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Analysis of the calibration results of ionization chambers for orthovoltage and brachytherapy

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An analysis of the exposure calibration coefficients for ionization chambers used for dose determination in orthovoltage radiotherapy and in brachytherapy in the Polish SSDL was performed. The coefficients were determined by calibrating the chambers in the X-ray beam of 235 kV or 290 kV and HVL of 2.5 mmCu or 4 mmCu respectively, and also in the Co-60 gamma beam. Calibration procedures followed IAEA recommendations in Report No. TECDOC 1274 and Technical Reports Series No. 277. The characteristics of the energy dependence of various types of chambers used in orthovoltage radiotherapy and in brachytherapy are presented. On the basis of the summarized data and on the energy dependence curves it was possible to conclude that: 1) in he case of calibration of the chambers for orthovoltage radiotherapy the energy dependence has to be established for the full range beam qualities; 2) in the case of calibration, of the investigated chambers, for brahytherapy with Cs-137 and Ir-192 sources, establishing of the exposure calibration factor for Co-60 is sufficient.

Key words: radiotherapy, brachytherapy, SSDL, calibration coefficients, ionization chambers.

Introduction

Over a long period of time in many radiotherapy centres in Poland the orthovoltage radiotherapy has been used for radical and palliative treatment of tumours. According to recent regulations of the Ministry of Health, the orthovoltage radiotherapy has to be

Table 1. A list of equipment for afterloading brachytherapy and orthovoltageadiotherapy in Poland (as of 31.12.2008)

No.	Hospital code	Number of units and year of installation							
		HDR		PDR		LDR		Therapy X-ray	
1	AA	1	2006	1	1998	1	1998		
2	AB	1	1996						
3	AC	1	2004			1	1993		
						1	1998		
4	AD	1	2001	1	1999	1	1999		
5	AE	1	2006						
6	AF	1	2006						
7	AG	1	1997			1	1993		
8	AH					1	1994		
9	AI			1	1999	1	1987		
10	AJ	1	2005						
		1	2006						
11	AK	1	1995					1	1984
12	AL	1	2004	1	2004	1	1994		
13	AN	1	1997						
14	AO	1	2002			1	1998		
		1	2006						
15	AP					1	1996	1	1976
						1	2000		
16	AQ	1	2007			1	1993		
17	AS	1	2004						
		1	2006						
		1	2007						
18	AT	1	2000						
19	AV	1	2007			1	1998		
20	AW					1	1997		
21	AX	1	1993						
22	AY					1	2005		
Total		21	–	4	–	15	–		

limited to palliative treatments exclusively [1]. The orthovoltage radiotherapy is the therapy with X-ray beams generated by therapeutic X-ray tubes operated at a voltage of over 100 kV, characterized by half value layers (HVL) in the range 0.5-4.0 mm Cu [2]. At present (2009), only two radiotherapy centres in Poland are performing such therapy (Table 1). In Europe, on the contrary, the orthovoltage therapy is undergoing a certain renaissance as a very effective and relatively cheap method of relieving pain caused by tumours.

The dosimeters for orthovoltage therapy are calibrated at the similar values of voltage as those used in radiotherapy, for several HVL values, smaller and higher as those used for treatment. The accuracy of HVL determination should be very high. It applies to the geometry of the measurement, to monitoring of radiation intensity, and to chemical purity of the metals used for filters.

The experience acquired by the Polish Secondary Standard Dosimetry Laboratory (SSDL) during the calibration of dosimeters for orthovoltage therapy was applied for the calibration of dosimeters used in brachytherapy.

The brachytherapy with the afterloading of radiation sources is presently used to irradiate about 20% of patients undergoing radiotherapy in Poland.

In Poland, in 22 radiotherapy centres about 40 afterloading units are installed (Table 1), including 21 high dose rate (HDR) units, 4 pulsed dose rate (PDR) units, and 15 low/medium dose rate (LDR/MDR) units. All units are from renowned European manufacturers, but about 50% of them are already 10 years old. Since 2006 the number of brachytherapy centres and the number of brachytherapy units have not increased [3]. On the other hand, the proportion of HDR units have increased, the new HDR units replacing the older LDR/MDR units. In HDR units, Ir-192 sources of the initial activity of the order of 370 GBq (10 Ci) are used, and in the PDR units the Ir-192 sources of the activity of the order of 37 GBq (1 Ci) are employed. In the LDR/MDR units Cs-137 sources are used, having activity of the order of 1.5 GBq (40 mCi).

The dose rate in HDR units is comparable with dose rate in teletherapy machines and therefore it has to be accurately determined because the treatment times are short, of the order of minutes. The dose rate in LDR/MDR units is much lower, of the 2-3 orders of magnitude, and treatment times are anywhere between ten and twenty hours. The treatment time of the PDR unit is of the order of minutes, applied to the patients several times.

In brachytherapy treatment planning, the basic value is Reference Air Kerma Rate – RAKR, measured in reference conditions. The radiation sources are initially calibrated by manufacturers and the results, stated as activity or RAKR, are given in the certificates provided together with the sources. However, in modern brachytherapy the required accuracy of dose determination is often higher than the uncertainty of the calibration given by the manufacturer (usually > ±5%). According to the regulations of the Minister of Health the activity of the source has to be checked before it might be used for treatment [1]. For the purpose of treatment planning the RAKR value has to be established. By using kerma rate instead of activity one may avoid errors introduced by the uncertainty of the ionization constant. Application in the treatment planning system of an ionization constant value different to that used for the calibration of the source may lead to significant errors.

There exist several methods to determine the RAKR: a) measurements in air, b) measurements in either water or solid phantom, c) measurements with a well chamber [4, 5, 6]. In each case the user has to have a dosimeter with a valid calibration certificate containing the exposure calibration coefficients. The SSDL determines these coefficients by calibrating the chambers in the X-ray beam of 235 kV or 290 kV and HVL of 2.5 mmCu or 4 mmCu respectively, and also in the Co-60 gamma beam. The data on the energies and corresponding HVLs of Ir-192, Cs-137 and Co-60 [7, 8] are given in Table 2. On this basis, the user determines by interpolation the calibration coefficient for the radioisotope used [5, 6, 9] and calculates the RAKR, using appropriate correction factors.

Table 2. Radionuclides used for calibration coeficients determination

Radionuclide	Half-life [days]*	Mean energy of gamma radiation [MeV]	HVL [mmCu]
Cesium-137	11019.59	0.662	10.8
Iridium-192	73.83	0.397**	8.3
Kobalt-60	1925.50	1.250	14.4

* 1 year = 365.25 days (30 years = 10957.5 days)

** according to [5]

Purpose

The purpose of this study is an analysis of calibration coefficients for ionization chambers used for dose determination in orthovoltage radiotherapy and in brachytherapy which were calibrated at the Polish SSDL in order to increase the quality of calibration procedures.

Material

The material for this study was:

a) exposure calibration coefficients for ionization chambers calibrated at the SSDL over the years for the purpose of orthovoltage radiotherapy;
b) exposure calibration coefficients for ionization chambers calibrated at the SSDL over the years for the purpose of brachytherapy.

Equipment

The equipment used for calibration is installed in Roentgen X-ray laboratory (Figure 1) and in Co-60 laboratory (Figure 2).

The source of the X-ray beam is a Pantak HF 320/50 unit with a RTS-Comet tube operating at voltages in the range of 50-320 kV. The internal filtration is 3 mm Be. Additional filters of high chemical purity enable to generate beams of HVL in the range 0.15-4.0 mm Cu. The positioning of the tube is done with a laser system. The beam parameters are checked regularly, especially the homogeneity of the radiation field at the distance of calibration measurements.

The Pantak unit was installed in 1995. Before a Mueller RT 250TU1 unit was used. This unit had an additional filter enabling to generate beams of the HVL values in the range according to the regulation of the Polish Committee of Normalization and Measures [10].

Additional equipment used during calibration included:

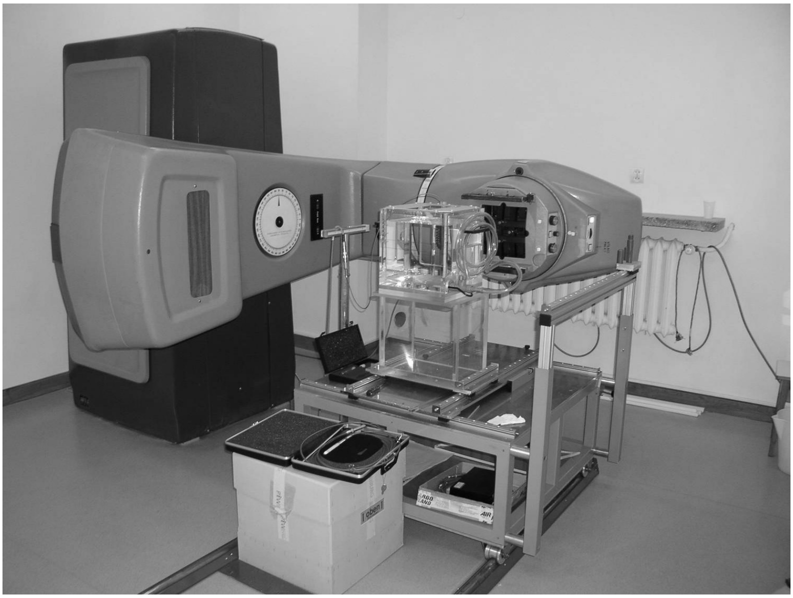

Figure 1. The equipment used for calibration of ionization chambers in a X-ray beam

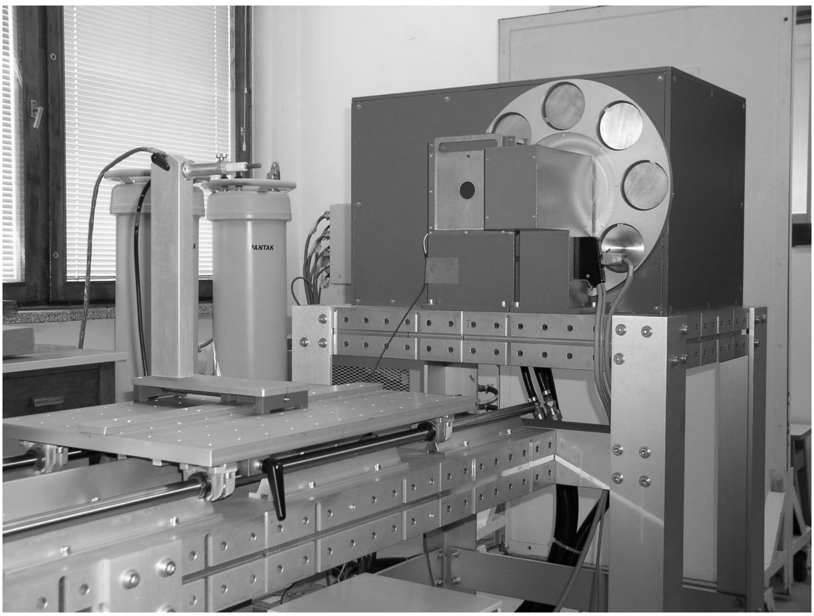

Figure 2. The equipment used for calibration of ionization chambers in a Co-60 beam

– radiation reference source (for cylindrical chambers) from PTW with Sr-90 emitter, activity 33 (0.892 mCi) as of 1977;
– calibration bench from PTW;
– a stand for calibration of ionization chambers in air;
– a thermometer for the range from −20°C to +50°C, with 0.2°C accuracy, with calibration certificate;
– mercury barometer type PS No. 7874;
– custom made software installed at the calibration site, used for steering of dosimeters and calibration data recording. It is based on the LabView from the National Instruments Corporation and it enables the steering of the reference dosimeters – Keithley type 6517, and a commonly used in Poland Unidos from PTW. The steering may be performed subsequently for the reference and calibrated dosimeter and simultaneously for both of them, depending on the calibration procedure adopted. The system automatically switches the dosimeters on and off for pre-selected time periods and measurement series. The results are stored in a database designed for their processing and presentation.

In the Cobalt Calibration Lab, Co-60 units have been used as the radiation source. Since 2007 a Theratron 780 E No. 626 with a Co-60 source of 233840GBq (6320 Ci) as of 1.06.2007 has been used. A laser system assures proper positioning of the cobalt unit head and the ionization chambers. The dosimetric and geometric parameters of the Co-60 unit are regularly checked.

Additional equipment used during calibration included:

– electric current calibrator source from Keithley Instruments Inc. type 26 (also used at the X-ray Lab);
– radiation reference source (for determining sensibility of cylindrical chambers), from Nuclear Enterprises Technology Limited type 2503/3 No. 2139 with Sr-90 source of 370 MBq (10 mCi) as of 1984;
– calibration bench of the IAEA-Heider System type;
– a stand for calibration of the chambers in air;
– a thermometer for the range from −20°C to +50°C, with 0.2°C accuracy, with calibration certificate;
– aneroid barometer from Luft, No. 99550;
– custom made software installed at the calibration site, used for steering of dosimeters and calibration data recording – analogous to the one in the X-ray Lab.

Over the period during which the calibration data were gathered, the following reference dosimeters were used a secondary standards: until 1990, an Ionex Dose/Doserate Meter 2500/3-A No. 1271; until 1997, a NPL 2560 No. 1228 and No. 204; until 1998 a Farmer Dosimeter type 2570/1A; until 1999 a Keithley Instruments Inc. type 657 No. 497711; until 2007, a Keithley Instr. type 3540 No. 64099, and, presently, a Keithley Instruments Inc. 6517-A No. 815930 with cylindrical ionization chambers from Nuclear Enterprises Technology Limited, type NE 2571 No. 2458 and No. 2885. Since 1999, the secondary standard is regularly calibrated at the International Atomic Energy Agency (IAEA).

Methods

Calibration procedures followed IAEA recommendations in Report No. TECDOC 1274 and Technical Reports Series No. 277 [9, 11].

In the case of X-ray beam the reference and calibrated chambers are placed consecutively in the horizontal beam at the same position in air, on axis of the collimated beam at 100 cm distance from the tube focus. The cross section of the beam at this distance is about 80 cm^2. The readings of the calibrated and reference chambers are normalized to the indication of the transit monitor chamber of the X-ray unit. The measurements are performed for several beam qualities (HVL) according to the needs of the user.

In the case of the Co-60 beam both chambers, reference and calibrated, are placed simultaneously in the horizontal beam in air. The beam cross-section at the calibration distance of 100 cm was 12 cm × 10 cm. The axes of both chambers were parallel to each other and perpendicular to the beam axis. The distance between the chambers' axes was 3 cm, each of the chambers 1.5 cm off the beam axis. Both chambers had build-up caps assuring the electronic equilibrium.

By comparing the indications of the calibrated dosimeter with the indications of the reference dosimeter, one may determine the exposure calibration factor N_x for various voltage values (kV) and HVL values (mmCu) — in case of X-rays and N_γ — in case of Co-60 radiation. On that basis the user may determine coefficients N_K for intermediate energies and in air kerma calibration factors in reference conditions, according to the formula:

$$N_K = N_{X(\gamma)} \cdot k \cdot \frac{W}{e} \cdot \frac{1}{1-g} \qquad \text{[Gy/nC]}$$

where:

$N_{X(\gamma)}$ — exposure calibration coefficient for X or γ rays [R/nC];
k — conversion coefficient of the units, $k = 2.58 \gamma 10^{-4}$ [C/kg R];
$W/e = 33.97$ [J/C] — mean energy required to produce an ion pair in air per unit charge;
g — fraction of the total transferred energy expanded in radiative interactions upon the slowing down of secondary electrons in air:
$1 - g = 0.997$ for Co-60,
$1 - g = 0.999$ for Cs-137,
$1 - g = 1.000$ for Ir-192,
$1 - g = 1.000$ for orthovoltage X-ray.

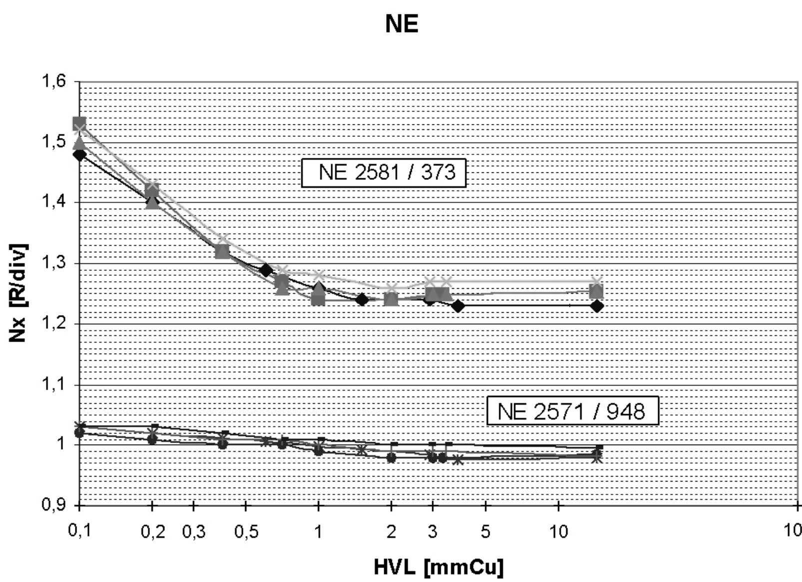

Figure 3. The energy dependence curves for a plastic chamber type NE 2581 (the upper part of the figure) and for a graphite chamber type NE 2571 (the lower part of the figure). Both chambers were calibrated 4 times over a period of 10 years.

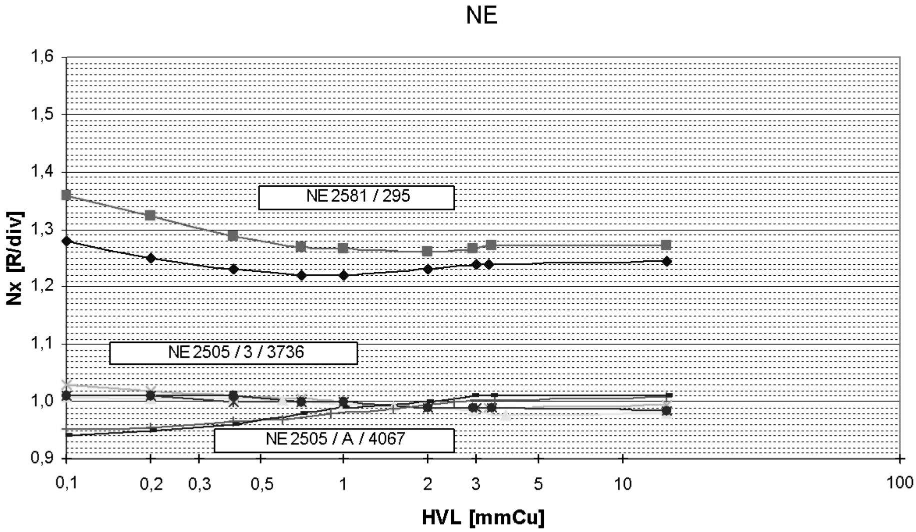

Figure 4. The upper part of the figure: the shifted energy dependence curves for the chamber NE 258 No. 295, which was damaged and repaired. The lower part of the figure: the descending energy dependence curves for the graphite chamber type NE 2505/3 No. 3736 (calibrated 4 times over a period of 11 years), and rising curves for the nylon chamber type NE 2505/A No. 4067 (calibrated 2 times over a period of 7 years).

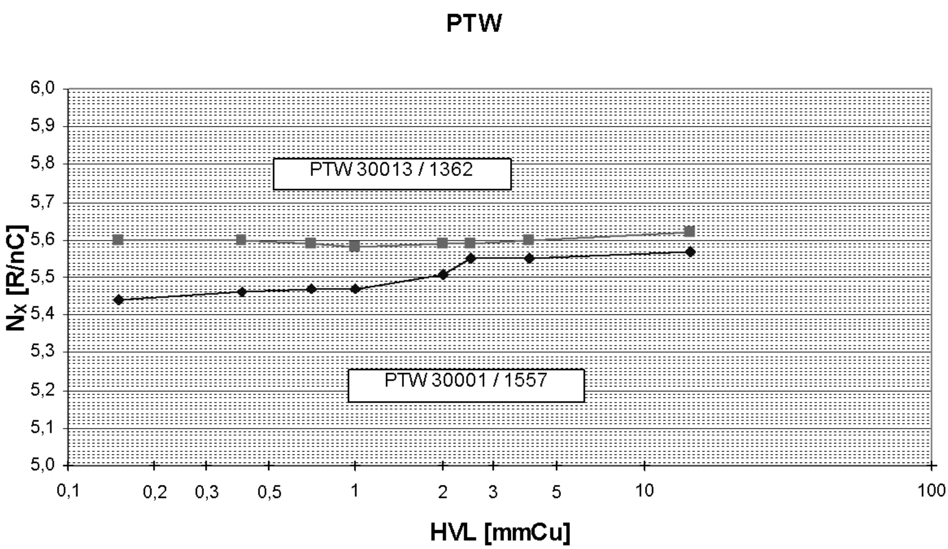

Figure 5. The energy dependence curves for two currently most popular chambers in Poland: PTW 30001 (No. 1557) and PTW 30013 (No. 1362) from two different radiotherapy centres.

Results

In Figures 3, 4 and 5, the characteristics of various types of chambers used in orthovoltage radiotherapy and in brachytherapy are presented. These are examples of the chambers energy dependence in the range of HVL values from 0.1 mmCu (voltage 100kV) to about 14.4 mmCu (Co-60 radiation energy) [8]. All energy dependence curves for particular chamber types were similar.

In the upper part of Figure 3, energy dependence curves for a plastic. chamber type NE 2581 No. 373 are presented. These chambers are characterized by significantly increased sensitivity in the soft par of the X-ray energy spectrum. In the lower part of Figure 3, energy dependence curves for graphite chamber type NE 2571 No. 948 are

Table 3. Mean values of exposure calibration factors for chambers calibrated at the SSDL

No.	Chamber type	Numer of		Nx			Units
		chambers	calibra-tions	235-250 kV	250-290 kV	Co-60	
				2.5-3 mmCu	3.3-4 mmCu	14.4 mmCu	
	NE						
1	2581	4	12	1.2	1.2	1.19	R/div
2	2571/g	7	26	1	1	1	R/div
3	2571/g	4	4	4.68	4.67	4.66	R/nC
4	2505/3/g	3	11	0.99	0.99	0.99	R/div
5	2505/A	1	2	1.01	1.01	1	R/div
				235 kV	290 kV		
				2.5 mmCu	4 mmCu		
	PTW						
6	30004/g	2	3	5.4	5.4	5.41	R/nC
7	30013	2	2	1.18	1.18	1.18	R/div
8	30013	7	7	5.5	5.51	5.53	R/nC
9	30001	19	21	5.48	5.49	5.5	R/nC
10	30010	1	1	5.46	5.47	5.49	R/nC
weighted mean of data in positions 8-10				5.48	5.5	5.5	R/nC

presented. Both chambers came from the same radiotherapy centre and were calibrated 4 times over a period of 10 years.

In the upper part of Figure 4, a shift of energy dependence for the chamber NE 2581 No. 295, which was damaged and repaired, is illustrated. In the lower part of Figure 4, energy dependence curves for chambers which are not any longer in use in Poland are presented: descending curves for chamber type NE 2505/3 No. 3736 (graphite), calibrated 4 times over a period of 11 years, and rising curves for chamber type NE 2505/A No. 4067 (nylon), calibrated 2 times over a period of 7 years. The energy dependence curves for graphite chambers type NE 2505 are very similar to those for graphite chambers type NE 2571.

All chambers, with the exception of those damaged and repaired, had a good long-term reproducibility of the calibration results.

In Figure 5, the energy dependence of exposure calibration factors for two currently most popular chambers in Poland: PTW 30001 (No. 1557) and PTW 30013 (No. 1362) from two different radiotherapy centres. Both curves, especially that for the chamber 30013, are pretty flat (taking into account the change in scale in comparison with Figures 3 and 4) with a slight rising tendency. Taking into account a trend of replacing orthovoltage by other radiation qualities it should not be expected to gather more data of calibration of the chambers in a wide range of HVLs. For this reason, for brachytherapy purposes, in Table 3 the calibration coefficients $N_{X(\gamma)}$, in three radiation quality ranges, X-ray and Co-60, were gathered and analyzed. The user could use these data for interpolation of calibration factors needed for calculation of RAKR. An analysis of these calibration factors may be useful in taking a decision whether in case of radioisotopes used in brachytherapy one should rely on a single calibration factor for Co-60, or weather one should interpolate between calibration factors for several HVL values established in an X-ray beam.

In the case of the chambers from Nuclear Enterprises (NE), commonly used in Poland in previous years the N_X factors were determined for HVL values and voltages in the range: a) 2.5-3 mmCu and 235-250 kV, and b) 3.3-4 mmCu and 250-290 kV. In the case of the chambers from PTW, commonly used in Poland presently, the SSDL set up calibration conditions to: a) 2.5 mmCu and 235 kV, and b) 4 mmCu and 290 kV. In Table 3 all calibration factors from the SSDL database are presented, although some mean values are not statistically significant because of their limited numbers.

On the basis of the data summarized in Table 3 and on the energy dependence curves determined over the wide range of the HVL values, it is possible to conclude that in the case of all chambers calibrated at the Polish SSDL, the exposure calibration factors, over the HVL range from 2.5 mmCu (at 235 kV) to 14.4 mm Cu (Co-60) converge on approximately one single value, with a slight decreasing tendency in case of NE chambers, and equally slight increase tendency in case of PTW chambers, all of them below 1% for both types of chambers.

Conclusions

1. In the case of calibration of the chambers for orthovoltage radiotherapy the energy dependence has to be established for the full range beam qualities characterized by the HVL values and voltage range used in a particular radiotherapy centre.
2. In the case of calibration of the chambers, listed in Table 3, for brahytherapy with Cs-137 and Ir-192 sources, establishing of the exposure calibration factor for Co-60 is sufficient.
3. The error of establishing exposure calibration factors for Cs-137 and Ir-192 on the basis of the Co-60 calibration factor is within the inaccuracy of the calibration methodology adopted.
4. On the basis of the calibration results obtained over a long period of time, the reproducibility of the results proves adopted calibration methodology is good and stable.

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References

[1] Rozporzadzenie Ministra Zdrowia z 25.08.05. w sprawie bezpiecznego stosowania promieniowania jonizujacego dla wszystkich rodzajow ekspozycji medycznej. Dziennik Ustaw Nr 194, poz. 1624, 1625. [Regulation of the Minister of Health of 25.08.05 on the safety of ionizing radiation use in all type of medical exposure]. Polish

[2] Andreo P, Seuntjens JP, Podgorsak EB. Calibration of photon and electron beams. In: Podgorsak EB, ed. Radiation Oncology Physics. Vienna: IAEA 2005. pp. 301-354.

[3] Bulski W, Gwiazdowska B, Pruszynski A, Rostkowska J. Infrastructure of radiotherapy In Poland. Infrastruktura radioterapii w Polsce. Nowotwory 2007, 57 (5): 487-517.

[4] Olszewska A, Bulski W, Kawczynska M. Calibration of high dose rate Ir-192 sources for brachytherapy. Pol J Med Phys Eng. 1998; 4 (1): 1-12.

[5] Goetsch SJ, Attix FH, Pearson DW, Thomadsen BR. Calibration of Ir-192 high-dose-rate afterloading systems. Med Phys. 1991; 18(3): 462-467.

[6] Mainegra-Hing E, Rogers DWO. On the accuracy of the techniques for obtaining the calibration coefficient NK of Ir-192 HDR brachytherapy sources.
Mrd Phys. 2006; 33(9): 3340-3347.

[7] Join Working Party of the British Institute of Radiologyand the Hospital Physicits' Association. Central Axis Depth Dose Data for Use in Radiotherapy.
Br J Radiol. 1983, Supplement No. 17.

[8] Publication Committee of the British Journal of Radiolgy. Cohen M, Jones D C A, Green D (ed.). Central Axis Depth Dose Data for Use in Radiotherapy.
Br J Radiol. 1972, Supplement No. 11.

[9] IAEA. Calibration of photon and beta ray sources used in brachytherapy. IAEA Report, Vienna, 2002; No. TECDOC-1274. (http://www-naweb.iaea.org/nahu/dmrp/ssdl.asp)

[10] Instrukcja Nr 22 Prezesa Polskiego Komitetu Normalizacji i Miar z dnia 24 wrzesnia 1977 r. o sprawdzaniu uzytkowych dawkomierzy terapeutycznych promieniowania X i gamma. Dziennik Normalizacji i Miar Nr 26, poz. 84, z dnia 22.10.1977. [Instruction No. 22 of the President of the Polish Committee of Normalization and Measures of 24.09.1977 on legalization of dosimeters used in radiotherapy with X and gamma rays]. Polish

[11] IAEA. Absorbed dose determination in photon and electron beams. An international code of practice. Technical Reports Series, second edition, Vienna, 1997; No. TRS 277.