VERIFICATION OF GEOMETRY RECONSTRUCTION AND DOSE CALCULATION MODULES OF THE PLATO RADIOTHERAPY PLANING SYSTEM

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SUMMARY

Purpose: Verification of reconstruction of application geometry and of calculations of dose distribution in the PLATO v. 13.7 system for brachytherapy treatment planning.
Materials and methods: The correctness of geometry reconstruction was verified using a Perspex phantom with lead markers. Dose calculations were verified by comparing values calculated by the system against values calculated „manually" and against published benchmark values.
Results: The average difference between marker co-ordinates in the phantom, as measured mechanically, and as reconstructed by the PLATO system, did not exceed 0.4 mm. The maximum relative difference between values of dose at given points, calculated by the PLATO system and values of dose calculated „manually" at those points, did not exceed 0.3%. The PLATO system was found to correctly reproduce the published benchmark data.
Conclusions: The geometry reconstruction software module unit and the dose distribution algorithm of the PLATO v. 13.7 planning system used at the Centre of Oncology in Kraków, were found to operate correctly.

Key words: Quality Assurance, Brachytherapy, Treatment Planning, PLATO, Selectron, microSelectron.

INTRODUCTION

Within a Quality Control programme in radiotherapy, verification of the computer treatment planning system with respect to the accuracy of the reconstruction of geometry and of the accuracy of algorithms used to calculate the distribution of dose, are required [1, 4, 5, 7]. We tested those elements in the PLATO v. 13.7 radiotherapy planning system which is applied at the Centre of Oncology in Krakow in intracavitary brachytherapy treatment using Selectron LDR/MDR or microSelectron PDR afterloading units, all manufactured by Nucletron.

In our Centre, radiographs of applicators loaded with dummy sources and spacer markers, required for calculating dose distributions, are obtained using the IBU (Integrated Brachytherapy Unit), also manufactured by Nucletron. This unit consists of an X-ray machine mounted on a movable C-arm, which enables radiographs to be obtained from various angles. On-line vision, i.e. connection of the X-ray machine vision track with a computer monitor, allows the physician to visualise and correct the placement of the applicators. After establishing their correct position, a train of dummy sources is inserted in the applicators, location radiographs are made and transferred digitally to the PLATO planning system. On the basis of these images, the positions of sources as well as positions of some selected points in the patient (in the bladder and rectum) are geometrically reconstructed in a three-dimensional co-ordinate system. The system calculates the exposure time and the dose distribution around sources

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in the applicators for a given source configuration and dose prescription, as defined by the operator. The IBU and the PLATO system have replaced an earlier brachytherapy planning system, in-house developed at the Centre of Oncology, in which an external frame with location markers and conventional semi-orthogonal radiographs were used in the 3D-reconstruction of applicator, source and patient geometry, and appropriate dose calculations performed [2].

METHODS AND RESULTS

Verification of the accuracy of geometry reconstruction

A solid Perspex phantom with built-in markers, manufactured at the Medical Physics Department of the Centre of Oncology *(fig. 1),* was used. The size of the phantom and the distribution of markers inside its volume (22 lead pellets of diameter 4.0 mm each) were designed to cover the volume of a typical gynaecological application. The co-ordinates of all markers in the phantom were measured mechanically (i.e., read out using a caliper) with an estimated accuracy of ± 0.1 mm. The phantom was placed on the IBU X-ray table and four digital location radiographs (AP, lateral and diagonal at the angles of 225 ° and 315 °) taken. The images were next transferred to the PLATO planning system and the spatial location of all markers in the phantom reconstructed using the PLATO system location unit. To compare the actual (mechanically measured) and calculated co-ordinates of the markers, their values were referred to the location of the central marker *(no. 9, see fig. 1).* For each marker, the difference between the actual and the calculated value of its X-, Y- and Z- co-ordinate was evaluated, for orthogonal *(Table 1)* and diagonal *(Table 2)* projections of the phantom.

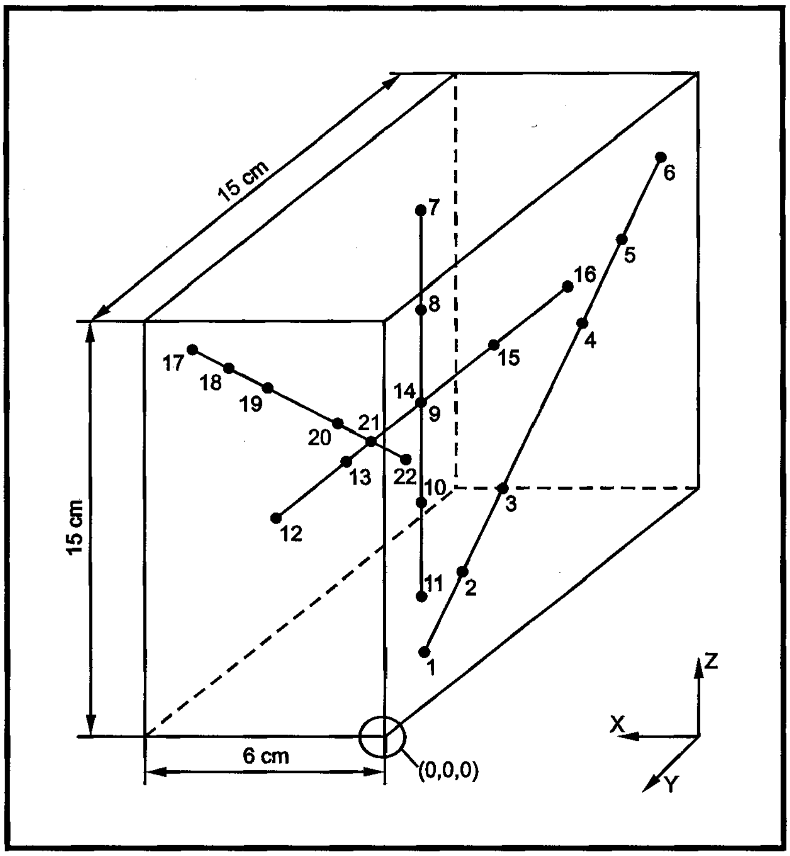


Fig. 1. Placement of markers in the solid Perspex phantom used to verify the geometry reconstruction module of the PLATO therapy planning system.

Table 1. Co-ordinate values of markers in the solid phantom (fig. 1) measured mechanically, and reconstructed from AP and lateral projections.

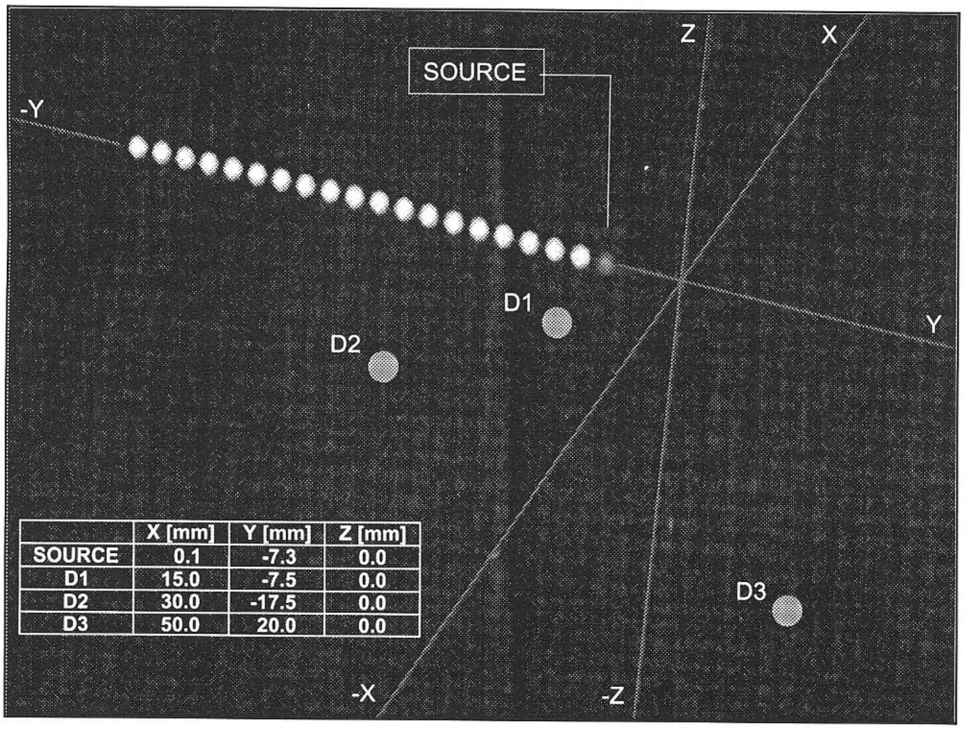
Marker No.	X coordinate [mm]	Y coordinate [mm]	Z coordinate [mm]
1	1.0	-0.1	0.8
2	1.0	-0.5	0.7
3	0.6	-0.5	0.8
4	0.2	0.6	-0.1
5	0.0	0.4	-0.5
6	-0.7	0.9	-0.4
7	0.3	0.0	-1.9
8	0.0	0.0	-0.3
9	0.0	0.0	0.0
10	0.1	-0.4	0.9
11	-0.1	-0.4	1.7
12	-0.1	-0.2	-0.4
13	0.3	-0.3	-0.3
14=9	0.0	-0.1	0.0
15	0.0	0.2	0.5
16	0.2	-0.1	1.2
17	-0.9	-0.8	-1.0
18	-0.5	-1.0	-0.6
19	-0.3	-0.2	0.0
20	-0.4	0.7	1.3
21	-0.7	0.2	1.7
22	-1.3	1.1	2.2
Mean	-0.07	-0.03	0.29
Std. Dev.	0.55	0.52	0.99

Table 2. Co-ordinate values of markers in the solid phantom (fig. 1): actually (mechanically) measured, and reconstructed from angled (225 ° and 315 °) projections.

Marker No.	X-coordinate [mm]	Y-coordinate [mm]	Z-coordinate [mm]
1	1.4	0.2	1.0
2	1.2	-0.5	0.7
3	0.4	-0.5	0.9
4	0.5	0.6	0.1
5	0.1	0.3	-0.7
6	-0.5	0.6	-0.5
7	-0.5	-0.3	-1.4
8	-0.7	-0.3	-0.5
9	0.0	0.0	0.0
10	-0.1	-0.1	1.3
11	0.7	-0.4	1.8
12	-0.5	0.0	-0.5
13	-0.1	0.2	-0.4
14	-0.1	0.0	0.1
15	-0.2	0.9	0.5
16	-0.3	0.4	0.6
17	-1.6	-0.4	-0.7
18	-1.3	-0.5	-0.2
19	-1.2	0.4	0.0
20	-1.0	0.9	1.3
21	1.7	1.9	4.4
22	-1.1	1.7	1.7
Mean	-0.15	0.22	0.43
Std. Dev.	0.87	0.67	1.23

Verification of dose calculation

The PLATO dose calculation module was verified using „manual" calculations and with a benchmark data set. In the "manual" approach, values of dose at a number of points of interest, selected for a „cylinder"- type gynaecological Selectron LDR/MDR applicator, as calculated by the PLATO system, were compared against values of dose calculated „manually" at the same points. One active pellet at position no.1 of the "cylinder"-type applicator and three user-defined points of interests were configured in the PLATO system *(fig. 2)*.



	X [mm]	Y [mm]	Z [mm]
SOURCE	0.1	-7.3	0.0
D1	15.0	-7.5	0.0
D2	30.0	-17.5	0.0
D3	50.0	20.0	0.0

Fig. 2. Geometry configuration used to verify the dose distribution calculation module of the PLATO therapy planning system. D1, D2 and D3 - "points of interest".

The co-ordinates of the source and of the points of interest were referred to a co-ordinate system related to the end of the applicator. For each point, the dose value calculated by the PLATO system was read out. The dose value at the same point was also calculated „manually" using the following formula, describing the contribution to the dose at a given distance from a point source:

$$D = \frac{RAKR \cdot t}{r^2} \cdot \left[\frac{\mu_n}{\rho} \right]_{air}^{water} \cdot S(r)$$

Where:
D- dose [cGy],
RAKR- Reference Air Kerma Rate $[cGy\cdot h^{-1}\cdot m^{-2}]$,
r- source-to-point distance [m],
t- irradiation time [h],
$[\mu_n/\rho]$- quotient of mass energy absorption coefficient in water and in air ($[\mu_n/\rho]=1.11$),
S(r)- factor describing effective energy transmission in water, given by the formula of Van Kleffens and Star [8], modified by Van der Laarse [6].

Data for dose calculations were provided by the Journal option of the PLATO system. The source-to-point distances for points D1, D2 and D3 *(fig. 2)* were determined from their spatial co-ordinates. The dose values at points D1, D2 and D3, calculated by the PLATO system and those calculated „manually" using the above formula, are compared in Table 3.

In the second procedure for verifying the dose calculation, values of dose rate were calculated at given points of interest for a specified caesium source configuration, and compared with a benchmark data set published by Meertens [3]. This data set describes a specified intracavitary gynaecological application performed with the LDR/MDR Selectron unit, in which the dose rate has been calculated at selected points of interest for a specified source configuration inside a specified applicator. The Reference Air Kerma Rate (RAKR) is assumed to be the same for all caesium sources. This benchmark data set has been derived by Meertens and tested using five planning systems in 11 brachytherapy centres in Holland, where, among other factors, dose rates at given locations were compared [3]. The published benchmark data set lists the co-ordinates of the sources (all of the same activity), and the values of dose rate at the reference points and at points of interest. The benchmark sets of co-ordinates of the sources and of the points of interest were entered into the PLATO system by means of a text file *(fig. 3).* The required RAKR value for the caesium sources, 56.94 [μGyh^{-1}m^{-1}], was entered by suitably selecting the date of a simulated application. In Table 4 the benchmark and system-calculated dose rate values at all points of interest, are compared.

Table 3. Dose values calculated "manually" (see text) and by the PLATO dose calculation module, for the configuration of source and points of interest shown in fig. 2.

Point	Dose calculated „manually" [cGy]	Dose calculated by PLATO system [cGy]	Relative difference [%]
D1	116.5	116.9	-0.3
D2	25.5	25.5	0.0
D3	7.6	7.6	0.0

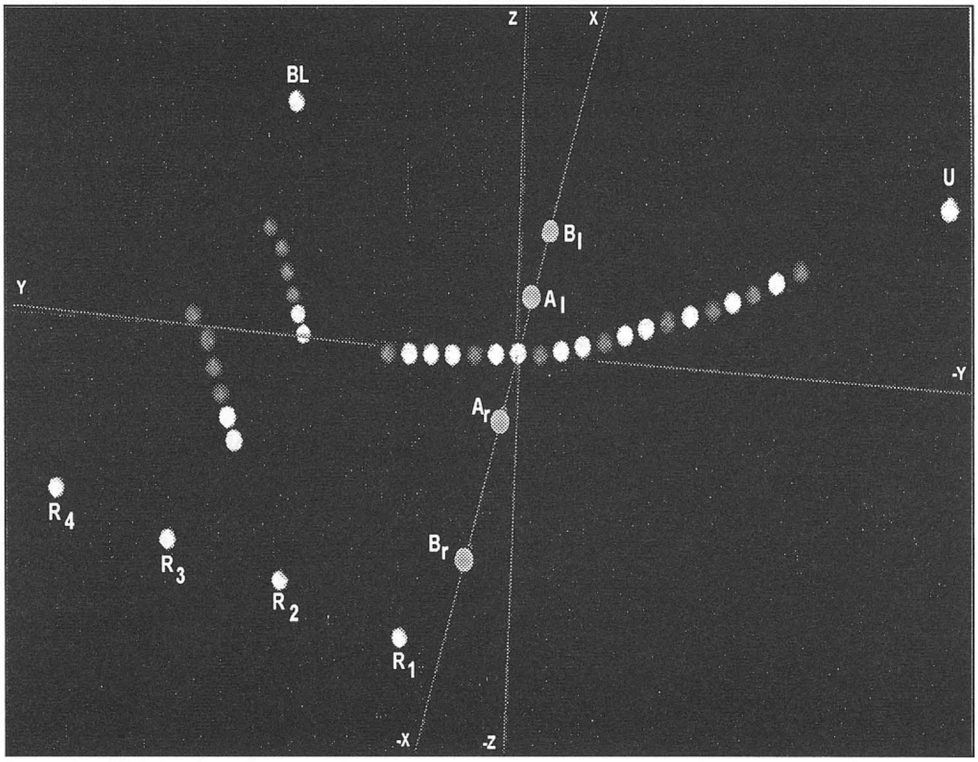


Fig. 3. Geometry configuration used to verify the dose distribution calculation module of the PLATO therapy planning system against the benchmark data of Meertens [3]. (•)-Cs-137 sources; R_1, R_2, R_3, R_4, BL, A_l, A_r, B_l, B_r, and U – points of interest.

Table 4. Dose rate values calculated by the PLATO dose calculation module, and benchmark values of Meertens [3] for the benchmark configuration of sources and points of interest shown in fig. 3.

Point of interest	Dose rate calculated by PLATO system [cGyh^{-1}]	Dose rate, benchmark value [cGyh^{-1}]	Relative difference [%]
A_l	113.6	113.5	0.1
A_r	106.0	105.9	0.1
B_l	35.3	35.3	0.0
B_r	29.6	29.6	0.0
R_1	70.1	70.1	0.0
R_2	83.8	83.7	0.1
R_3	78.3	78.2	0.1
R_4	54.4	54.5	-0.1
BL	106.7	106.5	0.2
U	65.9	66.3	-0.6

DISCUSSION

As estimated from the difference between the actual (mechanically measured) co-ordinates of markers inside the solid phantom and those reconstructed from orthogonal *(Table 1)* or diagonal *(Table 2)* projections, their shift, in most cases, does not exceed ±1 mm (only for the Z-axis, in two cases, does it exceed 2 mm). The mean values of this shift, for X- and Y- co-ordinates are within 0.2 mm, with standard deviations around these values well within SD = 1 mm. Reconstruction of the Z- co-ordinates of the markers appears to be somewhat less accurate, with SD = 0.99 mm and SD= 1.23 mm for orthogonal and diagonal projections, respectively. Thus, correct performance of the location module of the PLATO system has been clearly stated. We believe that occasional deviations exceeding ±1 mm (for markers no. 20, 21 and 22) may be caused by the limited precision, perhaps operator-dependent, of indicating the positions of these markers in the radiographs.

"Manual" and system-calculated values of dose at points D1, D2 and D3 around a "cylinder"-type applicator were found to agree extremely well, to within 0.3 %, as seen in Table 3. The relative difference between the values of dose rate at points of interest, calculated by the PLATO system and values listed in the benchmark data set of Meertens [3] was found not to exceed 0.6% *(Table 4)*. Thus, satisfactory accuracy of the dose distribution calculation module in the PLATO therapy planning system has been stated.

CONCLUSIONS

As a result of our Quality Assurance procedures, we have confirmed that the PLATO v. 13.7 brachytherapy planning system used at our Centre:

- correctly reconstructs the applicator and source geometry, accurately providing spatial co-ordinates of sources and of points of interest, for purposes of radiotherapy planning,
- correctly calculates the dose and dose-rate distribution for applicator and source

geometry, as applied in intracavitary gynaecological radiotherapy at the Centre of Oncology in Krakow.

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