# Application of a tandem ionization chamber in a quality control program of X-ray beams, radiotherapy level

**Maíra T. Yoshizumi*, Linda V. E. Caldas**

Instituto de Pesquisas Energéticas e Nucleares (IPEN - CNEN/SP), Av. Prof. Lineu Prestes, 2242, 05508-000, São Paulo, Brazil.

**Abstract.** A tandem ionization chamber, developed at the Instituto de Pesquisas Energéticas e Nucleares (IPEN), for X radiation beams, radiotherapy level, was applied into a quality control program of the Calibration Laboratory of IPEN. This ionization chamber is composed by two ionization chambers, with a volume of 0.6 $cm^3$ each one. Its inner plane-parallel electrodes and guard rings are made of different materials: one is made of aluminum and the other is made of graphite. Because of this difference in materials, the ionization chamber forms a tandem system. The relative response of the calibration factors of both sides of the chamber allows an easy verification of the X-ray beam qualities stability. The ionization chamber was submitted to some tests to verify the stability of its response: leakage current before and after exposure, repeatability and reproducibility. The performance of the ionization chamber was satisfactory.

***KEYWORDS: tandem system, quality control, X-rays.***

## 1. Introduction

Although there is a world tendency to substitute the orthovoltage equipments for linear accelerators in radiotherapy treatments, in Brazil there are still many of those equipments in operation.

The quality control of the radiation beam guarantees the dose delivery accuracy, which is one of the most important points in radiotherapy. For each kind of radiation beam specific characteristics are recommended for its performance. One of the procedures recommended for X-ray equipments is the verification of the constancy of the beam qualities in terms of the half-value layer (HVL) [1].

The conventional method to determine the HVLs consists of the addition of absorbers of known thickness to the radiation beam, which is a time consuming process. Therefore, this procedure is not realized by the users with the necessary frequency. An alternative for the HVL determinations is the utilization of tandem systems that provide an accurate response, and it is a faster verification [2-3].

A tandem system usually consists of two different dosimeters with specific characteristics that can be used to determine the effective energy of a radiation field. The fundamental principle of this system is the difference in the energy dependence of the dosimeters. This kind of system was initially used with thermoluminescent dosimeters [4-5]. At the Calibration Laboratory at Instituto de Pesquisas Energéticas e Nucleares (IPEN), some tandem systems were proposed using ionization chambers [2,6-9]. Some of the ionization chambers of those systems were developed by the metrology group of IPEN.

In this work a double faced ionization chamber was utilized as a tandem system [9]. This ionization chamber was tested using international recommendations [10] to verify its response stability. The objective of this work was to show the applicability of this ionization chamber in a quality control program to verify the constancy of the beam qualities of an X-ray equipment of low energies (25 to 50 kV).

* Presenting author, E-mail: mairaty@ipen.br

## 2. Materials

For this study, a special double-faced parallel plate ionization chamber, developed at IPEN was utilized. This ionization chamber was connected to a PTW (Physikalisch-Technische Werkstätten) electrometer, model MULTIDOS. The ionization chamber was described by Costa and Caldas [9]. This chamber presents two sensitive volumes and the difference between them is the material of its inner electrodes. One has graphite electrodes (Face G) and the other has aluminium electrodes (Face A). Because of this specific design of the ionization chamber it can be called a tandem ionization chamber. As the tandem chamber was stored for a period of time, it was initially opened and cleaned. The correction factors for the energy dependence of the ionization chamber response were determined again.

An industrial X-ray generator with standardized beam qualities, Rigaku-Denki, model Geigerflex, with a Philips tube, model PW 2184/00, inherent filtration of 1 mmBe and maximum operating voltage of 60 kV was utilized in this work. The characteristics of the radiation qualities of this X-ray equipment are presented in Table 1. The reference system for these beam qualities is a secondary standard plane-parallel ionization chamber, PTW, model M23344, traceable to the German primary laboratory Deutscher Kalibrierdienst, DKD, Germany, named S in this work, and an electrometer, PTW, model UNIDOS.

A check source device of $^{90}Sr$ + $^{90}Y$, PTW, model 8921, with nominal activity of 33.3 MBq (1988), was utilized to perform the stability tests of the ionization chamber response.

**Table 1:** Radiation beam characteristics of the Rigaku-Denki X-ray equipment, defined at a focus-detector distance of 50 cm at the Calibration Laboratory of IPEN

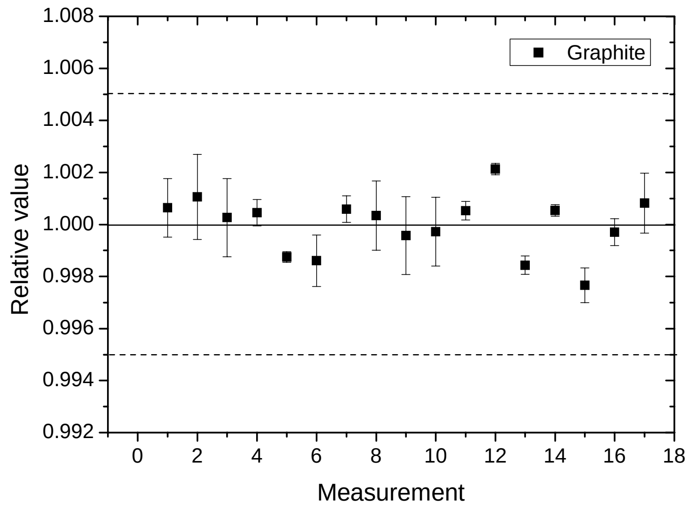
| Radiation Quality | Tube Potential (kV) | Additional Filtration (mmAl) | Half-value Layer (mmAl) | Effective Energy (keV) | Air Kerma Rate (mGy/min) |
|---|---|---|---|---|---|
| T25 | 25 | 0.44 | 0.25 | 14.3 | 400 |
| T30 | 30 | 0.54 | 0.36 | 15.5 | 421 |
| T40 | 40 | 0.68 | 0.53 | 17.7 | 592 |
| T45 | 45 | 0.73 | 0.59 | 18.7 | 562 |
| T50 | 50 | 1.02 | 0.89 | 21.2 | 464 |

## 3. Results

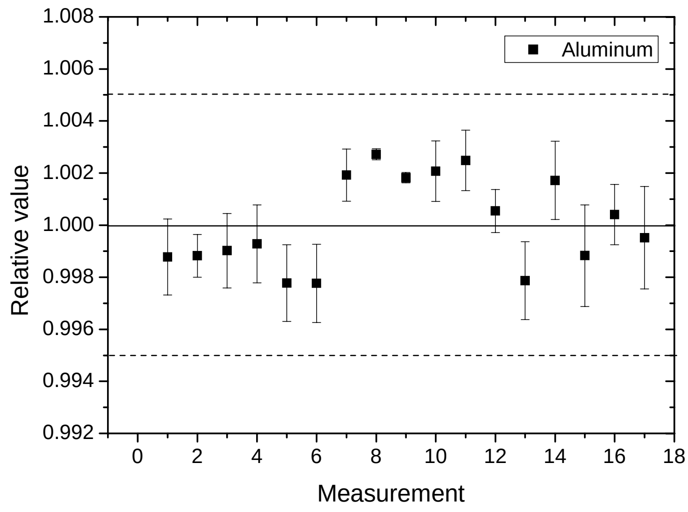
### 3.1 Response stability tests

To check the response stability of the tandem ionization chamber, the short- and medium-term response stabilities and the leakage current before and after irradiation were tested for both sides of the ionization chamber.

The short-term stability test consists of the evaluation of ten consecutive measurements of the chamber response. The standard deviation of these measurements presented a maximum value of 0.1% for Face G and 0.2% for Face A, which are both lower than the recommended value of 0.3% [10]. The short-term stability test was performed 15 times, and the medium values of the ten measurements are shown in Figure 1 that constitutes the medium-term stability test. For this test the tandem chamber response taken during a period of time shall not vary over 0.5% [10]. As can be seen in Figure 1, the ionization chamber response maximum variation was 0.2% for Face G and 0.3% for Face A, and therefore within the recommended value. The leakage current measured during the whole test period, before and after irradiation, was always negligible for both chamber faces.




(a)




(b)

**Figure 1:** Medium-term stability test of (a) Face G and (b) Face A. The dashed lines represent the recommended limits of ±0.5% [10].

### 3.2 Energy dependence and tandem curve

In order to obtain the energy dependence of the tandem ionization chamber, both sides of the chamber were calibrated against the secondary standard ionization chamber (chamber S). The calibration coefficients obtained were normalized to the T30 beam quality, the HVL of 0.36 mmAl (Table 2 and Figure 2). As can be seen in Figure 2, Face G presents a flatter response (9%) in the tested energy range than Face A (21%). The error bars represent the standard deviation of ten measurements for each HVL determination.

The tandem curve was obtained from the ratio between the responses of Face G and Face A as a function of the HVL values, as shown in Figure 3. The values obtained during the chamber calibration were used to determine the tandem curve, which presented a good curvature: the higher the curvature of the tandem curve, the higher is the accuracy in the HVL determination. The error bars represent the uncertainty in the experimental values, calculated from the propagation of the standard deviations associated to the mean values obtained for each chamber face.

**Table 2:** Energy dependence of the tandem ionization chamber (Faces G and A) and the reference ionization chamber (S).

| Radiation quality | Correction factor normalized for T30 beam quality | | |
|---|---|---|---|
| | Chamber S | Face G | Face A |
| T25 | 1.01 ± 0.02 | 0.98 ± 0.04 | 1.07 ± 0.04 |
| T30 | 1.00 ± 0.02 | 1.00 ± 0.03 | 1.00 ± 0.03 |
| T40 | 0.99 ± 0.02 | 1.03 ± 0.04 | 0.94 ± 0.03 |
| T45 | 0.99 ± 0.02 | 1.04 ± 0.04 | 0.92 ± 0.04 |
| T50 | 0.99 ± 0.02 | 1.07 ± 0.02 | 0.88 ± 0.03 |

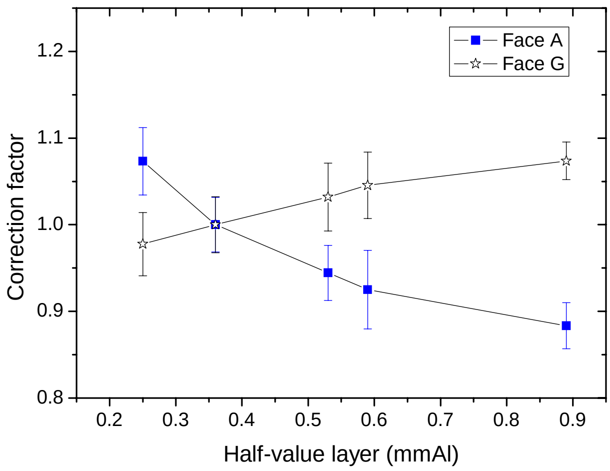



**Figure 2:** Energy dependence of the tandem ionization chamber, data normalized for the T30 beam quality.

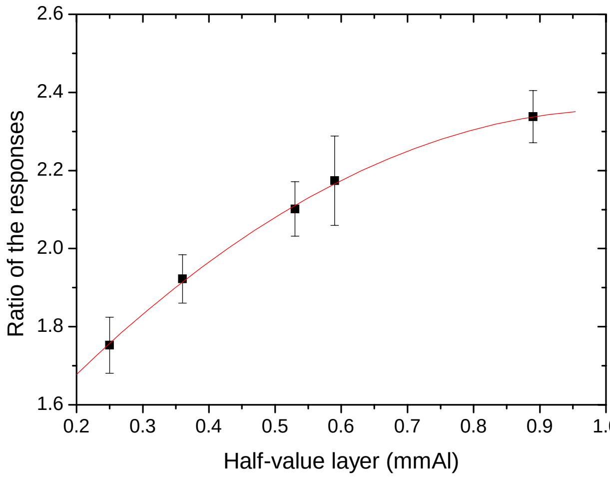



**Figure 3:** Tandem curve of the ionization chamber.

### 3.3 Constancy of beam quality

For the verification of the constancy of the beam quality, a constancy index was determined. This constancy index, CI(%), can be calculated as shown in Equation 1:

$$CI(\%) = \left| \frac{R - R_{ref}}{R_{ref}} x100 \right| \quad (1)$$

where $R$ is the ratio of the responses of Face G and Face A, and the index (*ref*) refers to the mean value of the first five measurements of the ratio responses of Face G and Face A. In Brazil, a maximum variation of ±3% of the constancy index is recommended [11]. The beam qualities of the X-ray equipment were tested 10 times and the results are shown in Figure 4. The error bars were determined from the error propagation of all measurements used in Equation 1. As can be seen in Figure 4, the maximum variation in these measurements was 1% (T25); in all cases the results were within the recommended value of ±3% [11].

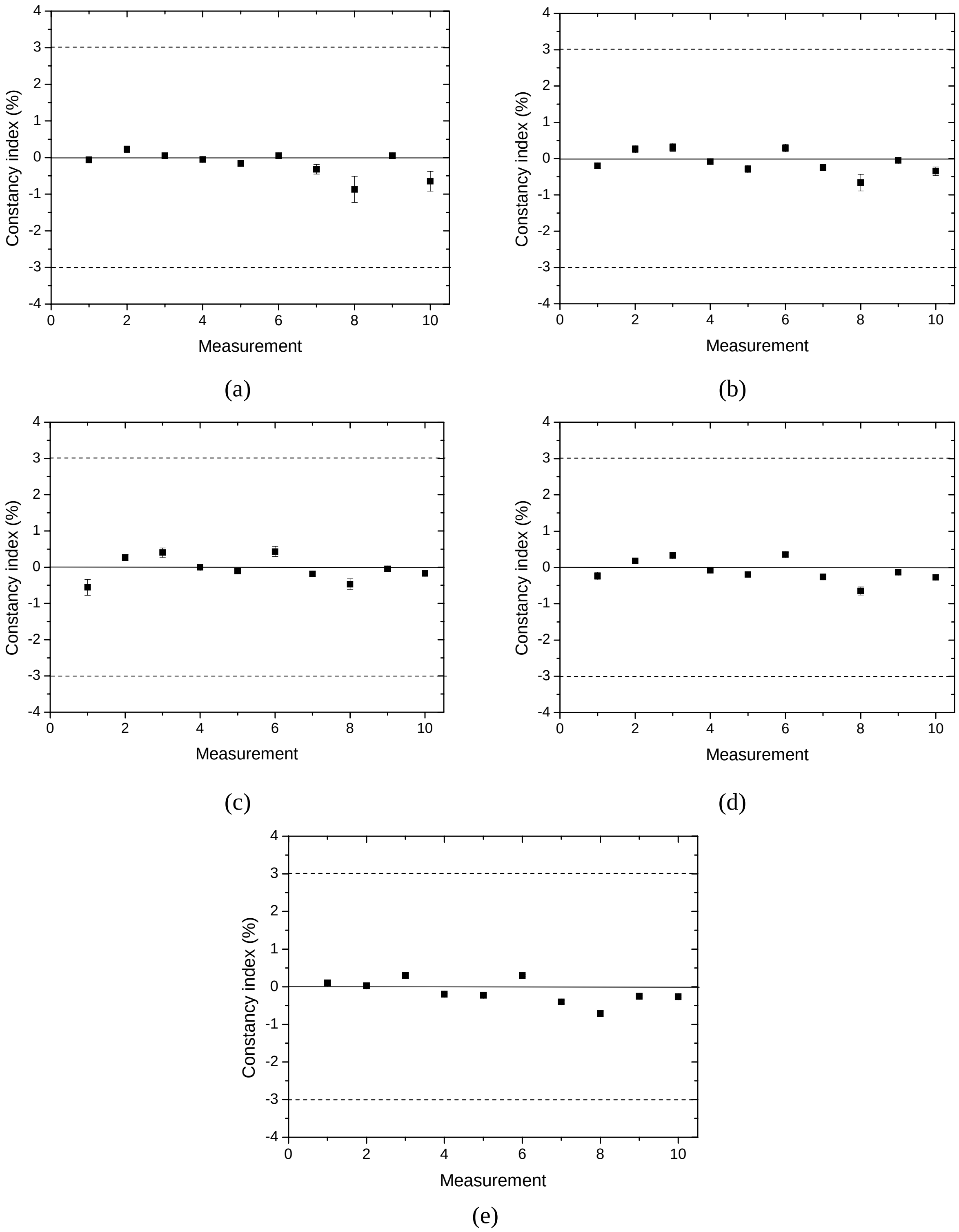



**Figure 4:** Constancy checks of the beam qualities: (a) T25, (b) T30, (c) T40, (d) T45 and (e) T50.

## 4. Conclusions

The response stability of the tandem ionization chamber is within the recommended limits and its tandem curve shows a good curvature, which implies in accurate HVL determinations. The tandem ionization chamber presented good results for the constancy checks of the X-ray beam qualities. The methodology of the HVL determination using the tandem chamber showed to be faster than the conventional method. Because of the simplicity in the utilization of this HVL determination method, it allows more frequent confirmations.


## Acknowledgements

The authors wish to thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil, for partial financial support.


## REFERENCES


[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of dosimeters used in radiotherapy, Technical Report Series No 374, IAEA, Vienna (1994).

[2] CALDAS, L.V.E., A sequential tandem system of ionisation chambers for effective energy determination of X radiation fields, Radiat. Prot. Dosim. 36 (1991) 47.

[3] MAIA, A.F., CALDAS, L.V.E., A simple method for evaluation of half-value layer variation in CT equipment, Phys. Med. Biol. 51 (2006) 1595.

[4] SPURNY, Z., MILU, C., RACOVEANU, M., Comparison of X-ray beams using thermoluminescent dosemeters, Phys. Med. Biol. 18 (1973) 276.

[5] Da ROSA, L.A.R., NETTE, H.P., Thermoluminescent dosemeters for exposure assessment in gamma or X-radiation field with unknown spectral distribution, Appl. Radiat. Isot. 39 (1988) 191.

[6] ALBUQUERQUE, M.P.P., CALDAS, L.V.E., New ionization chambers for beta and X-radiation, Nucl. Instrum. Meth. A 280 (1989) 310.

[7] SARTORIS, C.E., CALDAS, L.V.E., Application of a dosimetric methodology of therapeutic X-ray beams with a tandem system, Radiol. Bras. 34 (2001) 337.

[8] COSTA, A.M., CALDAS, L.V.E., A special ionisation chamber for quality control of diagnostic and mammography X ray equipment, Radiat. Prot. Dosim. 104 (2003) 41.

[9] COSTA, A.M., CALDAS, L.V.E., Response characteristics of a tandem ionization chamber in standard X-ray beams, Appl. Radiat. Isot. 58 (2003) 495.

[10] INTERNATIONAL ELECTROTECHNICAL COMMISSION, Medical electrical equipment. Dosimeters with ionization chambers as used in radiotherapy, Report 60731, IEC, Geneva (1997).

[11] BRASIL. MINISTÉRIO DA SAÚDE. INSTITUTO NACIONAL DO CÂNCER. TEC DOC-1151: Aspectos físicos da garantia da qualidade em radioterapia. Rio de Janeiro: INCA, (2000).