Electron Dosimetry Training: VARSkin 6

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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
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
  - \textit{density thickness} (mg/cm\textsuperscript{2}) is best indicator of electron range
  - important tissue depths $\rightarrow$ 7, 100, 300, 1000 mg/cm\textsuperscript{2}
Range-Energy Relationship for Electrons

Maximum range, cm

Beta ray energy, MeV

- air
- water
- aluminum
Advantage of Density Thickness

Maximum range, g/cm²

Beta ray energy, MeV

- air
- water
- aluminum
Electron Track Simulation

- Average Range
- ~90% Range
- "Maximum" Range
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:

\[ G(r, E) = \frac{E}{4\pi r^2 \rho r_0} F\left(\frac{r}{r_0}, E\right) \]

The function \( F\left(\frac{r}{r_0}, E\right) \) 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 \( \frac{r}{r_0} \) 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

\[ r_c = C_{thick} \cdot \left( \frac{r}{D_{rad}} \right) \]
\[ r_t = S_{dep} \cdot \left( \frac{r}{D_{rad}} \right) \]
\[ r_s = \left( D_{rad} - C_{thick} - S_{dep} \right) \cdot \left( \frac{r}{D_{rad}} \right) \]

\[ r_t = \frac{r_s \rho_s + r_c \rho_c + r_t \rho_t}{\rho_t} \]
Electron Dosimetry Theory - Advanced Scaling Parameters
Methods: Scaling Model

• Using EGSnrc Monte Carlo simulations:
  • Homogeneous point-source DPK’s for water at $0.01 \text{ MeV} \leq E \leq 8 \text{ MeV}$ (30 energies)
  • Non-homogeneous point-source DPK’s for $7.42 < Z \leq 94$ (18 solid elements) at $0.01 \text{ MeV} \leq E \leq 8 \text{ MeV}$
    • 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

- 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

Energy Scaling

- Homogenous
- Non-Homogenous
Volumetric Beta Dose vs Source Z

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$^{60}$Co ($E_{\text{max}} = 0.318$)

$^{106}$Rh ($E_{\text{max}} = 3.54$)

Source Z (1 mm dimensions)
Electron Dosimetry Theory - Backscatter Correction
Original Backscatter Determination

- Water ($\rho = 1 \text{ g/cm}^3$)
  - Isotropic Source
  - Dosimetry Zone
  - Tissue ($\rho = 1 \text{ g/cm}^3$)

- Air ($\rho = 0.001 \text{ g/cm}^3$)
  - Isotropic Source
  - Dosimetry Zone
  - Tissue ($\rho = 1 \text{ g/cm}^3$)
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$^{-2}$)
Point-Source BSCF

Source Scatter Correction: $^{90}\text{Y}/^{90}\text{Sr \, \beta^-}$

- O (8) - Mangini
- O (8) - Lee
- Al (13) - Mangini
- Al (13) - Lee
- Ti (22) - Mangini
- Ti (22) - Lee
- Pt (78) - Mangini
- Pt (78) - Lee
Scatter Scenarios

• Source scatter for top/bottom of source

• Source scatter for sides of source

• Air scatter for top/sides of source
Scatter for Top/Bottom of Source

![Diagram showing scatter for top/bottom of source with annotations for beta-particle range and source point.]

- Beta-Particle Range
- Source Point
- Dose Region
Scatter for Top/Bottom of Source
Scatter for Top/Bottom of Source

- Beta-Particle Range
- Source Point
- Downward Scattering
- Upward Scattering
- Dose Region
Air Scatter for Top/Sides of Source
Air Scatter for Top/Sides of Source
Volumetric BSCF

BSCF's for Uranium Oxide Slabs: $^{32}\text{P} \beta$-

- Source 3 - Mangini
- Source 3 - Durham
- Source 4 - Mangini
- Source 4 - Durham
- Source 5 - Mangini
- Source 5 - Durham

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SUMMARY

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