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Practical organization of clinical dosimetry

It is my task in this Review to outline the practical aspects of clinical dosimetry and to indicate where further research or development is needed. I ought to begin by defining « Clinical dosimetry ». This term is the title of Report 10d of the International Commission on Radiological Units and Measurements (ICRU, 1963) and it is interesting to note that, although the report contains a large number of definitions, « clinical dosimetry » itself is not defined! I think, however, we cannot go far wrong in describing « clinical dosimetry » as « dosimetry related specifically to the treatment of patients ». We thus exclude fundamental dosimetry which is concerned with the interaction of radiation with matter in general terms, including the definition and realization of dosage units, the determination of the properties of radiation sources and the calibration of standard and sub-standard measuring instruments.

This type of information may be needed for many other applications besides the treatment of patients, for example in radiobiology, in radiation protection and in studying the effects of radiation on the properties of solids. The physicist working in a hospital will certainly be concerned to some extent with fundamental dosimetry and probably also with applications other than clinical dosimetry, but all these fields are excluded from my present terms of reference.

I want to go one step further. The determination of dose distributions in a homogeneous phantom, such as a tank of water, is usually considered part of clinical dosimetry since

these distributions, in the form of isodose charts and tables of central axis depth dose values, are required mainly for assessing the dose in patients. This part of the hospital physicist's duties is important and is likely to occupy a substantial proportion of his time. Nevertheless I propose to devote only a few introductory words to this topic. Let us suppose that a new source of radiation, such as an X-ray machine or a cobalt unit, is installed in a hospital. The physicist must take the necessary steps to ensure that all physical data required for treatment are made available as soon as possible. This means that some measurements will certainly have to be made on the machine itself, including the radiation dose-rate in air and in water. In other cases, however, the physicist will have to decide whether the data must be measured locally or can safely be purchased from outside. The most important data in this category are single field isodose charts in water or an equivalent medium.

For medium energy X-rays (the conventional 200-250 kV range) a comprehensive collection of single-field isodose charts for 50 cm focusskin distance is now available (Tsien and Cohen, 1962) but of course these charts are not applicable to *every* condition. For high energy radiation, including cobalt and caesium gamma-rays, thousands of isodose charts have been measured in the past decade. Details of over 2600 of these charts are given in an international guide issued by the IAEA in 1962. An atlas containing representative charts will soon be published (Webster and Tsien, 1965).

The « Diagrams and Data Scheme » of the British Hospital Physicists' Association has now been taken over by the International Atomic Energy Agency and copies of many isodose charts may be purchased through the scheme. It is, however, the responsibility of the individual hospital physicist to make sure that isodose charts obtained from outside are applicable to the particular radiation sources and conditions to be used in his own hospital.

The physicist's responsibility for obtaining full data relevant to teletherapy units applies also to sealed sources used for interstitial, intracavitary and surface therapy. Fortunately nowadays an accurate measurement of the strength of each source is usually made by the manufacturer, and isodose curves for radium needles and tubes are also widely available. It is still advisable, however, to check the distribution of activity within the source by autoradiography, and to check all radium sources for leakage at 6 or 12 monthly intervals. The strength of shortlived seeds, including radon, ^{198}Au and $^{90}\gamma$, should also be measured before use, at least on a sampling

basis to check the values quoted by the supplier, and the same applies to isotopes used in wire form (^{182}Ta and ^{192}Ir) which may be cut to length before use.

Up to this point all measurements are made by the physicist and his assistants, and no collaboration is required from his medical colleagues, except the essential passive co-operation which the radiotherapist provides in allowing the physicist a reasonable period of time (usually several weeks) to carry out the measurements before the machine is put into clinical service. The only organization required is that the physicist must first persuade the radiotherapist to control his natural desire to treat patients the day after a new machine is installed and then he must get on with the measurement programme as quickly as possible. I suggest that, in today's discussions, we assume that all the preliminary physical measurements have been made and we consider only what happens when the treatment of patients is planned and carried out. From now on, I shall refer to « clinical dosimetry » in this more limited sense of what happens *after* the radiation machine has been brought into clinical service.

The physicist, having enjoyed full sovereignty over the X-ray or cobalt unit for several weeks, must now accept the fact that he is only one of a team. Clinical dosimetry is essentially a team effort and, as such, requires a certain amount of organization. The individualist will find, however, that there is still plenty of scope for research and development.

The 4 stages of clinical dosimetry

It is convenient to divide clinical dosimetry into 4 stages, which may be called topography, planning, treatment and reconsideration. These stages can be distinguished both in teletherapy and in therapy with small discrete sources, although the emphasis is somewhat different in the two fields.

In Table I the 4 stages are summarized, with particular reference to teletherapy. In each stage the requirements are set out as « minimum » and « optimum ». Neither term is strictly correct. I know of many parts of the world where patients are irradiated without even the minimum procedures stated on the table, but I think we should avoid calling such irradiation « radiotherapy ». On the other hand, the « optimum » procedures are somewhat idealistic. I doubt if any radiotherapy centre exists in which the full optimum procedure is carried through for every patient. Nevertheless it shows what we should aim at. The final column indicates the people who are likely to be involved at each stage. No signi-

TABLE I

ORGANIZATION OF CLINICAL DOSIMETRY

STAGE	*PROCEDURE*	*REQUIREMENTS*		*PERSONNEL*
		Minimum	*Optimum*	
1	*Topography*			
	Body contour Tumour size Tumour location	Direct measurement of body outline Palpation of tumour Radiography of tumour	Transverse tomography	Radiotherapist Radiologist
2	*Planning*			
	a) Prescription	Minimum tumour dose Maximum normal tissue	Description of required dose distribution	Radiotherapist
	b) Dose planning - « tank of water »	Dose at a few points (single plan)	Complete isodose chart plus integral dose (alternative plans)	Physicist Radiotherapist
	c) Dose planning - actual patient	None	Full correction or compensation for: body size body composition field obliquity	Physicist Radiotherapist
	d) Preparation for treatment	Mark skin of patient	Make individual cast and /or seting-up jigs Make compensating filter Check radiographically	Mould room technician Radiotherapist
3	*Treatment*	Check all apparatus settings Check setting-up of patient Immobilize patient Observe patient	Independent check by second person Monitor beam direction (e.g. fluoroscopy) Monitor patient movement (e.g. photocell) *In vivo* measurement of dose during treatment	Radiotherapy technician (radiographer) Radiotherapist Physicist
4	*Reconsideration*	None	Change treatment plan according to: I) results of *in vivo* measurements II) changes in patient's topography	Physicist Radiotherapist

ficance should be attached to the order in which they appear, nor is any judgement implied as to the allocation of legal or other responsibility. We see that at least 4 people, or groups of people, are involved in clinical dosimetry at one stage or another.

In *Stage 1* the extent of the tumour is determined and also its position in relation to the surface and deeper anatomy of the patient. Usually this is done by ordinary radiography, combined with direct measurement of the patient's outline using calipers, a lead strip or one of the many gadgets described in the literature (e.g. Friedman, Hine and Dresner, 1955; Pfalzner and Inch, 1956). There is little doubt, however, that a more accurate method is transverse tomography, which in any case is required if detailed corrections for body composition are to be made. I will return to this question later. Meanwhile it may be noted that *any* method in Stage 1 will introduce errors if the patient is measured in one position (e.g. standing up) and treated in another (e.g. lying down). Furthermore, during a course of treatment both the size of the tumour and the outline of the patient may change, so it is advisable to remeasure at least once.

Stage 2 is the planning stage, in which we decide on paper what we want to do. Treatment planning may be considered in 4 parts. First of all the radiotherapist prescribes the dose required. This prescription may comprise simply the dose in the middle of the tumour, or perhaps the minimum tumour dose, together with a maximum figure for the dose to skin or other normal tissue. Recently, however, some thought has been given to a more precise definition of « tumour dose » (Ellis and Oliver, 1961; Spiers and Meredith, 1962) and the future radiotherapist may prescribe the *median* tumour dose, the *average* tumour dose or even the *modal* tumous dose, together with permitted plus and minus deviations from this value. What is really required is for the radiotherapist to describe in some detail the dose distribution he requires, or at least the distribution which he is prepared to accept.

Treatment planning now passes to the physicist and his assistants, working of course in close collaboration with the radiotherapist. The minimum requirement is the dose at a few points in the patient, assuming the patient is equivalent to a large tank of water with flat sides. The optimum solution comprises a series of alternative treatment plans, each one fully worked out for the actual dimensions of the patient and corrected for the heterogeneous structure of the body and

for oblique incidence of the radiation beams. The detailed procedures which lead to a full or partial solution of this problem are too complex to show in Table I, but we shall return to this question by means of a separate table in a few minutes.

The last part of the planning stage is the preparation for actual treatment. This may be simply a question of putting a few ink marks on the patient's skin; on the other hand a good deal of work may be undertaken for each patient, including the production of a cast or jacket of Plaster of Paris or of plastic. For therapy with X-rays in the conventional deep therapy range, blocks of wax are usually mounted on the cast and these serve as entrance ports for the cones or applicators defining the beams. When high energy radiation is used, however, windows are usually cut in the cast at the entrance positions of the beams and it may then be necessary to use removable jigs as aids to setting up the fields (Cohen, Burns and Sear, 1960). At this stage, also, a compensating filter may be constructed to compensate for the obliquity of the beams.

Stage 3 in clinical dosimetry is the irradiation itself. We are concerned here only with those aspects of the treatment which may affect the value of the dose delivered to the tumour and to other tissues. It is difficult to generalize because the organization of the treatment, and the personnel involved, differ widely from country to country and from institution to institution. In some clinics the radiotherapist personally sets up the patient at each treatment session and supervises the irradiation. In other centres the treatment, after the first session, is carried out almost entirely by trained radiotherapy technicians (or therapy radiographers, as they are called in the U.K.) with only occasional supervision or intervention by the doctor. Elsewhere a system somewhere between these extremes is practised. Much depends on the quality and degree of training of the girls who operate the machines and the trust which the radiotherapist is prepared to place in them.

Whether the treatment is carried out by the doctor or by a technician, certain rules have to be observed. Errors in dosage are easily introduced by faulty settings of the controls of the machine (including inserting a wedge filter the wrong way round), by faulty setting-up procedures, by the use of inaccurate or badly adjusted beam directing devices and by movement of the patient during treatment. All these points need attention. Every stage in the procedure needs to be checked, preferably by a second person. Beam directing devices, in particular, require periodic checking since with

constant use they can easily become loose or distorted. It is most important to train the junior staff to look out for faults or mal-adjustments in the auxiliary equipment and to report these faults immediately.

In addition to the well-established methods of setting-up and beam directing such as the back pointer, a number of devices have recently been described which help in setting-up and immobilizing the patient (Kahr, 1963; Pfalzner, 1963; Perez-Tamayo and Seibert, 1963). Roswit *et al* (1960) described a simple photocell system for monitoring and restricting patient movement during treatment. Further accessories, designed particularly to shape the beam and protect sensitive organs, were described by Proimos (1960, 1961, 1963).

Continuous monitoring of the beam direction in rotation therapy, by means of fluoroscopy and closed-circuit television, has been tried in Sweden but I am not aware of any publication on this subject.

Finally, it is possible to make direct measurements of dose during the treatment. Small Sievert condenser chambers may be placed on the patient's skin, or within a natural body cavity such as the oesophagus or bladder. The precautions needed to ensure the accurate functioning of these chambers have been described in detail by Sköldborn (1959). The routine use of condenser chambers during treatment is highly developed in Swedish radiotherapy centres but elsewhere has been rather neglected. Measurements on the skin, at the port of entry, are essentially a check on the exposure calculations and on the settings of the equipment controls but give little information as to the dose within the patient's body. If the chambers are placed in the oesophagus, on the other hand, a direct reading is obtained of the dose within the body. Great care, is needed, however, in interpreting such measurements in terms of tumour dose. Apart from the physical characteristics of the chambers (e.g. leakage, directional properties, wavelength dependence, temperature dependence) which Sköldborn has shown can be closely controlled, the *position* of each chamber must be accurately known. Furthermore, if the tumour is in the bronchus rather than the oesophagus, the difficult task remains of converting an observed discrepancy (i.e. measured *versus* calculated dose) in one position into a correction at some point or points which may be several centimetres away. This problem occurs with *any* method of correcting for body composition and we shall return to it later.

In spite of these difficulties Dahl and Vikterlöf (1960) have demonstrated the value of intracavitary measurements. Fig. 1 shows a typical set of measurements with 8 chambers

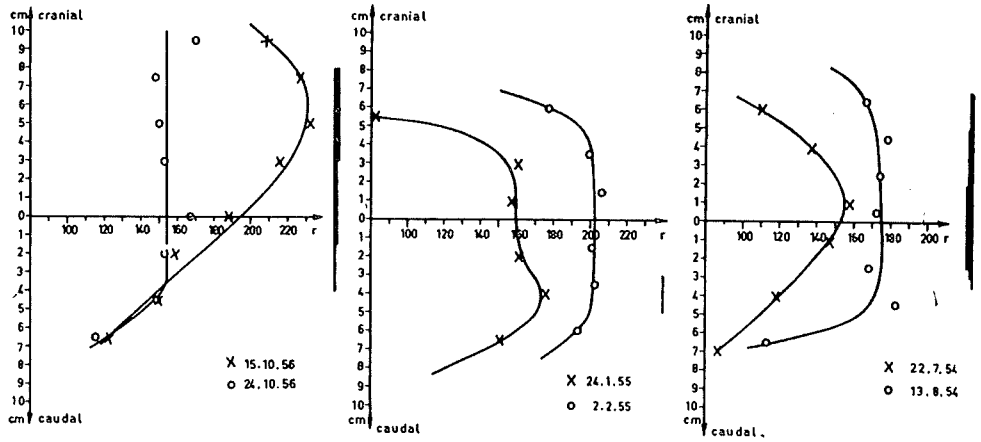


Figure 1 - *Doses measured in the oesophagus before and after the introduction of a compensating filter. (From: Dahl and Vikterlöf,* 1960).

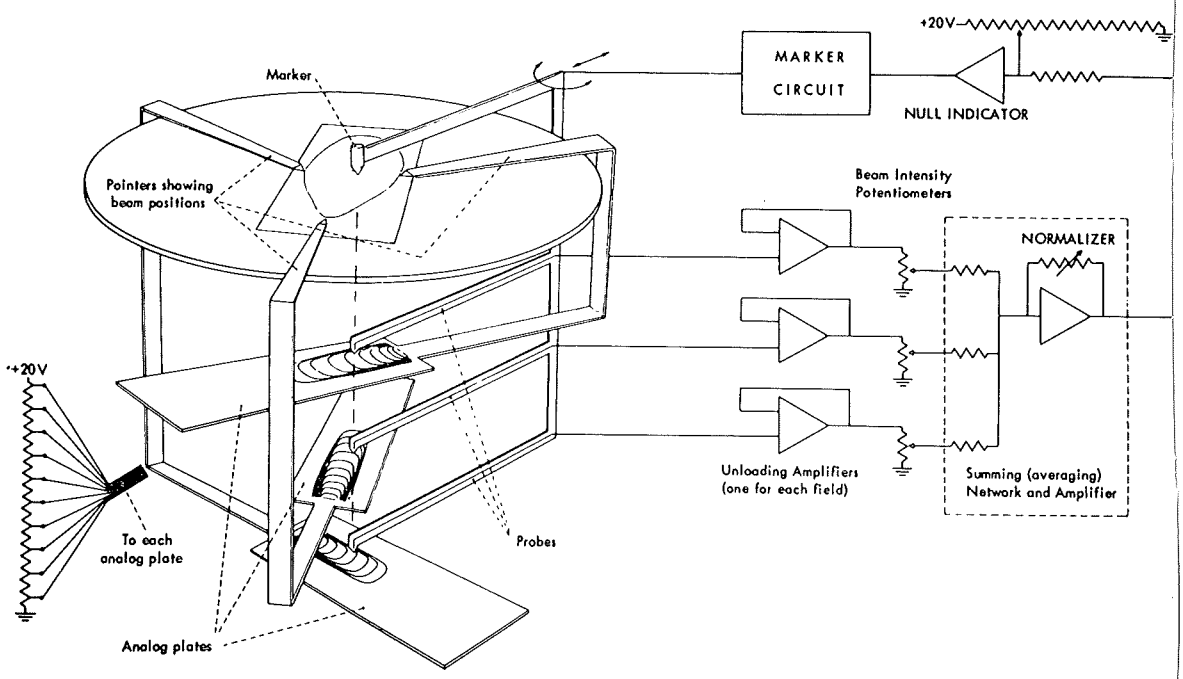


Figure 2 - *Diagrams of analogue multiple-field isodose computer, showing position of analogue plates and of the probes. (From: Howarth and Pick,* 1960).

in the oesophagus. The considerable variation along the length of the oesophagus is due to the variation in the thickness of the chest in the longitudinal direction, and a compensating filter may be constructed to equalize the dose, as the later measurements show.

Roswit and Malsky and co-workers (Malsky *et al*, 1960, 1961; Roswit *et al*, 1961a, 1961b) have developed microdosemeters comprising tiny gold-shielded glass rods which may be introduced not only into natural cavities of the body but even into ordinary tissues. They have positioned these rods in the heart, brain, naso-pharynx, floor of mouth and in several other sites. As in the case of Sievert chambers in the oesophagus, the difficult problem is not the measurement but its interpretation, including the assessment of the precise position of the detector. Recently Roswit and his colleagues have initiated a general survey of *in vivo* dosimetry systems (Roswit *et al*, 1963).

The results of *in vivo* measurements may be used to reassess the treatment and, since teletherapy is usually given in a number of sessions spread over several weeks, modifications may be made before the completion of the treatment. This is what I have called *Stage 4* of clinical dosimetry. It may also be necessary to modify the treatment because of changes in the patient's tomography. There are, of course, other methods, besides *in vivo* measurement, of assessing the dose for individual patients, such as the measurement of transit dose, and we shall discuss these methods in a few moments. However, these alternative techniques may be carried out *before* the first treatment session and the appropriate modifications made right from the beginning. That is why I have placed these correction techniques under Stage 2 (« Planning ») rather than Stage 4. But in practice this is a matter of individual preference and organization within the radiotherapy department: there is no reason why transit dose or similar measurements should not be postponed until after the treatment has begun and the application of the results of such measurements would then be called «Reconsideration» rather than « Planning ».

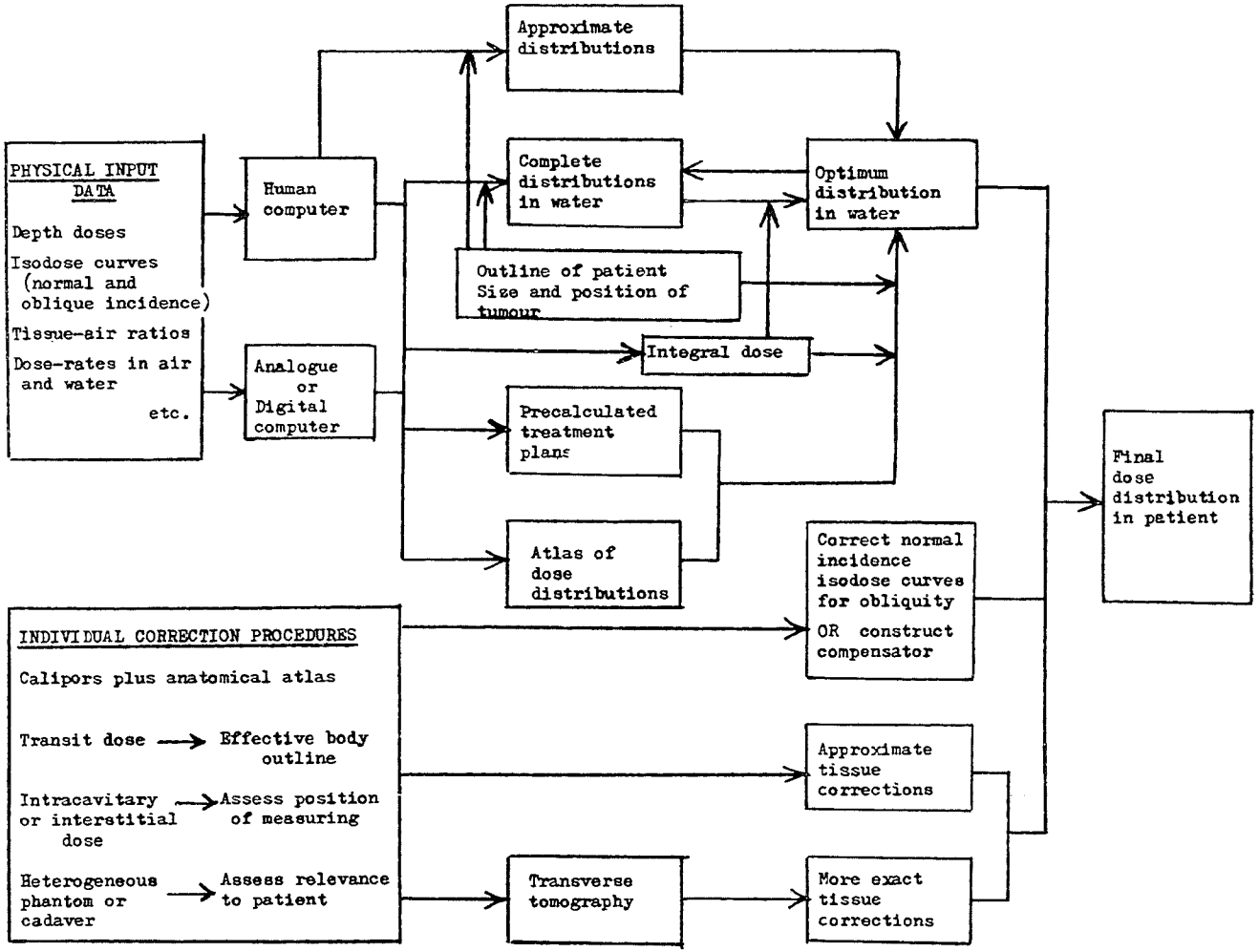
Treatment planning in teletherapy

Table II is an attempt to show the organization of the physics of treatment planning - i.e. Stages 2(a) and 2(c) plus Stage 4 - in block form. This is, of course, an idealized scheme which includes all possibilities, and the path following in an actual radiotherapy department will be a simplified version

of this diagram. Basically, the problem is to combine three types of data, so as to produce the final dose distribution in the patient. « Final », in this context means 2 things: the distribution has been deliberately chosen as being optimal for the patient concerned, and furthermore, the distribution refers to the actual, individual patient and not simply to a tank of water which may, or may not, simulate the patient. The 3 items of data are, firstly, the physical data such as isodose curves, secondly, the basic data referring to the patient, i.e. the body outline and the position of the tumour, and finally, more sophisticated data concerning the patient's anatomy from which individual corrections can be made.

Until quite recently the computer used to process the data would be, without question, a human being. Some of the problems of organizing a human computer service were discussed by Lindsay (1952). In 1955, however, Tsien described the use of a digital computer in multiple-field treatment planning (Tsien, 1955, 1958). The original method, based on polar co-ordinates, was suitable only for beams converging at a single point and required a considerable amount of preparatory work to convert the input data into digital form. The method was copied and further developed by Sterling *et al* (1961, 1963a) but in a later paper these authors (Sterling *et al*, 1963b) switched to a cartesian co-ordinate system which is a little less accurate (since an interpolation formula has to be used) but is more versatile and entails much less preparatory work. Furthermore, direct print-out of the results in the correct spatial arrangement is possible. A very similar system was developed independently by Halldén, Ragnhult and Roos (1963) and, in its latest form, this method requires less than 5 minutes to produce a complete multiple-field isodose chart.

For multiple-field treatment planning the major advantage of the electronic computer is its ability to reduce, almost to zero, the waiting time between planning and realizing a dose distribution. Thus it becomes possible to produce, for each patient, a number of alternative plans from which the most suitable one can be chosen. This would be virtually impossible if only a human computer were available and the final choice had to be based on a comparison of complete isodose charts. An alternative method, which has long been used in conventional X-ray therapy, is to calculate the dose at a limited number of discrete points, perhaps 10 or 12 but usually less, and to make the final choice on the basis of these points. Recently we have developed a new system whereby a rapid evaluation of treatment plans can be made without preparing full isodose charts. I will describe this method later in this paper. Once the optimum arrangement has been chosen from


Approximate distributions
PHYSICAL INPUT DATA
Depth doses
Isodose curves (normal and oblique incidence)
Tissue-air ratios
Dose-rates in air and water
etc.
Human computer
Complete distributions in water
Optimum distribution in water
Outline of patient Size and position of tumour
Integral dose
Analogue or Digital computer
Precalculated treatment plans
Atlas of dose distributions
Final dose distribution in patient
Correct normal incidence isodose curves for obliquity
OR construct compensator
INDIVIDUAL CORRECTION PROCEDURES
Calipors plus anatomical atlas
Transit dose → Effective body outline
Intracavitary or interstitial dose → Assess position of measuring
Heterogeneous phantom or cadaver → Assess relevance to patient
Approximate tissue corrections
Transverse tomography
More exact tissue corrections

a number of approximate distributions, the full isodose chart can be determined for this arrangement only: that is why, in Table II, a 2-way arrow links the boxes labelled « complete distributions in water » and « optimum distribution in water ».

In the case of moving beam therapy, it is a fairly easy matter to compute the dose at the centre of rotation, especially if the concept of tissue-air ratio is used (Johns *et al.*, 1953, 1956), but the calculation of a complete dose distribution is very complicated and time-consuming. In this connection reference may be made particularly to the work of Kligerman, Rosen and Quimby (1954), Castro, Soifer and Quimby (1955), Braestrup and Mooney (1955), Jones, Gregory and Birchall (1956), Gregory (1957) and van de Geijn (1963b). In general, these methods involve the summation of doses derived from a large number of stationary fields spaced at equal intervals of, say, 20°. Obviously such methods are well suited to calculation by a computer and the computer techniques already mentioned in connection with multiple-field additions have all been used also for moving-beam therapy. Indeed, in the absence of a computer, the quickest method of determining a complete isodose chart in rotation therapy is direct measurement in a phantom. (Dahl, Thoraeus and Vikterlöf, 1956; Dahl and Vikterlöf, 1960; Fowler and Farmer, 1957; Morrison, Bean and Kewley, 1957; Witcofski and Meschan, 1961). For a full bibliography of calculation and measurement methods in rotation therapy reference may be made to Tsien, Cunningham and Wright (1965).

Table II indicates that the computer, whether human or machine, can approach the problem of treatment planning in 3 distinct ways. Firstly, complete distributions can be produced, tailored to the requirements of a particular patient. Secondly, a set of treatment plans can be pre-calculated. The essential feature of a pre-calculated plan is that the dose distribution is either completely independent of the contours of individual patients or, at worst, dependent on one or two variables only which are readily assessed for each patient. Thirdly, treatment plans can be calculated and collected together to form an atlas. An atlas differs from a random collection in so far as the charts in an atlas are classified in an agreed way and arranged according to the system adopted. An atlas also differs from a set of pre-calculated charts in that the distributions included in the atlas are not necessarily independent of the body contour. We shall return to the use of pre-calculated charts and atlases towards the end of this review. We should, however, notice at this stage that whatever system is used, the characteristics of the individual patient and his tumour must be taken into account in selecting the

optimum distribution. The system determines only the point at which this information is introduced (see Table II).

Before leaving the question of computers, it is worth pointing out that the digital machine is not the only type which is able to calculate dose distributions for multiple and moving beams. It is also possible to use an *analogue computer*, in which the dose at each point of each field is represented by some physical quantity such as electrical potential. It is then a matter of placing the analogue plates, representing the various fields, in the correct spatial arrangement and adding the potentials at each point. The best example of this type of computer is the machine of Howarth and Pick (1961) which is shown diagrammatically in Fig. 2. The analogue plates are insulating plates on which conducting lines representing isodose curves are deposited. These lines are connected to a low voltage source *via* a potential divider. The space between the lines is rendered conducting by a spraying with graphite. An improved method of preparing the analogue plates has been described by Skaggs and Savic (1963).

Although analogue dosimetry by means of photographic films has been tried in connection with multiple radium sources (Loevinger and Spira, 1957), so far this method has not met with any success for field addition in teletherapy.

The advantage of the analogue computer, as compared with the digital machine is its much lower price. Against this, however, it is only fair to point out that the analogue machine takes longer to produce a dose distribution (at least in relation to the most recent digital methods) and the digital machine, once acquired, can be used for many purposes besides treatment planning.

Individual correction procedures

Up to this point we have assumed that the patient is equivalent to a tank of water. The only properties of the individual which have been taken into account are his external outline and the position of the tumour. We shall now consider briefly the correction procedures which may be applied to allow for the actual size, shape and composition of the individual patient. In Table II the information derived by these procedures is used to modify the optimum water-phantom treatment plan so as to produce the final distribution in the patient. Strictly speaking, these corrections should be fed into the system earlier, since a distribution which is optimum in a water phantom is not necessarily optimum in a real patient. This, however, is probably a counsel of perfection since none of

these correction procedures has yet reached the stage when it can be applied easily and rapidly to alternative plans.

The most important corrections are for field obliquity and for lung tissue. With high energy radiation it is desirable to preserve the build-up effect beneath the skin, so closed applicators, wax seatings and bolus filling are not normally used. An oblique field must be either corrected for or compensated. One possibility is to measure or calculate single field isodose curves for a series of angles of incidence. This assumes, however, that the body surface is reasonably flat. ICRU Report No. 10d (1963) describes 3 acceptable methods of making this correction: the effective SSD method, which corrects essentially by inverse-square law along each ray; the effective attenuation coefficient method (Murison and Hughes, 1957), in which the effective absorption along each ray is taken into account, e.g. 4.5% per cm for cobalt gamma-rays; finally, the isodose shift method (Dutreix and Dutreix, 1962; Garrett and Jones, 1962) which is an empirical method but nevertheless satisfactory. Recently a new method, based on tissue-air ratios, has been described by Du Sault and Legaré (1963).

The alternative to correction is compensation, i.e. to replace the « missing » tissue by a similar wedge-shaped block of material which is placed sufficiently far back in the beam to avoid irradiating the surface with secondary electrons which would destroy the build-up effect (Fig. 3). Obviously the *absorption* of radiation in a given mass of absorber is the same whatever its position in the beam, and only the contribution of scattered radiation from the « missing » tissue to points deeper in the body is lacking. Fortunately, for high energy radiation this scatter contribution is relatively small and can be allowed for by making the thickness or density of the compensating filter a few per cent less than would otherwise be needed. The accuracy of the method is illustrated in Fig. 4.

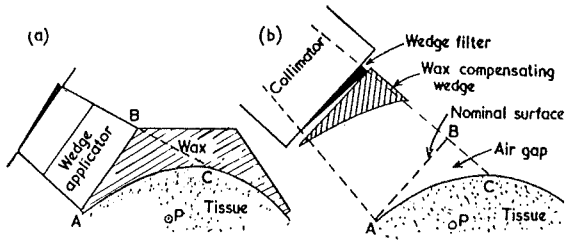


Figure 3 - *Method of setting-up an oblique (wedge) field,* (a) *with deep X-rays, using a wax jig;* (b) *with cobalt gamma rays, using a compensating filter. (From: Cohen, Burns and Sear,* 1960b).

If the source-skin distance is large, so that the beam divergence is small, the easiest way to construct a compensating filter is to mould a block of wax, of density 0.95 gm/cc, directly on the skin of the patient (Cohen, Burns and Sear, 1960b). Usually, however, it is necessary to take account of beam divergence and a metal compensator is constructed as described by Ellis, Hall and Oliver (1959) (Fig. 5). (See also: Hall and Oliver, 1961; van de Geijn, 1963a).

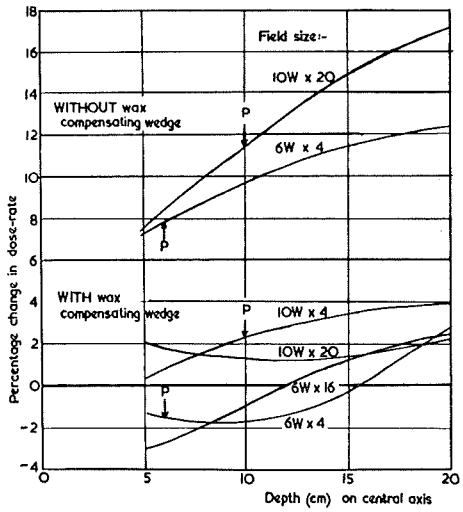


Figure 4 - *Dose at various depths on the central axis with and without a compensating filter (relative to dose expected from normal incidence isodose curves). (From: Cohen, Burns and Sear,* 1960b).

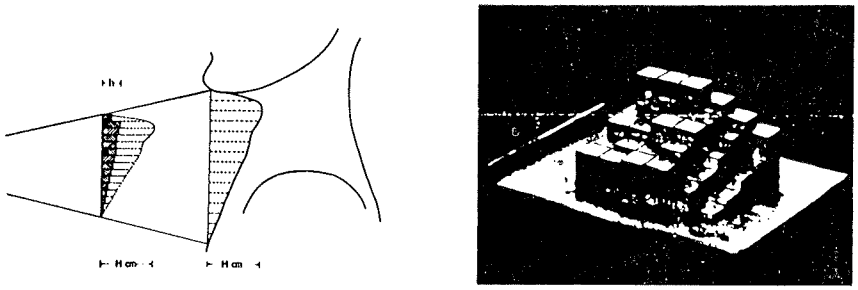


Figure 5 - *Metal compensating filter, with allowance for beam divergence. (From: Ellis, Hall and Oliver,* 1959).

Correction for body composition

The heterogeneous nature of the human body gives rise to many problems in clinical dosimetry. To deal with this subject adequately would require a whole conference to itself. I shall not attempt even a summary, but instead I propose to pick out one or two important features, particularly from the point of view of the practical correction procedures.

When X-rays of low and medium energy are used for therapy, the dose distribution pattern measured in water is seriously distorted by both bone and lung tissue (Spiers, 1946). It is, indeed, now widely appreciated that conventional X-rays should be avoided for therapy in body regions in which an appreciable mass of bone occurs. If we confine our attention to high energy radiation, however (including cobalt gamma-rays), only lung presents any serious problem. The low density of lung tissue (0.25-0.4 gm/cc) reduces both the attenuation of radiation and the production of scattered radiation. In general, the attenuation effect is more important so that the dose in a lung or oesophageal tumour is higher than would be expected from water phantom measurements. The increase may be 20 per cent, or even more, depending on the energy of the radiation and the precise geometrical relationship between the tumour and the lung tissue traversed by the radiation beam. For a given tumour, the correction depends on the path and direction of each beam, and one way of simplifying the correction problem is to avoid directing beams in such a way that the tissue traversed includes a triangular or irregularly-shaped block of lung. This point is illustrated in Fig. 6, which is taken from Stewart (1962).

The simplest approach to the lung problem is to apply a correction factor which depends only on the radiation energy (Jacobson and Knauer, 1956a and b; Massey, 1962). For example, when a beam of cobalt gamma-rays traverses 5 to 8 cm of lung tissue, the dose at subsequent points is increased by 20%. Somewhat more complex corrections, which take into account the position of the tumour in relation to the lung tissue, were proposed by Dutreix, Dutreix and Tubiana (1959, 1960).

A more individual approach is to measure the dose transmitted through the body and hence assess the difference between the actual absorption and that expected in a unit-density medium. If the measurements are made with the same broad beam of radiation as is used for the treatment, the effect of scattered radiation must be avoided and so a small transit chamber must be enclosed in a shield, as shown in Fig. 7 (O'Connor, 1956) or alternatively a large flat chamber is placed

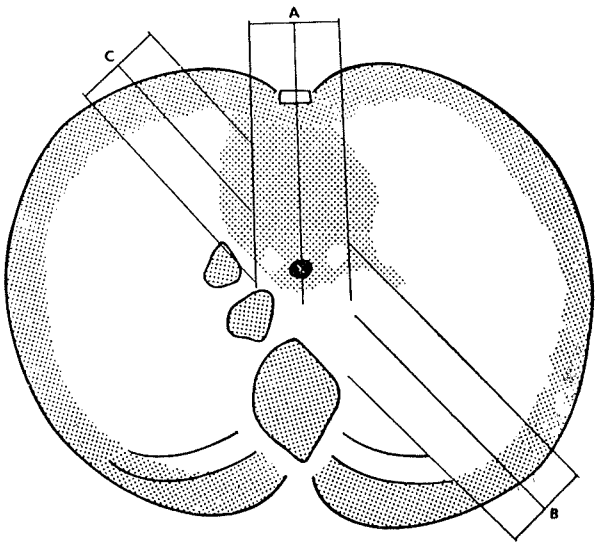


Figure 6 - *Arrangement of beams so as to avoid irregularly shaped lung tissue.* (*From*: *Stewart*, 1962).

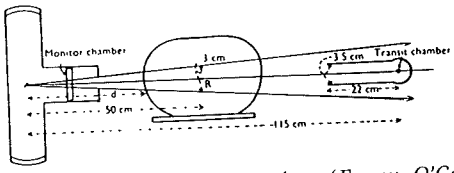


Figure 7 - *Shielded transit chamber.* (*From*: *O'Connor*, 1956).

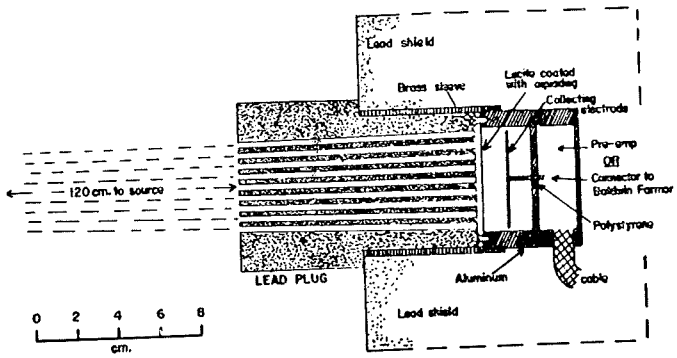


Figure 8 - *Focussed transit chamber.* (*From*: *Fedoruk and Johns*, 1957).

behind a collimating device (Fig. 8) which accepts only the primary radiation (Fedoruk and Johns, 1957). This instrument was designed to be housed in the counterweight of a cobalt rotating unit. A transmission chamber which accepts the whole of a broad beam of radiation, even if the scatter component is excluded, gives the average transmission over the whole cross-section of the beam. More detailed information for individual rays is obtained by means of measurements with a collimated scintillation counter used in conjunction with a weak cobalt source. This method is being developed by Holodny *et al.* (1964) and enables an effective contour to be plotted as shown in Fig. 9. A transmission chamber divided into 7 sections has recently been described by Nordberg (1963).

Instead of a transmission chamber it is also possible to use an *exit* chamber, i.e. one which is placed on the exit surface of the patient (Woodley, Bronstein and Laughlin, 1960), but in this case the relationship between the exit dose and the transit dose must first be found by careful calibration.

Now the measurement of either an exit or a transit dose does not in itself provide sufficient information for correcting the tumour dose. The effective thickness merely tells us that the absorption curve in water (curve A in Fig. 10) is not applicable. In the absence of any other information we can only assume that the whole path of the beam absorbs uniformly but to a less extent than water. This gives curve B, which is a better correction than none at all. In reality, however, the curve is discontinuous, depending on the thicknesses traversed of soft tissue, lung and again soft tissue. This is shown in curve C. If the lung section is not symmetrically placed, the curve will depend on the direction in which the beam travels. Obviously some knowledge of the cross-sectional anatomy of the patient is needed if the results of transit or similar measurements are to be correctly interpreted. Even an approximate estimate, based on anatomical atlases, is better than nothing, but for a comprehensive and accurate cross-section of an individual patient it is necessary to use transverse tomography.

The methods we have discussed so far can be used, on a routine basis, for correcting the tumour dose when the thorax is irradiated, but a good deal of additional work is involved if the complete distribution throughout the body section, and not simply the dose at one or two points, is to be corrected. Although this problem is theoretically soluble it is doubtful if the effort required is justified unless a computer is available. A promising alternative approach is to use a *tissue compensating filter* as proposed by Hall and Oliver (1962).

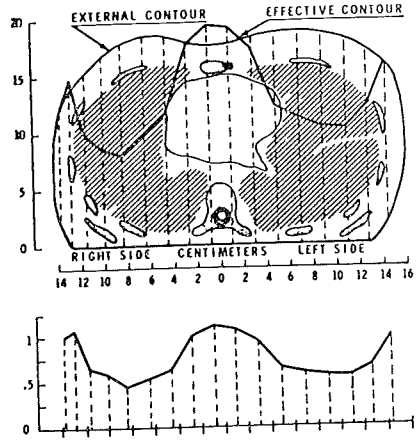


Figure 9 - *Effective body outline as measured by scintillation counter.* (*From*: *Holodny* et al, 1964).

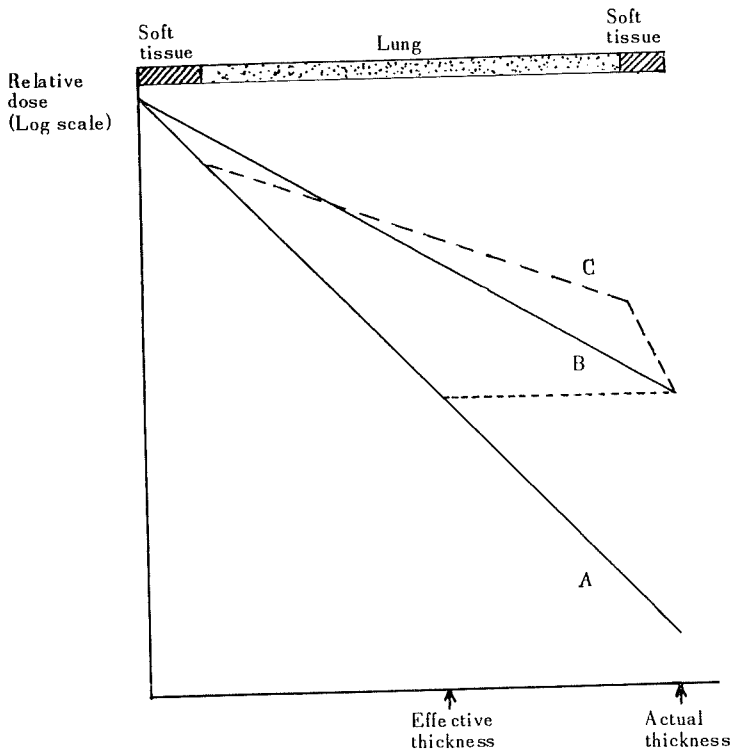


Figure 10 - *Depth dose curves in the thorax*:
Curve A: *assuming unit density throughout*
Curve B: *assuming less than unit density throughout, as indicated by transit dose measurement*
Curve C: *with knowledge of thickness of lung traversed.*

TABLE III

SOURCES OF ERROR IN CLINICAL DOSIMETRY

(Based on Section IX of ICRU Report 10d)

1) THE PATIENT

a) Estimation of contour

b) Localization of tumour

c) Changes in (a) and (b):
during the course of treatment
according to position of the patient
through movement of patient during exposure

d) Difference in dimensions of irradiated region and the phantom in which the doses were measured

e) Composition of the body

2) SETTING-UP FOR TREATMENT

a) Marking of skin

b) Fitting of jacket, plaster cast, etc.

c) Adjustment and use of beam directing and other auxiliary devices

d) Insertion of wedge filter

e) Adjustment of treatment position of the patient

f) Setting of SSD

g) Type and arrangement of bolus

3) EXPOSURE

a) Output variations

b) Calculation errors

c) Human errors in setting the meters on the radiation machine and delivering the exposure.

An alternative method of determining the dose distribution throughout the body section is to measure the distribution in an anatomical phantom, i.e. a phantom designed to resemble an average human being in size and structure (e.g. Cohen, 1955; Dahl and Wikterlöf, 1960). Recently a complete phantom system which is intended for routine computation of treatment plans on an analogue basis has been devised by Alderson *et al.* (1962) and is available commercially (Alderson Rando System, 1961) (Fig. 11). The main difficulty in such a system is to translate the phantom measurements into a dose distribution in an individual patient. An attempt is being made to simplify this transfer by constructing a number of phantoms of different sizes so that the measurements can be made in a phantom of approximately the correct size.

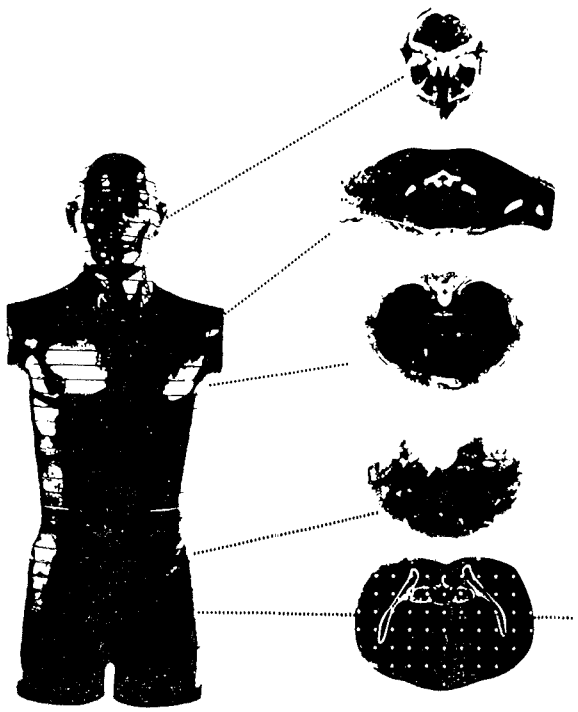


Figure 11 - *Alderson Rando phantom system.*

Summary of sources of error

To conclude the discussion on clinical dosimetry in teletherapy, which began with Tables I and II, the possible sources of error are summarized in Table III. A more extensive list,

including the errors involved in calibration of dosemeters, measurement of output and of isodose curves and similar topics excluded from this review, has been given in ICRU Report 10d (1963). I have resisted the temptation to add numerical values to each error, as the extent of the error likely, or even possible, depends on the individual circumstances. Martin, Evans and Anderson (1960), in a somewhat similar table of errors, included estimates of magnitudes, but many of these estimates were apparently based on X-ray sets used for rather superficial irradiation. Such estimates can be quite misleading if applied to high energy machines.

There is no golden path which leads to the elimination of errors in clinical dosimetry. However, certain rules have been found helpful:

1) Use high energy radiation.

2) Organize the clinical dosimetry service, and the actual delivery of the radiation, so that the various procedures are always carried out in the same sequence and each step is checked before the next is begun.

3) Train all staff, particularly junior and auxiliary personnel, to understand the meaning and purpose of each procedure. Errors are more likely if operations are carried out in parrot fashion.

4) Check the accuracy and alignment of auxiliary equipment (e.g. beam directing devices) at regular intervals.

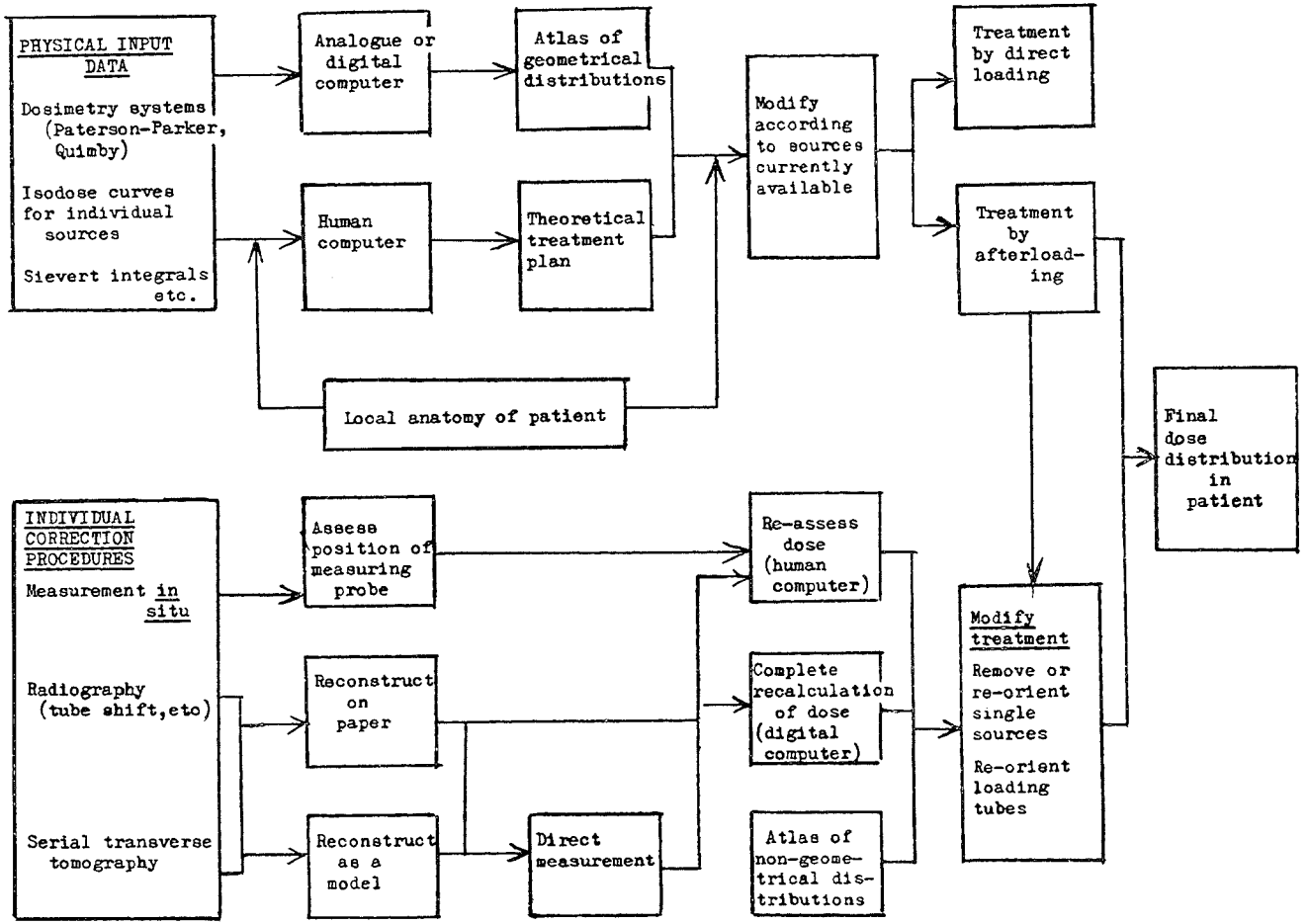
Organization of dosimetry in interstitial and intracavitary therapy

In Table IV the organization of dosimetry in interstitial and intracavitary therapy is shown in block form. Time does not permit us to discuss this in detail and I will therefore confine myself to drawing attention to one or two important features:

1) Firstly, the re-assessment of the dose is perhaps even more important than in teletherapy, and is certainly more widely practised. It is easy enough to plan an implant according to a strict geometrical pattern, but it is not so easy to carry out the plan in a living patient. Dosage control through radiography of the implant is therefore essential (Meredith and Stephenson, 1946; Nuttal and Spiers, 1946; Meredith, 1951; Farr, 1953). A number of methods whereby implants can be reconstructed, either on paper or as a model, have been described (Kligerman *et al.*, 1956; Mussel, 1956; Smith, 1958; Devois *et al.*, 1958; Vaeth and Meurk, 1963). The use of multi-

TABLE IV

TREATMENT PLANNING: INTERSTITIAL AND INTRACAVITARY THERAPY



section transverse tomography for visualizing implants is particularly worth mentioning (Egan and Johnson, 1960; Pierquin and Fayos, 1960; Pierquin, Chassagne and Gasiorowski, 1960).

2) Recently there has been a considerable interest in, and development of, *afterloading techniques*. By afterloading is meant the insertion into the tissues, or into a body cavity, of empty tubes or containers representing the radioactive sources. The actual sources are loaded into the empty tubes later on, under much fore favourable conditions of radiation protection. Afterloading is not only advantageous from the protection point of view, but is also conducive to accuracy since it is easier to insert, or re-insert, inactive containers into the body than active sources (Mowatt and Stevens, 1956; Henschke, 1960; Brasfield and Henschke, 1961; Suit *et al.*, 1961; Walstam, 1962; Pierquin and Chassagne, 1962; Ridings, 1963; Chassagne, Raynal and Pierquin, 1963).

3) Another recent development is the use of *computers* in the dosimetry of small sealed sources. The analogue computer of Kemp (1950) has been used for many years, but digital computers are now being brought into this field, both for the calculation in advance of treatment arrays and for the assessment of implants which have already been inserted into the patient (Shalek and Stovall, 1961; Stovall and Shalek, 1962; Laughlin *et al.*, 1963; Meurk and Adams, 1963).

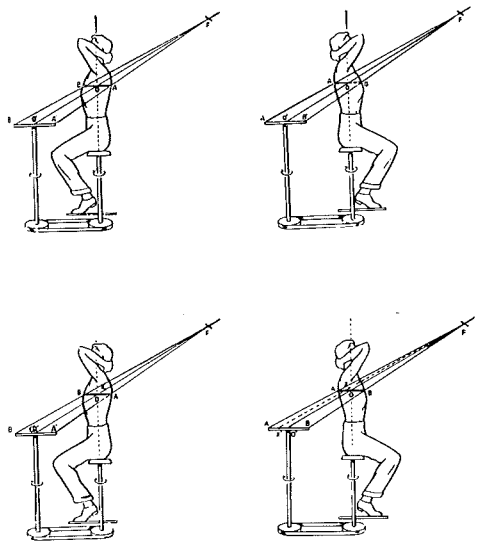
RECAPITULATION

Having completed a general survey of the organization of clinical dosimetry, I want to return now to one or two topics which we mentioned only in passing but which merit some additional consideration.

Transverse tomography

The first of these subjects is transverse tomography, which has been mentioned several times in connection with planning the treatment, assessing the effect of body composition, and rencostruction of an implant. I hesitate to lecture on transverse tomography to an Italian audience, since the method was very largely developed in this country by Prof. Vallebona, whereas in the Anglo-Saxon countries the technique has, on the whole, been disgracefully neglected, at least until quite recently. This is in spite of the fact that the theory was first expounded in an American journal (Kieffer, 1938) and one

of the earliest papers was in the British Journal of Radiology (Stevenson, 1950) from which Fig. 12 is taken. This diagram shows the working principle: when the film and the patient are simultaneously rotated, in the same direction, about parallel axes, only points lying in a single plane of the body, less than 1 mm thick, remain stationary on the film and therefore in focus. All other points are blurred out.



Alderson Research Labs. Technical Bulletin No. 35).
Figure 12 - *Principle of transverse tomography* (*From*: *Stevenson,* 1950).

The literature on this subject is abundant, and only a few of the papers will be mentioned: Vallebona, 1948, 1950; Frain and Lacroix, 1948; Frain *et al,* 1955; Roswit *et al,* 1959; Pierquin, 1961; Oliva, 1963. Papers on the use of transverse tomography for the reconstruction of implants have already been mentioned.

The *disadvantage* of transverse tomography as shown in Fig. 12 and described in the papers so far quoted is that the radiographs must be taken with the patient in the vertical position, whereas radiotherapy is usually given with the patient lying down. This introduces the possibility of a change in the shape of the body, and in the relative positions of internal structures, as previously stated. In order to overcome this difficulty Takahashi and Matsuda (1960) devised a new

form of tomograph, which they called the « universal rotatograph », shown in Fig. 13. As far as I know, however, this type of tomograph, in contrast to the more conventional form, is not available commercially.

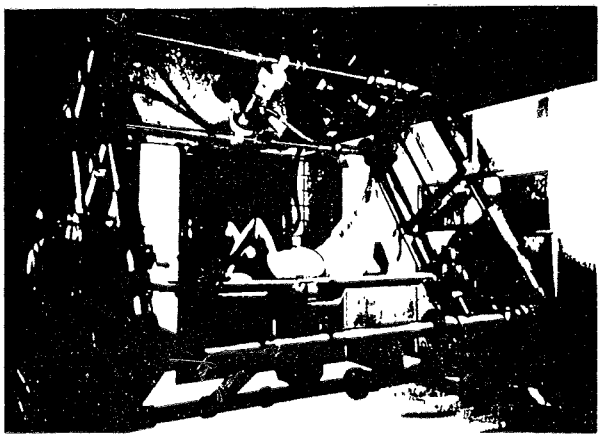


Figure 13 - *Universal rotatograph.* (*From*: *Takahashi and Matsuda,* 1960).

Pre-calculated treatment plans

It is sometimes said that when a pre-calculated treatment plan is used, the patient is made to fit the plan instead of adapting the plan to fit the patient. This is fortunately only a half-truth, since the rationale of the pre-calculated plan is that it should be independent of the contours of individual patients - or, at least, readily adaptable to any patient. Nevertheless is must be stated that a single pre-calculated plan is unlikely to be applicable to *all* patients and tumours and the method is useful only if a series of such plans is available to cover a broad range of conditions.

One of the best examples of the method is for 2 oblique wedge fields. This Technique was first used by Ellis and Miller (1944) for 200 kV X-rays and was further developed by Ellis *et al.* (1950). The method was systematized by Cohen (1959a and b) who analysed the effect of the different parameters of the system. A similar analysis was carried out by Cohen, Burns and Sear (1960a and b) for wedge filters used with cobalt-60 radiation and Fig. 14 shows some examples of isodose chart taken from this paper. The complete set of charts is, of course,

much larger, and the charts have to be used in conjunction with tables such as that illustrated in Table V.

The purpose of the wedge method is to treat tumours located near the surface of the body, but extending to some depth below the surface, by means of 2 fields on one side of the body only. Thus the size of the individual patient does not matter and the only aspect of the patient which comes into the picture is the necessity of fitting the curved entrance surface of the patient into the space defined by the 2 oblique fields. In the case of 250 kV X-rays this problem is solved by irradiating through a wax block which fills the space bet-

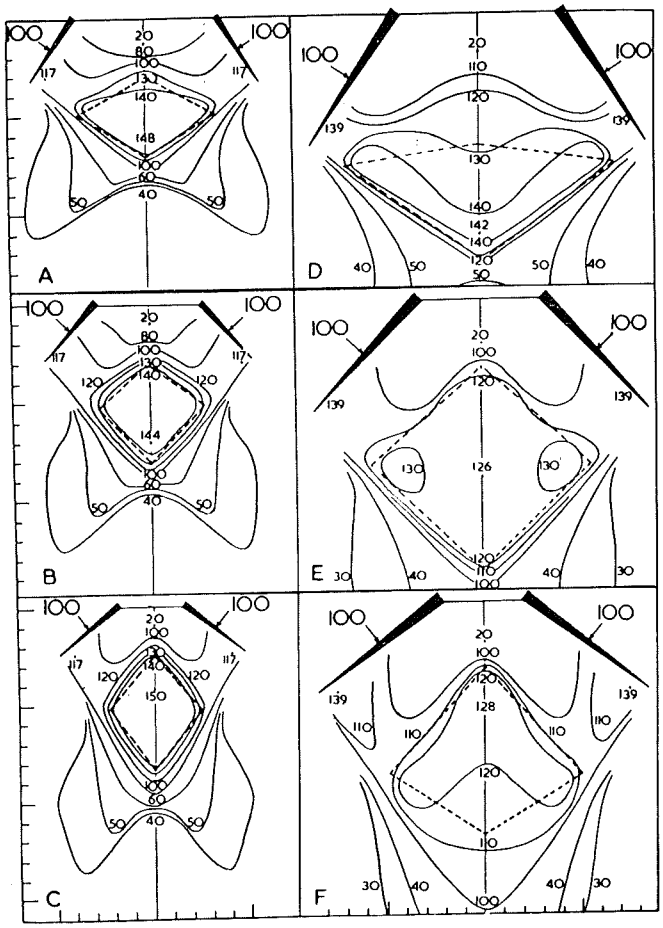


Figure 14 - *Pre-calculated wedge-field isodose charts. (From: Cohen, Burns and Sear,* 1960b).

TABLE V

DOSAGE TABLE FOR 4 cm WEDGE
(from Cohen, Burns and Sear, 1960b)

θ	*s* (cm)	*Plateau dimensions (cm)*		*Mean tumour dose (per cent)*	
		Max width	*Depth below base line*	*4 cm field length*	*16 cm field length*
70°	4.0	7.0	1.7— 6.3	160	161
	6.0		2.4— 7.0	145	147
	7.0		2.8— 7.4	138	141
	8.0		3.1— 7.7	132	135
	10.0		3.8— 8.4	120	123
80°	2.0	6.2	1.1— 6.0	167	169
	4.0		2.0— 6.9	151	153
	5.0		2.4— 7.3	144	146
	6.0		2.8— 7.7	136	139
	8.0		3.7— 8.6	123	126
90°	2.0	5.7	1.3— 6.7	158	159
	4.0		2.3— 7.7	141	144
	5.0		2.8— 8.2	133	136
	6.0		3.3— 8.7	126	130
	8.0		4.3— 9.7	113	117
100°	2.0	5.2	1.5— 7.4	151	153
	4.0		2.7— 8.6	133	136
	5.0		3.3— 9.2	125	129
	6.0		3.9— 9.8	118	122
	8.0		5.1—11.0	104	109
110°	1.0	4.6	1.0— 7.0	159	161
	2.0		1.7— 7.7	148	151
	3.0		2.4— 8.4	138	141
	4.0		3.2— 9.2	129	132
	5.0		3.9— 9.9	121	124
Hot spot (per cent)				117	117

ween the applicator end and the patient's skin. For high energy radiation, however, it is essential to use a compensating filter. The difference between these techniques has already been illustrated in Fig. 3.

Wedge filters are now very widely used in radiotherapy, especially with high energy radiation, and an extensive literature exists. I would like to mention only those papers which have made an important contribution, not merely to the design and construction of the filters, but to the concept of pre-calculated treatment plans: Miceli, Bono and Rimondi, 1964 (Cs-137); Cavina *et al.* 1962 (Co-60); Stewart 1960 (4 MV X-rays); Roosenbeek and Grimm, 1961 (22 MV X-rays), Sear, 1960 (general analysis).

Another important type of pre-calculated plan is derived from the method of Braestrup and Mooney (1955) which was further developed by Du Sault (1959). The basis of the method is the single-field isodose curve referred to 100 per cent at a depth in tissue instead of at a point at or near the surface. The isodose curves are supposed to extend indefinitely both above and below the reference point (Fig. 15). When a number of such fields converge at the reference point a combined field isodose chart is obtained which is independent of the contour of the individual patient. This contour may, in fact, be drawn on the chart and the dose which has to be applied to each field, to ensure equal contributions at the centre point, may be calculated (Fig. 16). In these circumstances the dose distribution in the centre of the chart is exactly reproduced, and errors are incurred only near the surface where, in general, the dose is not critical. The method has been further extended and improved by Pfalzner (1962).

Many other examples of pre-calculated plans could be given, for example for tangential irradiation of the breast and for parametrial irradiation by means of opposed fields following intracavitary radium treatment. The essential feature of the method is that only one or two parameters of the individual patient are relevant so that a set of plans covering all sizes of patients can be prepared and systematized.

Atlases of isodose charts

An atlas of isodose charts is, superficially, similar to a set of pre-calculated plans but in fact differs from such plans in that the charts in an atlas are not confined to situations which are independent of the individual patient. In a sense every radiotherapy department builds up its own atlas over a period of time, but these collections (which of course derive from treatment plans produced for actual patients) differ from

a true atlas in that they lack the two elements of systematization and analysis which are essential to a real atlas. Indeed, to turn a collection into an atlas is a formidable task, as we in IAEA discovered when we decided to prepare such atlases.

These atlases are for multiple fields and moving beams and sample pages are shown in Figs. 17 und 18 respectively. (A third atlas, for single fields, has also been prepared). Time does not permit a detailed discussion of these atlases and their use, but I would like to mention one or two important features of the multiple-field atlas. Classification is based on the number of fields and their arrangement, for example, 2 opposed fields, 3 fields bilateral irradiation and so on. Within

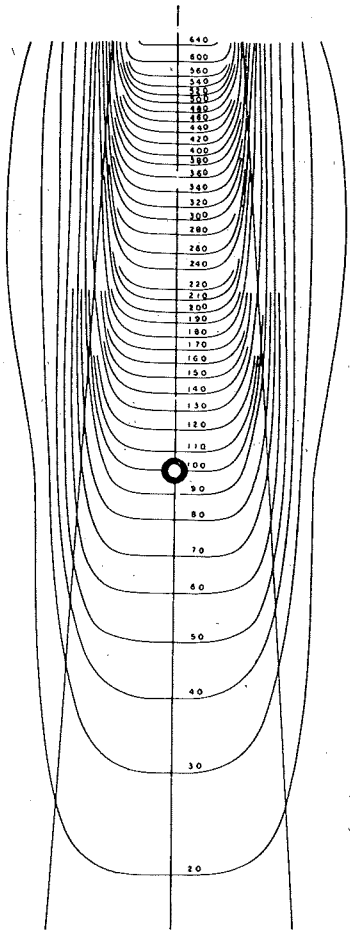


Figure 15 - *Single field isodose curve based on* 100 *per cent at a depth in tissue.* (*From Du Sault,* 1959).

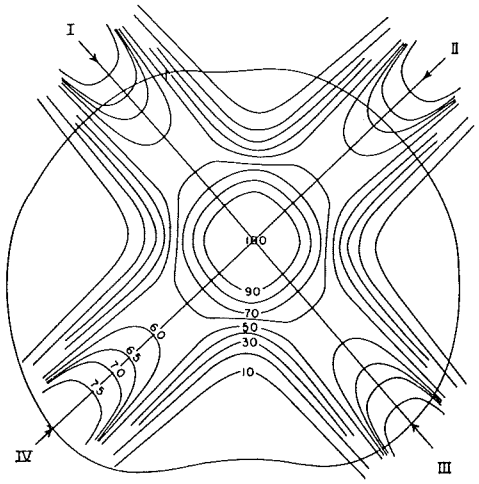


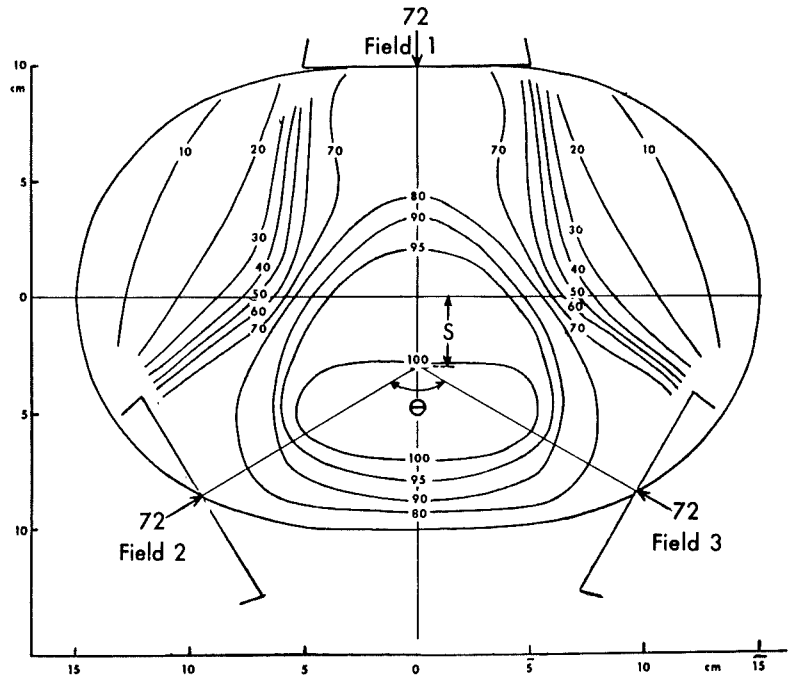
Figure 16 - *Four-field isodose chart with contour of patient added. (From: Du Sault.* 1959).

each main section there is a basic plan, with average or typical values of all parameters, and the other charts in the section are linked to this chart on an approximately radial basis as illustrated in Fig. 19. Each isodose chart is related to at least one other chart, and often to several other charts, by a change in one parameter only. The body contours are necessarily idealized, and for this purpose we have used the oval outline proposed by Haynes and Froese (1957). In this atlas, and in the moving-beam atlas, the isodose charts are supplemented by a detailed analysis of the effect of the various parameters on the dose distribution.

The atlases are now in the press and will be available shortly (Cohen, 1965; Tsien, Cunningham and Wright, 1965). Mention should also be made of the important sets of dose distributions for moving-beam therapy published by Dahl and Vikterlöf, 1958 (250 kV X-rays) and by Hultberg *et al.*, 1959 (cobalt-60 radiation).

Rapid assessment of treatment plans

As we saw earlier, it is difficult for a human computer to produce isodose charts for individual patients quickly enough to enable the final treatment plan to be chosen from a number of alternative charts. We have therefore devised a



PARAMETER	THIS CHART	LINKING CHARTS No:				
		32(B)	34	37		
Radiation	Cobalt					
S S D	60					
Field size	10×10					
Dose-ratio	1:1			2:3		
θ	120°					
S	-3	0	+3			
Penumbra	large					
Cross-section	30×20					

Figure 17 - *Sample page from Atlas of multiple-field isodose charts.* (*From*: *Cohen*, 1965).

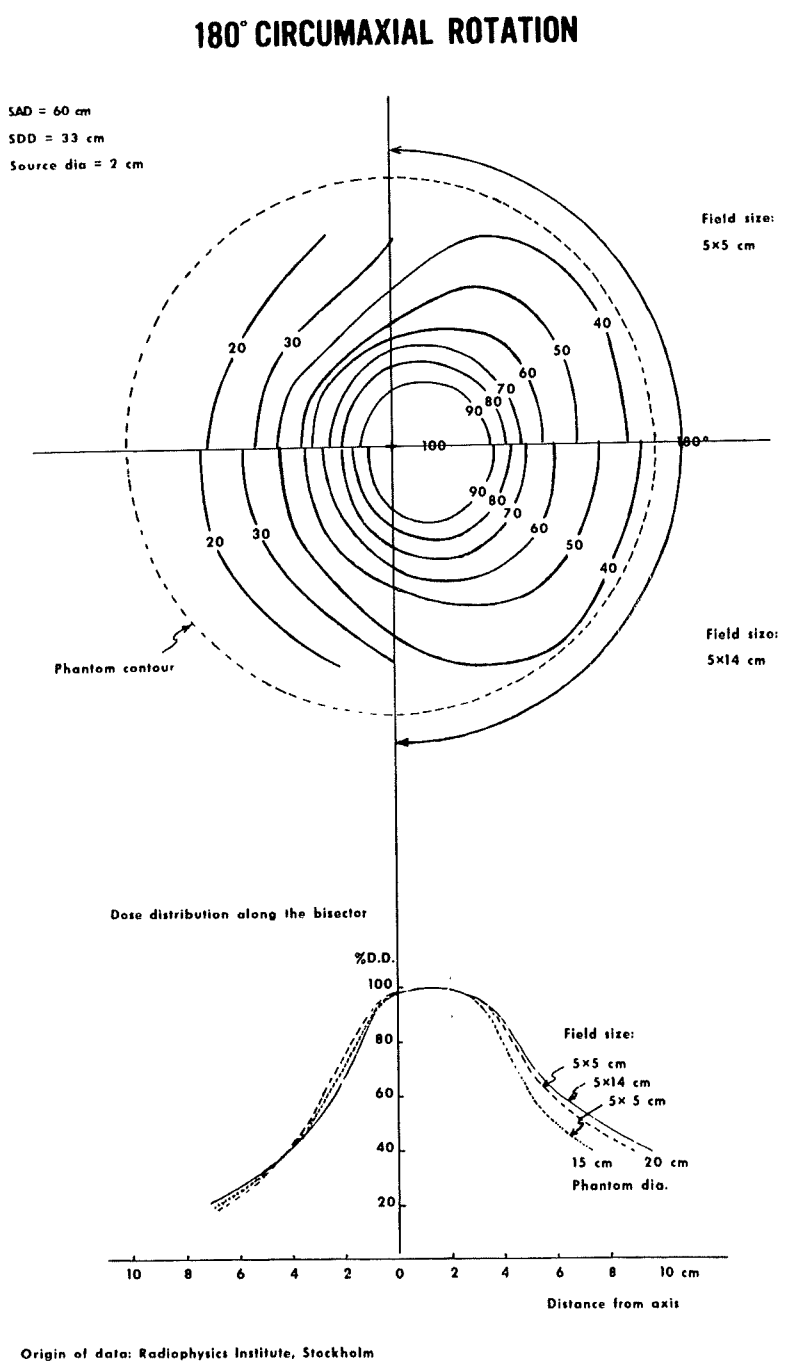


Figure 18 - *Sample page from Atlas of moving-field isodose charts.* (*From*: *Tsien, Cunningham and Wright,* 1965).

method whereby this choice can be made on the basis of data which are intermediate between a full isodose chart and the dose at one or two points only. At present the method has been fully worked out only for symmetrical field arrangements but it is being extended to asymmetrical arrangements. The following is intended only as a summary, since a detailed description of the method will be published elsewhere. Two operations are involved (Fig. 20):

1) The combined dose distribution is plotted along the axis of symmetry. This is rapidly done, without combining isodose curves, by drawing a line at the appropriate position on the single-field isodose chart. From the axial distribution curve may be read off (I) the maximum percentage depth

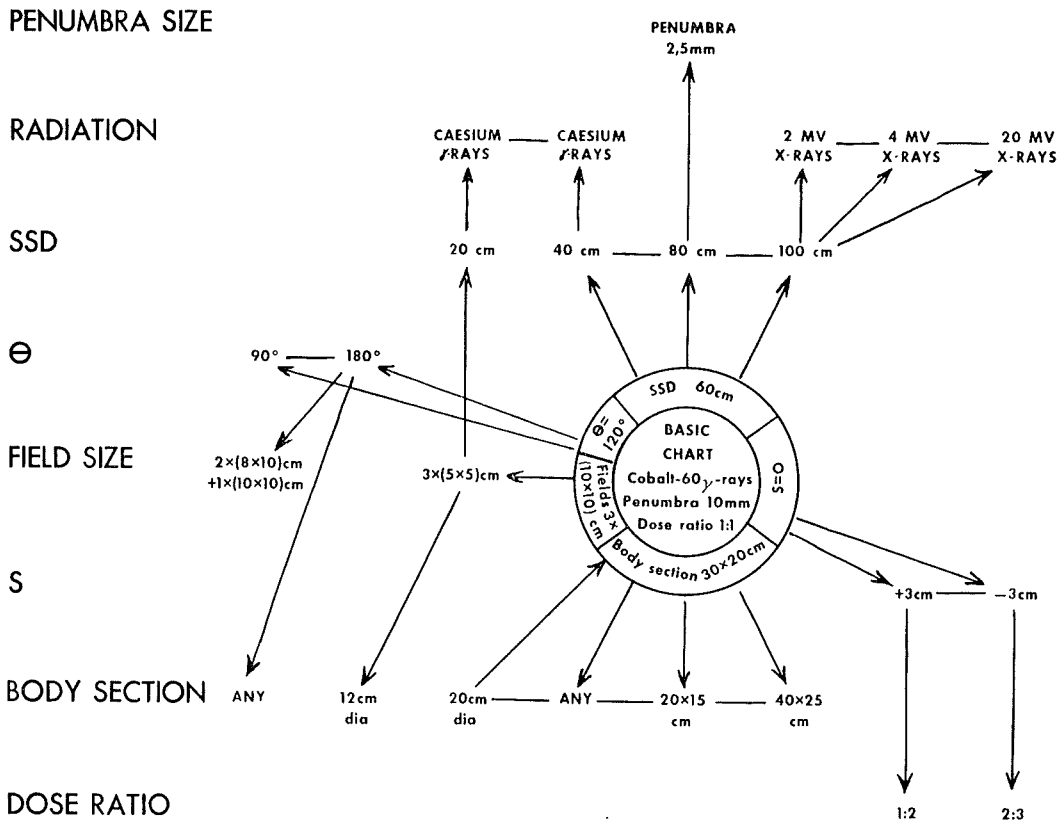


Figure 19 - *Arrangement of 3-field charts in section IV of the Atlas (From: Cohen, 1965).*

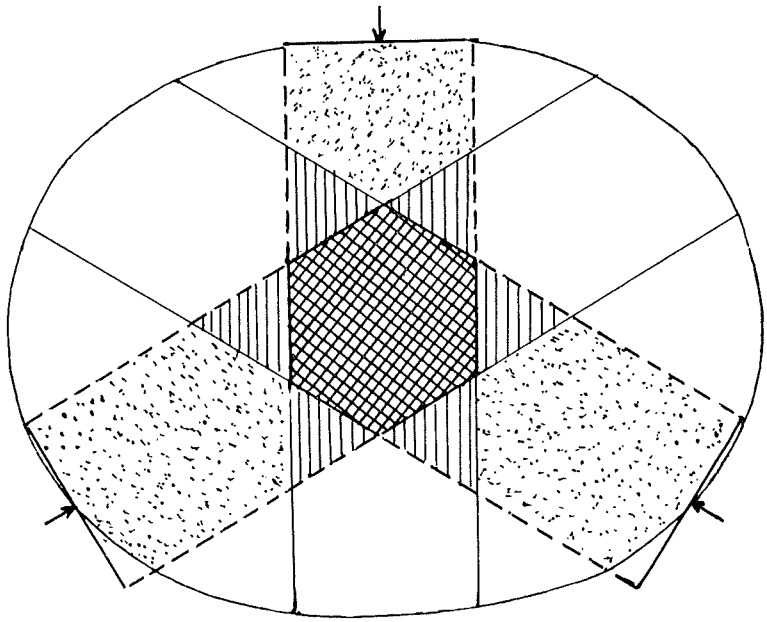


Figure 20 - *Method of rapid assessment of multiple-field isodose charts.*

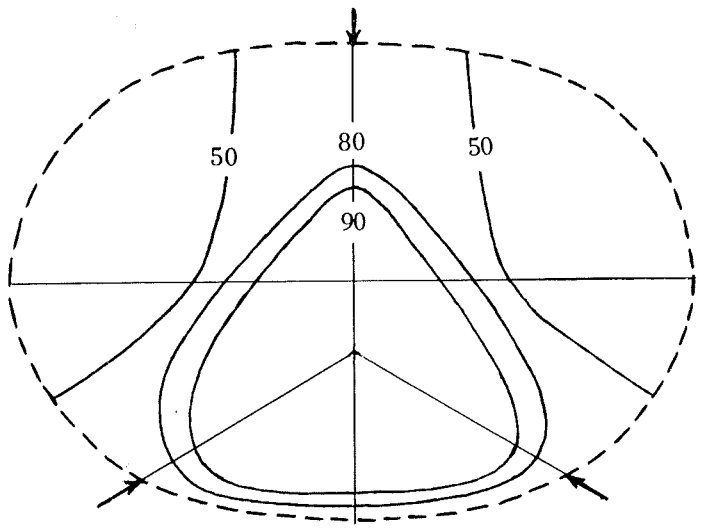


Figure 27 - *Abbreviated chart (« plateau diagram ») of the field arrangement shown in Figure 17.*

dose, which is called 100%, and (II) the positions of the 90, 80 and 50% dose levels.

2) The edges of the various beams are drawn on the outline representing the patient. Except for very short SSD's, beam divergence may be ignored. The area in which all the beams overlap represents the area enclosed by the 80% isodose curve, except that this area may be extended into certain areas in which some, but not all the beams overlap (e.g. 2 out of 3 beams or 3 out of 4). Simple rules may be propounded for these extensions. The envelope of the beam edges (excluding the exit positions of each beam) represents the 50% isodose curve, except in certain cases (for which, again, there is a simple rule) for which this envelope represents instead the 40 or 30% curve.

3) Combining (1) and (2) it is possible to sketch an abbreviated isodose chart which shows only the 90, 80 and 50 per cent isodose curves. Such a diagram in fact contains all the information needed to assess the suitability of a treatment, since it shows the position, size and shape of the region of uniformity (as depicted by the 90% line), the rapidity of the fall-off outside this region (as shown by the relationship between the 90 and 80% lines) and finally some information about the dose outside the tumour region (as represented by the 50% line). In Fig. 21 the abbreviated diagram for a 3-field arrangement is compared with the full isodose chart.

However, even if a full isodose chart is available, it is doubtful if we make use of much more information than this in assessing the value of the chart - in fact, a full isodose chart contains so much data that we are bound to extract the salient features before it can be comprehended. All that the proposed method does is to examine the nature of the extracted data and to produce this information, but no more, by a short cut.

Conclusions

Clinical dosimetry today is in a most interesting stage of its development. A few years ago the main pre-occupation in radiotherapy was the switch-over to high energy radiation. This process is, of course, continuing, but the centre of interest has moved towards more exact dosimetry with high energy units whose existence is taken for granted. Two problems must now be solved, not simply in a few large and advanced radiotherapy centres but in centres all over the world: firstly, how can we ensure that an optimum treat-

ment plan is prepared for each patient in accordance with the individual characteristics of the patient and his tumour; and, secondly, how can we take into account, on a routine basis, the obvious fact that a patient is not exactly the same as a rectangular tank of water.

It is fashionable nowadays to hail the digital computer as the answer to all dosimetric problems. Personally I do not regard the computer as a universal panacea, although I *do* hope that in the discussion at the end of this week, on the organization of hospital physics in Italy, serious consideration will be given to the possibility of setting up one or more computer centres to serve the needs of Italian radiotherapy departmens. The role of the computer in clinical dosimetry is by no means agreed. On the one hand it is argued that the computer will enable an individual treatment plan to be tailored to the needs of each patient. But it is also said (e.g. Shalek, 1963) that this is *not* the ideal role for the computer: instead, computers should be used to produce a large number of treatment plans, of the pre-calculated type, as well as bigger and better atlases of isodose charts. In my opinion there will be need, and scope, for both types of application and, indeed, it would be unwise to encourage too narrow a view as to the application of computers.

At this point a word of caution as to pre-calculated plans is perhaps necessary. There is no doubt that the judicious use of such plans is a god-send in a busy radiotherapy department. If half the patients are treated through pre-calculated plans then the other half, for whom such plans are inapplicable, will have a better chance of the individual calculations which their conditions demand.

Now it is easy to conclude from this that the more pre-calculated plans a department has available the more patients can be treated by this method and the better the choice for the individual. This is true up to a certain point, but beyond that the system can become self-defeating. Suppose, for example, you have 10, or even 20, isodose charts of pairs of wedge fields. These can be spread out side by side on the table and the choice for a given patient made by direct comparison. But if you have 200 such charts a direct comparison is no longer so easy. The rapid choice of the correct chart now depends on the use of a system of classification - not, however, classification on the basis of the physical parameters such as field size and angulation, but on the basis of the size and position of the tumour. The more treatment plans are produced, by computers or otherwise, the more urgent becomes the need for an acceptable analysis of the isodose charts them-

selves so that a rational comparison of large numbers of charts becomes possible. This is the kind of analysis we have tried to undertake in the atlases, and in the simplified method of assessing charts, which I have described.

Finally, what should be the policy on treatment planning of a radiotherapy centre with limited resources and trained staff, e.g. a centre with only one physicist and perhaps a technician or two? Is there an optimum division of time and effort between the different stages of clinical dosimetry and between the different types of treatment planning? No universal answer is possible, but I want to conclude by offering a 5-point plan as a basis for discussion:

1) During the first few months after his appointment, and again whenever new equipment is installed, the physicist must spend at least half his time on physical dosimetry.

2) For the first 2 or 3 years it is necessary to concentrate on « water phantom » dosimetry. Simple corrections should be applied for lung tissue but no attempt should be made to assess these corrections individually. During this period the physicist must become throughly familiar with treatment planning.

3) Right from the start simple corrections for field obliquity should be applied. Alternatively, compensating filters should be used routinely. Similarly, from the start, attention should be given to accuracy during the setting-up of the patient and delivery of the dose.

4) Routine treatment planning should eventually become the responsibility of either a technician specially trained for this purpose or of junior doctors who are training to be radiotherapists. In either case overall supervision should rest with the Senior Radiotherapist in association with the Physicist. It should be the aim of the physicist that, after the first 2 or 3 years he should not need to spend more than 10-20% of his time on routine planning. This will depend, of course, on the proportion of patients for whom pre-calculated plans are used. This proportion is a matter of individual preference and circumstances but, as a rough guide, 50% of patients may be found suitable for this method. However, before this stage is reached the physicist must produce, or obtain, suitable plans.

5) Eventually more and more of the physicist's time should be devoted to the final (« reconsideration ») stage of clinical dosimetry. This may be regarded as research in clinical dosimetry but the aim should be to produce a measurement and correction technique acceptable for routine use.

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INTERVENTI SULLA RELAZIONE

J. F. FOWLER

Concerning corrections for lung density, Mrs. Vesna Svarver and I have recently measured exit doses in lung cases for 8MV X-rays using lithium fluoride thermoluminescent powder in capsules, which makes it possible to obtain a large amount of information. We were surprised to find such large variations in exit dose, varying between —15% and +50%. Repeat measurements on the same patient agreed well; and in one case showed a slow increase in radio-transparency of the lung, at the same times as the tumour grew swallow as sham by X-ray films. On careful study of each patient, together with Dr. T. J. Deeley the radiotherapist, these variations were found to be entirely explicable. The —15% was directly through the centre of the spine, corresponded to the expected attenuation of bone 3 to 4 cm. thick having a density of 1-8. The +50% values were for posterior oblique fields through both lungs of large patients. Variation between similar fields in different patients were 30% (±15%) in exit dose, depending on the state of the lungs. It may or may not be necessary to allow for these differences in individual patients, but it is certain that unless measurements and corrections are made on individual patients, large variations will indeed occur.

F. ELLIS

a) I should like to congratulate Dr. Cohen on his masterly paper.

b) The transit dose method of producing an effective contour (Holodney, Laughlin et al.) is not really useful to obtain dosage at a tumour inside the chest unless the tumour is centrally placed and the lung and bone symmetrically disposed around it. The amount of matter in the path of each pencil of radiation is what determines the proportion of the radiation ready the tumour. The method under discussion does not provide the necessary information.

c) I hope I am not being immodest but I would like to correct Dr. Cohen's statement that Oliver and Hall were responsible for the suggestion of compensators for tissue heterogenecty. I will remember sitting down to think of something and how praod I was to feel that I had achieved a reasonable solution. I wrote a letter to the B.J.R. which was about 1 or 2 years before Oliver and Hall's publication, which was made after the physical aspects had been investigated at my request

d) I am pleased to find that Dr. Cohen uses data as a plural word which it is and not as the singular, as it is so often misused.

R. MILANESI

Ringrazio innanzi tutto il prof. Ellis per la Sua cortese precisazione e lo assicuro che dopo aver letto la sua « Filosofia in Radioterapia » non è più possibile fraintendere il suo pensiero (*).

Al dott. Cohen volevo chiedere come mai si ritiene più comodo usare il tipo di curve di isodose da lui indicate. Queste infatti oltre a presentare una notevole difficoltà di costruzione (a meno di possedere un fantoccio automatico) hanno lo svantaggio di essere costruite con una cortissima DSP per cui la trasmissione percentuale in profondità non sarà la stessa di quella che in effetti si avrà sul paziente.

Si chiede inoltre di conoscere se questa circostanza può essere esaltata nel caso di impiego di campi multipli e nella terapia di movimento, quando siano utilizzate appunto le curve di isodose in questione.

RISPOSTA DEL RELATORE

M. COHEN

1 - In reply to Dr. Ellis, the effective outline measured by the transmission method (Fig. 9 of my paper) allows one to make a correction only of the type shown in Curve B of Fig. 10, i. e one has to assume that the whole thorax is of uniform density. Fig. 9 was taken from a very recent note on « Work in Progress » by Holoday, Ragazzoni, Bronstein and Laughlin, and I raised this very point with Dr. Laughlin a few weeks ago. He confirmed that, if more accurate corrections are required, i. e Curve C in Fig. 10, it is necessary to combine the transmission measurements with tranverse tomography, or some other method of assessing the cross-sectional anatomy of the patient. However, it is worth pointing out that Curve B is better than no correction at all (i. e Curve A).

2 - With regard to Prof. Fowler's comment and question, I hope I did not give the impression that I advocate a uniform lung correction for all patients. I merely pointed out that this is the *simplest* procedure and, since one cannot do everything at once, it is probably necessary to accept this method during the period when both the radiotherapist and the physicist are struggling to establish methods and clinical data in a new department or with a new source of radiation. But it should certainly be their aim to introduce more elaborate and accurate corrections later on. One should not be too complacent about

(*) Vedasi discussione alla relazione di F. Ellis, pag. 344.

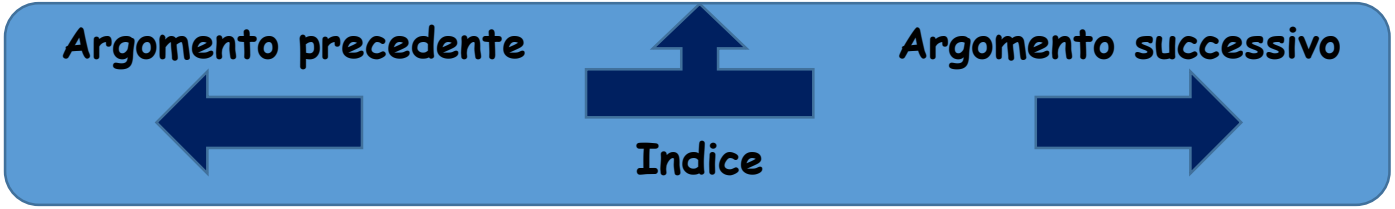
this, however, since there are many advanced radiotherapy centres which are quite content with a uniform lung connection (or even none at all!) and have no plans to introduce more accurate techniques.

3 - It is difficult to answer the question of Dr. Milanesi: the only real answer is to refer him to the original papers of Braestrup and Mooney and of Du Sault. (Although Fig. 15 is taken from a paper by Du Sault, the method originated with Braestrup and Monney). In these papers it is clearly shown that the only error introduced is at and near the surface of the patient, where, in general, the dose is not critical in any case. In the central region, corresponding to the tumour, there is little or no error. The advantage of the method is the case with which the same isodose chart for multiple beams (see, for example, Fig. 16) can be applied to different patients. It was not, however, the purpose of my paper to advocate the method, but merely to point out his existence. There is, in fact, one *disadvantage* of the method which needs to be mentioned. The given or applied dose to each field has to be adjusted according to the depth of the tumour (centre of convergence) so as to give equal contributions at the centre from each field.

This means that the further a field is from the tumours, the greater the dose applied through this field, and many consider this to be bad radiotherapeutic practice. Most people prefer to apply the greatest dose through the fields *nearest* the tumour. In order to overcome this disadvantage, the method has recently been modified by Pfalzner (1962) — see reference in the bibliography.

4 - I am not sure if I understood Prof. Meldolesi's comment properly. Does he mean that the apparatus built by the Italian Company in 1953 is able to take transverse tomograms with the patient in the horizontal position? If so, I would be glad to have further details. I fully agree with him about the importance of a radiotherapist also being a good diagnostician, but I confess I cannot follow the converse argument, which he used in an earlier session, that a diagnostic radiologist must also undertake therapy.

(PAGINA VUOTA NEL TESTO ORIGINALE)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Indice
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