# Treatment Planning by Computer

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## SUMMARY

**From measurements of central axis depth-dose data for fields of various sizes at various source-surface distances, tables were drawn up giving the depth-dose data expressed for position on a polar co-ordinate grid. These data have been permanently stored in the memory system of a computer. The computer has been programmed to use the data for dose planning for fixed- and moving-beam isocentric teletherapy.**

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Multifield radiation therapy with teletherapy machines is normally administered by one of two basic methods. The one method is to keep the source-skin distance constant and the other to keep the source-axis distance constant. The axis is a point within the patient at or near the centre of the tumour to be irradiated.

The second method, known as the isocentric method, has several advantages over the fixed source-skin distance method. These are: (*a*) greater accuracy in directing the treatment beam; (*b*) shorter patient positioning time; and (*c*) it embraces moving-beam treatment methods.

The disadvantage of the isocentric method is that the dosage planning is more complicated since normal isodose curves and depth-dose tables cannot be used. The length of time required to calculate dose distributions for moving-beam treatments, either arc or rotational, is a sufficient drawback to militate against their use. Moving-beam treatment would otherwise be the method of choice in treating many conditions.

The answer to this planning problem has been to devise a system whereby the work is done by computer. Various programmes have been devised by other workers, for example, Tsien *et al.*[1]

Some of these programmes are highly efficient in producing comprehensive dose plans. They cannot, however, merely be taken over and used as such, since they include extensive information on the treatment beam which varies for different teletherapy machines. It depends on source-axis distance, collimator type, distance and source dimensions. Furthermore, most programmes embody approximations of some kind, some of which may be acceptable and others not. It was decided to programme a planning method developed in the department. A resulting advantage is that computer-produced treatment plans can easily be manually checked for errors that may have occurred along the processing line.

## THE PLANNING METHOD

The first machine for which data for computer planning was prepared was the Theratron-60. Tables of the type shown in Table I were produced.

Table I shows the percentage dose at points on radial lines at 10° intervals on a polar grid and 4 cm from the

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TABLE I. PERCENTAGE DOSE TABLE FOR 8 X 8 COBALT-60 FIELD FOR POINTS 4 CM FROM ISOCENTRE

| Degrees | | Source-surface distance | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 |
| 0 | 360 | 29 | 30 | 32 | 34 | 36 | 38 | 40 | 43 | 46 | 48 | 51 | 54 | 57 | 60 | 63 | 66 | 68 | 71 | 74 | 77 | 79 | 82 |
| 10 | 350 | 28 | 29 | 31 | 33 | 35 | 37 | 39 | 42 | 45 | 47 | 50 | 53 | 55 | 58 | 61 | 64 | 66 | 69 | 72 | 75 | 77 | 80 |
| 20 | 340 | 27 | 28 | 30 | 32 | 34 | 36 | 38 | 41 | 44 | 46 | 49 | 51 | 53 | 57 | 59 | 63 | 65 | 67 | 70 | 73 | 75 | 78 |
| 30 | 330 | 26 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 42 | 45 | 47 | 48 | 51 | 55 | 57 | 60 | 61 | 63 | 68 | 70 | 72 | 75 |
| 40 | 320 | 25 | 26 | 28 | 30 | 32 | 33 | 35 | 37 | 39 | 42 | 45 | 46 | 49 | 52* | 54 | 57 | 58 | 60 | 64 | 67 | 70 | 73 |
| 50 | 310 | 24 | 25 | 26 | 28 | 30 | 31 | 33 | 35 | 37 | 39 | 42 | 44 | 47 | 49 | 51 | 54 | 56 | 59 | 61 | 64 | 66 | 69 |
| 60 | 300 | 18 | 20 | 21 | 22 | 23 | 25 | 27 | 28 | 30 | 32 | 34 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 | 52 | 54 | 56 |
| 70 | 290 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 27 | 28 | 29 | 31 | 33 | 34 | 36 | 38 | 39 | 41 |
| 80 | 280 | 12 | 13 | 14 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 23 | 24 | 25 | 27 | 28 | 30 | 32 | 33 | 34 | 36 | 37 |
| 90 | 270 | 10 | 11 | 12 | 13 | 14 | 14 | 15 | 16 | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 25* | 27 | 28 | 30 | 31 | 32 | 33 |
| 100 | 260 | 11 | 11 | 12 | 13 | 14 | 14 | 15 | 15 | 17 | 18 | 19 | 20 | 22 | 23 | 24 | 25 | 27 | 28 | 30 | 31 | 32 | 33 |
| 110 | 250 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 25 | 26 | 28 | 29 | 31 | 33 | 34 | 36 | 38 | 39 | 41 |
| 120 | 240 | 14 | 15 | 16 | 18 | 19 | 20 | 21 | 22 | 23 | 25 | 26 | 28 | 29 | 31 | 32 | 34 | 36 | 38 | 40 | 43 | 45 | 47 |
| 130 | 230 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 23 | 24 | 25 | 27 | 28 | 30 | 31 | 33 | 35 | 37 | 39 | 42 | 44 | 46 |
| 140 | 220 | 14 | 15 | 16 | 17 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 30 | 31 | 33 | 35 | 37 | 39 | 42 | 44 | 46 | 49 |
| 150 | 210 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 23 | 24 | 25 | 27 | 29 | 30 | 32 | 34 | 36 | 38 | 40 | 43 | 45 | 47 |
| 160 | 200 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 30 | 32* | 33 | 35 | 38 | 40 | 42 | 44 | 46 |
| 170 | 190 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 30 | 32 | 33 | 35 | 38 | 40 | 42 | 44 | 46 |
| 180 | 180 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 30 | 32 | 33 | 35 | 38 | 40 | 42 | 44 | 46 |

* Values used in a worked example explained in the text.

origin. The table is for an 8 × 8 cm$^2$ field and the dose values are given for variations in source-surface distance between 35 cm and 56 cm. Similar tables were prepared for points at distances from 0 cm to 16 cm from the origin and for a variety of field sizes.

## USING THE TABLES

This is illustrated in Fig. 1 which shows a contour of a patient. It is required to treat a tumour with three 8 × 8 cm$^2$ isocentric fields, at angles of 40°, 160° and 270° from the vertical. It can be seen that the source-skin distances for these 3 fields are (60 - 12) = 48 cm, (60 - 11) = 49 cm and (60 - 10) = 50 cm, respectively.

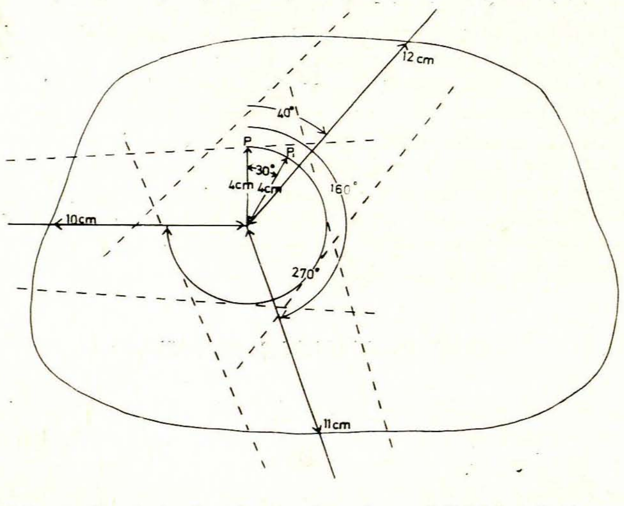

Fig. 1. Contour of patient undergoing a 3-field irradiation.

To calculate the dose at a point situated at 0° and 4 cm from the origin, for example, the 4-cm table must be used and the values for 40° 48 cm, 160° 49 cm and 270° 50 cm are added together. In Table I the required values are marked with an asterisk and are 52, 32 and 25. When summated they give 109 which is the percentage dose at point P after 100% has been administered to each of the 3 fields. The dose at 0,5 cm depth and 50 cm source-skin-distance for a single field of the same dimensions has been chosen as the 100% dose.

Consider now point P$_1$, which is situated off the O° radial line, say on the 30° radial line and 4 cm from the origin. The same table is used but the angles of incidence of the 3 fields are reduced by 30° so that the values read off are 10° - 48 cm, 130° - 49 cm and 240° - 500 cm. In this way dose values at all the points of intersection of radial lines and circles which form the polar grid can be determined. The number of fields is not limited and rotational or arc treatments can be regarded as the sum of fields situated at 10° intervals over the angle of the arc or rotation.

To undertake this procedure manually, even for a small number of points, would be most tedious and time-consuming. However, such procedures can be done very rapidly by computer. We are using the Burroughs computer of the Transvaal Provincial Administration.

The sets of tables for the various field sizes have been permanently stored in the memory of the computer. In order to obtain a treatment plan a form is filled in giving the contour of the patient in terms of the distances from the chosen isocentre to the skin surface at 10° intervals. In addition the field size is filled in and the angles of the fixed or arc fields to be applied. The printout is in the form of a table showing the percentage dose values at angles from 0 to 360° in 10° intervals about the isocentre and at distances of 0 to 16 cm from the isocentre, or to a distance corresponding to the skin surface, whichever is the lesser.

Refinements have been added to the programme. The total dose required, number of treatments and machine output are given and the daily treatment time, daily tumour and skin doses are then computed.

Furthermore, if required, alternative plans are computed for different isocentres. The desired changes of isocentre in millimetres vertically and horizontally are written onto the data input form and treatment plans are then automatically produced for all the isocentres. Graphical representation of the isodose distribution has also been programmed. The computer selects the highest dose value that occurs and expresses all the other dose values as percentages of this. Different symbols are then used for values that fall into the various 5% intervals from 0 to 100%. For example, an asterisk is printed for values between 97,5% and 100%, an A for values between 92,5% and 97,5% a 9 for values between 87,5% and 92,5% and so on. These symbols are printed on a polar grid in the positions in which they occur. It is then a simple matter to draw in the isodose curve manually if required.

Figs 2 and 3 are examples of isodose curves drawn in this way. Fig. 2 shows the isodose distribution resulting from two 10 × 10 cm$^2$ 120° arc fields. Fig. 3 shows the isodose distribution resulting from the treatment plan shown in Fig. 1.

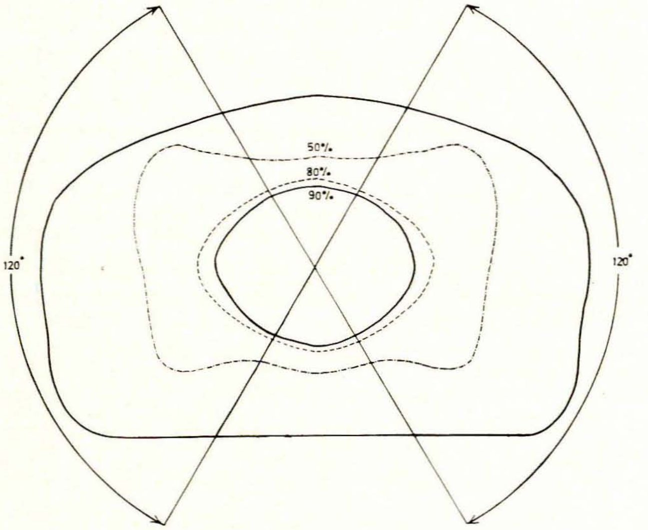

**Fig. 2. Isodose distribution in pelvis from 2 lateral 120° pendulum fields.**

## PRODUCTION OF THE DOSE TABLES

### Depth-dose Data for Points on the Central Axis of the Beam

Using a waterbath and Ionex dosimeter, dose rate measurements were made at various depths below the surface for various field sizes and source-surface distances.

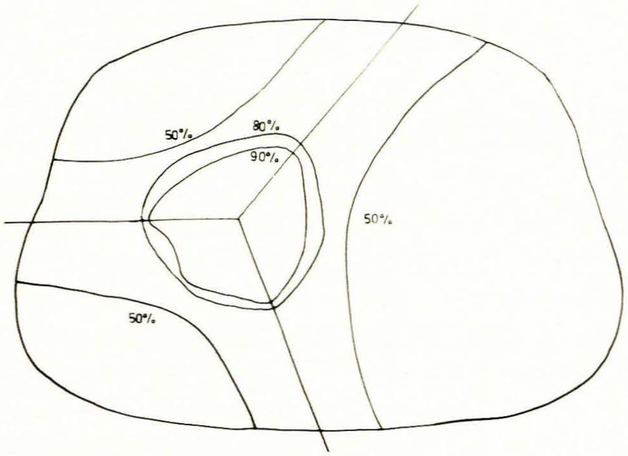

**Fig. 3. Isodose distribution in thorax from 3 stationary fields.**

Fig. 4 indicates the results of such measurements for a particular source-surface distance. From similar curves resulting from measurements made at other source-surface distances a family of curves was drawn from which the central axis dose rate at any depth and any source-surface distance could be interpolated. Fig. 5 shows this family of curves.

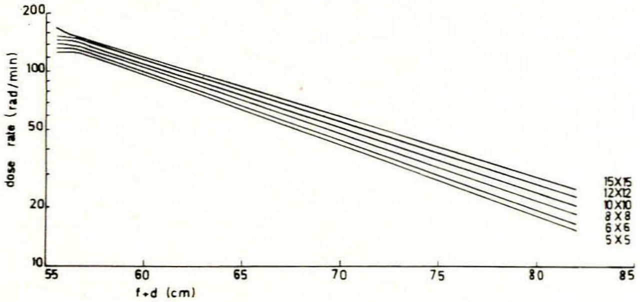

**Fig. 4. Central axis depth-dose curves for source-skin distance (f) of 55 cm. Depth below surface = d.**

### Depth-dose Data for Points Away from the Central Axis of the Beam

Using the isodose curves supplied with the Theratron-60 unit it was found that, for a particular field size, the ratio of the depth dose at an off-axis point to the depth dose on the central axis at the same depth was constant within tolerable limits for all points on the same radial line from the source. This ratio was also found to be independent of the source-surface distance. Fig. 6 shows how the dose diminishes with distance from the central axis. The distance from the central axis is expressed as a fraction of the semigeometrical field width at that depth and is denoted by the symbol X. Thus a value of X = 0 denotes positions on the central axis of the beam, values between 0 and 1 positions within the beam but not on

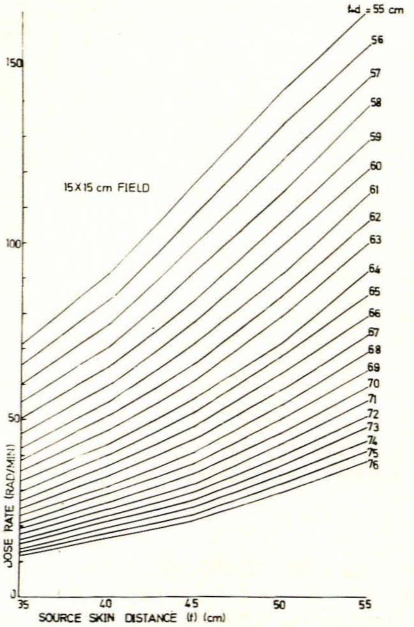

**Fig. 5. Variation of central axis depth-dose data with source-skin distance.**

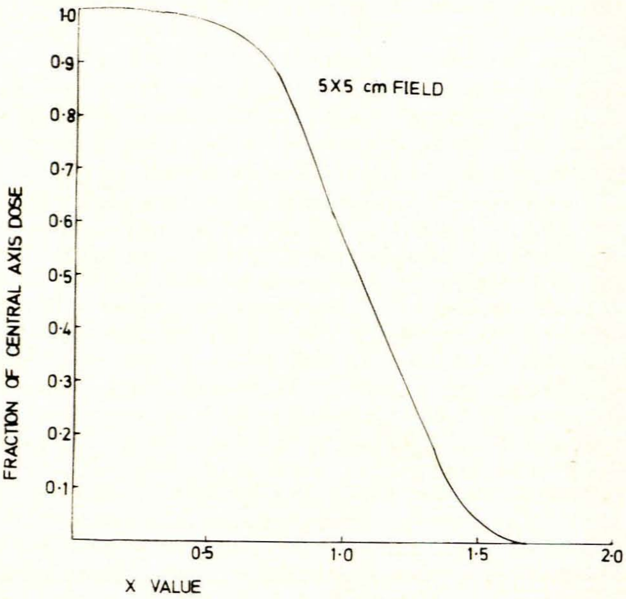

**Fig. 6. Variation of dose with distance from the central axis of the radiation beam where X is equal to the ratio of the distance of a point from the beam axis to the geometrical half-width of the beam at the same depth.**

the central axis. X-values greater than 1 indicate positions beyond the geometrical confines of the beam.

The X-value of any point can be calculated. Consider a point P situated h cm from the isocentre lying on the central axis of the beam. Should the beam rotate through an angle of $\theta$ away from its original position when the X-value of the point P becomes:

$$X = \frac{120\ h \sin \theta}{B\,(60 - h \cos \theta)} \quad . \; . \; . \; (1)$$

where B is the geometrical width of the beam at the isocentre. By using the central axis data from Fig. 5 and the off-axis fall-off from Fig. 6 in conjunction with the X-values calculated from equation (1), a set of tables of which Table I is an example, was drawn up.

In addition to the Theratron-60 unit, tables have also been drawn up for a Gammatron-3 telecobalt unit and for a 250 kv Stabilipan rotational X-ray unit. The tables for the X-ray depth-dose data were not measured but were calculated, mainly by the methods of Worthley[2] and Wheatly.[3]

X-ray arc therapy is being used mainly for lesions of the head. As a result of the ease with which the planning can be done, it has been found that many deep lesions can also be treated satisfactorily with X-ray arc teletherapy.

I wish to thank Mr C. T. van Schalkwyk, Senior Programmer of the Data Processing Department of the Transvaal Provincial Administration (who wrote the computer programme, and inquiries concerning the programme should be addressed to him), Mr C. T. H. Kruger, Under-Secretary of the Data Processing Department, and Senior Planning Radiographers, Miss E. Bester and Mrs S. T. Hugo.

## REFERENCES

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3. Wheatly, B. M. (1955): *Ibid.*, **28**, 566.