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Original Article

AIR KERMA BASED DOSIMETRY VERSUS ABSORBED DOSE TO WATER BASED DOSIMETRY FOR HIGH-ENERGY PHOTON.

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ABSTRACT

Introduction: In the last 5 years the American Association of Physicists in Medicine Task Group 51 (AAPM TG-51) and the International Atomic Energy Agency (IAEA) published a new high-energy photon and electron dosimetry protocol. These protocols are based on the use of an ion chamber having an absorbed-dose to water calibration factor. These are different from the previous NCS report-2 and IAEA TRS-277 protocols, which require air kerma calibration factor.

Aim of the Study: Is to present the dose comparison between various dosimetry protocols and the IAEA TRS-398 protocol for clinical reference dosimetry of high energy photon beams. The absorbed-dose to water measured according to the NCS Report-2, International Atomic Energy Agency technical Report Series No. 277 (IAEA TRS-277) and, TG-51 are compared to that measured using the TRS-398 protocol.

Results and Discussion: This study shows that the absorbed dose which is measured with The IAEA TRS-398 formalisms is higher than that calculated with NCS Report-2 and IAEA TRS-277 formalisms within range from 0.4 to 1.3% and from 0.7 to 2.1%, respectively, for different higher energy photon beams of Co-60, 6, 8 and 18 MV. as sensed by different ionization chambers, The chambers used are PTW 30001, 30004, and NE-2571; which have calibration factors N_K and $N_{D,W}$ traceable to the Bureau International des Poids et Mesures (BIPM). In contrast, the absorbed-dose to water measured according to TG-51 is in good agreement with TRS-398 within about 0.3% for photon beams.

Key Words: Dosimetry protocol, NCS Report-2, IAEA TRS-277, AAPM TG-51, IAEA TRS-398, air- kerma.

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INTRODUCTION

Until few years it has been recommended to perform reference dosimetry of clinical high energy photon and electron beams with reference ionization chambers calibrated in terms of air karma. To this time a large number of dosimetry formalism which depends upon air kerma has been developed (AAPM TG-21, NCS Report 2 and 5, IAEA TRS–277 and IAEA TRS 381)

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 more robust system of primary standards than air–kerma based standards and allow the use of a simple formalism et al. 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[1] and Rogers[2]. The IAEA developed a protocol for dosimetry of high –energy photon and electron beams: IAEA TRS 398.

Some studies have already been devoted to the comparison of the two dosimetry formalisms with each other. Fuji Araki and H. Dale Kubo performed a dosimetry study with four different ion chambers in four high–energy photon beams and in a Co-60 beam. These studies discussed the changes that result 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 Fuji et al. and Araki et al.

In the present study a set of three ionization chambers, two PTW and one NE has been calibrated both in terms of air kerma and absorbed dose to water in Co-60; where these types are recommended for reference dosimetry. A reference dosimetry with set of ionization chamber and accelerators from different manufacturers. The aim of present work is to determine the differences in absorbed-dose to water measured according to the four different protocols.

MATERIALS AND METHODS

Ionization chambers. and Electrometers.

The chamber types used in this study were PTW-

30004, PTW 30001 and NE-2571. The characteristics of these chambers can be found in IAEA TRS-398. These chambers are recommended to reference dosimetry in clinical high–energy photon beams. The Electrometers used are PTW UNIDOS E and NE FARMER Dosimeter.

Calibration.

All ionization chambers were calibrated as chain in terms of air-Kerma and absorbed dose to water at the National secondary standard laboratory (National Institute of Standards (NIS); which is traceable to the Bureau International des Poids et Mesures (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 $P_{ion.}$

High –energy photon beams.

Table (1) shows Clinical photon beams which are used in the measurements and their beam quality. Different four beams which are selected, Co-60 beam of THERATRON760C, 6 MV photon beam of Siemens primus, 8 and 18 MV photon beams of Varian Clinac 1800.

Table 1: Clinical photon beams and the beam quality

Machine	Nominal energy	$TPR_{20,10}$ Measured (M)	$\%dd(10)_x$
Theratron 780C	Co-60	0.578	57.4
Siemens primus	6 MV	0.68	66.6
Varian Clinac 1800	8 MV	0.708	70
Varian Clinac 1800	18 MV	0.784	81

NCS Report-2

According to NCS Report-2 (Mijnher et al.[2]) which is air Kerma based formalism the absorbed dose to water obtained by the following formula, this protocol is at present recommended in Belgium and the Netherlnds.

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

Equation (1) can be rewritten in the following form,

$$D_{W,u} = M_{corr} N_K (1\text{-}g) \pi K_i S_{w,air} \pi Pi \quad (2)$$

$D_{W,u}$ 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.

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, air temperature, pressure and humidity, ion recombination (P_{ion}), polarity effects (P_{pol}) and for electrometer correction factor (P_{elec}) in the users beam. The fully corrected ion chamber reading, M, is defined by the following formula.

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

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 have been defined 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 have been defined as the absorbed dose to water calibration factor ($N_{D.w}$).

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

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

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

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

The definitions of the factors used to calculate $C_{W,U}$ are presented in the NCS Report-2.In this study the data for the chamber types, NE2571 and NE2561 are presented in NCS Report-2. Therefore, all factors have been recalculated with the expressions and data in this work for the PTW-30001 and PTW-30004 ion chambers.

IAEA TRS-277 protocol. According to IAEA TRS-277, the absorbed-dose to water, $D_W (P_{eff})$ for the effective point of measurement of the ion chamber, P_{eff} , is given by

$$D_W (P_{eff}) = M\ N_D S_{W,a}\, p_u\, p_{cel} \text{ [cGy]} \quad (10)$$

Where $M = M_{raw} P_{tp} P_{ion} K_h$. K_h is correction factor for the humidity in the chamber cavity air. $S_{W,a}$ is the ratio of the mean, restricted collision mass stopping power of water to air. p_u is the correction factor for non water equivalent of the chamber wall material and air cavity. p_{cel} Corrects for non air equivalent of the material in the central electrode of the ion chamber the value of p_{cel} for 1mm diameter aluminum electrode is unity for a rang of the photon energy used in the present work. The absorbed dose to air chamber factor, N_D , is calculated from the air-kerma calibration factor, N_K, as flowing

N_D 0.= $N_K(1\text{-g})\, K_{att}\, K_m$, (11)

Where N_K is obtained by cross calibration in Co-60. is the fraction of the secondary electron energy converted into bremsstrahlung in air. The correction factors K_{att} and K_m take into account the scattering ant attenuation and the non air equivalent in the chamber wall and buildup cap, respectively. These values are obtained from tables in IAEA TRS-277 protocol. According to IAEA TRS-277, air-kerma to absorbed-dose to water conversion factor is

Where N_K is obtained by cross calibration in Co-60. is the fraction of the secondary electron energy converted into bremsstrahlung in air. The correction factors K_{att} and K_m take into account the scattering ant attenuation and the non air equivalent in the chamber wall and buildup cap, respectively. These values are obtained from tables in IAEA TRS-277 protocol. According to IAEA TRS-277, air-kerma to absorbed-dose to water conversion factor is

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

$D_{W,Q} = M_Q\, N_{D,W,Q0}\, k_{Q,Q0}$[cGy] (12)

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

$M = K_{ion}\, K_{tp}\, K_{elec}\, K_{pol}\, M_{raw}$ (13)

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.

AAPM TG-51 protocol According to TG-51 protocol, the absorbed-dose to water $D_{W,}$

$D_W = M\, k_Q\, N_{D,W}$ (cGy) (14)

Where M is the charge reading and consists of $M_{raw}\, P_{TP}\, P_{ion}\, P_{ele}\, P_{pol.}$ M_{raw} is the uncorrected ion chamber reading at the poitnt of measurement. P_{TP} is the temperature-pressure correction factor to standard ambient conditions. P_{ion} is the ion recombination correction factor. P_{ele} is the electrometer correction factor. P_{pol} is the polarity correction factor. k_Q is the beam quality conversion factor. k_Q is a chamber specific factor which accounts for the change in the absorbed-dose to water calibration factor between the user>s beam quality of interest,Q and the beam 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 obtained from the standards laboratory.

RESULTS AND DISCUSSION

1. Ion chamber calibration factors:

To measure the absorbed dose to water by different Ion chambers the chambers used must be calibrated directly in Primary Standard Dosimetry Laboratory (PSDL) or Substandard Dosimetry Laboratory (SSDL) to obtain ion chamber calibration factor in terms of air kerma and absorbed dose to water calibration factors (N_K and $N_{D,W}$). The three chambers used are calibrated at the National Institute of Standards (NIS), Egypt, which is traceable to BIBM. Table 2 shows the N_K and $N_{D,W}$ calibration factors of all used ionization chambers, and the ratio between $N_{D,W}$ and N_K calibration factors.

Table 2: N_K and $N_{D,W}$ calibration factors.

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-2571	4.129	4.533	1.098

2. Beam quality specification:

Before starting absorbed dose measurements specification of beam quality must be performed. The need for specification of radiation quality comes from the fact that several of the parameters required for absorbed dose determination depend on the photon or electron energy. Examples of such parameters are photon absorption coefficients, electron stopping power, and various perturbation factors,(TRS-277) .

According to NCS Report-2, TRS-277 and TRS-398, the beam quality is defined as the ratio of the absorbed dose to water at depths of 20 and 10 cm ($TPR_{20,10}$). Tables 3 and 4 show K_{att} K_m and the overall conversion factors for the chambers used in this work according to NCS Report-2 and TRS-277 as a function of the energy (Beam quality). Fig. 1 and 2 show the relation between $TPR_{20,10}$ and air Kerma to absorbed dose to water overall conversion factors (OCF) which denoted C_{wu} according to NCS Report-2 and that according to TRS-277 protocol. Table 5 shows beam quality for photon beams and K_Q for selected farmer type chambers according to TRS-398.

Table 3 : K_{att} K_m and absorbed dose to water overall conversion factors(OCF) according to NCS Report-2.

Beam quality ($TPR_{20,10}$)	NCS Report-2 PTW-30001	PTW-30004	NE2571
	K_{att} K_m		
	0.983	0.983	0.985
	Overall conversion factors (OCF)		
^{60}Co (0.578)	1.088	1.087	1.088
0.671	1.0775	1.0775	1.079
0.708	1.0755	1.0755	1.0765
0.784	1.055	1.056	1.057

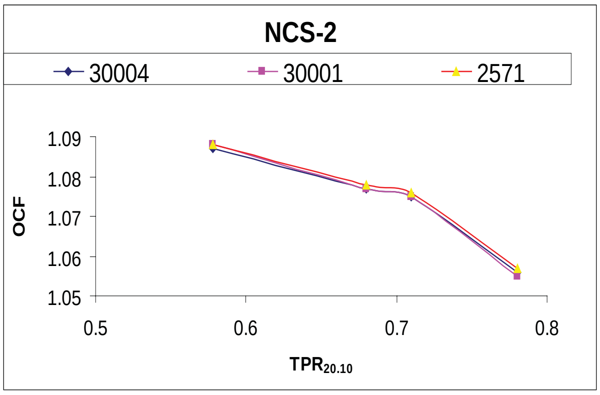

Fig. 1: Air kerma to absorbed dose to water overall conversion factors (OCF) according to NCS 2.

Table 4: K_{att} K_m and absorbed dose to water overall conversion factors (OCF) according to TRS-277.

Beam quality ($TPR_{20,10}$)	IAEA TRS-277 PTW-30001	PTW-30004	NE2571
	K_{att} K_m		
	0.972	0.982	0.985
	Overall conversion factors		
^{60}Co (0.578)	1.095	1.093	1.095
0.671	1.084	1.092	1.095
0.708	1.081	1.087	1.091
0.784	1.058	1.066	1.068

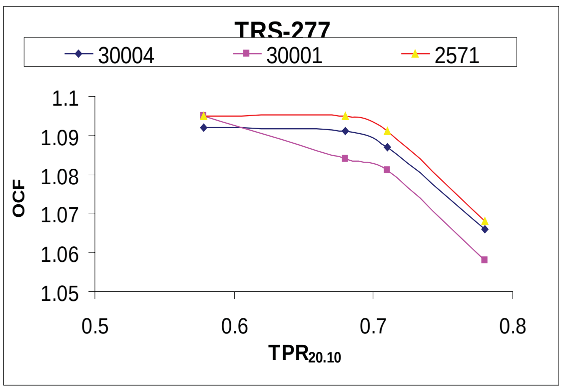

Fig. 2: Air kerma to absorbed dose to water overall conversion factors(OCF) according to TRS-277.

Table 5: Beam quality correction factor K_Q for TRS-398 as a function of $TPR_{20,10}$.

Photon beams	Beam quality $TPR_{20,10}$	K_Q PTW30004	PTW30001	NE2571
Co-60	0.578	1.000	1.000	1.000
6MV	0.671	0.995	0.991	0.994
8MV	0.708	0.991	0.987	0.990
18MV	0.784	0.974	0.967	0.973

Figure (3): shows the relation between $TPR_{20,10}$ and the beam quality conversion factor(K_Q) according to TRS-398 where the maximum value of K_Q is at Co-60 beam . K_Q decreases with increase in energy.

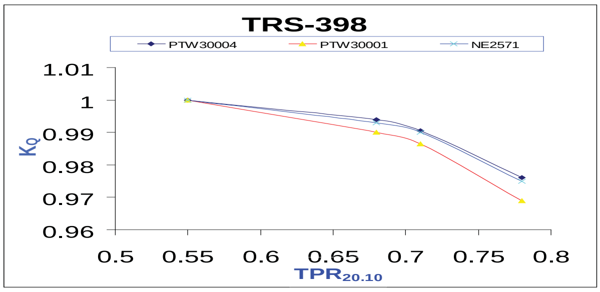

Fig. 3 : The relation between $TPR_{20,10}$ and K_Q According to IAEA TRS-398 protocol:

According to AAPM TG-51the beam quality of accelerator photon beams is specified by $\%dd\ (10)_x$, the percentage depth dose at 10cm depth in water phantom due to photons only (i.e excluding electron contamination). The beam quality is measured as described in session AAPM TG-51. Table 6 shows the values of $\%dd\ (10)_x$ and k_Q for selected farmer type chambers. Figure 4 shows the relation between $\%dd\ (10)_x$ and beam quality conversion factor(K_Q) according to TG-51for the three ionization chambers where the maximum value of K_Q is at Co-60 beam.

Table 6: Beam quality correction factor k_Q for TG-51.

Photon beams	$TPR_{20,10}$	%dd (10)	%dd (10)$_{pb}$	%dd (10)$_x$	k_Q Ionization chamber PTW 30004	PTW 30001	NE 2571
Co-60	0.578	57.4		57.4	1.000	1.000	1.000
6MV	0.671	66.6		66.6	0.992	0.988	0.992
8MV	0.708	70		70	0.989	0.985	0.989
18MV	0.784	79.3	80.8	81	0.983	0.976	0.972

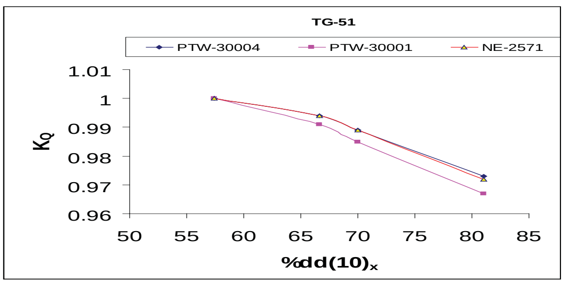

Fig. 4: Relation between $\%dd\ (10)_x$ and beam quality conversion factor (K_Q) according to TG-51.

3. Polarity and ion recombination:

The Polarity and ion recombination are measured according to recommendations in TRS-398 protocol. Tables 7 and 8 show that, for the three farmer chambers used in this work, the ion recombination and polarity correction factors are less than 0.3 and 0.2%, respectively.

Table 7: Experimental ion recombination correction factors P_{ion}.

Beam energy	Ion chamber PTW-30001	PTW-30004	NE2571
Co-60	1.000	1.000	1.000
6MV	1.001	1.001	1.001
8MV	1.000	1.001	1.002
18MV	1.003	1.002	1.002

Table 8: Experimental Polarity correction factors P_{pol}.

Beam energy	Ion chamber		
	PTW-30001	PTW-30004	NE2571
Co-60	1.000	1.000	1.000
6MV	1.000	1.000	1.000
8MV	1.002	1.002	1.000
18MV	1.000	1.000	1.001

4. Absorbed dose to water comparison among the four protocols.

The ratios of absorbed- dose to water according to TRS-398 obtained by direct measurements at reference conditions relative to that obtained according to different protocols are presented in Table 9. Among different energies the absorbed -dose measured with TRS-398 is approximately higher by 0.4 to 1.3 % than that with NCS Report-2 and by 0.7 to 2.1% with TRS-277. On the other hand, the doses in TRS-398 and TG-51 are in good agreement with in ± 0.3%. These results are in good agreement with the results of Cho et al.[3] and P. Andreo et al.[4] Differences from 0.4% to 2.1% obtained with the four protocols may be due to:

- Different conversion factors used to obtain $N_{D,W}$ from N_K.
- Variation of the Ratio of $N_{D,W}$ / N_K at different laboratories.

Different results will be found when calibration is traceable to different primary standard laboratories. The results obtained by Ding et al.[5] and Huq et al.[6] showed that the absorbed dose to water measured by TG-51 increase approximately by 1% for different photon beams, in comparison to TG-21 when calibration factors ($N_{D,w}$ and N_K) are traceable to the National Institute of Standards and Technology (NIST) in the United States. In contrast, results lower by 1.1% were obtained when using calibration factors traceable to the National Research Council (NRC) in Canada. showed that, when changing from AAPM TG-21 to AAPM TG-51 based on the NRCC standards, results obtained would increase by 0.4%. When based on the NIST standards on the other hand, the results would increase by 1.5%.

Table 9: Ratio of dose according to IAEA TRS-398 protocol relative to that according to TG -51, NCS Report-2 and TRS-277 protocols.

Chamber	Co-60	6MV	8MV	18MV
TG-51				
PTW-30004	1.000	0.998	1.001	1.003
PTW-30001	1.000	0.997	1.001	1.002
NE 2571	1.000	0.997	1.001	1.003
NCS-2				
PTW-30004	1.006	1.008	1.006	1.01
PTW-30001	1.005	1.004	1.002	1.004
NE 2571	1.009	1.011	1.011	1.013
TRS-277				
PTW-30004	1.007	1.014	1.013	1.014
PTW-30001	1.010	1.012	1.009	1.011
NE 2571	1.016	1.016	1.014	1.021

5. Relative response of the different ionization chambers.

Dose per monitor unit was measured for 18 MV at reference conditions according to each protocol. The results are tabulated in Table 10. Fig. 5 shows the dose response of different ionization chambers at18 MV. From figure 5 it is seen that:

i- The results obtained following TRS-398 are in good agreement with that following TG-51 and are higher than that obtained by NCS -2 and TRS-277 protocols.

ii- The average response of different chambers in this study is in good agreement within 0.4%.

iii- The results obtained following NCS report-2 and TRS-277 is in good agreement within 0.5%.

Table 10: Dose per monitor unit using different chambers for 18 MV photon beam.

Ionization chamber	TRS-398	TG-51	NCS-2	TRS-277
PTW-30004	1.016	1.0125	1.006	1.0013
PTW-30001	1.017	1.014	1.013	1.006
NE-2571	1.008	1.006	0.996	0.988

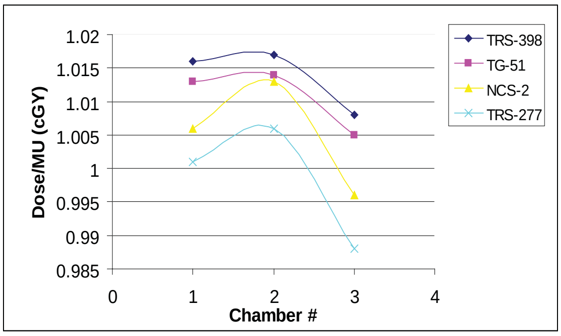

Fig. 5: Dose response of the different chambers for 18 MV photon beam determined according to the four protocols.

6.Estimated uncertainty in the determination of absorbed dose to water.

When a reference dosimeter is used for the determination of absorbed dose to water in the user beam, the uncertainties in different physical quantities or procedures that contribute to the dose determination can be divided into two steps. Step 1 considers uncertainties up to the calibration of the user reference dosimeter in terms of $N_{D,W}$ and N_K at the standards laboratory. Step 2 deals with the calibration of the user beam and includes the uncertainties associated with the measurement at the reference point in a water phantom. Step 2 also includes the uncertainties of the value of the beam quality correction factor K_Q. Combining the uncertainties in quadrature in the various steps yields the combined standard uncertainty for the determination of absorbed dose to water at the reference point. An estimate of the uncertainties in the measurements of this work is given in Table 11.

Table 11: Estimated uncertainty in measurement of absorbed dose to water.

Relative uncertainty (%)	**Physical quantity or procedure**
	Step 1: standard laboratory
0.47	N_{DW} calibration of secondary standard at NIS, Egypt.
0.1	Long term stability of secondary standard
0.4	N_{DW} calibration of the user at the standard laboratory
0.6	Combined uncertainty of step 1
	Step 2: user high energy photon beam
0.4	Establishment of reference conditions
0.002	Repeatability of Dosimeter reading relative to beam monitor
0.2	Correction for influence quantities Ki
1.0	Beam quality correction K_Q
1.095	Combined uncertainty of step 2
1.2	Combined uncertainty of D_{WQ} (steps 1+2)

CONCLUSIONS

Photon dosimetry in energies of, ^{60}Co. 6MV, 8MV and 18MV, has been done according to air-kerma based protocols (NCS-2 and TRS-277) and absorbed dose to water based protocols (TG-51 and TRS-398). Three graphite-walled cylindrical ionization chambers were used. The changes from air-kerma based protocols to absorbed dose to water based protocols were discussed where, absorbed dose to water and air-kerma calibration factors in the reference beam (^{60}Co) are traceable to BIPM, (Bureau international des Poids et Mesures). The ratio of the doses according to TRS-398 protocol and that according to NCS Report-2, and TRS-277 protocol are up to, +1.3% and +2.1% respectively. On the other hand there is good agreement between measured dose according to TRS-398 and that according to TG-51 within 0.3%. Overall, the conclusion is that the change from air kerma to absorbed dose to water based protocols does not substantially alter the results obtained in clinical reference dosimetry when using one of the chamber types of this study and when the calibrations are traceable to the BIPM.

There is good agreement between the results of the present work and previous results by Bangade et al.[7] and Hugo Palmans et al.[8].

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