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EXPERIMENTAL RESULTS IN PERCENTAGE DEPTH DOSE (PDD) DETERMINATION AT THE EXTENDED DISTANCES*

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Abstract. The paper presents experimental results in percentage depth dose determination at the extended distances. It is known that percentage depth dose (PDD) is an important dosimetric function in the radiotherapeutic treatment. Usually, PDD is determined experimentally at each radiotherapy installation, in geometry SSD =100 cm that means at isocenter of radiotherapy facility. Dosimetric instruments needed are 3D water phantom together with scanning system in three directions, ionization chambers (detectors) and electrometer. For extended distances this dosimetric system cannot be used. To determine the PDD to extended distances we used commercial acrylic phantom. Experimental results were compared with those calculated and from literature.

Key words: clinac, TBI, HBI, radiotherapy, dosimetry.

1. INTRODUCTION

Total body irradiation (TBI) is a technique used worldwide for the treatment of severe forms of leukemia, bone marrow transplant, etc. [1, 2]. The only way to do TBI and half body irradiation (HBI) with actual commercial photons accelerators is at extended distances.

In Romania there isn't any clearly established protocol for such treatments carried out at extended distances.

We want to implement this technique in our center, using linear accelerator Clinac 2100SC, already installed in a bunker with dimensions that allow treatments at extended distances. Treatment chamber dimensions require finding the optimal

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solution for patient positioning, from which results the measurement geometry at extended distances.

Because the radiotherapy unit is commonly used for conformational treatments, it is necessary to develop for this type of treatment a simple, rapid and reproducible method that does not consume much time.

In addition, the existing computerized treatment plan in our radiotherapy center can be adapted for TBI technique [3].

For commissioning treatment planning system, known commercially as Eclipse, the manufacturer recommends that the SSD used in calculations to no more than 30% of the phantom source distance: SSD = 100 cm. If SSD exceeds this limit, it is recommended to perform a new set of measurements at extended SSD and Eclipse recommissioning in these circumstances.

Because SSD distance has a value of 180 cm for the TBI technique developed by our center, it is obvious that we are not in the limits imposed by the manufacturer for standard commissioning, which is 70 cm < SSD < 130 cm.

In this article are presented experimental results in percentage depth dose (PDD) for large fields at extended distances which could be used for TBI technique in the Radiotherapy Center Timisoara, Romania.

2. MATERIALS AND METHODS

All measurements were taken at the Radiotherapy Center Timisoara using as radiotherapy unit the CLINAC 2100SC, produced by VARIAN. We used the photon beam energy of 6 MV with a dose rate of 240 cGy/min due to its future clinical applications.

PDD and TMR values at extended distances can't be determined by scanning existing water phantom of the laboratory because it allows only scanning the beam radiation with oriented floor upright. In a horizontal position the water tank must have a scan wall with thickness up to 0.5 mm so that measurements are not influenced by phantom wall.

For absolute measurements we used a setup composed from thimble ionization chamber PTW Farmer type 30001 and universal dosimeter UNIDOS from same company. The relative measurements were performed using water phantom MP3, two identical semiflex ionization chambers with sensitive volumes of 0.125 cm^3 and TANDEM dual channel electrometer all produced by the same PTW company.

First of all, we determined the radiation parameters as PDD, TMR, OF for square fields with vertical position of the beam at SSD = 100 cm and compared with data from literature. The measured fields sized were 10×10, 15×15, 20×20, 30×30 and 40×40 cm (Table 1).

All measured radiation parameters (PDD, TMR, OF) were determined at SSD = 180 cm for the vertical position of the beam and compared with PDD calculated values using the PDD conversion formula from one SSD to another (from 100 cm to 180 cm):

$$\mathrm{PDD}_2(d, \mathrm{SSD}_2, S) = \mathrm{PDD}_1(d, \mathrm{SSD}_1, S) \times F, . \tag{1}$$

where: d = depth; SSD_1=100 cm, and SSD_2=180 cm; S = field size at surface; F represents the corresponding Mayneord's factor and is given by:

$$F = \left(\frac{\mathrm{SSD}_1 + d}{\mathrm{SSD}_1 + d_{\max}} \right)^2 \times \left(\frac{\mathrm{SSD}_2 + d_{\max}}{\mathrm{SSD}_2 + d} \right)^2 . \tag{2}$$

3. RESULTS AND DISCUSSION

The restriction imposed by our existing dosimetric system, in example our water phantom can't be used for extended distances, raises the necessity of using a acrylic phantom type T2967 from PTW with dimensions of 30 cm × 30 cm × 30 cm for determining the percentage depth dose at extended distances.

For that we measured the percentage depth dose PDD for various collimator openings at SSD = 100 cm in water phantom (Table 1) and compared them with measured values in our phantom type 2967.

Table 1

PDD [%] experimental values at different depths (cm)
obtained by scanning water phantom for various collimator openings

Field size [cm] / Depth [cm]	10×10	15×15	20×20	30×30	35×35	40×40
1.5	99.8	99.98	99.9	100	99.9	100
2	99.2	99.3	98.8	99.1	99	99.3
3	95.1	95.68	95.6	95.4	95.7	96.2
4	90.9	91.55	91.8	92.2	92.2	93
5	86.6	87.73	88.4	88.4	88.7	88.9
6	82.7	83.82	84.4	84.9	85.1	85.9
7	78.6	79.98	80.4	81.5	81.9	82.2
8	74.4	76.17	77	78	78.6	78.6
9	70.7	72.6	73.6	74.6	75.5	75.7
10	66.9	68.92	70	71.7	72.3	72.6
11	63.5	65.92	67	68	69.1	69.9

Table 1 (continued)

12	60.1	62.42	64	65.4	66.1	66.7
13	56.8	59.4	60.9	62.4	63.3	63.9
14	53.7	56.42	58	59.6	60.7	61.2
15	51	53.45	55.2	57.1	57.8	58.5
16	48.1	50.62	52.7	54.3	55.1	55.7
17	45.6	48.23	49.9	52.1	52.8	53.4
19	40.8	43.45	45.2	47.2	47.8	48.8
20	38.5	41.18	43.1	45.1	45.8	46.5
21	36.4	38.88	40.8	42.9	43.5	44.5
22	34.4	36.97	38.8	40.9	41.7	42.4
23	32.6	35.08	37	38.7	39.6	40.7
24	30.6	33.23	34.9	37.1	37.8	38.6
25	29.1	31.68	33.1	35.2	36.2	37.1

From the above results (Table 1) using the conversion formula from one PDD to another at extended distances we calculated the PDD for different collimator openings at SSD = 180 cm (Table 2).

Table 2

Calculated PDD [%] values at SSD = 180 cm for different field sizes [cm × cm]

Field size [cm] / Prof. [cm]	18 × 18	27 × 27	36 × 36	54 × 54	63 × 63	72 × 72
1.50	99.78	99.97	99.88	99.98	99.88	99.98
2.00	99.61	99.71	99.21	99.51	99.41	99.71
3.00	96.32	96.91	96.82	96.62	96.92	97.43
4.00	92.84	93.50	93.76	94.17	94.17	94.99
5.00	89.19	90.35	91.04	91.04	91.35	91.55
6.00	85.87	87.03	87.63	88.15	88.36	89.19
7.00	82.27	83.72	84.16	85.31	85.73	86.04
8.00	78.50	80.36	81.24	82.29	82.93	82.93
9.00	75.18	77.20	78.26	79.33	80.28	80.49
10.00	71.69	73.85	75.01	76.83	77.47	77.80
11.00	68.56	71.17	72.34	73.42	74.61	75.47
12.00	65.38	67.90	69.62	71.15	71.91	72.56

Table 2 (continued)

13.00	62.25	65.10	66.74	68.39	69.37	70.03
14.00	59.28	62.28	64.03	65.80	67.01	67.56
15.00	56.71	59.43	61.38	63.49	64.27	65.05
16.00	53.86	56.68	59.01	60.81	61.70	62.37
17.00	51.42	54.39	56.27	58.75	59.54	60.22
19.00	46.64	49.67	51.67	53.96	54.65	55.79
20.00	44.31	47.40	49.60	51.91	52.71	53.52
21.00	42.17	45.05	47.27	49.70	50.40	51.56
22.00	40.12	43.11	45.25	47.70	48.63	49.45
23.00	38.26	41.18	43.43	45.42	46.48	47.77
24.00	36.14	39.26	41.22	43.82	44.65	45.59
25.00	34.59	37.66	39.34	41.84	43.03	44.10

Measuring the PDD for the same fields sizes and in the same depths in acrylic phantom at extended distance of 180 cm (Table 3) we compare the relative difference between measured and calculated values (Table 4).

Table 3

PDD [%] measured values at different depths (cm) in acrylic phantom for various collimator openings at SSD = 180 cm

Field size [cm × cm] / Depth [cm]	18 × 18	27 × 27	36 × 36	54 × 54	63 × 63	72 × 72
1.50	100	100	100	100	100	100
2.00	98.66	98.72	98.56	99.88	99.8	99.66
3.00	95.66	95.98	96	97.8	97.63	97.58
4.00	92.66	93.2	93.26	95.97	95.81	95.76
5.00	89.21	89.94	90.01	93.21	93.06	93
6.00	85.68	86.61	86.7	89.95	89.78	89.74
7.00	82.15	83.26	83.36	87.48	87.33	87.29
8.00	78.58	79.89	80	85.81	85.65	85.58
9.00	75.14	76.61	76.74	81.66	81.51	81.47
10.00	71.85	73.43	73.61	76.72	76.6	76.58
11.00	68.58	70.3	70.52	74.34	74.22	74.2
12.00	65.33	67.21	67.44	72.81	72.71	72.67

Table 3 (continued)

13.00	62.21	64.2	64.44	70.5	70.4	70.38
14.00	59.22	61.29	61.52	67.41	67.31	67.32
15.00	56.33	58.5	58.7	62.99	62.9	62.92
16.00	53.64	55.83	56.07	59.64	59.58	59.58
17.00	51.05	53.27	53.53	58.72	58.66	58.68
19.00	46	48.29	48.59	55.45	55.4	55.44
20.00	43.71	46.01	46.31	51.67	51.65	51.69
21.00	41.56	43.86	44.15	49.32	49.31	49.36
22.00	39.58	41.83	42.13	48.41	48.4	48.45
23.00	37.59	39.8	40.1	47.49	47.48	47.55
24.00	35.6	37.77	38.08	46.58	46.57	46.64
25.00	33.61	35.74	36.05	45.67	45.65	45.74

Table 4

Relative difference between measured and calculated values for PDD at SSD =180 cm

Field size [cm × cm]	18 × 18	27 × 27	36 × 36	54 × 54	63 × 63	72 × 72
Depth [cm]	RD [%]	RD [%]	RD [%]	RD [%]	RD [%]	RD [%]
1.50	-0.219	-0.035	-0.118	-0.018	-0.118	-0.018
2.00	0.956	0.995	0.656	-0.370	-0.391	0.053
3.00	0.680	0.956	0.849	-1.222	-0.729	-0.155
4.00	0.194	0.326	0.533	-1.913	-1.743	-0.816
5.00	-0.027	0.457	1.131	-2.384	-1.874	-1.579
6.00	0.220	0.480	1.065	-2.039	-1.607	-0.615
7.00	0.148	0.549	0.945	-2.547	-1.871	-1.453
8.00	-0.107	0.585	1.525	-4.272	-3.283	-3.199
9.00	0.051	0.762	1.945	-2.943	-1.529	-1.211
10.00	-0.226	0.567	1.866	0.145	1.129	1.563
11.00	-0.023	1.227	2.520	-1.249	0.523	1.688
12.00	0.078	1.018	3.136	-2.338	-1.115	-0.150
13.00	0.063	1.380	3.450	-3.091	-1.481	-0.499
14.00	0.105	1.591	3.919	-2.454	-0.448	0.358
15.00	0.665	1.567	4.362	0.787	2.129	3.269
16.00	0.414	1.502	4.989	1.918	3.439	4.479
17.00	0.723	2.061	4.871	0.054	1.480	2.553

Table 4 (continued)

19.00	1.379	2.784	5.967	-2.761	-1.380	0.626
20.00	1.355	2.930	6.642	0.456	2.015	3.415
21.00	1.451	2.639	6.599	0.770	2.158	4.260
22.00	1.336	2.967	6.889	-1.497	0.471	2.013
23.00	1.759	3.346	7.662	-4.552	-2.154	0.461
24.00	1.508	3.784	7.627	-6.292	-4.301	-2.293
25.00	2.833	5.099	8.373	-9.152	-6.091	-3.721

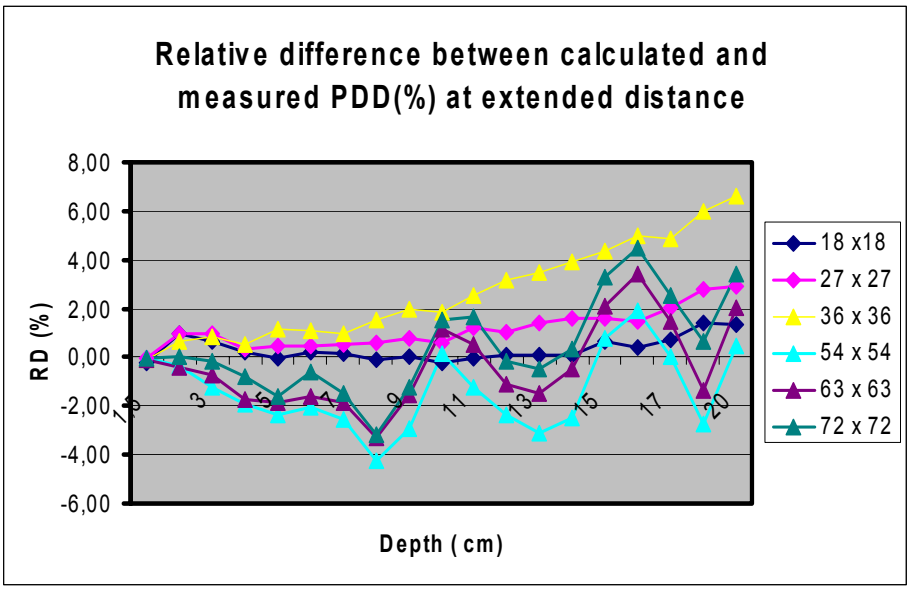

Fig. 1 – Relative difference between measured and calculated values for PDD at SSD=180 cm (after Table 4.)

The relative difference between measured and calculated PDD at SSD = 180 cm is below 2% for depths until 10 cm in phantom for smaller field (until 36 cm × 36 cm) but is increasing until 10% in the maximum depth measured of 25 cm due to the phantom limitations (Fig. 1).

Using the conversion formula from PDD to TMR, we obtain:

$$\mathrm{TMR}\left(\mathrm{d,S}\right)=\mathrm{PDD}\left(d\right)\times\left(\left(\mathrm{SSD}+d\right)^{2}/\left(\mathrm{SSD}+d_{\max}\right)^{2}\right), \tag{3}$$

where d is the measuring depth, S is the field size, we obtained our TMR factors for measured data points (Table 5) and compare them with literature [4].

Table 5

TMR(%) for square fields at extended distance SSD = 180 cm

Depth [cm]	Conversion factor	Field size [cm × cm]	Field size [cm × cm]	Field size [cm × cm]	Field size [cm × cm]	Field size [cm × cm]	Field size [cm × cm]
		18 ×18	27 × 27	36 ×36	54 × 54	63 × 63	72 × 72
1.50	1	100	100	100	100.00	100.00	100
2.00	1.01	99.20	100.26	99.10	100.43	100.35	100.21
3.00	1.02	97.25	98.51	97.59	99.42	99.25	99.20
4.00	1.03	95.23	96.10	95.85	98.63	98.47	98.42
5.00	1.04	92.68	93.87	93.51	96.84	96.68	96.62
6.00	1.05	89.98	91.40	91.05	94.47	94.29	94.25
7.00	1.06	87.20	88.87	88.49	92.86	92.70	92.66
8.00	1.07	84.31	86.22	85.83	92.07	91.89	91.82
9.00	1.08	81.48	83.71	83.21	88.55	88.39	88.34
10.00	1.10	78.74	80.93	80.67	84.07	83.94	83.92
11.00	1.11	75.95	78.82	78.10	82.33	82.19	82.17
12.00	1.12	73.11	75.98	75.47	81.48	81.37	81.32
13.00	1.13	70.34	73.61	72.86	79.72	79.60	79.58
14.00	1.14	67.66	71.16	70.29	77.01	76.90	76.91
15.00	1.15	65.02	68.60	67.76	72.71	72.61	72.63
16.00	1.17	62.55	66.10	65.39	69.55	69.48	69.48
17.00	1.18	60.14	64.08	63.06	69.18	69.11	69.13
19.00	1.20	55.30	59.71	58.41	66.66	66.60	66.65
20.00	1.21	53.07	57.55	56.23	62.74	62.72	62.76

Our TMR data obtained at 180 cm was compared with literature and we found that the relative difference between measured and literature is within 0.2% and 3%. Our experimental results and those calculated for TMR obtained from PDD at extended distances were also analyzed from the perspective approached by W.J. Curran and others [5]. They evaluate the ratio between TMR at extended distance and TMR at standard distance. These comparisons give us confidence in the correctness of the experimental results.

4. CONCLUSIONS

We implemented a method for relative and absolute dosimetry starting from standard water phantom measurements which will be used for dosimetric measurement at extended distance in our radiotherapy center.

Based on the results obtained we are setting up a database with dosimetric parameters which later will be used for TBI or HBI treatment planning in our center.

Before the implementation of TBI technique we need to do more dosimetric measurements at even longer distance due to the fact that with a collimator opening of 40 cm × 40 cm the equivalent field at 180 cm is only 72 cm × 72 cm which in some cases is not enough.

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