DOSIMETRIC VERIFICATION OF DYNAMIC WEDGED FIELDS

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SUMMARY

Purpose: Verification of dynamic wedge algorithm generation in the Clinac 2100 CD accelerator, and in the Cad Plan- Treatment Planing System.
Material: In order to calculate the dose distribution for dynamic wedge modified fields, the Cad Plan planning system uses an algorithm which is a combination of measurement results for open fields and the GSTT files. No additional measurement data are required from the user.
Method: To this end, measurements verifying the calculations of monitor units realized by the planning system for dynamically modified fields were conducted. The following profiles were compared: the measured profile and the profile generated by the Varian system. The measurements were carried out for the energy of 6 MeV, for EDW 15°, 20°, 30° and 45°, using a water phantom and ionization chambers with active volumes of 0.6ccm and 0.1ccm.
Results: The results are presented in the form of diagrams and tables. Differences in the calculations of monitor units do not exceed 3%. The differences between the analyzed profile areas averaged out at 2.4%.

Discussion: The compliances confirmed by measurements corroborate the correctness of the system operation. The measurements became a guideline for the creation of a routine system of dynamic wedge control.

Key words: Dynamic wedge, GSTT (Golden Segmented Treatment Table), profile.

INTRODUCTION

1.1. Introduction to the problem.

There is a number of clinic situations when the use of wedges is necessary to modify dose distributions, e.g. in the case of a nominal entry of beams. Traditional physical wedges have numerous limitations such as an inadequate number of wedge angles, available wedging dimension smaller than that for open fields, long irradiation times, change of the power spectrum after the beam crosses the wedge, and possible collisions of the wedge holder with the therapeutic table in isocentric techniques. Also one should not overlook the problem of a considerable weight of the 60° wedge, which is of importance for a technician placing the wedge in the collimator holder. The dynamic wedge may replace or may be used to supplement the commonly used physical wedges. To ensure their more user friendly character, the beam was modulated to obtain a shape of a wedge and became referred to as a “dynamic wedge’’.

For the first time, the modulation of a beam into a wedge shape by the motion of one of collimator jaws was proposed by Kijewski in 1978 (1). One of the first products using the name of a dynamic wedge was proposed by Varian in the early 1990s.

The characteristic parameter of physical and dynamic wedges is the wedge angle.

The angle Θ of a physical wedge is defined for the field of 10x10cm: it is included between the 80% profile isodose contour and the perpendicular to the beam axis. In order to determine the dynamic wedge angle, one must draw a 10 cm profile and make a perpendicular to the beam axis. The field width will, thus, be divided into four equal parts and through points determined in this way one can draw parallels to the beam axis. The lines dividing the field into quarters cut the profile in two points which should be connected by a line. The angle between such delimited line and the perpendicular line in the direction of the beam axis is the dynamic wedge angle. This definition is illustrated in *Figs.1 and .2.*

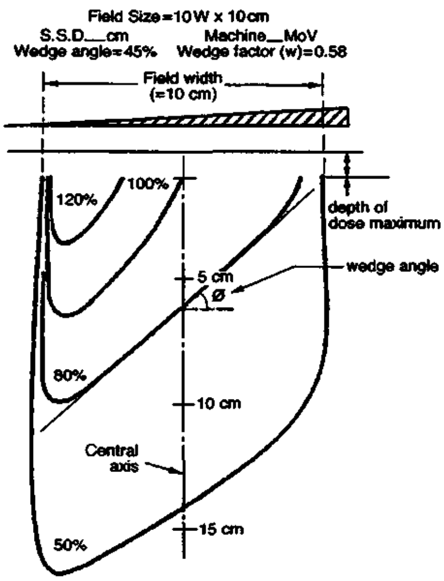

Fig. 1. Physical wedge

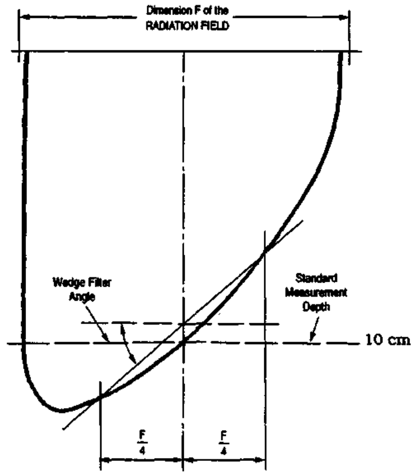

Fig. 2. Dynamic wedge

The dynamic wedge technique is implemented by a sweeping action of one of the independent collimator jaws from an open to a closed position while the beam is on. The field is never entirely closed, there is always 0.5cm of disclosed area. The dynamic wedge generation technique can be divided into two parts: (1) irradiation with a big open field (max 30 cm), and (2) the resulting ever smaller fields created by a collimator sweeping to a closed position. The irradiated field is thus a sum of overlaying fields *(cf. Fig. 5).* The figure below presents the above technique of wedge beam generation by a dynamic field change. (2)

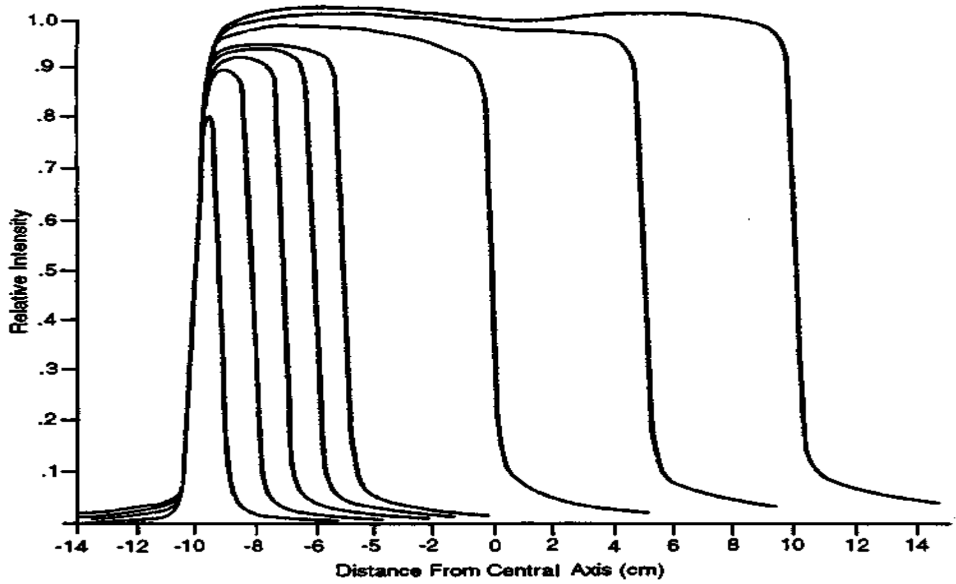

Fig. 5. Partial fields.

During the collimator jaw motion, the dose rate for particular partial fields changes. The collimator motion is not uniform. When the speed of the sweeping collimator jaw decreases, the dose rate delivered to particular partial fields grows but never exceeds the dose rate assigned to an open field, *(Fig. 6 and 7).* The entire process is controlled by an accelerator computer.

As a consequence, the dose is a function of three variables: collimator jaw speed (v), dose rate (D′) and time (t).

Dose v.s. (v, D′, t)

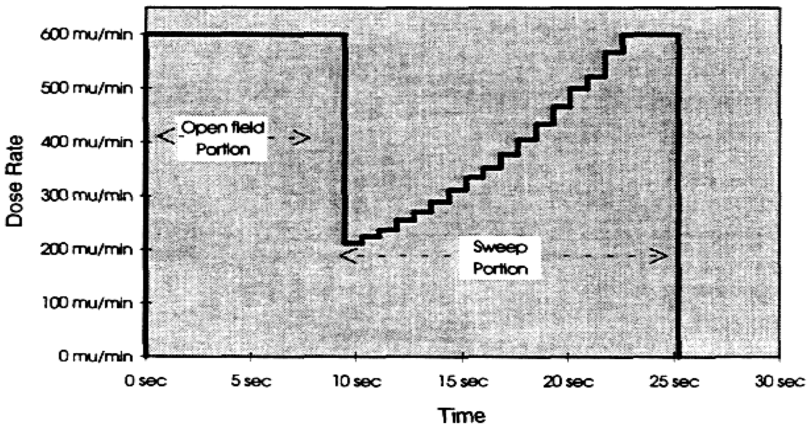

Fig. 6. Change in dose rate in the creation of an EDW.

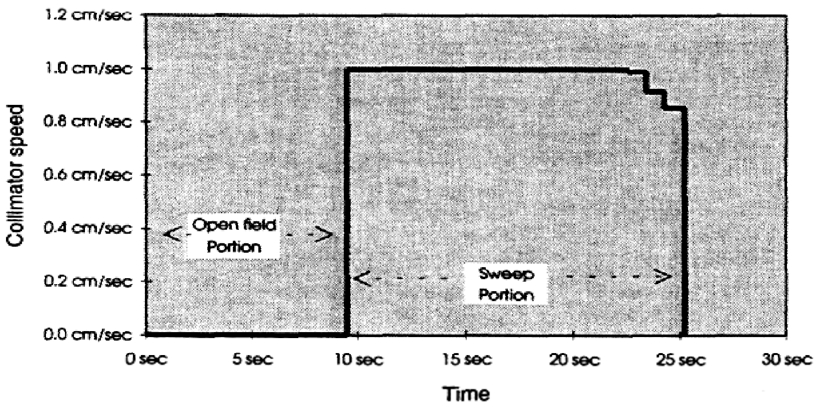

Fig. 7. Collimator speed during the creation of an EDW.

Depending on whether the Y1 jaw (or Y2 jaw) is defined as movable, we obtain applicable wedge orientation. The sharp profile part always corresponds to the immovable side of the collimator jaw. This corresponds to the simple dependence that the longest irradiated field receives the biggest dose.

The core of the dynamic wedge generation system are Segmented Treatment Tables (STT), which describe the dose rate as a function of the position of the jaw closing the irradiation field. In the first Dynamic Wedge (DW) implementations, there were 132 tables, for each wedge angle and for the field dimension every 0.5 cm. Along with the progress of beam modulation technique, Varian has developed an option of dynamic wedges and created Enhanced Dynamic Wedge (EDW). The main advantages resulting from this progress were as follows: a higher number of angles (10, 15, 20, 25, 30, 45, 60°), increase in the field size to 30 cm and availability of asymmetric fields. The number of STTs also changed. For an EDW, for a given energy, there is a so-called Golden Segmented Treatment Table (GSTT), on which individual tables are generated for a given wedge angle and for a given field size. The individual table generating process takes place in the accelerator computer always after the beam parameters have been set up but before the start of the irradiation process.

1.2. STT Generation Procedure based on the GSTT file.

The STT defines what dose, with a different rate, is delivered as a function of the position of the collimator movable jaw sweeping across the treatment field. It should be stressed here that the collimator jaw sweeping motion varies with regard to its speed. The first generation of dynamic wedges required individual STTs, for fields every 0.5 cm and for four wedge angles, which in total made up 132 tables.

The situations is different in the case of EDWs. For each beam energy a reference dynamic wedge and a reference profile are defined and both these values make up a reference STT, which corresponds to a 30 cm wide field and a 60° wedge angle, which is the case of the above-mentioned GSTT.

For a field whose dimensions are X, Y and at the (Θ) angle of EDW, an individual STT is created. To this end, it is necessary to define at the panel the following paremeters: energy, wedge orientation, wedge angle, field size and number of monitor units. With these parameters selected, an STT can be created.

1. The GSTT for a given energy rate is read from the computer disk.
2. Then, an STT is computed for a given Θ wedge angle.
3. A sub-table for a given field size is separated from the above table.
4. Renormalization of the created table to a monitor units (MU) is computed for this case.
5. Calculation of dose rate and collimator speed is made for particular segments.

Let us now go through the STT generation process for a wedge angle different from 60°. The STT for any wedge angle is a combination of the table for a 60° wedge and a 0° wedge, i.e. an open field. The effective angle is calculated by means of a weighted average of an open field and 60°(3). In the calculation of applicable ratios, a tangent method is applied. The weights W(0°) and W(60°) are calculated according to the following formulas:

$$W(0°)=(\tan 60°-\tan \Theta°)/\tan 60°$$

$$W(60°)=\tan\Theta°/\tan 60°$$

The STT for a given wedge is calculated from the following formula(4):

$$STT(\Theta°)=W(0°)*STT(0°)+W(60°)*STT\ 60°$$

$$STT(\Theta°)=(1–tg\ \Theta°/tg\ 60°)STT(0°)+(tg\ \Theta°/tg\ 60°)STT\ 60°$$

Table 1. Weight ratios for different EDWs.

wedge angle	Weight ratios for open field $W_0{}^o$	Weight ratios for 60°wedge $W_{60}{}^o$
10°	0.89820	0.10180
15°	0.84530	0.15470
20°	0.78986	0.21014
25°	0.73078	0.26922
30°	0.66667	0.33333
45°	0.42265	0.57735
60°	0.00000	l.00000

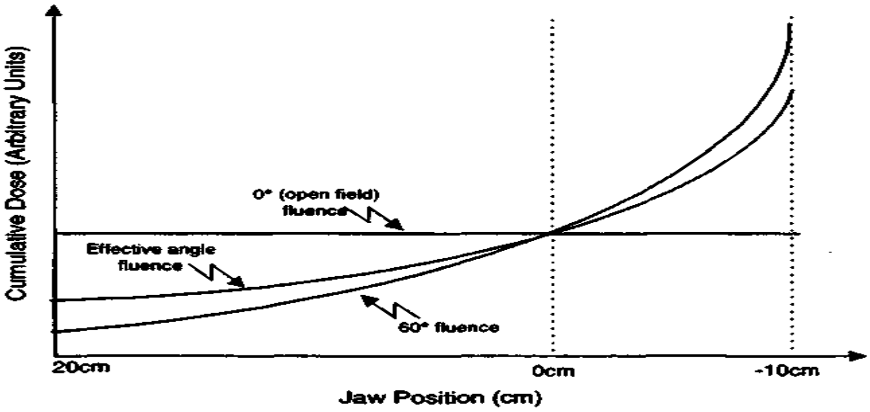

Fig. 8. Graphic representation of STT generation for a given wedge angle.

From a table generated in this manner for a selected wedge angle, a part corresponding to the operator-selected field is separated. This is illustrated in the diagram below. Points P1 and P2 correspond to collimator jaws Y1 and Y2, which delimit the field width. The full STT corresponds to a field from 20 to –10 cm.

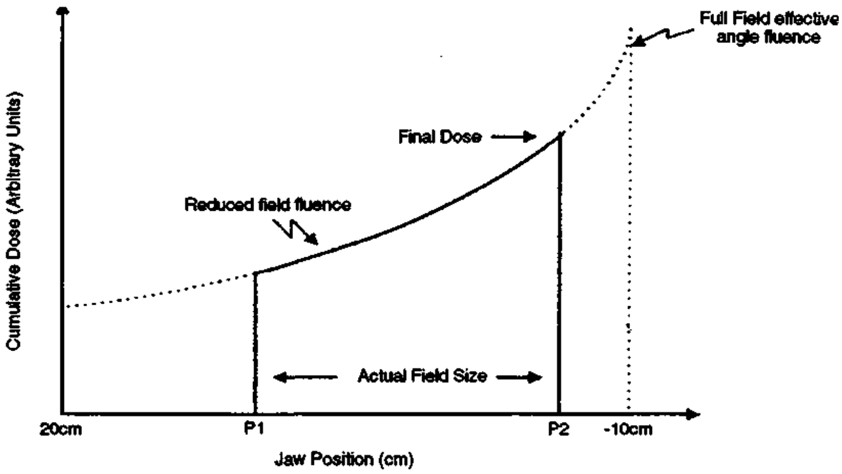

Fig. 9. STT creation for a selected field.

The basic table - GSTT – includes information which part of a dose is delivered as a function of the position of the movable jaw. If one wishes to deliver a determined number of units, e.g. 100 MU, the table is renormalized pro rata, and the process takes place prior to the exposure start.

The GSTT tables are recorded on the hard disk of the accelerator computer and in the treatment planning system. When computing the EDW, the Cad Plan uses only STTs and data for open fields, i.e. profiles, diagonal profiles, percentage depth doses and output rates factors. In view of the above, we have decided to analyze how the Varian-proposed algorithm corresponds to the user's measurement reality.

The purpose of the study was to verify the accuracy of the generation of dynamic wedges from the point of view of a dose in the beam axis and profile.

2. MATERIAL AND METHOD

The measurements were carried out using the Clinac 2100 CD accelerator, for 6MeV photons, for four selected angles of a dynamic wedge, i.e. 15°, 20°, 30° and 45°.

The study was divided into two parts: The first part involved the accuracy of the Cad Plan calculations in the beam axis were verified – it involved the comparison of computations made by the Cad Plan with results of measurements in a water phantom and the accuracy of calculations out of the beam axis was compared, using the profiles measured, with the Cad Plan calculations.

The measurements were made in a water phantom using an ionization chamber with an active capacity of 0.6 ccm and a Farmer dosimeter. The effective measurement point was at the depth of 5 cm. The dose rates were measured for symmetric rectangular fields: of x = 6, 8, 10, 15, 20 cm, y = 6, 8, 12 cm. The measurements were made for a dynamic wedge (15, 20, 30, 45) and a given field size, for two different wedge orientations (motion Y1 or Y2). Using the percentage depth doses for open fields, the dose rates for the above-mentioned fields and wedge angles were calculated for a maximum value. Then, a graph of the dependence of dose rate in a maximum value, as a function of the field width, for three different heights (y = 6, 8, 12cm) was ploted. The interpolation method was used to calculate the value of dose rates for fields with the same value of "y" but for different values of x = 7, 9, 12, 16, 18, 20 cm. Given the fact that the dose rate is a slow-changing function of the field size, the error made during interpolation may be neglected. Using the results of the calculations, the number of monitor units necessary to obtain a dose of 5 Gy at the depths of 15° EDW - 6cm, 20° EDW-10cm, 30° EWD - 7cm, 45° EDW- 8cm was established. The number of monitor units for given depths was calculated using the Cad Plan. Then, the ionization chamber was irradiated with the number of monitor units computed by the planning system at the depths as defined above. Such combination gave us a possibility to verify and compare the monitor units and doses established based on the measurements with the units and doses from the treatment planning system.

The second part of the work was the verification of profiles for a field of 10 x 10, for three depths - dmax, 5, 10cm. The experiment was conducted for one selected energy (i.e. 6 MeV), for four wedge angles - 15°, 20°, 30°, 45°, and at the wedge orientation of IN (i.e. during the Y1 jaw motion). The measurements were made in a Wellhofer water phantom, using an ionization chamber with an active capacity of 0.1ccm. The selection of this chamber was to ensure a more accurate measurement in the penumbra area. The profiles were drawn based on fifteen measurement points, five points in the treatment area, and five points each on both sides of the field in the penumbra area. Then, a comparison was made with the curves generated in the Cad Plan planning system. The objective of the second part of the study was to show trends in differences between calculations and measurement profiles.

3. RESULTS

The results of the first part of the experiment are presented in *diagrams No. 10, 11, 12, 13* and *in tables No. 2, 3, 4, 5*, each for a separate wedge angle. *Fig. 10* presents a dependence of the dose rate in the max depht as a function of the field width for a 15° EDW. Other diagrams corresponded to other analyzed angles of the EDW. Each curve of the diagram was made for another value of "y". The lowest curve corresponds to y = 12cm, the middle one to y = 8cm and the curve of the highest values to y = 6cm. These characteristics were used to determine the dose rates for fields of other dimensions than the measured ones.

Table 2 (for 15° EDW) presents:

- the number of monitor units determined based on dose rate measurements and necessary to obtain a dose of 5Gy at the depth of 6cm, and the number of monitor units calculated by the planning system (columns 2 and 3, and differences in column 4),
- the doses measured at the depth of 6cm (for 15° EDW), obtained during irradiation established by the treatment planning system, with a set dose of 5 Gy (columns 6 and 7).

Table 3 presents data for 20° EDW, dose of 5 Gy at 10 cm.

Table 4 presents data for 30° EDW, dose of 5 Gy at 7 cm.

Table 5 presents data for 45° EDW, dose of 5 Gy at 8cm.

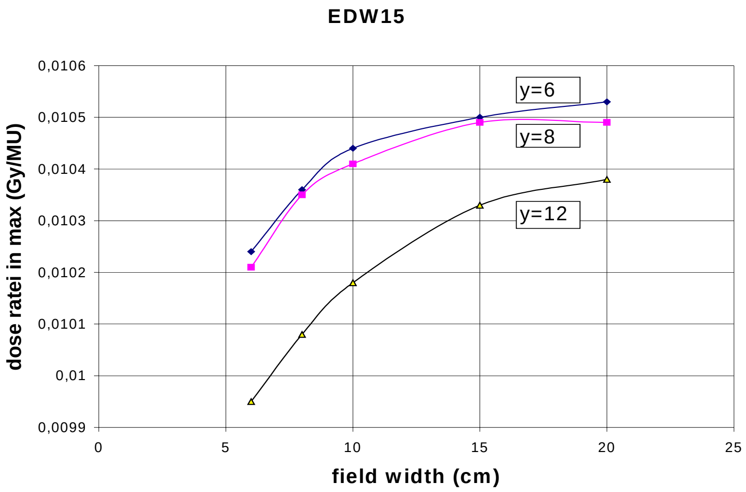

Fig. 10. Dependence of dose rate in the max depth on field size for 15° EDW.

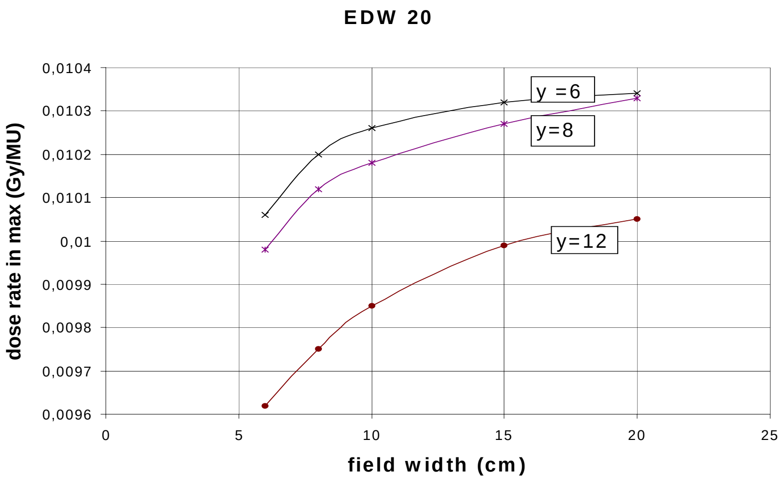

Fig. 11. Dependence of dose rate in the max depth on field size for 20° EDW.

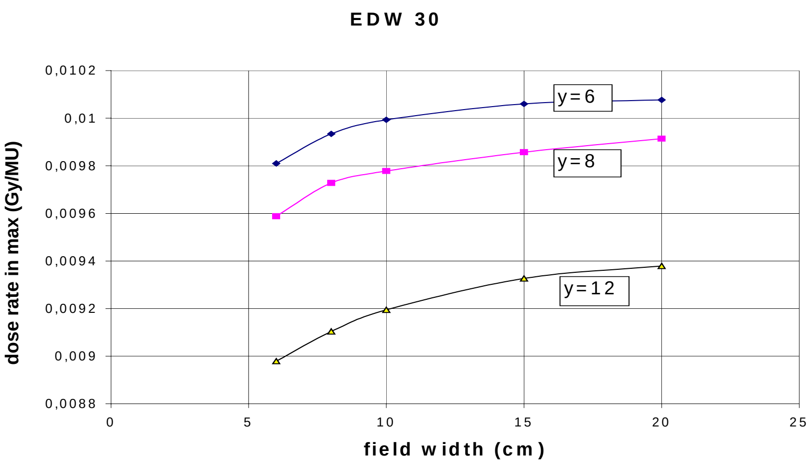

Fig.12. Dependence of dose rate in the max depth on field size for 30° EDW.

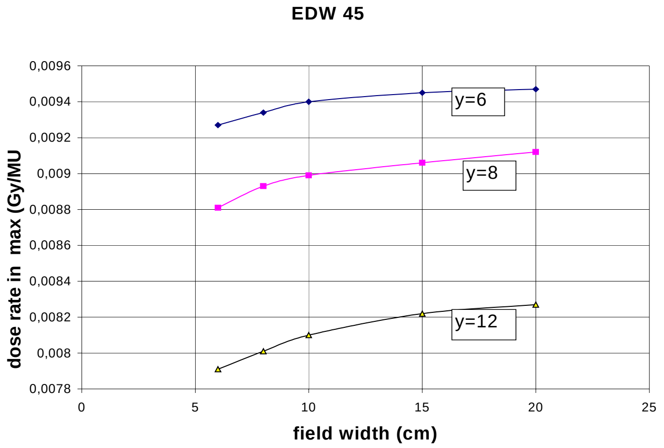

Fig. 13. Dependence of dose rate in the max depth on field size for 45° EDW.

Table 2. Comparison of monitor units and doses established based on measurements with monitor units and doses calculated by the Cad Plan, for 15° EDW, depth of chamber: 6 cm, dose: 5Gy.

X	Y	MU measurement	MU Cadplan	ΔMU (%)	D measurement	ΔD (%)
7	6	600	610	1,6	5,041	0,8
9	6	590	605	2,5	5,056	1,1
12	6	588	603	2,5	5,059	1,8
16	6	584	599	2,5	5,094	1,9
18	6	582	599	2,8	5,105	2,1
7	8	600	610	1,6	5,059	1,2
9	8	592	602	1,7	5,064	1,3
12	8	586	594	1,4	5,056	1,1
16	8	580	592	2,0	5,082	1,6
18	8	578	591	2,2	5,086	1,7
7	12	612	620	1,3	5,055	1,1
9	12	603	609	1	5,054	1,1
12	12	592	600	1,3	5,055	1,1
16	12	585	594	1,5	5,059	1,2
18	12	583	591	1,4	5,055	1,1

Table 3. Comparison of monitor units and doses established based on measurements with monitor units and doses calculated by the Cad Plan, for 20° EDW, depth of chamber: 10 cm, dose: 5Gy.

X	Y	MU measurement	MU cadplan	ΔMU (%)	D measure ment	ΔD (%)
7	6	766	776	1,3	5,004	0,1
9	6	754	764	1,3	5,037	0,7
12	6	744	758	1,8	5,067	1,3
18	6	734	754	2,7	5,108	2,1
20	6	733	752	2,5	5,109	2,1
7	8	764	775	1,4	5,043	0,9
9	8	750	763	1,7	5,061	1,2
12	8	739	747	1,1	5,038	0,8
18	8	724	739	2,0	5,071	1,4
20	8	721	740	2,6	5,096	1,9
7	12	784	791	0,9	5,031	0,6
9	12	767	776	1,2	5,054	1,1
12	12	748	757	1,2	5,038	0,8
18	12	731	743	1,6	5,054	1,1
20	12	727	738	1,5	5,041	0,8

Table 4. Comparison of monitor units and doses established based on measurements with monitor units and doses calculated by the Cad Plan, for 30° EDW, depth of chamber: 7 cm, dose: 5Gy.

X	Y	MU measurement	MU cadplan	ΔMU (%)	D measurement	ΔD (%)
7	6	663	672	1,3	4,994	-0,1
9	6	654	669	2,2	5,035	0,7
12	6	650	661	1,7	5,032	0,6
16	6	645	661	2,4	5,072	1,4
18	6	643	659	2,4	5,071	1,4
7	8	674	682	1,2	5,0	0
9	8	665	674	1,3	5,019	0,4
12	8	656	663	1,1	5,005	0,1
16	8	649	661	1,8	5,038	0,8
18	8	647	660	2,0	5,045	0,9
7	12	716	719	0,4	4,992	-0,2
9	12	701	705	0,6	4,990	-0,2
12	12	689	695	0,9	5,003	0,1
16	12	680	686	0,9	4,990	0
18	12	677	685	1,2	5,013	0,3

Table 5. Comparison of monitor units and doses established based on measurements with monitor units and doses calculated by the Cad Plan, for 45° EDW, depth of chamber: 8 cm, dose: 5Gy.

X	Y	MU measurement	MU CadPlan	ΔMU (%)	D measure ment	ΔD (%)
7	6	746	752	0,8	4,998	-0,04
9	6	736	744	1,1	5,015	0,3
12	6	727	736	1,27	5,020	0,4
16	6	721	735	1,9	5,057	1,1
18	6	719	732	1,8	5,053	1,0
7	8	775	775	0	4,976	-0,5
9	8	762	765	0,4	4,993	-0,1
12	8	752	757	0,7	5,011	0,2
16	8	743	749	0,8	5,014	0,3
18	8	740	748	1,1	5,025	0,5
7	12	857	855	-0,2	4,98	-0,4
9	12	839	836	-0,4	4,973	-0,5
12	12	821	824	0,4	5,001	0
16	12	809	810	0,1	4,987	-0,3
18	12	806	806	0	4,986	-0,3

Results of the second part of the experiment, i.e. the comparison of profiles generated by the Cad Plan and the measured profiles are presented in *diagrams No. 14….25*, and in *Tables No., 6, 7, 8, 9*.

Results for a 15° EDW: comparison of the measured profile with the profile generated by the Cad Plan, at three depths: max (1.4), 5 and 10 cm. The table below *(Table No. 6)* presents relative differences between the points of the measured profile and the computed profile. The results were compared for 80% of the width of the field examined, i.e. for 8cm. The 0 coordinate was assigned to the field center and at this point both profiles were normalized to 100%.

Results for a 15° EDW.

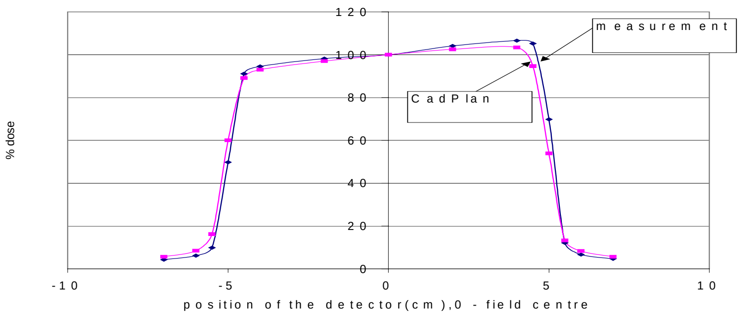

Fig. 14. Measurement and Cad Plan profiles: 15 EDW, depth of 1.4 cm

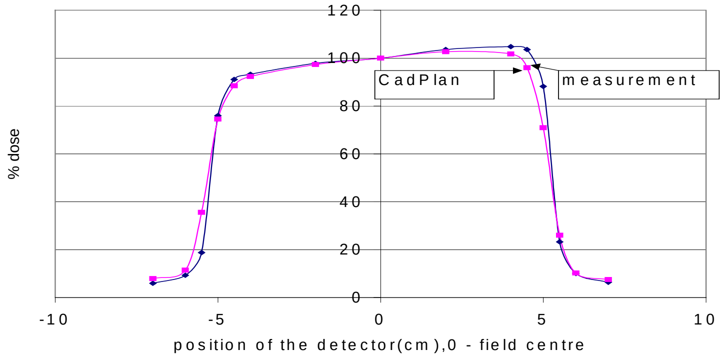

Fig. 15. Measurement and Cad Plan profiles: 15 EDW, depth of 5 cm

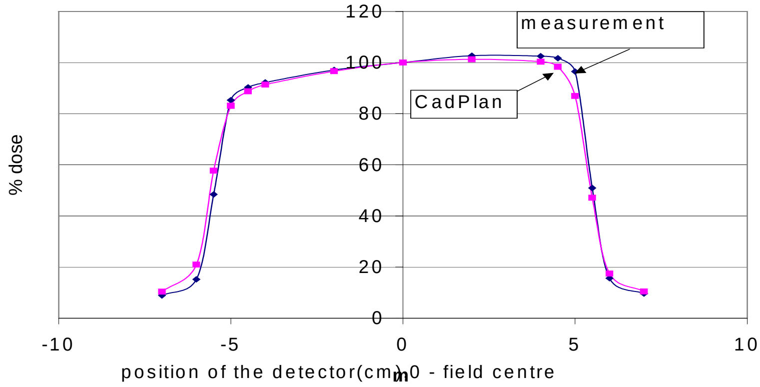

Fig. 16. Measurement and Cad Plan profiles: 15 EDW, depth of 10 cm

Table 6. Presentation of relative dose differences in the measured and the computed profiles for 80% of width of the field examined for a 15 EDW.

Depth (cm)	**Position of detector (cm), 0 – field center**					**Average (%)**
	-4	**-2**	**0**	**2**	**4**	
	differences in the measured and the computed profiles					
1,4	1,64	1,25	0	1,56	3,14	1,9
5	1,09	0,5	0	0,9	3,0	1,37
10	0,92	0,51	0	1,4	2,15	1,25

Results for a 20° EDW.

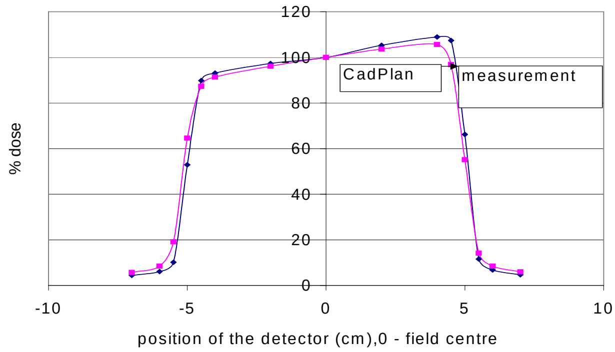

Fig. 17. Measurement and Cad Plan profiles: 20 EDW, depth of 1.4 cm

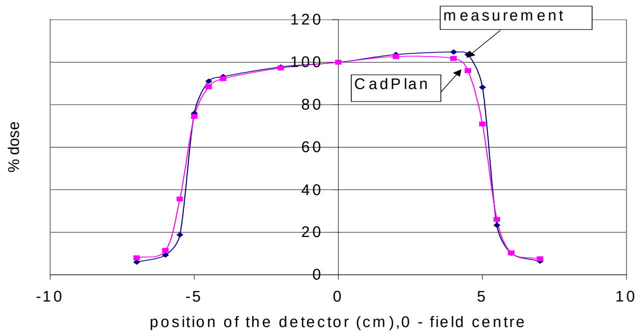

Fig. 18. Measurement and Cad Plan profiles: 20 EDW, depth of 5 cm.

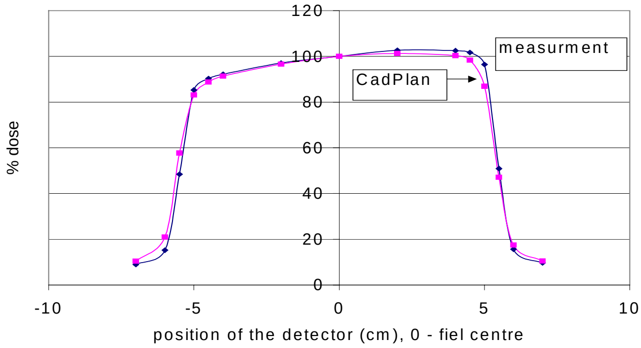

Fig. 19. Measurement and Cad Plan profiles: 20 EDW, depth of 10 cm.

Table 7. Presentation of relative dose differences in the measured and the computed profiles for 80% of width of the field examined for a 20 EDW.

Depth (cm)	**Position of detector (cm), 0 – field center**					**Average (%)**
	-4	**-2**	**0**	**2**	**4**	
	differences in the measured and the computed profiles					
1,4	1,92	1,27	0	1,62	3,1	1,98
5	1,1	0,29	0	0,31	2,86	1,14
10	0,79	1,23	0	1,52	2,55	1,77

Results for a 30° EDW

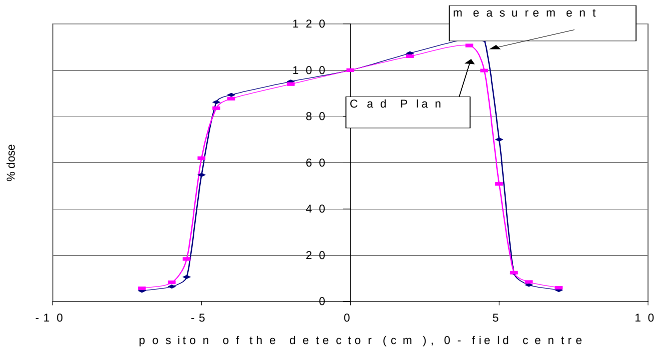

Fig. 20. Measurement and Cad Plan profiles: 30 EDW, depth of 1.4 cm.

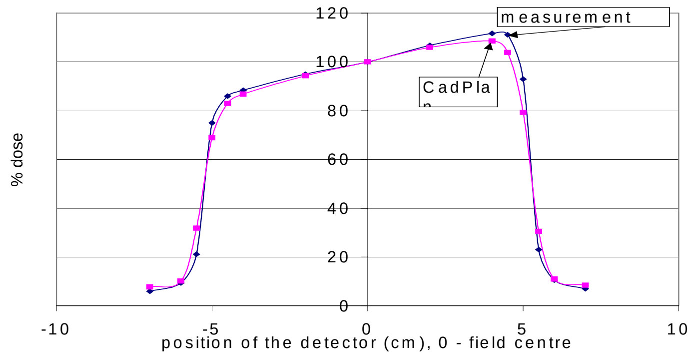

Fig. 21. Measurement and Cad Plan profiles: 30 EDW, depth of 5 cm

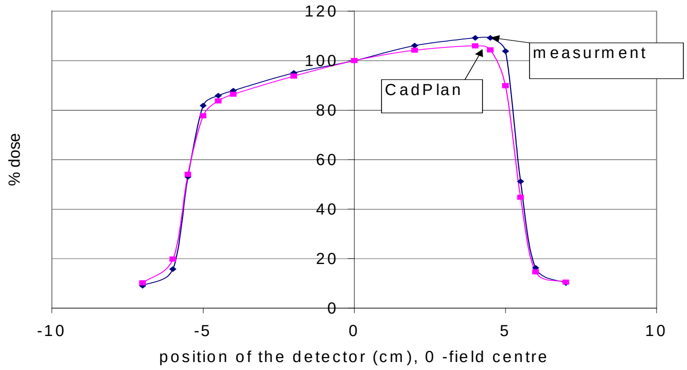

Fig. 22. Measurement and Cad Plan profiles: 30 EDW, depth of 10 cm.

Table 8. Presentation of relative dose differences in the measured and the computed profiles for 80% of width of the field examined for a 30 EDW.

Depth (cm)	**Position of detector (cm), 0 – field center**					**Average (%)**
	-4	**-2**	**0**	**2**	**4**	
	differences in the measured and the computed profiles					
1,4	1,87	1,18	0	1,23	2,89	1,79
5	1,87	0,79	0	0,76	2,85	1,55
10	1,72	1,39	0	1,79	3,0	1,98

Results for a 45° EDW.

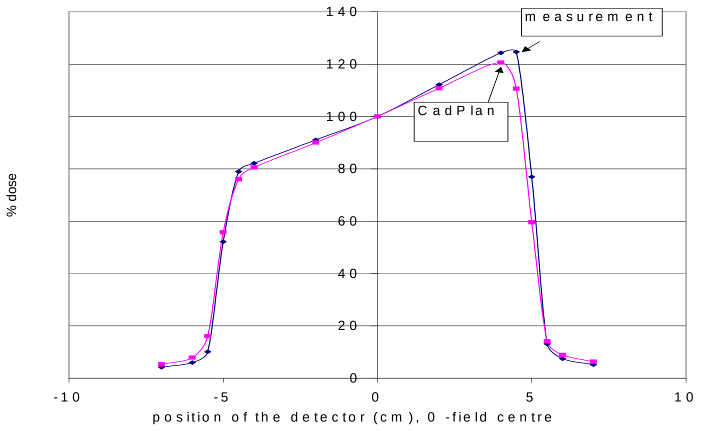

Fig. 23. Measurement and Cad Plan profiles: 45 EDW, depth of 1.4 cm.

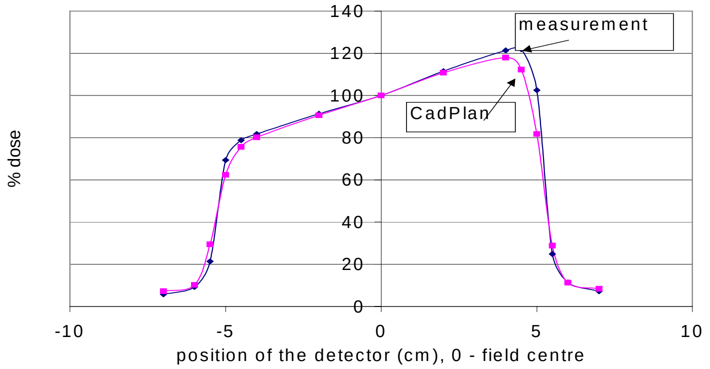

Fig. 24. Measurement and Cad Plan profiles: 45 EDW, depth of 5 cm.

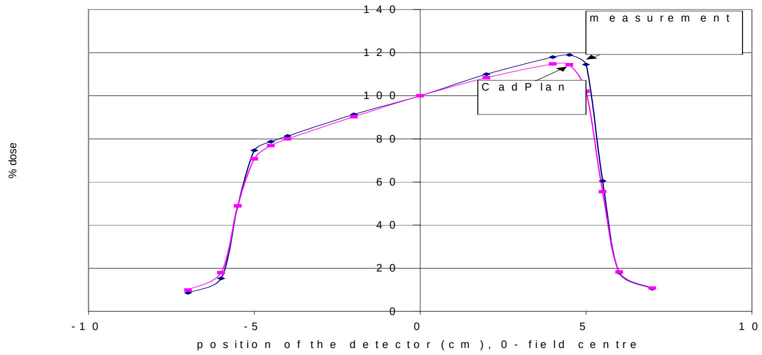

Fig. 25. Measurement and Cad Plan profiles: 45 EDW, depth of 10 cm.

Table 9. Presentation of relative dose differences in the measured and the computed profiles for 80% of width of the field examined for a 45 EDW.

Depth (cm)	Position of detector (cm), 0 – field center					Average (%)
	-4	-2	0	2	4	
	differences in the measured and the computed profiles					
1,4	1,97	1,14	0	1,28	3,03	1,89
5	1,92	0,79	0	0,7	2,91	1,58
10	1,71	1,17	0	1,50	2,78	1,79

4. CONCLUSION

The purpose of the proposed control system was to verify the algorithm put forward by VARIAN.

The calculation of monitor units is fairly good, being compliant with measurements. Differences between calculations and measurements increase along with the growth of the field width. The maximum deviation is noticeable in the case of rectangular fields, where the relation of sides is higher than 2(x/y>2). It is still, however, below 3%. The differences between the calculations of the planning system and the measurements decrease with an increase in the wedge angle: for 15° EDW they amount to 2.8%, and for 45° EDW to 1.9%. Similar tendencies are maintained in the case of dose calculations. For 15° and 20° dynamic wedges, the dose calculated by the system is higher than the dose measured by maximum 2.1%. Better compliance is noticeable in the case of 30° and 45° wedges, where the differences do not exceed 1.4%.

The comparison of the measured profiles with those generated by the Cad Plan shows slight differences in the treatment field range. The differences increase with the distance from the central axis of the field, and grow considerably in the direction of the sharp end of the wedge, reaching 3.1%. The measured profile was always on top of the profile calculated by the planning system. Deviations in the compared profiles are similar for all wedge angles examined.

5. DISCUSSION

In radiation therapy, it is of utmost importance to have highly accurate calculations. Modern conformal radiation therapy tools, such as dynamic profile modification to wedge shape requires that the user is specially careful. The problem of configuration and verification of the planning system becomes a task for a physicist and a creation of a system of verification is a basic aspect of Quality Assurance. Lack of appropriate dosimetry equipment, e.g. a line detector array, calls for an establishment of an individual control system. One can observe that the percentage share of GSTT (x from 20 to -10cm and Θ=60°) for a given EDW angle is of importance. The higher share of the primary GSTT, i.e. the bigger the wedge angle, the better conformity between the measurements and calculations.

It should also be noted that the biggest differences in the profile are in those places where the irradiation field is never fully covered by the sweeping collimator. The irradiation always ends at the open position of Δx=0.5 cm.

The above facts allow one to conclude that the dynamic wedge generation algorithm proposed by Varian is compliant with the user's measurement reality.

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