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Long-term stability of radiotherapy dosimeters calibrated at the Polish Secondary Standard Dosimetry Laboratory

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HIGHLIGHTS

- Dosimetry electrometers were calibrated 3–4 times over long period of time.
- Farmer and plane-parallel ionization chambers with electrometers were calibrated.
- Accuracy of of electrometers and long-term stability of chambers was examined.
- The accuracy of electrometers was 0.1% and the stability of chambers was 0.2%.

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ABSTRACT

Unidos 10001, Unidos E (10008/10009) and Dose 1 electrometers from 14 radiotherapy centres were calibrated 3–4 times over a long period of time, together with Farmer type (PTW 30001, 30013, Nuclear Enterprises 2571 and Scanditronix-Wellhofer FC65G) cylindrical ionization chambers and plane-parallel type chambers (PTW Markus 23343 and Scanditronix-Wellhofer PPC05). On the basis of the long period of repetitive establishing of calibration coefficients for the same electrometers and ionization chambers, the accuracy of electrometers and the long-term stability of ionization chambers were examined. All measurements were carried out at the same laboratory, by the same staff, according to the same IAEA recommendations. A good accuracy and long-term stability of the dosimeters used in Polish radiotherapy centres was observed. These values were within 0.1% for electrometers and 0.2% for the chambers with electrometers. Furthermore, these values were not observed to vary over time. The observations confirm the opinion that the requirement of calibration of the dosimeters more often than every 2 years is not justified.

1. Introduction

The use of calibrated radiotherapy dosimeters with ionization chambers, traceable to primary standards directly or through secondary standards, is essential for the accurate evaluation of patient radiation dose delivery in radiotherapy.

In Poland, the radiotherapy dosimeters are calibrated at the Secondary Standard Dosimetry Laboratory (SSDL), which maintains the secondary standard for dosimetry. The Polish SSDL is an integral part of the Medical Physics Department of the Maria Skłodowska-Curie Memorial Cancer Centre – Institute of Oncology in Warsaw. The Polish SSDL was created in accordance with the decision of the Minister of Health in 1966. In 1988, the SSDL was incorporated into the international SSDL network coordinated by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO): the IAEA/WHO Network of Secondary Standard Dosimetry Laboratories (SSDLs). Therapy level dosimetry standards of the Polish SSDL are traceable to the IAEA Dosimetry Laboratory in Seibersdorf, Austria. There, since 1999, the Polish SSDL reference dosimeter (Keithley 6517 electrometer with NE 2571 ionization chambers) has been periodically calibrated against a secondary standard. The IAEA dosimetry standards are traceable to Le Bureau International des Poids et Mesures (BIPM) in Sèvres, France.

The good quality of the calibration measurements carried out at the SSDL, and also the quality of the dosimetry equipment used at Polish radiotherapy centres, is assured not only by their precision and accuracy, which is demonstrated through comparisons with the IAEA, but also by their long-term stability.

The stability of the therapy level dosimeters used in Polish hospitals has already been verified earlier when analysing the results over a long period of time (Bulski et al., 2008; Ulkowski

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et al., 2010). In the first study, the analysis of calibration coefficients of plane-parallel type ionization chambers calibrated in Co-60 and electron beams was compared over a 7 year period (1994–2002) to prove the equivalence of the two calibration methods performed according to IAEA (2001). In the second study, an analysis of the energy dependence of the exposure calibration coefficients for ionization chambers used for dose determination in orthovoltage radiotherapy and in brachytherapy in the Polish SSDL was performed for a period of 7–11 years.

Independently of this previous analysis at the SSDL, a systematic investigation of the measurements of the long-term stability of calibration coefficients for the ionization chambers, and of the charge for the electrometers, has been introduced at the SSDL in order to establish the necessary frequency of dosimeter calibration.

2. Materials and methods

A group of measuring devices popular in Poland was examined; electrometers: Unidos 10001 in use since 1999 and Unidos E 10008/10009 in use since 2003, both from the Physikalisch-Technische Werkstaetten (PTW, Freiburg Germany) and Dose 1 from Scanditronix-Wellhofer (SW, Schwarzenbruck, Germany) in use since 2004; and the ionization chambers: thimble cylindrical Farmer type 30001, 30013 (formerly 30006), FC65G (previously IC70) and 2571, (Table 1) and plane-parallel: Markus 23343 and PPC05 (Table 2). The dosimeters which were examined came from 14 Polish radiotherapy centres.

The accuracy of the electrometers was checked with an electrical calibrator source (Keithley Instruments Inc., USA, type 263). The measurements were carried out by connecting the output of the electrical current source with the input signal of the electrometer and selecting the time interval (integer number of seconds) during which the charge is measured by the electrometer. The readings are normalized to the indication at 5.00 nC input charge. The stability of this source, declared by the manufacturer for the 2 nA range, is 0.065% over a year, and in practice it turned out to be even better. Over the last 10 years, the stability of the electrical calibration source has been verified against each of around 50 incoming brand new electrometers during their first calibration at the SSDL. The readings in the SSDL were compared with the data from the manufacturer's calibration certificates delivered together with new electrometers. The electrometers used for checking the electrical calibrator source in the SSDL in Warsaw were manufactured either by PTW or Scanditronix-Wellhofer/IBA Dosimetry. Both manufacturers use their own electrical calibrator source standards, which are traceable to the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. No other recalibration of the SSDL's electrical calibrator source has been performed. The aforementioned methodology is considered sufficient for the purpose of this work.

For calibration of ionization chambers, the substitution method was used. The calibration coefficients $N_{(D,W)}$ were established for cylindrical and plane parallel chambers, in a Co-60 beam, by comparing the readings of the calibrated dosimeter with the readings of the reference dosimeter under reference conditions (Bulski et al., 2008) defined in the Technical Report TRS-398 (IAEA, 2001). The reference dosimeter used was the secondary standard electrometer, Keithley Instruments Inc. 6517 S/N:815930, with cylindrical ionization chambers from Nuclear Enterprises Technology Limited (NE) type 2571, S/N:2458 (since 1999 to 2010) and S/N:2885 (since 2003), with a calibration certificate not older than 4 years from the IAEA Dosimetry Laboratory. The dosimetry secondary standards used at the SSDL in Warsaw are calibrated every 3–4 years at the IAEA Dosimetry Laboratory. The stability of the standards was estimated according the formula (2) and are 0.06%/year for S/N:2458 chamber and 0.02%/year for S/N:2885 chamber.

The uncertainty estimation for the calibration coefficients $N_{(D,W)}$ determination in SSDL in Warsaw was performed on the basis of the methodology described in the TECDOC-1585 guide (IAEA, 2008). The dose to water calibration coefficient $N_{(D,W)}$ for a dosimeter is determined according to the following formula:

$$N_{(D,W)} = \frac{D_W}{M}, \qquad (1)$$

where D_W is the dose to water determined with the standard according to TRS-398 (IAEA, 2001) and M is the user dosimeter reading corrected for the temperature and pressure. The uncertainties of the dose determination D_W and the reading M are calculated by summing in quadrature the type A and type B uncertainties.

For D_W determined with the standard, uncertainty type A is related to measurements with the standard, repeated 10 times: $u_A < 0.1\%$, and the uncertainties type B, u_B, are:

(a) 0.55% – uncertainty of the standard's calibration coefficient (determined by the IAEA Dosimetry Laboratory),
(b) 0.23% – uncertainty related to long-term stability of the standard,
(c) 0.06% – uncertainty related to the non-linearity coefficient of the standard electrometer,
(d) 0.12% – uncertainty related to the positioning of water phantom in respect to the beam source,
(e) 0.12% – uncertainty related to the positioning of the chamber in respect to the water phantom,
(f) 0.04% – uncertainty related to air temperature,
(g) 0.02% – uncertainty related to air pressure.

For M reading with the user dosimeter the uncertainty type A is related to measurements repeated 10 times: $u_A < 0.1\%$, and the uncertainties type B, u_B are:

(a) 0.06% – uncertainty related to the resolution of the user electrometer,
(b) 0.12% – uncertainty related to the positioning of water phantom in respect to the beam source,
(c) 0.12% – uncertainty related to the positioning of the chamber in respect to the water phantom,
(d) 0.04% – uncertainty related to air temperature,
(e) 0.02% – uncertainty to air pressure.

The combined standard uncertainty (i.e. $k=1$) of the calibration coefficient $N_{(D,W)}$ is $u_{N(D,W)} = 0.67\%$. For achieving approximately

Table 1
Technical details of Farmer type cylindrical chambers.

Symbol	Manufacturer	Active volume (cm^3)	Length (mm)	Radius (mm)	Wall material	Wall thickness	Central electrode material	Water-proof
IC70/FC65G	SW	0.67	23	3.1	Graphite	0.068	Al	Yes
2571	NE	0.60	24	3.2	Graphite	0.065	Al	No
30001	PTW	0.60	23	3.1	PMMA	0.045	Al	No
30006/30013	PTW	0.60	23	3.1	PMMA	0.057	Al	Yes