Dosimetry study comparing NCS Report-2 versus IAEA Report TRS-398 for high energy photon beams

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Abstract

In this work a dosimetry study is presented in which the results of absorbed dose data determined under reference condition according to the IAEA TRS-398 protocol and the NCS report-2 are compared. The IAEA TRS-398 protocol for absorbed dose calibration is based on ionization chamber having an absorbed dose to water calibration factor $N_{D,W}$, while the NCS-2 report for absorbed dose calibration is based on an ionization chamber having an air- kerma calibration factor N_K. This study shows that the absorbed dose calculated with the IAEA TRS-398 formalisms is higher than that calculated with the NCS Report-2 formalism within a range of 0.4 to 0.9% in a cobalt-60 beam, and from 0.2 to 1.1% for photon beams of 6, 8 and 18 MV. The chambers used are PTW 30001, 30004, and NE-2571, which have calibration factors N_K and $N_{D,W}$ traceable to the BIPM (Bureau International des Poids et Mesures).

Keywords

Dosimetry protocol, NCS report-2, Air-kerma, IAEA TRS-398.

Introduction

Until few years it has been recommended to perform reference dosimetry for clinical high–energy photon and electron beams with reference ionization chambers calibrated in terms of air-kerma. To this time a large number of formalisms based on air kerma have been developed (AAPM TG-21, NCS Reports 2 and 5, IAEA TRS–277 and IAEA TRS 381) (1, 2).

In recent years the major emphasis in primary standards laboratories around the world has shifted from standards for exposure or air kerma to those for absorbed dose to water. The rationale is to establish a better basis for dosimetry that relates directly to the quantity of interest in the clinic, absorbed dose to water. Furthermore, the new standards of absorbed dose to water offer the possibility of reducing the uncertainty in the dosimetry of radiotherapy beams, provide a more robust system of primary standards than air kerma based standards and allow the use of a simple formalism (3). In the last 15 years, reference dosimetry based on absorbed dose to water calibration factors has gained much attention. The concept of dosimetry based on absorbed dose to water calibration factor was developed further by Andreo (1992) and Rogers (1992) (4,5). The IAEA (Andreo et al 2000) developed a protocol for dosimetry of high energy photon and electron beams: IAEA TRS 398 (3) based on absolute dose to water calibration.

Some studies have already been devoted to the comparison of the two dosimetry formalisms. Araki and Kubo in 2002 (6) performed a dosimetry study with four different ion chambers in four high–energy photon beams and in a Co-60 beam. Their study discussed the changes resulting from moving from air-kerma formalisms to absorbed dose to water based formalisms in the high energy photon beams. Differences in absorbed dose according to the two different formalisms were limited to the range of 0.2 to 1.9 % in photon beams (6, 7).

In the present study a set of three ionization chambers recommended for reference dosimetry and calibrated both in terms of air kerma and absorbed dose to water in Co-60 were used. A reference dosimetry with a set of ionization

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chambers was performed in four high energy photon beams with different energies delivered by a cobalt machine and linear accelerators from different manufacturers. The aim of the present work is to determine the differences in absorbed dose to water calculated by the two different formalisms.

Materials and Methods

Ionization chambers

The chamber types used in this study were PTW-30004, PTW 30001, and NE-2571. The characteristics of these chambers can be found in the IAEA TRS-398. These chambers are recommended for reference dosimetry in clinical high energy photon beams.

Calibration

All ionization chambers were calibrated in terms of air Kerma and absorbed dose to water at the National secondary standard laboratory *NIS which is traceable to the **BIPM. The ionization chamber reading was corrected for atmospheric conditions as well as for recombination and polarity effects. The two–voltage method was used to evaluate the recombination correction factor P_{ion}. Table 1, shows the N_K and $N_{D,W}$ calibration factors of all ionization chambers, and the ratio between $N_{D,W}$ and N_K calibration factors. Table 2 shows the differences between measured and calculated $N_{D,W}$.

High–energy photon beams

Table 3 shows the characteristics of the clinical photon beams which were used in the measurements also the beam quality specifics ($TPR_{20,10}$) measured and calculated and the difference between them. $TPR_{20,10}$ has been measured directly and also calculated from depth dose measurements by the expression taken from Rogers (1996). $TPR_{20,10} = -0.6391+0.029348X (\%dd(10)_x) - 0.00014498 x (\%dd(10)_x)^2$. Four beams were selected, Co-60 beam of Theratron, 6 MV photon beams of Siemens linac, 8 and 18 MV photon beams from a Varian 1800 linac.

NCS Report-2

The air kerma based data were analyzed using NCS Report-2 (Mijnher et al 1986). According to the air kerma based formalism the absorbed dose to water is obtained by the following formula.

$$D_{W,u} = M_{corr} N_K C_{W,U} [Gy] \quad (1)$$

Equation (1) can be re-written in the following form,

$$D_{W,u} = M_{corr} N_K (1-g) \pi Ki Sw,air \pi Pi \quad (2)$$

Ionization chambers	$N_K (cGy\ nC^{-1})$	$N_{D,W} (cGy\ nC^{-1})$	$N_{D,W} / N_K$
PTW-30001/0141	4.963	5 .423	1.093
PTW-30004/1216	4.992	5 .454	1.093
NE-2561	9.484	10 .35	1.091
NE-2571	4.129	4 .533	1.098

Table 1: N_K and $N_{D,W}$ calibration factors.

Ionization chambers	Measured (M). $N_{D,W} (cGy\ nc^{-1})$	Calculated (C). $N_{D,W} (cGy\ nc^{-1})$	Diff. bet. M.&C. $N_{D,W} (cGy\ nc^{-1})$
PTW-30001/0141	5.423	5.395	0.5%
PTW-30004/1216	5.454	5.430	0.4%
NE-2561	10.35	10.233	1.1%
NE-2571	4.533	4.492	0.9%

Table 2: Difference between measured and calculated $N_{D,W}$.

**NIS: National Institute of Standards **BIPM: Bureau International des Poids et Mesures.*

Machine	Nominal energy	$TPR_{20,10}$ Measured (M)	$TPR_{20,10}$ Calculated (C)	Difference between (M)&(C)
Theratron	Co-60	Co-60	Co-60	
Siemens Primus	6 MV	0.68	0.676	0.58%
Varian 1800	8 MV	0.708	0.705	0.43%
Varian 1800	18 MV	0.784	0.782	0.24%

Table 3: Measured and calculated $TPR_{20,10}$ and the difference between them.

$D_{W,u}$ the absorbed dose to water in the user beam at the position of the center of the chamber when the chamber is replaced by water. The measurements done by shifting the center of ion chamber to 0.75 r where the effective point was exist.

M the electrometer reading corrected for any difference between the ambient air condition affecting the chamber at the time of measurement and the standard ambient air condition for which the calibration factor applied, corrections for air temperature, pressure and humidity, ion recombination (P_{ion}), polarity effects (P_{pol}) and for electrometer reading (P_{elec}) in the users beam. The fully corrected ion chamber reading, M is defined by the following formula,

$$M = M_{uncorr} P_{ion} P_{pol} P_t P_p P_{elec} \quad (3)$$

N_K the air- kerma calibration factor given by the standard laboratory, which converts the ionization chamber reading to air kerma for the calibration quality.

g is the fraction of energy of secondary charged particles which is converted to bremsstrahlung in air at the calibration quality.

πk_i is the product of a number of correction factors to be applied to the exposure or air-kerma calibration factor.

$$\pi k_i = K_{att} K_m K_{st} K_{ce} \quad (4)$$

$S_{w,air}$ is the water to air mass stopping – power ratio at the user's quality Q.

π Pi is the product of a number of correction factors to be applied to the measurements in the water phantom at the photon radiation quality Q.

$$\pi Pi = P_{wall} \ P_d \ P_{ce} \quad (5)$$

The product N_K (1-g) πK_i has been defined in other dosimetry protocols ((Mijnher et al 1986).[1] as the absorbed dose to air cavity calibration factor ($N_{D.air}$).

$$N_{D.air} = N_K (1\text{-}g) \pi K_i \quad (6)$$

The product $N_{D.air} S_{w,air} \pi$ Pi has been defined as the absorbed dose to water calibration factor ($N_{D.w}$). (According to Mijnher et al 1986).[1]

$$N_{D.w} = N_K (1\text{-}g) \pi K_i S_{w,air} \pi P_i \quad (7)$$

$$N_{D.w} = N_K C_{W,U} \quad (8)$$

$C_{W,U}$ the air-kerma to absorbed dose to water conversion factor. It depends on the chamber type and the radiation quality of the users beam. According to NCS Report-2 the conversion factor $C_{W,U}$ can be calculated by the following formula,

$$C_{W,U} = (1\text{-}g) K_{att} K_m K_{st} K_{ce} S_{w,air} P_{wall} P_d P_{ce} \quad (9)$$

In this study, the definitions of the factors used to calculate $C_{W,U}$ are presented in NCS Report-2. The correction factors that were calculated from NCS Report-2 listed in Table 4. The conversion factors for the chambers and the distribution of beam quality are shown in Figure 1.

IAEA TRS-398 protocol.

According to IAEA TRS-398, the absorbed dose to water, $D_{W,Q}$, for an arbitrary photon beam with the beam quality, Q, is given by

$$D_{W,Q} = M_Q N_{D,W,Q0} k_{Q,Q0} \text{ [Gy]} \quad (10)$$

In the IAEA TRS-398 protocol the fully corrected ion chamber reading, M, is defined as

Beam quality	Ion chamber				
		PTW-30001	PTW-30004	NE2561	NE2571
	$K_{att}\ K_m$	0.983	0.983	0.980	0.985
	Overall conversion factors($C_{W,U}$)				
Co-60		1.088	1.087	1.079	1.088
0.68		1.077	1.077	1.069	1.078
0.71		1.075	1.075	1.067	1.076
0.78		1.055	1.056	1.050	1.057

Table 4: $K_{att}\ K_m$ and $C_{W,U}$ according to NCS report-2.

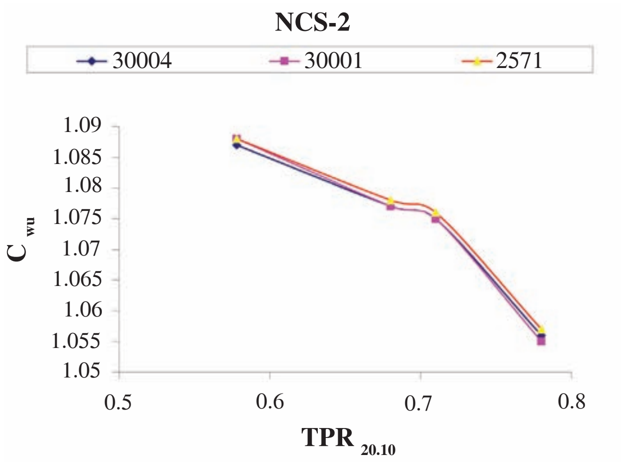

Fig. 1: Air kerma to absorbed dose to water overall conversion factors according to NCS Report-2.

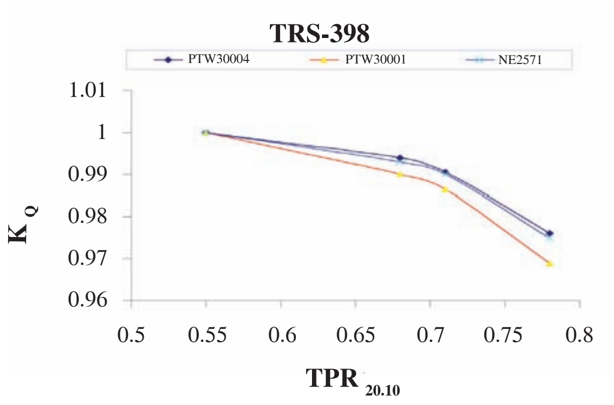

Fig. 2: The relation between $TPR_{20,10}$ and Absorbed dose beam quality conversion factor K_Q According to IAEA TRS-398 protocol.

$$M = K_{ion}\ K_{tp}\ K_{elec}\ K_{pol}\ M_{raw}, \quad (11)$$

where K_{ion} is the correction factor to take into account the incomplete collection of charge from an ion chamber; K_{tp} is the temperature pressure correction factor; K_{elec} is the electrometer correction factor (C/ rdg); K_{pol} is the polarity correction factor; and M_{raw} is the uncorrected reading of ion chamber at the point of measurement (rdg).

$K_{Q,Q0}$ is the beam quality conversion factor, chamber specific factor which accounts for the change in the absorbed-dose to water calibration factor between the beam quality of interest Q, and the quality for which the absorbed –dose calibration factor applies Q_0, (usually Co-60)

$N_{D,W}$ is the absorbed dose to water calibration factor under reference conditions.

Figure 2 shows the relation between four beams quality $TPR_{20,\ 10}$ and the beam quality conversion factors K_Q for four chambers according IAEA TRS-398.

Results and Discussion

In discussing the absolute dose values obtained with the two different formalisms, we have two causes that could lead to different results:

i- Differences related to the standard, (air-kerma calibration factor N_K or absorbed dose to water calibration factor $N_{D,W,Q0}$)

ii- Differences in conversion factors ($C_{W,U}$) or (K_Q)

Polarity and recombination correction.

The polarity and recombination correction factors have been determined as recommended by NCS Report-2 and IAEA TRS-398. The recombination correction factor P_{ion} has been determined using the two voltage method (10) with voltages of 400 volt (the operating voltage) and 100 volt, the reduced voltage according to IAEA TRS-398 and NCS Report-2. The values of P_{ion} are tabulated in Table 5 which shows that they were smaller than 0.1% for the Co-60 beam and 0.3% for the others beam qualities.

Beam quality specifier measured and calculated

Table 3 shows that for the beams applied in this study the difference between directly measured $TPR_{20,10}$ values and $TPR_{20,10}$ data calculated from percent depth dose data at SSD=100 cm, according to the expression taken from Rogers[11.12] are up to +0.004. This shows that the per cent-dose data at SSD=100 cm are accurate enough for deriving the $TPR_{20,10}$ quality index of the beam.

Beam quality	Ion chamber		
	PTW-30001	PTW-30004	NE2571
Co-60	1.0000	1.0000	1.0001
0.68	1.0016	1.0012	1.0001
0.71	0.9999	0.9996	0.9999
0.78	1.0030	1.0028	1.0009

Table 5: Experimental recombination correction factors P_{ion}.

Absorbed dose to water calibration factor measured and calculated.

Absorbed dose to water calibration factors have been recalculated according to the equations 6, 7 and 8 in NCS Report-2. The differences between measured and calculated $N_{D,W}$ are tabulated in Table 2, which shows that the difference is smaller to the PTW-chambers but higher for the NE-chambers.

Relative response of the different ionization chambers

Figure 3 shows the dose per monitor unit obtained with different ionization chambers at 18 Mv photon beam . The chambers used are PTW-30001, PTW-30004 & NE2571 which are refered to in (Fig. 3) as 1,2 and 3 respectively.

The results calculated with the two dosimetry formalisms are plotted, and from the figure we observe that.

i- The results obtained by TRS-398 are higher than that obtained by NCS Report-2 within 0.2-1.1%.

ii- The average response of all chambers in this study was in good agreement even for different types.

Absorbed dose to water based dosimetry versus air kerma based dosimetry.

The ratio of the absorbed dose to water at the reference depths determined according to the NCS Report-2 and IAEA TRS-398 have been obtained at depths recommended by each protocol: 5 cm at a quality index less than 0.75 and 10 cm at a quality index higher than 0.75 in NCS Report-2, and 10 cm in IAEA TRS-398. Table 6 shows the average ratio of the dose obtained with IAEA TRS-398 and the dose obtained with NCS report-2. The variations are consistent without considerable variation with beam quality. The overall average values are 1.0035, 1.0075, and 1.0098 for chambers PTW 3001, PTW 30004, and NE-2571 respectively. The relatively small

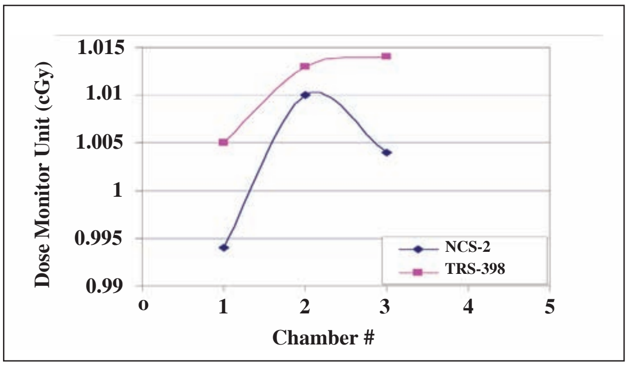

Fig. 3: Dose per monitor unit of the different ionization chambers in an 18 MV photon beam calculated with the two dosimetry protocols.

differences between doses obtained with the two different formalisms are due to:

- The conversion factors which have been used to obtain $N_{D,W}$ from N_K.
- The ratio of $N_{D,W}$ and N_K.

So, the traceability of the calibration factors play an important role in the determination of these ratios and different results will be found when the calibration is traceable to another primary standard laboratory. The results obtained by Ding et al [7], and Huq and Andreo[8] show that the use of TG-51 increases the absorbed dose to water values by approximately 1% for photon beams in comparison to TG-21 when calibration factors ($N_{D,w}$ and N_x) are traceable to the National Institute of Standards and Technology (NIST) in the United States. In contrast, the results become 1.1% lower when using calibration factors traceable to the National Research Council (NRC) in Canada. Shortt et al[9] show when changing from AAPM TG-21 to AAPM TG-51 based on the NRCC standards the result of clinical reference dosimetry using an NE-2571 will increase with 0.4% , when based on the NIST standards on the other hand, the results will increase with 1.5%. Table 6 shows the ratio of the dose obtained with TRS –398 and the dose obtained with NCS Report-2. Any reference on comparison of NCS and TRS 398.

Beam quality	PTW-30001	PTW-30004	NE2571
Co-60	1.004	1.005	1.007
0.68	1.006	1.008	1.009
0.71	1.003	1.007	1.010
0.78	1.003	1.010	1.011

Table 6: Ratio of the absorbed dose values obtained with IAEA TRS-398 and NCS Report-2.

Conclusion

In this study the ratio of the absorbed dose to water between the existing NCS Report-2 and the new TRS–398 protocol are calculated using various Farmer type chambers for different energies. The absorbed dose determined with TRS–398 increases by 0.2 - 1.1% in comparison to those derived with NCS Report-2. There is similar in magnitude of the change determined in other studies [13,17]. Using the present types of chambers with standards traceable to the Bureau International des Poids et Measures (BIPM). There is good agreement between absorbed dose to water measured according to NCS Report-2 as air kerma based protocol and that measured according to IAEA TRS-398 as absorbed-dose to water based protocol.

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