Electron Beams:
Physical Principles and Dosimetry

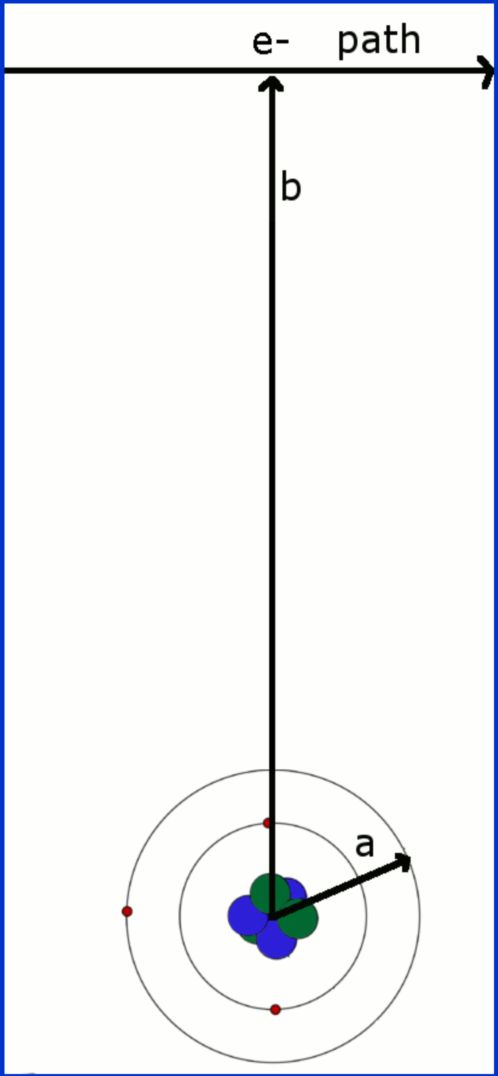
Kent A. Gifford, Ph.D.
Department of Radiation Physics
UT M.D. Anderson Cancer Center
kagifford@mdanderson.org

Medical Physics III: Spring 2015

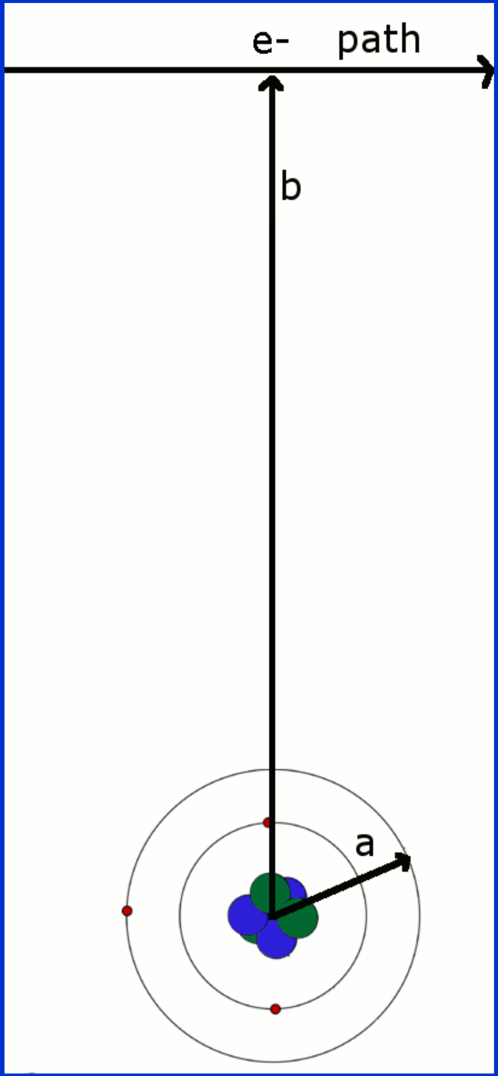
THE UNIVERSITY OF TEXAS
MD ANDERSON
CANCER CENTER

Physical aspects

Electron Interactions w/matter (b >> a)



Electron Interactions w/matter (b >> a)

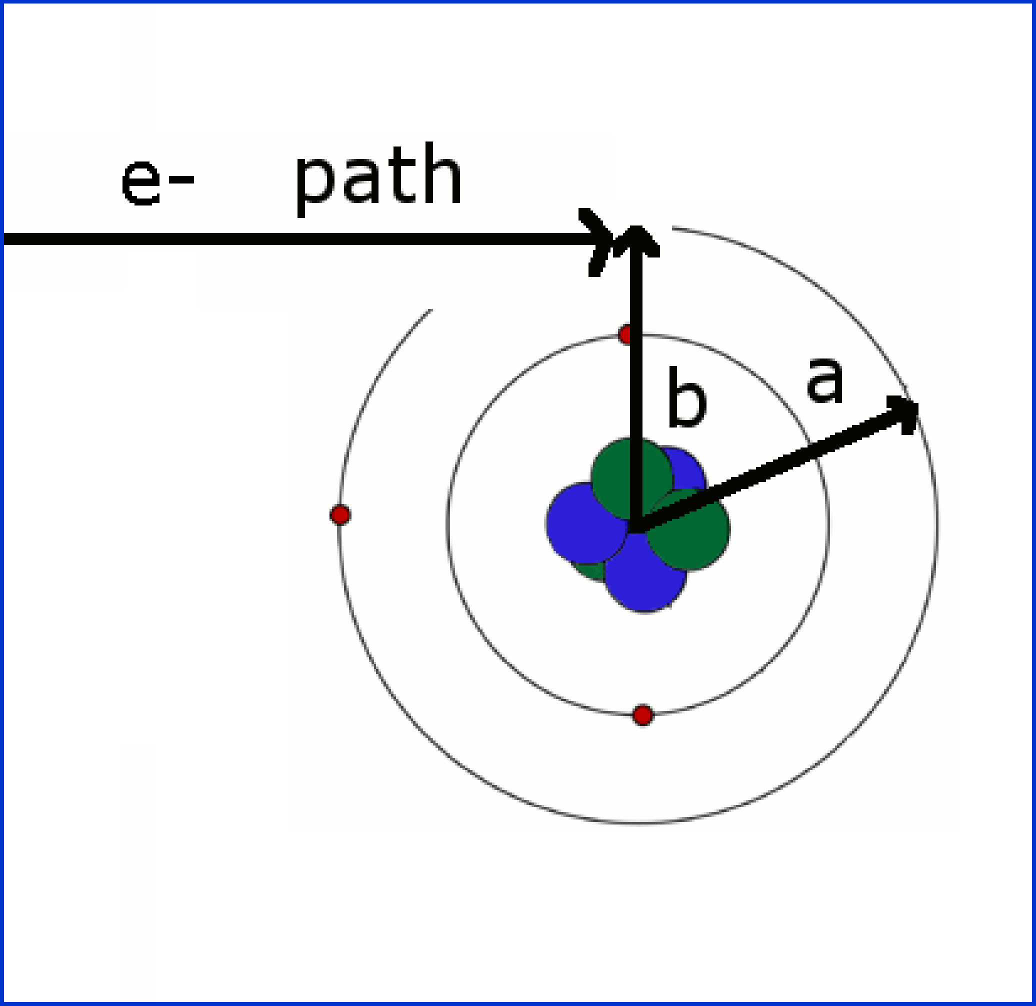


Coulomb force on atom resulting in:

- Ionization (ejection of valence e-)
- Excitation

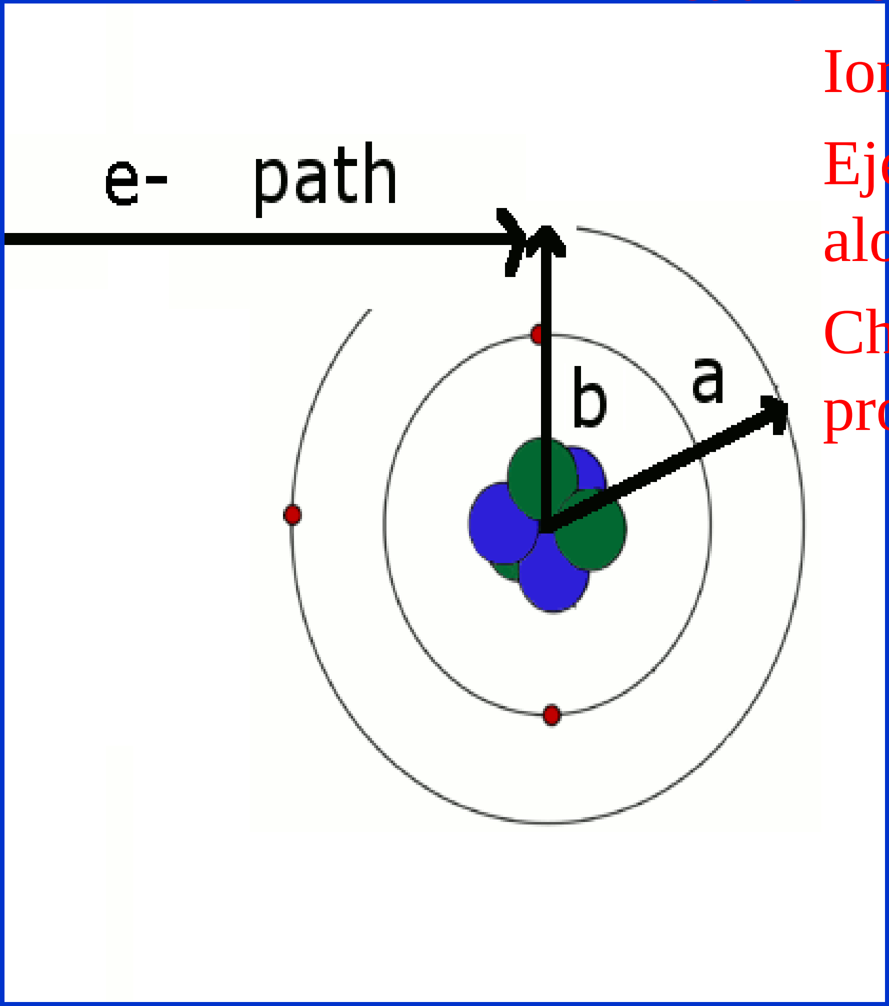
Termed “soft” interactions

Electron Interactions w/matter
(b ~ a)



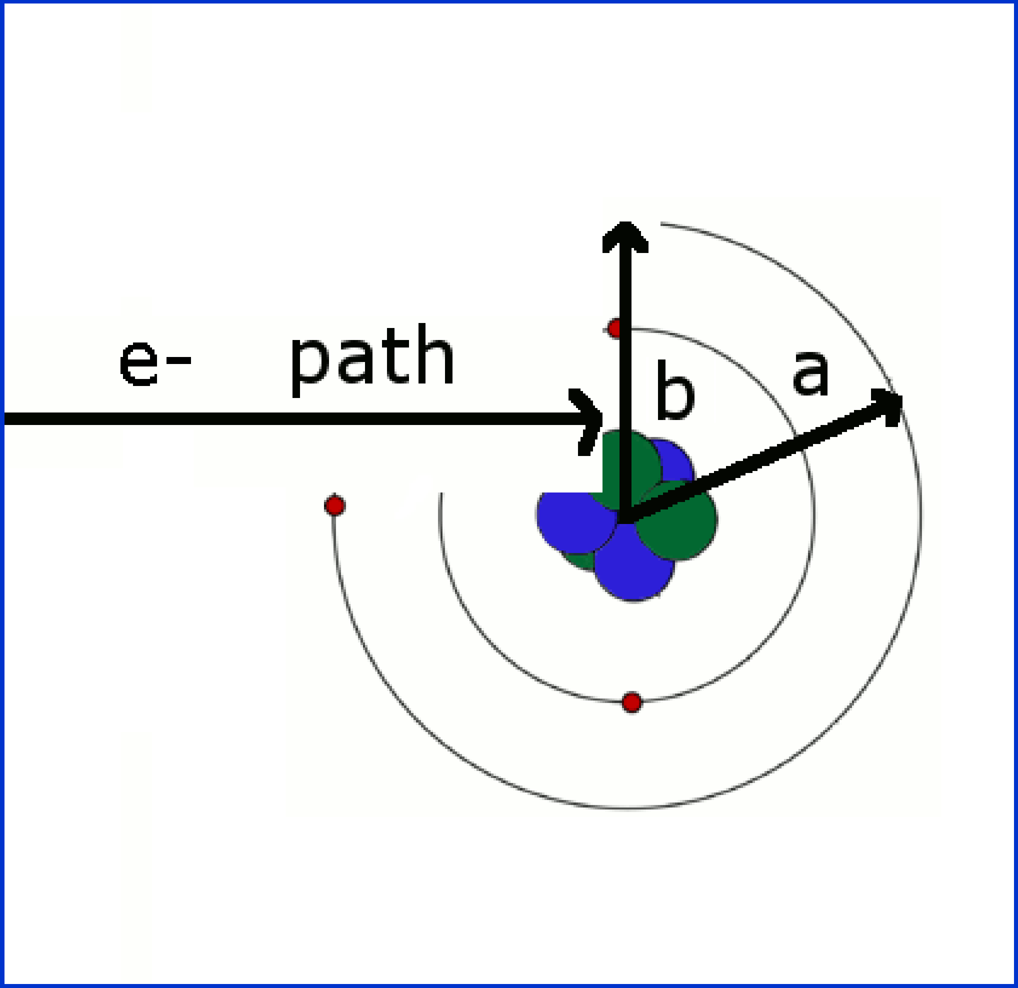
Electron Interactions w/matter

Head on collision resulting in:

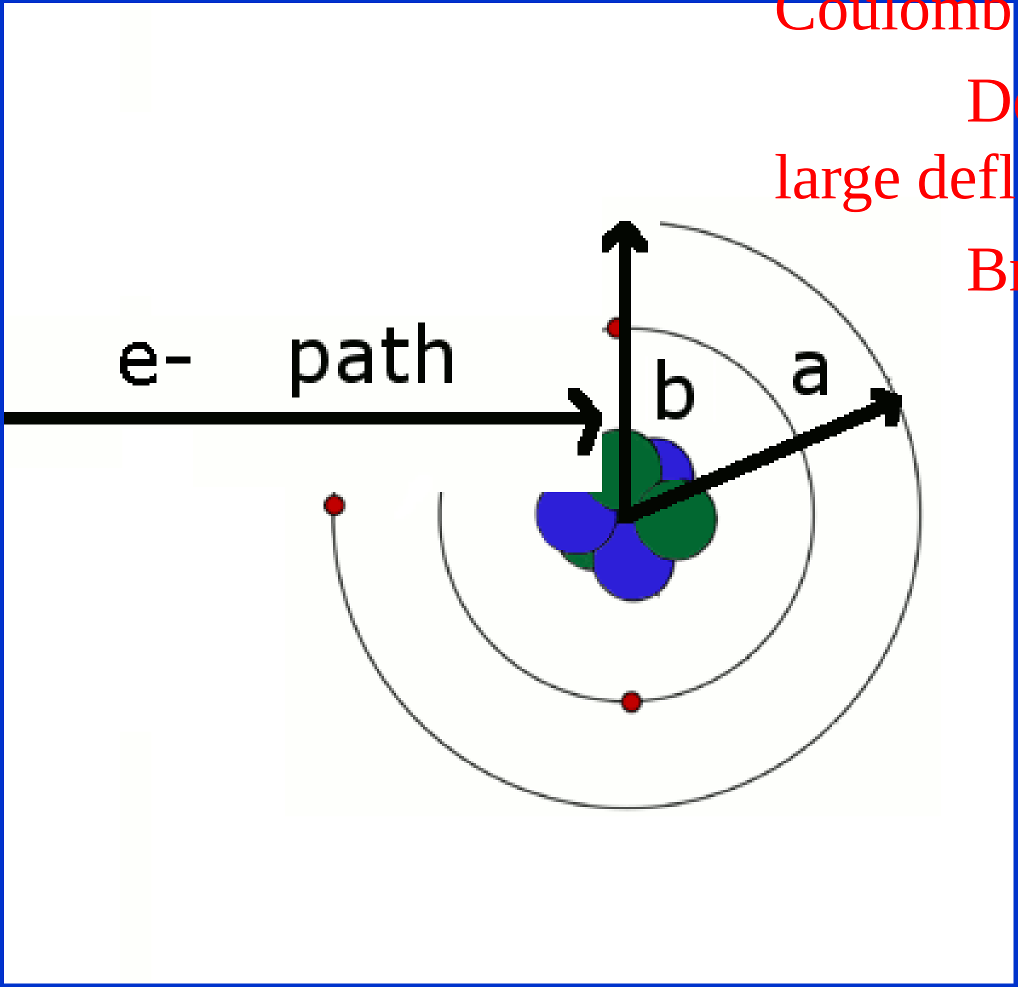


- Ionization (ejection of e- w/ high K.E.)
- Ejected e- (δ ray) dissipates energy along its path
- Characteristic X-ray or Auger e- produced

Electron Interactions w/matter
(b << a)



Electron Interactions w/matter (b << a)



Coulomb interaction resulting in:

Deflection of primary e-, large deflection

Bremmstrahlung

Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_ec^2)^2}\right] + F(\tau) - \delta - \frac{2C}{Z}\right\}$$

$$F^-(\tau) \equiv 1 - \beta^2 + \frac{\tau^2/8 - (2\tau+1)ln2}{(\tau+1)^2}$$

$$\tau = \left(\frac{T}{m_ec^2}\right)$$

Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_e c^2)^2}\right]+F(\tau)-\delta-\frac{2C}{Z}\right\}$$

- For what do the four terms in the brackets account?

Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_ec^2)^2}\right]+F(\tau)-\delta-\frac{2C}{Z}\right\}$$

- For what do the four terms in the brackets account?
  - First term- soft collisions

Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_ec^2)^2}\right]+F(\tau)-\delta-\frac{2C}{Z}\right\}$$

- For what do the four terms in the brackets account?
  - First term- soft collisions
  - Second term- Möller (e-) or Bhabha (e+) scattering (hard coll.)

Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_e c^2)^2}\right] + F(\tau) - \delta - \frac{2C}{Z}\right\}$$

- For what do the four terms in the brackets account?
  - First term- soft collisions
  - Second term- Möller (e-) or Bhabha (e+) scattering (hard coll.)
  - Third term- density effect
    - Condensed medium stopping power reduced due to atoms closer to particle polarized and screen distant atoms from particle's electric field

Electron Interactions w/ matter Stopping power

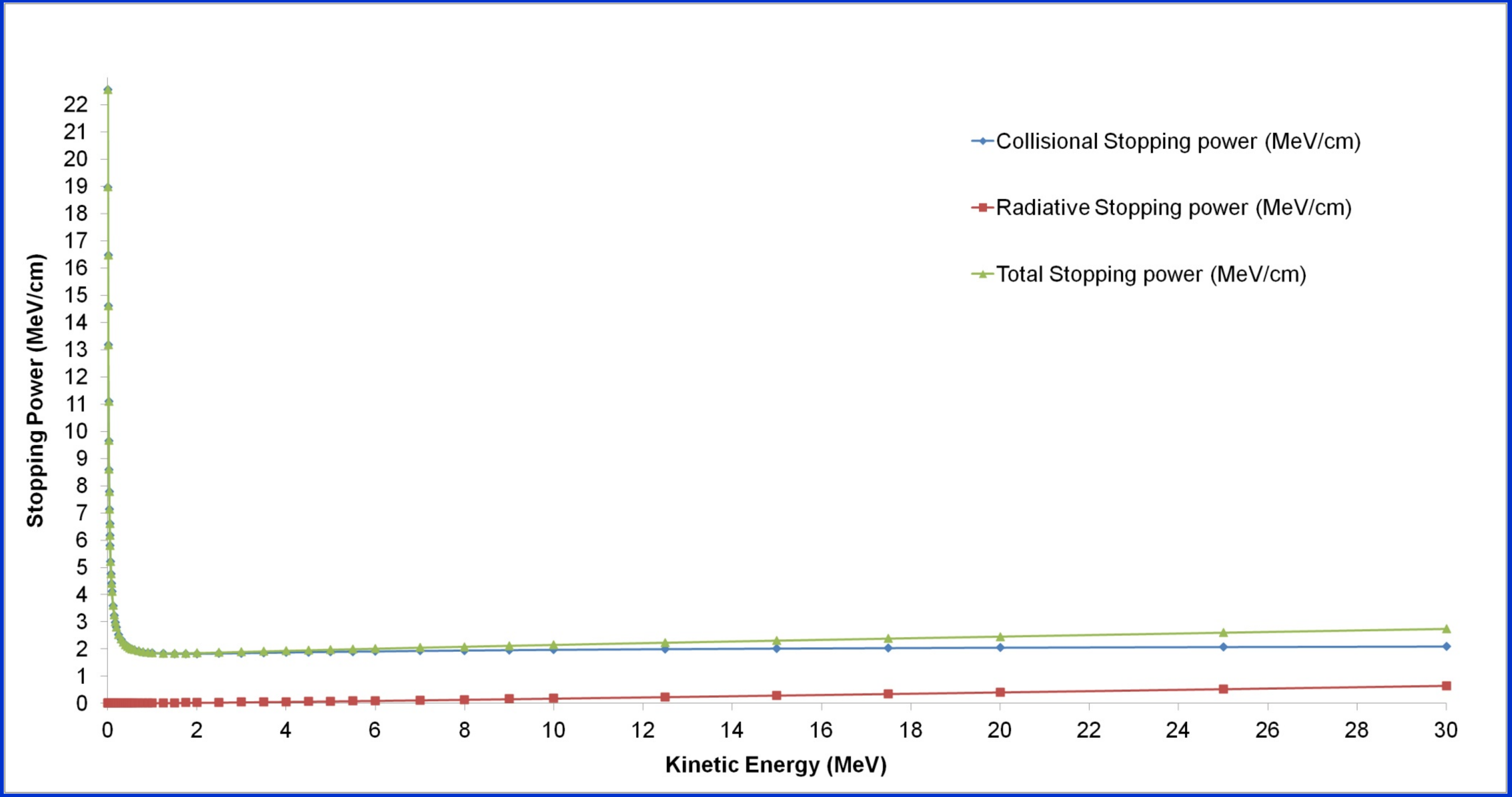
$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{coll} = 0.1535\frac{1}{\beta^2}\left\langle\frac{Z}{A}\right\rangle\left\{ln\left[\frac{\tau^2(\tau+2)}{2(I/m_e c^2)^2}\right]+F(\tau)-\delta-\frac{2C}{Z}\right\}$$

- For what do the four terms in the brackets account?
  - First term- soft collisions
  - Second term- Möller (e-) or Bhabha (e+) scattering (hard coll.)
  - Third term- density effect
  - Fourth term- shell correction
    - Born approximation did not account for binding energy of electrons

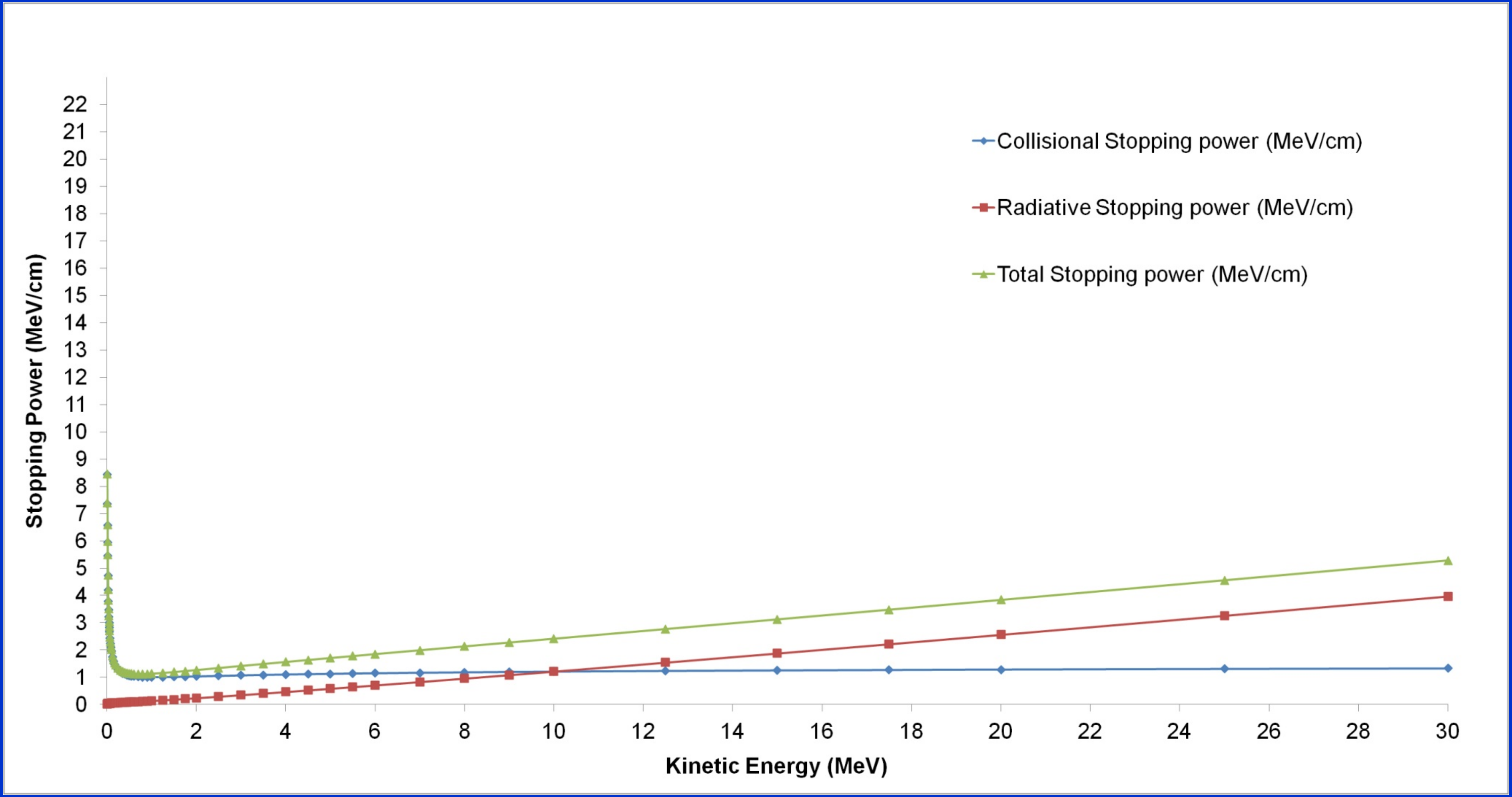
Electron Interactions w/ matter
Stopping power

$$\frac{1}{\rho}\left(\frac{dE}{ds}\right)_{rad} = \sigma_0 \frac{N_A Z^2}{A}\left(T + m_0 c^2\right)\overline{B_r}$$

Electron Interactions w/ matter
Stopping power



Electron Interactions w/ matter
Stopping power



Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on the interacting medium?

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on the interacting medium?
  - Z/A

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on the interacting medium?
  - Z/A
  - -ln I

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on the interacting medium?
    - Z/A
    - ln I
        - Which is greater S_{coll}/ρ (Pb or Be) at 20 MeV?

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on the interacting medium?
  - Z/A
  - ln I
    - Which is greater S_{coll}/ρ (Pb or Be) at 20 MeV?
      - Be 1.623 MeV cm^2 g^{-1} vs. Pb 1.277 MeV cm^2 g^{-1}

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle velocity?

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle velocity?
  - $1/\beta^2$

Electron Interactions w/ matter
Stopping power

- How do does S_{coll}/ρ depend on particle velocity?
  - $1/\beta^2$
  - This is the reason for the steep rise in S_{coll}/ρ and Bragg peak (Heavy ions)

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle mass and charge?

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle mass and charge?
  - None

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle mass and charge?
  - None
  - z^2

Electron Interactions w/ matter
Stopping power

- How does S_{coll}/ρ depend on particle mass and charge?
  - None
  - z^2

Electron Interactions w/ matter
Range

- What is the Range, R, of a charged particle?

Electron Interactions w/ matter
Range

- What is the Range, R, of a charged particle?
  - Expectation value of pathlength, <p>, until it comes to rest

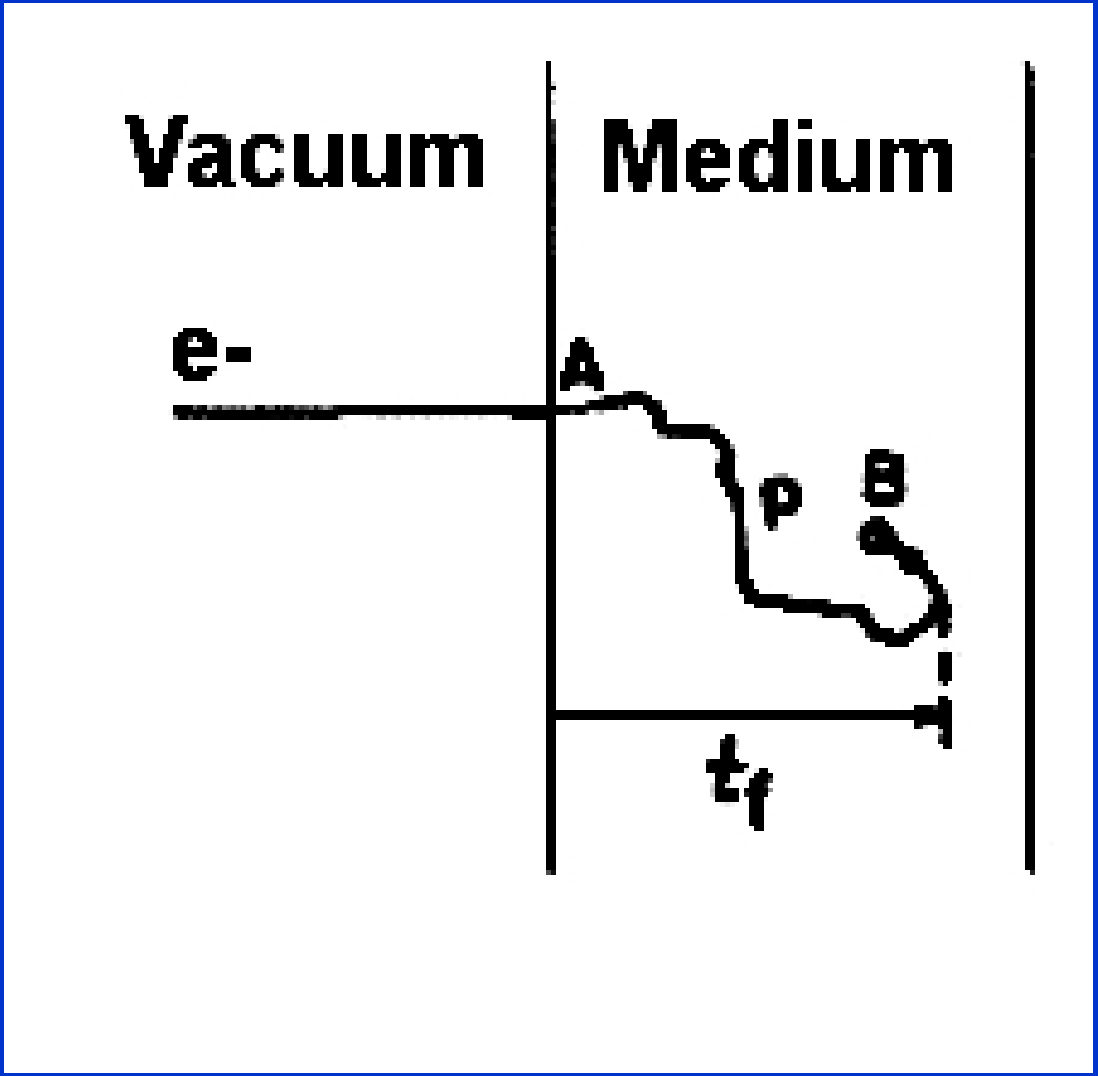
Electron Interactions w/ matter
Range

- What is the projected range, <t>, of a charged particle?

Electron Interactions w/ matter
Range

- What is the projected range, <t>, of a charged particle?
  - Expectation value of farthest depth, t_f, of the particle in its initial direction

Electron Interactions w/ matter
Range



Electron Interactions w/ matter
Range

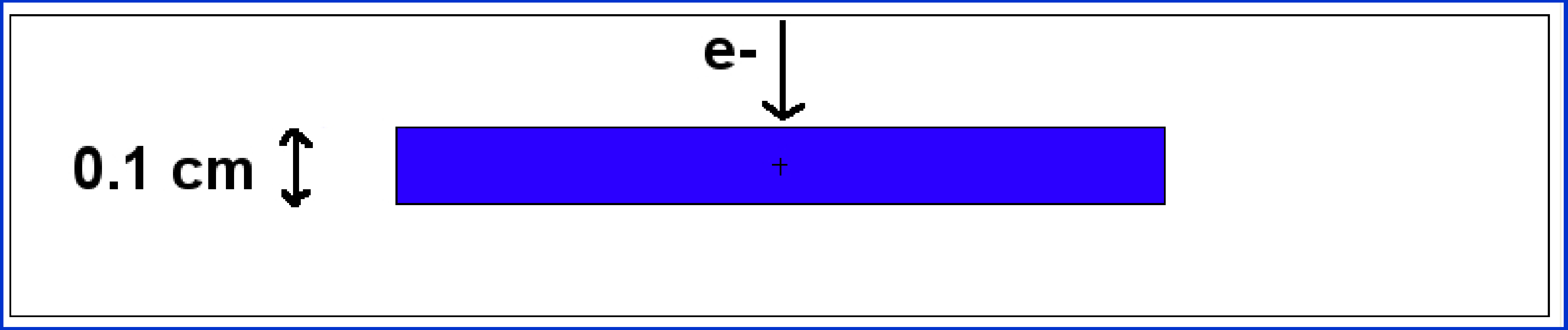
- What is the CSDA range, of a charged particle?

$$\mathcal{R}_{CSDA} \equiv \int_0^{T_0} \left(\frac{dT}{\rho\, dx} \right)^{-1} dT$$

$\left[g/cm^2 \right]$ $\quad$ $\left[\frac{MeV \cdot cm^2}{g} \right]$ $\quad$ $\left[MeV \right]$

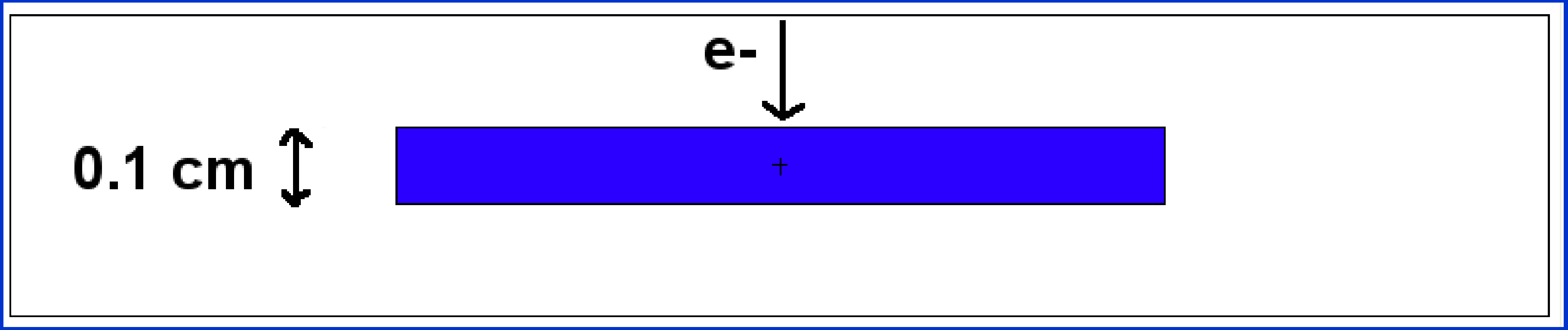
Electron Interactions w/ matter Energy deposition

- Assume parallel beam of e-, perpendicular to “thin” foil, Be
- Electron energy, 10 MeV
- Calculate average energy deposition in foil



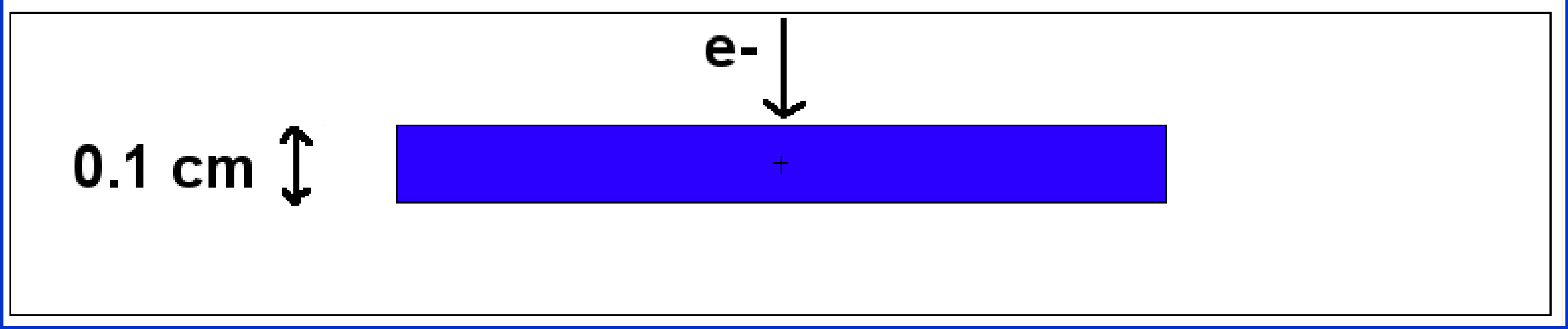
Electron Interactions w/ matter
Energy deposition

- S_{coll}/ρ for Be at 10 MeV = (1.527 MeV·cm^2/g)(1.848 g/cm^3) =2.905 MeV/cm
- ΔE=(2.905 MeV/cm)(0.1 cm)= 0.2905 MeV



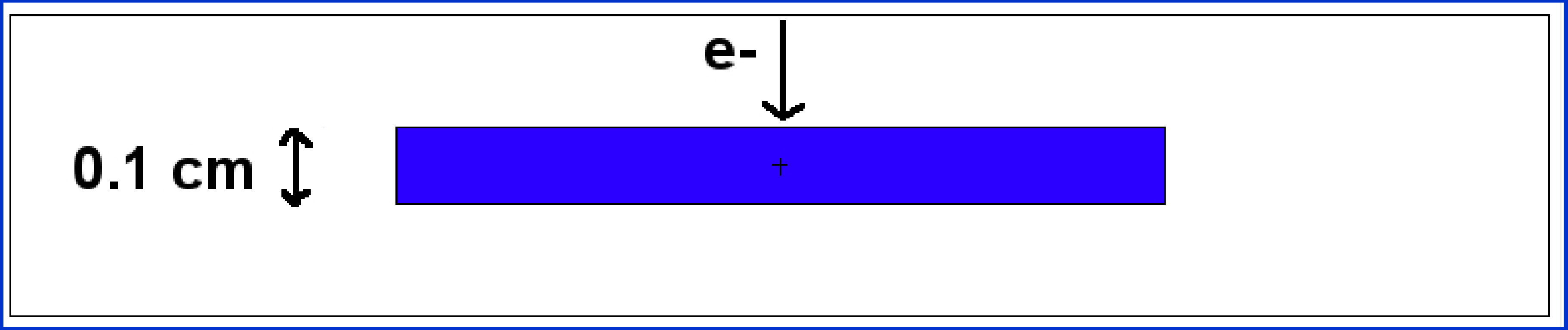
Electron Interactions w/ matter
Energy deposition

- S_{coll}/ρ for Be at 10 MeV = (1.527 MeV·cm^2/g)(1.848 g/cm^3) =2.905 MeV/cm
- ΔE=(2.905 MeV/cm)(0.1 cm)= 0.2905 MeV
- Actual answer = 0.262 MeV or an 11% overestimate
- Why?



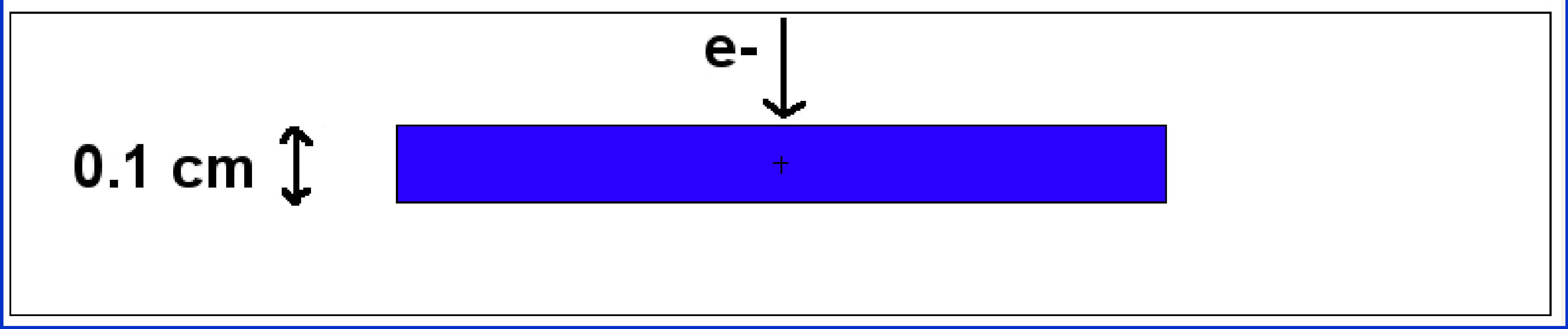
Electron Interactions w/ matter
Energy deposition

- Actual answer = 0.262 MeV or an 11% overestimate
- Why?
- Delta rays escape the foil and for higher Z foils, bremsstrahlung
- How to rectify?



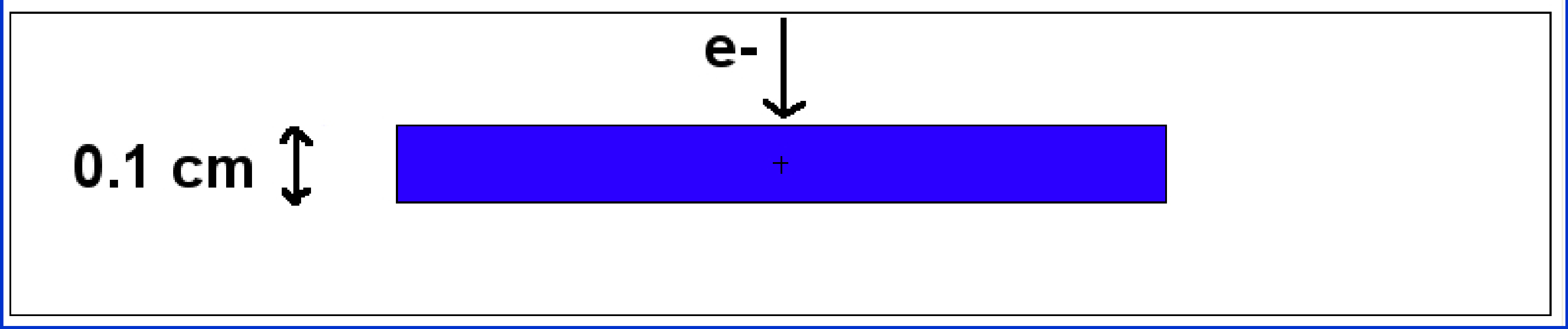
Electron Interactions w/ matter
Energy deposition

- Actual answer = 0.262 MeV or an 11% overestimate
- Why?
- Delta rays escape the foil and for higher Z foils, bremsstrahlung
- How to rectify? Add buildup to establish CPE
- 0.2905 MeV vs. 0.28 MeV, ~3% error or less



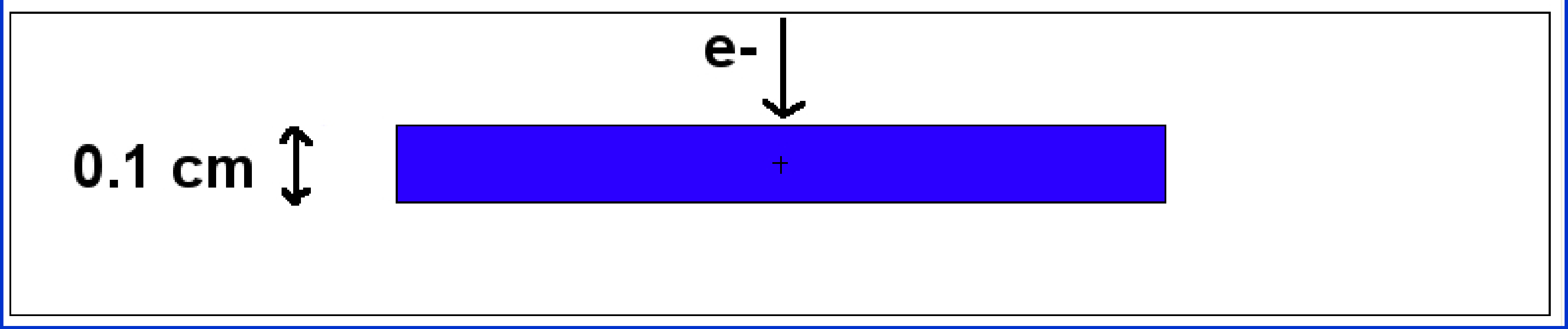
Electron Interactions w/ matter Energy deposition

•Do all electrons lose an identical amount of energy when traversing foil?



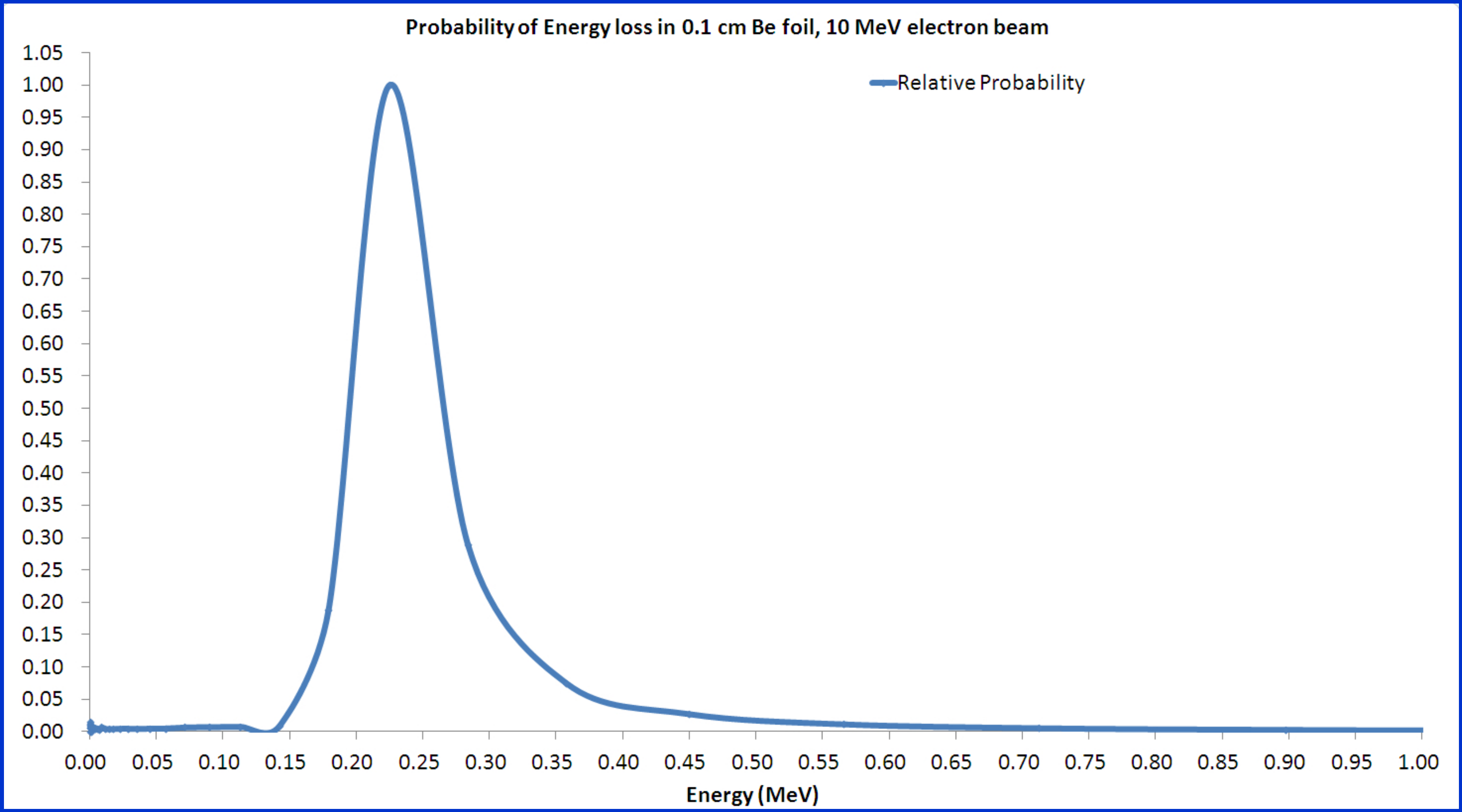
Electron Interactions w/ matter
Energy deposition

- Do all electrons lose an identical amount of energy when traversing foil?
- No, why?
- And what would the energy loss distribution look like?



Electron Interactions w/ matter
Energy deposition

- And what would the energy loss distribution look like?



Electron Interactions w/ matter Restricted Stopping power

– Restricted Mass Stopping Power $(L/\rho)_\Delta$:

$$\left(L/\rho \right)_\Delta = dE/\rho dl$$

$$\mathbf{E < \Delta}$$

- AKA LET (linear energy transfer) or energy loss per unit path length (for local absorption not radiated away)

Electron beam characteristics

- Rapid rise to 100%
- Region of uniform dose (proximal 90% to distal 90%)
- Rapid dose fall-off
- High surface dose
- Clinically useful range 5-6 cm depth

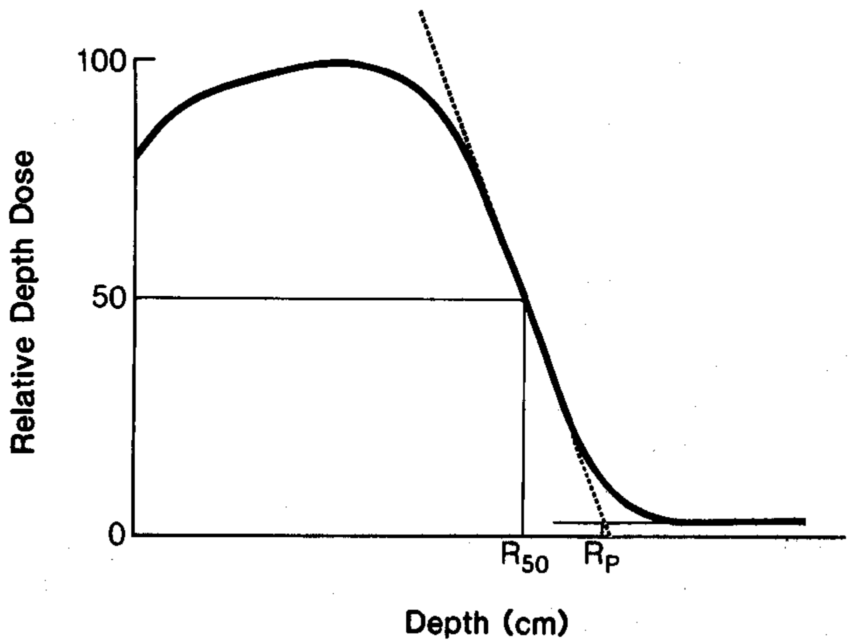
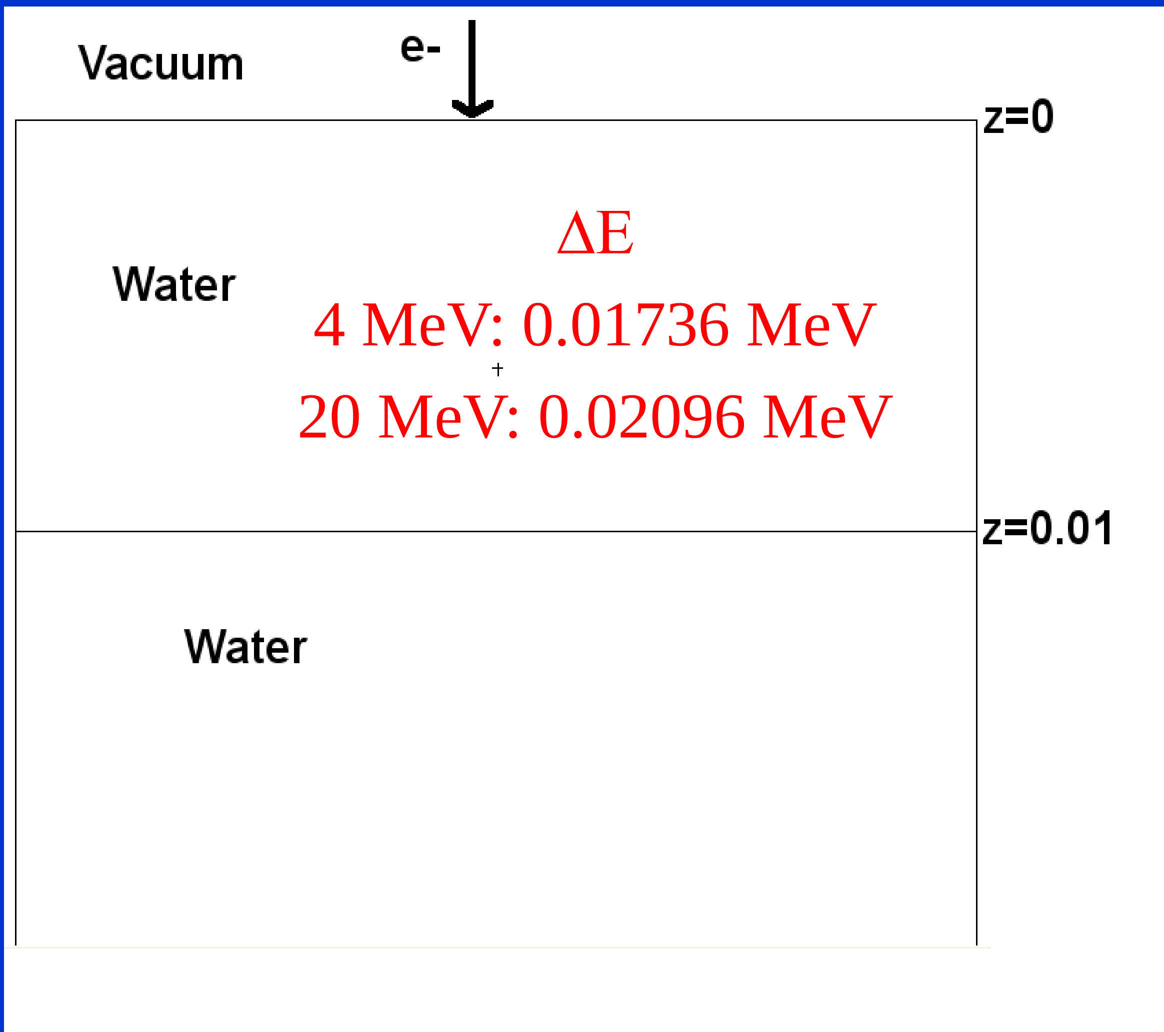


Figure 14.3. Depth dose curve illustrating the definition of R_p and R_{50}.

Electron beam characteristics- surface dose
6×6 cm^2 4 & 20 MeV e- beams on large H_2O tank



Net E entering

4 MeV: 3.99334 MeV

20 MeV: 19.99691 MeV

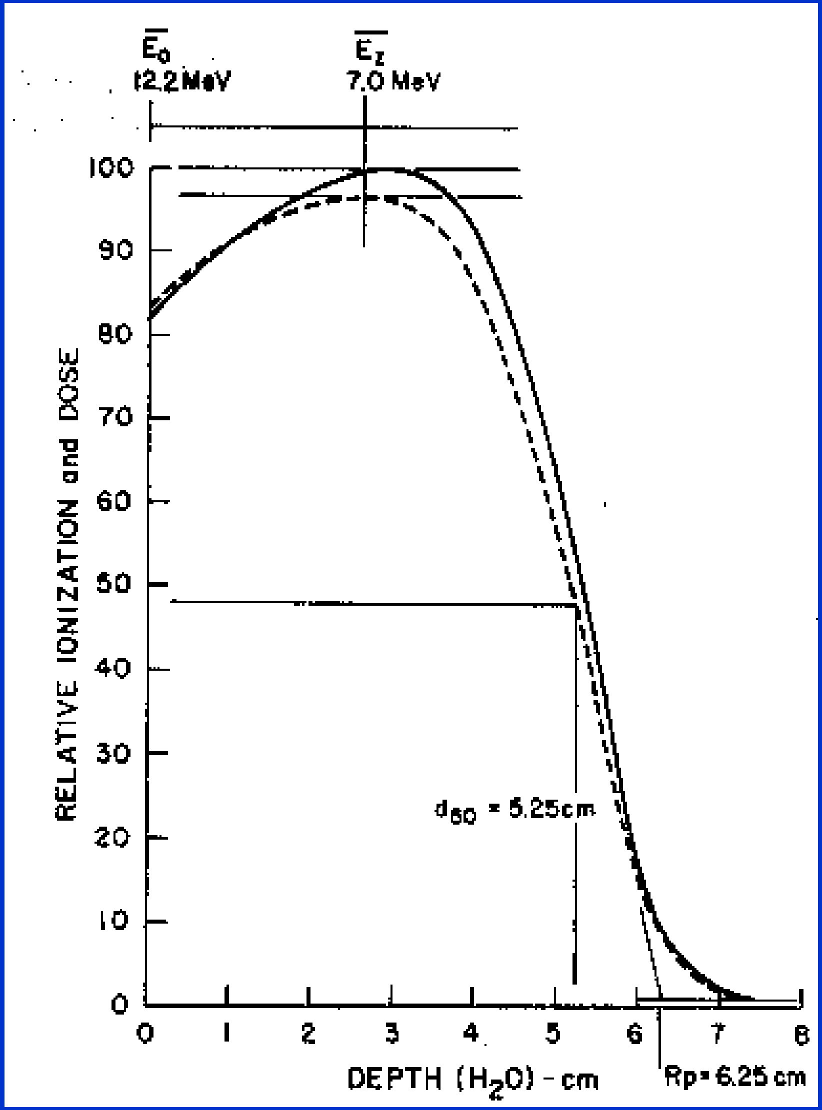
Net E leaving

4 MeV: 3.97598 MeV

20 MeV: 19.97595 MeV

Electron Energy Specification

- $\bar{E}_0$ (the average energy of the spectrum)
- E_{p0} (most probable energy @ surface)
- $\bar{E}_z$ (average energy at depth z)



Electron Energy Specification

- Energy specification:
  - R_{50} - depth of the 50% dose
  - R_p - maximum range of electrons

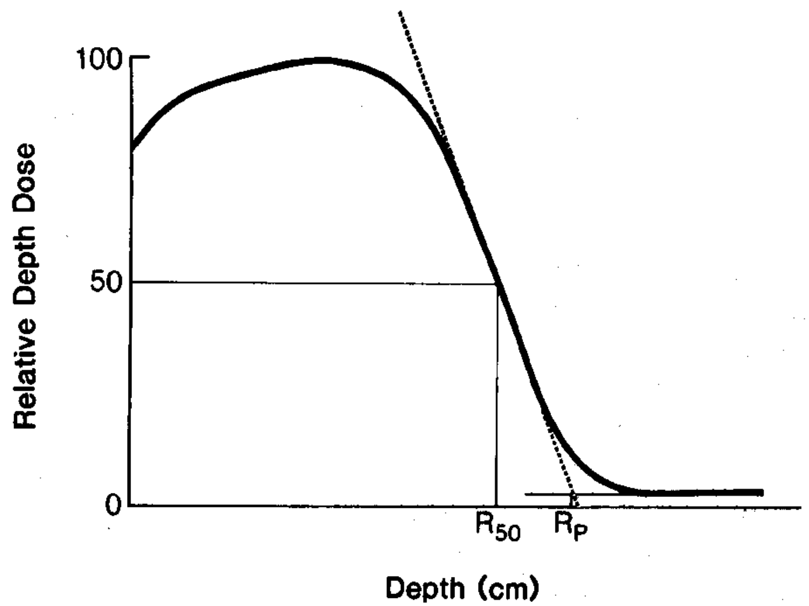


Figure 14.3. Depth dose curve illustrating the definition of R_p and R_{50}.

Electron Energy Specification

$E_{nominal}$ (MeV)	$(E_p)_o$ (MeV)	E_o (MeV)
6	6.49	5.94
9	9.34	8.78
12	12.25	11.64
16	15.54	14.76
20	20.54	19.19

MDACC 21EX

– Average Energy (***E_0***):

$$\overline{E}_0 = (2.33)\,R_{50}$$

– Most Probable Energy (***E_{p0}***):

$$E_{p,0} = 0.22 + 1.98 \times R_p + 0.0025 \times R_p^{\,2}$$

– Energy (***E_z***) at depth *z*

$$\overline{E}_z = \overline{E}_0 \left(1 - \frac{z}{R_p}\right)$$

AAPM TG-25 Med Phys 18(1), 73-109 (1991)

Determination of Absorbed Dose

- Calibration in water with ion chambers
  - ADCL-calibrated system
    - Cylindrical-chamber reference point located upstream of the chamber center by 0.5 r_{cav}
  - Reference conditions 100 cm SSD for a 10×10 cm^2 field $d_{ref} = 0.6\,R_{50} - 0.1$
  - Formalism:

$$D_w^Q = M\,k_Q\,N_{D,w}^{^{60}Co}$$

Depth-Dose Distribution

Dose is calculated from ionization measurements:

$$\%D_W = \left(\frac{\left\{ M \times \left(\frac{\bar{L}}{\rho} \right)_{air}^{W} \times \left(\Phi \right)_{air}^{W} \times P_{repl} \right\}}{\left\{ numerator_{\max} \right\}} \right) \times 100$$

- ***M*** is ionization
- $\left(\frac{\bar{L}}{\rho} \right)_{air}^{W}$ is the ratio of water-to-air mean restricted stopping powers
- $\left(\Phi \right)_{air}^{W}$ is the ratio of water-to-air fluence
- P_{repl} is a chamber replacement correction

Clinical aspects and dosimetry

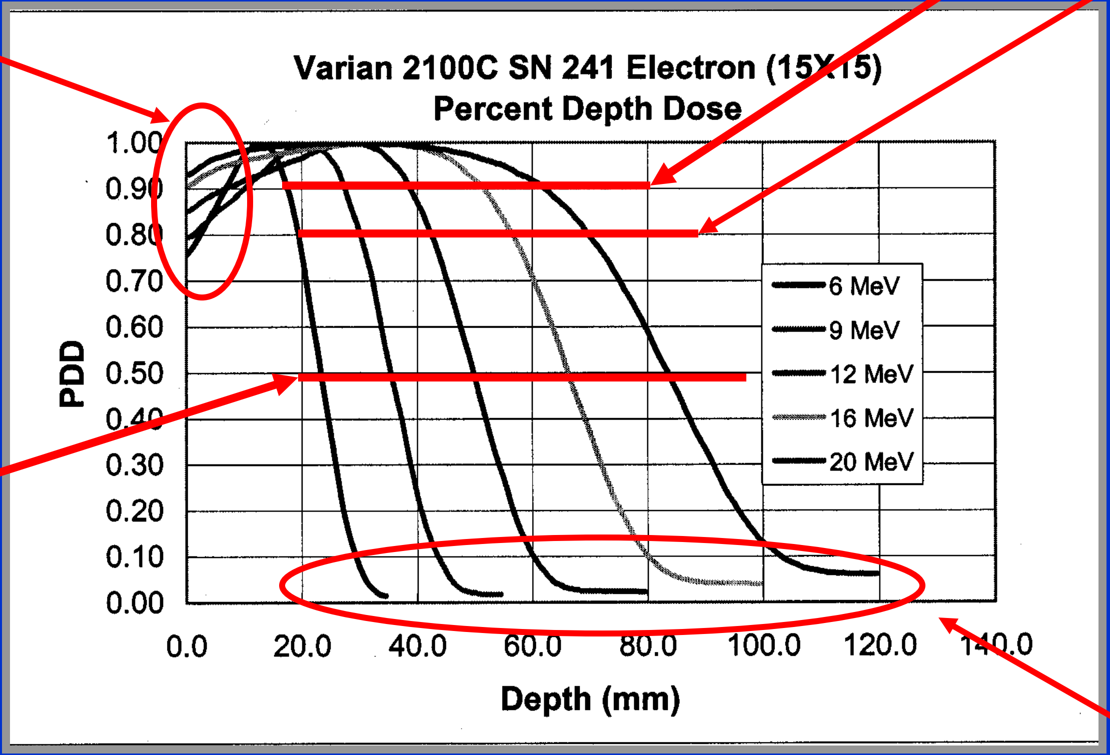
Characteristics of clinical electron beams

Surface Dose

Depth of 90% Dose

Depth of 80% Dose

Depth of 50 % dose



X-Ray Contamination

Characteristics of Clinical Electron Beams

- Surface Dose:
  - Surface dose increases with increasing electron energy

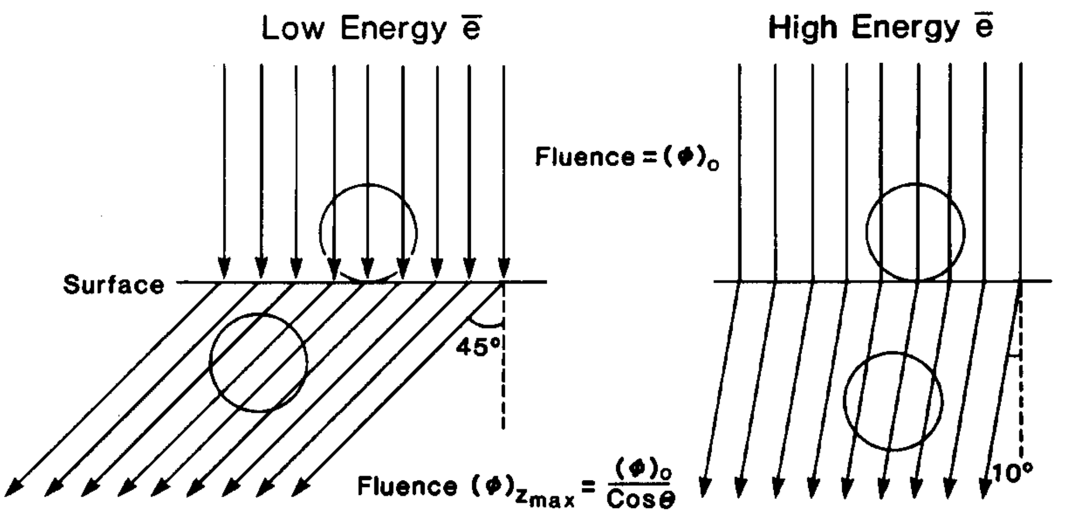


Figure 14.10. Schematic illustration showing the increase in percent surface dose with an increase in electron energy. From Khan FM. Clinical electron beam dosimetry. In: Keriakes JG, Elson HR, Born CG, eds. Radiation oncology physics—1986. AAPM Monograph No. 15. New York, American Institute of Physics, 1986:211.

From: Khan

Characteristics of Clinical Electron Beams

- Depth of the 80% Dose:
  - Equal to approximately **$E_{nom}/2.8$** :

$E_{nominal}$	E_{nom} / 2.8	Actual
6	2.14	2.20
9	3.21	3.30
12	4.28	4.30
16	5.71	5.50
20	7.14	7.00

MDACC 21EX

  - Depth of 90% is approximately **$E_{nom}/3.2$**

$E_{nominal}$	E_{nom} / 3.2	Actual
6	1.88	2.00
9	2.81	3.00
12	3.75	4.00
16	5.00	5.00
20	6.25	6.10

Characteristics of clinical electron beams

- Practical Range:
  - Equal to approximately 1/2 nominal energy:

$E_{nominal}$	E_{nom} / 2	R_p
6	3.0	3.15
9	4.5	4.58
12	6.0	6.04
16	8.0	7.66
20	10.0	10.13

  - Energy loss is about **2 MeV / cm**

MDACC 21EX

Characteristics of clinical electron beams

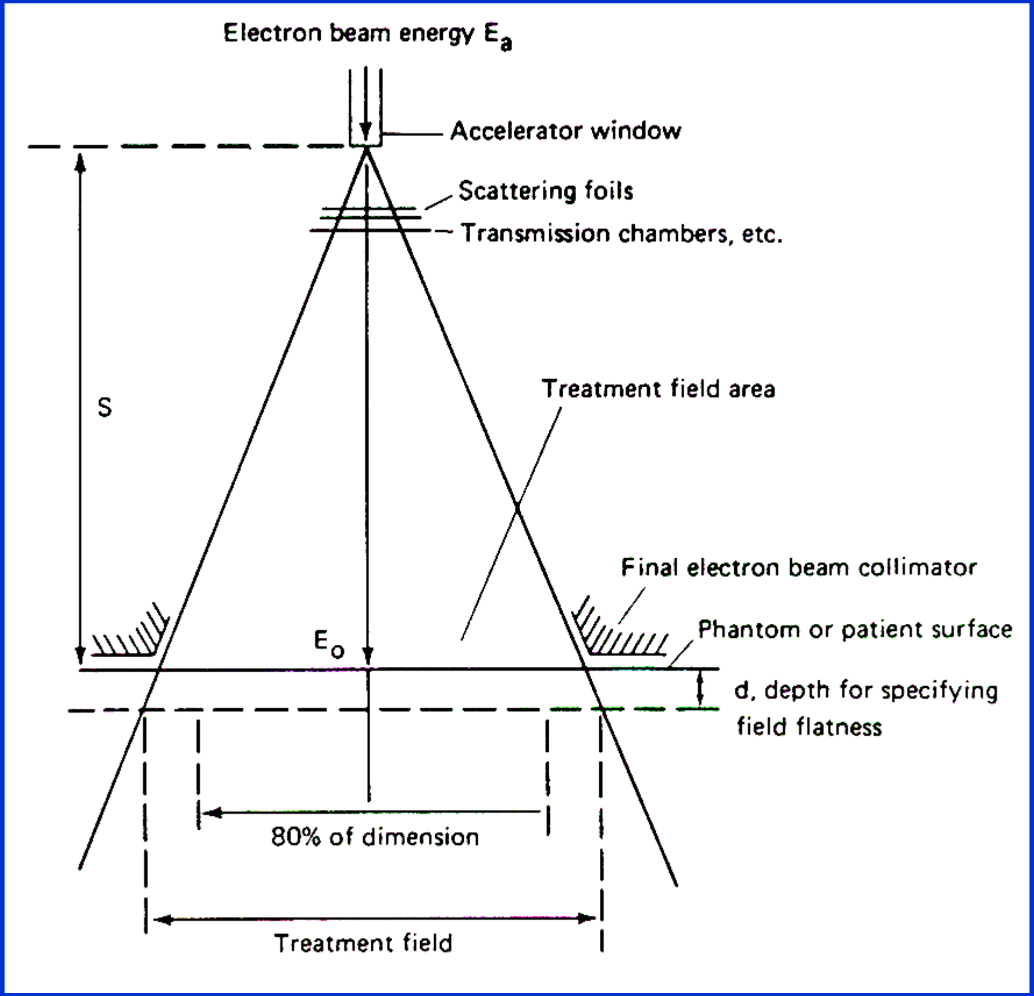
- X-Ray Contamination:
  - Increases with energy:
  - Varies with accelerator design
  - Defined as R_P+2 cm

E_{nom}	X-ray %
6	0.7%
9	1.2%
12	1.9%
16	3.7%
20	5.9%

MDACC
21EX

Characteristics of clinical electron beams

- **Accelerator design variations**
  - **Penumbra**
  - **X-ray Contamination**

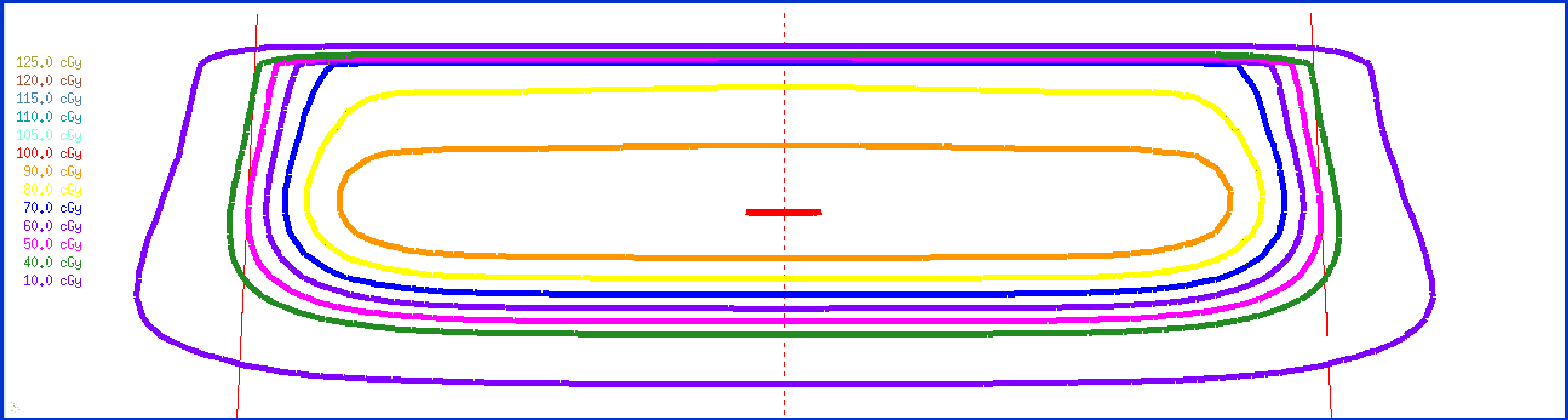


Characteristics of clinical electron beams

- Penumbral Effects:
  - Low energies show expansion of isodose values
  - High energies show constriction of high isodose values with bowing of low values.

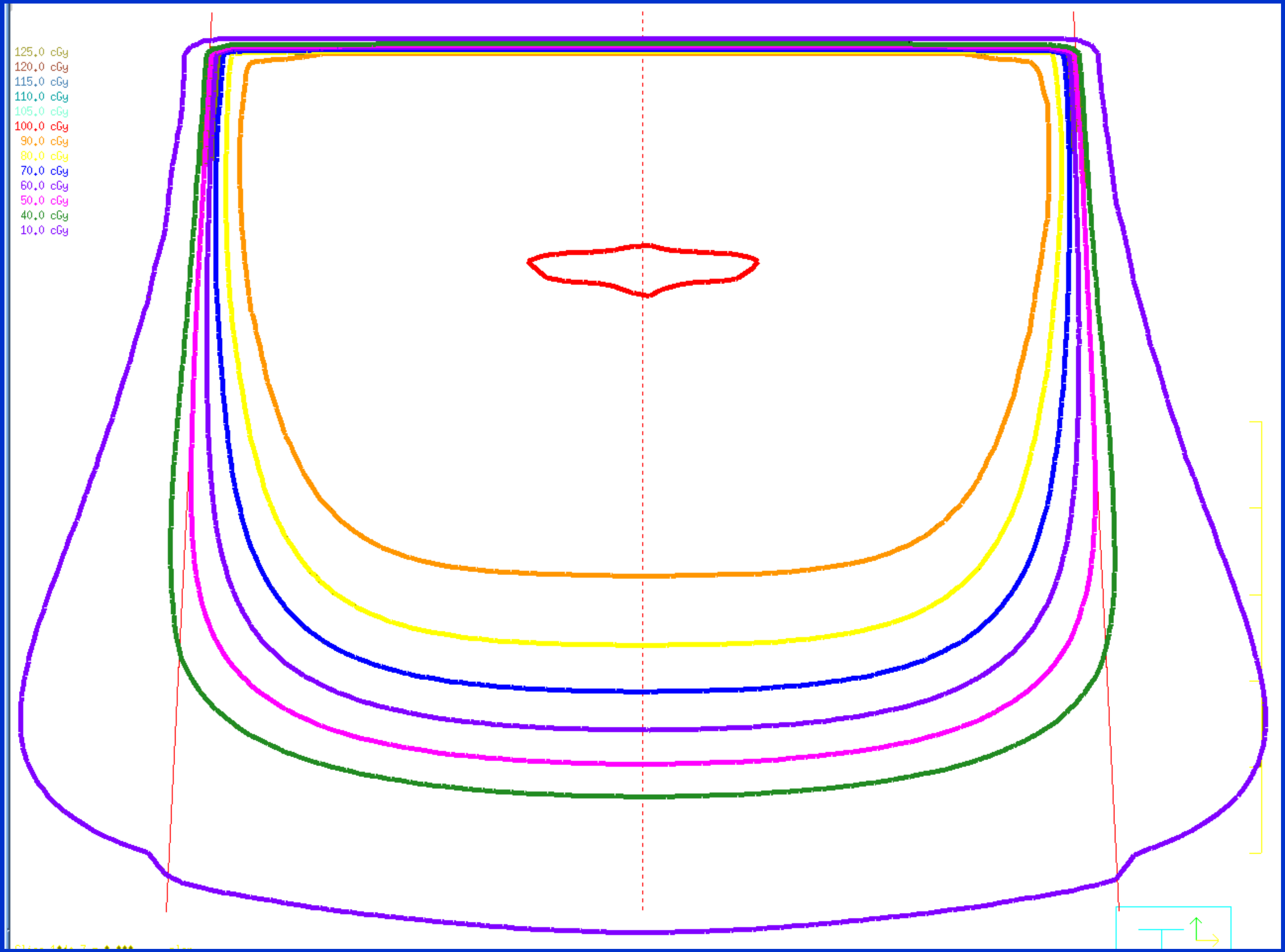
Electron Beam Dosimetry

Isodoses (6 MeV)



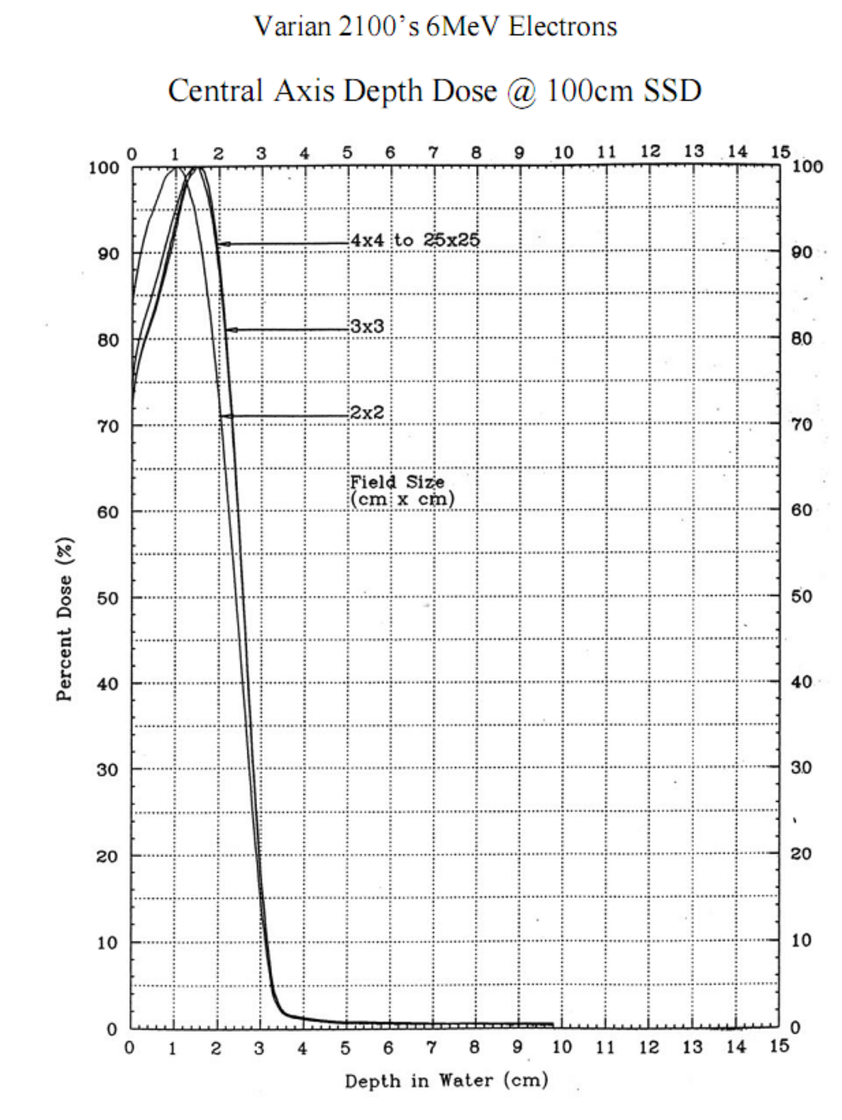
Electron Beam Dosimetry

Isodoses (20 MeV)



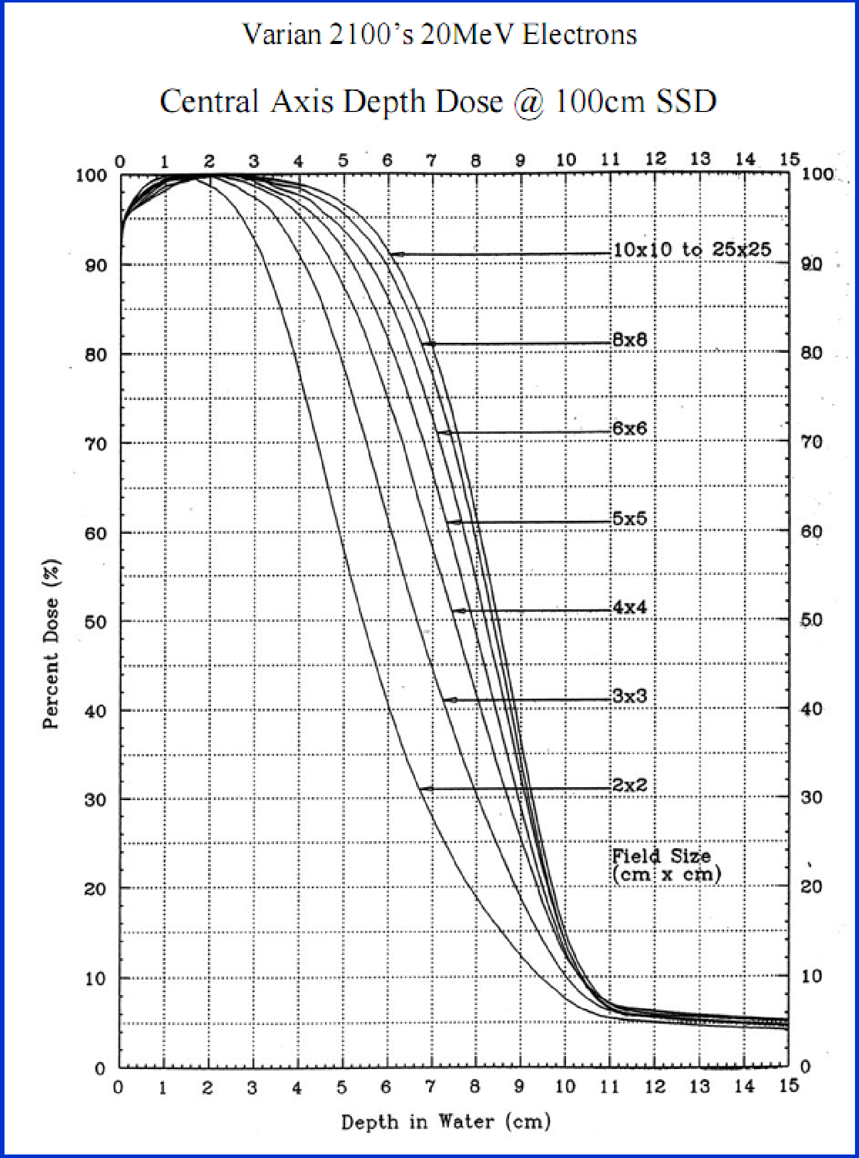
Electron Beam Dosimetry

PDD- effect of field size (6 MeV)



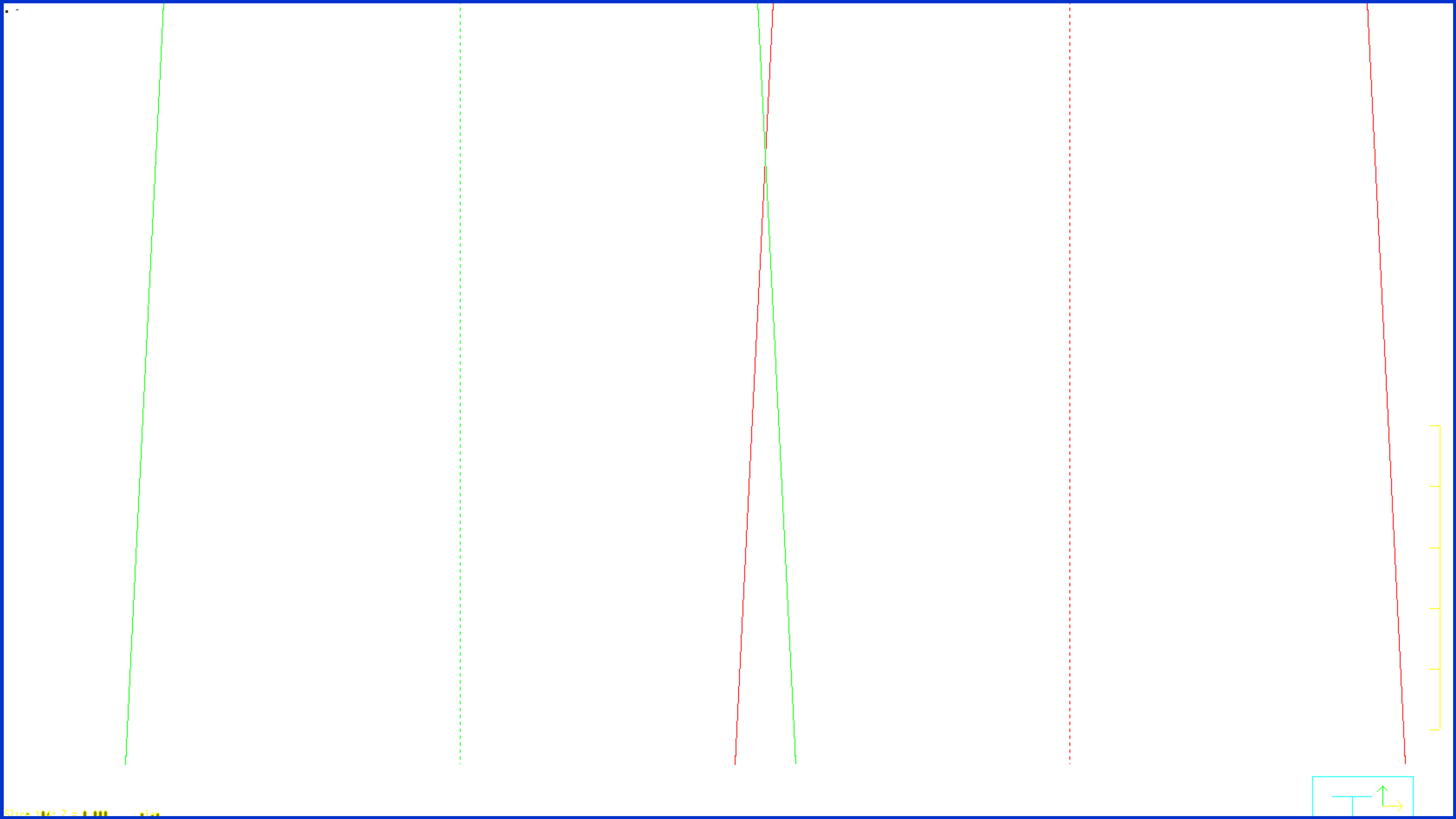
Electron Beam Dosimetry

PDD- effect of field size (20 MeV)



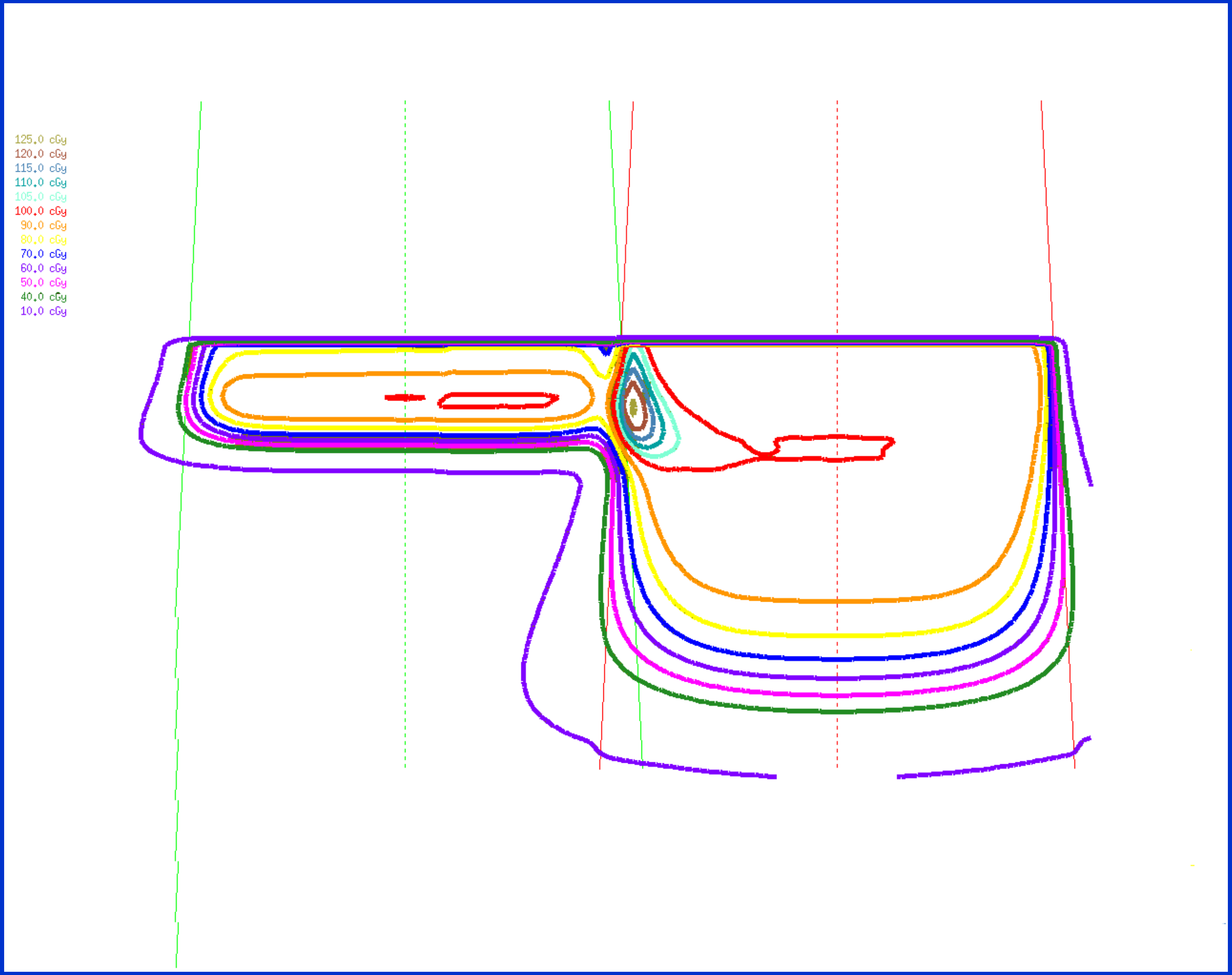
Electron Beam Dosimetry

Beam abutment



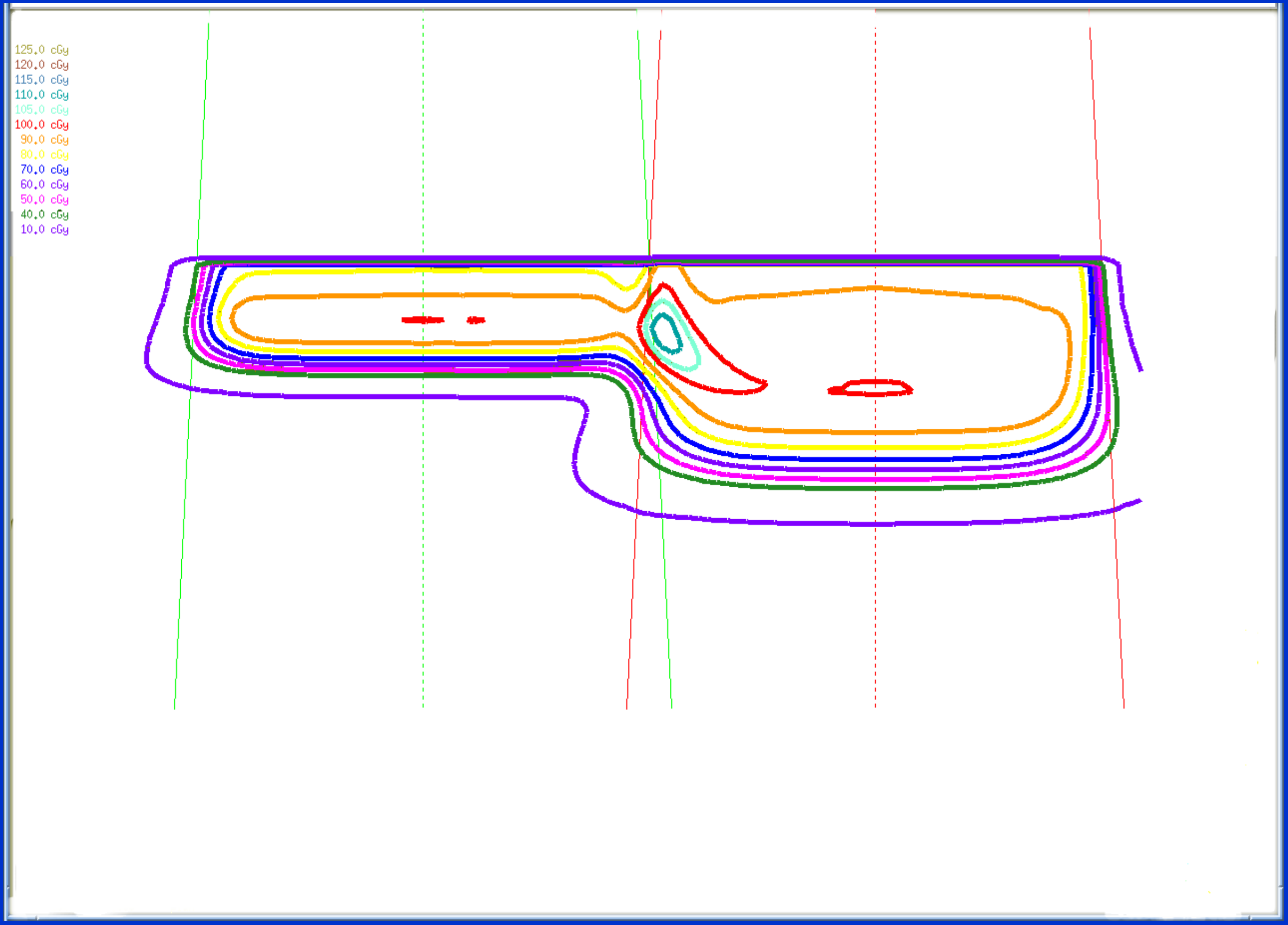
Electron Beam Dosimetry

Beam abutment- electrons (6 & 20 MeV)



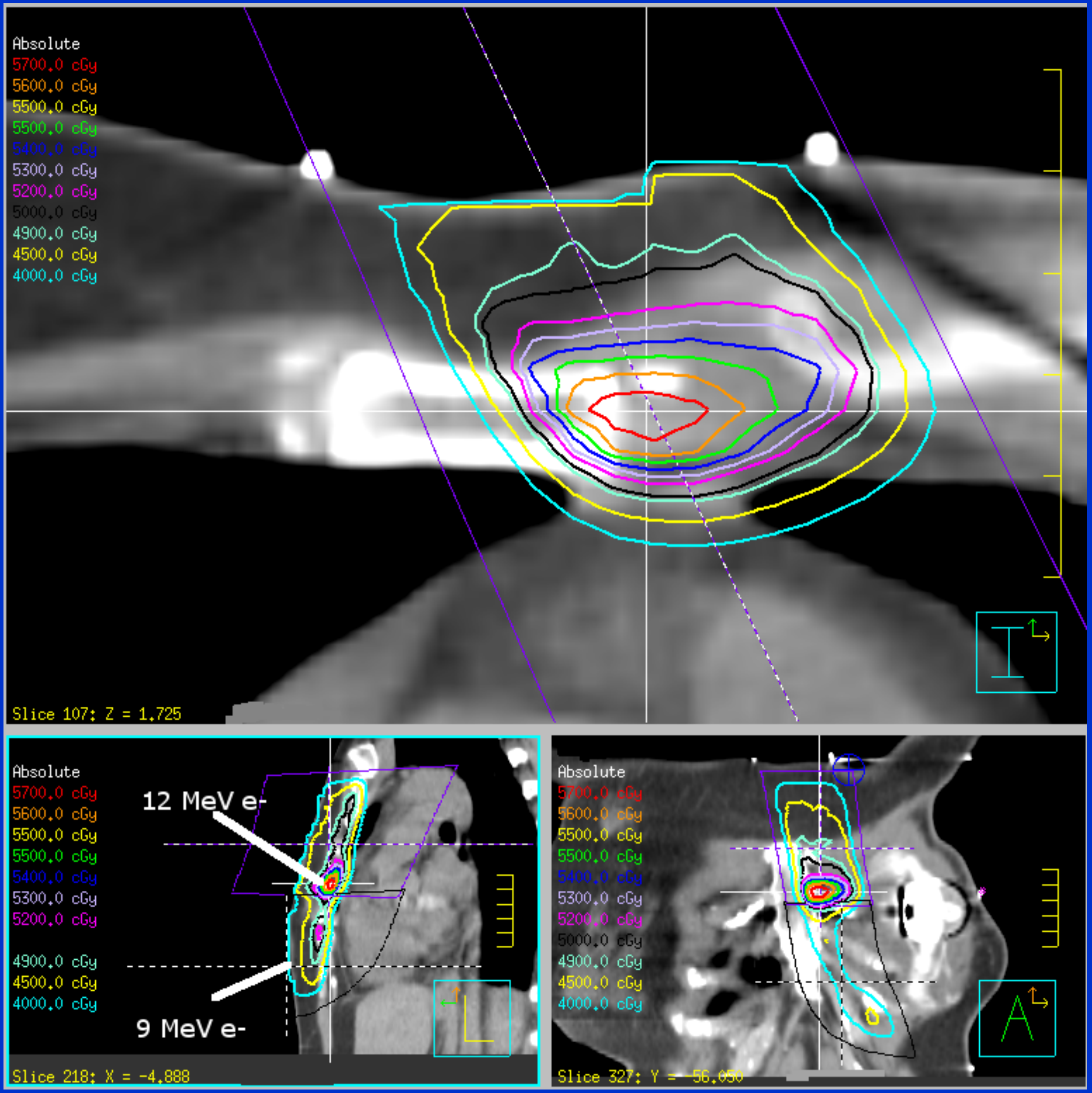
Electron Beam Dosimetry

Beam abutment- electrons (6 & 12 MeV)



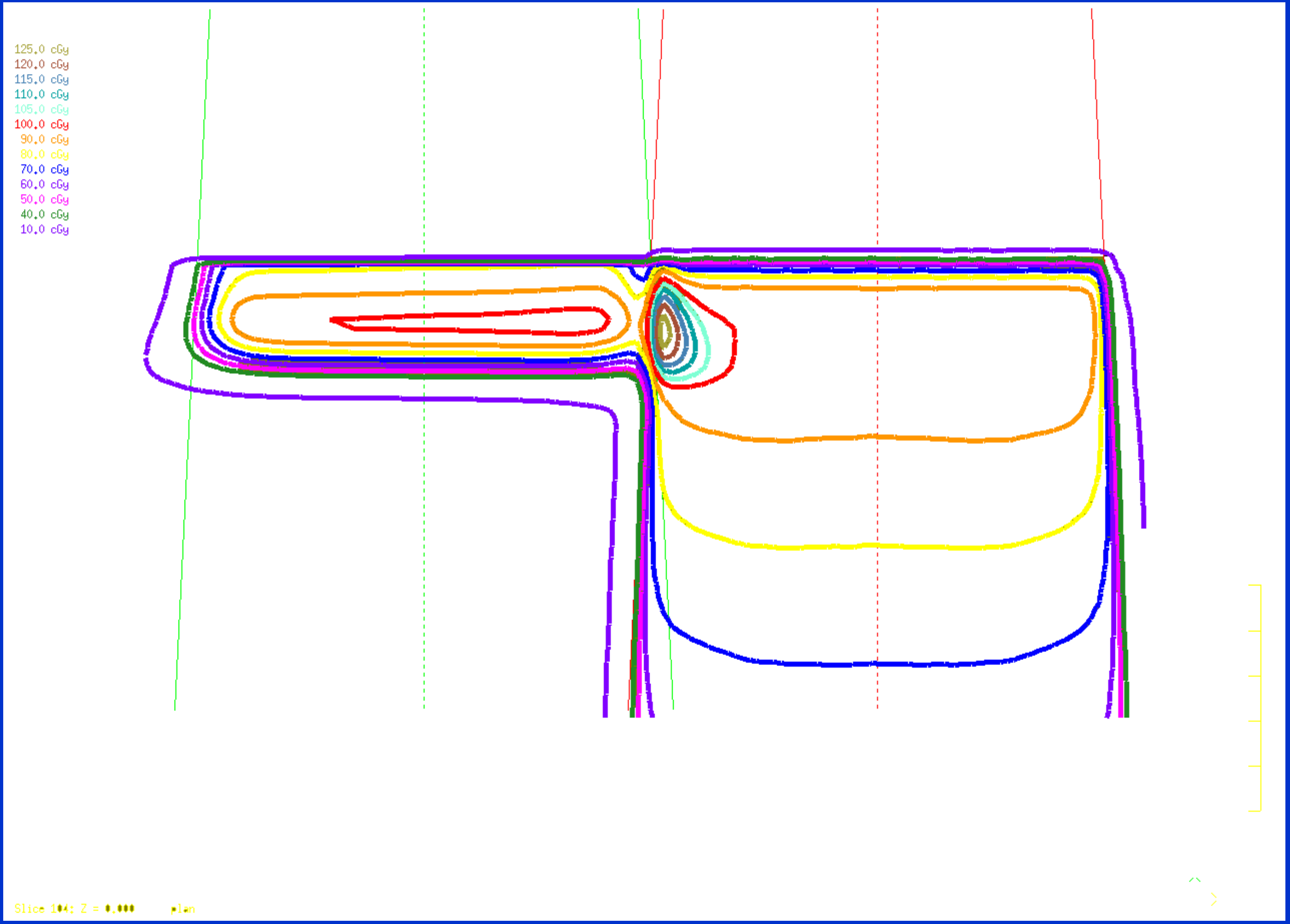
Electron Beam Dosimetry

Beam abutment- electrons



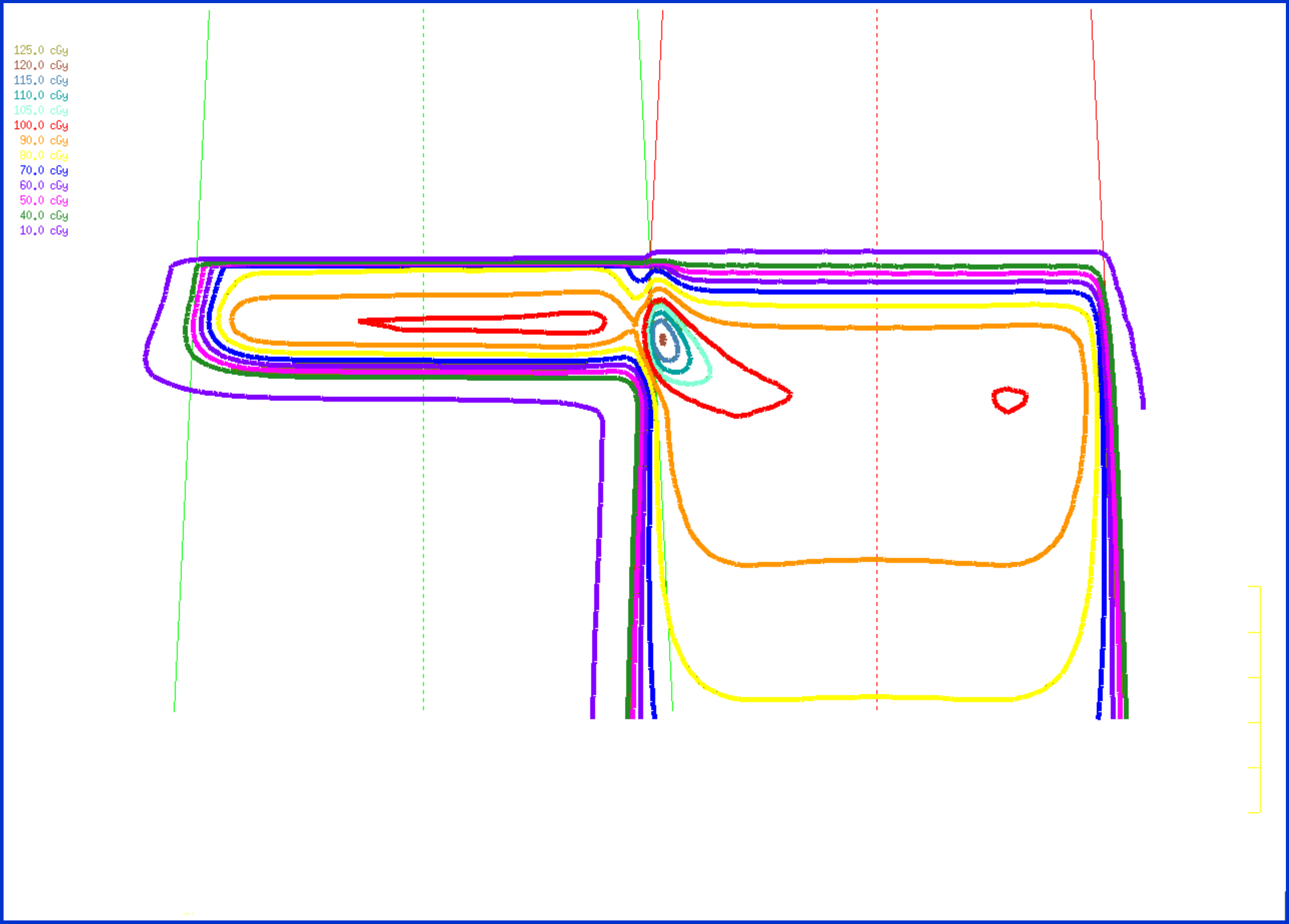
Electron Beam Dosimetry

Beam abutment- photon & electron (6 MeV & 6 MV)



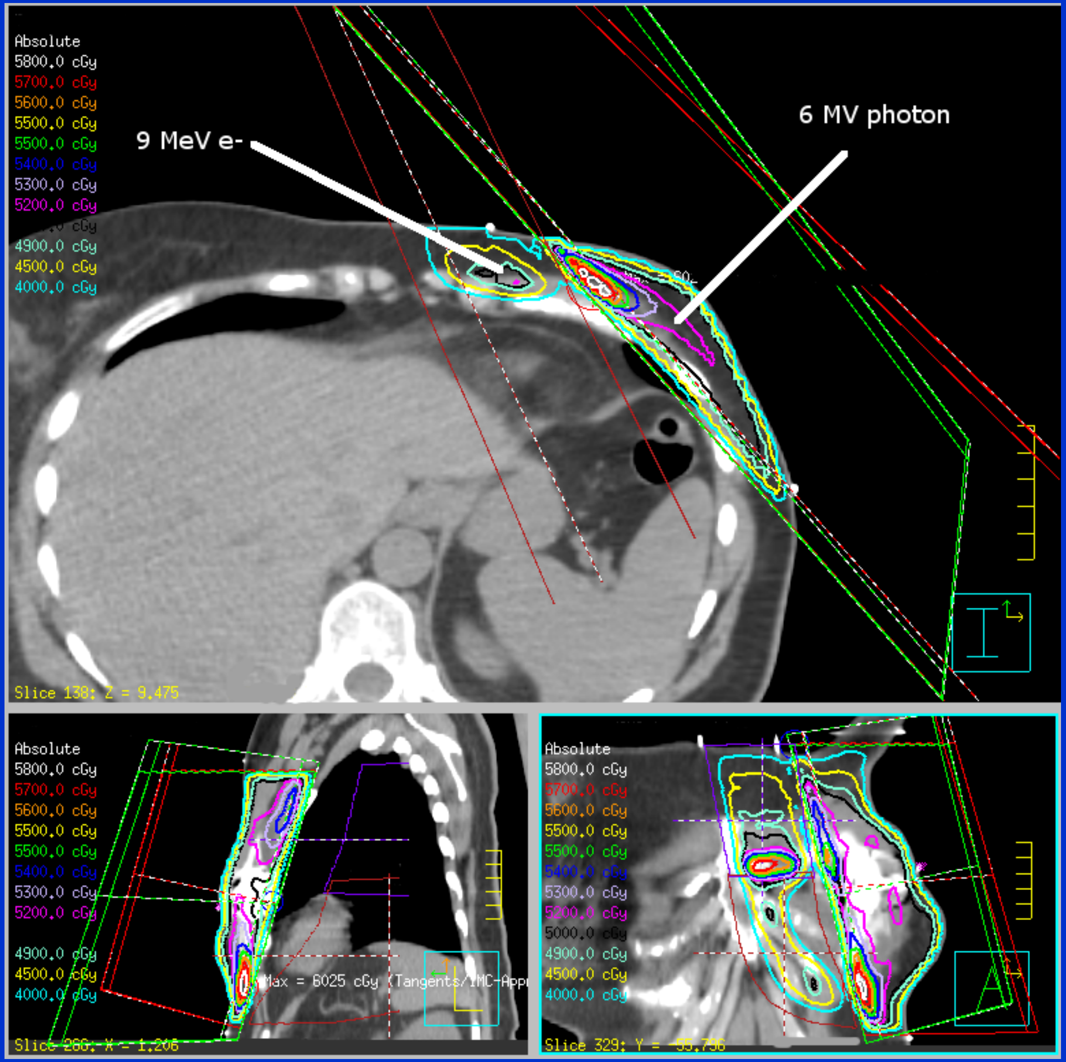
Electron Beam Dosimetry

Beam abutment- photon & electron (6 MeV & 18 MV)



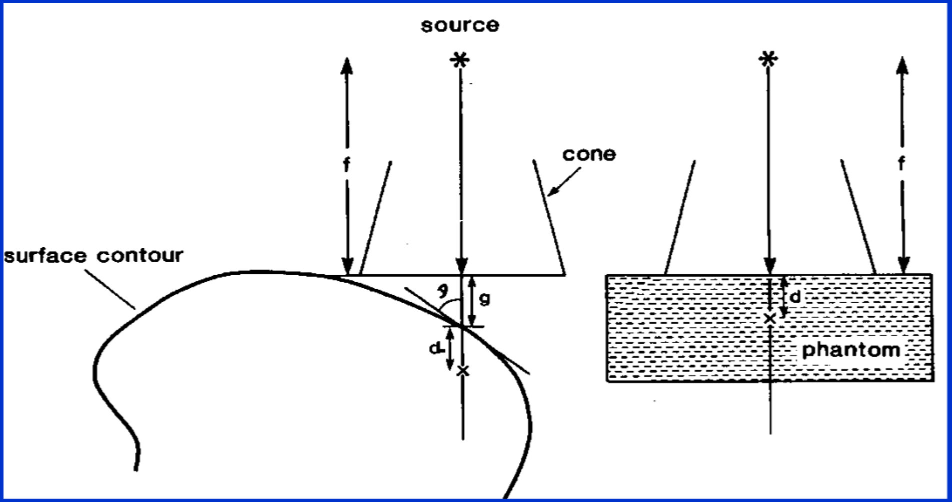
Electron Beam Dosimetry

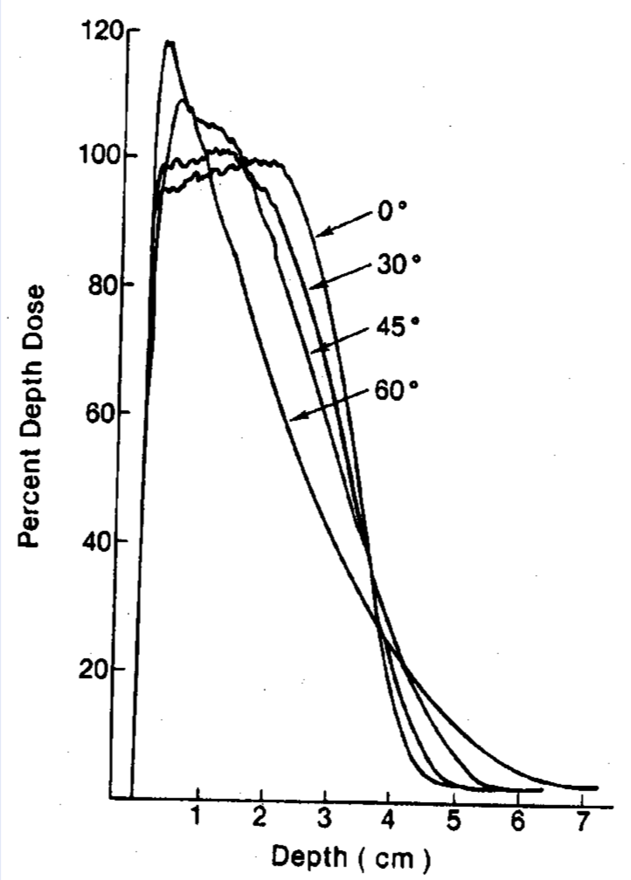
Beam abutment- photon & electron (IMC & tangents)



Electron Beam Dosimetry

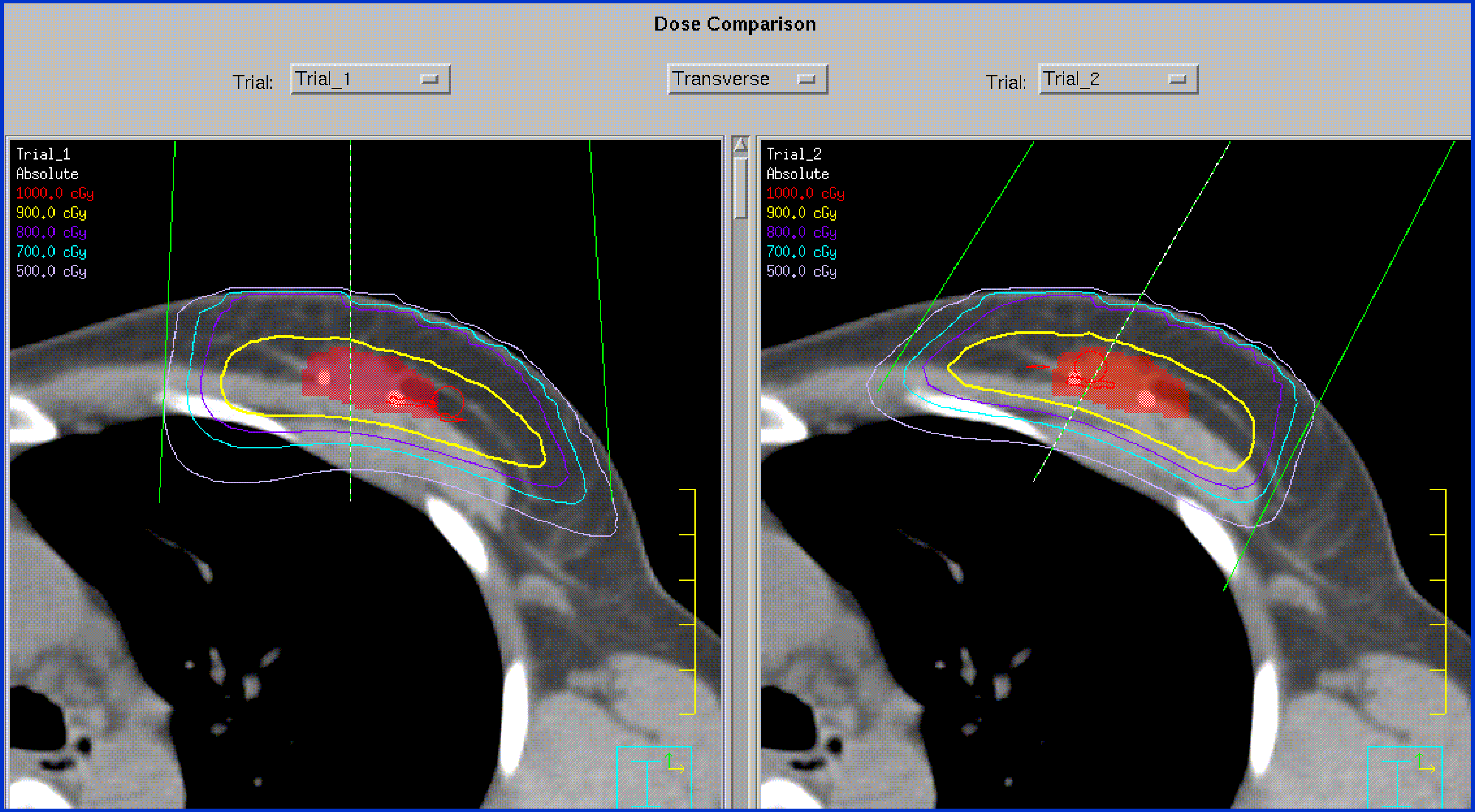
- Obliquity Effects
  - Oblique incidence results in pdd shifts





From: Khan

Electron Beam Dosimetry
Obliquity effects



Electron Beam Dosimetry

- Field Shaping:
  - Lead and/or Cerrobend is normally used
  - Thickness should be sufficient to stop electrons:

$$t = \frac{E_0}{2} + 1$$

t = mm Pb
E_0 = Nom E (MeV)

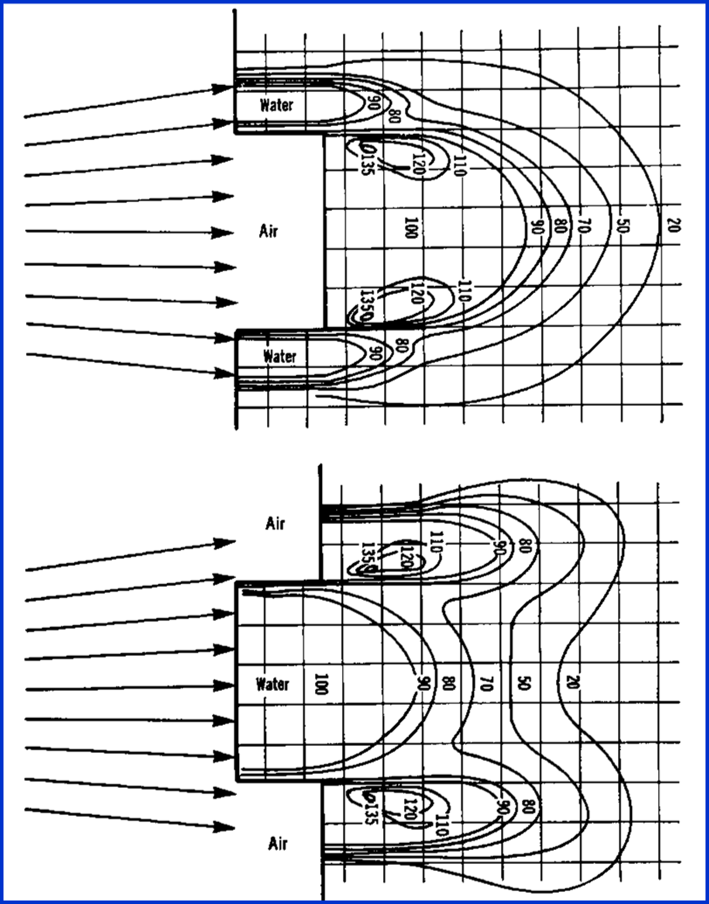
Lead / Cerrobend Recommended Shielding Thicknesses
(Thickness in mm to completely absorb electrons only)

Energy	6 MeV	9 MeV	12 MeV	16 MeV	20 MeV
Lead	3.0	4.4	6.1	7.9	10.1
Cerrobend	3.6	5.3	7.3	9.5	12.1

(Reference: AAPM TG – 25, Med Phys 18, 73, 1991.)

Electron Beam Dosimetry

- Contour Irregularities:
  - Sharp contour irregularities result in hot and cold spots
- Bolus:
  - Place as close to skin as possible
  - Use tissue-equivalent material
  - Bevel bolus to smooth sharp edges



From: Khan

Electron Beam Dosimetry

- Effects of inhomogeneities:
  - **CET - c**oefficient of **e**quivalent **t**hickness
  - The CET of a material is approximately equal to its electron density relative to water

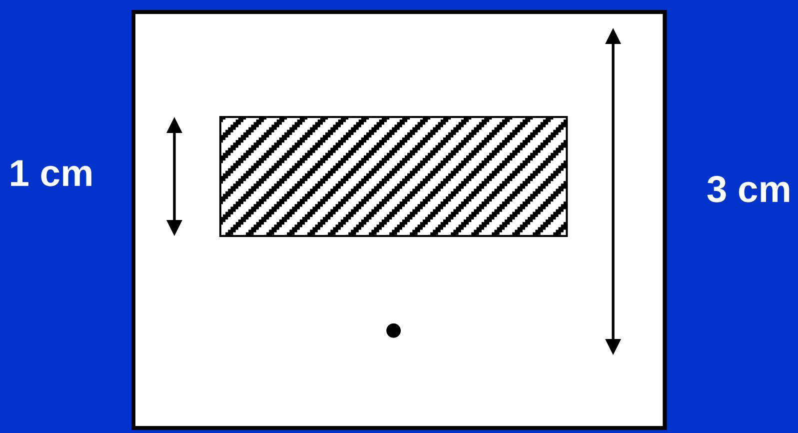
$$d_{eff} = d - z(1 - CET)$$

Tissue	CET
Lung	0.25
Bone	1.65

From: Khan

Electron Beam Dosimetry

- **CET:**
  - **Sample calculation**



Tissue	CET
Lung	0.25
Bone	1.65

$$d_{eff} = d - z\,(1 - CET)$$

For Lung:

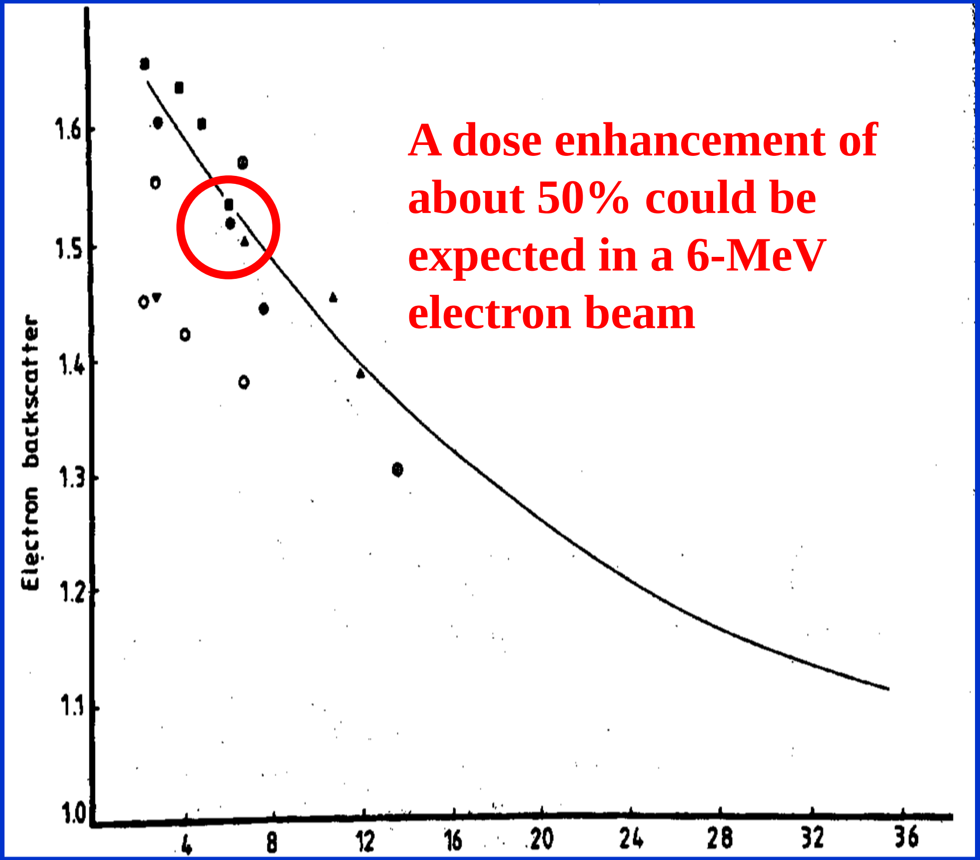
$$d_{eff} = 3 - 1\,(1 - 0.25) = 2.25\ cm$$

For Bone:

$$d_{eff} = 3 - 1\,(1 - 1.65) = 3.65\ cm$$

Electron Beam Dosimetry

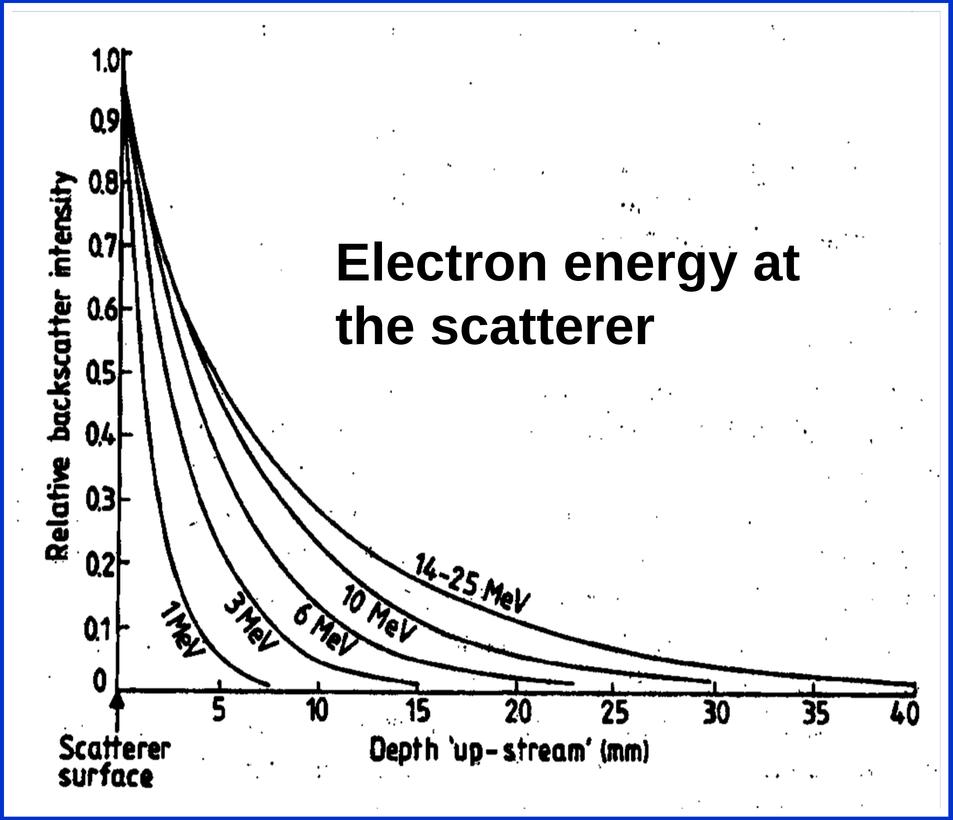
- Internal Shielding:
  - Used to protect tissues beyond treatment volume
  - Backscattered electrons produce “dose enhancement”



From: Khan (Note E in MeV)

Electron Beam Dosimetry

- Internal Shielding:
  - Reduce the intensity of backscatter by introducing a tissue-equivalent absorber upstream from the shield



From: Khan

Electron Beam Monitor-Unit Calculations

- Electron-beam monitor units (MU) are normally calculated to a point at d_{max} along the central axis
- A dose D_{Rx} that is prescribed to a point other than d_{max}, can be related to the d_{max} dose D_{dmax} through the precription isodose level *%D*:

$$D_{dmax} = \left(D_{Rx} / \%D \right)$$

Electron Beam Monitor-Unit Calculations

- The MU setting (MU) that is necessary to deliver a dose Ddmax is a function of the electron beam's "output" (in cGy per MU) at the calculation point:

$$MU = \left(D_{dmax} \big/ O_{FS,\,SSD} \right)$$

- Here $\boldsymbol{O}_{FS,SSD}$ is the dose output as a function of field size (*FS*) and distance (*SSD*)

Electron Beam
Monitor-Unit Calculations

- For an electron beam calibrated such that 1 MU = 1 cGy at 100 cm SSD for a 10×10 field at d_{max}:

Electron-beam output for a field size FS at a distance SSD

$$O_{FS,\,SSD} = (O_{10,100}) \times (OF_{FS}) \times (F_{SSD})$$

Calibrated output for a 10X10 cm field at 100 cm SSD

Output factor for field size FS relative to field size 10X10

Distance-correction factor for distance SSD relative to 100 cm SSD

Monitor-Unit Calculations

- Field-Size Corrections $\boldsymbol{OF_{FS}}$:
  - Field-size corrections generally account for the aperture produced by two devices:
    - Cones or Applicators, and Customized Inserts
  - The field-size dependent output factor OF_{FS} can then be thought to consist of cone and insert output factors, OF_{CS} and OF_{IS}:

$$OF_{FS} = OF_{CS} \times OF_{IS}$$

Monitor-Unit Calculations

- Field-Size Corrections - $OF_{CS,\, IS}$:
  - When used separately, cone factors, OF_{CS}, are normalized to the 10×10 (or 15×15) cone, and insert factors, OF_{IS}, are normalized to the open cone into which inserts are placed
  - Alternatively, they can be combined into a single factor, $OF_{CS,\, IS}$, that is normalized to the open 10×10 (or to the 15×15) cone :

$$OF_{FS} = OF_{CS} \times OF_{IS} = OF_{CS,\, IS}$$

Monitor-Unit Calculations

- Field-Size Corrections - $OF_{L\times W}$:
  - For rectangular fields, the field-size dependent output factor, OF_{FS}, is determined from square-field output factors using the "square root method". Thus, for a rectangular field L×W:

$$OF_{LxW} = \sqrt{OF_{LxL} \times OF_{WxW}}$$

  - For example, the 4×12 output factor $OF_{4\times12}$ is the square-root of the product of the 4×4 output factor, $OF_{4\times4}$, and the 12×12 output factor, $OF_{12\times12}$

Monitor-Unit Calculations

- Distance (SSD) Corrections F_{SSD}:
  - The variation of electron-beam output with distance does not follow a simple conventional inverse-square relationship
    - Due to attenuation and scattering in air and in beam collimation and shaping devices
  - Distance corrections take two forms:
    - Use of an "**effective SSD**" that can be used in an inverse-square fashion
    - Use of an "**air-gap factor**" that can be used in addition to a conventional inverse-square factor

Monitor-Unit Calculations

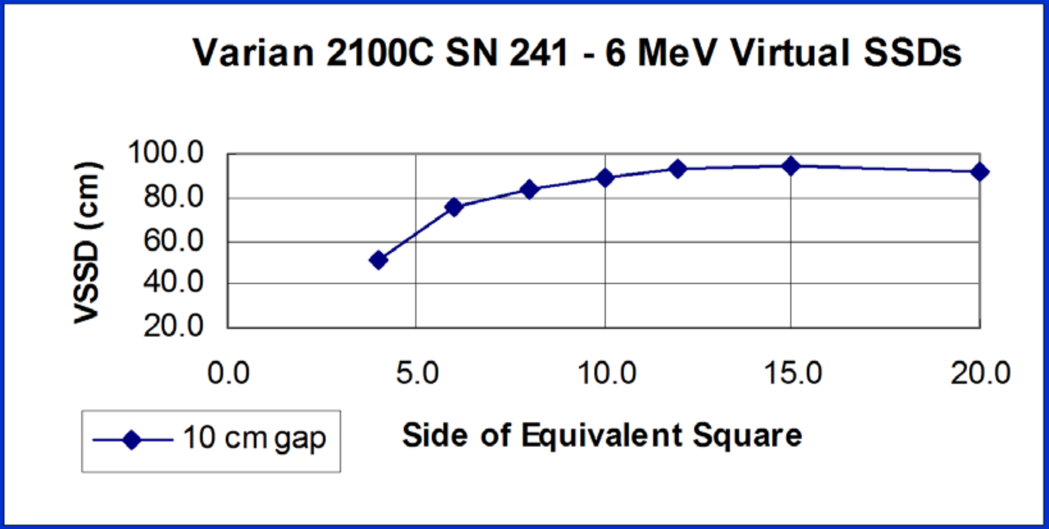
- Distance Corrections - SSD_{eff}:
  - Assuming that an inverse-square relationship exists in which a reduced distance to a "virtual" source of electrons exists, then the distance correction, F_{SSD} is:

$$F_{SSD} = ISF_{SSD_{EFF}} = \left(\frac{SSD_{eff} + d_m}{SSD_{eff} + d_m + g} \right)^2$$

    - where SSD_{eff} is the effective (or virtual) SSD and g is the distance (gap) between the "nominal" SSD (100 cm) and the actual SSD; d_m is the d_{max} depth

Monitor-Unit Calculations

- Distance Corrections - SSD_{eff} :
  - The "effective SSD" is a virtual distance that is utilized so that an inverse-square approximation can be used
    - Effective SSDs vary with energy and field size as well as with electron collimation design



Monitor-Unit Calculations

- Distance Corrections - f_{air} :
  - An alternative method of applying distance corrections utilizes a conventional inverse-square correction and an air gap factor, f_{air} , that accounts for the further reduction in output that is unaccounted-for by the inverse-square correction alone:

$$F_{SSD} = ISF_{SSD_{nom}+g} = \left(\frac{SSD_{nom} + d_m}{SSD_{nom} + d_m + g} \right)^2 \times f_{air}$$

    - SSD_{nom} is the nominal (100 cm) SSD

Monitor-Unit Calculations

- Distance Corrections - f_{air}:
  - f_{air} also varies with energy and field size (it is derived from the same data set that can be used to also determine SSD_{eff})
  - For rectangular fields, as with any electron field-size correction, the square-root method is used:

$$f_{air\,LxW} = \sqrt{f_{air\,LxL} \times f_{air\,WxW}}$$

Monitor-Unit Calculations

- Use of Bolus:
  - When bolus is used, the depth-dose curve shifts "upstream" by a distance equal to the bolus thickness (e.g. if 1 cm bolus is used, the depth of dmax shifts by a distance of 1 cm toward the skin surface)
  - The output at this shorter distance is:

$$O_{SSD,\,b} = O_{SSD} \times \left(\frac{SSD + d_m}{SSD + d_m - b} \right)^2$$

    - where *b* is the bolus thickness in cm, and *SSD* is the nominal SSD

Electron Monitor-Unit Calculations - Sample Problems

1. **What energy beam is appropriate for the treatment of a lesion to a depth of 4 cm ?**

2. **What is the highest energy beam that can be used in a treatment situation to protect an organ-at-risk 6-cm deep?**

Electron Monitor-Unit Calculations - Sample Problems

1. What energy beam is appropriate for the treatment of a lesion to a depth of 4 cm ?

$$d_{90} = E/3.2 \rightarrow E = d_{90} \times 3.2 = 4 \times 3.2 \approx 12 \text{ MeV}$$

2. What is the highest energy beam that can be used in a treatment situation to protect an organ-at-risk 6-cm deep?

$$R_p = E/2 \rightarrow E = R_p \times 2 = 6 \times 2 = 12 \text{ MeV}$$

Electron Monitor-Unit Calculations - Sample Problems

3. Roughly, what is the energy of a 12 MeV electron beam at a depth of 5 cm?

Electron Monitor-Unit Calculations - Sample Problems

3. Roughly, what is the energy of a 12 MeV electron beam at a depth of 5 cm?

$$E_{lost} = \left(2\ Mev/cm\right) \times d_{cm} = 2 \times 5 = 10\ MeV$$

$$E_{left} = E_{initial} - E_{lost} = 12 - 10 = 2\ \ MeV$$

Electron Monitor-Unit Calculations - Sample Problems

4. What is the monitor-unit setting necessary to deliver a dose of 200 cGy per fraction to d_{max} using 9 MeV electrons, 10x10 field, at 100 cm SSD?

Electron Monitor-Unit Calculations - Sample Problems

4. What is the monitor-unit setting necessary to deliver a dose of 200 cGy per fraction to d_{max} using 9 MeV electrons, 10x10 field, at 100 cm SSD?

$$MU = \left(\frac{\left(D_{Rx} \big/ \left(IDL_{\%}/100 \right) \right)}{\left(O_{10,100} \times OF_{FS} \times OF_{SSD} \right)} \right)$$

$$MU = \left(200 \big/ (1.0) \times (1.0) \times \left(1.0\right) \right) = 200$$

Electron Monitor-Unit Calculations - Sample Problems

5. What is the monitor-unit setting necessary to deliver a dose of 200 cGy per fraction to d_{max} using 9 MeV electrons, 6x10 field in a 10x10 cone, at 100 cm SSD?

Electron Monitor-Unit Calculations - Sample Problems

5. What is the monitor-unit setting necessary to deliver a dose of 200 cGy per fraction to d_{max} using 9 MeV electrons, 6x10 field in a 10x10 cone, at 100 cm SSD?

$$OF_{LxW} = \sqrt{OF_{LxL} \times OF_{WxW}}$$

$$OF_{6x10} = \sqrt{OF_{6x6} \times OF_{10x10}} = \sqrt{1.003 \times 1.0} = 1.002$$

$$MU = \left({200}\Big/{(1.0) \times (1.002) \times \left(1.0\right)} \right) = 199.6 \rightarrow 200$$

Electron MU Sample Problems

6. What is the monitor-unit setting necessary to deliver a dose of 200 cGy per fraction to the 90% isodose using 9 MeV electrons, 6x10 field in a 15x15 cone, at 105 cm SSD?

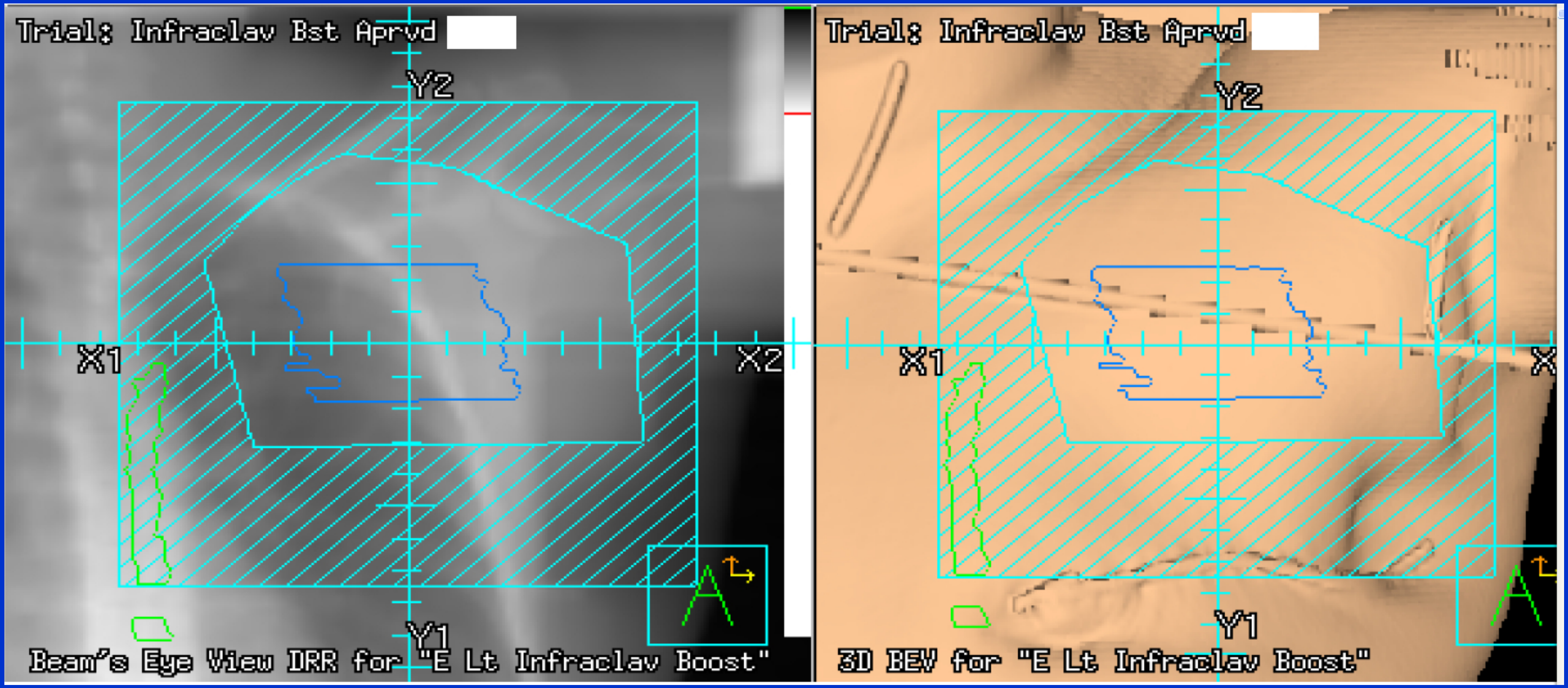
$$F_{SSD} = ISF_{SSD_{nom}+g} = \left(\frac{SSD_{nom+d_m}}{SSD_{nom}+d_m+g}\right)^2 \times f_{air}$$

$$F_{SSD} = \left(\frac{100+2.3}{100+2.3+5}\right)^2 \times \sqrt{0.978 \times 0.984} = 0.909 \times 0.981 = 0.892$$

$$OF_{6x10}^{15Cone} = \sqrt{OF_{6x6} \times OF_{10x10}} = \sqrt{0.997 \times 1.003} = 1.0$$

$$MU = \left(\frac{\left(200 / (90/100)\right)}{(1.0 \times 1.0 \times 0.892)}\right) = \left(\frac{222.2}{0.892}\right) = 249.1 \rightarrow 249$$

Electron MU Sample Problems



Electron MU Sample Problems

Lt Infraclav Boost

Machine	
Machine	Varian 2100
Energy	16e
Prescription	
Dose	150.0 cGy
Rx Isodose	100 %
Parameters	
SSD	102.0 cm
Applicator	15x15
Eff Field Width	12.0 cm
Eff Field Length	9.0 cm
Eff Field Defined at	100 cm
Skin Coll Correction	NO
Eff Skin Coll Width	15.0 cm
Eff Skin Coll Length	15.0 cm
Results	
MU/fx for this field	157
RTP MU/fx for this field	-N/A-
Difference (%)	-N/A-
Modifier Mode	Factor
Modifier Factor	1.000
Bolus	None
Electron Output Factor	0.996
Air Gap Factor	0.995
IVSQ Factor	0.962
Skin Coll Factor	--N/A--
Dmax	3.4 cm
Depth: 100 % isodose (cm)	3.4 cm
Depth: 90 % isodose	5.0 cm
Depth: 10 % isodose	7.8 cm
Monitoring	
Dose at Dmax	------------
Acceptable Range	------------
Diode/TLD Reading	------------

Electron MU Sample Problems

Varian 2100 Electron output factors
16 MeV 15x15 cone

SSD	Insert size					
	15	10	6	4	3	2
100	0.988	0.997	0.988	0.971	0.957	0.942
101	0.968	0.975	0.965	0.945	0.933	0.916
102	0.949	0.955	0.943	0.921	0.910	0.891
103	0.930	0.934	0.922	0.897	0.887	0.866
104	0.912	0.915	0.902	0.873	0.866	0.843
105	0.894	0.895	0.882	0.851	0.844	0.820
106	0.876	0.877	0.862	0.831	0.823	0.793
107	0.857	0.859	0.843	0.811	0.803	0.768
108	0.840	0.841	0.825	0.793	0.783	0.743
109	0.823	0.824	0.807	0.774	0.764	0.719
110	0.806	0.807	0.790	0.756	0.745	0.696
111	0.792	0.793	0.775	0.741	0.728	0.674
112	0.778	0.778	0.761	0.727	0.711	0.652
113	0.764	0.764	0.747	0.713	0.695	0.631
114	0.751	0.751	0.733	0.699	0.679	0.610
115	0.738	0.738	0.720	0.685	0.664	0.590
116	0.725	0.724	0.705	0.670	0.648	0.569
117	0.712	0.710	0.692	0.656	0.632	0.549
118	0.699	0.697	0.678	0.641	0.617	0.529
119	0.686	0.684	0.665	0.627	0.602	0.510
120	0.674	0.672	0.652	0.613	0.587	0.492