FROM THE DEPARTMENT OF RADIATION THERAPY, TEMPLE UNIVERSITY MEDICAL SCHOOL AND HOSPITAL, PHILADELPHIA, U.S.A.

EFFECTS OF DIFFERENT PARAMETERS ON DOSE DISTRIBUTIONS IN COBALT 60 PLANAR ROTATION

by

K. C. TSIEN, J. R. CUNNINGHAM and D. J. WRIGHT

The problems involved in making a comparative study of moving field dose distributions are well known. The foremost of these is the need for a large number of comparable dose distribution data with different values of parameters, such as field sizes, degrees of rotation, sizes and shapes of phantom, etc. Because the calculations (or measurements) involved in determining moving field dose distributions are tedious, several earlier works developed approximate methods of calculation but the procedures were still too time-consuming to obtain a large number of dose distributions. Another problem has been that in most cases the results obtained by different methods of calculation cannot be used in a comparative study owing to the different assumptions being introduced into them. The development of the use of digital computers in the calculation of moving field distributions (4, 9, 15, 16, 18, 20, 21, 22, 24, 25, 27) has removed these problems and the effects of different physical and geometrical parameters on dose distributions can now be studied more completely.

The present study of the effects of different parameters in planar rotation of cobalt 60 beams is based on part of the findings in a project on the study of

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radiation dose distributions sponsored by the International Atomic Energy Agency (23). The calculations were carried out at the Institute of Computer Science of the University of Toronto using an IBM 7090 computer. The details of the method of calculation will be described elsewhere.

Studies on the effects of different parameters to moving field dose distributions in general follow one of two different approaches. One approach is to take the so-called 'efficiency of therapy' defined either as the ratio of the maximum skin dose to the dose at the target center (17), or as the ratio of the integral dose in the target volume to the total integral dose in the body (5). This latter ratio is also called the 'integral dose efficiency factor' (3). As has been pointed out by FRANK ELLIS, (1959), the integral dose is not of great importance as long as it remains below a level between 25 and 30 megagram-rad. The homogeneity of dosage throughout the tumour, the avoidance of 'hot spots' and the dose level in the healthy tissue should be of major importance. The second approach is to compare directly the complete dose distribution patterns, and this is the approach adopted in the present study.

Scope of study

Physical and geometrical parameters in moving beam therapy can be considered in three categories: (1) characteristics of the radiation beam, (2) motion of the beam and (3) the characteristics of the irradiated body. The different parameters in each category are as follows:

1. *Radiation beam:*
   Energy of the radiation*
   Field size
   Dose distributions of single stationary beam (penumbra and shape of isodose curves)

2. *Motion:*
   Type of motion*
   Distance from the source to the centre of rotation, SAD

3. *Irradiated body:*
   Shape and size of the body
   Position of the centre of rotation in the irradiated body
   Composition of body material*

This paper is limited to a study of cobalt 60 dose distributions in homogeneous unit-density phantoms using simple planar rotation, i.e. with the central

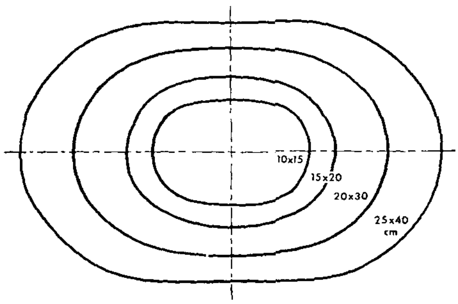

Fig. 1. Different sizes of oval phantom according to HAYNES and FROESE's equation.

ray of the beam describing a plane perpendicular to the long axis of the patient, a motion which is also known as circumaxial moving beam (7). Other moving beam techniques, such as bi-arc and bi-centric planar rotation, or conical rotation, are not included. In this study, the three parameters indicated by an asterisk (*) in the above list remained unchanged. The effects of the other parameters studied in this paper are based on dose distributions from measured single field isodose curves for a cobalt 60 beam of a 2 cm diameter source at 33 cm from the distal end of the collimator and 75 cm from the center of rotation. The values of field sizes, degrees of rotation, and shapes and sizes of body contour (idealized) used in this study were as follows:

1. *Field sizes:*
   Geometrical definition at the center of rotation
   4 × 4 cm   6 × 6 cm   8 × 8 cm
   10 × 10 cm   12 × 12 cm   15 × 15 cm

2. *Degrees of rotation:*
   360°, 300°, 240°, 180° and 120°

3. *Shapes and sizes of phantom:*
   Circular: 10 cm, 20 cm, 30 cm and 40 cm diameter
   Oval: (see Fig. 1)
   10 × 15 cm   15 × 20 cm   20 × 30 cm   25 × 40 cm

HAYNES and FROESE's (1957) equation of idealized body contour is

$$r = A - B \cos 2\,\theta$$

where $A = (a + b)/2$; $B = (a - b)/2$; a and b are the semi-major and semi-minor axes of the phantom.

In calculation of dose distributions the tissue dose at the centre of rotation was always taken as 100. The advantages of this are that the dose at a definite point is taken as the reference, thus excluding any possible ambiguity, and

Table 1

Distances in cm from center of 360 degree rotation to various percentage isodose curves in a 30 cm diameter circular phantom with six different field sizes, and ratios of these distances to the half field widths

% Dose	Field sizes in centimeters					
	4 × 4	6 × 6	8 × 8	10 × 10	12 × 12	15 × 15
	Distance from center of rotation					
100	0	0	0	0	0	0
90	1.4	2.5	3.7	4.9	6.1	7.7
80	2.0	3.2	4.5	5.7	6.9	8.7
70	2.5	3.7	5.2	6.5	7.9	10.0
60	3.0	4.4	5.9	7.5	9.2	11.9
50	3.6	5.2	6.9	9.0	11.2	14.6
40	4.4	6.3	8.6	11.7	14.5	—
30	5.8	8.7	12.0	—	—	—
20	9.4	—	—	—	—	—
	Ratio of distance to half field width					
90	0.75	0.83	0.93	0.98	1.02	1.03
80	1.00	1.07	1.12	1.14	1.15	1.16
60	1.50	1.46	1.48	1.50	1.53	1.59
50	1.80	1.73	1.73	1.80	1.87	1.95

further that the isodose curve is then tied to the only point where a dose calculation can be carried out simply from a knowledge of the patient's contour and tabled quantities, such as tissue-air ratios. It may be noted, however, that as a result, in the cases of arc rotation or in cases when the centre of rotation is not at the geometrical centre of the idealized phantom (eccentric set-up), the maximum doses in the calculated dose distributions have values higher than 100, and will no longer always be at the centre of rotation.

The analyses of data are presented in four sections as below:

I. Center of rotation at center of the phantom, 360 degree rotation
II. Center of rotation at center of the phantom, arc rotation
III. Center of rotation not at center of the phantom, 360 degree and arc rotation.

(In addition, dose distributions of a cobalt 60 beam under other geometrical conditions were also calculated, and they are discussed in a further section.)

IV. Comparsion of dose distributions for beams with different sizes of penumbra and at different source-axis distances.

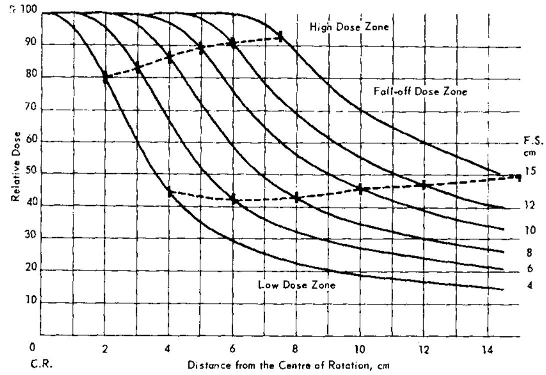

Fig. 2. Dose profiles on a radius of a 30 cm diameter circular phantom with field sizes 4 × 4, 6×6, 8 × 8, 10 × 10, 12×12 and 15 × 15 cm of cobalt 60 360 degree rotation.

I. Center of rotation at center of phantom, 360 degree rotation

The dose distributions of 360 degree rotation with the center of rotation at the center of a circular phantom are simplest and the isodose curves in such cases are a series of circles with a common centre at the centre of rotation. As long as the phantom remains circular, a change in the values of various parameters, such as field size, size of the phantom, etc, will affect only the length of radii of the isodose circles, and, therefore, comparison of different dose distributions may be made by simple comparing of the lengths of radii of different percentage isodose circles. When the phantom is oval in shape, the isodose curves are also oval but with their long axes at right angles to the major axis of the oval phantom. However, the oval pattern is less prominent for the high percentage isodose curves than for the lower ones. The 90 % and 80 % isodose curves, for instance, are generally very nearly circles.

A. *Effect of field size in the plane of rotation.* As has been pointed out by several investigators (11, 12, 13, 26), the length of the field perpendicular to the plane of rotation has little effect on the dose distribution in the plane of rotation. Only the field width in the plane of rotation is important. Our findings also confirmed this conclusion. In practice the dose distribution in the plane of rotation for any square field can be equally used for other field sizes, so long as the field width in the plane of rotation remains the same. The increase of field width in the plane of rotation has two important effects on dose distributions: (1) the area of the continuously irradiated region is increased, and (2) the doses at points outside the continuously irradiated region become higher.

The effect of the field size on dose distributions may be first considered by noting the variation of doses on any radius of a circular phantom with 360 degree rotation.

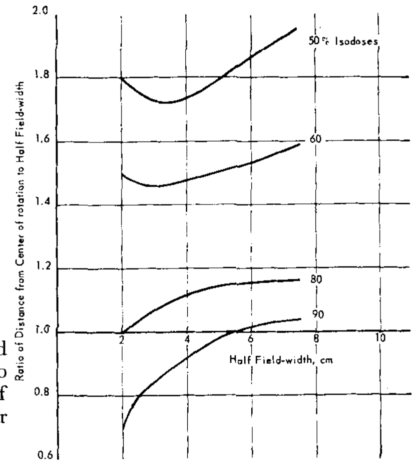

Fig. 3. Ratio of distances between center of rotation and the 90 %, 80 %, 60 % and 50 % isodose curves to corresponding half field, width plotted against the half field width: 360 degree rotation with a 30 cm diameter circular phantom.

The distances from the centre of rotation to various percentage isodose curves for a 30 cm circular phantom with field sizes 4 × 4 cm, 6 × 6 cm, 8 × 8 cm, 10 × 10 cm, 12 × 12 cm and 15 × 15 cm are given in Table 1. A graphical representation of the same data are given in Fig. 2. We further marked off the distances corresponding to half of the field width and the full field width from the center of rotation on each curve in Fig. 2, and joined each series by a dotted line. The upper dotted line shows the variation of dose at the edge of different geometrical widths of the field. The dose at this position is smaller for smaller field widths (14). It is 80 % for a field width of 4 cm, and 93 % for a field width of 15 cm. The lower dotted line in Fig. 2 shows the variation of dose at distances equal to the full length of the field width from the centre, which is in the range of 40 % to 50 % for all field widths. Since the dose fall-off is most predominant in the region between these two dotted lines, we indicated this as the fall-off dose zone and noted that in this zone the change of dose is slower for larger fields.

In order to further investigate the effects of field width, the ratio of the distances from 90 %, 80 %, 60 % and 50 % isodose curves to the centre to the corresponding half-field width were calculated (second part of Table 1) and plotted in Fig. 3. These data show that the ratios for field sizes 4 × 4 cm to 15 × 15 cm vary from 0.70 to 1.03 for the 90 % isodoses, from 1.00 to 1.16 for the 80 %, 1.50 to 1.59 for the 60 %, and 1.80 to 1.95 for the 50 %. In all cases, the 50 % isodose curves are just within the boundary of twice of the half-field width. It is shown by Fig. 3 that whereas the ratio for the 90 % increases faster when the field-width is increased from 4 cm to 10 cm, on the

Table 2

Distances in cm from center of 360 degree rotation to various percentage isodose curves, on both major and minor axes of a 20 × 30 cm oval phantom, with six different field sizes

% Dose	Field sizes in centimeters: 4 × 4 Minor	4 × 4 Major	4 × 4 Diff.	6 × 6 Minor	6 × 6 Major	6 × 6 Diff.	8 × 8 Minor	8 × 8 Major	8 × 8 Diff.
100	0	0	0	0	0	0	0	0	0
90	1.5	1.4	0.1	2.6	2.4	0.2	3.9	3.5	0.4
80	2.1	1.9	0.2	3.3	3.0	0.3	4.6	4.2	0.4
70	2.6	2.3	0.3	4.0	3.6	0.4	5.4	4.9	0.5
60	3.1	2.8	0.3	4.7	4.2	0.5	6.3	5.6	0.7
50	3.8	3.4	0.4	5.6	4.9	0.7	7.4	6.4	1.0
40	4.9	4.0	0.9	7.0	5.8	1.2	9.3	7.7	1.6
30	6.6	5.2	1.4	9.5	7.5	2.0	—	10.3	—
20	—	7.9	—	—	13.0	—			

% Dose	10 × 10 Minor	10 × 10 Major	10 × 10 Diff.	12 × 12 Minor	12 × 12 Major	12 × 12 Diff.	15 × 15 Minor	15 × 15 Major	15 × 15 Diff.
100	0	0	0	0	0	0	0	0	0
90	5.1	4.7	0.4	6.3	5.9	0.4	8.0	7.4	0.6
80	6.0	5.5	0.5	7.2	6.6	0.6	9.0	8.4	0.6
70	6.9	6.2	0.7	8.3	7.5	0.8	—	9.3	—
60	8.0	7.0	1.0	9.6	8.6	1.0	—	10.9	—
50	9.6	8.3	1.3	—	10.1	—	—	13.3.	—
40	—	10.3	—	—	12.7	—			
30	—	14.0	—						

other hand, the ratio for 50 % dose increases faster for field widths larger than 10 cm. From these results we may draw the conclusion that when the field width is over 10 cm, the increase of the area of 100—90 % high doses with the field width becomes more gradual as compared with the increase of area with doses in the range of 90—50 %.

Similar data for a 20 × 30 cm oval phantom are given in Table 2. Irrespective of the field width, the distance from the centre to any isodose curves on the minor axis is always greater than the corresponding distance on the major axis of the phantom. As the field width is increased, the difference between the distances on the two axes also increases, and this difference is more marked for the lower percentage isodose curves.

Table 3

Distance in cm from center of 360 degree rotation to the 90 %, 80 % and 50 % isodose curves in four different sizes of circular phantom with field sizes 6 × 6 cm and 15 × 15 cm

Circular phantom	F.S. 6 × 6 cm			F.S. 15 × 15 cm		
diameter, cm	90 %	80 %	50 %	90 %	80 %	50 %
10	2.4	3.1	—	—	—	—
20	2.5	3.2	5.2	—	—	—
30	2.5	3.2	5.2	7.8	8.7	—
40	2.5	3.2	5.2	7.8	8.8	16.3
Max. diff.	0.1	0.1	0	0	0.1	—

If we compare the results for a 20 × 30 cm oval phantom with those for a 30 cm diameter circular phantom, it is seen that for a given field width, the distance of the same percentage isodose curve from the centre on the minor axis of the oval phantom is always greater than that for the circular phantom, whereas the corresponding distance on the major axis of the oval phantom is always smaller. The effects of the changes in shape and size of the phantom is further dsicussed in the following section.

B. *Effect of the shape and size of phantoms.* There have been some references to the effects of the shape and size of the phantom on the dose distribution pattern of moving beam in several papers (2, 19). Some have reported that the size of phantom has little effect on the dose distributions, but without any indication as to the magnitude of the effect. BRAESTRUP & MOONEY (1959), however, have shown that the cobalt 60 isodose distribution curves for a 32 × 46 cm elliptical phantom can be applied to other sizes of phantom, varying from each other by a fixed radial increment in all directions, such as 28 × 42 cm, 24 × 38 cm, 20 × 34 cm and 16 × 30 cm.

In the present study, dose distributions were calculated for eight different phantoms: 10, 20, 30, and 40 cm diameter circular phantoms, and 10 × 15 cm, 15 × 20, 20 × 30 and 25 × 40 cm oval phantoms. The distances from the centre of rotation to the 90 %, 80 % and 50 % isodose curves for field sizes 6 × 6 cm and 15 × 15 cm with 360 degree rotation for the shapes and sizes of phantoms mentioned above are given in Tables 3 and 4. It may be seen from Table 3 that irrespective of the field size, the change in the distance of the 90 % and 80 % isodose curves to the centre does not exceed 1 mm when the diameter of the circular phantom is increased from 10 to 40 cm.

Table 4

Distances in cm from center of 360 degree rotation to the 90 %, 80 % and 50 % isodose curves, on both major and minor axes in four different sizes of oval phantom, with field sizes 6 × 6 cm and 15 × 15 cm

Oval phantom cm	90 %		80 %		50 %	
	Minor	Major	Minor	Major	Minor	Major
Field size 6 × 6 cm						
10 × 15	2.5	2.4	3.2	3.1	—	5.0
15 × 20	2.6	2.5	3.2	3.1	5.3	5.0
20 × 30	2.6	2.4	3.3	3.0	5.6	4.9
25 × 40	2.7	2.4	3.4	3.0	5.9	4.7
Max. diff.	0.2	0.1	0.2	0.1	0.6	0.3
Field size 15 × 15 cm						
15 × 20	—	—	—	—	—	—
20 × 30	8.0	7.4	9.0	8.4	—	13.3
25 × 40	8.4	7.3	9.6	8.3	—	13.0
Max. diff.	0.4	0.1	0.6	0.1	—	0.3

In the cases of oval phantoms, changes in the size of the phantom have only slightly more marked effects for larger field sizes. The data in Table 4 show that, while for field size 6 × 6 cm the maximum difference between the distances of 90 % or 80 % isodoses to the centre for different phantoms is 2 mm on both the minor and the major axes, so is for field size 15 × 15 cm the difference 4 mm between the distances of the 90 % isodoses on the minor axis and 6 mm of the 80 % isodoses. The difference between distances of 90 % or 80 % isodoses to the centre on the major axis is in all cases only 1 mm though the difference between the distances of the 50 % isodoses are somewhat larger. As the phantom size increases, the differences between the distances for all percentage isodose curves on the minor and major axes also increases.

Based on these results, a composite dose distribution chart for any particular field size can be drawn, which would be applicable within a range of different sizes of both circular and oval phantoms. In Fig. 4, an example is given of such a composite dose distribution chart for a field size 6 × 6 cm. In practice this composite chart can be used for all fields with a width 6 cm in the plane of rotation and for 10 to 40 cm diameter circular phantoms and 10×15 cm to 25 × 40 cm oval phantoms, provided that the centre of rotation is at the geometrical centre of the phantom. Although the isodose curves in the composite

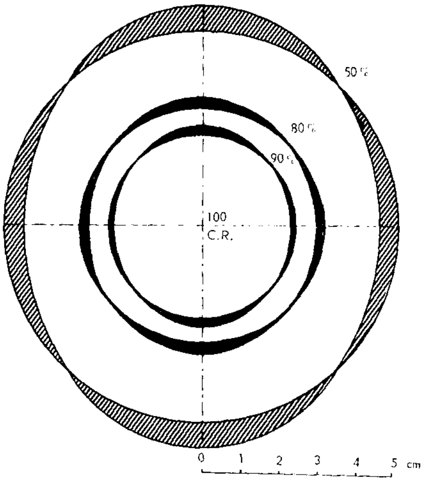

Fig. 4. Composite cobalt 60 360 degree rotation dose distribution plan for a field width 6 cm in the plane of rotation (applicable to circular phantoms 10 to 40 cm in diameter and to oval phantoms 10 × 15 cm to 25 × 40 cm in size).

chart are not thin lines, especially the 50 % isodose curves (see Fig. 4), this limited uncertainty of the exact position of isodose curves need not hinder its use in treatment planning. In fact, in the region of greatest interest, i.e. near the target, this composite chart is accurate to within 6 mm for all phantom sizes studied.

II. Center of rotation at center of phantom, arc rotation

The comparison of the effects of different parameters on the dose distribution patterns is more complicated in arc rotation than in 360 degree rotation, mainly because of the introduction of a new variable, i.e. the arc dimensions. Dose distributions for field sizes 4 × 4 cm, 6 × 6 cm, 8 × 8 cm, 10 × 10 cm, 12 × 12 cm, and 15 × 15 cm with 300, 240, 180, 120 degrees arc rotation were calculated. No attempt is made to reproduce all the data here, since they will appear in an atlas of radiation dose distributions (1). A few selected examples are presented here for the purpose of illustrating some of the effects of certain parameters on the dose distributions. However, instead of dealing separately with effects of individual parameters, the following sections will discuss in more general terms the changes in the characteristics of dose distributions of arc rotation, with special reference to the magnitude and the position of the maximum dose, the dose profiles on the arc bisecting line, and the shape of isodose curves.

A. *Magnitude and position of maximum dose.* The most distinct feature of dose distributions in arc rotation, irrespective of the shape of the phantom and the

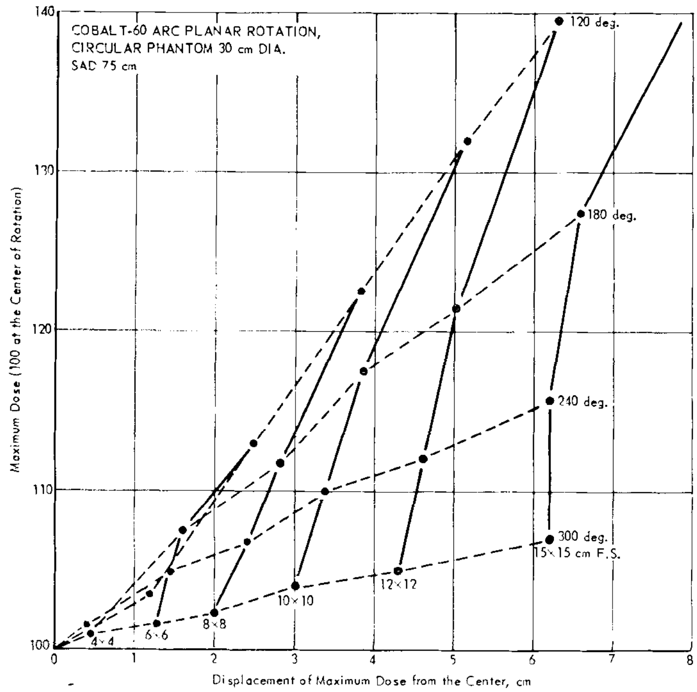

Fig. 5. Maximum doses and their displacements from center of rotation of a 30 cm diameter circular phantom for 300, 240, 180 and 120 degrees of rotation with field sizes 4 × 4, 6 × 6, 8 × 8, 10 × 10, 12 × 12 and 15 × 15 cm.

field size, is the shift of the maximum dose away from the center of rotation. This is in contrast to 360 degree rotation where the maximum dose is always at the center of rotation, unless the center of rotation is not at the geometrical center of the phantom, or the phantom is very irregular in shape.

In this study, the maximum dose has been calculated always relative to the dose at the center of rotation, which is taken as 100. The effect of changes in the degree of rotation is illustrated by plotting the magnitudes of the relative maximum doses and their displacements from the center of rotation as a function of the field width and the degree of rotation as in Fig. 5, which is for a 30 cm diameter circular phantom. This interesting lattice pattern provides an overall picture of the effects of both the field size and the angle of rotation. Taking a special case, it is seen that for a field width of 12 cm and 120 degree angle of rotation the relative maximum dose is nearly 40 % higher than the dose at the center of rotation and is displaced about 6 cm away from the center. From this graph it is seen that, in general, the magnitude of the relative maxi-

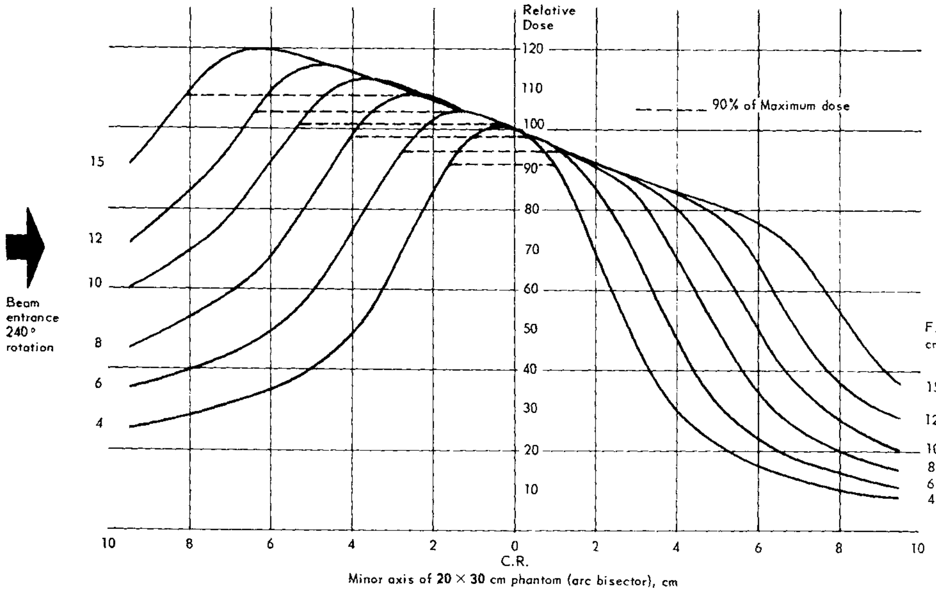

Fig. 6. Dose profiles of 240 degree rotation on the minor axis of a 20 × 30 cm oval phantom with field sizes 4 × 4, 6 × 6, 8 × 8, 10 × 10, 12 × 12 and 15 × 15 cm.

mum dose and its displacement from the center increases with the increase of the field size and with the decrease in the degree of rotation. The maximum dose relative to the dose at the center of rotation is higher and further away from the center of rotation for the same degree of arc when the field width is larger; this is also the case when the field width is constant but the angle of rotation is smaller. It may also be noted in passing that a graph such as Fig. 5 can also be used to estimate the relative maximum dose for other field widths and degrees of rotation within the range given in the graph.

B. *Dose profiles on the arc bisecting line.* The curves in Fig. 6 give one example of dose profiles on the arc bisecting line in arc rotation. The data are for 240 degree rotation on the minor axis of a 20 × 30 cm oval phantom and six field sizes from 4 × 4 cm to 15 × 15 cm. It is seen that while the magnitude of the relative maximum dose increases with larger field widths, as mentioned in the last section, the gradient at the central portion of the dose profiles remains constant irrespective of the field width. It has been found that the dose profiles on the arc bisecting line for other degrees of rotation also show this same characteristics, but the smaller the arc of rotation the steeper the dose gradient in the central portion of the dose profiles, showing that the dose distribution

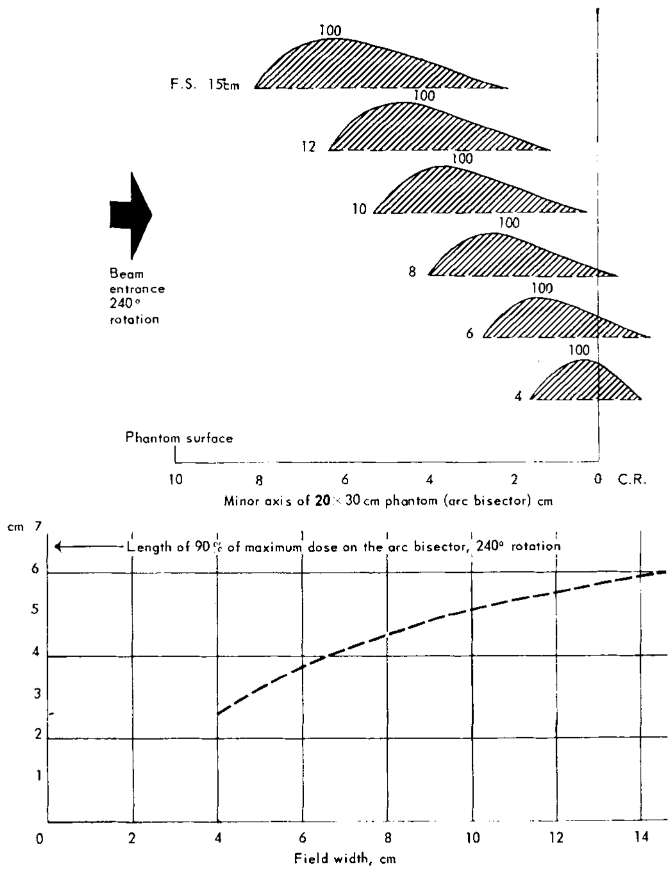

Fig. 7. *Upper diagram.* Dose profiles (90 % of maximum dose portion) of 240 degree rotation on the minor axis of a 20 × 30 cm oval phantom. *Lower diagram.* Length of the 90 % of maximum dose on the minor axis of a 20 × 30 cm oval phantom plotted against the field width.

in that region is less uniform. For this reason small angles of rotation are not advantageous for practical purposes.

If we take the maximum dose on the dose profiles as 100 %, the dotted horizontal lines in Fig. 6 indicate the positions where the dose is 90 % of the maximum dose for different field widths. The length of the dotted line for each field width thus represents the size of the actual 90 % dose region along the minor axis of the phantom. The changes of the length of the 90 % dose region and its position on the minor axis (arc bisecting line) with the field width can be seen more clearly in the upper diagram of Fig. 7, where the

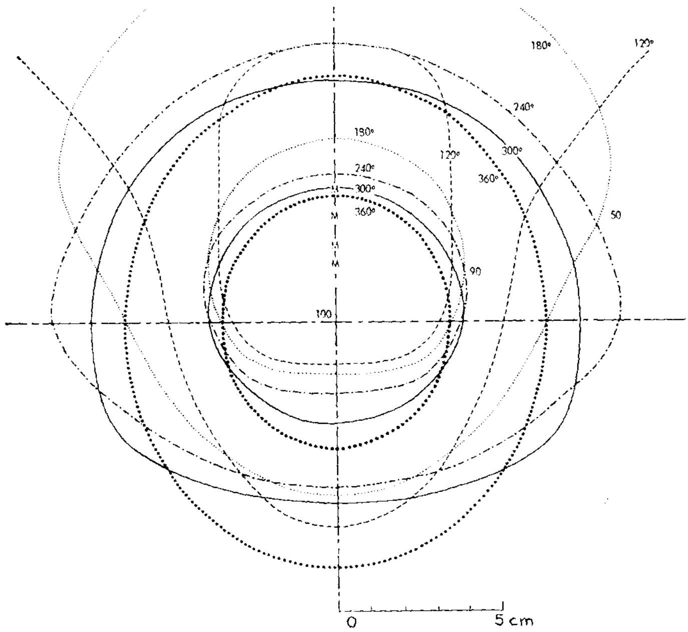

Fig. 8. 90 % and 50 % isodose curves for a field size 8 × 8 cm with 360, 300, 240, 180 and 120 degrees of rotation and with a 20 × 30 cm oval phantom taking the minor axis as the arc bisector. (M indicates the position of the maximum dose.)

respective curves for different field widths are no longer superimposed. The curve above the 90 % dose dotted line for each field width give indication of the variation of the doses between 90 % and 100 % along this section of the arc bisecting line. In the lower diagram of Fig. 7, the length of the dotted line is plotted against the respective field width and we see that this length does not proportionally increase with the increase of the field width. In fact, the increase becomes relatively small when the field width increases above 8 cm.

C. *Shape of isodose curves.* In arc rotation, the shapes of different percentage isodose curves are distinctly different and change with the degree of rotation. The 90 % and 50 % isodose curves are shown in Fig. 8 for 360, 300, 240, 180 and 120 degrees arc rotation, with a field size 8 × 8 cm, by using a 20 × 30 cm oval phantom, taking the minor axis of the phantom as the arc bisecting line.

As seen in the case of the 90 % and 50 % isodose curves, when the degree of rotation becomes less than 360 degrees, the isodose curves are deformed in such a way that the lower portion (the side opposite to the beam entrance surface) of the curve becomes flatter with the decrease in the degree of rotation.

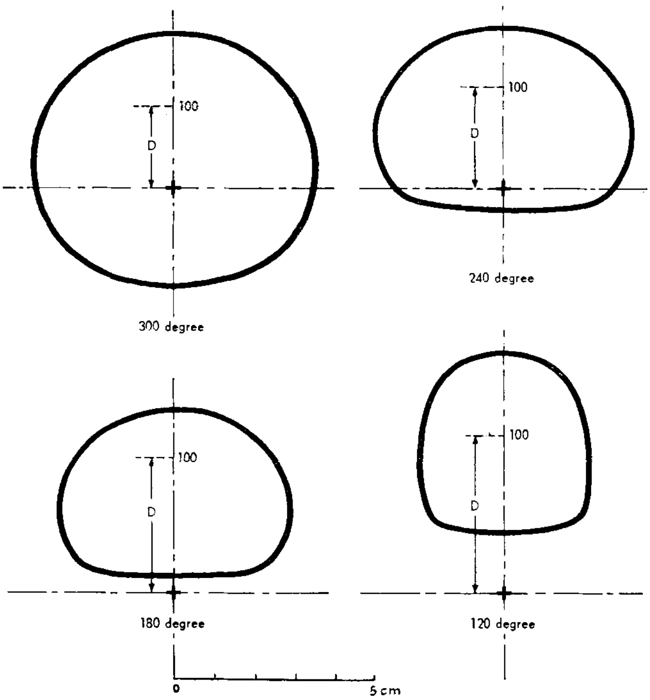

Fig. 9. Position and shape of 90 % isodose curves (maximum dose as 100) for a field size 8 × 8 cm with 300, 240, 180 and 120 degrees of rotation and with a 20 × 30 cm oval phantom taking the minor axis as the arc bisector.

But when the degree of rotation is 180 degrees, or less, the change in the shape of 50 % isodose curves are in the opposite direction, and the lower portion of the curves is convex downwards as shown in Fig. 8.

Taking the maximum dose as 100 %, the positions and shapes of 90 % isodose curves for 300, 240, 180 and 120 degrees of rotation are shown in Fig. 9. It is seen that with the decrease in the angle of rotation, the area enclosed by the 90 % (of maximum dose) isodose curves becomes smaller and more oblong in shape, and moves away from the center of rotation.

III. Center of rotation not at center of phantom (eccentric rotation), 360 degree and arc rotation

Theoretically, the center of rotation may be located anywhere in the phantom. However, discussion in the present paper is limited to cases in which the center of rotation is always located on the arc bisecting line for arc rotation and remains on the major or minor axis when an oval phantom is used.

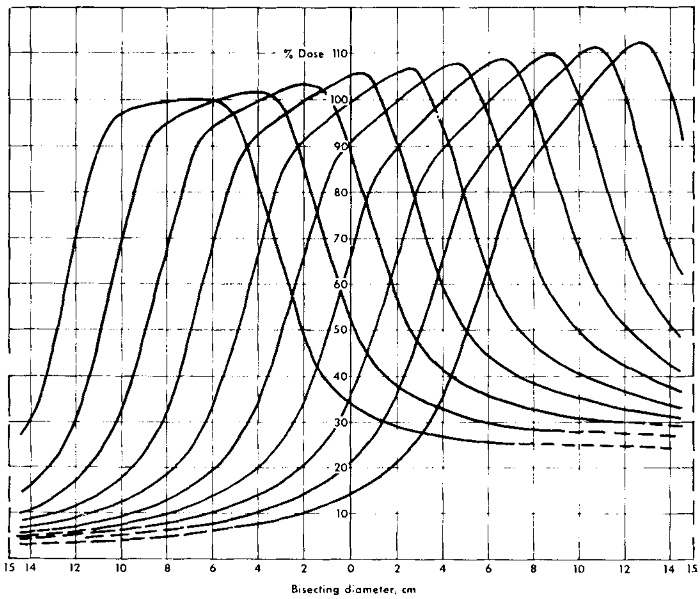

Fig. 10. Dose profiles of 240 degree rotation on the arc bisecting diameter of a 30 cm circular phantom with field size 8 × 8 cm, the center of rotation displaced 2, 4, 6, 8, 10 cm anteriorly and 2, 4, 6, 8 cm posteriorly from the center of the phantom.

A. *Magnitude and position of the maximum dose.* In 360 degree eccentric rotation, the maximum dose is also no longer located at the center of rotation, but moves to the side with less absorbing medium. The relative magnitude of the maximum dose and its position depend on how far the center of radiation is away from the geometrical center of the phantom. However, it has been found in this study that the magnitude is never too great in comparison with the dose at the center of rotation in all cases with 360 degree rotation.

When the angle of rotation is less than 360 degrees, whether the center of rotation on the arc bisecting line is situated between the center of the phantom and the entrance side of the beam, or on the opposite side, is also an important factor affecting the dose distribution.

When the center of rotation is situated on the arc bisecting line between the the center of the phantom and the entrance side of the beam, the relative maximum dose is generally greater than that obtained with the center of rotation at the center of the phantom. The two factors, the arc rotation and the difference of the lengths of absorbing medium in different directions of beam entrance increase the effect on the maximum dose. On the other hand, when the

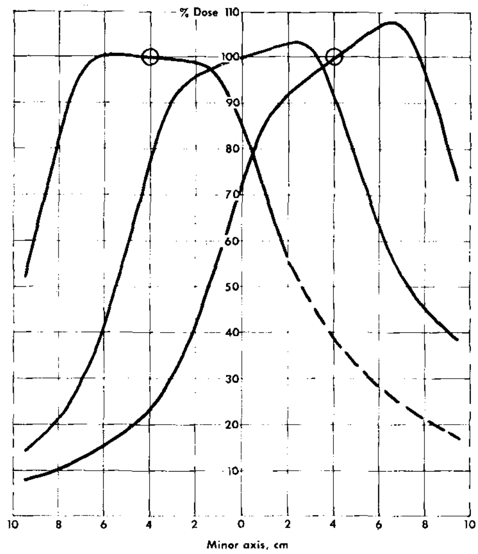

Fig. 11. Dose profiles of 300 degree rotation on the arc bisecting minor axis of a 20 × 30 cm oval phantom with field size 8 × 8 cm, the center of rotation displaced 4 cm anteriorly and posteriorlv from the center of the phantom.

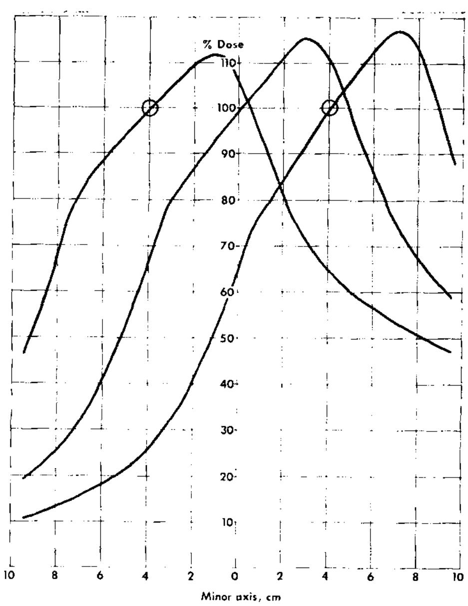

Fig. 12. Dose profiles of 180 degree of rotation on the arc bisecting minor axis of a 20 × 30 cm oval phantom with field size 8 × 8 cm, the center of rotation displaced 4 cm anteriorly and posteriorly from the center of the phantom.

center of rotation is situated on the opposite side of the beam entrance the effect of these two factors on the maximum dose will tend to cancel out each other; therefore, in some cases of this arrangement a uniform dose distribution is obtained around the center of rotation, and the maximum dose is again located at the center of rotation. However, when the rotation is less than 180 degrees, this can not happen, because there is no beam entering from the side with less absorbing medium of the phantom.

B. *Dose profiles on the arc bisecting line.* The dose profiles with a field size 8 × 8 cm under three different irradiating conditions are shown in Figs 10 to 12. The dose profiles on the arc bisecting line are given in Fig. 10 for 240 degree rotation with a 30 cm diameter circular phantom, when the center of rotation is displaced in 2 cm steps on the arc bisecting diameter from the center of the phantom. In Fig. 11, the dose profiles on the arc bisecting line are given for 300 degree rotation with 20 × 30 cm oval phantom when the center of rotation

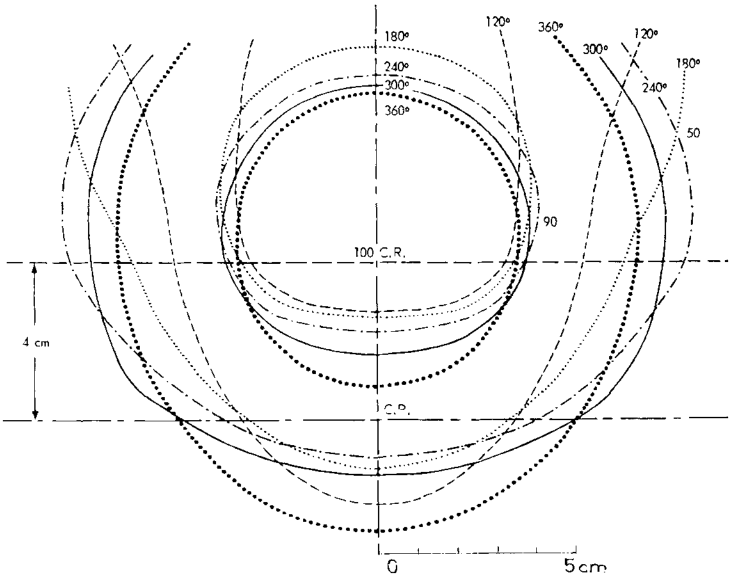

Fig. 13. 90 % and 50 % isodose curves for field size 8 × 8 cm with 360, 300, 240, 180 and 120 degrees of rotation and with center of rotation displaced 4 cm anteriorly from center of phantom on the minor axis of a 20 × 30 cm oval phantom (minor axis as the arc bisector).

is displaced along the minor axis (arc bisecting line) of the phantom 4 cm to either side of the center of phantom. In Fig. 12, the dose profiles under the same conditions as in Fig. 11, but for 180 degree of rotation, are given.

In Fig. 10, when the center of rotation is displaced 8 cm from the center of the phantom on the side opposite to the beam entrance for 240 degree of rotation, and in Fig. 11, when the center of rotation is displaced 4 cm also on the side opposite to the beam entrance for 300 degree of rotation, the central part of the dose profiles in both cases is nearly flat, which shows that the doses are uniform in that region. From these results it can be seen that a treatment arrangement, by placing the center of rotation between the center of the phantom and the side opposite to the beam entrance on the arc bisecting line, can be a very useful technique with arc rotation. In fact the use of this technique has been suggested by Hale (8) several years ago. However, the use of this technique, presently called 'reverse arc technique', cannot possibly have this advantage if the angle of rotation is less than 180 degrees.

C. *Shape of isodose curves.* From the foregoing discussion we have seen that the relative magnitude and the position of the maximum dose, and the dose

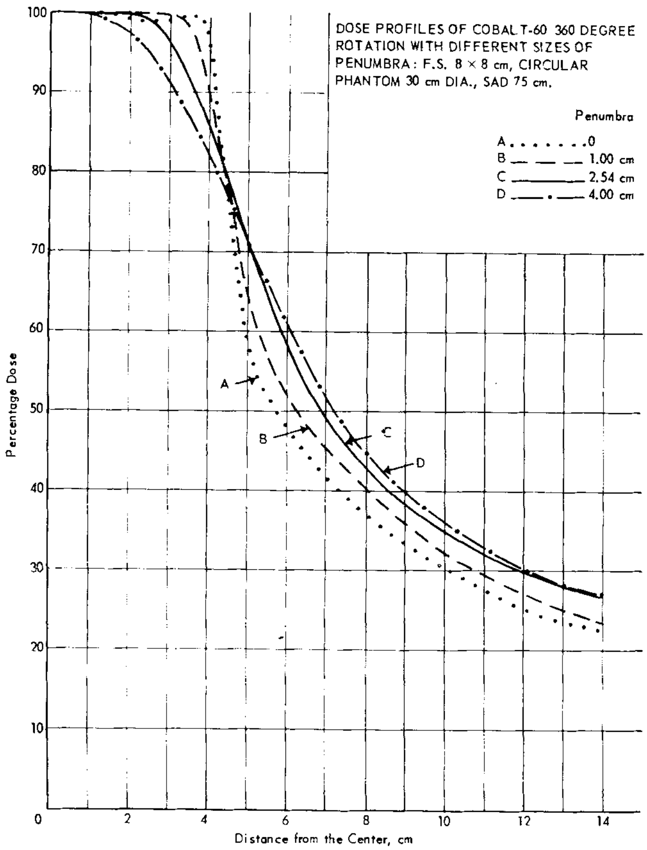

Fig. 14. Dose profiles of 360 degree rotation on a radius of a 30 cm diameter circular phantom for field size 8 × 8 cm of cobalt 60 beams with different size of penumbra at a source axis distance 75 cm.

profiles on the arc bisecting line change both when the degree of rotation is changed and when the center of rotation is displaced. The shapes of the 90 % and 50 % isodose curves with a field size 8 × 8 cm are shown in Fig. 13 for 360, 300, 240, 180 and 120 degree rotation using a 20 × 30 cm oval phantom, with the center of rotation displaced 4 cm away from the center of the phantom on the minor axis towards the entrance side of the beam. If we compare this diagram with Fig. 8, in which case the center of rotation was at the center of the phantom, it is seen that, in spite of a difference of 4 cm between the positions of the center of rotation, the general pattern of isodose curves in these two cases for the various degrees of rotation remains the same.

Table 5

Distances in cm from center of 360 degree rotation to the 90 %, 80 % and 50 % isodose curves in a 30 cm diameter circular phantom with a field size 8 × 8 cm of four different cobalt 60 beams

Type of beam, SAD 75 cm			Distance from center of rotation in cm		
Source diameter cm	SDD cm	Penumbra at 75 cm	90 %	80 %	50 %
Hypothetical point source	—	0	4.2	4.5	5.8
2.0	50	1.00	4.1	4.5	6.3
2.0	33	2.54	3.7	4.5	6.9
2.0	25	4.00	3.2	4.3	7.2

IV. Comparison of dose distributions for beams with different sizes of penumbra and at different source-axis distances

The effects of the size of the penumbra of the beam on dose distributions in planar rotation were studied by comparing three sets of data, all for 360 degree of rotation with a 30 cm diameter circular phantom. The three sets of data used in this study are as follows: (1) dose distributions of four beams with different geometrical sizes of penumbra: i.e. zero (point source), 1.00 cm, 2.54 cm, and 4.00 cm, at SAD 75 cm; (2) dose distributions of three beams, each with approximately the same size of penumbra 1 cm, at SAD 55 cm, 75 cm, and 95 cm; (3) dose distributions of two beams with approximately the same size of penumbra 2.5 cm, at SAD 55 cm and 75 cm. The isodose curves used in the calculation for the beams with zero and 4 cm penumbra at SAD 75 cm are hypothetical.

Using the first set of data, the dose profiles for a field size 8 × 8 cm are shown in Fig. 14. The distances from the center of rotation to the 90 %, 80 % and 50 % isodose curves in these four cases are set out in Table 5. It can be seen that the distance from the center of rotation to the 90 % isodose curve decreases from 4.2 cm to 3.2 cm with the increase in size of penumbra. The distance to the 80 % isodose curve remains constant at 4.5 cm as the penumbra is increased from 0 to 2.54 cm, but decreases to 4.3 mm for the beam with a hypothetical large penumbra of 4 cm. On the other hand, the distance to the 50 % isodose curve increases from 5.8 cm to 7.2 cm when the penumbra of the beam is increased from 0 to 4 cm. If we discount the two hypothetical beams with 0 and 4 cm penumbra, the magnitude of the change in distances from the

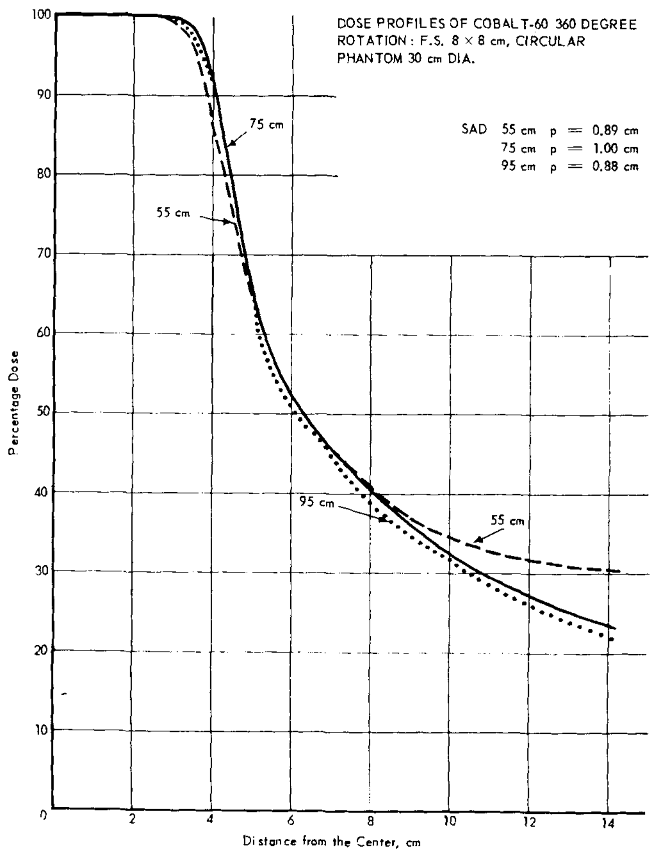

Fig. 15. Dose profiles of 360 degree rotation on a radius of a 30 cm diameter circular phantom for field size 8 × 8 cm of cobalt 60 beams with approximate 1.00 cm penumbra at source axis distances 55 cm, 75 cm and 95 cm.

center of rotation to the 90 %, 80 % and 50 % isodose curves for beams with penumbra between 1 and 2.5 cm is not of great importance in the cases at 75 cm SAD.

In Fig. 15, the dose profiles for beams with penumbra 0.89 cm at SAD 55 cm, 1 cm at SAD 75 cm, and 0.88 cm at SAD 95 cm, are shown. It is seen that the dose profiles of these three beams are nearly the same, except at the region approaching the surface, where the doses with SAD 55 cm are a little higher than others. However, the differences of dose profiles for a beam with penumbra 2.63 cm at SAD 55 cm, and 2.54 cm at SAD 75 cm, are greater, as shown in Fig. 16.

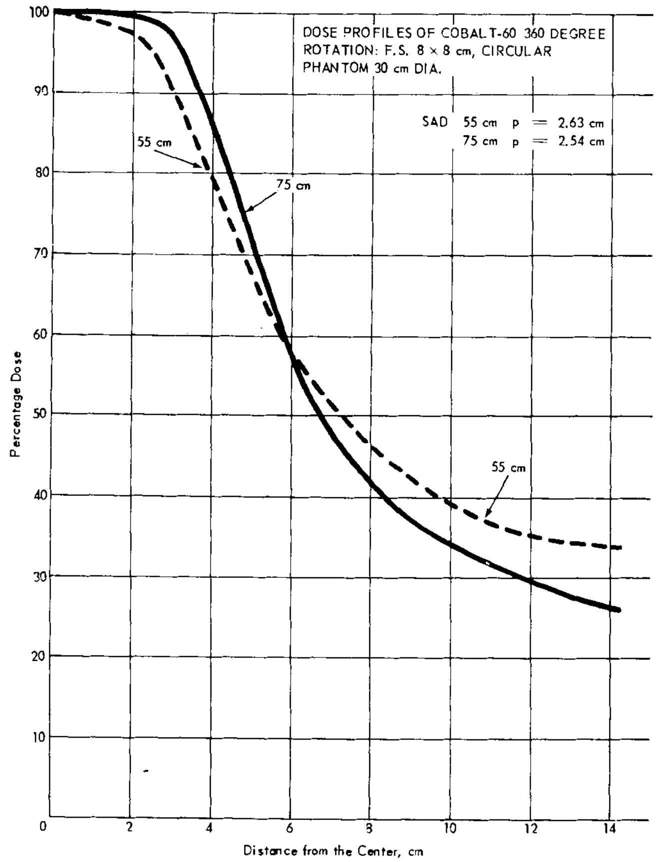

Fig. 16. Dose profiles of 360 degree rotation on a radius of a 30 cm diameter circular phantom for field size 8 × 8 cm of cobalt 60 beams with approximate 2.5 cm penumbra at source axis distances 55 cm and 75 cm.

Additional information is obtained by plotting the distances from the center of rotation to 90 %, 80 % and 50 % isodose curves against the geometrical sizes of penumbra at the center of rotation with different source-axis distances, as shown in Fig. 17. This figure gives us an overall picture of the effect of the size of penumbra at different SAD on the dose distributions. It shows that there are nearly no differences in the dose distribution for beams with the same penumbra at SAD 75 cm and 95 cm. However, though the dose distributions for SAD 55 cm show little difference from those for beams at SAD 75 cm and 95 cm, when the penumbra of the beams are all small, there is a greater difference as the size of the penumbra is increased, say over 2 cm. We may

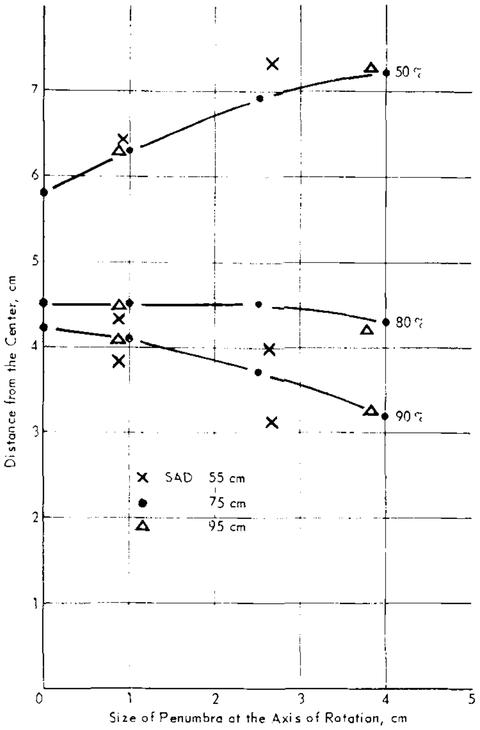

Fig. 17. Distances from the center of rotation of a 30 cm diameter circular phantom to the 90 %, 80 % and 50 % isodose curves with field size 8 × 8 cm plotted against the geometrical size of respective penumbra of cobalt 60 beams at source axis distances 55 cm, 75 cm and 95 cm.

conclude from these results that the beam with a large penumbra is more undesirable in using rotation techniques with the SAD 55 cm than when the SAD is longer. In other words, it is more important for a beam to have a smaller penumbra when a short source-axis distance is used.

Conclusions

The results of the foregoing study of the effects of different parameters on dose distributions in cobalt 60 planar rotation suggest some of the optimum conditions in which the rotation technique may be used to the best advantage in radiotherapy.

In the first place, full advantage is obtained with the rotation technique only when the field width required in the plan of rotation is not more than 10 cm and when the degree of rotation is larger than 180 degrees. This is because with larger field widths, the dose 'fall-off' outside the constantly irradiated region becomes increasingly less steep, and with smaller arcs of rotation, the dose in the target volume becomes less uniform. Nevertheless, in some cases, which necessitate the use of a large field width, the use of the rotation technique may be preferred, because the doses received in certain regions outside the target volume is still somewhat less than when using multiple fields. On the other hand, cases which might be treated by small-arc technique usually can be treated by other methods more adequately, namely by shifting the center of rotation to the center of the target volume, or by using wedge-filtered beams.

The effect on dose distribution due to the size of body contour was studied in considerable detail with eight different shapes and sizes of phantoms. The results obtained not only support previous findings that this effect is not large, but show the magnitude of the displacement of specific isodose curves with changes in the size of body contours. It was found that change in the position of the 80 % isodose curve with a field size 15 × 15 cm is of the magnitude of only 6 mm for different sizes of oval phantoms. This leads to the conclusion that for practical purposes a composite isodose curve drawn somewhat thicker than usual can be used for a large number of different shapes and sizes of body contours.

The results of this study also lead to the conclusion that there is little or no advantage in using a long source-axis distance in rotation with cobalt 60 radiation. There is no appreciable difference in the dose distributions for rotating beams with the same size of geometrical penumbra either at SAD 75 cm or 95 cm. However, a beam with a smaller penumbra is desirable when the rotation is at a SAD 55 cm; when a larger SAD is used, a larger penumbra of the beam is permissible. This is because the dose distributions at the SAD 75 cm are relatively insensitive to penumbra changes between 1 and 2.5 cm, while at 55 cm SAD the dose distributions for beams with different sizes of penumbra differ considerably. For beams with 1 cm penumbra at both 55 cm and 75 cm SAD, the dose distributions are about the same.

From these findings it appears that for any particular cobalt 60 rotating unit, if an atlas of dose distributions, with different field widths, arc of rotation, and positions of the center of rotation in the body, is prepared, then in most routine cases of rotational therapy, it would be possible to estimate the positions of the important isodose curves in the body, such as 90 %, 80 % and 50 % curves, within an acceptable degree of accuracy.

SUMMARY

The effects of different parameters on dose distributions in cobalt 60 planar rotation were studied with the use of a digital computer. The parameters considered were field size, angle of rotation, position of the center in the phantom, shape and size of the phantom, and the penumbra of the beam. On the basis of the results obtained, the conditions under which the rotation technique can be most advantageously used are discussed.

ZUSAMMENFASSUNG

Der Effekt verschiedener Parameter auf die Dosis-Distribution in planärer Kobalt-60-Rotationstherapie wurde mit Hilfe eines digitalen Rechenautomaten studiert. Die verschiedenen Parameter waren: Feldgrösse, Rotationswinkel, Position des Zentrums im Phantom, Form und Grösse des Phantoms und der Penumbra des Strahlenbündels. Auf Grund der erhaltenen Resultate wurden die besten Bedingungen bei der Verwendung der Rotationstechnik untersucht.

RÉSUMÉ

L'effet de divers paramètres sur la distribution de dose en cobalt-thérapie rotatoire plane a été étudié au moyen d'une calculatrice digitale. Les paramètres étudiés sont les dimensions du champ, l'angle de rotation, la position du centre de rotation dans le fantôme, la forme et les dimensions du fantôme et la pénombre du faisceau. Les auteurs examinent, sur la base des résultats obtenus, les conditions les plus avantageuses de l'emploi de la technique rotatoire.

REFERENCES

1. (An) ATLAS OF RADIATION DOSE DISTRIBUTIONS. Vol. III. MOVING FIELD ISODOSE CHARTS. To be publ. by IAEA, Vienna 1966.
2. BRAESTRUP C. B. and MOONEY R. T.: Cobalt isodose patterns for moving beams. *In:* Roentgens, rads and riddles, p. 471. Edit. by FRIEDMAN, BRUCER & ANDERSON. USAE Commission, 1959.
3. CLINICAL DOSIMETRY. ICRU Report 10d. Handbook 87. National Bureau of Standards, Washington 1963.
4. CUNNINGHAM J. R. and WRIGHT D. J.: Scientific exhibit 'moving beam isodose distributions — An improved method of calculation'. Int. Congr. Radiology, Montreal 1962.
5. DRESNER J.: Optimum physical factors for rotation X-ray therapy. Brit. J. Radiol. 27(1954), 340.
6. ELLIS F.: Contraindications to moving-field therapy. *In:* Roentgens, rads and riddles, p. 180. USAE Commission, 1959.
7. — and OLIVER R.: On the specification of moving beam therapy techniques. Brit. J. Radiol. 28 (1955), 226.
8. HALE J.: Private communications.
9. HALLDEN H., RAGNHULT I. and ROOS B.: Computer method for treatment planning in external radiotherapy. Acta radiol. Ther. Phys. Biol. 1(1963), 407.
10. HAYNES R. H. and FROESE G.: Idealized body contours in rotation dosimetry. Acta radiol. 48 (1957), 209.
11. HULTBERG S., DAHL O., THORAEUS R. et coll.: Kilocurie cobalt-60 therapy at the Radiumhemmet, equipment, technique and dose measurement. Acta radiol. (1959) Suppl. No. 179.
12. JACOBSON L. E., KOECK G. P., HILLSINGER W. R. and SCHWARZ M. E.: Co-60 isodose curves for 240° rotation, showing displacement of the center of dose from the center of rotation. Radiology 77(1961), 66.
13. JONES D. E. A.: Private communications.
14. KUTTIG H. and FRISCHBIER H. J.: Zur Herddosisbestimmung und Dosisverteilung bei der Telekobalt-Pendelbestrahlung. Strahlentherapie 112 (1960), 251.

15. MAUDERLI W. and FITZGERALD L. T.: A computor programme for automatic rotational treatment planning. Phys. in Med. Biol. 9 (1964), 102.
16. PEREZ-TAMAYO R. A. and DALTYMPLE G. V.: The use of the digital computer in treatment planning. Int. Congr. Radiology, Montreal 1962.
17. QUIMBY E. H. and COHEN B. S.: Effects of radiation quality, target-axis distance, and field size on dose distribution in rotation therapy. Amer. J. Roentgenol. 78 (1957), 819.
18. RICHTER J. and SCHIRRMEISTER D.: Ein Verfahren zur Berechnung der Dosisverteilungen mit digitalen Rechenautomaten. Strahlentherapie 123(1964), 45.
19. ROBERTS J. E.: Limiting factors of moving-field dosimetry. *In:* Roentgens, rads and riddles, p. 29. USAE Commission, 1959.
20. SCHIRRMEISTER D. and RICHTER J.: Die Berechnung von Dosisverteilungnen mit digitalen Rechenautomaten bei mehraxialer Pendelbestrahlung. Strahlentherapie 125 (1964), 14.
21. SILER W. and LAUGHLIN J. S.: A computer method for radiation treatment planning. Communications Assoc. Computing Machinery 5 (1962), 407.
22. — RITTER F. and LAUGHLIN J. S.: Patient simulation in X-ray therapy. Ann. N.Y. Acad. Sci. 115:2 (1964), 1038.
23. THERAPEUTIC DOSE DISTRIBUTIONS WITH HIGH ENERGY RADIATION. IAEA Vienna 1961.
24. TSIEN K. C.: The application of automatic computing machines to radiation treatment planning. Brit. J. Radiol. 28(1955), 432.
25. — A study of basic external radiation treatment techniques with the aid of automatic computing machines. Brit. J. Radiol. 31(1958), 32.
26. WITCOFSKI R. L. and MESCHAN I.: An analysis of isodose patterns obtained with 180 degree rotation of a telecobalt unit, 60 cm source to center of rotation distance. Amer. J. Roentgenol. 85(1961), 919.
27. WOOD R. G.: The computation of dose distributions in cobalt rotational therapy. Brit. J. Radiol. 35(1962), 482.