Characteristics of a tandem system of ionization chambers in X-ray beams, mammography level

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Abstract: Performance check tests of standard equipment are very important in dosimetric procedures. The good performance has to be assured not only for the dosimetric equipment, but also for the characteristics of the X-ray beams utilized in calibration laboratories. Two parallel plate ionization chambers (inserted in slab phantom) recently assembled at IPEN were studied in relation to their operational characteristics for use in the quality control of X-ray beams, mammography level. The chambers have only one difference: one has an inner collecting electrode made of graphite and the other, of aluminum. These ionization chambers make up a tandem system, which may be employed to verify X-ray beams energy constancy, by the confirmation of half-value layers and effective energies, also allowing the determination the air kerma rates. The ionization chambers presented good results for the operational tests (saturation, ionic recombination, polarity effects, etc.), as recommended internationally.

Keywords: ionization chamber, calibration, tandem system.

INTRODUCTION

There is a worldwide concern in order to understand, quantify and avoid health damage related to the utilization of ionizing radiation. Damage prevention for workers, patients and the general public that are submitted to diagnostic radiology procedures and radiotherapy treatments is achieved by keeping radiation use under acceptable (and/or controllable) limits.

For this reason, it is advisable to know very well the beams characteristics before its utilization at radiotherapy and radiation diagnostic clinics, and laboratories for radiation detectors calibration. Then, a quality control program for diagnostic radiology and therapy procedures may minimize dose application to the patient and improve accuracy in determining related absorbed doses.

Regarding this subject, the International Atomic Energy Agency has published several recommendations and procedures related with calibration of radiation beams and radiation detectors, and the determination of absorbed doses using different types of instruments and radiation.

Many papers have been published on the design and the construction of ionization chambers then appropriate for the present needs. These works take into account international recommendations related to the ionization chamber performance, and they also aim easy procedures for routine data acquisition.

Ankerhold et al (1999) developed the first prototype of a parallel plate ionization chamber as a secondary standard system, optimized to achieve a nearly constant response for personal dose equivalent measurements in a phantom. Vivolo (2006) extended this work by assembling two similar ionization chambers, however, with one difference: one ionization chamber has the inner collecting electrode made of graphite and the other has the inner collecting electrode made of aluminum.

The similar ionization chambers with different inner collecting electrode materials make up a tandem system, which consists of two dosimetric systems with different energy dependence that allows the determination of characteristics as the effective energy and air kerma rates of X-ray beams. The tandem system also allows the confirmation of the half-value layers or effective energies in X radiation beams, previously determined by the conventional method using well known absorber layers. The tandem system is a very simple measurement system: it is only necessary to study the ratio of the responses of the dosimeters obtained in X-ray beams to verify their energy constancy.

These ionization chambers were initially assembled to be used as secondary standard systems for calibration at radioprotection level, and this objective has been achieved successfully. In this work, the objective was to verify these chambers performance characteristics at mammography level X rays beams.

MATERIALS AND METHODS

Two parallel plate ionization chambers inserted in slab phantoms (with dimensions of 30 x 30 x 12 cm), assembled at IPEN, made of different inner collecting electrode materials (graphite and aluminum) with sensitive volume of 10 cm^3, were coupled to a PTW electrometer (model Unidos) that allows the polarization voltage to vary from -400 V to +400 V. An X-ray system, a Rigaku Denki generator, coupled to a Philips tube, model PW 2184/00, with 1 mm of Beryllium window was utilized. A Radcal 9015 ionization chamber, model 10X5-6M with sensitive volume of 6 cm^3 was the reference detector system.

RESULTS AND DISCUSSION

The ionization chambers behaviors were studied in relation to their saturation curves, ions collection efficiencies, polarity effects and linearity of response due to air kerma variation, following international recommendations (IEC 60731, (1997), and IEC 61674, (1997) and IAEA TRS398, (2000).

Saturation Curves

When an ionization chamber is subjected to a radiation field, the measured ionizing current initially increases with the voltage, and then it stabilizes. The initial ionization current increase is caused by the incomplete ion collection at low voltage values. Positive and negative ions tend to recombine themselves, unless they are quickly separated by an electric field. This recombination may be minimized by increasing the electric field. If the voltage is increased excessively, ions may reach enough energy to produce ionization from collision with the gas molecules, which would result in a fast ions multiplication, leading to a strong dependence between the current and the voltage. Therefore, the ionization chamber has to be utilized at the saturation region, so that little modifications at voltage do not result in changes in the ionization current.

The ionization chambers assembled at IPEN were positioned successively with the ionization chambers sensitive volume centers as reference, perpendicularly to the incident radiation beam, at 1 m from the focal spot of the X-rays tube. Varying the polarization voltage in steps of 50 V (from -400 V to +400 V), the ionization chambers were irradiated in the mammography X-rays field produced with the tube potential of 35 kV and current of 30 mA. Sets of ten consecutive ionizing current readings were taken at each polarization voltage value. The uncertainties presented by the reading sets did not exceed ±0.15% for both chambers. Afterwards, the saturation curves were plotted for both ionization chambers, shown in Figures 1 and 2.

These saturation curves (Figs. 1 and 2) showed an adequate behavior, with the saturation achieved immediately above 50 V. This result shows that these ionization chambers can be used with the most common electrometers, which have polarization voltages above 50 V.

Ion Collection Efficiency

From the data obtained at the saturation tests, the ion collection efficiency was determined for each ionization chamber. The polarization voltages of 200 V and 400 V (positive and negative) were used for the calculation (method of two voltages, IEC 60731, 1997; and IAEA TRS398, 2000) by the equation

$$K_S = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)},$$

where M_1 and M_2 are the ionization currents measured at the polarization voltages V_1 and $V_2 = V_1/2$. The ion collection efficiency determined by this method was better than 99.9% for both ionization chambers, for negative and positive polarization voltages, as shown in Table 1. This result demonstrates that the losses by ionic recombination are below 1%, as recommended by IEC 60731, 1997; and IAEA TRS398, 2000).

Table 1 - Ion Collection Efficiency of both ionization chambers for the tube potential of 35kV (mammography level)

Ionization chamber with inner collector electrode made of	Ion Collection Efficiency	
	Positive Polarization Voltage	Negative Polarization Voltage
Aluminum	1.0004	1.00006
Graphite	0.9996	0.9994

Polarity Effects

Sometimes the charge collected by an ionization chamber changes when the polarity voltage is inverted. The polarity effect must be lower than 1% (IEC 60731, (1997), and IEC 61674, (1997). It means that the ratio between the charges collected with maximum voltage values (positive and negative) may vary from 0.99 to 1.01. The ionization chamber with graphite electrode presented polarity effect results within the recommended range for all polarization voltage values (Table 2). The ionization chamber with aluminum electrode presented polarity effect results within this range for most polarization voltage values; the polarity effect for 50 V and 100 V presented results slightly out of the recommended range, not resulting in a problem, once the operational polarization voltages are usually higher than 200 V (Table 3). The operational voltage was chosen to be 400 V.

Table 2 – Polarity effect of the ionization chamber with inner collector electrode made of graphite.

Polarization Voltage (V)	Charge (nC)	Ratio (Q+ / Q-)
+50/-50	1.770/1.754	1.009
+100/-100	1.772/1.762	1.006
+150/-150	1.770/1.761	1.005
+200/-200	1.768/1.759	1.005
+250/-250	1.767/1.758	1.005
+300/-300	1.767/1.757	1.006
+350/-350	1.766/1.757	1.005
+400/-400	1.765/1.757	1.005

Table 3 – Polarity effect of the ionization chamber with inner collector electrode made of aluminum.

Polarization Voltage (V)	Charge (nC)	Ratio (Q+ / Q-)
+50/-50	2.814/2.779	1.0124
+100/-100	2.817/2.787	1.0108
+150/-150	2.817/2.790	1.0097
+200/-200	2.818/2.792	1.0095

+250/-250	2.818/2.792	1.0093
+300/-300	2.819/2.793	1.0093
+350/-350	2.821/2.792	1.0104
+400/-400	2.822/2.792	1.0108

Linearity of the Ionization Chamber Response

The ionization chamber response variation due to air kerma rate was studied by varying the current at the X-rays tube between 2 mA and 55 mA, at the tube potential of 35 kV. The polarization voltage of 400 V was used. Sets of ten consecutive readings were taken at each current value. Both ionization chambers showed the expected results, presenting a linear behavior due to tube current variation, as shown in Figures 3 and 4. It also means that the X-rays generator system presented a stable behavior.

Energy Dependence

The chamber was irradiated at 1 m of distance from the focal spot of the X-rays tube. The air kerma calibration coefficients were determined from the measurements obtained with the secondary standard ionization chamber, Radcal 9015, model 10X5-6M, with sensitive volume of 6 cm^3. The characteristics of the utilized beams, used and the calibration coefficients are listed in Table 1.

Table 4 - Characteristics of the Rigaku-Denki X-rays system at mammography level.

Radiation Quality	Tube Potential (kV)	Half-value Layer (mmAl)	Air kerma Rate (mGy.min^{-1})	Calibration Coefficient (aluminum) x 10^5 (Gy/C)	Calibration Coefficient (graphite) x 10^5 (Gy/C)
M 25	25	0.33	32.9 $\pm$ 1.9	57.8 $\pm$ 3.4	87.4 $\pm$ 5.3
M 28	27,5	0.34	39.3 $\pm$ 2.3	56.3 $\pm$ 3.3	84.6 $\pm$ 5.1
M 30	30	0.35	45.1 $\pm$ 2.7	54.3 $\pm$ 3.2	82.1 $\pm$ 4.9
M 35	35	0.38	59.5 $\pm$ 3.6	49.2 $\pm$ 2.9	75.8 $\pm$ 4.6
M 25x	25	0.58	1.46 $\pm$ 0.08	35.4 $\pm$ 2.1	58.0 $\pm$ 3.5
M 28x	27,5	0.61	2.02 $\pm$ 0.12	32.1 $\pm$ 1.9	52.4 $\pm$ 3.1
M 30x	30	0.67	2.78 $\pm$ 0.16	29.2 $\pm$ 1.7	49.5 $\pm$ 3.0
M 35x	35	0,85	4.70 $\pm$ 0.28	21.9 $\pm$ 1.3	42.5 $\pm$ 2.6

* The tube current was 30 mA.

Tandem System Formation

Since 1963, thermoluminescent tandem systems (Kenney et al, 1963) have been used to verify the constancy of X-ray beams. A tandem system consists of two individual dosimeters with different energy dependence that allows the determination of characteristics as effective energy, exposure and air kerma rate of unknown X-ray beams (Dewerd, 1999). Studies have been realized at the Calibration Laboratory of Instituto de Pesquisas Energéticas e Nucleares, including tandem systems composed by different ionization chambers [(Caldas, 1991-1992); (Costa, 2003].

The tandem system is a very easy measurement system: it is only necessary to use the ratio of the responses of the dosimeters obtained in X-ray beams to verify their constancy. One ionization chamber was developed with inner graphite collecting electrode and the other with inner aluminum collecting electrode. The two ionization chambers can be used as a tandem system. The different energy response of the two ionization chambers allowed the development of the tandem system that is very useful for the checking of the constancy of beam qualities. Figure 5 and 6 presents the tandem curve for X-rays beam qualities, mammography level, direct and attenuated beams.

CONCLUSIONS

Both ionization chambers showed a satisfactory performance in the X-ray beams mammography level. The results obtained show that the ionization chambers can be used as a work reference system at the Calibration Laboratory of IPEN, inclusive for intercomparison programs among laboratories. The main advantage of this type of tandem system is no need the use of expensive measurement systems; and only with the use of two ionization chambers allow to verify the X-ray beam constancy of the calibration set-up in calibration laboratories, clinics, etc. too, with low cost, in a very simple and quick verification.

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REFERENCES

ANKERHOLD, U.; BEHRENS, R.; AMBROSI, P. A prototype ionisation chamber as a secondary standard for the measurement of personal dose equivalent, $H_p(10)$, on a slab phantom. ***Radiat. Prot. Dosim.,*** v. 86, n. 3, p. 167-173, 1999.

CALDAS, L. V. E. A sequential Tandem system of ionization chambers for effective energy determination of X radiation fields. ***Radiat. Prot. Dosim.,*** v. 36, n. 1, p. 47-50, 1991.

CALDAS, L. V. E.; ALBUQUERQUE, M. P. P. Calibration of parallel plate ionization chambers in different kinds of radiation. ***Proceed. 8th International Congress of IRPA,*** Montreal, Canada, 17-22 May 1992, p. 144-147, 1992.

COSTA, A. M. da.; CALDAS, L. V. E. Response characteristics of a Tandem ionization chamber in standard X-ray beams. ***Appl. Radiat. Isot.***, v.58, n.4, p.495-500, 2003.

COSTA, A. M. da.; CALDAS, L. V. E. A special ionization chamber for quality control of diagnostic and mammography X-ray equipment. ***Radiat. Prot. Dosim.***, v.104, n.1, p.41-45, 2003.

DEWERD, L. A.; WAGNER, L. K. Characteristics of radiation detectors for diagnostic radiology. ***Appl. Radiat. Isot.***, v. 50, p. 125-136, 1999.

INTERNATIONAL ATOMIC ENERGY AGENCY. ***Absorbed dose determination in external beam radiotherapy: implementation of the international code of practice on dosimetry in radiotherapy (TRS 398): review of testing results.*** Jun. 2005 (Final Report) IAEA, Vienna, 2000, (IAEA-TECDOC-1455).

INTERNATIONAL ELECTROTECHNICAL COMMISSION. ***Medical electrical equipment. Dosemeters with ionization chambers as used in radiotherapy.*** IEC, Geneva, Jul. 1997. (IEC 60731).

INTERNATIONAL ELECTROTECHNICAL COMMISSION. ***Medical electrical equipment. Dosemeters with ionization chambers and/or semi-conductor detectors as used in X-ray diagnostic imaging.*** IEC, Geneva, Oct. 1997. (IEC 61674).

KENNEY, G. N.; CAMERON, J. R. ***X-ray beam quality measurements utilizing TL dosimeters.*** Progress Report, AEC Contract No AT 11-1-1105-TID-19112,1963.

VIVOLO, V. ***Desenvolvimento de um sistema de referência para determinação do equivalente de dose pessoal e da constância de feixes de radiação-X.*** São Paulo: 2006. Tese (Doutorado) - Instituto de Pesquisas Energéticas e Nucleares, Universidade de São Paulo .

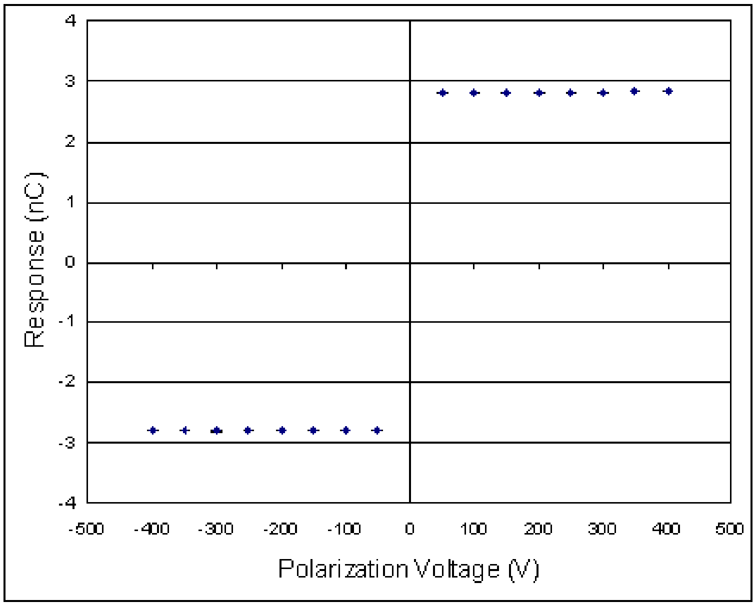

Figure 1 – Saturation curve for the ionization chamber with inner electrode made of aluminum.

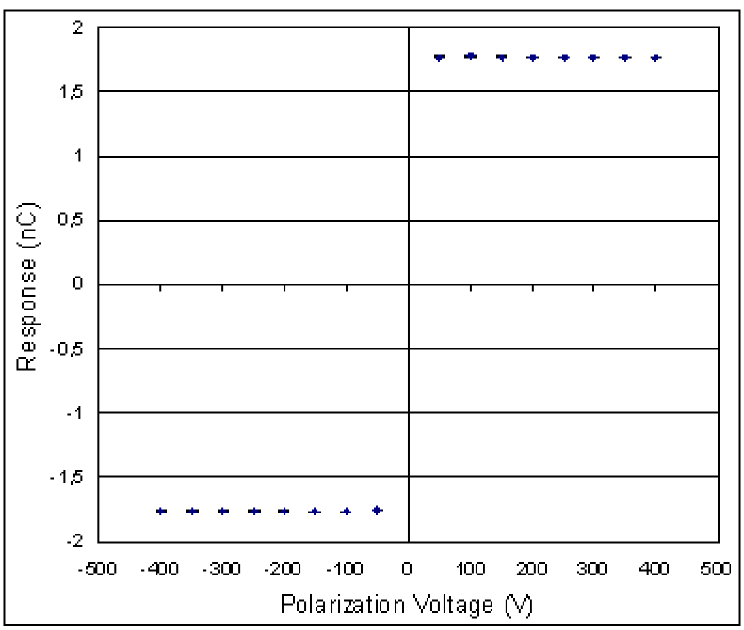

Figure 2 – Saturation curve for the ionization chamber with inner electrode made of graphite.

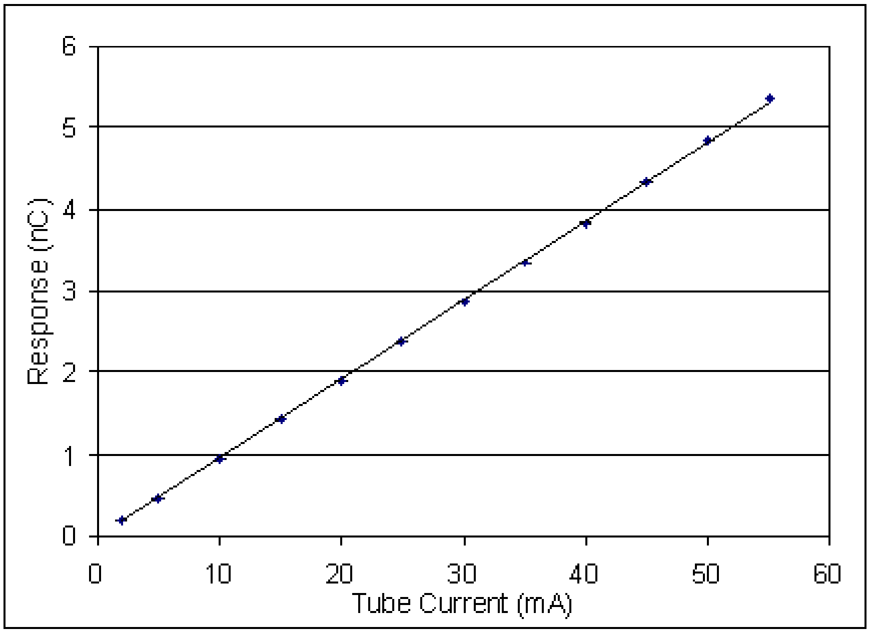

Figure 3 – Linearity of the response of the ionization chamber with inner electrode made of aluminum versus X-rays tube current.

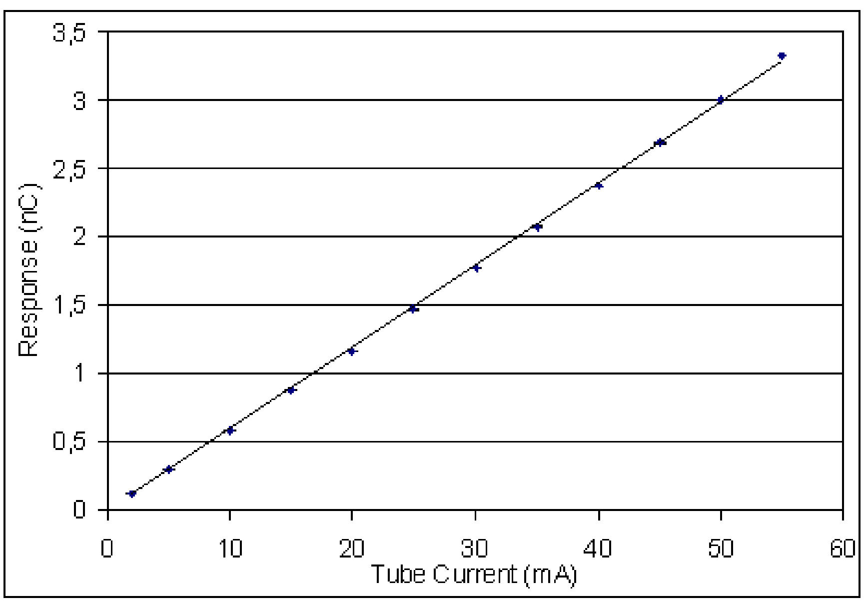

Figure 4 – Linearity of the response of the ionization chamber with inner electrode made of graphite versus X-rays tube current.

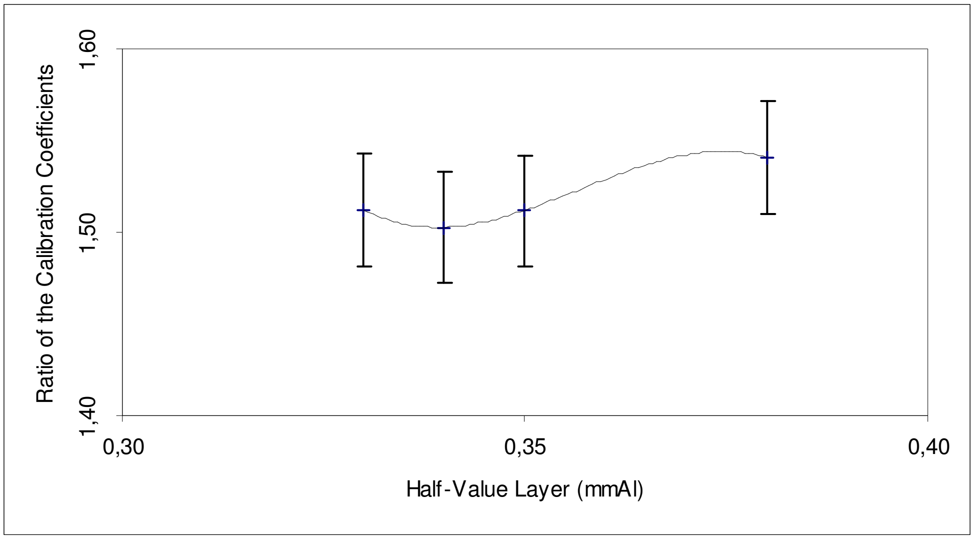

Figure 5 – Tandem curve for X-ray beams, mammography level, direct beams, of the ionization chambers with inner collector electrodes of aluminum and graphite.

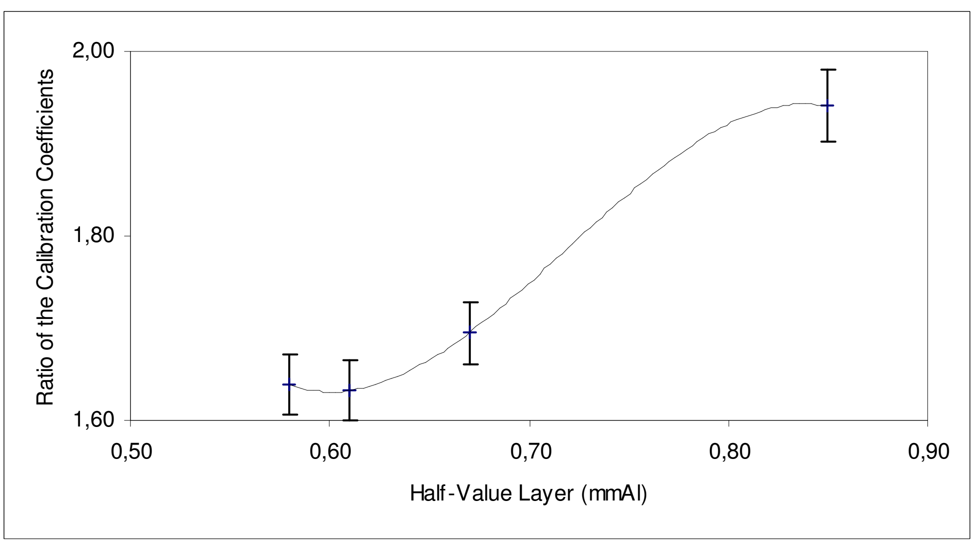

Figure 6 – Tandem curve for X-ray beams, mammography level, attenuated beams, of the ionization chambers with inner collector electrodes of aluminum and graphite.