Comparative Study of the Response Stability of Monitor Ionization Chambers in X-radiation Beams

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Abstract. International organizations recommend the utilization of a monitor ionization chamber for quality assurance during calibration services in X-radiation beams. The monitor chamber may be "transparent" to radiation, and it shall cover the whole radiation field. A cylindrical chamber (Farmer type) can also be used for this purpose, but it has to be positioned in the radiation penumbra region. At IPEN two ring-shaped ionization chambers were developed. These chambers unify the other two types of monitor chambers. In this work, a comparative study of the response stability in X-radiation beams of four monitor chambers (a cylindrical, a parallel-plate and two ring-shaped ionization chambers) was performed.

Introduction

Ionization chambers are the most utilized radiation detectors. The ionization chambers are simple and, depending on their material and design, they are useful for many purposes. The parallel-plate, cylindrical and spherical types are the most commonly used ionization chambers [1].

A special ionization chamber type is the monitor chamber. This kind of chamber is utilized as X-ray beam monitor, since the equipment response may oscillate due to power supply variations. This kind of ionization chamber usually remains fixed in front of the X-ray tube exit and its large sensitive volume may cover the whole radiation beam section [2]. The Farmer-type chamber, also called "thimble chamber", is a cylindrical ionization chamber that can be used as a monitor chamber if positioned at the penumbra region of the radiation beam [3].

Two ring-shaped ionization chambers were developed at IPEN [4,5]. These chambers are of parallel-plate type, and they have a large sensitive volume in a ring-shaped design. The ring-shaped chambers have a central hole that allows the direct beams to pass through with no interference; only the penumbra radiation is measured. There are two differences between the two ring-shaped ionization chambers: the collecting electrode material and the central hole diameter, which in the first one are aluminum and 6 cm, and in the other one are a graphite coating on a PMMA plate and 7 cm, respectively.

The response stability, short- and long-terms, is a very important characteristic of the monitor chambers, as the radiation beam intensity will be monitored by them. The reliability of the chamber response can be determined by the long-term stability test of the ionization chamber response.

The aim of this work was to perform a comparative study of the response stability of four monitor ionization chambers: a commercial transmission chamber, a Farmer-type chamber and two ring-shaped chambers developed at IPEN.

Materials

An industrial X-ray system Pantak/Seifert, model ISOVOLT 160-HS, which operates from 5 kV to 160 kV, was utilized. The characteristics of the established diagnostic radiation qualities, defined by the International Electrotechnical Commission, IEC 1267 (1994) [6], are listed in Table 1.

Table 1. Diagnostic radiology qualities of the X-ray equipment Pantak/Seifert [IEC, 1994]

Radiation quality		Voltage (kV)	Tube current (mA)	Additional filtration (mmAl)	Half-value layer (mmAl)	Effective energy (keV)	Air kerma rate (mGy/min)
Direct beams	RQR 5	70	10	2.5	2.35	30.15	47.17
	RQR 7	90	10	2.5	2.95	33.05	74.51
Attenuated beams	RQA 5	70	20	23.5	6.86	49.40	3.40
	RQA 7	90	20	32.5	9.22	59.70	4.87

In this work four ionization chambers were tested:

a) A commercial transmission chamber, Physikalisch-Technische Werkstätten (PTW), model 34014, Germany. This monitor chamber is routinely used in the calibration services of the Calibration Laboratory of IPEN.
b) A cylidrical chamber, Nuclear Enterprises (NE), model 1229, England.
c) Two ring-shaped chambers developed at IPEN [4,5].

The body of the ring-shaped ionization chambers is made of PMMA, and the entrance window is a thin foil of aluminized polyester. The main difference between them is the collecting electrode material: one chamber has an aluminum collecting electrode (Chamber A) and the other has a graphite coated PMMA plate collecting electrode (Chamber G). There are some other differences between the chambers, such as the central hole diameter and the sensitive volume, which are, respectively, 6 cm and approximately 200 cm^3 (Chamber A) and 7 cm and 160 cm^3 (Chamber G). These last differences show, as a consequence, a decrease of the response intensity of the Chamber G in comparison of Chamber A response. Figure 1 shows a picture of Chamber G.

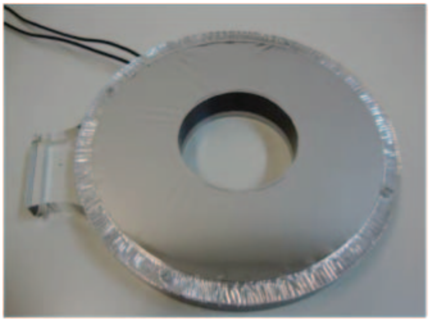


Fig. 1. Ring-shaped ionization chamber with graphite coated collecting electrode (Chamber G) [5]

All ionization chambers were connected to electrometers PTW, model UNIDOS, except the commercial transmission chamber that was connected to an electrometer PTW, model UNIDOS E.

Results and Discussion

All four monitor chambers were positioned, one at a time, at 30 cm from the X-ray tube focal spot. A collimation system was used, as shown in Figure 2.

(a) (b)

Fig. 2. Ionization chambers positioned in the radiation beam: (a) ring-shaped and transmission chambers (Chamber A); and (b) Farmer-type chamber, in the penumbra region

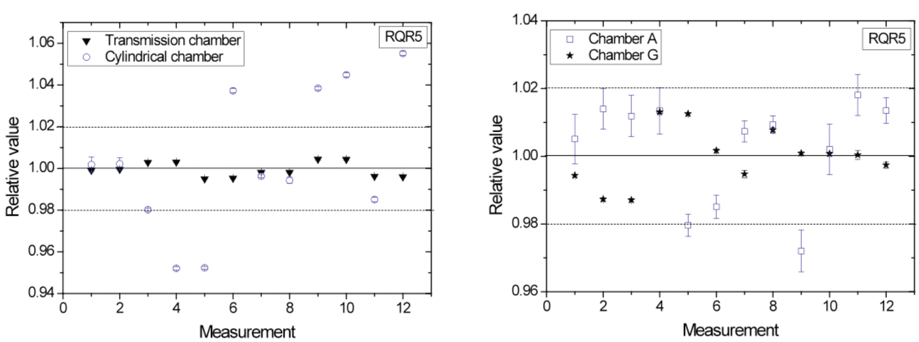
For the repeatability test, 10 consecutive readings were taken in each radiation quality. The coefficient of variation of these readings shall be less than 3% [7]. This coefficient of variation is the standard deviation of the measurements, and it is calculated as a percentage of the mean value. In this work, 12 repeatability tests were performed with each ionization chamber in all four radiation qualities. In Table 2, the maximum coefficients of variation obtained in these tests are presented, showing that all ionization chambers are within the recommended values [7].

Table 2. Maximum coefficient of variation, obtained in the repeatability tests

Ionization chamber model	Maximum coefficient of variation (%)			
	RQR5	RQR7	RQA5	RQA7
Transmission chamber	0.03	0.05	0.03	0.04
Cylindrical chamber	0.41	0.27	0.31	0.31
Ring-shaped chamber (Chamber A)	1.14	1.20	2.11	1.44
Ring-shaped chamber (Chamber G)	0.19	0.03	0.07	0.05

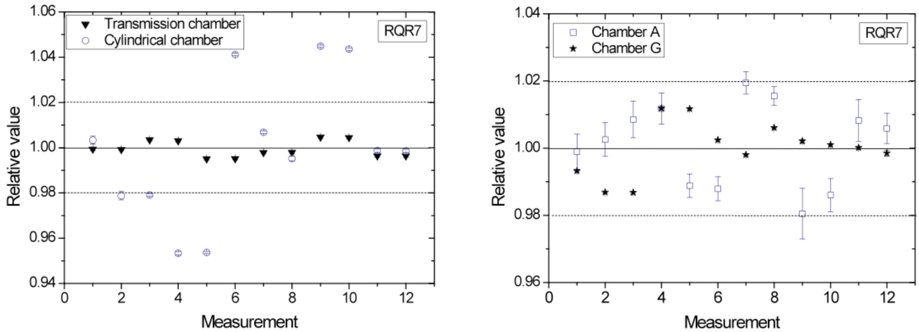
The long-term stability test was performed using the repeatability tests results. The mean value of each set of 10 readings was evaluated, as shown in Figures 3 to 6. The recommended limits of response variation are ±2% [7]; these limits are presented as dashed lines in the graphs.

In Figures 3 to 6, it can be observed that the cylindrical chamber response is outside the recommended limits for all tested radiation qualities. This fact probably occurs due to positioning difficulties, despite the laser localization system. As this ionization chamber has a small sensitive volume (0.6 cm^3), any positioning error induces a significant response variation. The maximum response variation obtained for this chamber was 5.5% in the case of the RQR5 radiation quality.



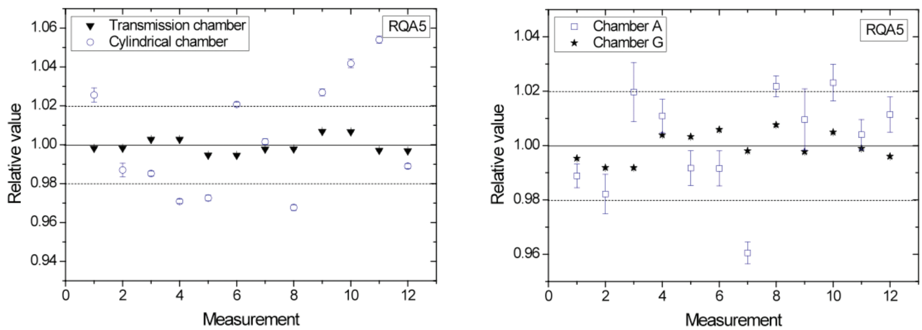
(a) (b)

Fig. 3. Long-term stability test using the radiation quality RQR5 (direct beam).
a) Commercial chambers; and b) Ring-shaped chambers A and G



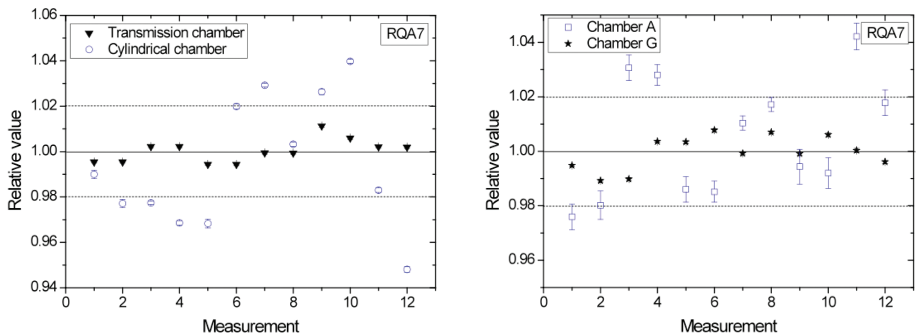
(a) (b)

Fig. 4. Long-term stability test using the radiation quality RQR7 (direct beam).
a) Commercial chambers; and b) Ring-shaped chambers A and G



(a) (b)

Fig. 5. Long-term stability test using the radiation quality RQA5 (attenuated beam).
a) Commercial chambers; and b) Ring-shaped chambers A and G



(a) (b)

Fig. 6. Long-term stability test using the radiation quality RQA7 (attenuated beam).
a) Commercial chambers; and b) Ring-shaped chambers A and G

The commercial transmission chamber presented a very stable response to all tested radiation qualities (maximum variation of 0.7% in the case of the RQA5 radiation quality). This result was expected since this chamber has a very large sensitive volume and it covers the entire radiation beam section.

Chamber A presented a good response stability in the direct beams, but still too close or even outside the recommended limits [7]. Chamber G was designed and assembled exclusively to improve the response stability of the chamber in X-ray beams. As can be seen in Figures 3 to 6, the aim was achieved, once Chamber G presented a stable response in all tested radiation qualities. The maximum variations obtained were 4.2% for Chamber A and 1.4% for Chamber G.

Conclusions

In this work the response behavior of four monitor ionization chambers was studied. All chambers presented good short-term stability in their response, i.e., repeatability of the response. The maximum coefficient of variation was 2.1% for the ring-shaped chamber with aluminum collecting electrodes (Chamber A) in the RQA5 radiation quality.

The long-term stability test results showed that the cylindrical ionization chamber and the Chamber A responses are not stable in X-ray beams, thus their responses are not reliable in this condition. However, the transmission chamber and the ring-shaped chamber with graphite coated collecting electrode (chamber G) presented very good results, within the recommended limits.

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