests performed: saturation curve, ion collection efficiency, polarity effect, response linearity and response stability. An improvement on its response stability was achieved, in comparison to the previous ring-shaped aluminium chamber, because of the electrode material. This result is very important since this chamber will be used to monitor X-ray beams.

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