Backscattered Radiation into a Transmission Ionization Chamber: Measurement and Monte Carlo Simulation

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Abstract: Backscattered radiation (BSR) from field-defining collimators can affect the response of a monitor chamber in X-radiation fields. This contribution must be considered since this kind of chamber is used to monitor the equipment response. In this work, the dependence of a transmission ionization chamber response on the aperture diameter of the collimators was studied experimentally and using a Monte Carlo (MC) technique. According to the results, the BSR increases the chamber response of over 4.0% in the case of a totally closed collimator and 50 kV energy beam, using both techniques. The results from Monte Carlo simulation confirm the validity of the simulated geometry.

Keywords: transmission ionization chamber, X-radiation, backscattered radiation, Monte Carlo simulation.

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INTRODUCTION

To assure an accurate operation of a radiation detector, it has to be calibrated periodically at a calibration laboratory. In general, there are two general calibration methods: calibration using a reference instrument and calibration in a well known radiation field (IAEA 2002).

At the Calibration Laboratory of Instituto de Pesquisas Eenrgéticas e Nucleares (IPEN), standard X-ray beams are used to calibrate radiation detectors, levels radiotherapy, diagnostic radiology and radioprotection. For this purpose, the laboratory maintains secondary standard chambers calibrated at various X-ray energies. These chambers operate as reference instruments since their calibration factors are traceable to primary or secondary standard laboratories. This calibration method is commonly used, which is reliable, but it is a relatively time-consuming method.

One possible solution for this problem would be the transference of the calibration factor of the reference chamber to the transmission ionization chamber after a proper study of its adequacy in terms of metrological quality. This chamber is a plane-parallel type which is fixed in front of the X-ray tube output, and it monitors the intensity of the beam during the calibration procedure. All measurements are taken with the transmission chamber positioned in the direct beam; even the half-value layers are usually determined under this condition, following international recommendations (IEC 1994). In order to use the transmission chamber as a reference chamber, it is necessary to guarantee its performance. It has to be stable, and all characteristics have to be studied.

At the Calibration Laboratory of IPEN, it was observed that the collimation system of the X-ray equipment generates backscattered radiation influencing the transmission chamber response.

Several authors (Duzenli et al., 1993; Yu et al., 1995; Hounsell, 1998) have already studied this fact in monitor chambers of linear accelerators utilized in radiotherapy treatments, obtaining an increase of chamber response up to 2.4%. Das and Chopra (1995) reported that BSR effect is also significant for kilovoltage photon beams. Other authors used Monte Carlo simulation to study the scattered radiation (Chan and Doi, 1982; Papin and Rielly, 1988; Jarry et al., 2006) and the backscattered radiation (Liu et al., 2000) effects on the radiation beam output.

The aim of this work was to quantify the influence of BSR in the response of a commercial transmission ionization chamber, in the diagnostic radiology energy range, with measurements taken at the laboratory and using a MC computer code, MCNP version 4c. The objective of the use of the MC method was to simulate the geometry of the equipment studied in this work and validate this simulation.

MATERIALS AND METHODS

The measurements were obtained utilizing an X-ray equipment, Pantak/Seifert, model ISOVOLT 160-HS, operating in the range from 5 to 160 kV; the current varied from 0.1 to 45.0 mA. The field collimators were of high purity lead, over 99.9% purity, with different aperture diameters – totally closed, 17.0 mm, 34.0 mm, 40.0 mm, 50.8 mm and 70.5 mm. The transmission plane-parallel ionization chamber, Physikalisch-Technische Werkstätten (PTW), model 34014 (Fig. 1), was connected to a PTW electrometer, model UNIDOS E.

Three beam qualities, of the diagnostic radiology energy range, were utilized in this work to study the behavior of the BSR in relation to the energy beam. These radiation qualities are presented in Table 1. All collimators were tested in these three beam qualities; the same procedure was followed with no collimator in the beam, to compare the results.

The transmission ionization chamber, the collimation system and the X-ray beam were simulated using the MC code MCNP version 4C (Briesmeister, 2000). The simulation of the transmission chamber was based on its dimensions given in the manufacturer manual, and it was carefully modeled (Fig. 2). The X-ray beam data needed for the simulation was taken from the spectra measurements using a sodium iodide spectrometer.

The photons produced by the X-ray tube in the energy range selected for this work may interact with the ionization chamber active air volume in three different ways: photoelectric effect, Compton scattering and Rayleigh scattering. The selection of which interaction the photon will suffer is determined by a random number generated according to a uniform probability density function and the interaction cross section. Both the random number generator and the cross section table used in this work were defaults of MCNP code. In order to obtain a standard deviation below 1%, 10^8 primary photon histories were simulated. Kinetic energy cut-offs were 1 keV for electrons and 1 keV for photons.

RESULTS AND DISCUSSION

Comparative graphs of the response of the transmission ionization chamber obtained experimentally and simulated using a Monte Carlo technique are presented in Figures 3-5. These figures show the ionization chamber response in function of the aperture diameter of the field collimator in different beam qualities. In all cases, the curve showed a quadratic behavior, which was expected because of the collimator diameter variation, that is, the area of the material at the backside of the ionization chamber (that contributes for the BSR production) was varied through the collimators. The chamber response was normalized to the response obtained without any collimator in the radiation beam.

For the results measured in the laboratory the variation obtained of the chamber response was over 4.0% of unity in the case of the totally closed collimator and beam quality RQR 3. The maximum deviation of the relative response of the measurements was 0.008%.

The Monte Carlo simulation results agreed with the measurements obtained at the laboratory. A maximum variation of the chamber response occurred for the totally closed collimator in the 50 kV energy beam (RQR 3). The maximum deviation of the relative response was 1.52%. An increase in the number of primary histories would provide a better response deviation, but this procedure demands many hours of computer processing that sometimes it is unfeasible. Some simulations performed in this work lasted over 50 hours (processor Pentium D® 3.40 GHz and 1 GB of RAM).

CONCLUSIONS

The backscattered radiation from collimators into a transmission ionization chamber response utilizing X-radiation was quantified by experimental measurements and the Monte Carlo method. It resulted in an increase greater than 4.0% in the response of the transmission chamber for both techniques. The maximum variation was observed in the case of the totally closed collimator in the less energetic radiation beam (50 kV).

The results obtained demonstrate the need of the application of a correction factor in each irradiation condition. These correction factors should be obtained for the most usual calibration conditions, resulting in a requirement for the use of the transmission chamber as a reference instrument in calibration procedures.

From the results obtained with the MC computer code it is possible to conclude that the transmission ionization chamber, the collimation system and the X-ray beam source were simulated adequately. This fact indicates that this technique may be applied to other studies of the transmission chamber characteristics, as, for instance, studies that can not be performed experimentally.

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Figure captions:

Figure 1 – Transmission ionization chamber and collimation system positioned in front of an X-ray equipment at the Calibration Laboratory of IPEN.

Figure 2 – Geometry of the transmission ionization chamber and the collimation system as implemented in the MNCP inputs.

Figure 3 – Backscattered X-radiation effect in the transmission ionization chamber response for diagnostic radiology level RQR 3, for experimental measurements and Monte Carlo technique.

Figure 4 – Backscattered X-radiation effect in the transmission ionization chamber response for diagnostic radiology level RQR 5, for experimental measurements and Monte Carlo technique.

Figure 5 – Backscattered X-radiation effect in the transmission ionization chamber response for diagnostic radiology level RQR 7, for experimental measurements and Monte Carlo technique.

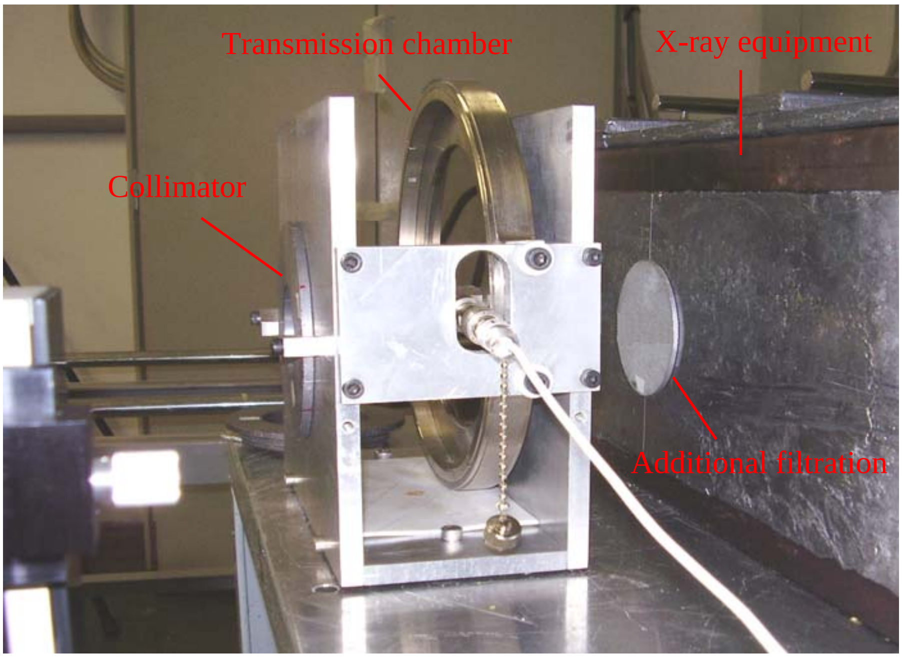

Transmission chamber
X-ray equipment
Collimator
Additional filtration

Fig. 1

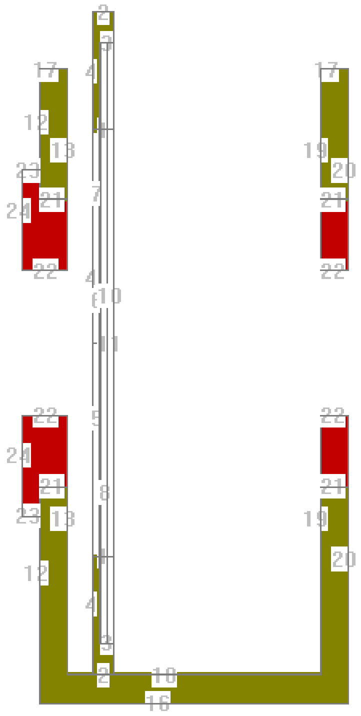
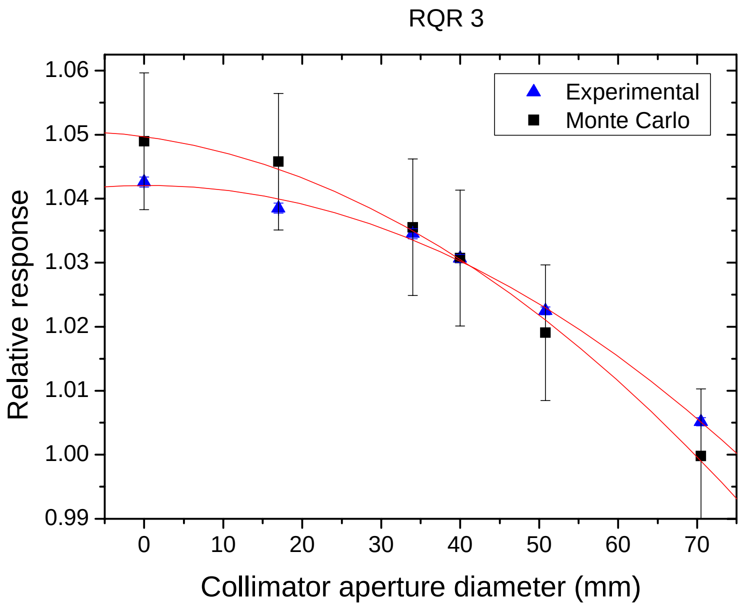


Fig. 2



RQR 3
Experimental
Monte Carlo
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
Relative response
0
10
20
30
40
50
60
70
Collimator aperture diameter (mm)

Fig. 3

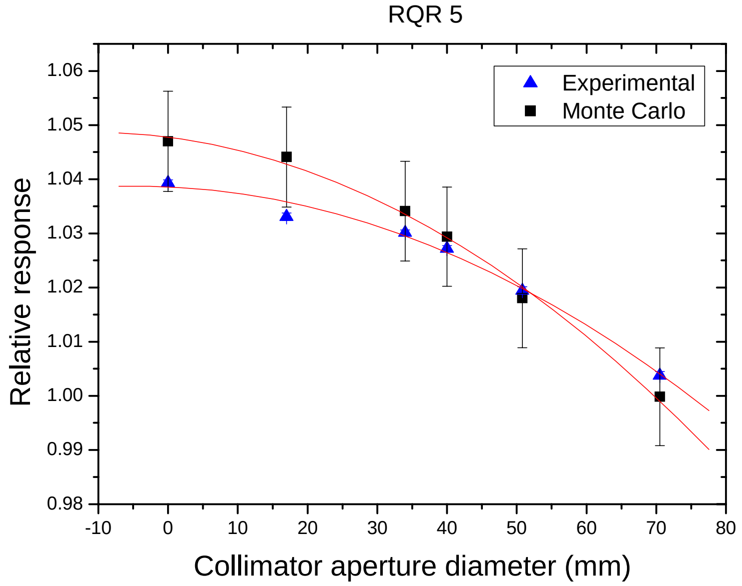

RQR 5
Experimental
Monte Carlo
Relative response
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
-10
0
10
20
30
40
50
60
70
80
Collimator aperture diameter (mm)

Fig. 4

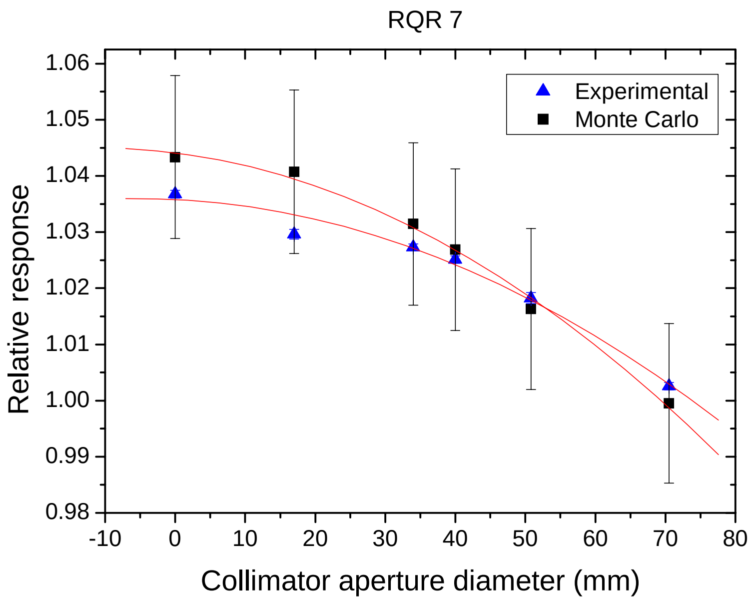

RQR 7
Relative response
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
-10
0
10
20
30
40
50
60
70
80
Collimator aperture diameter (mm)
Experimental
Monte Carlo

Fig. 5

Table 1 – Radiation qualities of the X-ray equipment, diagnostic radiology level, defined at 100 cm from the focus.

Radiation Quality	Voltage (kV)	Additional Filtration (mmAl)	Half-value Layer (mmAl)	Effective Energy (keV)	Air Kerma Rate at 30 cm (mGy/min)
RQR 3	50	2.5	1.79	27.15	278.1
RQR 5	70	2.5	2.35	30.15	544.2
RQR 7	90	2.5	2.95	33.05	857.0