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A COMPARISON OF PROTOCOLS FOR DETERMINATION OF 300 kV X-RAY ABSORBED DOSE IN RADIOTHERAPY

POREĐENJE PROTOKOLA ZA ODREĐIVANJE APSORBOVANE DOZE 300 kV X-ZRAČENJA U RADIOTERAPIJI

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aposrbovana doza, kilo-voltažna radioterapija, poređenja, protokol prakse

Key words
absorbed dose, kilo-voltage radiotherapy, comparison, code of practice

Abstract

The paper compares four of the most frequently used protocols for determination of absorbed dose in water for kilovoltage X ray beam (HPA, IAEA Technical Reports Series No.277, IPEMB and IAEA Technical Reports Series No.398). Measurements based on careful implementation of procedures contained within the various protocols have been carried out in effort to determine differences among the protocols where measurements have been done at standard radiotherapy conditions on the radiotherapy machine Philips RT–305 at Radiotherapy Department of Military Medical Academy in Belgrade. Absorbed dose was measured using cylindrical ionization chamber type NE 2571. The values of the absorbed dose obtained according to the given protocols and differences have been compared to the values obtained by the recent protocol IAEA 398. The differences for HPA protocol reach up to 40 %. The results obtained from IPEMB and IAEA 277 protocols were found to be up to 2.7 % and 1.4 % smaller than the results obtained from IAEA 398 protocol. The values of absorbed dose measurement uncertainties have been estimated.

INTRODUCTION

Absorbed dose is the most important physical value estimated in clinical dosimetry. In clinical dosimetry the absorbed dose in the tissue is relevant. As a human body mainly consists of water, that water is used as a referential material in clinical dosimetry. Therefore absorbed dose is determined in water, D_w. This paper compares four most frequently used protocols for determination of absorbed dose in water for kilovoltage X ray by ionizing chamber: HPA [1] , IAEA 277[2], IPEMB[3] and IAEA 398 [4]. The compared protocols use different ionization chamber calibration factors: calibration factor in terms of exposure, N_X (HPA), calibration factor in terms of air kerma, N_K (IAEA 277 and IPEMB) and calibration factor in terms of absorbed dose to water for a dosimeter at reference beam quality Q_o,N_D (IAEA 398). The comparison has been done according to recent protocol IAEA 398.

2. MATERIALS AND METHODS

The measurements have been done on radiotherapy X ray machine Philips RT–305 with X ray tube TRC 300, with inherent filtration of 1.5 mm Cu. In order to have similar conditions to as the therapy applicators with end plates have been used. The characteristics of the applicators are presented in table 1., where SSD source surface distance i.e. the distance from the focus to the end of the applicator, HVL half value layer, B backscatter factor determined with measurement uncertainties of 1 % and $(\mu_{en}/\rho)_{w,air}$ ratio of the mean mass energy – absorption coefficients of water and air, averaged over a photon spectrum, determined with statistical measurement uncertainties of 1 %.

The beam quality is determined by voltage on a tube (300 kV), a total filtration and half value layer. The cylindrical ionization chamber type NE 2571, calibrated by former Federal Bureau of Measure and Precious Metals (FBMPM, Belgrade, now Direction for measurement and precious met-

Table 1. The characteristics of the applicators used for comparison

Applicator [cm x cm]	SSD [cm]	HVL [mmCu]	Inh. filtr. [mmCu]	B	Equiv. radius [cm]	$(\mu_{en}/\rho)_{w,air}$
8 x 10	30	4.4	4.8	1.11	5.01	1.109
10 x 15	30	4.4	5.0	1.22	6.77	1.108
15 x 20	30	4.4	5.2	1.34	9.68	1.107
20 x 24	40	3.3	2.7	1.38	12.30	1.100

Table 2. Characteristic of ionization chamber

Chamber type and serial number		**NE 2571, No.334**
Calibration factor: N_X N_K N_D	Expanded uncertainty: 0.6 % 0.6 % 1.5 %	Calibration factor value: $1.218\ C\ kg^{-1}\ C^{-1}$ $4.138\ 10_7$ Gy/C $4.074\ 10_7$ Gy/C
Chamber volume Internal radius Material, wall thickness Electrode material and external diameter		$0.69\ cm^3$ 3.15 mm Graphite, 0.36 mm or $0.065\ g/cm^2$ Aluminum, 1 mm

als) has been used. Calibration factors have been declared by FBMPM, which are participant in the international key intercomparison, and they are comparable to those of the primary air kerma and absorbed dose standards. Chamber data are given in table 2.

The electrometer was Farmer type NE 2570. Absorbed dose has been determined in the water phantom type NE 2545/3A.

Depending on the protocol applied to absorbed dose determined formalism is given below.

2.1. HPA protocol[1]

The absorbed dose is calculated by the formula

$D = M\ \ k\ \ N_X\ \ C_\lambda\ \ B\ \ f_{SSD}$,

where are:

M - instrumental reading on the electrometer corrected for the difference in the temperature and pressure related to reference conditions,

k - factor to account for variations in spectral distribution of X rays used for the ionization chamber calibration free in air and that used by the user in water

N_X - ionization chamber calibration factor in terms of exposure,

C_λ - conversion factor that depends on the chamber (e.g. composition of wall, buildup cap) and beam quality and

f_{SSD} - factor of the correction due curving of the applicator end and has a value of $f_{SSD}=((SSD+r)/SSD)^2$ (SSD - source – surface distance i.e. the distance from the focus to the end of the applicator and r is the distance from the applicator to the center of the chamber.

2.2. IAEA Technical Reports Series No.277[2]

The absorbed dose is calculated by the formula

$D = M\ \ N_K\ \ k_u\ \ (\mu_{en}/\rho)_{w,air}\ p_u$

where are:

N_K - ionization chamber calibration factor in terms of air kerma,

k_u - factor to account for variations in spectral distribution of X rays used for the ionization chamber calibration free in air and that used by the user in water and

p_u - factor to allow for non water equivalence of ionization chamber (i.e. chamber material and air cavity), in the user's beam. An effective point of measurement is to be used when applying this correction factor.

2.3. IPEMB protocol [3]

The absorbed dose is calculated by the formula

$D = M\ \ N_K\ \ k_{ch}\ \ (\mu_{en}/\rho)_{w,air}$

k_{ch} - factor that accounts differences between calibration and user beam.

2.4. IAEA Technical Reports Series No.398 [4]

The absorbed dose is calculated by the formula

$D=M\ \ N_D\ \ k_{Q,Q_o}$, where are:

N_D - calibration factor in terms of absorbed dose to water for a dosimeter at reference beam quality Q_o,

k_{Q,Q_o} - factor to correct for the difference between the response of an ionization chamber in the reference beam quality Q_o used for calibrating the chamber and in the actual user beam quality, Q.

2.5. Estimation of uncertainties

Uncertainties are defined as a relative standard uncertainty type A (u_A) and type B (u_B) according to the recommendations given by ISO[5]. The method of evaluation of standard uncertainty of u_A is expressed by statistical analysis of a series of observations, whereas the u_B expresses the estimated measurement uncertainties. u_A and u_B are combined in order to receive the combined standard uncertainty u_c

given by expression $u_c=(u_A^2 + u_B^2)^{1/2}$ and by confidence level of 95%.

3. RESULTS AND DISCUSSION

Dose estimation factors are shown in the table 3.

The measurements uncertainties uB for the compared protocols are given in the table 4. They have been calculated upon the known measurement uncertainties of backscatter factor and ratio of the mean mass energy – absorption coefficients of water and air (Table 1.), calibration factors (Table 2.), dose estimation factors (Table 3.) and corrected reading on the electrometer (M). The combined measurement uncertainty of the corrected reading on the electrometer is 0,7 % and it is consisted of measurement uncertainty of instrumental reading R (0.5 %, k=2) and measurement uncertainty of the correction factor which take into account the difference in reference condition air density in chamber cavity during the measurement and calibration, k_{pt} (0.5 %, k=2).

Table 3. Dose estimation factors

Protocol	**Dose estimation factors (measurement uncertainty)**		
HPA	k=1 (1 %)	C_λ=37.21 J/C (3 %)	f_{SSD}=1.02 (1%)
IAEA 277	k_u=0.996 (0.2 %)		p_u=1.01 (2 %)
IPEMB	k_{ch}=1.019 (3 %)		
IAEA 398	$k_{Q,Qo}$=1 (1 %)		

Table 4. The measurements uncertainties for the protocols

Protocol	Measurement uncertainty u_B [%] k =2
HPA	3.6
IAEA 277	2.4
IPEMB	3.3
IAEA 398	1.9

Table 5. The absorbed dose values with combined measurement uncertanity

Applicator [cm]	M [10^{-9}C]	u_A [%]	D_{HPA} [Gy]	u_c [%]	$D_{IAEA277}$ [Gy]	u_c [%]	D_{IPEMB} [Gy]	u_c [%]	$D_{IAEA398}$ [Gy]	u_c [%]
8 x 10	16.73	3.5	0.858	5.0	0.772	4.2	0.782	4.8	0.762	4.0
10 x 15	17.37	1.2	0.979	3.8	0.802	2.7	0.812	3.5	0.791	2.2
15 x 20	18.54	3.7	1.148	5.2	0.856	4.4	0.867	5.0	0.844	4.2
20 x 24	19.99	4.5	1.275	5.8	0.923	5.1	0.935	5.6	0.910	4.9

Table 6. The differences between protocols

Applicator [cm]	IAEA 398– HPA [%]	IAEA 398–IPEMB [%]	IAEA 389–IAEA 277 [%]
8 x 10	-12.6	-2.6	-1.3
10 x 15	-23.8	-2.6	-1.4
15 x 20	-30.0	-2.6	-1.4
20 x 24	-40.0	-2.7	-1.4

Five measurements have been done for each applicator. Table 5. presents the average values of the corrected reading of electrometer with statistical component of uncertainty from these five measurements as well as the determined absorbed dose with the combined measurement uncertainty. The measurement were performed for 60 seconds, at 10 mA.

Based on the calculated values of the absorbed doses according to four different protocols the following differences between those values have been noted and shown in the table 6.

Obtained results of absorbed dose determination in case of HPA protocol have been overestimated comparing to all protocols, because this dose is determined upon the measurement of the exposure. For kilovoltage X–ray tube, voltage higher than 100 kV, exposure is not appropriate quantity for radiotherapy purposes. The difference between IAEA 398 and IPEMB protocols reaches up to 2.7 % which is the ratio between N_D and N_K , k_{ch} $(\mu_{en}/\rho)_{w,air}$ for the used applicator. The difference between IAEA 398 and IAEA 277 protocols reaches up to 1.4% which is the ratio between N_D and N_K, k_u $(\mu_{en}/\rho)_{w,air}$ for the used applicator.

4. CONCLUSION

It can be concluded that HPA protocol generally overesstimates the absorbed dose, for each of the used applicators from 12.6 % up to 40.0 % related to IAEA 389. Therefore, it's usage for kilovoltage radiation is unacceptable in nowdays. IPEMB protocol in relation with IAEA 398 protocol gives higher value of the absorbed dose from 2.6 % to 2.7 % depending of the used applicator. The differences of the IAEA 277 protocol in relation with IAEA 398 protocol, depending of the used applicator, is from 1.3 % to 1.4 %. The estimated measurement uncertainty is the lowest for the IAEA 398 protocol and it is 1.9 % which is the consequence of the calibration which is done in the best possible conditions i.e in the user radiation quality. It gives the best value of determining absorbed dose, because there is the smallest number of factors that should taken into consideration while calculating absorbed dose. In accordance with this the received value of absorbed dose also have the lowest value of the combined measurement uncertainty for the used applicator.

All Serbian radiotherapies centers use the recent protocol IAEA 398

Apstrakt

U ovom radu su upoređena četiri najčešće korišćenja protokola za određivanje aposrbovane doze u vodi za snop X zračenja (HPA, IAEA 277, IPEMB i IAEA 398). Izvršena su merenja prema uslovima iz protokola i određene su razlike. Merenja su izvršena pri standardnim radioterapijskim uslovima na terapijskoj mašini tipa RT'305 na Odelenju za radioterapiju Vojnomedicinske akademije u Beogradu. Apsorbovana doza je merena cilindričnom jonizacionom komorom tipa NE 2571. Vrednosti apsorbovane doze određene prema različitim protokolima poređene su sa protokolom IAEA 398 koji je sada u upotrebi. Razlike za HPA protocol dostižu do 40 %. Rezultati dobijeni IPMB I IAEA 277 protokolima su 2.7 % i 1.4 % niže od vrednosti dobijenih protokolom IAEA 398. Procenjene su i merne nesigurnosti procene apsorbovane doze različitim protokolima.

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