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Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology

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INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

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Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology

1. Introduction

In 1978, the ICRU published Report 29, *Dose Specification for Reporting External Beam Therapy with Photons and Electrons* (ICRU, 1978). The present report deals with the problem of dose and volume specification for reporting intracavitary therapy. The principal subject is dose and volume specification for the intracavitary treatment of cervix carcinoma. However, the concepts developed in this report are designed to be applicable to other types of intracavitary applications, such as uterine body, etc.

Intracavitary therapy is often used in combination with external beam therapy and, therefore, the same terminology and definitions of terms are advocated. In particular, it would be desirable, whenever possible, to use the concepts of *target volume*, *treatment volume* and *irradiated volume*, as defined for external beam therapy. However, due to the high dose-gradient around the sources (throughout the tumor and target volume), the specification of the target absorbed dose in terms of the dose absorbed either at one or several reference point(s) within the target volume is not considered meaningful; therefore, the approach used in external beam therapy cannot be used.

The problem of dose specification is still more complicated when two or more target volumes are identified, some being treated either by external, or by intracavitary therapy and some by both methods. Furthermore, attention should be paid to the different time-dose patterns linked to each treatment method.

Based on clinical experience, different systems have been proposed for the treatment of cervix carcinoma. Three basic systems have been developed: the *Stockholm system* (Kottmeier, 1964)[1], the *Paris system* (Lamarque and Coliez, 1951)[1] and the *Manchester system* (Paterson, 1948)[1]. Most of the systems used throughout the world are derived from these three basic systems.

As used here, the term "system" denotes a set of rules taking into account the source strengths, geometry and method of application in order to obtain suitable dose distributions over the volume(s) to be treated. For reporting, the system includes recommendations for specifying the application and possibly, as in the Manchester system, for calculating the dose rate (or dose) at specific points.

Typical applications according to the Stockholm system and the historical Paris system are presented in Figures 1.1 and 1.2, respectively. In both systems, applications have been reported in terms of "mg·h" (milligram hours), i.e., the product of the total mass or radium contained in the sources (in mg) and of the duration of the application (in hours).

The Manchester system (Paterson and Parker, 1934), derived from the original Paris system, initiated about 1920, was designed to deliver a constant dose rate to defined points near the cervix, irrespective of variation in size and shape of the uterus and vagina. In the Manchester system, an application was specified in terms of the "dose" in roentgens delivered at specific points such as points "A" and "B" (Figure 1.3). Points A and B are still widely used throughout the world, although their exact meaning and their definition have not always been interpreted in the same way in different centers and even in a given center over a period of time. In particular, some centers relate point A to anatomical references in the patient, others to the geometry of the sources.

The different methods of definition provide different values for the calculated dose rate to point A. As a result, where a prescribed dose to point A is used to calculate the total time for an insertion, different values of time

[1] The references quoted are not the first references but those which seem to be the most comprehensive.

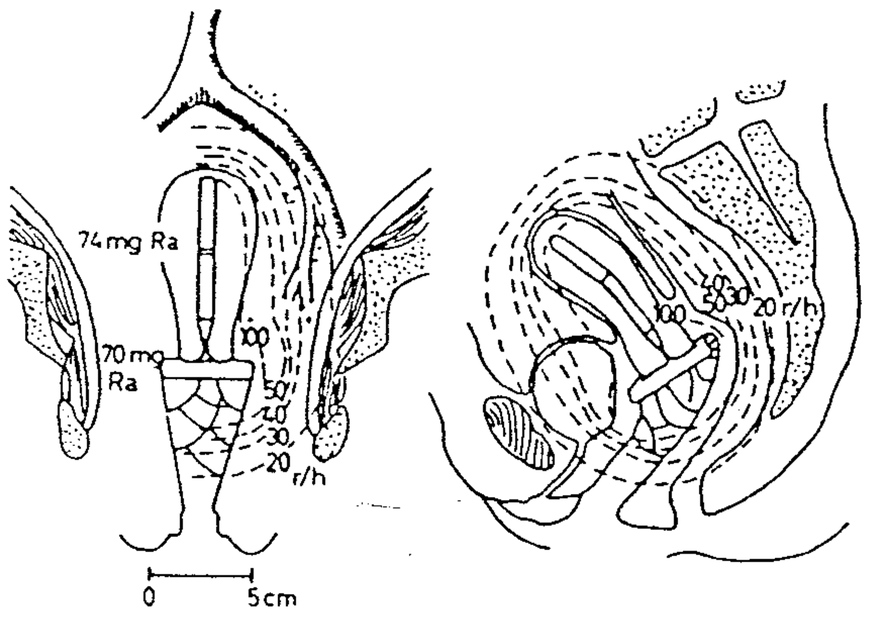


Fig. 1.1. The Stockholm system. Typical treatment of a cervix carcinoma with a radium application (uterus normal in size and shape). The intrauterine rod-shaped applicator is loaded with 53–88 mg radium (74 mg in the example shown). The vaginal applicator usually consists of a flat box containing 60–80 mg radium (70 mg in the example shown), but in special cases other forms of vaginal applicators may be used. Classically, the two applicators are not fixed to each other, but fixed or semi-fixed combinations have been developed. The vaginal applicator is held against the cervix and lateral fornices by careful and systematic gauze packing. Typically, 2 or 3 applications are given with 3-week intervals, each application lasting for 27–30 hours. Modifications of the Stockholm method, using larger amounts of radium, allow for application times of 10–18 hours at each treatment. The figure shows a typical application and the amount of radium in the two applicators as well as the dose-rate (Figure from Walstam, 1954).

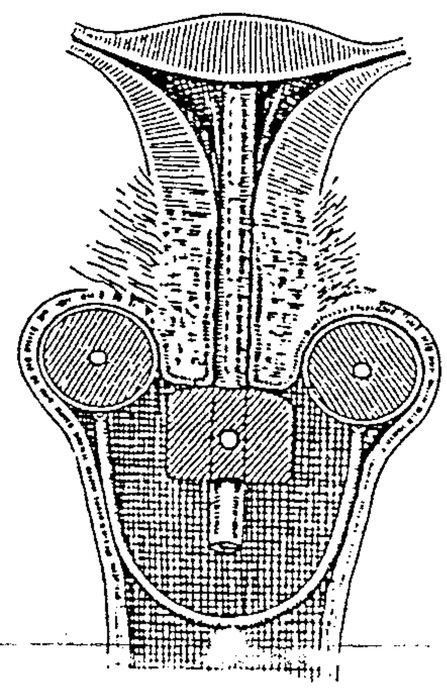


Fig. 1.2. The historical Paris system. Typical radium application for a treatment of cervix carcinoma consisting of: 3 individualized vaginal sources (one in each lateral fornix and one central in front of the cervical os), 1 intrauterine source made of 3 radium tubes (in so-called tandem position). Possible variations of the Paris system include: 2 vaginal sources (or only one) in case of a narrow vaginal cavity; only 2 intrauterine radium tubes (or only one) in case of short uterus. The active length of the sources is usually 16 mm, their linear activity being between 6 and 10 mg per cm, and their strength between 10 and 15 mg of radium. The total activity used is one of the lowest in use for such treatments and implies a typical duration of the application of 6–8 days. Typically, the ratio of the total activity of the vaginal sources to the total activity of the uterine sources should be 1 (with variations between 0.66 and 1.5). As far as the method of application is concerned, the historical Paris system does not imply any fixed distance between the vaginal sources, nor connection between vaginal and uterine sources (Pierquin, 1964).

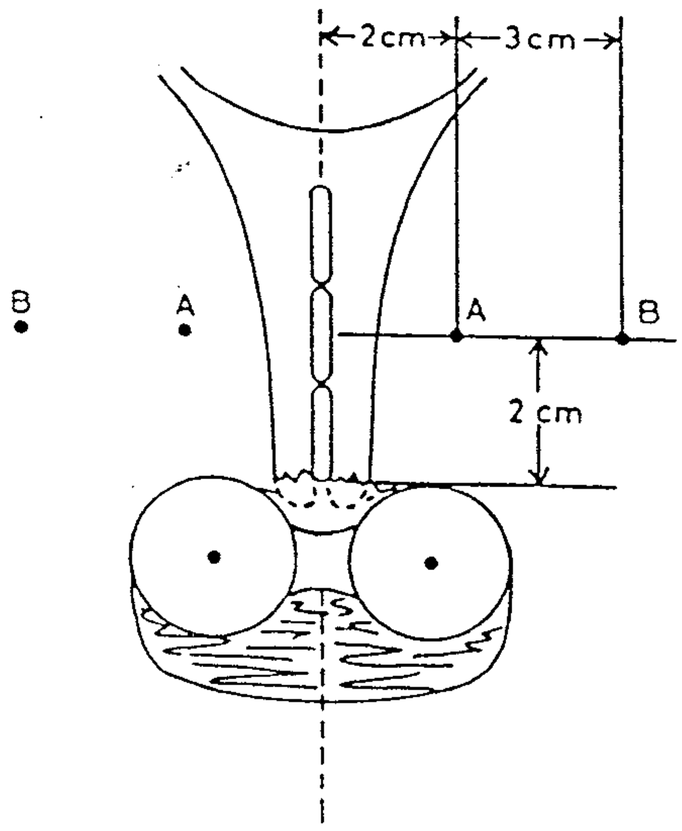


Fig. 1.3. The Manchester system. Definition of points "A" and "B". In the classical Manchester system, point A is defined as a point 2 cm lateral to the central canal of the uterus and 2 cm up from the mucous membrane of the lateral fornix, in the axis of the uterus. Point B is defined as being in the transverse axis through points A, 5 cm from the midline. In clinical practice, dose calculations are often made from radiographs and point A is taken 2 cm up from the flange of the intrauterine source and 2 cm lateral from the central canal as indicated in the figure (Meredith, 1967). In a typical application, the loading of intrauterine applicators varied between 20 and 35 mg of radium and between 15 and 25 mg of radium for each vaginal ovoid. The resultant treatment time to get 8000 R at point A was 140 hours.

will be obtained, depending on the method used. It is therefore important to give a precise description of the method used to calculate the dose rate at specific points.

On the other hand, the Manchester system is based on a set of strict rules concerning the method of inserting the radium sources (in particular the choice of vaginal ovoids and their separation, and the relative strengths of the intrauterine and intravaginal sources). Assuming that the Manchester definition of point A is used, this will be the location where there is least variation in the dose rate from one source arrangement to another one.

It is opportune now to reconsider dose and volume specification for several reasons:

(i) radium is being progressively replaced by gamma-ray emitting substitutes (^{137}Cs, ^{192}Ir and ^{60}Co)[2];
(ii) new sets of sources are available, for which the old systems are not always suitable;
(iii) SI units are now being widely used in the field of radiology; and
(iv) computers are routinely used for calculations and complete sets of intracavitary dose distribution in several planes are now becoming available, from which new information and relationships can be derived.

[2] Californium-252, a neutron emitter, is also used but will not be discussed in this document.

2. Definition of Terms and Concepts Currently Used in Intracavitary Therapy

2.1 Treatment Techniques

2.1.1 Radium Substitutes

When radium was the only available radionuclide, the characteristics of the sources used for intracavitary applications were similar and their activities were of the same order of magnitude. Typically, the elementary radium tubes most frequently used were 1.5 to 2.2 cm long, with source strengths ranging from 5 to 20 mg of radium and a total Pt filtration of 1 to 2 mm (see Appendix).

The replacement of radium by ^{137}Cs, ^{192}Ir and ^{60}Co may be accomplished according to two options. In the first option, the new sources (mainly ^{137}Cs) are similar in size and shape and have an output similar to radium sources. The same technique of application can then be applied and the clinical experience gained with radium remains fully relevant. The principal advantages of the replacement of the radium concern radiation protection; these include no contamination from leakage and less shielding in the case of ^{137}Cs and ^{192}Ir.

The second option takes advantage of the improved technology in the preparation of the sources, the increased specific activities available with artificial radionuclides and the technical possibility of making miniaturized sources. These new types of source are designed to allow the use of new and better techniques of application, for instance, afterloading, and to improve the dose distribution by providing, for instance, greater flexibility in the selection of the relative source-activities, source lengths or both.

In addition, the large range of source activities at present available allows the therapist to modify completely the time-dose pattern of application. Irradiation times ranging from 6 to 8 days, with radium in the Paris system, could be reduced to a few minutes (O'Connell *et al.*, 1967). Thus, continuous low dose-rate irradiation can be replaced by fractionated high dose-rate irradiation. It should be stressed that such drastic changes in the time-dose pattern require a modification of the total dose and that the clinical experience accumulated over many decades with relatively low dose-rate radium applications can no longer be applied without careful evaluation, not only as far as normal tissue tolerance is concerned, but also for effects on the tumor.

2.1.2 Simulation of Linear Sources

In many of the modern application devices, linear sources are simulated by a set of point sources. These point sources may be of equal activity and equally spaced, thus simulating a uniform linear activity. In other applications, more complex arrangements are used, involving different activities or different spacing in order to modify and improve the shape of the relevant isodose surfaces (Cardis and Kjellman, 1967; Chassagne *et al.*, 1969; Björnsson, 1980; Van der Laarse, 1981).

In the simple case where a linear source is simulated by a series of regularly spaced point sources of equal activity, each point source is equivalent to a given length of the linear source. The linear source simulated by the point sources is longer than the distance between the extreme point sources (see Figure 2.1). At distances larger than half the spacing between the point sources, the dose distribution around the point sources is similar to that around a linear source of the same total activity (Dutreix and Wambersie, 1968).

Linear sources can also be simulated by moving point sources of appropriate activity. Variations of the type of movement, continuous or stepwise, of the speed and dwell times of the source at different positions, will modify the shape of the isodose surfaces (Henschke *et al.*, 1966; Joslin *et al.*, 1969; Twiss and Bradshaw, 1970; Busch, 1973; Busch *et al.*, 1977; Himmelmann *et al.*, 1980; Von Essen, 1980).

2.1.3 Dose Rates

In conventional brachytherapy with radium tubes, the dose rate at the point or surface where the dose is prescribed, lies between 0.4 and 2 rays per hour. It is common practice to refer to this type of treatment as *low dose-rate brachytherapy*.

The introduction of remote afterloading devices into clinical medicine (see Section 2.1.4. below) has pre-

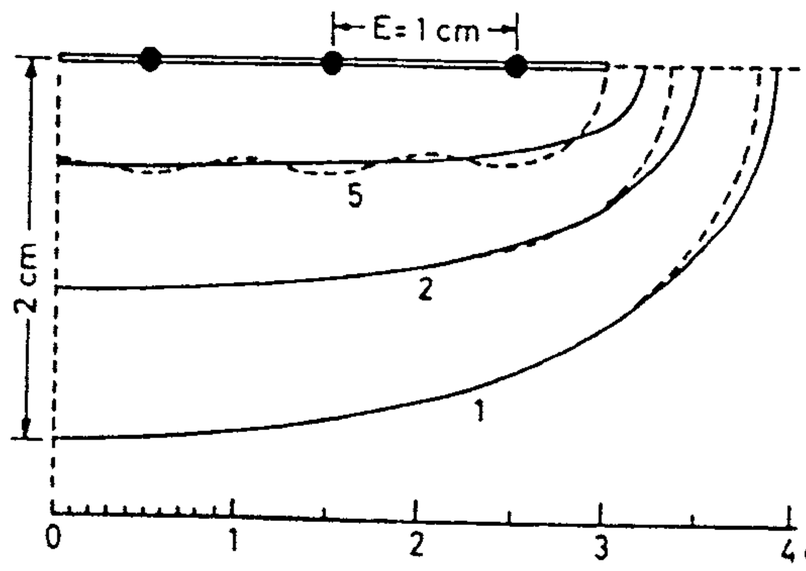


Fig. 2.1. Comparison of dose distributions between "n" small sources of activity a_0 spaced by a distance E, and a linear source of length $l = nE$ and of total activity $a = na_0$. The curves are labeled 5, 2, 1 for relative dose rate. The dotted lines result from a series of point sources and the full lines from a linear source. The dose is not corrected for oblique filtration (Dutreix and Wambersie, 1968).

sented an opportunity for investigating different dose rates and, in particular, very high dose rates. In this Report, the term *high dose rate* refers to any dose rate higher than 0.2 gray per minute (12 grays per hour), although it usually refers to dose rates as high as 2 to 5 grays per minute, i.e., treatment sessions of a few minutes duration.

Some radiotherapists are now exploring intermediate dose rates, between 2 and 12 grays per hour and we propose to refer to such dose rates as *medium dose rates.*

Such definitions of low dose rate, medium dose rate and high dose rate are arbitrary and debatable. In this connection, it must be stressed that the treatment duration should always be clearly reported (see Section 4).

2.1.4 Afterloading Techniques

Modifications of application techniques in intracavitary therapy are often made for purposes of radiation protection. As already discussed, some advantage is obtained by replacing radium by γ-emitters of lower energy (the shielding problems are easier and the risk of contamination is also avoided). However, the main improvement in radiation protection derives from the introduction of afterloading techniques.

In afterloading techniques, unloaded applicators or guides are introduced into the patient cavities, according to a chosen plan and without exposure of the staff. The treatment sources are inserted later, after the position of the applicators has been radiographically checked using dummy sources. The dose distribution can also be computed so that the position of the guides can be corrected if necessary before the sources are inserted.

Afterloading techniques help to ensure the correct and safe positioning of the radioactive sources in the patient, in addition to facilitating the transfer of the sources to and from a shielded storage container. Afterloading techniques may be *manual* or *remotely controlled.*

In *remotely controlled afterloading techniques*, source insertion and removal are operated from a control panel distant from the patient, thus eliminating exposure of the clinical staff. With some of the more advanced devices, the sources are automatically retracted into the storage container when the door of the patient's room is opened. While either manual or mechanical afterloading techniques may be used for low dose-rate applications, remote afterloading techniques are mandatory for medium and high dose-rate applications in order to ensure good radiation protection of the staff.

Afterloading is an important aspect of intracavitary therapy. Moreover, as more centers are now adopting afterloading techniques as well as modifying their irradiation procedures, attention needs to be given to the problems of dose specification and dose-time relationships. As already stressed, *the clinical experience accumulated with radium techniques cannot be applied to new irradiation conditions without careful consideration.*

2.2 Absorbed-Dose Pattern and Volumes

2.2.1 Absorbed-Dose Pattern

The pattern of the absorbed dose to the soft tissue in intracavitary therapy differs from the dose pattern encountered in external therapy. In external beam therapy, one aim is to reduce variations in dose over the target volume. In general, variations greater than $\pm 10\%$ are not deemed acceptable. Outside the treatment volume the dose falls off more or less steeply. For example, pelvic irradiation with a ^{60}Co "box technique" (see Figure 2.2a) produces a dose distribution within the treatment volume which is rather flat; the dose falls off rapidly at the edges of the treatment volume and in the lateral directions (Fields 3 and 4) remains fairly constant at about 30% of the dose at the center of the treatment volume. With intracavitary therapy, the dose is maximum adjacent to the sources and at the center of the treated volume, and it falls off continuously with distance from the sources. Consequently, the size of the treatment volume cannot be deduced from a simple inspection of the isodose pattern. Therefore, the radiotherapist has to indicate which dose level defines the treatment volume. In Figure 2.2c, the absorbed dose has been arbitrarily normalized to 100% at a distance of 2 cm from the uterine axis in order to allow a comparison of the absorbed dose patterns. Although the dose gradient (dose change per unit distance) at the border of the treatment volume is similar for either technique, as shown in Figure 2.2c, the dose patterns differ substantially within the treatment volume as well as in healthy tissues distant from the treated region.

2.2.2 Volumes

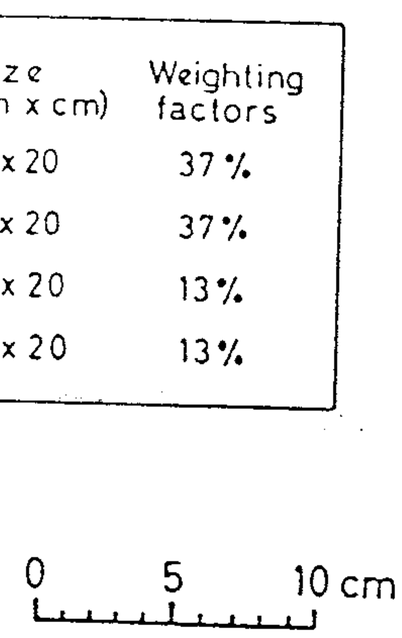
The definitions given in ICRU Report 29 for external beam therapy will be modified where necessary for intracavitary therapy situations.

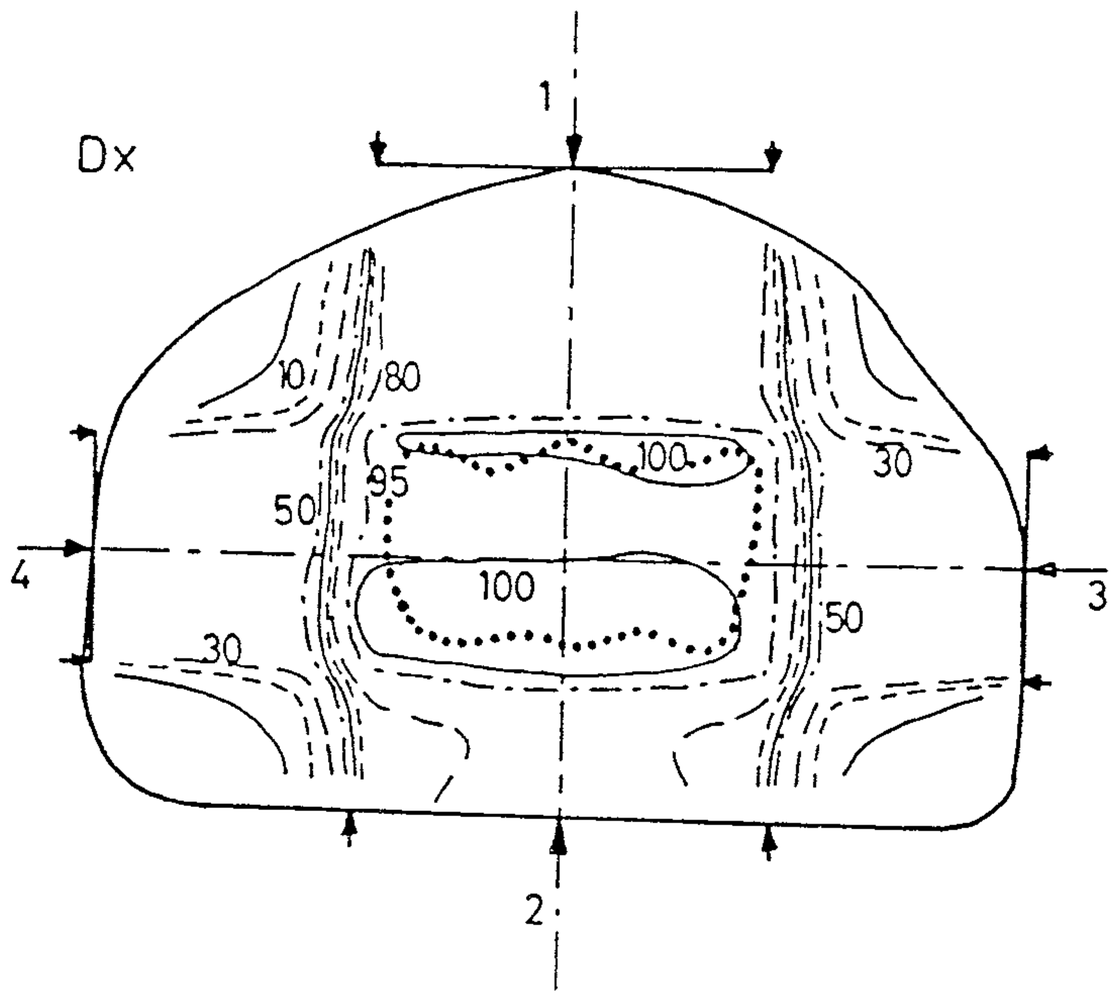
Target Volume

The target volume contains those tissues that are to be irradiated to a specified absorbed dose according to a specified time-dose pattern. For curative treatment, the target volume consists of the demonstrated tumor(s), if present, and any other tissue with presumed tumor.

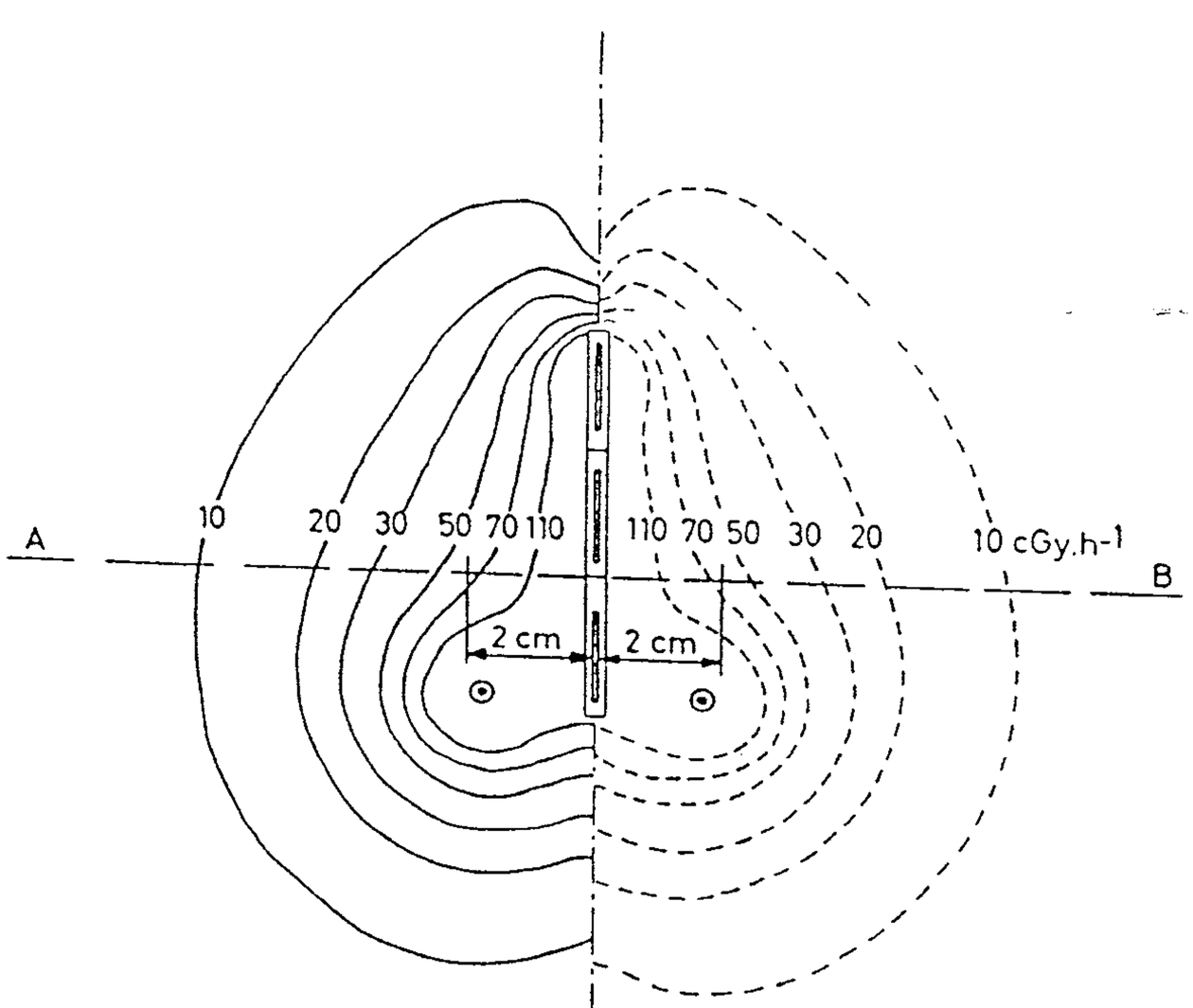
For any given situation, there may be more than one target volume. This is particularly the case for treat-

Field No	Size (cm x cm)	Weighting factors
1	17 x 20	37 %
2	17 x 20	37 %
3	10 x 20	13 %
4	10 x 20	13 %





2.2a



——— RADIUM TUBES

uterine tubes 3 x 10 mg

vaginal tubes 2 x 15 mg

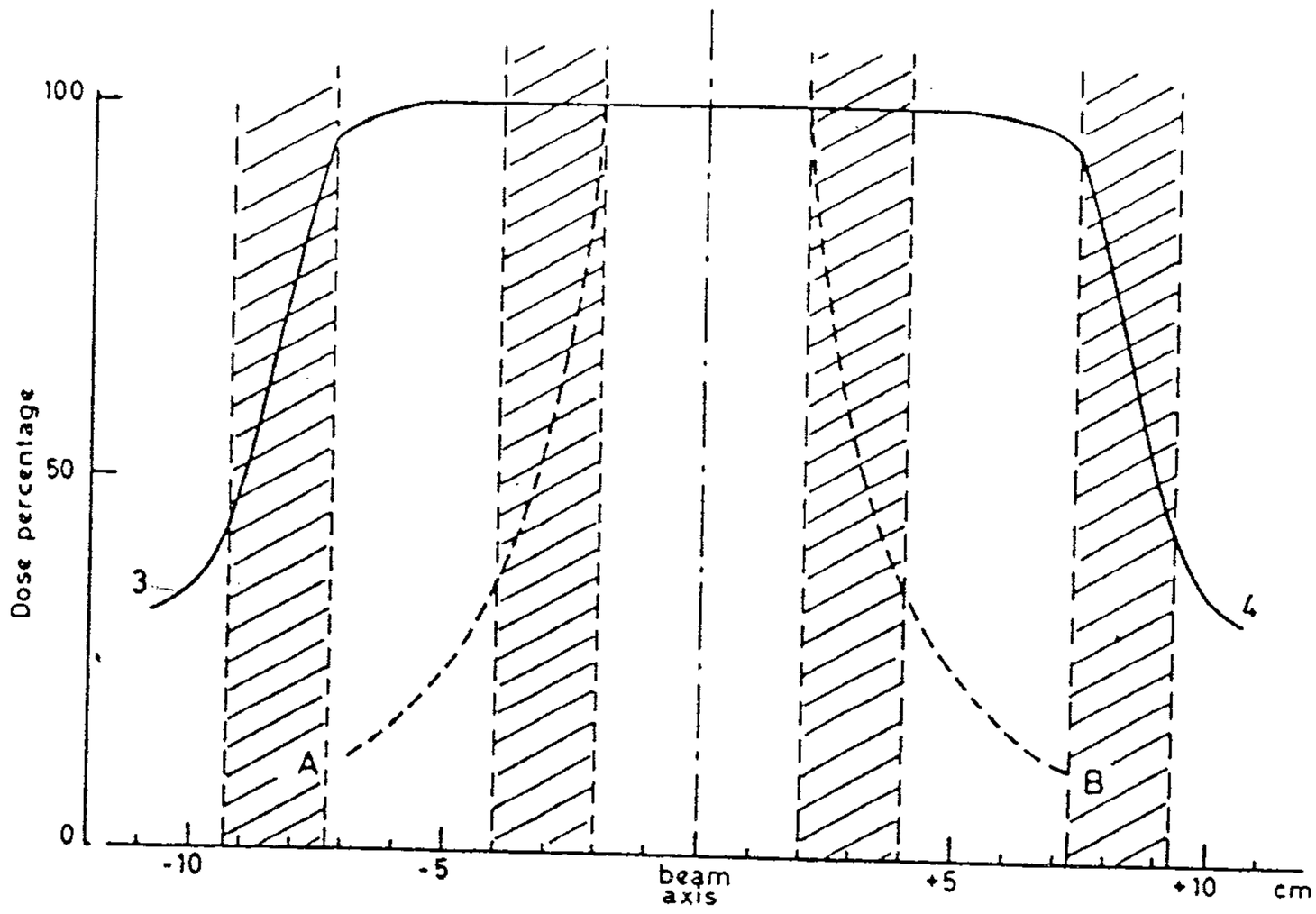
filtration 1 mm Pt

----- IRIDIUM WIRES

(same reference air kerma rates as radium tubes)

correction made for oblique filtration

2.2b



2.2c

Fig. 2.2. Comparison of absorbed dose patterns between external and intracavitary therapy. **2.2a** shows the dose distribution for an irradiation of the pelvis with a ^{60}Co teletherapy machine and four fields—the so-called "box technique" (see ICRU Report 29, Figure 3.4). The border of the target area is indicated by the heavy dotted line. **2.2b** shows a typical dose distribution in an intracavitary application (IAEA, 1972; Dutreix *et al.*, 1982). **2.2c** shows the dose variation along a lateral axis. The full line refers to external therapy (Figure 2.2a, along the beam axis 3 and 4). The dotted line refers to intracavitary therapy (Figure 2.2b, along the AB axis). The absorbed dose has been normalized to 100% at a distance of 2 cm from the uterine axis. The shaded areas (2 cm wide) show the high dose-gradient regions beyond the border of each of the two treatment volumes.

ment of cervix carcinoma where, depending on the extent of disease, some target volumes may be treated partly or totally by an intracavitary application, while others are treated mainly by external therapy. The target volume(s) must always be described, independently of the dose distribution, in terms of the patient's anatomy, topography and tumor volume. For the purpose of reporting intracavitary treatment, that part of the target volume which has to be irradiated by means of intracavitary application should be separately described. It should also be stated whether this volume will receive treatment only by intracavitary application or will receive treatment by both modalities. The physical dimensions of the target volume must be given. Examples illustrating target volumes in patients with carcinoma of the cervix are given in Figure 2.3.

Treatment Volume

The treatment volume is defined as the volume enclosed by a relevant isodose surface selected by the radiotherapist, and encompasses at least the target volume. In intracavitary therapy, it is not feasible to express the value of the isodose surface enclosing the treatment volume as a percentage of the dose at any point within the treatment volume. This is because of the steep dose gradient around the sources and the variation encountered in the techniques used. It is necessary to plan the treatment to include the *target volume* within the *treatment volume*.

Reference Volume

The reference volume is defined as the volume enclosed by the *reference isodose surface*. In order to facilitate intercomparisons between radiotherapy centers, it is necessary to agree upon a *reference dose level*. The treatment dose level defining the treatment volume may be equal to or different from this reference dose level. For reporting intracavitary therapy, it is necessary to determine the dimensions of the reference volume.

Irradiated Volume

The irradiated volume is that volume, larger than the treatment volume, which receives an absorbed dose

8 . . . 2. *Definition of Terms and Concepts Currently Used in Intracavity Therapy*

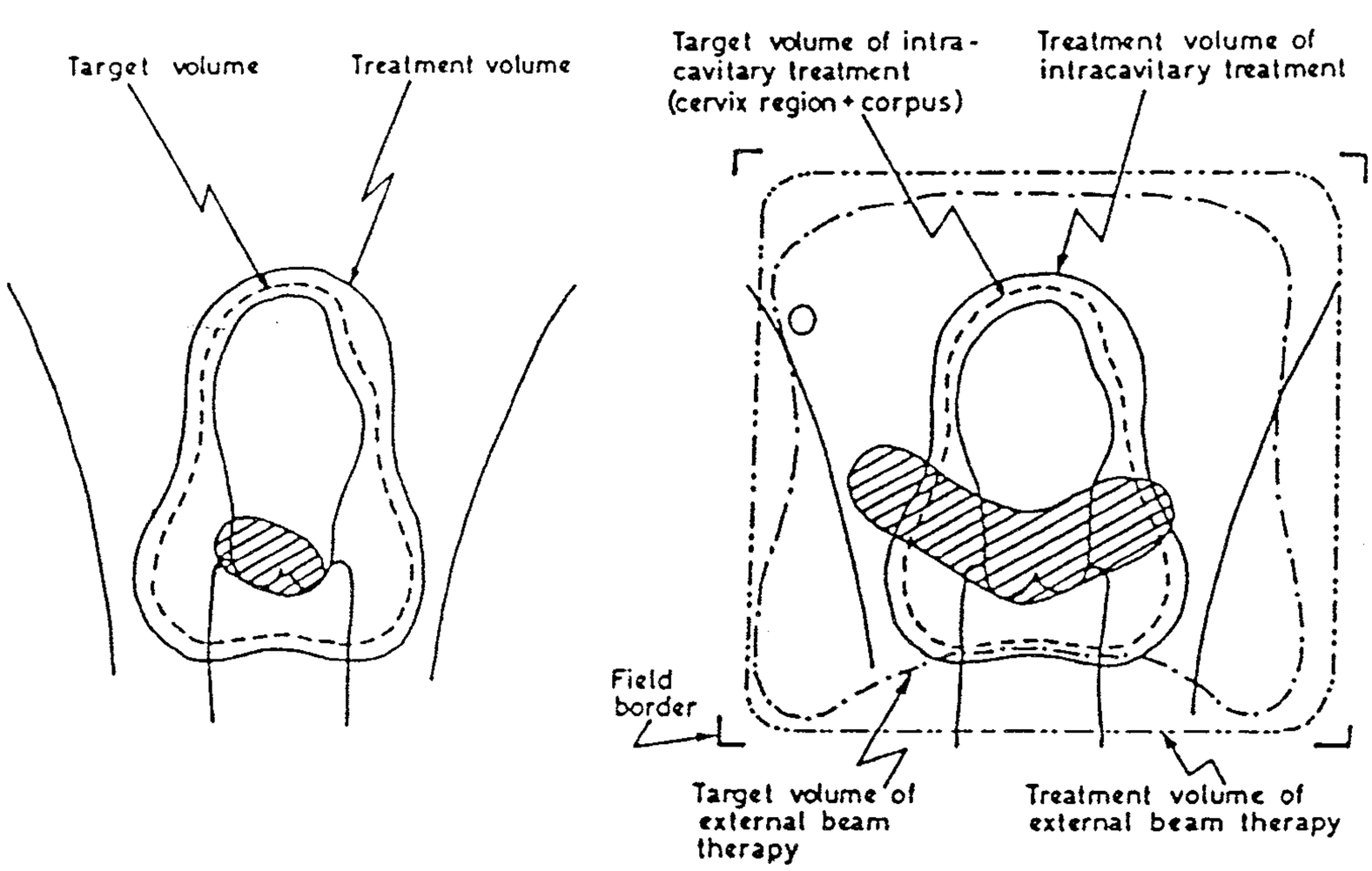


Fig. 2.3. Treatment of cervix carcinoma. Stage II.b. Examples of target volumes and treatment volumes. A—Tumor volume (hatched): 4 cm × 3 cm × 2 cm. The almost pear-shaped target volume includes the entirety of palpable and visible tumor as well as the whole uterus. The planned, pear-shaped treatment volume encompasses the target volume. Additional methods such as combined surgery or combined external radiation may be used. B—Tumor volume (hatched): 9 cm × 5 cm × 4 cm. The target volume for brachytherapy will only include the major parts of the tumor volume, but will include the whole uterus. To treat the rest of the tumor volume and further subclinical disease throughout the pelvis and the regional lymphatics, external beam therapy will be used, and brachytherapy will be used as boost therapy.

considered to be significant in relation to tissue tolerance. The significant absorbed dose level can be expressed as a percentage (e.g., 50%) of the agreed dose level (see Section 3.3.2.a).

Organs at Risk

Organs at risk are those radiosensitive organs in or near the target volume which would influence treatment planning and/or the prescribed dose. For example, in an intracavitary application for cervix carcinoma, the main organs at risk are rectum, bladder, ureters and possibly sigmoid colon.

2.3 Specification of Radioactive Sources

It is recommended that radioactive sources be specified in terms of "*reference air kerma rate*". The reference air kerma rate of a source is the kerma rate to air, in air, at a reference distance of 1 meter, corrected for air attenuation and scattering. For this purpose this quantity is expressed in $\mu Gy \cdot h^{-1}$ at one metre.

The *total reference air kerma* is the sum of the products of the reference air kerma rate and the duration of the application for each source.

3. Recommendations for Reporting Absorbed Doses and Volumes in Intracavitary Therapy

3.1 Introduction

As the absorbed dose to soft tissue from intracavitary applications is so highly nonuniform throughout the target volume, the concepts of maximum, mean, median and modal target absorbed dose, as defined in ICRU Report 29 (ICRU 1978), are not relevant. The minimum target absorbed dose is the only useful concept and is, by definition, equal to the treatment absorbed dose level.

For external beam therapy, it has been recommended that the target absorbed dose be the absorbed dose at one or more specification points which are representative of the dose distribution throughout the target volume. These specification points could be established with respect to the target volume or to the beam axes, or both.

The situation is more difficult in intracavitary therapy due to the steep dose gradient in the vicinity of the sources, i.e., throughout the tumor or the target volume. Under these conditions, the specification of the target absorbed dose in terms of the absorbed dose at specific point(s), in the vicinity of the sources, becomes less meaningful and a different approach is required. Instead of a target-dose specification, a volume specification is recommended.

Specification of an intracavitary application in terms of the "reference volume" enclosed by the reference isodose surface is proposed in this Report. However, as the different isodose surfaces are close to each other, *the indication of the reference volume must be supplemented, for safety reasons, by the indication of the total reference air kerma* which, for radium treatments, is proportional to the number of "mg·h". *In addition, a record of absorbed dose at reference points related to organs at risk or to bony structures is recommended. The time-dose pattern* shall also be clearly indicated (see Section 4).

The present recommendations do not imply a modification of the method used for the calculation of the treatment duration, but they imply the calculation of specific quantities to be determined for reporting.

The recommendations presented in this Report must be considered a minimum requirement for reporting. On the other hand, the reported parameters will be meaningful only to the extent that *the technique of the particular intracavitary application* has been completely described.

This report deals mainly with the treatment of cervix carcinoma for which the anatomical region of interest is similar for every patient and the possible variation in the position of the radioactive sources is limited. However, for other gynecological intracavitary situations the same philosophy can be adopted, but some of the numerical values and definitions may need to be modified according to the type of application.

3.2 Description of the Technique

It is recommended that the technique be described on the basis of the guidance given below.

3.2.1 The Sources

(i) radionuclide;
(ii) reference air kerma rates;
(iii) shape, filtration, etc.

3.2.2 Simulation of Linear Sources

a) When a linear source is simulated by a set of point sources, the activity of these point sources and their separation(s) must be indicated.
b) When moving sources are used to simulate a set of different sources in fixed position, in order to produce an appropriate dose distribution, the following indications are required:
   (i) type of movement (continuous or stepwise, step distance);
   (ii) unidirectional or oscillating movement;
   (iii) range of movement or oscillation;
   (iv) speed in different sections of the applicator, or dwell times of the source at different positions.

3.2.3 The Applicator

Reference to the applicator is sufficient when a complete description has already been published, provided that there is no significant difference between the applicator used and the one described in the literature. To avoid confusion, it is recommended that the applicator be described, including the name of the manufacturer. The description should include information on the following points:

(i) rigid (or not), consequently with fixed known geometry (or not) of the complete applicator;
(ii) rigid uterine source with fixed curvature (or not);
(iii) connection between vaginal and uterine applicators, i,e., fixed, loose (semi-fixed), free;
(iv) type of vaginal sources, number and orientation of line sources, special sources (box, ring, etc.);
(v) high atomic number shielding materials in vaginal applicator (or not).

3.3 Recommendations for Reporting

Three approaches are proposed to specify intracavitary application for cervix carcinoma; they complement each other and it is recommended that they be combined.

3.3.1 Total Reference Air Kerma

When radium was used exclusively, the product of the "quantity of radioactive material" and the duration of the treatment was given as minimal information. This is the *"concept of the mg-h"*. It becomes increasingly difficult to use the product mg-h for specifying an intracavitary application with other radionuclides, even if milligrams of radium are replaced by the term "milligram-radium equivalent" which can be misleading (see Appendix). As noted in Section 2.3, the use of total reference air kerma is proposed in this Report. This quantity is unambiguous and easy to calculate. It is proportional to the integral dose to the patient and can also serve as a useful index for radiation protection of personnel.

In addition, the inverse square law applied to the total reference air kerma allows evaluation, to a reasonable approximation, of the absorbed dose delivered during treatment at distances from the sources down to 20–10 cm. When the distance of a point P from the center C of the volume occupied by the sources is larger than 2.5 times the largest dimension of that volume, the dose rate obtained at P from the actual distribution of sources differs by less than 4% from that obtained by assuming that all of the sources are located at C (Dutreix *et al.*, 1982).

However, the simple calculation of the total reference air kerma does not allow one to derive, even roughly, the absorbed dose in the immediate vicinity of the sources (i.e., in the tumor or target volume) and, in particular, it should be stressed that an accurate and simple relation cannot be derived between total reference air kerma and absorbed doses at specific points such as A and B (see Figure 1.3.).

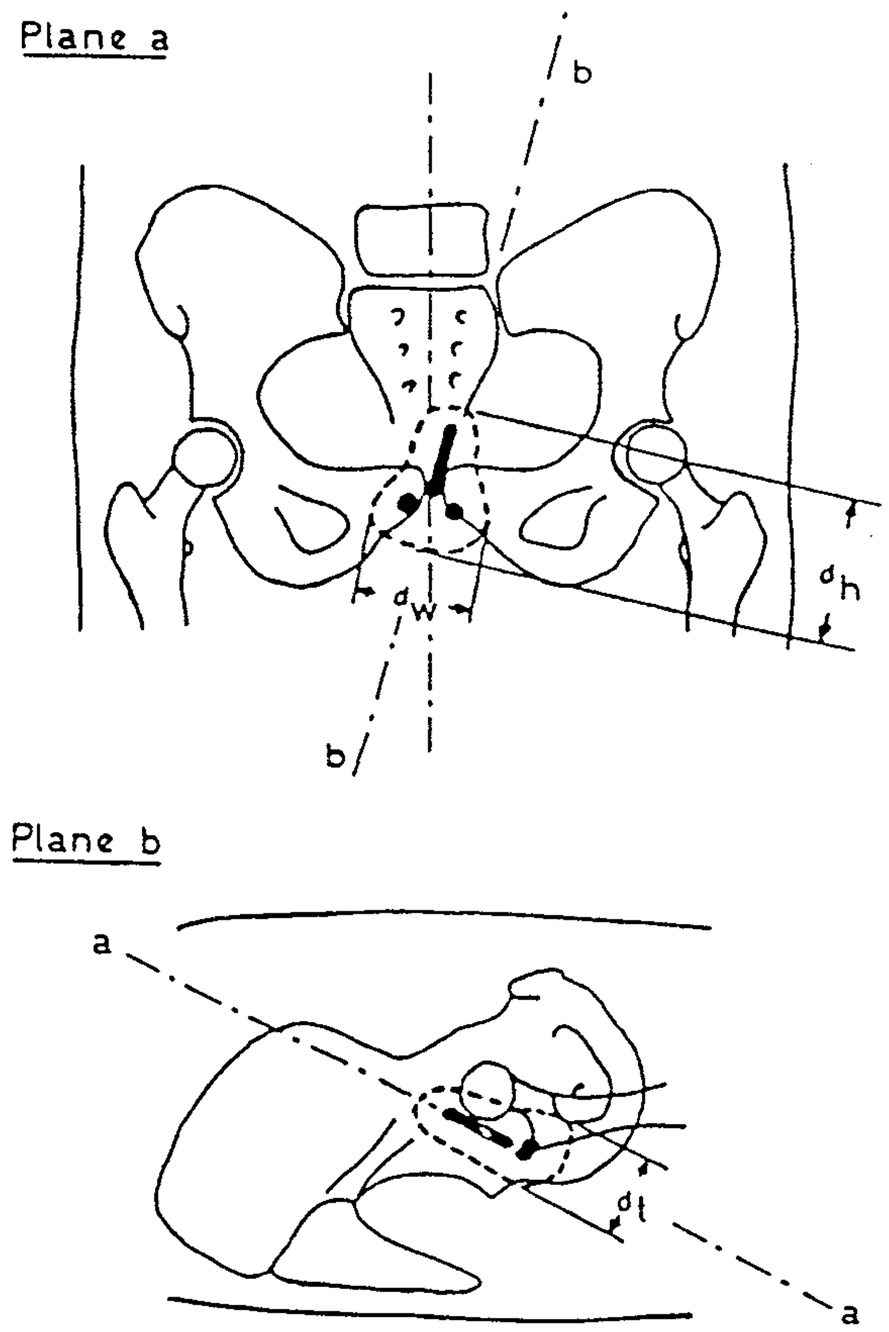


Fig. 3.1. Geometry for measurement of the size of the pear-shaped 60 Gy isodose surface (broken line) in a typical treatment of cervix carcinoma using one rod-shaped [illegible] applicator and 2 ovoidal applicators. **Plane a** is the "oblique" frontal plane that contains the intrauterine device. The oblique frontal plane is obtained by rotation of the frontal plane around a transverse axis, **Plane b** is the "oblique" sagittal plane that contains the intrauterine device. The oblique sagittal plane is obtained by rotation of the sagittal plane around AP axis. The *height* (d_h) and the *width* (d_w) of the reference volume are measured in *plane a* as the maximal sizes parallel and perpendicular to the uterine applicator, respectively. The *thickness* (d_t) of the reference volume is measured in *plane b* as the maximal size perpendicular to the uterine applicator.

3.3.2 Description of the Reference Volume

The description of the *reference volume*, i.e., the tissue volume encompassed by a reference isodose surface, is proposed for specification in reporting. The reasons for this approach are described in Sections 2.2.1., 2.2.2. and 3.1.

a. Dose Level

An absorbed dose level of 60 Gy is widely accepted as the appropriate reference level for *classical low dose-rate therapy*. When two or more intracavitary applications are performed, the absorbed dose to consider is that resulting from all applications. The time-dose pattern should be clearly stated (see Section 4.2).

When intracavitary therapy is combined with external beam therapy, the isodose level to be considered is the difference between 60 Gy and the dose delivered at the same location by external beam therapy. For example, if a dose of 20 Gy were delivered to the whole pelvis by external beam therapy, the isodose level to be considered would be 60 − 20 Gy = 40 Gy. Nevertheless, it is recognized that the combined dose does not nec-

essarily produce the same effect as a similar dose from intracavitary therapy alone.

For intracavitary therapy at medium or high dose rates, the therapist has to indicate the dose level which he believes to be equivalent to 60 Gy delivered at the classical low dose rate and should clearly state this.

b. Reference Volume: Description of the Pear-Shaped Volume

When uterine source(s) are combined with vaginal sources, or when the uterine source is more heavily loaded at the lower end, the tissue volume to be described presents a pear shape with its longest axis coincident with the intrauterine source. This reference volume is defined by means of three dimensions (see Figure 3.1):

(i) the *height* (d_h) is the maximum dimension along the intrauterine source and is measured in the oblique frontal plane containing the intrauterine source;

(ii) the *width* (d_w) is the maximum dimension perpendicular to the intrauterine source and is measured in the same oblique frontal plane;

(iii) the *thickness* (d_t) is the maximum dimension perpendicular to the intrauterine source and is measured in the oblique sagittal plane containing the intrauterine source.

The definitions of d_h, d_w and d_t are proposed in order to minimize the number of calculations. These dimensions are usually expressed in cm. The volume estimated from the intersections of the surface of a pear-shaped volume on two conventional planes does not necessarily represent the size of the true reference volume. However, for most applications they do not differ from the maximum dimensions of the reference volume by more than 1 or 2 mm.

3.3.3 Absorbed Dose at Reference Points

Several reference points are in current use. Some are relatively close to the sources and related either to the sources or to organs at risk; others are relatively far from the sources and are related to bony structures. The following definitions apply to the case where the doses are calculated from two perpendicular radiographs, AP and lateral. When other methods are used, such as stereographic x-ray films, oblique perpendicular radiographs or transverse sections (CT scans), the calculations need to be modified.

a. Reference Points Close to the Sources and Related to the Sources

As such points are located in a region where the dose gradient is high, any inaccuracy in the determination of distance results in large uncertainties in the absorbed doses evaluated at these points. Such calculated absorbed doses do not, therefore, seem an appropriate means of characterizing an intracavitary application and/or of specifying the target absorbed dose, particularly if rigid source combinations are not used. Such points are not recommended.

b. Reference Points Relatively Close to the Sources but Related to Organs at Risk

The determination and specification of the absorbed dose to organs at risk (bladder, rectum, etc.) are obviously useful with respect to normal tissue tolerance limits. However, such information will be meaningful only to the extent that it is obtained *and expressed* in precise and well-codified ways.

(i) *Calculated Values:* Reference points for the expression of the absorbed dose to the bladder and the absorbed dose to the rectum (see Figure 3.2.) have been proposed by Chassagne and Horiot (1977).

The *bladder reference point* is obtained as follows. A Foley catheter is used. The balloon must be filled with 7 cm^3 of radio-opaque fluid. The catheter is pulled downwards to bring the balloon against the urethra. On the lateral radiograph, the reference point is obtained on an anterio-posterior line drawn through the center of the balloon. The reference point is taken on this line at the posterior surface of the balloon. On the frontal radiograph, the reference point is taken at the center of the balloon.

The *point of reference for the rectal dose* is obtained as follows. On the lateral radiograph, an anteroposterior line is drawn from the lower end of the intrauterine source (or from the middle of the intravaginal sources). The point is located on this line 5 mm behind the posterior vaginal wall. The posterior vaginal wall is visualized, depending upon the technique, by means of an intravaginal mould or by opacification of the vaginal cavity with a

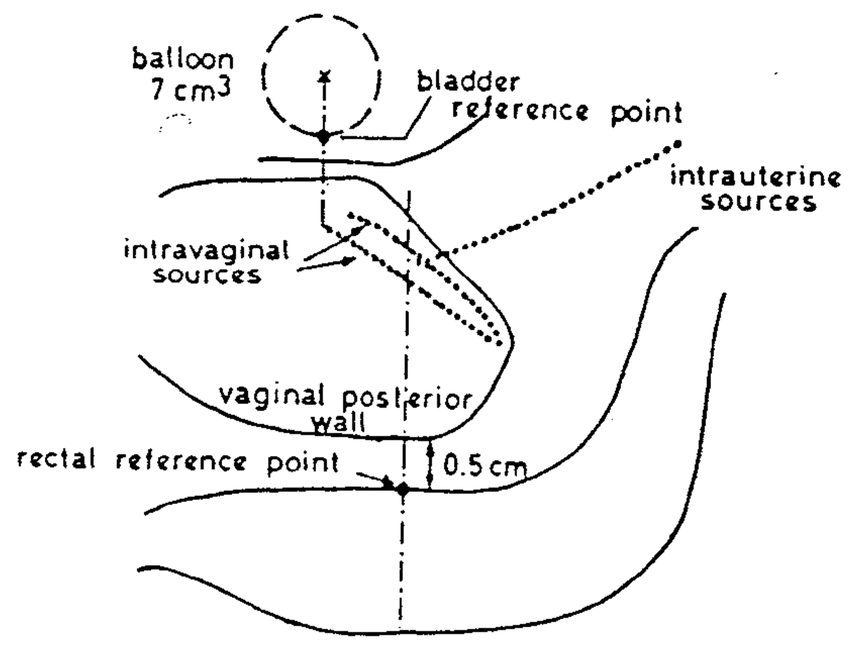


Fig. 3.2. Determination of the reference points for bladder and rectum (see text).

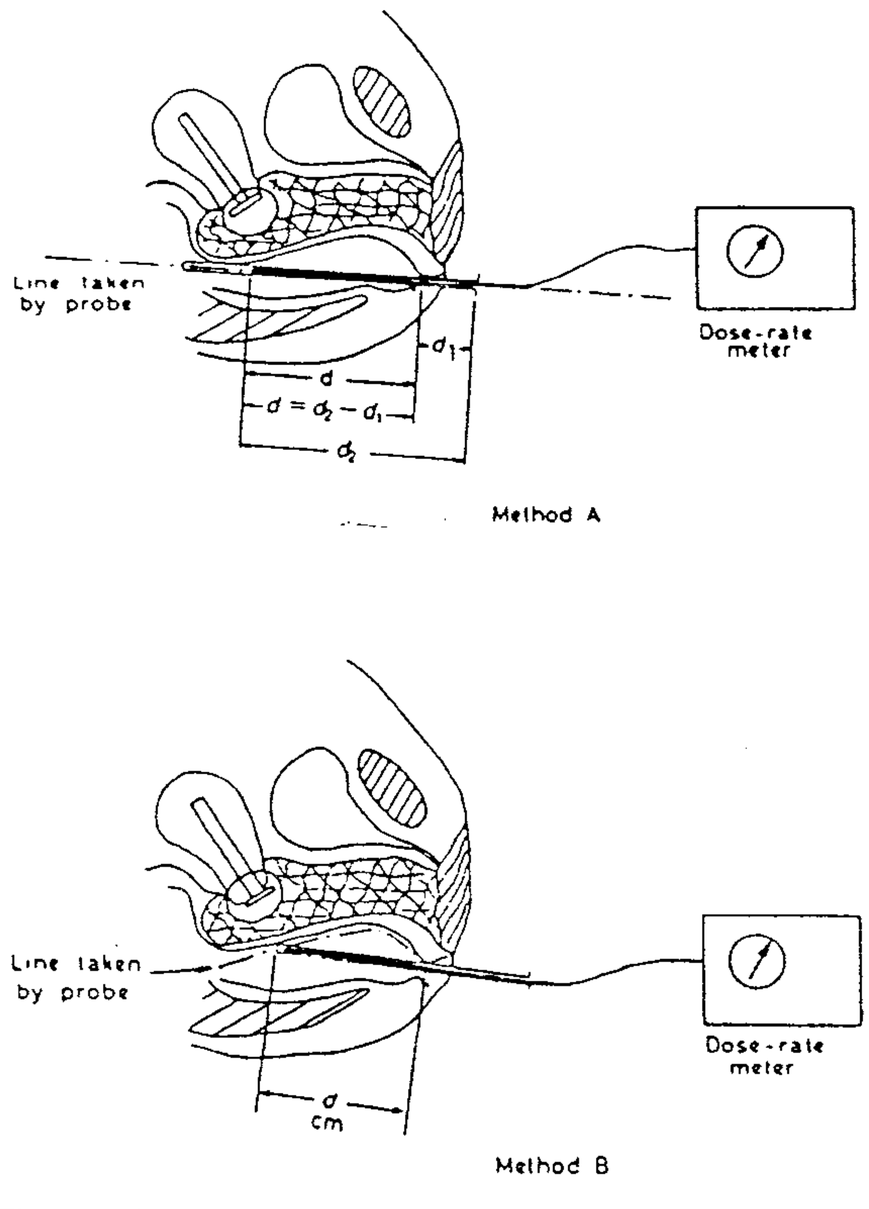


Fig. 3.3. Measurement of the rectal dose rate. Following the insertion of the source applicators, either pre-loaded (low-activity treatment) or manually loaded with *low*-activity sources identical in design to those used during *high*-activity after-loaded treatment, the rectal dose is measured.

Method A: The measuring probe is moved relative to a rigid guide tube inserted into the rectum and held in position. The point of maximum rectal dose rate is noted and the distance "*d*" in cm from the anal verge deduced.

Method B: The measuring probe is moved so that the tip of the probe is moved along the mid-line of the recto-vaginal septum until the point of maximum dose rate is reached. Distance is taken as a direct reading on the central tube at the anal verge. The dose-rate and distance are recorded.

The major disadvantage of method "A" is that the probe tip cannot follow closely the surface of the anterior rectal wall. However, allowance for the distance of the probe sensor from the vagino-rectal septum needs to be taken into account.

radio-opaque gauze used for the packing. On the AP radiograph, this reference point is at the lower end of the intrauterine source or at the middle of the intravaginal source(s).

(ii) *Monitoring of the Absorbed Dose Rate to the Rectum:* An alternative to calculating the rectal dose is to measure the dose, or dose rate, at different points along the anterior rectal wall to ensure that no area of the rectal mucosa receives a dose above the tolerance level. This type of measurement requires special care in positioning the measuring probe. An example is given in Figure 3.3. (O'Connell *et al.*, 1967; Joslin *et al.*, 1972).

c. *Reference Points Related to Bony Structures*

(i) The *lymphatic trapezoid* is obtained as follows (see Figure 3.4): A line is drawn from the junction of S1-S2 to the top of the symphysis. Then a line is drawn from the middle of that line to the middle of the anterior aspect of L4. A trapezoid is constructed in a plane passing through the transverse line in the pelvic brim plane and the midpoint of the anterior aspect of the body of L4. A point 6 cm lateral to the midline at the inferior end of this figure is used to give an estimate of the dose rate to mid-external iliac lymph nodes (labeled R. EXT and L. EXT for right and left external, respectively). At the top of the trapezoid, points 2 cm lateral to the midline at the level of L4 are used to estimate the dose to the low para-aortic area (labeled R. PARA and L. PARA). The midpoint of a line connecting these two points is used to estimate the dose to the low common (labeled R. COM and L. COM) iliac lymph nodes (from Fletcher, 1980).

(ii) The *pelvic-wall reference point* (Chassagne *et al.*, 1977) can be visualized on an AP and a lateral radiograph and related to fixed bony structures. This point is intended to be representative of the absorbed dose at the distal part of the parametrium and at the obturator lymph nodes (see Figure 3.5.). On an AP radiograph, the pelvic-wall reference point is intersected by the following two lines: a horizontal line tangential to the highest point of the acetabulum, a vertical line tangential to the inner aspect of the acetabulum. On a lateral radiograph, the highest points of the right and left acetabulum, in the cranio-caudal direction, are joined and the lateral projection of the pelvic-wall reference point is located at the mid-distance of these points.

Evaluation of the absorbed dose at reference points, related to well-defined bony structures and lymph node areas, is particularly useful when intracavitary therapy is combined with external beam therapy. It is also useful in helping to avoid an overdose when intracavitary therapy is to be followed by surgery.

3.3.4. Calculation of Dose Distribution

The present recommendation, in particular the description of the reference volume encompassed by the 60-Gy isodose surface, necessitates the *computation of complete dose distributions in several planes.*

The respective planes for which the dose distribution is to be computed will depend on the technique and the particular clinical situation. However, as a minimum

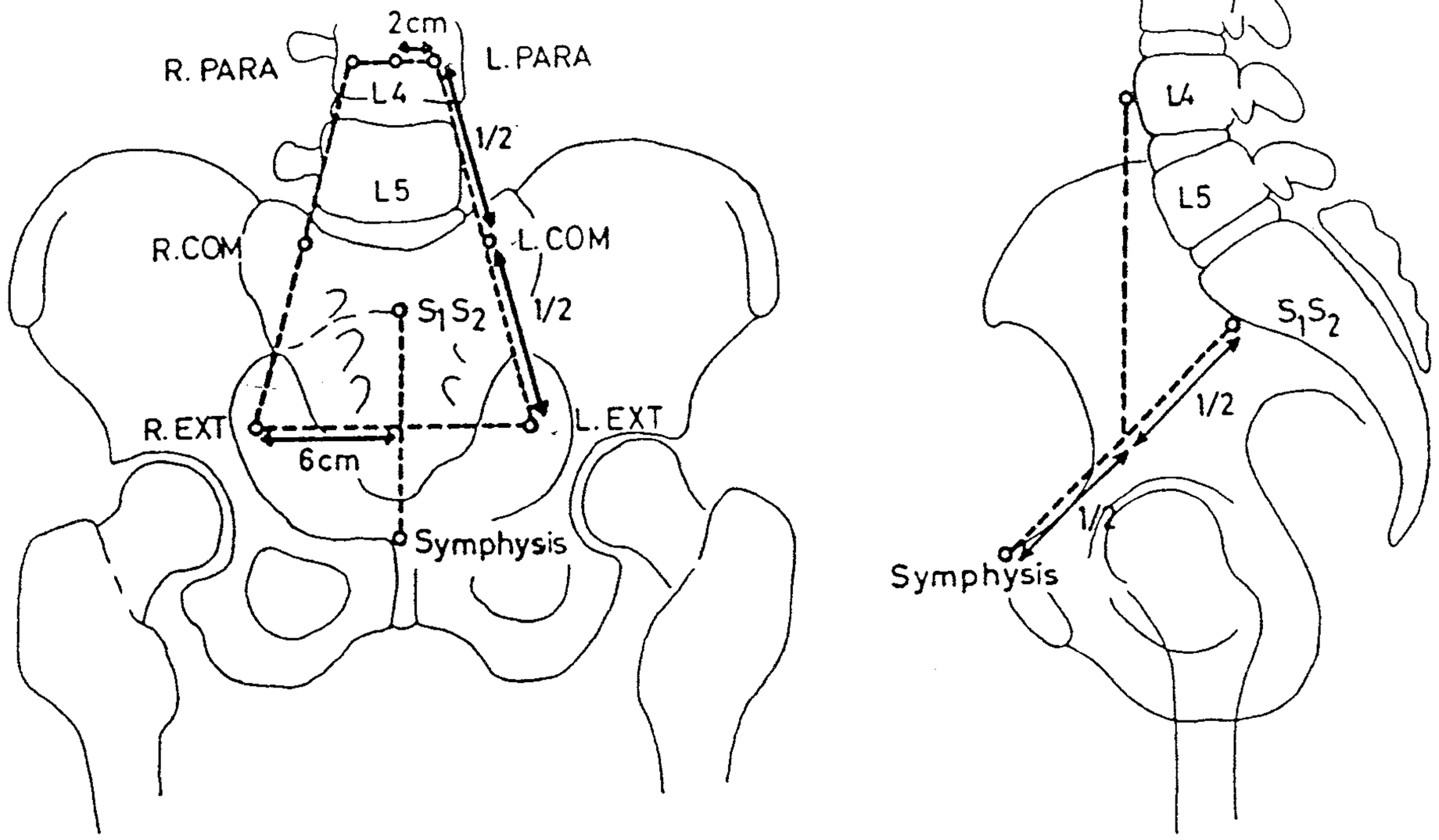


Fig. 3.4. Determination of the lymphatic trapezoid (see text). On the left is an anteroposterior view and on the right a lateral view.

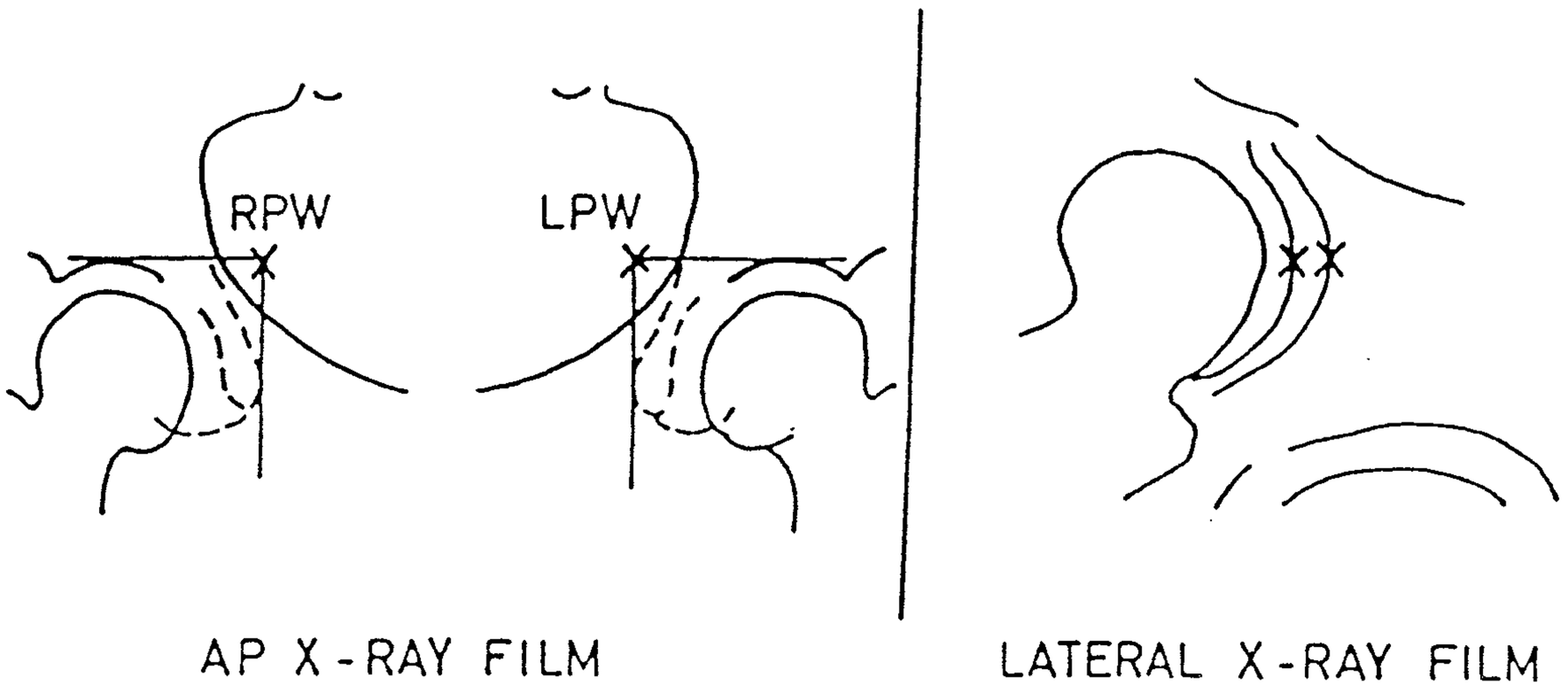


Fig. 3.5. Determination of the right (RPW) and left (LPW) pelvic wall reference points (see text).

requirement, it is recommended that the dose distributions be computed in two planes: the oblique frontal plane and the oblique sagittal plane both containing the intrauterine source.

When practicable, it is recommended that dose distributions be calculated in additional sets of planes and that these dosimetric data be correlated with that obtained from radiographs or CT sections, in order to determine the absorbed dose at any relevant anatomical point.

While this additional information will be of value in assessing effects in any individual patient, it will also provide:

(i) the possibility of comparing the methods of specification used in different centers and of evaluating their respective merits;

(ii) the possibility of comparing the methods of specification used in historical series (mg·h, points "A" and "B") with the methods recommended in the present Report;

(iii) the possibility of deriving new clinical and radiobiological data and correlations which could improve treatment techniques and develop further the method of specification.

3.4 Definition of the 60 Gy Reference Volume in Special Situations

3.4.1 One Linear Source Only

In some situations only one linear source is present:

—in the case of a narrow vagina with a uterine source protruding into the vaginal cavity,

—in the case of vaginal irradiation with a central source from a cylindrical applicator.

In estimating the volume (Section 3.3.2.b) in this simple case, the width is equal to the thickness.

3.4.2 Vaginal Sources Only

When only vaginal sources are present, width is the largest dimension from right to left in an oblique frontal plane through the main axis of the vagina.

Thickness is the largest dimension in a direction perpendicular to the above oblique plane. Height is measured along the vaginal axis, and is commonly shorter than the other two dimensions.

3.4.3 Rigid Applicator

Provided that there is a fixed connection between vaginal and uterine sources, pre-calculated isodose surfaces can be obtained for given loadings of the applicator. Therefore, pre-calculated dimensions of height, width and thickness can be given (IAEA, 1972).

3.4.4 Uterine Packing (In Endometrial Cancer)

In connection with uterine packing, the same definitions of height, width and thickness given in Section 3.3.2 can be used. However, two facts need to be noted:

—width and thickness are usually located at the level of the uterine fundus (the pear-shaped volume is reversed),

—height should be determined in the oblique frontal plane, which gives the maximum dimension.

4. Time-Dose Pattern

4.1 Radiobiological Considerations

Radiobiological effects often depend on dose rate but to a greater or lesser extent according to the actual level of the dose rate and the nature of the effect (Hall, 1978). For example, it is generally observed for mammalian cells irradiated *in vitro* that for dose rates larger than about 1 Gy·min^{-1} survival is independent of dose rate, but becomes increasingly dependent on dose rate at lower rates. For dose rates below about 1 Gy·h^{-1} survival again becomes independent of dose rate.

The relationship between dose rate and *tissue* response *in vivo* is complex because many factors have to be taken into account such as cell distribution, repair of potentially lethal lesions, and, for tumors, reoxygenation. As far as cell proliferation is concerned, its role is probably a minor one in brachytherapy applications.

In each brachytherapy application, there is necessarily both a marked *dose gradient* and a marked *dose rate gradient* as a function of distance from the sources.

The possible importance of changes in time factors (dose rate) in determining the biological or clinical effect should not be underestimated since there may be a shell of tissues surrounding the sources where differences in dose rate may be significant (Van Limbergen *et al.*, 1985). Its location and thickness will vary with the total reference air kerma rate and the application time. In addition, the time between fractions is important in the case of fractionated high dose-rate intracavitary therapy.

It can be concluded that any significant change in the source strength and the time-dose pattern should be made with the greatest care. Furthermore, early tissue reactions alone should not be used to select the prescribed dose since late reactions, which are most relevant, depend to a greater extent on dose rate.

4.2 Recommendations for Reporting Time-Dose Pattern

Sufficient data on the effect of dose-rate on various tissues are not available at the present time. Therefore, no correction factors for dose rate can be recommended, but *the duration of the application should be stated.*

When more than one application is performed, the duration of each should be reported, as well as the time interval(s) between them.

Similarly, when external beam therapy and intracavitary therapy are combined, the time-dose schedule of the whole treatment should be reported.

5. Conclusions and Final Recommendations

In intracavitary therapy, due to the high dose-rate gradient, the specification of the target absorbed dose as that dose observed at one (or several) reference point(s) within the target volume or close to the sources, does not appear to be meaningful. Under these conditions, the same approach to reporting as in external beam therapy cannot be recommended.

The following are proposed in this Report (see Table 5.1).

First, as already pointed out in ICRU Report 29 (ICRU, 1978), any method of specification will be meaningful only to the extent that *the treatment technique* has been completely described.

Second, the *total reference air kerma* should be stated. For a given method of application (source geometry and relative loads), the doses delivered at the different tissues or organs are directly proportional to the total reference air kerma.

Third, it is recommended that the *reference volume be described in terms of the height, width and thickness* of the volume enclosed in the 60 Gy isodose surface for cervix-carcinoma treatment by low dose rates. For higher dose rates a dose level lower than 60 Gy has to be selected.

Fourth, the absorbed dose at reference points in organs at risk (rectum, bladder) should be determined (computed or measured) and expressed in well-codified ways to provide additional safety limits.

In addition, the absorbed dose(s) at reference point(s) related to bony structures (*lymphatic trapezoid and pelvic-wall reference points*) should also be reported.

Finally, the *time-dose pattern* should be completely specified.

TABLE 5.1—*List of data needed for reporting intracavitary therapy in gynecology*

Data Needed	Paragraph	Page
DESCRIPTION OF THE TECHNIQUE USED	3.2	9
TOTAL REFERENCE AIR KERMA (cGy at 1 metre)	3.3.1	10
DESCRIPTION OF THE REFERENCE VOLUME	3.3.2	10
—Dose level if not 60 Gy	3.3.2.a	10
—Dimensions of the reference volume (height, width, thickness)	3.3.2.b	11
ABSORBED DOSE AT REFERENCE POINTS	3.3.3	11
Bladder reference point	3.3.3b	11
Rectal reference point	3.3.3b	11
Lymphatic trapezoid	3.3.3c	12
Pelvic wall reference point	3.3.3c	12
TIME DOSE PATTERN	4	15

APPENDIX

Specification of Radioactive Sources Used in Intracavitary Therapy

Only some aspects of the problem of the specification of sources will be reported here since this topic will be dealt with at length in a forthcoming ICRU Report and has been treated recently (Dutreix *et al.*, 1982).

(1) When radium tubes were the only radioactive sources used in intracavitary therapy, their strength was specified in terms of the *mass of radium* in mg contained in the tube.

(2) When artificial radionuclides became available, the sources were first specified in terms of their *activity* in mCi.

(3) Due to the influence of self-absorption and filtration within the source and its sheath, the *"contained activity"* was of little practical interest and the concept of "apparent activity" was introduced. The apparent activity of a source was defined as the activity of a point source of the same radionuclide which would deliver the same exposure rate in air at the same distance from the center of the actual source (the distance should be large enough so that the actual source can be considered as a "point source").

Instead of the term apparent activity, the expression "equivalent activity" has also been used (IAEA, 1967 and ICRU, 1970), but it could lead to some confusion with the expression "milligram-radium equivalent". This is because sources of different radionuclides with the same apparent activity will not give equivalent dose distributions.

(4) In order to compare radium substitutes directly with radium itself, sources were specified in "milligram-radium equivalent". The radium equivalent mass (mg-Ra equivalent) of a source is the mass of radium filtered by 0.5 mm of platinum which leads to the same exposure rate as that from the radioactive source of interest at the same distance. Thus, the dose rate at a given distance from a typical 10 mg radium tube filtered by 1 or 2 mm of platinum is less than the dose rate delivered at the same distance by a 10 mg Ra equivalent source which was standardized to 0.5 mm platinum.

(5) Later, the strength of a source was specified in terms of its output, i.e., exposure rate at a reference distance. The reference exposure rate in milliroentgens per hour at 1 meter was used ($mR \cdot h^{-1} \cdot m^2$) (Wambersie *et al.*, 1973; NCRP, 1974; Dutreix, 1974; Dutreix and Wambersie, 1975).

(6) Recently, the Comité Français pour la Mesure des Rayonnements Ionisants (CFMRI, 1983) has recommended that radioactive sources be specified in terms of *"reference air kerma rate"* ("débit de kerma normal dans l'air"). The reference air kerma rate of a source is the kerma rate to air, in air, at a reference distance of one metre, corrected for air attenuation and scattering. This quantity is expressed in $\mu Gy \cdot h^{-1}$ at 1 m. For example, a "point" source containing 1 mg of radium, 0.5 mm Pt filtration, produces an exposure rate of 8.25 ± 0.10 $R \cdot h^{-1}$ at 1 cm or 8.25×10^{-4} $R \cdot h^{-1} \cdot m^2$. Taking into account the conversion factor from exposure to air kerma (0.873 $cGy \cdot R^{-1}$) and the correction for the difference in filtration (0.93), a source containing 10 mg of radium, 1 mm Pt filtration, produces an air kerma rate of 67 $\mu Gy \cdot h^{-1}$ at 1 m.

(7) The *total reference air kerma* is the sum of the products of the reference air kerma rate and the duration of the application for each source.

By way of example, we consider an application performed with 25 mg of radium as an intrauterine source and 40 mg of radium as the vaginal sources. If the radium tubes are filtered by 1 mm Pt, 65 mg of radium yield a reference air kerma rate of 435 $\mu Gy \cdot h^{-1} \cdot m^2$. Therefore, for example (for radioprotection purposes), at one metre from the patient the dose equivalent rate will not exceed about 0.4 $mSv \cdot h^{-1}$.

Assuming that the sources are left *in situ* for 6 days (144 hours), the total reference air kerma is equal to $435 \times 144 \times 10^{-6}$ Gy or 6.27 cGy at 1 m. The dose delivered to the sigmoid for example (assumed to be 10 cm from the center of the sources) is approximately 6.27×10^2 cGy or 6.27 Gy, neglecting tissue attenuation and the tissue-kerma to air-kerma ratio.

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