Pol J Med Phys Eng 2007;13(3):163-174.
PL ISSN 1425-4689
doi: 10.2478/v10013-007-0015-4
website: http://www.pjmpe.waw.pl

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Analysis of Calibration Coefficients of Plane-Parallel Markus Type Ionization Chambers Calibrated in Co-60 and Electron Beams

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The Polish Secondary Standard Dosimetry Laboratory is part of the IAEA/WHO network of such laboratories. The SSDLs are usually not equipped with accelerators generating high energy electron beams for calibration of dosimeters. The access to medical accelerators is seriously limited due to the heavy patient load. Therefore attempts are made to use Co-60 beams for calibration of plane parallel chambers and calculate the calibration coefficients for other radiation quality, the high energy electron beam.

The Markus ionization chambers, most frequently used in Poland, were analyzed in this study. The material was composed of 36 plane parallel chambers, from 20 radiotherapy centers in Poland, calibrated at the Polish SSDL during the period of 2003-2006. Before actual calibration, a number of chamber parameters were tested: long term stability, dark current, chamber sensitivity, non-linearity of dosimeter readings. Each chamber was calibrated in two different radiation beams: a) Varian 2300 accelerator 22 MeV electron beams, beam output 1.2 cGy/MU at 300 MU/min; b) Co-60 Theratron 780/403 unit with a Cobalt-60 source of 155700 GBq (4208 Ci) activity as of 6.01.2006. A reference dosimeter Keithley Instruments Inc. 6517-A with cylindrical ionization chambers Nuclear Enterprises Technology Limited type 2571 was used as the reference standard. The methods of IAEA Code of Practice for Dosimetry TRS 398 were adopted. The long term stability was analyzed on basis of calibration coefficients of 23 Markus chambers calibrated several times during the period 1994-2002.

Very small differences in calibration coefficients were detected between the two calibration methods used. They ranged between −0.3 to +0.5%, the mean value being 0.1%. A very good long term stability of calibration coefficients of Markus chambers, related to the mean value over the 7 year period, ranging between −0.5 to +0.3%, was recorded.

Very small differences in the results for the two calibration methods, confirmed by small standard deviations observed, indicate that these two calibration methods in the case of Markus-type plane parallel chambers may be used alternatively.

Key words: calibration, dosimetry, ionization chambers.

Introduction

The dose determination at radiotherapy departments has to be carried out with a radiotherapy field dosimeters with ionization chambers which have calibration certificate traceable to a secondary or primary reference dosimeter.

In Poland, the calibration of field dosimeters is carried out at the Secondary Standard Dosimetry Laboratory (SSDL) which is a part of he Medical Physics Department (MPD) of the Maria Skłodowska-Curie Memorial Cancer Centre and Institute of Oncology in Warsaw. The SSDL was created on the basis of the regulation of the Ministry of Health in 1966. In 1988, the laboratory was included into a network of such laboratories coordinated by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) – the IAEA/WHO Network of Secondary Standard Dosimetry Laboratories (SSDLs). As a result of that the Polish SSDL has the right to calibrate its dosimeters, used as secondary standards, at the IAEA dosimetry laboratory in Seilbersdorf (Austria).

In dosimetry of electron beams the plane-parallel ionization chambers have been recommended since mid-ninetieths [1, 2]. They are also recommended for measurements of percentage depth doses for photon beams because of their good spatial resolution in the direction of the chamber axis and their small active volume as compared with cylindrical ionisation chambers. For the majority of users plane-parallel chambers are the only means for measurements of depth doses in the build-up region. The cylindrical chambers are no good for these kind of measurements because they tend to overestimate the measured doses [3]. A device recommended for this kind of measurements is an extrapolation chamber, but it is in most cases not available for the radiotherapy department. In the build-up region there is no electron equilibrium, the extent of it is depending on construction parameters of the collimating system of a particular accelerator. The plane-parallel chambers, because of the additional electrode, (guard ring), are more effective in reducing the perturbation effects.

In Poland, the Markus type plane-parallel chambers are most popular. It is due to the fact that radiotherapy centres are mostly equipped with the therapeutic beams analysers “Mephisto” from PTW, which provide Markus chambers. As a result these chambers, or their substitutes, acquired in later years (PPC05 chambers), became most commonly used in Poland.

The calibration of plane-parallel chambers are recommended to be done in water, in an electron beam of maximum energy available, usually about 20 MeV, against a cylindrical chamber calibrated in a Co-60 photon beam – so called cross-calibration [7]. The calibration in a high energy electron beam guarantees that the perturbation factor of the reference cylindrical chamber is close to unity, and the same factor for the plane-parallel chamber is practically equal 1. However, calibration of the chambers in high electron beams of a linear accelerator, used in clinical irradiations, is a source of organizational problems. The accelerators are available for calibration only during the weekends.

Therefore, a study of calibrating the plane-parallel chambers Markus type in water, in a Co-60 beam, and recalculation of the calibration factor for different beam quality – electron beam of a given energy, were undertaken. Calibration coefficients determined both in high energy electron beams and in Co-60 photon beams have been compared.

At the initial stage of this study a long term stability of plane-parallel chambers’ calibration coefficients have been examined.

Material

The comparison of calibration coefficients determined in electron and in a Co-60 beam was based on the calibration protocols archived in the Polish SSDL during 2003-2006 period. 36 plane-parallel Markus type chambers (including 4 PPC05) from 20 Polish radiotherapy departments were calibrated in both beams (Table 1, columns a and b).

The long term stability were analysed on the basis of data for 23 plane-parallel chambers Markus type, calibrated during the period of 1994-2002 in electron beam. 63 calibration measurements were performed, 13 chambers were calibrated 2 times, 6 chambers 3 times, 3 chambers 4 times, one chamber 7 times (Table 2).

Table 1. Percentage deviations Δ [%] of the calibration coefficients established in the Co-60 beam, compared to the coefficients established in 22 MeV electron beam for Markus-type plane-parallel chambers

Radiotherapy Department code	Chamber number	Δ [%]
AA	249(PPCO5); 639; 248(PPCO5)	0.2; 0.3; −0.2
AC	2819	−0.1
AD	2482; 2773; 2811	0.3; 0.5; 0.3
AE	2782; 3623; 3623; 3624; 3624	0.1; 0.2; 0; 0.2; 0.2
AF	2821	−0.2
AG	440	0.2
AH	2038	0.2
AI	2812; 2775	0.2; 0.2
AJ	2772	−0.2
AK	2817	0.2
AM	246(PPCO5)	0.1
AN	2818	0.2
AO	2823; 2523; 2523	−0.1; 0.5; −0.2
AP	2820	−0.1
AR	2213; 2771	0; −0.3
AS	3403; 2809; 1821	−0.2; 0.1; −0.1
AT	3162; 3161	0; 0
AU	3099; 2822	−0.2; 0.3
AW	3523	0.1
AZ	176(PPCO5)	0.2
		Mean = 0.1%

Table 2. The results of the long-term stability of the calibration coefficient of the Markus-type plane-parallel chamber no. 1821.

Calibration date	Reference chamber no.	N_D	Δ [%]
February 1996	2465	47.81	−0.5
January 1997	2453	47.92	−0.3
June 1998	2453	48.06	0
October 1999	2453	48.18	0.3
February 2000	2458	48.15	0.2
May 2001	2458	48.09	0.1
October 2002	2458	48.12	0.1
	Mean	48.05	−0.01

Methods

Control measurements

Before the actual calibration, the following parameters were measured: (a) dark current of the dosimeter; (b) sensitivity of the ionization chambers in the control radioactive sources; (c) correction factors for non-linearity of dosimeter indications.

The dark current was measured with and without ionization chamber, for 15 min., in the charge mode.

The control source from Nuclear Enterprises Technology Limited, type 2503/3 No 2139, containing Sr-90, of 370 MBq (10 mCi) activity was used for sensitivity measurements of cylindrical chambers. The control source from PTW type 1892-1566, containing Sr-90, of 11.1 MBq (0.3 mCi) activity was used for sensitivity measurements of plane parallel chambers. In the calibration protocol issued by the Polish SSDL, a regular check of the sensitivity of the chambers in the Sr-90 control source, or in he Co-60 beam, or in an electron beam is suggested to the users [8].

The non-linearity of the indications was checked by connecting the dosimeter to the calibrator/source type 263 from Keithley Instruments Inc. The non-linearity correction factors – k_z, valid for all chambers used with a given electrometer, were determined within the range of electrometer indications of 1.00-100.00 nC, and were referred to the indication of 5.00 nC, for which the correction factor was set to $k_z = 1$.

Calibration in the electron beam

The calibration was performed at the Teletherapy Department of the Centre of Oncology in Warsaw. A linear accelerator Clinac 2300 from Varian, emitting electron beam of 22 MeV nominal energy, was used. The beam quality, defined as the in water depth of 50% maximum dose was: $R50 = 8.74$ g/cm^2. (The beam quality determination was the subject of separate measurement procedure). The beam output for electron beam was 1.2 cGy/MU, with accelerator setting of 300 MU/min.

The control dosimeter used as the reference was an electrometer from Keithley Instruments Inc. 6517-A No 815930 with cylindrical chambers from Nuclear Enterprises Technology Limited type 2571 No 2458 and No 2885 having calibration certificates.

The measurement conditions as of IAEA TRS 398 were adopted [7]. Two water phantoms were used: (a) until September 2004 a phantom from MedTech – USA, later (b) a phantom from PTW, type 4322. The distance between the source and phantom surface was SSD = 100 cm; field size at this distance was 10 cm × 10 cm. The middle point of the inner surface of the plane-parallel chamber was adopted as the reference point. The central point of the active volume of the cylindrical chamber was adopted as the reference point. During the measurements, the reference point of the plane-parallel chamber was placed in water at the reference depth $z_{ref} = 5.14$ g/cm^2. The reference point of the cylindrical chamber was placed deeper than z_{ref} by the half of the internal diameter of the chamber, at 5.29 cm depth. The precise positioning of the chambers in the phantom was possible due to the use of a special holder with a micrometer which allowed for the positioning accuracy of ±0.05 mm.

The calibration was carried out using the substitution method. During the calibration, the following correction factors were established: recombination factor ks and polarization factor k_p, for the reference chamber and for the calibrated plane-parallel chamber. The recombination correction factor was worked out using the two voltage method, for plane-parallel chamber voltage of +300 V and +100 V [9].

The calibration coefficient for absorbed dose in water $N_{D,W,Qcross}$ [cGy/nC] for the calibrated plane-parallel chamber was established by a comparison of its indications with the dose values measured with the reference dosimeter using the same number of monitor units (within the range of 150-250 MU).

The value of the absorbed dose in water for a given beam quality different form this used during the calibration, the user may calculate using the formula:

$$D_{w,Q} = M_Q \, N_{D,w,Qcross} \, k_{Q,Qcross} \text{ [cGy]} \tag{1}$$

where:

M_Q [nC] – the reading of the calibrated dosimeter, corrected for influence quantities;

$N_{D,w,Qcross}$ [cGy/nC] – the calibration coefficient provided in the calibration protocol of the SSDL, for calibration in water for the plane-parallel chamber, for beam quality Q_{cross}; in this case the Q_{cross} refers to the electron beam quality of R_{50} = 8.74 g/cm^2, used for the calibration at the SSDL;

$k_{Q,Qcross}$ – correction factor depending on the type of the chamber taking into account the difference between the beam quality of the user's beam and the beam used for the calibration.

Calibration in the Co-60 beam

The calibration was carried out in a Co-60 beam of the unit installed at the SSDL in Warsaw. A Theratron 780/403 Co-60 unit with a source of 155700 GBq (4208 Ci) activity as of January 2006 was used.

The same reference dosimeter as for the electron beam was used.

Dedicated computer systems were designed and installed at the calibration stand for dosimeter control and gathering the calibration data. The system made possible controlling the reference Keithley 6517-A electrometer and user's Unidos dosimeter form PTW, widely used in Poland.

The measurement conditions as of IAEA TRS 398 were adopted [7]. The calibrated plane-parallel chamber and reference cylindrical chamber were placed sequentially in a water phantom from PTW type 4322. The distance between the source and the chamber's reference points was 80 cm; the field size at this distance was 10 cm × 10 cm. During the measurements the reference points of the chambers were positioned in water at the reference depth of z_{ref} = 5.0 g/cm^2. The plane-parallel chamber was installed in PTW type 4322/U2 holder and initially irradiated for 30 min. in order to stabilize the indications.

The calibration coefficient for absorbed dose in water $N_{D,W,Qo}$ for the calibrated plane-parallel chamber was established by a comparison of its indications with the dose values measured with the reference dosimeter with the same Co-60 beam dose values of 1.50 Gy (beam output was about 1.0 Gy/min as of 2006) and provided in the calibration certificate.

The value of the absorbed dose in water for a given beam quality different form this used during the calibration, the user may calculate using the formula:

$$D_{w,Q} = M_Q N_{D,w,Qo} k_{Q,Qo} \text{ [cGy]} \tag{2}$$

where:

M_Q [nC] – the reading of the calibrated dosimeter, corrected for influence quantities;

$N_{D,w,Qo}$ [cGy/nC] – the calibration coefficient provided in the calibration protocol of the SSDL, for calibration in water for the plane-parallel chamber, for beam quality Q_0; in this case Q_0 corresponds to the Co-60 beam.

$k_{Q,Qo}$ – correction factor depending on the type of the chamber taking into account the difference between the beam quality of the user's beam and the beam used for the calibration; in this case Q_0 corresponds to the Co-60 beam [7].

Evaluation of the long-term stability of calibration coefficients

For the evaluation of the long-term stability of the calibration coefficients an electron beam was used. The measurement system followed the IAEA TRS 277 [10]. The measurements were carried out in a plastic slab phantom (PMMA) from PTW, in the substitution mode. The reference dosimeter used was an electrometer from Keithley Instruments Inc. No 64099 with cylindrical ionisation chambers from Nuclear Enterprises Technology Limited type 2571, No 2465, No 2453 and No 2458. The stability of particular Markus ionisation chambers, with Unidos electrometer, was evaluated using the ratio:

$$N_D / N^{av}{}_D \tag{3}$$

where:

N_D – calibration coefficients from subsequent calibrations of a particular chamber;

$N^{av}{}_D$ – average value of calibration coefficients from subsequent calibrations of a given chamber.

Results and discussion

The calibration coefficients of 36 plane-parallel Markus-type chambers established with two methods were within the range:
in electron beam: $N_{D,W,Qcross}$ from 46.45 to 50.93 cGy/nC
in Co-60 beam: $N_{D,w,QokQ,Qo}$ from 46.60 to 50.92 cGy/nC

Mean values and standard deviations were:
in electron beam: 48.67 ± 0.98 cGy/nC
in Co-60 beam: 48.72 ± 0.99 cGy/nC

In Figure 1 the results, according to increasing values of calibration coefficients in electron beams – $N_{D,W,Qcross}$ are presented (triangles) and corresponding values of coefficients from Co-60. recalculated for the beam quality of the electron beam of 22 MeV – $N_{D,w,Qo}\,k_{Q,Qo}$ (circles). Minimal differences in the calibration factors, confirmed by the small standard deviations, indicate the possibility of alternative use of the two calibration methods.

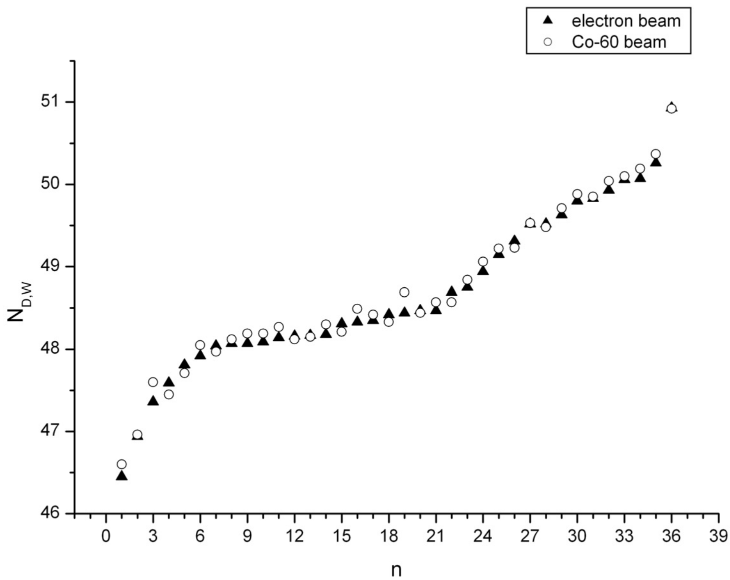

Figure 1. Calibration coefficients, in the increasing order, for electron beam calibrations $N_{D,W,Qcross}$ (triangles) and corresponding calibration coefficients for Co-60 beam, recalculated for the 22 MeV electron beam quality (circles); n – chamber number.

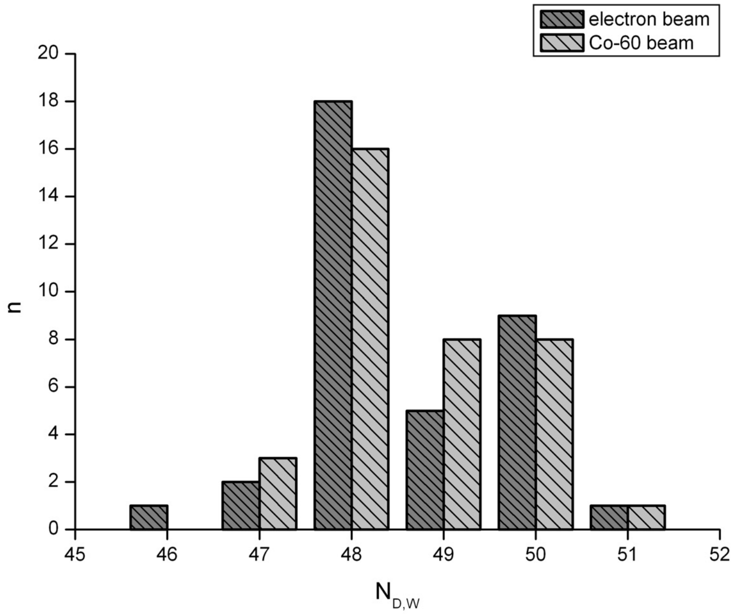

Figure 2. Histograms of calibration coefficients in two different beams, in 22 MeV electrons – left bars, and in the Co-60 beam – right bars.

In Figure 2 the histograms of both coefficients are presented. These histograms confirm the agreement between the both coefficients. The shape of the histograms, not following the normal distribution, suggests the manufacturing differences between particular chambers.

In Table 1, the percentage values of coefficient deviations in Co-60 beams, calculated in relation to the electron beam, Δ [%], for Markus plane-parallel chambers, are presented. They are in the range of ±0.3% do +0.5%, the mean value being 0.1%.

In Table 2, the results of long term stability of calibration coefficients of a chamber No 1821 during the period 1996-2002 are presented. The percentage deviations of calibration coefficients calculated in relation to the mean value, are in a narrow range of ±0.5% to +0.3%, despite of long term period of measurements, and despite different reference chambers used during this period. The results for other chambers, over a shorter period of time, were within the same limits.

Conclusions

1. In the case of Markus-type plane-parallel chambers a very good agreement between calibration coefficients in water, in 22 MeV electron beam and in Co-60 beam, recalculated for the electron beam quality, was observed.

2. The agreement of calibration coefficients in water is within the measurement accuracy limits generated in the case of calibration methods in electron and Co-60 beams, cited in calibration certificates. The value of this accuracy is in accordance with the IAEA Report TRS 398.

3. On the basis of the calibration measurements over a long period of time, and multiple cases of establishing calibration coefficients for particular chambers of Markus type, a very good long-term stability has been stated.

Acknowledgements

The study was supported by the Polish National Atomic Energy Agency with the grant No 12/SP/2006.

The Polish SSDL was supported by a grant from the International Atomic Energy Agency within the Technical Cooperation programme No POL/1/012.

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