Dose Calculation Concepts for Photons

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Outline

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7.1 INTRODUCTION

General considerations for photon beams:

- Almost dogma in external beam radiotherapy:

  Successful radiotherapy requires a uniform dose distri-bution within the target (tumor).

- 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 sur-rounding the target.

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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.

7.1 INTRODUCTION

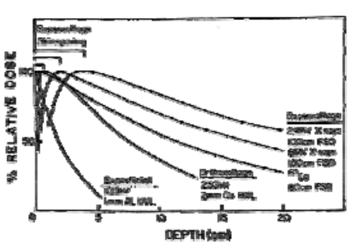
To achieve this goals set by the ICRU, modern radiotherapy is carried out with a variety of:

- Beam energies
- Beam types
- Field sizes

7.1 INTRODUCTION

Beam energies used in external beam photon radiotherapy :

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



7.1 INTRODUCTION

Methods of Patient setup:

- Photon beam radiotherapy is carried out under two setup conventions

Constant Source-Surface Distance	Isocentric setup with a constant Source-Axis Distance
(SSD technique)	(SAD technique).

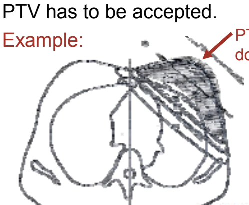
7.3 DOSE SPECIFICATION

- 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.

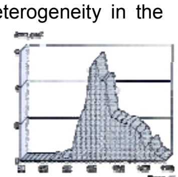
7.3 DOSE SPECIFICATION

- 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:



PTV = dotted area



Frequency dose-area histogram for the PTV

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).

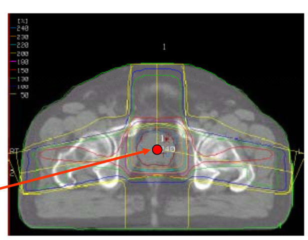
7.3 DOSE SPECIFICATION

- 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.

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.

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).

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.

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.

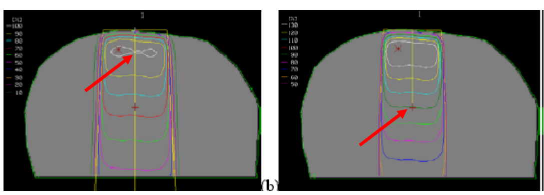
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.1 Isodose curves

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.

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.

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

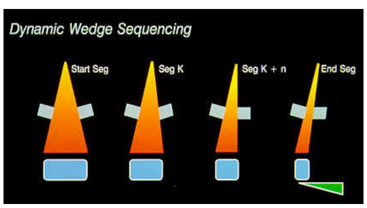
- Physical wedge:
  is an angled piece of lead or steel that is placed in the beam to produce a gradient in radiation intensity.
- Motorized wedge:
  is a similar physical device, integrated into the head of the unit and controlled remotely.

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.

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

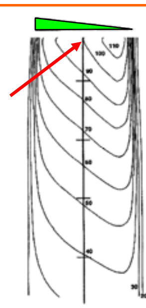
- A dynamic wedge produces the same wedged intensity gradient by having one jaw close gradually while the beam is on.



7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

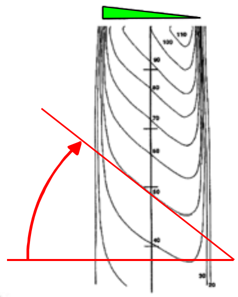
Isodose curves for a wedged 6 MV photon beam. The isodoses have been normalized to z_{max} with the wedge in place.

- The 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.



7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

- The wedge angle is defined as the angle between the 50% isodose line and the perpendicular to the beam central axis.
- Wedge angles in the range from 10° to 60° are commonly available.



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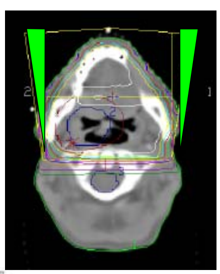
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

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.



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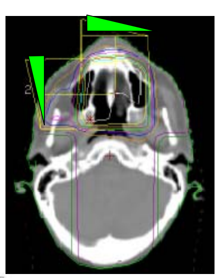
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

- 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.



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7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

There are two main uses of wedges

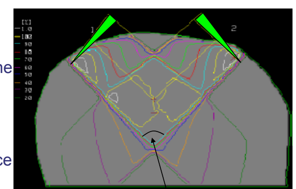
- Wedges can also be used in the treatment of relatively low lying lesions where two beams are placed at an angle (less than 180°) called the hinge angle.
- The optimal wedge angle (assuming a flat patient surface) may be estimated from:

$$Wedge\_angle = 90^o - \left(\frac{1}{2} \cdot Hinge\_angle\right)$$

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°.



7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.2 Wedge filters

Wedge factor

- The 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.
- This factor is used in monitor unit calculations to compensate for the reduction in beam transmission produced by the wedge.
- The wedge factor depends on depth and field size.

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.3 Bolus

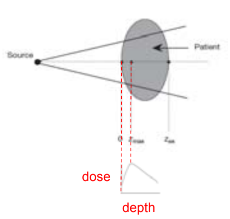
- Bolus is a tissue-equivalent material placed in contact with skin to achieve one or more of the following:
  - Increase the skin dose in megavoltage photon beams. Often this is achieved with a bolus layer that is thick enough to provide full buildup over the skin surface.
  - Compensate for missing 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.

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.3 Bolus

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

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.3 Bolus

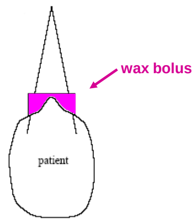
- To increase the skin dose with bolus, a layer of uniform thickness bolus is often used (0.5 –1.5 cm), since it does not significantly change the shape of the isodose curves at depth.
- Because of the dose buildup in megavoltage beams between the surface and the dose maximum (at a certain depth z_{max}),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



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.



7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.4 Compensating filters

- A compensating filter achieves the same effect on the dose distribution as a shaped bolus but does not cause a loss of skin sparing.
- Compensating filters can be made of almost any material, but metals such as lead or Cerrobend are the most practical and compact.
- Compensating filters can produce a gradient in two dimensions.
- They are usually placed in a shielding slot on the treatment unit head.

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_o 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.

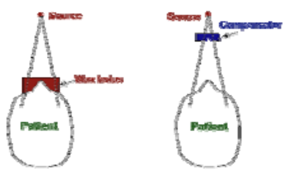
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.4 Compensating filters

Use of compensating filters	
Advantage	**Disadvantages**
❑ Preservation of the skin sparing effect	❑ Generally more labour intensive and time consuming than use of bolus ❑ Difficult to calculate the resulting dose distribution. ❑ Additional measurements may be required.

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.



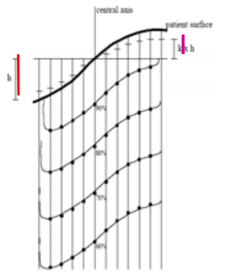
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.5 Corrections for contour irregularities

- 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.

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.



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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)
< 1	0.8
^{60}Co - 5	0.7
5 – 15	0.6
15 – 30	0.5
> 30	0.4

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7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.5 Corrections for contour irregularities

(2) Effective attenuation coefficient method

- The 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.

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7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.5 Corrections for contour irregularities

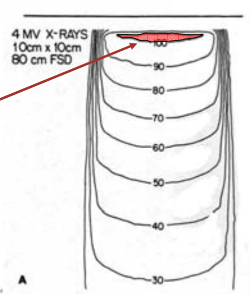
(3) TAR method

- 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:

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

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 than at depth.



5.7 Slide 1 (136/232)

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.

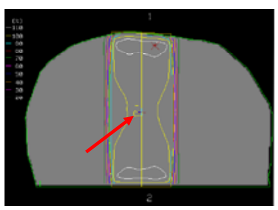
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

Fixed SSD vs. isocentric techniques

- The dosimetric advantages of SSD techniques over the isocentric techniques are small.
- With the exception of very large fields exceeding 40x40 cm^2, the advantages of using a single set-up point (i.e., the isocenter) greatly outweigh the dosimetric advantage of SSD beams.

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).

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

7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

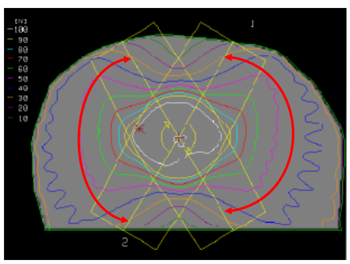
Multiple co-planar beams: General characteristics

- 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.

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).



7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

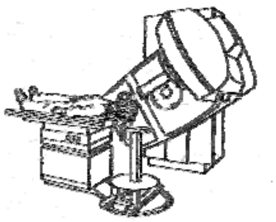
Rotational techniques: General characteristics

- 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.

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.



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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 co-planar beam arrangement.
- Dose distributions from combinations of non-coplanar beams yield similar dose distributions to conventional multiple field arrangements.

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7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

Multiple non-coplanar beams: General characteristics

- 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.

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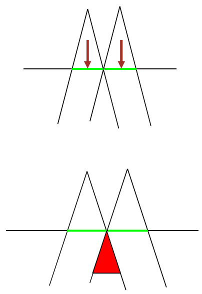
7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

Field matching

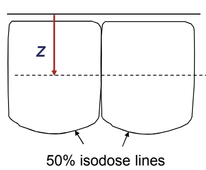
- Field matching on the skin surface is the easiest field matching technique.
- However, due to beam divergence, this will lead to significant overdosing of tissues at depth and is only used in regions where tissue tolerance is not compromised.



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*.

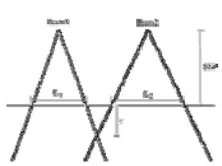


7.5 CLINICAL CONSIDERATIONS FOR PHOTON BEAMS
7.5.7 Beam combinations and clinical application

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:

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



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.

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.

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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.

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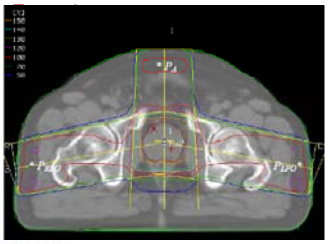
7.6 TREATMENT PLAN EVALUATION
7.6.1 Isodose curves

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

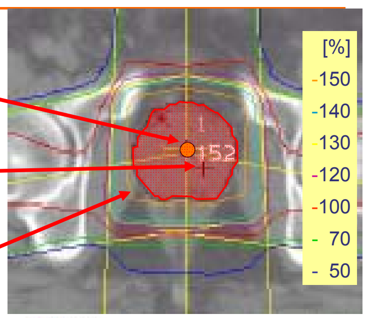
The isodose curve, covering the periphery of the target, is compared to the isodose value at the isocentre.



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.

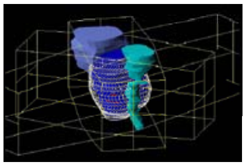


7.6 TREATMENT PLAN EVALUATION
7.6.2 Orthogonal planes and isodose surfaces

- When a larger number of transverse planes are 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.

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.



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.

7.6 TREATMENT PLAN EVALUATION
7.6.3 Dose statistics

From the location of matrix points within an organ and 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.

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.

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.

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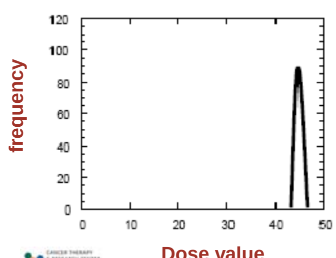
7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

- 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.



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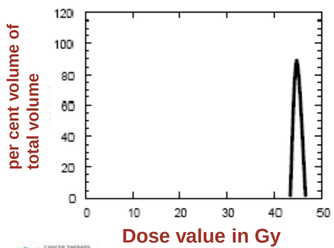
7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

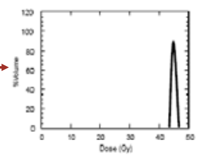
- Rather than displaying the frequency, DVHs are usually displayed in the form of "per cent volume of total volume" on the ordinate against the dose on the abscissa.



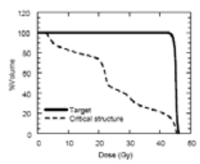
7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

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.



7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

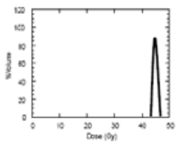
Direct (Differential) Dose Volume Histogram

- 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.

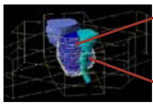
7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

Example: Prostate cancer

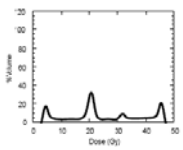
Differential DVHs



Target



Rectum



7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

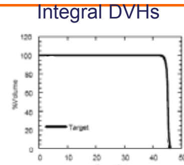
Cumulative (Integral) Dose Volume Histogram

- 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.

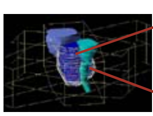
7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

Example: Prostate cancer

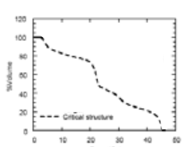
Integral DVHs



Target



Critical structure: rectum



7.6 TREATMENT PLAN EVALUATION
7.6.4 Dose-volume histograms

For this reason, 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.

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.

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.

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.

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

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.

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.

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.

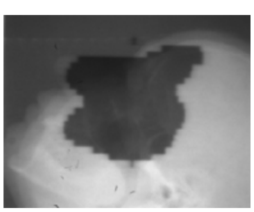
7.6 TREATMENT PLAN EVALUATION
7.6.5 Treatment evaluation

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.

7.6 TREATMENT PLAN EVALUATION
7.6.5 Treatment evaluation

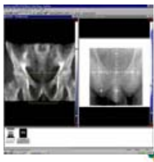
Double exposure technique: Two examples



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.



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.

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.

7.6 TREATMENT PLAN EVALUATION
7.6.5 Treatment evaluation

- Matrix ionisation chamber detectors:

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 fluoro-scopic systems.

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.

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).
    or the
  - Monitor units (for megavoltage linacs).

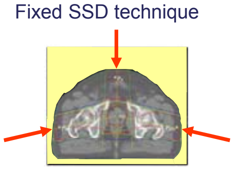
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

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.

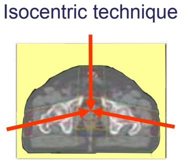
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

Fixed SSD technique



Fixed SSD technique results in an isodose distri-bution 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).

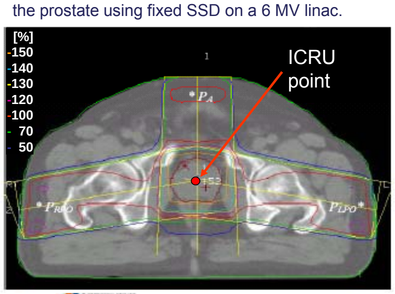
Methods used for dose prescription

- 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 ICRU: the ICRU reference point).
  - Prescription of an absolute dose at this point.

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.



Methods used for dose prescription (continued)

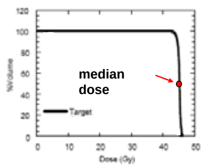
- There are also other methods, such as using a dose volume histogram (DVH).
- This method is particularly useful for IMRT when the evaluation of a treatment plan is based on the DVH of the target.
- The method consists of assigning the prescribed dose to the median dose in the target volume.

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.

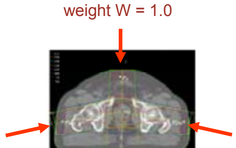
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

- 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:
    - the ICRU point IP (used for isocentric techniques).
    - the point of maximum dose D_{max} of each field (used for fixed SSD techniques).

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 cm^2 open field
weight W = 1.0



Right posterior field:
6.5×7.5 cm^2 wedge field
weight W = 0.8
wedge factor WF =0.53

Left posterior field:
6.5×7.5 cm^2 wedge field
weight W = 0.8
wedge factor WF =0.53

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, $D_i(\mathrm{IP})$, is calculated by (using 100 MU):

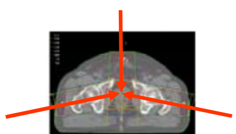
$$D_i(\mathrm{IP}) = \dot{D}(z_{max}, A_{ref}, f, h\nu) \cdot \frac{\mathrm{PDD}(z, A, f, h\nu)}{100} \times \mathrm{RDF}(A, h\nu) \times \mathrm{WF} \times 100$$

$\dot{D}(z_{max}, A_{ref}, f, h\nu)$	is the calibrated output of the machine
$\mathrm{PDD}(z, A, f, h\nu)$	is the percentage depth dose value
WF	is the wedge factor
$\mathrm{RDF}(A, h\nu)$	is the relative dose factor (see next slide)

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

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, $D_i(\mathrm{IC})$, is calculated by (using 100 MU):

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

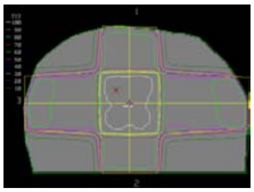
where:

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

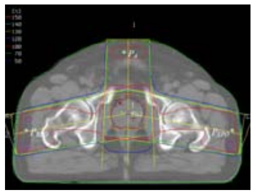
7.7 TREATMENT TIME AND MONITOR UNIT CALCULATIONS

7.7.3 Normalization of dose distributions

Important:
Dose distributions can be normalized in different ways:



Normalized to maximum dose



Normalized such that 100% = 100cGy

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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 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.

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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 calculations, it is of utmost importance to know exactly what the isodose lines mean.

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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.
- A correction for shutter error should be included in the time set.