Physics of Electron Beams

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review course
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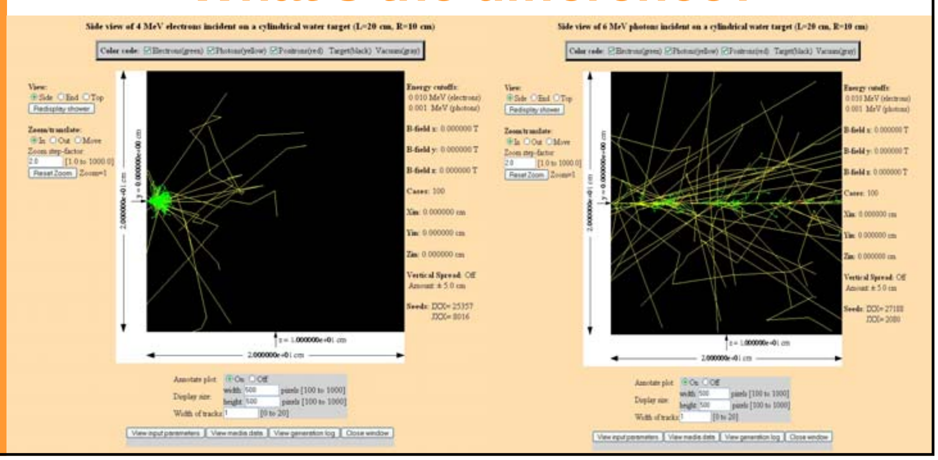
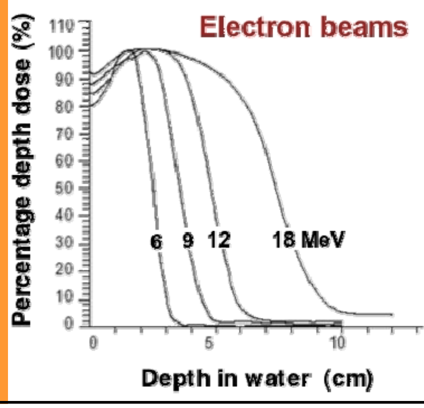
2008

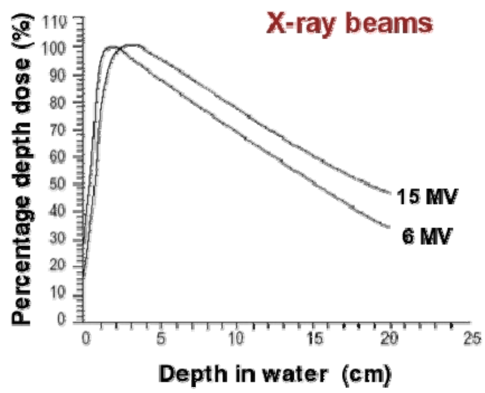
Electron and Photon Comparison

What's the difference?

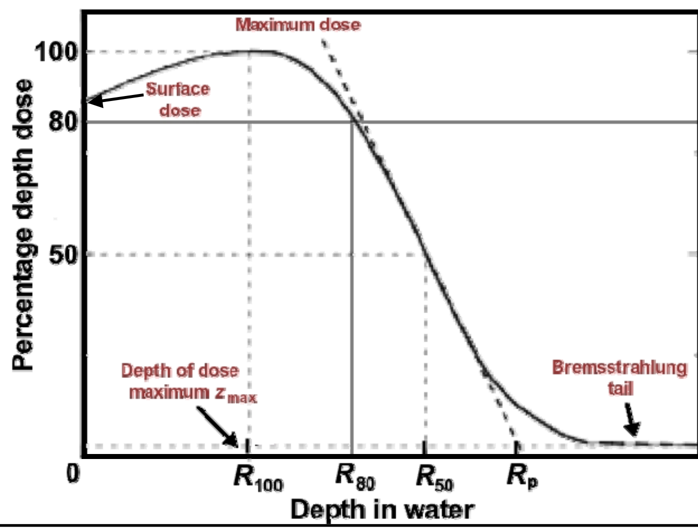


Central Axis Depth Dose Distributions
What's the difference?

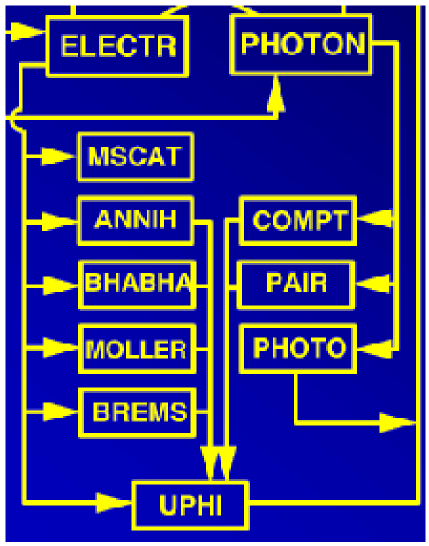




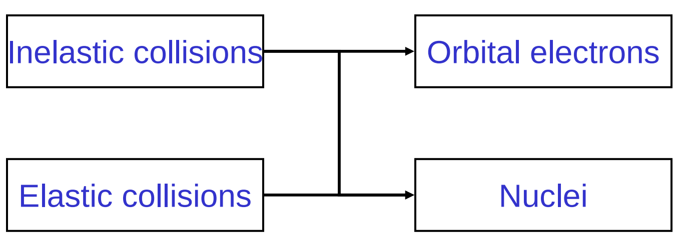
Central Axis Depth Dose Distribution



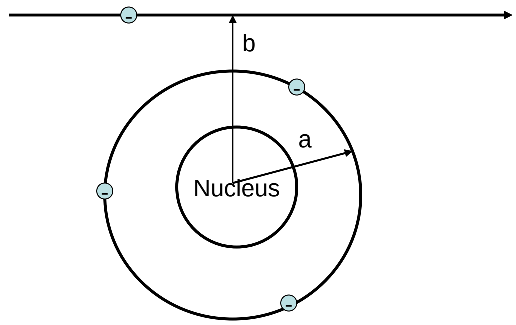
Electron and Photon Interaction With Media



Electron interactions with absorbing medium



Electron interactions with absorbing medium



b>>a: soft collision

b~a: hard collision

b<<a: nuclear field

Electron Energy Loss in absorbing medium

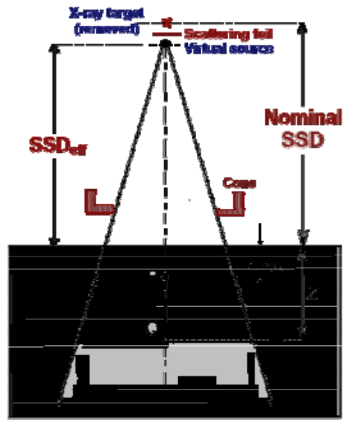
- ionization collisions
- radiation collisions

The rate of energy loss per gram and per cm^2 is called the mass stopping power.

- Mass collision stopping power
- Mass radiation stopping power

The rate of energy loss for a therapy electron beam in water and water-like tissues, averaged over the electron's range, is about 2 MeV/cm.

Inverse square law



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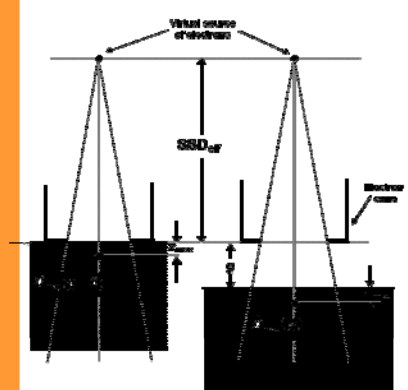
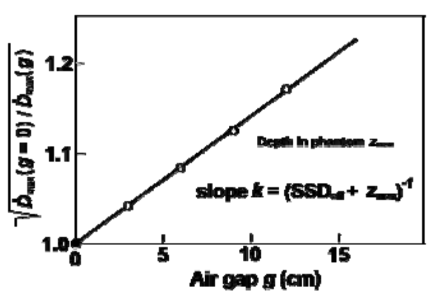
Measurement of the Virtual Source SSD





$$SSD_{eff} = \frac{1}{k} + z_{max}$$

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Continuous Slowing Down Approximation (CSDA)

$$R_{\text{CSDA}} = \int_0^{E_o} \left[\frac{S(E)}{\rho} \right]^{-1} \mathrm{d}E$$

Electron energy (MeV)	CSDA range in air (g/cm^2)	CSDA range in water (g/cm^2)
6	3.255	3.052
7	3.756	3.545
8	4.246	4.030
9	4.724	4.506
10	5.192	4.975
20	9.447	9.320
30	13.150	13.170

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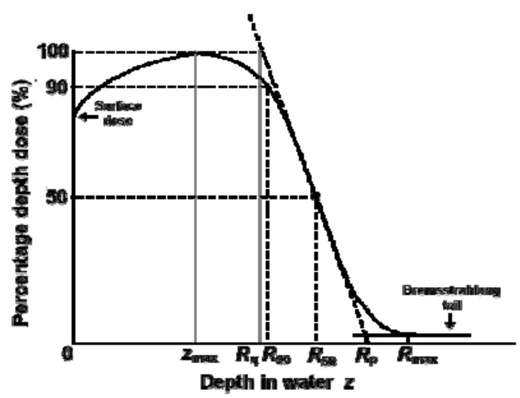
Other Electron Range

- Maximum range *R*max
- Practical range *R*p
- Therapeutic range *R*90
- Therapeutic range *R*80
- Depth *R*50
- Depth *R*q



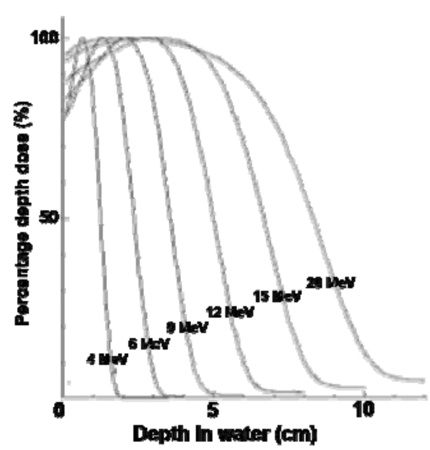
Electron Dose Gradient (G)

$$G = \frac{R_p}{R_p - R_q}$$

Buildup region

Unlike in photon beams, the percentage surface dose in electron beams increases with increasing energy.

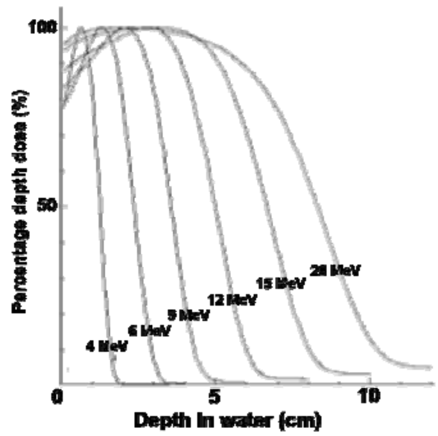
In contrast to photon beams, z_{max} in electron beams does not follow a specific trend with electron beam energy; it is a result of machine design and accessories used.



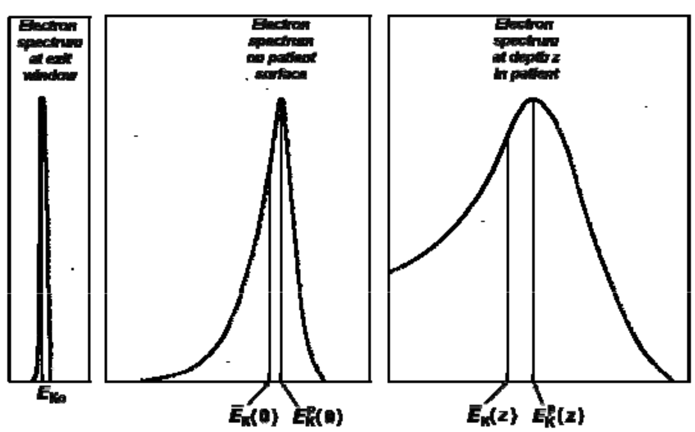
Bremsstrahlung Contamination

The bremsstrahlung contamination of electron beams depends on electron beam energy and is typically:

- Less than 1% for 4 MeV electron beams.
- Less than 2.5% for 10 MeV electron beams.
- Less than 4% for 20 MeV electron beams.



Spectrum of the Electron Beam



Electron Beam Energy Specification

$$\bar{E}_K(0) = CR_{50}$$

The constant C for water is 2.33 MeV/cm

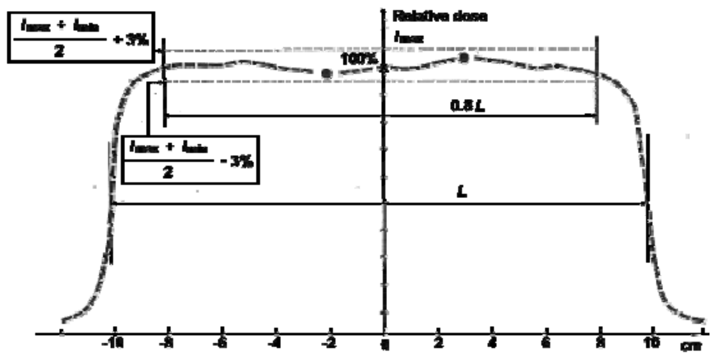
Rule of Thumb

R90 = E_K/4 in cm of water, where E_K is the nominal kinetic energy in MeV of the electron beam.

*R*80 = E_K/3 in cm of water.

Energy (MeV)	R_{90} (cm)	R_{80} (cm)	R_{50} (cm)	R_p (cm)	(MeV)	Surface dose %
6	1.7	1.8	2.2	2.9	5.6	81
8	2.4	2.6	3.0	4.0	7.2	83
10	3.1	3.3	3.9	4.8	9.2	86
12	3.7	4.1	4.8	6.0	11.3	90
15	4.7	5.2	6.1	7.5	14.0	92
18	5.5	5.9	7.3	9.1	17.4	96

Flatness and symmetry



Clinical Considerations

- Electron beam therapy is usually applied in treatment of superficial or subcutaneous disease.
- Treatment is usually delivered with a single direct electron field at a nominal SSD of 100 cm.
- The dose is usually prescribed at a depth that lies at, or beyond, the distal margin of the target.

Clinical Considerations

- To maximize healthy tissue sparing beyond the tumor and to provide relatively homogeneous target coverage treatments are usually prescribed at z_{max}, R_{90}, or R_{80}.
- If the treatment dose is specified at R_{80} or R_{90}, the skin dose may exceed the prescription dose.
- Since the maximum dose in the target may exceed the prescribed dose by up to 20%, the maximum dose should be reported for all electron beam treatments.

Clinical Considerations

In electron beam therapy, the air gap is defined as the separation between the patient and the end of the applicator cone. The standard air gap is 5 cm.

With increasing air gap:

The low value isodose curves diverge.

The high value isodose curves converge toward the central axis of the beam.

The physical penumbra increases.

Clinical Considerations

To achieve a more customized electron field shape, a lead or metal alloy cut-out may be constructed and placed on the applicator as close to the patient as possible.

Field shapes may be determined from conventional or virtual simulation, but are most often prescribed clinically by a physician prior to the first treatment.

As a rule of thumb, divide the practical range R_p by 10 to obtain the approximate thickness of lead required for shielding (<5%).

Clinical Considerations

For certain treatments, such as treatments of the lip, buccal mucosa, eyelids or ear lobes, it may be advantageous to use an internal shield to protect the normal structures beyond the target volume.

Internal shields are usually coated with low atomic number materials to minimize the electron back-scattering into healthy tissue above the shield.

Clinical Considerations

Extended SSDs have various effects on electron beam parameters and are generally not advisable.

In comparison with treatment at nominal SSD of 100 cm at extended SSD:

- Output is significantly lower
- Beam penumbra is larger
- PDD distribution changes minimally.

An effective SSD based on the virtual source position is used when applying the inverse square law to correct the beam output at z_{max} for extended SSD.

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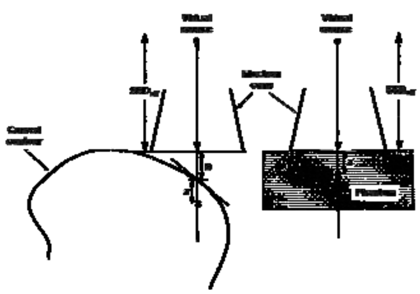
Irregular Surface Correction



$$D(\mathrm{SSD_{eff}} + g, z) = D_o(\mathrm{SSD_{eff}}, z)\left\{\frac{\mathrm{SSD_{eff}} + z}{\mathrm{SSD_{eff}} + g + z)}\right\}^2$$

g = air gap
z = depth below surface
$\mathrm{SSD_{eff}}$ = distance between the virtual source and surface

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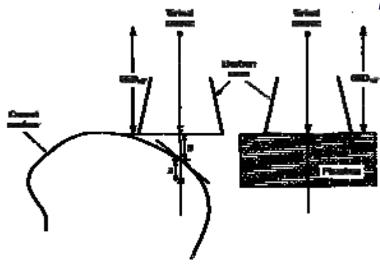
Irregular Surface Correction



$$D(\mathrm{SSD}_{\mathrm{eff}} + g, z) =$$

$$= D_o(\mathrm{SSD}_{\mathrm{eff}}, z)\left\{\frac{\mathrm{SSD}_{\mathrm{eff}} + z}{\mathrm{SSD}_{\mathrm{eff}} + g + z}\right\}^2 \mathrm{OF}(\theta, z)$$

= obliquity factor which accounts for the change in depth dose at a point in phantom at depth z for a given angle of obliquity but same $\mathrm{SSD}_{\mathrm{eff}}$ as for

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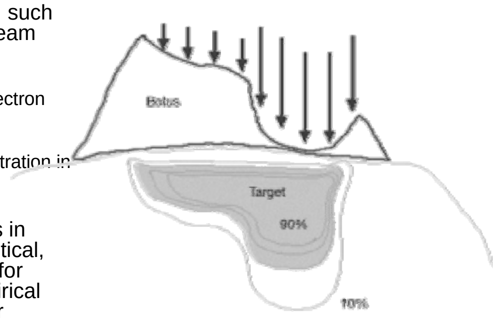
Bolus

Bolus made of tissue equivalent material, such as wax, is often used in electron beam therapy:

- To increase the surface dose.
- To shorten the range of a given electron beam in the patient.
- To flatten out irregular surfaces.
- To reduce the electron beam penetration in some parts of the treatment field.

Although labor intensive, the use of bolus in electron beam therapy is very practical, since treatment planning software for electron beams is limited and empirical data are normally collected only for standard beam geometries.



Inhomogeneity Corrections

Coefficient of equivalent thickness (CET).

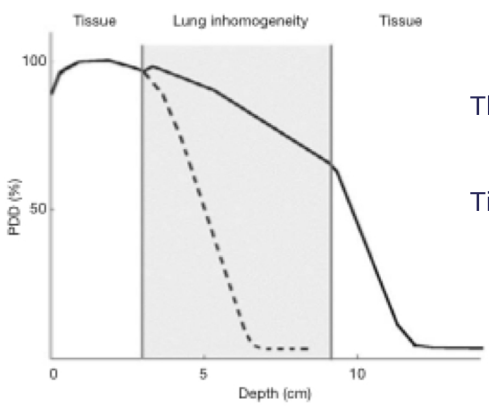
$$z_{\text{eff}} = z - t(1 - \text{CET})$$

z = actual depth of the point of interest in the patient
t = thickness of the inhomogeneity

Lung has approximate density of 0.25 g/cm3 and a CET of 0.25.
A thickness of 1 cm of lung is equivalent to 0.25 cm of tissue.

Solid bone has approximate density of 1.6 g/cm3 and a CET of 1.6.
A thickness of 1 cm of bone is equivalent to 1.6 cm of tissue.

Inhomogeneity Corrections



Thickness t of lung inhomogeneity: 6 cm

Tissue equivalent thickness:
z_{eff} = 1.5 cm

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Electron beam combinations

➢ Occasionally, the need arises to abut electron fields. When abutting two electron fields, it is important to take into consideration the dosimetric characteristics of electron beams at depth in the patient.

➢ The large penumbra and bulging isodose lines produce hot spots and cold spots inside the target volume.

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Electron beam combinations

➢ In general, it is best to avoid using adjacent electron fields.

➢ If the use of abutting fields is absolutely necessary, the following conditions apply:

- ❑ Contiguous electron beams should be parallel to one another in order to avoid significant overlapping of the high value isodose curves at depth in the patient.

- ❑ Some basic film dosimetry should be carried out at the junction of the fields to ensure that no significant hot or cold spots in dose occur.

Electron beam combinations

➢ Electron - photon field matching is easier than electron - electron field matching.

➢A distribution for photon fields is readily available from a treatment planning system (TPS) and the location of the electron beam treatment field as well as the associated hot and cold spots can be determined relative to the photon field treatment plan.

➢ The matching of electron and photon fields on the skin will produce a hot spot on the photon side of the treatment.

Summary

- Central axis depth dose distributions in water
- Dosimetric parameters of electron beams
- Clinical considerations in electron beam therapy

Reference:

"Radiation Oncology Physics: A Handbook for Teachers and Students" published by IAEA

Sample Problems: Electrons

What is the range of a 8 Mev electron beam?

Sample Problems: Electrons

- What is the range of a 8 MeV electron beam?
- 2 MeV/cm so the range for 8 MeV is approximately 4 cm in tissue

Sample Problem: Electrons

What electron beam energy is required to treat a volume that extends to a depth of 6 cm?

Sample Problem: Electrons

- What electron beam energy is required to treat a volume that extends to a depth of 6 cm?

- Energy/3 = depth in cm of 90% line
- 6 cm * 3 = Energy = 18 MeV

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Sample Problem: Electrons

- If I want to use electrons to treat an area 4 cm in width, what size electron field should I use?
- 4 cm
- Less than 4 cm
- Greater than 4 cm

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Sample Problem: Electrons

- If I want to use electrons to treat an area 4 cm in width, what size electron field should I use?
- 4 cm
- Less than 4 cm
- Greater than 4 cm

Sample Problem: Electrons

What factors affect output for electron cones?

- SSD
- Cone size
- Cutout size
- Energy
- Position of collimators

Sample Problem: Electrons

A physician uses 9 MeV to treat a boost field with a 6x6 cone (open) at an SSD of 105. The prescription is written to the 95% isodose line, and the machine is calibrated to 1.00 cGy/MU at 100 cm SSD at dmax for a 10x10 cone. How many mu's should be given? (The cone factor = 1.007 and SSD factor = 0.899)

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Sample Problem: Electrons

- Dose rate = 1.00 cGy/mu * 1.007 * 0.899* 0.95
- Dose rate = 0.86 cGy/mu
- 100 cGy/0.86 cGy/mu = 116 mu

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