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The comparison of absorbed dose measurements for water and artificial body fluid

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Background: Advances in radiation dosimetry concepts and the development of primary measurement standards based on absorbed dose to water over the last decades offer the possibility to calibrate ionisation chambers directly in terms of absorbed dose to water. The aim of this study is the investigation on utility of artificial body fluid (ABF) instead of water by comparing dosimetric measurements for radiotherapy between water and ABF which is more close to human tissue. *Materials and Methods:* The measurements were done using ^{60}Co gamma source with a radiation field sizes of 5×5, 10×10, 15×15, 20×20 and 25×25 cm^2 at PTW Freiburg MP3 water phantom front surface. The comparisons of the dose measurements were obtained by using IAEA TRS-398 dosimetry protocols and Mephysto mc^2 dose analyzer program. Percent depth dose (PDD), dose profiles and penumbras are compared for water and ABF. *Results:* When the results of the PDD for water and ABF were compared, the maximum difference was observed in big field sizes. The difference in penumbras was found 2.3 mm averagely for depth of maximum dose (d_{max}). In addition same differences were observed between water and ABF when the dose profiles were compared. It is found that PDD values taken for water are good agreed with PDD values published in British Journal of Radiology (BJR) Supplement 25. *Conclusion:* Since the ABF is more equivalent to human tissue than water, it is suggested that advanced dosimetric studies should be performed with ABF instead of water. **Iran. J. Radiat. Res., 2012; 10(3-4): 157-164**

Keywords: *Radiation dosimetry, absorbed dose measurement, artificial body fluid.*

INTRODUCTION

A wide variety of ionising radiation effects on matter, whether they be physical, chemical or biological, have been suggested as a basis for radiation dosimetry (1, 2). These depend on the sort of changes imparted into a given material by the deposition of radiation energy, and if such changes are measurable, stable and well characterised system may be practicable for radiation measurements (3). Absolute dosimetry of external beam radiotherapy is carried out by the use of ionization chambers. These chambers must be calibrated at a standard dosimetry laboratory before any use in clinical dosimetry. The expanded uncertainties in the determination of air kerma and absorbed dose to water are estimated to be 2% and 2.3% at approximately 95% confidence level, respectively (4). Absorbed dose to water is the quantity of interest to specify the amount of radiation to be used in radiotherapy and has the advantage that it can be measured more directly than the quantity air kerma. Advances in radiation dosimetry concepts and the development of primary measurement standards based on absorbed dose to water over the last decades offer the possibility to calibrate ionisation chambers directly in terms of absorbed dose to water (5). The ionization chambers should preferably be designed for absorbed dose measurements in water and the construction should be as homogeneous and water equivalent as possible (6). In order to be useful, radiation dosimeters must exhibit several desirable characteristics (7). For example, in radiotherapy exact knowledge of both the absorbed dose to water at a specified point and its spatial distribution are of importance, as well as the possibility of deriving the dose to an organ of interest in the patient (3). In this context, the

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desirable dosimeter properties will be characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution for water and ABF. In this paper the measurements have been done for PDD and dose profiles absorbed dose to both water and ABF. Although the water is assumed as the tissue equivalent in dosimetric measurements for radiotherapy, it is not true exactly.

Therefore, in this paper measurements of PDD and dose profiles for both water and ABF have been done separately. Assuming blood plasma is more equivalent to human tissue than water, artificial blood plasma solution has been prepared [8,9]. The depth dose, dose profiles and beam quality parameters of different field sizes have been measured according to the IAEA TRS–398 with ^{60}Co photon unit by mephysto mc^2 dose analysis program in MP3 water phantom [5, 10-13]. The same of dosimetric parameters at the same measurement setup have been measured with distilled water. The measurements results obtained for both water and ABF have been compared.

MATERIALS AND METHODS

Prepared artificial body fluid

The ABF, known as metastable buffer solution by means of ion concentration, including the same chemical composition as human blood plasma, has been investigated [14-20]. Taş [14] made up more suitable ABF as blood plasma ion concentration changing the values HCO_3^- and Cl^- of ABF prepared by Kokubo [18]. Pasinli *et al.* [8] prepared the Cl^- in concentration in blood plasma as 103 mM value. This prepared ABF showed resemble content to blood plasma for the first time, in terms of all inorganic ions. The patent of the chemical components used in this prepared ABF has been used [21]. The ion concentrations of human blood and ABF have been shown in table 1.

The ABF was prepared using NaCl (sodium chloride), $NaHCO_3$ (sodium hidrocarbonate), KCl (kollium chloride), $Na_2HPO_4.2H_2O$ (disodium hydrogen phospate di water), $MgCl_2.6H_2O$ (magnesium chloride hekzo water), Na_2SO_4 (sodium sulfate), $(CH_2OH)_3CNH_2$ (hidroxylmethylamine methane), $CaCl_2.2H_2O$ (calcium chloride di water) and HCl (hydrogen chloride). The chemical substances given in table 2 were dissolved in deionised water [14].

Purely prepared 750 ml of 1M HCl was added to the solution right away without adding $CaCl_2.2H_2O$, otherwise turbidity occur in the solution. The residual HCl was added to the solution during the titration. After the adding $(CH_2OH)_3CNH_2$, solution temperature was increased from medium temperature to body temperature 37 ^{0}C. At this temperature, pH kept as 7.4 with 1 M of HCl and deionised water is added to the solution up 50 L final volume to be able to prepare ABF. The physical intensity for ABF prepared in this way was found 1.075 g/cm^3.

Table 1. Human plasma and ABF ions concentration (mM) [8, 14, 18].

Ion	Kokubo	Taş	Lac-SBFx1	Human Plasma
Na	142.0	142.0	142.0	142.0
Cl^-	147.8	125.0	**103.0**	**103.0**
HCO_3^-	4.2	27.0	27.0	27.0
K+	5.0	5.0	5.0	5.0
Mg^{2+}	1.5	1.5	1.5	1.5
Ca^{2+}	2.5	2.5	2.5	2.5
HPO_4^{2-}	1.0	1.0	1.0	1.0
$SO4^{2-}$	0.5	0.5	0.5	0.5

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Table 2. The chemical composition of ABF solution* (total volume=50 L) [14].

Order	Chemical Substance	Amount (g/L)	g/50 L
1	NaCl	6.547	327.36
2	$NaHCO_3$	2.268	113.40
3	KCl	0.373	18.66
4	$Na_2HPO_4.2H_2O$	0.178	8.90
5	$MgCl_2.6\ H_2O$	0.305	15.26
6	$CaCl_2.2H_2O$	0.368	18.40
7	Na_2SO_4	0.071	3.56
8	$(CH_2OH)_3CNH_2$	6.057	302.86

* *patent pending. Turkish Patent İnstitute, Turkey, Appl.No.99-0037,11 January 1999.*

Dosimetric measurements

Experimental depth and profile dose curves of this paper have been obtained in a Theratron1000E ^{60}Co radiotherapy unit provided by the Yuzuncu Yil University, medicine faculty, and department of Radiation Oncology, which has also provided all the facilities necessary to obtain measured data. Cobalt units use a ^{60}Co radioactive source which is placed in the treatment head. To deliver dose to patients, the radiation beam provided from the source is collimated by jaws [22]. Because the energy of cobalt radiation is lower than those of linear accelerators, cobalt units are normally used to treat relatively shallow diseases such as those of the head and neck. One of the main reasons of using the Theratron1000E in this study was the fact that the Cobalt spectrum of the irradiation beam is already known and, therefore, easier to model.

The facility comprises a Theratron radiotherapy irradiator positioned to give a beam focused on a water tank. The cobalt unit has a collimator to provide rectangular fields from 5cmx5cm to 40cmx40cm. The measurements were performed in a detector placed in a motorized guide of the cube-shaped phantom with side 50 cm (PTW Freiburg MP3 water phantom) [10]. Dose rates can be measured accurately in this phantom because precise positioning of high resolution detectors can be easily accomplished using a guide driven by reinforced toothed belts. The used detector, a PTW Freiburg Semiflex 0.125cc thimble chamber, is able to register the dose contribution of photons [11, 23]. The phantom has been irradiated with different field sizes, always maintaining the source-to-surface distance (SSD) equal to 100 cm [5]. The detector movement for each of the collimator openings is controlled by the software, Mephysto mc^2 which has been programmed to make a high speed sweep, in both the beam direction and perpendicular to it, in order to obtain depth dose curve and dose profiles at different layers, respectively.

The measurement of the absorbed dose to water and ABF was performed following the IAEA protocol (IAEA TRS–398) [5]. Ion chamber was placed at in water and ABF. The field size at the surface of the phantom was 5×5, 10×10, 15×15, 20×20 and 25×25 cm^2. The alignment of the radiation field and the water phantom was adjusted using three lasers. The absorbed dose was measured by absorbed dose analysis program by using software mephysto mc^2. The measurements were performed first in the distilled water instead of the discharge water then the ABF was placed in the phantom at the same setup.

RESULTS AND DISCUSSION

The measurement results of PDD, dose profiles and beam quality parameters

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between ABF and water was compared. In addition, our PDD measurement results for water were compared with depth dose measurement results of BJR supplement 25 [24] which accepted as reference literature for same setup. Results of the comparing PDD measurements values of ^{60}Co photons, in SSD=100 cm distance for water, whole measured fields with BJR 25 and our work have been stated below.

For 5×5 cm² field; differences until 20 cm depth was found too much below according to the 2% [25] margin of tolerance while 25 cm depth was found 2.95%, for 10×10 cm² field; differences until 20 cm depth was found too much below according to the 2% [25] margin of tolerance too while 25 cm depth was found 3.9%, 15×15 cm² and 20×20 cm² fields; whole differences until 25 cm depth was found too much below according to 2%, 25×25 cm² field; differences in 5, 15 and 20 cm depth was found below according to the 2% while 10 and 25 cm depth was found a few above 2% (figure 1a, 1b, 1c, 1d,1e and table 3).

Normally, the difference between absorbed dose measurement values with the same radiation supply and in the same

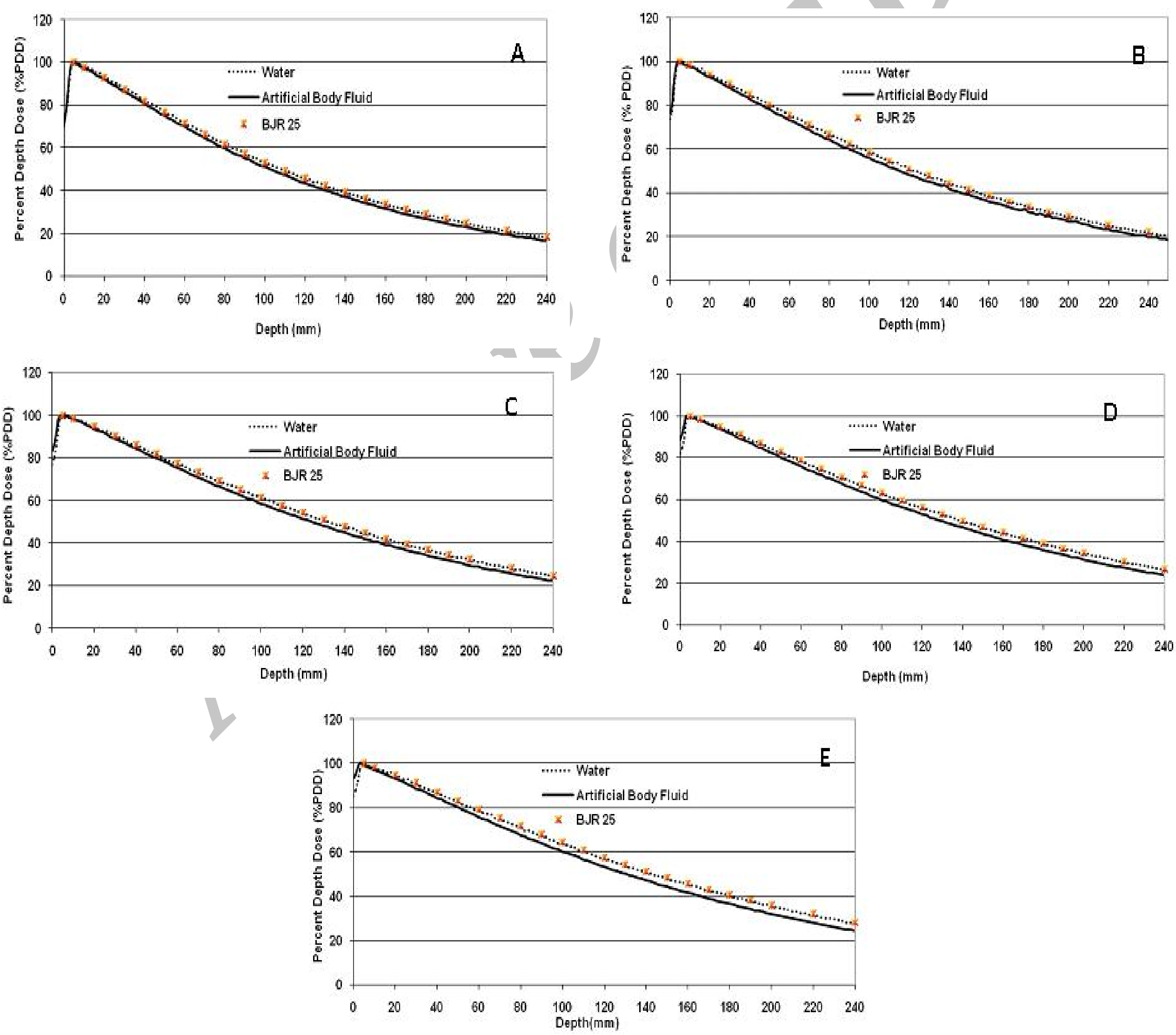

Figure 1. Percent depth dose measured by water and ABF in water phantom for a for 5×5 cm² (A); 10×10 cm² (B); 15×15 cm² (C); 20×20 cm² (D) and 25×25 cm² (E) field size with ^{60}Co teletherapy machine.

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material is unexpected. However, since the collimator systems of devices in which there is radiation supply differs from each other partially, this difference is usual. But there is not any difference for water and ABF because of the same device is used for them. As a result, our PDD values in all field sizes and depths have been found compatible with the reference values of BJR Supplement 25. There was not a very good agreement between PDDs of ABF and water in 5×5, 10×10, 15×15, 20×20 and 25×25 cm² size fields. Some differences which are unignorable values such as %2.42-13.36 have been observed for all field sizes and depths (table 3). But it was not observed remarkable differences between the maximum dose depths (d_{max}) of ABF and water (figure 1a - e).

Table 3 shows the percentage of differences for the PDDs in fields 5×5, 10×10, 15×15, 20×20 and 25×25 cm². It is seen from Table 3, the percentage of difference increase for the PDDs between water and ABF when the depth and field size were increased.

Table 3. Percentage of differences (differences %) of percent depth doses values between water and ABF for all field sizes and 5, 10, 15, 20, 25 cm depths.

Depth (cm)	BJR 25 [24] PDD	Water PDD	ABF PDD	Difference % Water-BJR 25	Difference % Water-ABF
Field 5×5 cm²					
5	76.70	77.02	75.20	0.42	2.42
10	53.30	53.34	51.04	0.07	4.31
15	36.50	36.51	34.29	0.03	6.08
20	24.90	24.62	22.88	1.14	7.07
25	17.10	16.61	15.43	2.95	7.10
Field 10×10 cm²					
5	80.40	80.23	78.08	0.21	2.75
10	58.70	58.71	55.96	0.02	4.68
15	41.60	41.52	38.98	0.19	6.12
20	29.30	29.14	27.08	0.55	7.07
25	20.80	20.06	18.56	3.69	7.48
Field 15×15 cm²					
5	82.00	81.91	79.86	0.11	2.57
10	61.60	61.53	58.60	0.11	4.76
15	44.90	44.61	42.05	0.65	5.74
20	32.40	32.12	29.59	0.87	7.88
25	23.40	23.06	19.98	1.47	13.36
Field 20×20 cm²					
5	83.00	82.11	80.02	1.08	2.61
10	63.30	62.60	59.63	1.12	4.74
15	47.10	46.63	43.31	1.01	7.12
20	34.50	34.12	31.11	1.11	8.82
25	25.40	24.92	22.16	1.93	11.08
Field 25×25 cm²					
5	83.40	82.62	80.29	0.94	2.90
10	64.40	62.64	60.27	2.81	3.78
15	48.60	47.91	44.39	1.44	7.35
20	36.00	35.53	32.10	1.32	9.65
25	26.80	26.10	22.88	2.68	12.34

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Dose profiles were obtained for each field in the depths of d_{max} (0.5), 5, 10, 15 and 25cm. It is observed that there was not very good agreement between dose profiles of ABF and water in 5×5, 10×10, 15×15, 20×20 and 25×25 cm^2 size fields (figure 2a, 2b, 2c, 2d, 2e).

Dosimetric penumbra width is defined as lateral distance between 80% and 20% positions of the dose values [3]. Different values of dosimetric penumbra were obtained using dose profiles at the depth of d_{max} for water and ABF. It was seen that there were differences between calculated penumbra values of ABF and water. These differences are more than 2 mm for all field sizes (table 4). It is seen that penumbra is bigger than acceptable value of 2 mm [25]. The reason of the bigger penumbra values of ABF from water is that density of ABF is bigger than water and count of scattered photon is directly proportional with density. Because; when the count of photons that made Compton interaction (dn) divided into fraction of photon (n), the equation is given by ($dn/n = N_A \cdot \rho \cdot (Z/A) \cdot \sigma_e \cdot dx$) [26]. ($N_A$: the count of Avogadro, ρ: density of absorbent material, σ_e : cross-section, dx: distance obtained in absorbent material of photon).

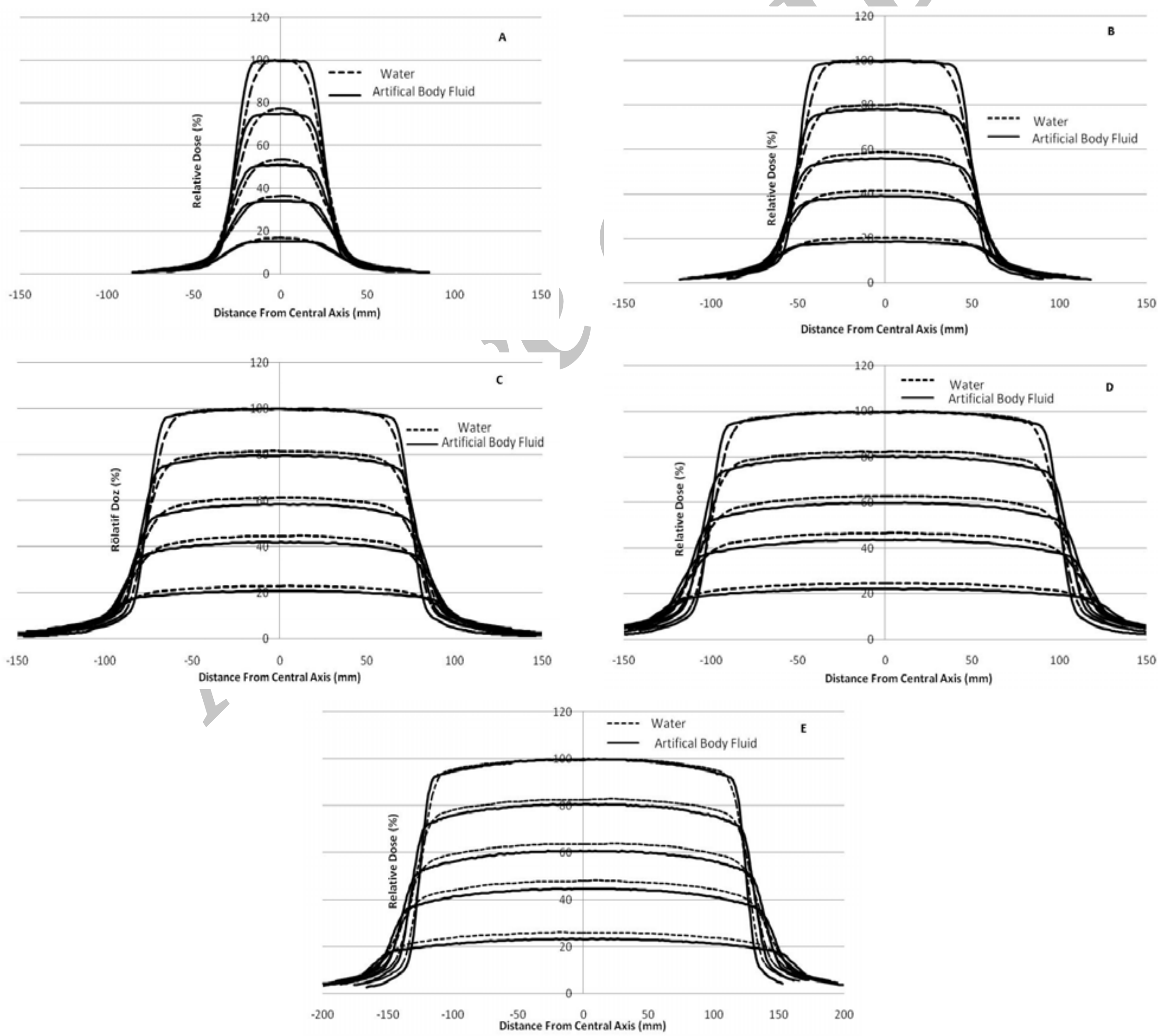

Figure 2. Dose profile measured by water and ABF in water phantom for 5×5 cm^2 (A); 10×10 cm^2 (B); 15×15 cm^2 (C); 20×20 cm^2 (D) and 25×25 cm^2 (E) field size and d_{max} (0.5), 5, 10, 15, 25cm depths with ^{60}Co teletherapy machine.

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Table 4. Differences of penumbra values between water and ABF at the depth of d_{max} for all field sizes.

Field Size (cm^2)	Penumbra water (mm)	Penumbra ABF (mm)	Difference (mm)
5×5	111.90	14.22	2.32
10×10	112.86	14.97	2.11
15×15	113.36	15.62	2.26
20×20	113.83	16.23	2.40
25×25	114.30	16.71	2.41

CONCLUSION

Although the water is accepted as an equivalent value of tissue in terms of absorption and dispersion features in dosimetric measurements for radiotherapy applications [3], from the results presented, it is obvious that the water has not an equivalent value of human tissue because of the presence of various elements in the tissue and its higher density. Therefore, considerable differences have been found between PDD, dose profile and penumbra in dosimetric studies performed for water and ABF. According to our study, the main reason for this difference might be due to the interaction of photon with water (which is composed of only two elements), and the interaction of photon with ABF (which is composed of 11 different elements). In addition, the characteristics of absorbed dose and dose dispersion are different because of the differences in density of water and ABF. The reason of higher values of penumbra in ABF compared to water might be due to the density of electron which has been snapped of ABF composed of 11 elements, much higher than the water.

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