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Inter-comparison of absorbed dose to water in a Co-60 therapy beam using IAEA and HPA protocols

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Summary
The absorbed dose water in a Co-60 teletherapy beam has been measured with four different standard ionisation chambers applying two codes of practice and also, with a Fricke dosimeter. Measured values agree generally within 2.3%. There is a remarkable agreement of less than 0.3% variation, between ionisation chambers NE 2561 and NE 2481 when the IAEA protocol is applied. The HPA protocol is applicable to only NE 2561 and a variation of about 1.4% was observed between measurements made with this ionisation chamber applying the two protocols. The IAEA protocol shows very accurate results. With a deviation of about 2.2%, the Frickle dosimeter appears to be the least accurate for therapy dose measurement despite its simplicity of application.

Keywords: *Absorbed dose, teletherapy, Co-60 beam quality, dosimeters*

Résumé
La quantité d'eau absorbée la teletheraphy Co-60 a été mésurée avec quatre chambre standard d'ionisation differentes appliquant deux codes de pratique et aussi, avec le desomtre de Fricke. Les valeurs mecurées sont généralement acceptées dans les 2,3%. Il ya un agrement remarguable de variation de moins de 0,3% entre les chambres d''ionisation NE 2561 et une variation d'environ 1,4% était obervée entre mesures prises avec cette chambre d'ionisation en applicant les deux protocoles. Le protocole IAEA donne des resultants exacts. Avec une deviation d'environ 2,2%, le dosimetre de Fricke parait être de moins exact pour la mesure de dose de thereapy bien que simple en application.

Introduction

Therapy doses to the tissue must be very accurately delivered. International Commission for Radiation Units and Measurements (ICRU) [1] recommends an accuracy of ± 5% of the prescribed dose. Brahme [2] indicates that better accuracy is required for a successful treatment. The accuracy of the therapy dose depends on the accuracy of the standardisation techniques of the therapy centre. There are presently many procedures or protocols for the determination of absorbed dose to water. Two of them are the Hospital Physicist's Association, HPA protocol [3] and the International Agency for Atomic Energy, IAEA protocol [4]. This paper compares absorbed dose to water in a Co-60 beam using four secondary ionisation chambers applying the two protocols.

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The four ionization chambers are the most commonly used especially in the region of Africa. In a number of therapy centres in the region, much older protocols are used and there may be serious questions on the accuracy of the doses delivered.

Dosimetry protocols

According to the HPA code, there is a direct proportionality between instrument reading and the dose to water at the centre of the ionisation chamber at a specified depth in the water phantom. The code is given in the formula:

$$D = R.\ N_x\ .C\lambda \qquad \text{.........................1}$$

where D is the dose to water (Gy), R is the instrument reading corrected to temperature and pressure, N_x is the calibration factor in terms of exposure and C_λ is the conversion factor relating the ionisation chamber response to exposure in air to its response in absorbed dose to water in the phantom. This factor was initially assumed to depend on radiation quality only but was later realised [5] to depend on size, shape and construction of the ionisation chamber. A revised code published by HPA [6] updates the new values C_λ which were specifically recommended for the ionisation chamber NE 2561.

In keeping with the need for increased accuracy through a standardised procedure that is applicable to the large variety of ionisation chambers available worldwide, IAEA published the international code [3]. According to this code, the formula for the determination of the absorbed dose to water, D_W, at the effective point of measurement is given by:

$$D_W = M_U\ N_D\ (S_{w,air})_u\ P_u\ P_{cel} \qquad \text{............2}$$

where M_U is the meter reading for the mean absorbed dose corrected to temperature and pressure values, $S_{w,air}$ is the water to air stopping power ratio at the photon quality, P_{cel} is the correction factor for the non-air equivalence of the central electrode material. P_U is the perturbation correction factor of the chamber in water and it is given by:

$$P_U = \alpha\{S_{wall,air}\ (\mu_{en}/P)_{w,wall} + (1-\alpha)\ S_{w,air}\}/S_{w,air} \qquad \text{.........3}$$

N_D is the absorbed dose to air calibration factor which depends on a number of factors. These factors are summarised in the equation:

$N_D = N_k\,(1\text{-}g)\,K_{att}\,.K_m$ 4

where N_k is the air kerma calibration factor of the ionisation chamber used, g is the fraction of the energy of secondary electrons that is lost to bremsstrahlung, k_{att} is the factor to take into account the attenuation (by scattering an absorption) of the photons in the ionisation chamber material (including the build-up cap) k_m is the correction factor to take into account the non-air equivalence of the ionisation chamber material. The constant α, $S_{wall,air}$, $(\mu_{en}/P)_{w,wall}$ and $S_{w,air}$ relate to the status of the wall-air, water-air and water-wall interfaces when the ionisation chamber is positioned. Detailed description of the physical significance of all these quantities and their values for various ionisation chambers at different qualities are given the IAEA TRS 277(2).

Materials and methods

The output of the Co-60 (8.9 TBq or 240.7 Ci) gamma beam of the Eldorado 8 teletherapy unit at the Secondary Standard Dosimetry Laboratory (SSDL) at the Malaysian Institute for Nuclear Technology Research (MINT) was measured, using a set of four secondary ionisation chambers, NE 2561 series no. 261, NE 2571 series no. 1028, NE 2581 series no 334 and TK01 series no. 108. Their characteristics are given in Table 1. The values of the factors applied in eqns.1 to 4 for each chamber and the calibration data from standard laboratories at temperature 20°C and 1013.25 mbar pressure are given in Table 2.

Table 1: Ionisation chamber characteristics:

Type of Chamber	Internal length (mm)	Internal radius (mm)	Wall Material	Wall thickness ($g.cm^{-2}$)	Cap Material	Thickness of cap($g.cm^{-2}$)
NE 2561 ($0.325\ cm^3$)	9.2	3.70	Graphite	0.090	Delrin	0.600
NE 2571 ($0.6cm^3$)	24.0	3.15	Graphite	0.065	Delrin	0.551
NE 2571 ($0.6cm^3$)	24.0	3.15	A-150	0.041	PPMA	0.584
TK 01 ($0.4cm^3$)	12.0	3.50	Delrin	0.071	Delrin	0.430

Table 2: Factors Applied at the Co – 60 beam quality(2)

Factor	NE 2561	NE 2571	NE 2581	TK01
g	0.003	0.003	0.003	0.003
k_{att}	0.984	0.990	0.990	0.989
k_m	0.995	0.994	0.969	0.989
$S_{w,air}$	1.133	1.133	1.133	1.133
α	0.630	0.520	0.400	0.550
$S_{wall,air}$	1.002	1.080	1.107	1.080
$(\mu_{en}/P)_{w,wall}$	1.113	1.042	1.029	1.042
P_u	0.990	0.994	1.002	1.016
P_{cel}	1.000	1.000	1.000	1.000
N_x	1.064 R/sd	1.011	5.961R/nC	8.862R/nC
N_k	9.3525 mGy/sd	8.887mGy/R	52.41 mGy/nC	77.92 mGy/nC
C_λ	0.951	-	-	-

sd = scale division

The ionization chambers were placed in Perspex sheath and fixed in the water phantom such that their axes were perpendicular to beam axis. At the Co-60 radiation beam quality, the source to the surface of the phantom distance (SSD) applied for measurements was 80.0 cm. The field size at the phantom surface (FS) was 10 cm x 10 cm and the depth in water was 5.0 cm. Ionisation chamber NE 2561 was connected to NPL secondary standard therapy level x-ray exposure meter NE 2560 series no. 151, ionisation chamber NE 2571 was connected to Farmer dosimeter 2570A series no. 535, ionisation chamber NE 2581 was connected to PTW-UNIDOS model 10005 serial no. 50013 while the fourth ionisation chamber TK01, was connected to Digital Currentintegrator NP 2100. The calibration factors given in Table 2 for each ionisation chamber relate to the scale of the electrometer used. All measurements were repeated 10 times in order to have a good statistics. Standard deviations were generally less than 0.09%. Fricke dosimeter was used to measure the dose at the same point in water for the purpose of inter-comparison.

Results

The absorbed dose to water at the specified depth has been computed for each ionisation chambers by applying the IAEA protocol given by the formula in equation 2, after correcting all meter readings to the temperature and pressure of calibration. Calculation of the absorbed dose to water has been based on equation 1 for the HPA protocol and equation 4 for the IAEA protocol. The HPA protocol is applicable to only ionisation chamber NE 2561. Results are given in Table 4. The deviation (%) given in the table are based on the value obtained with NE 2561 as the standard ionisation chamber, judging from its performance in yearly participation in the IAEA/WHO inter-comparison exercises [7]. Deviation in the table has been defined as $[(X-X_{2561})/X_{2561}]100\%$

Table 4: Dose rate at the SSDL, MINT

Dosimeter	D_w(mGy/min) [IAEA]	D_w(mGy/min) [HPA]	Deviation (%)
NE 2561	553.128±0.02%	546.548±0.02%	-
NE 2571	561.648±0.08%		+1,540
NE 2581	553.634±0.04%		-0.091
TK 01	547.166±0.02%		-1.077
Frickle Dosimeter	540.828±0.12%		-2.223

Measurements were repeated at the Radiotherapy Department, Hospital Universiti Kebangsaan Malaysia (HUKM), Kuala Lumpur with only NE2561 and NE 2581 ionisation chambers at their treatment plan of SSD = 100 cm and FS = 10 x 10 cm. The therapy machine used in the Department is a Co-60 Theratron 1000 Serial No 129 – 1. The results are presented in Table 5.

Table 5: Dose rate at the Therapy Department, HUKM

Dosimeter	D_w(mGy/min) [IAEA]	D_w(mGy/min) [HPA}	Deviation (%)
NE2561	131.264±0.02%	129.407 (1.414%)	0.000
NE2581	130.8700.02%		0.300

Discussion and conclusion

The results presented above give a fair basis for the assessment of the performance of the four ionisation chambers and the Fricke dosimeter. All measurements agree within 2.3% which is well within the ICRU recommendation of ± 5%. There is a consistent agreement with less than 0.3% variation, between NE 2561 and NE 2581 when the IAEA protocol for dose calculation was applied. The HPA protocol is applicable to only NE 2561 and there is a variation of up to 1.4% between measurements with the ionisation chamber based on the two protocols. The IAEA protocol can be applied with accurate results to a wide variety of ionisation chambers. The apparent complicated calculation procedure in the IAEA protocol becomes easier as the method is applied on routine basis, especially with the same ionisation chamber.

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