Treatment Planning I: **Isodose Distributions**

Ref:. F.M.Khan, 3rd ed. Chapter 11

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Spring semester

Outline

1. **Isodose chart**
2. Measurement of isodose curves
3. Parameters of isodose curves
4. Wedge filters
5. Combination of radiation fields
6. Isocentric techniques
7. Wedge field techniques
8. Tumor dose specification for external photon beams.

What is isodose curve?

- Isodose curve
  - Lines passing through points of equal dose
  - Drawn at regular intervals of absorbed dose
  - Expressed as a percentage of the dose at a reference point
- Isodose chart
  - It consists of a family of isodose curves.

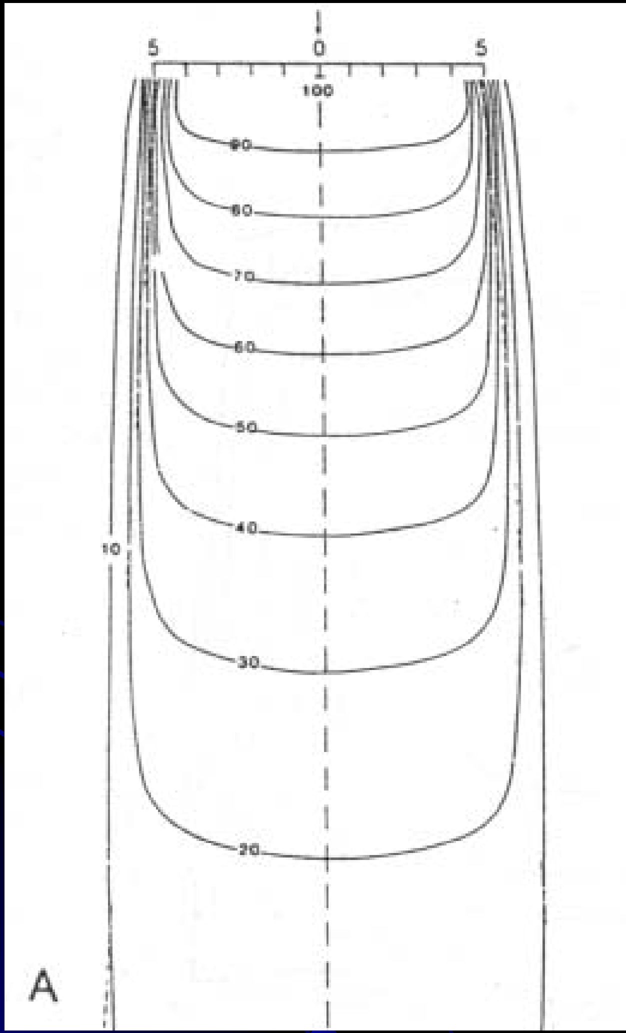
What is isodose chart?

- Isodose chart of a beam
  - A chart consists of a family of isodose curves.
  - A chart is drawn at equal increment of percent depth dose.
  - The depth dose values of the curves are normalized:

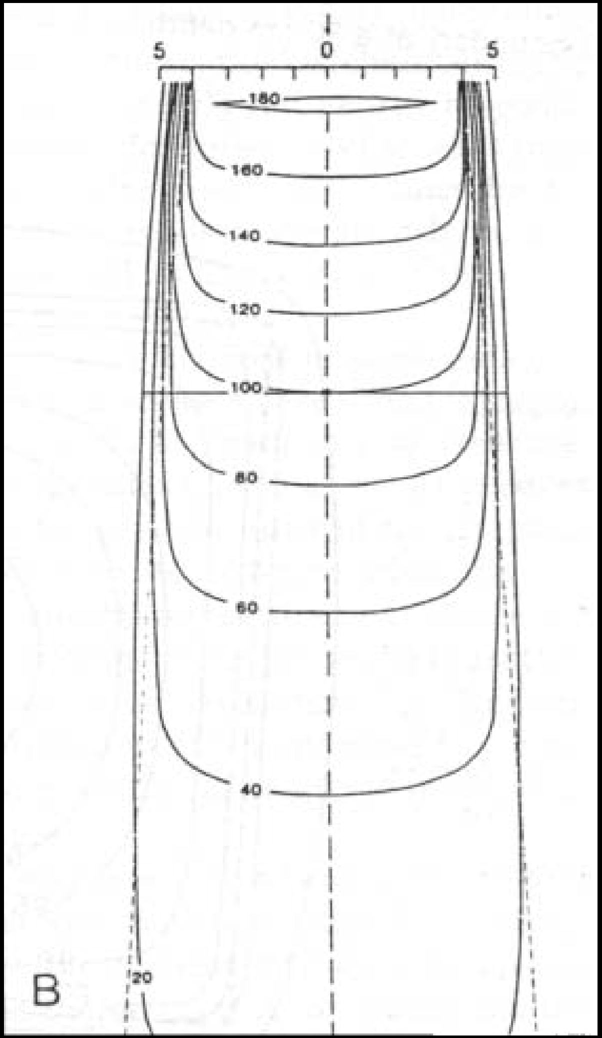
    1) At the point of maximum dose on the central axis
    2) At a fixed distance along the central axis in the irradiated medium.

Isodose Chart: depth dose

Co-60 γ-ray
10cm x10cm



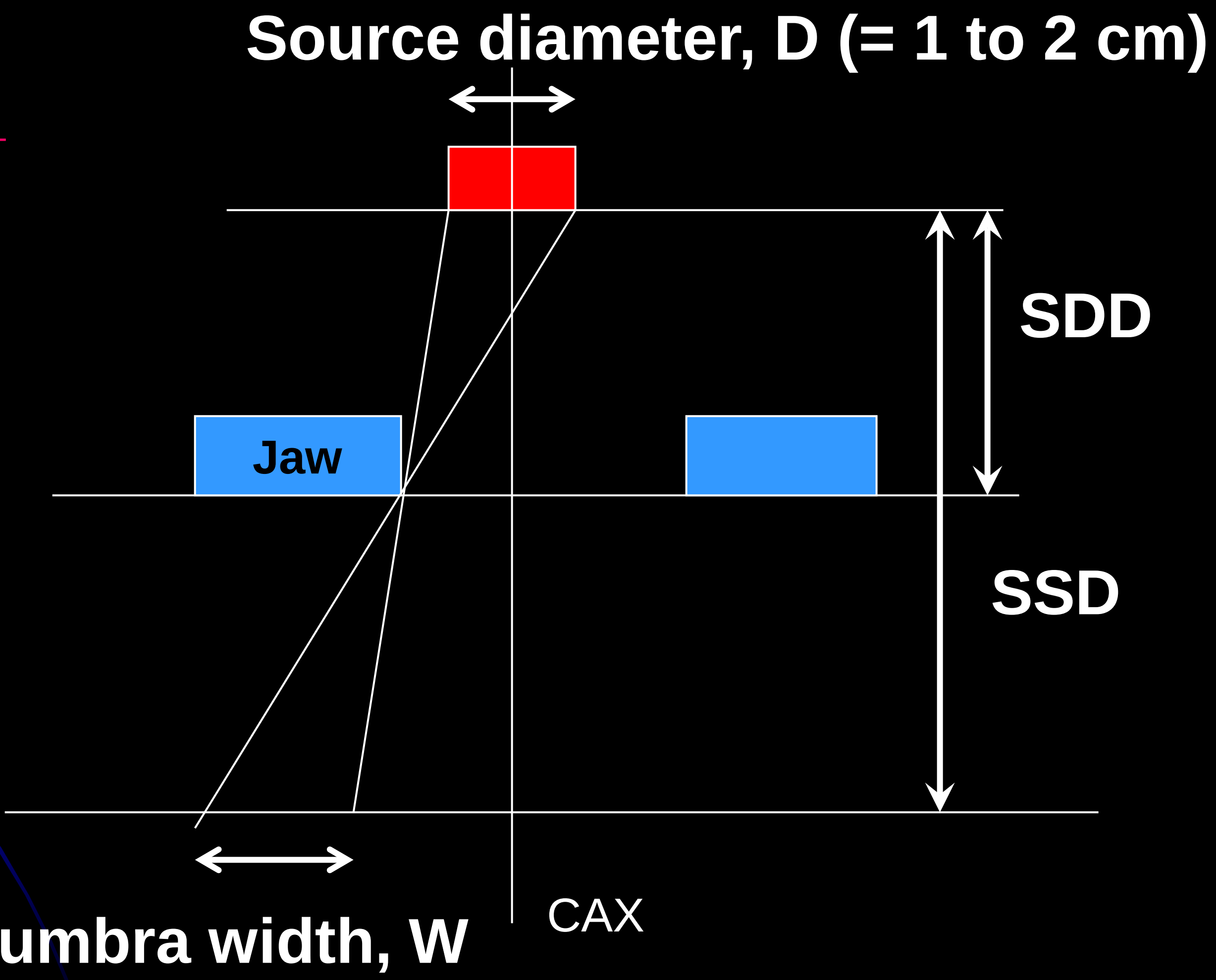
SSD=80 cm



SAD=100 cm

Geometric Penumbra

$$W = D\frac{SSD - SDD}{SDD}$$



Geometric Penumbra (con't)

Co-60 teletherapy

- SDD = 40 cm
- SSD = 80 cm
- D = 1 cm

→ W = 1 cm

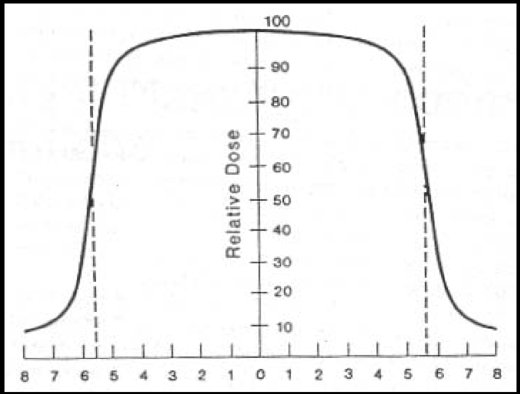
High energy linac

- SDD = 45.5 cm
- SSD = 100 cm
- D = 0.3 cm

→ W = 0.36 cm

Isodose Chart: beam profile (1)

- Falloff of the beam
  - By the geometric penumbra
  - By the reduced side scatter
  - Physical penumbra width

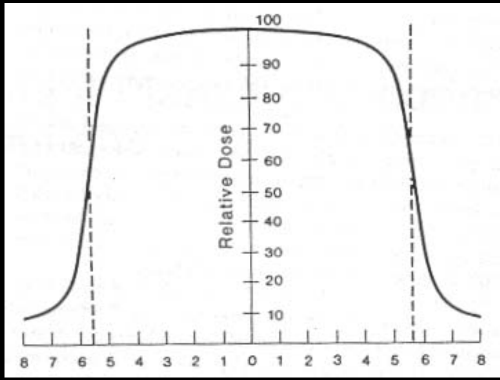


Co-60 beam
80cm SSD
10cmx10cm
At 10 cm depth

- Outside the geometric limits of the beam and the penumbra, the dose variation is the result of
  - side scatter from the field
  - both leakage and scatter from the collimator system.

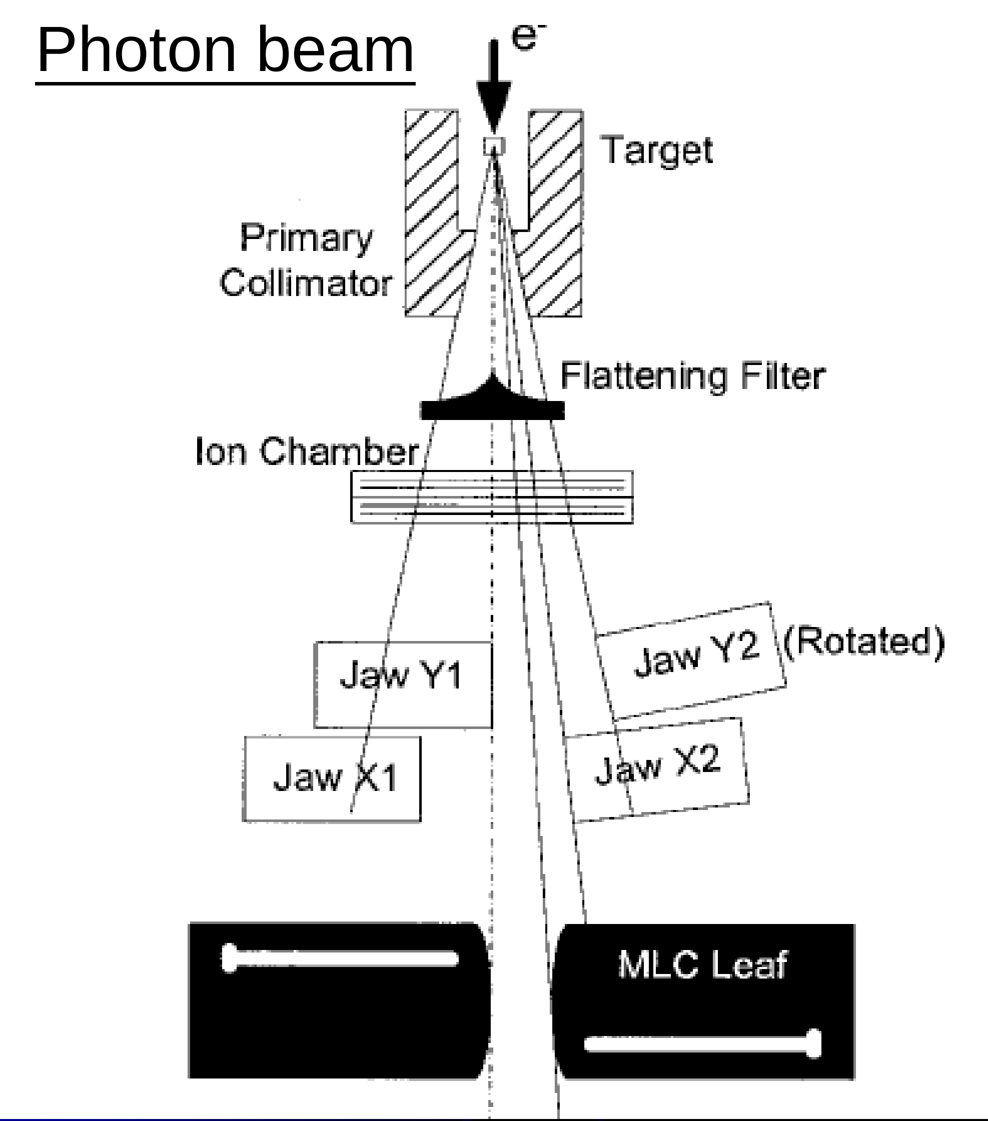
Isodose Chart: beam profile (2)

- The penumbra region
  - The dose rate decreases rapidly as a function of lateral distance from the beam axis.
  - The width of geometric penumbra depends on source size, distance from the source, and source-to-diaphragm distance.



Co-60 beam
80cm SSD
10cmx10cm
At 10 cm depth

Accelerator head



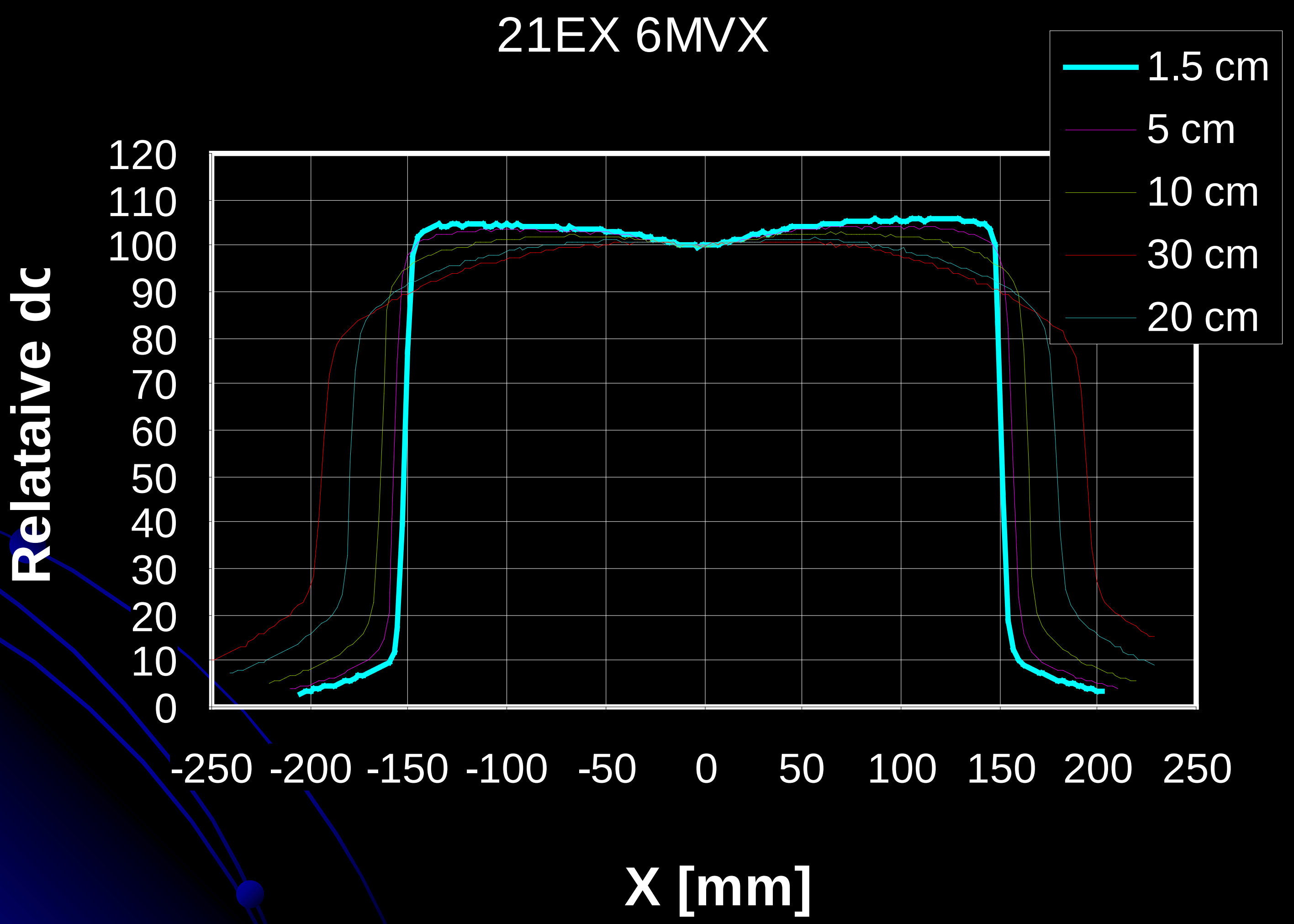
For electron beam
- No target
- Scattering foil
- Electron cone

Kim et al, Med Phys 28,2457 (2001)

Isodose Chart: beam profile (3)

- High dose or 'horns' near the surface in the periphery of the field
  - Created by the flattening filter
  - Under-compensate near the surface in order to obtain flat isodose curves at greater depths (10 cm)

Beam profile: 6MV photon



Beam Profiles: flatness and symmetry

- flatness
  - usually specified at 10 cm
  - within ±3%. over 80% of the field
- symmetry
  - usually specified at 10 cm
  - within ±2%. over 80% of the field

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6. Isocentric techniques
7. Wedge field techniques
8. Tumor dose specification for external photon beams.

Measurement of Isodose Curves

- Ion chambers
  - Relatively flat energy response and precision
  - Waterproof and small size
- Solid state detectors
- Radiographic films
- The computer-driven devices for measuring isodose curves

Beam Analyzing System
3D water phantom

- Two ion chambers
  - Detector A–To move in the tank of water to sample the dose rate
  - Monitor B–fixed at some point in the field to monitor the beam intensity with time
  - The final response A/B is independent of fluctuations in output.

IBA-Wellhofer Blue Phantom

Sources of Isodose Charts

- To verify that the central axis depth dose data correspond to PDD data measured independently in a water phantom
- A deviation of 2% or less in local dose is acceptable up to depth of 20 cm.
- For selected FS and depths, an agreement within 2 mm in the penumbra region is acceptable.

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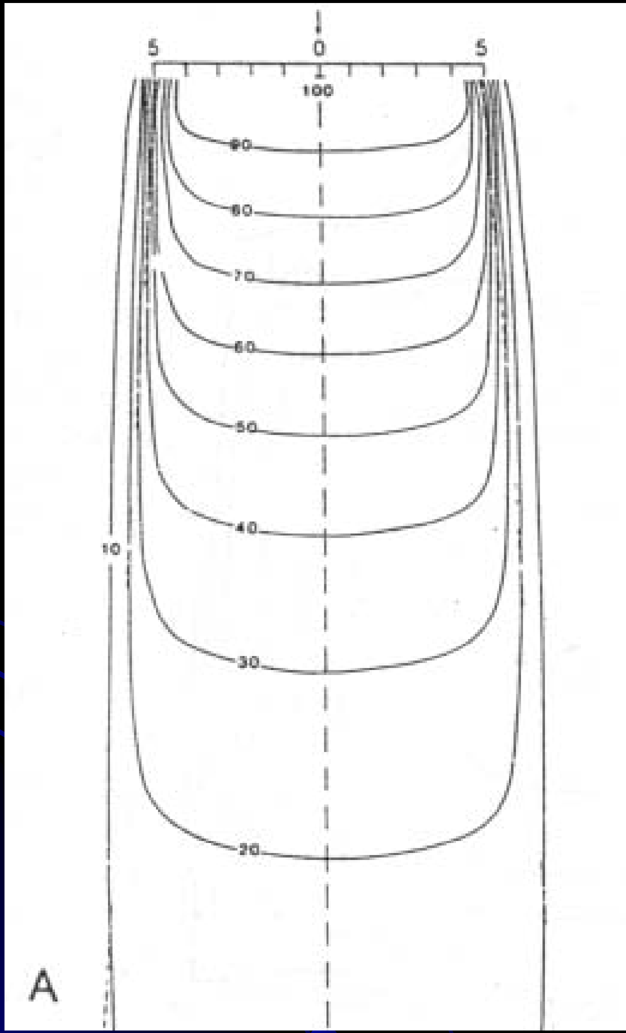
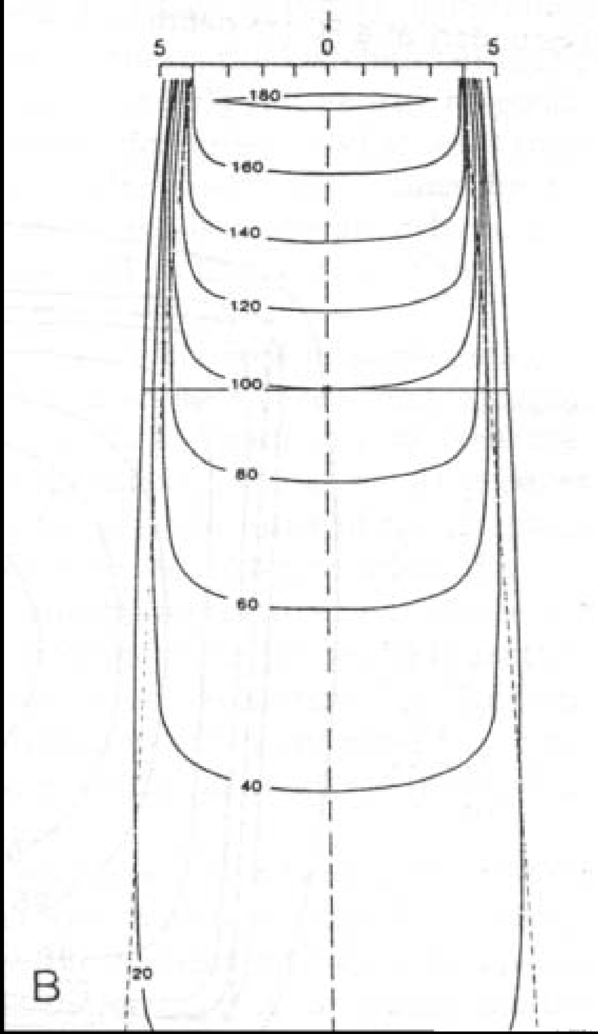
Isodose Chart: depth dose



SSD=80 cm



SAD=100 cm

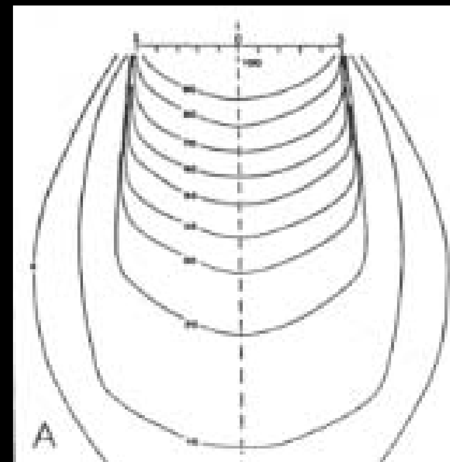
Co-60 γ-ray
10cm x10cm

Parameters of Isodose Curves

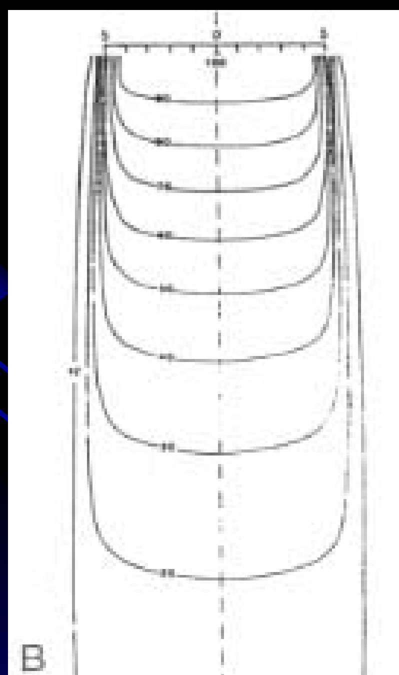
- The parameters that affect the single-beam isodose distribution are:
  - Beam quality
  - Source size, SSD, and SDD - the penumbra effect
  - Collimation and flattening filter
  - Field size

Beam Quality

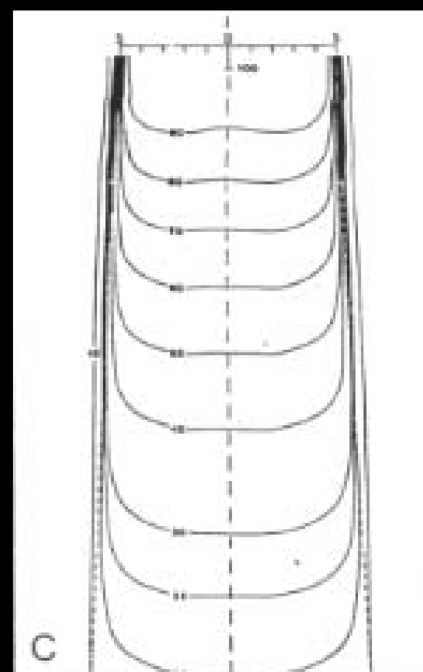
- The depth of a given isodose curve increases with beam quality.
- Greater lateral scatter associated with lower-energy beams
- For megavoltage beams, the scatter outside the field is minimized as a result of forward scattering and becomes more a function of collimation than energy.



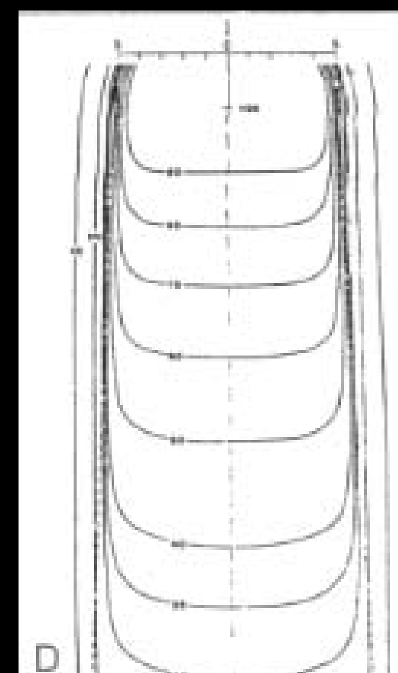
200 kVp,
SSD=50 cm



^{60}Co, SSD=80 cm



4 MV, SSD=100 cm



10 MV, SSD=100 cm

Photon beam quality: depth dose

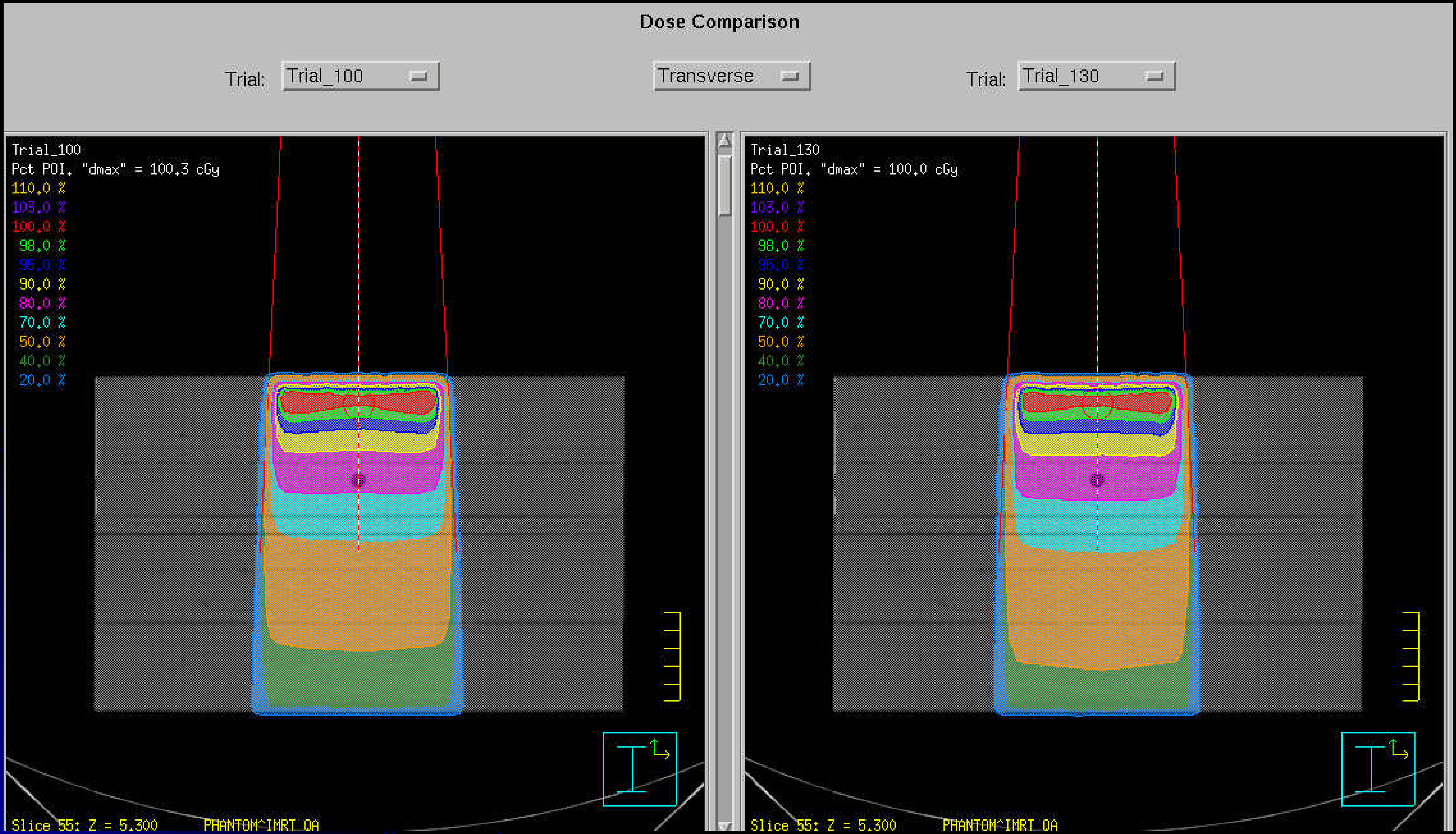
Beam	d-max, cm	PDD10 cm	TPR^{20}_{10}
Co-60	0.5	56.4	0.512*
6MV	1.7	67.8	0.679
10MV	2.5	73.2	0.713
18MV	3.5	78.8	0.774
6MV	1.7	67.3	0.672
25MV	4.0	81.9	0.801

(*) TAR ratio

Source Size, SSD, and SDD

- Source size, SSD, and SDD affect the isodose curves by the geometric penumbra.
- The SSD affects the PDD and the depth of the isodose curves.
- The dose variation across the field border is a complex function of geometric penumbra, lateral scatter, and collimation.

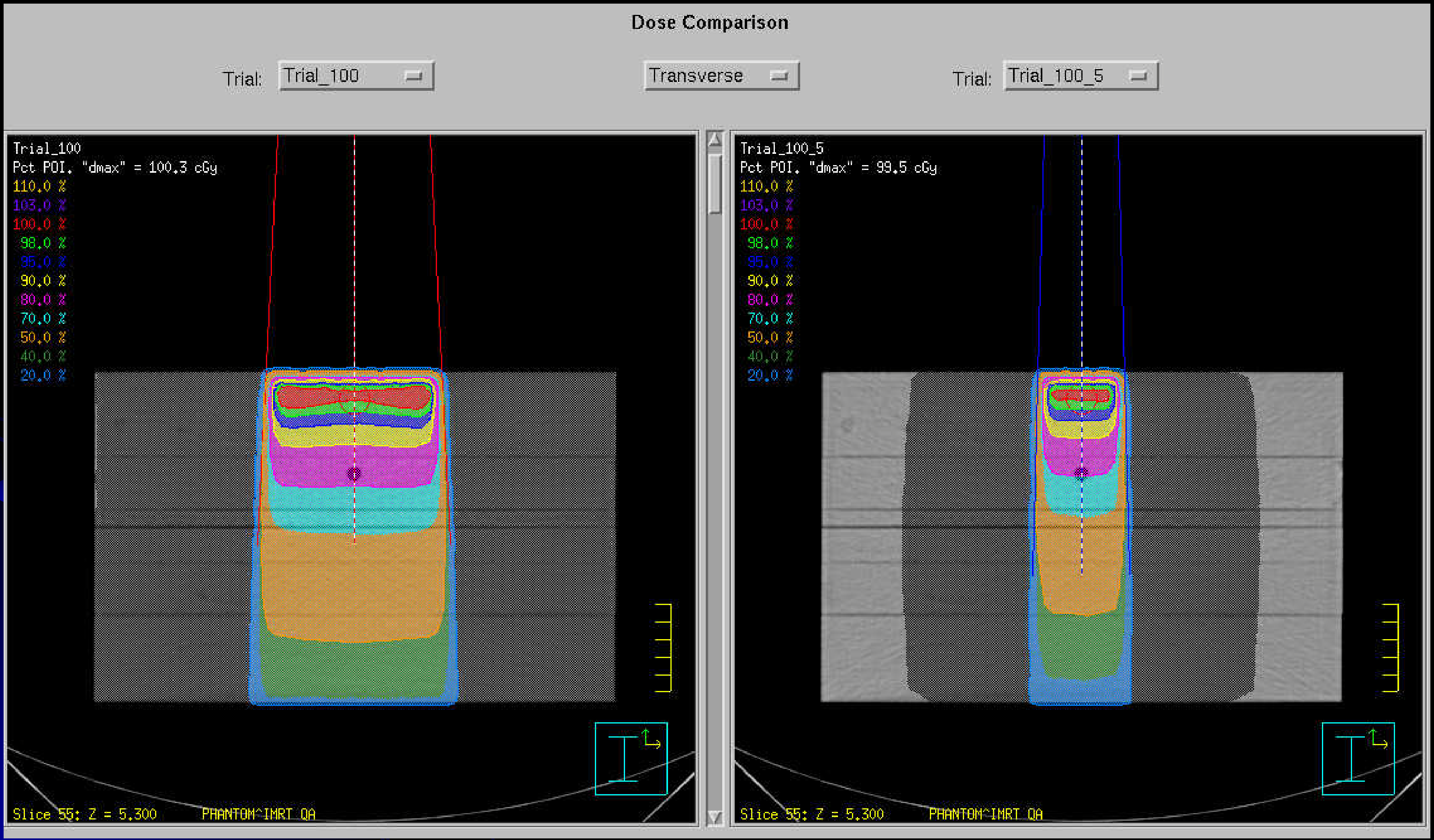
SSD effect: 100 vs. 130 cm 6MV photon beam



Field Size

- One of the most important parameters in treatment planning
- Field size smaller than 6 cm
  - Relative large penumbra region
  - Bell shape
  - TPS should be mandatory for small field size.

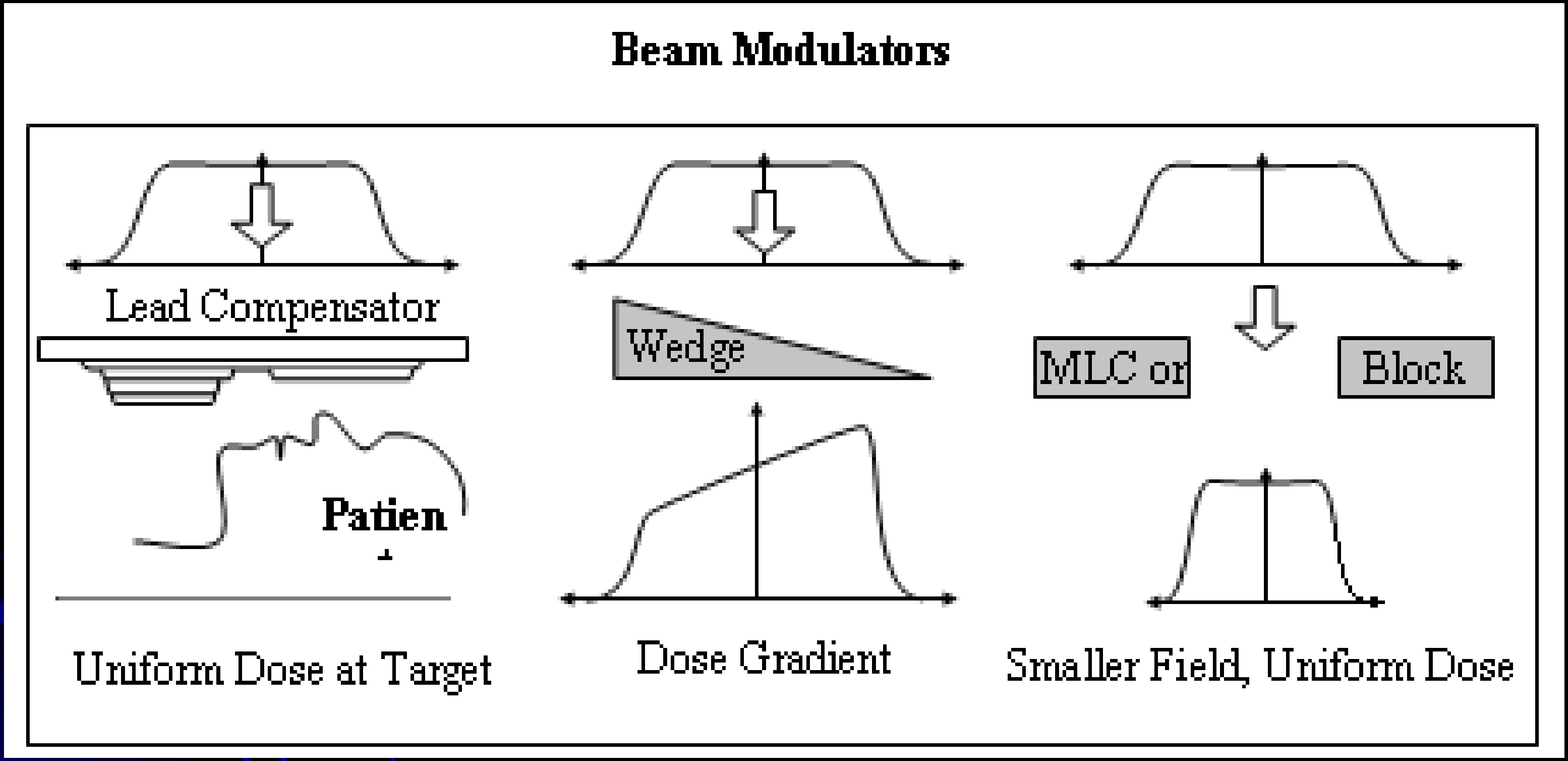
Field size effect: 10x10 vs. 5x5 6MV photon beam



Collimation and Flattening Filter

- Collimation
  - Blocks
  - The flattening filter
    - To make the beam intensity distribution relatively uniform across the field
    - The cross-sectional variation of the filter thickness causes variation in the photon spectrum or beam quality cross the field.
  - Other absorbers or scatterers between the target and the patient

Beam modulators



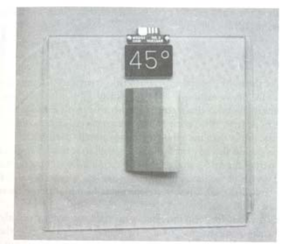


FIG. 11.7. Photograph of a 45 degree wedge filter for a 4-MV x-ray Linac (ATC 400).

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Wedge Filters

- The most commonly used beam-modifying device
- Made of a dense material, such as lead or steel
- Mounted on a (transparent plastic) tray
- Arranged at a distance of at least 15 cm from the skin surface

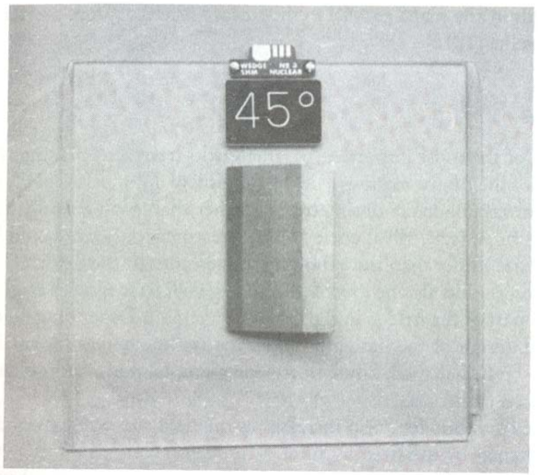
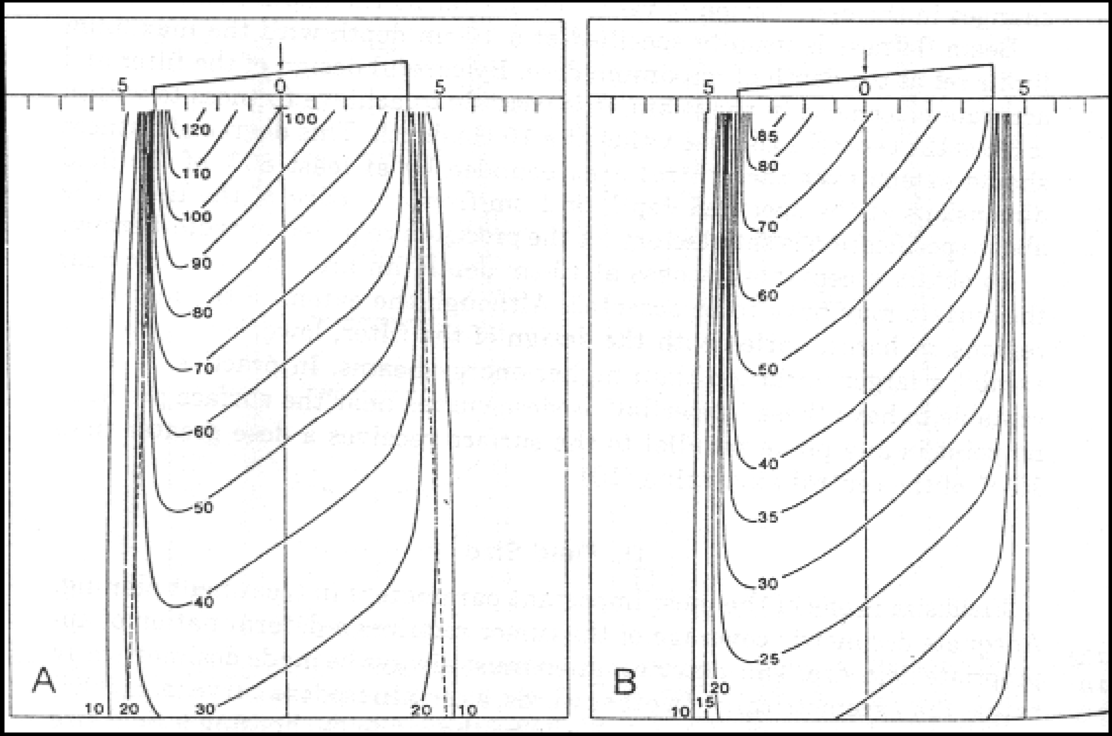
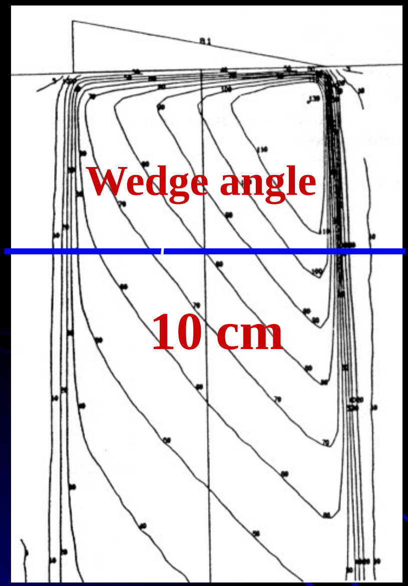


FIG. 11.7. Photograph of a 45 degree wedge filter for a 4-MV x-ray Linac (ATC 400).



(A) Normalized at d-max.
(B) Norm. at d-max of open field.

Wedge Isodose Angle

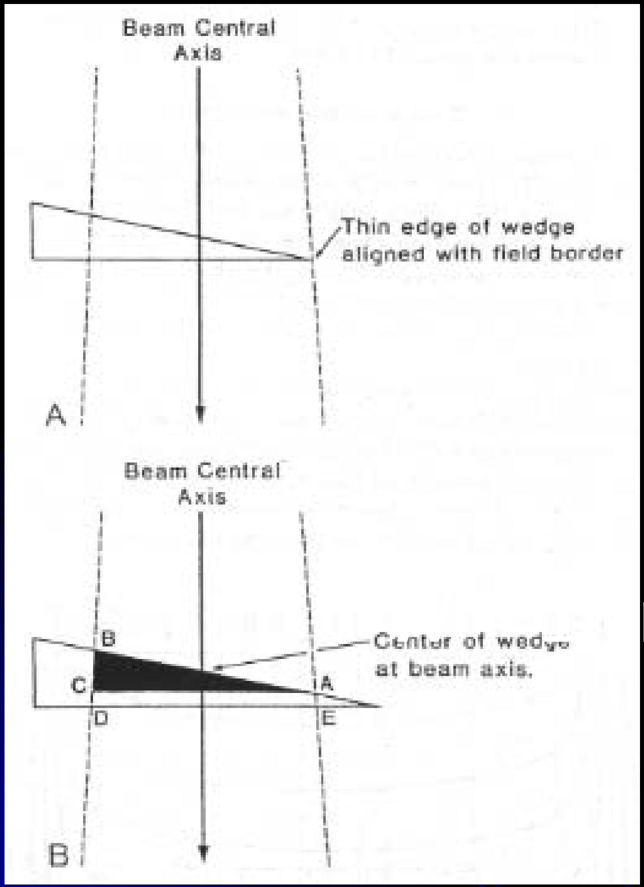


- Wedge angle
  - the angle through which an isodose curve is titled at the central ray of a beam at a specified depth. (10 cm)
  - The angle between the isodose curve and the normal to the central axis
- The angle of isodose tilt to decrease with increasing depth in the phantom

Wedge Transmission Factor

- The presence of a wedge filter decreases the output of the machine.
- Wedge factor
  - The ratio of doses with and without the wedge, at a point in phantom along the central axis of the beam
  - Measured at a suitable depth beyond d_{max} (5 to 10 cm)
  - Sometimes incorporated into the isodose curves

Wedge Systems



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- Individualized wedge system
  - A separate wedge for each beam width
  - To minimize the loss of beam output
  - To align the thin end of the wedge with the border of the light field
  - Used in ^{60}Co
- Universal wedge system
  - A single wedge for all beam widths
  - Fixed centrally in the beam
  - Used in Linac

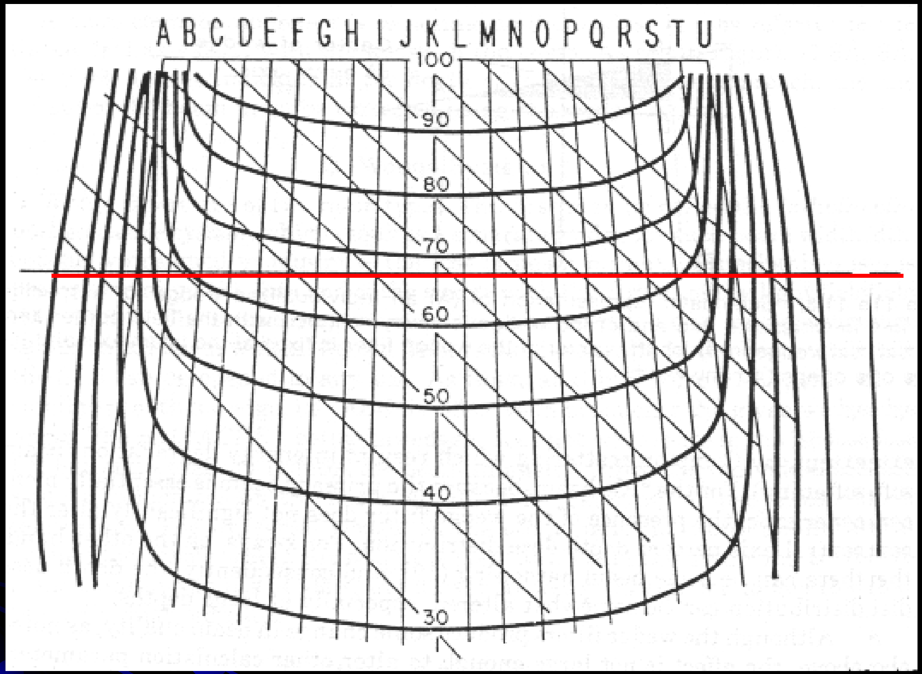
Advanced wedge systems

- Omni wedge (Elekta)
  - There is only one universal wedge (60 degrees) attached above the jaws.
  - To control the wedge angle, an appropriate combination of open and wedged fields are used.
- Dynamic wedge (Varian)
  - One side of jaws move in (or close) while beam is on.
  - Wedge angle is determined by controlling the speed of the moving jaw.

Wedge Effect on Beam Quality

- Attenuating the lower-energy photons (beam hardening)
- By Compton scattering which results in energy degradation (beam softening)
- For x-rays, there can be some beam hardening, especially the PDD at large depths.
- TARs and TMRs may be assumed unchanged for small depths (less than 10 cm)

Design of Wedge Filters

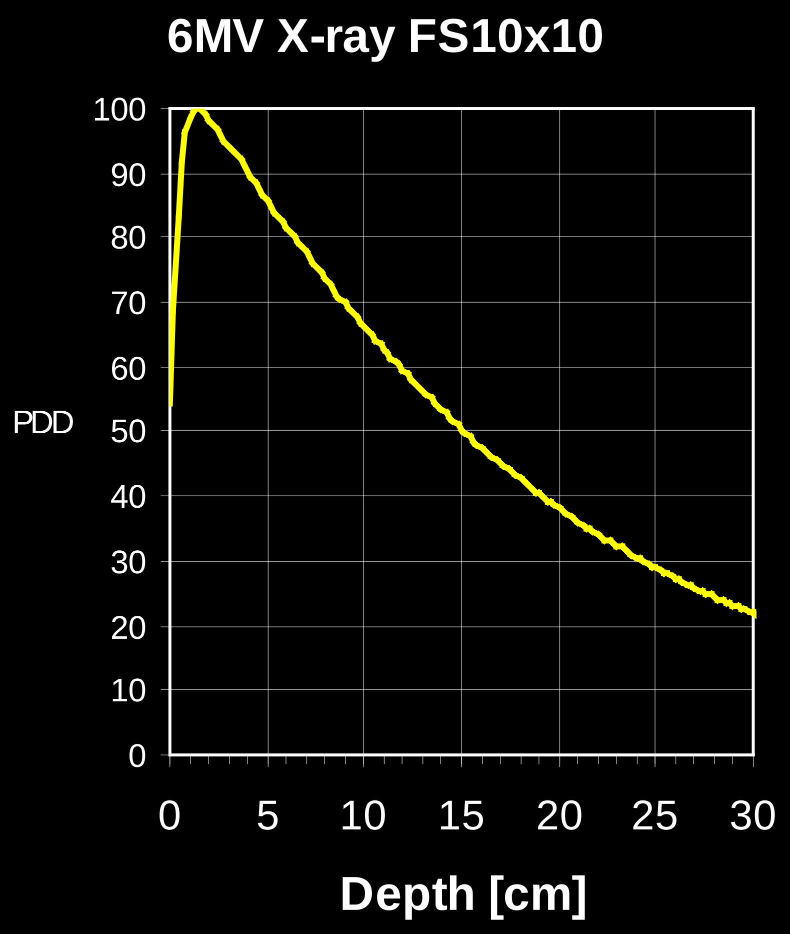
A  B

1) Draw line (A-B) at the depth where wedge angle is determined.
2) Obtain the non-wedge dose from the isodose curves of an open field.
3) Draw parallel lines at the wedge angle you are calculating.
4) Estimate the dose at a point where line AB and a oblique line crosses. ➔ wedge isodose.
5) The ratio is the relative wedge transmission factor.

	A	B	C	E	G	I	K	M	O	Q	S	T	U
Nonwedge isodose	40	55	62	65	67	68	68	68	67	65	62	55	40
Wedge isodose	35	39	41	47	53	60	68	76	86	95	105	110	115
Wedge/nonwedge	0.875	0.710	0.660	0.720	0.790	0.880	1.00	1.12	1.28	1.46	1.70	1.20	2.88
Transmission ratio			0.387	0.425	0.462	0.515	0.59	0.66	0.75	0.86	1.0		
mm Pb			15.2	13.6	12.2	10.5	8.3	6.5	4.5	2.3	0		

Bolus

- Tissue-equivalent material
- Used to increase the skin/surface dose to treat tumors at a shallow depth with high energy photon beams.
- The thickness is usually 0.5 cm to 1.5 cm.



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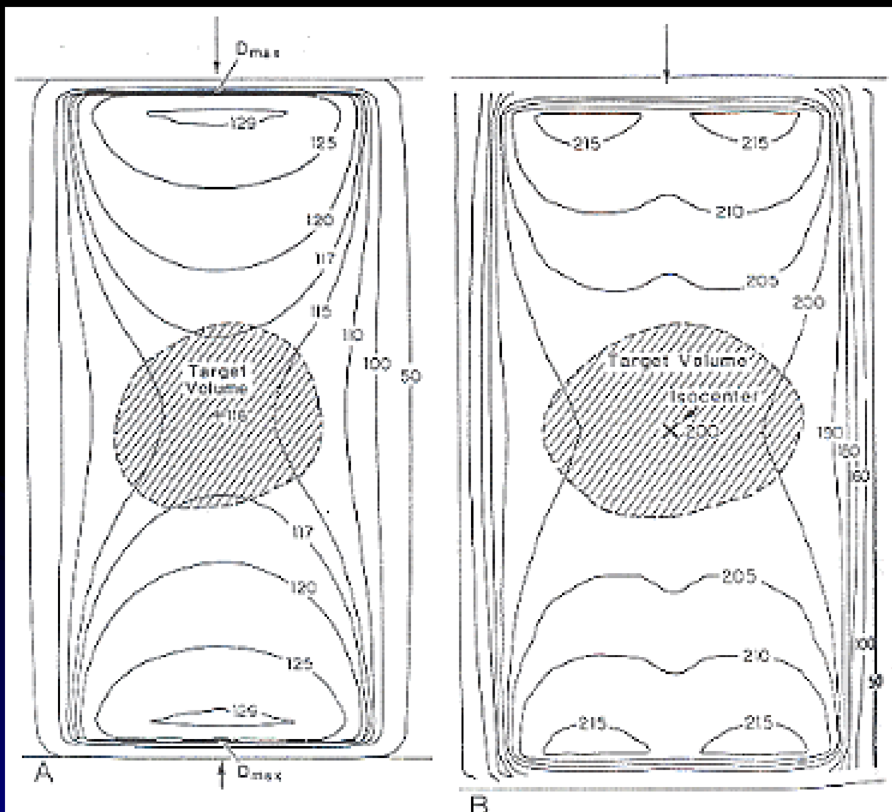
Combined Open Field Technique

Criteria

- The dose distribution within the tumor volume is reasonably uniform (±5%).
- The maximum dose to the tissue in the beam is not excessive (not more than 110% of the prescribed dose).
- Normal critical structures in the beam do not receive doses near or beyond tolerance.

Parallel Opposed Fields



A, Each beam weighted 100 at D_{max}.

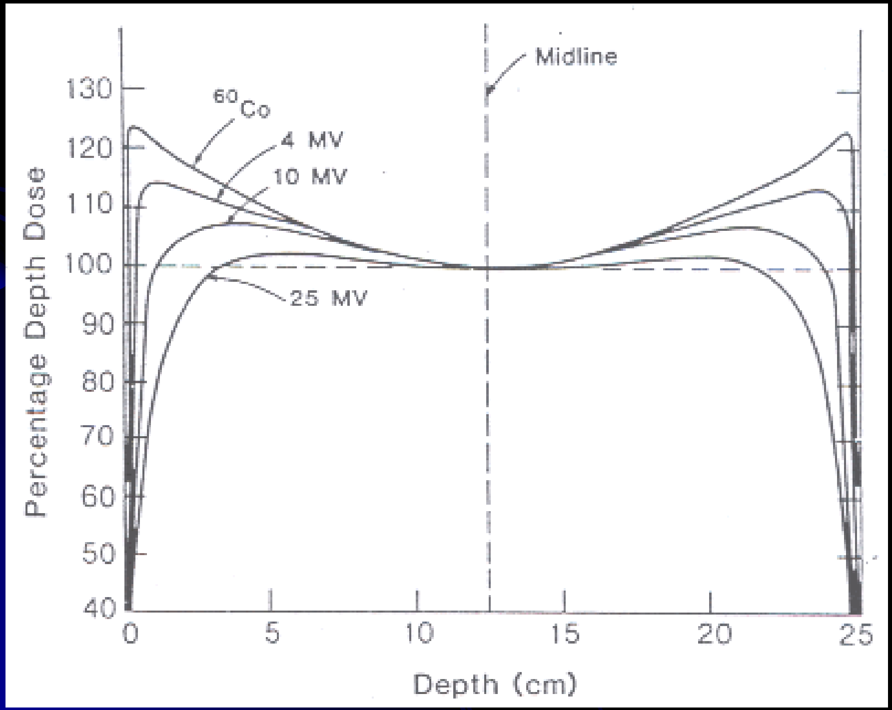
B, Each beam weighted 100 at the isocenter.

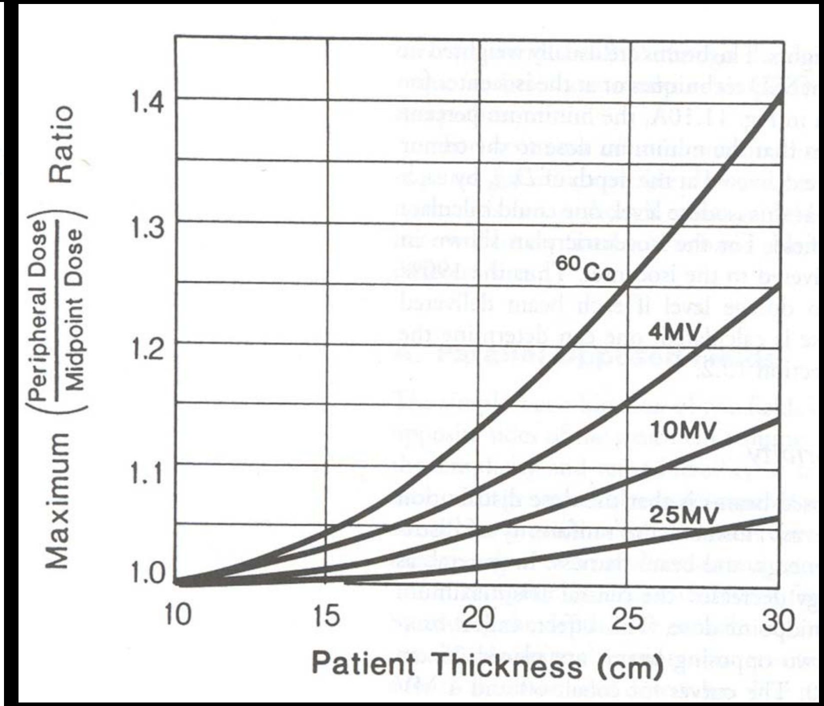
- Advantages
  - The simplicity and reproducibility of setup
  - Homogeneous dose to the tumor
  - Less chances of geometrical miss
- Disadvantage
  - The excessive dose to normal tissues and critical organs above and below the tumor

Patient Thickness v.s. Dose Uniformity

- Tissue lateral effect
  - The patient thickness ↑ or the beam energy ↓

  ⇒the central axis maximum dose near the surface ↑ relative to the midpoint dose.





Can we use one field per day alternately?

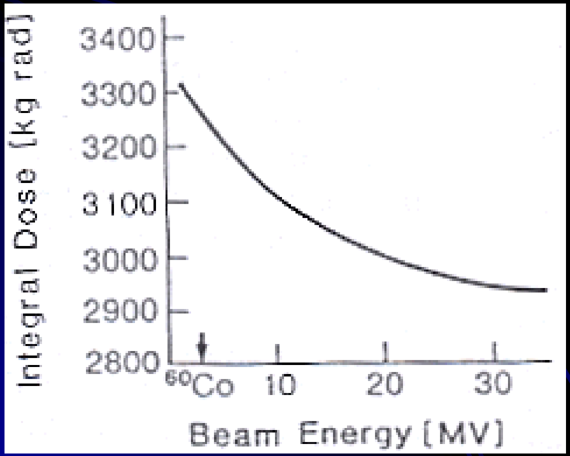
Edge effect (or the tissue lateral damage)

- For parallel opposed beam, treating with one field per day produces greater biologic damage to normal subcutaneous tissue than treating with two fields per day.
- The problem becomes more severe when larger thickness (≥20 cm) are treated with on field per day using a lower-energy beam (≤6 MV).

Integral Dose

unit: g-rad, kg-Gy or J (1 Gy =1 J/kg)

- A measure of the total energy absorbed in the treated volume
- For a uniform dose, the integral dose is the product of mass and dose.
- For a single beam, Mayneord formulation



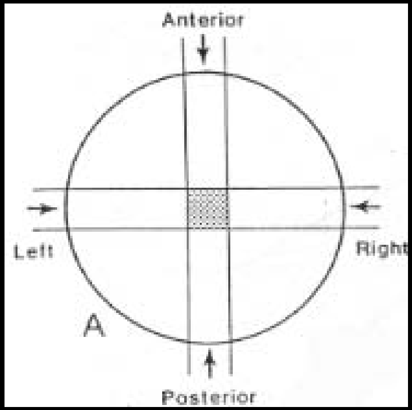
10cm diam. Field, d=25cm
100cm SSD, 10Gy at midpoint.

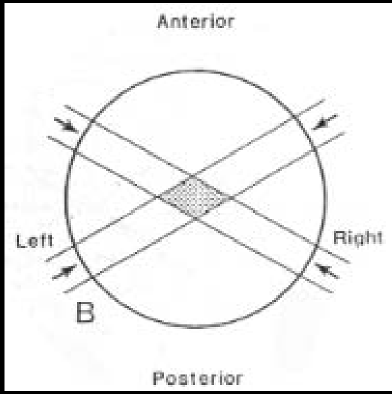
$$\Sigma = 1.44 D_0 A\, d_{1/2} (1 - e^{-0.693\, d / d_{1/2}})(1 + \frac{2.88 d_{1/2}}{SSD})$$

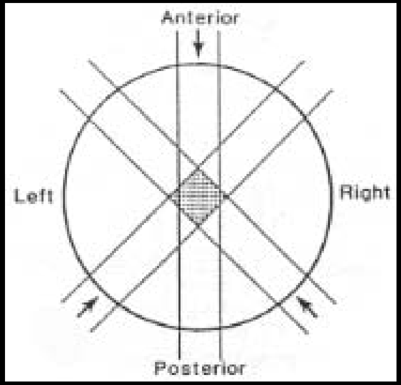
D_0= the peak dose along the central axis
A= the geometric area of the field
$d_{1/2}$= the half value depth of the beam
d = the total thickness of patient.

Multiple Fields (1)

- To deliver maximum dose to the tumor and minimum dose to the surrounding tissues
  - Using fields of appropriate size
  - Increasing the number of fields or portals
  - Selecting appropriate beam directions
  - Adjusting beam weights
  - Using appropriate beam energy
  - Using beam modifiers

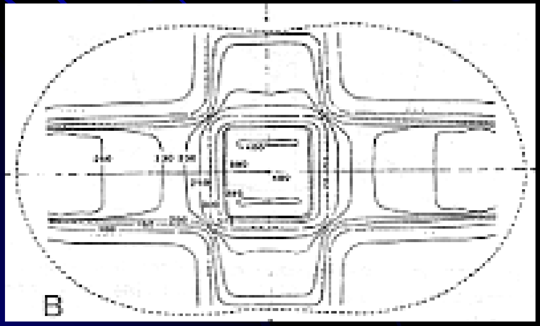


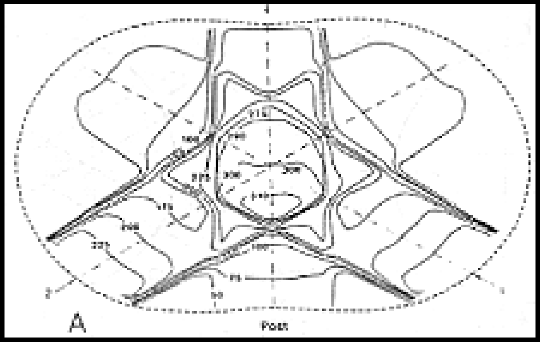




Multiple Fields (2)

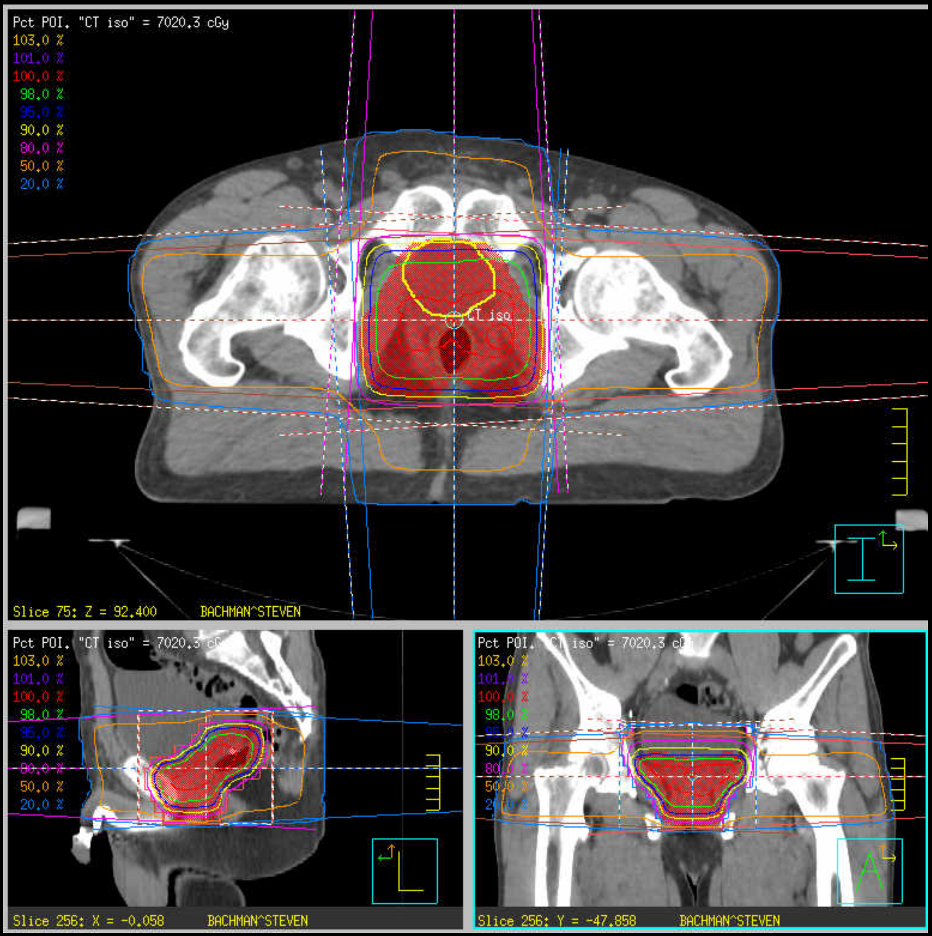
- Certain beam angles are prohibited.
  - The presence of critical organs in those directions
  - The setup accuracy of a treatment may be better with parallel opposed beam arrangement
  - The acceptability of a treatment plan depends not only on the dose distribution but also on
    - The practical feasibility
    - Setup accuracy
    - Reproducibility of the treatment technique





4FL Prostate Plan

- 18MV 4 field photon
- 4500cGy (180x25)
- 2520cGy (180x14) boost later
- Beam weights: AP/PA/RLAT/LLAT =30/20/25/25



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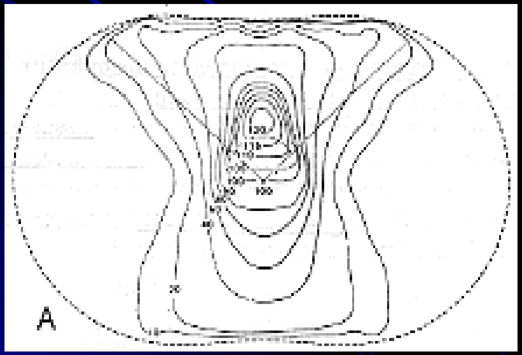
Isocentric Techniques

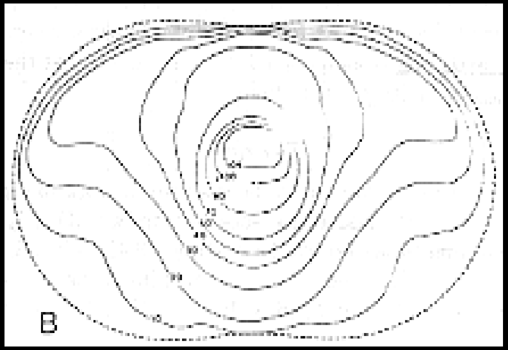
- The isocenter is the point of intersection of the collimator axis and the gantry axis of rotation.
- Isocentric technique
  - Placing the isocenter at a depth with the patient and directing the beams from different directions
  - SSD = SAD-d
- Stationary beams

Rotation Therapy (1)

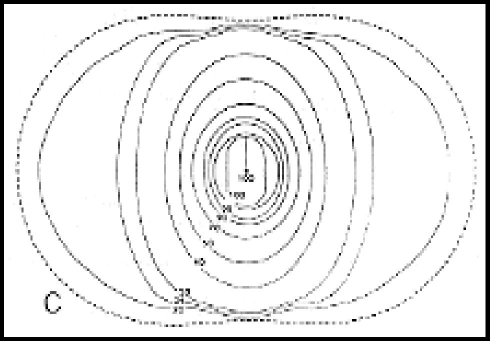
- The beam moves continuously about the patient, or the patient is rotated while the beam is held fixed.
- For small and deep-seated tumors, not for
  - Too large
  - The external surface differs markedly from a cylinder.
  - The tumor is too far off center.
- Past pointing



100 degree arc



180 degree arc



full arc

Rotation Therapy (2)

The dose rate at the isocenter

$$\dot{D}_{iso} = \dot{D}_{ref} \times \overline{T}$$

$\dot{D}_{ref}$ = the reference dose rate related to the quantity $\overline{T}$ which may be average TAR or TMR

Using TMR system

$$\dot{D}_{iso} = \dot{D}_0 \times S_c \times S_p \times \overline{TMR}$$

$\dot{D}_0$ = the D_{max} dose rate for a 10×10 field at the SAD

Ex: $\dot{D}_{iso} = 200 \times 0.98 \times 0.99 \times 0.746 = 144.8\ cGy/\text{min}$

$$\text{Treatment time} = \frac{250\ cGy}{144.8\ cGy/\text{min}} = 1.73\ \text{min}$$

$$\text{Total MU to be set} = 200\ (\text{MU/min}) \times 1.73\ \text{min} = 345\ \text{MU}$$

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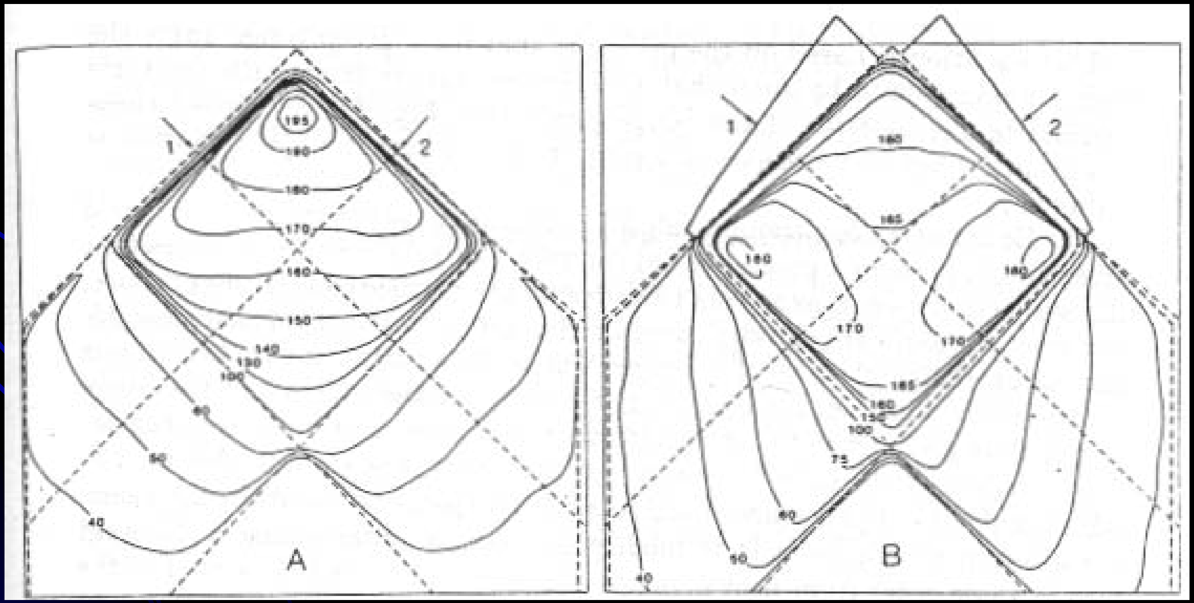
Wedge Field Techniques

- The dose gradient in the overlap region is minimized.
- The dose falls off rapidly beyond the region of overlap or the "plateau" region.



The Wedge Angle

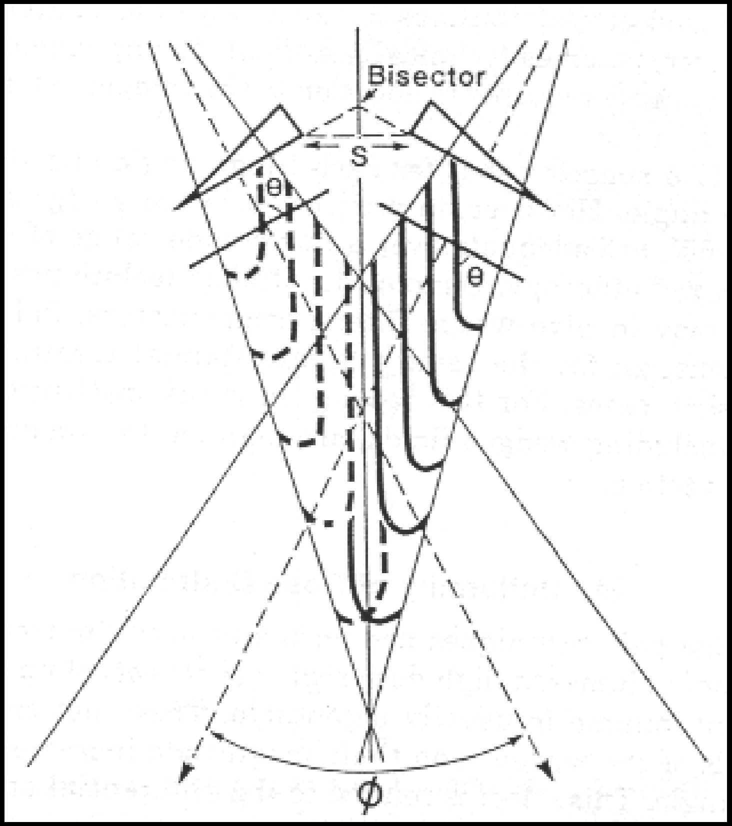
The wedge should be such that the isodose curves from each field are parallel to the bisector of the hinge angle. When the isodoses are combined, the resultant distribution is uniform.

$$\theta = 90^\circ - \phi/2$$

θ = the wedge angle

ϕ = the ***hinge*** angle

S = the separation or the distance between the thick ends of the wedge filters as projected on the surface



Compensators

- Contours are usually curved or irregular in shape.
- Compensators
  - To make the skin surface effectively flat and perpendicular to each beams
  - To modify the wedge angle (given by $\theta = 90^{o} - \phi/2$) so that a part of the wedge angle acts as a compensators

Uniformity of Dose Distribution

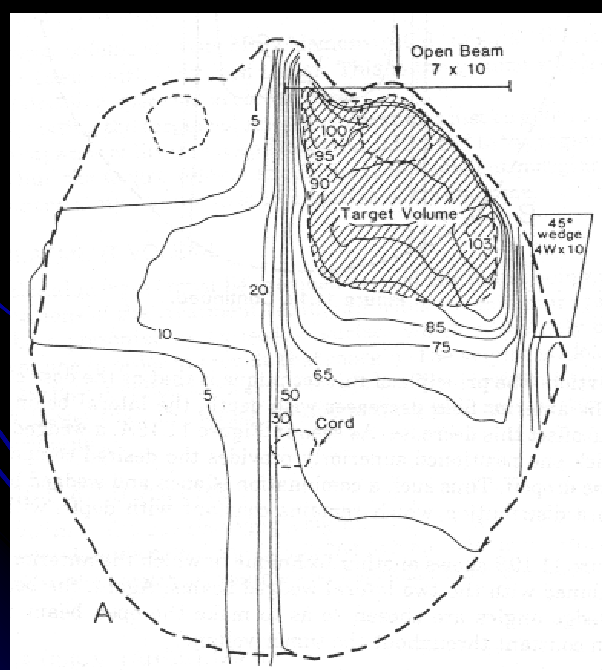
- A high-dose region (hot spot) of up to +10% within the treatment volume is usually acceptable.

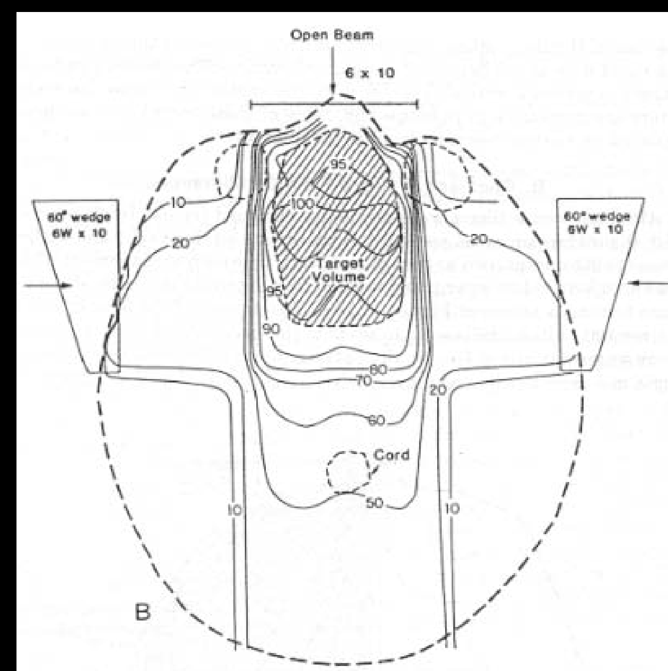
Open and Wedged Field Combinations

- The dose contribution from the anterior field decreases with depth, the lateral beam provides a boost to offset this decrease.

(A) The weights of AP and LLAT are 100 and 15.

(B) AP and opposed lateral fields



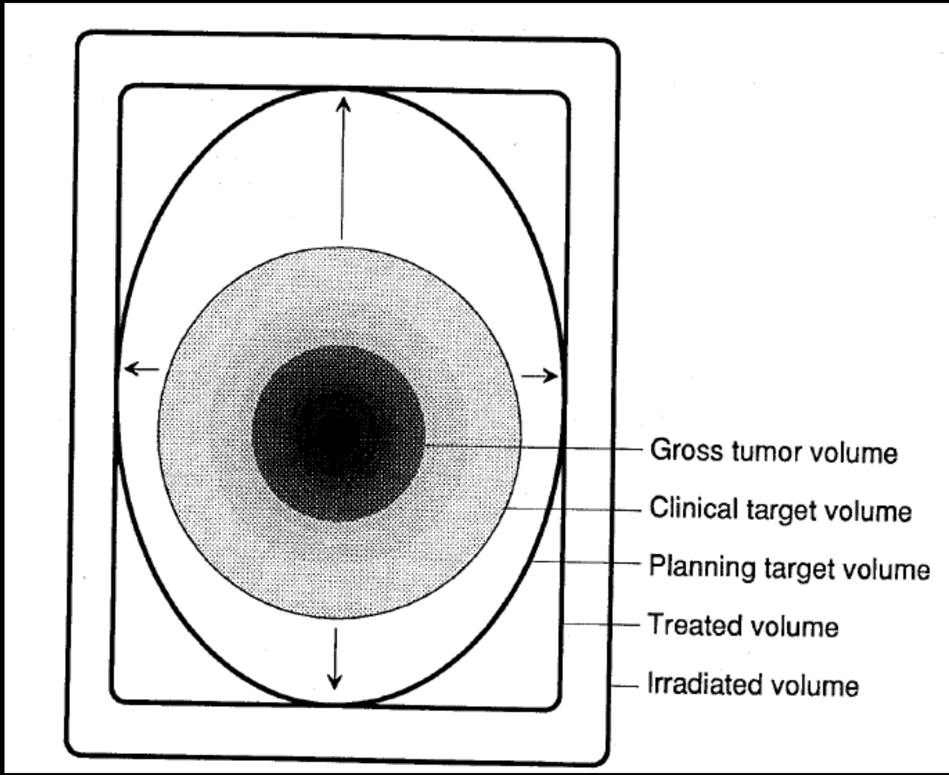


Outline

1. Isodose chart
2. Measurement of isodose curves
3. Parameters of isodose curves
4. Wedge filters
5. Combination of radiation fields
6. Isocentric techniques
7. Wedge field techniques
8. **Tumor dose specification for external photon beams.**

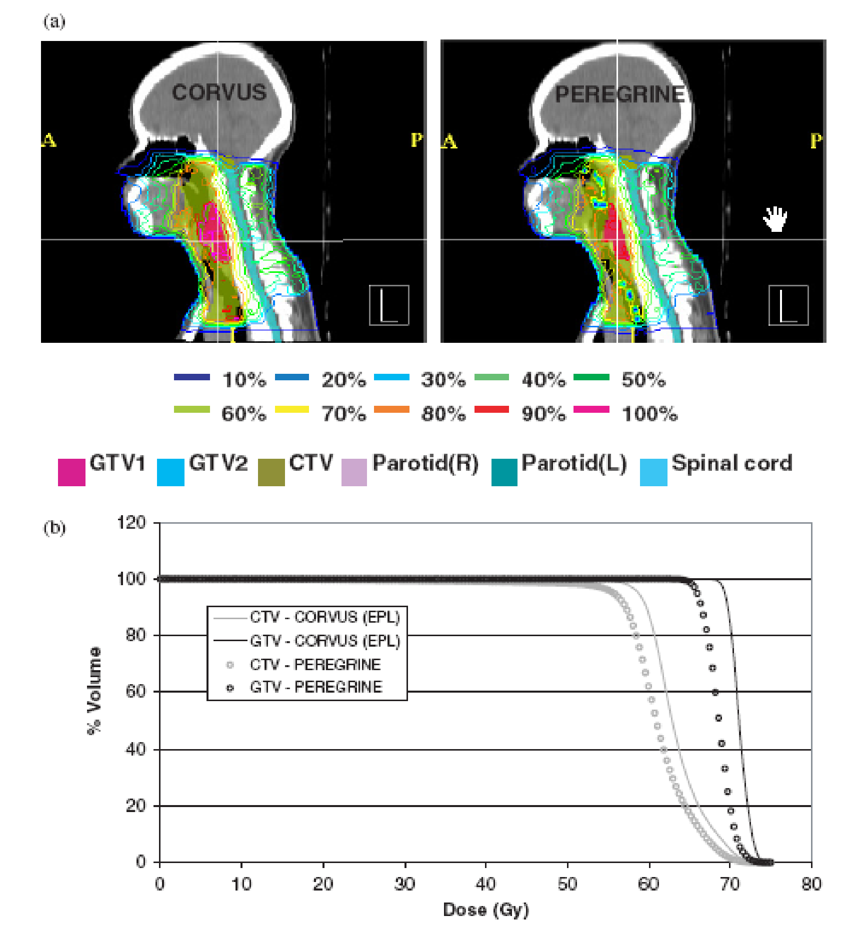
Illustration of treatment volume

- Gross tumor volume (GTV)
  - The demonstrated tumor
- Clinical target volume (CTV)
  - The demonstrated tumor and volumes with suspected (subclinical) tumor
- Planning target volume (PTV)
  - The CTV and a margin to account for variations in size, shape, and position relative to the treatment beams
- Treated volume
  - The volume that receives the a dose that is considered necesary for local cure or palliation.
- Irradiated volume
  - The volume that receives a dose that is considered significant in relation to normal tissue tolerance.



Dose Volume Histogram (DVH)

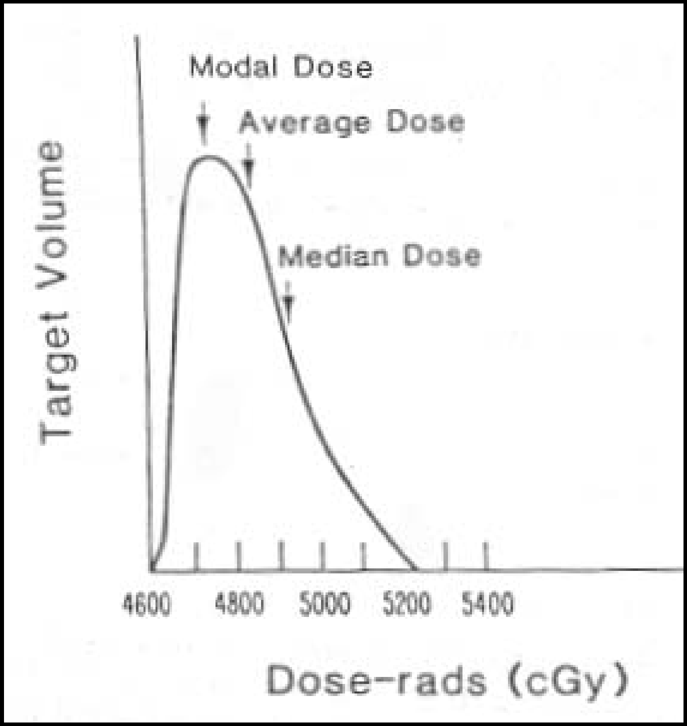
- DVH (or cumulative dose volume histogram) is one of the most important dosimetric evaluation tool used for treatment plans.
- DVH is only valid when 3D volumetric images are used.



C.Boudreau et al. Phys Med Biol 50:879 (2005)

Target volume-dose frequency curve (Differential Dose Volume Histogram)

- Maximum target dose
- Minimum target dose
- Mean target dose
- Median target dose
- Modal target dose
- Hot spots



Specification of target dose

- The maximum target dose alone cannot be used.
- The minimum target dose alone cannot be used.
- The mean, median, and modal doses are too difficult to calculate.
- The target dose can be specified at a ICRU reference point.

ICRU Reference Point (Report no.62)

- The point should be selected so that the dose at this point is clinically relevant and representative to the dose throughout the PTV.
- The point should be easy to define.
- The point should be selected where the dose can be accurately calculated.
- The point should not line in the penumbra or where there is a steep dose gradient.