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Constancy check of beam quality in conventional diagnostic X-ray equipment

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ABSTRACT

A tandem ionization chamber was developed for quality control programs of X-ray equipment used in conventional radiography and mammography. A methodology for the use of the tandem chamber in the constancy check of diagnostic X-ray beam qualities was established. The application at a medical X-ray imaging facility of this established methodology is presented. The use of the tandem chamber in the constancy check of diagnostic X-ray beam qualities is a useful method to control the performance of the X-ray equipment.

1. Introduction

Ionization chambers are the most frequently used dosimetry systems in diagnostic radiology. They have various geometries depending on the application. The two main types of ionization chamber geometries in use in diagnostic radiology are plane-parallel and cylindrical ionization chambers. An electrometer is used in conjunction with an ionization chamber to collect the charge generated in the gas (typically air) within the sensitive volume of the chamber.

For accurate dosimetry, the ionization chamber and electrometer must be sent to a standards laboratory for a calibration in terms of air kerma in X-ray beams of known qualities. In the case of X-rays used in diagnostic radiology, the beam quality is specified in terms of the peak value of the high voltage applied across the X-ray tube (peak voltage), and the first half-value layer (HVL), expressed in millimeters of aluminum (mm Al).

A quality control program for X-ray equipment used for diagnostic procedures, necessary for providing adequate diagnostic information at acceptable levels of the patient and staff exposure, includes the measurement on a routine basis of various parameters that affect the performance characteristics of X-ray systems. One of these parameters is the beam quality, specified in terms of the HVL. Minimum HVL limits are recommended to ensure that the lowest energies in the unfiltered spectrum are removed (IPEM, 2005). The procedure for the determination of HVL is a time consuming process (IAEA, 1994), and a simple method to check the constancy of beam qualities could be very useful.

A double-faced plane-parallel ionization chamber, hereafter named tandem chamber, for measurements of air kerma and air kerma rate values in X-radiation fields used in conventional radiography and mammography was developed at the Instituto de Pesquisas Energéticas e Nucleares (Costa and Caldas, 2003). Measurements in conventional radiography beams are taken using one face of the tandem chamber (face A) and measurements in mammography are accomplished using the other face (face G). The different energy responses of the two faces of the tandem chamber can be used for the constancy check of the beam qualities in quality control programs (Albuquerque and Caldas, 1989; Caldas, 1991; de Souza et al., 1996; Maia and Caldas, 2006). A methodology of use of the tandem chamber in the constancy check of diagnostic X-ray beam qualities was established, with the elaboration of the respective procedures. The objective of this work was the application at a medical X-ray imaging facility, for a length of time, of these procedures.

2. Materials and methods

The tandem chamber developed is disc-shaped, and the only difference between the two faces is in the inner collecting and guard electrode materials: one has aluminum electrodes (face A), and the other has graphite electrodes (face G). The tandem

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chamber body is made of polymethylmethacrylate (Lucite). The inner electrode is 3 mm thick and 20 mm in diameter. The guard rings are 4 mm thick and 3 mm wide. The outer electrodes (entrance windows) are made of an aluminized polyester film. The distance between the inner and the outer electrodes is 8 mm. The measuring volumes are approximately 2.5 cm^3, and the chamber is unsealed. Fig. 1 shows a schematic diagram of the tandem chamber (Costa and Caldas, 2003). This tandem chamber was used with an Keithley electrometer, model 35617, with a voltage supply of +300 V. The calibration of the tandem chamber was performed by the substitution method (IAEA, 1994) using the radiation qualities recommended by the international standard IEC 61267 (IEC, 2005) at the Calibration Laboratory of the Instituto de Pesquisas Energéticas e Nucleares.

The long term stability of the combined response of the tandem chamber and electrometer was obtained using a stability check device. This device consists of a radioactive source of $^{90}Sr+^{90}Y$ from Physikalisch-Technische Werkstätten, type 8921, and a special holder was developed in order to provide a reproducible geometry for the measurements.

The irradiations were carried out using a general purpose radiographic system at a medical X-ray imaging facility in a public hospital of Ribeirão Preto, Brazil. Measurements were taken at the two peak voltage values more used for clinical examinations. Aluminum absorbers of different thicknesses were used in the determination of the HVL of the radiation beams. The attenuation measurements were taken using the face A of the tandem chamber. Subsequently, three sets of measurements of air kerma with both faces of the tandem chamber were taken under the same conditions on different days. The weighted mean values of the ratios between the air kerma values measured with the face G and face A of the tandem chamber were considered as the baseline values in the constancy check of the beam qualities related to the HVL determined. Each ratio was weighted inversely as the square of its own uncertainty. The analysis of uncertainties was made in accordance with the conventions of the ISO's Guide on the Expression of Uncertainty in Measurement (ISO, 1995).

3. Results and discussion

Ten sets of 10 successive readings taken over a period of one month at intervals of a few days were taken for both faces of the tandem chamber, exposed to the $^{90}Sr+^{90}Y$ source. The standard deviation determined from each set of 10 readings was less than 2.7% of the mean value obtained in each set for face A and less than 2.3% for face G. The tandem chamber meets the International Electrotechnical Commission (IEC) requirement, namely, that the standard deviation of a single measurement with the stability check device as determined from repeated measurements shall not exceed 3% of the mean output value (IEC, 1997). The long-term stability was represented by the standard deviation of the mean values of each set of 10 readings. This standard deviation was 1.6% for face A and 1.9% for face G.

The constancy of beam qualities was controlled by monitoring the ratios between the air kerma values measured with the face G and face A of the tandem chamber, hereafter named the constancy index, over a period of one year at intervals of not greater than one month. The upper and lower control limits for each beam quality were set as the baseline values plus their expanded uncertainty and baseline values minus their expanded uncertainty, respectively. The long-term stability for face A and face G of the tandem chamber was included in these uncertainties. The beam qualities used in this study and baseline values of the constancy index are given in Table 1.

The constancy index was plotted versus the series number of the measurement for each beam quality. The data are presented in Figs. 2 and 3. The solid lines are the baselines and the dashed lines are the upper and lower control limits.

The average variation in the constancy index in comparison with the baseline values was about 1.2% with a maximum of 2.3%

Table 1
Beam qualities and baseline values of the constancy index

Nominal peak voltage (kV)	Half-value layer (mm Al)	Baseline value
80	2.906	1.02 ± 0.03
100	3.755	1.08 ± 0.03

The numbers after the symbols ± are the numerical values of the expanded uncertainties based on standard uncertainties multiplied by a coverage factor 2, corresponding to a confidence level of approximately 95%.

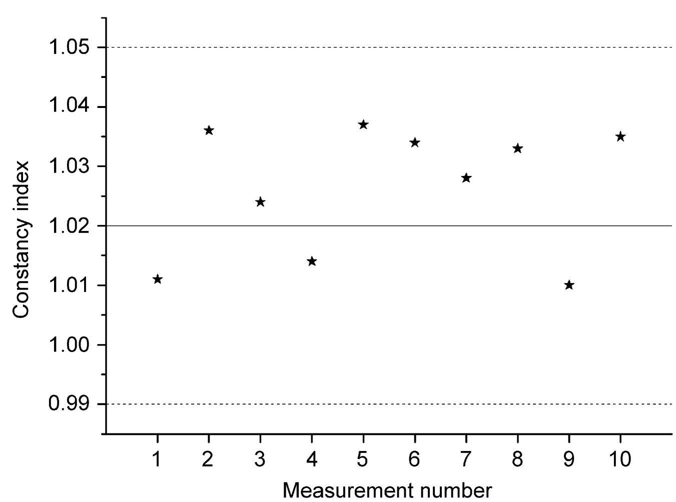

Fig. 2. Constancy index for the nominal peak voltage of 80 kV beam.

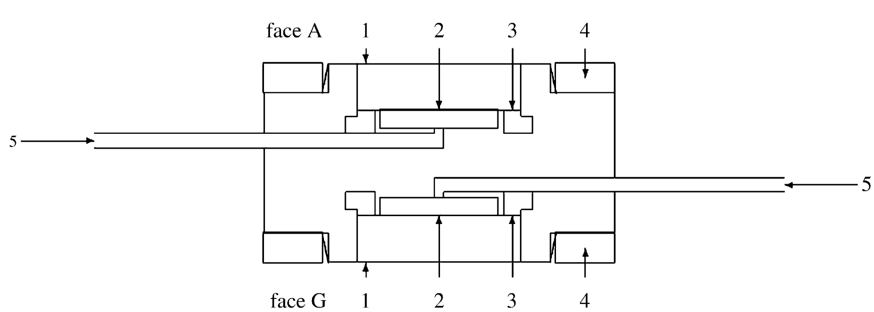

Fig. 1. Schematic diagram of the tandem ionization chamber: (1) entrance windows, (2) collecting electrodes, (3) guard rings, (4) entrance windows fixation ring, (5) cables. The measuring volumes are 2.5 cm^3.

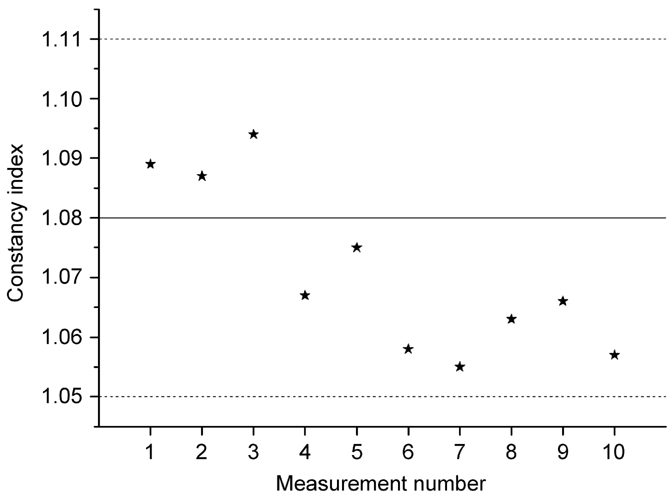

Fig. 3. Constancy index for the nominal peak voltage of 100 kV beam.

for the nominal peak voltage of 100 kV beam and a minimum of 0.087% for the nominal peak voltage of 80 kV beam. These results imply that the variations in beam qualities were negligible. However, the downward trend of the 100 kV data shown in Fig. 3 is a indication that the measurement is changing, and it requires investigation.

This method is appropriate to detect significant changes in the HVL with time, and is therefore a useful preventative check procedure. A similar idea can be adopted by using the energy dependence of the ratio between the responses of two different ionization chambers (Albuquerque and Caldas, 1989; Caldas, 1991; de Souza et al., 1996) or a single chamber having two different coverings (Maia and Caldas, 2006).

4. Conclusions

The application at a medical X-ray imaging facility, over a period of one year, of the established procedures for use of a tandem chamber in the constancy check of diagnostic X-ray beam qualities presented good results. In relation to the usual procedure for the determination of HVL, the use of the tandem chamber allows more frequent confirmations of the beam quality. The use of the tandem chamber in the constancy check of diagnostic X-ray beam qualities is a useful method for quality control programs of X-ray equipment.

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