RADIUM DOSAGE

The Manchester System

COMPILED FROM ARTICLES BY

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PREFACE

THE papers which form the basis of this volume are still in great demand, although the first of them was published as long ago as 1934. It was, therefore, felt desirable to present them in one volume as a complete dosage system covering all phases of mould, intra-cavitary and interstitial gamma-ray therapy.

The volume is divided into two main parts. Part I consists of the clinical aspects of the constituent papers re-written to form a continuous whole. Nothing that is essential to the use of the system has been omitted, but unification has allowed the omission of repetitions, whilst some small additions have been made in the light of clinical experience. More attention has been paid to examples of the application of the various rules and, in view of the aim of the National Radium Commission to standardize their containers, the examples are almost always worked with tubes and needles appearing on the Commission's list. It must be emphasized that the examples are meant to illustrate the use of the rules and tables and do not necessarily represent the most suitable treatment for the part considered. Every effort has been made, however, to keep close to current clinical practice. In Part I no attempt has been made to prove or justify any of the rules or data set forth since this is unnecessary for their clinical application. The purely physical aspects of the work can be found in Part II which consists of the physical sections of the papers presented almost completely in their original form.

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W. J. M.

March 1947.

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CLINICAL ASPECTS

CHAPTER I

GENERAL INTRODUCTION

THE evolution of scientific dosimetry in relation to radium therapy must occur in two stages. The first stage is the physical one concerned with the methods of administering the radiation and the measurement of the dose. The second, dependent on the first, is the therapeutic stage concerned with the determination of the optimum therapeutic dose. With the exception of casual reference to the latter, the following pages deal exclusively with the first stage and attempt to reduce to simple terms the answers provided by the physicist to various problems and to present them in such a form that they can be applied in everyday clinical use—not just in single cases, but over the whole therapeutic field—even by those not mathematically minded.

In general the study of dosage in practical radium therapy raises two main questions :

(1) How much radium will be required ?
(2) How must it be arranged ?

The first question ultimately involves the measurement of the amount of radiation energy delivered throughout, or at a point in, a treated region and this in turn involves the use of a suitable unit of radiation dosage. The second aspect is equally vital and concerns the need for the arrangement of the radio-active sources on applicators or in the tissues in such a way as to produce uniformity of irradiation over the treated area or throughout the treated volume.

The correlation of a method of *dosage measurement* with a *scheme of distribution* giving homogeneity constitutes a system of dosage which will consist of :

(1) A series of Dosage Tables, or graphs, based on the accepted dosage unit ; and
(2) " Distribution Rules " to be used with the graphs or tables.

The Unit of Dosage.—The unit chosen for this work is the Roentgen, and the specific gamma-ray dose rate in air (that is the dose rate at 1 cm. from 1 milligramme of radium filtered by 0·5 mm. of platinum) taken as 8·4 *r* per hour. This is in close agreement with the most up-to-date determinations.

Dosage Tables.—1000 roentgens has been taken as the clinical working unit and a series of tables showing the number of milligramme-hours required to produce 1000 *r* in various situations has been drawn up. (These tables, from which graphs may be drawn for practical use, are given in the Appendix.) In each case, except for line source treatments, the tables are for use with radium filtered by 0·5 mm. of platinum. If other filtrations are used corrections have to be applied.

Using the Tables.—The tables (or the graphs which may be produced from them) are used in the following way :—The dose in thousand roentgens having been decided, the table reading for the area, length, cylinder diameter or volume, under consideration is multiplied by the chosen number of thousand roentgens, this giving the number of milligramme-hours required to produce the desired dose. If the duration of the treatment has been decided the amount of radium required may be found by dividing the number of milligramme-hours by the number of hours intended. If radon is being used the initial number of millicuries is obtained by dividing by the number of millicurie hours per initial millicurie for the time in question. Alternatively if the amount of radium has been decided, the duration of the treatment may be found by the reverse calculation. The tabulated values for zero area or zero length may be used in the calculation of the dose from point sources.

It should be pointed out that, in the preparation of the tables, no cognizance is taken of the fact of scatter from, or absorption by, the tissues and that the whole system has been calculated on an " in-air " basis. From available data it would appear, however, that, for the thicknesses of tissue met with in the application of these methods, this is not likely to introduce any considerable inaccuracy.

Filtration Corrections.—Where all, or some, of the radium used is filtered with other than 0·5 mm. platinum, corrections *to the radium being used* have to be made as outlined below.

Correction Factors.

Platinum.—To find, for radium filtered with *more* than 0·5 mm. of platinum, the equivalent radium at 0·5 mm. of platinum, *subtract* from the radium 2 per cent. for each 0·1 mm. of platinum of the difference from 0·5 mm. If the filter is *less* than 0·5 mm. of platinum *add* the 2 per cent. per 0·1 mm. correction.

Gold.—As platinum.

Lead and Silver.—As half their thickness in platinum.

Monel, Brass, etc.—As one-third their thickness in platinum.

Example.—A 13·33 mg. tube filtered with 1·0 mm. platinum is equivalent to $13{\cdot}33-(2{\cdot}0\times 5)\%=13{\cdot}33\times 90\%=12{\cdot}0$ mg. at 0·5 mm. of platinum filtration.

The line source tables are given for filtrations of 0·5 and 1·0 mm. of platinum because the correction given above does not apply with accuracy to this case where oblique filtration may be considerable. Should the radium tube used have neither of the above filtrations, the 2 per cent. per 0·1 mm. rule should be applied to convert the radium to the nearer of the filtrations for which tables are given.

Excluding radium beam therapy, which is not covered by the dosage systems being described, radium therapy may be divided into two main sections, each of which may be subdivided. The two main divisions are :

(1) Where the radium is mounted on or in applicators or " *Moulds*," and
(2) Where the radium is *Implanted* into the tissues.

The two methods, which will be referred to as " Mould " and " Interstitial " treatments respectively, have many points of similarity, but, having a number of points of vital difference, will be dealt with separately. The question of dosage in cancer of cervix uteri is dealt with as a separate problem.

CHAPTER II

MOULD TREATMENTS

MOULD treatments may be divided into three main classes :—

(1) *Planar*, by which is implied that the radium is mounted on one or more " planes " whose curvature is less than that corresponding to a hemisphere or semi-cylinder. The " Area " tables are used for this type. (See Appendix Table A.)

(2) *Line Source*, where the radium is mounted along the central axis of a tube and for which the " Line Source " tables are used. (See Appendix Table B.)

(3) *Cylinder*, in which the radium is mounted on the surface of a cylinder. The calculations are based on the " Cylinder formula and factors ". (See Appendix Table C.)

In each of these types of treatment the aim is to deliver a certain dose to a *surface*, and distribution rules have been formulated which, if carried out, produce over that surface a remarkably homogeneous radiation field for a wide variation in conditions. As a starting point it was accepted that to demand absolute homogeneity was impracticable and that some variation from point to point over the treated field had to be allowed. It was decided that for a field to be described as homogeneous the variation should not be more than ± 10 per cent. and no generalization was allowed unless this condition was met. Actually the variation resulting from an absolute application of the rules very seldom exceeds ± 5 per cent.—a striking degree of accuracy for clinical work.

Definition applying to each Type of " Mould " Treatment

The thickness of the applicator or the distance separating the radium from the surface at which the dose is assessed (i.e. the treated surface) will be referred to as the " distance ".

RULES FOR PLANAR MOULD TREATMENTS

In this type of treatment, as in all the others, the amount of radium to be used is first determined from the dosage tables (in this case the " Area " tables) for the particular treating distance being used, and then that amount of radium is arranged upon the applicator in one of the following ways, all of which ensure homogeneous irradiation of the treated surface. In all cases the radium-bearing surface should be parallel to the treated surface.

Circles.—Use circles wherever possible. Arrange the radium uniformly round the circumference, employing as many radio-active foci as possible : a circular arrangement may, however, be considered as obtaining if, with a minimum of *six* containers, a space not exceeding the "distance" exists between the active ends of each tube or needle.

(1) A single circle alone is sufficient where the diameter is *less* than *three* times the "distance". The circle whose diameter is 2·83 times the "distance" is "ideal".

(2) Where the diameter is from three to six times the "distance" 5 per cent. of the radium should be placed at the centre.

(3) For large areas use two concentric circles and a centre spot as follows:

(*a*) Put 3 per cent. of the total radium at the centre.

(*b*) Use percentages of radium for the outer circle as indicated in this table:

Diameter divided by "distance"	6	7½	10
Per cent. radium outer circle	80%	75%	70%

(*c*) Distribute the remainder round a circle of half diameter.

(4) For circles at small "distances" the last arrangement may not be practicable and the following can be substituted but is less accurate:

Diameter 6–7 times "distance" = 10 per cent. of total radium at centre.
Diameter 7–9 times "distance" = 20 per cent. of total radium at centre.
The remainder to be distributed round the periphery.

Squares.—Radium should be distributed in a line round the periphery with uniform linear density (i.e. the number of milligrammes per centimetre). An attempt should be made to have active radium along the whole length of any line, but a linear arrangement is considered as obtaining if a space not exceeding the "distance" exists between the active ends of each needle or tube in line.

(1) If the length of the side of the square does not exceed twice the "distance" no further lines are required.

(2) Additional lines should be added, if required, parallel to the side to divide the area into strips of width twice the "distance".

(*a*) For one added line, linear density to be half that of the periphery.

(*b*) For two or more lines, linear density to be two-thirds that of the periphery.

Rectangles.—The tables apply strictly for circles and squares. For rectangles proceed as for squares, adding additional lines parallel to the longer side and make a correction in the direction of increased milligramme-hours as follows :

Ratio of sides of rectangle .	2 : 1	3 : 1	4 : 1
Percentage to be added . .	5%	9%	12%

Irregular Areas.—Distribute radium uniformly round the periphery and either

(*a*) if the irregular area be roughly rectangular, add lines parallel to the longer length to divide the area into strips of width twice the " distance " as for rectangles, or

(*b*) if the area be roughly elliptical, add a centre spot, etc., appropriate to the mean of the two diameters, as for circles.

Curved Areas.—These rules apply strictly to flat areas, the radium area and treated area being equal. For curvatures up to a degree corresponding to a hemisphere or a semi-cylinder all the above rules may be applied with the following provisos :

(1) *Convex Areas.*—If the area being treated is convex the amount of radium to be used should be ascertained from the tables for the *area treated*, but should be spread over the larger, but corresponding, area on the applicator.

(2) *Concave Areas.*—In these cases the area for purposes of dosage calculations is the *area of the applicator* regardless of the area treated. Care should be taken to include the correction for elongation of rectangles. Should the applicator area become small relative to the treated area the arrangement should be discarded and a greater " distance " employed so as to permit the use of a linear source or of a point source.

Single Foci.—A radium container or group of containers should be considered as a single focus (point source) if of small size relative to the " distance ".

Dosage at Other Levels

It is frequently necessary to determine the dose at a plane or planes other than the " treated area " but parallel to it, either to assess the dose being delivered at the base of the tumour (depth dose) or in calculations for " sandwich " applicators.

This dose is obtained in thousand roentgens by dividing the number of milligramme-hours actually used by the table reading at the *new* distance for the area in question. In doing this the fact that, at such other distances, irradiation may not be so homogeneous must be kept in mind.

Double or " Sandwich " Moulds.—It is often possible and highly desirable to " sandwich " a growth between two moulds in such a way that a considerable degree of homogeneity of dosage is obtained through the block of tissue: the fall in intensity with distance from one mould being almost balanced by the rise from the other, as will be seen from Fig. 1. To achieve this an applicator is planned consisting of two moulds parallel to one another and enclosing between them the tumour-bearing tissue. The calculation for this type of mould is more complicated than that for single moulds, but if the example (F) given later is followed and mastered the planning of the sandwich mould should present no real difficulty, whilst the mould is often of great value. Sandwich moulds are especially useful for lesions of the lip, the ear and the floor of the mouth (e.g. see Melville, 1940).

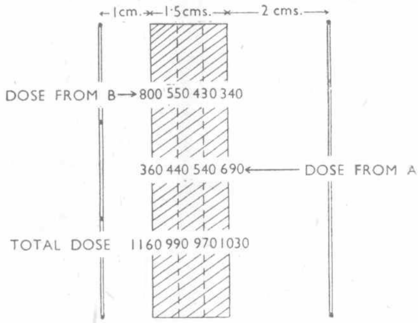

FIG. 1

General Remarks on the Rules

The generalizations made in the "Rules" given above, for curved surfaces, have not been mathematically substantiated for irregular surfaces, but have been proved to hold good for numerous examples of symmetrical form, e.g. sectors of cylinders and of spheres of varied curvatures at varied distances. It is possible, therefore, that they hold good even for a considerable degree of curvature and it was decided to accept them subject to the limitations stated.

Figs. 2 and 3 show diagrams of a number of distributions illustrating the strict application of the "Rules". Whilst these are exact plans of distributions to produce homogeneous intensity at 1 cm., they may equally be considered as plans to scale of distributions to produce homogeneous intensity at 2 cm. if all dimensions are doubled, and similarly they may be used as a basis for 3 cm. distributions with dimensions tripled: and so on.

THE PRACTICAL APPLICATION OF THE PLANAR MOULD RULES

In planning skin applicators or dental moulds, an attempt is made to treat an area at least one or two centimetres wide of apparent tumour, and to use a distance which will give adequate dose at sufficient depth. In practice it is found that "circle" distributions are very much easier to employ, and these are used as frequently as possible. It is quite often possible, particularly with small lesions, to choose as a suitable distance that distance which allows for the use of a single "ideal" circle, namely, where the diameter of the treating circle is 2·83 times the applicator "distance" (e.g. examples A and E). Where this is possible, an unexpected clinical advantage arises, viz. the ability to expose the lesion for accurate placing and for dressings, etc., through a hole in the middle of the applicator.

The rectangular distributions are used rather less frequently, but are found useful for large areas at a short distance, such as applicators for post-operative skin recurrences from breast carcinoma (Example D). It would appear, on physical grounds, that for areas which are large relative to the " distance " the rectangular distributions may be preferable to the circular.

In the treatment of skin lesions such regular arrangements can usually be employed, but within the mouth limitations of space are much greater and here the rules for irregular areas find frequent use for intra-oral moulds (as in Example C).

The rules for curvature allow these general principles to be applied fairly extensively, but they are not applicable with safety to very marked degrees

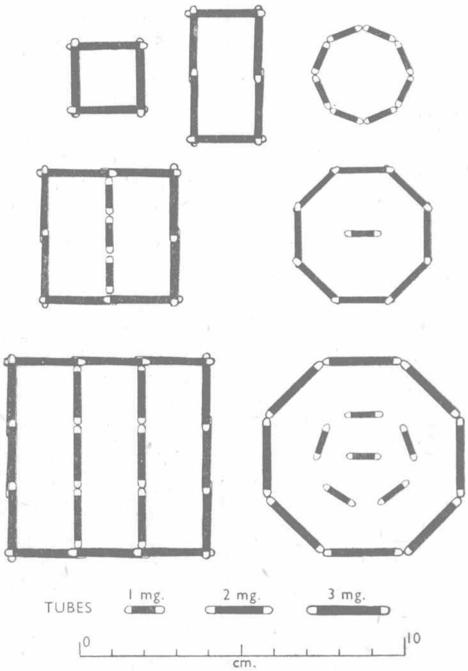

FIG. 2

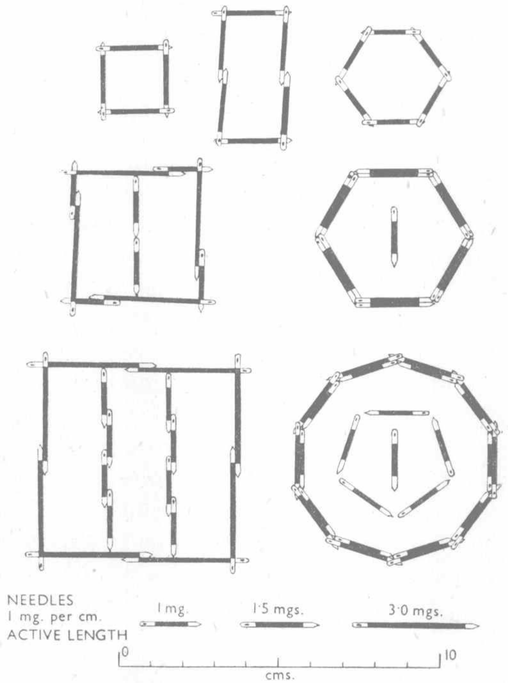

FIG. 3

of curvature such as are found, for example, with applicators enclosing the lip. (This type of case is best calculated on the basis of the sandwich applicator (Example F).)

SOME EXAMPLES OF THE APPLICATION OF THE SYSTEM

In all the following examples the radium tubes specified are those listed in the National Radium Commission's recent list of standard tubes (Circular 35, 1943) unless otherwise stated. Wherever used the symbol " h " stands for the " distance ". Other abbreviations which will be used are :

A.L. for Active Length.
T.L. for Total Length of a tube or needle.
Ftr. will be used for Filtration or Filter.

(*A*) "Ideal" Circle Mould—Chin

Size of lesion $5\times3\frac{1}{2}$ cm.

Treatment by nidrose applicator. (See Fig. 4A.)

To give 6000 *r* in about eight days (continuous irradiation).

Distribution.

Area to be treated is a *convex* surface, therefore for purposes of calculation measure *area treated*.

Treat an ellipse $7\frac{1}{2}\times6$ cm., i.e. mean diameter $6\frac{3}{4}$ cm.

"Ideal" distance to treat with single ring $=\dfrac{6\cdot75}{2\cdot83}=2\frac{1}{2}$ cm. approx.

Calculation.

Area $=\dfrac{\pi}{4}\times7\cdot5\times6=35\cdot3$ sq. cm.

From Area Table for h=2·5 cm.

Milligramme-hours per 1000 *r*=2027 (for 0·5 mm. Pt.).

Therefore for 6000 *r*, $2027\times6=12{,}162$ mg.-hrs. are required.

This can be achieved in 192 hours with approximately 63 mg. Use seven 10 mg. tubes (A.L.=1 cm. Ftr. 1 mm. Pt.) as a single ring over larger area corresponding to the skin ellipse.

(Distance between active ends of adjacent tubes is less than 2·5 cm.)

Total radium at 0·5 mm. platinum=70·0−10%=63·0 mg.

$$\text{Actual treatment time}=\frac{12{,}162}{63}=\mathbf{193\ hrs.}$$

(*B*) Mould with Centre Spot—Dorsum of Hand

Size of lesion 3·0 cm. diameter.

Treatment by mould at 1 cm. treating distance.

To give 5500 *r* in 8 days (the mould being worn about 12 hours daily).

Calculation.

Treat area 5·0 cm. diameter=19·6 sq. cm.

From Area Table for h=1 cm.

Milligramme-hours per 1000 *r* for 19·6 sq. cm.=634.

For 5500 *r* we require $634\times5\cdot5=3486$ mg.-hrs.

(N.B. at 0·5 mm. Pt. filtration.)

This would be achieved with 36 mg. for approx. 97 hours.

Distribution.

Diameter is 5 times the "distance".

Therefore we require a single circle plus a 5 per cent. centre spot.

Use eight 5 mg. tubes (A.L. 1 cm. Ftr. 1 mm. Pt.) in a circle with one 2·5 mg. tube (A.L. 0·3 cm. Ftr. 1 mm. Pt.) as centre spot. (See Fig. 4B.)

(Distance between active ends=0·96 cm. (i.e. less than h).)

∴ Total radium at 0·5 mm. Pt. Ftr. $=(8\times5+1\times2\cdot5)-10\%=38\cdot25$ mg.

Actual treatment time=3486/38·25=**91 hrs.**