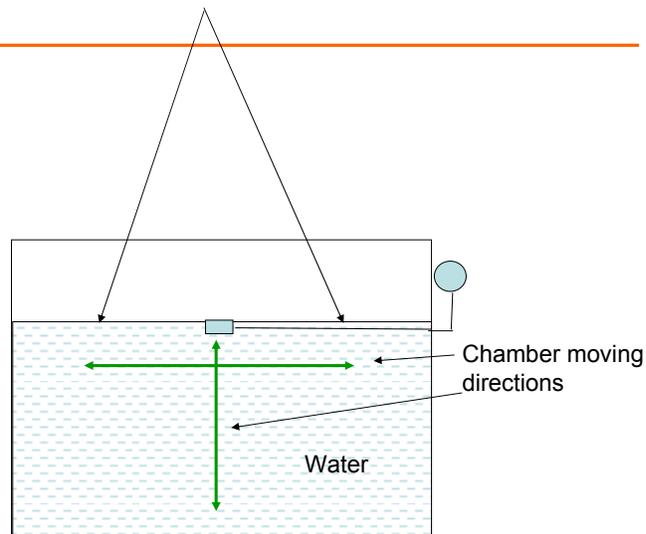
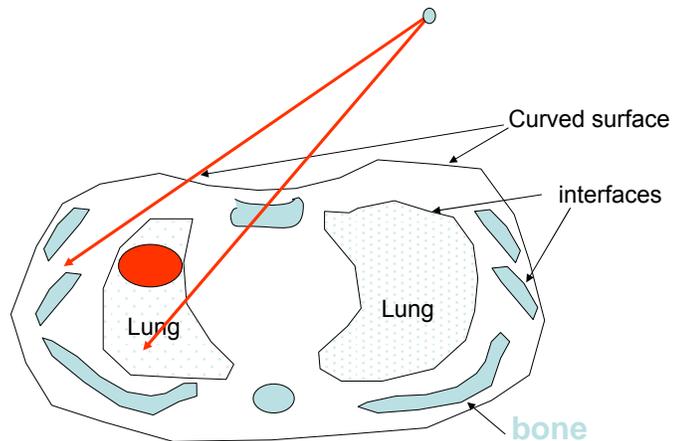

Off Axis Calculations/Photon Inhomogeneities

Sotirios Stathakis, PhD

Conditions of Beam Data Collection



In Reality



Dose Computation Algorithms

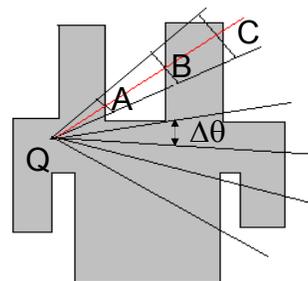
- Correction-based algorithms: they are semi-empirical and measurement data based.
- Model-based Algorithms:
 1. Convolution-superposition method
 2. Monte Carlo dose calculation method

Irregular Fields

- Clarkson's method used to calculate depth dose distribution in an irregularly shaped field
- Based on the principle that the scattered component of the depth dose (dependent on the field size and shape) can be calculated separately from the primary component (independent of field size and shape)

Irregular Fields

- An irregular field at depth d may be divided into n elementary sectors with radii emanating from the point of calculation Q
- A Clarkson type integration may be performed to give averaged scatter maximum ratio for the irregular field r_d



Irregular Fields

- Clarkson method is not practical for routine calculations
- Instead of Clarkson method effective fields can be used
- Remember:
 - S_c is related to the collimator field
 - PDD, TMR and S_p corresponds to the effective field

Irregular Fields

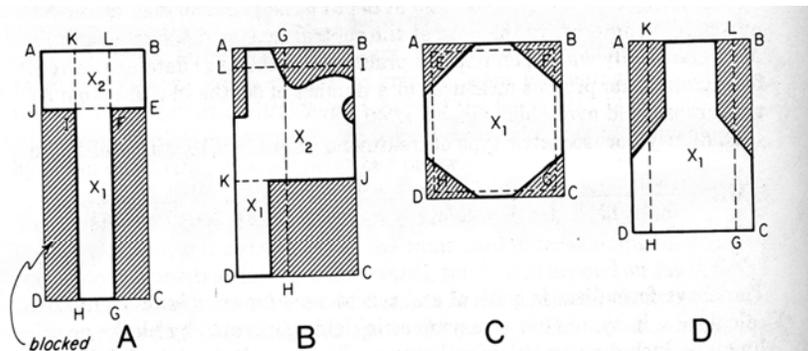
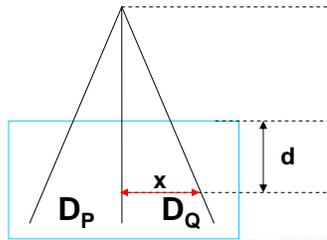


Figure 10.8. Examples of irregularly shaped fields. Equivalent rectangles for dose at points of interest are shown by dashed lines. Points versus equivalent rectangles are **A**, 1 *GHKL*; 2, *ABEJ*; **B**, 1, *AGHD*; 2, *LIJK*; **C**, 1, *EFGH*; **D**, 1, *KLGH*. Reprinted with permission from Levitt SH, Khan FM, Potish RA, eds. *Technological basis of radiation therapy: practical and clinical applications*. 2nd ed. Philadelphia: Lea & Febiger, 1992:73.

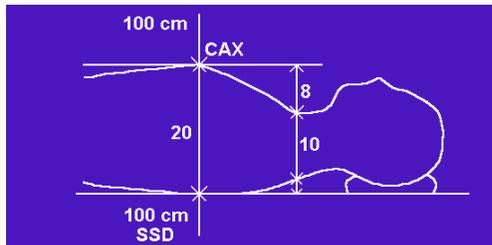
Off Center Factor

- Off center factor (OCF) is the ratio of dose at off-axis point of interest to the dose at the central axis at the same depth for a symmetrically wide open field



$$OAR(d,x) = \frac{D_q}{D_p}$$

Off Axis Point Calculation & Irregular Fields



Acquisition of Patient Data

- Include: body contour, outline, density of relevant internal structures, location, and extent of the target volume.
- Final accuracy of treatment planning is strongly dependent on the availability of the patient data.

Localization of Surface and Internal Structures

- Computed Tomography
- MRI
- Ultrasound
- Fusion of data sets

Treatment Verification

Port films

- Verify treatment volume under actual conditions of treatment
- Anatomic interpretation of a port film is helped by obtaining a full field exposure on top of the treatment port exposure.
- Double exposure to show surrounding anatomy
- Lead screen and special (TL) film
 - 2 or 3 mu per exposure
- Ready pack (XV) film with no screen
 - Left in place during the entire treatment

Port Films

Limitations:

1. Viewing is delayed because of time required for processing
2. It is impractical to do port films before each treatment
3. Film image is of poor quality especially for photon energies greater than 6MV

Treatment Verification

Electronic portal imaging device

- Overcomes first two problems of portal images by viewing images instantaneously.
- Matrix of liquid ionization chambers used as detectors.
- Solid state detectors
- Fluorescent screen / mirror system
- Linear array of zinc tungstate scintillating crystals attached to photodiodes.

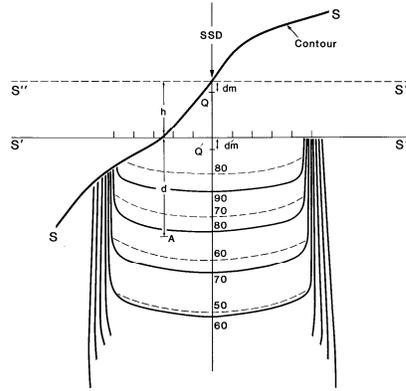
Corrections for Contour Irregularities (Surface Corrections)

Up to now—homogeneous, unit density, flat surface, perpendicular beam entry

- Effective SSD
- Isodose Shift Method

Effective SSD

- PDD does not change rapidly with SSD (assuming that the SSD is large)
- Slide the isodose chart down so its surface line is at S', read off the PDD at A and multiply it by the inverse square law to give correct PDD



$$P_{\text{CORR}} = P' \left(\frac{\text{SSD} + d_m}{\text{SSD} + h + d_m} \right)^2$$

Effective SSD Example

Example 1: (pg. 285)

$h = 3\text{cm}$ and $d = 5\text{cm}$.

Calculate PDD at A.

Given: Co-60 beam, $\text{TAR}(5, 11 \times 11) = 0.910$ and $\text{TAE}(8, 11 \times 11) = 0.795$ and $\text{SSD} = 80\text{cm}$

PDD at A = 78.1

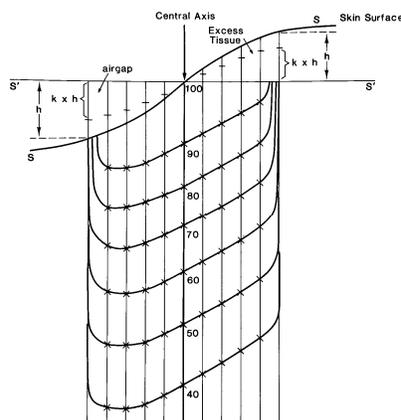
Inv. Sq. law = $(80 + 0.5 / (80 + 3 + 0.5))^2 = 0.929$

Corrected PDD at A = $78.1 \times 0.929 = 72.6$

Isodose Shift Method

- For manual treatment planning
- Empirical method
- S-S is patient contour on transparent paper
- S'-S' is flat surface line passing through point of intersection of CAX with contour.
- From S'-S', draw vertical lines, parallel to CAX 1 cm apart.
- Place standard isodose chart under paper and align central line of chart with grid
- Mark PDD values on CAX

Isodose Shift Method



12.15. Diagram illustrating isodose shift method of correcting isodose curves

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Isodose Shift Method

- For each grid line, slide isodose chart up or down, depending on whether tissue excess or deficit, by amount $(k \times h)$ where k is factor less than one.
- Mark isodose values at point of intersection of given grid line and shifted isodose curves
- Join marked points having same isodose values
- k depends on radiation quality, field size, depth of interest, and SSD

Isodose Shift Method

- Depth of isodose line changes by $k \times h$
- Used to construct isodose curves manually

Table 12.1.
Isodose Shift Factors for Different Beam Energies

Photon Energy (MV)	Approximate Factor k
Up to 1	0.8
^{60}Co -5	0.7
5–15	0.6
15–30	0.5
Above 30	0.4

Data from Giessen PH. A method of calculating the isodose shift in correcting for oblique incidence in radiotherapy. Br J Radiol 1973;46:978.

Khan, p 285

Isodose Shift

- Isodose curves beyond inhomogeneity are moved manually by amount equal to n times thickness of inhomogeneity as measured along a line parallel to central axis and passing through point of interest
- Toward the skin for bone, away from the skin for lung

Table 12.2.
Isodose Shift Factors* for Inhomogeneities†

Inhomogeneity	Shift Factor n
Air cavity	-0.6
Lung	-0.4
Hard bone	0.5
Spongy bone	0.25

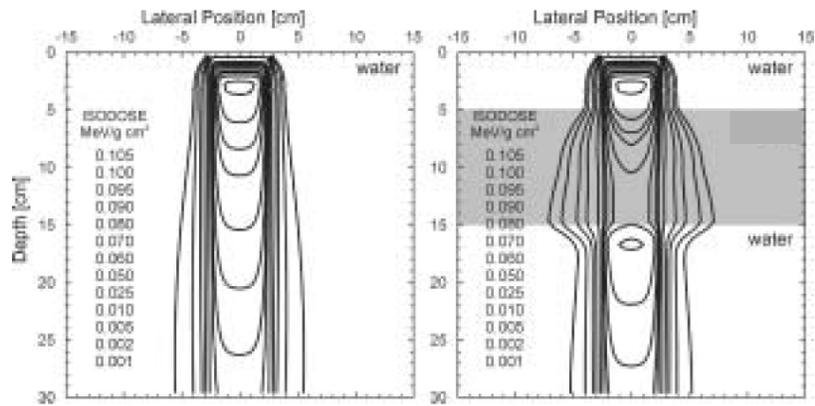
* Approximate factors, determined empirically for ^{60}Co and 4-MV x-rays.
† Greene D, Stewart JR. Isodose curves in non-uniform phantoms. Br J Radiol 1965; 38:378. Sundblom L. Dose planning for irradiation of thorax with cobalt in fixed beam therapy. Acta Radiol 1965;3:342.

Khan, p 289

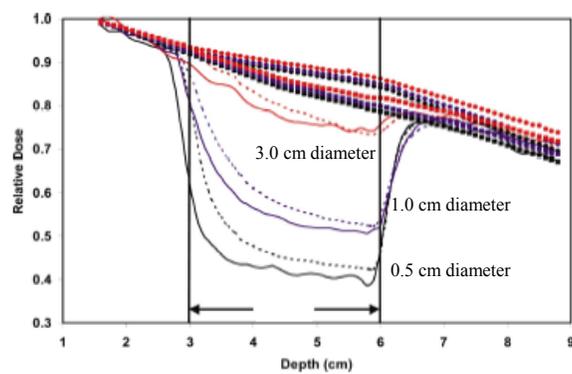
Corrections for Tissue Inhomogeneities

- Inhomogeneities
 - Lung
 - Air
 - Bone
 - Prosthetic devices
- Effects of tissue inhomogeneities:
 - changes in absorption of primary beam and associated pattern of scattered photons
 - changes in secondary electron fluence

Isodose lines and inhomogeneity



Field size and Inhomogeneity correction



Monte Carlo (Solid)

Collapsed cone convolution (dashed)

Effective path-length (circles)

Corrections for Tissue Inhomogeneities

- Changes in attenuation and scatter
 - Megavoltage region
 - Compton effect—dependent upon electron densities
 - Lung or air
- Changes in absorption
 - Orthovoltage
 - Photoelectric absorption—varies as Z^3
 - Bone

Corrections for Tissue Inhomogeneities

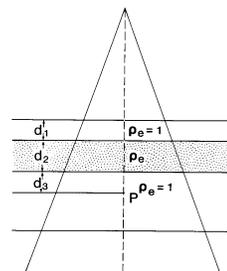
- Attenuation and scattering correction
- Correction beyond the inhomogeneity: predominant effect is attenuation of primary
- Depends on
 - Energy
 - Extent of the field and the inhomogeneity
 - Distance from the surface and from the inhomogeneity
- $CF = \text{Dose with IH} / \text{Dose without IH}$ so
 - $\text{Dose Rate} = \text{Dose Rate without IH} \times CF$

Corrections for Tissue Inhomogeneities

- Effective depth
- Tissue-air ratio method
- Power law tissue-air ratio method
- Equivalent TAR Method

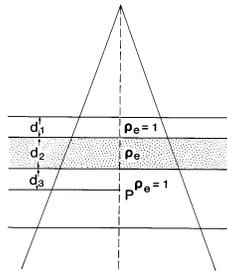
Effective depth

$$d' = d_1 + \rho_e d_2 + d_3$$



$$\text{TAR}(\text{FS}, P) = \text{TAR}(\text{FS}, d')$$

TAR method



Khan, p 286

- Based on radiological depth, d'
 - $d' = d_1 + \rho_e d_2 + d_3$
- $CF = TMR(d', r_d) / TMR(d, r_d)$
- Independent of distance to inhomogeneity

TAR method

- CF applies to dose at P if entire phantom was water equivalent.
- Overestimates dose for all energies

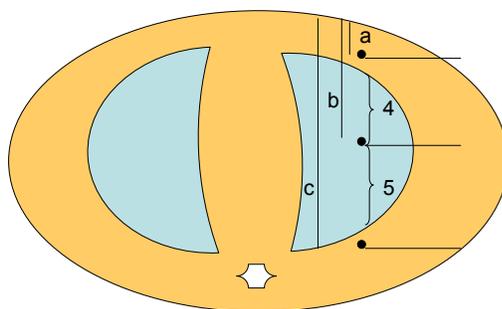
Tissue-Air (or Tissue Maximum) Ratio Method

- Based on principle: TAR or TMR does not depend on SSD and is a function of depth and field size at the depth only.
- Correction factor is ratio of TARs or TMRs for depths d and $d+h$.

$$\text{Correction factor (CF)} = \frac{T(d, r_A)}{T(d', r_A)}$$

where T stands for TAR or TMR, r_A is field size projected at point A (i.e., at distance of $SSD+d+h$ from source)

Example



$a=2$
 $b=7$
 $c=18$
 Field size = 10x10
 4MV
 $P_{lung}=0.3$

RTAR method

Point a
CF=1

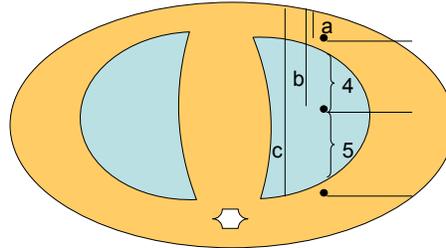
Point b

$$CF = \frac{TAR((d_1 + d_2 \times \rho), FS)}{TAR(d, FS)}$$

$$CF = \frac{TAR(((7 - 4) + 4 \times 0.3), 10)}{TAR(7, 10)}$$

$$CF = \frac{TAR(4.2, 10)}{TAR(7, 10)} = \frac{0.943}{0.853}$$

$$CF = 1.105$$



Point c

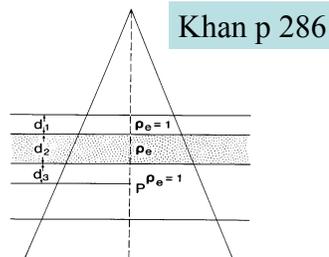
$$CF = \frac{TAR((d_1 + d_2 \times \rho), FS)}{TAR(d, FS)} = \frac{TAR(((18 - 4 - 5) + (4 + 5) \times 0.3), 10)}{TAR(18, 10)}$$

$$CF = \frac{TAR(11.7, 10)}{TAR(18, 10)} = \frac{0.7097}{0.528} = 1.344$$

Batho Power Law

- $CF = [TMR(d_2 + d_3, r_d) / TMR(d_3, r_d)]^{\rho_e - 1}$
- A more general form

$$CF = \frac{T(d_3, r_d)^{\rho_3 - \rho_2}}{T(d_2 + d_3, r_d)^{1 - \rho_2}}$$



- For dose on the other side of lung ($\rho_e \sim 0.33$)
– $CF = [TMR(d_3, r_d) / TMR(d_2 + d_3, r_d)]^{0.66}$

Batho Power Law

- CF depends on location of inhomogeneity relative to P but not relative to the surface (based on theoretical considerations assuming Compton interactions only)
- It does not apply to points inside inhomogeneity or in build-up region.
- Generalized Batho: best in high energy range (>10 MV)

Batho Power Law

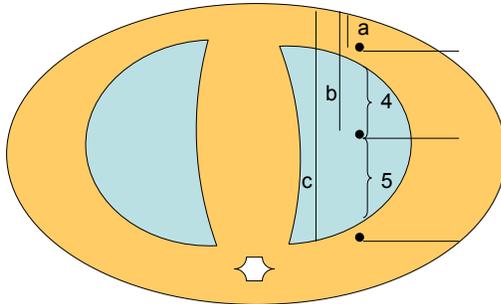
- More general form (Sontag and Cunningham) allows for correction of dose to points within inhomogeneity as well as below it.

- $$CF = \frac{T(d_3, r_d)^{\rho_3 - \rho_2}}{T(d_2 + d_3, r_d)^{1 - \rho_2}}$$

where ρ_3 is density of material in which P lies and d_3 is depth within this material. ρ_2 is density of overlying material, and $d_2 + d_3$ is depth below upper surface of it. This equation reduces to the previous equation if P lies in a unit density medium.

Example

$a=2$
 $b=7$
 $c=18$
 Field size = 10x10
 4MV
 $P_{lung}=0.3$



Batho Power Law method

Point a
CF=1

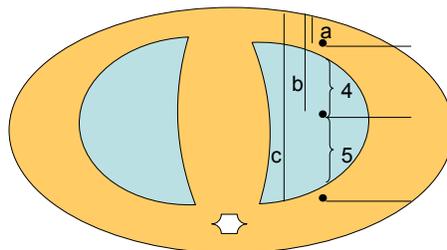
Point b

Batho does not apply

Point c

$$CF = \frac{TAR(d_1, FS)^{3-p_2}}{TAR(d_2 + d_3, FS)^{3-p_2}} = \frac{TAR(6, 10)^{0.7}}{TAR(15, 10)^{0.7}}$$

$$CF = \frac{0.882}{0.614} = 1.289$$



Equivalent TAR Method

- Computer method
- Water equivalent depth corrects for primary component of dose.
- Change in scattered dose isn't correctly predicted because the effect of scattering structures depends on geometric arrangement with respect to P.
- $CF = \frac{T(d', r')}{T(d, r)}$ where d' is water equivalent depth, d is actual depth, r is beam dimension at depth d, r' = ρ *weighted density

Equivalent TAR Method

$$\text{Weighted Density} = \bar{\rho} = \frac{\sum_i \sum_j \sum_k \rho_{ijk} W_{ijk}}{\sum_i \sum_j \sum_k W_{ijk}}$$

where ρ_{ijk} are relative electron densities of scatter elements and W_{ijk} are weighting factors assigned to these elements in terms of relative contribution to scattered dose at point of calculation.

- Weighting factors calculated using Compton scatter cross-sections and integrating scatter over entire irradiated volume for each point of dose calculation.
- Best suited for lower-energy beams (≤ 6 MV)

Typical Correction Factors

- None of above methods can claim accuracy of 5% for all irradiation conditions encountered in radiotherapy.

Typical Correction Factors

Table 1: Isodose shift factors for inhomogeneities

Inhomogeneity	Shift factor n
Air cavity	-0.6
Lung	-0.4
Hard bone	0.5
Spongy bone	0.25

Typical Correction Factors

Table 2: Increase in dose to tissues beyond healthy lung

Beam quality	Correction factor
Orthovoltage	+10%/cm of lung
Co-60 γ rays	+4%/cm of lung
4-MV x-rays	+3%/cm of lung
10 MV x-rays	+2%/cm of lung
20 MV	+1% of lung

Typical Correction Factors

Table 3: Reduction in dose beyond 1 cm of hard bone

Beam quality	Correction factor (%)
Co-60	-3.5
4 MV	-3
10 MV	-2

Limitations of the Methods

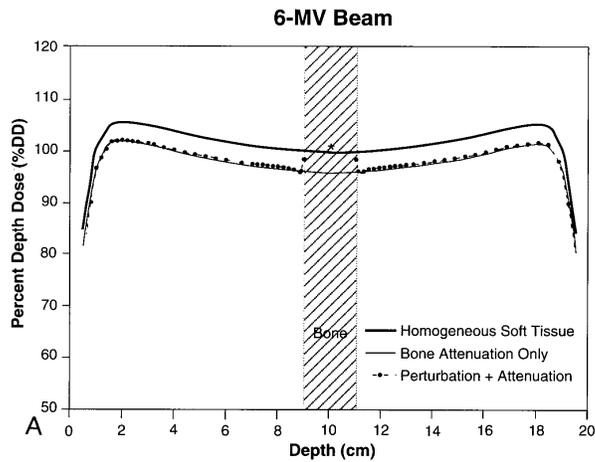
1. The RTAR method does not take into account the position of the inhomogeneity relative to point P.
2. The Batho-Power law method does not depend on d_1 and does not apply to points inside the inhomogeneity.
3. The third ETAR is better, but not accurate.

All of the above methods account for only the primary photon transport in an approximate manner. The secondary electron transport is completely ignored.

Opposed Treatment Fields through Bone

- Bone dose is higher than tissue dose
- Soft tissue doses are lower than if there had been no bone
- Interface dose is energy dependent
 - Low energy, equal or lower doses at interface
 - High energy, higher dose at interface

Opposed Treatment Fields through Bone—6 MV

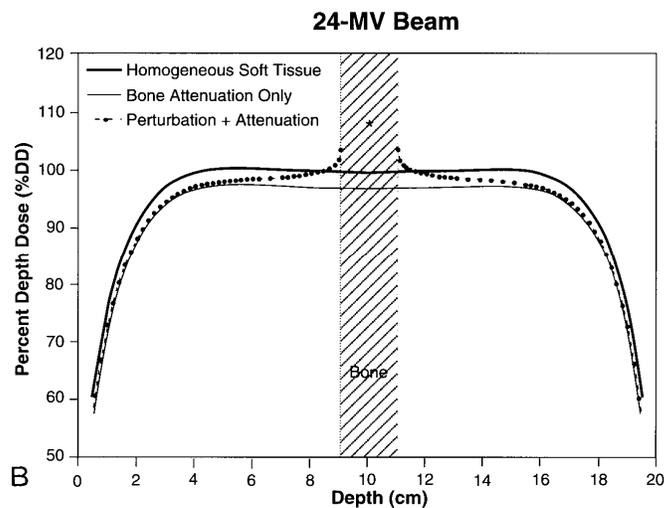


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Opposed Treatment Fields through Bone—24 MV



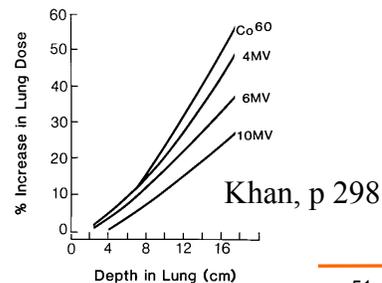
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Dose in Lung Tissue

- Low density gives higher doses in an beyond lung, 10-15% in mediastinum
- Loss of electron equilibrium, greatest problem for
 - Smallest fields
 - Highest energies



Conclusions

- Inhomogeneity effect is significant in lung treatment than in head/neck treatments, and is worse with higher energy.
- Only approximated inhomogeneity correction methods are implemented in some commercial treatment planning systems.
- The inhomogeneity effect can be studied most accurately by Monte Carlo method.
- Monte Carlo has a more important role in electron dose calculation.