ICRU REPORT 62

Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50)

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The Commission wishes to express its appreciation to the individuals involved in the preparation of this Report for the time and effort which they devoted to this task and to express its appreciation to the organizations with which they are affiliated.

(For detailed information of the availability of this and other ICRU Reports, see page 48.)

Preface

The International Commission on Radiation Units and Measurements (ICRU), since its inception in 1925, has had as its principal objective the development of internationally acceptable recommendations regarding:

1. Quantities and units of radiation and radioactivity,
2. Procedures suitable for the measurement and application of these quantities in clinical radiology and radiobiology and
3. Physical data needed in the application of these procedures, the use of which tends to assure uniformity in reporting.

The Commission also considers and makes similar types of recommendations for the radiation protection field. In this connection, its work is carried out in close cooperation with the International Commission on Radiological Protection (ICRP).

Policy

The ICRU endeavors to collect and evaluate the latest data and information pertinent to the problems of radiation measurement and dosimetry and to recommend the most acceptable values and techniques for current use.

The Commission's recommendations are kept under continual review in order to keep abreast of the rapidly expanding uses of radiation.

The ICRU feels that it is the responsibility of national organizations to introduce their own detailed technical procedures for the development and maintenance of standards. However, it urges that all countries adhere as closely as possible to the internationally recommended basic concepts of radiation quantities and units.

The Commission feels that its responsibility lies in developing a system of quantities and units having the widest possible range of applicability. Situations may arise from time to time when an expedient solution of a current problem may seem advisable. Generally speaking, however, the Commission feels that action based on expediency is inadvisable from a long-term viewpoint; it endeavors to base its decisions on the long-range advantages to be expected.

The ICRU invites and welcomes constructive comments and suggestions regarding its recommendations and reports. These may be transmitted to the Chairman.

Current Program

The Commission recognizes its obligation to provide guidance and recommendations in the areas of radiation therapy, radiation protection and the compilation of data important to these fields and to scientific research and industrial applications of radiation. Increasingly, the Commission is focusing on the problems of protection of the patient and evaluation of image quality in diagnostic radiology. These activities do not diminish the ICRU's commitment to the provision of a rigorously defined set of quantities and units useful in a very broad range of scientific endeavors.

The Commission is currently engaged in the formulation of ICRU reports treating the following subjects:

Absorbed Dose Standards for Photon Irradiation and Their Dissemination
Assessment of Image Quality in Nuclear Medicine
Beta Rays for Therapeutic Applications
Bone Densitometry
Chest Radiography—Assessment of Image Quality
Clinical Proton Dosimetry—Part II: Dose Specifications for Reporting, Treatment Planning and Radiation Quality
Determination of Body Burdens for Radionuclides
Dose and Volume Specifications for Reporting Intracavitary Therapy in Gynecology
Dose Specification in Nuclear Medicine
Dosimetric Procedures in Diagnostic Radiology
Mammography—Assessment of Image Quality
Measurement of Operational Quantities for Neutrons
Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection
Prescribing, Recording and Reporting Electron Beam Therapy
Requirements for Radioecological Sampling
Retrospective Assessment of Exposure to Ionizing Radiation
ROC Analysis
Stopping Power for Heavy Ions

In addition, the ICRU is evaluating the possibility of expanding its program to encompass nonionizing radiation, particularly the quantities and units aspects.

The Commission continually reviews radiation science with the aim of identifying areas where the development of guidance and recommendation can make an important contribution.

ICRU's Relationships with Other Organizations

In addition to its close relationship with the ICRP, the ICRU has developed relationships with other organizations interested in the problems of radiation quantities, units and measurements. Since 1955, the ICRU has had an official relationship with the World Health Organization (WHO), whereby the ICRU is looked to for primary guidance in matters of radiation units and measurements and, in turn, the WHO assists in the world-wide dissemination of the Commission's recommendations. In 1960, the ICRU entered into consultative status with the International Atomic Energy Agency (IAEA). The Commission has

a formal relationship with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), whereby ICRU observers are invited to attend annual UNSCEAR meetings. The Commission and the International Organization for Standardization (ISO) informally exchange notifications of meetings, and the ICRU is formally designated for liaison with two of the ISO technical committees. The ICRU also corresponds and exchanges final reports with the following organizations;

Bureau International de Métrologie Légale
Bureau International des Poids et Mesures
European Commission
Council for International Organizations of Medical Sciences
Food and Agriculture Organization of the United Nations
International Committee of Photobiology
International Council of Scientific Unions
International Electrotechnical Commission
International Labor Office
International Organization for Medical Physics
International Radiation Protection Association
International Union of Pure and Applied Physics
United Nations Educational, Scientific and Cultural Organization

The Commission has found its relationship with all of these organizations fruitful and of substantial benefit to the ICRU program. Relations with these other international bodies do not affect the basic affiliation of the ICRU with the International Society of Radiology.

Operating Funds

In the early days of its existence, the ICRU operated essentially on a voluntary basis, with the travel and operating costs being borne by the parent organizations of the participants. (Only token assistance was originally available from the International Society of Radiology.) Recognizing the impractibility of continuing this mode of opeation on an indefinite basis, operating funds were sought from various sources.

In recent years, principal financial support has been provided by the European Commission, the National Cancer Institute of the U.S. Department of Health and Human Services and the International Atomic Energy Agency.

In addition, during the last 10 years, financial support has been received from the following organizations:

American Society for Therapeutic Radiology and Oncology
Atomic Energy Control Board
Bayer AG
Central Electricity Generating Board
Dutch Society for Radiodiagnostics
Eastman Kodak Company
Ebara Corporation
Électricité de France
Fuji Medical Systems
Hitachi, Ltd.
International Radiation Protection Association
International Society of Radiology
Italian Radiological Association
Japan Industries Association of Radiological Systems
Konica Corporation
National Electrical Manufacturers Association
Philips Medical Systems, Incorporated
Radiation Research Society
Scanditronix AB
Siemens Aktiengesellschaft
Sumitomo Heavy Industries, Ltd
Theratronics
Toshiba Corporation
University Hospital Lund, Sweden

In addition to the direct monetary support provided by these organizations, many organizations provide indirect support for the Commission's program. This support is provided in many forms, including, among others, subsidies for (1) the time of individuals participating in ICRU activities, (2) travel costs involved in ICRU meetings and (3) meeting facilities and services.

In recognition of the fact that its work is made possible by the generous support provided by all of the organizations supporting its program, the Commission expresses its deep appreciation.

André Wambersie
Chairman, ICRU

Bruxelles, Belgium
15 February 1999

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Contents

Executive Summary

Relation to ICRU Report 50

The present report is a Supplement to ICRU Report 50, *Prescribing, Recording, and Reporting Photon Beam Therapy,* published in 1993. Report 50 contained recommendations on how to report a treatment in external photon beam therapy. These recommendations were formulated in such a way that they can generally be followed in all centers worldwide.

Publication of Report 50 and its application to clinical situations stimulated broad interest, raised new questions, and sometimes triggered vigorous discussions and debates.

In the intervening years since Report 50 was published, irradiation techniques have advanced with many new procedures introduced. Driving this process are the considerable improvements in three-dimensional imaging which allow exquisite definition of target volumes, volumes of interest, as well as organs at risk. Naturally, treatment planning systems kept pace with these advances allowing improved radiation prescriptions.

Aim of Present Supplement

For these reasons, the ICRU decided to publish a supplementary document in order to formulate more accurately some of the definitions and concepts and to take into account the consequences of the technical and clinical progress. This new report complements the recommendations contained in the previous one and reflects these developments.

When delivering a radiotherapy treatment, the volumes and the doses must be specified for several purposes: prescribing, recording, and reporting. It is not the goal nor the task of the ICRU to recommend treatment techniques and absorbed dose levels. *Prescription* of a treatment is the responsibility of the radiation-oncology team in charge of the patient. *For reporting purposes,* it is important that clear, well-defined, unambiguous, and universally accepted concepts and terminology are used to ensure a common understanding. Only under these conditions can a useful exchange of information between different centers be achieved.

Volumes and Margins

The development of conformal therapy and the expected therapeutic gain, as well as the increased risk of missing some of the cancer cells, require a more accurate definition of the *margins around the target volumes.* The concepts of Gross Tumor Volume (GTV) and Clinical Target Volume (CTV) need not to be reconsidered, since they are oncological concepts independent of any technical development. However, the different factors to be taken into account when delineating the Planning Target Volume (PTV) and the corresponding margins deserve more accurate identification.

In the present Supplement, the Internal Margin (IM) is defined so as to take into account variations in size, shape, and position of the CTV in relation to anatomical reference points (*e.g.,* filling of stomach or bladder, movements due to respiration, etc.). The Set-up Margin is added to take into account all uncertainties in patient-beam positioning.

Segregating the Internal Margin and the Set-up Margin reflects the differences in the source of uncertainties. The Internal Margin is due mainly to physiologic processes which are difficult or impossible to control. In contrast, the Set-up Margin (SM) is added because of uncertainties related mainly to technical factors that can be reduced by more accurate set up and immobilization of the patient, as well as by improved mechanical stability of the machine.

The global concept and definition of the PTV as given in ICRU Report 50 is not changed. For each volume defined, a color code is proposed to assure clarity of interpretation.

Probability of Benefit versus Risk of Complications

Finally, this supplement recognizes that the linear addition of the margins for all types of uncertainties would generally lead to an excessively large PTV. This could result in exceeding the patient tolerance and fail to reflect the actual clinical consequences.

The risk of missing part of the cancer cell population must be balanced against the reduction of the risk of severe normal tissue complications. The balance between disease control and risk of complications often dictates acceptance of reduced probability of cure in order to avoid severe and serious treatment-related complications.

Therefore, the selection of a composite margin and the delineation of the border of the PTV involve a compromise that relies upon the experience and the judgment of the radiation-oncology team.

Organs at Risk

The compromise to be accepted when delineating the PTV is due to the presence of Organs at Risk. Such Organs at Risk are normal tissues whose radiation sensitivity and location in the vicinity of the PTV may significantly influence treatment planning and/or the absorbed dose level to be employed. The problems resulting from the presence of Organs

at Risk is discussed in more detail in this Supplement to Report 50.

The system of classifying Organs at Risk as "serial", "parallel", or "serial-parallel" is discussed, and the use of this system to interpret tolerance of various Organs at Risk is explained. A typical example of a tissue with a high "relative seriality" is the spinal cord, implying that a dose above the tolerance limit, even to a small volume, can totally impair the function of the organ (myelitis). In contrast, the lung has a low "relative seriality", implying that the main parameter for impairing pulmonary function is the proportion of the organ that receives a dose above the tolerance level. The heart can be considered as having a combined "serial" (coronary arteries) and "parallel" (myocardium) structure.

Planning Organs at Risk Volumes (PRV)

The present Supplement stresses the fact that for the Organs at Risk, as for the CTV, movements and changes in shape and/or size, as well as the set-up uncertainties, must be considered. A margin must be added to compensate for these variations and uncertainties, which leads to the concept of the *Planning Organ at Risk Volume (PRV)*. Thus, for the Organs at Risk, the PRV is analogous to the PTV for the Clinical Target Volume. For reporting, the description of the PRV (like that of the PTV) should include the size of the margins in all directions. The PTV and the PRV may overlap, and often do so, which implies searching for a compromise as discussed above.

Conformity Index

The concept of a Conformity Index (CI) is introduced and defined as the quotient of the Treated Volume and the volume of the PTV. This definition of the CI implies that the Treated Volume totally encompasses the PTV. Note that the Treated Volume is the tissue volume that receives at least the dose selected and specified by the radiation oncology team as being appropriate to achieve the purpose of the treatment, tumor eradication or palliation.

Not surprisingly, optimization of the CI may result in deterioration of other desired parameters, such as the size of the Irradiated Volume or the absorbed dose homogeneity in the PTV. Again, to optimize the CI, some overall compromises may be required.

Dose Specification for Reporting

Recommendations contained in Report 50 for dose specification for reporting are maintained. First, the absorbed dose at the ICRU Reference Point should be reported. Then, the best estimates of the maximum and the minimum doses to the PTV should be reported. Furthermore, any additional relevant information should be given, when available, *e.g.,* Dose-Volume Histograms (DVHs). The absorbed doses to the Organs at Risk should also be given.

Reporting Doses in a Series of Patients

ICRU Report 50 dealt with dose reporting in an individual patient. Different issues are encountered when reporting treatments for a series of patients.

First, the treatment prescription or protocol should be described in detail, including the volumes, absorbed-dose levels, and fractionation. The treatments should be reported following the above recommendations, and the deviations from the prescription should be stated. In particular, the proportion of patients in whom the dose variation is less than $\pm 5\%$, ± 5–10%, and more than $\pm 10\%$ of the prescribed dose at the ICRU Reference Point should be reported.

When reporting the treatments in scientific journals, it is recommended that the prescribed CTV and PTV and corresponding doses be illustrated in an isodose distribution chart, giving the total absorbed doses in Gy.

The Three Levels for Reporting

The three levels of complexity for reporting the irradiations that were introduced in Report 50 are retained. However, since its publication in 1993, the limits between the three levels were modified due to the recent improvements in irradiation techniques and developments in imaging and in treatment planning.

Clinical Examples

Finally, the present Supplement to ICRU Report 50 contains an Appendix with three examples illustrating how the recommendations can be applied in clinical situations. The first example compares the irradiation of the internal mammary chain using a single electron beam or a combination of an electron beam and a photon beam. The second example deals with irradiation of prostatic adenocarcinoma. The third example illustrates how to report an irradiation of a bronchus carcinoma.

Conclusions

This Supplement to ICRU Report 50 provides updated recommendations that include the many advances in treatment techniques, treatment planning, and image based target definition. To assist the necessary decision-making process in therapy, the concept of a "Conformity Index" is defined and introduced. Finally, clear guidance is provided for reporting treatments of individuals and series of patients. Hence, this Supplement will guide and assist the process of modern radiation therapy.

Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50)

1. Introduction

If irradiation techniques were perfect, it would be possible to irradiate the full "volume to be treated" in a homogeneous way (*e.g.,* 60 Gy) and with no dose to the surrounding normal tissues. For example, in this ideal situation, the prescribed dose would be 60 Gy, the recorded dose (in the patient's treatment chart) would also be 60 Gy, and the reported dose (*e.g.,* for publication, or in multicenter studies) would also be 60 Gy.

Unfortunately, this cannot be achieved; and, within the target volume, the dose may vary between rather large limits, depending on the technical conditions. Actually, due to the limitations of available irradiation techniques, the difference between the maximum and the minimum doses in the target volume often reaches 10, 15, or even 20%. Therefore, large discrepancies can be introduced, depending on the criteria used for prescribing, recording, and reporting the treatment. An additional problem may be that some normal tissues receive doses at levels that are often similar to the prescribed dose and which sometimes approach or exceed the tolerance limits.

Dische *et al.* (1993) stated that there was evidence from published clinical data and a suggestion from an analysis of the CHART pilot study data that a dose difference as small as 5% may lead to real impairment or enhancement of tumor response, as well as to an alteration of the risk of morbidity. Such a 5% uncertainty in dose can easily be introduced by different methods for reporting (e.g., by reporting without clarification the 100%, 95%, 90%, or 85% dose levels). A review of published papers (Dische *et al.* 1993) indicates that an acceptable level of reporting was found in less than 40% of the papers. Inadequate reporting may lead to a false interpretation of a study and to its wrongful application. Dische *et al.* strongly recommend that it should be editorial policy to publish only those papers in which the radiation dose is adequately and unambiguously described, and recently Bentzen (1998) also gave such recommendations. The problem has also been reviewed by Landberg and Nilsson (1993).

The International Commission on Radiation Units and Measurements (ICRU) recognized the importance of these problems many years ago and, in 1978, published Report 29, *Dose Specification for Reporting External Beam Therapy with Photons and Electrons* (ICRU, 1978).

Since then, it has become clear that further interpretation of the concepts of dose specification has become necessary and that additional guidelines are needed if the recommendations published first in ICRU Report 29 are to be applied more widely. In addition, the rapidly expanding use of computers in radiotherapy, allowing for better planning and evaluation of three-dimensional (3-D) dose distributions, is changing clinical practice; and, in 1987, the ICRU published Report 42, *Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photons and Electrons* (ICRU, 1987). In 1993, the ICRU published Report 50, *Prescribing, Recording, and Reporting Photon Beam Therapy* (ICRU, 1993), which superseded Report 29. Since electron beam therapy and dosimetry present some specific problems, it is useful to treat them separately from photons; this will be the purpose of another ICRU report, which is in preparation.

For other radiotherapy techniques, dose specification has been covered in ICRU Report 38, *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology* (ICRU, 1985), and ICRU Report 58, *Dose and Volume Specification for Reporting Interstitial Therapy,* (ICRU, 1997). Forthcoming ICRU reports will deal with dose specification for proton and neutron beams.

Five years after publication of Report 50, the ICRU decided that it would be appropriate to define additional concepts and to formulate more accurately some definitions related to volumes, margins, organs at risk, and dose variations and uncertainties in order to further promote a common language and thus facilitate exchange of scientific and clinical information. This document is the result. The revisions specified here do not contradict the recommendations in Report 50, but rather reflect developments

which have occurred since 1993. Several reasons justify this update of ICRU Report 50.

First, recent improvements in staging and imaging procedures, as well as improvements in the delivery of precision radiotherapy, permit larger doses in the malignant tissues and/or smaller doses to Organs at Risk by means of techniques in which the dose distribution is made to "conform" more precisely to the prescription than previously possible. This may result in an improved therapeutic gain, but increases the risk that "marginal" (geometric) misses may become more frequent, undermining the purpose of the new techniques. The different types of safety margins that must be added to the Clinical Target Volume in order to compensate for different types of anatomical and geometrical variations and uncertainties will, with the new techniques, require better definition; this is an area of active research (see, *e.g.,* Ross *et al.,* 1990; Holmberg *et al.,* 1994; Michalski, 1994; Schwartz *et al.,* 1994; Purdy *et al.,* 1996; and Ekberg *et al.,* 1997).

Secondly, advances in our understanding of normal tissue response also require additional recommendations, *e.g.,* on volume, dose, and fractionation, for a proper and unambiguous exchange of information (see, *e.g.,* Wolbarst *et al.,* 1982; Withers *et al.,* 1988; Lyman, 1985, and Olsen *et al.,* 1994).

Changes or additions to ICRU Report 50 are indicated below. All other portions of Report 50 remain unchanged. The present report should be considered as a companion volume to ICRU Report 50.

Chapter 2 of the present report supersedes Section 2.3, in ICRU Report 50, and, in addition:

- gives more detailed recommendations on the different margins that must be considered to account for anatomical and geometrical variations and uncertainties (Section 2.4 in this Report),
- introduces a Conformity Index (CI) (Section 2.5.2 in this Report),
- gives information on how to classify different types of Organs at Risk (Section 2.7.1 in this Report),
- introduces the Planning Organ at Risk Volume (PRV) (Section 2.7.2 in this Report),
- gives recommendations on graphics (Section 2.8 in this Report).

Section 3.6 of the present report supplements section 2.4, in ICRU Report 50 and gives additional recommendations on how to report dose(s) not only in a single patient but also in a series of patients.

This Report gives clinical examples of the use of the recommendations given in this Report, and in ICRU Report 50.

Two important remarks should be made here.

Firstly, although the title of this Report reads "Prescribing, Recording, and Reporting Photon Beam Therapy," reporting is emphasized. Obviously the ultimate responsibility for patient care, and thus the treatment prescription, resides with the attending physician. It must be recognized that, at present, in different centers in different countries, the prescription of the treatment is made using different medical, oncological, dosimetric, and radiation therapy principles.

However, to achieve appropriate exchange of information between centers, it is essential that the same terms, definitions, and concepts be used. The same treatments performed in different centers should be described in the same way; and any radiation oncologist reading a description of a treatment performed in a given center should fully understand what has been done.

This being said, it is obvious that adoption of the same concepts and definitions for prescribing, recording, and reporting a treatment will make the procedure simpler and certainly reduce the risk of confusion and errors. The long-term benefit is self-evident. Such a terminology should provide a link to previous results, but should also facilitate developments in radiation oncology.

The second matter requiring special attention at this point is the level of completeness or complexity in the recommendations for reporting.

Specifically, the *basic* recommendations must be sufficiently simple to allow for their use in all centers. The potential drawback of such an approach, if not supplemented by additional recommendations, is obvious; some additional useful and relevant information may not be reported and could be lost. Therefore, in this Report (as in ICRU Report 50), different levels of treatment planning complexity are recognized for reporting, thus allowing for the reporting of more complete information. However, the limits between the levels are updated.

Reporting at level 1 should be simple enough to allow for its use in all centers. Level 2 contains more complete and relevant information, and level 3 is appropriate for developmental and/or special techniques. Reporting at level 1 is sometimes sufficient in many centers and also in well-equipped and staffed centers for some simple treatments, such as some palliative treatments.

It is stressed throughout this report that all relevant information should be reported using definitions of terms and concepts discussed here and in Report 50. In Report 50 and in the present document, the ICRU seeks to establish unambiguous and simple concepts and definitions that can be accepted by the radiotherapy community.

The full implementation of all recommendations will require treatment planning at least from level 2; but, at the same time, reporting of basic parameters (level 1) will provide a link to less sophisticated treatment planning, past, present, or future.

2. Volumes

2.1 Introduction (Reference Points, Coordinate Systems and Volumes)

To achieve accurate radiation therapy, it must be possible to precisely relate the positions of tissues, organs or volumes in the patient to the positions and orientation of beams used for both imaging or therapy. This requires the use of three coordinate systems, one within the patient, one related to the imaging unit and one related to the treatment machine. The positions of organs, tissues and treatment-related volumes are related to anatomical reference points or alignment marks and the coordinate system within the patient. The position and orientation of the imaging and treatment machines are defined in coordinate systems related to these machines. The reference points serve to link the coordinate systems since they can be defined in both patient and machine coordinates. The coordinates of the "target" can then be defined in the external coordinate system during dose planning.

2.1.1 Reference Points

Alignment of the patient in a reproducible and stable position is a prerequisite for correct definition of volumes and set-up of beams. Adequate patient immobilization systems are the most effective means to accomplish this. Reference points, either internal or external or alignment points or lines are then used to establish the patient coordinate system and for reproducible alignment of the patient for imaging or treatment.

Internal Reference Points are anatomical landmarks (*e.g.,* bony structures or gas-filled cavities) which may be used for localization of the Gross Tumor Volume (GTV) and Clinical Target Volume (CTV) and for accurate set-up at the imaging unit, simulator and treatment unit. Often separate reference points must be used for different beams and if there is more than one GTV or CTV.

External Reference Points are palpable or visible points located on or near the surface of the body or on the surface of immobilization devices that fit closely to the exterior of the body (*e.g.,* face masks, bite blocks and shells). As External Reference Points, one may also use skin markings or alignment tattoos that are reproducibly related to the body as a whole (*e.g.,* to skeletal structures).

2.1.2 Coordinate Systems

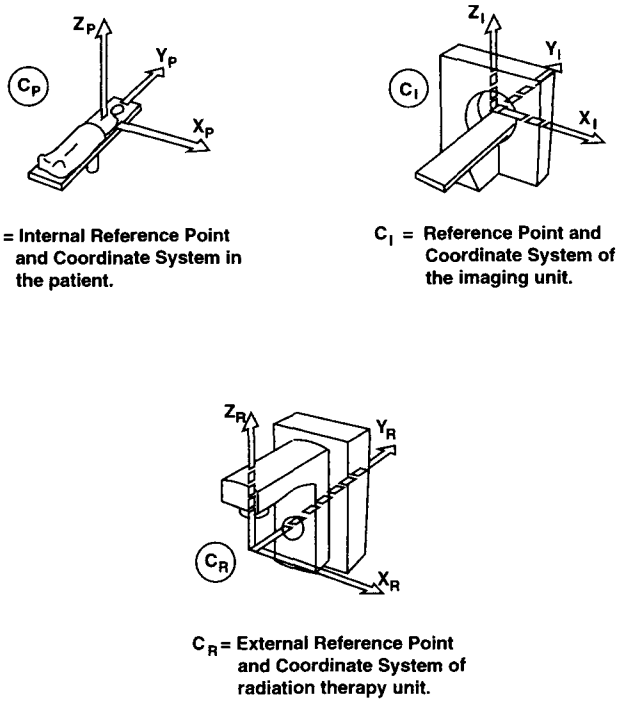
Three types of coordinate systems are involved in the planning and execution of radiation treatments.

Coordinate System Related to the Patient. The reference coordinate system for the patient is based on either internal or external reference points. The coordinate system is defined with one of the reference points as origin and other reference points for orientation of the system and alignment of the patient.

Coordinate Systems Related to Imaging and Treatment Units. These coordinate systems are defined with respect to the gantry, collimators, radiation beam, light beams, laser-alignment beams and couch-top system.

For example, Fig. 2.1. (modified from ICRU Report 42 [ICRU 1987]) presents a set of three different coordinate systems:

- for the patient,
- for the imaging units,
- for the treatment machine.



C_P = Internal Reference Point and Coordinate System in the patient.

C_I = Reference Point and Coordinate System of the imaging unit.

C_R = External Reference Point and Coordinate System of radiation therapy unit.

Fig. 2.1. Example of a suggested set of coordinate systems:
C_P = The reference system related to the patient, in relation to an internal reference point.
C_I = The reference system related to the imaging unit used for collecting information (*e.g.,* CT scanner).
C_R = The reference system related to the therapy unit for variations in patient and beam geometry, in relation to an external reference point.
(Modified from ICRU Report 42 (ICRU, 1987).)

2.1.3 Volumes

The process of determining the volumes for the treatment of a patient with malignant disease consists of sequentially specifying different tissues, organs, and volumes three-dimensionally.

These volumes are (Figs. 2.13, 2.14, and 2.16):
Gross Tumor Volume (GTV),
Clinical Target Volume (CTV),

Planning Target Volume (PTV),
Treated Volume,
Irradiated Volume,
Organs at Risk (OR), and
Planning Organ at Risk Volume (PRV).

Each of these are discussed below. It should be noted that the GTV and the CTV represent volumes with known or suspected tumor involvement, and the OR represents normal tissues; the others are purely geometric concepts, which do not strictly correspond to tissue or organ borders.

2.2 Gross Tumor Volume (GTV)

The Gross Tumor Volume (GTV) is the gross demonstrable extent and location of the malignant growth.

The GTV consists of primary tumor ("GTV primary") and possibly metastatic lymphadenopathy ("GTV nodal") or other metastases ("GTV M"). The GTV almost always corresponds to those parts of the malignant growth where the tumor cell density is the highest. Hence, an adequate dose must be delivered to the whole GTV to achieve the aim of radical therapy.

It may not be possible to define a GTV after surgical intervention.

The shape, size, and location of a GTV may be determined by clinical examination (*e.g.,* inspection, palpation, endoscopy) and/or various imaging techniques (*e.g.,* x-ray, CT, digital radiography, ultrasonography, MRI, and radionuclide methods). The methods used to determine the GTV should meet the requirements for scoring the tumor according to the TNM (UICC, 1997) and AJCC (AJCC, 1997) systems. The definition of the GTV should then be in full agreement with the criteria used for the TNM-classification. An example is given in Fig. 2.2.

The GTV (primary tumor, metastatic lymphadenopathy, other metastases) may appear different in size and shape, sometimes significantly, depending on which examination technique is used for evaluation, *e.g.,* palpation, mammography, x-ray, and macroscopic examination of the surgical specimen for breast tumors (example given in Fig. 2.3.), CT, and MRI for some brain tumors. The radiation oncologist should indicate which method has been used for evaluation and for the definition of the GTV. However, even using the same techniques, inter-observer variation may be significant (Fig. 2.4.).

A GTV may be confined to only part of an organ (*e.g.,* a T1 breast cancer) or may involve a whole organ (*e.g.,* in multiple metastases to the brain). The GTV may or may not extend outside the normal borders of the organ tissue involved.

For reporting, the Gross Tumor Volume should be described in standard topographical or anatomical terms, *e.g.,* "18 mm × 12 mm × 20 mm tumor in the left lobe of the prostate adjacent to but not breaching the capsule." In many situations, a verbal description might be too cumbersome; therefore, for the purpose of data recording and analysis, a classification system is needed. Several systems are proposed for coding the anatomical description; some of them are mentioned in ICRU Report 50 (ICRU, 1993).

There are at least three reasons to describe and report the GTV in a complete and accurate way. Firstly, as indicated above, it is required for staging, *e.g.,* according to the TNM system. Secondly, an adequate dose must be delivered to (at least) the whole GTV in order to obtain local tumor control in radical treatments (otherwise the probability of local control decreases). Thirdly, regression of the GTV during treatment may be used with care as predictive of tumor response.

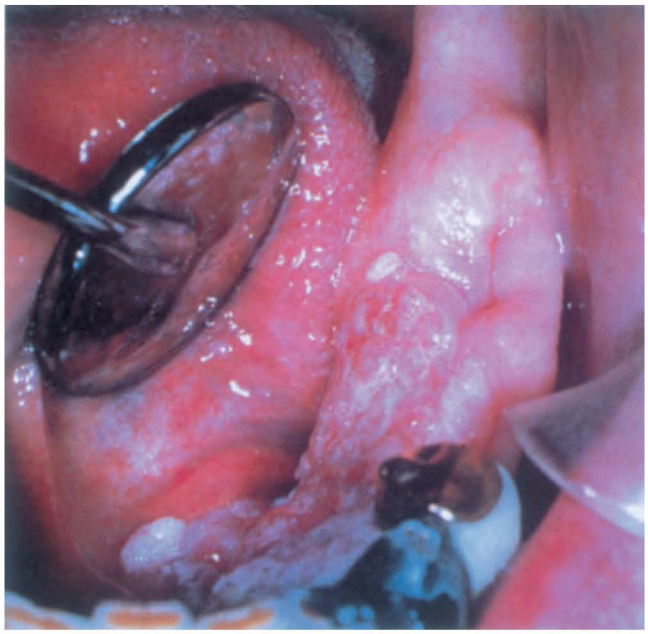


Fig. 2.2. Clinical examination of a patient with a carcinoma of the floor of the mouth (case number 4, Appendix, ICRU Report No. 50).

Examination shows a 45 mm × 35 mm × 40 mm large partly ulcerated tumor in the left part of the floor of the mouth. The tumor extended into the tongue, deeply infiltrated the muscles, but did not reach the midline. No regional lymphadenopathy. Biopsy showed moderately well differentiated infiltrating squamous cell carcinoma.

Thus:

Clinical diagnosis:	Oral carcinoma (ICD-02 = C04.9)
Tumor type and grade:	Moderately well differentiated infiltrating squamous cell carcinoma, (SNOMED = 807032, TNM grade = G2).
Clinical tumor extent and stage:	T4 N0 M0 = IVA.
GTV:	site = floor of the mouth left and mobile tongue left (anatomical code, ICRU 50, Table I.2 = C04.9-2 + C02.9-2).

(Courtesy of the Malmö University Hospital, Sweden)

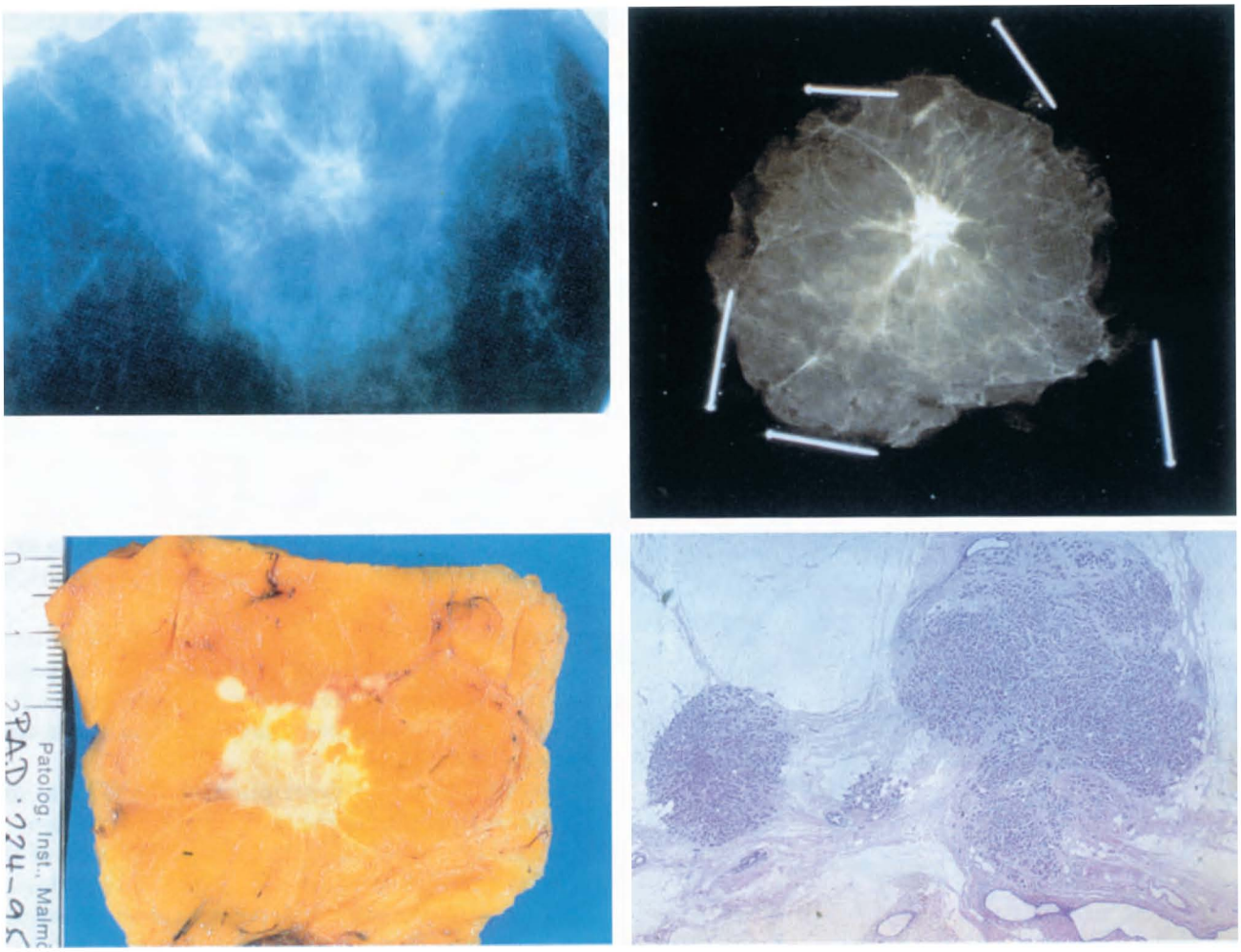


Fig. 2.3. Appearance of a tubulo-ductal breast cancer on:

top left — mammography,
top right — x-ray image of the surgical specimen,
bottom left — macroscopy of the surgical specimen,
bottom right — microscopy of the surgical specimen.

Depending on which examination method is used to establish the size of the Gross Tumor Volume, one may arrive at different T/pT-categories (and even different stages) in the TNM-classification.
(Courtesy of the Malmö University Hospital, Sweden.)

2.3 Clinical Target Volume (CTV)

The Clinical Target Volume (CTV) is a tissue volume that contains a demonstrable GTV and/or subclinical malignant disease that must be eliminated. This volume must be treated adequately in order to achieve the aim of radical therapy.

The Clinical Target Volume is, like the GTV, a purely clinical-anatomical concept and can be described as including structures with clinically suspected but unproved involvement, in addition to any known tumor (hence "subclinical disease").

Macroscopically, tumors may seem relatively well demarcated or may have no distinct borders (Fig. 2.5.).

When microscopic examination of a cancer is performed, one often finds subclinical extensions around the GTV (Fig. 2.6.). Furthermore, areas suspected of subclinical involvement, *e.g.,* regional lymph nodes (N0), may be considered for therapy.

Thus, two types of subclinical disease (surrounding the GTV and at a distance, *e.g.,* lymph nodes) can be envisaged, as illustrated in Fig. 2.7. The prescription is then based on the assumption that, in some anatomically definable tissues/organs, there may be cancer cells at some probability level, even though they cannot be detected with present day techniques; these are subclinical. The estimate of probability is based on clinical experience from adequately documented treatments and follow-up. For prescription of treatment, these subclinical deposits (or their probability of existence) can be described in terms of risk for later detectable manifestations if not treated adequately at this subclinical stage.

In a particular patient, there may be more than

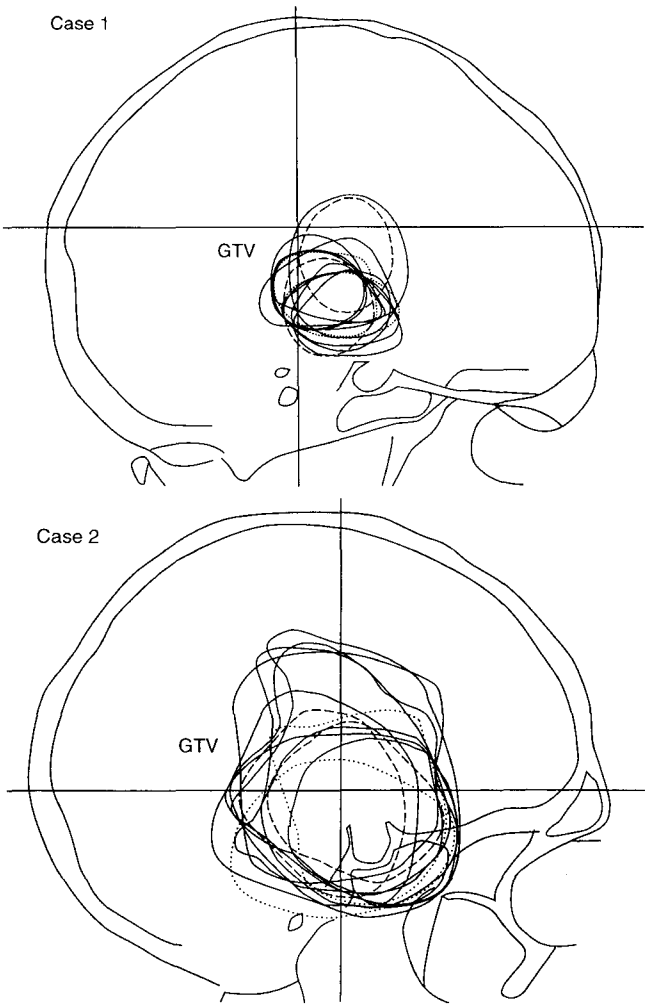


Fig. 2.4. Schematic drawings on lateral radiographs for two patients with brain tumors, where the Gross Tumor Volume was delineated by:
8 radiation oncologists (——),
2 radiodiagnosticians (····),
2 neurosurgeons (----).
(Adapted from Leunens *et al.*, 1993.)

one CTV for which different doses are prescribed. One situation is illustrated (Fig. 2.7.) by considering a primary tumor and its regional lymphatics separately (*e.g.*, in breast saving procedures) where the primary tumor and its regional lymphatics are separated anatomically. In other situations, the aim is to treat two or more CTVs to different dose levels. One example of this is boost therapy, where often the high-dose volume (often containing the GTV) is located inside the low-dose volume.

2.3.1 Prescription of Treatment of Subclinical Extensions Adjacent to a GTV

Clinical experience indicates that outside the GTV there is generally subclinical involvement, *i.e.*, individual malignant cells, small cell clusters, or microextensions that cannot be detected by the staging procedures. The GTV, together with this surrounding volume of local subclinical involvement, can be defined as a Clinical Target Volume (CTV) if the same dose is prescribed. This CTV will then usually be denoted Clinical Target Volume One (CTV I). If the GTV has been removed by radical surgery, but radiotherapy is considered necessary for the tissues that remain close to the site of the removed GTV, this volume is also usually designated as CTV I.

2.3.2 Prescription of Treatment of Subclinical Extensions at a Distance from a GTV

Additional volumes (CTVs) with presumed subclinical spread (*e.g.*, regional lymph nodes) may also be considered for therapy. They are also defined as Clinical Target Volumes and may be designated CTV II, CTV III, etc.

For reporting, the Clinical Target Volume must be defined in plain anatomical terms and/or according to a corresponding code (see for example Table I.2. in ICRU Report 50) in conformity with the recommendations for the GTV.

Identification and description of the GTV(s) and CTV(s) is thus part of the treatment prescription.

It must be stressed that the prescriptions of the GTV(s) and CTV(s) are based on general oncological principles, and they are independent of any therapeutic approach. In particular, they are not specific to the field of radiation therapy. For instance, in surgery, a safety margin is taken around the Gross Tumor Volume according to clinical judgment, and this implies the same use of the Clinical Target Volume concept as in external beam radiation treatments. Also in brachytherapy, volumes to be treated must be defined, and thus the concept of CTV is used. The definitions of GTV(s) and CTV(s) constitute part of the basic prescription of the treatment; they are essential to the medical record. Their definition must *precede* the selection of the treatment modality and the subsequent treatment planning procedures.

2.4 Planning Target Volume (PTV)

2.4.1 Margins for Geometric Variations and Uncertainties

Once the CTV(s) has (have) been defined and external-beam radiation treatment adopted as the treatment modality, a suitable arrangement of beam(s) must be selected in order to achieve an acceptable dose distribution. Computation of dose distribution can currently be done only for a static representation; whereas, in fact, there are variations and uncertainties in the positions, sizes and shapes, and orientations of both the tissues, patient, and the

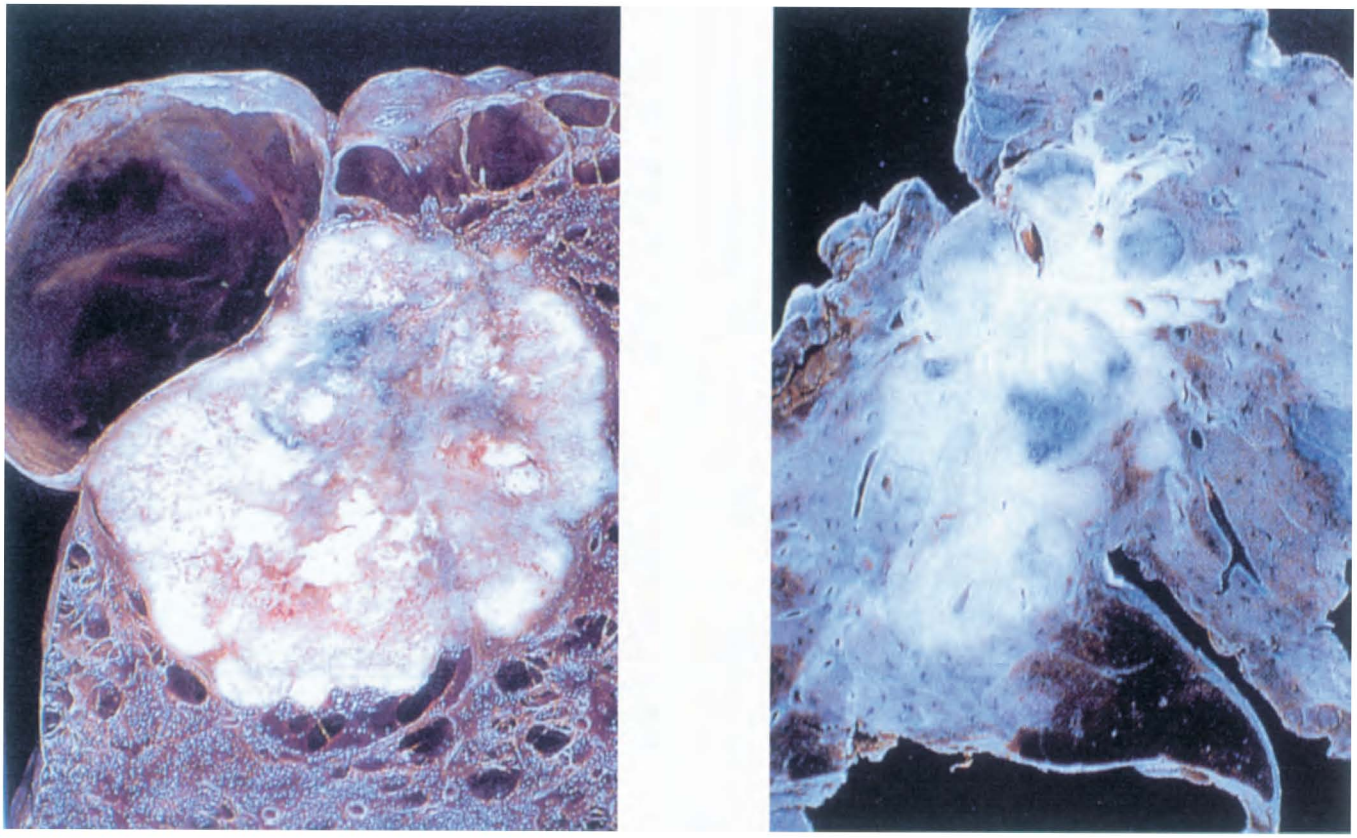


Fig. 2.5. Example of two different macroscopic growth patterns for lung tumours. To the left a large-cell carcinoma, arising in the periphery of the lung. The tumour is well circumscribed. To the right a case of small-cell anaplastic lung cancer (SCLC), with an irregular tumour and invasion along the bronchial tree.
(From: Dana-Farber Cancer Institute, Atlas of Diagnostic Oncology. T. Skarin M.D. (Ed.). J. B. Lippincott Publishing, 1991. By kind permission.)

beams in relation to the common coordinate system. This will be seen both during a single session (intrafractionally) and from one session to another (interfractionally). Errors can also be introduced between the imaging procedure and the treatment planning and between the treatment planning and first treatment session.

Dose distributions represent static situations and do not inherently reflect uncertainties in positioning of the organ/patient with respect to the beams. If this is not taken into account and if no margins are added, some of the tissues may, for part of the treatment, move in or out of the therapeutic beam; and this will result in over- or underdosage. Other parts of the tissues may move around in a dose gradient, and then it will be difficult to state the exact dose received by each part of the tissues. On the other hand, using margins that are very large will result in unnecessary morbidity. There is no ideal solution, and one must search for an acceptable compromise.

To avoid significant deviation from the prescribed dose in any part of the CTV(s), one must add margins to the CTV(s) for variations in tissue position, size, and shape, as well as for variations in patient position and beam position, both intrafractionally and interfractionally. This leads to the concept of the Planning Target Volume (PTV), (ICRU Report 50 [ICRU, 1993]).

It is difficult to quantify the different types of variations and uncertainties, as well as their interactions. One is thus forced to make assumptions and, in some cases, to combine the different variations and uncertainties accordingly. Recent developments, *e.g.,* in electronic portal imaging (Holmberg *et al.,* 1994; Ekberg *et al.,* 1998) and other techniques (Ross *et al.,* 1990; Schwartz *et al.,* 1994) now allow for a better quantification of some of these parameters. Other technical improvements, such as respiratory gating of the beam output, may influence the width of the selected margins.

For the final treatment plan (definition of beam sizes, *etc.*), all the variations and uncertainties must be considered, and their overall effect should define a static volume (Planning Target Volume [PTV]). The need for the margins, included in the PTV, thus results from a number of geometrical variations and uncertainties in relation to the reference point and coordinate system. They are listed in Table 2.1, and clinical examples are given in Figs. 2.8–2.13 and in Table 2.3. The dose to the PTV is representative of the dose to the CTV.

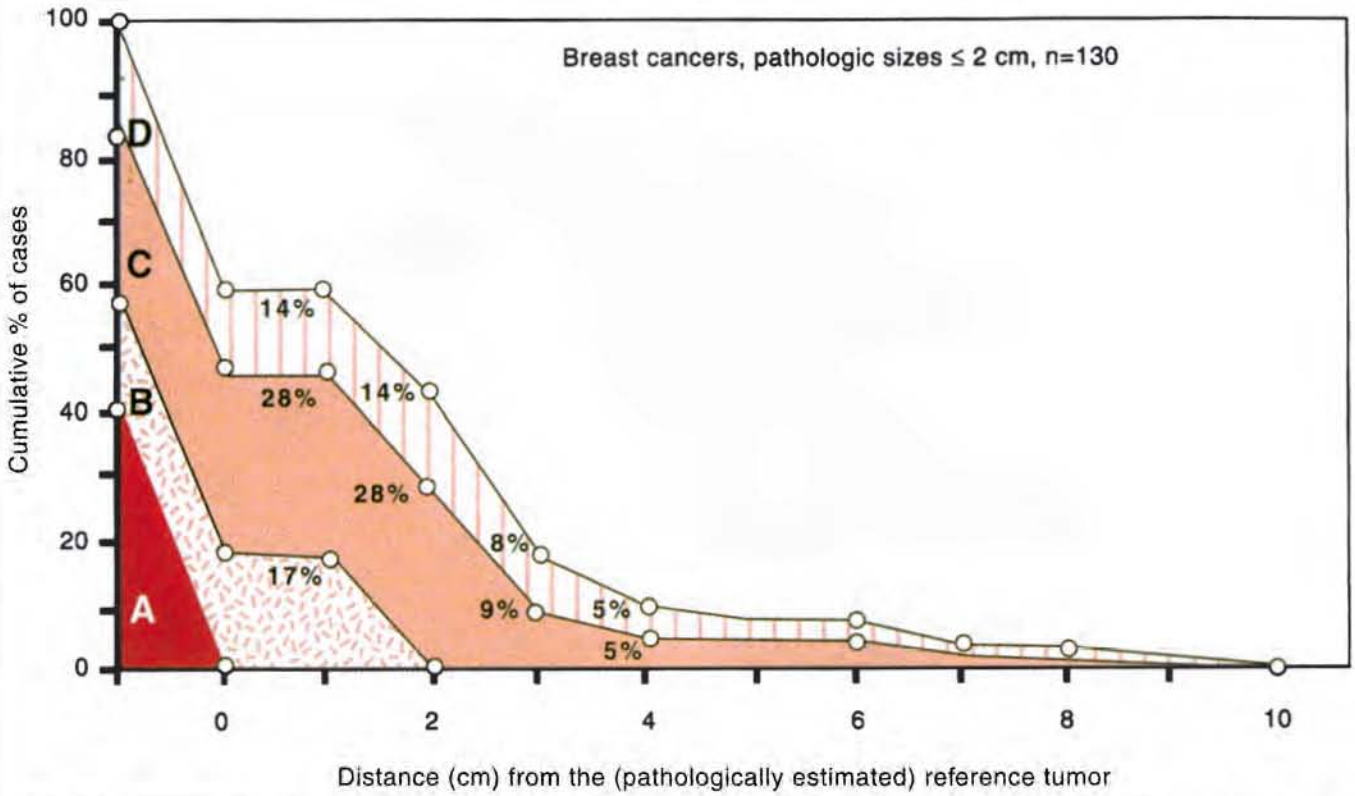


Fig. 2.6. Example of the distribution of tumor foci at different distances from the border of the Gross Tumor Volume ("reference tumor"). This graph shows the remaining proportion of cases with tumor foci at or beyond the specified distance from the reference tumor. The percentages given within the groups indicate the proportion of cases with tumor foci located at or beyond the point given on the abscissa (i.e., distance from reference tumor).

A: No tumor foci outside the reference tumor. These cases constitute 41% of all cases.

B: Tumor foci within 2 cm of the reference tumor. These cases constitute 17% of all cases. The exact distance of these foci and their invasive or noninvasive character was not further specified.

C: Noninvasive tumor foci extending farther than 2 cm from the reference tumor. These cases constitute 28% of all cases.

D: Invasive tumor foci extending farther than 2 cm from the reference tumor. These cases constitute 14% of all cases.

Redrawn from Holland *et al.*, 1985. [CANCER, **56,** 1985, 979–990. Copyright © 1985 American Cancer Society. Reprinted by permission of Wiley-Liss, Inc., a subsidiary of John Wiley & Sons, Inc.]

The definition of a margin can either account for all potential variations and uncertainties or include only a certain proportion (*e.g.,* 2 standard deviations). Other considerations may also be needed, *e.g.,* if only normal breathing is included, but the effects of an occasional deep breath are disregarded (see Table 2.2). Information on such decisions is useful.

The problem of margins to allow for geometrical variations and uncertainties is currently the subject of much interest. General overviews of the problem, including the application of risk philosophy and biometrical models can be found in reports by Michalski (1994), Austin-Seymour *et al.* (1995a, 1995b), Purdy *et al.* (1996), and Aaltonen-Brahme *et al.* (1997). Some papers have specifically addressed clinical situations. Problems encountered in the radiotherapy of the pelvic region have been discussed by Ten Haken *et al.* (1991), Hunt *et al.* (1995), Roeske *et al.* (1995), and Tinger *et al.* (1996), and beam positional problems in treatment of the thoracic region by Willet *et al.*, (1987), Creutzberg *et al.* (1992), Weltens *et al.* (1993), Balter *et al.* (1996), and Jacobs *et al.* (1996). The situation for head-and neck tumors was analyzed by Hunt *et al.* (1993), McParland (1993), and Hess *et al.* (1995); for breast cancer by Fein *et al.* (1996); and for the abdominal region by Lax *et al.* (1994), and Moerland *et al.* (1994). Stereotactic radiosurgery was evaluated by Yeung *et al.* (1994).

In order to determine margins, it is useful to think of the two types of uncertainties, internal and set-up margins.

2.4.1.1. Internal Margin (IM) and Internal Target Volume (ITV). A margin must be added to the CTV to compensate for expected physiologic movements and variations in size, shape, and position of the CTV during therapy in relation to an Internal Reference Point and its corresponding Coordinate System. It is now denoted as the Internal Margin (IM).

The Internal Margin, commonly asymmetric around the CTV, is intended to compensate for all

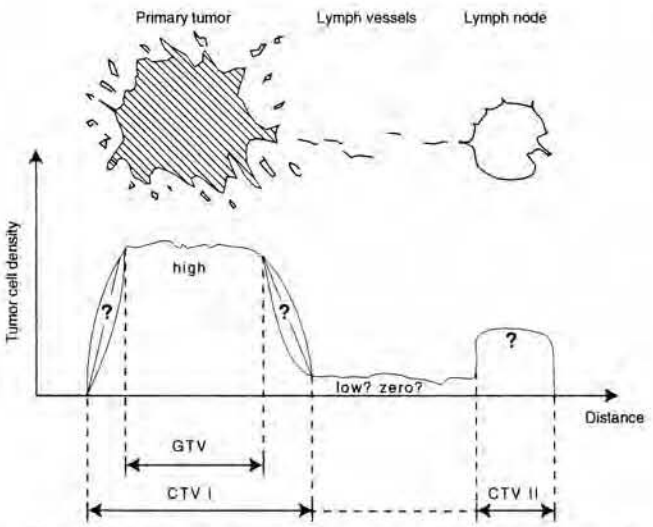


Fig. 2.7. Schematic example of a GTV (demonstrable tumor = striated area) and also for CTVs to care for suspected, subclinical extensions surrounding the Gross Tumor Volume (CTV 1, here also including the GTV) and to regional lymph nodes (CTV II, = open area). The tumor cell density is high in the GTV, but may be heterogeneous (*e.g.*, due to necrosis). Close to the GTV (supposing that there is no natural anatomical border such as the parietal pleura in mediastinal lymphomas), one has to expect a zone with subclinical extensions, probably with overall decreasing tumor cell density with distance. The true variation in cell density in this zone (safety margin) is difficult to assess and probably varies with tumour type and location. For the clinical example shown here, in the regional lymphatics and lymph nodes, no Gross Tumor could be demonstrated (N0); but, based on clinical experience, it was assumed that there could be subclinical extensions to the lymph nodes, but not to the connecting lymph vessels.

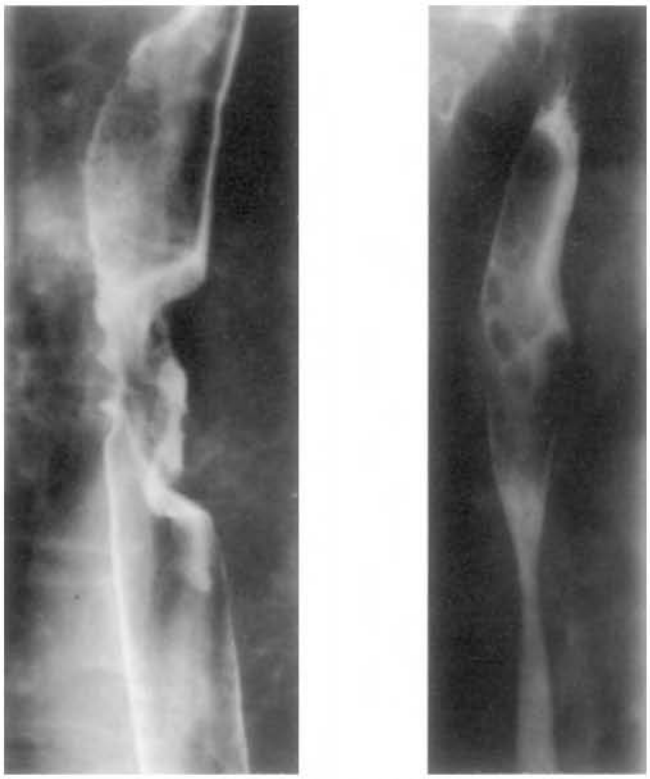


Fig. 2.8. Clinical example of change in size of the GTV during treatment (interfractional variation). Patient with carcinoma of the esophagus. Barium swallow shows that the tumor, which was bulky before radiotherapy (left), has diminished during the course of treatment and finally disappeared macroscopically (right).

movements and all variations in site, size, and shape of the organs and tissues contained in or adjacent to the CTV. They may result, *e.g.*, from respiration, different fillings of the bladder, different fillings of the rectum, swallowing, heart beat, movements of the bowel.

These internal variations are thus basically physiological ones, and they result in changes in site, size, and shape of the CTV. They cannot be easily controlled. They do not depend on external uncertainties in beam geometry, but could depend on patient day-to-day set-up.

The term Internal Target Volume (ITV) has been proposed (Landberg *et al.*, 1996; and Aaltonen-Brahme *et al.*, 1997) as representing the volume encompassing the CTV and the Internal Margin. The ITV is related to the patient coordinate system.

2.4.1.2 Set-up Margin (SM). To account specifically for uncertainties (inaccuracies and lack of reproducibility) in patient positioning and alignment of the therapeutic beams during treatment planning and through all treatment sessions, a Set-up Margin (SM) for each beam is needed. The Set-up Margin is referenced in the external coordinate system. The uncertainties to be compensated for may vary with different anatomical directions, and thus the size of such margins depends on the selection of beam geometries. The uncertainties depend on different types of factors, such as:

- variations in patient positioning,
- mechanical uncertainties of the equipment (*e.g.*, sagging of gantry, collimators, and couch),
- dosimetric uncertainties,
- transfer set-up errors from CT and simulator to the treatment unit,
- human factors.

These may vary from center to center and, within a given center, from machine to machine. The use of patient immobilization devices, the application of quality assurance programs, and human factors such as skill and experience of the radiographers/radiotherapists are important and must be taken into account. The use of different record and verification systems (in real time or not) may also be important and may significantly alter the size of the needed set-up margins. Fig. 2.14. illustrates schematically the different margins and volumes, as well as their relations.

Note that in some cases, the Internal Margin approaches a very low value, (*e.g.*, with brain tumors), and in other cases the Set-up Margin may be very small (*e.g.*, with on-line correction for the different set-up errors and variations).

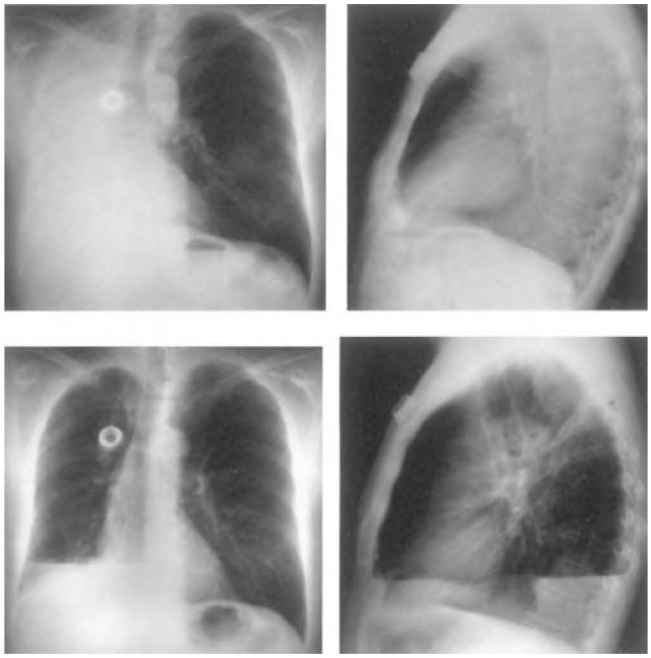


Fig. 2.9. Clinical example of change in position of the CTV during treatment (interfractional variation). Patient with right-sided central bronchogenic carcinoma, locally recurrent after previous chemotherapy. Upper pictures show chest radiographs before radiotherapy, with total atelectasis of the right lung. Lower pictures show chest radiographs after 36 Gy to the PTV. There is a partial re-aeration of the lung, pleural effusion, and partial pneumothorax. Compared with examination before radiation treatment, there is a 26 mm shift of the mediastinum (including the CTV) towards the left. Without replanning during the course of radiotherapy, there could have been a serious underdosage to the PTV.

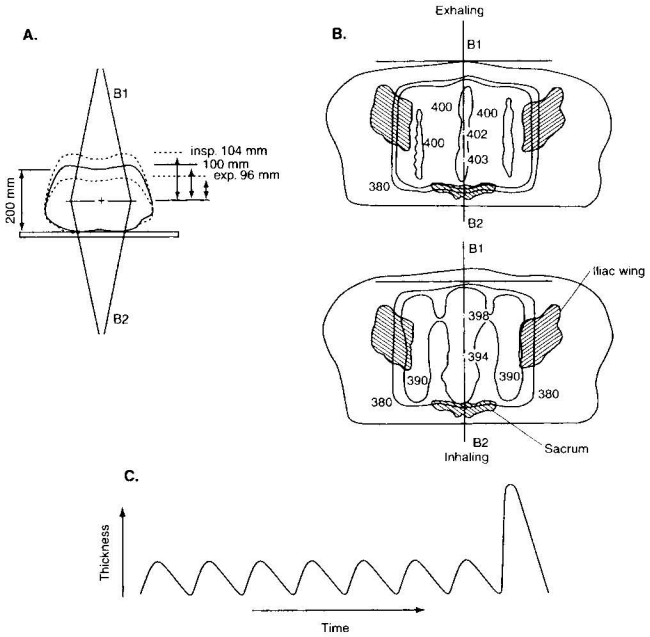


Fig. 2.10. Influence of respiration on body contour, movements of internal structures and dose distribution.

A. Patient treated for a lesion of the lower abdominal region. The thickness of the patient, measured on CT scans, varies in each direction by 4 mm from the average thickness.

B. The dose distributions are compared for two parallel opposed beams (B1 AP direction and B2 PA direction) in end expiration (above) and end inspiration (below). The dose distributions are displayed in a transverse plane containing the beam axes at the level of the lower abdomen.

C. The variation with time of the thorax thickness, shows that, in normal breathing, expirations lasts longer than inspiration. As illustrated in the right part of the figure, there may be occasionally a deep inspiration.

(Adapted from Jacobs *et al.* (1996), by kind permission.)

2.4.2 The Concept of Planning Target Volume (PTV)

The Planning Target Volume (PTV) is a geometrical concept used for treatment planning, and it is defined to select appropriate beam sizes and beam arrangements, to ensure that the prescribed dose is actually delivered to the CTV.[1]

Delineation of the PTV is a matter of compromise, implying the judgment, and thus the responsibility, of the radiation oncologist and the radiation physicist together.

The border of the PTV must be clearly identified on charts for treatment planning. For the purpose of dose specification for reporting and for evaluation of a Conformity Index (see below), the surface that defines the PTV must be closed, even if this may not be necessary for the proper selection of beam parameters (see *e.g.*, Beam's Eye View, BEV, Fig. 2.15., and AP-PA treatments, Fig. 2.17.a.1).

As will be discussed below, the different variations and uncertainties may be either of type A or B ("random" or "systematic"); they may be independent from each other or related in different ways. Their size may differ for different parts of a CTV (*e.g.*, base versus apex of the bladder and prostate), and at different times (*e.g.*, with the respiratory cycle). The situation for a single patient may be quite different from that for a patient population.

Depending on the clinical situation (*e.g.*, patient condition and site of the CTV) and the chosen technique, the PTV could be very similar to the CTV (*e.g.*, small skin tumors, pituitary tumors) or, by contrast, much larger (*e.g.*, lung tumors). Since the PTV is a purely geometric concept that must be related to the basic anatomical description, it may extend beyond normal anatomical borders (*e.g.*, include parts of clinically unaffected bony structures).

In a typical example of tangential irradiation of the breast, respiratory movements cause the PTV to move and extend outside the average position of the body contour (Fig. 2.13.). The situation should be handled according to general rules when appropriate

[1] Note that the definition of the Planning Target Volume (PTV) as introduced in ICRU Report 50 (ICRU, 1993), and used in this Report, is identical to the previous definition of "Target Volume" in Report 29 (ICRU, 1978).

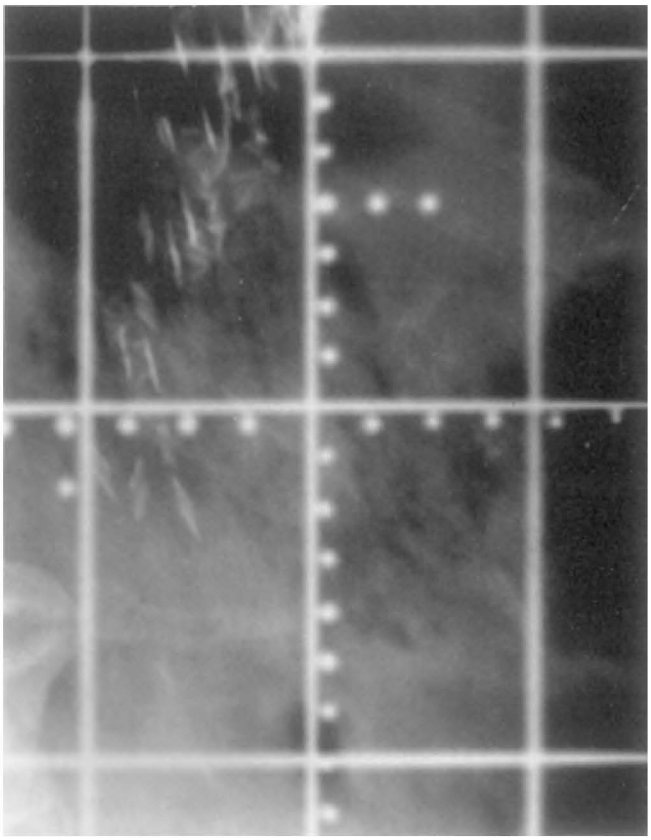


Fig. 2.11. Clinical example of possible intrafractional displacement of the GTV (carcinoma of the pancreas) in relation to internal fixed point(s) (the vertebral body, visible to the left). Due to respiratory movements, the implanted metallic clips in the tumor move at least 6 mm during an exposure of 1 second duration at the simulator. The borders of the proposed treatment field are also shown (the dots are 1 cm apart).

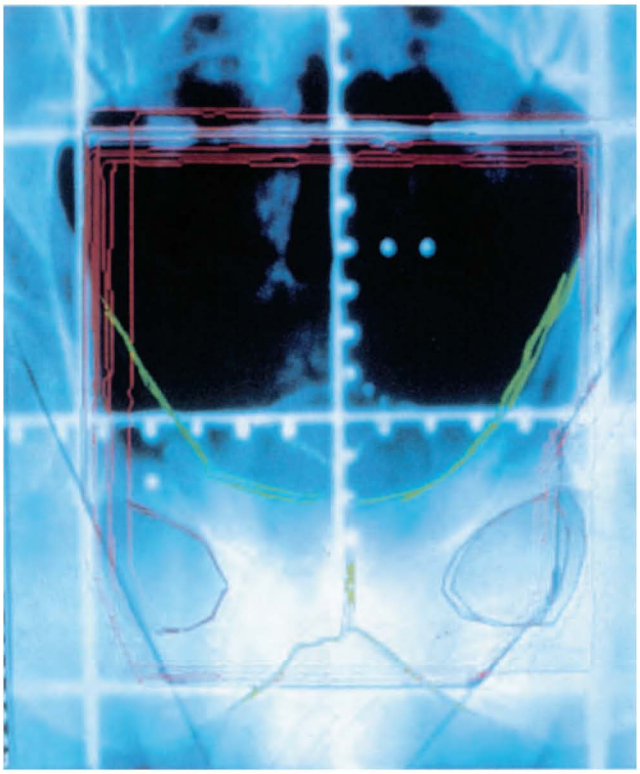


Fig. 2.12. Example of significant variations in patient/beam positioning. In the simulator film of a treatment of a pelvic tumor, the prescribed anterior field is indicated by white lines. The red lines represent the borders of the beam at successive fractions, using treatment verification images. This is likely indicative of both type A and B uncertainties (see text section 2.4.3.).
(Courtesy, Lars Ekberg, MD, Dept. of Oncology, Malmö, Sweden.)

beam sizes are selected to compensate for these geometrical uncertainties. However, in these cases, there will be a problem when the absorbed dose distribution for the PTV is calculated and displayed, since this cannot be done in a meaningful way outside the body contour, when shown in a single, "average," static representation. As an approximation, one can perform the dose computation assuming the normal tissues to be in the extreme position (moved towards the surface, see Fig. 2.13., dashed line) so that the absorbed dose distribution to the CTV is similar to the one that would be found if there were no geometrical uncertainties and then calculate and display the dose distribution to the PTV. In any case, it is recommended that a description be given of the method that was used.

One difficulty in choosing a PTV results from the presence of radiosensitive normal tissue(s) (Organs at Risk, see definition below). If a compromise between an adequate selection of a PTV and the risk of complications is unsatisfactory for a provisional beam arrangement, then alternative beam arrangements must be considered as part of an optimization procedure. If the PTV and the PRV overlap (see section 2.7.2.), this must be considered when prescribing dose and fractionation. In some cases, it may be necessary to change the prescription (for volumes and/or dose levels) and then accept a changed probability of benefit. When, for radical treatments, the probability of local control diminishes, then the aim of therapy may shift from radical to palliative.

2.4.3 Adding or Combining the Margins

When choosing a PTV, the different types of margins identified above must be added or combined. Different scenarios are depicted in Fig. 2.16.

In choosing margins, the risk of missing part of the CTV must be balanced against the risk of complications due to making the PTV too large. For instance, if margins are added linearly, the resulting PTV may often be too large, with a consequent risk of exceeding patient tolerance.

Since margins are introduced to compensate for both random and systematic uncertainties, a quadratic combination approach similar to that recommended by the Bureau International des Poids et Mesures (BIPM, 1981) is often employed. This may provide a means to combine random and systematic,

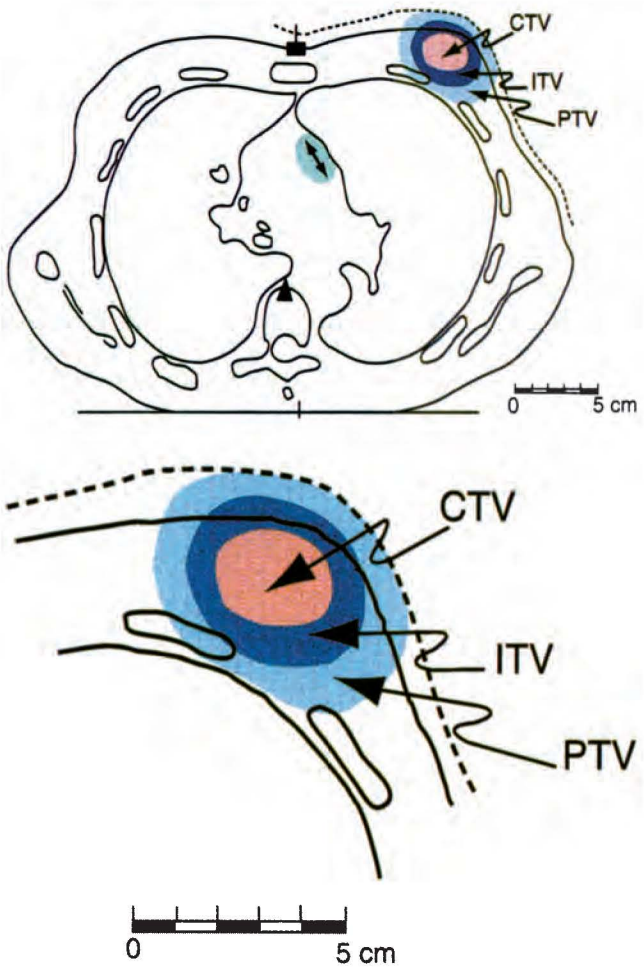


Fig. 2.13. Patient with cancer of the left breast after lumpectomy (no GTV present) considered for postoperative radiotherapy to the whole breast (not shown here, but given as shown in Fig. 2.6., ICRU Report 50), and a boost (shown here) to the tumor bed. The relations between the different volumes and margins are shown in one planar section. The internal and external reference points are indicated. Due to the respiratory movement, the PTV extends outside the average position of the body contour.

Light red	= CTV (Clinical Target Volume),
Dark blue	= ITV (Internal Target Volume),
Light blue	= PTV (Planning Target Volume),
◄►	= OR (Organ at Risk, in this case the Left Anterior Descending Coronary Artery, shown here as projected onto the section),
Light green	= PRV (Planning Organ at Risk Volume),
———	= Average position of the contour and tissues,
– – –	= Extreme position of the normal tissues (see section 2.4.2.),
▲	= Internal Reference Point,
■	= External Reference Point,

as well as correlated and uncorrelated uncertainties. In many instances, this process provides realistic and acceptable results (Mijnheer *et al.*, 1987). Unfortunately, this ideal approach can be applied strictly only in situations where one can identify the causes or errors and quantify the uncertainties (*e.g.*, by standard deviation). Currently, this is not generally possible except for a few situations (*e.g.*, some conformal therapy protocols).

In practice, at present, the PTV must be delineated by the radiation oncology team based on experience and judgment drawn from observation and evaluation of the risk of failure and complications. In any case, the method used to select margins and their widths must be clearly reported.

NOTE: THE PENUMBRA

The penumbra of the beam(s) is not considered when delineating the PTV. However, when selecting the beam sizes, the width of the penumbra has to be taken into account and the beam size adjusted (enlarged) accordingly.

2.5 Treated Volume

2.5.1 General Aspects

Due to limitations of irradiation techniques, the volume receiving the prescribed dose does not generally match the PTV; it may be larger (sometimes much larger) and in general more simply shaped. This leads to the concept of Treated Volume.

The Treated Volume is the tissue volume that (according to the approved treatment plan) is planned to receive at least a dose selected and specified by the radiation oncology team as being appropriate to achieve the purpose of the treatment, e.g., tumor eradication or palliation, within the bounds of acceptable complications.

The Treated Volume is the volume enclosed by the isodose surface corresponding to that dose level. The relative value of the isodose that was selected to define the Treated Volume in relation to the dose at the ICRU Reference point should be stated when reporting. Alternatively, the value of the dose level that was selected to define the Treated Volume can be expressed in absolute values. For example, if the prescribed dose at the ICRU Reference Point is 60 Gy and if a dose variation between +7% and −5% is accepted in the PTV, the Treated Volume is enclosed by the 57 Gy (= 95% of the 60 Gy) isodose surface.

The delineation of the Treated Volume is completed when the treatment planning procedure is completed and the beam arrangement, as well as all other irradiation parameters, have been verified. It is the aim of Quality Assurance Procedures to ensure that actual Treated Volume corresponds to the planned Treated Volume.

It is important to identify the Treated Volume and its shape, size, and position in relation to the PTV for several reasons. One is to evaluate and

TABLE 2.1—*Factors to be considered when defining a planning target volume*

Category	Intrafractional variations (Variations during a single fraction)		Interfractional variations (Variations during the entire course of treatment)	
	Random	Systematic	Random	Systematic
Variations of CTV				
In size	Physiological processes (circulation, respiration, peristalsis)	Physiological processes (circulation)	Physiological processes (*e.g.*, degree of bladder filling, bowel gas)	Tumor reduction or swelling
In position relative to a fixed point in the patient	Physiological processes (circulation, respiration, peristalsis)	Change in treatment position (prone-supine)	Physiological processes (*e.g.*, degree of filling of cavities)	Weight loss
Variations in position of the patient relative to the treatment beams	Patient movements		Daily set-up	Technical errors

interpret causes for local recurrences ("in-field" versus "marginal"). Another is to evaluate and interpret complications in normal tissues (encountered outside the PTV but within the Treated Volume).

2.5.2 Conformity Index (CI)

A Conformity Index (CI) can be employed when the PTV is fully enclosed by the Treated Volume, then being the quotient of the Treated Volume and the volume of the PTV. A similar "Radiation Conformity Index (RCI)" was proposed by Knöös *et al.* (1998).

The CI can be used as part of the optimization procedure. It must be stressed that when defining the CI, it is implied that the Treated Volume totally encompasses the PTV.

2.6 Irradiated Volume

The Irradiated Volume is the tissue volume that receives a dose that is considered significant in relation to normal tissue tolerance.

If the Irradiated Volume is reported, the significant dose must be expressed either in absolute values (in Gy) or relative to the specified dose to the PTV. The Irradiated Volume depends on the treatment technique used.

Note that the size of the Irradiated Volume relative to the Treated Volume may increase as the number of beam directions increases (Fig. 2.17 and Table 2.3.). This implies a compromise, and it is the responsibility of the radiation oncology team to select what is judged to be the optimal treatment.

In "conformal therapy" using beam shaping, *e.g.*, by MLC (Multi Leaf Collimator), or customized blockings, both Treated Volume and Irradiated Volume can be reduced.

TABLE 2.2—*Range of movements (mm) of the CTV in relation to an internal fix-point (vertebral body) in 20 patients with lung cancer, studied fluoroscopically during normal respiration*[a]

	Medio-lateral	Cranio-caudal	Dorso-ventral
Maximum movement	5.0	12.0	5.0
Average movement	2.4	3.9	2.4
Standard deviation	1.4	2.6	1.3

[a]From Ekberg *et al.*, 1998.

2.7 Organs at Risk (OR)

2.7.1 Definition of Organs at Risk

Organs at Risk ("critical normal structures") (see also section 3.5.) are normal tissues (e.g., spinal cord) whose radiation sensitivity may significantly influence treatment planning and/or prescribed dose

TABLE 2.3—*Variation of Treated Volume and Irradiated Volume for different beam arrangements*

Beam arrangement	PTV (359 cm³)	Volume ratio: Treated volume / PTV	Volume ratio: Irradiated volume / PTV
A. OPEN BEAMS:			
Two Parallel Opposed Beams	1	4.35	8.56
Three Intersecting Beams	1	2.61	11.90
Four Intersecting Beams	1	2.61	9.58
Arc Therapy	1	2.18	9.14
B. MULTILEAF COLLIMATOR:			
Three Intersecting Beams	1	1.74	7.40
Four Intersecting Beams	1	1.60	6.38

Note: An example of treatment of a prostatic adenocarcinoma, using 2, 3, and 4 intersecting beams and arc therapy (open beams *i.e.*, square or rectangular), and 3 and 4 intersecting beams with multileaf collimator (conformal therapy). The dose distributions are displayed in Fig. 2.17. The 100% isodose is taken at the ICRU Reference Point (intersection of beam axes). The Treated Volume is enclosed in the 95% isodose surface, and the Irradiated Volume by the 50% isodose surface. When the number of beams is increased, the Conformity Index (CI_{95}), (*i.e.*, the ratio between the Treated Volume and the PTV) decreases (comes closer to unity). This is not the case with the Irradiated Volume. The use of the multileaf collimator definitely improves the situation. (From N. Gupta, Ph.D., The Ohio State University).

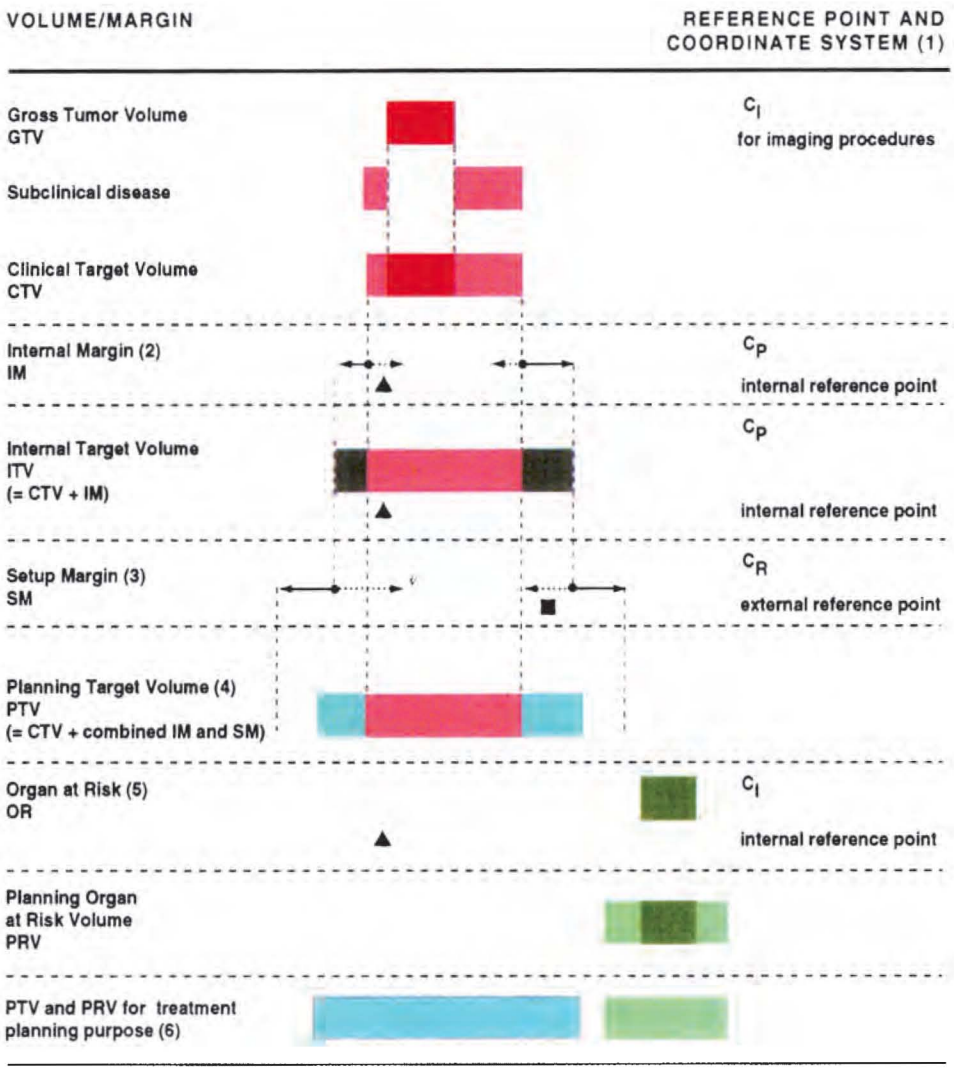


Fig. 2.14. Schematic representation of the different volumes/margins.

Notes:

(1) For explanation, see Sections 2.1–2.7.
(2) The Internal Margin may be asymmetrical.
(3) Like the Internal Margin, the Set-up Margin may also be asymmetrical.
(4) To delineate the PTV, the IM and SM are not added linearly (since this could result in an excessively large PTV), but are combined essentially subjectively (for explanation, see text). The PTV is thus smaller than if one would simply have added the IM and SM linearly.
(5) For Organs at Risk (OR), margins are added in the same way as for the PTV.
(6) The PTV and PRV may or may not overlap.

Presently, our knowledge about the sensitivity of normal tissues is derived mainly from clinical observations. However, different approaches have been proposed for the modeling of normal tissue complication probability (NTCP): the empirical model introduced by Wolbarst *et al.* (1982); and also described by Lyman (1985), and the functional models based on the FSU (Functional Sub Unit) concept (Withers *et al.* [1988], Källman *et al.* [1992], and Olsen *et al.* [1994]).

The FSU-concept suggests that, for the purpose of evaluation of the volume-fractionation-response, the tissues of an Organ at Risk can be considered to be functionally organized as either "serial," "parallel," or "serial-parallel" structures (Fig. 2.18.). For example, the spinal cord has a high "relative seriality," implying that a dose above tolerance limit to even a small volume of this Organ at Risk may be deleterious; whereas, the lung usually has a low "relative seriality," meaning that the most important parameter is the relative size of the volume that is irradiated above tolerance level.

Late effects from mantle treatment for Hodgkin's disease may serve as an example (Gustavsson *et al.*,

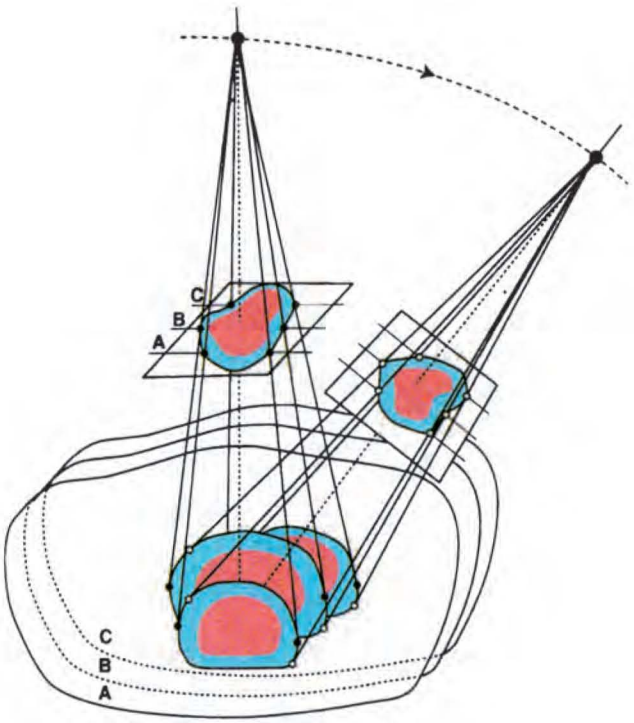


Fig. 2.15. Illustration of Beam's Eye View (BEV) for two isocentric beams. The CTV and PTV are indicated (light red, and light blue, respectively in the three body sections). The projections of the CTV and PTV on the two planes perpendicular to the beam axis are shown. Closed circles and open circles are used to illustrate the projection geometries.

1990, 1992). At similar doses, the late effects from the (partial) irradiation of the lungs (a parallel tissue) were much less serious than those from the heart (a combined serial [coronary arteries] and parallel [myocardium] tissue).

For the moment, the model has not been tested enough to allow for firm recommendations, but indeed it highlights an important problem. It may be useful to state whether the Organ at Risk is considered to be arranged mainly serially, mainly in parallel, or mainly in a mixed serial-parallel fashion.

2.7.2 Planning Organ at Risk Volume (PRV)

As is the case with the Planning Target Volume, any movements of the Organ(s) at Risk during treatment, as well as uncertainties in the set-up during the whole treatment course, must be considered.

An integrated margin must be added to the OR to compensate for these variations and uncertainties, using the same principles as for the PTV. In particular, Internal and Set-up margins can be identified.

This leads, in analogy with the PTV, to the concept of *Planning Organ at Risk Volume (PRV)*.

For reporting, it is recommended that, as for the PTV, the PRV be described by including the size of the combined margins of the Organ at Risk in different directions.

Note that a PTV and a PRV may overlap.

2.8 Recommendations for Recording and Reporting Volumes

When reporting a radiation treatment, some important oncological information must be given first, *e.g.*, the description (plural, when relevant) of the

- Gross Tumor Volume (GTV),
- Clinical Target Volume (CTV).

Then, the information concerning the treatment itself must be given, in particular:

- Planning Target Volume (PTV),
- Treated Volume,
- Irradiated Volume,
- Planning Organ at Risk Volume (PRV).

The description of the Planning Target Volume is a key point in the description of the treatment. Delineation of the Planning Target Volume is always a compromise, implying the judgment, experience, and thus the responsibility of the radiation oncology team. The different margins that were added or combined as well as the Organs at Risk that were considered when defining the PTV should be clearly described so that the aim of the treatment and the doses that are reported can be understood unambiguously.

Furthermore, as a general recommendation, additional relevant information should be reported.

Graphics

It is common practice to mark the position of anatomical structures with different colors to promote the proper interpretation of the decisions made. A common example is to depict "the tumor" in red. In treatment planning, different colors will be used for anatomic structures, "regions of interest," beam geometry, and distribution of absorbed dose. The colors must be easily interpreted.

For the moment, there is no general agreement on the choice of different colors or shades for these purposes.

In this report the following convention is recommended and has been used:

GTV: Gross Tumor Volume — dark red
CTV: Clinical Target Volume — light red
ITV: Internal Target Volume — dark blue
PTV: Planning Target Volume — light blue
OR: Organ at Risk — dark green
PRV: Planning Organ at Risk Volume — light green
Landmarks — black

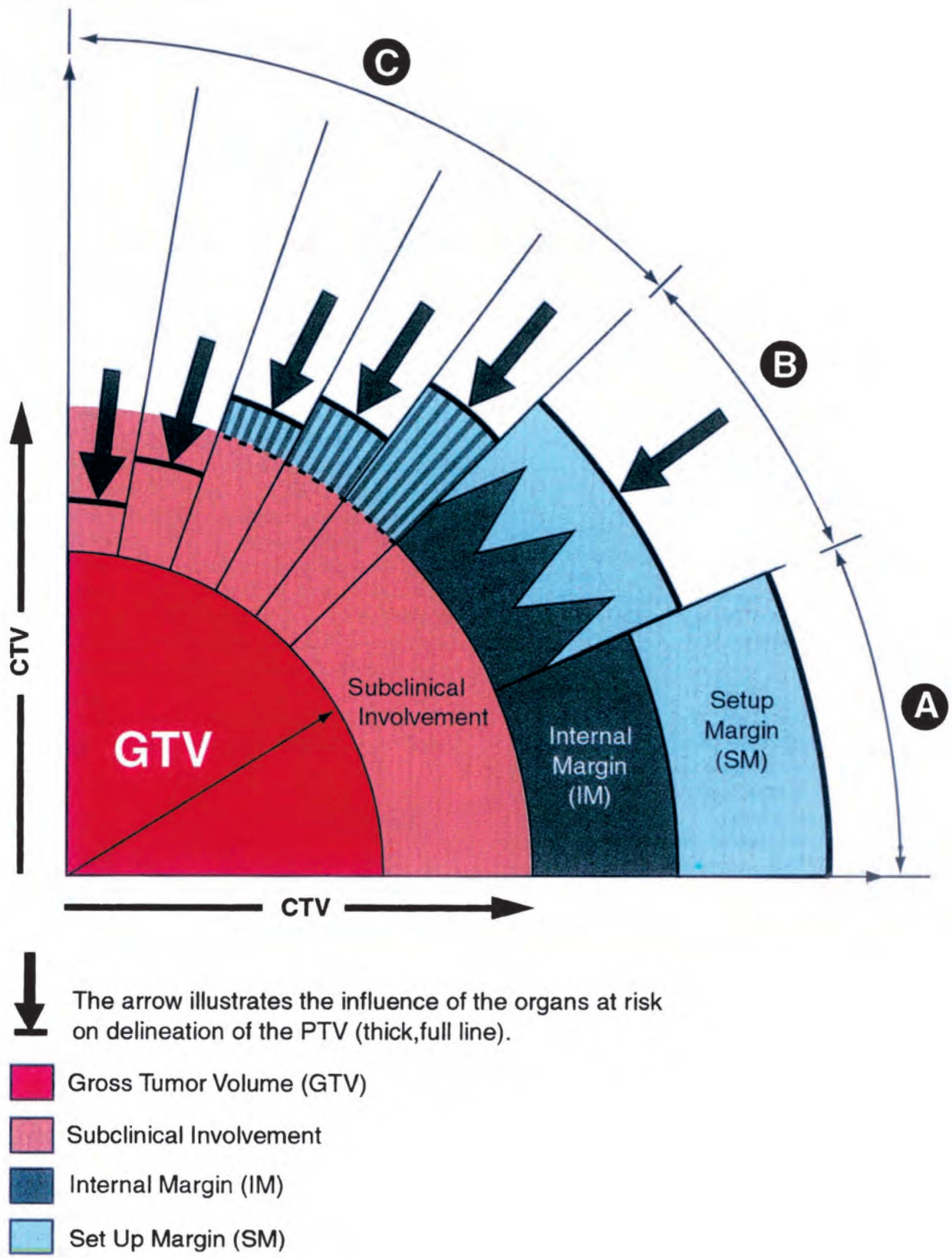


Fig. 2.16. Schematic representations of the relations between the different volumes (GTV, CTV, PTV, and PRV) in different clinical scenarios.

[Caption continued on page 17.]

In case further ORs are identified, to avoid confusion, additional colors can be selected, *e.g.,* yellow (or brown) (dark color indicating the OR, and corresponding light color indicating the PRV). Where the figures in this report have been prepared specifically for this document, the recommended color code has been used, but where the figures are taken from other sources, the original author's scheme is replicated.

The volumes should be presented as color surfaces (Fig. 2.13.) and not just their contours.

It is important that new conventions such as these should be introduced in a department only if they can be expected to promote safety and when there is no risk of increased error or confusion.

2.9 Probability of Benefit and Risk of Complications

A safety margin around the GTV is generally irradiated to treat subclinical disease. Also regional lymph node areas are often irradiated for the same reason. This leads to the concept of the CTV (see section 2.3.). An additional safety margin is added to take into account the movements and the variations in shape and size of the CTV, as well as the variation and uncertainties in patient-beam positioning. This leads to the concept of the PTV (see section 2.4.).

The concept of a safety margin can also be applied to the OR, since, because of the movements of the organs in the body and the uncertainties in positioning of the beams in relation to the patient, there is a risk that the OR will receive an excessive dose.

Ideally, one would prefer to irradiate only the tissues containing malignant cells, *i.e.,* the GTV and the normal tissues actually involved by subclinical disease. In practice, one takes the risk of irradiating non-invaded tissues if the probability of involvement is high enough.

The probability of subclinical involvement around the GTV and in the regional lymph nodes can only be learned from clinical experience. It is then a matter of clinical judgement whether treatment of these tissues is justified. Other factors must be taken into consideration when making such a decision: the efficacy of irradiation of subclinical disease, or alternative methods of treatment (surgery or chemotherapy). One also must consider morbidity. In addition, one must avoid overtreating patients who will fail either locally or at a distance, or patients already cured by successful treatment of the GTV. Future diagnostic (imaging) methods can be expected to improve detection of (previously) subclinical disease, which can then become part of the GTV. However, the problem will not be eliminated totally; only the probability levels will be modified.

During the treatment planning procedure, additional margins must be added to the CTV in order to avoid underdosage of part of the CTV. Similarly, margins must be added around the OR in order to avoid overdosage of part of the OR. These two types of volumes and margins may overlap, and the best possible compromise must be found; it depends on the experience, judgement, and skill of the radio-

Fig. 2.16. (Continued)

Scenario A.

A margin is added around the Gross Tumor Volume (GTV) to take into account potential "subclinical" invasion. The GTV and this margin define the Clinical Target Volume (CTV).

In external beam therapy, to ensure that all parts of the CTV receive the prescribed dose, additional safety margins for geometric variations and uncertainties must be considered.

An Internal Margin (IM) is added for the variations in position and/or shape and size of the CTV. This defines the Internal Target Volume.

A Set-up Margin (SM) is added to take into account all the variations/uncertainties in patient-beam positioning.

CTV + IM + SM define the Planning Target Volume (PTV) on which the selection of beam size and arrangement is based.

Scenario B.

The simple (linear) addition of all factors of geometric uncertainty, as indicated in scenario A, often leads to an excessively large PTV, which would be incompatible with the tolerance of the surrounding normal tissues.

In such instances, instead of adding linearly the Internal Margin and the Set Up Margin, a compromise has to be sought, and a smaller PTV has to be accepted. However, when aiming at optimizing the width of the "global" safety margin, a quantitative approach (*e.g.,* using the $\sqrt{\Sigma\sigma^2}$ formalism) is only relevant if all uncertainties, and their σ, are known, *i.e.,* in a few sophisticated protocols.

Scenario C.

In the majority of the clinical situations, a "global" safety margin is adopted. In some cases, the presence of Organs at Risk dramatically reduces the width of the acceptable safety margin (presence of the spinal cord, optical nerve, *etc.*). In other situations, larger safety margins may be accepted.

Since the incidence of subclinical invasion may decrease with distance from the GTV (see Fig. 2.6.), a reduction of the margin for subclinical invasion may still be compatible with chance for cure, albeit at a lower probability rate.

It is important to stress that the thickness of the different safety margins may vary with the angle from which one looks at the PTV (*e.g.,* bony structures or fibrotic tissue may prevent, at least temporarily, malignant cell dissemination).

(Note that if an adequate dose cannot be given to the whole GTV, the whole aim of therapy shifts from radical to palliative.)

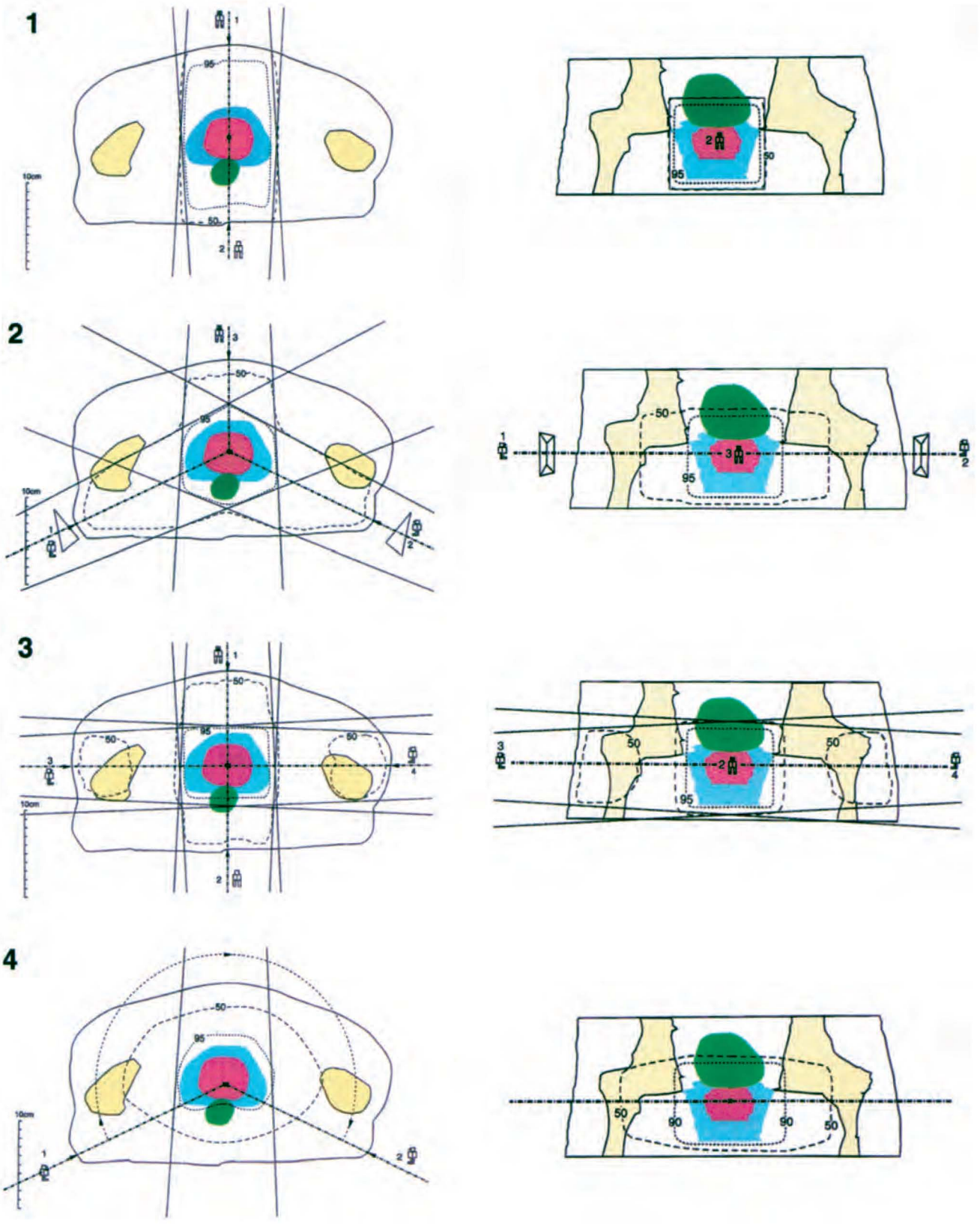


Fig. 2.17.a. Comparison of six different Treated Volumes resulting from the irradiation of the same Planning Target Volume for the treatment of prostate adenocarcinoma using two (2.17.a.1), three (2.17.a.2), four (2.17.a.3) fields and arc therapy (2.17.a.4) with open fields, and three (2.17.a.5), and four (2.17.a.6) fields with Multi Leaf Collimator (MLC). Examples of dose distributions are shown in transverse and coronal sections, respectively. The CTV is in light red. The PTV is light blue. The rectum is indicated in dark green, and the bony structures are yellow. The dose at the ICRU Reference Point is taken as 100%. Six figures compare the dose distributions in central planes. The Treated Volumes are enclosed in the 95% isodose surface (····). The Irradiated Volumes are enclosed in the 50% isodose surface (----). For the treatment plans involving 3 and 4 beams, the dose distributions obtained with unblocked fields and with conformal blocking (MLC) are compared.

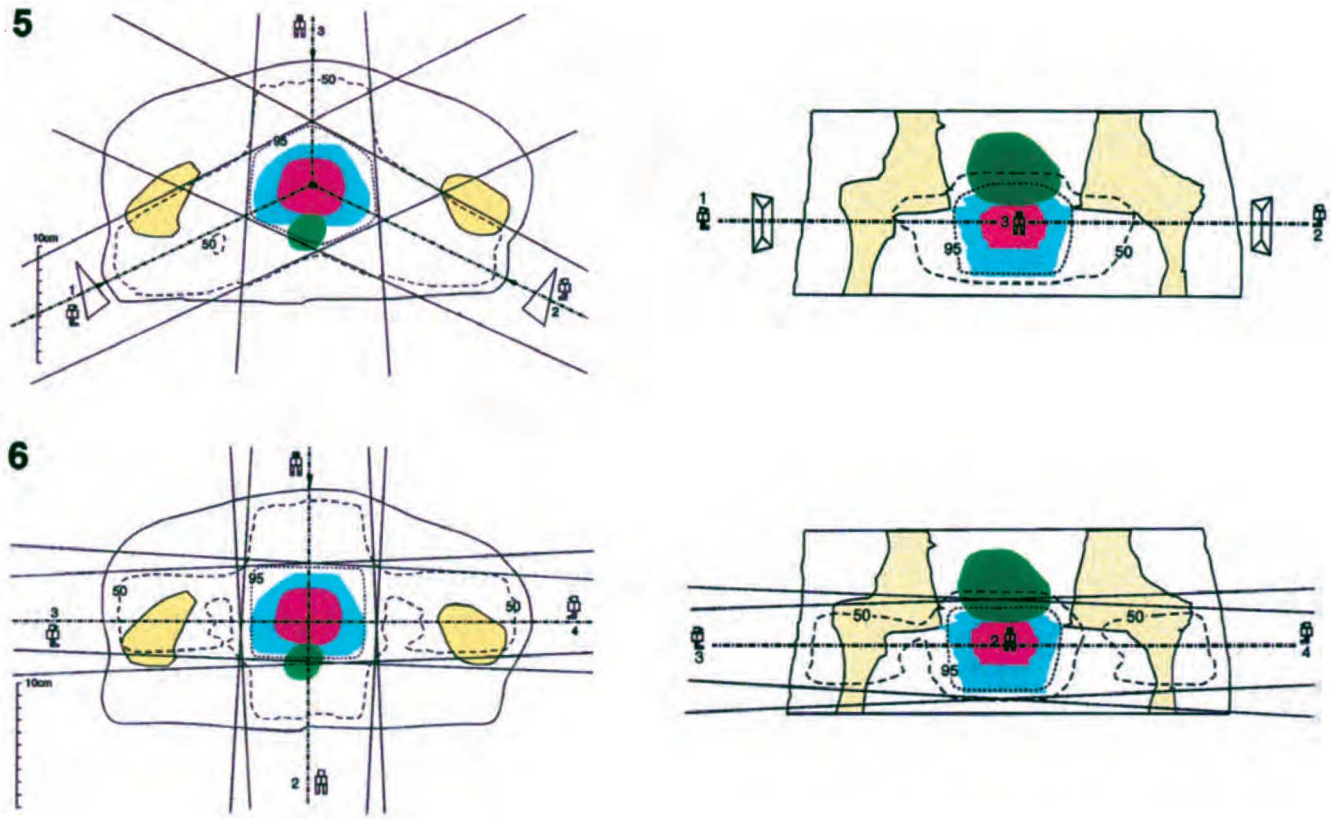


Fig. 2.17.a. (Continued)

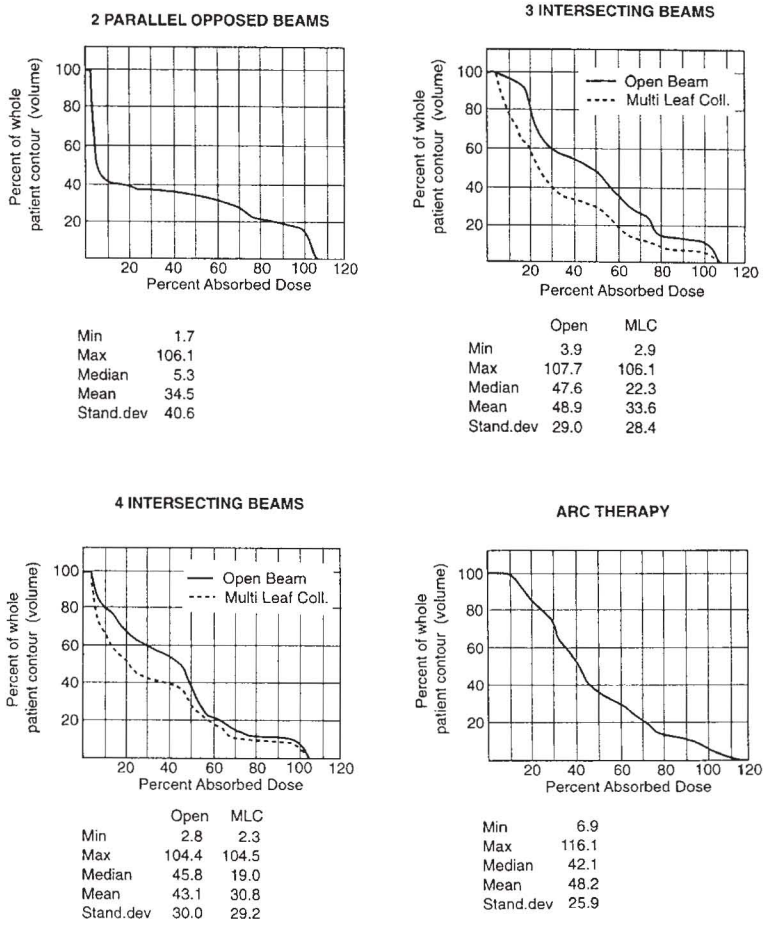


Fig. 2.17.b. Same examples as in Fig. 2.17.a. Cumulative dose-volume histograms for the external patient surface (volume) are compared for all treatment plans shown in Fig. 2.17.a. For 3 and 4 beams, the dose volume histogram with open beams and Multi Leaf Collimator are compared on the same figure.

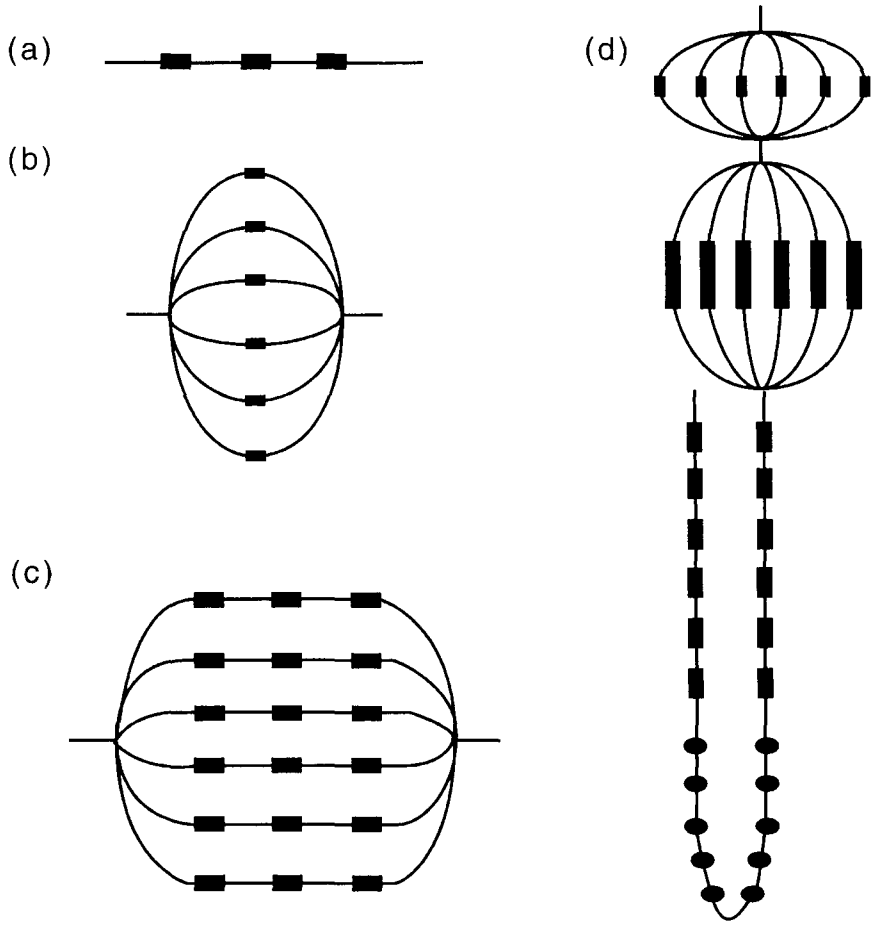


Fig. 2.18. Schematic examples of tissue organization structures in the parallel-serial model.
(a) a serial string of subunits (*e.g.*, the spinal cord),
(b) a parallel string of subunits (*e.g.*, the lungs),
(c) a serial-parallel string of subunits (*e.g.*, the heart),
(d) a combination of parallel and serial structures (*e.g.*, a nephron).
(Modified from Withers *et al.*, (1988) and Källman *et al.*, (1992).)

therapy team and also on the technical equipment and facilities available.

In any case, the presence of ORs always implies compromises, and it is necessary to apply the risk philosophy. When increasing or decreasing the width of the safety margins, the risk of missing part of the cancer cell population must be balanced by the risk of increasing the number and/or severity of the complications. Further clinical quantitative information about the cost/benefit ratio will help to make the decisions more objective.

These situations are illustrated in Fig. 2.16. A reasonable balance will have to be found for each individual patient.

3. Absorbed Doses

3.1 From Prescribing a Therapeutic Irradiation to Recording and Reporting

Prescription of treatment remains the responsibility of the radiation oncology team in charge of the patient, and it is not the purpose of this report to make recommendations about treatment prescription itself. However, it is obvious that adoption of the same concepts and definitions for prescribing, recording, and reporting will facilitate the procedure and reduce the risk of confusion.

In order to make exchange of information precise and accurate, it is important that treatments performed in different centers be *reported* in the same way, using the same concepts and definitions.

The following recommendations for reporting are aimed at establishing a set of minimum information items on which there should be general agreement and which should be reported in all cases. This would meet the general goal of the present report, but, of course, any additional information considered as relevant should be added.

Such additional information could be related to:

* A more accurate and detailed description of the dose distribution, *e.g.,* average dose and its standard deviation, dose-volume histograms (DVH), *etc.*
* An accurate description of the dose at different anatomical sites (including Organs at Risk).

Reporting such additional information is encouraged, since it could ultimately contribute to developments and improvements in radiotherapy.

3.2 The ICRU Reference Point

As a general principle, the present system of recommendations for reporting doses is based on the selection of a point within the PTV, which is referred to as the *ICRU Reference Point.*

The ICRU Reference Point shall be selected according to the following general criteria:

(1) the dose at the point should be clinically relevant;
(2) the point should be easy to define in a clear and unambiguous way;
(3) the point should be selected so that the dose can be accurately determined;
(4) the point should be in a region where there is no steep dose gradient.

These recommendations will be fulfilled if the ICRU Reference Point is located:

- *always at the center (or in a central part) of the PTV, and*
- *when possible, at the intersection of the beam axes.*

The dose at the ICRU Reference Point is the ICRU Reference Dose and shall always be reported.

3.3 The Dose Variation Throughout the CTV

Tumor control depends on the dose to the CTV and its variation. However, the variation in CTV dose can only be estimated from the variation in the PTV dose.

A certain degree of inhomogeneity of the absorbed dose throughout the PTV is always present. A dose variation may even be desirable in some instances.

According to the recommendations already published (ICRU Report 50, ICRU [1993]), as a *basic* requirement, the following doses shall be reported:

- the dose at the ICRU Reference Point,
- the maximum dose to the PTV,
- the minimum dose to the PTV.

The PTV and the PRV are fixed volumes related to fixed anatomical structures, and thus allow for an accurate computation of the dose at the center, the maximum dose, and the minimum dose and for the presentation of dose-volume histograms. Such histograms should be reported for the PTV and PRV, when available.

Since the CTV can move in space and can change size and shape, the dose at the center, the maximum and the minimum dose, and the dose-volume histograms cannot be determined with high accuracy. As far as the dose at the center of the CTV is concerned, its value is generally close to that of the dose at the center of the PTV, which thus can be reported as a reasonable estimate of the dose at the center of the CTV.

As far as the maximum dose to the CTV is concerned, its value is generally close to that of the maximum dose to the PTV, which thus can be reported as a reasonable estimate of the maximum dose to the CTV.

As far as the minimum dose to the CTV is concerned, it is by definition, equal to or larger than the minimum dose to the PTV. The minimum dose to the PTV can thus be considered as a lower limit of the possible range of minimum dose values for the CTV.

A dose-volume histogram can be computed for the PTV, since this is a fixed volume. Some parts (close to the border) of the PTV could (for presentation in an average section) be outside the body contour. In such situations, dose distributions, such as dose-volume histograms, must be computed only for that part of the PTV completely enclosed by the average body surface (see Fig. 2.13.).

Furthermore, such information for the GTV, CTV, and ITV should, when feasible, be reported.

3.4 The Three Levels of Dose Evaluation for Reporting

The level of completeness and accuracy of reporting therapeutic irradiation depends to a large extent on the situation in the department and on the aim of the treatment. Different levels of ambition for dose evaluation can be identified for different clinical situations. Three levels have been selected for reasons given below, but it is recognized that intermediate levels could also be identified.

In the following paragraphs, only the basic, minimal requirements are outlined. However, as a general rule, reporting of any additional available information considered to be clinically relevant is recommended.

Since the publication of ICRU Report 50 in 1993, some experimental techniques have been fully implemented and have become available as commercial software and equipment. Hence, the description of the three levels had to be changed accordingly. This is reflected in the definitions of the three reporting levels in this Report.

Level 1.

The requirements should be followed in all centers, for all patients. They constitute the minimum standard below which safe and accurate radiotherapy cannot be performed. At this level, it is assumed that the dose at the ICRU Reference Point can be accurately determined as well as an estimate of the maximum and minimum doses to the PTV, using at least central-axis depth dose tables and standard isodose charts.

These basic level requirements imply that medical and physics expertise as well as appropriate equipment are available (see, e.g., Official Journal of the European Commission, 1997; Aletti and Bey, 1995).

Level 2.

The standards of dose planning at this level allow the exchange of more complete and relevant information between different centers.

At this level, it is assumed that the GTV, CTV, OR, PTV, and PRV can be defined using reliable patient data acquisition tools and/or modern imaging techniques under reliable conditions (*e.g.,* a series of CT and/or MRI sections). It is also assumed that complete dose distributions are available in planes or volumes, with inhomogeneity corrections, when appropriate.

There must be a full quality assurance program covering the whole procedure.

Level 3.

Level 3 includes the development of new techniques for which reporting criteria are not yet established (*e.g.,* BNCT, intensity modulation, etc.).

Some procedures, which are now at level 3, can become level 2 with the development of techniques, equipment and standards.

At any level, the dose at the ICRU Reference Point and the best estimation of the maximum and the minimum dose to the PTV should be reported.

3.5 Organs at Risk (OR)

To be able to calculate the probability of late effects in normal tissues, one must consider not only dose and fractionation, but also volumes of the Organ at Risk irradiated.

For each Organ at Risk, when part of the organ or the whole organ is irradiated above the accepted tolerance level, the *maximum dose* should be reported as defined in ICRU Report 50, Section 2.4.3 (Level 1).

Examples: Maximum spinal cord dose = 42 Gy, 10 cm C1–C4; left kidney dose = 21 Gy, whole kidney.

The volume receiving more than the accepted tolerance dose should be evaluated from the dose-volume histograms (Level 2 and above).

3.6 Reporting Doses in a Series of Patients

3.6.1. Introduction

The first part of the present report, as well as ICRU Reports 29 and 50, deal with dose reporting in a single individual patient. A different situation is encountered when reporting the results of treatment in a series of patients. For that purpose, the following rules are recommended.

3.6.2 Reporting Prescription of Treatment (Protocol)

The description of *volumes* must be consistent with the definitions used in this report (see above).

The prescribed *dose* to be given to the PTV and its *fractionation* must also be described as indicated in this report. An example of such a description is given in Table 3.1 and is also illustrated for the cases in the Appendix.

TABLE 3.1—*Typical prescription of treatment for a study involving a series of patients (derived from RTOG, Purdy et al. 1996)*

A. Example of definition of GTV, CTV, and PTV for a prostate cancer dose escalation study.

(a) Gross Tumor Volume Definition by Group.
- Group 1: GTV = Prostate.
- Group 2: GTV = Prostate.
- Group 3: GTV = Prostate + bilateral seminal vesicles.

(b) Clinical Target Volume Definition by Group.
- Group 1: CTV is the GTV (prostate).
- Group 2: CTV_1 is the Prostate + the bilateral seminal vesicles.
  CTV_2 is the GTV (prostate).
- Group 3: CTV is the GTV (prostate + bilateral seminal vesicles).

(c) Planning Target Volume Definition by Group.
- Group 1: PTV is the CTV with a 0.5 to 1.0 cm margin.
- Group 2: PTV_1 is the CTV_1 with a 0.5 to 1.0 cm margin.
  PTV_2 is the CTV_2 with a 0.5 to 1.0 cm margin.
- Group 3: PTV is the CTV with a 0.5 to 1.0 cm margin.

B. Example of prescription dose to PTV_1 and PTV_2 (as defined above in A.). Dose escalation schedule delivered in 2.0 Gy fractions, all fields treated daily, 5 fractions per week.
- Prescription dose is the ICRU Reference Point Dose within the PTV, which is defined at or near the center of the target (typically intersection of beams at isocenter). The minimum dose to the PTV should not be less than 93% of the ICRU Reference Point Dose. The maximum dose to the PTV should not exceed the ICRU Reference Point Dose by more than 3%.
- The reported doses shall include the dose to the ICRU Reference Point, the maximum dose, and minimum dose to the PTVs.
- Tissue heterogeneity correction will not be used.

Groups 1 and 3:

PTV ICRU Reference Point Dose
72.0 Gy
78.0 Gy
84.0 Gy

Group 2:

PTV_1 ICRU Ref. Pt Dose		PTV_2 (boost) ICRU Ref. Pt Dose		Total PTV_2 ICRU Ref. Pt Dose
60 Gy	+	12.0 Gy	=	72.0 Gy
60 Gy	+	18.0 Gy	=	78.0 Gy
60 Gy	+	24.0 Gy	=	84.0 Gy

3.6.3 Description of Actual Treatment in a Series of Patients

In clinical practice, it is not always possible to deliver the prescribed dose and dose distribution within the PTV for each patient. When collecting data over a considerable time span, such as in retrospective analyses, great variation in dose and fractionation may be encountered, as exemplified in Figure 3.1. There may also have been changes in the policy regarding factors such as prescription (*e.g.*, the use of the ICRU Reference Dose rather than minimum dose), and dose normalization. Such changes may significantly influence the doses that were given to the patients, even though such a change may not be easily recognized. Even within a controlled clinical trial, some variations occur (Figure 3.2.). However, it is important that, for a series of patients, the principles for reporting volumes and doses follow the general recommendations for each individual patient.

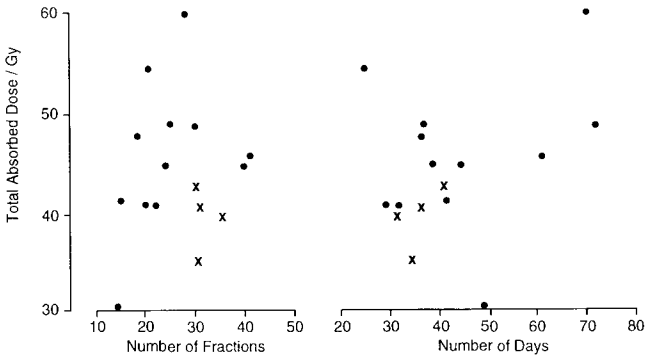


Fig. 3.1. Results obtained in 16 patients with medulloblastoma, treated between 1946–1975. The dose at the ICRU Reference Point in the position of the posterior fossa, distributed in number of fractions (left) and number of treatment days (right) for 16 patients, who, after a complete clinical remission, stayed either continuously symptom-free (twelve patients = ●), or relapsed in the posterior fossa (four patients = ×). (Landberg *et al.*, 1980).

Reasons for deviations from the prescribed dose level may arise from interruptions due to deteriorating patient condition, hardware break down, or re-evaluation of the patient resulting in a different prescription (*e.g.*, change from radical to palliative intent). Thus, the final dose variation in a series of patients may be considerable and not lend itself to being reported according to the previously recommended principles.

Hence, that proportion of patients in whom the dose variation is less than ±5%, ±5–10%, and more than ±10%, respectively, relative to the prescribed dose at the ICRU Reference Point shall be reported.

This can be illustrated in a simple diagram, as exemplified in Figure 3.3. The reasons for not delivering the prescribed dose should be clearly stated. Preferably, analysis of important end-points such as survival and local tumor control should be carried out for the entire patient series, as well as for those patients who fulfilled the prescription and for those who did not.

When reporting treatment, *e.g.*, in a scientific journal, it is recommended that the prescribed CTV and PTV and the corresponding doses be illustrated in an isodose distribution chart, giving the total dose in Gy.

The reporting of treatment techniques only in terms of field sizes and/or portal boundaries relative to anatomical structures (*e.g.*, 10 cm × 12 cm pelvic field) is not sufficient.

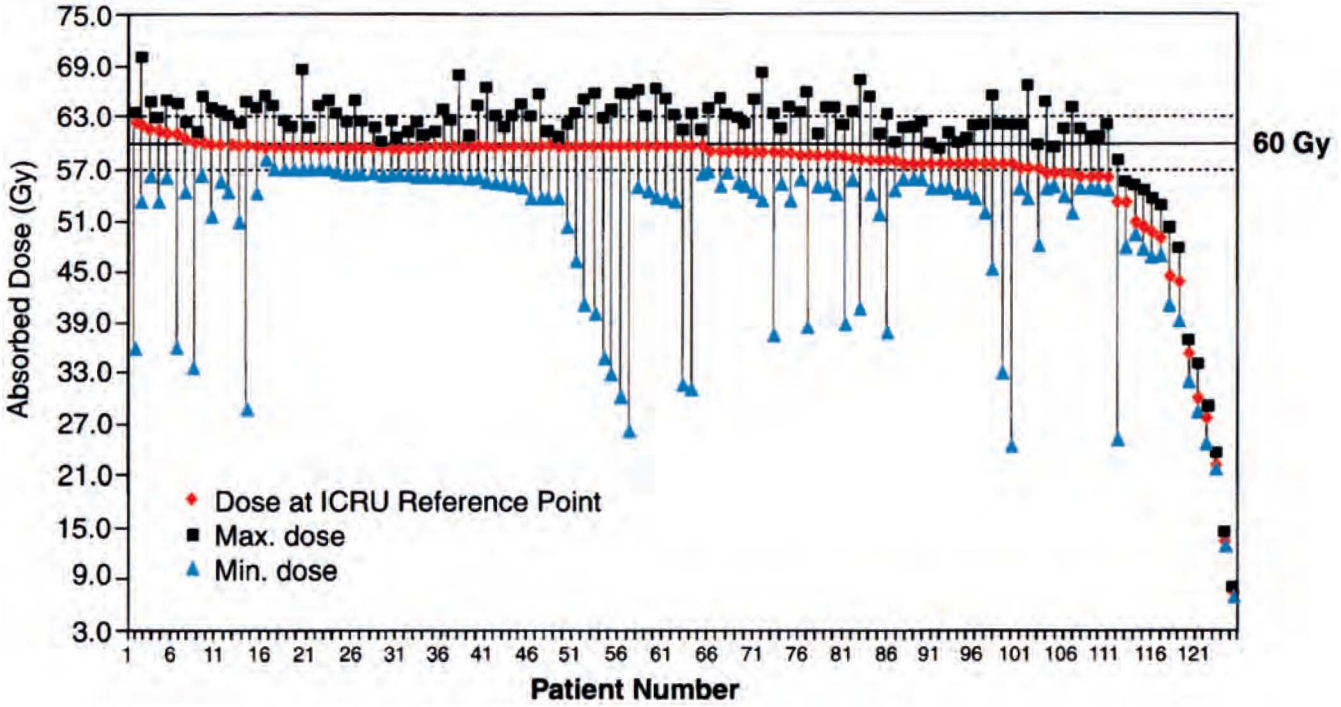


Fig. 3.2. Diagram showing the dose delivered to 125 patients in a non-small-cell lung cancer trial. The prescribed dose was 60 Gy ± 5% at the ICRU Reference Point. The patients are sorted in descending order of (1) dose at the ICRU point, and (2) minimum dose. The dotted lines indicate the permissible dose variation of ±5% from the prescribed dose. As regards dose to the ICRU point, 102 patients fulfilled the criteria; whereas, 23 patients received higher or lower doses to the ICRU Reference Point. (Courtesy of Ann-Margret Engström, RN, Oncological Centre, Lund, Sweden).

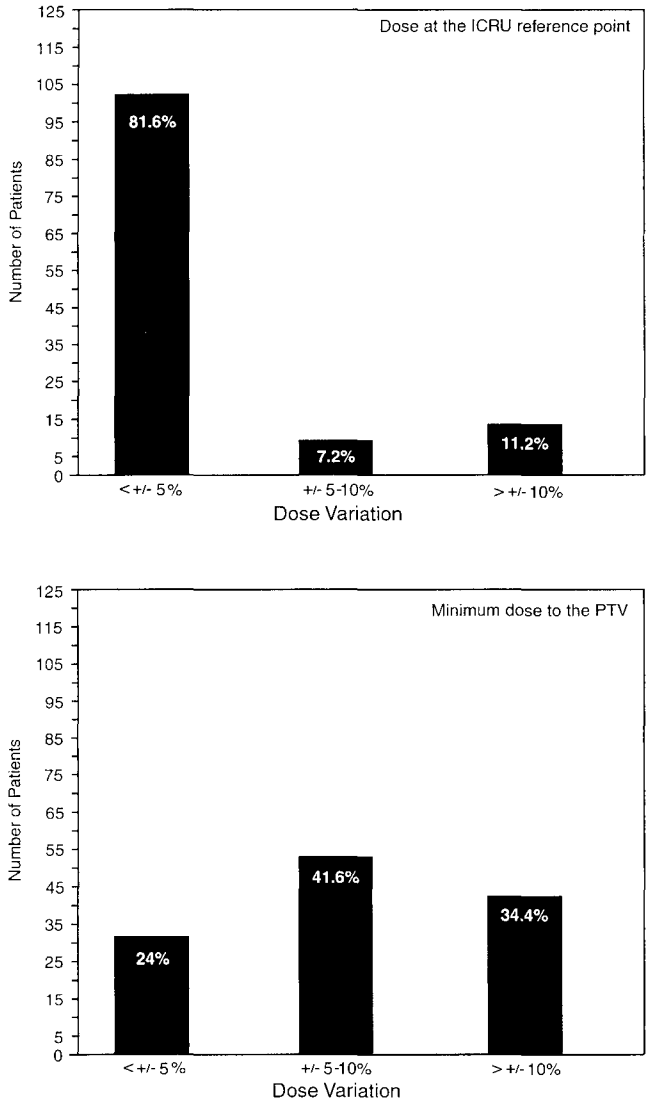


Fig. 3.3. Graph showing the proportion of a series of patients receiving an absorbed dose within three defined deviations from the prescribed dose in the protocol (same patient material as in Fig. 3.2.).
Upper Figure: dose at ICRU point.
Lower Figure: minimum dose to the PTV.
(Courtesy of Ann-Margret Engström, RN, Oncological Centre, Lund, Sweden).

Appendix

Clinical Examples

Three clinical examples are presented in which the ICRU recommendations for reporting external beam therapy are applied.

Note I: In the three following clinical examples, the anatomical sites of the different volumes (such as the GTV, CTV and OR) are described according to the International Classification of Diseases for Oncology (ICD-O [10]) (Reference: WHO, 1990). Part of the WHO document is cited in ICRU Report 50 (pp. 41–43). The anatomical levels of section(s) for treatemnt planning follow the "code for sections" presented in Table I.3 (page 44) in ICRU Report 50.

Note II: The color code recommended (Section 2.8.) has been used. For Cases Nos. 2 and 3, yellow has also been used to indicate an additional Organ at Risk. Also note that for Cases Nos. 2 and 3, the photographs are taken directly from the screen and the recommended colors appear changed in some instances due to the blending of the colors of any overlapping transparent volumes.

Case number 1.	**Breast Cancer: treatment of internal mammary nodes.**
CLINICAL SITUATION	48-year old female presented with a 0.5 cm × 1.0 cm hard, mobile lump in the upper inner quadrant of the left breast. There was no fixation to skin or underlying muscle and no palpable regional lymphadenopathy. Mammography showed a mass suspicious of malignancy. Clinical diagnosis T1b N0 M0 carcinoma. Wide local excision was performed. Histology showed a completely excised ductal carcinoma. The patient accepted no further treatment at the level of the breast. Due to the localization of the tumor, the internal mammary node chain only was considered to be at risk, and was accepted for radiotherapy.
AIM OF THERAPY	Radical radiotherapy after radical surgery. No systemic therapy.
GTV	No GTV to be defined.
CTV	The homolateral internal mammary lymph nodes [C77.1D-2], defined from CT-scans. Diameter 12 mm in the transverse section, cranio-caudal length 100 mm.
PTV	A margin of 9 mm to the CTV. The CTV, ITV, and PTV are shown in a transverse section at the level of the nipple in Fig. A.1.a. The cranio-caudal length of the PTV is 11.0 cm.
PRESCRIBED DOSE	50 Gy in 25 fractions over 5 weeks.
BEAM ARRANGEMENT	Two different techniques were evaluated: a: a single electron beam, b: a combination of one photon and one electron beam.
PATIENT POSITIONING	Supine with arms raised. Chest and head immobilized in a plastic cast. Arm poles and foot board. A Styrofoam wedge under the patient to make the surface over sternum horizontal.
SECTION FOR DOSE PLANNING	Transverse section through the center of the CTV [24].
ORGANS AT RISK	A: lung tissue [Parallel structure] [C34.9-2]. B: myocardium [C38.0] (left anterior descending coronary artery, LADC (Serial structure), indicated by the arrow in Fig. A.1.a.).
ACCEPTED DOSES TO ORGANS AT RISK	A: 30 Gy in at most 200 cm^3. B: 30 Gy.
TECHNIQUE	*Technique a (Fig. A.1.b.):* The dose is prescribed on the central beam axis, at the depth of the center of the PTV. Electron beam 18 MeV. Beam perpendicular to skin. Beam direction 0°. SSD 100 cm. Field width 45 mm. Field length 130 mm. For electron beams, the dose is prescribed and reported at the maximum of the depth dose curve. *Technique b (Fig. A.1.c.):* A combination of one electron beam and one photon beam was chosen, each of them contributing to half of the prescribed dose, respectively. The dose is prescribed at the ICRU Reference Point, on the central axes of the two (coaxial) beams at the depth of the center of the PTV. The beam sizes are defined by the 50% isodoses (thus including half of the penumbra). (1) Photon beam 6 MV. Beam perpendicular to skin. Beam direction 0°. SSD 100 cm. Field width 45 mm. Field length 130 mm. (2) Electron beam 18 MeV. Beam perpendicular to skin. Beam direction 0°. SSD 100 cm. Field width 45 mm. Field length 130 mm.
DOSE CALCULATION	*For technique a (a single electron beam) (Fig. A.1.b.):* Multiple plane dose calculation using 3-D pencil beam electron algorithm (Level 2) *For technique b (combined coaxial photon and electrons beams) (Fig. A.1.c.):* Multiple plane dose calculation using photon beam generating functions with correction for oblique incidence and tissue inhomogeneity and correction for loss of side-scatter in 3-D. Electron beam calculation based on 3-D pencil beam electron algorithm (Level 2).
CONTROL MEASURES	Simulator portfilms. Verifications films of photon beams once a week. Diode measurements of entrance dose preformed twice.
DOSE SPECIFICATION FOR REPORTING	See capitons of Figs. A.1.b.–c.

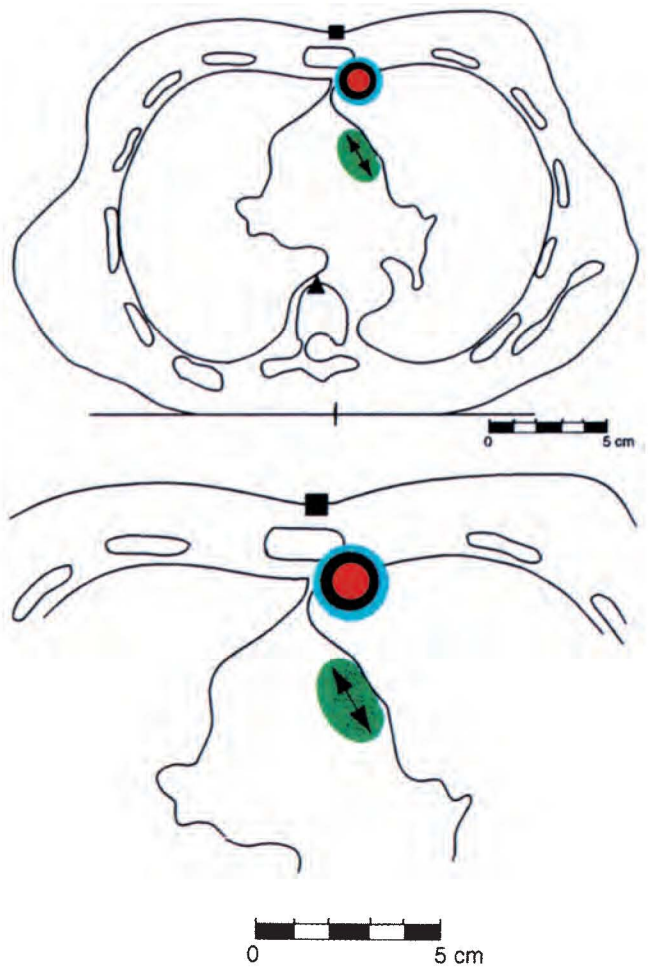


Fig. A.1.a. The CTV, ITV, PTV, and PRV in a transverse section through the center of the internal mammary nodes (= central plane).

Light red = CTV (Clinical Target Volume),
Dark blue = ITV (Internal Target Volume),
Light blue = PTV (Planning Target Volume).
◄–► = Projection onto the central plane of Left Anterior Descending Coronary Artery (Organ at Risk, OR). The tops of the arrows (posterior and anterior) correspond to the projection of the upper and lower part of the descending coronary artery at risk (*i.e.*, in the beam) respectively.
Light green = PRV (Planning Organ at Risk Volume),
■ = External Reference Point,
▲ = Internal Reference Point.

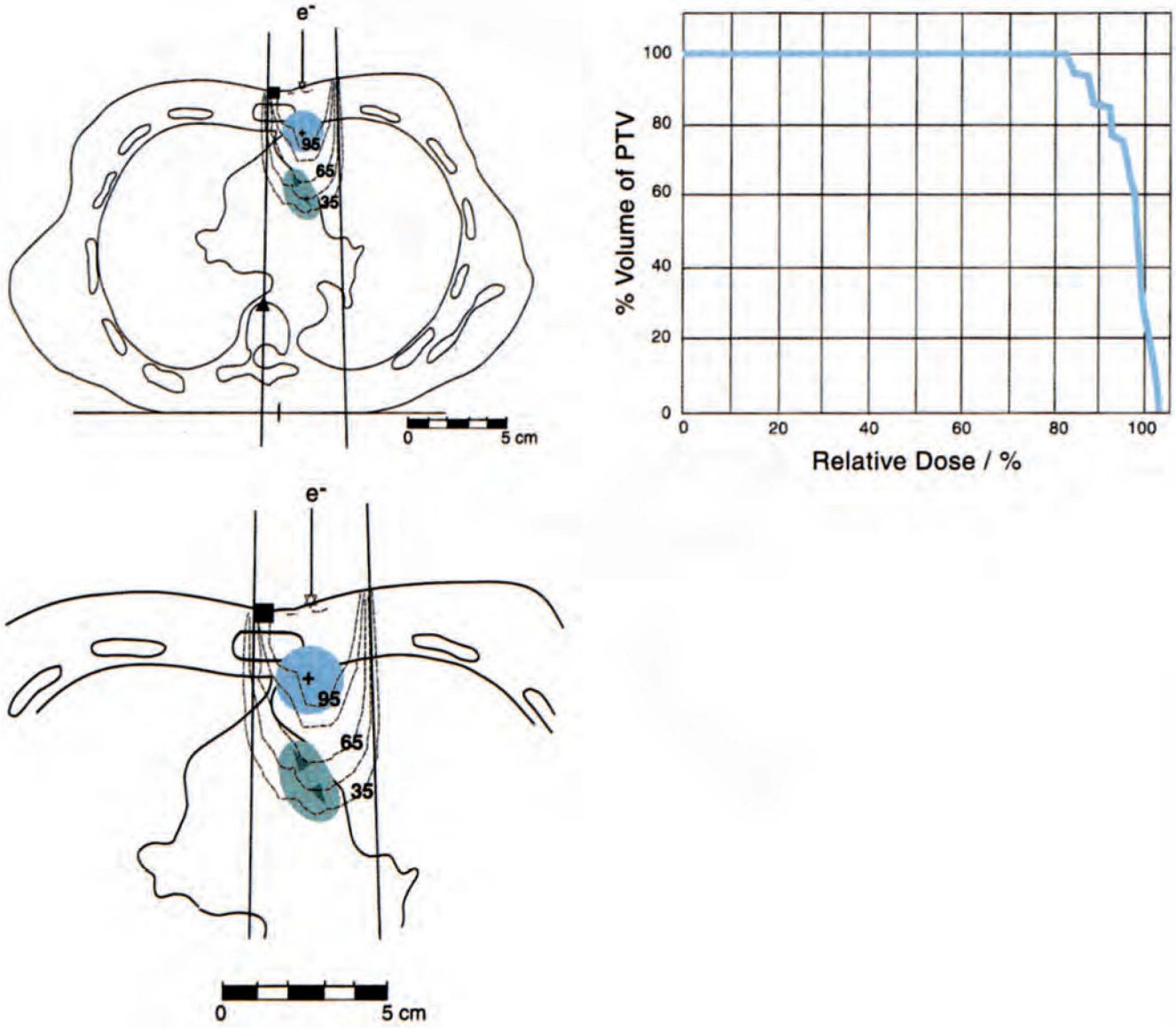


Fig. A.1.b. Dose distribution for one anterior 18 MeV electron beam. The figures on the left show the dose distribution in a transverse plane, after correction for tissue heterogeneity. The 95, 85, 65, 50 and 35% isodoses are drawn; the 100% dose is the dose at the center of the PTV (= ICRU Reference Point). The cumulative dose-volume histogram (DVH) for the PTV is shown on the right.

Dose specification for reporting at level 2:

Doses are corrected for tissue heterogeneity.

* Central dose in the PTV (ICRU Reference Point +) = 100%.
* Maximum dose in the PTV = 103%.
* Minimum dose in the PTV = 84%.
* Dose to the left anterior descending coronary artery (PRV): ranging from 73 to 28%.
* Dose to the lung: in the central plane, only 15 cm^2 receive a dose greater than 30 Gy.
* The average (mean) dose to the PTV is 96% with a standard deviation of 5.1%, and the median dose is 98%.

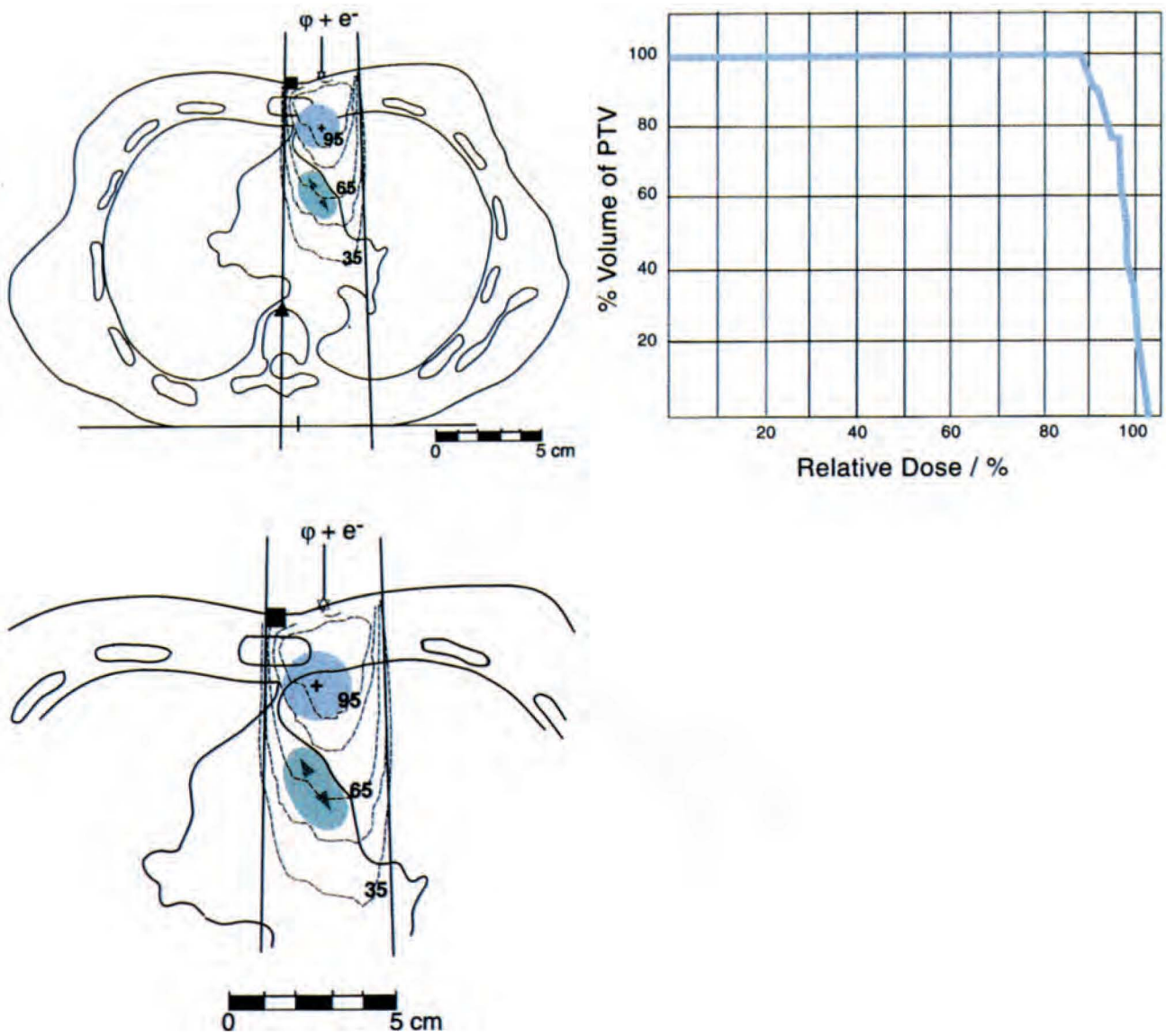


Fig. A.1.c. Dose distribution for one anterior 18 MeV electron beam and one anterior 6 MV photon beam, each beam giving the same dose contribution at the ICRU Reference Point. The figures on the left show the dose distribution in a transverse plane, after correction for tissue heterogeneity. The 95, 85, 65, 50 and 35% isodoses are drawn; the 100% dose is the dose at the center of the PTV (= ICRU Reference Point). The cumulative dose-volume histogram (DVH) for the PTV is shown on the right.

Dose specification for reporting at level 2:
Doses are corrected for tissue heterogeneity.

* Central dose in the PTV (ICRU Reference Point +) = 100%.
* Maximum dose in the PTV = 103%.
* Minimum dose in the PTV = 85%.
* Dose to the left anterior descending coronary artery (PRV): ranging from 80 to 55%.
* Dose to the lung: in the central plane, only 16 cm^2 receive a dose greater than 30 Gy.
* The average (mean) dose to the PTV is 98% with a standard deviation of 3.8%, and the median dose is 98%.

Case number 2.	**Cancer of the Prostate.**
CLINICAL SITUATION	64-year old male developed acute urinary retention. Rectal examination revealed a hard prostate gland with an enlarged left lateral lobe. No palpable extensions outside the prostate. Clinical diagnosis T2 carcinoma of the prostate. No other abnormality on physical examination. Cystoscopy revealed prominent left lateral lobe of the prostate gland. Biopsy showed a poorly differentiated (G3) adenocarcinoma of the prostate gland. I.V. pyelography, isotopic bone scan, chest radiograph, and acid phosphatases were all normal. CT scan of the pelvis confirmed T2 staging. No involvement of seminal vesicles or lymph nodes.
AIM OF THERAPY	Radical radiotherapy to prostate gland. (This case is illustrated in Figures A.2.a–A.2.h.)
GTV	Tumor within the prostate gland.
CTV	The entire prostate gland and a margin of 3 mm. Defined by CT scan and palpation [C61.9].
PTV	An 8 mm margin was added to the CTV to account for organ movements and variations in beam/patient positioning.
PRESCRIBED DOSE	74 Gy minimum dose to the PTV in 41 fractions over 57 days.
BEAM ARRANGEMENT	Seven beams (anterior, right and left lateral, right and left anterior oblique beams, right and left posterior oblique beams).
PATIENT POSITIONING	Supine with head on standard head rest and arms on chest, feet rubber banded. Alpha cradle immobilization. Laser alignment and skin, cradle marks.
DOSE PLANNING	A volumetric treatment planning CT scan was used to define GTV, CTV, and OR. The treatment planning CT was acquired with the patient in the same position, immobilization devices, and conditions, as used for treatment. The CT scan of the pelvis started at approximately the iliac crest down to the perineum. CT scan thickness was 0.4 cm through the region that contains the PTV (*i.e.,* from the bottom of the sacroiliac joints down to the penile urethra). The region above and below the target volume region was scanned with slice thickness 0.8 mm.
ORGANS AT RISK	A: Rectum [C20.9]. B: Bladder [C67.9]. C: Femoral heads [C41.4G-4].
ACCEPTED DOSES TO ORGANS AT RISK	A: Minimize rectum volume where the dose exceeds 60 Gy. B: Minimize bladder volume where the dose exceeds 65 Gy. C: Minimize femoral head volume where the dose exceeds 52 Gy.
TECHNIQUE	Seven 18 MV photon beams. Anterior, anterior/posterior oblique, right and left lateral beams. Beam directions: 1. Left Posterior Oblique, 135° (LPO), 2. Left Anterior Oblique, 45° (LAO), 3. Left Lateral, 90° (L. lateral), 4. Anterior, 0° (anterior), 5. Right Anterior Oblique, 315° (RAO), 6. Right Lateral, 270° (Rt. lateral), 7. Right Posterior Oblique, 225° (RPO). Isocentric technique. All fields custom shaped with MLC to provide 7 to 12 mm aperture margin from PTV, to allow for penumbra. Beam weights at the ICRU Reference Point: 12.9%, 22.2%, 12.9%, 3.9%, 12.9%, 22.2%, and 12.9%, respectively. Note that the anterior field was used primarily as a set-up field.
DOSE CALCULATION	Bently-Milan dose calculation model, corrected for oblique incidence, no tissue heterogeneity correction.
CONTROL MEASURES	Anterior and lateral orthogonal Digitally Reconstructed Radiographs (DRR) compared to analogous orthogonal simulator films. Portal DRRs compared to simulator port films. Orthogonal DRRs compared to orthogonal 1st day treatment films. Portal DRRs compared to 1st day port film. Verification films of photon beams once a week.
DOSE SPECIFICATION FOR REPORTING	• At isocenter (ICRU Reference Point). • Maximum dose in the PTV. • Minimum dose in the PTV. • Mean dose in the PTV.

Courtesy, the Mallinckrodt Institute of Radiology, St. Louis, MO.

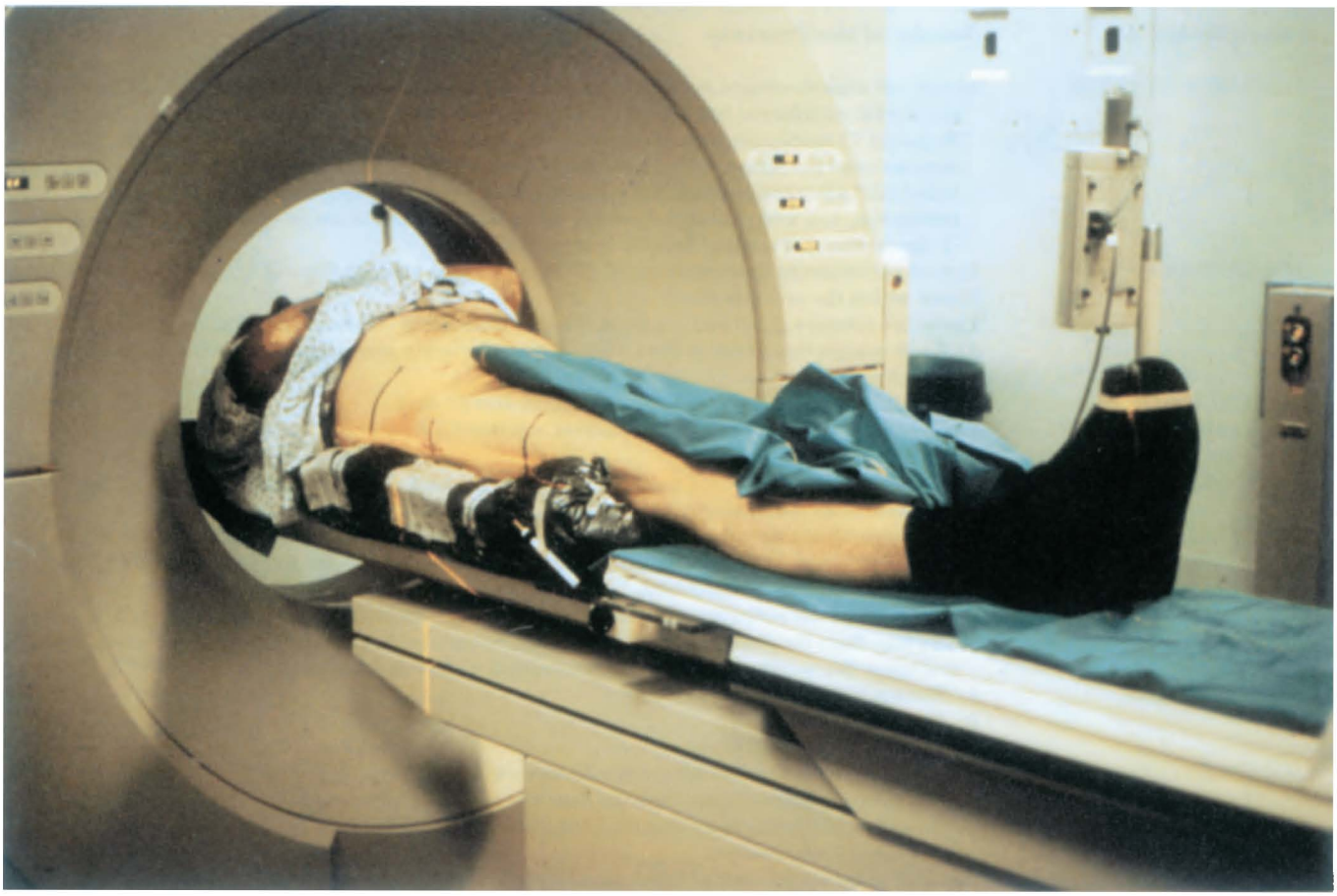


Fig. A.2.a. Prostate cancer patient, held in place in supine position in Alpha Cradle immobilization device, in preparation for CT planning scan. Multiple laser set-up points on the patient and positioning device are used to assist in coordinate transformation for 3-D planning and eventual plan implementation.

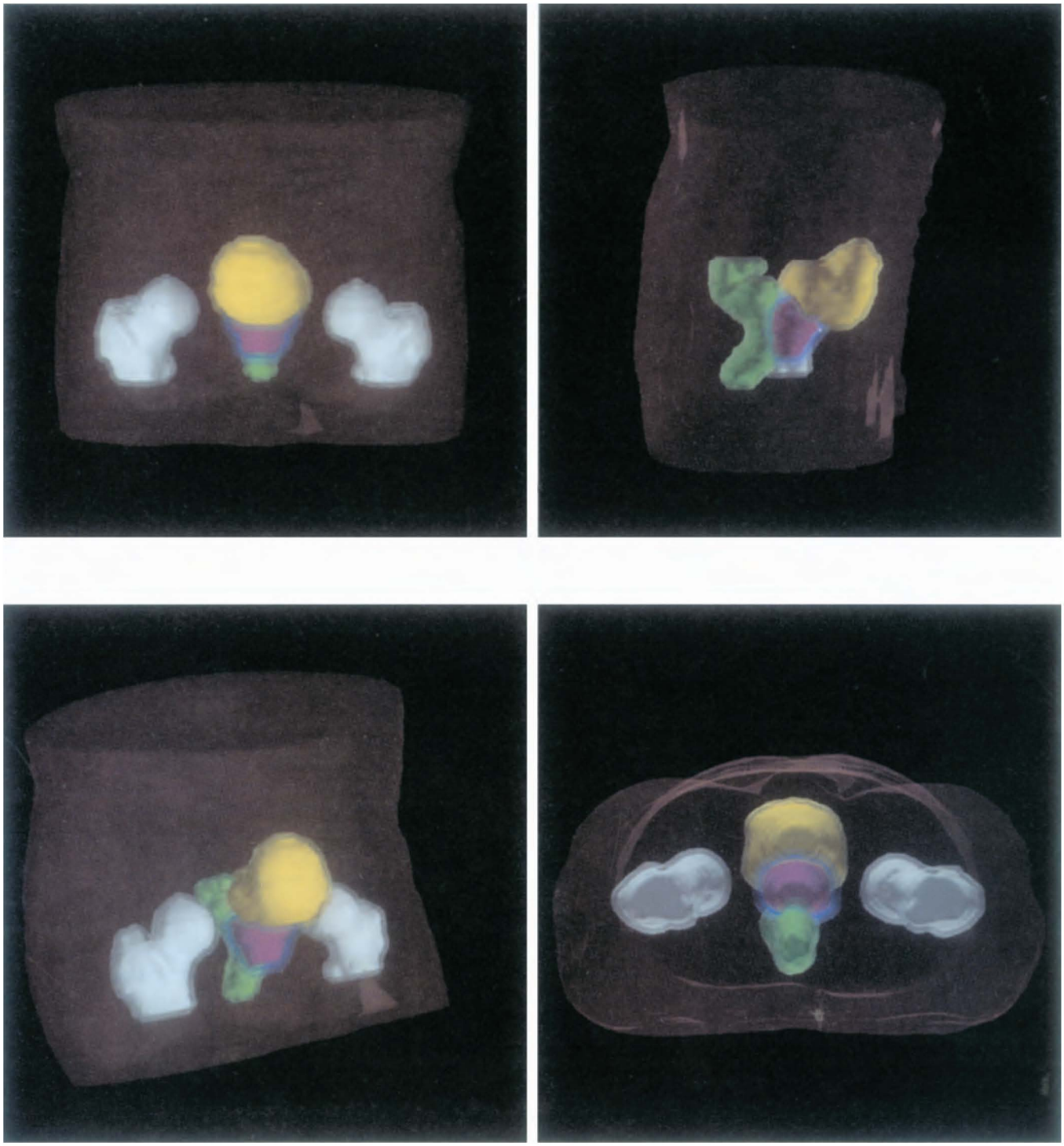


Fig. A.2.b. Color wash display for supine prostate cancer patient, showing external skin surface, CTV, ITV, PTV, and PRV for rectum, bladder and femoral heads.

Upper left: anterior view.
Upper right: lateral view (note right femoral head was digitally suppressed).
Lower left: oblique view.
Lower right: inferior view.
Following color code is used for all figures of the prostate case:

prostate GTV	not indicated	PRV rectum	light green
CTV	red	OR bladder	dark yellow
ITV	dark blue	PRV bladder	light yellow
PTV	light blue	OR femoral heads	white
OR rectum	dark green	PRV femoral heads	grayish white

See also, Note II, page 26.

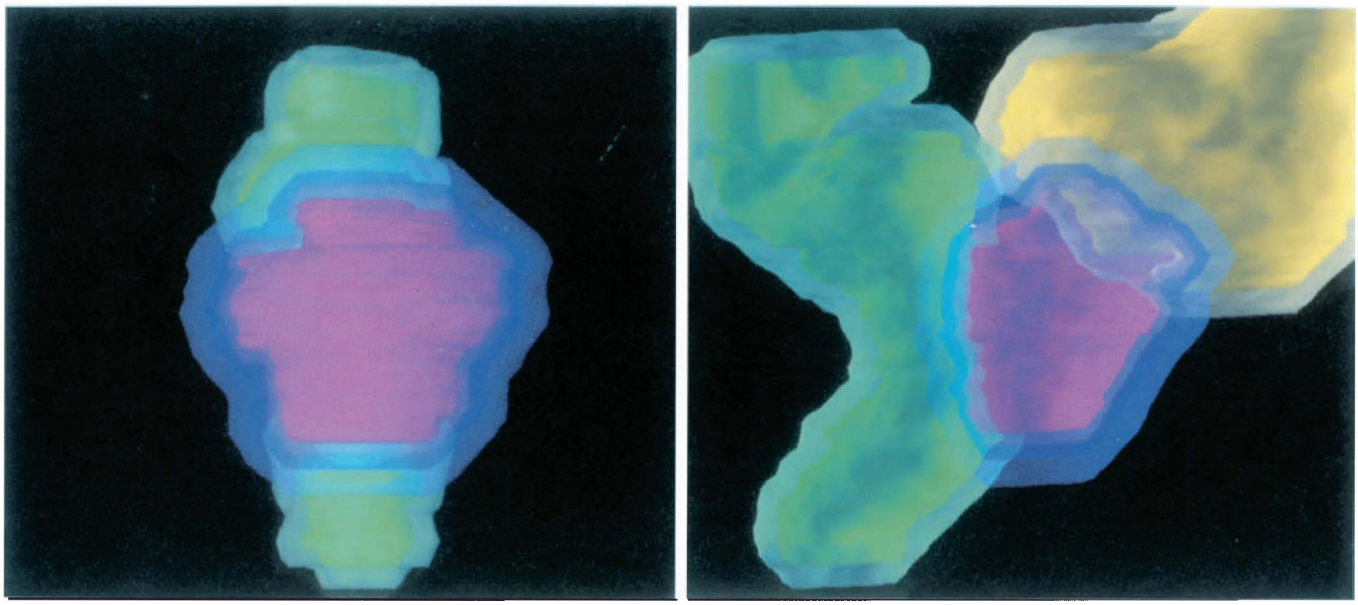


Fig. A.2.c. Color wash display, showing close up of CTV, ITV, PTV, OR and PRV for rectum, OR and PRV for bladder.
Left: anterior view.
Right: lateral view.
Note skin surface and femoral heads are digitally suppressed.

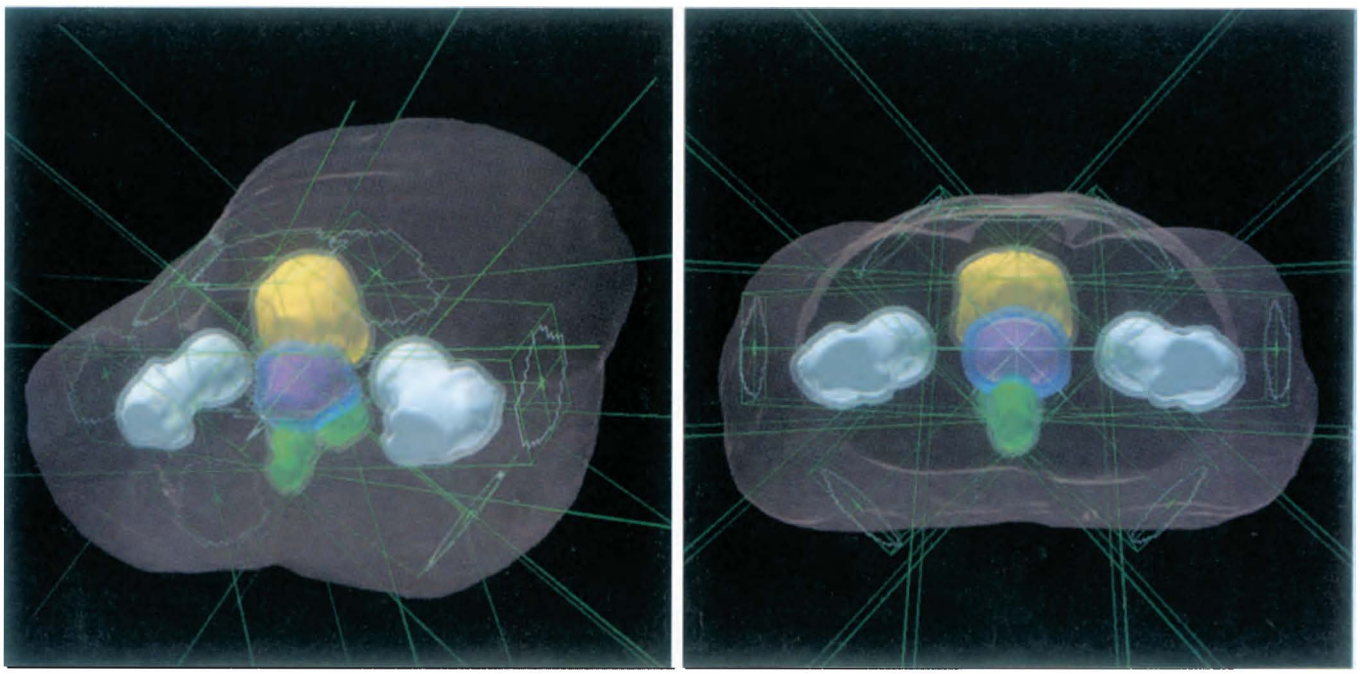


Fig. A.2.d. Color wash displays for prostate cancer patient showing 7-field technique. External skin surfaces, beams, CTV, ITV, PTV, as well as OR and PRV for rectum, OR and PRV for bladder, and OR and PRV for femoral heads are shown. The ICRU Reference Point, which is defined at the intersection of the 7 beams, is clearly seen.
Left: oblique view.
Right: inferior view.
Note this view gives a clear view of the ICRU Reference Point, defined at the intersection of 7 fields.

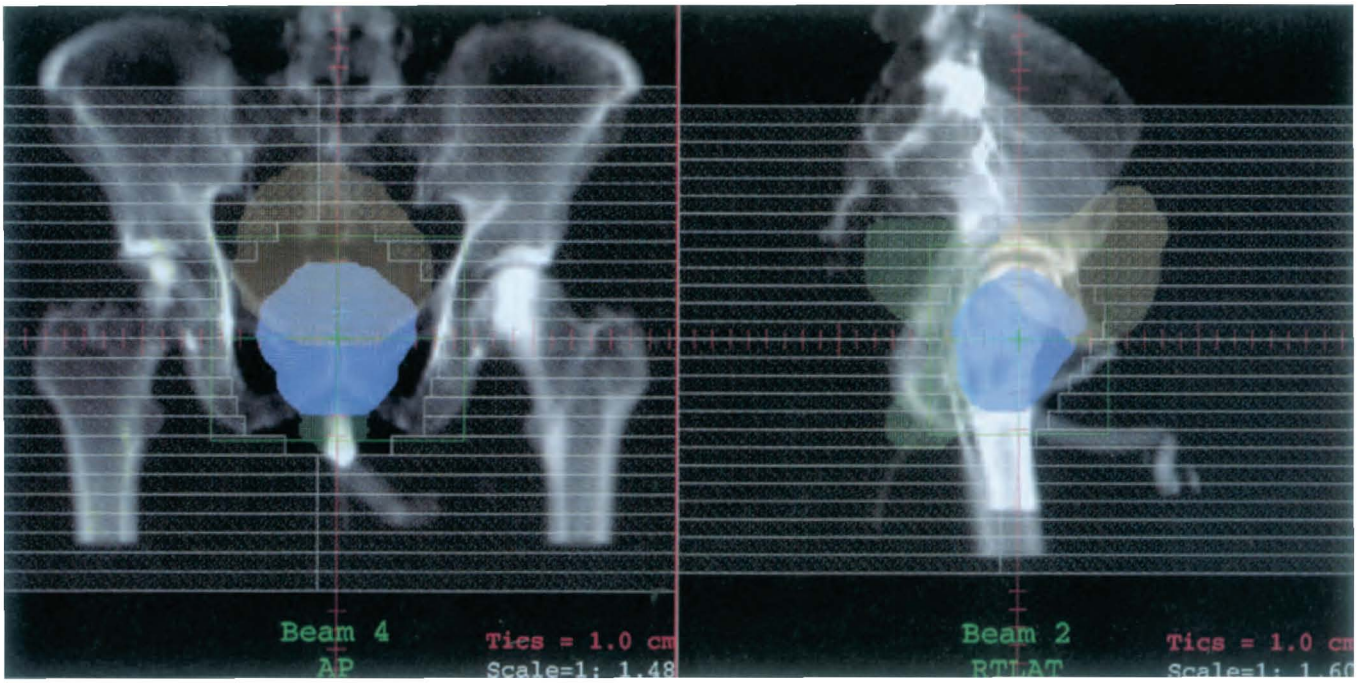


Fig. A.2.e. Anterior and right lateral field BEV DRR (Digitally Reconstructed Radiographs) display showing the prostate PTV, PRV for rectum and bladder, beam aperture (multi-leaf collimator), and fiducial cross hair grid.

Left: anterior view.
Right: lateral view.

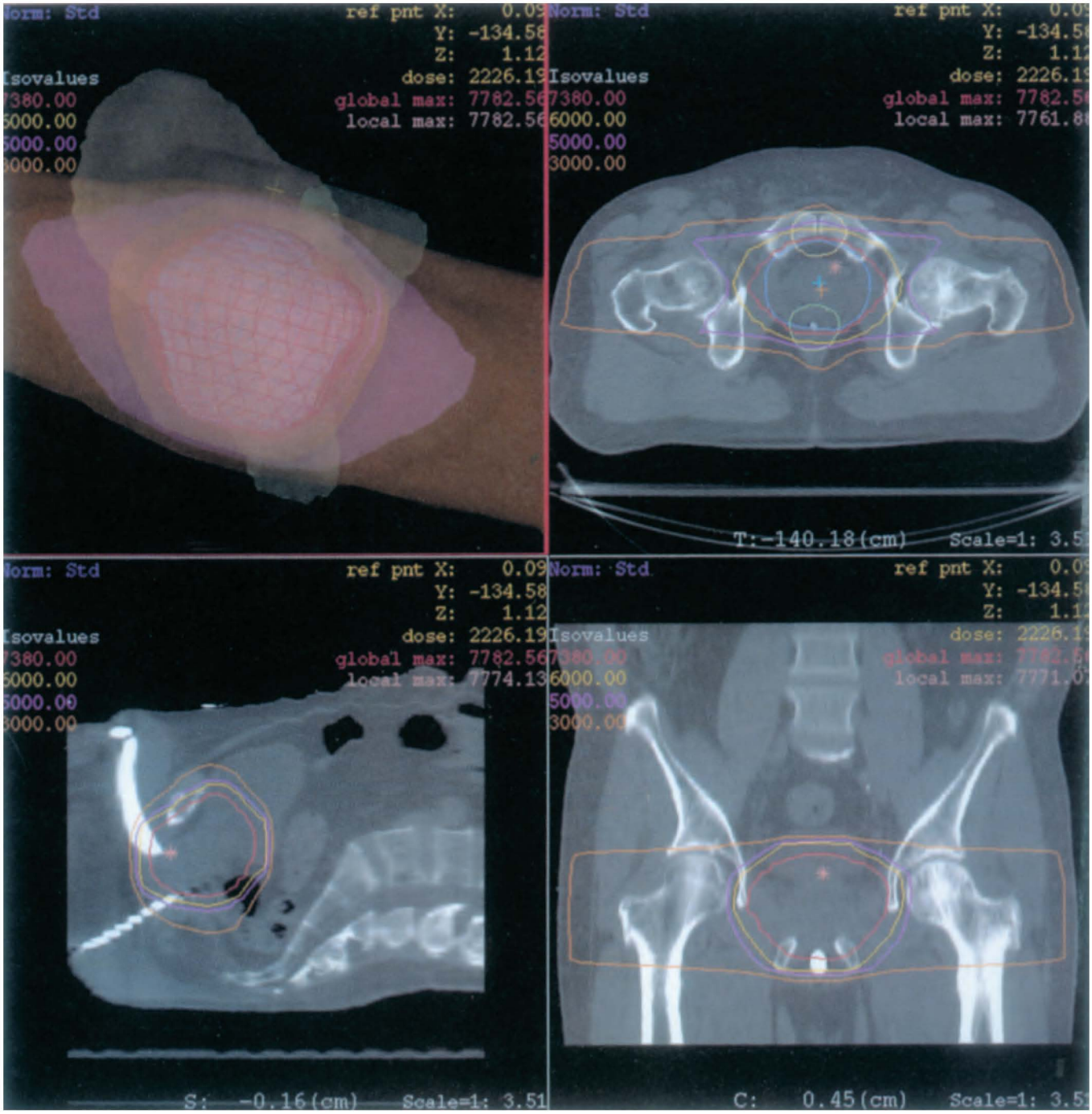


Fig. A.2.f. Four panel display showing isodose (cGy) distribution of the total treatment. The dose specified for prescription is the minimum dose (74 Gy) to the PTV. Shown are 3D transverse, sagittal, and coronal views, with superimposed color-coded isodose lines (74, 60, 50, and 30 Gy).

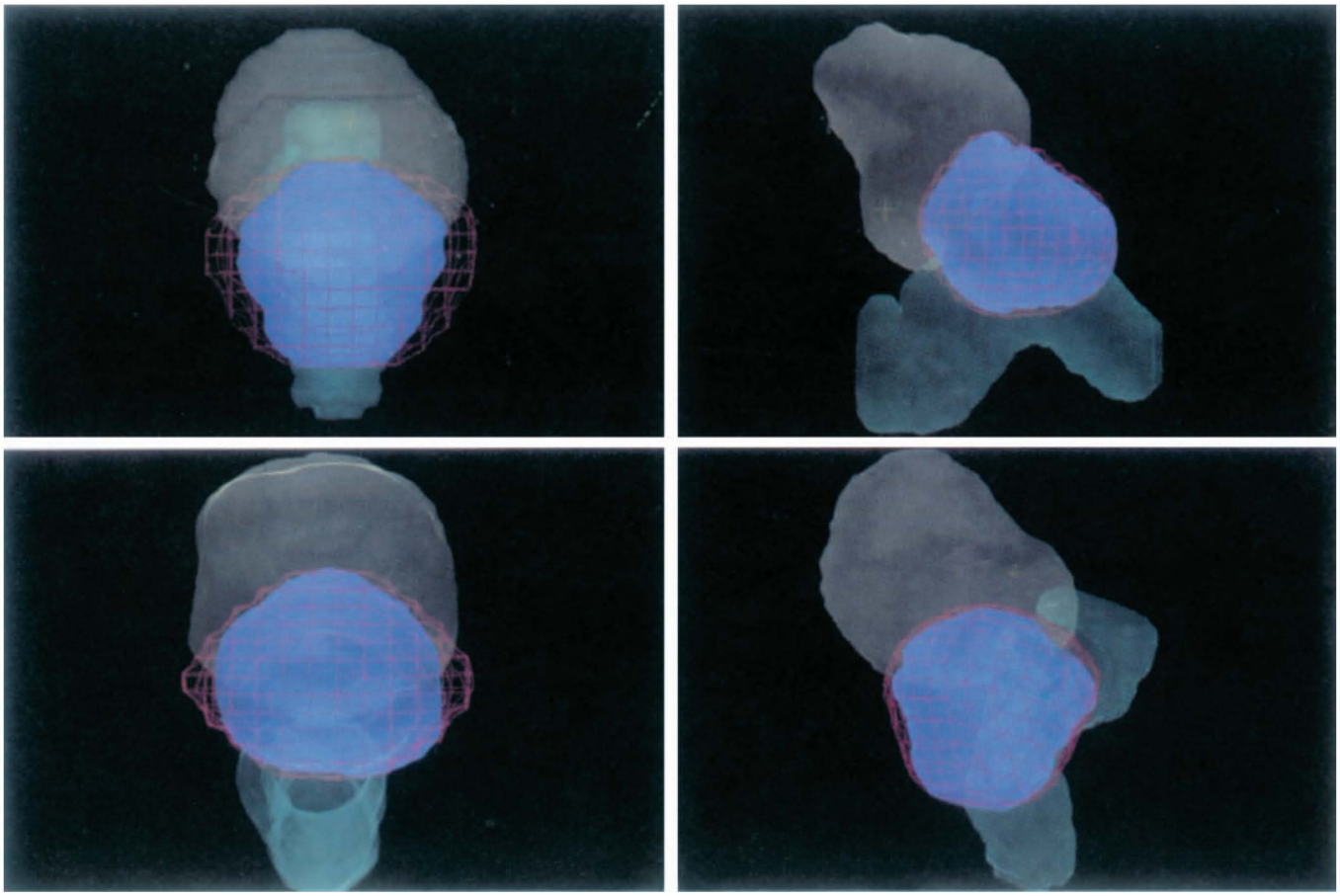


Fig. A.2.g. Display showing PTV, PRV for rectum, PRV for bladder, and 74 Gy isodose Treated Volume. The dose specified for prescription is the minimum dose (74 Gy) to the PTV.

Upper left: anterior view.
Upper right: lateral view.
Lower left: inferior view.
Lower right: oblique view.
The colors are darkened due to the reasons given in Note II, page 26.

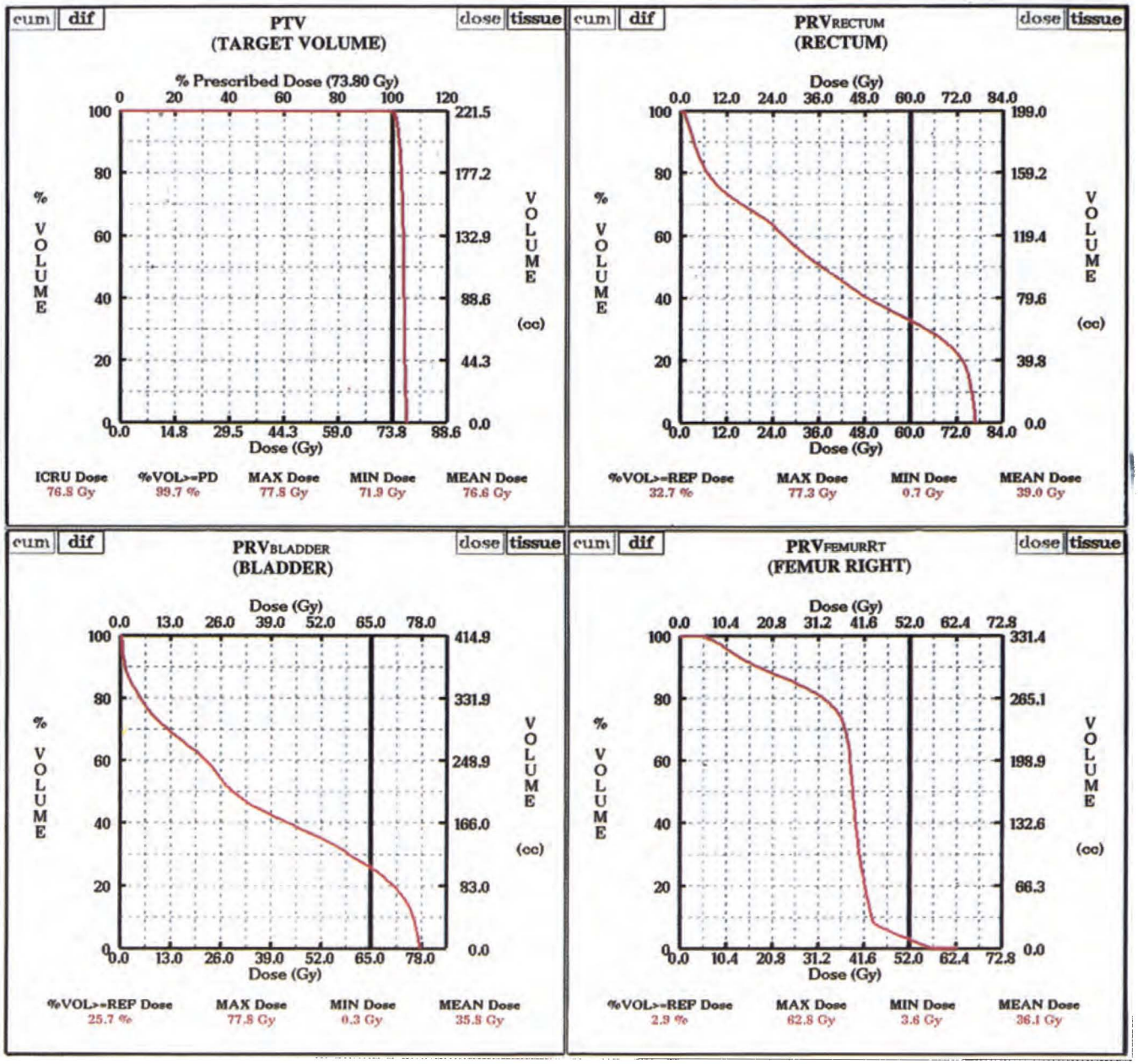


Fig. A.2.h. Cumulative DVH display of the dose distribution for the PTV, PRV for rectum, PRV for bladder, and PRV for right femoral head. Note for PTV reported dose at bottom of DVH's include ICRU Reference Point Dose, Maximum, Minimum, and Mean doses.

Case number 3.	**Lung Cancer.**
CLINICAL SITUATION	65-year-old female smoker, presented with a persistent cough. Clinical examination normal. Chest radiography showed a right hilar mass. Bronchoscopy showed endobronchial tumor in the right main bronchus. Biopsy revealed a squamous cell carcinoma. CT scan confirmed a 35 mm × 35 mm lesion in the right bronchus, and in addition a 3 cm × 3 cm mass of lymphadenopathy at the right hilum. No evidence of mediastinal lymphadenopathy. Clinical stage IIB (T2 N1 M0). (This case is illustrated in Figures A.3.a to A.3.f.)
AIM OF THERAPY	Radical radiotherapy.
GTV	1. Primary endobronchial tumor [C34.0-1]. 2. Hilar lymphadenopathy; [C771C-1].
CTV	The combined CTV includes GTV 1 + GTV 2 + local subclinical extensions.
PTV	A 10 mm margin was added to the CTV to account for organ movements and variations in patient/beam positionings.
PRESCRIBED DOSE	71 Gy to the ICRU Reference Point in 33 fractions over 43 days. 66 Gy accepted as minimum dose to the PTV.
BEAM ARRANGEMENT	4 isocentric beams.
PATIENT POSITIONING	Supine with head on standard head rest and arms above the head. Alpha cradle immobilization. Laser alignment and skin, cradle marks.
VOLUME FOR DOSE PLANNING	A series of CT sections were used to define GTV, CTV, and OR. The treatment planning CT was acquired with the patient in the same supine position, immobilization device, and conditions as used for treatment.
ORGANS AT RISK	A: Spinal cord [C72.0B]. B: Left lung [C34.9-2]. C: Heart [C38.0]. D: Oesophagus [C15.9].
ACCEPTED DOSES TO ORGANS AT RISK	A: Less than 47 Gy at the spinal cord. B: As low as possible to left lung. C: Less than 40 Gy, if possible. D: Less than 66 Gy, if possible.
TECHNIQUE	4 18 MV photon beams. Right anterior oblique, left posterior oblique, right posterior oblique, and left anterior oblique beams. Beam directions: 1. Left Anterior Oblique, 22° (LAO). 2. Left Posterior Oblique, 142° (LPO), 3. Right Posterior Oblique, 202° (RPO), 4. Right Anterior Oblique, 322° (RAO). Isocentric technique. All fields custom shaped with 7 to 12 mm aperture margin from PTV. Contributions of the beams at the ICRU Reference Point = 21.2%, 36.0%, 23.8%, and 19.0%. Dose distribution, see Fig. A.3.d.
DOSE CALCULATION	Bently-Milan dose calculation model, corrected for oblique incidence, no tissue heterogeneity correction.
CONTROL MEASURES	Orthogonal DRRs compared to orthogonal simulator films. Portal DRRs compared to simulator port films. Orthogonal DRRs compared to orthogonal 1st day treatment films. Portal DRRs compared to 1st day port film. Verifications films of photon beams once a week.
DOSE SPECIFICATION FOR REPORTING	• ICRU Reference Point at the isocenter, in the central parts of the PTV (100%). • Maximum and minimum dose to the PTV according to the dose plan (105%–61%). • Hot spot (outside the PTV) = 105%, (peripheral in the lung).

Courtesy, The Mallinckrodt Institute of Radiology, St. Louis MO.

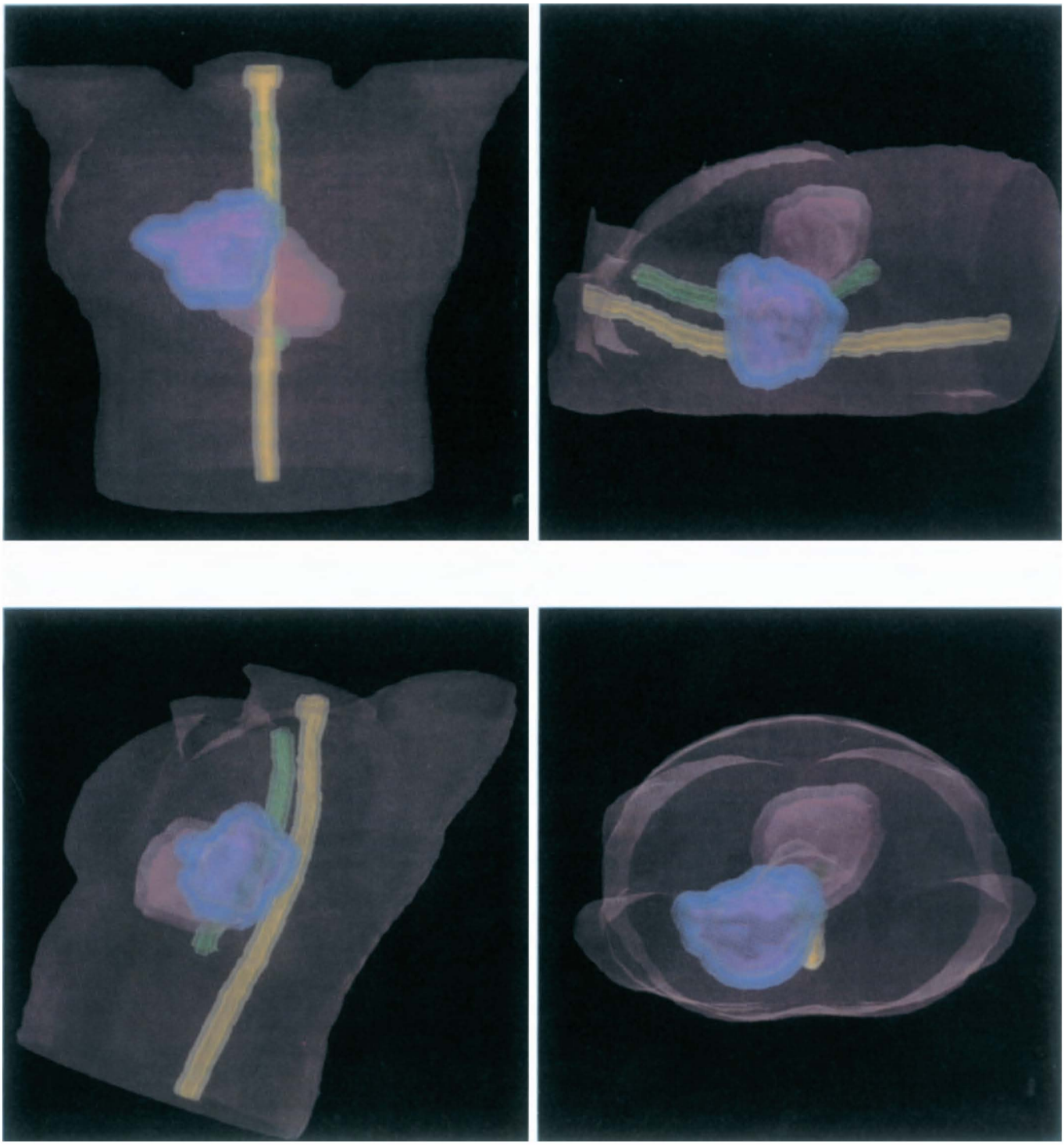


Fig. A.3.a. Display for lung cancer patient, showing external skin surface, CTV, ITV, PTV, heart, spinal cord and esophagus.

Upper left: anterior view.
Upper right: lateral view.
Lower left: oblique view.
Lower right: inferior view.
Following color code is used for all figures of the lung case:

GTV	not indicated	PRV heart	light orange
CTV	red	OR spinal cord	dark yellow
ITV	dark blue	PRV spinal cord	light yellow
PTV	light blue	OR esophagus	dark green
OR heart	dark orange	PRV esophagus	light green

See also, Note II, page 26.

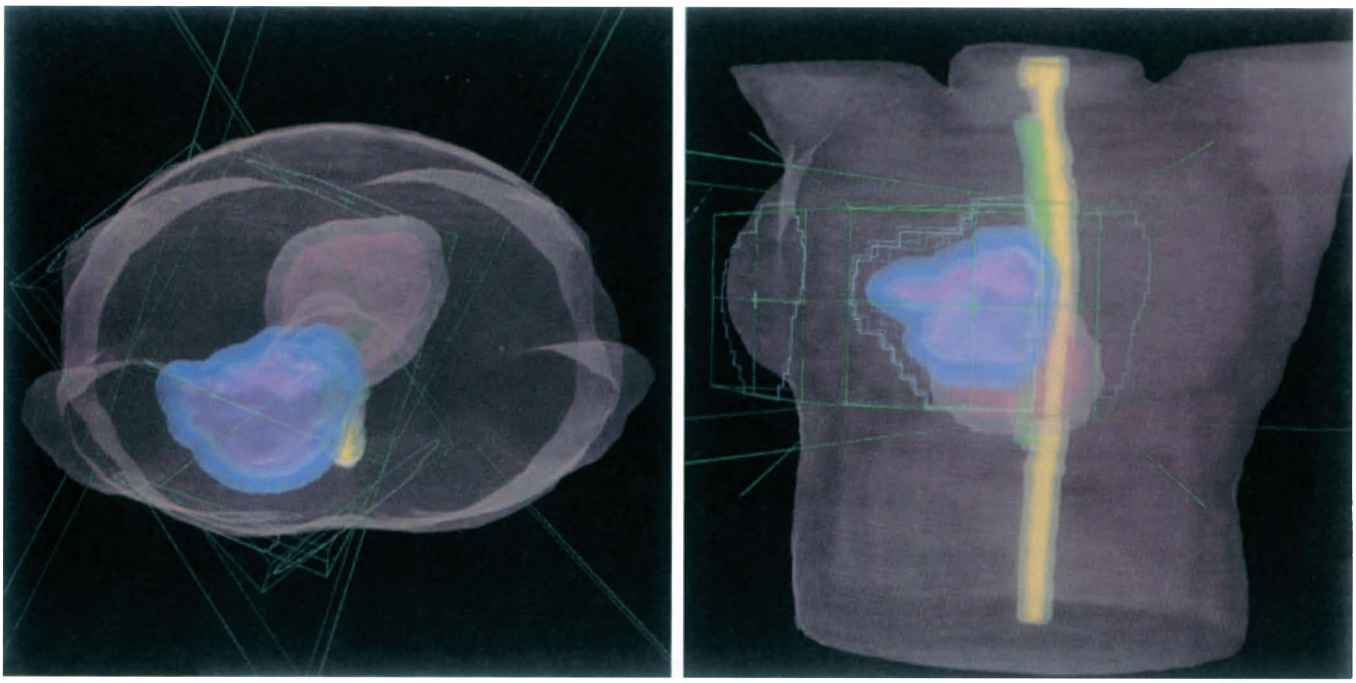


Fig. A.3.b. Display for lung cancer patient, showing beams, external skin surface, PTV, heart, spinal cord and esophagus. All other volumes have been digitally suppressed.

Left: inferior view.
Right: oblique view.

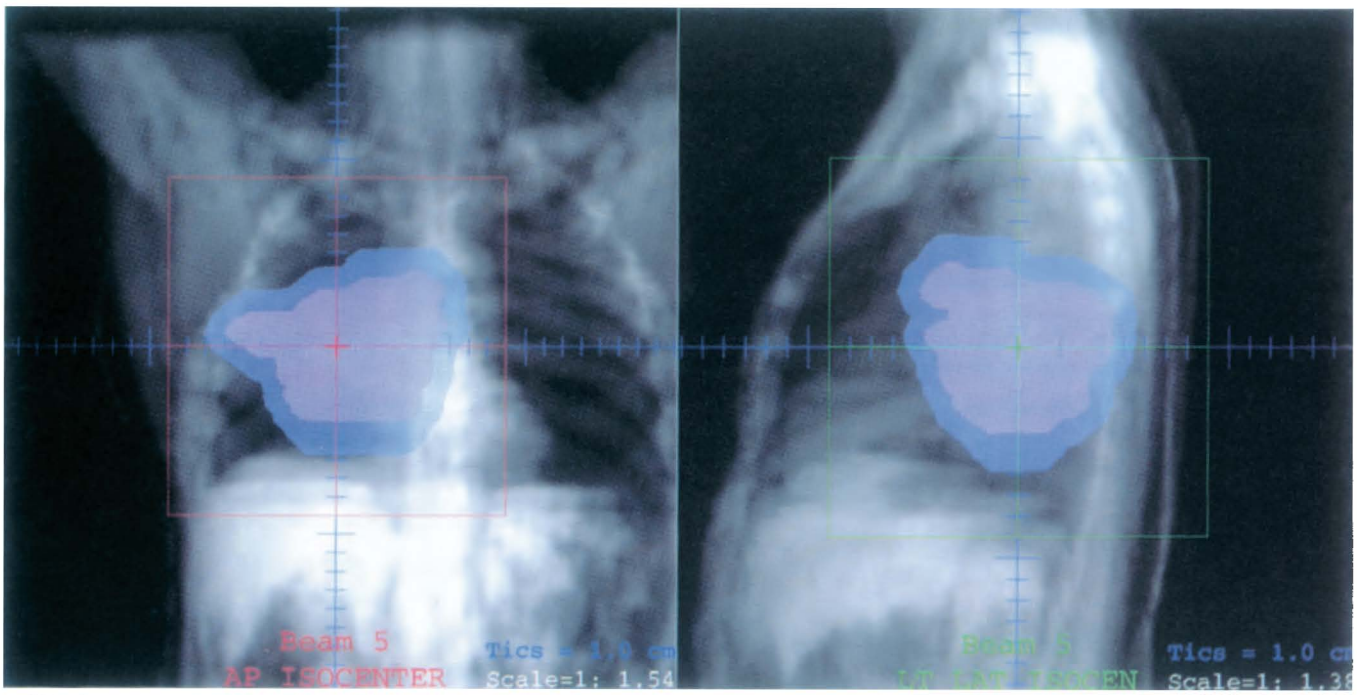


Fig. A.3.c. BEV (Beam Eye View) DRR (Digitally Reconstructed Radiographs) display showing CTV, PTV, and fiducial cross hair grid.
Left: anterior view.
Right: lateral view.

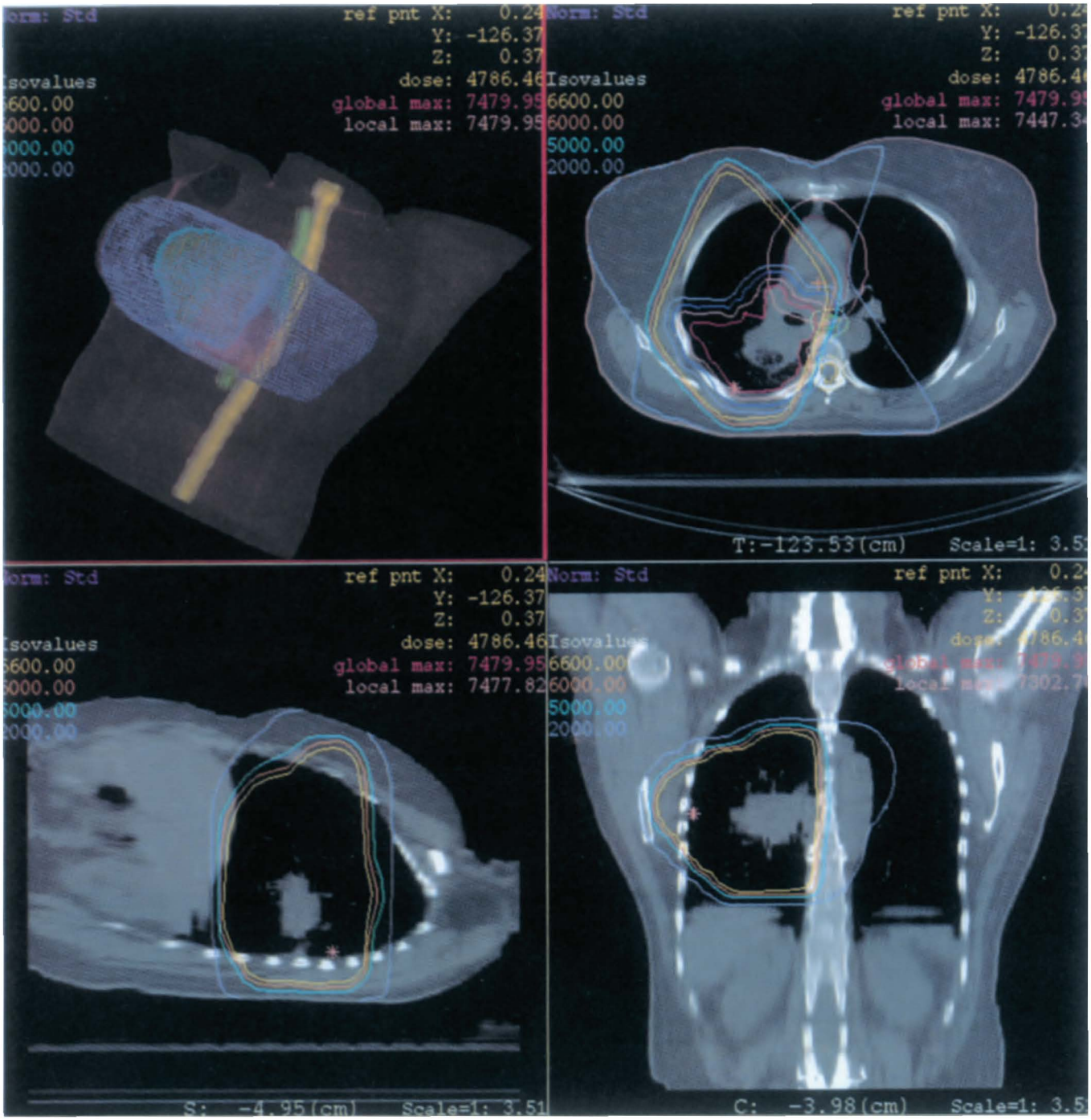


Fig. A.3.d. Four panel display showing isodose (cGy) distribution of the total treatment. The dose specified for prescription and for recording is the ICRU Reference Point Dose (71 Gy) within the PTV with a minimum of 66 Gy. Shown are 3-D transverse, sagittal and coronal views, with superimposed color-coded isodose lines.

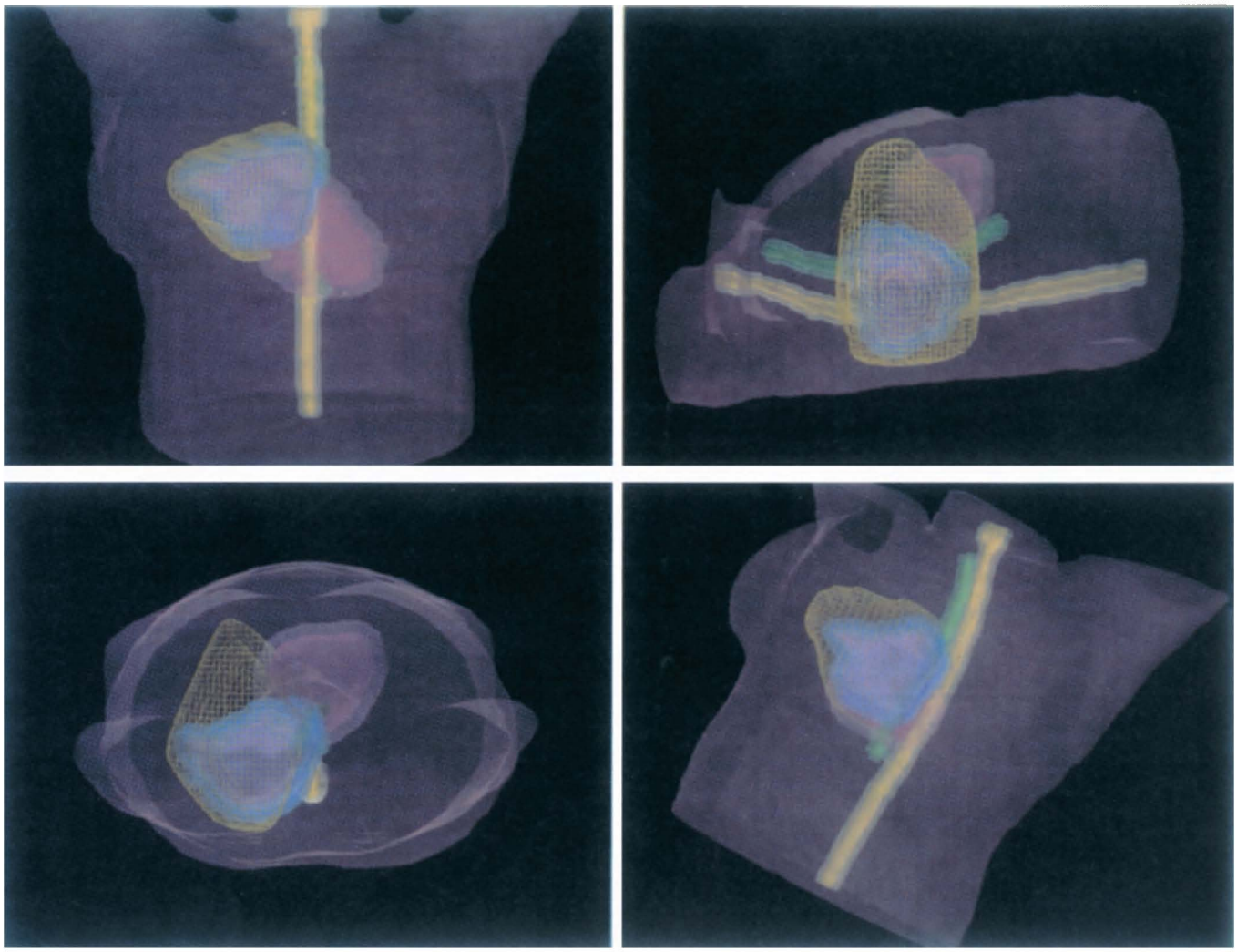


Fig. A.3.e. View showing PTV, OR and PRV for heart, OR and PRV for spinal cord, OR and PRV for esophagus, and 66 Gy isodose Treated Volume.

Upper left: anterior view.
Upper right: lateral view.
Lower left: inferior view.
Lower right: oblique view.

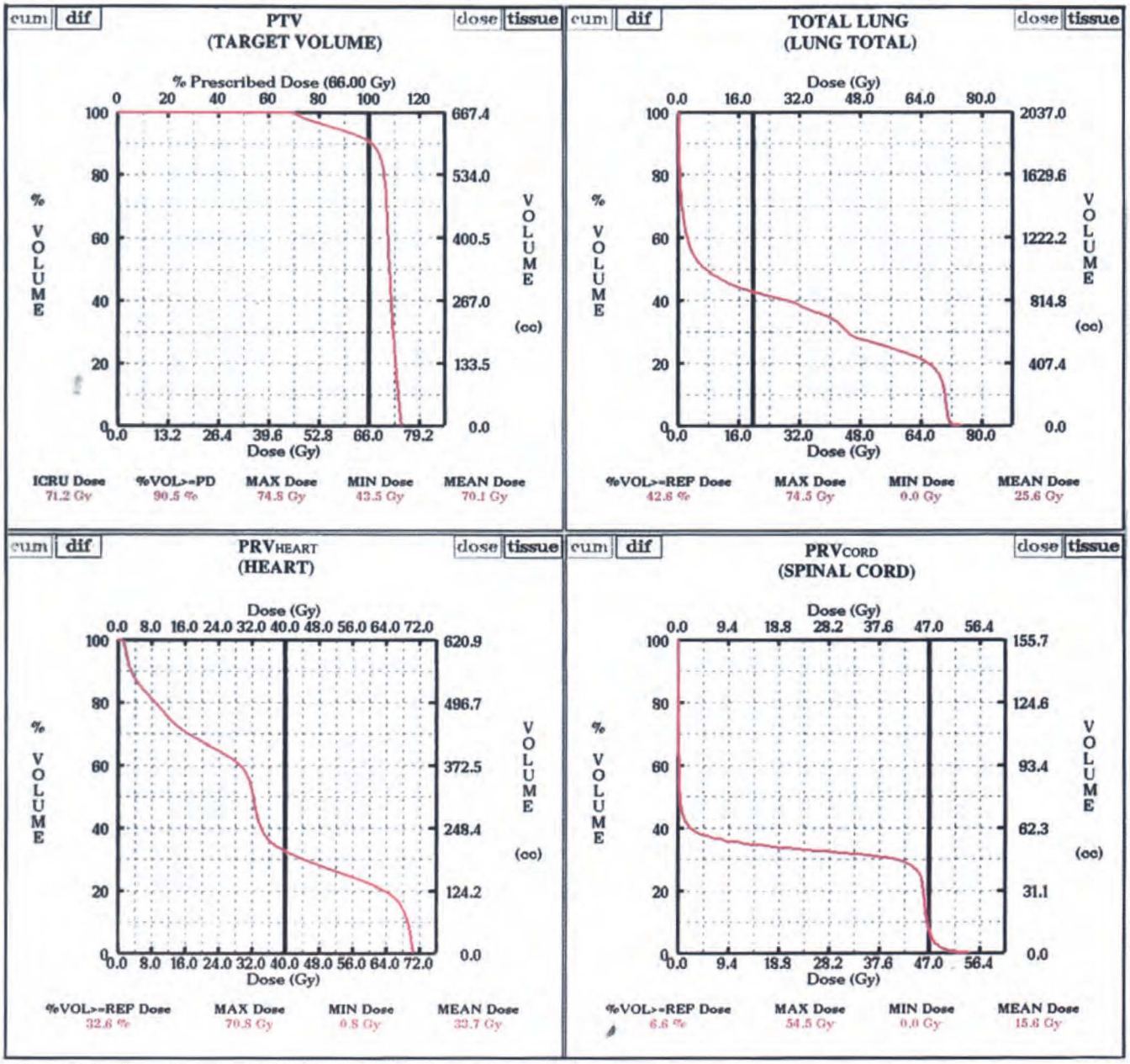


Fig. A.3.f. Cumulative DVH display of the dose distribution for the PTV, PRV total lung, PRV heart, and PRV spinal cord. Note for PTV reported doses at bottom of DVHs include ICRU Reference Point Dose, Maximum, Minimum, and Average doses.

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