Original Article

COMPARISON OF ABSORBED DOSE TO AIR CALIBRATION FACTORS FOR A PARALLEL PLATE IONIZATION CHAMBER*

Roseli T. Bulla[1], Linda V.E. Caldas[2]

* Study developed at Instituto de Pesquisas Energéticas e Nucleares (IPEN), Comissão Nacional de Energia Nuclear, São Paulo, SP, Brazil.

1. Master in Sciences, Nuclear Technology.

2. Doctor in Science, Nuclear Physics.

Mailing address: Dra. Linda V.E. Caldas. Avenida Professor Lineu Prestes, 2242, Cidade Universitária. São Paulo, SP, Brazil, 05508-000. E-mail: lcaldas@ipen.br / rtbulla@ig.com.br

Received May 5, 2005. Accepted after revision August 27, 2005.

Abstract

OBJECTIVE: The objective of this study was to compare the absorbed dose to air calibration factors determined in gamma (^{60}Co) and electron beams. MATERIALS AND METHODS: An irradiator with a ^{60}Co source and a Varian, Clinac 2100C linear accelerator with photon and electron beams were utilized. One thimble-type and three parallel-plate ionization chambers were tested. RESULTS: The measurement systems were submitted to preliminary tests (response stability and leakage current), with quite good results. The absorbed dose to air calibration factors were determined using four measurement systems and two types of phantoms. Results were obtained in compliance with the international recommendations. CONCLUSION: Absorbed dose to air calibration factors obtained for parallel plate ionization chambers, determined in ^{60}Co beams, at maximum, are 1.2% higher than the values obtained in high energy electron beams.

Keywords: Ionization chambers; Electron beams; Calibration of instruments.

INTRODUCTION

In measurements of absorbed dose in photon and electron beams, the most used dosimeter is the ionization chamber recommended by international protocols(1-11), due to its precision.

However, this type of chamber frequently does not have the calibration factor in terms of absorbed dose to air, $N_{D,ar}$, that relates the dose in the chamber gas and the collected charge. As a result, there is a need for a calibration aiming at having an indication of the most precise possible absorbed dose.

The determination of a $N_{D,ar}$ calibration factor for a parallel plate ionization chamber in ^{60}Co and electron beams, has not an assured traceability, but, in terms of N_K; the $N_{D,ar}$ value comes from this term and different procedures are recommended by dosimetry protocols considering that the international recommendation is the utilization of the TRS 381 protocol[10]. In this case, the $N_{D,ar}$ calibration factor for the parallel plate ionization chamber is obtained from a comparison of the absorbed dose to water value D_W determined in a high energy electron beam with a cylindrical reference chamber that has a known $N_{D,ar}$ value. A similar intercomparison with a phantom in a ^{60}Co gamma radiation beam also allows the $N_{D,ar}$ determination for this type of chamber, provided the appropriate correction for the difference between the chamber composition and the simulator (phantom) material is taken into consideration[12–16].

Several studies have estimated $N_{D,ar}$ values for several parallel plate ionization chambers and some of them show that the $N_{D,ar}$ value is higher in calibration with ^{60}Co beams in phantoms than with high energy electron beams[12,13]. So, this study was performed aiming at analyzing some clinical dosimeters calibration techniques, determining the calibration factor $N_{D,ar}$ for parallel plate ionization chambers in ^{60}Co gamma radiation beams of the Laboratório de Calibração de Instrumentos (Laboratory of Instruments Calibration) of Instituto de Pesquisas Energéticas e Nucleares (LCI-IPEN/São Paulo) and with high energy electron beams of Hospital Israelita Albert Einstein (HIAE).

MATERIALS AND METHODS

The calibration factors for parallel plate ionization chambers were determined employing four measurement systems: one cylindrical chamber (System A) as calibration factor in terms of air kerma and, consequently, as a calibration factor in terms of known absorbed dose to air, in ^{60}Co beams as a reference chamber, and three parallel plate chambers (systems B, C and D). All the chambers coupled with their respective electrometers as well as their specifications are shown in Table 1.

The parameters employed in the $N_{D,ar}$ value calculation are those included in the TRS 381 protocol (Table 2). Considering that a difference in calibration factors $N_{D,ar}$ values is expected between the two measurement methods (i.e., in ^{60}Co and electron beams), maximum attention should be paid aiming at minimizing errors and reproducing the recommended calibration conditions (Table 3) in compliance with the TRS 381 protocol.

The cambers positioning during procedure calibration in the LCI-IPEN and HIAE, was achieved with the assistance of laser beam systems lined up with the geometrical center of collimation systems. The chambers were positioned paralleling the beams and, aiming at reducing the random uncertainty in the charge measurement, this was done by means of ten consecutive readings corresponding to a measurement (taking the average value) in each voltage.

1. Radiation systems

Devices utilized were: a Philips Model XR2000 irradiator with a ^{60}Co source owned by LCI-IPEN; a Varian Clinac 2100C linear accelerator owned by the HIAE, with two photon beams with nominal energies of 6 and 18 MeV and five electron beams with nominal energies of 4, 6, 9, 12 and 16 MeV.

Environmental conditions, both in the LCI-IPEN and in the HIAE Department of Radiotherapy were controlled by means of air conditioning systems and dehumidifiers, with the support of a portable barometer, a digital thermometer and a hygrometer.

2. Measurement systems

Measurement systems were employed with ionization chambers coupled with their respective electrometers – Keithley, model 35614 EBS and Physikalisch-Technische Werkstätten (PTW) model 0002, whose specifications are found in Table 1. The reference system employed was a thimble-type model 2505/3A Nuclear Enterprises (NE) chamber series 2080, with traceability to the Laboratório Nacional de Metrologia das Radiações Ionizantes (LNMRI) (Rio de Janeiro).

The stabilization time of the systems constituted by chambers and their electrometers was 30 minutes before the measurements start.

3. Phantoms

The following simulators (phantoms) were utilized:

a) Water phantom produced by International Atomic Energy Agency (IAEA) measuring 30 x 30 x 30 cm^3, with acrylic (PMMA) walls and supports, owned by IPEN.

b) Solid phantom projected and produced in the IPEN, measuring 30 x 30 x 20 cm^3, with acrylic (PMMA) walls and supports, owned by IPEN.

c) PTW water phantom, measuring 40 x 40 x 40 cm^3, with acrylic (PMMA) walls and supports, owned by HIAE.

4. Electron beam parameters

The dosimetric properties of the clinical electron beams depend significantly on the energy spectrum (or energy distribution) This spectrum can be characterized by parameters like those for nominal energy of 16 MeV:

$(E_p)_0$ = 16.70 MeV, the most probable energy on the phantom surface;

$(\bar{E}_0)^2$ = 15.85 MeV, the average energy on the phantom surface;

$(E_p)_z$ = 11.19 MeV, the most probable energy in a reference depth;

E_z/E_0 = 0.706.

RESULTS

1. Calibration in a phantom in ^{60}Co beams

The parallel plate ionization chambers calibration was performed in ^{60}Co beams in the LCI-IPEN Philips irradiator.

Parallel plate chamber was calibrated in comparison with a cylindrical ionization chamber previously calibrated in a water phantom. The chambers were alternately positioned at a reference depth in a phantom, the $N_{D,ar}$ factor being a result from the comparison of the absorbed dose obtained with both chambers.

In this method, the effective point of measurement for the chambers is positioned at a 5 cm reference depth, i.e., the center of the frontal surface of the parallel plate chamber air cavity is defined in an effective point of the cylindrical chamber that is equal to 0.6 r in front of the chamber center (r is the cavity radius). However, for practical reasons, the center of the cylindrical chamber is placed at a depth of 5 cm and the correction for the displacement effect is made with a (P_{dis}^{Ref}) factor. This displacement factor guarantees that the center of any cylindrical ionization chamber used in a phantom is at a same depth, independently of the chamber diameter.

Figure 1 presents an experimental mounting diagram employed for measurements in ^{60}Co.

By means of the expression (1), $N_{D,ar}$ was obtained for the parallel plate ionization chamber.

$$N_{D,ar}^{pp} = N_{D,ar}^{Ref} \cdot \frac{M^{Ref}}{M^{pp}} \cdot \frac{P_{wall}^{Ref} \cdot P_{cel}^{Ref} \cdot P_{dis}^{Ref}}{P_{wall}^{pp}} \quad (1)$$

where:

$N_{D,ar}^{pp}$ = the chamber calibration factor in terms absorbed dose to air;

M^{Ref} and M^{pp}: ($M = \overline{M_o} \cdot f_{T,p} \cdot k_h \cdot P_S$) – readings of the cylindrical and parallel plate ionization chambers, respectively, for environmental reference corrections: pressure and temperature, ($F_{T,p}$), and air relative humidity (k_h); and for recombination correction (P_s);

P_{wall}^{Ref} : correction factor for attenuation of the reference cylindrical chamber wall;

P_{cel}^{Ref} : factor that takes into consideration the non-air equivalence of the material in the central electrode of an ionization chamber;

P_{dis}^{Ref} : 1 – 0,004.r, where r is the internal radius of the reference chamber in mm, for a ^{60}Co beam, according to Johansson *et al.*[14], an article on which the TRS 381 publication[10] is based.

P_{wall}^{pp} : parallel plate chamber wall attenuation correction factor.

In this procedure, the ionization chambers calibration factors are obtained in terms of air kerma and, consequently, the calibration factors in terms of absorbed dose to air ($N_{D,ar}$), are determined in ^{60}Co gamma radiation beams. The measurements performed in the IPEN Laboratory of Clinical Dosimeters Calibration for $N_{D,ar}$ (mGy/nC) determination employing PMMA water phantoms (as per Table 3), and the NE 2505/3A reference chamber of the system A with the systems B and C of LCI-IPEN and system D of HIAE are shown in Table 4.

For the measurements performed in the solid phantom, it is necessary to make a correction in the measure $M_{plást}$ reading, by means of the expression: $M^{pp} = M_{plast}^{pp} \cdot h_m$, where h_m = 1,00975 for a maximum reference depth. In the case of the ^{60}Co, 5 cm of water are necessary for obtaining the calibration factor in the reference conditions.

In Table 4 it is possible to observe that, when we simultaneously compare the two calibration methods (in water and in PMMA), the behavior of the system C parallel plate ionization chamber may be considered as excellent, with a variation between methods of only 0.05%. In comparison, system D presents a 2.1% variation. Each value corresponds to the average of several factors obtained in different dates, with an uncertainty rate not exceeding 1.4%.

In the calculation of the associated uncertainties, one has taken into consideration the equipment uncertainty in the system calibration in standard laboratory, environmental factors (temperature, pressure and air relative humidity), the uncertainties in the experimental measurement instrument, chambers stabilization time and perturbation factors for each type of radiation.

2. Calibration with electron beams

The parallel plate ionization chambers calibration was performed in electron beams with nominal energy of 16 MeV in a model Clinac 2100C linear accelerator owned by HIAE.

In this method, the measures were obtained in a solid phantom with the same methodology applied in water phantom, where parallel plate ionization chambers were calibrated in comparison with a previously calibrated cylindrical chamber and with a known $N_{D,ar}$ at a reference depth (for electron of 16 MeV nominal energy, 2 g/cm² in water). Corrections were made in $M_{plást}$ measures, with the solid plate phantom that should be of the same material as the parallel plate chamber and in reference conditions included in Table 3.

The Figure 2 presents an experimental mounting diagram for measurements in the linear accelerator.

The calibration factor $N_{D,ar}$ is calculated by means of the expression (1); the correction parameters employed in calculations, in compliance with the TRS 381, protocol are shown in Table 2.

In this procedure, the ionization chambers calibration factors were obtained in terms of absorbed dose to air, determined in electron beams with nominal energy of 16 MeV. Results of measurements performed in HIAE, $N_{D,ar}$ (mGy/nC), with the use of water and PMMA phantoms (Table 3), the system A NE 2505/3A reference chamber, the LCI-IPEN systems B and C and the HIAE system D, are shown in Table 4.

In this table, comparing the two calibration methods (in water and PMMA phantoms), the system C presents a percentage difference < 0.1% and the system D a maximum difference of 0.8%. The maximum uncertainty rate associated with the calibration factor is 1.8% in calibrations with parallel plate chambers, which is within the limit recommended by IAEA protocols [3,11].

DISCUSSION AND CONCLUSIONS

Results show that the $N_{D,ar}$ values for the parallel plate chambers determined in ^{60}Co beams are 1.2% higher than the value obtained in high energy electron beams. This difference in measurements series may be related, like in some published studies[12,13,17], but this hypothesis is promptly discarded, since, in the charge measurement, the maximum uncertainty between measurements is ±0.15% for each voltage. So, this discrepancy is assigned to parallel plate chambers walls attenuation correction factors supplied by the protocol, which should not be coherent when calibration in photon beams is performed.

McEwen *et al.*[18] have shown that Markus-type parallel plate ionization chambers responses are not very reliable in relation to other chambers in electron beams, due to the perturbation factor great variation of this type of chamber as a result of the E_Z energy, i.e., a great P_u variation may occur as a function of E.

The system C parallel plate ionization chamber behavior can be considered as excellent, with a percentage difference of only 0.05% between the two calibration methods employing two different phantoms.

This study results are perfectly in compliance with international recommendations suggested for calibration of this type of chamber in relation to the total uncertainty associated with the chamber calibration factor, in terms of absorbed dose to air in both ^{60}Co gamma radiation beams and electron beams.

Acknowledgements

The authors express their gratitude to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the partial financial support to the development of this project; to Mr. Marcos Xavier for the technical support; to Dr. Laura Natal Rodrigues for her important suggestions on this text; to Hospital Israelita Albert Einstein for the opportunity to utilize the linear accelerator; and especially to Dr. José Carlos Cruz, for the profitable discussions.

REFERENCES

1. A protocol for the determination of absorbed dose from high-energy photon and electron beams. Med Phys 1983;10:741–771.

2. Haybittle JL, Bradshaw AL, Burns JE, Morris WT, Pitchford WG. Code of practice for electron beam dosimetry in radiotherapy. Phys Med Biol 1985;30:1169–1194.

3. International Atomic Energy Agency. Absorbed dose determination in photon and electron beams. An international code of practice. Technical Reports Series No. 277. Vienna: IAEA, 1st ed. 1987, 2nd ed. 1997.

4. International Commission on Radiation Units and Measurements. Radiation dosimetry: electron beams with energies between 1 and 50 MeV. ICRU Report 35. Bethesda, MD: ICRU, 1984.
5. Procedures in external radiation therapy dosimetry with electron and photon beams with maximum energies between 1 and 50 MeV. Recommendations by the Nordic Association of Clinical Physics (NACP). Acta Radiol Oncol 1980;19:55–79.
6. Electron beams with mean energies at the phantom surface below 15 MeV. Supplement to the recommendations by the Nordic Association of Clinical Physics (NACP) 1980. Acta Radiol Oncol 1981;20:401–415.
7. Sociedad Española de Física Médica. Procedimientos recomendados para la dosimetria de fotones y electrones de energias compreendidas entre 1 MeV y 50 MeV en radioterapia de haces externos. Publicación n.1. Madrid, Spain: SEFM, 1984.
8. Sociedad Española de Física Médica. Suplemento al documento Procedimientos recomendados para la dosimetria de fotones y electrones de energias comprendidas entre 1 MeV y 50 MeV en radioterapia de haces externos. Publicación n.2. Madrid, Spain: SEFM, 1987.
9. International Atomic Energy Agency. Review of data and methods recommended in the international code of practice: IAEA Technical Reports Series No. 277, absorbed dose determination in photon and electron beams. Tec-Dos-897. Vienna: IAEA, 1996.
10. International Atomic Energy Agency. The use of plane parallel ionization chambers in high energy electron and photon beams. An international code of practice for dosimetry. Technical Reports Series No. 381. Vienna: IAEA, 1997.
11. IAEA Network of Secondary Standard Dosimetry Laboratories. Dose determination with plane-parallel ionization chambers in therapeutic electron and photon beams. Vienna: IAEA/WHO, 1999.
12. Kubo H. N_{gas} values of the memorial parallel-plate chambers determined in ^{60}Co and high-energy electron beams. Med Phys 1991;18:749–752.
13. Murali V, Meenaskshi S, Lakshmanam AV. Comparison of the calibration fator N_{gas} for a plane-parallel ionization chambers determined in ^{60}Co and high-energy electron beams. Phys Med Biol 1993;39:1503–1507.
14. Johansson KA, Mattsson LO, Lindborg I, Svensson H. Absorbed dose determination with ionization chambers in electron and photon beams with energies between 1 and 50 MeV. *In:* International Symposium on National and International Standardization of Radiation Dosimetry. Atlanta 1977. IAEA-SM-222/35;1978.

15. Mattsson LO, Johansson KA, Svensson H. Calibration and use of plane-parallel ionization chambers for the determination of absorbed dose in electron beams. Acta Radiol Oncol 1981;20:385–399.

16. Attix FH. A proposal for the calibration of plane-parallel ion chamber by accredited dosimetry calibration laboratories. Med Phys 1990;17:931–933.

17. Bjerke H, Järvinen H, Grimbergen TWM, *et al*. Comparison of two methods of therapy level calibration at ^{60}Co gamma beams. Phys Med Biol 1998;43:2729–2740.

18. McEwen MR, Williams AJ, DuSautoy AR. Determination of absorbed dose calibration factors for therapy level electron beam ionization chambers. Phys Med Biol 2001;46:741–755.

COMPARAÇÃO ENTRE FATORES DE CALIBRAÇÃO

Tabelas e Figuras

Table 1 Physical characteristics and codes of ionization chambers utilized in this study.

Characteristics	Ionization chambers			
Chamber	A	B*	C	D
Manufacturer	NE	IPEN	PTW	PTW
Type	Thimble	Parallel plates	Parallel plates	Parallel plates
Model	2505/3A	—	23.343	23.343
Series	2019	—	2395	1369
Nominal volume (cm^3)	0.6	0.056	0.055	0.055
Wall: material	Graphite	PMMA	PMMA	PMMA
thickness (g/cm^2)	0.065	—	—	—
Cavity radius (mm)	3.2	—	—	—
Electronic equilibrium cover: material	PMMA	PMMA	PMMA	PMMA
thickness (g/cm^2)	0.551	0.500	0.500	0.500
Eletcrode: diameter (mm)	—	6.0	6,0	6,0
spacing (mm)	—	2	2	2
Window: material	—	Mylar aluminized	Polietilene graphite	Polietilene graphite
thickness (mg/cm^2)	—	0.2	102	102
Guard ring width (mm)	—	0.7	0.2	0.2

* This system chamber is not impermeable and should be utilized only with solid phantom. The other systems have impermeable chambers and can be used with water and solid phantoms.

Table 2 Parameters employed in calculations.

Radiation	Correction factors	Ionization chambers		
		NE 2505	PTW 23.343	IPEN
^{60}Co	P_{wall}	0.9908	1.009 (in water) 1.006 (PMMA)	1.000 (PMMA)
	P_{cel}	1.0000	—	—
	P_{dis}	0.9872	—	—
Electrons	P_{wall}	1.0000	1.000	1.000
	P_{cel}	0.9980	—	—
	P_{cav}	0.9825	1.000	1.000

Table 3 Reference conditions for ^{60}Co gamma radiation beams and electron beams.

	^{60}Co (IPEN)	Elétrons (HIAE)
Water phantom – dimensions (cm^3)	30 × 30 × 30	40 × 40 × 40
Solid phantom – dimensions (cm^3)*	30 × 30 × 20	30 × 30 × 20
Radiation field (cm^2)	10 × 10	10 × 10
Source–chamber or surface–source distances (cm)	100	100
Reference depth in phantom (cm)	5†	2‡

* Solid phantom: set of PMMA plates measuring 30 × 30 × 1 cm^3 each; this material was chosen due to characteristics of model PTW/Markus parallel plate chamber (systems B and C). † In solid or PMMA phantoms this depth is equivalent to 4.74 cm, since 1 mm of water corresponds to 0.874 mm of PMMA. ‡ According to IAEA[11], corrected for plastic.

Table 4 Ionization chambers calibration factors in terms of absorbed dose to air, $N_{D,ar}$ (mGy/nC), determined in ^{60}Co and electron beams, in PMMA and water phantoms.

Systems	$N_{D,ar}$ (mGy/nC)			
	NE reference cylindrical chamber (system A)			
	^{60}Co		Electrons	
	Method in water	Method in PMMA	Method in water	Method in PMMA
B	—	312.71	—	317.19
C	473.27	473.52	467.83	468.06
D	448.46	439.05	455.84	452.35

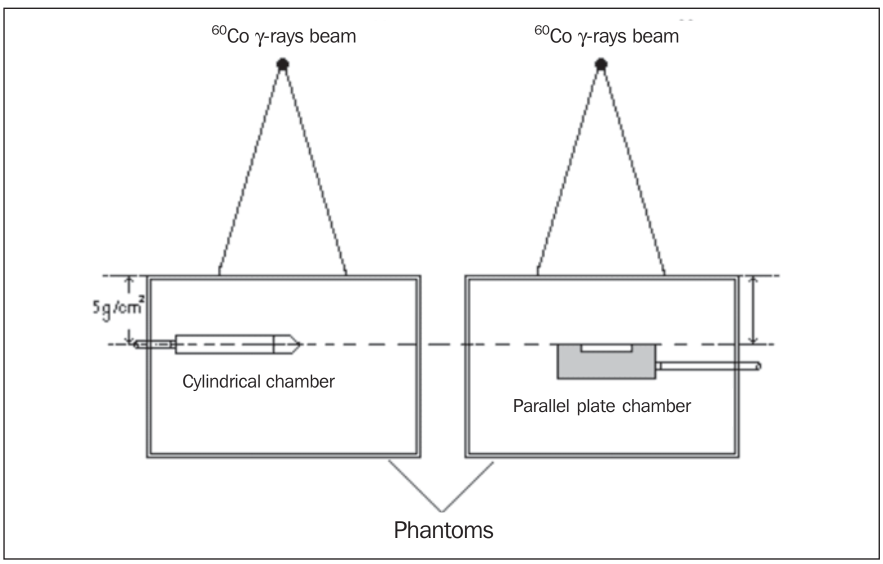

Figure 1. Experimental mounting in ^{60}Co beams.

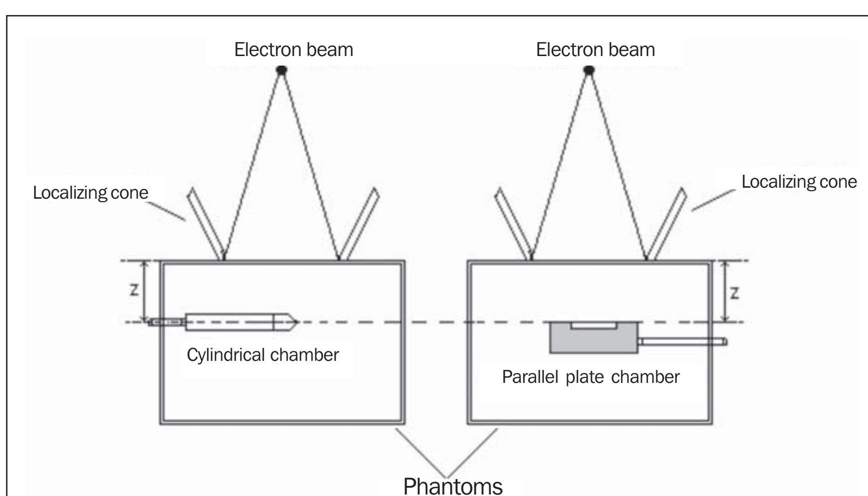

Figure 2. Experimental mounting in electron beams.