

Chapter 7

Clinical Treatment Planning in External Photon Beam Radiotherapy

This set of 232 slides is based on Chapter 7 authored by W. Parker and H. Patrocinio of the IAEA publication (ISBN 92-0-107304-6):

**Radiation Oncology Physics:
A Handbook for Teachers and Students**

Objective: To familiarize students with modern photon beam radiotherapy techniques used to achieve a uniform dose distribution inside the target volume and a dose as low as possible in the healthy tissues surrounding the target.



Slide set prepared in 2006 (updated Aug2007)
by G.H. Hartmann (DKFZ, Heidelberg)

Comments to S. Vatnitsky:
dosimetry@iaea.org

CHAPTER 7. TABLE OF CONTENTS

- 7.1 Introduction
- 7.2 Volume Definition
- 7.3 Dose Specification
- 7.4 Patient Data Acquisition and Simulation
- 7.5 Clinical Considerations for Photon Beams
- 7.6 Treatment Plan Evaluation
- 7.7 Treatment Time and Monitor Unit Calculations



7.1 INTRODUCTION

□ General considerations for photon beams:

- Almost dogma in external beam radiotherapy:

Successful radiotherapy requires a uniform dose distribution within the target (tumour).



- External photon beam radiotherapy is usually carried out with multiple radiation beams in order to achieve a uniform dose distribution inside the target volume and a dose as low as possible in healthy tissues surrounding the target.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 1 (3/232)

7.1 INTRODUCTION

□ Criteria of a uniform dose distribution within the target

- Recommendations regarding dose uniformity, prescribing, recording, and reporting photon beam therapy are set forth by the International Commission on Radiation Units and Measurements (ICRU).
- The ICRU report 50 recommends a target dose uniformity within +7% and -5% relative to the dose delivered to a well defined prescription point within the target.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 2 (4/232)

7.1 INTRODUCTION

To achieve these goals set by the ICRU, modern radiotherapy is carried out with a variety of:

- ☐ Beam energies
- ☐ Beam types
- ☐ Field sizes

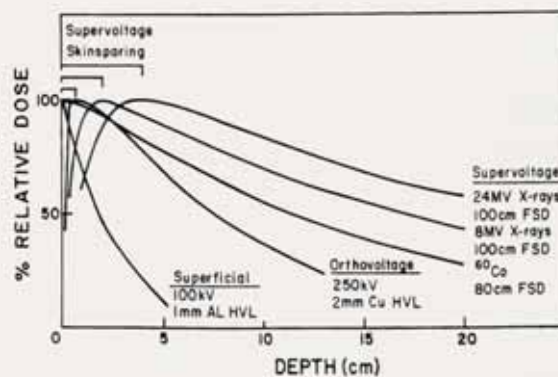


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 3 (5/232)

7.1 INTRODUCTION

☐ Beam energies used in external beam photon radiotherapy:

- ☐ Superficial (30 kVp to 80 kVp)
- ☐ Orthovoltage (100 kVp to 300 kVp)
- ☐ Megavoltage or supervoltage energies (Co-60 to 25 MV)



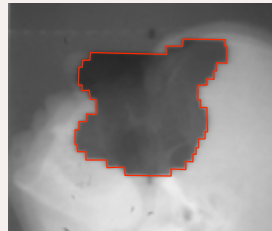
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 4 (6/232)

7.1 INTRODUCTION

- Field sizes range from:



Small **circular** fields used in radiosurgery



Standard rectangular and **irregular** fields



Very **large** fields used for total body irradiations



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 5 (7/232)

7.1 INTRODUCTION

Methods of Patient setup:

- Photon beam radiotherapy is carried out under two setup conventions

Constant
Source-**Surface** Distance

(SSD technique)

Isocentric setup
with a constant Source-
Axis Distance

(SAD technique).

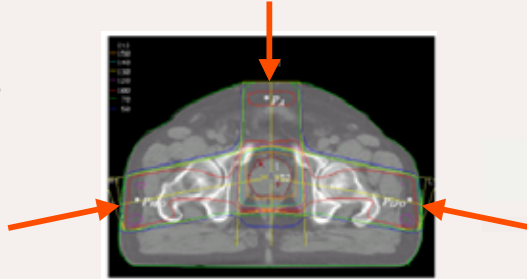


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 6 (8/232)

7.1 INTRODUCTION

□ SSD technique

- Distance from the source to the **surface** of the patient is kept **constant** for all beams.

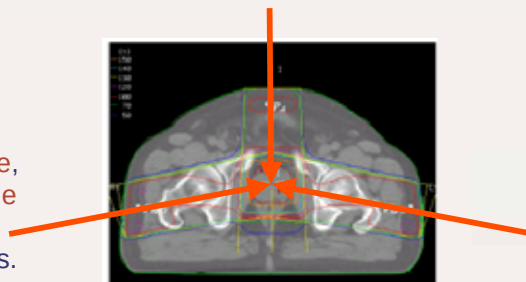


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 7 (9/232)

7.1 INTRODUCTION

□ SAD technique

- Center of the target volume is placed at the machine **isocentre**, i.e., the **distance to the target point** is kept constant for all beams.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 8 (10/232)

7.1 INTRODUCTION

☐ Note:

- In contrast to SSD technique, the **SAD technique** requires **no** adjustment of the patient setup when turning the gantry from one field to the next field.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.1 Slide 9 (11/232)

7.2 VOLUME DEFINITION

- ☐ The process of determining the **volume for the treatment** of a malignant disease consists of several distinct steps.
- ☐ In this process, **different volumes** may be defined due to:
 - Varying concentrations of malignant cells.
 - Probable changes in the spatial relationship between volume and beam during therapy.
 - Movement of patient.
 - Possible inaccuracies in the treatment setup.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2 Slide 1 (12/232)

7.2 VOLUME DEFINITION

❑ The ICRU 50 and 62 Reports define and describe several target and critical structure volumes that:

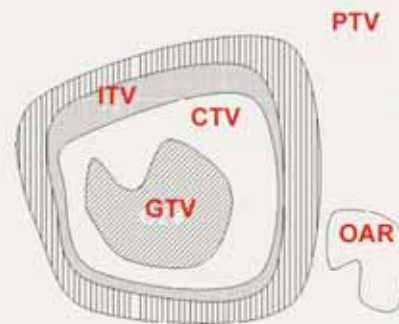
- Aid in the treatment planning process
- Provide a basis for comparison of treatment outcomes.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2 Slide 2 (13/232)

7.2 VOLUME DEFINITION

The following slides describe these "ICRU volumes" that have been defined as principal volumes related to three-dimensional treatment planning.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2 Slide 3 (14/232)

7.2 VOLUME DEFINITION

7.2.1 Gross Tumor Volume (GTV)

- ❑ The **Gross Tumor Volume** (GTV) is the gross palpable or visible/demonstrable extent and location of malignant growth.
- ❑ The GTV is usually based on information obtained from a combination of:
 - **Imaging modalities** (CT, MRI, ultrasound, etc.)
 - **Diagnostic modalities** (pathology and histological reports, etc.)
 - **Clinical examination.**



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.1 Slide 1 (15/232)

7.2 VOLUME DEFINITION

7.2.2 Clinical Target Volume (CTV)

- ❑ The **Clinical Target Volume** (CTV) is the tissue volume that contains a **demonstrable GTV** and/or **sub-clinical microscopic malignant disease**, which must be eliminated.
- ❑ This volume thus has to be treated adequately in order to achieve the aim of therapy, cure or palliation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.2 Slide 1 (16/232)

7.2 VOLUME DEFINITION

7.2.2 Clinical Target Volume (CTV)

- ❑ The CTV often includes the area **directly surrounding the GTV** that may contain microscopic disease and other areas considered to be at risk and require treatment.
- ❑ **Example: positive lymph nodes.**
 - The CTV is an **anatomical-clinical volume**.
 - It is usually determined by the **radiation oncologist**, often after other relevant specialists such as pathologists or radiologists have been consulted.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.2 Slide 2 (17/232)

7.2 VOLUME DEFINITION

7.2.2 Clinical Target Volume (CTV)

- ❑ CTV is usually stated as fixed or variable margin around the GTV.
Example: $CTV = GTV + 1 \text{ cm margin}$
- ❑ In some cases the CTV is the same as the GTV.
Example: Prostate boost to the gland only.
- ❑ It is possible to have several non-contiguous CTVs that may require different total doses to achieve treatment goals.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.2 Slide 3 (18/232)

7.2 VOLUME DEFINITION

7.2.3 Internal Target Volume (ITV)

General consideration on margins:

- ❑ Margins are most important for clinical radiotherapy. They depend upon:
 - Organ motion → internal margins
 - Patient set-up and beam alignment → external margins
- ❑ Margins can be non-uniform but should be in 3D.
- ❑ A reasonable way of thinking would be: “Choose the margins so that the target is in the treated field at least 95% of the time.”

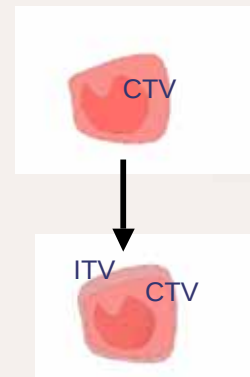


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.3 Slide 1 (19/232)

7.2 VOLUME DEFINITION

7.2.3 Internal Target Volume (ITV)

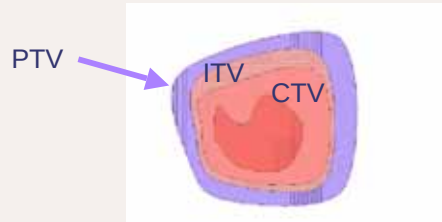
- ❑ The **Internal Target Volume (ITV)** consists of the CTV plus an internal margin.
- ❑ The **internal margin** is designed to take into account the variations in the size and position of the CTV relative to the patient's reference frame (usually defined by the bony anatomy), i.e., variations due to organ motion, such as breathing, bladder or rectal contents, etc.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.3 Slide 2 (20/232)

7.2 VOLUME DEFINITION

7.2.4 Planning Target Volume (PTV)



- ❑ In contrast to the CTV, the Planning Target Volume (PTV) is a geometrical concept.
- ❑ It is defined to select appropriate beam arrangements, taking into consideration the net effect of all possible geometrical variations, in order to ensure that the prescribed dose is actually absorbed in the CTV.

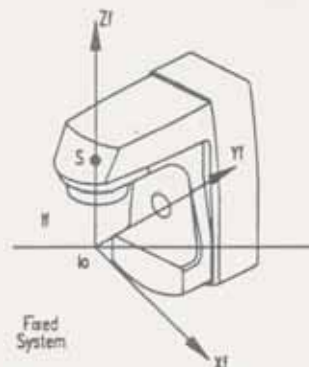


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.4 Slide 1 (21/232)

7.2 VOLUME DEFINITION

7.2.4 Planning Target Volume (PTV)

- ❑ PTV includes the internal target margin and an additional margin for:
 - Set-up uncertainties
 - Machine tolerances
 - Intra-treatment variations.
- ❑ PTV is linked to the reference frame of the treatment machine (IEC 1217: "Fixed System").



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.4 Slide 2 (22/232)

7.2 VOLUME DEFINITION

7.2.4 Planning Target Volume (PTV)

- ❑ The PTV is often described as the CTV plus a fixed or variable margin.

Typical example: $PTV = CTV + 1 \text{ cm}$

- ❑ Usually a single PTV is used to encompass one or several CTVs to be targeted by a group of fields.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.4 Slide 3 (23/232)

7.2 VOLUME DEFINITION

7.2.4 Planning Target Volume (PTV)

- ❑ The PTV depends on the precision of such tools as:
 - Immobilization devices
 - Patient positioning lasers
- ❑ The PTV does **NOT** include a margin for dosimetric characteristics of the radiation beam as these will require an additional margin during treatment planning and shielding design.

Examples not included:

- Penumbra areas
- Build-up region



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.4 Slide 4 (24/232)

7.2 VOLUME DEFINITION

7.2.5 Organ at Risk (OAR)



- ❑ **Organ at Risk (OAR)** is an organ whose sensitivity to radiation is such that the dose received from a treatment plan may be significant compared to its tolerance, possibly requiring a change in the beam arrangement or a change in the dose.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.5 Slide 1 (25/232)

7.2 VOLUME DEFINITION

7.2.5 Organ at Risk (OAR)

- ❑ Specific attention should be paid to organs that, even though not immediately adjacent to the CTV, have a very low tolerance dose.

Example of such OAR:

- Eye lens during nasopharyngeal or brain tumor treatments

- ❑ Organs with a radiation tolerance that depends on the fractionation scheme should be outlined completely to prevent biasing during treatment plan evaluation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.2.5 Slide 2 (26/232)

7.3 DOSE SPECIFICATION

- ❑ The **complete prescription** of radiation treatment must include:
 - Definition of the **aim** of therapy
 - **Volumes** to be considered
 - **Prescription dose and fractionation.**
- ❑ Only detailed information regarding **total dose, fractional dose and total elapsed treatment time in days** allows for proper comparison of outcome results.
- ❑ Various concepts have been developed to satisfy this requirement.

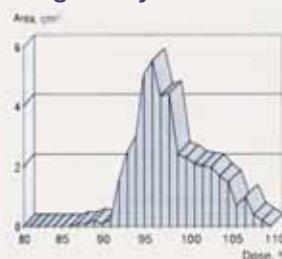
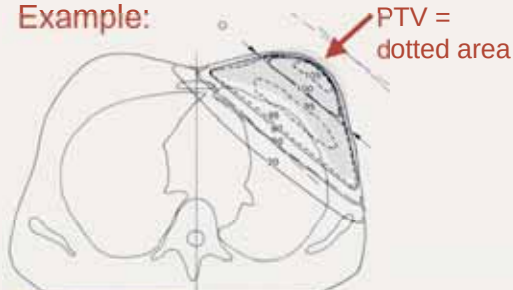


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 1 (27/232)

7.3 DOSE SPECIFICATION

- ❑ When the dose to a given volume is prescribed, the corresponding delivered dose should be as homogeneous as possible.
- ❑ Due to technical reasons, some heterogeneity in the PTV has to be accepted.

Example:



Frequency dose-area histogram for the PTV



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 2 (28/232)

7.3 DOSE SPECIFICATION

- ❑ The ICRU Report 50 recommends a target dose uniformity within +7% and –5% relative to the dose delivered to a well defined prescription point within the target volume.
 - Since some dose heterogeneity is always present, a method to describe this dose heterogeneity within the defined volumes is required.
 - The ICRU Report 50 suggests several methods for the representation of a spatial dose distribution.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 3 (29/232)

7.3 DOSE SPECIFICATION

- ❑ Parameters to characterize the dose distribution within a volume and to specify the dose are:
 - Minimum target dose
 - Maximum target dose
 - Mean target dose
 - Reference dose at a representative point within the volume.
- ❑ The ICRU has given recommendations for the selection of a representative point (the so-called ICRU reference dose point).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 4 (30/232)

7.3 DOSE SPECIFICATION

❑ The **ICRU reference dose point** is located at a point chosen to represent the delivered dose using the following criteria:

- The point should be located in a region where the dose can be calculated accurately (i.e., no build-up or steep gradients).
- The point should be in the central part of the PTV.
- For multiple fields, the isocenter (or beam intersection point) is recommended as the ICRU reference point.



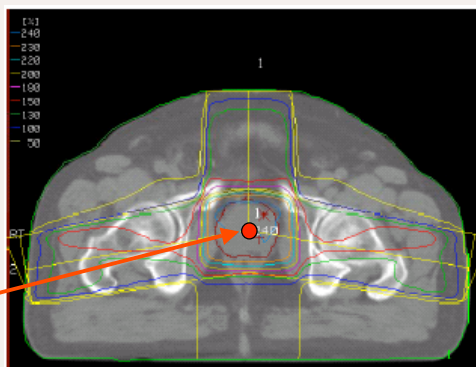
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 5 (31/232)

7.3 DOSE SPECIFICATION

ICRU reference dose point for multiple fields

Example: 3 field prostate boost treatment with an isocentric technique.

The **ICRU reference dose point** is located at the isocenter.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 6 (32/232)

7.3 DOSE SPECIFICATION

- ❑ Specific recommendations are made with regard to the position of the ICRU (reference) point for particular beam combinations:
 - **For single beam:**
the point on central axis at the center of the target volume.
 - **For parallel-opposed equally weighted beams:**
the point on the central axis midway between the beam entrance points.
 - **For parallel-opposed unequally weighted beams:**
the point on the central axis at the centre of the target volume.
 - **For other combinations of intersecting beams:**
the point at the intersection of the central axes (insofar as there is no dose gradient at this point).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.3 Slide 7 (33/232)

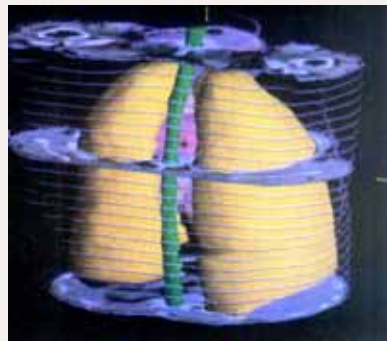
7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.1 Need for patient data

- ❑ Within the simulation process of the entire treatment using the computerized treatment planning system, the patient anatomy and tumor targets can be represented as three-dimensional models.

Example:

- ❑ CTV: Mediastinum (violet)
- ❑ OAR:
 - Both lungs (yellow)
 - Spinal cord (green)



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.1 Slide 1 (34/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.1 Need for patient data

- ❑ Patient data acquisition to create the patient model is the initial part of this simulation process.
- ❑ The type of gathered data varies greatly depending on the type of treatment plan to be generated.

Examples:

- Manual calculation of parallel-opposed beams



requires less effort

- Complex 3D treatment plan with image fusion



requires large effort



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.1 Slide 2 (35/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.1 Need for patient data

- ❑ General considerations on patient data acquisition:
 - Patient dimensions are always required for treatment time or monitor unit calculations, whether read with a caliper, from CT slices or by other means.
 - Type of dose evaluation also dictates the amount of patient data required (e.g., DVHs require more patient information than point dose calculation of organ dose).
 - Landmarks, such as bony or fiducial markers, are required to match positions in the treatment plan with positions on the patient.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.1 Slide 3 (36/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.2 Nature of patient data

- ❑ The **patient information** required for treatment planning varies from rudimentary to very complex data acquisition:



- Distances read on the skin.
- Manual determination of contours.
- Acquisition of CT information over a large volume.
- Image fusion (also referred to as image co-registration) using various imaging modalities, such as CT, MRI, and PET.



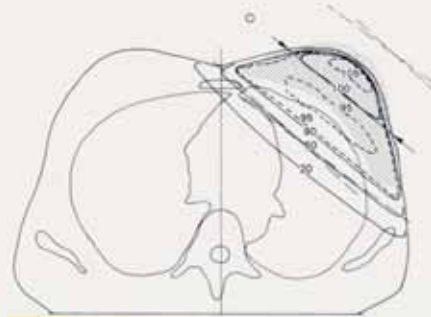
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 1 (37/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

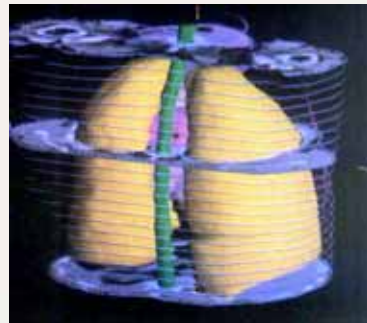
7.4.2 Nature of patient data

- ❑ The **patient information** required for treatment planning in particular depends on which system is used:

Two-dimensional system



Three-dimensional system



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 2 (38/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.2 Nature of patient data

□ 2D treatment planning

- A **single patient contour**, acquired using lead wire or plaster strips, is transcribed onto a sheet of graph paper, with reference points identified.
- **Simulation radiographs** are taken for comparison with port films during treatment.
- For **irregular field calculations**, points of interest can be identified on a simulation radiograph, and SSDs as well as depths of interest can be determined at simulation.
- **Organs at risk** can be identified and their depths determined on simulator radiographs.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 3 (39/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.2 Nature of patient data

□ 3D treatment planning

- CT dataset of the region to be treated is required with a **suitable slice spacing** (typically 0.5 cm - 1 cm for thorax, 0.5 cm for pelvis, 0.3 cm for head and neck).
- An external contour (representative of the skin or immobilization mask) must be drawn **on every CT slice** used for treatment planning.
- Tumor and target volumes are usually drawn on CT slices.
- Organs at risk and other structures of importance should be drawn in their **entirety**, if dose-volume histograms are to be calculated.



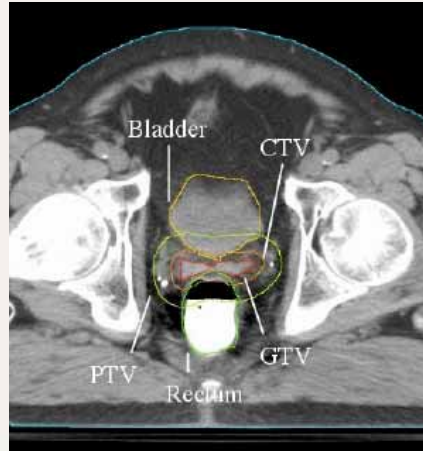
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 4 (40/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.2 Nature of patient data

Contours for various volumes have been drawn on this CT slice for a prostate treatment plan:

- GTV
- CTV
- PTV
- organs at risk (bladder and rectum).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 5 (41/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.2 Nature of patient data

❑ 3D treatment planning (cont.)

- MRI or other studies (PET) are required for image fusion (co-registration).
- With many treatment planning systems, the user can choose:
 - To ignore inhomogeneities (often referred to as heterogeneities).
 - To perform bulk corrections on outlined organs.
 - To or use the CT data itself (with an appropriate conversion to electron density) for point-to-point correction.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 6 (42/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

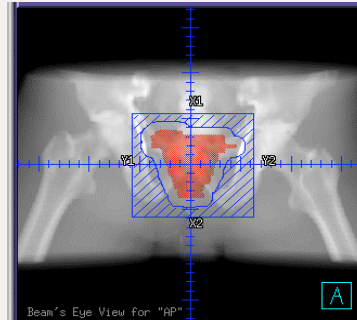
7.4.2 Nature of patient data

❑ 3D treatment planning (cont.)

- CT images can be used to produce digitally reconstructed radiographs (DRRs)
- DRRs are used for comparison with portal films or beam's eye view to verify patient set up and beam arrangement

Example:

A **digitally reconstructed radiograph** with super-imposed beam's eye view for an irregular field.

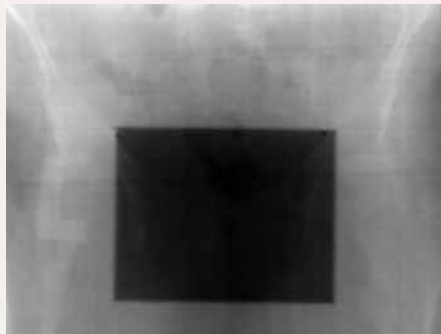


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.2 Slide 7 (43/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

- #### ❑ Patient simulation
- was initially developed to ensure that the beams used for treatment were correctly chosen and properly aimed at the intended target.



Example: The double exposure technique

The film is irradiated with the treatment field first, then the collimators are opened to a wider setting and a second exposure is given to the film.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 1 (44/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

□ Presently, treatment simulation has a more expanded role in the treatment of patients consisting of:

- Determination of **patient treatment position**.
- Identification of the **target volumes** and **OARs**.
- Determination and verification of treatment **field geometry**.
- Generation of **simulation radiographs** for each treatment beam for comparison with treatment port films.
- **Acquisition of patient data** for treatment planning.



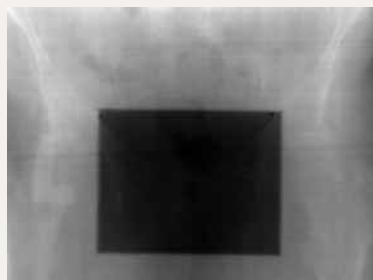
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 2 (45/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

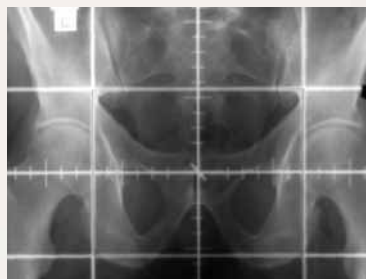
7.4.3 Treatment simulation

Comparison of simple simulation with portal image (MV) and conventional simulation with diagnostic radiography (kV) of the same anatomical site (prostate) demonstrates the higher quality of information on anatomical structures with kV imaging.

Check portal film (MV)



Reference simulator film (kV)



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 3 (46/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

❑ It is neither efficient nor practical to perform simulations with portal imaging on treatment units.

- There is always heavy demand for the use of treatment units for actual patient treatment
- Using them for simulation is therefore considered an inefficient use of resources.
- These machines operate in the megavoltage range of energies and therefore do not provide adequate quality radiographs for a proper treatment simulation.

➡ Poor image quality



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 4 (47/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

❑ Reasons for the poor quality of port films:

- Most photon interactions with biological material in the megavoltage energy range are Compton interactions that produce scattered photons that reduce contrast and blur the image.
- The large size of the radiation source (either focal spot for a linear accelerator or the diameter of radioactive source in an isotope unit) increases the detrimental effects of beam penumbra on the image quality.
- Patient motion during the relatively long exposures required and the limitations on radiographic technique also contribute to poor image quality.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 5 (48/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

Dedicated equipment –
fluoroscopic simulator -
has been developed and
was widely used for
radiotherapy simulation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 6 (49/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.3 Treatment simulation

Modern simulation systems
are based on computed
tomography (CT) or
magnetic resonance (MR)
imagers and are referred to
as CT-simulators or
MR-simulators.



A dedicated radiotherapy CT simulator



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.3 Slide 7 (50/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ Patients may require an external immobilization device for their treatment, depending upon:

- Patient treatment position,
or
- Precision required for beam delivery.

Example:
Precision
required in
radiosurgery



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 1 (51/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ Immobilization devices have two fundamental roles:
 - To **immobilize** the patient during treatment.
 - To provide reliable means of **reproducing the patient position** from treatment planning and simulation to treatment, and from one treatment to another.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 2 (52/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ The immobilization means include masking tape, velcro belts, elastic bands, or even a sharp and rigid fixation system attached to the bone (stereotactic frame).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 3 (53/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ The simplest immobilization device used in radiotherapy is the **head rest**, shaped to fit snugly under the patient's head and neck area, allowing the patient to lie comfortably on the treatment couch.



Several examples of headrests used for patient positioning and immobilization in external beam radiotherapy



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 4 (54/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

❑ Other types of immobilization accessories:

- Patients to be treated in the head and neck or brain areas are usually immobilized with a **plastic mask** which, when heated, can be moulded to the patient's contour.
- The **mask is affixed directly onto the treatment couch** or to a plastic plate that lies under the patient thereby preventing movement.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 5 (55/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- #### ❑ For **extra-cranial** treatments (such as to thoracic or pelvic area), a variety of immobilization devices are available.

Vacuum-based devices are popular because of their re-usability.



A pillow filled with tiny styrofoam balls is placed around the treatment area, a vacuum pump evacuates the pillow leaving the patient's form as an imprint in the pillow.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 6 (56/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ Another system, similar in concept to the vacuum pillow, uses a chemical reaction between two reagents to form a rigid mould of the patient.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 7 (57/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

Yet another system uses a mask method adopted to the body.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 8 (58/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.4 Patient treatment position and immobilization devices

- ❑ Special techniques, such as **stereotactic radiosurgery**, require such high precision in patient setup and treatment that conventional immobilization techniques are inadequate.

- In radiosurgery, a rigid **stereotactic frame** is attached to the patient's skull by means of screws
- The frame is used for target localization, patient setup, and patient immobilization during the entire treatment procedure.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.4 Slide 9 (59/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.5 Patient data requirements

- ❑ For simple hand calculations of the dose distribution along the central axis of the beam and the beam-on time or linac monitor units, the source-surface distance along the central ray only is required.

Examples:

- Treatment with a direct field;
 - Parallel - opposed fields.
- Basic requirement: a flat beam incidence.



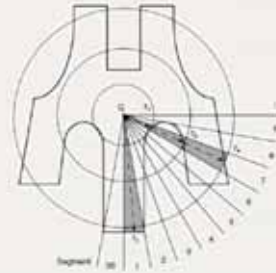
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.5 Slide 1 (60/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.5 Patient data requirements

- ❑ If simple algorithms, such as **Clarkson integration**, are used to determine the dosimetric effects of having blocks in the fields or to calculate the dose to off-axis points, their coordinates and source to surface distance must be measured.

The Clarkson integration method
(for details see chapter 6)



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.5 Slide 2 (61/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.5 Patient data requirements

- ❑ For simple computerized **2D treatment planning**, the patient's shape is represented by a single transverse skin contour through the central axis of the beams.
- ❑ This contour may be acquired using lead wire or plaster cast at the time of simulation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.5 Slide 3 (62/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.5 Patient data requirements

- ❑ The patient data requirements for modern 3D treatment planning systems are more elaborate than those for 2D treatment planning.
- ❑ The nature and complexity of data required, limit the use of manual contour acquisition.
- ❑ Transverse CT scans contain all information required for complex treatment planning and form the basis of CT-simulation in modern radiotherapy treatment.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.5 Slide 4 (63/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.5 Patient data requirements

- ❑ The patient data requirements for 3D treatment planning include the following:
 - The external shape of the patient must be outlined for all areas where the beams enter and exit (for contour corrections) and in the adjacent areas (to account for scattered radiation).
 - Targets and internal structures must be outlined in order to determine their shape and volume for dose calculation.
 - Electron densities for each volume element in the dose calculation matrix must be determined if a correction for heterogeneities is to be applied.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.5 Slide 5 (64/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

- ❑ A **fluoroscopic simulator** consists of a gantry and couch arrangement similar to that on a isocentric megavoltage treatment unit.

The radiation source of a simulator is a **diagnostic quality x-ray tube** rather than a high-energy linac or a cobalt source.



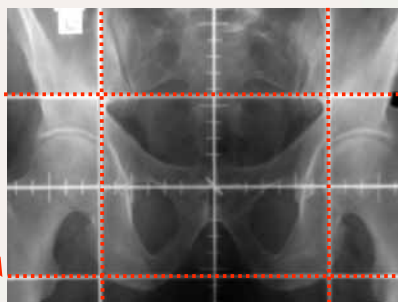
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 1 (65/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

- ❑ **Modern simulators** provide the ability to mimic most treatment geometries attainable on megavoltage treatment units, and to visualize the resulting treatment fields on radiographs or under fluoroscopic examination of the patient.

Adjustable bars made of tungsten or the so-called **delineation wires** can mimic the planned field size superimposed on the anatomical structures.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 2 (66/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

- ❑ The photons produced by the x-ray tube of a simulator are in the kilovoltage range and are preferentially attenuated by higher atomic number Z materials, such as bone through photoelectric interactions.
 - The result is a high quality diagnostic radiograph with limited soft-tissue contrast, but with excellent visualization of bony landmarks and high Z contrast agents.
 - A fluoroscopic imaging system may also be included in a simulator and would be used from a remote console to view patient anatomy and to modify beam placement in real time.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 3 (67/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

- ❑ For the vast majority of sites, the disease is not visible on the simulator radiographs.
- ❑ Therefore, shielding block positions can be determined only with respect to anatomical landmarks visible on the radiographs (usually bony structures, lead wire clinically placed on the surface of the patient, or surgically implanted fiducial markers).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 4 (68/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

❑ Determination of treatment beam geometry

- Typically, the patient is placed on the simulator couch, and the final treatment position of the patient is verified using the fluoroscopic capabilities of the simulator (e.g., patient is straight on the table, etc.).
- The position of the treatment isocenter, beam geometry (i.e., gantry, couch angles, etc.) and field limits are determined with respect to the anatomical landmarks visible under fluoroscopic conditions.



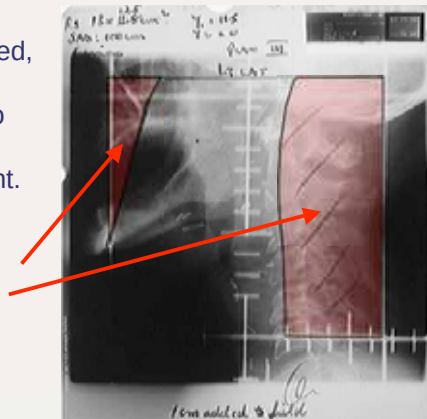
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 5 (69/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

❑ Determination of treatment beam geometry

- Once the final treatment geometry has been established, radiographs are taken as a matter of record, and are also used to determine shielding requirements for the treatment.
- Shielding can be drawn directly on the films, which may then be used as the blueprint for the construction of the blocks.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 6 (70/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

□ Acquisition of patient data

- After the proper determination of beam geometry, **patient contours** may be taken at any plane of interest to be used for treatment planning.
- Although more sophisticated devices exist, the simplest and most widely available method for obtaining a patient contour is through the use of lead wire.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 7 (71/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

□ Acquisition of patient data (cont.)

- The **lead wire** method:
 - The wire is placed on a transverse plane parallel to the isocenter plane.
 - Next, the wire is shaped to the patient's contour.
 - The shape of the wire is then transferred to a sheet of graph paper.



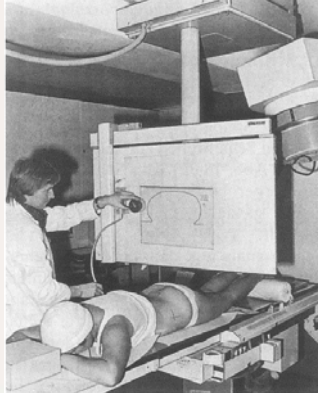
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 8 (72/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.6 Conventional treatment simulation

❑ Acquisition of patient data (cont.)

- Use of a special drawing instrument



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.6 Slide 9 (73/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

❑ Data acquisition with Computed Tomography

- With the growing popularity of computed tomography (CT) in the 1990s, the use of CT scanners in radio-therapy became widespread.
- Anatomical information on CT scans is presented in the form of transverse slices, which contain anatomical images of very high resolution and contrast.

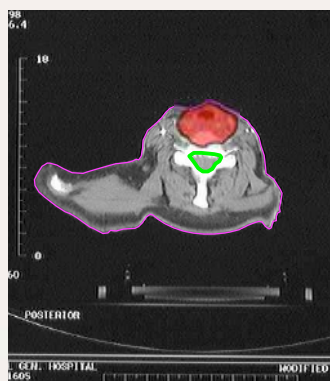


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 1 (74/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

- ❑ CT images provide excellent soft tissue contrast allowing for greatly improved tumor localization and definition in comparison to conventional simulation.
- ❑ Patient contours can be obtained easily from the CT data:
 - Patient's skin contour —
 - Target volume —
 - Any organs of interest —



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 2 (75/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

- ❑ The position of each slice and therefore the target can be related to bony anatomical landmarks through the use of scout or pilot images obtained at the time of scanning.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 3 (76/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

□ Scout films

- Pilot or scout films are obtained by keeping the x-ray source in a fixed position and moving the patient (translational motion) through the stationary slit beam.
- The result is a high definition radiograph which is divergent on the transverse axis, but non-divergent on the longitudinal axis.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 4 (77/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

□ Scout films

- Target position can also be determined through comparison between the CT scout and pilot films.
- Note: A different magnification between simulator film and scout film must be taken into account.
- This procedure allows for a more accurate determination of tumor extent and therefore more precise field definition at the time of simulation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 5 (78/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.7 Computed tomography-based conventional simulation

❑ Scout films

- If scanned in treatment position, **field limits and shielding parameters** can be directly set with respect to the target position, similar to conventional treatment simulation.
- The result is that the treatment port more closely conforms to the target volume, reducing treatment margins around the target and increasing healthy tissue sparing.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.7 Slide 6 (79/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

❑ Virtual Simulation

- Virtual simulation is the treatment simulation of patients based **solely on CT information**.
- The premise of virtual simulation is that the CT data can be manipulated to render **synthetic** radiographs of the patient for arbitrary geometries.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 1 (80/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

□ CT-Simulator

- Dedicated CT scanners for use in radiotherapy treatment simulation and planning have been developed.
- They are known as CT-simulators.

Example of a modern CT-simulator



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 2 (81/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

- CT-simulator components:
- **CT scanner**, including scanners with a large bore (with an opening of up to 85 cm to allow for a larger variety of patient positions and the placement of treatment accessories during CT scanning);
 - **Movable lasers** for patient positioning and marking;
 - A **flat table top** to more closely match radiotherapy treatment positions;
 - A **powerful graphics workstation**, allowing for image manipulation and formation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 3 (82/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

❑ Virtual Simulation

- Synthetic radiographs can be produced by tracing ray-lines from a virtual source position through the CT data of the patient to a virtual film plane and simulating the attenuation of x-rays.
- The synthetic radiographs are called Digitally Reconstructed Radiographs (DRRs).
- Advantage of DRRs is that anatomical information may be used directly in the determination of treatment field parameters.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 4 (83/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

❑ Example of a DRR

Note: Gray levels, brightness, and contrast can be adjusted to provide an optimal image.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 5 (84/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

❑ Beam's eye view (BEV)

Beam's eye views (BEV) are **projections** through the patient onto a **virtual film plane perpendicular** to the beam direction.

❑ The projections include:

- Treatment beam axes
- Field limits
- Outlined structures



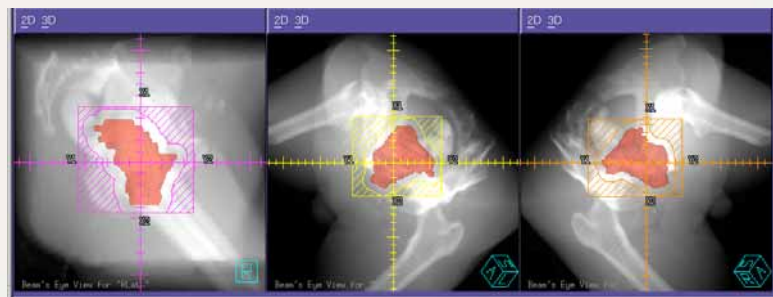
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 6 (85/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

❑ Beam's eye view (BEV)

- BEVs are frequently superimposed onto the corresponding DRRs resulting in a synthetic representation of a simulation radiograph.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 7 (86/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.8 Computed tomography-based virtual simulation

☐ Multi-planar reconstructions (MPR)

- Multi-planar reconstructions (MPR) are images formed from reformatted CT data.
- They are effectively CT images through arbitrary planes of the patient.
- Although typically sagittal or coronal MPR cuts are used for planning and simulation, MPR images through any arbitrary plane may be obtained.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.8 Slide 8 (87/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.9 Conventional simulator vs. CT simulator

Conventional simulator

Advantages

- ☐ Useful to perform a fluoroscopic simulation in order to verify isocenter position and field limits as well as to mark the patient for treatment.

Disadvantages

- ☐ Limited soft tissue contrast.
- ☐ Tumour mostly not visible.
- ☐ Requires knowledge of tumor position with respect to visible landmarks.
- ☐ Restricted to setting field limits with respect to bony landmarks or anatomical structures visible with the aid of contrast.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.9 Slide 1 (88/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.9 Conventional simulator vs. CT simulator

CT simulator

Advantages	Disadvantages
❑ Increased soft tissue contrast. ❑ Axial anatomical information available. ❑ Delineation of target and OARs directly on CT slices. ❑ Allows DRRs. ❑ Allows BEVs.	❑ Limitation in use for some treatment setups where patient motion effects are involved ❑ Requires additional training and qualification in 3D planning



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.9 Slide 2 (89/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.9 Conventional simulator vs. CT simulator

- ❑ Another important advantage of the CT-simulation process over the conventional simulation process is that the patient is not required to stay after the CT-scanning has taken place.
- ❑ The patient only stays the minimum time necessary to acquire the CT data set and mark the position of reference isocenter; this provides the obvious advantage as the radiotherapy staff may take their time in planning the patient as well as try different beam configurations without the patient having to wait on the simulator couch.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.9 Slide 3 (90/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

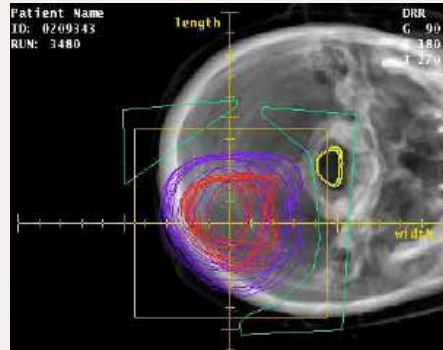
7.4.9 Conventional simulator vs. CT simulator

- ❑ Another important advantage of CT-simulation:
A CT-simulator allows the user to generate DRRs and BEVs even for beam geometries which are impossible to simulate with a conventional simulator.

- ❑ Example:

A DRR with superimposed beam's eye view for a **vertex field** of a brain patient.

This treatment geometry would be impossible to simulate on a conventional simulator because the film plane is in the patient.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.9 Slide 4 (91/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.10 Magnetic resonance imaging for treatment planning

- ❑ MR imaging plays an increasingly more important role in treatment planning.
- ❑ The **soft tissue contrast** offered by magnetic resonance imaging (MRI) in some areas, such as the brain, is **superior to that of CT**, allowing small lesions to be seen with greater ease.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.10 Slide 1 (92/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.10 Magnetic resonance imaging for treatment planning

❑ Disadvantages of MRI:

MRI cannot be used for radiotherapy simulation and planning for several reasons:

- The physical dimensions of the MRI and its accessories limit the use of immobilization devices and compromise treatment positions.
- Bone signal is absent and therefore digitally reconstructed radiographs cannot be generated for comparison to portal films.
- There is no electron density information available for heterogeneity corrections on the dose calculations.
- MRI is prone to geometrical artifacts and distortions that may affect the accuracy of the treatment.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.10 Slide 2 (93/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.10 Magnetic resonance imaging for treatment planning

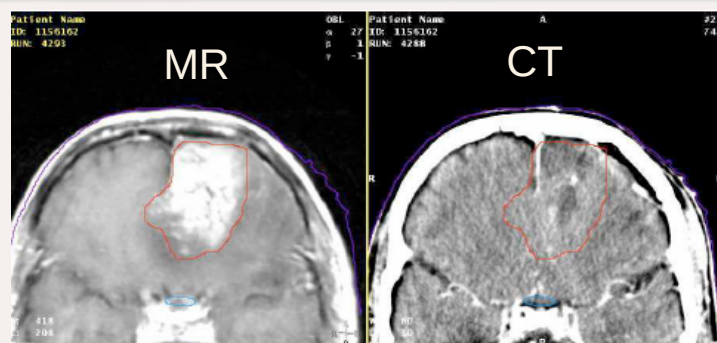
- ❑ To overcome these problems, many modern virtual simulation and treatment planning systems have the ability to combine the information from different imaging studies using the process of image fusion or co-registration.
- ❑ CT-MR image co-registration or fusion combines the
 - Accurate volume definition from MR with
 - Electron density information available from CT.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.10 Slide 3 (94/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.10 Magnetic resonance imaging for treatment planning



On the left is an MR image of a patient with a brain tumour. The target has been outlined and the result was superimposed on the patient's CT scan. Note that the particular target is clearly seen on the MR image but only portions of it are observed on the CT scan.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.10 Slide 4 (95/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.11 Summary of simulation procedures

Goals and tools in conventional and CT simulation

Goals	Conventional	CT simulation
Treatment position:	Fluoroscopy	Pilot/scout views
Identification of target volume:	Bony landmarks	From CT data
Determination of beam geometry:	Fluoroscopy	BEV/DRR
Shielding design:	Bony landmarks	Conformal to target
Contour acquisition:	Manual	From CT data



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.11 Slide 1 (96/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.11 Summary of simulation procedures

☐ Six steps of a typical **conventional** simulation procedure:

- Determination of patient **treatment position** with fluoroscopy
- Determination of **beam geometry**.
- Determination **field limits and isocenter**.
- Acquisition of **contour**.
- Acquisition of **beam's eye view** and **set-up radiographs**.
- **Marking** of patient.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.11 Slide 2 (97/232)

7.4 PATIENT DATA ACQUISITION AND SIMULATION

7.4.11 Summary of simulation procedures

Nine steps of a typical **CT** simulation procedure:

- ☐ Determination of **patient treatment** position with pilot/scout films.
- ☐ Determination and marking of **reference isocenter**.
- ☐ **Acquisition of CT data** and transfer to virtual simulation workstation.
- ☐ Localization and contouring of **targets** and **critical structures**.
- ☐ Determination **treatment isocenter** with respect to target and reference isocenter.
- ☐ Determination of **beam geometry**.
- ☐ Determination of **field limits and shielding**.
- ☐ **Transfer of CT and beam data** to treatment planning system.
- ☐ Acquisition of **beam's eye view** and setup **DRRs**.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.4.11 Slide 3 (98/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

❑ Clinical considerations for photon beams include the following:

- Isodose curves
- Wedge filters
- Bolus
- Compensating filters
- Corrections for contour irregularities
- Corrections for tissue inhomogeneities
- Beam combinations and clinical application.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5 Slide 1 (99/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.1 Isodose curves

- ❑ Isodose curves are defined as lines that join points of equal dose.
- ❑ They offer a planar representation of the dose distribution.
- ❑ Isodose curves are useful to characterize the behavior of
 - One beam
 - Combination of beams
 - Beams with different shielding
 - Wedged beams
 - Bolus, compensators, etc.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.1 Slide 1 (100/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.1 Isodose curves

❑ How are isodose curves obtained?

- They can be measured directly using a beam scanning device in a water phantom.
- They can be calculated from percentage depth dose and beam profile data.
- They can be adopted from an atlas for isodose curves.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.1 Slide 2 (101/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.1 Isodose curves

❑ To which dose values do isodose curves refer?

- While isodose curves can be made to display the actual dose in Gy (per fraction or total dose), it is more common to present them normalized to 100% at a fixed point.
- Possible point normalizations are:
 - Normalization to 100% at the depth of **dose maximum** on the central axis;
 - Normalization at the **isocenter**;
 - Normalization at the **point of dose prescription**.

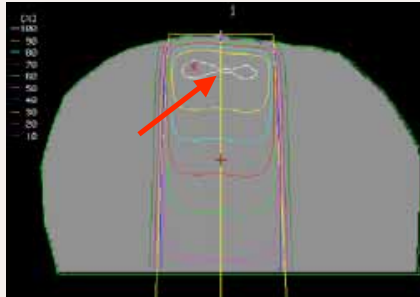


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.1 Slide 3 (102/232)

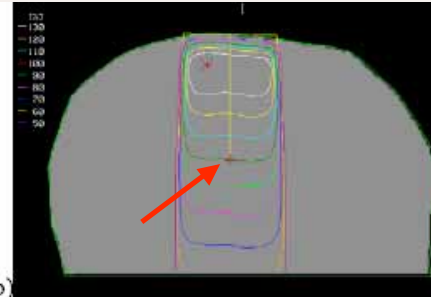
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.1 Isodose curves

- ❑ Different normalizations for a single 18 MV photon beam incident on a patient contour



Isodose curves for a fixed SSD beam normalized at the depth of dose maximum.



Isodose curves for an isocentric (SAD) beam normalized at the isocenter.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.1 Slide 4 (103/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

Three types of wedge filters are currently in use:

- (1) Physical (requiring manual intervention)
- (2) Motorized
- (3) Dynamic

- ❑ **Physical wedge:**
is an angled piece of lead or steel that is placed in the beam to produce a gradient in radiation intensity.
- ❑ **Motorized wedge:**
is a similar physical device, integrated into the head of the unit and controlled remotely.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 1 (104/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

☐ Physical wedge:

A set of wedges (15°, 30°, 45°, and 60°) is usually provided with the treatment machine.

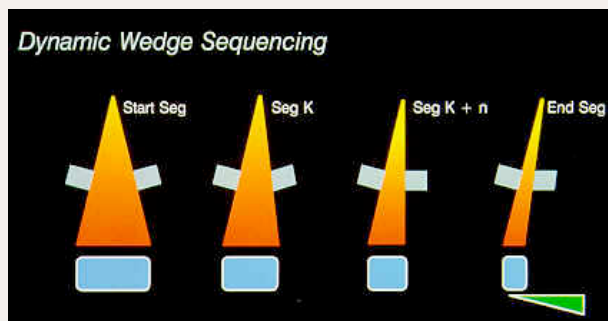


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 2 (105/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

- ☐ A **dynamic wedge** produces the same wedged intensity gradient by having one jaw close gradually while the beam is on.



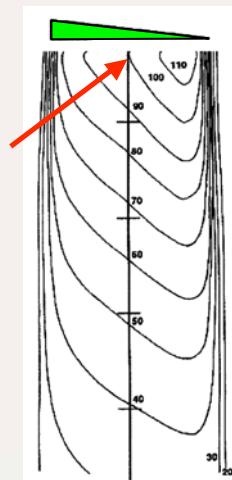
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 3 (106/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

- Isodose curves for a wedged 6 MV photon beam. The isodose contours are normalized to $z_{\max}$ with the wedge in place.

- Ratio of the dose at $z_{\max}$ for the wedged beam to the dose at $z_{\max}$ for an open beam is referred to as the **wedge factor**.
- Calculations of beam-on time or of monitor units must account for wedge factor, when a wedge is used.



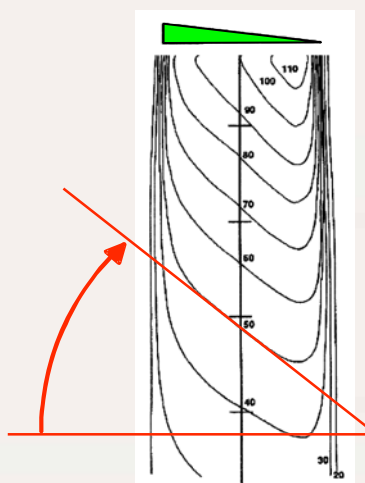
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 4 (107/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

- **Wedge angle** is defined as the angle between the 50% isodose contour and the perpendicular to the beam central axis.

- Wedge angles in the range from 10° to 60° are commonly available.
- The thick end of the wedge is called the heel and the dose is lowest under this end. The thin edge of the wedge is called the toe.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 5 (108/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

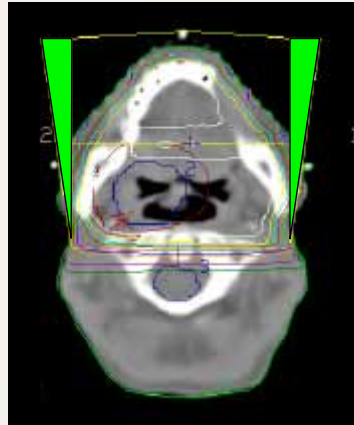
7.5.2 Wedge filters

There are two main uses of wedges:

- ❑ Wedges can be used to compensate for a sloping surface.

Example 1:

Two 15° wedges are used in a nasopharyngeal treatment to compensate for the decreased thickness anteriorly.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 6 (109/232)

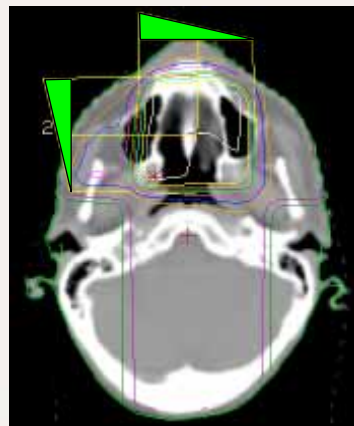
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

- ❑ Wedges can be used to compensate for a sloping surface.

Example 2:

A wedged pair of beams is used to compensate for the hot spot that would be produced with a pair of open beams at 90° to each other.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 7 (110/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

There are two main uses of wedges (cont.)

- ❑ Wedges can also be used in the treatment of relatively low lying lesions where two beams are placed at an angle (less than 180°) called the **hinge angle**.
- ❑ The optimal wedge angle (assuming a flat patient surface) may be estimated from:

$$\text{Wedge angle} = 90^\circ - \text{Hinge angle}$$



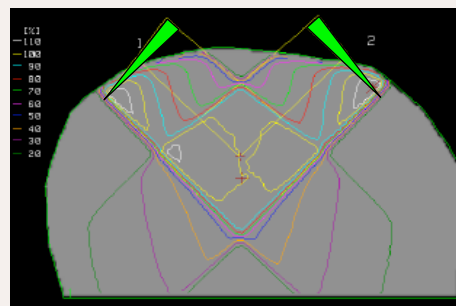
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 8 (111/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

Example:

- ❑ A wedge pair of 6 MV beams incident on a patient.
- ❑ The hinge angle is 90° (orthogonal beams) for which the optimal wedge angle would be 45°.
- ❑ However, in this case the **additional obliquity** of the surface requires the use of a higher wedge angle of 60°.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 9 (112/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.2 Wedge filters

□ Wedge factor

- Wedge factor is defined as the ratio of dose at a specified depth (usually z_{max}) on the central axis **with the wedge** in the beam to the dose under the same conditions **without the wedge**.
- Wedge factor is used in monitor unit calculations to compensate for the reduction in beam transmission produced by the wedge.
- Wedge factor depends on depth and field size.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.2 Slide 10 (113/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.3 Bolus

□ Bolus is a tissue-equivalent material placed in contact with skin to achieve one or more of the following:

- **Increase the skin dose** in megavoltage photon beams. Often this is achieved with a bolus layer that is thick enough to provide full buildup over the skin surface.
- **Compensate for missing tissue** to even out the irregular patient contour and present a flat surface to the beam.
- **Compensate for lack of scatter**, such as near extremities or the head during total body irradiation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.3 Slide 1 (114/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.3 Bolus

- ❑ Various materials are used as bolus in radiotherapy. Most of these materials are tissue equivalent.
- ❑ Examples of bolus material are:
 - Paraffin wax mixed with beeswax.
 - Mixture of flour and rice.
 - Cellophane wrapped wet towels or gauze.

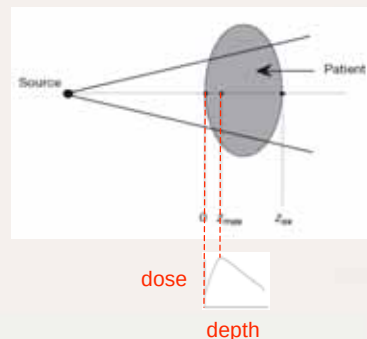


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.3 Slide 2 (115/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.3 Bolus

- ❑ To increase the skin dose with bolus, a layer of uniform thickness bolus is often used (0.5 –1.5 cm), since it does not significantly change the shape of the isodose curves at depth.
- ❑ Because of the dose buildup in megavoltage beams between the surface and the dose maximum (at a certain depth z_{max}), the dose may not be sufficient for superficial targets.



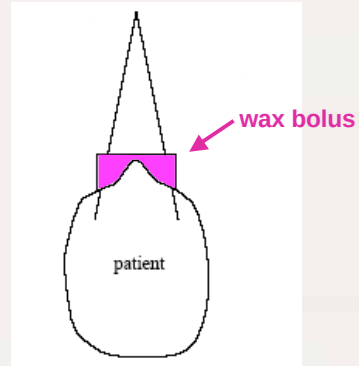
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.3 Slide 3 (116/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.3 Bolus

Bolus is also used to achieve **compensation for missing tissue**.

- A custom made bolus can be built such that it conforms to the patient skin on one side and yields a flat perpendicular incidence to the beam.
- The result is an isodose distribution that is identical to that produced on a flat phantom.
- However, skin sparing is not maintained with bolus, in contrast to the use of a compensator.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.3 Slide 4 (117/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.4 Compensating filters

❑ **Compensating filter** achieves the same effect on the dose distribution as a shaped bolus but does not cause loss of skin sparing.

- Compensating filters can be made of almost any material, but metals such as lead or Cerrobend (Lipowitz's metal) are the most practical and compact.
- Compensating filters can produce a dose gradient in two dimensions.
- Compensating filters are usually placed in a shielding slot on the treatment unit head.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.4 Slide 1 (118/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.4 Compensating filters

- ❑ Thickness of the compensator is determined on a point-by-point basis depending on the fraction I/I_0 of the dose without a compensator which is required at a certain depth in the patient.
- ❑ The thickness of compensator x along the ray line above that point can be solved from the attenuation law:

$$I/I_0 = e^{-\mu x}$$

where μ is the linear attenuation coefficient for the radiation beam and material used to construct the compensator.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.4 Slide 2 (119/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.4 Compensating filters

Use of compensating filters

Advantage

- ❑ Preservation of the skin sparing effect.

Disadvantages

- ❑ Generally more labour intensive and time consuming than use of bolus.
- ❑ Difficult to calculate the resulting dose distribution.
- ❑ Additional measurements may be required.



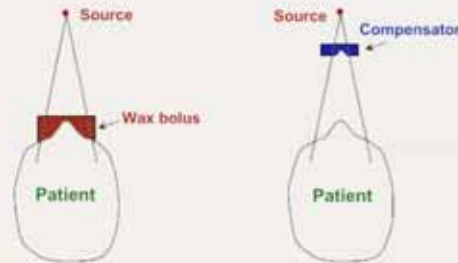
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.4 Slide 3 (120/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.3 Bolus

❑ Difference between bolus and compensating filter:

- A wax bolus is used. Skin sparing is lost with bolus because the bolus is in direct contact with skin.
- A compensator achieving the same dose distribution as with using bolus is constructed and attached to the treatment unit. Because of the large air gap skin sparing is maintained.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.4 Slide 5 (121/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.5 Corrections for contour irregularities

- ❑ Measured dose distributions apply to a flat radiation beam incident on a flat homogeneous water phantom.
- ❑ To relate such measurements to the actual dose distribution in a patient, corrections for irregular surface and tissue inhomogeneities have to be applied.
- ❑ Three methods for contour correction are used:
 - (1) Manual isodose shift method.
 - (2) Effective attenuation coefficient method.
 - (3) TAR/TMR method.

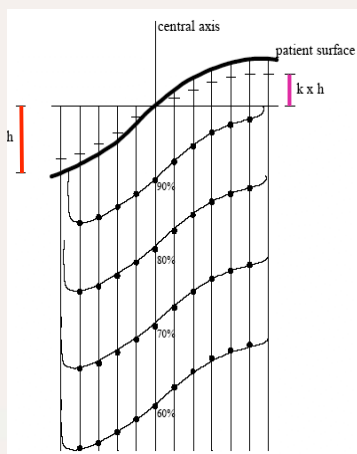


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.5 Slide 1 (122/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.5 Corrections for contour irregularities

(1) Manual isodose shift method



- Grid lines are drawn parallel to the central beam axis all across the field.
- The tissue deficit (or excess) h is the difference between SSD along a grid-line and the SSD on the central axis.
- k is an energy dependent parameter given in the next slide.
- The isodose distribution for a flat phantom is aligned with the SSD central axis on the patient contour.
- For each gridline, the overlaid isodose distribution is shifted up (or down) such that the overlaid SSD is at a point $k \times h$ above (or below) the central axis SSD.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.5 Slide 2 (123/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.5 Corrections for contour irregularities

Parameter k used in the isodose shift method

Photon energy (MV)	k (approximate value)
< 1	0.8
^{60}Co - 5	0.7
5 – 15	0.6
15 – 30	0.5
> 30	0.4



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.5 Slide 3 (124/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.5 Corrections for contour irregularities

(2) Effective attenuation coefficient method

- ☐ Correction factor is determined from the attenuation factor $\exp(-\mu x)$, where x is the depth of missing tissue above the calculation point, and μ is the linear attenuation coefficient of tissue for a given energy.
- ☐ For simplicity the factors are usually pre-calculated and supplied in graphical or tabular form.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.5 Slide 4 (125/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.5 Corrections for contour irregularities

(3) TAR method

- ☐ The tissue-air ratio (TAR) correction method is also based on the attenuation law, but takes the depth of the calculation point and the field size into account.
- ☐ Generally, the correction factor C_F as a function of depth z , thickness of missing tissue h , and field size A , is given by:

$$C_F = \frac{\text{TAR}(z-h, A)}{\text{TAR}(z, A)}$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.5 Slide 5 (126/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

- ☐ Corrections for **tissue inhomogeneities (heterogeneities)**.
 - In a simple approach to calculate the dose and its distribution in a patient, one may assume that all tissues are water-equivalent.
 - However, in the actual patient the photon beam traverses tissues with varying densities and atomic numbers such as fat, muscle, lung, air, and bone.
 - This will influence the attenuation and scatter of photons beam such that the depth dose curve will deviate from that in water.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 1 (127/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

- ☐ Tissues with densities and atomic numbers that are different from those of water are referred to as **tissue inhomogeneities** or **heterogeneities**.
- ☐ Inhomogeneities in the patient result in:
 - Changes in absorption of the primary beam and associated scattered photons.
 - Changes in electron fluence.
- ☐ Importance of each effect depends on the position of the point of interest relative to the inhomogeneity.

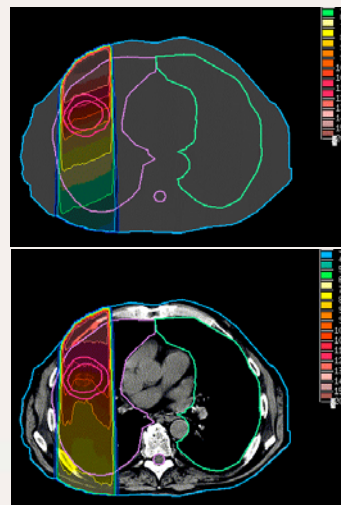


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 2 (128/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

- ❑ Differences in isodose distributions obtained using a single vertical 7x7 cm² field.
 - **Top:**
Assuming that all tissues (including the lung) have water-equivalent density
 - **Bottom:**
Taking into account the real tissue density



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 3 (129/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

- ❑ In the megavoltage range the Compton interaction predominates and its cross-section depends on the **electron density** (in electrons per cm³).
- ❑ The following four methods are used to correct for the presence of inhomogeneities within certain limitations:
 - **TAR method**
 - **Batho power law method**
 - **Equivalent TAR method**
 - **Isodose shift method**

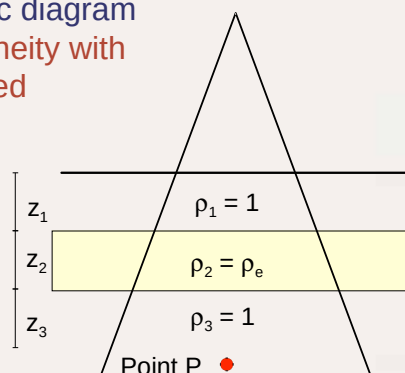


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 4 (130/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

- The four methods for inhomogeneity correction are studied using the schematic diagram which shows an inhomogeneity with an electron density ρ_e nested between two layers of water-equivalent tissue.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 5 (131/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

(1) TAR method

The dose at each point is corrected by the factor C_F :

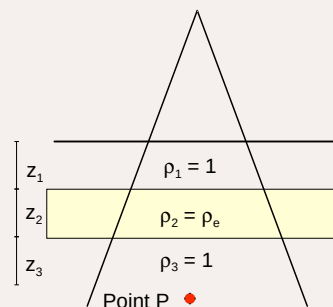
$$C_F = \frac{\text{TAR}(z', r_d)}{\text{TAR}(z, r_d)}$$

where

$$z' = z_1 + \rho_e z_2 + z_3$$

and

$$z = z_1 + z_2 + z_3$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 6 (132/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

(2) Batho Power-law method

Dose at each point is corrected by correction factor C_F :

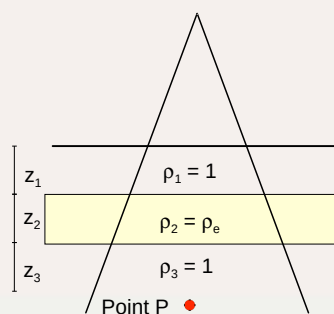
$$C_F = \frac{\text{TAR}(z', r_d)^{\rho_3 - \rho_2}}{\text{TAR}(z, r_d)^{1 - \rho_2}}$$

where

$$z' = z_1 + \rho_2 z_2 + z_3$$

and

$$z = z_1 + z_2 + z_3$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 7 (133/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

(3) Equivalent TAR method

The method is similar to the TAR method. The field size parameter r_d is now modified into r'_d as a function of density and the correction factor C_F is:

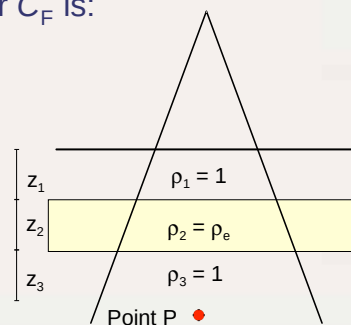
$$C_F = \frac{\text{TAR}(z', r'_d)}{\text{TAR}(z, r_d)}$$

where

$$z' = z_1 + \rho_2 z_2 + z_3$$

and

$$z = z_1 + z_2 + z_3$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 8 (134/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.6 Corrections for tissue inhomogeneities

(4) Isodose shift method

- ❑ The isodose shift method for the dose correction due to the presence of inhomogeneities is essentially identical to the isodose shift method outlined in the previous section for contour irregularities.
- ❑ Isodose shift factors for several types of tissue have been determined for isodose points beyond the inhomogeneity.
- ❑ The factors are energy dependent but do not vary significantly with field size.
- ❑ The factors for the most common tissue types in a 4 MV photon beam are: air cavity: -0.6; lung: -0.4; and hard bone: 0.5. The total isodose shift is the thickness of inhomogeneity multiplied by the factor for a given tissue. Isodose curves are shifted away from the surface when the factor is negative.

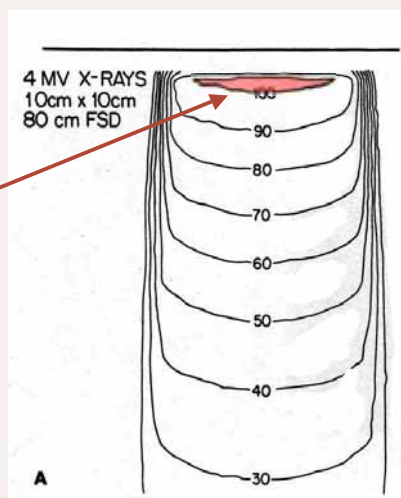


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.6 Slide 9 (135/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

- ❑ Single photon beams are of limited use in the treatment of deep-seated tumors, since they give a **higher dose** near the entrance at the depth of dose maximum $z_{\max}$ than at depth.

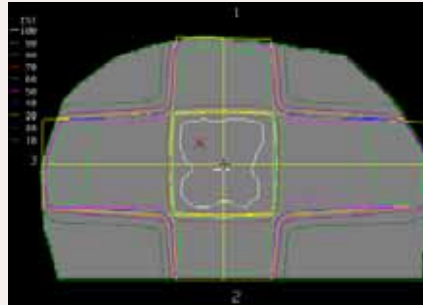


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 1 (136/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

- ❑ Single fields are often used for **palliative treatments** or for relatively **superficial lesions** (depth < 5-10 cm, depending on the beam energy).
- ❑ For deeper lesions, a **combination** of two or more photon beams is usually required to concentrate the dose in the target volume and spare the tissues surrounding the target as much as possible.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 2 (137/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

- ❑ **Weighting and normalization**
 - Dose distributions for multiple beams can be normalized to 100% just as for single beams:
 - At $z_{\max}$ for each beam.
 - At isocenter for each beam.
 - This implies that each beam is equally weighted.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 3 (138/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

□ Weighting and normalization

- A **beam weighting** may be additionally applied at the normalization point for a given beam.
- **Example:**
A wedged pair with $z_{\max}$ normalization weighted as 100 : 50% will show one beam with the 100% isodose at $z_{\max}$ and the other one with 50% at $z_{\max}$.
- A similar isocentric weighted beam pair would show the 150% isodose at the isocenter.



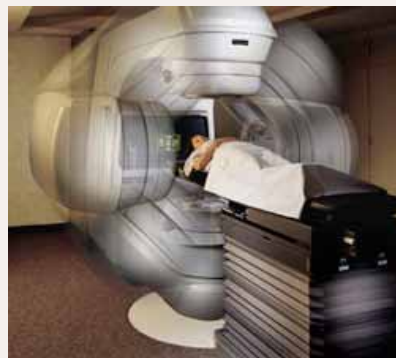
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 4 (139/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

□ Fixed SSD vs. isocentric technique

- **Fixed SSD techniques** require adjusting the patient such that the skin is at the correct distance (nominal SSD) for each beam orientation.
- **Isocentric techniques** require placing the patient such that the target (usually) is at the isocenter.
- The machine gantry is then rotated around the patient for each treatment field.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 5 (140/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Fixed SSD vs. isocentric techniques

- There is little difference between fixed SSD techniques and isocentric techniques with respect to the dose:
- Fixed SSD arrangements are usually at a **greater SSD** than isocentric beams because the machine isocenter is on the patient skin.
- SSD techniques have therefore a slightly **higher PDD** at depth.
- Additionally, beam **divergence is smaller** with SSD due to the larger distance.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 6 (141/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Fixed SSD vs. isocentric techniques

- The dosimetric advantages of SSD techniques over the isocentric techniques are minor.
- With exception of very large fields exceeding 40x40 cm², **the advantages of using a single set-up point** (i.e., the isocenter) greatly outweigh the dosimetric advantage of SSD beams.



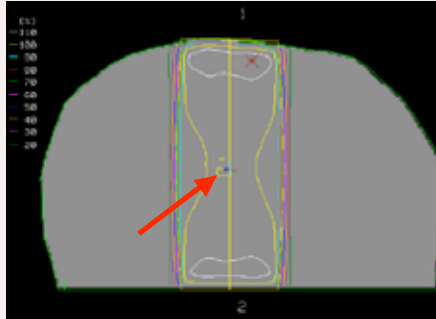
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 7 (142/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

□ Parallel opposed beams

- **Example:**
A parallel-opposed beam pair is incident on a patient.
- Note the large rectangular area of relatively uniform dose (<15% variation).
- The isodoses have been normalized to 100% at the isocenter.



- This beam combination is well suited to a large variety of treatment sites (e.g., lung, brain, head and neck, etc).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 8 (143/232)

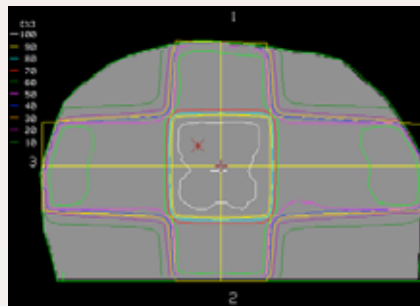
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

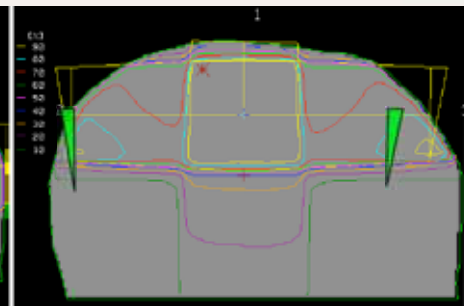
□ Multiple co-planar beams:

- A multiple coplanar beam setup allows for a higher dose in the beam intersection region.
- **Examples:**

4-field box



3-field technique incorporating wedges



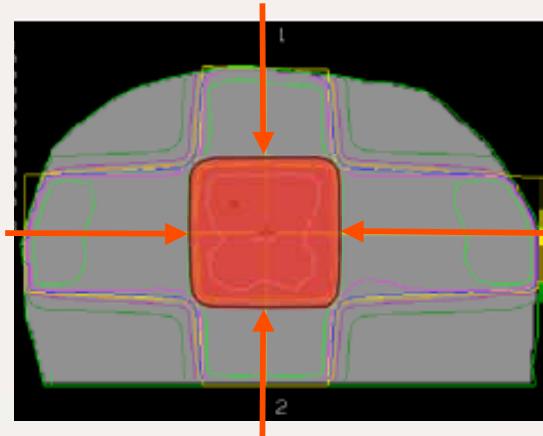
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 9 (144/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

☐ Multiple co-planar beams:

- 4-field box technique
- A 4-field box allows for a very high dose to be delivered at the **intersection** of the beams.



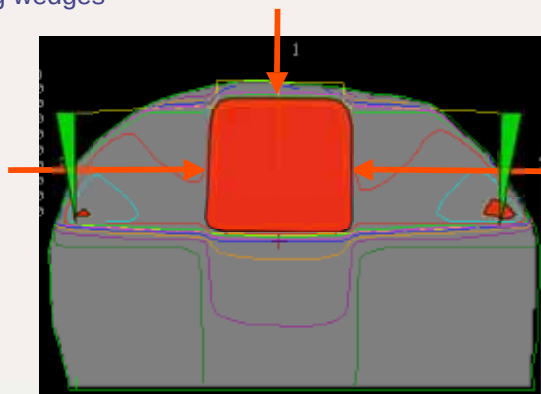
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 10 (145/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

☐ Multiple co-planar beams

- 3-field technique using wedges
- A 3-field technique requires the use of wedges to achieve a **similar result**.
- **Note** that the latter can produce significant **hot spots** near the entrance of the wedged beams and well outside the targeted area.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 11 (146/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

Multiple co-planar beams: General characteristics

Type	Characteristics	Used for:
Wedge pairs	Used to achieve a trapezoid shaped high dose region	Low-lying lesions (e.g., maxillary sinus and thyroid lesions).
4-field box	Produces a relatively high dose box shaped region	Treatments in the pelvis, where most lesions are central (e.g., prostate, bladder, uterus).
Opposing pairs at angles other than 90°	The high dose area has a rhombic shape	Similar indications



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 12 (147/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

☐ Multiple co-planar beams: General characteristics

- **Wedge pair:**
Two beams with wedges (often orthogonal) are used to achieve a trapezoid shaped high dose region. This technique is useful in low-lying lesions (e.g., maxillary sinus and thyroid lesions).
- **4-field box:**
A technique of four beams (two opposing pairs at right angles) producing a relatively high dose box shaped region. The region of highest dose occurs in the volume portion that is irradiated by all four fields. This arrangement is used most often for treatments in the pelvis, where most lesions are central (e.g., prostate, bladder, uterus).
- **Opposing pairs at angles other than 90°:**
also result in the highest dose around the intersection of the four beams, however, the high dose area here has a rhombic shape.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 13 (148/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Multiple co-planar beams: General characteristics

- Occasionally, **three sets of opposing pairs** are used, resulting in a more complicated dose distribution, but also in spread of the dose outside the target over a larger volume, i.e., in more sparing of tissues surrounding the target volume.
- The **3-field box technique** is similar to a 4-field box technique. It is used for lesions that are closer to the surface (e.g., rectum). Wedges are used in the two opposed beams to compensate for the dose gradient of the third beam.



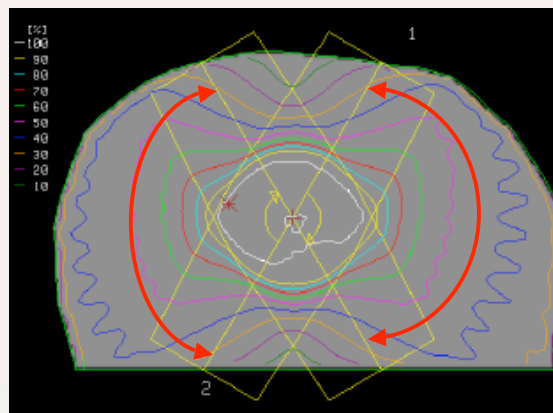
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 14 (149/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Rotational techniques

- Isodose curves for two bilateral arcs of 120° each.
- **Note:**
The isodose curves are tighter along the angles avoided by the arcs (anterior and posterior).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 15 (150/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

□ Rotational techniques: General characteristics

- The target is placed at the isocenter, and the machine gantry is rotated about the patient in one or more arcs while the beam is on.
- Rotational techniques produce a relatively concentrated region of high dose near the isocenter.
- Rotational techniques also irradiate a greater amount of normal tissue to lower doses than fixed-field techniques.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 16 (151/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

□ Rotational techniques: General characteristics (cont.)

- Useful technique used mainly for prostate, bladder, cervix and pituitary lesions, particularly boost volumes.
- The dose gradient at the edge of the field is not as sharp as for multiple fixed field treatments.
- Skipping an angular region during the rotation allows the dose distribution to be pushed away from the region; however, this often requires that the isocentre be moved closer to this skipped area so that the resulting high-dose region is centered on the target .



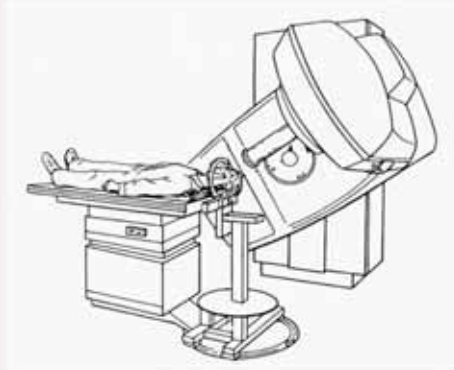
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 17 (152/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Multiple non-coplanar beams: General characteristics

- Non-coplanar beams arise from non-standard couch angles coupled with gantry angulations.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 18 (153/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Multiple non-coplanar beams: General characteristics

- Non-coplanar beams may be useful to get more adequate critical structure sparing compared to conventional coplanar beam arrangement.
- Dose distributions from combinations of non-coplanar beams yield similar dose distributions to conventional multiple field arrangements.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 19 (154/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Multiple non-coplanar beams: General characteristics

- When planning the use of non-coplanar beams care must be taken to ensure no collisions occur between the gantry and patient or couch.
- Non-coplanar beams are most often used for treatments of brain as well as head and neck disease where the target volume is frequently surrounded by critical structures.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 20 (155/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Multiple non-coplanar beams: General characteristics (cont.)

- Non-coplanar arcs may also be used in radiotherapy.
- The best-known example is the multiple non-coplanar converging arcs technique used in stereotactic radio-surgery.



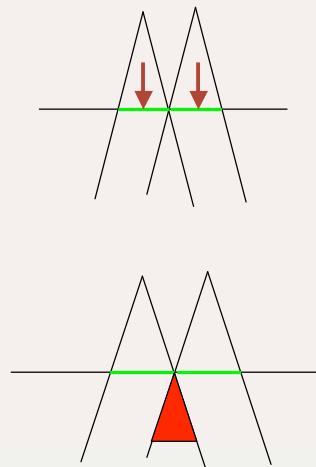
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 21 (156/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

Field matching

- Field matching on the skin surface is the easiest field matching technique.
- However, due to beam divergence, this will lead to significant overdosing of tissues at depth and is only used in regions where tissue tolerance is not compromised.



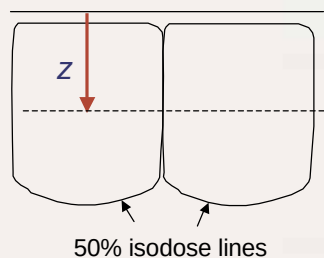
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 22 (157/232)

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

Field matching

- For most clinical situations field matching is performed **at depth** rather than at the skin.
- To produce a junction dose similar to that in the center of the open fields, beams must be matched such that their diverging edges **match at the desired depth z** .



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 23 (158/232)

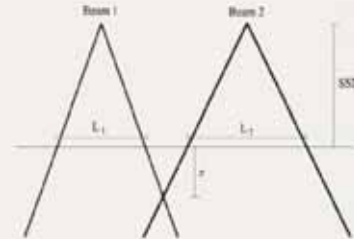
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS

7.5.7 Beam combinations and clinical application

❑ Field matching

- For two adjacent fixed SSD fields of different lengths L_1 and L_2 , the surface gap g required to match the two fields at a depth z is:

$$g = 0.5 \cdot L_1 \cdot \left(\frac{z}{SSD} \right) + 0.5 \cdot L_2 \cdot \left(\frac{z}{SSD} \right)$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.5.7 Slide 24 (159/232)

7.6 TREATMENT PLAN EVALUATION

- ❑ It is essential to assess the "quality" of a treatment plan regardless whether or not the dose calculations are performed:
 - On a computer
 - or
 - By hand.
- ❑ Good "quality" means that the calculated dose distribution of the treatment plan complies with the clinical aim of the treatment. Therefore, a radiation oncologist must evaluate the treatment plan before clinical use.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6 Slide 1 (160/232)

7.6 TREATMENT PLAN EVALUATION

- ❑ Depending on the method of calculation, the dose distribution may be obtained:
 - Only for a **few significant points** within the target volume.
 - For a **two-dimensional grid** of points over a contour or an image.
 - For a **full three-dimensional array** of points that cover the patient's anatomy.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6 Slide 2 (161/232)

7.6 TREATMENT PLAN EVALUATION

- ❑ The treatment plan evaluation generally consists of verifying:
 - **Treatment portals** to ensure that the desired PTV is covered adequately.
 - **Isodose distribution** to ensure that target coverage is adequate and that critical structures surrounding the PTV are spared as necessary.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6 Slide 3 (162/232)

7.6 TREATMENT PLAN EVALUATION

❑ The following tools are used in the evaluation of the planned dose distribution:

- Isodose curves.
- Orthogonal planes and isodose surfaces.
- Dose distribution statistics.
- Differential Dose Volume Histogram.
- Cumulative Dose Volume Histogram.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6 Slide 4 (163/232)

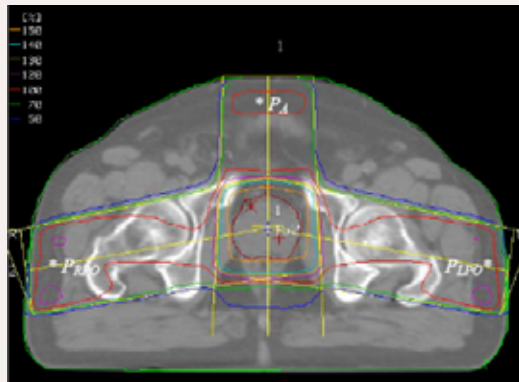
7.6 TREATMENT PLAN EVALUATION

7.6.1 Isodose curves

❑ Isodose curves are used to evaluate treatment plans along a single plane or over several planes in the patient.

❑ Example:

The isodose curve, covering the periphery of the target, is compared to the isodose value at the isocentre.



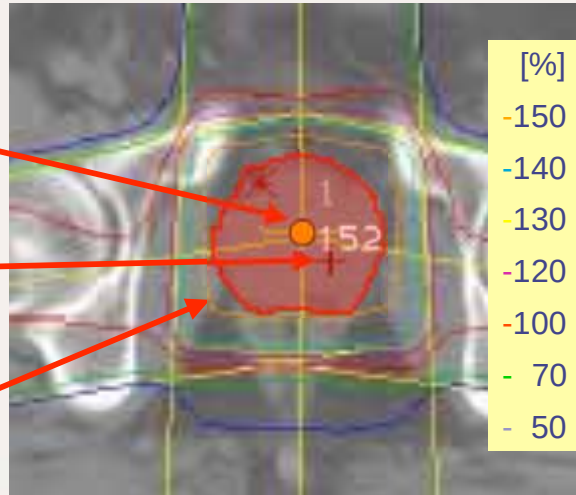
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.1 Slide 1 (164/232)

7.6 TREATMENT PLAN EVALUATION

7.6.1 Isodose curves

Same example:

- The isodose line through the ICRU reference point is 152%.
- The maximum dose 154%.
- The 150% isodose curve completely covers the PTV.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.1 Slide 2 (165/232)

7.6 TREATMENT PLAN EVALUATION

7.6.1 Isodose curves

- ☐ If the ratio of the isodose surface covering the periphery of the target to that at the isocentre is within a desired range (e.g., 95-100%), then the plan may be acceptable provided critical organ doses are not exceeded.
- ☐ This approach is ideal if the number of transverse slices is small.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.1 Slide 3 (166/232)

7.6 TREATMENT PLAN EVALUATION

7.6.2 Orthogonal planes and isodose surfaces

- ❑ When a larger number of transverse planes is used for calculation, it may be impractical to evaluate the plan on the basis of axial slice isodose distributions alone.
- ❑ In such cases, isodose distributions can also be generated on **orthogonal CT planes**, reconstructed from the original axial data.
 - For example, **sagittal and coronal** plane isodose distributions are usually available on most 3D treatment planning systems.
 - Displays on **arbitrary oblique planes** are also becoming increasingly common.

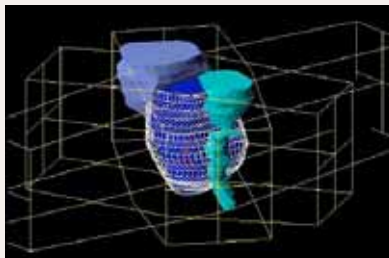


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.2 Slide 1 (167/232)

7.6 TREATMENT PLAN EVALUATION

7.6.2 Orthogonal planes and isodose surfaces

- ❑ An alternative way to display isodoses is to **map them in three dimensions** and overlay the resulting isosurface on a 3D display featuring surface renderings of the target and or/other organs.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.2 Slide 2 (168/232)

7.6 TREATMENT PLAN EVALUATION

7.6.2 Orthogonal planes and isodose surfaces

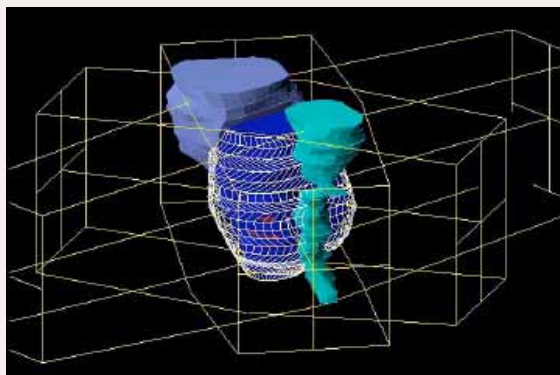
❑ Example: Treatment of prostate cancer

Target volume:
blue

Prescription isodose:
white wireframe

Bladder and rectum
also shown.

Beams: also shown



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.2 Slide 3 (169/232)

7.6 TREATMENT PLAN EVALUATION

7.6.2 Orthogonal planes and isodose surfaces

Such displays are useful to assess target coverage in a qualitative manner.

Disadvantage:

❑ The displays:

- Do not convey a sense of distance between the isosurface and the anatomical volumes.
- Do not give a quantitative volume information.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.2 Slide 4 (170/232)

7.6 TREATMENT PLAN EVALUATION

7.6.3 Dose statistics

- ❑ In order to get more quantitative information, various statistical tools have been introduced.
 - In contrast to isodose tools, the dose statistics tools cannot show the spatial distribution of dose superimposed on CT slices or anatomy that has been outlined based on CT slices.
 - Instead, they can provide quantitative information on the **volume** of the target or critical structure, and on the **dose received by that volume**.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.3 Slide 1 (171/232)

7.6 TREATMENT PLAN EVALUATION

7.6.3 Dose statistics

- ❑ From the location of matrix points within an organ and from the calculated doses at these points, a **series of statistical characteristics** can be obtained.
- ❑ These include:
 - **Minimum dose to the volume.**
 - **Maximum dose to the volume.**
 - **Mean dose to the volume.**
 - **Dose received by at least 95% of the volume.**
 - **Volume irradiated to at least 95% of the prescribed dose.**



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.3 Slide 2 (172/232)

7.6 TREATMENT PLAN EVALUATION

7.6.3 Dose statistics

- ❑ Target dose statistics as well as organ dose statistics can be performed.
 - "Dose received by at least 95% of the volume" and the "Volume irradiated to at least 95% of the prescribed dose" are only relevant for the target volume.
 - Organ dose statistics are especially useful in dose reporting, since they are simpler to include in a patient chart than the more complex dose-volume histograms.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.3 Slide 3 (173/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

- ❑ Dose volume histograms (DVHs) summarize the information contained in a three-dimensional treatment plan.
 - This information consists of dose distribution data over a three-dimensional matrix of points over the patient's anatomy.
 - DVHs are extremely powerful tools for quantitative evaluation of treatment plans.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 1 (174/232)

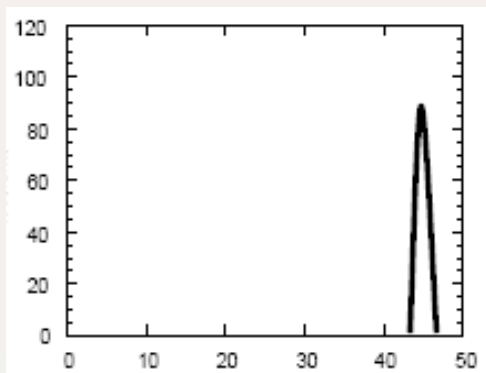
7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

- In its simplest form a DVH represents a **frequency distribution of dose values** within a defined volumes such as:

- The PTV itself
- A specific organ in the vicinity of the PTV.

Frequency



Dose (Gy)



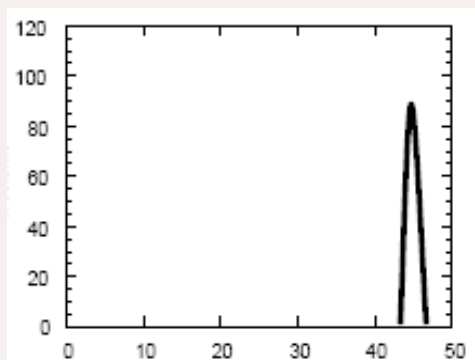
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 2 (175/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

- Rather than displaying the frequency, DVHs are usually displayed in the form of “**per cent volume of total volume**” on the ordinate against the dose on the abscissa.

Per cent volume of total volume



Dose (Gy)



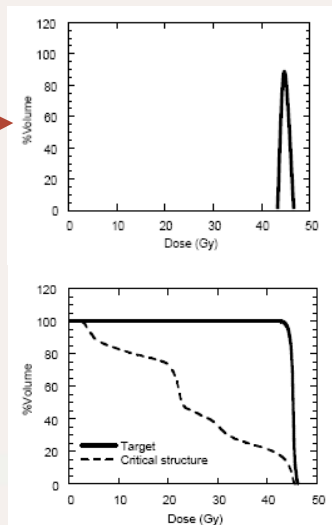
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 3 (176/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

Two types of DVHs are in use:

- Direct (or differential) DVH
- Cumulative (or integral) DVH
Definition: The volume that receives **at least** the given dose and plotted versus dose.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 4 (177/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

□ Direct (Differential) Dose Volume Histogram

- To create a direct DVH, the computer sums the number of voxels which have a specified dose range and plots the resulting volume (or the percentage of the total organ volume) as a function of dose.
- The ideal DVH for a **target volume** would be a single column indicating that 100% of the volume receives the prescribed dose.
- For a critical structure, the DVH may contain several peaks indicating that different parts of the organ receive different doses.

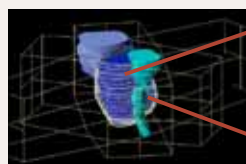


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 5 (178/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

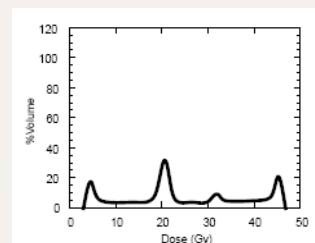
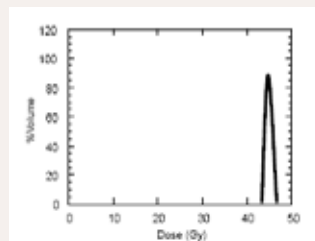
Example: Prostate cancer



Target

Rectum

Differential DVHs



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 6 (179/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

❑ Cumulative (Integral) Dose Volume Histogram

- Traditionally, physicians have sought to answer questions such as: "How much of the target is covered by the 95% isodose line?"
- In 3-D treatment planning this question is equally relevant and the answer cannot be extracted directly from the direct (differential) DVH, since it would be necessary to determine the area under the curve for all dose levels above 95% of the prescription dose.

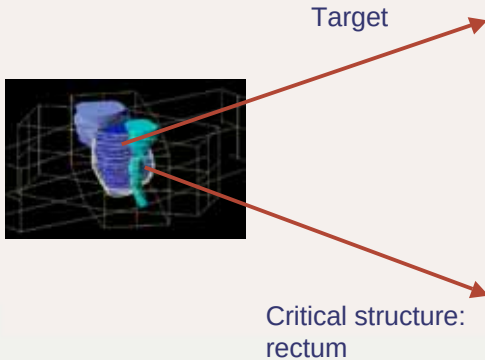


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 7 (180/232)

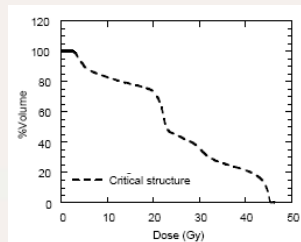
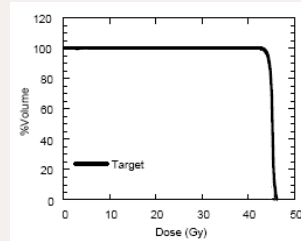
7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

Example: Prostate cancer



Integral DVHs



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 8 (181/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

❑ Cumulative DVH displays are more popular.

- The computer calculates the volume of the target (or critical structure) that receives at least the given dose and plots this volume (or percentage volume) versus dose.
- All cumulative DVH plots start at 100% of the volume for zero dose, since all of the volume receives at least no dose.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 9 (182/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

- ❑ While displaying the **percent volume** versus **dose** is more popular, it is also useful in some circumstances to plot the **absolute volume** versus dose.
 - **For example**, if a CT scan does not cover the entire volume of an organ, such as the lung and the un-scanned volume receives very little dose, then a DVH showing percentage volume versus dose for that organ will be biased, indicating that a larger percentage of the volume receives dose.
 - Furthermore, in the case of some critical structures, tolerances are known for irradiation of fixed volumes specified in cm^3 .



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 10 (183/232)

7.6 TREATMENT PLAN EVALUATION

7.6.4 Dose-volume histograms

- ❑ The main drawback of the DVHs is the **loss of spatial information** that results from the condensation of data when DVHs are calculated.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.4 Slide 11 (184/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

□ Port films

- A port film is usually an emulsion-type film, often still in its light-tight paper envelope, that is placed in the radiation beam beyond the patient.
- Port film is sometimes referred to as check film.



Since there is no conversion of x rays to light photons as in diagnostic films, the film needs not be removed from its envelope.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 1 (185/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

□ Port films

- Two types of portal imaging are available.
- Depending on their sensitivity (or speed) port films can be used for:
 - **Localization:**
A fast film is placed in each beam at the beginning or end of the treatment to verify that the patient installation is correct for the given beam.
 - **Verification:**
A slow film is placed in each beam and left there for the duration of the treatment.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 2 (186/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

Localization (fast) vs. verification (slow) films

Advantages	Disadvantage
❑ Fast films generally produce a better image. ❑ Recommended for verifying small or complex beam arrangements. ❑ Patient or organ movement during treatment will not affect the quality of the film.	❑ Not recommended for larger fields for example where as many as 4 films may be required to verify the treatment delivery.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 3 (187/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

- ❑ **Localization films** used in radiotherapy do not require intensifying screens such as those used in diagnostic radiology.
 - Instead, a single thin layer of a suitable metal (such as copper or aluminum) is used in front of the film (beam entry side) to provide for electronic buildup that will increase the efficiency of the film.
 - A backing layer is often used with double emulsion films to provide backscatter electrons.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 4 (188/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

Port films can be taken in single or double exposure technique.

☐ Single exposure:

The film is irradiated with the treatment field alone. This technique is well suited to areas where the anatomical features can clearly be seen inside the treated field. Practically all verification films are of the single exposure type.

☐ Double exposure:

- The film is irradiated with the treatment field first.
- Then the collimators are opened to a wider setting, all shielding is removed, and a second exposure is given to the film.
- The resulting image shows the treated field **and** the surrounding anatomy that may be useful in verifying the beam position.

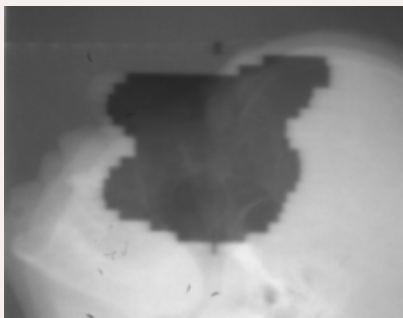


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 5 (189/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

☐ Double exposure technique: Two examples:



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 6 (190/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

Online portal imaging

☐ Online portal imaging systems consist of:

- Suitable **radiation detector**, usually attached through a manual or semi-robotic arm to the linac.
- **Data acquisition system** capable of transferring the detector information to a computer,
- **Software** that will process it and convert it to an image.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 7 (191/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

☐ Portal imaging systems use a variety of detectors, all producing computer based images of varying degrees of quality.

☐ **Online portal imaging systems** currently include:

- Fluoroscopic detectors.
- Ionisation chamber detectors.
- Amorphous silicon detectors.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 8 (192/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

❑ Fluoroscopic portal imaging detectors:

- Work on the same principle as a simulator image intensifier system.
- The detector consists of a combination of a metal plate and fluorescent phosphor screen, a 45° mirror and a television camera.
- The metal plate converts incident x-rays to electrons and the fluorescent screen converts electrons to light photons.
- The mirror deflects light to the TV camera, reducing the length of the imager, and the TV camera captures a small fraction (<0.1%) of the deflected light photons to produce an image.
- Good spatial resolution (depends on phosphor thickness).
- Only a few MU are required to produce an image.

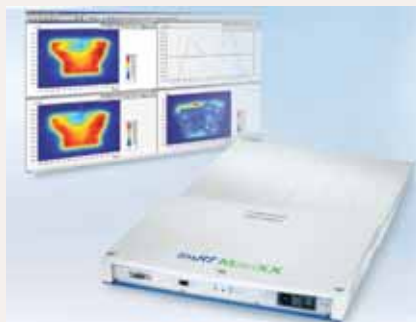


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 9 (193/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

❑ Matrix ionisation chamber detectors:



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 10 (194/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

❑ Matrix ionisation chamber detectors:

- Are based on grid of ion chamber-type electrodes that measure ionisation from point to point.
- The detector consists of two metal plates, 1 mm apart with the gap filled with isobutene. Each plate is divided into 256 electrodes and the plates are oriented such that the electrodes in one plate are at 90° to the electrodes in the other.
- A voltage is applied between two electrodes across the gap and the ionisation at the intersection is measured. By selecting each electrode on each plate in turn, a 2D ionisation map is obtained and converted to a grayscale image of 256 x 256 pixels.
- The maximum image size is usually smaller than for fluoroscopic systems.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 11 (195/232)

7.6 TREATMENT PLAN EVALUATION

7.6.5 Treatment evaluation

❑ Amorphous silicon detectors:

- Solid-state detector array consisting of amorphous silicon photodiodes and field-effect transistors arranged in a large rectangular matrix.
- Uses metal plate/fluorescent phosphor screen combination like the fluoroscopic systems. Light photons produce electron-hole pairs in the photodiodes whose quantity is proportional to the intensity allowing an image to be obtained.
- Produces an image with a greater resolution and contrast than the other systems.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.6.5 Slide 12 (196/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

□ Background remark

- The process of treatment planning and optimization may be considered complete, when the calculated **relative** dose distribution shows an acceptable agreement with the PTV.
- **For example**, the 80% isodose curve may well encompass the PTV. It then remains to determine the most important final parameter which controls the **absolute** dose delivery, that is:
 - **Treatment time** (for radiation sources and x-ray machines).
 - **Monitor units** (for megavoltage linacs).

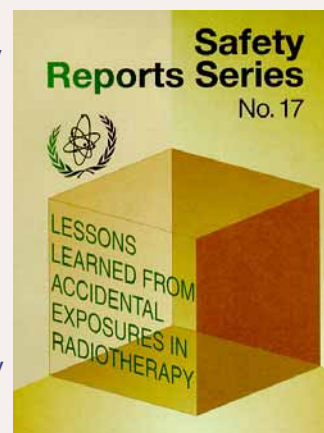


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 1 (197/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

□ Data on **treatment time** and/or **monitor units** are usually provided by modern TP systems after having passed the "dose prescription" procedure.

- However, a **manual calculation method** to obtain such data independent from the TPS is of utmost importance.
- Accidents in radiotherapy can and do happen. See, for example, IAEA Safety Report Series No. 17.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 2 (198/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

Before going into the details of manual calculation methods for an individual plan, a clear understanding of the following associated issues is required:

- ☐ The technique used for **patient setup**:
 - Fixed SSD setup
 - Isocentric setup
- ☐ The methods used for :
 - **Dose prescription**
 - **Adding the dose** from multiple fields.
- ☐ Formulas and algorithms used for **central axis dose calculations**.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 3 (199/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

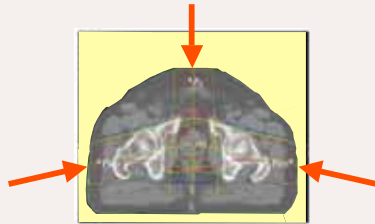
- ☐ **Methods used for patient setup:** (already discussed previously)
 - The patient treatments are carried out either with a fixed SSD or an isocentric technique.
 - Each of the two techniques is characterized with a specific dose distribution and treatment time or monitor unit calculation.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 4 (200/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

Fixed SSD technique



Fixed SSD technique results in an isodose distribution that is typically governed by percentage depth dose data.

Isocentric technique



Isocentric technique results in an dose distribution that is typically governed by tissue-maximum ratios (or tissue-phantom ratios).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 5 (201/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

□ Methods used for dose prescription

- The determination of treatment time or monitor units (whether by the treatment planning system or manually) is directly related to the two following actions:
 - Selection of an appropriate point for dose prescription (recommended by the ICRU: the ICRU reference point).
 - Prescription of an absolute dose at this point.



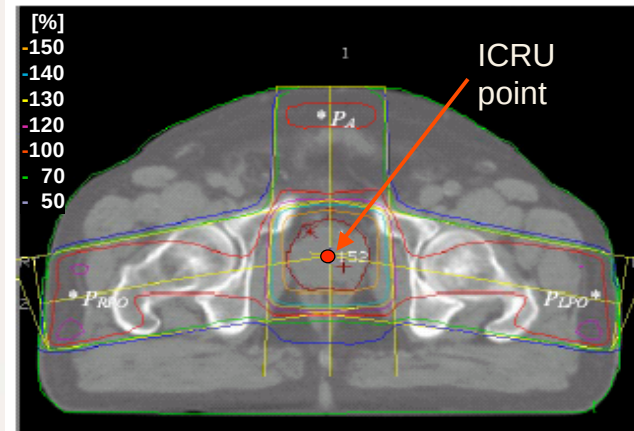
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 6 (202/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

Example:

Isodose distributions of a three field treatment of the prostate using fixed SSD on a 6 MV linac.

- ❑ **ICRU point**
is located at the intersection of three fields.
- ❑ **Dose of 200 cGy per fraction**
is prescribed at the ICRU point.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 7 (203/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

- ❑ **Methods used for dose prescription (continued)**
 - There are also other methods, such as using a **dose volume histogram (DVH)**.
 - This method is particularly useful for IMRT treatment when the evaluation of a treatment plan is based on the DVH of the target.
 - The method consists of assigning the prescribed dose to the **median dose** in the target volume.



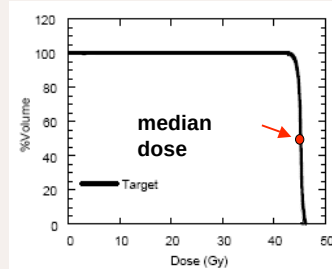
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 8 (204/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

❑ Methods used for dose prescription (continued)

- An example is shown on the DVH at left:

The median dose is the dose at the 50% volume level.



- ❑ Since this method is not applicable in manual dose calculations, it is not further explained in the following slides.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 9 (205/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

❑ Methods used for adding the dose at the ICRU point from multiple fields:

- The simplest method (usually not used): Each field contributes to the total prescribed dose at the ICRU point using an **equal number** of MU (or equal treatment time).
- Each field contributes to the total prescribed dose at the ICRU point with **different weights**.
- Prescribed weights for individual fields may refer to:
 - ICRU reference point IP (used for isocentric techniques).
 - Point of maximum dose $D_{\max}$ of each field (used for fixed SSD techniques).



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 10 (206/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

- ❑ In the following slides two examples are shown to calculate treatment time or monitor units when using different weights at the ICRU point.
- ❑ The method used is divided into 5 steps and is based on well known central axis formulas for the dose calculation (at the ICRU point).
- ❑ Note: This method deviates slightly from that given in the Handbook.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 11 (207/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

- ❑ The five steps are as follows:
 - Get the calibrated output of the machine at the calibration reference point.
 - Determine the dose at the ICRU point (IP) from each beam, initially for an arbitrary value of 100 MU.
 - Rescale the MUs such that the dose contributions (at IP or $D_{\max}$) are proportional to the pre-defined weights and sum up the total resultant dose using the rescaled MUs.
 - Determine the ratio between the prescribed dose and the sum dose at IP obtained in step 3.
 - Rescale again the MUs (from step 3) by the ratio obtained in step 4 to get finally the required MU.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 12 (208/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

□ Step 1: Calibrated output of the treatment machine

- For kilovoltage x-ray generators and teletherapy machines the output is usually given in Gy/min.
- For clinical accelerators the output is given in Gy/MU.
- For superficial and orthovoltage beams, and occasionally for beams produced by teletherapy radionuclide machines, the basic beam output may also be stated as the air kerma rate in air (Gy/min) at a given distance from the source and for a given nominal collimator or applicator setting.

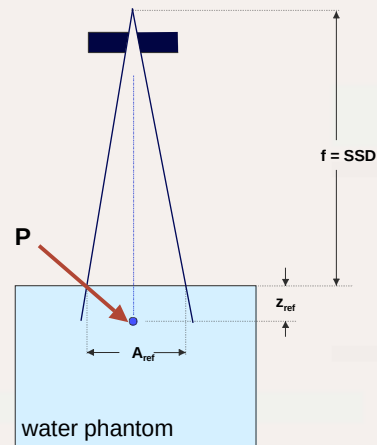


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 13 (209/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

Output for a radiotherapy machine is usually stated as follows:

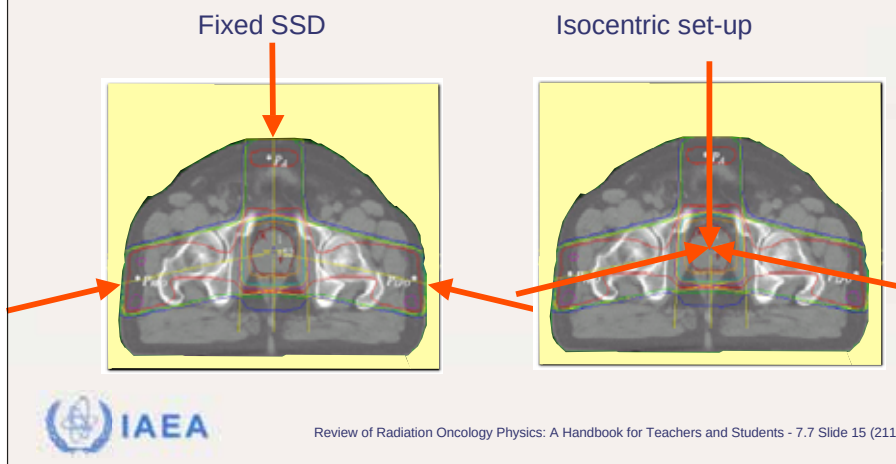
- In a water phantom
- As the dose rate for a point P at a reference depth z_{ref} (often the depth of maximum dose z_{max}).
- For a nominal source-surface distance (SSD) or source to axis distance (SAD).
- For a reference field size A_{ref} (often $10 \times 10 \text{ cm}^2$) on the phantom surface or at the isocenter.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7 Slide 14 (210/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

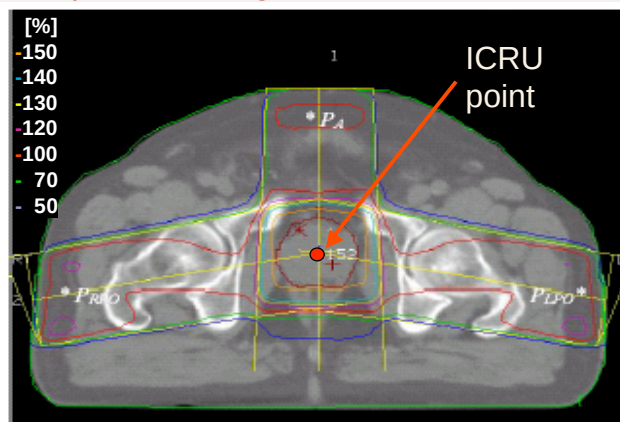
- The second step is performed differently depending upon whether **fixed SSD set-up** or **isocentric set-up** is used.



7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

- Example of isodose distributions of a three field treatment of the prostate using fixed SSD on a 6 MV linac

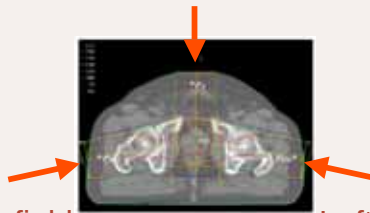


7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

- Field parameters as obtained from the treatment planning:

Anterior field:
7.5×7.5 cm² open field
weight $W = 1.0$



Right posterior field:
6.5×7.5 cm² wedge field
weight $W = 0.8$
wedge factor $WF = 0.53$

Left posterior field:
6.5×7.5 cm² wedge field
weight $W = 0.8$
wedge factor $WF = 0.53$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 2 (213/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

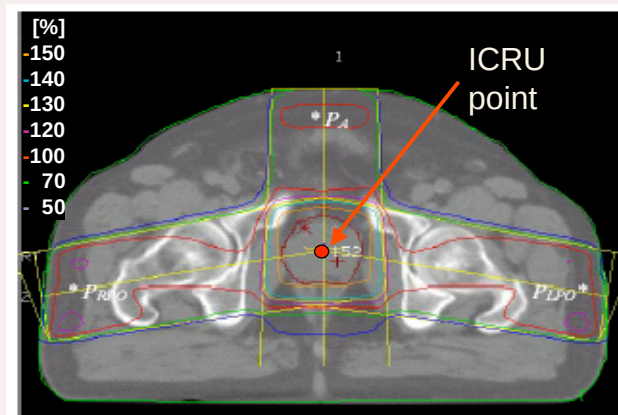
7.7.1 Calculations for fixed SSD set-up

- Note:**
The prescribed weights refer to the point of maximum dose in each field:

P_A $W = 1.0$

P_{RPO} $W = 0.8$

P_{LPO} $W = 0.8$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 3 (214/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

❑ Method of normalization:

Normalization was first performed for each field individually:

Anterior field:

$D_{\max}$ refers to 100%

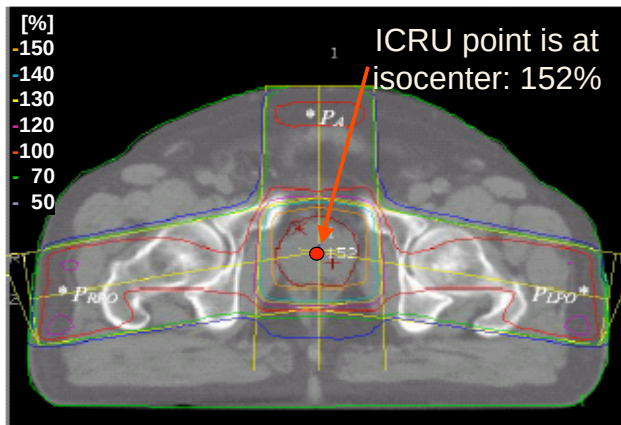
Right posterior field:

$D_{\max}$ refers to 80%

Left posterior field:

$D_{\max}$ refers to 80%

The isodose lines are then obtained by summing up the individual %-values.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 4 (215/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

❑ **Step 2:** For each field i , the dose at the ICRU point, $D_i(IP)$, is calculated by (using 100 MU):

$$D_i(IP) = \dot{D}(z_{\max}, A_{\text{ref}}, f, hv) \cdot \frac{\text{PDD}(z, A, f, hv)}{100} \times \text{RDF}(A, hv) \times \text{WF} \times 100$$

$\dot{D}(z_{\max}, A_{\text{ref}}, f, hv)$ is the calibrated output of the machine

$\text{PDD}(z, A, f, hv)$ is the percentage depth dose value

WF is the wedge factor

$\text{RDF}(A, hv)$ is the relative dose factor (see next slide)



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 5 (216/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

□ Relative dose factor RDF describes field size dependence:

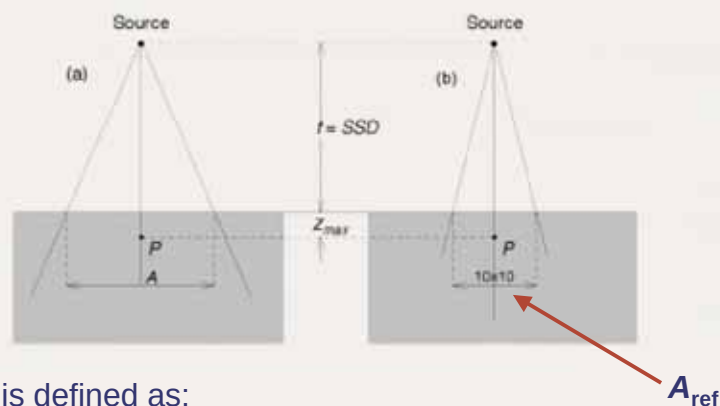
- For a given beam energy $h\nu$, the dose at the calibration point P (at depth z_{ref}) depends on the field size A .
- The ratio of dose to that of reference field size A_{ref} is called the **output factor**, also known as **total scatter factor**.
- The IAEA Handbook is using the expression: **relative dose factor (RDF)**:



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 6 (217/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up



□ RDF is defined as:

$$\text{RDF}(A, h\nu) = \frac{D_P(z_{\text{ref}}, A, f, h\nu)}{D_P(z_{\text{ref}}, A_{\text{ref}}, f, h\nu)}$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 7 (218/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

Step 3: Rescale the MUs so that the dose contributions at $D_{\max}$ are proportional to the pre-defined weights and sum up the total resultant dose using the rescaled MUs.

field	starting MU	dose at $D_{\max}$	weight	weighted dose at $D_{\max}$	rescaled MU	dose at IP
anterior	100	98.0	1.0	100%=98.0	100	69.5
left post.	100	51.4	0.8	80%=78.4	152	39.7
right post.	100	51.4	0.8	80%=78.4	152	39.7



$$\Sigma(\text{dose}) = 148.96$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 8 (219/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

- ☐ **Step 4:** Determine the ratio between the prescribed dose and the sum dose at IP obtained in step 3.

Prescribed dose = 200 cGy

Calculated dose = 148.96 cGy

$$\text{ratio} = \frac{200}{148.96} = 1.343$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 9 (220/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.1 Calculations for fixed SSD set-up

❑ **Step 5:** Rescale again the MUs (from step 3) by the ratio obtained in step 4 to get finally the required MU.

- Anterior field: $100 \text{ MU} \times 1.343 = 134 \text{ MU}$
- Left posterior field: $152 \text{ MU} \times 1.343 = 205 \text{ MU}$
- Right posterior field: $152 \text{ MU} \times 1.343 = 205 \text{ MU}$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.1 Slide 10 (221/232)

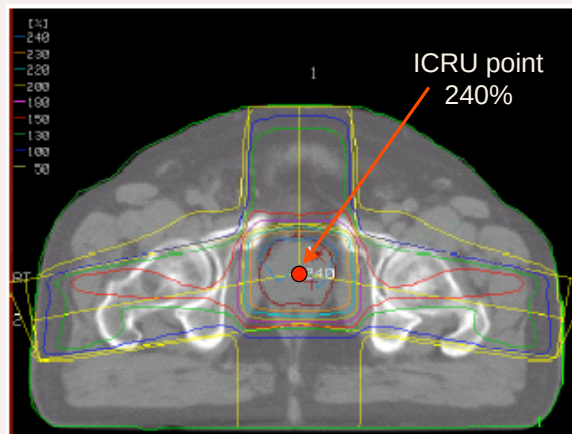
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

Example for an isodose distribution obtained for a 3 field prostate boost treatment with an isocentric technique

In this example, the normalization was performed for each beam individually such that $D_{\text{isocenter}}$ is 100% times the beam weight.

The isodose lines are then obtained by summing up the individual %-values.



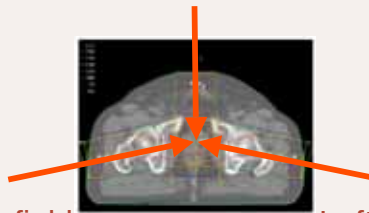
Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 1 (222/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

- Field parameters as obtained from the treatment planning:

Anterior field:
8×8 cm² open field
PDD = 70.9, W = 1.0



Right posterior field:
7×8 cm² wedge field
PDD = 50.7, W = 0.7
wedge factor WF = 0.53

Left posterior field:
7×8 cm² wedge field
PDD = 50.7, W = 0.7
wedge factor WF = 0.53



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 2 (223/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

- Step 2:** For each field i , the dose at the ICRU point, $D_i(\text{IC})$, is calculated by (using 100 MU):

$$D_i(\text{IC}) = \dot{D}(z_{\text{max}}, A_{\text{ref}}, f, hv) \times \text{TMR}(z, A_Q, hv) \times \text{ISF} \times \text{RDF}(A, hv) \times \text{WF} \times 100$$

where:

$\dot{D}(z_{\text{max}}, A_{\text{ref}}, f, hv)$	is the calibrated output of the machine
$\text{TMR}(z, A_Q, hv)$	is the tissue-maximum-ratio at depth z
WF	is the wedge factor
$\text{RDF}(A, hv)$	is the relative dose factor
ISF	is the inverse-square factor (see next slide)



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 3 (224/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

- ❑ When the calibrated output factor $\dot{D}(z_{\max}, A_{\text{ref}}, f, hv)$ is used in isocentric calculations, it must be corrected by the inverse-square factor ISF, unless the machine is actually calibrated at the isocenter:

$$\text{ISF} = \left[\frac{\text{SSD} + z_{\max}}{\text{SSD}} \right]^2$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 4 (225/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

Step 3: Rescale the MUs such that the dose contributions at the IP are proportional to the pre-defined weights and sum up the total resultant dose using the rescaled MUs.

field	starting MU	dose at IP	weight	weighted dose at IP	rescaled MU
anterior	100	73.1	1.0	100%=73.1	100
left post.	100	28.7	0.7	70% =51.2	178
right post.	100	28.7	0.7	70% =51.2	178



$$\Sigma(\text{dose}) = 175.44$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 5 (226/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

- ❑ **Step 4:** Determine the ratio between the prescribed dose and the sum dose at IP obtained in step 3.

- Prescribed dose = 200 cGy
- Calculated dose = 175.44 cGy

$$\text{ratio} = \frac{200}{175.44} = 1.140$$



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 6 (227/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.2 Calculations for isocentric set-ups

- ❑ **Step 5:** Rescale again the MUs (from step 3) by the ratio obtained in step 4 to get finally the required MU.

- Anterior field: 100 MU x 1.14 = 114 MU
- Left posterior field: 178 MU x 1.14 = 203 MU
- Right posterior field: 178 MU x 1.14 = 203 MU

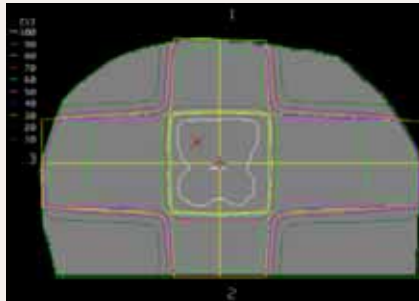


Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.2 Slide 7 (228/232)

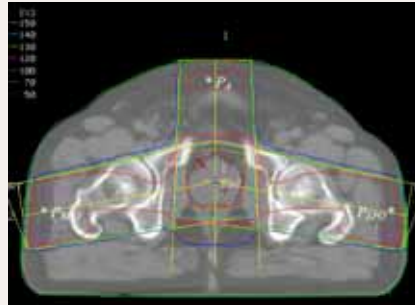
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.3 Normalization of dose distributions

- ❑ **Important:** Dose distributions can be normalized in various ways:



Normalized to maximum dose



Normalized such that 100% = 100 cGy



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.3 Slide 1 (229/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.3 Normalization of dose distributions

- ❑ Frequently, the dose distribution is normalized to the maximum dose.
- The ICRU recommends normalization of the dose distribution to 100% at the ICRU dose prescription point.
 - As a consequence, values of the dose distribution larger than 100% will be obtained if the prescription point is not located at the point of maximum dose.
 - If the isodose values generated by the TPS itself are used for the monitor calculations, the **method of normalization used in the TPS** must be understood and taken into account.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.3 Slide 2 (230/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.4 Inclusion of output parameters in dose distribution

- ☐ Modern treatment planning systems give the user the ability to take into account several dosimetric parameters in the dose distribution affecting the beam output.
- ☐ For example, the isodose values in a dose distribution may already include:
 - Inverse square law factors for extended distance treatments.
 - Effects on dose outputs from blocks in the field.
 - Tray and wedge factors.
- ☐ If the isodose values generated by the TPS are used for the monitor unit calculations, it is of utmost importance to know exactly what the isodose contours mean.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.4 Slide 1 (231/232)

7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.5 Orthovoltage and cobalt-60 units

- ☐ Treatment time calculations for orthovoltage units and cobalt-60 teletherapy units are carried out similarly to the above examples except that machine outputs are stated in cGy/min and the treatment timer setting in minutes replaces the monitor setting in MU.
- ☐ An adjustment of time set on the machine timer for shutter correction should be included in the time set.



Review of Radiation Oncology Physics: A Handbook for Teachers and Students - 7.7.5 Slide 1 (232/232)