Electron Dosimetry Training: VARSKIN 6

RENAISSANCE
CODE DEVELOPMENT

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Outline

- Electron Dosimetry Theory
  - Basics
  - Scaling Parameters
  - Backscatter
- Summary

Electron Dosimetry Theory - Basics

Electron Interactions

- As energetic electrons pass through material, they transfer energy
  - primarily via “soft collisions”, i.e., Coulombic interactions
  - or, “hard” collisions with orbital electrons
- Energy loss is a function of KE & charge density
- Energy loss can result in:
  - excitation – characteristic X-rays
  - ionization – scattered energetic electrons
  - Bremsstrahlung (>1 MeV electrons) – low-energy photons
- Scattered electrons may produce additional ion pairs
  - e.g., clusters, delta rays, further excitation/ionization

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Range-Energy Observations

- Electrons lose energy via tortuous paths
- Electron range (penetration depth) increases with increasing energy
- Linear range is largely dependent on electron density of the absorber atoms
- And, to a lesser degree, range is a function of Z
  - result has practical implications for shielding
  - *density thickness* (mg/cm^2) is best indicator of electron range
  - important tissue depths → 7, 100, 300, 1000 mg/cm^2

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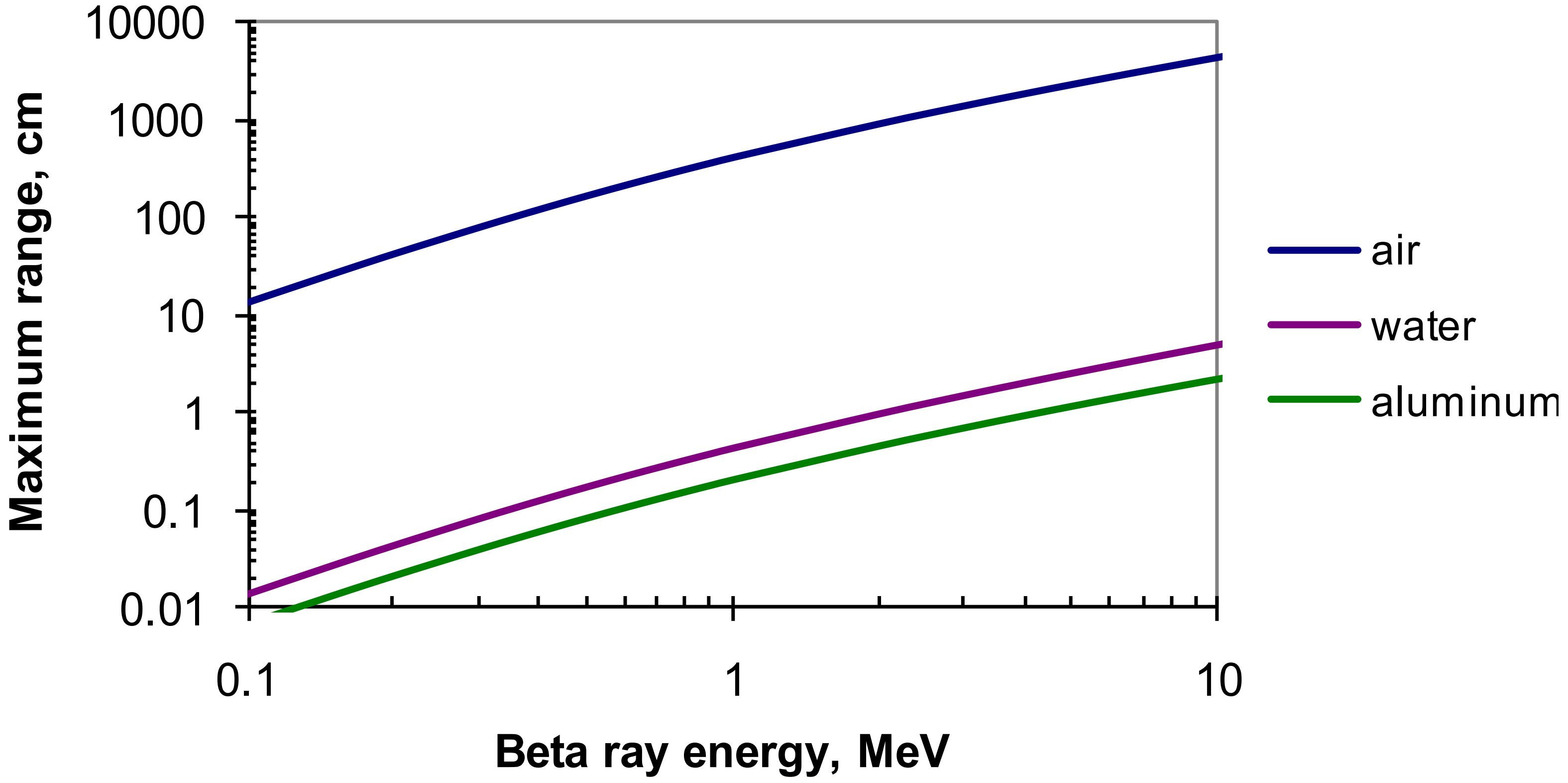
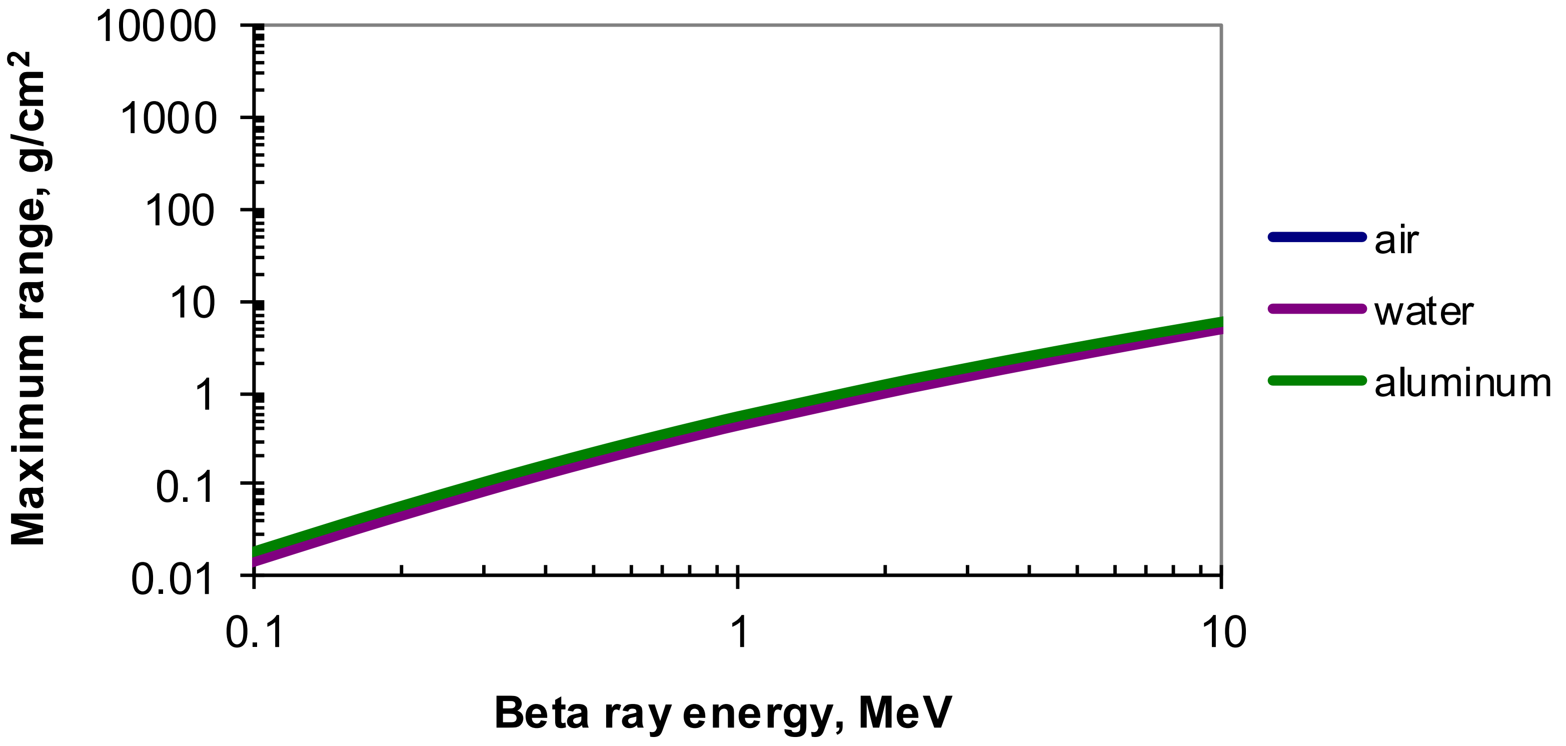
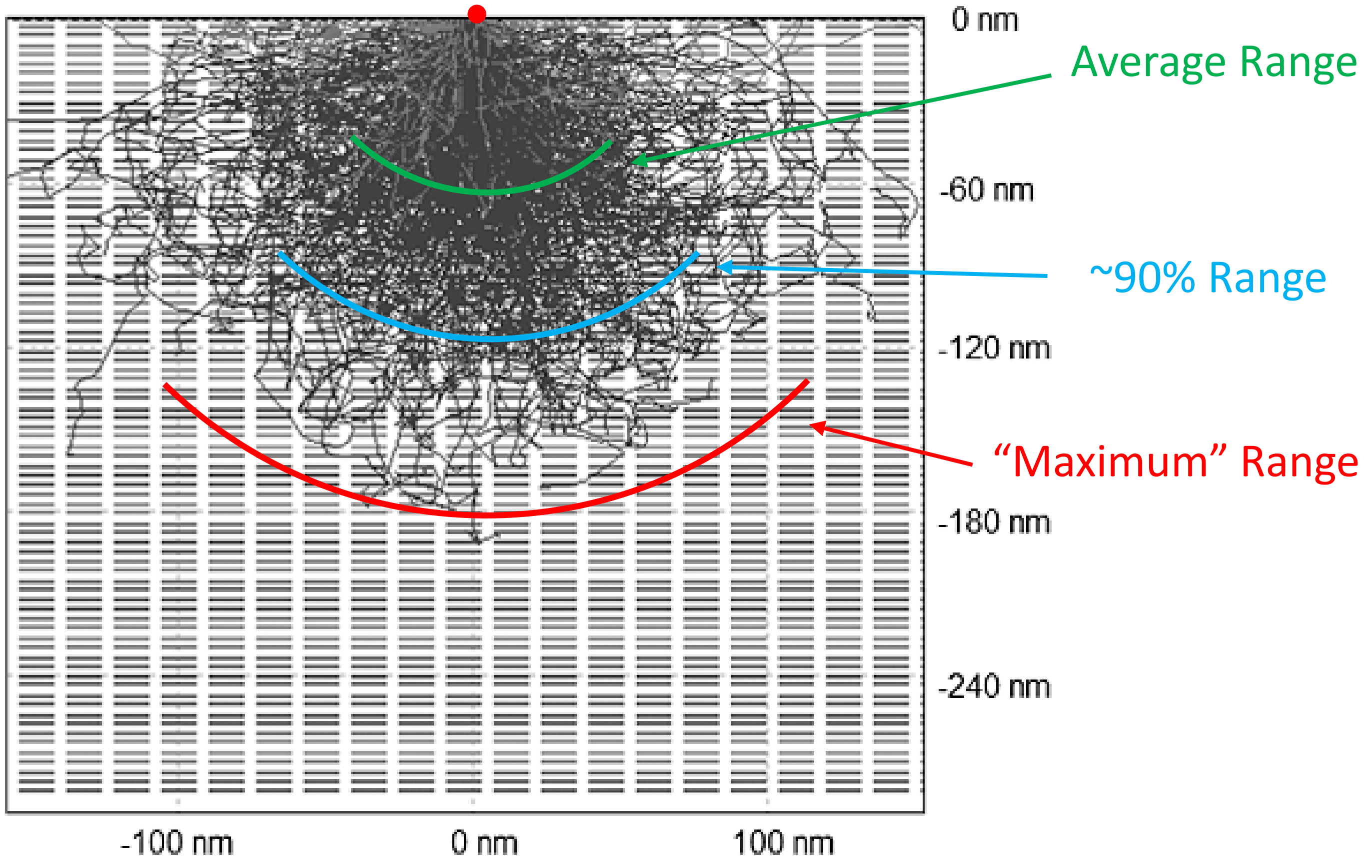
Range-Energy Relationship for Electrons



Advantag


10000
1000
100
10
1
0.1
0.01
Maximum range, g/cm²
0.1
1
10
Beta ray energy, MeV
air
water
aluminum

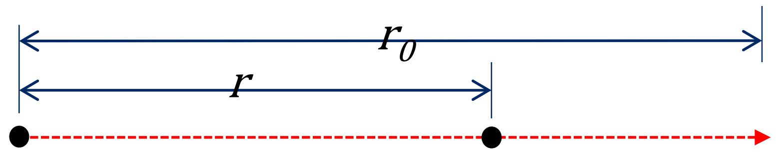
Electron Track Simulation



Electron Point-Kernel Dosimetry

As with photons, the point-kernel method can be used for mono-energetic electron dosimetry in which dose is integrated over all source and receptor points:

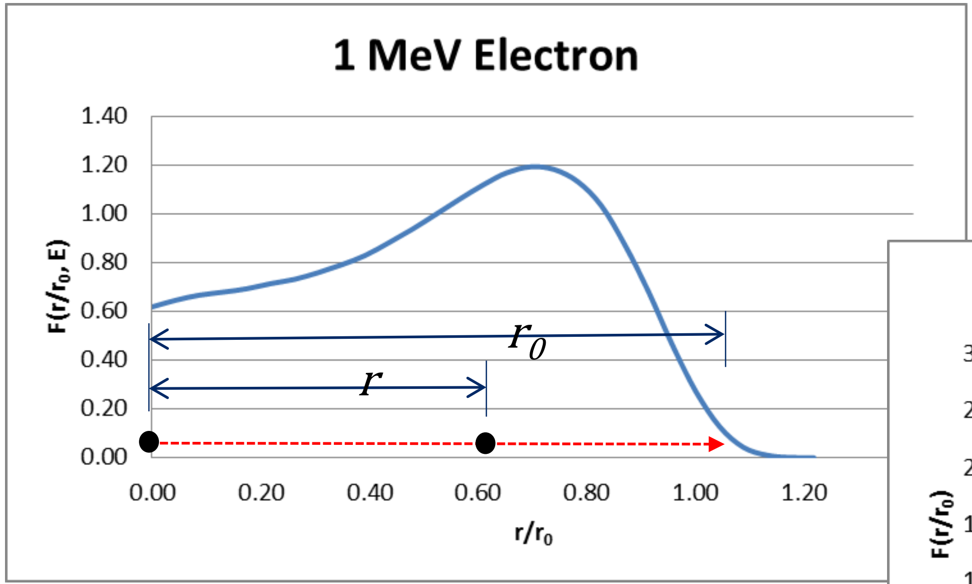
$$G(r,E) = \frac{E}{4\pi r^2 \rho r_0} F(r/r_0, E)$$

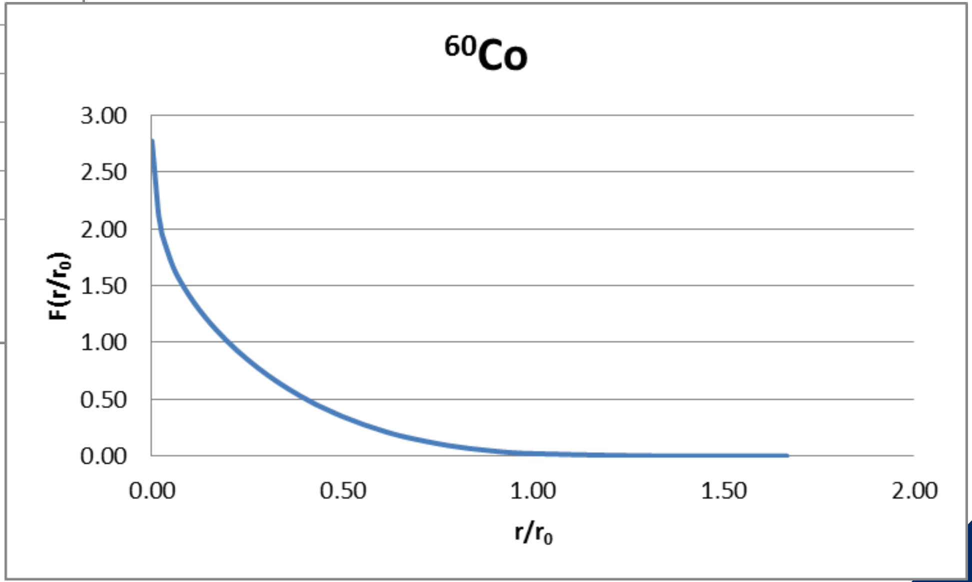


The function $F(r/r_0, E)$ is a “scaled absorbed dose distribution” (essentially a normalized Bragg curve) that is dependent on the electron initial energy and the fraction of *maximum* range (r/r_0) that the electron has achieved by the time it reaches the dose location.

Scaled Absorbed Dose Distributions

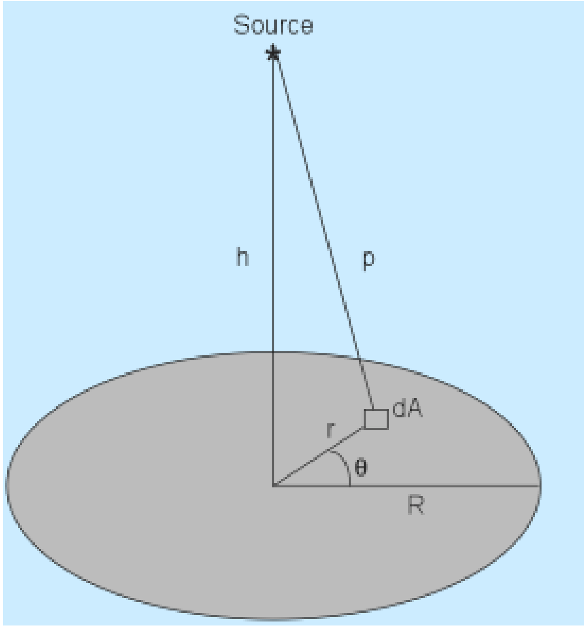
The factor $F(r/r_0,E)$ is shown for electrons of energy E, and for beta particles of distributed E, normalized over their *maximum* range, r_0





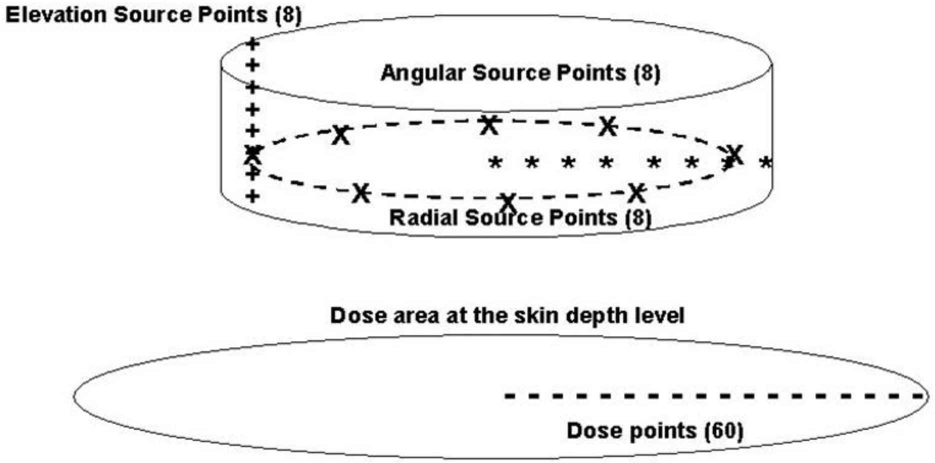
Fundamentally …

- Point-kernel method employed
- Source on skin surface
- Dose calculated to a given averaging area at the user-specified depth
- Energy absorption based on calculated stopping power at depth



Symmetric-Source Dose Calculation

- Original VARSKIN begins at the center dose point of the irradiation area
- The code divides the source into very small sub-volumes (source points)
- The number of source points chosen is sufficient for convergence (checked along the way)



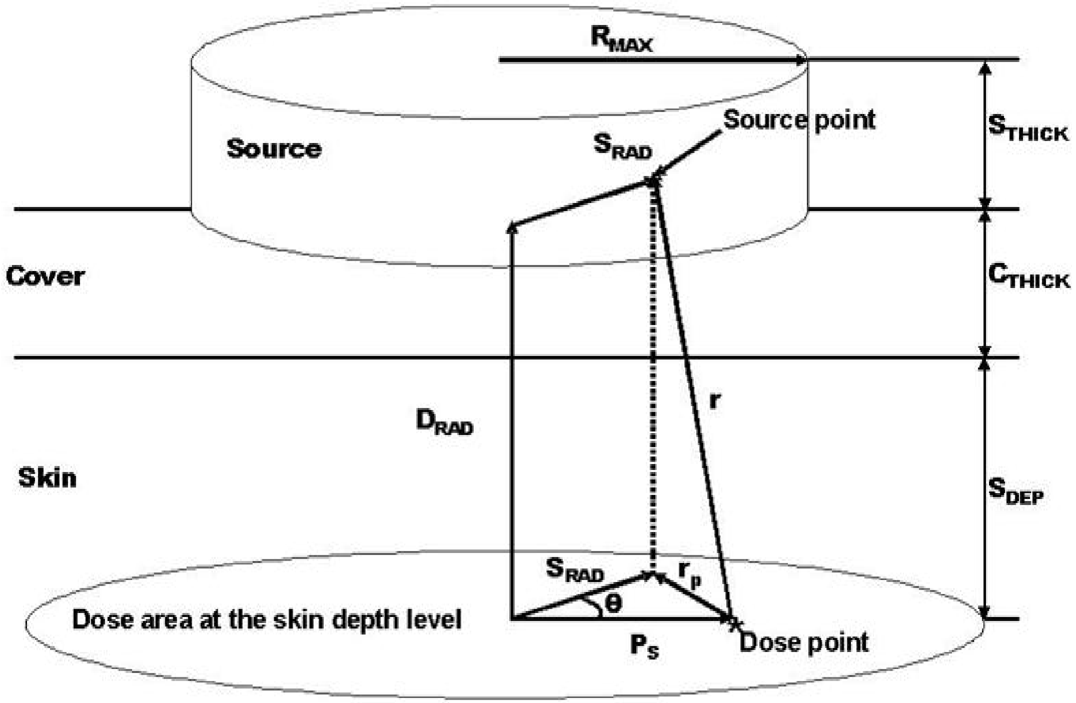
Density Correction Model

$$r_c = C_{thick} \cdot \left(r / D_{rad} \right)$$

$$r_t = S_{dep} \cdot \left(r / D_{rad} \right)$$

$$r_s = \left(D_{rad} - C_{thick} - S_{dep} \right) \cdot \left(r / D_{rad} \right)$$

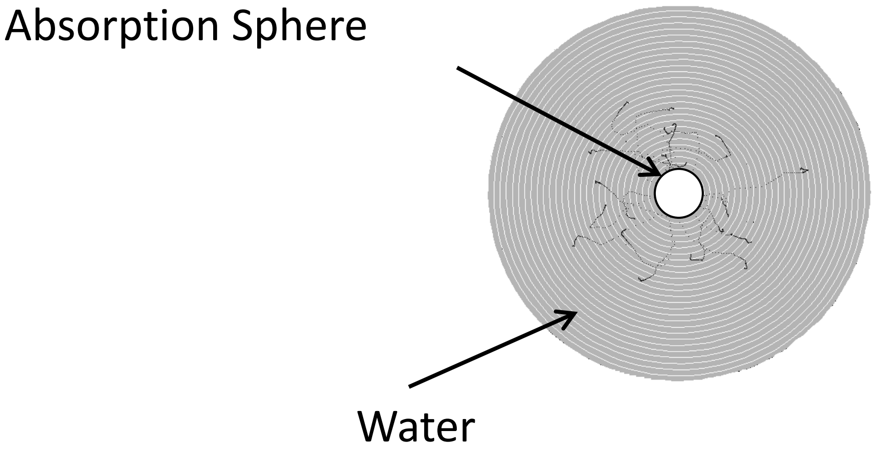
$$r_1 = \frac{\left(r_s \rho_s + r_c \rho_c + r_t \rho_t \right)}{\rho_t}$$



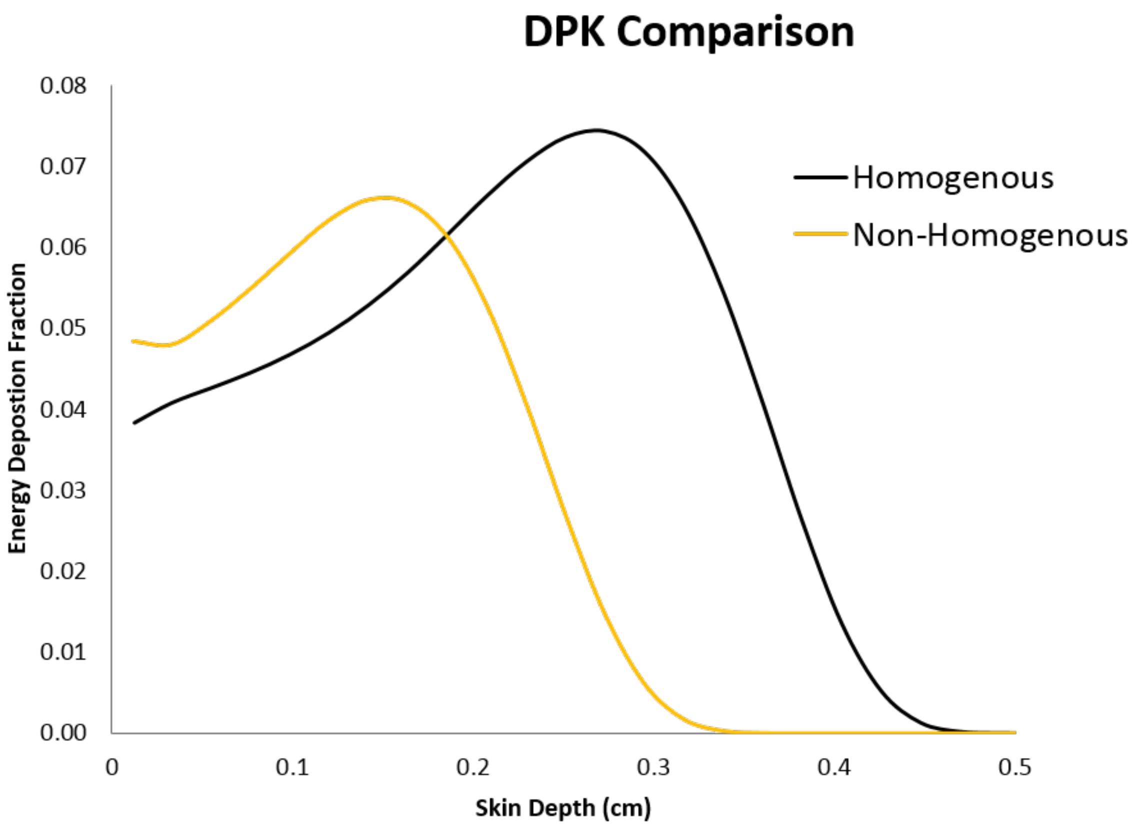
Electron Dosimetry Theory - Advanced Scaling Parameters

Methods: Scaling Model

- Using EGSnrc Monte Carlo simulations:
  - Homogeneous point-source DPK's for water at 0.01 MeV ≤ E ≤ 8 MeV (30 energies)
  - Non-homogeneous point-source DPK's for 7.42 < Z ≤ 94 (18 solid elements) at 0.01 MeV ≤ E ≤ 8 MeV
    - water absorption sphere
    - radii varied between 5% to 110% of the X_{90} value



Scaling Model



- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

Scaling Model

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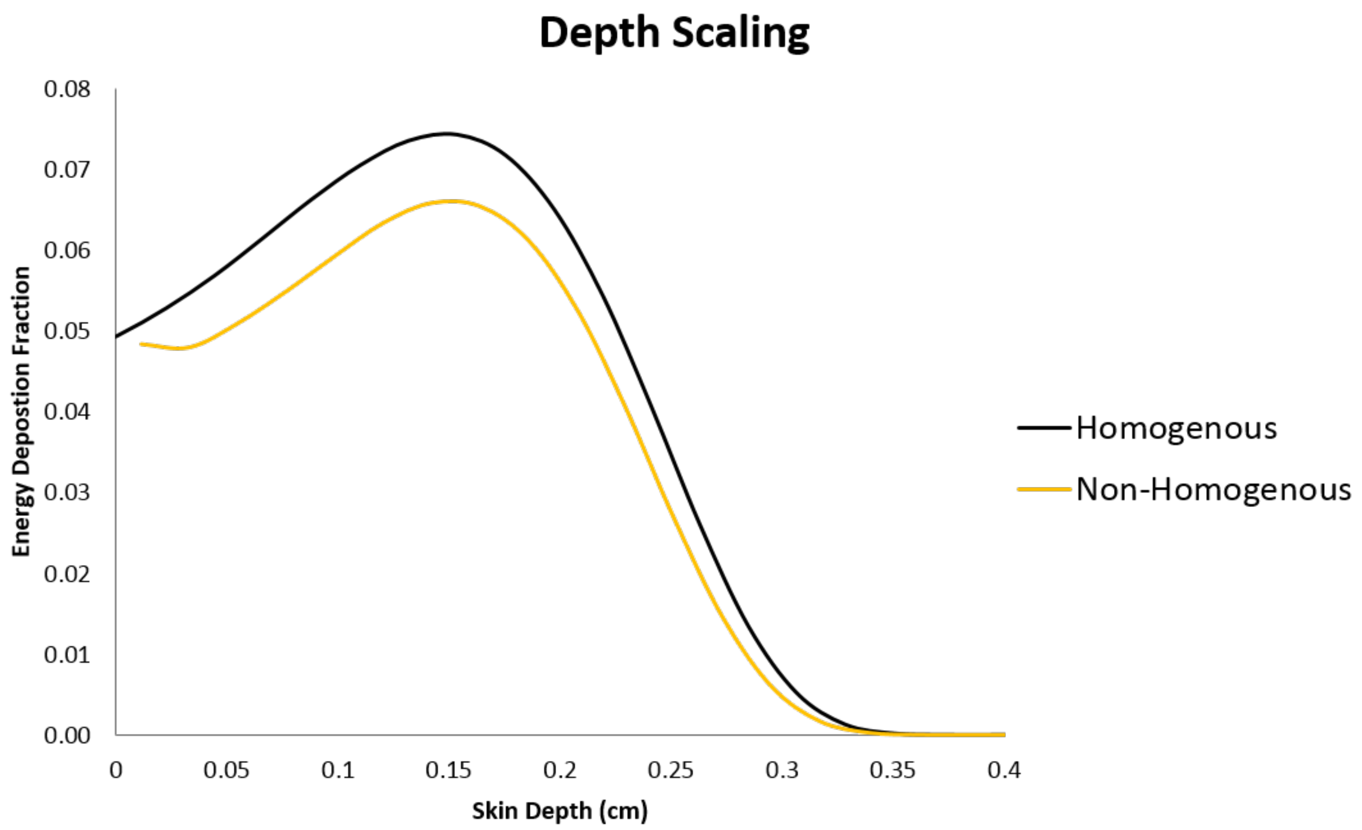

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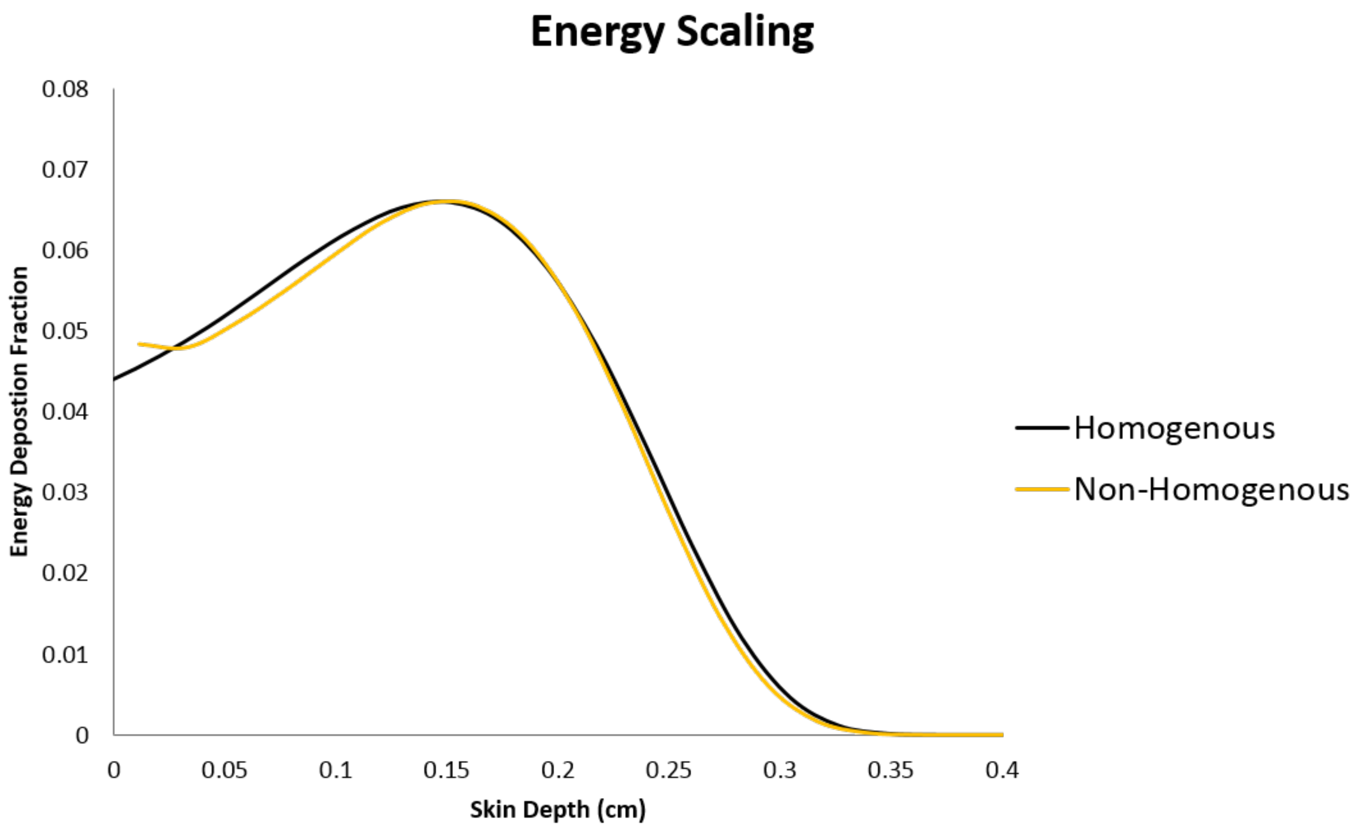
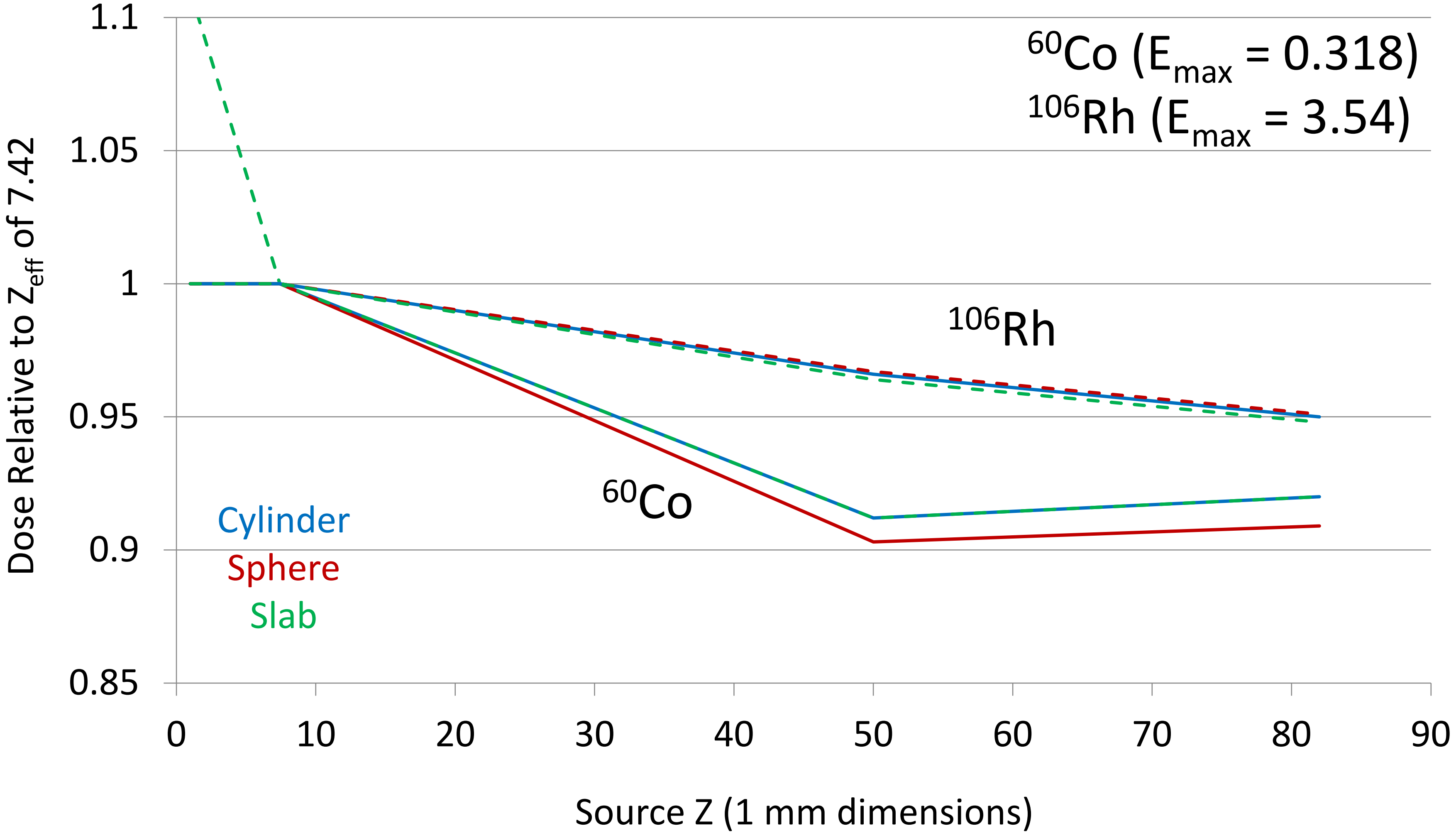
Scaling Model



Volumetric Beta Dose vs Source Z



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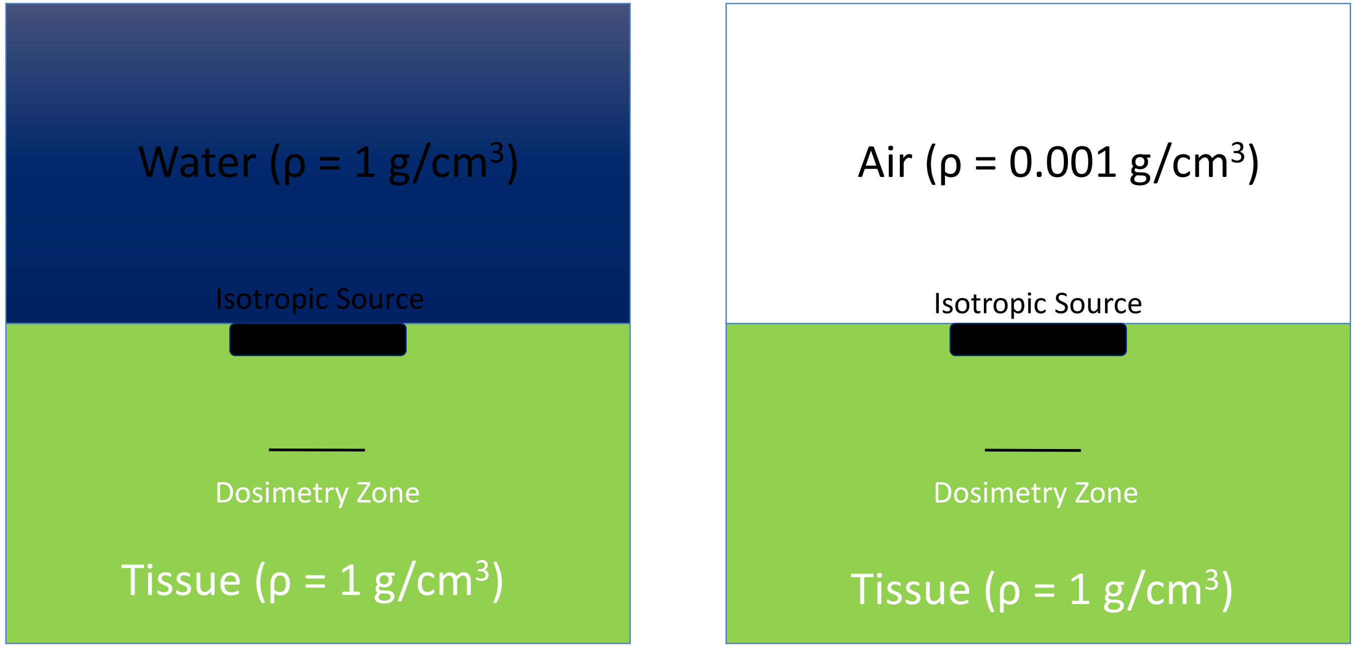
Electron Dosimetry Theory - Backscatter Correction

Original Backscatter Determination



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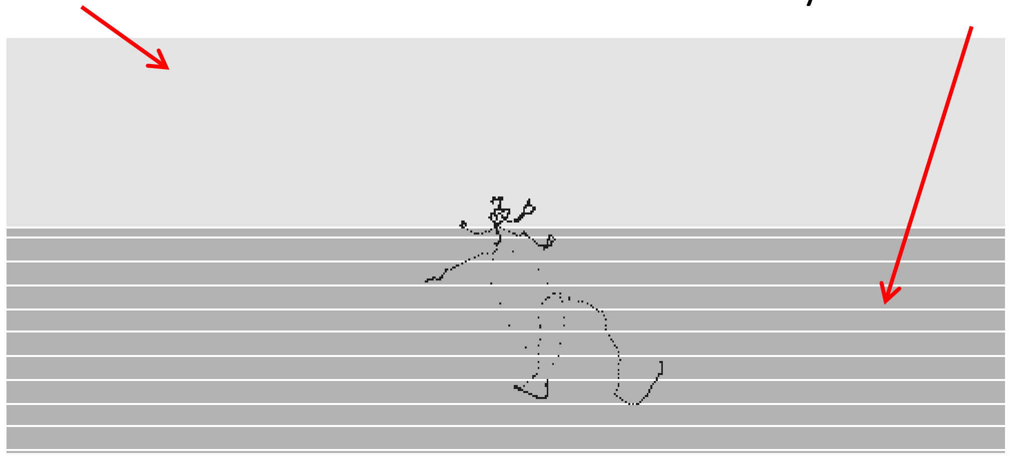
New Backscatter Model

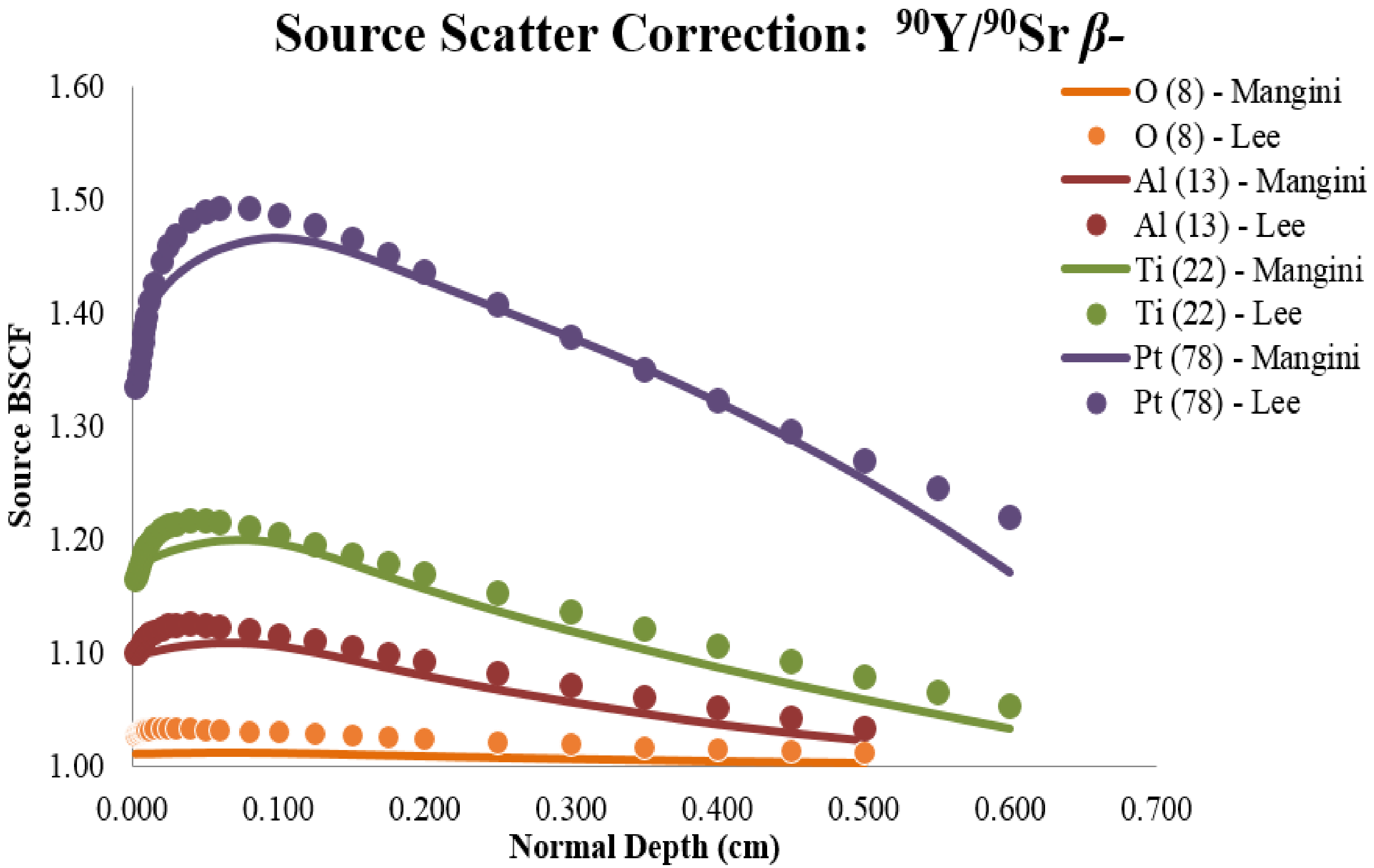
- Point-source planar dose profiles for water, air, and $7.42 < Z \leq 94$ scattering media at $0.01\ \text{MeV} \leq E \leq 8\ \text{MeV}$ using EGSnrc Monte Carlo simulations
- Dose averaging areas of 1 and 10 cm^2
- Normal depths every 1 mg cm^{-2} (up to 1000 mg cm^{-2})

Scattering Medium ("infinite" thickness)

Cylindrical Dose Planes



Point-Source BSCF



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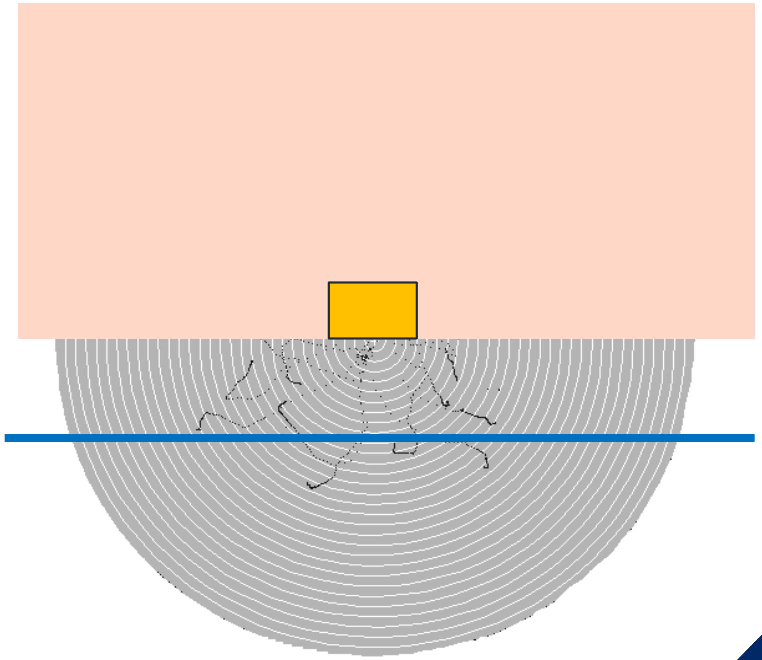
Scatter Scenarios

- Source scatter for top/bottom of source
- Source scatter for sides of source
- Air scatter for top/sides of source



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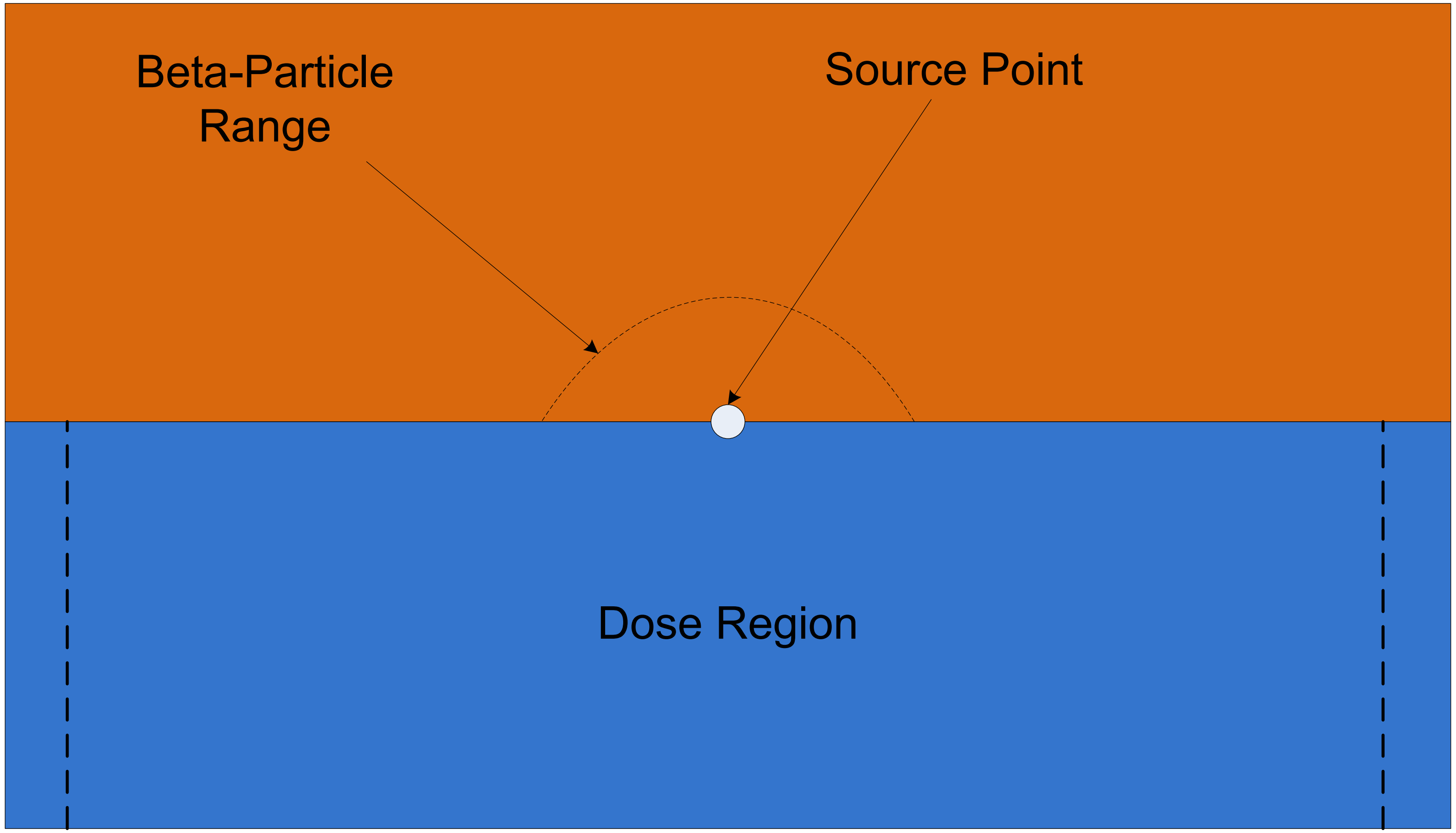
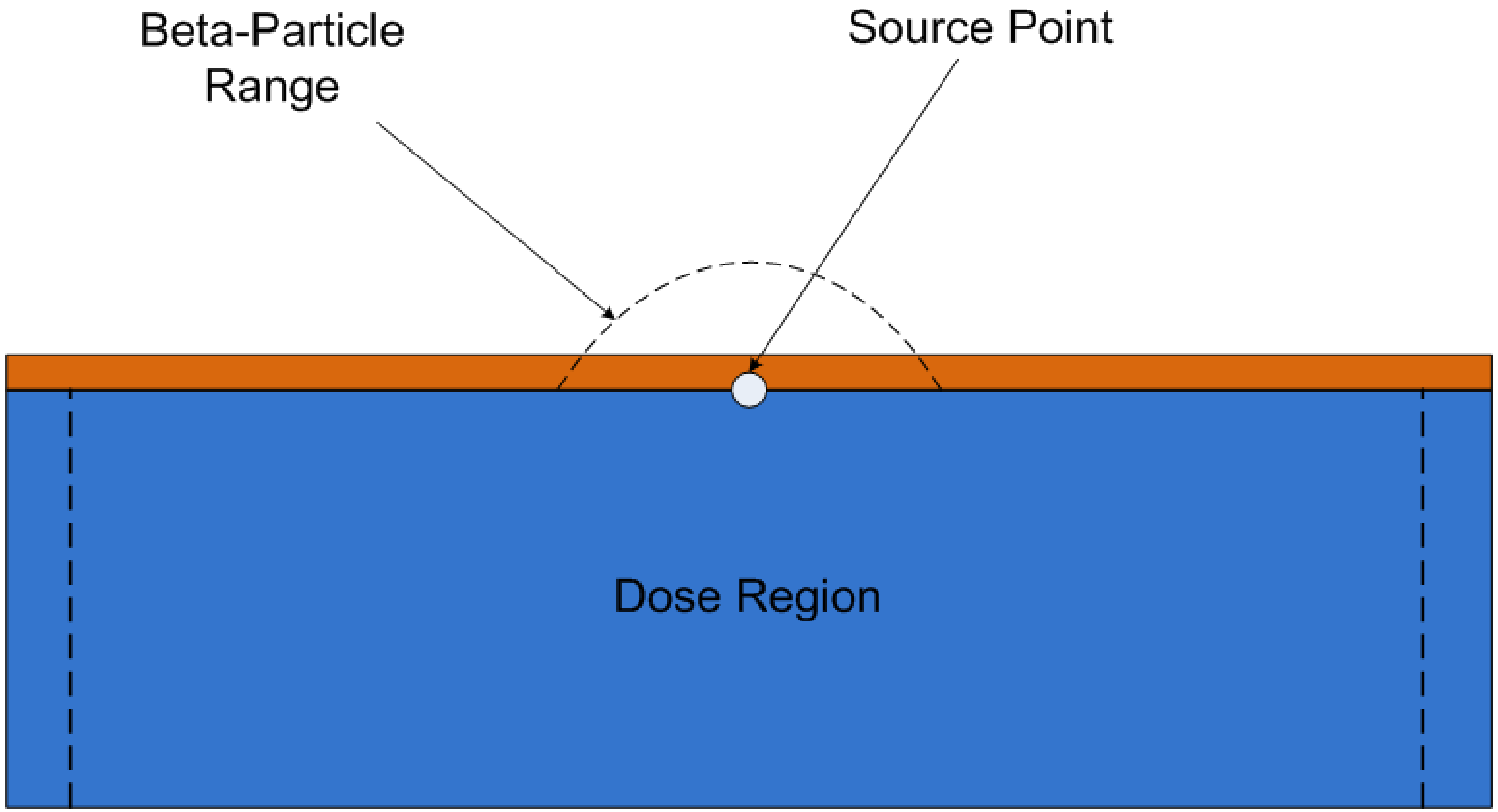
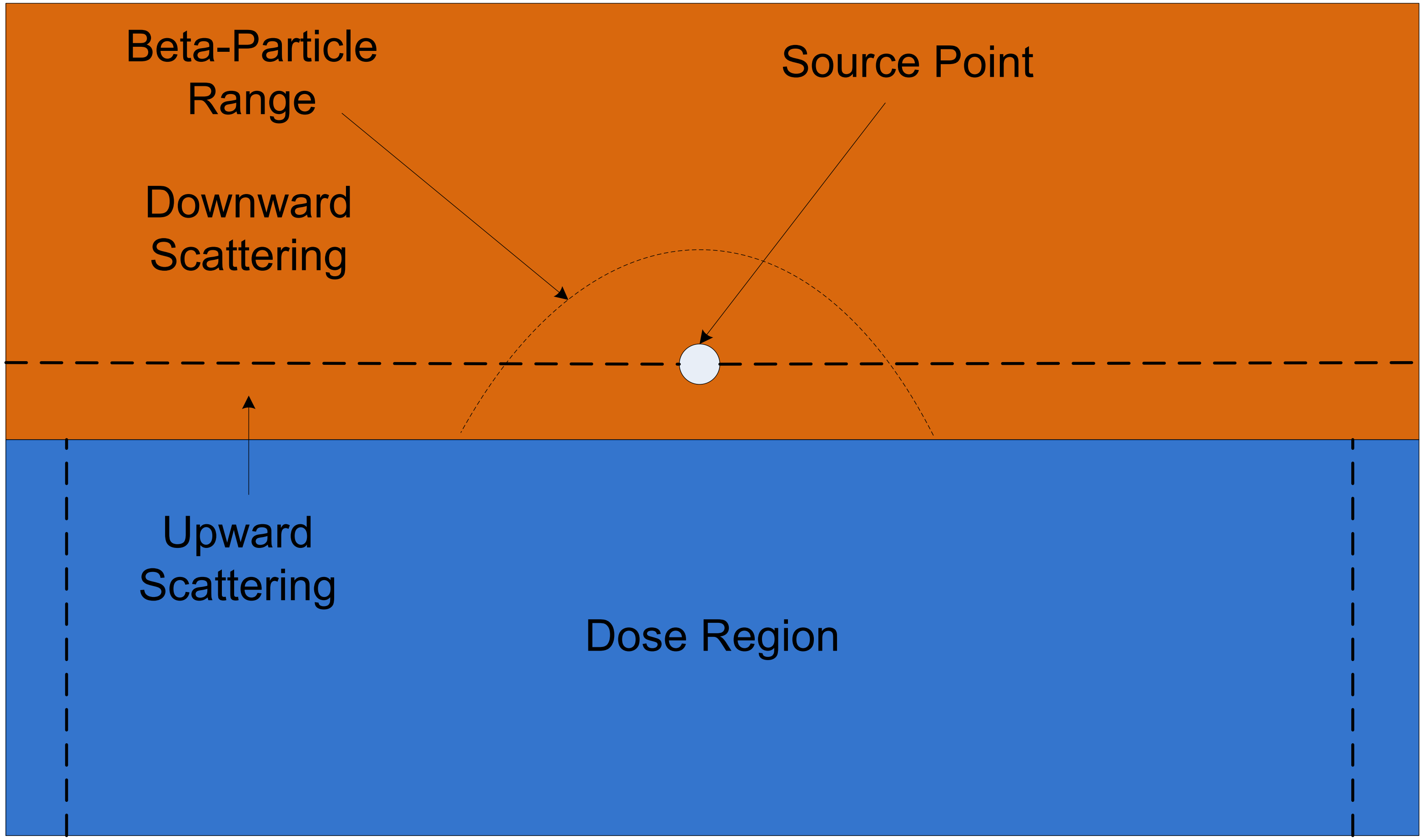
Scatter for Top/Bottom of Source



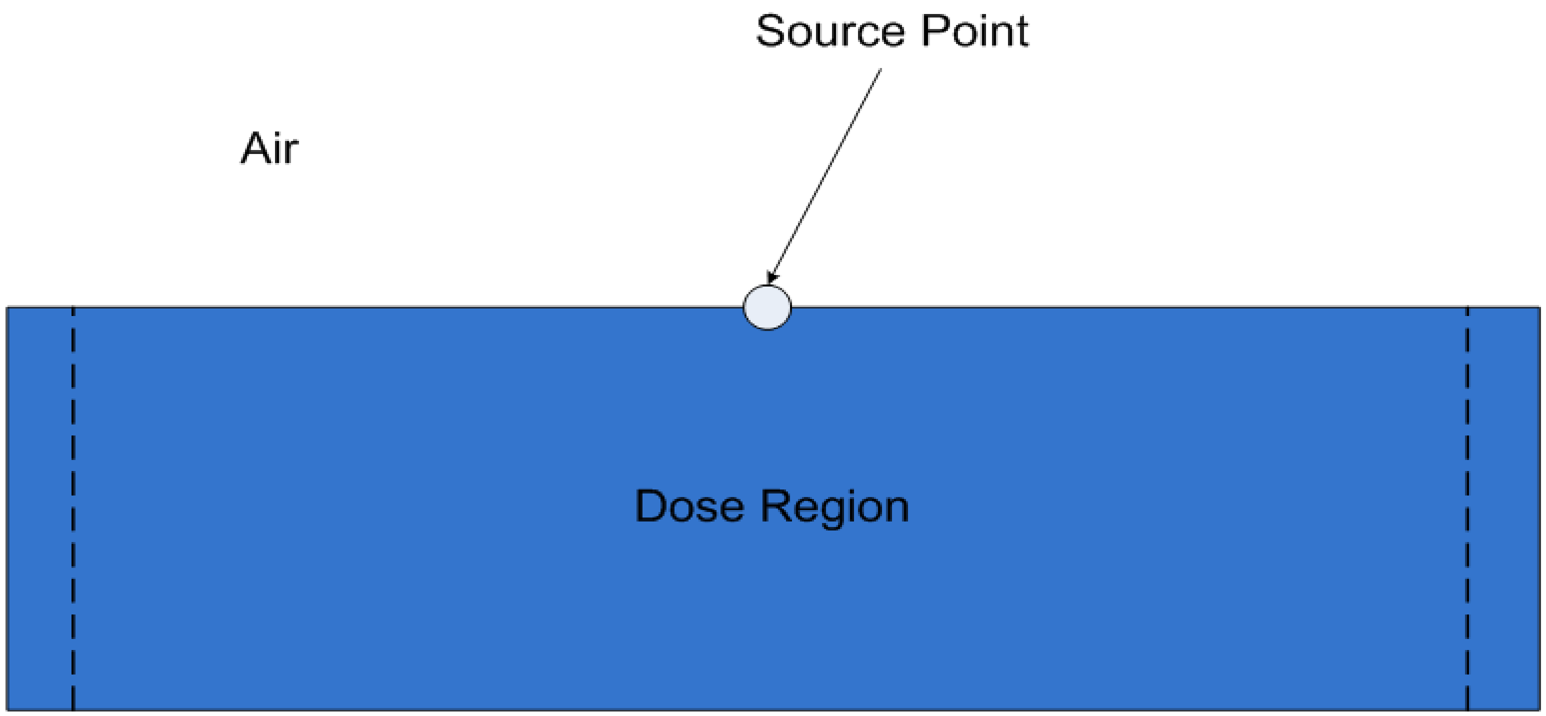
Scatter for Top/Bottom of Source



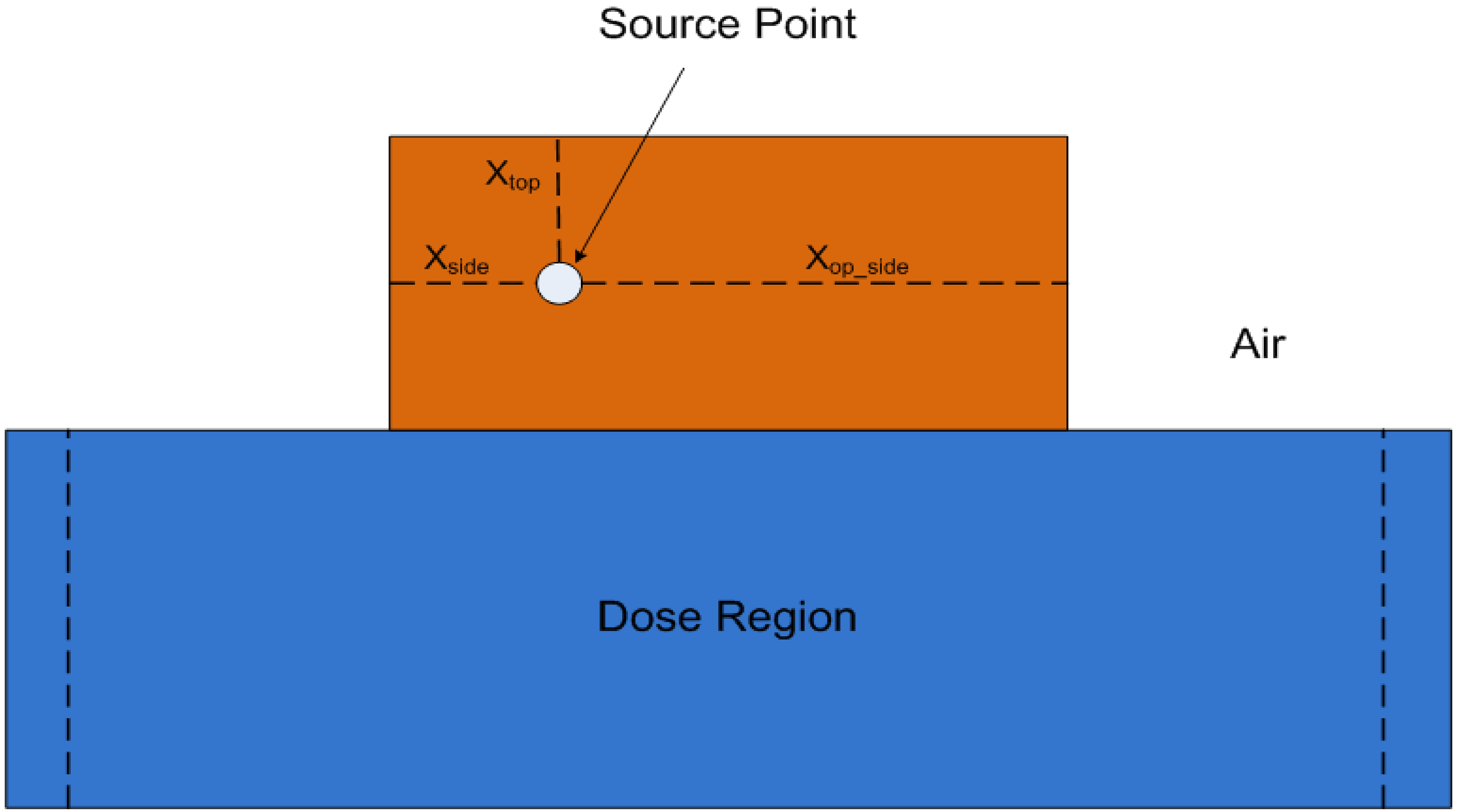
Scatter for Top/Bottom of Source



Air Scatter for Top/Sides of Source



Air Scatter for Top/Sides of Source



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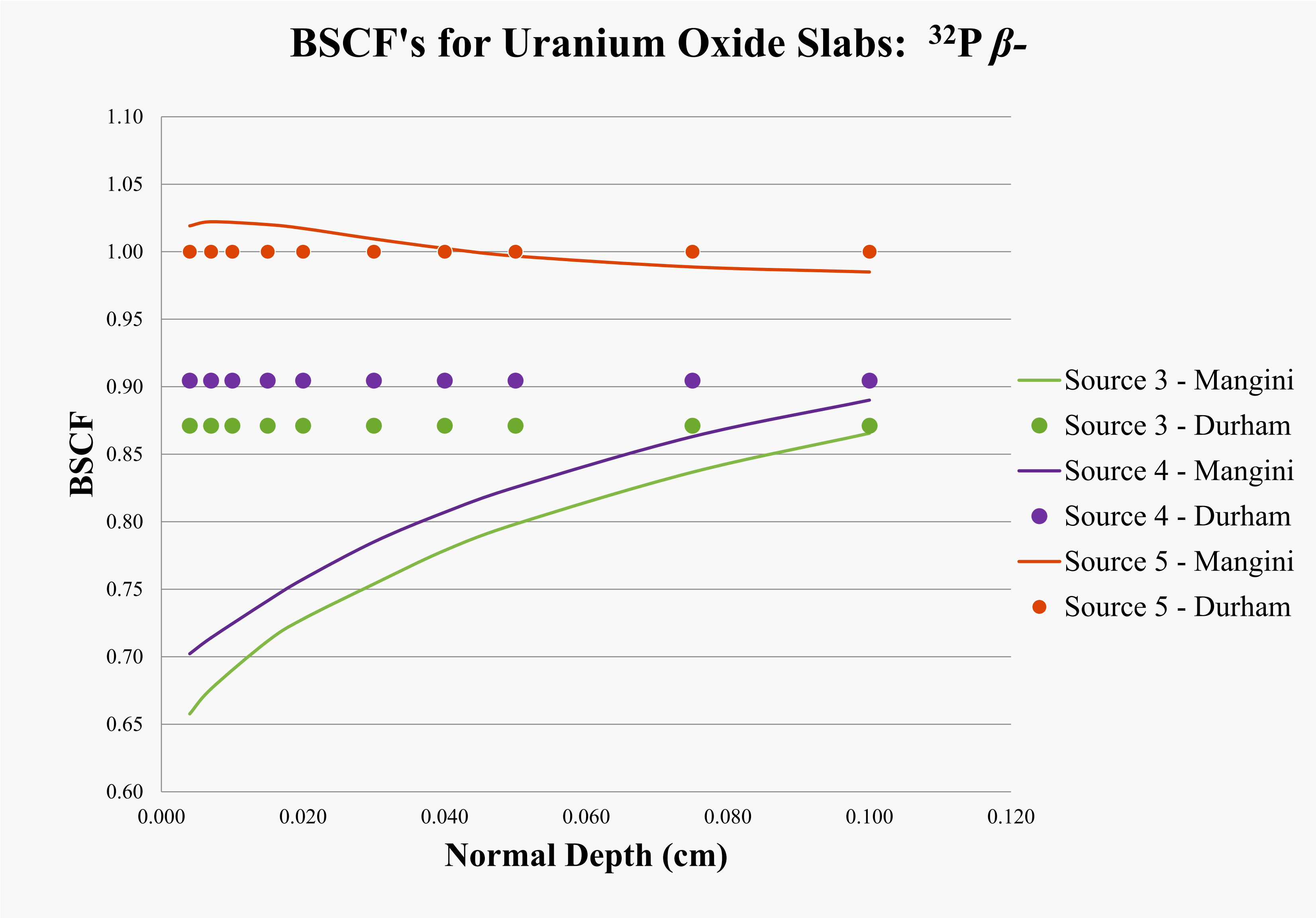
Volumetric BSCF



SUMMARY

- Electron Interactions --> Electron energy distribution
- Energy scaling model
- Range scaling model
- Backscatter correction factors
- Numerical Integration of Dose-Point Kernels

Questions