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Applied Radiation and Isotopes 58 (2003) 495–500

Applied Radiation and Isotopes

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Response characteristics of a tandem ionization chamber in standard X-ray beams

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Received 14 November 2002; accepted 9 December 2002

Abstract

A tandem ionization chamber was developed for quality control programs of the kilovoltage X-ray equipment used in radiotherapy. This chamber was tested and calibrated in low-energy X-ray beams in accordance with international recommendations, and it showed a satisfactory level of performance, mainly with regard to its main use, namely formation of a tandem system for confirmation of half-value layers in X-radiation beams previously determined by the conventional method. In this developed system no absorbers or special setups are necessary.

Keywords: Ionization chambers; X-radiation; Quality control; Radiotherapy; Tandem system

1. Introduction

Quality control in radiotherapy is needed for providing accurate dose delivery.

Quality control in radiotherapy comprises specific recommendations for each type of treatment unit (linear accelerators, ^{60}Co units, kilovoltage X-ray equipment, simulators, brachytherapy equipment, etc). The tests for kilovoltage X-ray equipment include the constancy check of the beam quality in terms of the half-value layer (HVL).

The conventional method for determining the HVL by adding absorbers of known thicknesses and materials takes a long time; consequently, the beam dosimetry becomes a delayed process and is never carried out at clinics at the recommended frequency.

The tandem method has been in use for several decades (Kenney and Cameron, 1963; Gorbics and Attix, 1968; Spurny et al., 1973; da Rosa and Nette, 1988). It consists of two individual dosimeters with different energy dependences and makes it possible to determine the effective energy in unknown radiation fields.

At the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares, tandem systems composed of different ionization chambers were formed (Albuquerque and Caldas, 1989; Caldas, 1991). They consist of two individual chambers with different energy dependences, which enable one to confirm the values of the HVLs or effective energies in X-radiation beams previously determined by the conventional method.

Plane parallel ionization chambers are recommended for beam dosimetry in radiation therapy with low- and high-energy X-rays; and also with high-energy electrons (IAEA, 1997; Almond et al., 1999; IAEA, 2000; Ma et al., 2001; Solimanian et al., 2001).

In this work, a special double-faced plane parallel ionization chamber was developed with collecting electrodes of different materials in a tandem system. It was tested and calibrated in low-energy X-ray beams in accordance with international recommendations (IAEA, 1994; IEC, 1997).

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0969-8043/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0969-8043(03)00026-5

2. Materials and methods

The special plane parallel ionization chamber with a double face, a tandem chamber, 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 chamber body is made of polymethylmethacrylate (Lucite). The inner electrode is 5 mm thick and 20 mm in diameter. The guard rings are 10 mm thick and 3 mm wide. The outer electrodes (entrance windows) are made of an aluminized polyester film ($1.7\,\mathrm{mg} \times \mathrm{cm}^{-2}$). The distance between the inner and the outer electrodes is 2 mm. The measuring volumes are approximately $0.6\,\mathrm{cm}^3$, and the chamber is unsealed. Fig. 1 shows a schematic diagram of the tandem chamber. This chamber was attached to an electrometer PTW (Physikalisch-Technische Werkstätten), model MULTIDOS.

The irradiations were carried out using a Rigaku-Denki X-ray system, model Geigerflex, with a Philips tube, model PW 2184/00, a beryllium window of 1 mm and a tungsten target, and maximum generating potential of 60 kV. Table 1 presents the characteristics of this X-ray system.

The reference standard system consists of a plane parallel ionization chamber model M23344 ($0.2\,\mathrm{cm}^3$) and an electrometer model UNIDOS 10001, both from PTW.

For the repeatability test of the combined response of the tandem chamber and electrometer, a stability check device was utilized. This device consists of a radioactive source of ^{90}Sr (nominal activity of 33.3 MBq, 1988) from PTW, type 8921, and a special holder was developed in order to provide a reproducible geometry for the measurements.

As the chambers used in this work are unsealed, the measurements were corrected to the reference conditions of temperature and pressure, i.e, 20°C and 101.3 kPa.

The reported uncertainties of all measurements are expanded uncertainties based on standard uncertainties multiplied by a coverage factor 2, corresponding to a confidence level of approximately 95%.

3. Results and discussion

The tandem ionization chamber was studied in relation to the characteristics of leakage current without irradiation, linearity of response, short-term stability, dependence on radiation quality, dependence on field size and chamber orientation.

3.1. Leakage current without irradiation

The leakage current without irradiation was determined from charge measurements for 20 min after the

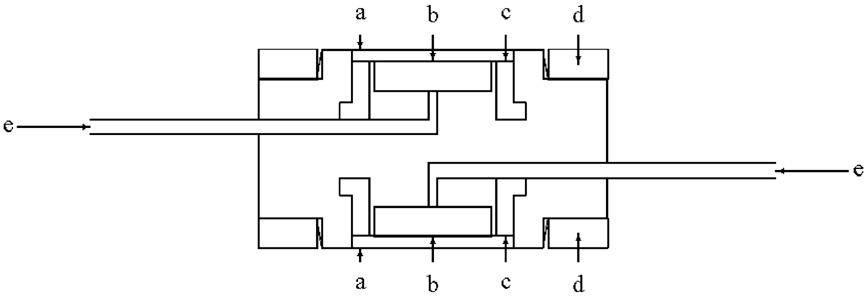

Fig. 1. Schematic diagram of the tandem ionization chamber: (a) entrance windows, (b) collecting electrodes, (c) guard rings, (d) entrance window fixation ring, and (e) cables.

Table 1
Characteristics of the Rigaku-Denki X-ray sxystem; inherent filtration: 1 mm Be

Generating potential (kV)	Tube current (mA)	Added filtration (mm Al)	Half-value layer (mm Al)	Air kerma rate ($\mathrm{mGy\,min}^{-1}$)
25	30	0.44	0.25	400
30	30	0.54	0.36	421
40	30	0.68	0.53	592
45	25	0.73	0.59	562
50	25	1.02	0.89	464

application of the polarizing voltage of +400 V sequentially to both faces of the tandem chamber.

The leakage current, expressed as percentage of the ionization current produced by the minimum air kerma rate to which the chamber was exposed, was less than 0.02% in all cases for both the faces of the tandem chamber. This chamber meets the requirement of the International Electrotechnical Commission (IEC, 1997), which prohibits values exceeding ±0.5%.

3.2. Linearity of response

The linear relationship between ionization current and air kerma rate was determined by irradiating sequentially both faces of the tandem chamber at 30 kV X-ray tube voltage (HVL of 0.36 mm Al) and varying the tube current. The chamber was placed in the radiation field at a distance of 50 cm from the source taking its front faces (entrance windows) as the reference points. The air kerma rates were determined by utilizing the reference standard.

The data are presented in Figs. 2 and 3. The straight lines are the results of a linear fit to these data. The uncertainty obtained for the angular coefficient, i.e., the uncertainty obtained in linearity of response was ±0.45% for face A and ±0.37% for face G.

3.3. Short-term stability

Ten successive measurements corrected to the reference conditions of temperature and pressure were taken for both faces of the tandem chamber exposed to the ^{90}Sr source. The experimental standard deviation was 0.06% of the mean value obtained for face A and 0.03% for face G. The tandem chamber meets the IEC (IEC, 1997) requirement, namely, that the standard deviation of a single measurement with the stability check device as determined from repeated measurements shall not exceed 0.3% of the mean output value.

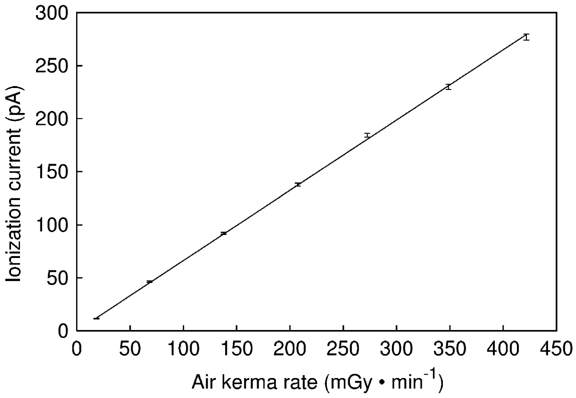

Fig. 2. Ionization current as a function of air kerma rate for the tandem chamber, face A, 30 kV X-ray tube voltage and HVL 0.36 mm Al. The straight line is the result of a linear fit to the data.

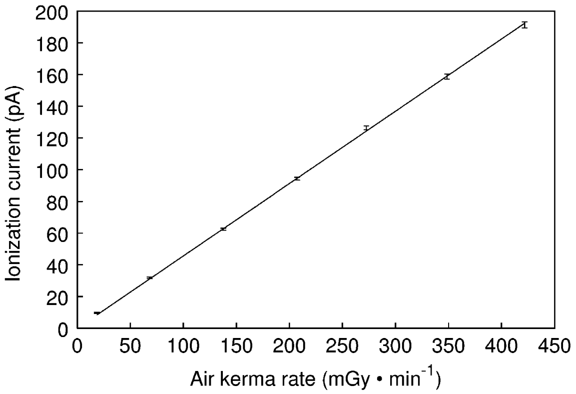

Fig. 3. Ionization current as a function of air kerma rate for the tandem chamber, face G, 30 kV X-ray tube voltage and HVL of 0.36 mm Al. The straight line is the result of a linear fit to the data.

Table 2
Calibration coefficients of the tandem chamber

Half-value layer (mmAl)	Calibration coefficient (mGy nC^{-1})	
	Face A	Face G
0.25	23.6±0.5	36.6±0.8
0.36	22.1±0.5	37.0±0.8
0.53	21.0±0.5	37.6±0.9
0.59	20.6±0.5	37.8±0.9
0.89	19.6±0.5	37.9±0.9

3.4. Dependence on radiation quality

The energy variation in response of the tandem chamber over the range of low-energy X-rays was studied using the radiation qualities listed in Table 1. The irradiation conditions were as follows: focus-to-chamber distance was 50 cm, and the diameter of the circular field was 6.66 cm. The response of the tandem chamber in terms of the calibration coefficients (Meghzifene and Shortt, 2002) was determined in relation to the conventional true value of air kerma rate by utilizing a reference standard.

The calibration coefficients of both faces of the tandem chamber are given in Table 2, and the energy dependence of the correction factors is shown in Fig. 4. The correction factors were normalized to the HVL of 0.36 mm Al (IEC, 1997). As can be seen, the maximum variation in response of face A (20%) is greater than in response of face G (3.4%). Taking into account the uncertainties in the measurements (±2.3%), one can assume that face G presents a flat response over the energy range concerned. In this case, face G of the tandem chamber can be utilized for the measurement of air kerma (and air kerma rate) in low-energy X-radiation fields as recommended for dosimetry in radiation therapy (IEC, 1997; IAEA, 2000). The response variation range specified by the IEC (IEC, 1997) is ±2.0%; the IAEA recommendation is that a variation in response would be less than 5% over the energy range used (IAEA, 2000).

The ionization chamber used for the determination of HVLs by the conventional method should be selected to have a minimum dependence on radiation quality over the range in question. Therefore, face G of the tandem chamber can also be used for attenuation measurements in low-energy X-radiation beams.

The different energy responses of the two faces of the tandem chamber can be used for the constancy check of the beam quality in the quality control program by utilizing the tandem system. The tandem curve, obtained by the ratio between the responses of face G and the responses of face A as a function of the HVLs is shown in Fig. 5. It shows a very useful curvature, and the HVLs can be determined with an uncertainty of approximately ±3%.

3.5. Dependence on field size

According to the requirements of IEC (IEC, 1997), the limit of variation in the response due to the field size shall not exceed ±2.0%. For this test, circular fields with different diameters were utilized. Both faces of the tandem chamber were irradiated at the focus to chamber distance of 50 cm in the radiation qualities given in Table 1, and varying the beam limiting collimators. The compliance with this performance requirement was checked by comparing the tandem chamber response with the response of a chamber model 23342 from PTW, which is independent of field size (IEC, 1997).

Tables 3 and 4 present the relative response as a function of the field size for the tandem chamber. Table 5 shows that the relative response of the PTW 23342 chamber is independent of the field size. The

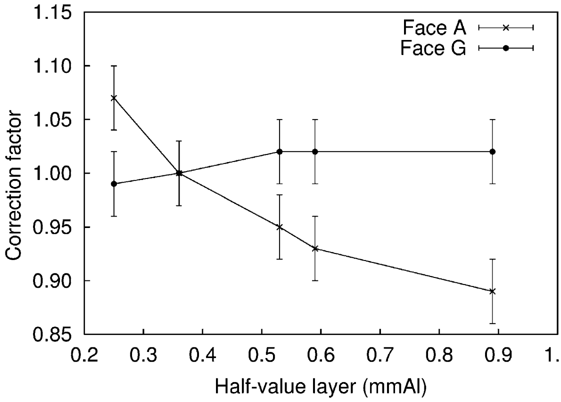

Fig. 4. Correction factors of the tandem chamber as a function of the radiation quality normalized to the HVL of 0.36 mm Al.

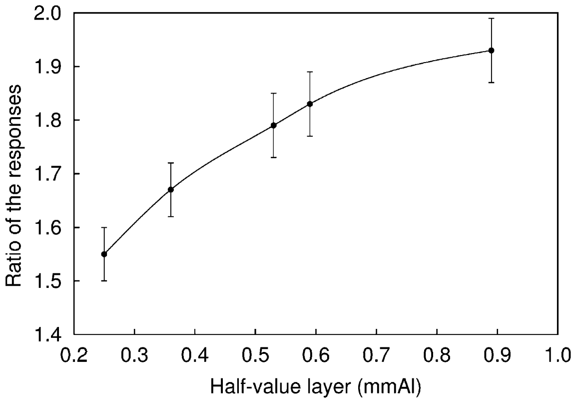

Fig. 5. Tandem curve of the tandem chamber for low-energy X-radiation beams.

Table 3
Relative response as a function of the field size for the tandem chamber, Face A

Field diameter (cm)	Half-value layer				
	0.25 mm Al	0.36 mm Al	0.53 mm Al	0.59 mm Al	0.89 mm Al
3.04	0.982	0.976	0.969	0.966	0.960
3.52	0.991	0.986	0.981	0.978	0.973
4.01	0.991	0.987	0.984	0.982	0.979
5.35	0.994	0.993	0.992	0.991	0.990
6.66	1.000	1.000	1.000	1.000	1.000
9.95	0.997	0.996	0.997	0.997	0.998
10.0	1.000	0.999	0.999	1.000	1.000

The relative uncertainty is less than 0.7%. The values are normalized to field diameter of 6.66 cm.

responses were normalized to the field size normally used at the calibration procedure of such chambers, i.e., diameter of 6.66 cm. The tandem chamber has an outer diameter of 6.0 cm. As can be seen from Tables 3 and 4, the maximum variation of the response occurs at the field sizes in which the tandem chamber is not uniformly irradiated, i.e., between diameters of 3.04 and 5.35 cm. Consequently, the developed tandem chamber must be used in field sizes greater than 6.0 cm in diameter.

3.6. *Chamber orientation*

The variation in response of the tandem chamber was studied in function of the plane of the entrance window tilted by ±5° from its reference position, perpendicular to the axis of the radiation beam. The tests were performed measuring the tandem chamber response, faces A and G, at tilt angles of 1° apart using the minimum and the maximum radiation qualities given in

Table 4
Relative response as a function of the field size for the tandem chamber, Face G

Field diameter (cm)	Half-value layer				
	0.25 mm Al	0.36 mm Al	0.53 mm Al	0.59 mm Al	0.89 mm Al
3.04	0.967	0.957	0.941	0.936	0.923
3.52	0.978	0.973	0.962	0.958	0.949
4.01	0.979	0.978	0.969	0.968	0.961
5.35	0.987	0.989	0.986	0.986	0.984
6.66	1.000	1.000	1.000	1.000	1.000
9.95	0.993	0.998	0.999	1.002	1.003
10.0	0.991	0.996	0.996	0.999	0.998

The relative uncertainty is less than 0.8%. The values are normalized to the field diameter of 6.66 cm.

Table 5
Relative response as a function of the field size for the PTW 23342 chamber

Field diameter (cm)	Half-value layer				
	0.25 mm Al	0.36 mm Al	0.53 mm Al	0.59 mm Al	0.89 mm Al
3.04	0.996	0.995	0.994	0.986	0.983
3.52	0.999	0.999	0.997	0.995	0.993
4.01	0.996	0.995	0.996	0.990	0.988
5.35	0.998	0.997	0.998	0.988	0.986
6.66	1.000	1.000	1.000	1.000	1.000
9.95	1.002	1.002	1.003	1.007	1.009
10.0	1.002	1.002	1.003	1.002	1.003

The relative uncertainty is less than 1%. The values are normalized to the field diameter of 6.66 cm.

Table 6
Relative response of the tandem chamber as a function of the angle of tilt

Angle of tilt (deg.)	Face A		Face G	
	0.25 mm Al	0.89 mm Al	0.25 mm Al	0.89 mm Al
−5	1.007±0.011	0.993±0.008	1.004±0.012	1.002±0.009
−4	1.002±0.009	0.991±0.008	1.005±0.010	1.002±0.008
−3	1.002±0.008	0.991±0.008	1.004±0.010	1.004±0.009
−2	1.001±0.009	0.987±0.008	1.006±0.010	1.003±0.009
−1	0.998±0.008	0.988±0.007	1.005±0.010	1.001±0.009
0	1.000±0.008	1.000±0.008	1.000±0.012	1.000±0.009
+1	0.996±0.009	0.989±0.007	1.003±0.010	0.999±0.009
+2	0.999±0.008	0.994±0.008	1.005±0.010	1.004±0.009
+3	0.999±0.008	0.993±0.008	1.008±0.013	1.003±0.009
+4	1.000±0.008	0.994±0.008	1.005±0.010	1.004±0.008
+5	1.000±0.008	0.995±0.007	1.001±0.013	1.002±0.009

Table 1, focus to chamber distance of 100 cm and field size diameter of 6.0 cm.

The results are given in Table 6. The responses were normalized to the reference position (0°). As can be seen, both faces of the tandem chamber meet the IEC requirement, i.e., the limits of variation of response are within ±1.0% (IEC, 1997).

4. Conclusions

A double-faced chamber was developed and tested in accordance to international recommendations (IEC, 1997) at the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares for use in therapeutic beams. It showed a satisfactory level of performance. The different energy response of the two faces of the tandem chamber allowed the formation of a tandem system for the constancy check of the beam quality of low-energy X-radiation fields. The main advantage of this type of chamber is that it allows simple and quick measurements, which enables quality control tests to be performed at a much higher frequency than usually in practice. No absorbers or any special setups are necessary for dosimetry procedures with the tandem chamber.

Acknowledgements

The authors would like to thank the partial financial support from Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil.

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