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ORIGINAL ARTICLE

ABSORBED DOSE TO WATER DETERMINATION USING IAEA, HPA, NACP, AAPM, NCRP AND ICRU PROTOCOLS FOR 1.25 MEV GAMMA RAY 6 MV AND 10 MV X-RAYS: AN INTERCOMPARISON OF RESULTS WHEN IAEA WAS TAKEN AS A STANDARD PROTOCOL

M T Dolah, S B Samat and T Kadni*

School of Applied Physics, Universiti Kebangsaan Malaysia
43600 UKM BANGI, Selangor, Malaysia

***Secondary Standard Dosimetry Laboratory Malaysia**
Malaysian Institute for Nuclear Technology Research
43000 KAJANG, Selangor, Malaysia

Absorbed dose to water was measured with ionisation chambers NE 2561 (#267), NE 2581 (#334), NE 2571 (#1028), using the IAEA standard water phantom. The ionisation chamber was inserted in the water phantom at a reference depth dependent on the type of the radiation quality used. Three radiation qualities were used namely 1.25 MeV gamma ray, 6 MV x-rays and 10 MV x-rays. The values of the absorbed dose to water were determined by the N_K- and N_X- based methods, i.e with the use of IAEA, HPA, NACP, AAPM, NCRP and ICRU protocols. The aim of this study was to make an intercomparison of the results, by taking the IAEA protocol as a standard. The largest deviation contributed by any of these protocols was recorded for each quality. It was found that AAPM, NCRP and ICRU protocols contributed 0.94% for 1.25 MeV gamma ray, NACP contributed 2.12% for the 6 MV x-rays, and NACP contributed 2.35% for 10 MV x-rays. Since the acceptable limit of deviation set by the IAEA for this absorbed dose work is ± 3%, it is clear that the overall deviations obtained were all satisfactory.

Key words : *gestational Diabetes mellitus, diagnosis, management*

Introduction

At present there are many protocols that are being used in variaus countries to determine the absorbed dose to water. In 1987, International Atomic Energy Agency (IAEA) recommended a protocol for absorbed dose to water determination for high energy photon dosimetry (1). Prior to this recommendation, several protocols have been recommended, for example; Hospital Physicists' Association in 1983 with its HPA protocol (2), American Association of Physicists in Medicine in 1983 with AAPM protocol (3), National Council on Radiation Protection and Measurement in 1981 with its NCRP protocol (4), Nordic Association of Clinical Physics in 1980 with its NACP protocol (5) and International Commission on Radiation Units and Measurement in 1973 with its ICRU protocol (6). Table 1 summarises these six protocols together with their respective formulae for calculating the absorbed dose to water. The, meanings of symbols that are used in the formulae are given in the final part of this paper.

For the purpose of dosimetry accuracy in radiotherapy, these six protocols should in practice yield a single value in the absorbed dose to water,

Table 1. *Absorbed dose to water* D_W *formulae according to variaus protocols*

Protocols		Equation no. this work	References
Name	*Dw* formulas		
IAEA	$M_u N_k (1\text{-}g) K_{att} K_m (S_{w\,air}) P_u P_{dis}$	1	[1]
HPA	$1.139\, M\, N_K\, C_\lambda$	2	[2]
NACP	$M_u N_K (1\text{-}g) K_{att} K_m (S_{w\,air}) P_u$	3	[5]
AAPM	$M N_X K_q\, ^{(a} (Li\ p)_{med.gas} P_{ton} P_{repl} P_{wall}$	4	[3]
NCRP	$M N_x C_\lambda$	5	[4]
ICRU	$M N_x C_\lambda$	6	[6]

$$^{a}k_q = \frac{k \times (W/e) \times A_{ion} \times A_{wall} \times \beta_{wall}}{\alpha \times \left(\bar{L}/p\right)^{wall}_{air} \times \left(\bar{\mu}_{en}/p\right)^{wall}_{air} + (1\text{-}\alpha) \times \left(\bar{L}/p\right)^{cap}_{air} \times \left(\bar{\mu}_{en}/p\right)^{air}_{cap}}$$

Table 2. *The radiotherapy machices that provided the three radiation qualities*

Radiation quality		Machine		
No.	Energy	Name	Model	Located at
1	1.25 MeV	Co-60 teletherapy unit	Eldorado-8 (#104)	SSDL Malaysia
2	6 MV x-ray	Medical linear accelerator (linac)	Mevatron KD2	Radiotherapy and Oncology Unit, HUKM
3	10 MV x-ray	Linac	Mevatron KD2	Radiotherapy and Oncology Unit, HUKM

Table 3. *Calibration factor of the three ionisation chambers*

Ionisation chamber		Calibration faktor	
Model	Serial number	N_K	N_X
NE 2561	267	9.353 mGy/sd[(a]	1.064 R/sd[(u]
NE 2581	334	52.94 mGy/sd[(b]	6.022 R/nC[(d]
NE 2571	1028	41.34 mGy/sd[(c]	4.703 R/nC[(d]

[u]Certificate values as reference (8).

[b]Certificate values as reference (9).

[c]Certificate values as reference (10).

[d]Derived from the N_K *Value*.

for a given radiation quality and reference condition. The study acms to confirm whether the different protocols yield almost identical absorbed dose to water result, for a given radiation quality and experiment set-up.

The goalo of this study are: (1) to determine the absorbed dose to water using IAEA, HPA, NACP, AAPM, NCRP and ICRU protocols for 1.25 MeV gamma ray, 6 MV x-rays and 10 MV x-rays; and (2) to compare the results obtained by the HPA, NACP, AAPM, NCRP and ICRU with the most commonly used IAEA protocol (7).

Material and Methods

2.1 The dependence of the three elements (calibration factors, dosimeter readings and the interaction coefficients) on radiation quality and ionisation chamber in the protocol formulae.

The six formulae (given by the six protocols) for the determination of the absorbed dose to water in Table 1, mainly comprise of three elements namely:

(i) the ionisation chamber calibration factors (N_K or N_X), which depend on the type of chamber used,
(ii) the dosimeter reading (M or M_u), which depends on both the chamber and the radiation quality, and
(iii) the interaction coefficients, which depend on the ionisation chamber, the radiation quality and the protocol used.

The present work investigated the determination of the absorbed dose to water in three

Table 4. Dosimeter reading of the three ionisation chambers, in three radiation qualities

Dosimeter models		Dosimeter average reading $M^{(a}$ or $M_u^{(b}$		
Ionisation chanber	Electrometer	1.25 MeV gamma ray	6 MV x-ray	10 MV x-ray
NE 2561 (#267)	NE 2560 (n151)	28.979 ± 0.040 sd/min	85.933 ± 0.047 sd/100mu	201.347 ± 0.12 sd/300mu
NE 2581 (#334)	PTW-Unidos 10005 (n 50013)	4.957 ± 0.002 nC/min	35.336 ± 0.042 nC/230mu	-
NE 2571 (#1028)	PTW-Unidos 10005 (n 50013)	6.109 ± 0.004 nC/min	15.701 ± 0.000 nC/80mu	-

(a For HPA, AAPM, NCRP and ICRU protocols
(b For IAEA and NACP protocols

Table 5. Values of interaction coefficients as a function of radiation quality, ionisation chamber, and protocol.

		1.25 MeV gamma ray								
		NE 2561	NE 2581	NE 2571	NE 2571	NE 2581	NE 2571	NE 2551	NE 2581	NE 2571
IAEA										
	$(1\text{-}g)$	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
	K_{att}	0.995	0.995	0.994	0.995	0.975	0.974	0.995	0.995	0.994
	K_m	0.984	0.99	0.991	0.984	0.99	0.991	0.984	0.99	0.991
	$(S_{w,air})$	1.133	1.133	1.133	1.119	1.119	1.119	1.105	1.105	1.105
	P_u	0.993	1.0075	0.993	0.9946	1.006	0.9946	0.9966	1.2407	0.9966
	P_{dis}	0.985	0.987	0.987	0.985	0.987	0.987	0.985	0.987	0.987
HPA										
	C_λ	0.951	0.951	0.951	0.95	0.95	0.95	0.943	0.943	0.943
NACP										
	$(1\text{-}g)$	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
	K_{att}	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	K_m	0.991	0.963	0.991	0.991	0.963	0.961	0.961	0.963	0.991
	P_u	0.97	0.99	0.97	0.98	0.99	0.98	0.985	0.99	0.985
	$(S_{w,air})_u$	1.15	1.15	1.15	1.14	1.14	1.14	1.125	1.125	1.125
AAPM										
	$(1\text{-}g)$	0.0085(a	0.0085	0.0086(b	0.0085(a	0.0085(a	0.0086(b	0.0085(a	0.0085	0.0086(a
	$(L/p)_{med,gas}$	1.134	1.134	1.134	1.127	1.127	1.127	1.117	1.117	1.117
	P_{ion}	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	P_{repl}	0.9953	0.9958	0.9958	0.9955	0.9961	0.9961	0.9925	0.9936	0.9936
	P_{wall}	0.9965	1.0099	0.9970	0.9965	1.0050	0.9960	0.9976	2.0047	0.9976
NCRP	C_λ	0.95 md/R	0.95 md/R	0.95 md/R	0.94 md/R	0.94 md/R	0.94 md/R	0.93 md/R	0.93 md/R	0.93 md/R
ICRU	F	0.95 md/R	0.95 md/R	0.95 md/R	0.94 md/R	0.94 md/R	0.94 md/R	0.93 md/R	0.93 md/R	0.93 md/R

Reference (12)

radiation qualities using three different ionisation chambers.

Table 2 shows types of machines that provided these radiation qualities and the their location.
Table 3 shows the three chambers used together with their calibration factors.
Table 4 shows the dosimeter readings obtained from the three chambers in the three radiation qualities.

The types of electrometers used with these ionisation chambers to yield the readings (charge) are given in this table. To obtain these readings, for example in the 1.25 MeV Co-60 beam, experimental set-up as shown in Fig 1 was used. Similar set up was used for the x-rays beam. Source to chamber distance (SCD) was set at 110 cm for 10 MV x-ray, and 105 cm for other radiations.

The final part of the absorbed dose to water formula is the interaction coefficients. Table 5 shows these coefficients with their values (1, 2, 3, 4, 5, 6, 11, 12). It can be seen that these values vary with the type of radiation quality, the type of ionisation chamber used for measurement and the protocol used.

2.2 Numerical examples for calculating the absorbed dose to water and the percentage deviation in absorbed dose to water

2.2.1 The absorbed dose to water

Example 1. Suppose that the absorbed dose to water in the 1.25 MeV gamma ray beam is to be determined using NE 2561 ionisation chamber based on the IAEA protocol. By looking at Table 1, eqn. 1 is the formula that should be used. For the present work, the values for eqn. 1 are: N_K = 9.353 mGy/sd (Table 3); M_u = 28.979 ± 0.040 sd/min (Table 4); $(1\text{-}g)$ = 0.997, K_{att} = 0.995, K_m = 0.984, $S_{w,air}$ = 1.133, P_u = 0.933 and P_{dis} = 0.985 (Table 5). Upon calculating, we obtained D_W = 293.24 mGy/min.

Example 2. Suppose that the absorbed dose to water in the 6 MV x-rays beam is to be determined

Table 6. D_W and D values for three ionisation chambers, calculated using six protocols, and three radiation qualities.

Radiation quality	Ionisation chamber	Units	*Dw* (Eqns. (1) to (6))						& (Eqn. (7))				
			IAFA	HPA	NACP	AAFM	NCRP	ICRU	HPA	NACP	AAPM	NCRP	ICRU
1.25 MeV	NE2561	mGy/min	293.24*	293.57	295.74	296.00	292.92	292.92	0.11*	0.85	0.94	-0.11	-0.11
gamma	NE 2581	mGy/min	281.65	284.25	283.98	286.57	283.59	283.59	-0.14	-0.23	0.67	-0.37	-0.37
ray	NE 25 71	mGy/min	275.53	273.56	275.56	275.81	272.94	272.94	-0.72	0.01	0.10	-0.94	-0.94
6 MV x-ray	NE 2561	Gy/100mu	0.860	0.870	0.878	0.869	0.859	0.859	1.12	2.12	1.05	-0.07	-0.07
	NE 2581	Gy/230mu	2.001	2.024	2.007	2.021	2.000	2.000	1.16	0.29	1.00	0.04	0.04
	NE 2571	Gy/80mu	0.701	0.702	0.712	0.709	0.694*	0.694	0.26	1.66	1.14	-0.92	-0.92
10 MV x-ray	NE 2561	Gy/30mu	1.994	2.002	2.041	2.014	1.992	1.992	1.42	2.35	1.00	-0.10	-0.10

Table 7. Comparison of absorbed dose to water let the present study and previous students

Two protocol that are being compared	Study		Previous student			Comments on the results of present study
	Condition	Results of deviation (%)	Condition	Results of deviation %	Reference	
HPA, in comparison with AIEA	Radiation quality Co-60, 6 MV and 10 MV using NE 2561 chamber	0.11% to 1.42%	Same as present work	-1.29% to -0.22%	13	It is in a good agreement
AAPM, in comparison with AIEA	Radiation quality Co-60, 6 MV and 10 MV using NE 2561, NE 2581and NE 2571 chambers	0.10% to 1.14%	Different from present study: This other study uses radiation quality Co-60, 4 MV and 25 MV using PTW, Capintec and Farmer chambers	-0.40% to-1.20%	14	One to one comparison cannot be done as conditions are different

with NE 2571 ionisation chamber using the NCRP protocol. By looking at Table 1, eqn. 5 is the formula that should be used. For the present work, the values for eqn. 5 are: N_X = 4.703 R/nC (Table 3); M_u = 15.701 ± 0.000 nC/80mu (Table 4); C_l = 0.94 rad/R (Table 5). Upon calculating, we obtained D_W = 0.694 Gy/80mu

Similar methods as shown in examples 1 and 2 were used to calculate D_W for other radiation qualities using the three chambers for the six protocols. The results are shown in Table 6.

2.2.2 The percentage deviation in absorbed dose to water

The percent age deviation in the absorbed dose when we compare with the IAEA protocol is

$$\frac{D_W\,(\text{Other protocol}) - D_W\,(\text{IAEA protocol})}{D_W\,(\text{IAEA protocol})} \times 100\%$$

Example 3. Suppose the deviation of the absorbed dose to water in the HPA protocol results (obtained in the determination of absorbed dose to water in 1.25 MeV gamma-ray beam using an NE 2561 chamber) is to be calculated. By looking at Table 6, we have 𝕊 = 100% x (293.57 – 293.24)/ 293.24 = 0.11 %.

Similar method as shown in example 3 was used for the other protocols to calculate other 𝕊 for the three radiation qualities using the three chambers. The results are shown in Table 6.

Result and Discussion

Column 4 of Table 6 shows the values of the absorbed dose to water determined by the IAEA protocol for three radiation qualities using the three types of ionisation chambers. Columns 5, 6, 7, 8 and 9 show the absorbed dose to water calculated by the HPA, NACP, AAPM, NCRP and ICRU protocols respectively. Columns 10, 11, 12, 13 and 14 show how the other protocols deviate from the IAEA results.

In this study the NCRP and ICRU protocols yielded results which are in good agreement with the IAEA protocols, followed by the HPA, AAPM and NACP protocols. From Table 6, it can be seen that all the deviation values given by these two (NCRP and ICRU) protocols are lower than ±1%.

Table 7 shows the comparison between the present study and present studies. For the HPA

Figure 1. Experimental set-up for the absorbed dose to water determination in a 60 Co beam at the SSDL.

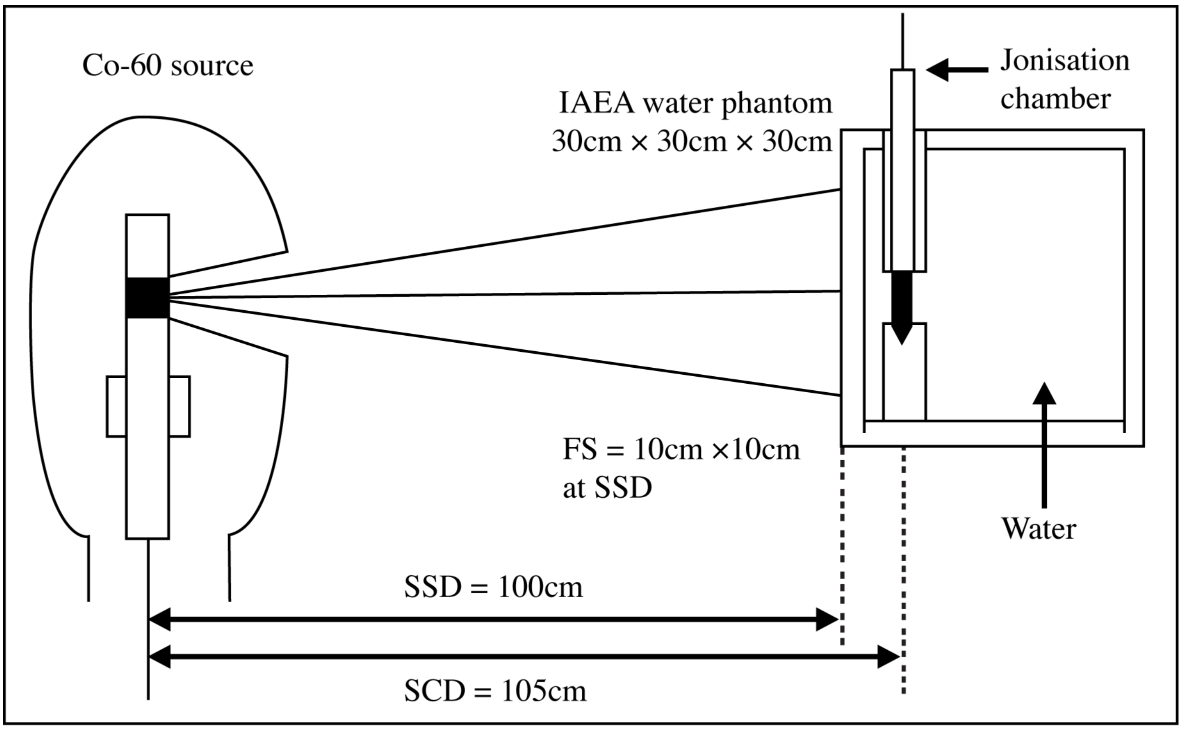

Figure 2. List of symbols and meaning.

List of symbols

(l-g)	Value for fragtion energy of secondary charges particles that is lost to bremsstrahlung
α	Fraction of ionization due to electron from buildup cap
A_{ion}	Ion collection efficiency
A_{wall}	Wall corection factor
β_{wall}	Absorbed dose/collision fraction of kerma
C_{λ}	Exposure to absorbed dose conversion factor
D_w	Absorbed dose to water
F	Coefficient relating the exposure in roentgens to absorbed dose in water expressed in cGy
k	Charge per unit mass of air per unit exposure
K_{att}	Attenuation factor
K_m	Non-air
k_q	Chamber correction factor
(L/ρ)	Stopping power ratio-medium to gas
M or M_u	Electrometer reading
N_K	Air kerma calibration faktor
N_X	Exposure calibration factor
P_{dis}	Correction for displacement correction
P_{repl}	Replacement correction
P_u	Perturbation factor

protocol, a study that was newformed by Kadni [13] shawed a good agreement with the present study. The other study done by Huq and Nath [14] however can not be compared to this study as different conditions were used.

The largest deviation contributed by any of these protocols was recorded for each quality. It was found that AAPM, NCRP and ICRU contributed 0.94% for 1.25 MeV gamma ray, NACP contributed 2.12% for the 6 MV x-rays, and NACP contributed 2.35% for 10 MV x-rays. Since the acceptable limit of deviations set by the IAEA for this absorbed dose work is ± 3% [15], it is clear that the overall deviations obtained were all satisfactory.

Conclusions

HPA, NACP, AAPM, NCRP and ICRU protocols have not yielded significant differences in absorbed dose to water value when compared with the recent IAEA protocol. The differences in data for interaction coefficients have minor influences on the final results. It can be concluded that, despite the many differences in the values of these protocols, the final results were almost identical. Therefore, not suprisingly, the five protocols are still being used in the western countries. In Malaysia, a preliminary survey [16] showed that four out of thirteen health institutions use the HPA protocol while two health institutions use the ICRU and AAPM protocols.

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Correspondence :

Dr. M T Dolah
School of Applied Physics
Universiti Kebangsaan Malaysia
43600 UKM BANGI, Selangor, Malaysia

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