Dose measurement verification in solid state phantom in place of field connection for non-standard radiotherapy conditions

Marta GABOR, Marcin LITOBORSKI

SUMMARY

BACKGROUND: This work describes chosen combinations of therapeutic fields during the patient's total body irradiation (TBI). The TBI technique requires as large a radiation field as one can achieve [1][2]. That is why the source-skin distance (SSD) is greater than 100 cm (SSD for standard treatment conditions). In such non-standard radiotherapy conditions all the measurements described in this paper were done.

MATERIALS/METHODS: All beam profiles were obtained by irradiating films with 20 MV (nominal energy) photon rays in non-standard conditions of radiotherapy. The method of measurement (film dosimetry) and used materials (self-developing GAFCHROMIC EBT films) are presented in the Material and Method section [3].

AIM: Because in the therapy some areas must receive a greater dose than others, the size of the therapeutic fields must be adjusted. That is why the areas where two fields overlap inside the patient's body differ. The diversity of absorbed dose in these areas was measured and presented in the schemas in the Results section.

RESULTS: The profiles presenting dose distribution in the areas where therapeutic fields overlap in most cases show increase of the delivered dose. For the most often used therapeutic fields the increase exceeds 180% of the planned dose in the sector about 2.5 - 10 cm. There were also two cases where the delivered dose was lower than the planned one (about 29 - 86% of the planned dose). Chosen measurements and combinations of the therapeutic fields are discussed in detail and all the results are collected in a table at the end of the section.

CONCLUSIONS: The profiles obtained from the scans of the irradiated GAFCHROMIC EBT films and their digital processing include 0.05 Gy noise. This means that the described method requires a high quality scanner, dedicated to RTG films. The spectrophotometer measurements showed high film dependency on light wavelength. It seems that using a monochromatic source of light may give better results.

KEY WORDS: teletherapy, TBI, film dosimetry, dose distribution

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Nicolaus Copernicus University
Faculty of Physics
Astronomy and Informatics NCU
ul. Grudziądzka 5, 87-100 Toruń
Medical Physics Department
Great Poland Cancer Centre
ul. Garbary 15
61-866 Poznań

Address for correspondence:
Marta Gabor
Medical Physics Department
Lubuskie Cancer Centre
ul. Zyty 26
65-045 Zielona Góra
e-mail skalaludek@wp.pl

BACKGROUND

There are two total body irradiation techniques: anterior-posterior (AP) (or vice versa PA) and lateral [1]. While using the anterior-posterior technique the patient needs to lie flat on the floor, under the accelerator's head. The maximum distance from the source of radiation is about 1.5 m (depending on the height of the apparatus). Usually one radiation field does not cover his/her whole body. That is why the patient is irradiated sequentially in several fields (usually 2 up to 4). The edges of the fields meet on the patient's skin. Because of the shape of the X-ray stream some parts inside the patient's body are irradiated twice by overlapping beams, which results in high diversity of absorbed doses [4].

AIM

The aim of this paper is to examine the dose distribution with film dosimetry at defined depths in the superposition area of two therapeutic fields in non-standard radiotherapy conditions.

MATERIAL

In this work self-developing GAFCHROMIC EBT films were used. These films are designed for dosimetry measurement and specially prepared for this purpose. They consist of two 17-μm active layers separated by a 6-μm surface, and covered with polyester (Figure 1) [5].

Clear polyester – 97 microns
Active layer – 17 microns
Surface layer – 6 microns
Active layer – 17 microns
Clear polyester – 97 microns

Fig. 1. Structure of a GAFCHROMIC EBT film

The films are sensitive to dose values in the range of 1–800 cGy. They are almost independent of radiation energy and do not need to be developed.

The extent of blackout on the film represents the absorbed dose. The dependency between the extent of blackout of the GAFCHROMIC EBT films and absorbed dose, as stated by the manufacturer, is characterized by a third-degree exponential curve.

The films can be analysed by using a densitometer, spectrophotometer or high-quality scanner designed for scanning films [5].

METHOD

To obtain a real dose distribution in a phantom where the fields overlap, self-developing GAFCHROMIC EBT films were put exactly in the middle of the phantom. Their upper edge corresponded with the upper surface of the phantom (Figure 2a). The phantom was composed of eight Plexiglas slabs (30 x 30 x 2.5 cm). The films were stabilized between the slabs by some sticking plasters in such a way that their upper edge (20.3 cm) crossed the line of contact of two fields at a right angle.

a)

b)

Fig. 2. a) GAFCHROMIC EBT film placed on a Plexiglas slab; b) Farmer ionisation chamber type TM 30013 (PTW Freiburg)

The longer edge of the film (25.5 cm) was parallel to the X-ray beam axis.

All materials were irradiated with a Clinac 2300 C/D machine, Varian company. The films were irradiated with a 20 MeV X-ray beam and the same number of monitor units (353 MU) for each field. This number of monitor units gave a 1 Gy dose at 5 cm depth, for the 40 x 40 cm field [6]. The dose was measured with a Farmer chamber type TM 30013 (Figure 2b) and UNIDOS dosemeter, PTW Freiburg company. The source-phantom surface distance (SSD) equalled 145.8 cm.

The irradiation field size was adjusted by moving the jaws only along the X axis. The field size in the Y axis was fixed for all measurements at 40 cm. Due to the location of the jaws at the X axis during irradiation, there are three types of field:

– when X_1 equals X_2 – **symmetrical fields**
– when X_1 and X_2 are different – **asymmetrical fields**
– when one of the X jaws is moved beyond the middle of the field (its position is described by the value of displacement beyond the middle of the field, in centimetres with the minus sign) – **small asymmetrical fields**.

The phantom with a film was situated at the Y axis in the middle of the field. However, at the X axis the phantoms' and the films' centres were on the edge of the field (Figure 3).

Because the phantom with the film was always placed on the edge of the field, the range of the SSD was changing for the different fields (from 145 cm for the 40x40 cm^2 field to 139.7 cm for the asymmetrical field where X1= 0 cm, X2= 20 cm, Y = 40 cm).

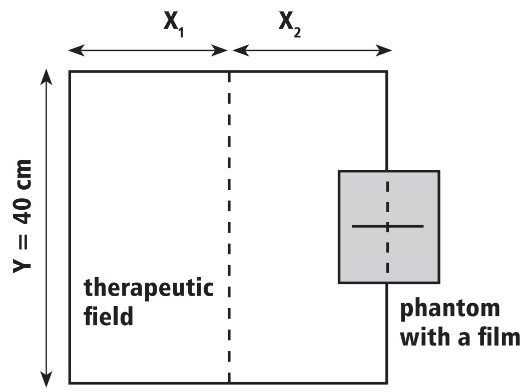

Fig. 3. Localization of the jaws in treatment field (view above)

Calibration

The aim of this work was to gain profiles showing changes of the dose value at definite depths. To achieve this the dose dependence on scanner light transmission through the film had to be found. Therefore some pieces of the film (about 3 x 3 cm) were irradiated with well-known doses (from 0.5 Gy to 8.0 Gy) under a control Farmer ionization chamber TM 30013 type and UNIDOS dosemeter of PTW Freiburg company [7].

Dependence of a film blackout caused by the X-rays was examined by the measurement of the film transparency to the light in the Plustek Opti Pro ST64+ scanner. The GAFCHROMIC EBT films were scanned at 600 dpi resolution and in 16-bit grey range (bit depth 16 bpp). This method allows the film image to be represented by over 65 500 grey tints. To achieve better image contrast

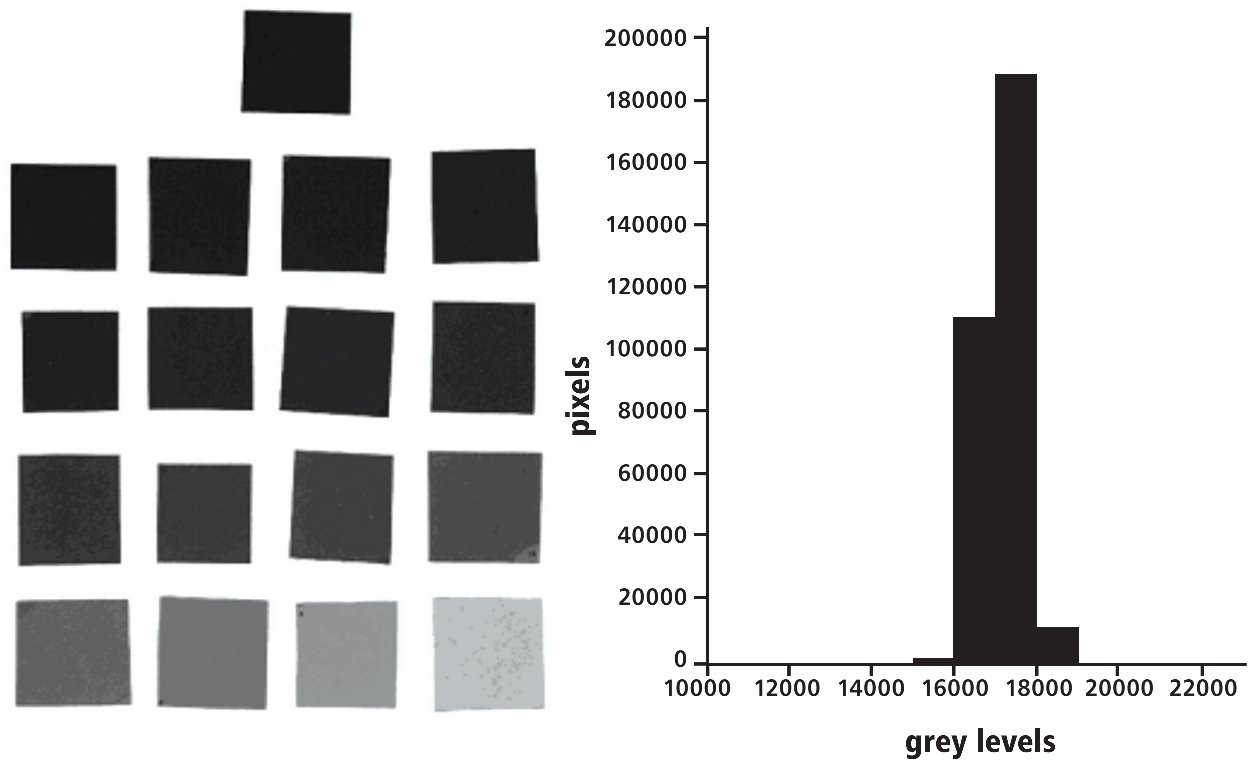

Fig. 4. Scanned calibration films and histogram of the brightness level for one of them

the double light transmission through the film was analysed [3].

The images gained from the scanner were saved as TIFF files (Tagged-Image File Format). This is a standard format of a bitmap file which saves all colours without any losses of information. Each brightness level for individual pixels is stored in turn without any changes.

Analysis was done with the Origin 7.5 Evaluation Copy. For each calibration film a histogram for brightness level values was created. The histograms showed high homogeneity of the obscuration (Figure 4). They were used to determine the mean value of the obscuration for a definite dose.

The values of the grey levels for precise doses were used to prepare a graph. Then, with the smallest square method, third-degree exponential curves were fitted (according to manufacturer's recommendations):

$$\mathbf{y = A_1 \cdot exp(-x/t_1) + A_2 \cdot exp(-x/t_2) + A_3 \cdot exp(-x/t_3) + y_0} \quad [8]$$

y – dose
x – value of the pixel
y_0 = – 0.42 ± 0.01
A_1 = 5.32 ± 0,02
A_2 = 6.21 ± 0.02
A_3 = 126 ± 3
t_1 = 12980 ± 220
t_2 = 14405 ± 200
t_3 = 2330± 280
Variation: $\sigma = (x, A_1, A_2, A_3, t_1, t_2, t_3) = 0.00982$

The calibration curve (Figure 5) was used to analyse the dose distribution at irradiated films in the place where two fields overlap.

The non-irradiated GAFCHROMIC EBT film was also scanned and measured to estimate the level of noise which is generated during signal processing (Figure 6):

The calibration curve for GAFCHROMIC EBT film was also gained from spectrophotometer measurements. Irradiated calibration films were examined by light in the 400–800 nm wave range, with steps of 0.2 nm. The plots of transparency for some films are presented in Figure 7:

To obtain the calibration curve for light transparency through the film, the field under

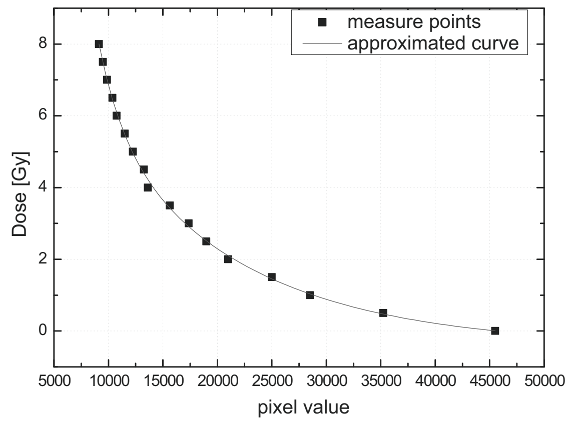

Fig. 5. The calibration curve for GAFCHROMIC EBT film and Optic Pro ST64+ Plustek scanner

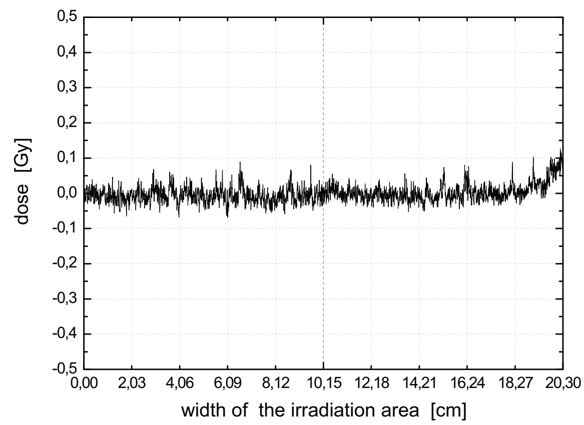

Fig. 6. The non-irradiated film – horizontal profile; the level of noise equals about 0.05 Gy

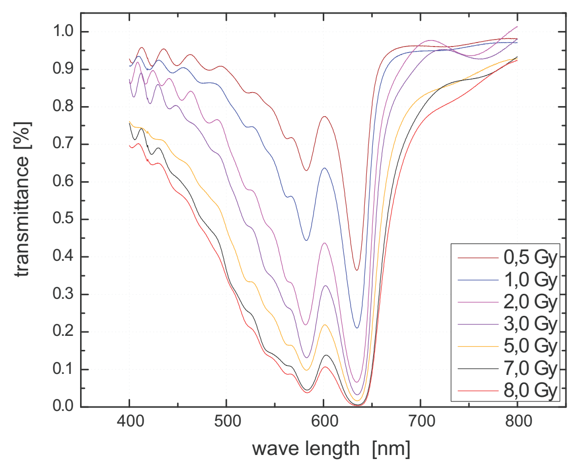

Fig. 7. Some irradiated calibration films – measurement of light transparency for non-irradiated film placed in reference path

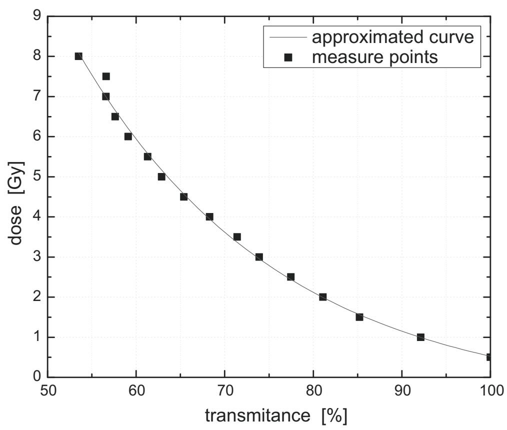

Fig. 8. The calibration curve for films measured with spectrophotometer

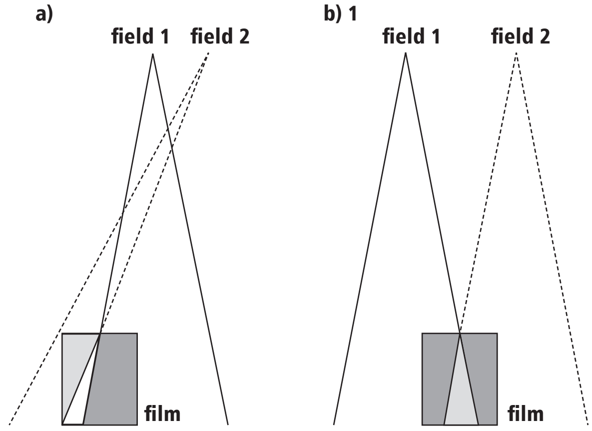

Fig. 9. Two fields overlapping during irradiation
a) for small asymmetrical field with symmetrical field;
b) for two symmetrical fields

the transparency curve was integrated. The results of the measurements and third-degree exponential curve fitted to them are presented below (Figure 8)

All measurements carried out during the work confirmed exponential dependency of the dose on the film black-out described by the GAFCHROMIC EBT manufacturer.

RESULTS

There are many ways to combine two fields during the treatment. Therefore to investigate a real dose distribution in the region where fields overlap, the following combinations were measured:

– Y axis – collimator jaws opened at 40 cm in all cases
– X axis – asymmetrical collimator jaws: -10 x 20 cm, and 0 x 20 cm
– symmetrical collimator jaws: 10 cm, 20 cm, 30 cm, 40 cm

At all times the place where two fields meet was in the middle of the film at the phantom surface. The scheme of the film arrangement toward the radiation beam is presented in Figure 9:

In this paper only some of the profiles (for the most often used therapeutic fields) are presented. All examined profiles were placed at 5 cm, 10 cm, 15 cm, 20 cm and 25 cm depth.

Figure 10 presents profiles for the region where small asymmetrical field:

X_1 = –10 cm, X_2= 20 cm, Y = 40 cm, and symmetrical field: X_1 = X_2 = 5 cm, Y = 40 cm overlaps. The vertical line in the middle of the scheme fixes the centre of the film. On the left side is the region irradiated by symmetrical field X_1 + X_2 = 10 cm, Y = 40 cm. On the right side is the region irradiated by asymmetrical field X_1 = –10 cm, X_2 = 20 cm, Y = 40 cm.

Figure 11 presents profiles in the region irradiated with an asymmetrical field:

X_1= 0 cm, X_2= 20 cm, Y = 40 cm and symmetrical field: X_1 = X_2 = 20 cm, Y = 40 cm. On the left side is the asymmetrical irradiation field area (X_1 =0 cm, X_2 = 20 cm, Y = 40 cm), and on the right side is the symmetrical irradiation field area (X_1 = X_2 = 20 cm, Y = 40 cm).

The dose distribution for the region irradiated with symmetrical treatment fields: X_1 + X_2= 40 cm, Y = 40 cm and X_1+X_2 = 40 cm, Y = 40 cm is shown in Figure 12. Dose decrease with depth and dose increase when the irradiation area is growing can be observed in all schemes.

The results of all measurements done in this work are collected in a table (Table 1). The table presents delivered dose dependency (in percentages) on planned dose to a patient, in the area where two fields overlap.

The percentage of planned dose which was analysed in the field overlap area was determined in the schemes. The relation between

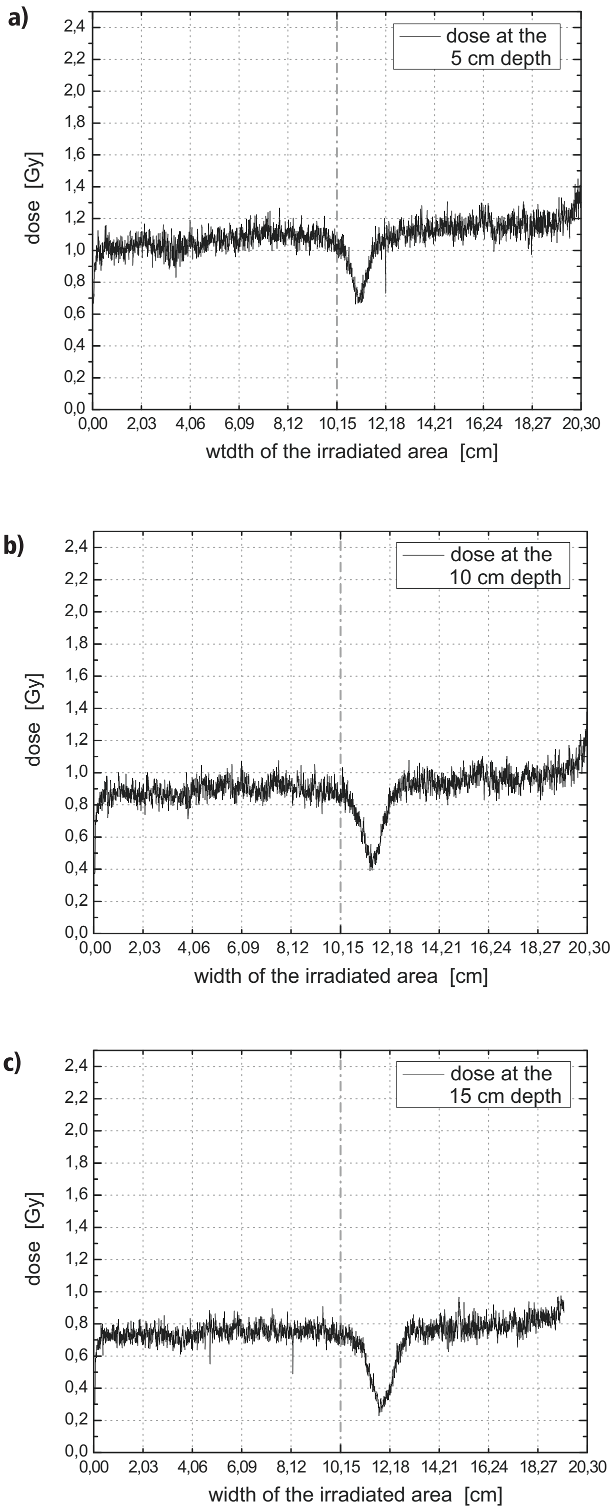

Fig. 10. The dose distribution for the region irradiated with X_1= -10 cm, X_2= 20 cm and X_1+X_2 = 10 cm fields; a) at 5 cm depth, b) at 10 cm depth, c) at 15 cm depth

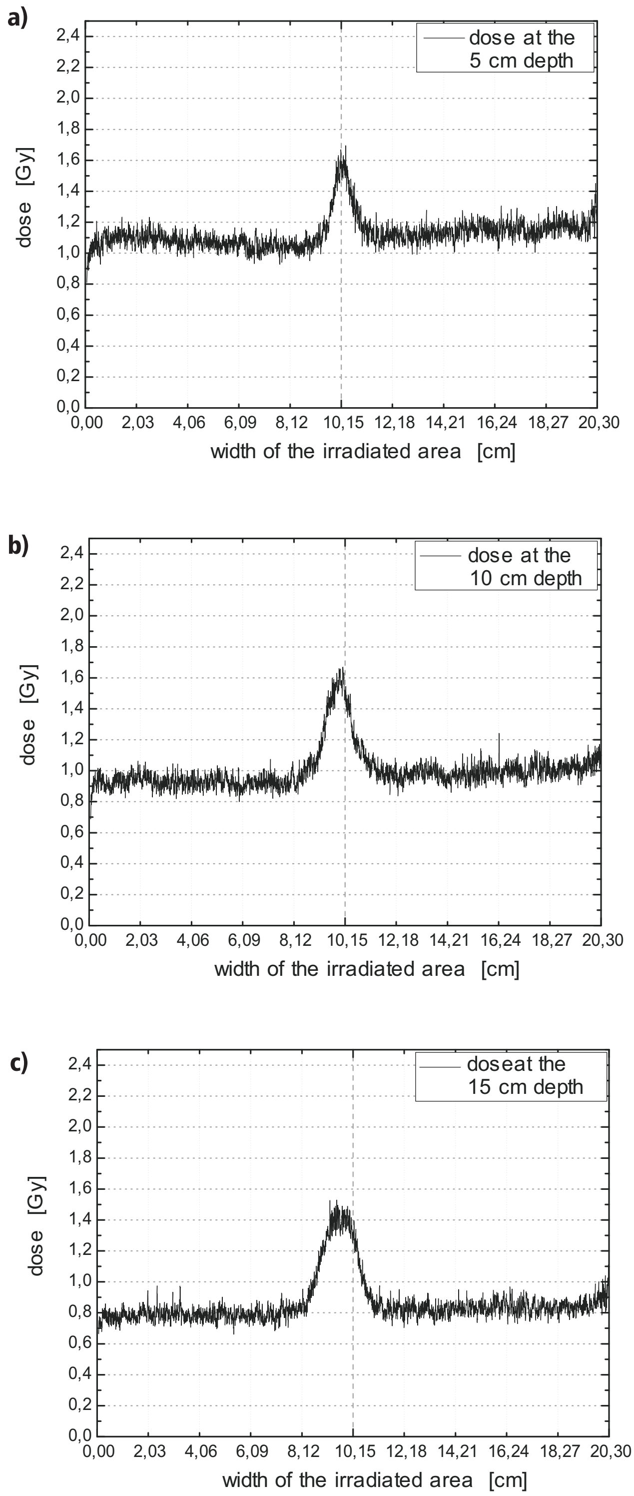

Fig. 11. Dose distribution for the region irradiated with X_1= 0 cm, X_2= 20 cm and X_1+X_2 = 40 cm fields; a) at 5 cm depth, b) at 10 cm depth, c) at 15 cm depth

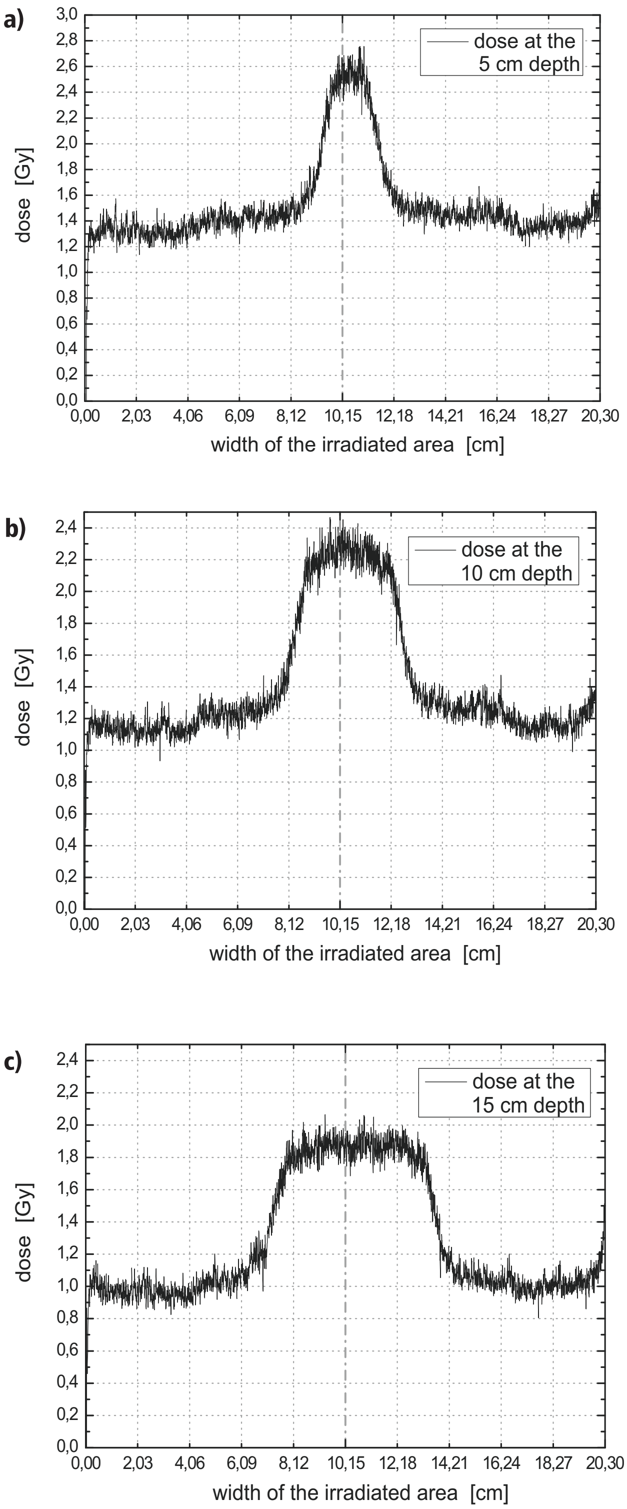

Fig. 12. The dose distribution for the region irradiated with $X_1 + X_2 = 40$ cm and $X_1+X_2 = 40$ cm fields; a) at 5 cm depth, b) at 10 cm depth, c) at 15 cm depth

the maximal dose measured in the observed region (Dp + DD) and mean dose measured outside the region (Dp) was calculated using the formula:

$$D\,[\%] = \frac{(Dp + \Delta D)}{Dp} \cdot 100\%$$

Dp – mean dose measured outside the region where therapeutic fields overlap.
ΔD – difference between mean value of the dose outside the overlapping field area and maximal dose measured in the region where the treatment fields overlap.

Width S of the area where the fields overlap was also measured on the graph. The way of finding values described above is presented in Figure 13.

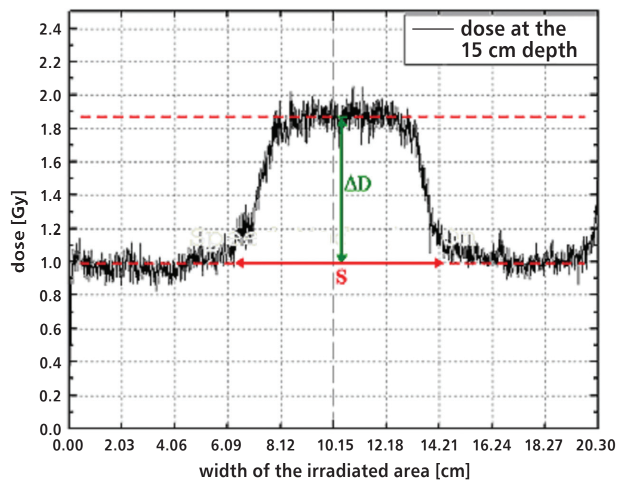

Fig. 13. Some values used to calculate a maximal dose delivered to a patient in the region where therapeutic fields overlap

In the case shown in Figure 13 the mean dose Dp = 1 Gy and ΔD = 0.87 Gy. Calculated maximal delivered dose D = 1.87 ± 0.06 Gy, which amounts to 187% of the planned dose. This result was obtained for the combination of two 40x40 cm^2 symmetrical fields.

DISCUSSION

All beam profiles were obtained by irradiating films with 20 MV (nominal energy) photon rays in non-standard conditions of radiotherapy. The source-phantom surface distance was included between 145 cm (the edge of symmetrical field 40 x 40 cm^2) and 139.7 cm (the edge of asym-

Table 1. Maximal dose measured in the field overlap region (D [%] – maximal value of the dose measured, expressed in percentages, S [cm] – width of the field overlap region, where a dose change caused by the overlapping fields was observed)

	Used fields $X_1 + X_2$ [cm], Y = 40 cm	5 Depth [cm]		10 Depth [cm]		15 Depth [cm]		20 Depth [cm]		25 Depth [cm]	
		S [cm]	**D [%]**	S [cm]	**D [%]**	S [cm]	**D [%]**	S [cm]	**D [%]**	S [cm]	**D [%]**
SMALL ASYMMETRICAL FIELDS	**-10+20/ 5+5**	1.22	**65**	1.46	**47**	1.63	**36**	1.98	**35**	2.36	**29**
	-10+20/ 10+10	0.98	**86**	0.64	**87**	0.61	**86**	------	-----	-------	-----
	-10+20/ 15+15	1.15	**116**	1.34	**134**	1.54	**149**	1.87	**162**	2.31	**160**
	-10+20/ 20+20	2.05	**140**	2.25	**163**	2.52	**180**	2.81	**182**	3.62	**184**
ASYMMETRICAL FIELDS	**0+20/ 5+5**	------	-----	1.26	**117**	1.41	**135**	1.89	**148**	1.93	**151**
	0+20/ 10+10	1.65	**144**	2.35	**166**	2.46	**180**	3.08	**186**	3.22	**187**
	0+20/ 15+15	2.06	**158**	2.46	**175**	2.93	**183**	3.36	**186**	3.62	**184**
	0+20/ 20+20	2.17	**165**	3.12	**176**	3.90	**178**	4.66	**176**	5.30	**177**
SYMMETRICAL FIELDS	**5+5/ 5+5**	1.60	**157**	2.24	**171**	2.51	**174**	2.98	**187**	3.18	**187**
	5+5/ 10+10	2.02	**163**	2.45	**179**	2.92	**186**	3.34	**180**	4.20	**192**
	5+5/ 15+15	2.15	**164**	2.86	**173**	3.66	**187**	4.45	**189**	5.16	**185**
	5+5/ 20+20	2.38	**244**	3.08	**188**	4.22	**183**	5.18	**190**	6.34	**187**
	10+10/ 10+10	2.02	**168**	3.12	**185**	3.60	**190**	4.67	**187**	5.14	**182**
	10+10/ 15+15	2.28	**170**	3.47	**181**	4.56	**178**	5.39	**176**	6.20	**182**
	10+10/ 20+20	2.50	**181**	4.10	**188**	5.14	**190**	5.82	**189**	7.55	**189**
	15+15/ 15+15	2.42	**178**	3.54	**188**	5.39	**191**	6.14	**190**	7.18	**187**
	15+15/ 20+20	3.02	**181**	4.04	**186**	6.08	**193**	7.15	**184**	8.54	**177**
	20+20/ 20+20	3.18	**179**	5.02	**187**	7.70	**187**	8.16	**183**	10.03	**179**

metrical field X_1 = 0 cm X_2 = 20 Y= 40 cm). That is why during measurements the phantom had to be moved. In spite of immobilising the film and the phantom with some plasters, there was a possibility of the film's displacement. Such displacement has an influence on the shape and orientation of the beam profile. It can change a readout of a dose value.

The GAFCHROMIC EBT films were scanned in the Plustek Opti Pro ST64+ scanner at 600 dpi resolution. The images scanned from the films were saved as TIFF files. This allowed dose values to be measured every 0.05 mm. The measurement precision equalled 0.2 mGy. During the scanning all films were oriented at the same position, parallel to the scanner sides. This was important because of the difference between horizontal and vertical resolution of the scanner but also the anisotropic character of the film material.

The non-irradiated GAFCHROMIC EBT film was scanned and measured to estimate the level of noise which is generated during signal processing. This profile (Fig. 6) showed noise level of about 0.05 Gy. This means that the error in reading values for doses lower than 1 Gy exceeds 5%.

To gain profiles showing changes of the dose value at a definite depth it was necessary to find the calibration curve for the GAFCHROMIC EBT films. The extent of the blackout of the film, caused by the X-rays, was examined by the Plustek Opti Pro ST64+ scanner and spectrophotometer. Calibration curves presented in this paper were fitted to average results of the measurements. Scanner as well as spectrophotometer measurement results gave exponential dependency of the dose on film blackout.

The profiles presenting dose distribution in the areas where therapeutic fields overlap in most cases show increase of the delivered dose. For the most often used therapeutic fields the increase exceeds 180% of the planned dose in the sector of about 2.5–10 cm. This should be taken into account during treatment planning because of the sizes and placement of the radiation-sensitive organs [9]. In the AP/PA technique a patient is irradiated twice: X-rays go through a patient first from the front to the back, and next inversely. That is why the delivered dose can be much higher than the planned one. Such a big difference in values of the dose can strongly influence the patient's treatment. That is why precise location of the region of overlapping fields is necessary [4].

There were also two cases where the delivered dose was lower than the planned one (about 29–86% of the planned dose). That was the combination of the small asymmetrical fields: X_1 = –10 cm, X_2 = 20 cm, Y= 40 cm and: $X_1 + X_2$ = 10 cm, Y= 40 cm; X_1= –10 cm, X_2 = 10 cm, Y= 40 cm and $X_1 + X_2$ = 10 cm, Y= 40 cm. This is because in this case the fields overlap above the phantom, and remove each other inside. It generates an area located outside the beam. A dose measured in the area is caused by the irradiation dispersion effect inside the phantom.

CONCLUSION

The measurements described in this work show real differences between delivered and planned doses. The dose was in the majority higher, equalling about 116–193% of the planned dose. Lower dose regions were also observed (29–86% of planned dose). Such big divergences in dose values can cause significant clinical implications.

The profiles obtained from the scans of the irradiated GAFCHROMIC EBT films and their digital processing include 0.05 Gy noise. This means that the described method is not recommended to analyse doses lower than 1 Gy, because of the error exceeding 5%. However, a high quality scanner, dedicated to RTG films, could increase measurement accuracy [10].

The spectrophotometer measurements showed high film dependency on light wavelength. This also could be the reason for such high noise. It seems that using a monochromatic source of light (above 650 nm) could give better results.

The measurements of the dependency of GAFCHROMIC EBT film blackout on the delivered dose, by spectrophotometer as well as by scanner, show its exponential character.

REFERENCES

1. Kosicka G, Malicki J, Stryczyńska G, Wachowiak J, Bruczkowski D: 10 lat stosowania techniki TBI, czyli napromieniania całego ciała w Wielkopolskim Centrum Onkologii. Rep Pract Oncol Radiother, 2003; 8(S2): 264
2. Barret A: Total Body Irradiation. Rep Pract Oncol Radiother, 1999; 4 (4): 92–106
3. Mack A, Mack G, Weltz D, Scheib SG, Böttcher H D, Seifert V: High precision film dosimetry with GAFCHROMIC® films for quality assurance especially when using small fields. Med Phys, 2003; 30: 2399–409
4. Malicki J, Kosicka G: An analysis of the doses calculated and measured in-vivo during total body irradiation. Rep Pract Oncol Radiother, 2001; 6: 18
5. GAFCHROMIC EBT self-developing film for radiotherapy dosimetry, International Specialty Products, Oakville 2005
6. Hendee W R: Radiation therapy physics. John Wiley, Hoboken 2005
7. Williamson JF, Khan F M, Sharma SC: Film dosimetry of megavoltage photon beams: A practical method of isodensity-to-isodose curve conversion. Med Phys, 1981; 8: 94–8
8. Bielski A, Ciuryłło R: Podstawy metod opracowania pomiarów. Wydawnictwo UMK, Toruń 2001
9. Malicki J, Kosicka G, Stryczyńska G, Wachowiak J: Cobalt 60 versus 15 MeV photons during total body irradiation: Doses in the critical organs and complexity of the procedure. Ann Transplant, 2001; 6: 16–20
10. Mersseman B, de Wagter C: Characteristics of a commercially available film digitizer and their significance for film dosimetry. Phys Med Biol, 1998; 43: 1803–12
11. Dempsey J F, Low D A, Mutic S, Markman J, Kirov A S, Nussbaum G H, et al: Validation of a precision radiochromic film dosimetry system for quantitative two-dimensional imaging of acute exposure dose distributions. Med Phys, 2000; 27: 2462–75
12. Malicki J, Wachowiak J, Kosicka G, Stryczyńska G, Nowak A, Pracz J: Total body irradiation before bone marrow transplantation: aims and results. Adv Exp Med Biol, 2001; 495: 277–82

13. Boruczkowski D, Malicki J, Pieczonka A, Stryczyńska G, Leda M, Wachowiak J: Allogeniczna transplantacja szpiku kostnego poprzedzona frakcjonowanym napromienianiem całego ciała u dzieci z ostrą białaczką limfoblastyczną. Wsp Onkol, 1999; 3 (5): 209–11
14. Malicki J, Dymnicka M, Kierzkowski J, Kosicka G: Comparison of the dose accuracy during radiotherapy of the different target localizations in a body. The analysis of in-vivo dose measurements in a group of 700 patients. Radiother Oncol, 2002; 64(supl. 1): 44
15. Łobodziec W: Dozymetria promieniowania jonizującego w radioterapii. Wydawnictwo Uniwersytetu Śląskiego, Katowice 1995
16. Dobrzyński L, Droste E, Trojanowski W: Elementy fizyki promieniowania jonizującego. Instytut Problemów Jądrowych, Świerk 2002
17. Dobrzyński L, Trojanowski W: Wybrane zagadnienia z radiobiologii człowieka. Instytut Problemów Jądrowych, Świerk 2002
18. Jaracz P: Promieniowanie jonizujące w środowisku człowieka. Wydawnictwa Uniwersytetu Warszawskiego, Warszawa 2001
19. Hrynkiewicz AZ, editor: Człowiek i promieniowanie jonizujące. Wydawnictwo Naukowe PWN, Warszawa 2001
20. Hrynkiewicz AZ, Rokita E, editors: Fizyczne metody diagnostyki medycznej i terapii. Wydawnictwo Naukowe PWN, Warszawa 2000