Wojciech Bulski, Piotr Ulkowski, Barbara Gwiazdowska,
Joanna Rostkowska

An analysis of calibration coefficients measured in water and in air for Farmer-type cylindrical ionization chambers

Department of Medical Physics, Center of Oncology,
02-781 Warsaw, Roentgena 5, Poland
e-mail: w.bulski@zfm.coi.pl

A comparison of calibration coefficients of Farmer-type cylindrical ionization chambers calibrated in a Co-60 beam according to the IAEA Reports 277 and 398 formalisms.

91 calibration coefficients measured in air and in water.

The $^{398}N_{D,W}/^{277}N_{D,W}$ ratios were calculated, taking into account the wall material of the chambers. The correlation between $^{398}N_{D,W}$ and $N_K, N_{D,air}$ $^{277}N_{D,W}$ was made and the equations of the regression straight lines were determined.

Calibration coefficients, determined according to the IAEA Report 398, are higher by about 1% than those determined according to the IAEA Report 277, and they depend slightly on the wall material of the chamber.

The introduction of the IAEA dosimetry Report 398 resulted in an increase in the doses delivered to patients by about 1% as compared with the period of application of Report 277. The regression equations may assure increased accuracy in retrospective comparative calculation of doses according to both reports as compared with the correction based on mean percent values.

Key words: calibration, dosimeters, ionization chambers, radiotherapy, SSDL.

Introduction

To ensure consistency in dose determination among different radiotherapy departments, at the end of the 1980s, at the recommendation of the Polish Secondary

Standard Dosimetry Laboratory (SSDL), a common dosimetry protocol was adopted by all radiotherapy centers in Poland [1]. Since then, all ionization chambers have been calibrated according to this protocol, prepared and published as a report by the International Atomic Energy Agency (IAEA Technical Report Series 277) [2]. Like other protocols used in various countries (e.g. Scandinavia, America, etc) [3, 4, 5] it was based on the determination of the absorbed dose from the air-kerma in air. This is a complex procedure, which introduces a number of correction factors, and is difficult for many users to adopt. It has been a source of conceptual and calculation errors.

The whole procedure was greatly simplified in the IAEA Technical Report Series 398 [6], published in 2000. The procedure was based on dose determination in water, in conditions very much similar to those in which the chambers are used in routine conditions. This eliminates the necessity of using correction factors and it takes into account the characteristic parameters of individual units of a particular type of chamber.

A detailed analysis of both formalisms of dose determination suggests that the absorbed dose to water coefficient $^{398}N_{D,W}$, established in direct calibration measurements in water, may differ from the coefficient $^{277}N_{D,W}$, established from the air-kerma in air coefficient measured during in air calibration.

The intention of the authors of the IAEA Technical Report Series 398 was that the SSDLs should, for a period of at least two years, provide users with both calibration coefficients in order to avoid serious errors which might be a result of wrong interpretation of the new procedure.

Purpose

The aim of this study was an intercomparison of calibration coefficients of the Farmer-type cylindrical ionization chambers calibrated in Co-60 beam according to the IAEA Reports 277 and 398 formalisms.

Material

The material consisted of 91 calibration coefficients measured in air and in water for 87 cylindrical ionization chambers (four chambers were calibrated twice during the

analyzed period), sent to the SSDL from regional radiotherapy centers. In Table 1 the details of the chamber construction are presented.

Table 1. Characteristics of calibrated chambers

No.	Type	Cavity volume [cm ³]	Cavity length [mm]	Cavity radius [mm]	Wall material	Central electrode material	Number of chambers
1.	PTW 30002	0.6	23	3.1	Graphite	Graphite	3
2.	PTW 30004	0.6	23	3.1	Graphite	Al.	2
3.	Sc-W FC65-G	0.67	23	3.1	Graphite	Al.	2
4.	NE 2571	0.6	24	3.2	Graphite	Al.	26
5.	PTW 30006/30013	0.6	23	3.1	PMMA	Al.	17
6.	PTW 30001	0.6	23	3.1	PMMA	Al.	32
7.	NE 2581	0.6	24	3.2	A-150	Al.	5
							87

Methods

A calibrated and a reference chamber were positioned in a collimated Co-60 gamma beam emitted by the Theratron 780/403 unit installed at the SSDL. The reference dosimeter was a Keithley Instruments Inc. Type 3540 no. 64099 with ionization chambers NE 2571 no. 2458 and no. 2885.

In the case of in-air calibration, both the calibrated and the reference chamber, were placed simultaneously in a 12 cm × 10 cm horizontal beam at 100 cm from the source. Both chamber axes were perpendicular to the beam axis and parallel to each other. The distance between the chamber axes was 3 cm and the chambers' active reference points were 1.5 cm from the beam axis. Both chambers were equipped with build-up caps. By comparing the readings of the calibrated and reference dosimeters the exposure calibration coefficients were determined. On this basis, the following coefficients were

calculated: air-kerma in air – N_K , dose in air – $N_{D,air}$, and dose absorbed in water – $N_{D,W}$, according to the IAEA Report 277:

$$N_K = N_X \cdot k \cdot \frac{W}{e} \cdot \frac{1}{1-g} \quad [\text{cGy} / \text{nC}]$$

where:

- N_X is the exposure calibration coefficient [R/nC];
- $k = 2.58 \cdot 10^{-4}$ C/kg R is the unit conversion coefficient;
- $(W/e) = 33.97$ [J/C] is the mean energy required to produce an ion pair in air per unit charge; and
- g is the fraction of the total transferred energy expended in radioactive interactions on the slowing down of secondary electrons in air, ($g = 0.3\%$ in the case of Co-60).

$$N_{D,air} = N_K (1-g) \cdot k_{att} \cdot k_m \cdot k_{cel} \quad [\text{cGy} / \text{nC}]$$

where:

- k_{att} is a correction factor for photon attenuation and scatter in the chamber wall;
- k_m is a correction factor for the non-air equivalence of chamber wall and build-up cap (needed for an air-kerma in air measurement); and
- k_{cel} is a correction factor for the non-air equivalence of the central electrode of the cylindrical ionization chamber.

$$^{277}N_{D,W} = N_{D,air} \cdot S_{D,air} \cdot p_Q \quad [\text{cGy} / \text{nC}]$$

where:

- $S_{w,air}$ is the ratio of the mean restricted mass stopping powers of water and air; and
- p_Q is a perturbation correction factor accounting for perturbations caused by the chamber inserted into the medium.

In the case of in water calibration, calibrated and reference chambers were placed successively in a water phantom, in a 1 mm thick waterproof PMMA holder at the level of the chamber. The size of the horizontal beam was 10 cm × 10 cm at 100 cm from the

Figure 1. Ratios of calibration coefficients ${}^{398}N_{D,W}/{}^{277}N_{D,W}$ for the Farmer type ionization chambers in the order of increasing values (closed circles – graphite chambers, open circles – plastic chambers)

Figure 2. Histograms of the ratios ${}^{398}N_{D,W}/{}^{277}N_{D,W}$ for 91 calibration coefficients of the Farmer type ionization chambers

Figure 3. Histograms of the ratios $^{398}N_{D,W}/^{277}N_{D,W}$ for 91 calibration coefficients of the Farmer type chambers made of different materials (black – graphite chambers, gray – plastic chambers)

source. Both chamber axes were perpendicular to the beam axis. The depth of the measurement reference point was $d = 5 \text{ g/cm}^2$.

By comparing the readings of the calibrated and reference dosimeters, the absorbed dose coefficient in water $^{398}N_{D,W}$ was determined directly for the Co-60 radiation.

The $^{398}N_{D,W}/^{277}N_{D,W}$ ratios were calculated and are presented in Figure 1. Their mean values, depending on the material of which the chambers were made, were calculated. The histograms of the $^{398}N_{D,W}/^{277}N_{D,W}$ ratios are presented in Figures 2 and 3.

The correlation between $^{398}N_{D,W}$ and $N_K, N_{D,air}, ^{277}N_{D,W}$ (i.e. for $^{398}N_{D,W}$ and every step of the calculation process of the calibration coefficient according to the IAEA Report 277) was made and the equations of the regression straight lines were determined.

Results and discussion

As seen from Figures 1, 2 and 3, for all calibrated Farmer-type chambers, the calibration coefficients determined according to Report 398 are higher than the corresponding coefficients determined according to Report 277. This fact has also been noted by other authors [7, 8].

Mean values of the ratio $\frac{N_{D,W}^{398}}{N_{D,W}^{277}}$ are:

- for all chambers: 1.0084 ± 0.0015 ,
- for PMMA or A-150 chambers: 1.0088 ± 0.0014 ,
- for graphite chambers: 1.0073 ± 0.0014 .

The differences between the ratios $^{398}N_{D,W}/^{277}N_{D,W}$ for two types of chambers (seen in Figure 3) may be caused by the different wall material and also by the values of the correction factors published in Report 277, used in the calculation. Higher values of the correction factors for graphite chambers than those for plastic chambers reduce the ratio $^{398}N_{D,W}/^{277}N_{D,W}$. (E.g. the product of the correction factors $k_{att}k_m k_{cel}$ and p_Q , according to Report 277, for graphite chambers NE2571 is $0.9879 \cdot 0.9726 = 0.96083$, and it is higher than for most plastic chambers. For PTW30001 chambers it is $0.9749 \cdot 0.9823 = 0.95764$ and for PTW30013 it is $0.9749 \cdot 0.9815 = 0.95686$. The correction factor $S_{w,air}$ has the same value for all chambers).

The equations of the regression straight lines are as follows:

$$\begin{aligned}
 ^{398}N_{D,W} &= 1.0937 N_K + 0.0028 & N_K &= 0.9143 ^{398}N_{D,W} + 0.0025 \\
 ^{398}N_{D,W} &= 1.1218 N_{D,air} - 0.0061 & N_{D,air} &= 0.8913 ^{398}N_{D,W} + 0.0060 \\
 ^{398}N_{D,W} &= 1.0088 ^{277}N_{D,W} - 0.0015 & ^{277}N_{D,W} &= 0.9912 ^{398}N_{D,W} + 0.0015
 \end{aligned}$$

All straight lines are strongly correlated. This was to be expected, but nevertheless it proves that the quality of calibration with two independent methods is very good.

Conclusions

Calibration coefficients for ionization cylindrical chambers of the Farmer-type determined according to IAEA Report 398 are higher by about 1% than those determined according to the IAEA Report 277.

The introduction of IAEA dosimetry Report 398 resulted in a decrease in doses delivered to patients by about 1% as compared with the period of application of Report 277.

The regression equations may assure increased accuracy in retrospective comparative calculations of doses according to both reports, as compared with correction factors based on the mean percent value.

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