Electron Beam Therapy

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STANFORD
SCHOOL OF MEDICINE
Stanford University Medical Center

ASTRO's view on physics teaching

REPORT

ASTRO'S 2007 CORE PHYSICS CURRICULUM FOR RADIATION ONCOLOGY RESIDENTS

AD HOC COMMITTEE ON TEACHING PHYSICS TO RESIDENTS: ERIC E. KLEIN, PH.D.,[*] BRUCE J. GERBI, PH.D.,[†] ROBERT A. PRICE, JR., PH.D.,[‡] JAMES M. BALTER, PH.D.,[§] BHUDATT PALIWAL, PH.D.,[||] LESLEY HUGHES, M.D.,[¶] AND EUGENE HUANG, M.D.[#]

The resident should learn:

1. *the basic characteristics of electron beams for therapy, including components of a depth–dose curve as a function of energy, electron interactions, isodoses, oblique incidence, skin dose, and electron dose measurement techniques.*
2. *the nature of treatment planning with electrons, including simple rules for selecting energy based on treatment depth and range, effect of field size, bolus, and field shaping (especially for small fields), about field matching with photons and other electron fields, internal shielding, backscatter, and the effects of inhomogeneities on electron isodoses.*

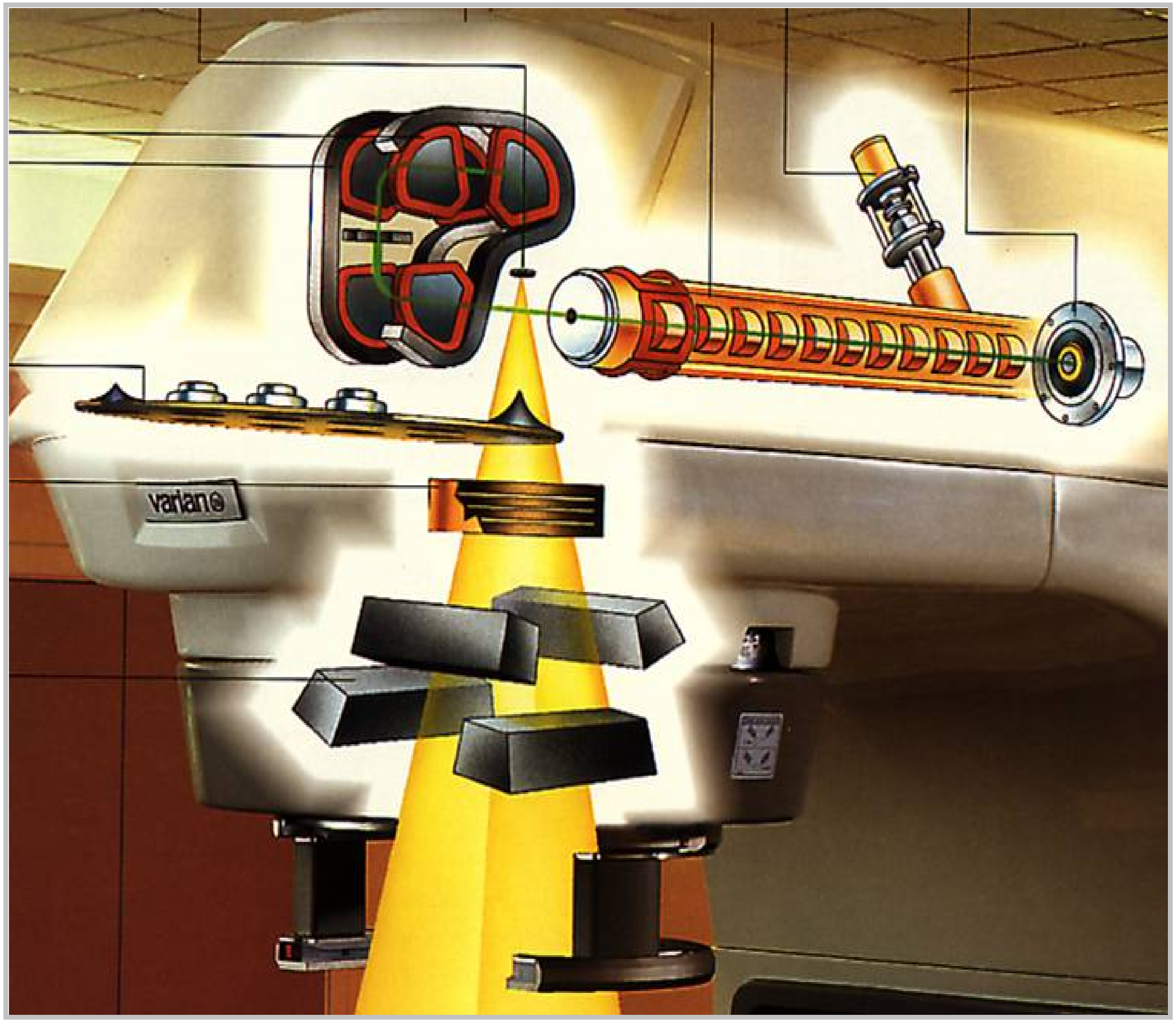
Select the correct answer:

- The percent depth dose at 5 cm for a 6 MeV beam is approximately: 100%, 90%, 80%, 50%, <5%?
- To treat a lesion extending to a depth of 5 cm you will use: 6 MeV, 10 MeV, 15 MeV, 20 MeV?
- What is the approximate range of a 6 MeV beam in lung overlaying 1 cm of tissue: 1-3 cm, 7-9 cm, > 12 cm?
- A 4x8 cut-out is placed in a 10x10 beam cone for 20 MeV treatment. What changes is: 90% depth, cGy/MU, d_max, skin dose, all of the preceding?

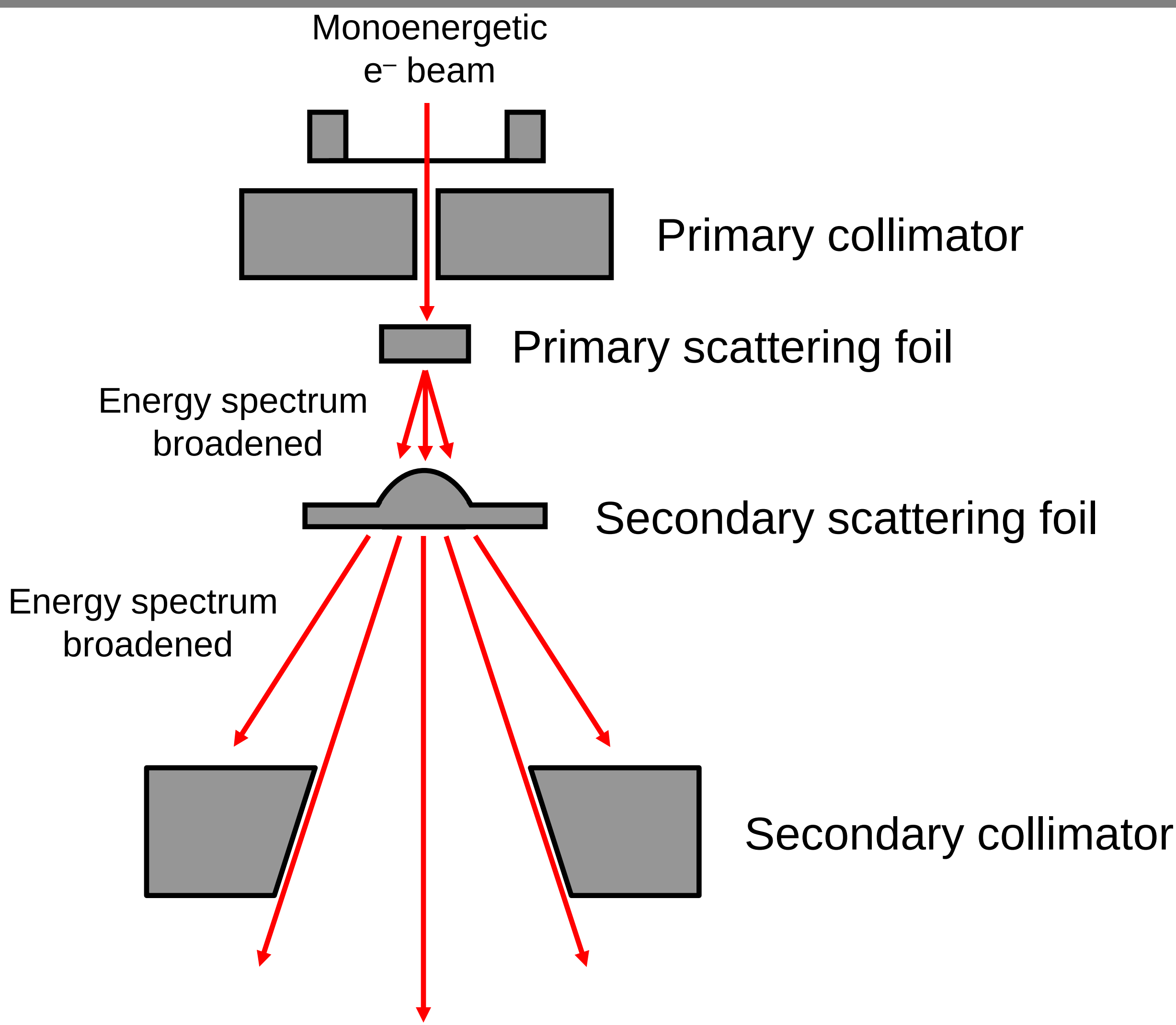
Outline

- Production of electron beams
- Interactions of electron beams with matter
- Electron beam characteristics
- Treatment planning

Electron Beam Production



Field Flatness and Uniformity



Dual foil system for producing a uniform electron beam

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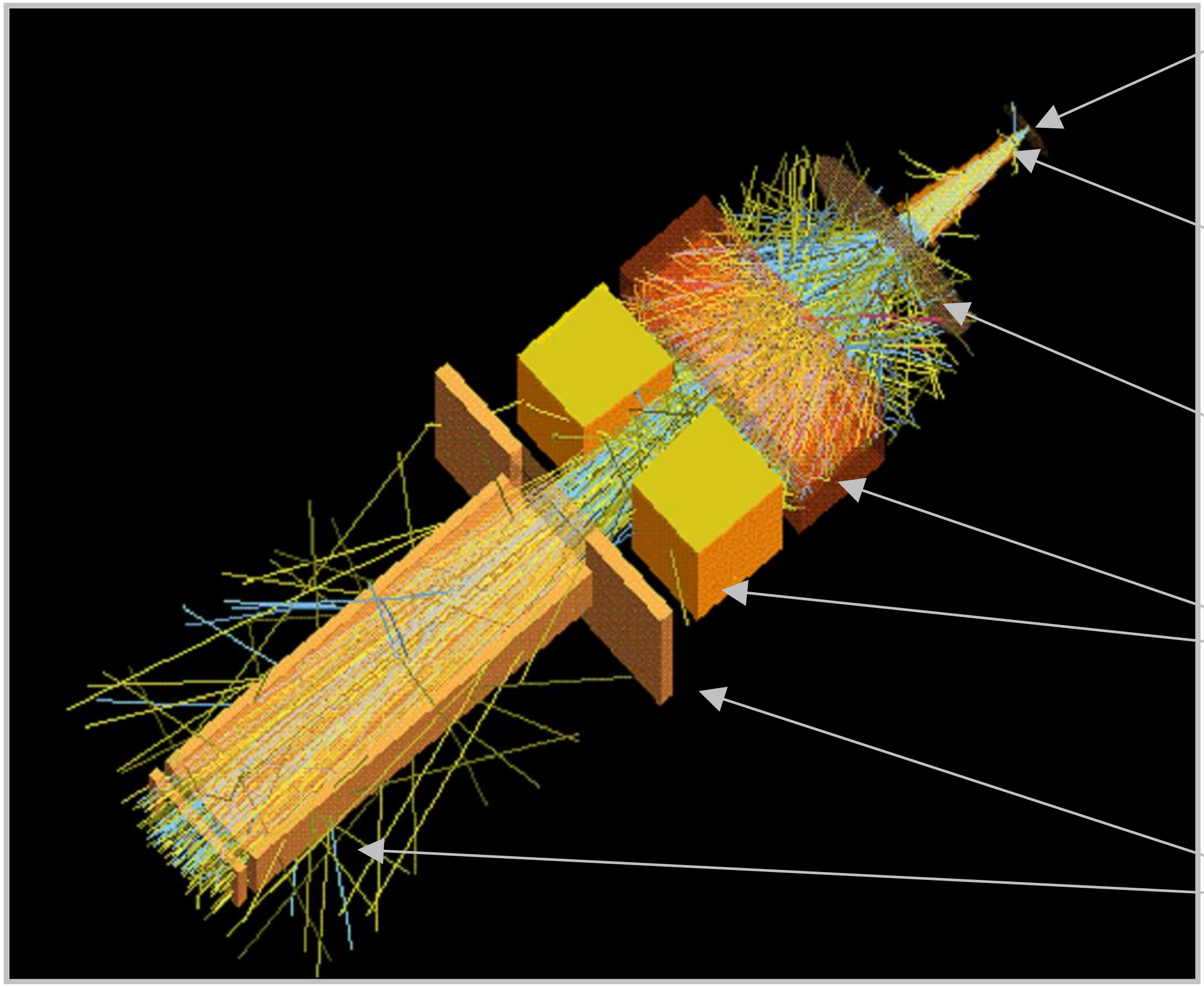
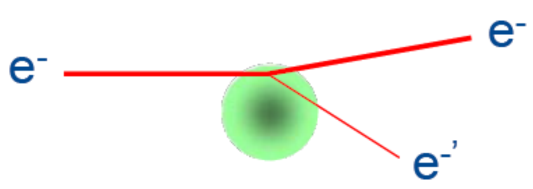
Electron Beam Production



Charged particle interactions

Collisional stopping power:

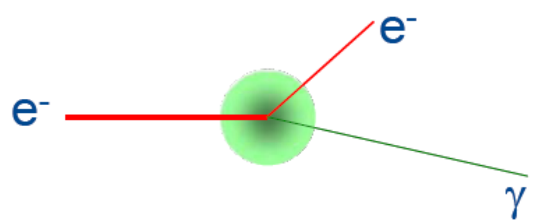


Energy loss by ionisation

Dominates for lower energies and low-Z material

Absorbed dose delivered to material via this process

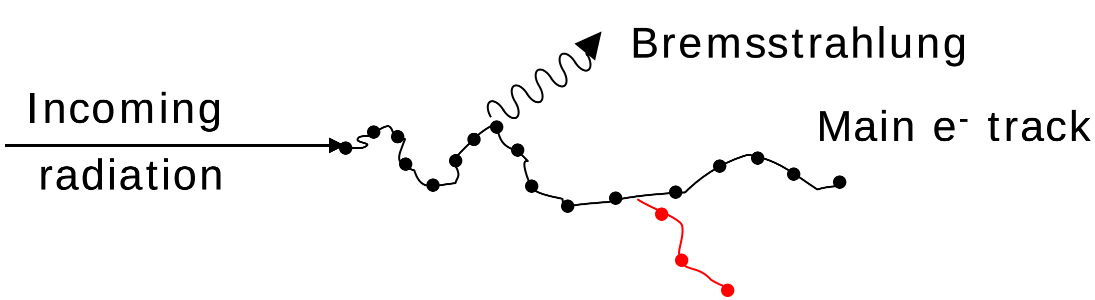
Radiative stopping power:



Scattering, mainly by nuclei

Energy loss by photon emission (bremsstrahlung)

Dominates for higher energies and high-Z material



Electron-Matter Interactions

- Collisional losses
  - Inelastic (excitation, ionization)
  - Elastic

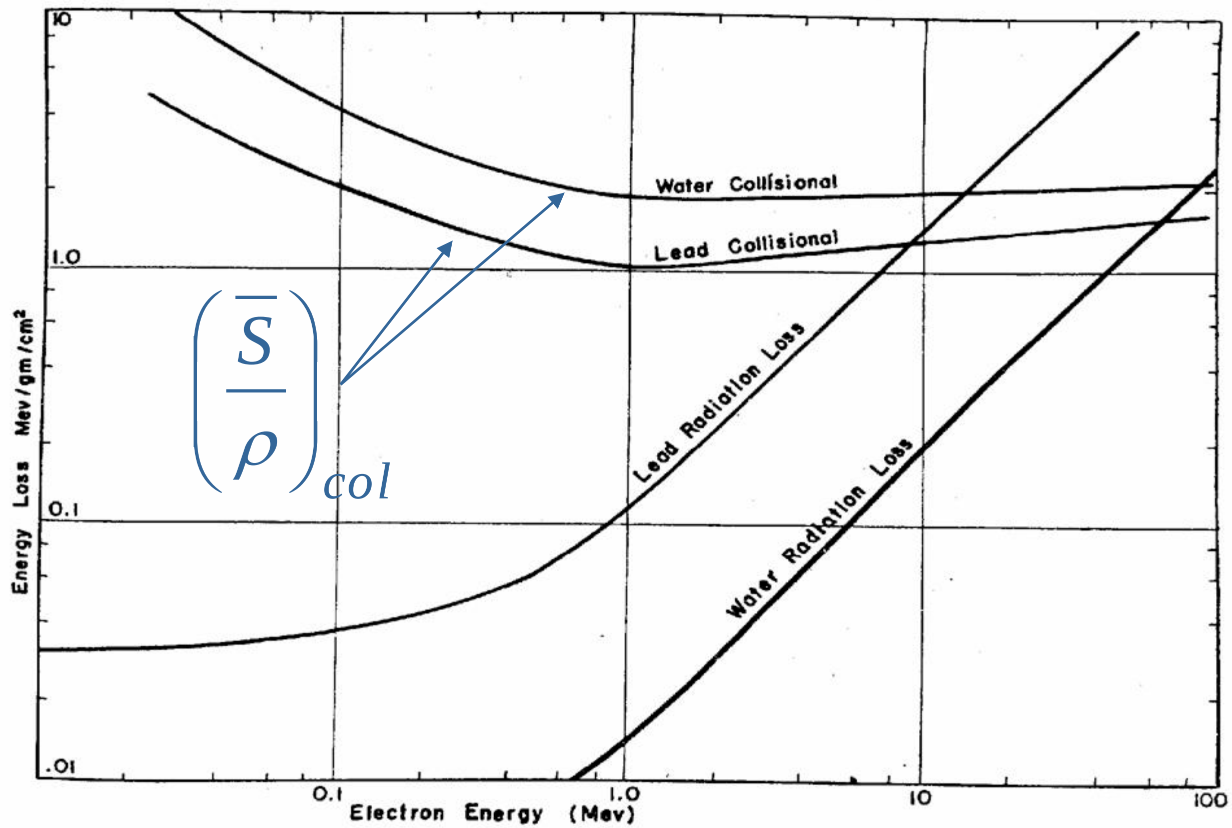


Figure 14.1. Rate of energy loss in MeV per g/cm² as a function of electron energy for water and lead. From Johns HE, Cunningham JR. The physics of radiology. 3rd ed. Springfield, IL: Thomas, 1969. Reprinted by permission.

Electron-Matter Interactions

- Radiative losses :Bremsstrahlung

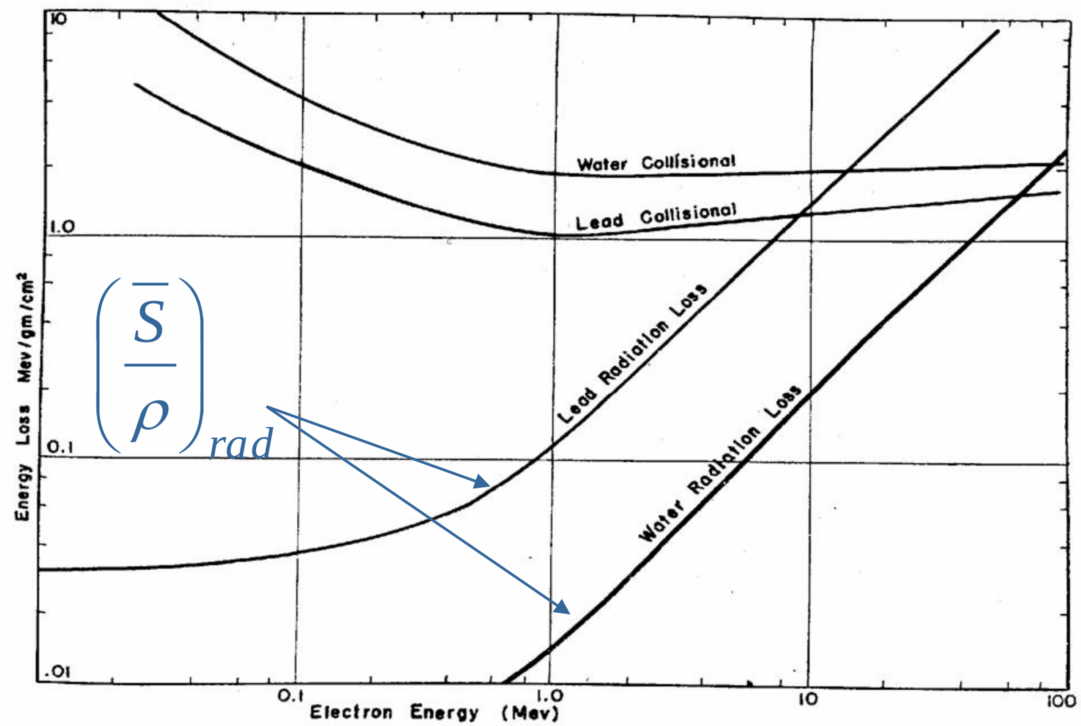
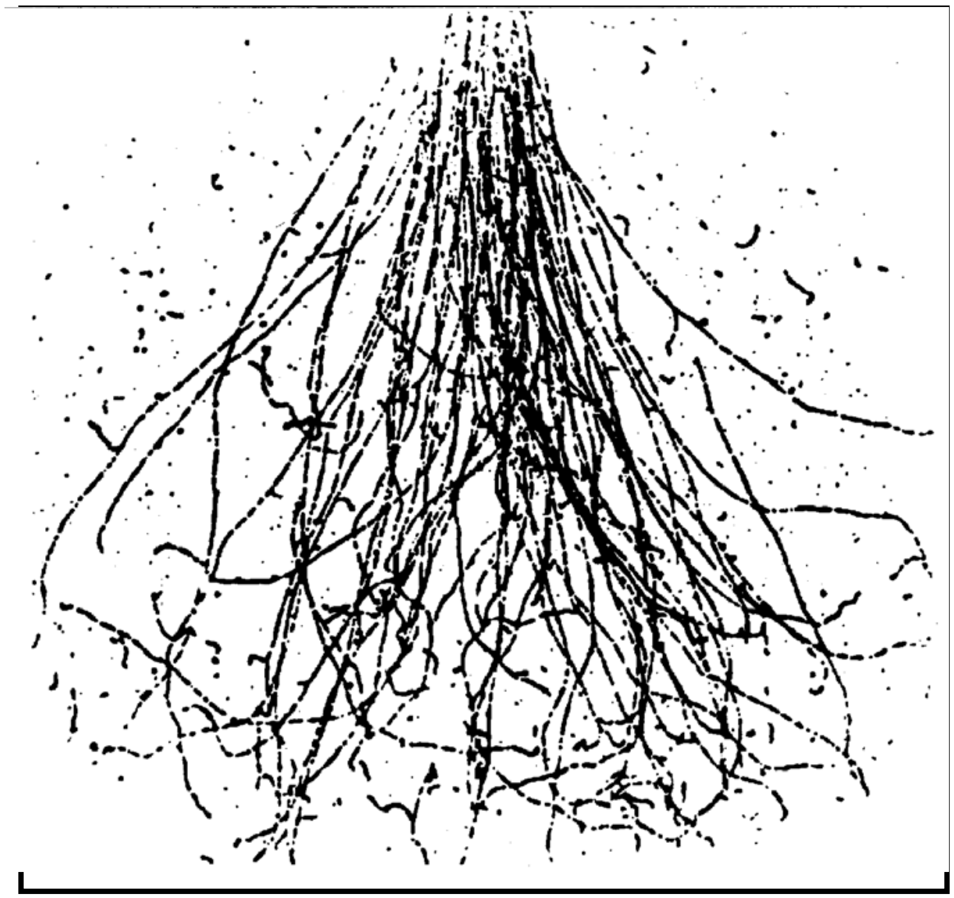


Figure 14.1. Rate of energy loss in MeV per g/cm^2 as a function of electron energy for water and lead. From Johns HE, Cunningham JR. The physics of radiology. 3rd ed. Springfield, IL: Thomas, 1969. Reprinted by permission.

Total mass stopping power

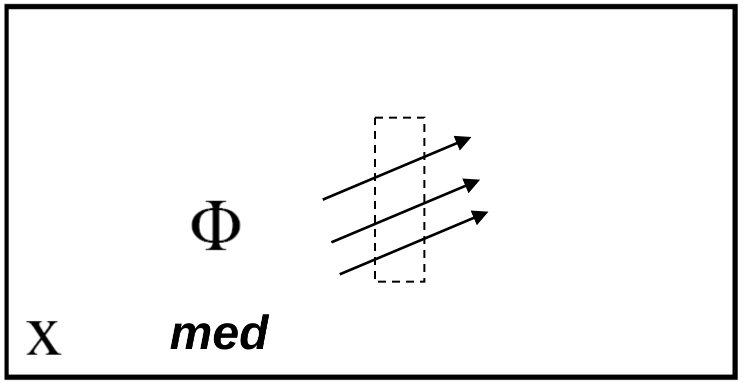
$$\left(\frac{\overline{S}}{\rho}\right)_{tot} = \left(\frac{\overline{S}}{\rho}\right)_{col} + \left(\frac{\overline{S}}{\rho}\right)_{rad}$$

Electron Scattering



Pencil electron beam tracks in a bubble chamber

Relation of Absorbed Dose to Fluence

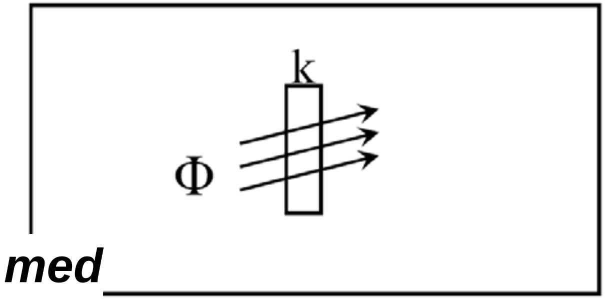


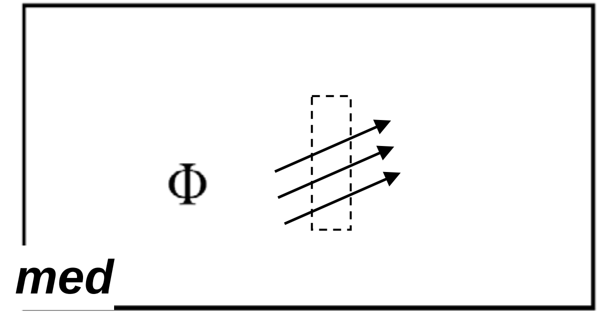
$$D = \int_{\Delta}^{E_{\max}} \Phi_E \left(\frac{L}{\rho}(E) \right)_{col,\Delta} dE$$

- **Φ** is the differential fluence in energy of identical **charged** particles
- *L/ρ* is the restricted *mass* collision stopping power with a cutoff energy

Electron Dose Measurement

Bragg-Gray Cavity Theory





$$D_k = \Phi\left(\frac{\overline{S}}{\rho}\right)_{k,col} = \left(\frac{1}{\rho}\frac{\overline{dT}}{dx}\right)_{k,col}$$

$$D_{med} = \Phi\left(\frac{\overline{S}}{\rho}\right)_{med,col} = \left(\frac{1}{\rho}\frac{\overline{dT}}{dx}\right)_{med,col}$$

$$\frac{D_{med}}{D_k} = \left(\frac{\overline{S}}{\rho}\right)_{med,col} \Big/ \left(\frac{\overline{S}}{\rho}\right)_{k,col}$$

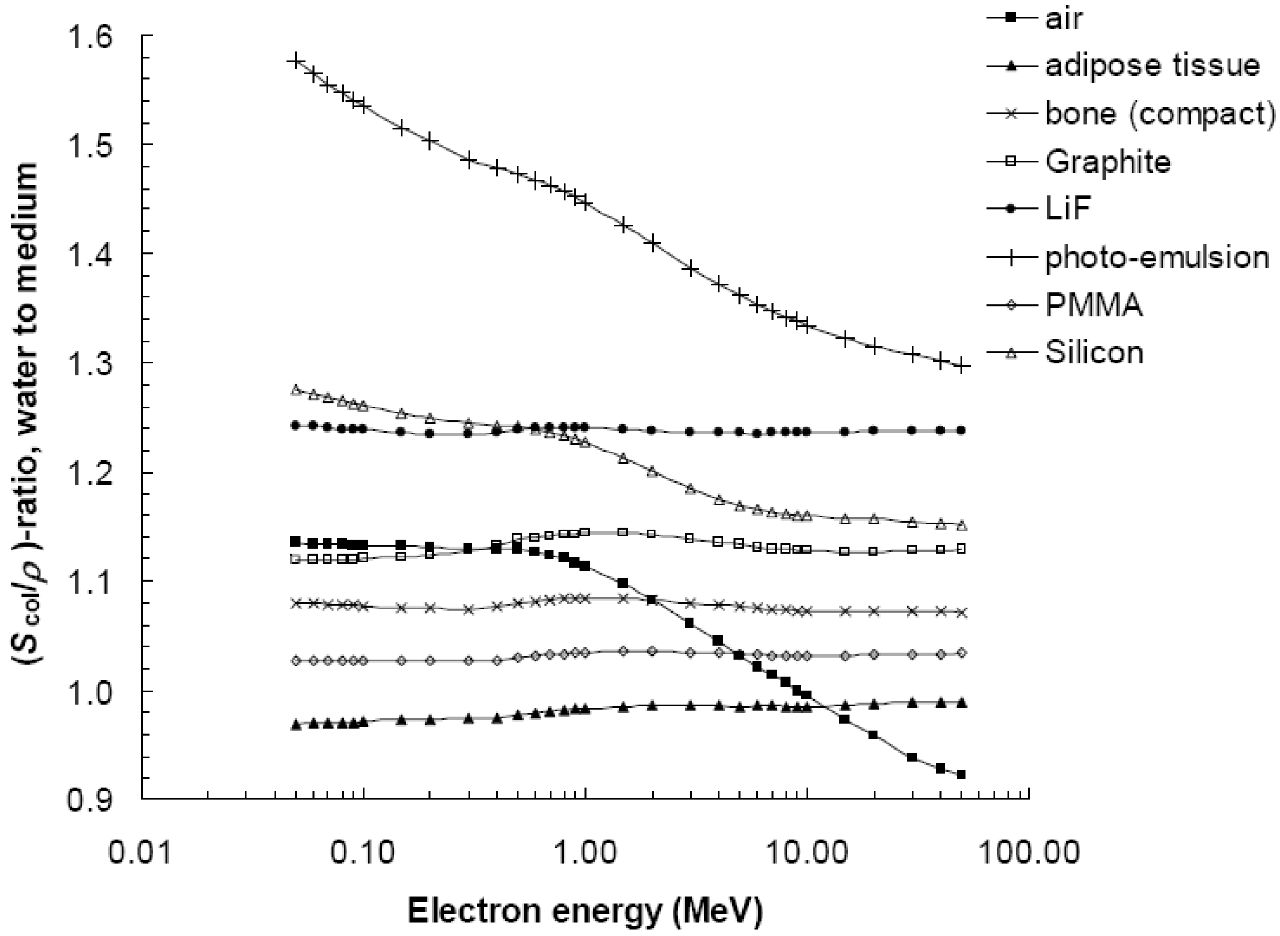
The Bragg-Gray Cavity Theory

- The ionization produced in a gas-filled cavity placed in a medium is related to the energy absorbed in the surrounding medium.

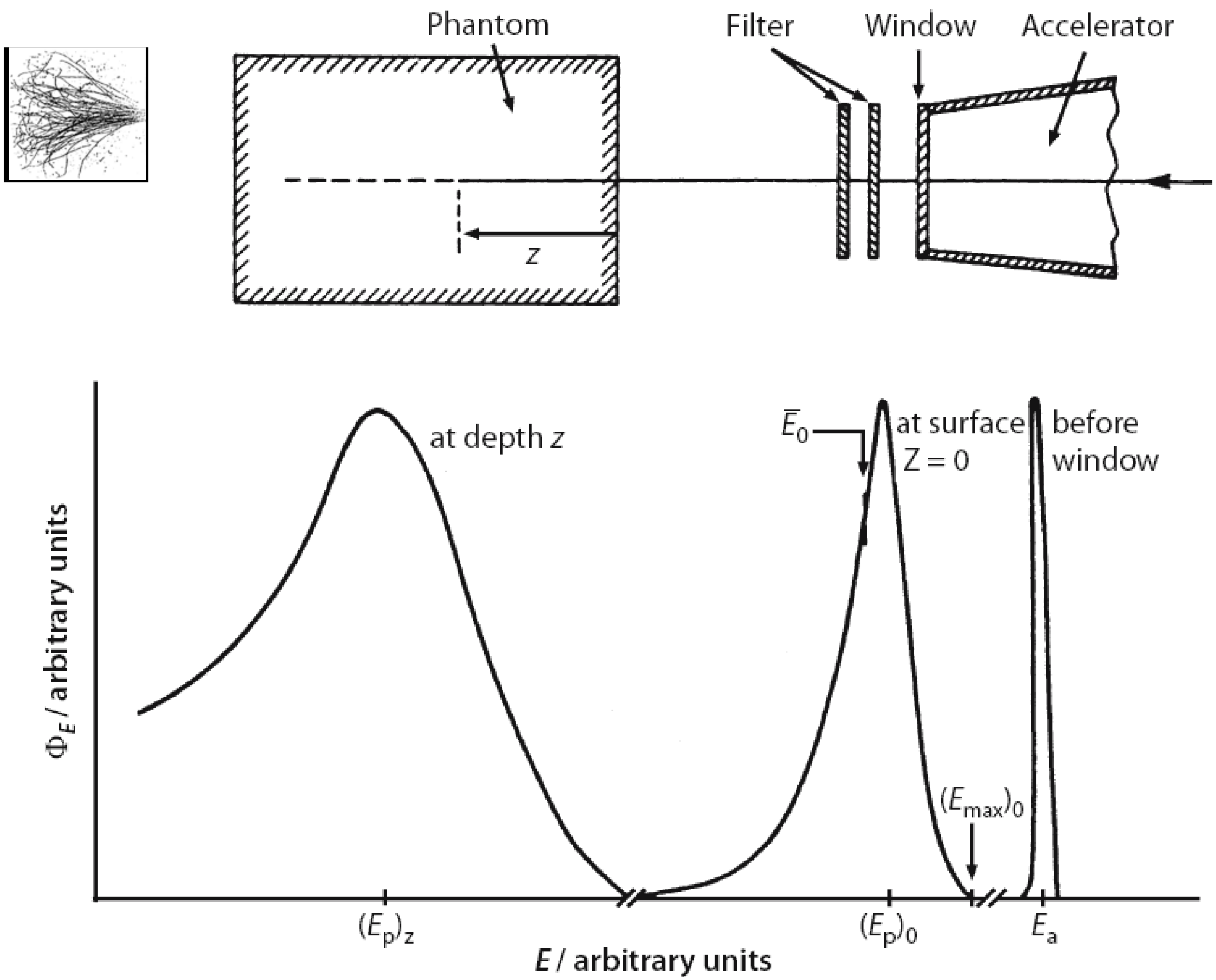
- When the cavity is sufficiently small, electron fluence does not change.

$$\frac{D_{med}}{D_k} = \left(\frac{\overline{S}}{\rho}\right)_{med,col} \Bigg/ \left(\frac{\overline{S}}{\rho}\right)_{k,col}$$

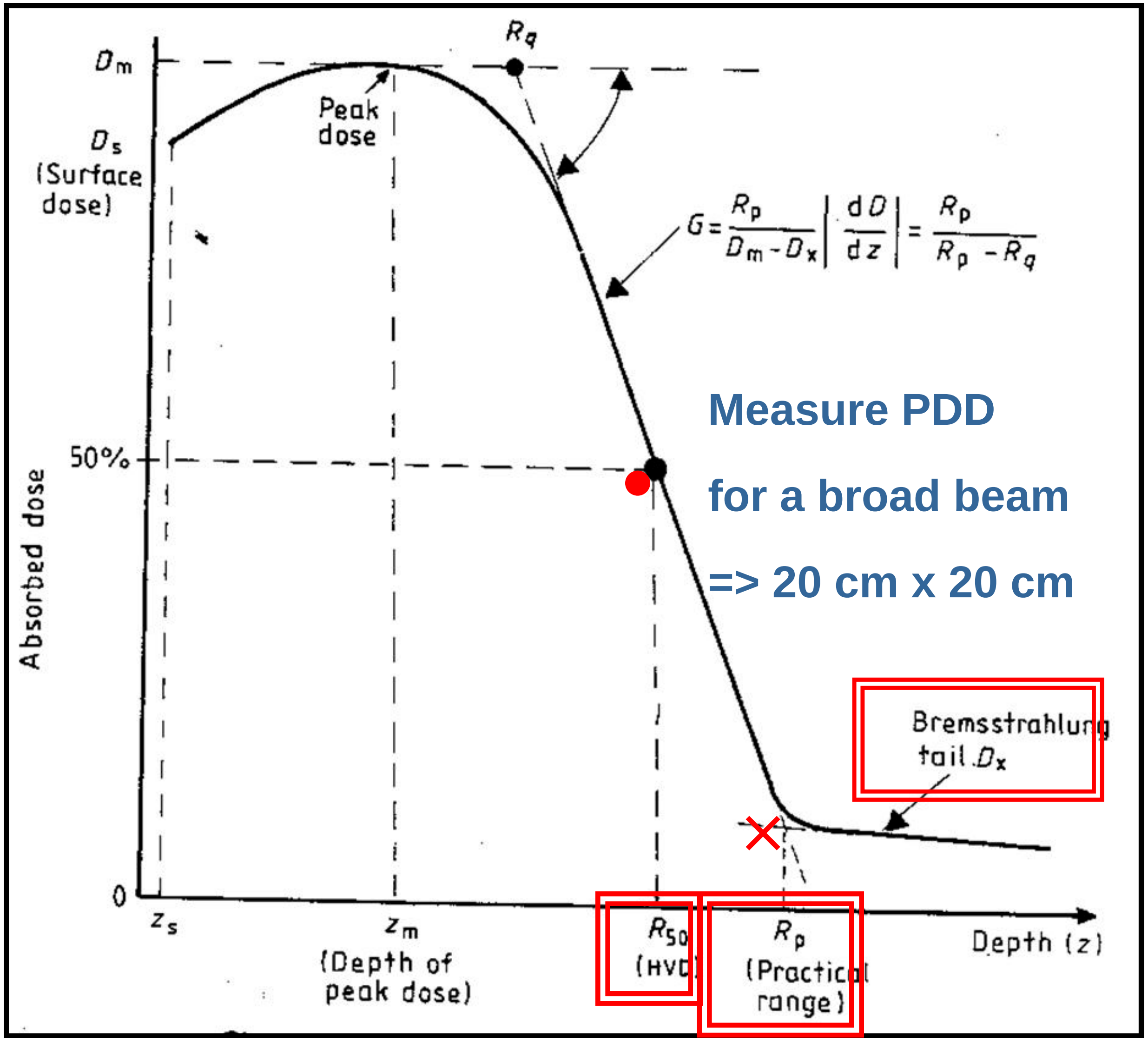
The Bragg-Gray Cavity: stopping power ratios



Energy specification and measurement



Energy specification and measurement



Measure PDD

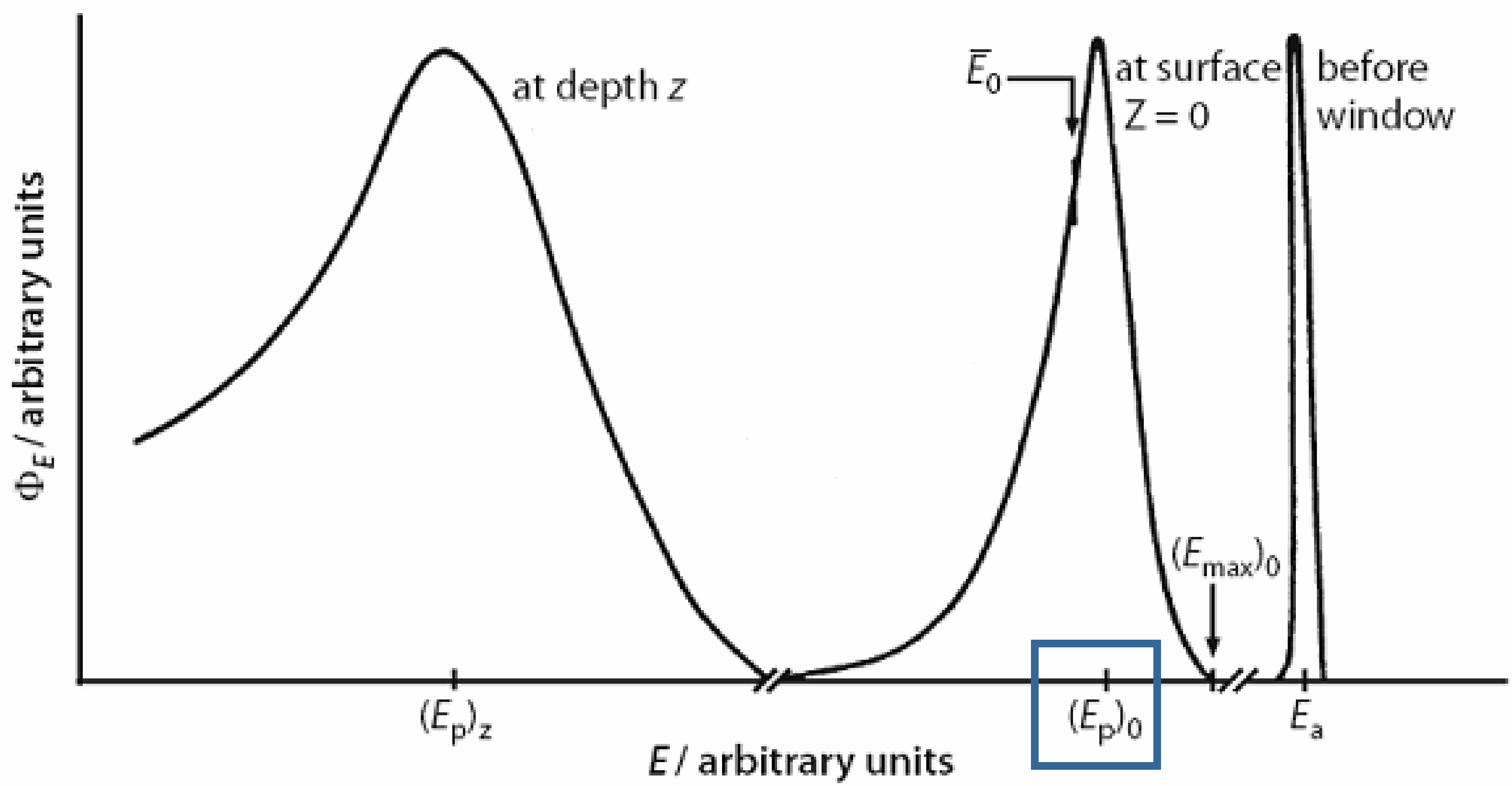
for a broad beam

=> 20 cm x 20 cm

Energy specification and measurement

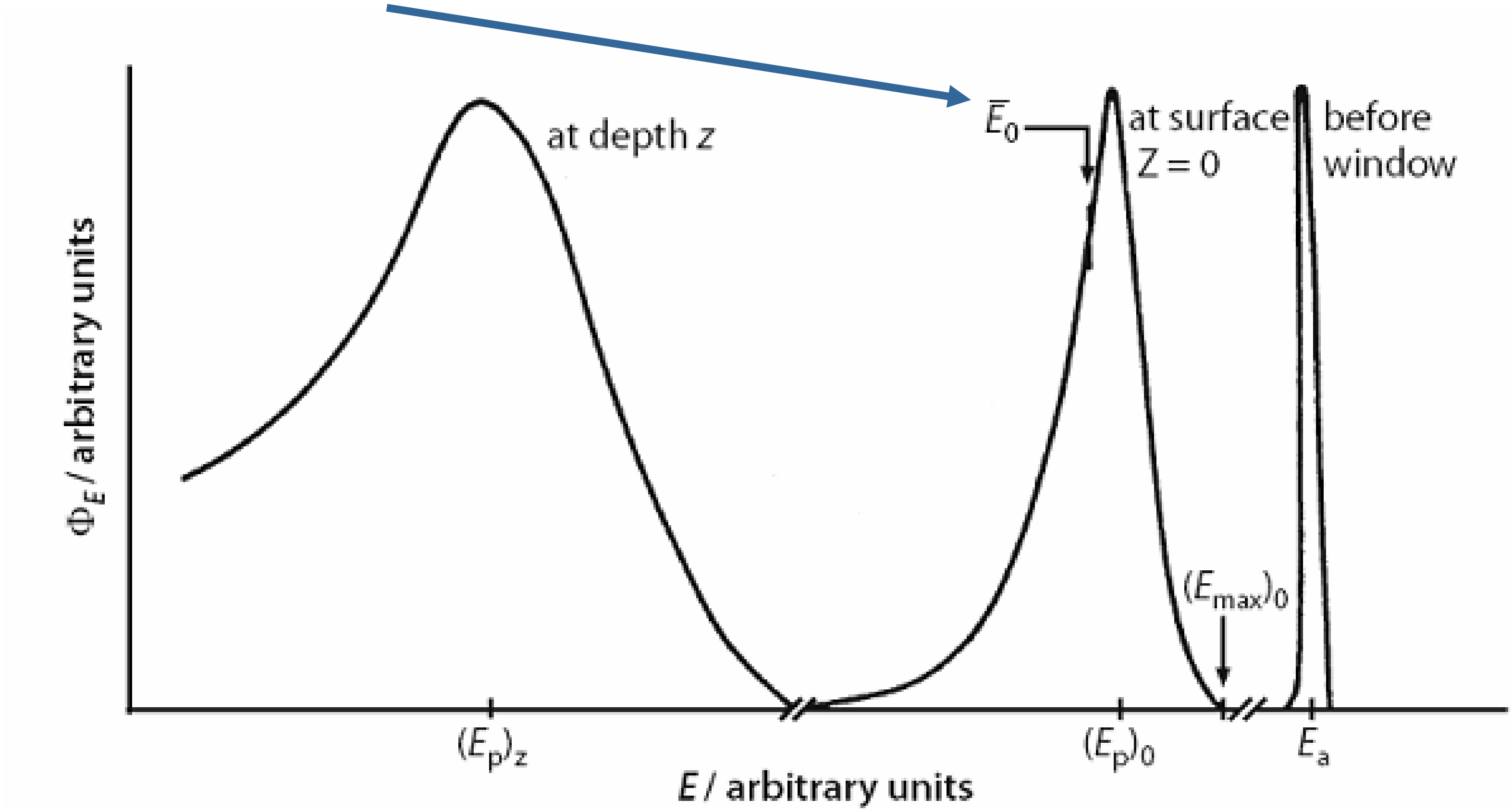
$$\left(E_p\right)_0 = C_1 + C_2 \times R_p + C_3 \times R_p^2,$$

$$C_1 = 0.22 MeV; C_2 = 1.98 MeVcm^{-1}; C_2 = 0.0025 MeVcm^{-2}$$



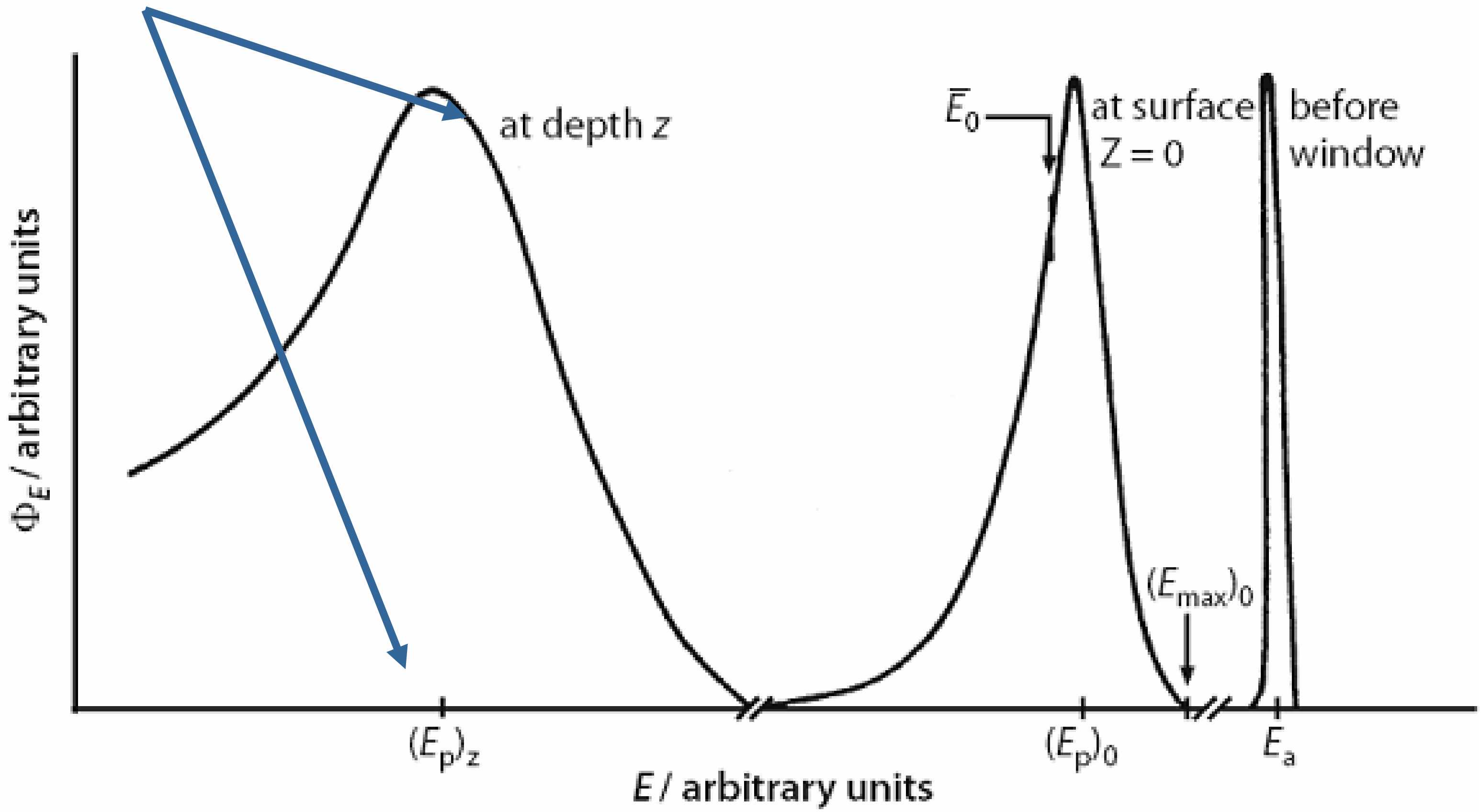
Energy specification and measurement

$$\overline{E_0} = (2.33 MeV / cm) \times R_{50}$$



Energy specification and measurement

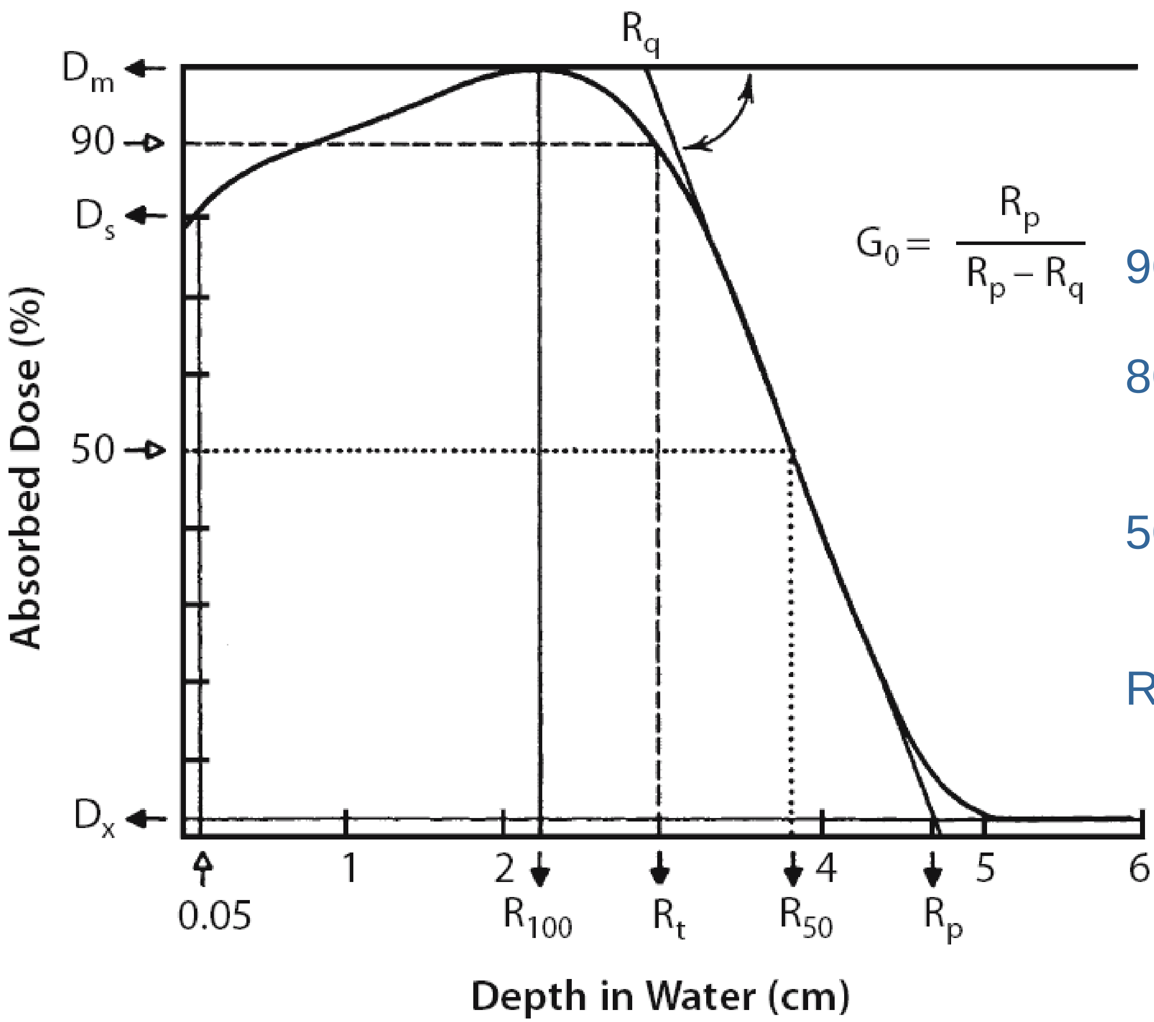
$$\left(E_p\right)_z = \left(E_p\right)_0 \left(1 - z / R_p\right)$$



Electron and Photon Beams

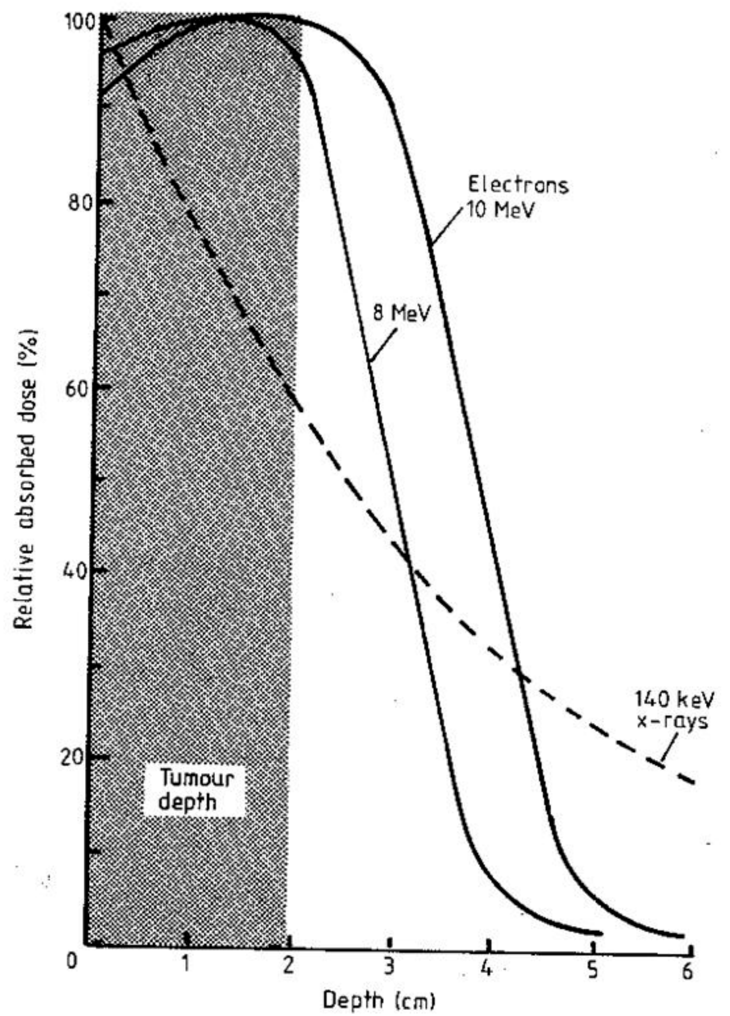
- Photon beams
  - indirectly ionizing
  - exponential attenuation
- Electron beams
  - directly ionizing
  - definite range

Electron Depth Dose: Rules of thumb



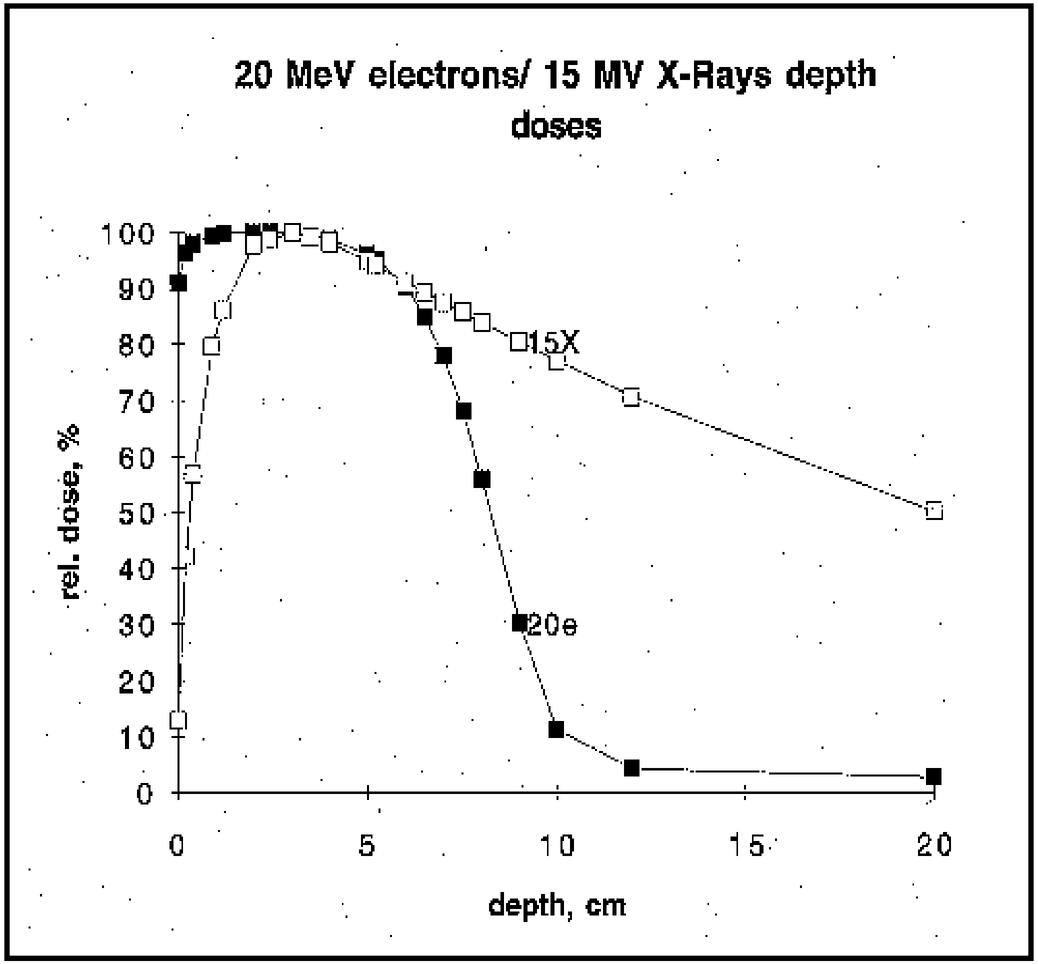
90%	(E/3.2) cm
80%	(E/2.8) cm
50%	(E/2.33) cm
R_p	(E/1.98) cm

Electron and Photon Depth Dose



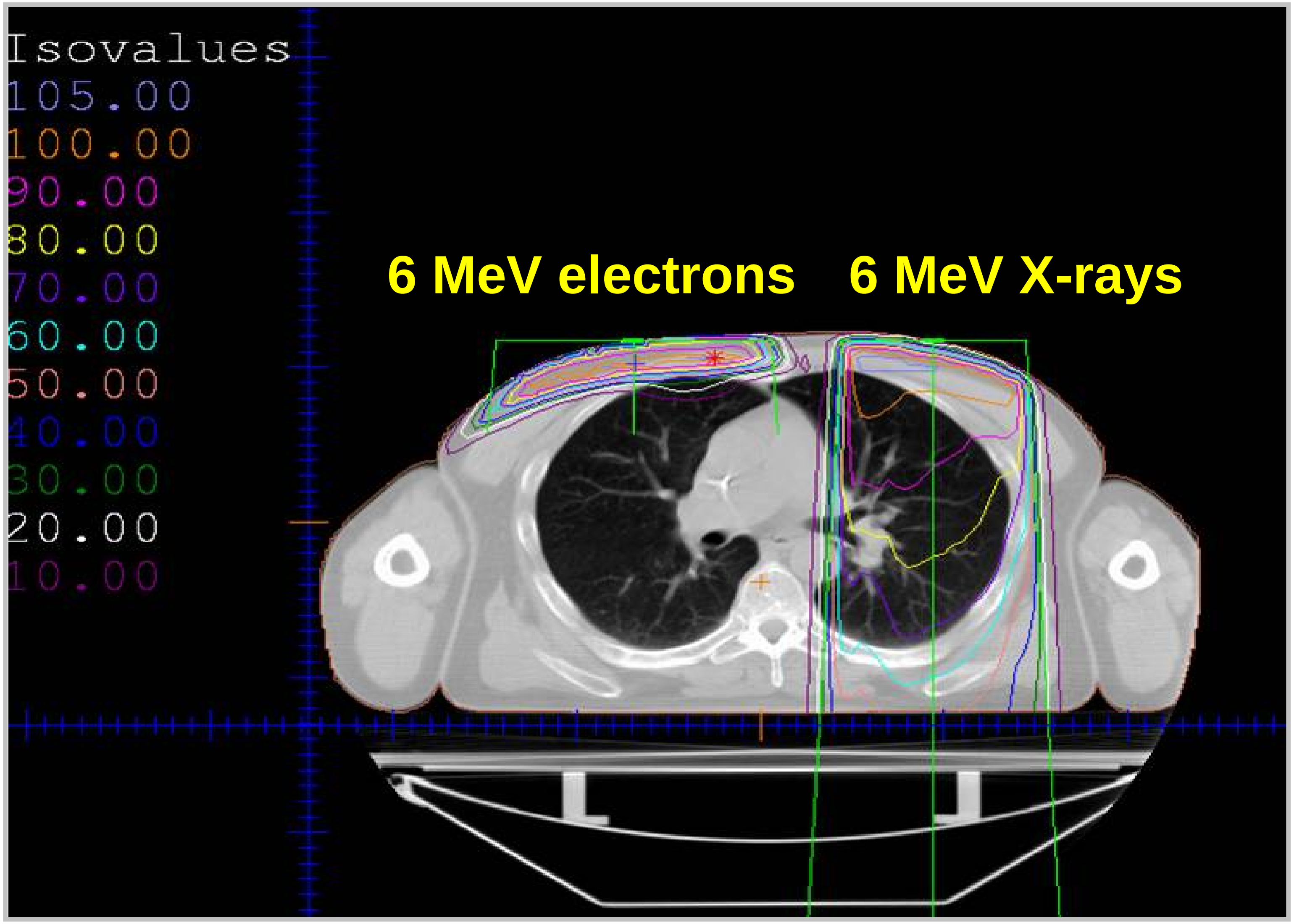
Comparison of the central axis distributions obtained with low-energy x-rays and electron beams.

Electron and Photon Depth Dose



Depth doses for 20 MeV electrons compared to 15 MeV X-Rays

Electron and Photon Depth Dose



Central Axis PDDs: field size dependence

6 MeV electrons

2x2

25x25

4x4

Little changes beyond field radius exceeding

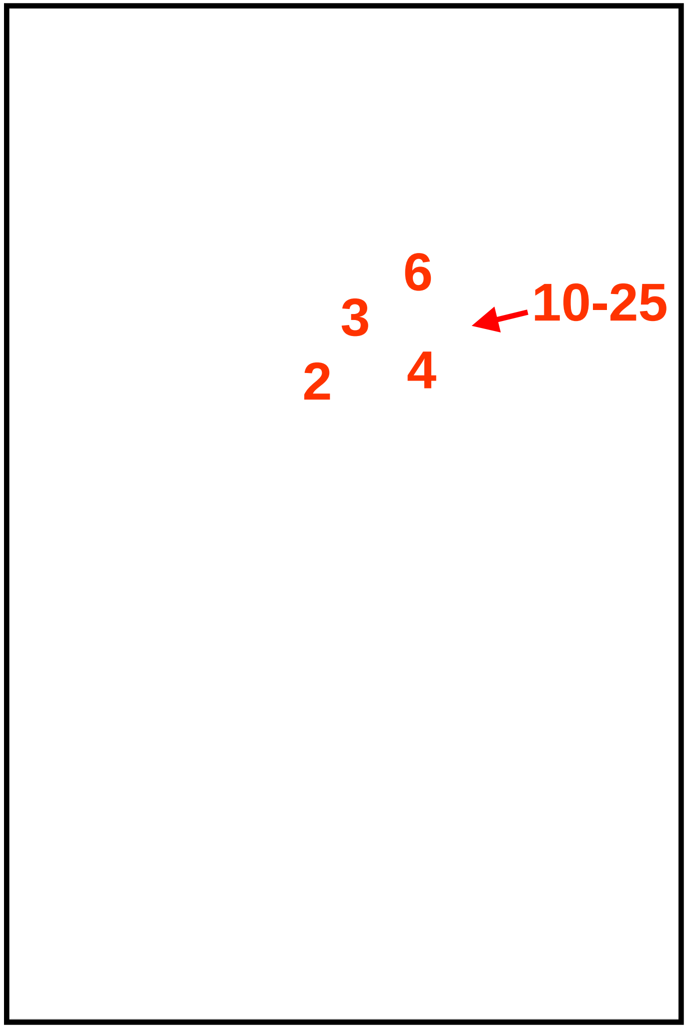
$$R_p \cong 0.88\sqrt{E_{p,0}}$$

Central Axis PDDs: field size dependence

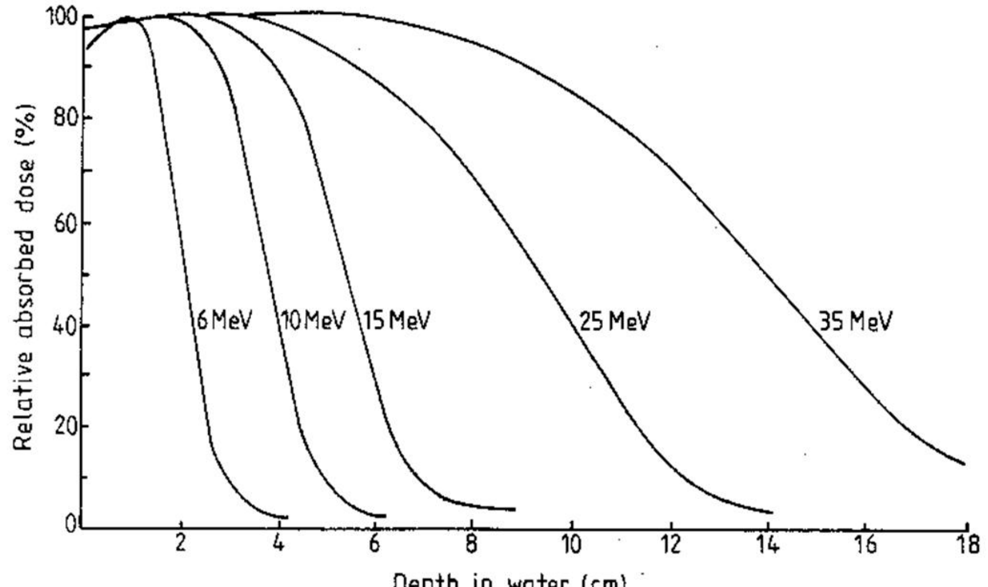
Little changes beyond field radius exceeding

$$R_p \cong 0.88\sqrt{E_{p,0}}$$

16 MeV electrons



Central Axis PDDs: energy dependence

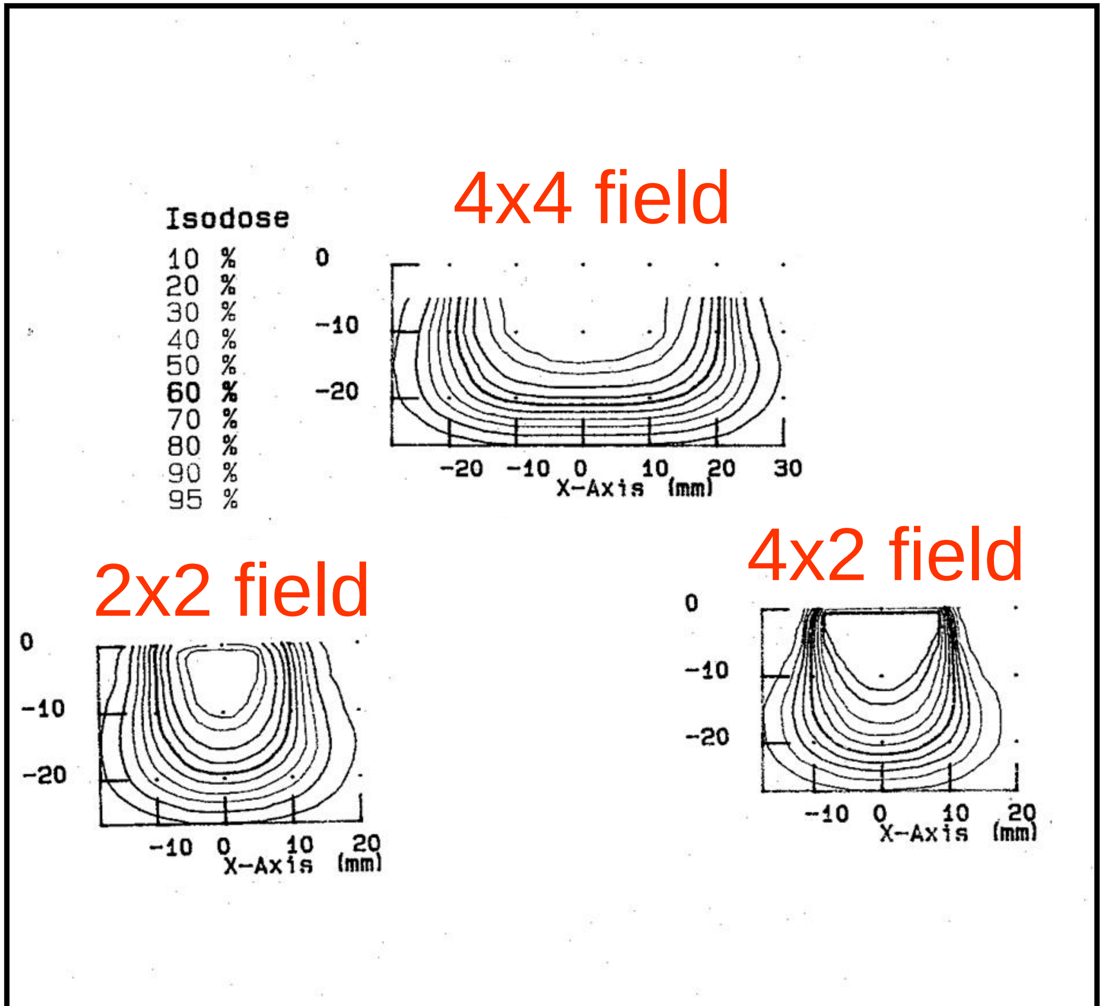


Central axis depth absorbed dose curves obtained at various electron beam energies.

Energy (MeV)	4	6	9	12	16	20
Surface Dose (% of maximum)	73.8	74.3	80.0	84.9	90.5	90.8

Electron Dose Distributions

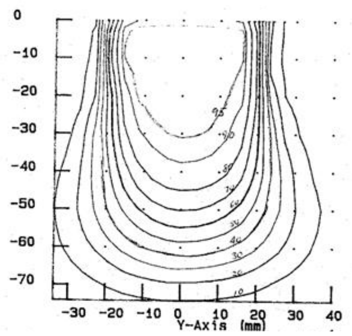
6 MeV electrons



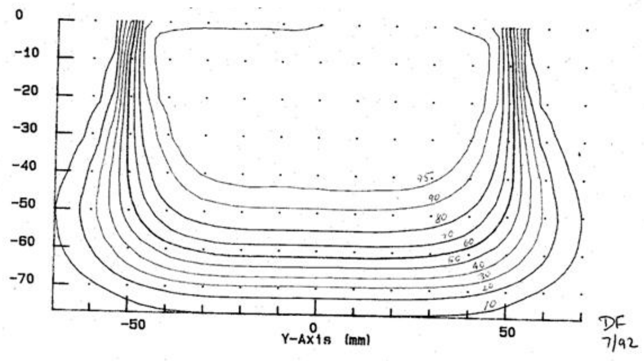
Electron Dose Distributions

16 MeV electrons

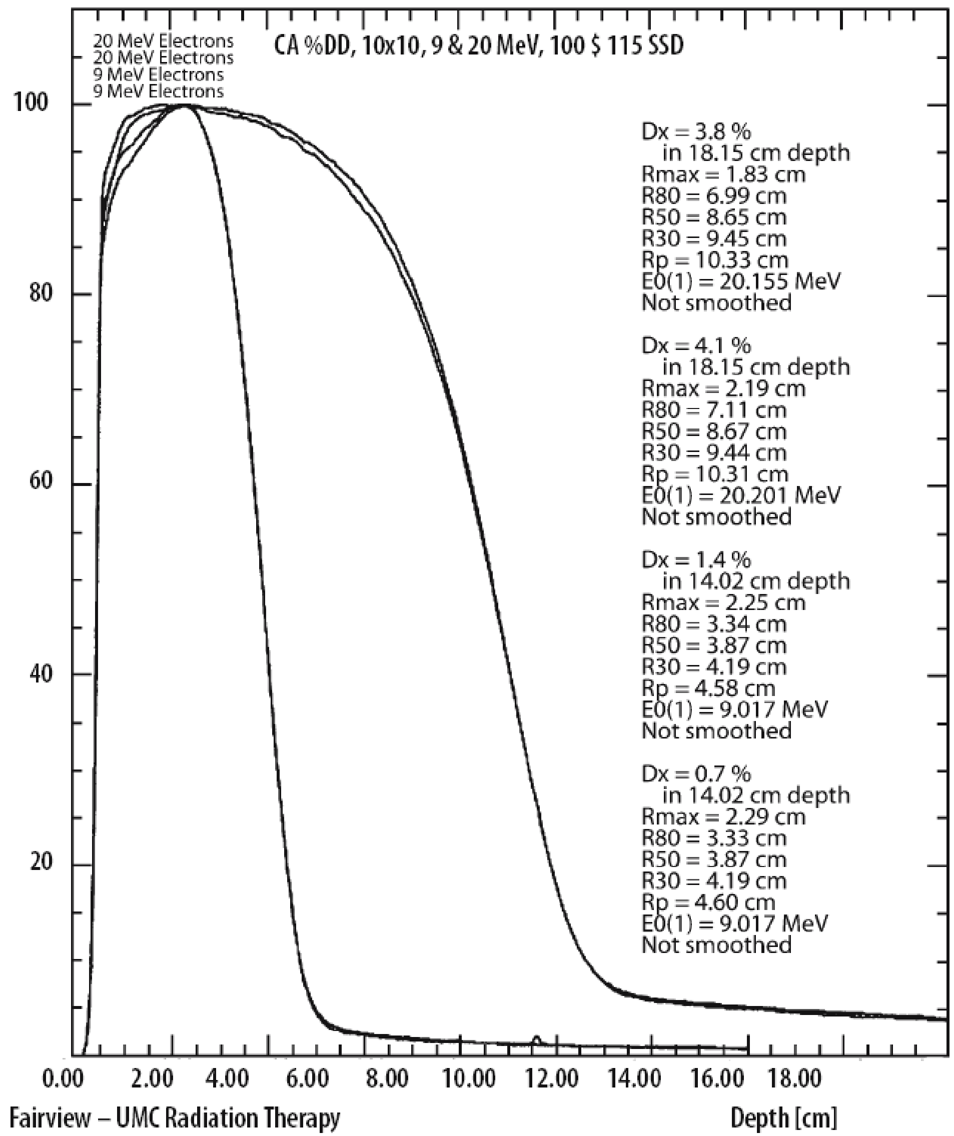
4x4 field



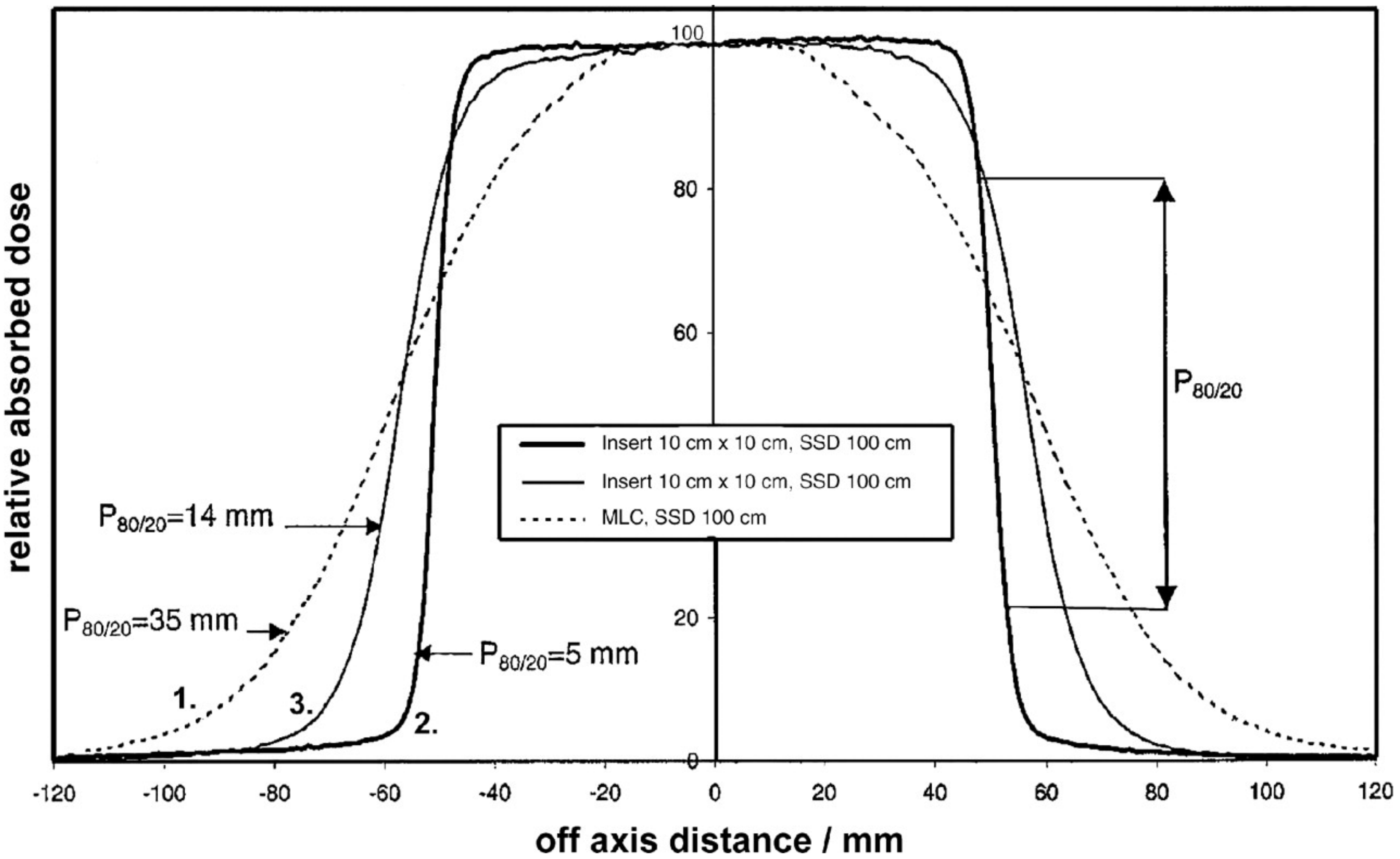
10x10 field



Central Axis PDD: SSD dependence

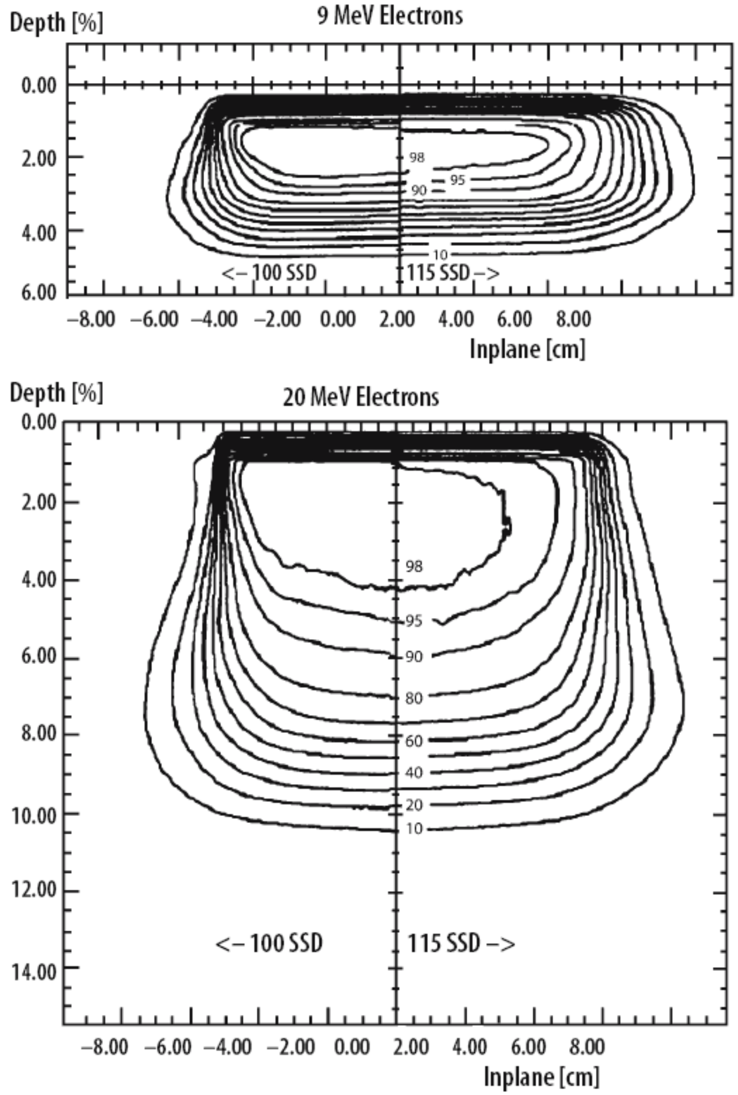


Profiles: SSD dependence



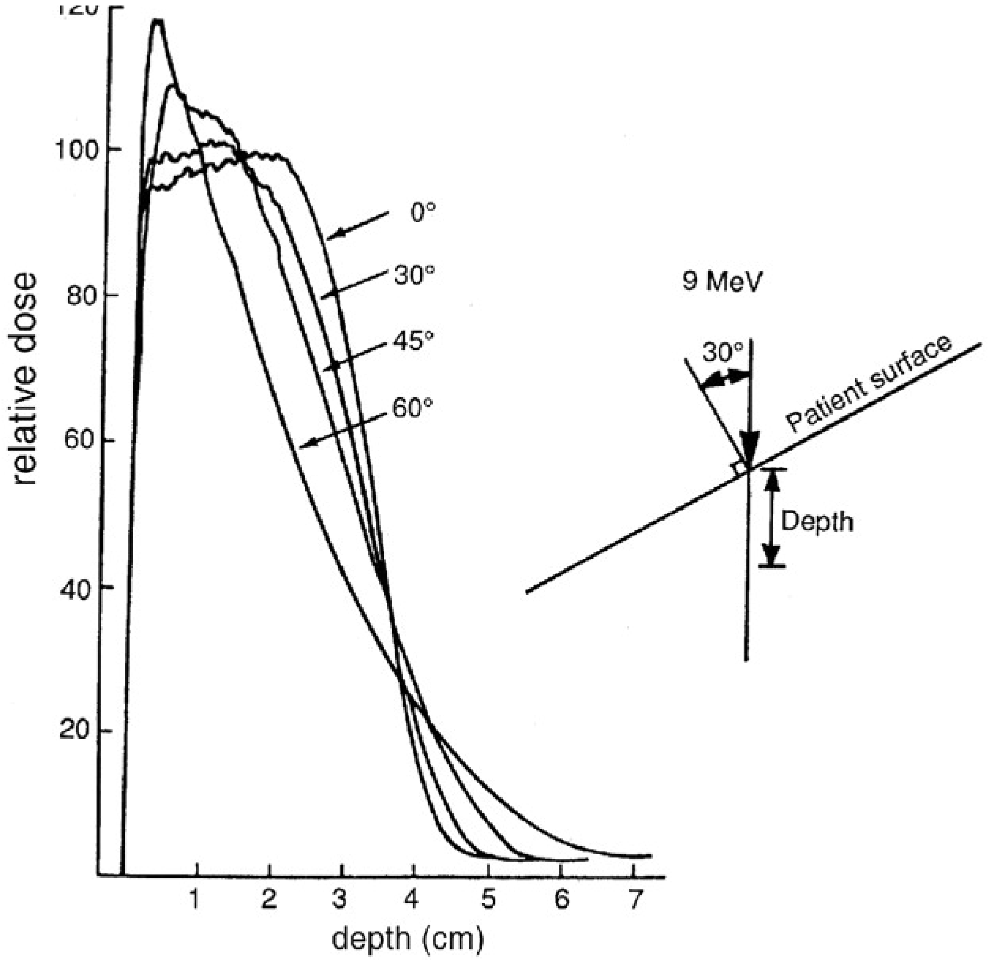
Dose profiles, at 15 mm depth at *E*p,0 = 9 MeV

Dose Distributions: SSD dependence



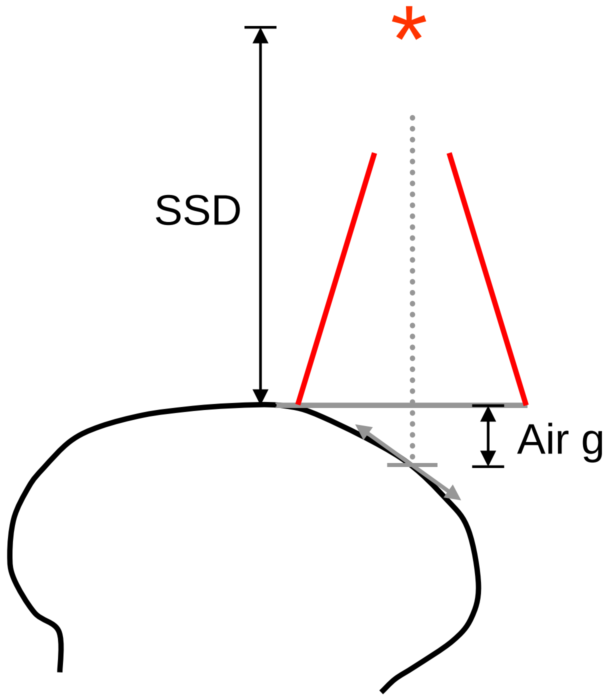
Increased penumbra

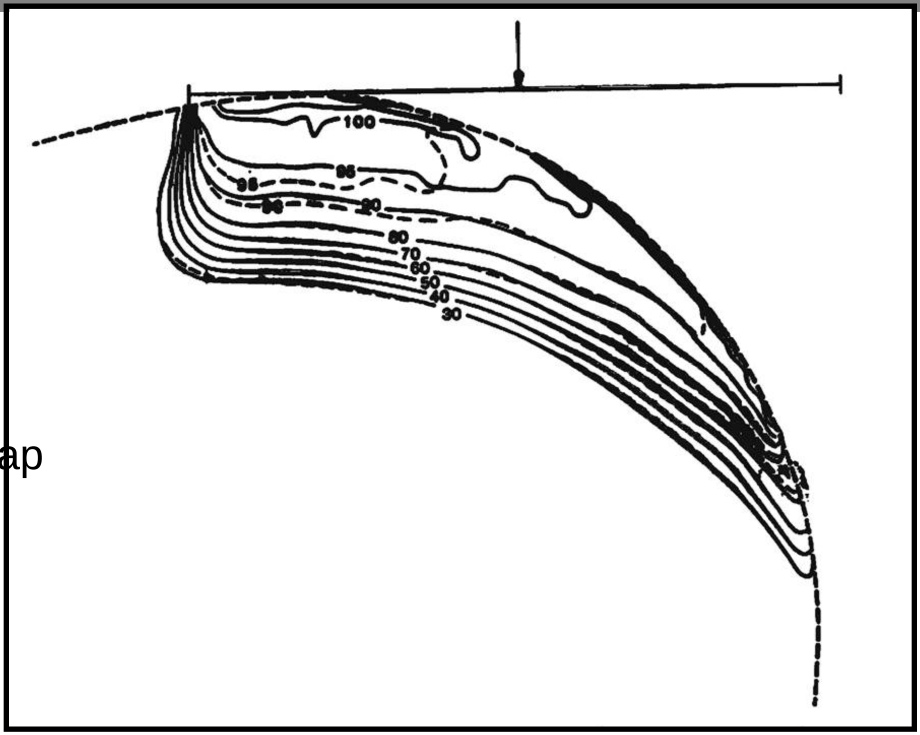
Angular dependence



Central axis depth dose curves plotted as a function of the angle of incidence of the beam

Curved Surface Dose Distributions



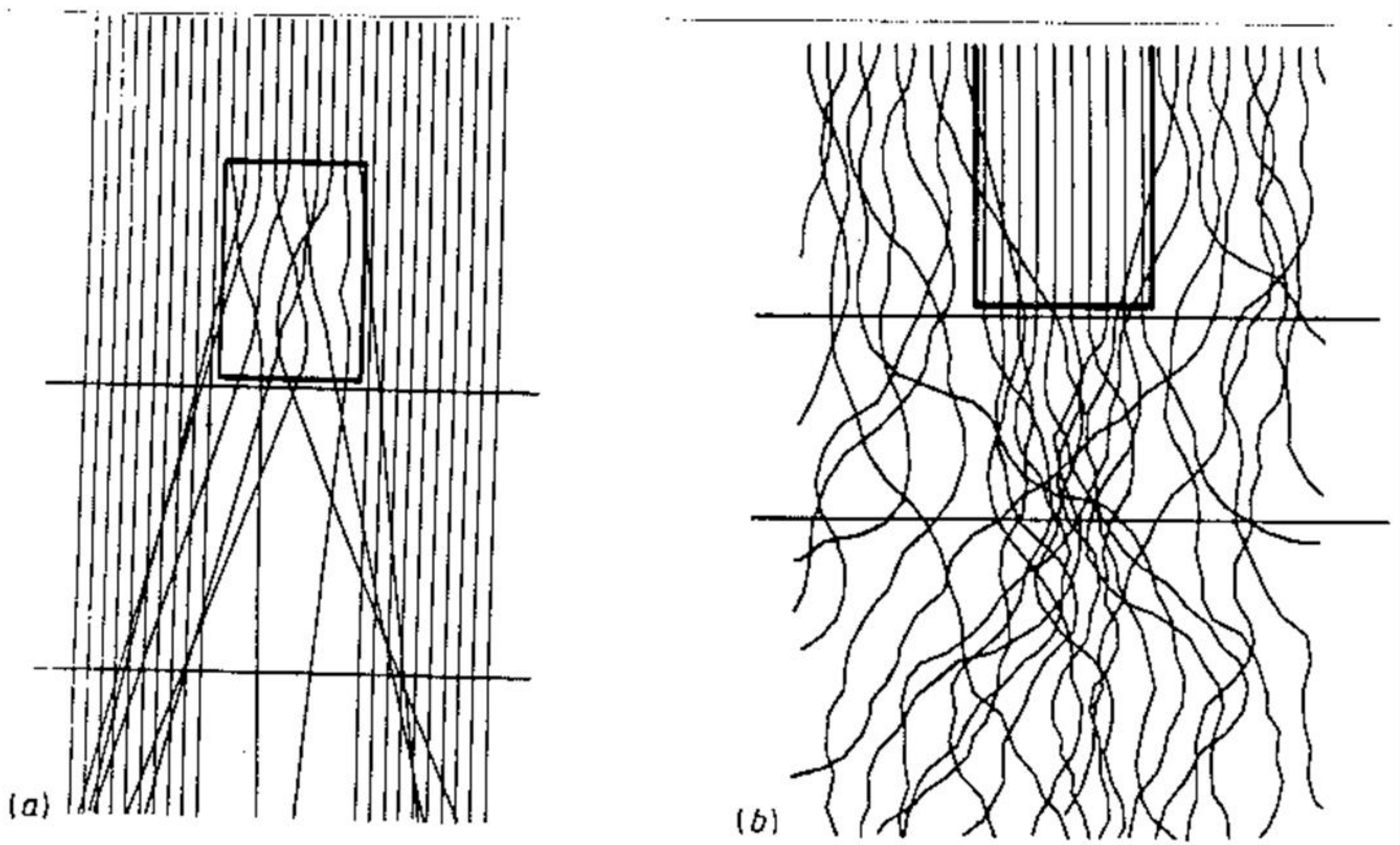


Must correct predicted dose distributions for:

- Scatter of electron beam in tissue (angular dependence)
- Air gap (inverse square falloff in exposure)

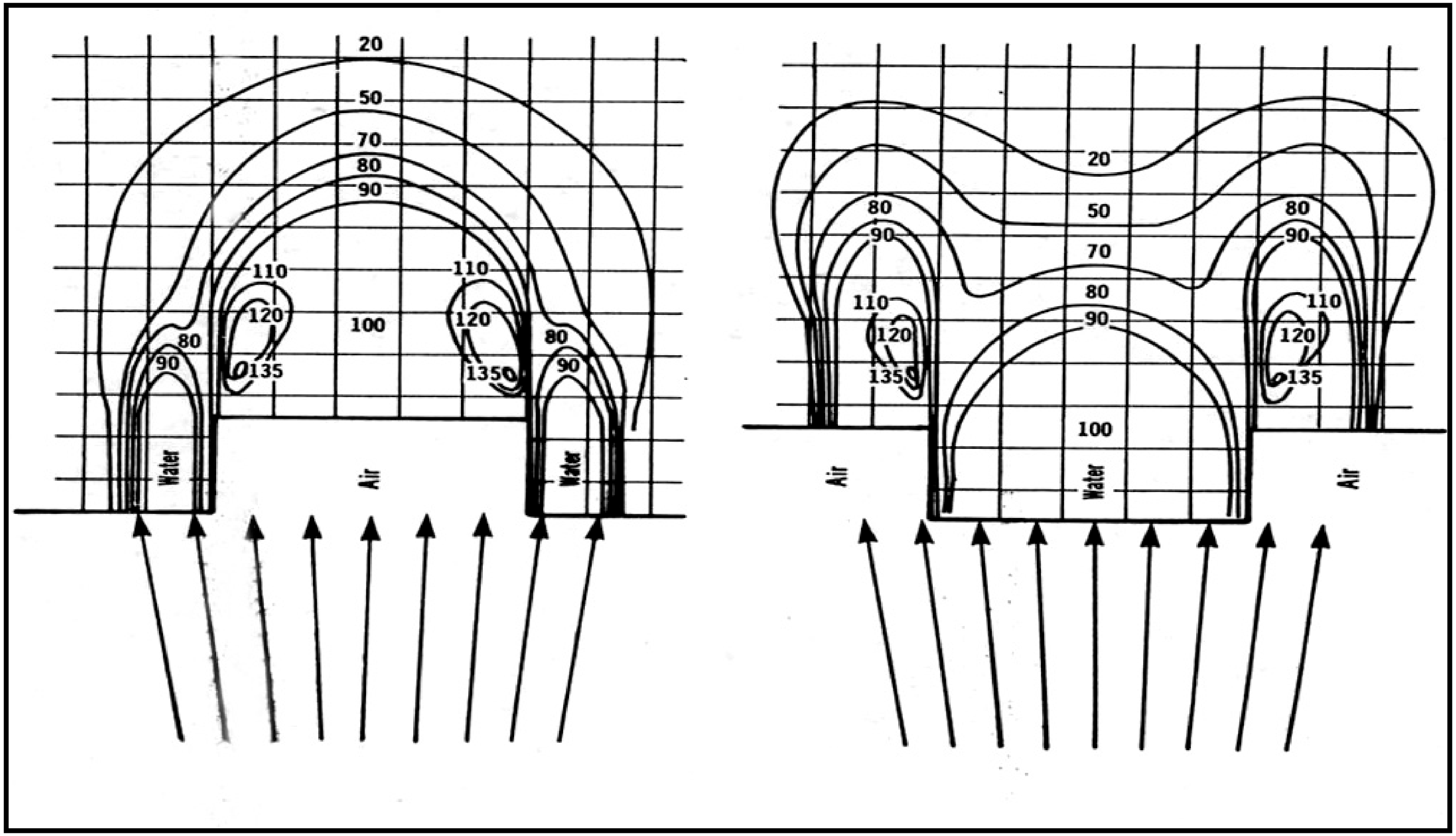
Water-equivalent materials can be used as “bolus” to smooth out uneven target surfaces

Tissue Inhomogeneity



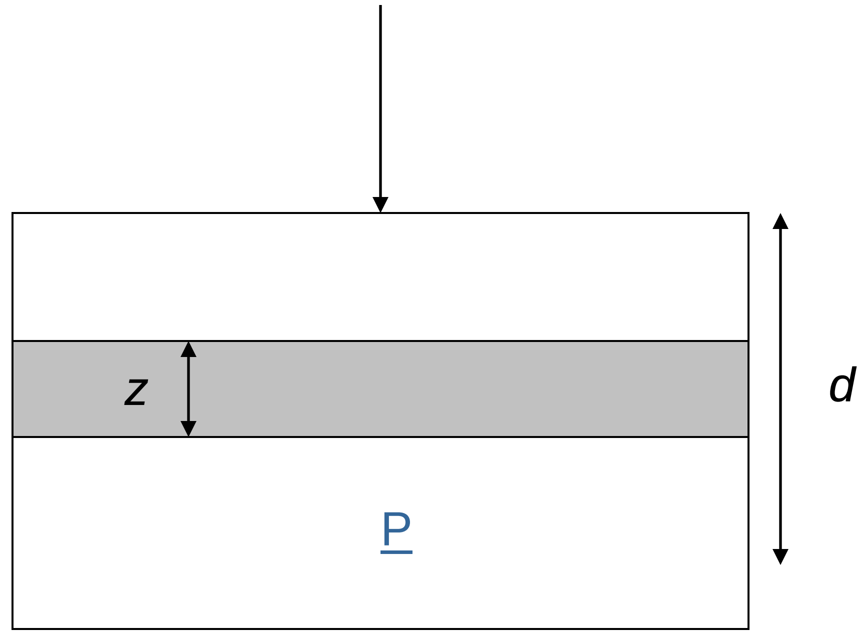
Electron fluence perturbation caused by scattering observed in (*a*) bone-type inhomogeneity and (*b*) air cavity in dense medium (adapted from Brenner 1969).

Irregular Surface Dose Distributions



Tissue Inhomogeneity

$$D_{eff} = d - z(1 - CET)$$



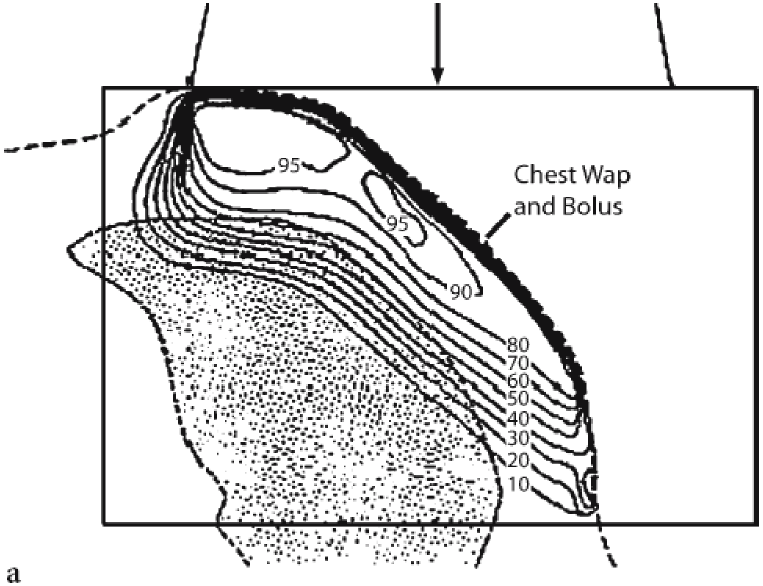
CET: Coefficient of Equivalent Thickness

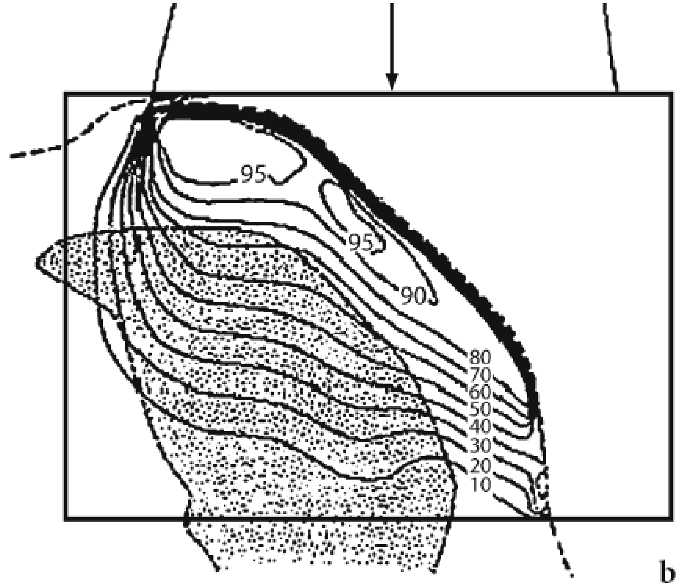
Compact bone CET: 1.65

Lung CET: 0.2-0.25

Tissue inhomogeneity

$$z_{lung} = z_{water} / \rho_{lung}$$

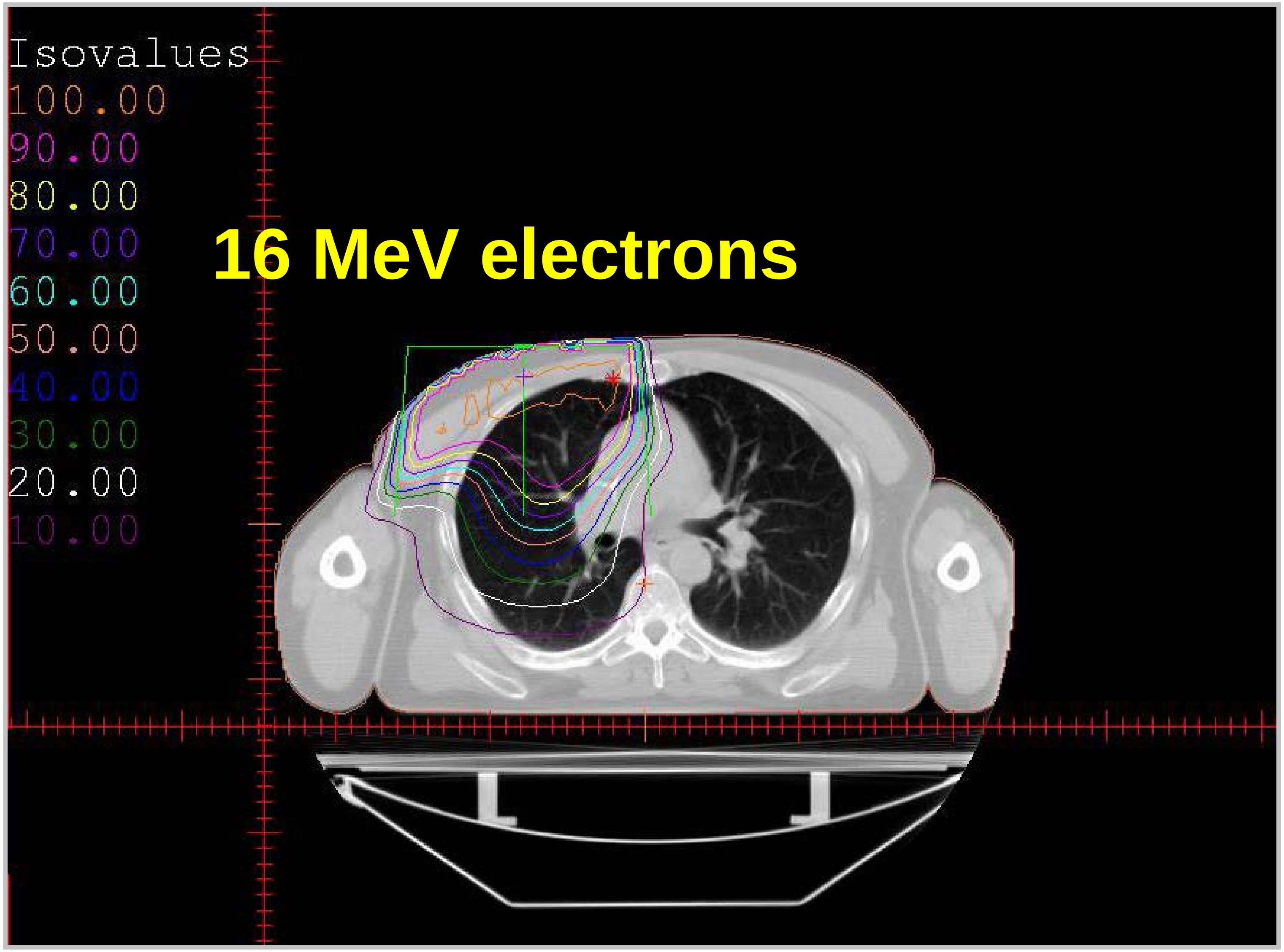




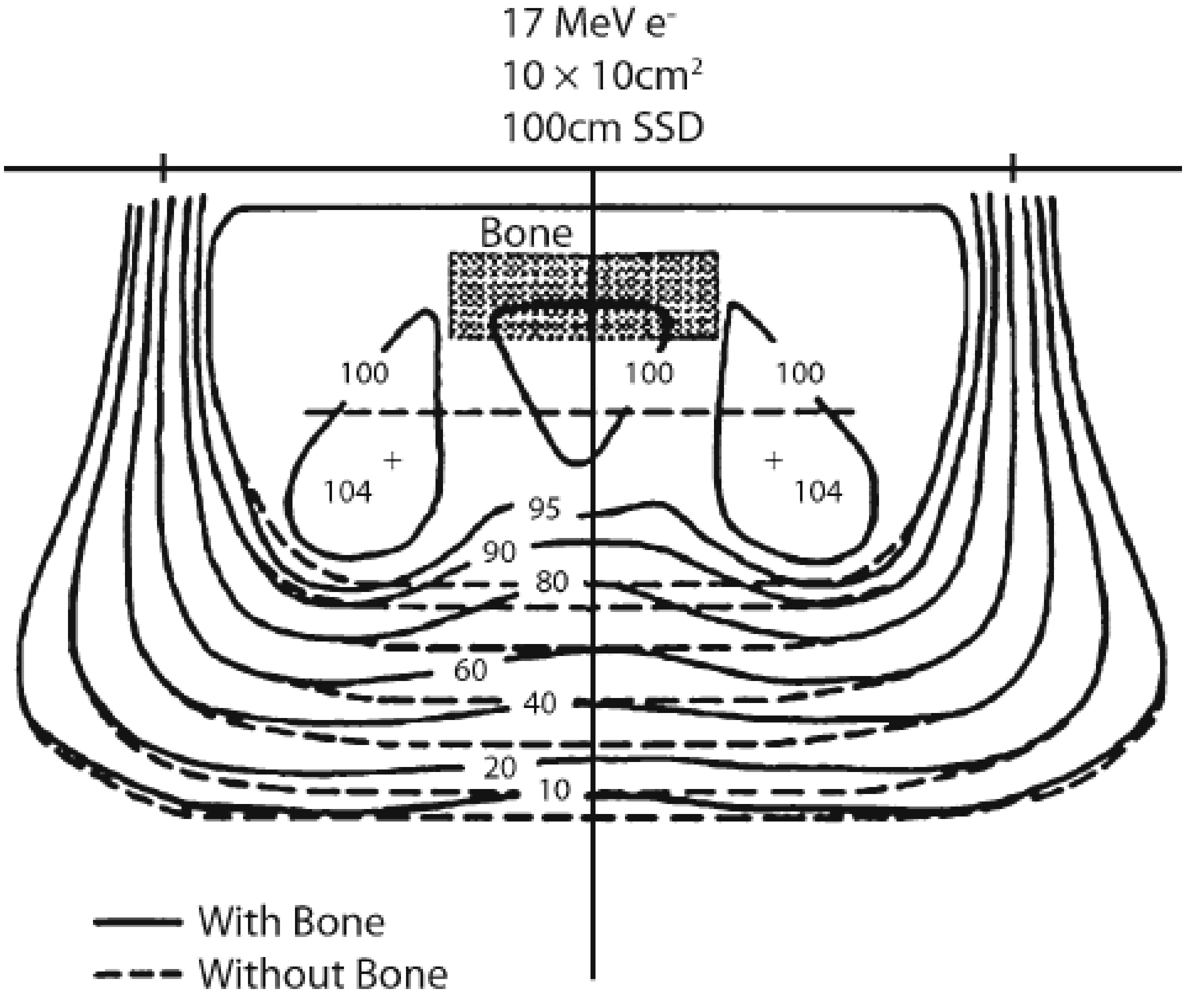
uncorrected calculation

corrected calculation

Tissue Inhomogeneity



Tissue Inhomogeneity



Lead shielding for electrons

Thickness (mm) = E (MeV)/2 +1

Electron Backscatter

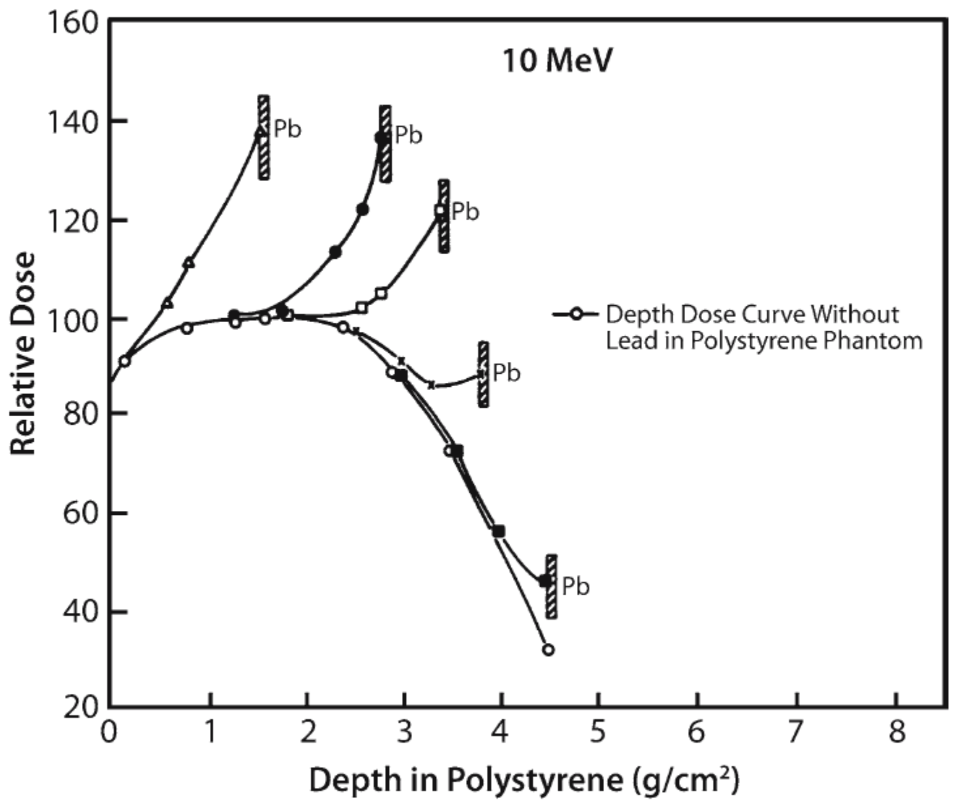
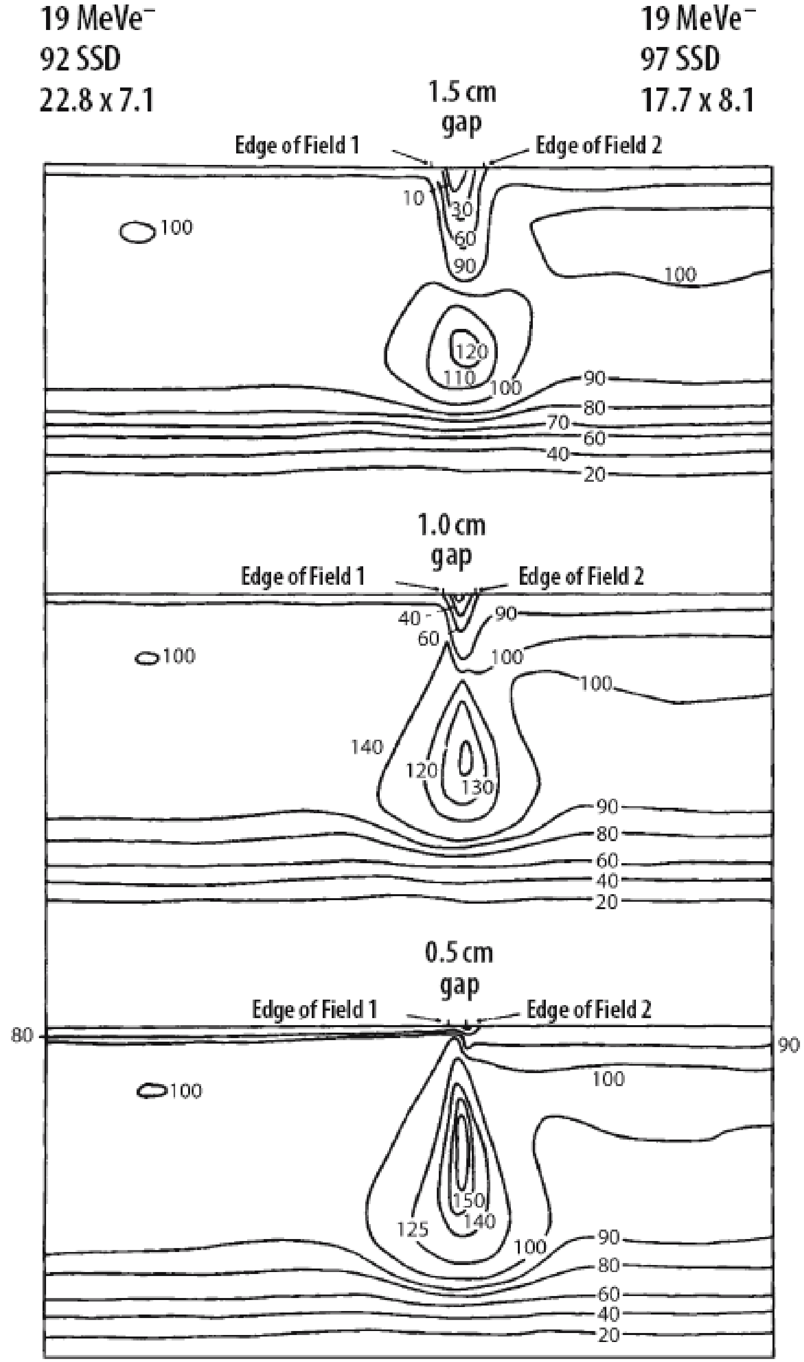


Fig. 7.18. Increase in the dose upstream from a lead shield thickness = 1.7 mm) at various depths in polystyrene. [Reprinted with permission from KHAN et al. (1976)]

Solution: place a low atomic number absorber (bolus) on the surface of the shield to absorb the dose due to backscatter


19 MeVe⁻
92 SSD
22.8 x 7.1
19 MeVe⁻
97 SSD
17.7 x 8.1
1.5 cm gap
Edge of Field 1
Edge of Field 2
10
30
60
90
100
100
120
110
100
90
80
70
60
40
20
1.0 cm gap
Edge of Field 1
Edge of Field 2
40
60
90
100
100
100
140
120
130
90
80
60
40
20
0.5 cm gap
Edge of Field 1
Edge of Field 2
80
90
100
100
150
140
125
100
90
80
60
40
20

Summary

- Electron beam depth dose characteristics offer advantages for treating superficial lesions
- Tissue inhomogeneities, and surface irregularities alter dose distributions significantly.
- Modern treatment planning systems and dose-calculation algorithms open the possibility of wider use of electron beams as a treatment modality.

Select the correct answer:

- The percent depth dose at 5 cm for a 6 MeV beam is approximately: 100%, 90%, 80%, 50%, <5%?
- To treat a lesion extending to a depth of 5 cm you will use: 6 MeV, 10 MeV, 15 MeV, 20 MeV?
- What is the approximate range of a 6 MeV beam in lung overlaying 1 cm of tissue: 1-3 cm, 7-9 cm, > 12 cm?
- A 4x8 cut-out is placed in a 10x10 beam cone for 20 MeV treatment. What changes is: 90% depth, cGy/MU, d_max, skin dose, all of the preceding?