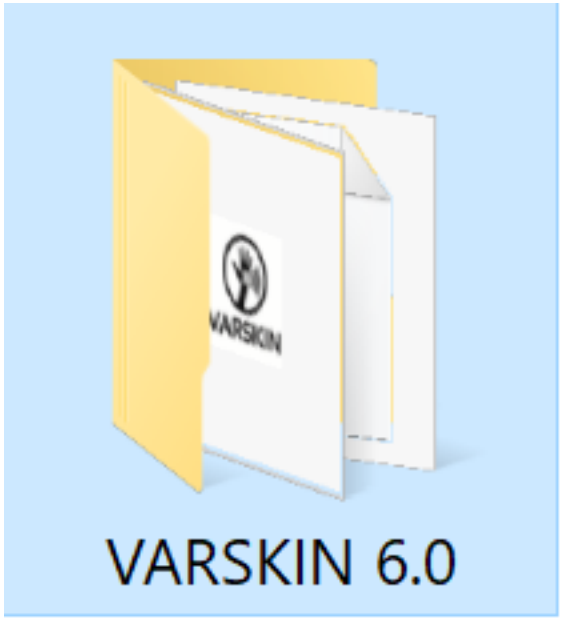
VARSKIN 6

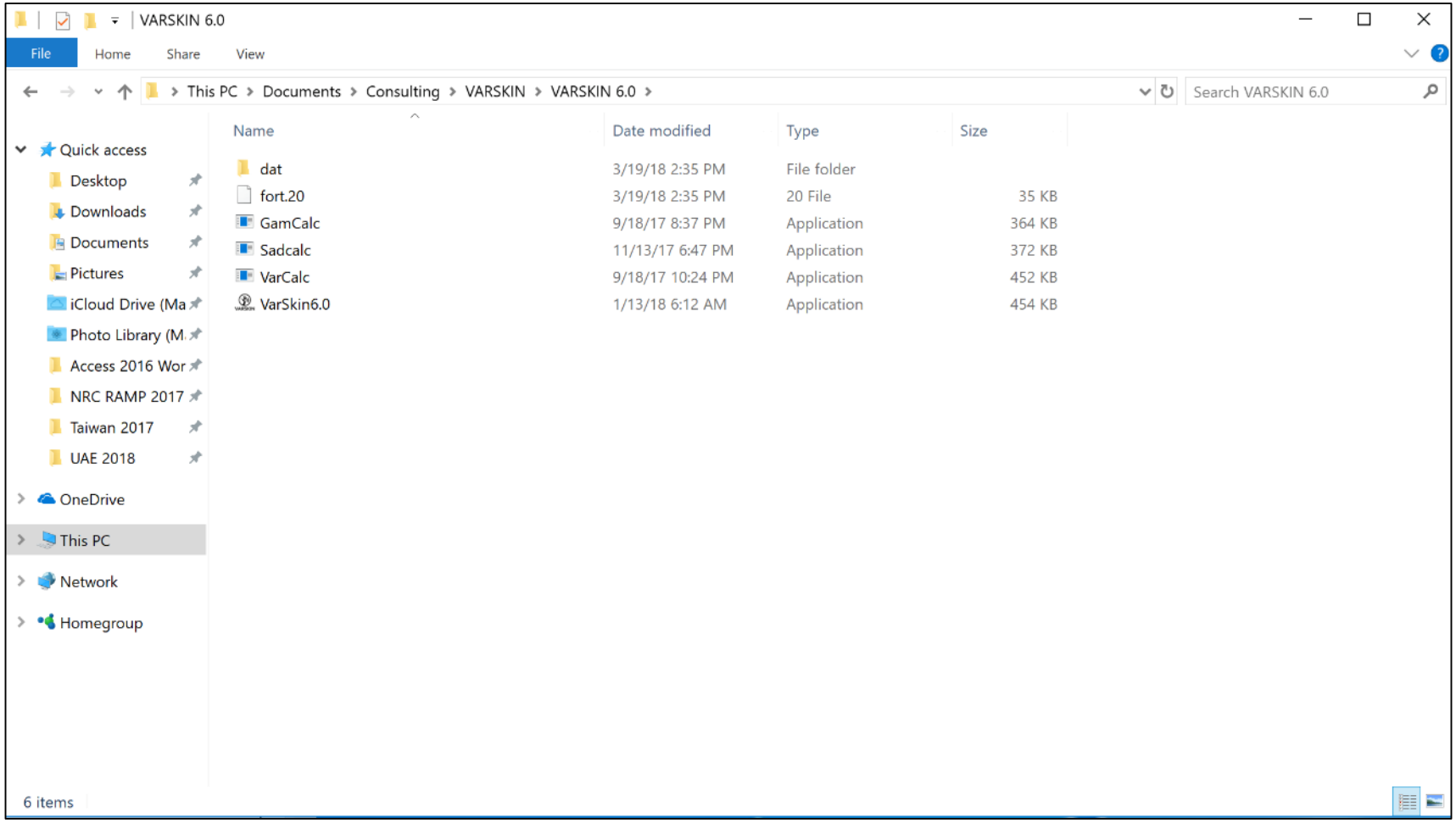
Intro to VARSKIN and Dose Calcs

USING VARSKIN

CODING structure

- GUI written in C#
  - controls I/O functions and executables
- Three modules written in FORTRAN
  - SadCalc.exe; VarCalc.exe; GamCalc.exe
- GamCalc.exe file written to execute photon dose model
- No need to “install” the code
  - simply double-click the VARSKIN 6 executable file


VARSKIN
VARSKIN 6.0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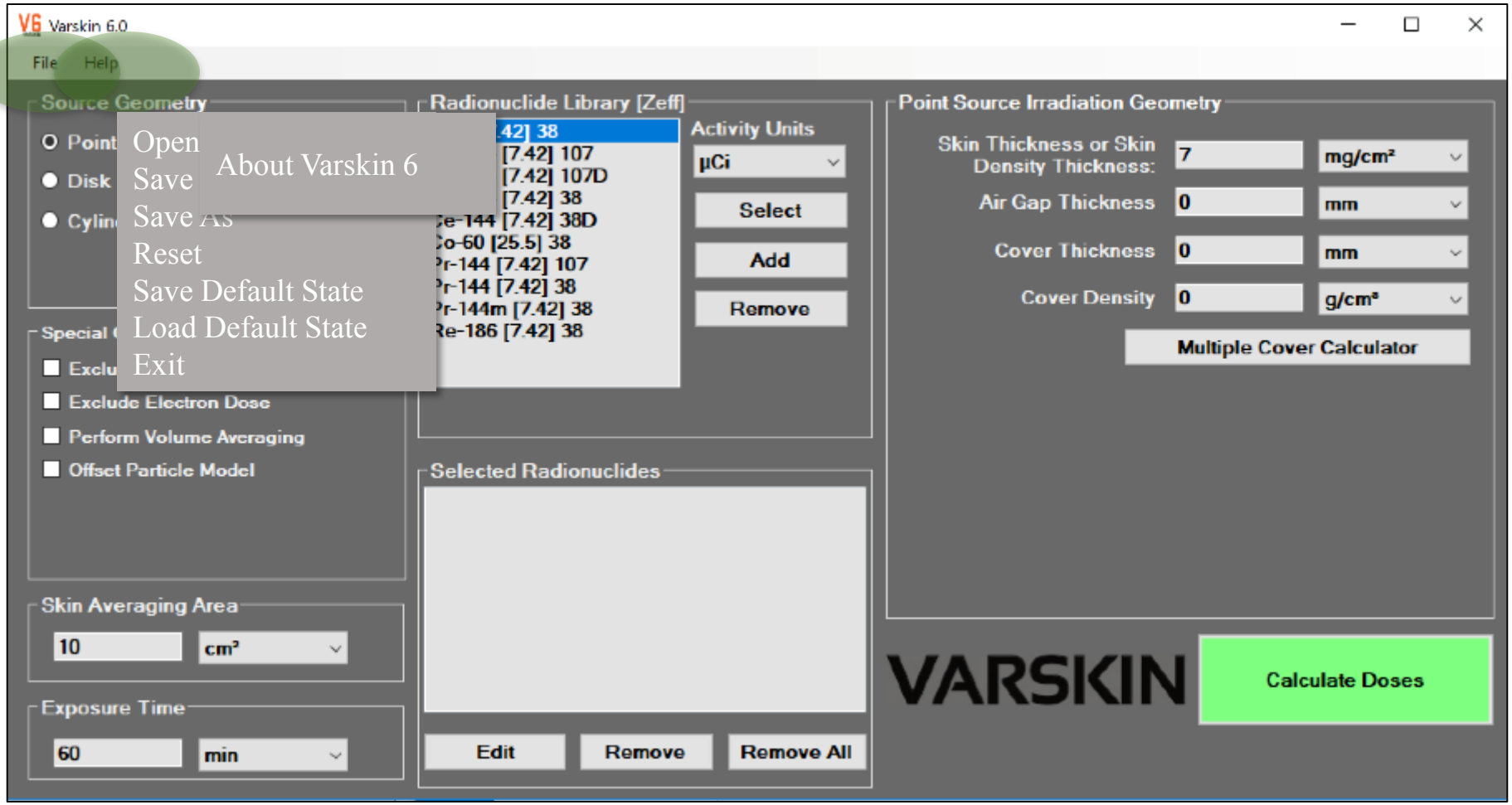
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Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
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Cover Thickness
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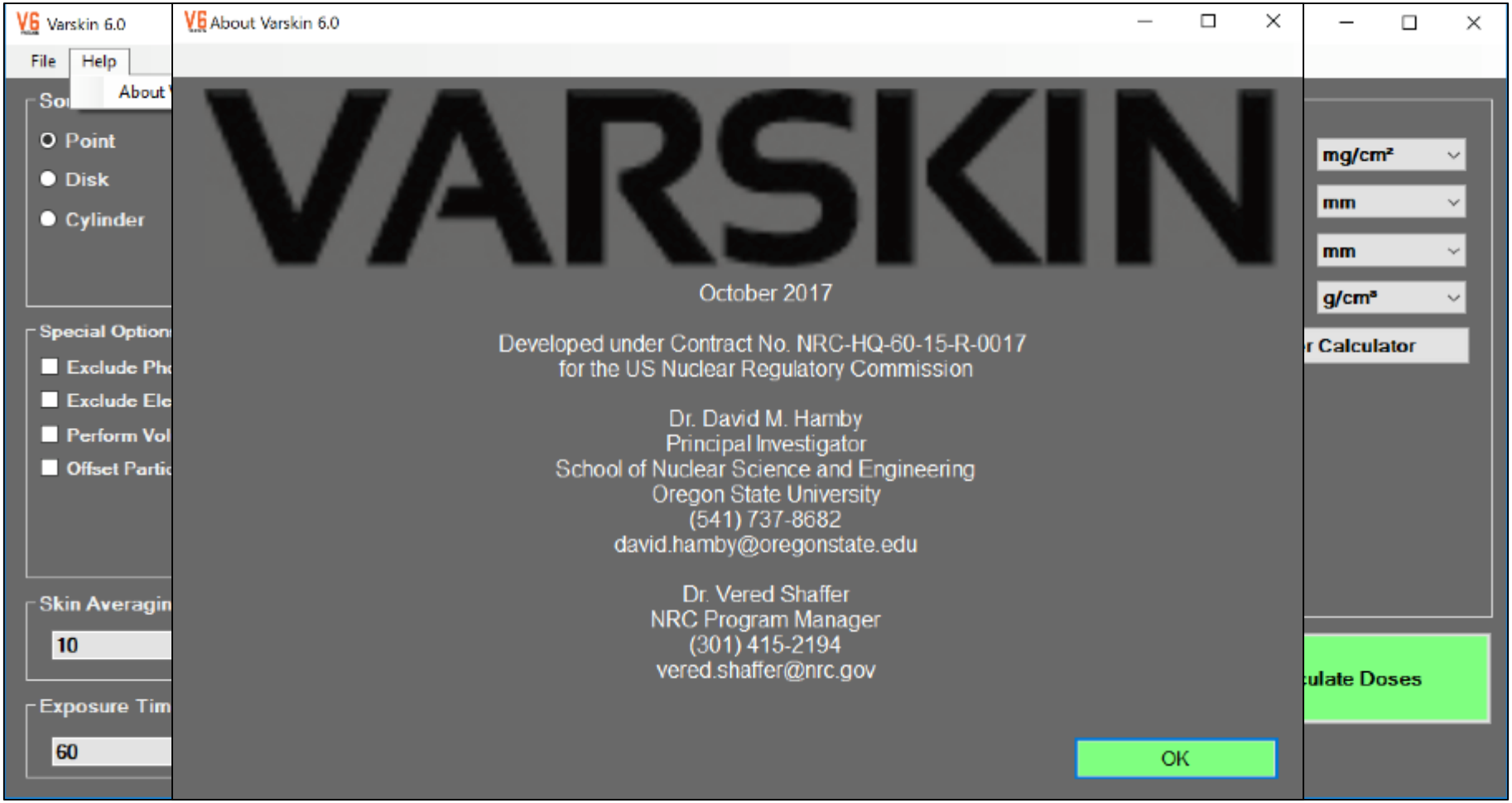
Multiple Cover Calculator
VARSKIN
Calculate Doses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About Varskin 6.0
VARSKIN
October 2017
Developed under Contract No. NRC-HQ-60-15-R-0017
for the US Nuclear Regulatory Commission
Dr. David M. Hamby
Principal Investigator
School of Nuclear Science and Engineering
Oregon State University
(541) 737-8682
david.hamby@oregonstate.edu
Dr. Vered Shaffer
NRC Program Manager
(301) 415-2194
vered.shaffer@nrc.gov
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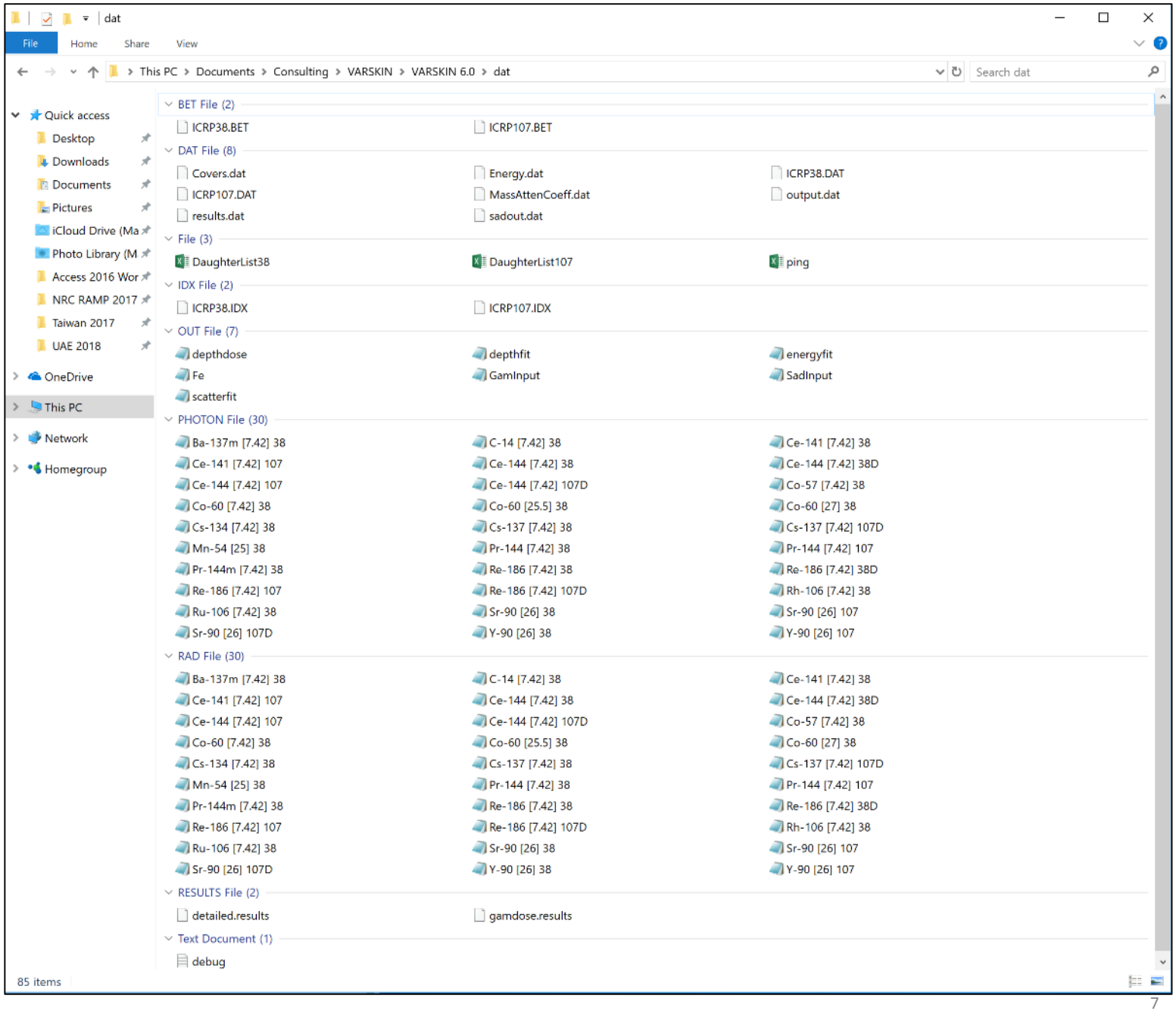
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ICRP107.BET
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Energy.dat
ICRP38.DAT
ICRP107.DAT
MassAttenCoeff.dat
output.dat
results.dat
sadout.dat
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DaughterList107
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ICRP107.IDX
OUT File (7)
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GamInput
SadInput
scatterfit
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Y-90 [26] 107
RESULTS File (2)
detailed.results
gamdose.results
Text Document (1)
debug
85 items

.rad and .photon dat files

Co-60 [7.42] 38 - Notepad

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7.42                    $ sngZsrc
False                   $ Include daughter products
False                   $ Use ICRP107 instead of 38
0.09690186              $ sngEavg
0.03300993              $ sngX90
1.00245                 $ sngYield
46205.6                 $ sngHalfLife
2.69586                 $ sngFit[0]
2.50338                 $ sngFit[1]
2.3109                  $ sngFit[2]
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1 99.9824 1.33247
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How is Beta Dose Determined?

Electron Interactions

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

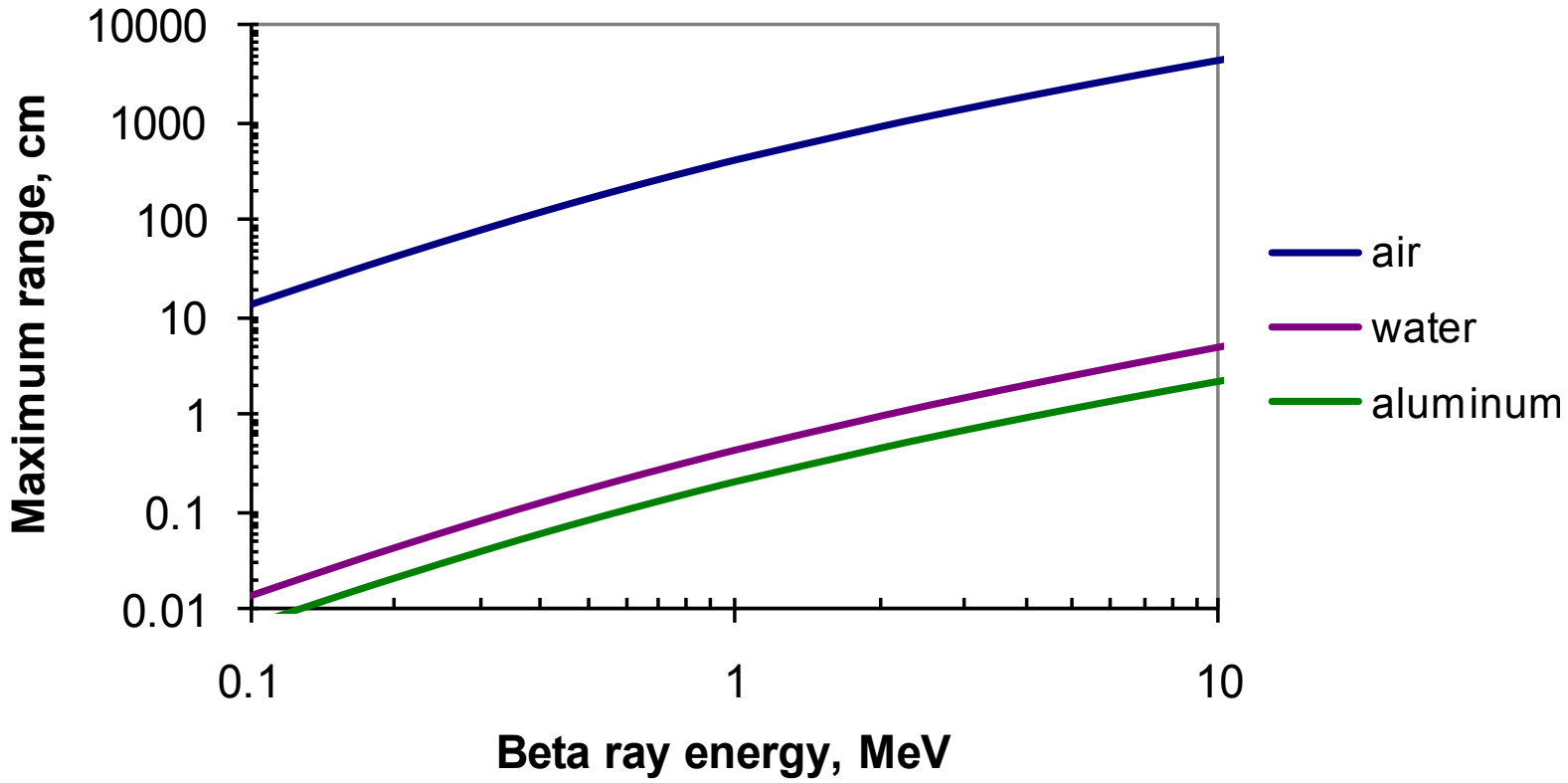
Characteristics Important for Dosimetry

- The depth at which electrons penetrate in tissue
  - Range and “Attenuation”
- The rate at which electron energy is lost
  - Stopping Power
- Relative to the primary electron location, the proximity to which energy is absorbed
  - Bremsstrahlung
- The fraction of electrons scattering without ever entering the dose material
  - Backscatter

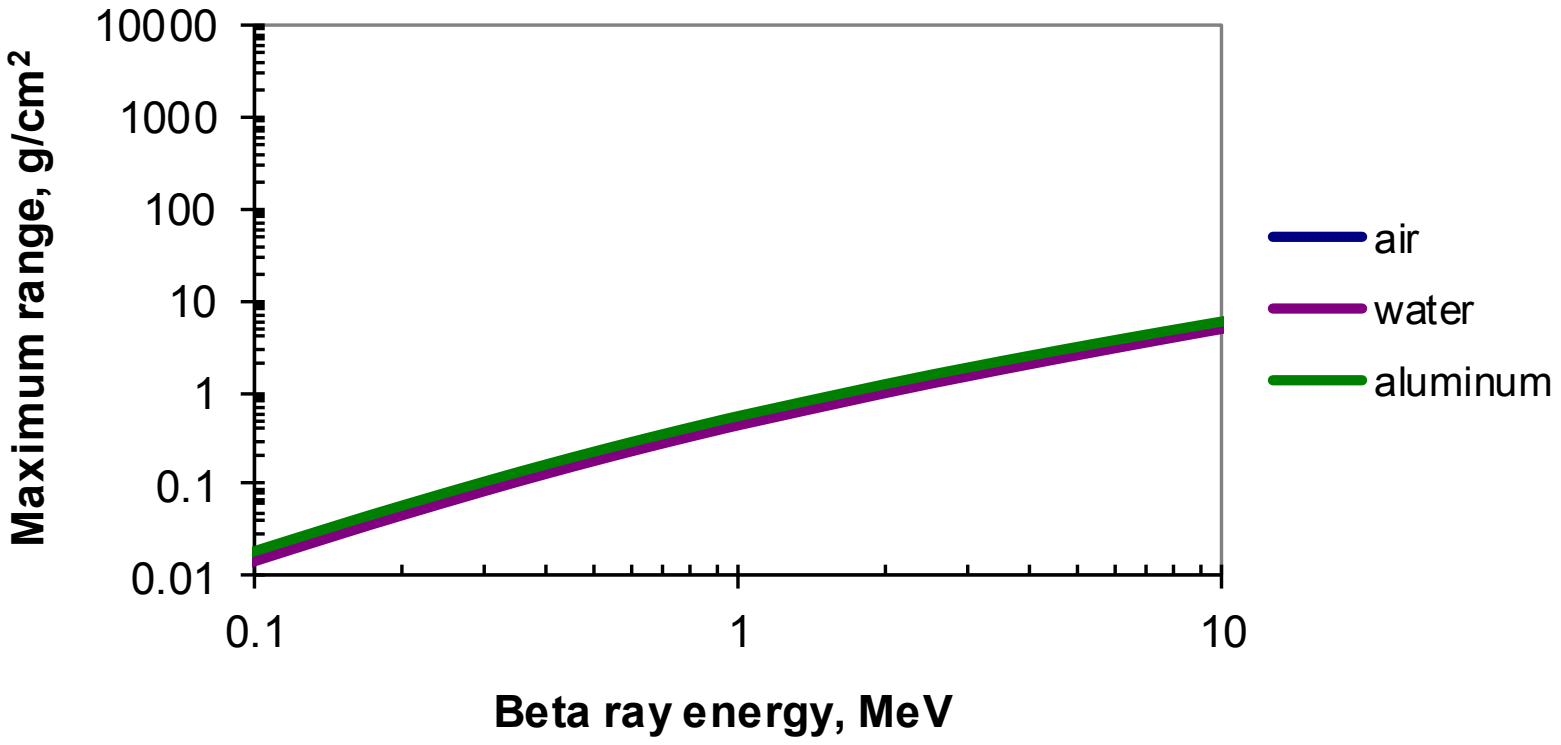
Range-Energy Observations

- 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

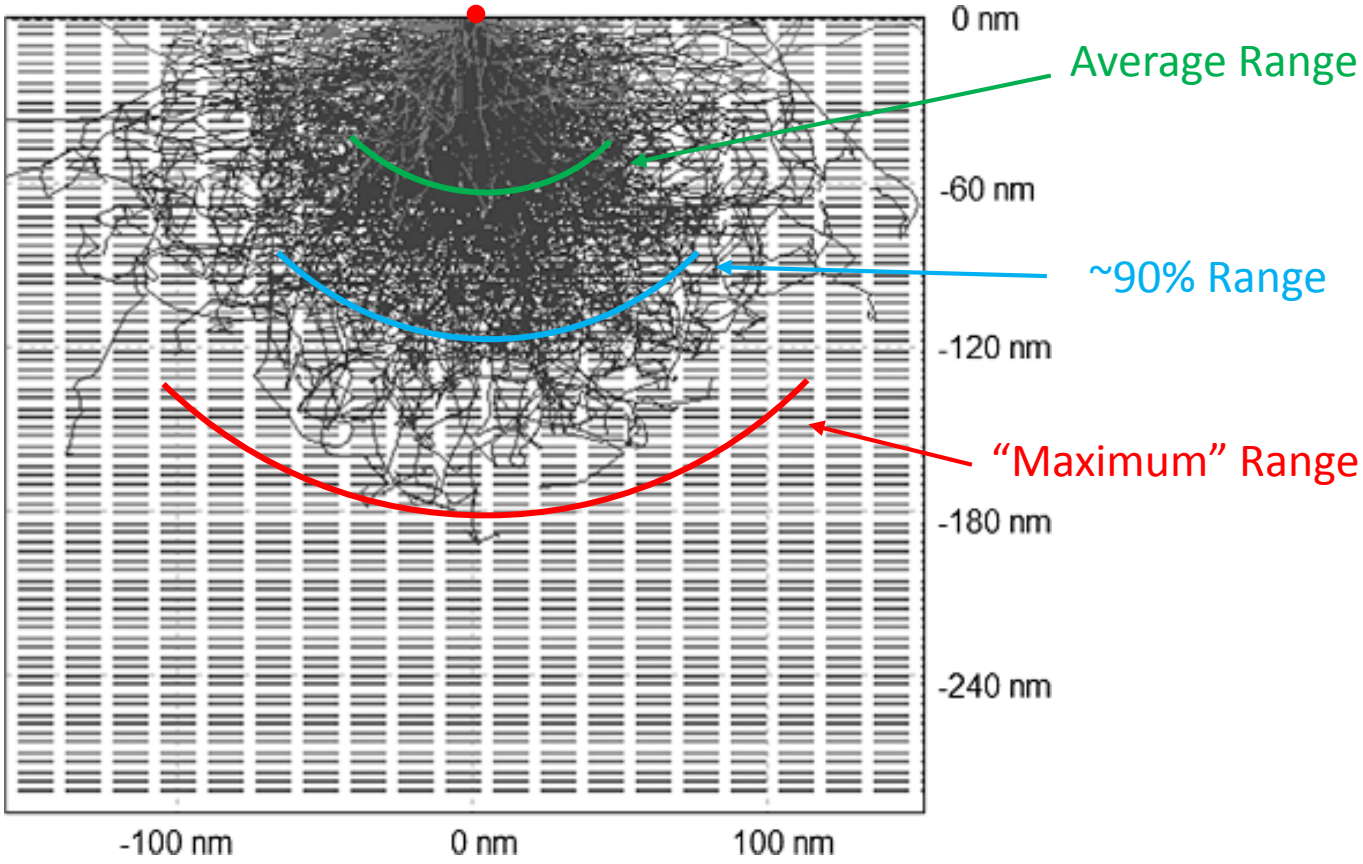
Range-Energy Relationship for Electrons



Advantage of Density Thickness



Electron Track Simulation



Electron "Attenuation"

Method assumes that electrons attenuate similar to photons:

$$\phi_\beta(x) = \phi_{\beta,0}(x) \cdot e^{-\mu_\beta(\rho x)}$$

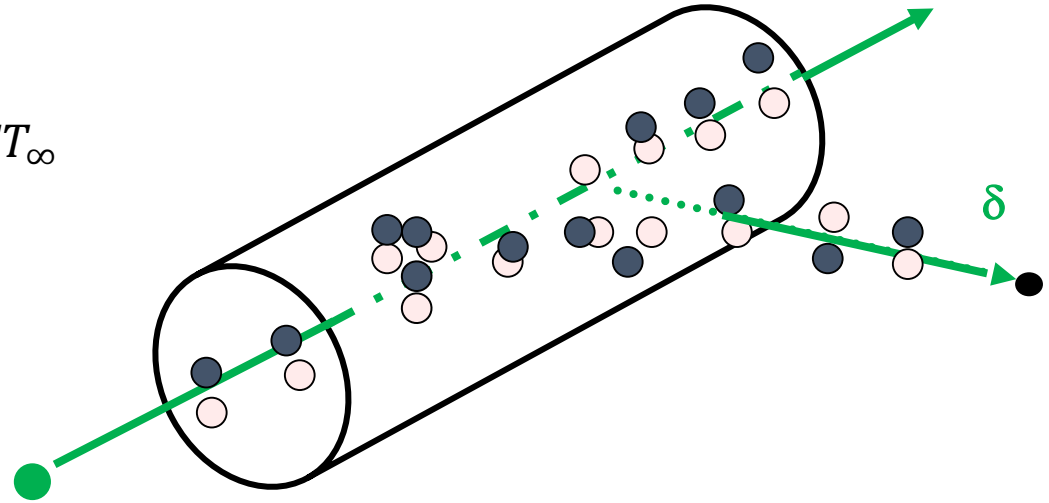
then,

$$\dot{D}_\beta\left[\frac{\text{Gy}}{\text{sec}}\right] = \phi_\beta\left[\frac{\beta}{\text{sec}\cdot\text{cm}^2}\right] \cdot \bar{E}_\beta\left[\frac{\text{J}}{\beta}\right] \cdot \mu_\beta\left[\frac{\text{cm}^2}{\text{kg}}\right]$$

"Beta absorption coefficient"

Energy Transfer vs Absorption

$$-\frac{dE}{dx} = LET_{\infty}$$



- "Stopping Power" (-dE/dx) is a measure of energy loss
- "LET" is a measure of energy deposited locally
- Not all energy lost (transferred) is absorbed <u>locally</u>
  - due to delta rays or bremsstrahlung
  - "local" is defined by the radius of a cylinder within which energy is deposited, e.g., $LET_{0.1}$

Mass Stopping Power

- Stopping power is often expressed relative to the absorber density (i.e., “mass stopping power”)

$$\frac{S}{\rho} = \left(-\frac{dE}{dx} \right) \Big/ \rho$$

- With units of energy per density thickness, it is a very useful parameter in charged-particle dosimetry

$$\left[\frac{S}{\rho} \right] = \frac{MeV \cdot cm^2}{g}$$

Total Mass Stopping Power

$$\frac{S_{total}}{\rho} = \frac{1}{\rho}\left(\frac{-dE}{dx}\right)_c + \frac{1}{\rho}\left(\frac{-dE}{dx}\right)_r$$

- Total energy loss as the electron moves through a medium
- Considers both collisional and radiative energy losses
- Generally, for dosimetry we assume that transfer = absorption
  - i.e., energy loss (per unit density) is used to calculate dose
  - a 3 MeV electron in water loses only 1% of its energy via bremsstrahlung

Electron Backscatter

- Because electrons are interacting with other electrons, the phenomenon of “backscatter” is an important issue
- In thin foils, backscatter isn’t significant to dosimetry
- In thick materials, however, some portion of the electron energy flux is redirected in the reverse direction and the average absorbed dose throughout the material is less than expected
- Empirical relationships appear in many different forms for estimating the backscatter effect
- Backscatter for particles on skin introduces additional difficulties in electron skin dosimetry

Backscatter Considerations

- Energy loss functions are often developed with the initial assumption that the absorbing medium is homogeneous (i.e., 4π water)
- But, there are significant dose implications for scattered electrons when the medium is heterogeneous
  - source in air, with a tissue interface
  - volumetric high-Z source on skin
  - either into, or out of, the dose receptor
- Most significant for situations with:
  - low-energy electrons
  - thick, high-Z targets
- If dose calculations are based on homogeneous emission/absorption, backscatter must be considered

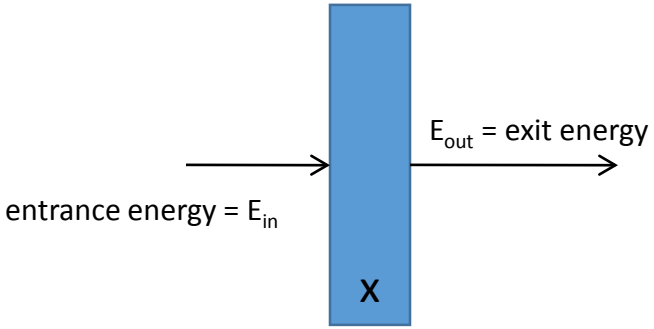
Simplified Electron Dosimetry

In thin slices that are uniformly exposed, the dose rate from charged particles can be expressed simply as the product of particle flux and mass stopping power:

$$\dot{D}\left[\frac{Gy}{sec}\right] = \phi\left[\frac{particles}{sec \cdot cm^2}\right] \cdot \frac{\frac{dE}{dx}\left[\frac{J}{cm}\right]}{\rho\left[\frac{kg}{cm^3}\right]}$$

Simplified Electron Dosimetry

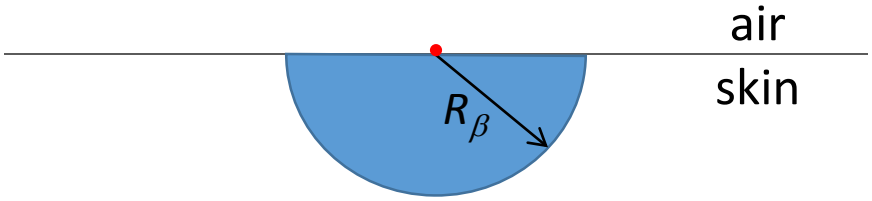
And, in thick materials (uniformly exposed), the average dose rate from charged particles can be determined from estimates of the particle range and related energy loss:



$$\dot{D}\left[\frac{\text{Gy}}{\text{sec}}\right] = \frac{\phi\left[\frac{\text{particles}}{\text{sec}\cdot\text{cm}^2}\right]\left(E_{in} - E_{out}\right)[\text{J}]}{\rho\left[\frac{\text{kg}}{\text{cm}^3}\right]x[\text{cm}]}$$

Simple Hot-Particle Dosimetry

Given an isotropic source, and assuming that all energy is deposited within a hemisphere of skin that has a radius equal to the maximum range (or some percentage thereof):

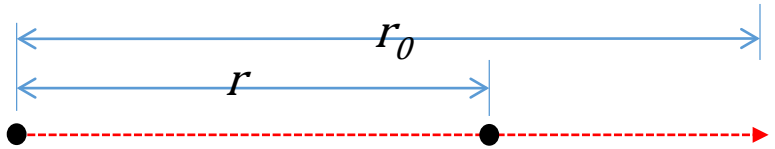


$$\dot{D}_\beta\left[\frac{\text{Gy}}{\text{sec}}\right] = \frac{\frac{1}{2}\cdot A\left[\frac{\text{dis}}{\text{sec}}\right]\cdot Y\left[\frac{\beta}{\text{dis}}\right]\cdot \bar{E}_\beta\left[\frac{\text{J}}{\beta}\right]}{\frac{1}{2}\cdot\frac{4}{3}\pi\cdot R_\beta^3\left[\text{cm}^3\right]\cdot\rho\left[\frac{\text{kg}}{\text{cm}^3}\right]}$$

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:

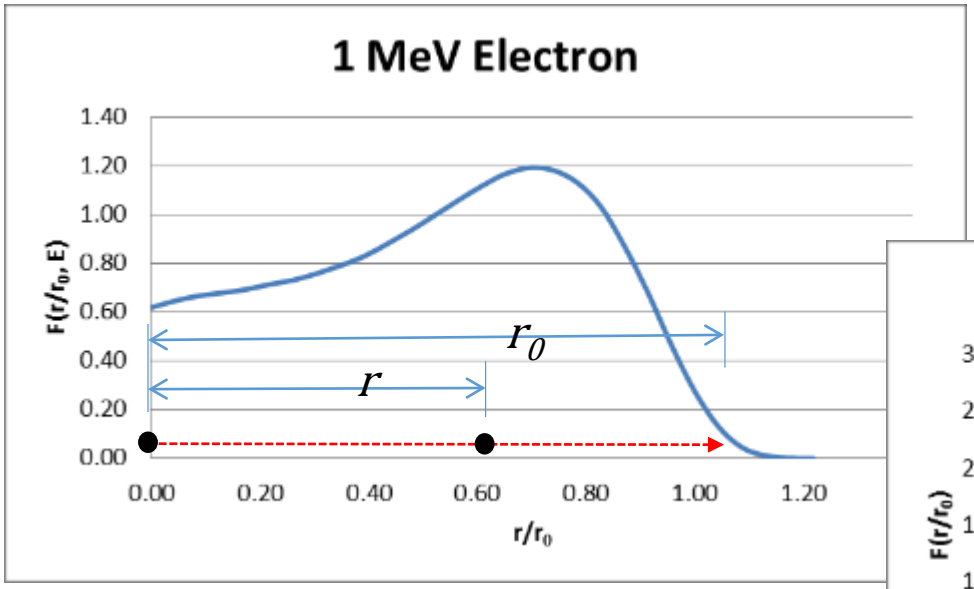
$$G(r,E)=\frac{E}{4\pi r^2 \rho r_0}F(r/r_0,E)$$

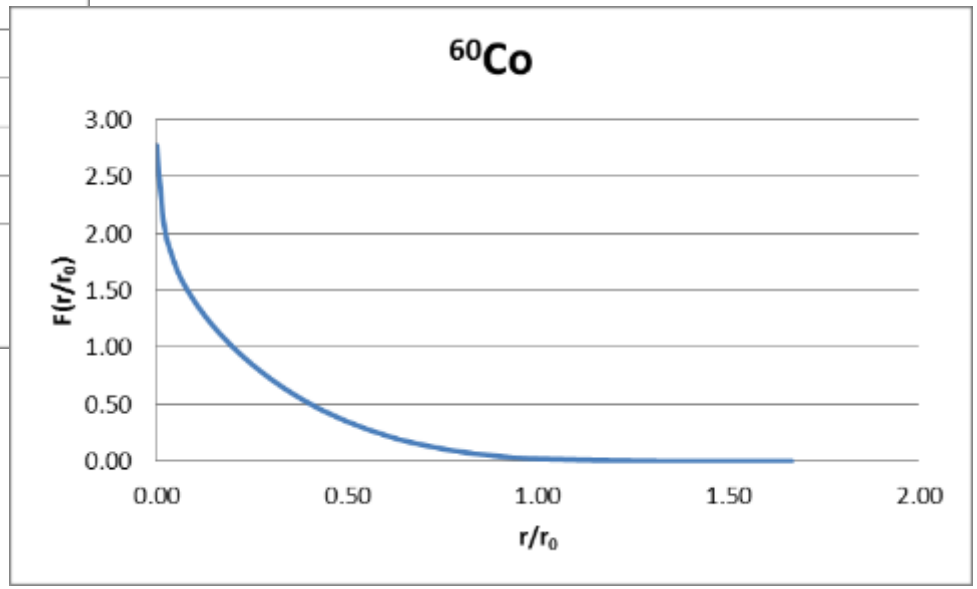


The function $F(r/r_0,E)$ is a "scaled absorbed dose distribution" (essentially a normalized Bragg curve) that is dependent on the electron initial energy and the fraction of *maximum* range (r/r_0) that the electron has achieved by the time it reaches the dose location.

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



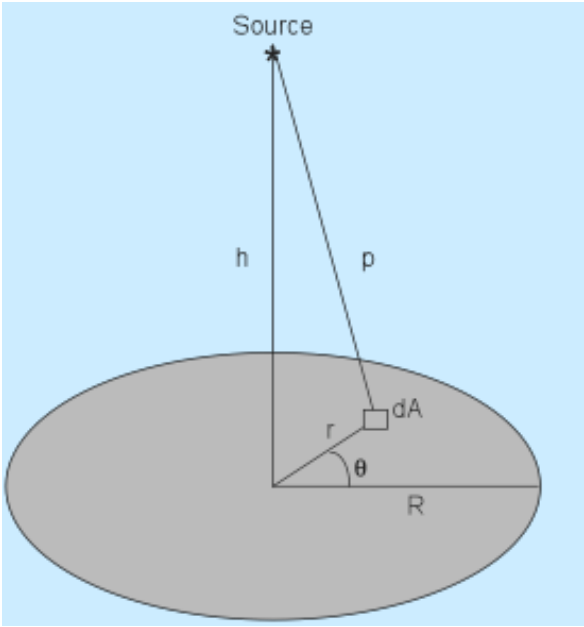


VARSKIN 6

A Brief Review of the
Original VARSKIN Beta Dosimetry

Fundamentally …

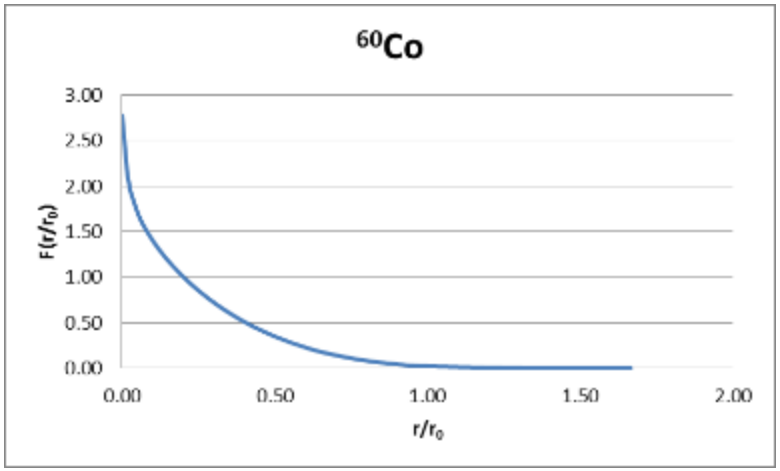
- Point-kernel method employed
- Source on skin surface
- Dose calculated to a given averaging area at the user-specified depth
- Energy absorption based on calculated stopping power at depth



Previous Beta Dosimetry Model

- Using Berger dose point-kernel, B(r) (*MIRD Pamphlet No. 7, 1971*)
- Numerically integrated over source and dose volumes
- r_1 is a *modified* path length based on a density ratio
- r_0 represents the *maximum* path length, in Berger's case the X_{90}

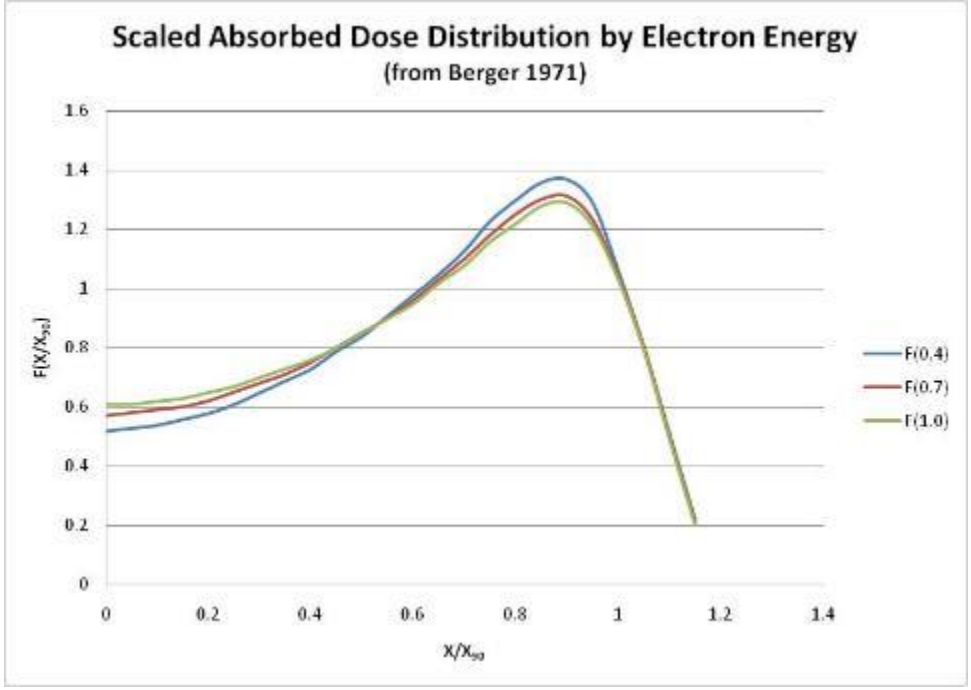
$$B(r) = \frac{kY\bar{E}F_\beta\left({}^{r_1}/_{r_0}\right)}{\pi r^2 \rho r_0}$$



Scaled Absorbed Dose Distribution

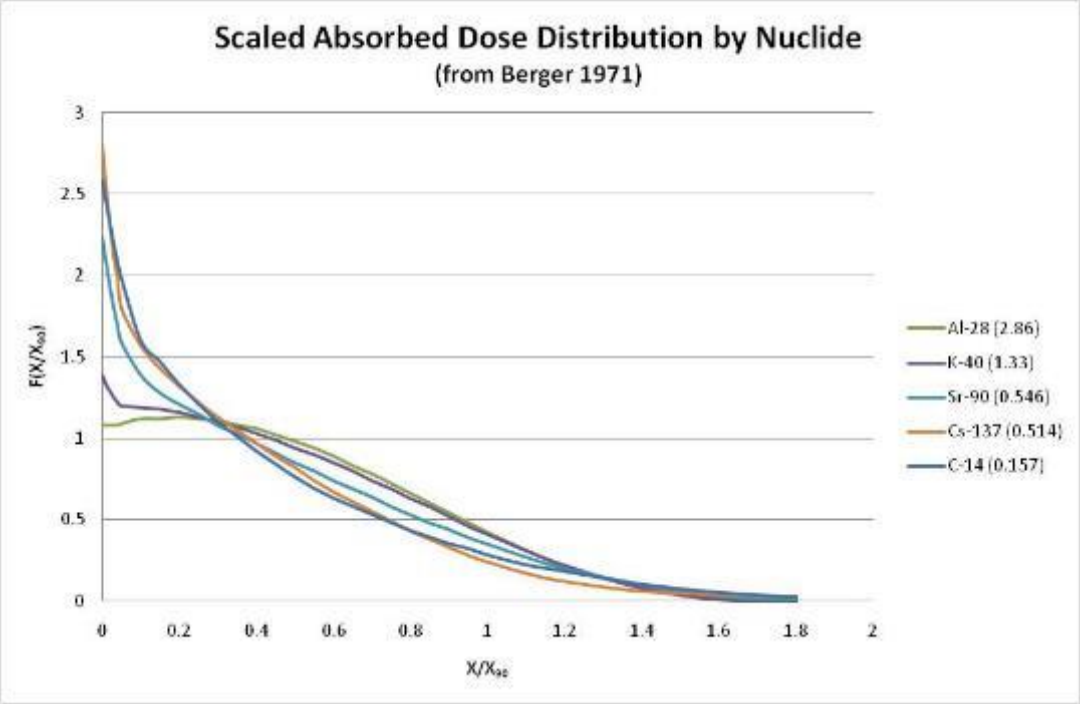
Berger determined the absorbed dose distribution for electrons of a given energy and depth of penetration (X); this is essentially a Bragg curve for monoenergetic electrons traveling through the absorber (water in this case).

When depth of penetration is normalized by the depth required to absorb 90% of its original energy (X_{90}), a Scaled Absorbed Dose Distribution is generated. The SADD is referred to by Berger as $F(X/X_{90})$.



SADD - By Nuclide

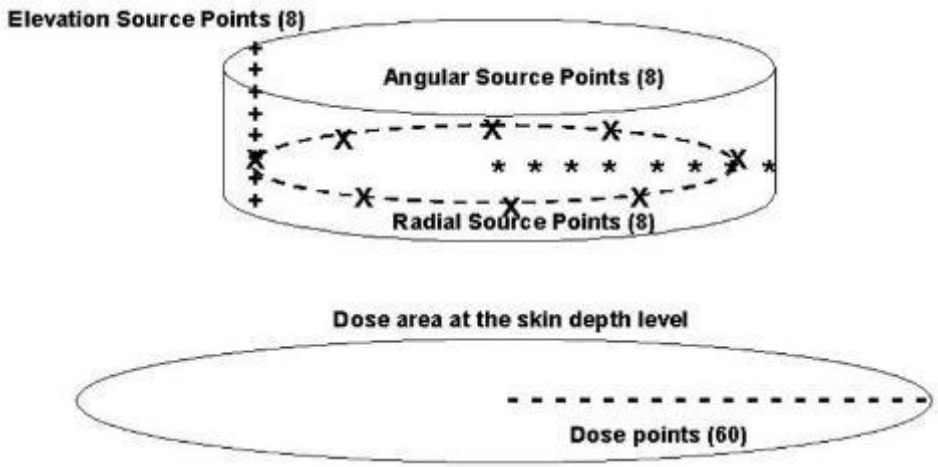
The beta energy emission spectra is folded with the energy-dependent scaled absorbed dose distribution to derive the nuclide-specific SADD.



Berger (1971) provides $F(X/X_{90})$ values for 75 beta emitters.

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)



Varskin 3/4 Beta Dosimetry

- The dose rate at the next dose point along the radius is calculated until values are obtained at all sixty dose points
- If the dose profile defined by these sixty points as a function of target radius r is denoted by D(r), then the skin dose, averaged over area of the disk, is given by:

$$\overline{D} = \frac{2\pi \int_0^R D(r) \cdot r \; dr}{\pi R^2}$$

Density Correction Model

- The original VARSKIN uses a *modified* path length to determine the energy lost in air or cover material(s) prior to entering the skin
- For small-diameter sources, the electron path from the source point to the dose point may pass through the side of the source (e.g., the path may exit the source and pass through air before penetrating the skin)
- The actual path length within the source is multiplied by the source density, and the path length outside the source and above the cover material is multiplied by the density of the material outside the source (air)
- The point-kernel distance is therefore “density modified”

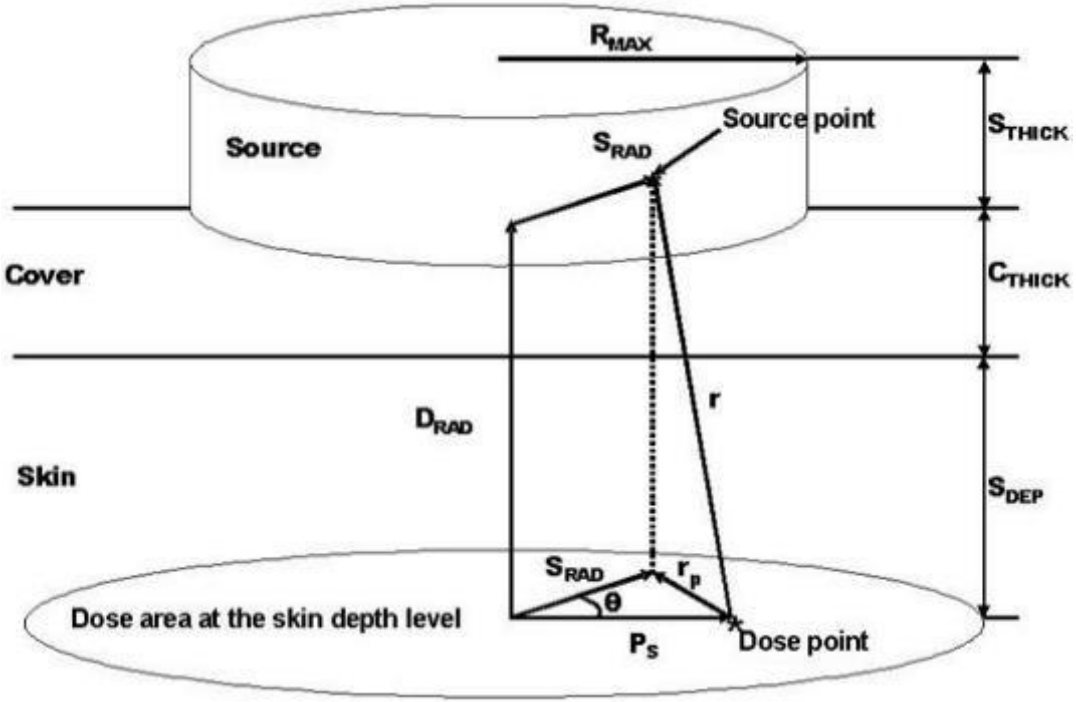
Density Correction Model

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

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

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

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



How is Gamma Dose Determined?

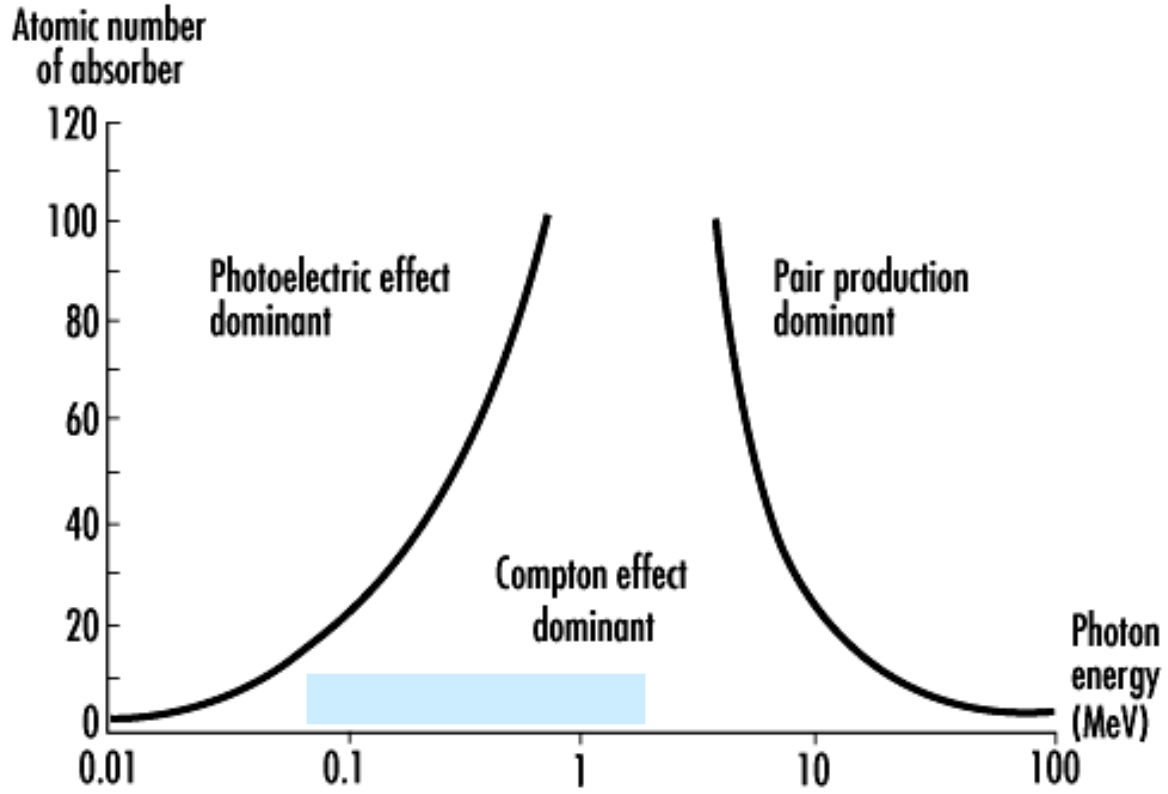
VARSKIN 6

Photon Interactions and Dosimetry

Interaction Fundamentals

- Photon interactions are ‘semi-random’ events
- Photons generally interact with orbital electrons
- Interaction probability is governed by:
  - material (Z, electron density)
  - photon energy (E)
- … and is described by an interaction coefficient
- Principal mechanisms of interaction include (by increasing energy):
  - Thomson/Rayleigh scatter (no E transfer)
  - photoelectric
  - Compton scatter
  - pair production
  - photo-disintegration (very high E)

Relative Importance by Interaction Type



Attenuation

- Attenuation is exponential and governed by the Beer-Lambert law
- Photon intensity *never* reaches zero
- Photon attenuation can be described by:

$$I = I_o e^{-\mu x}$$

  - I_0 = photon intensity (flux) prior to material
  - I = photon intensity after material
  - x = material thickness
  - μ = interaction coefficient (probability of interaction by any mechanism)

- For dosimetry considerations, coefficients are often necessary to describe the probability of interaction resulting in energy absorption
  - referred to as *mass absorption coefficient*, with units of area per unit mass

Energy Transfer - KERMA

- Kinetic Energy Released in Matter
- Has units of energy per unit mass of material (J/kg, but not Gy)
- KERMA is directly related to:
  - the average energy transferred to material as a result of that interaction;
  - uncollided photon fluence; and
  - the probability (per unit density thickness) of a photon interaction.

$$K = \bar{E}_{tr} \cdot \Phi_0 \cdot \frac{\mu}{\rho}$$

Energy Absorption - Dose

- "Absorbed Dose" also has units of energy per unit mass (J/kg or Gy)
- Different from KERMA in that the energy is absorbed (rather than simply transferred)
- DOSE is directly related to:
  - the average energy absorbed in material as a result of that interaction;
  - uncollided photon fluence; and
  - the probability (per unit density thickness) of a photon interaction.

$$D = \bar{E}_{en} \cdot \Phi_0 \cdot \frac{\mu}{\rho}$$

Relationship Between KERMA and Dose

$$K = \bar{E}_{tr} \cdot \Phi_0 \cdot \frac{\mu}{\rho} = E_0 \cdot \Phi_0 \cdot \frac{\mu_{tr}}{\rho}$$

$$D = \bar{E}_{en} \cdot \Phi_0 \cdot \frac{\mu}{\rho} = E_0 \cdot \Phi_0 \cdot \frac{\mu_{en}}{\rho}$$

- $\frac{\mu_{tr}}{\rho}$ = probability per unit mass that energy is transferred to charged particles
- $\frac{\mu_{en}}{\rho}$ = probability per unit mass that energy is absorbed locally
- For low-energy photons, nearly all of energy transferred is deposited locally, therefore, KERMA is insignificantly different than absorbed dose

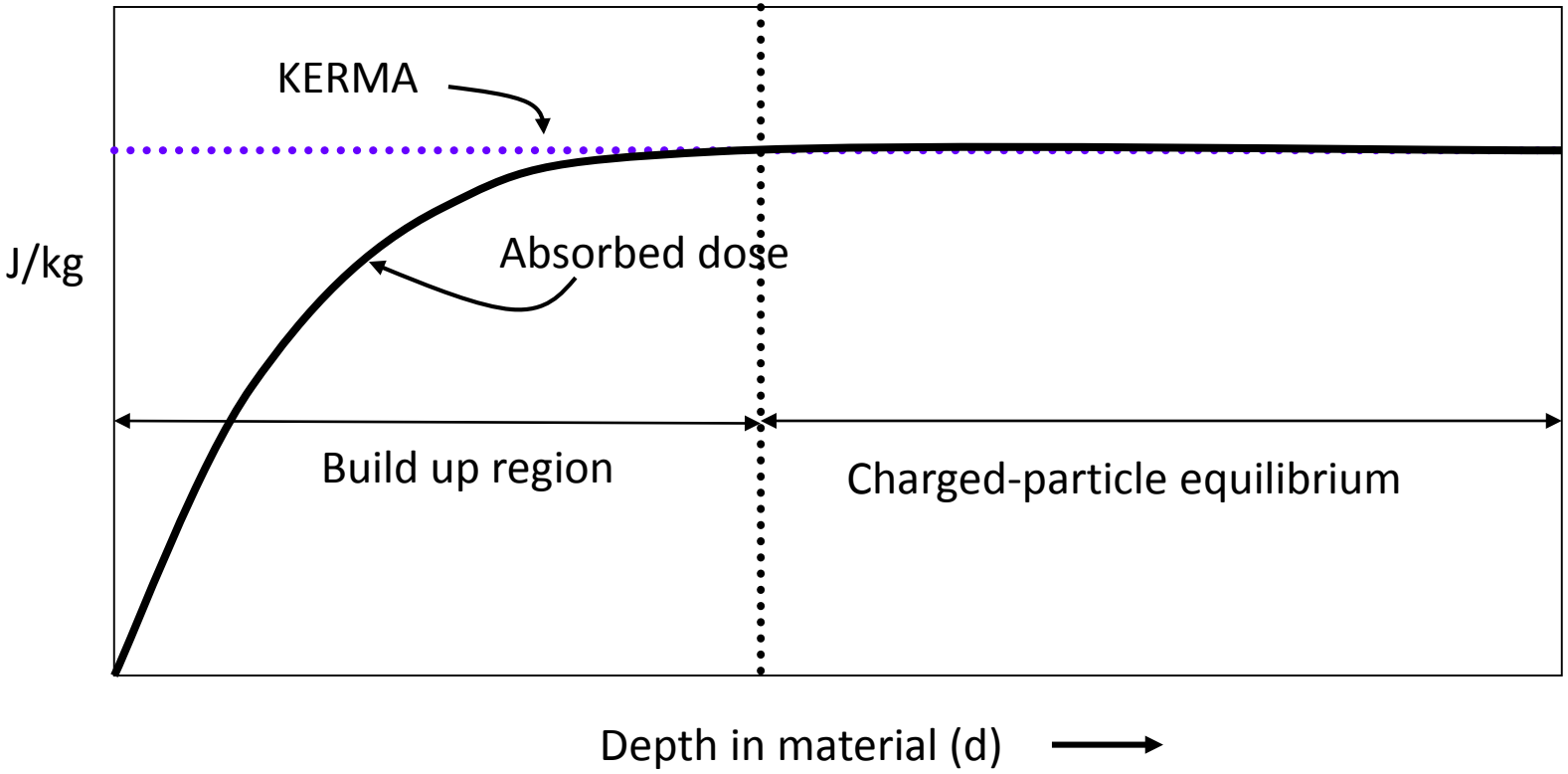
$$D = K \cdot \frac{\mu_{en}}{\mu_{tr}}$$

- For a given photon energy, and once "charged-particle equilibrium" is established:

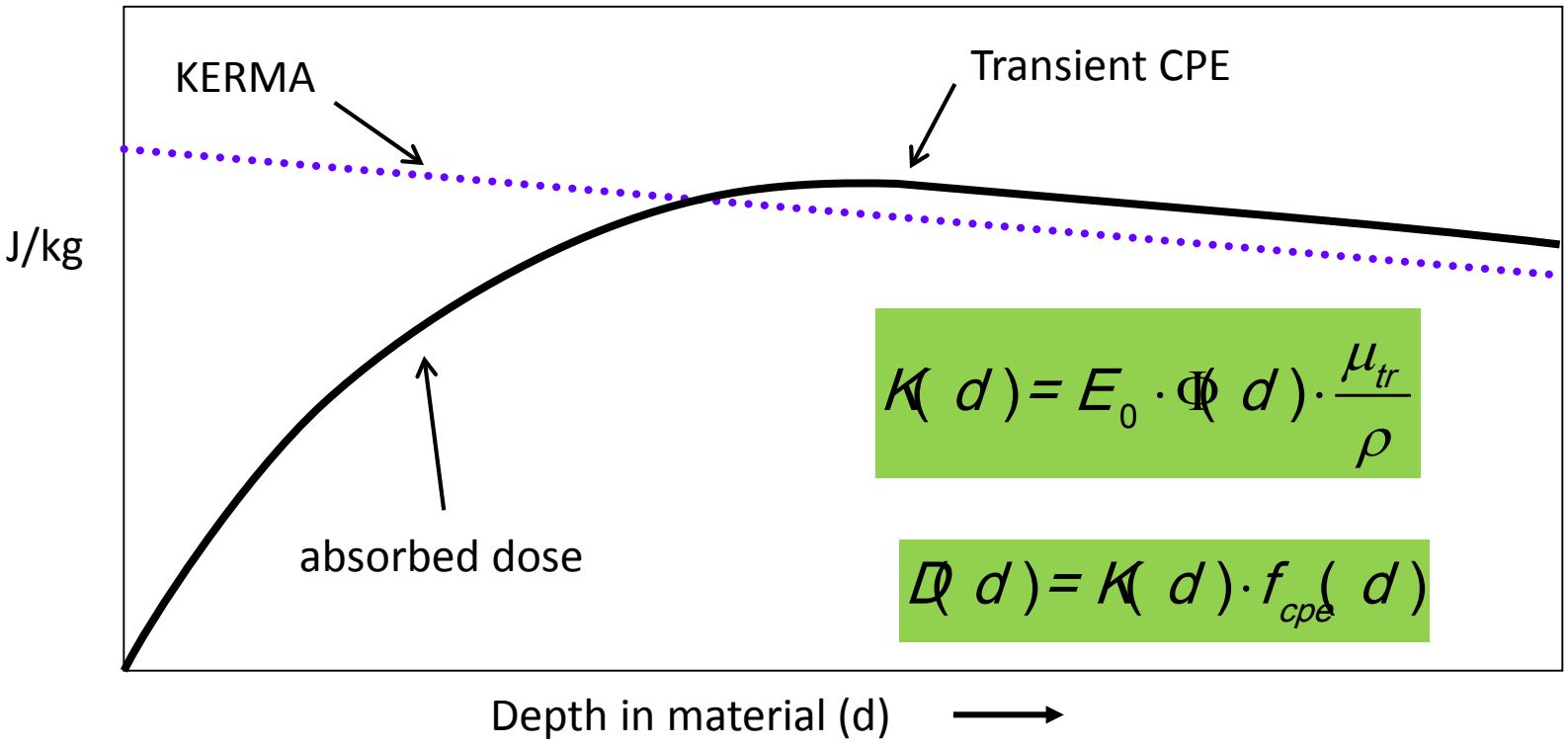
Charged-Particle Equilibrium

- Using a transfer coefficient, KERMA is easily estimated from photon flux
- Dose, as a function of depth, must then be determined from a conversion of KERMA based on the *buildup* of electronic charge, also as a function of depth
- *Charged-Particle Equilibrium* (cpe) is established once this charge buildup is complete

KERMA and Dose Buildup w/o Attenuation

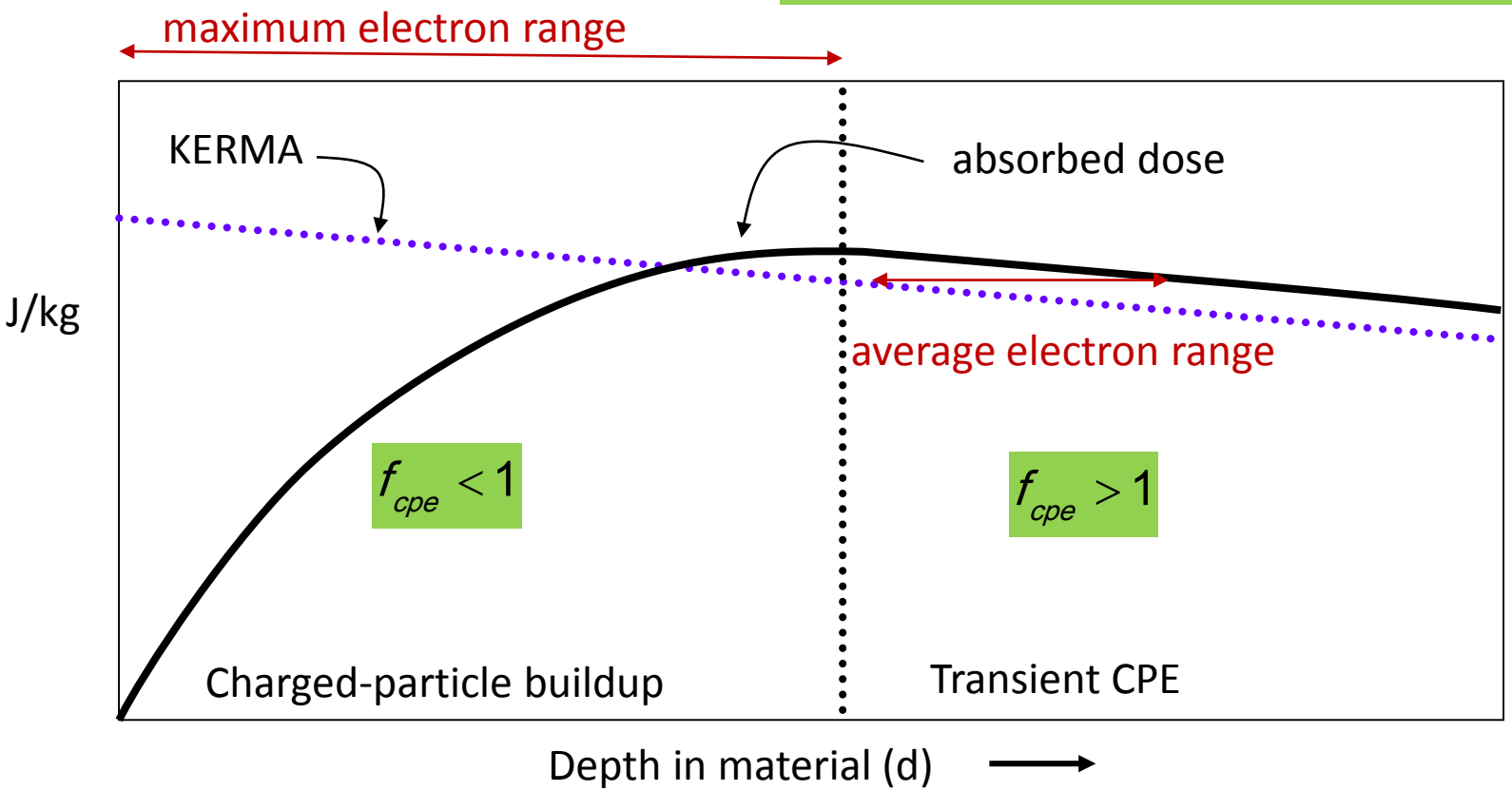


KERMA and Dose Buildup



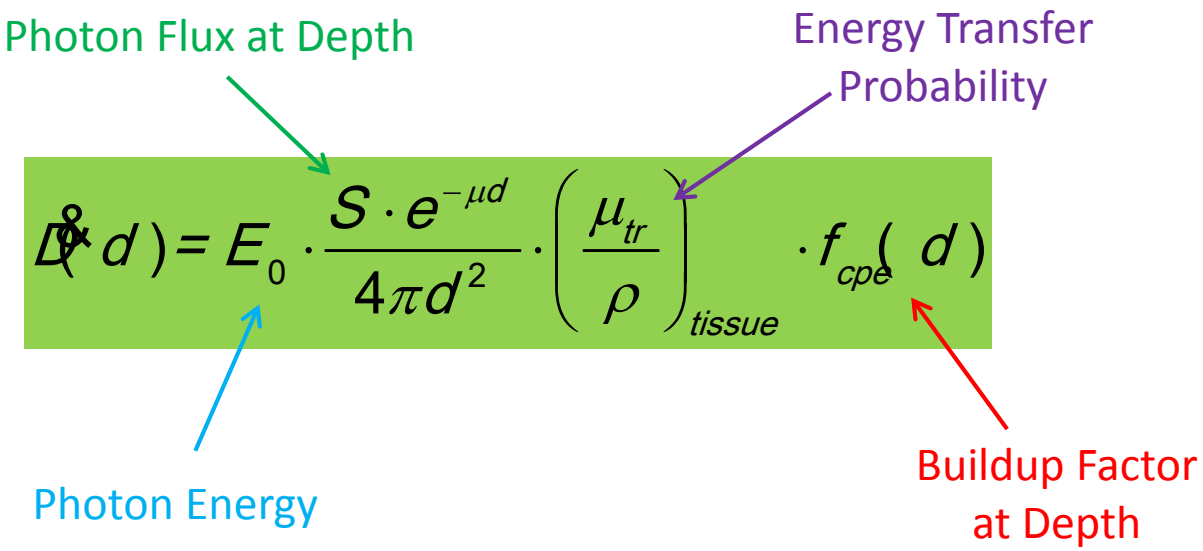
details …

$$D(d) = E_0 \cdot \Phi_0 e^{-\mu d} \cdot \frac{\mu_{tr}}{\rho} \cdot f_{cpe}(d)$$



Photon Dose at Shallow Depths

- Thus, with the flux attenuated by material and geometry, and charged particle buildup taken into account, the dose rate at depth d, is determined using:



VARSKIN Photon dosimetry

Varskin 3 Photon Dosimetry Model

- Expanded version of a method developed by Lantz and Lambert (1990)
- A point source is assumed (point at bottom center of all volumetric sources)
- All material between the source and target is considered *tissue*
- Estimated depth at which CPE is established is based on highest-energy photon
- Skin attenuation is not included, therefore low-E photons contribute to dose at all depths
  - low-E cutoff is offered as a way to account for this
- Dose calculated assuming 1 rad in tissue is equivalent to 1 R:

$$\Gamma\left[\frac{rad\ cm^2}{hr\ mCi}\right] = 1938\left[\frac{rad\ kg\ cm^2}{MeV\ mCi\ m^2\ hr}\right] \cdot \left[\sum_{i=1}^{n} f_i \cdot E_i[MeV] \cdot \left(\frac{\mu_{en}}{\rho}\right)_{E_i,tissue}\left[\frac{m^2}{kg}\right]\right]$$

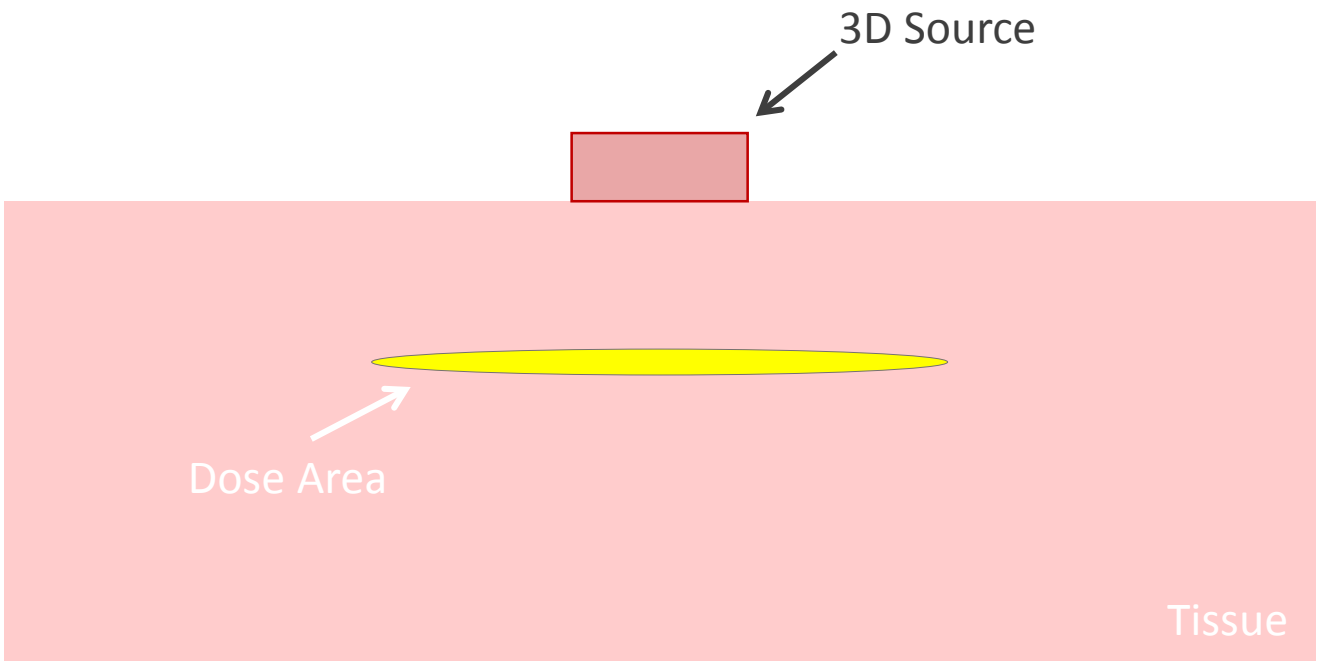
- Relevant data obtained from NIST, ICRU-44, and NUCDECAY files

VARSKIN 4/5/6 Photon Dosimetry

- The new VARKSIN photon dosimetry model introduced in VARSKIN 4 considers:
  - photon point-kernel methodology
  - charge-particle buildup; attenuation; off-axis scatter
  - numerical integration of 300 dose points for each source point
- Employs many of the same assumptions from the electron model:
  - multiple geometries (point, disk, cylinder, sphere, slab)
  - dose calculated to averaging disk (0.01 to 100 cm^2) beneath skin at user specified depth
  - variable dose averaging
    - 2D averaging areas (regulatory compliance)
    - 3D averaging volumes (detector simulation)

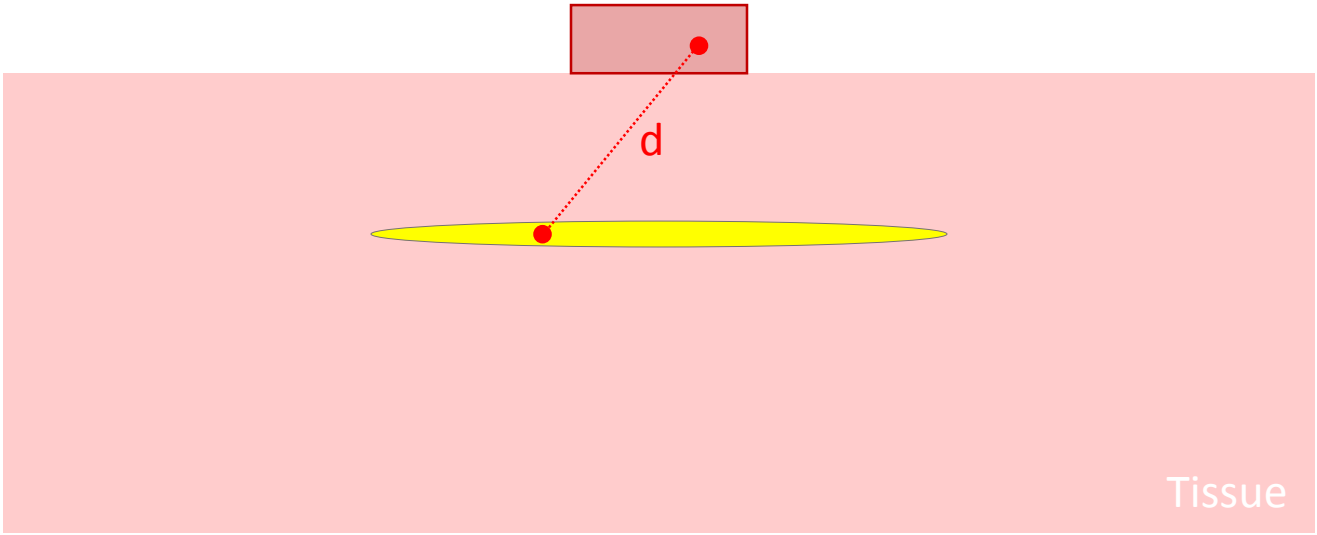
“Point Kernel” Concept

Now, let’s put the dose equation to use …



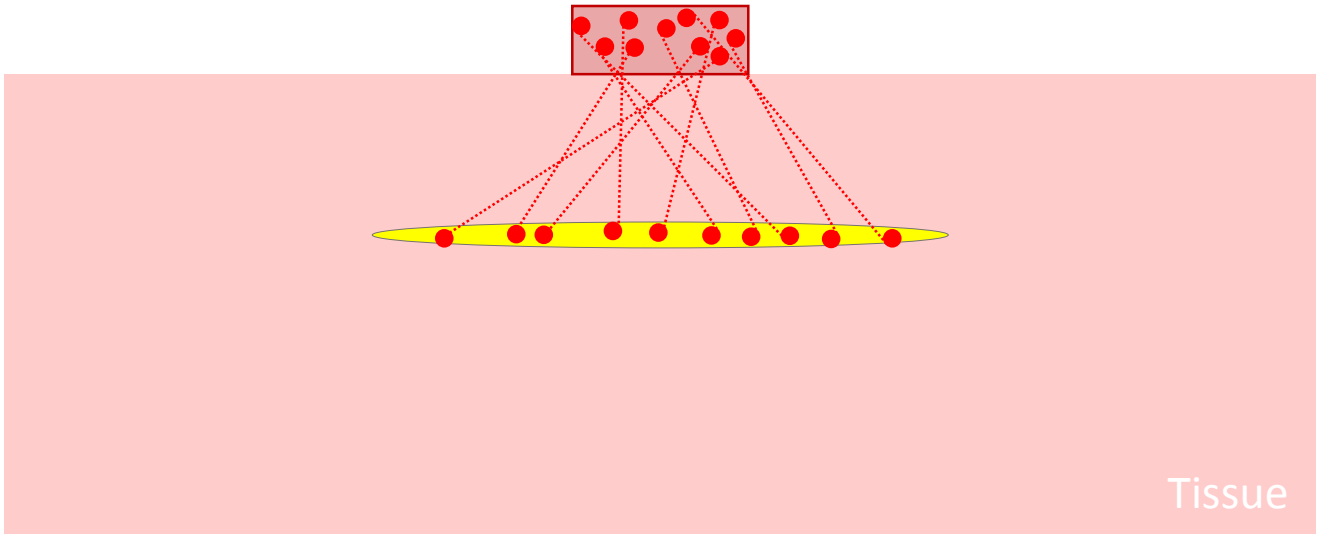
“Point Kernel” Concept

$$\frac{\dot{D}(d)}{S} = E_0 \cdot \frac{e^{-\mu d}}{4\pi d^2} \cdot \frac{\mu_{tr}}{\rho} \cdot f_{cpe}(d)$$



Integrate Point Kernels Over Source/Dose Volume

$$D(h) = \sum_i w_i \cdot D(d,\theta) = \sum_i w_i \cdot E_0 \cdot \frac{S}{4\pi d^2} e^{-\mu d} \cdot \frac{\mu_{tr}}{\rho} \cdot f_{cpe}(d)$$



Estimating Tissue Mass Attenuation Coefficients

- As used in VARSKIN 4/5, an empirical relationship to estimate μ/ρ for tissue as a function of incident photon energy (in MeV) is given below.
- For energies less than or equal to 20 keV,

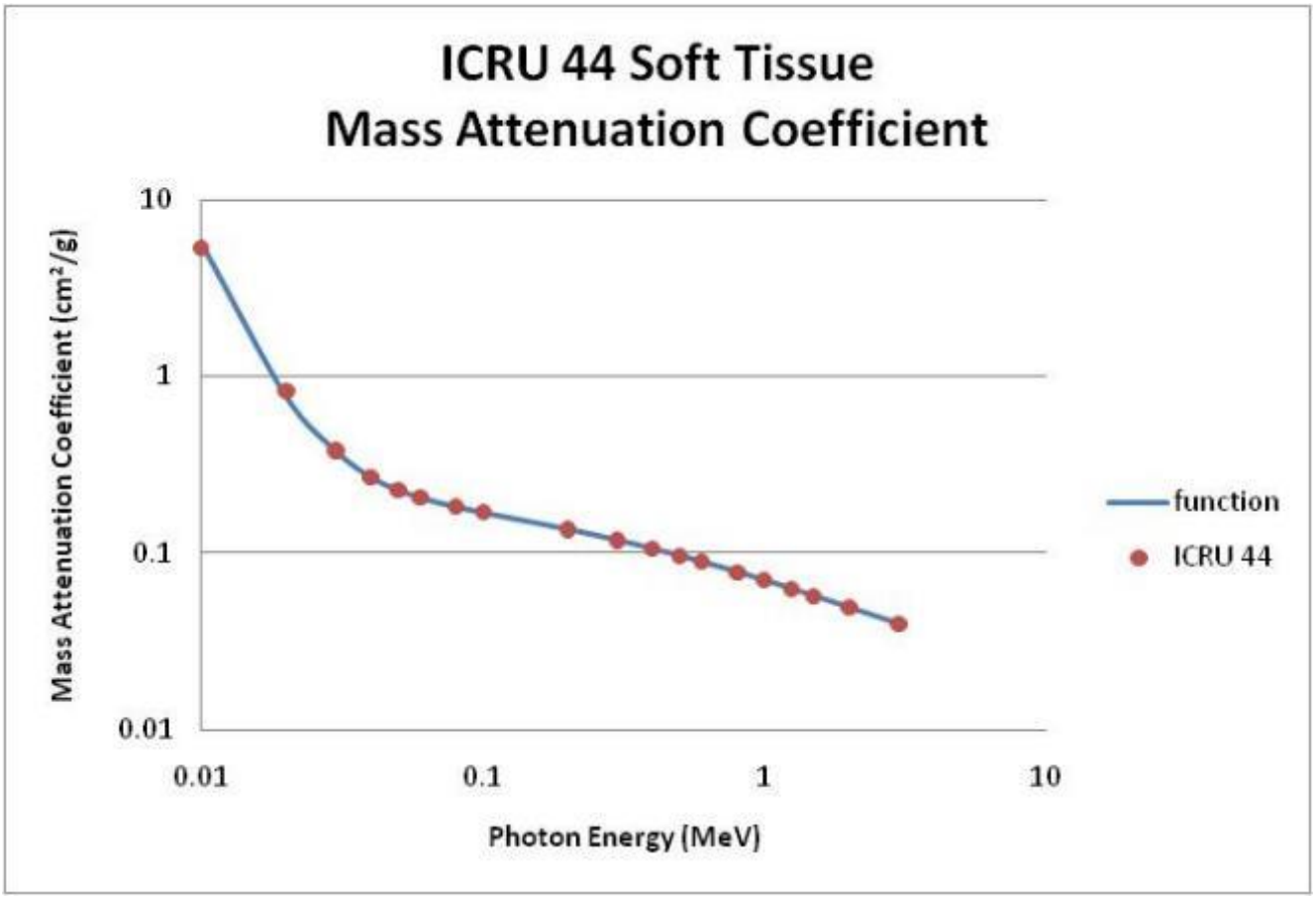
$$\frac{\mu}{\rho}(E) = \frac{1}{0.0000145 + 3810E^{2.5} + 134400E^{3}}$$

- and for energies greater than 20 keV,

$$\frac{\mu}{\rho}(E) = e^{\left[-3.22 - 0.11(lnE)^{2} + 0.5566\sqrt{E} - 0.7713\,lnE + \left({}^{0.000721}/_{E^{2}}\right)\right]}$$

,

ICRU 44 soft tissue mass attenuation coefficients



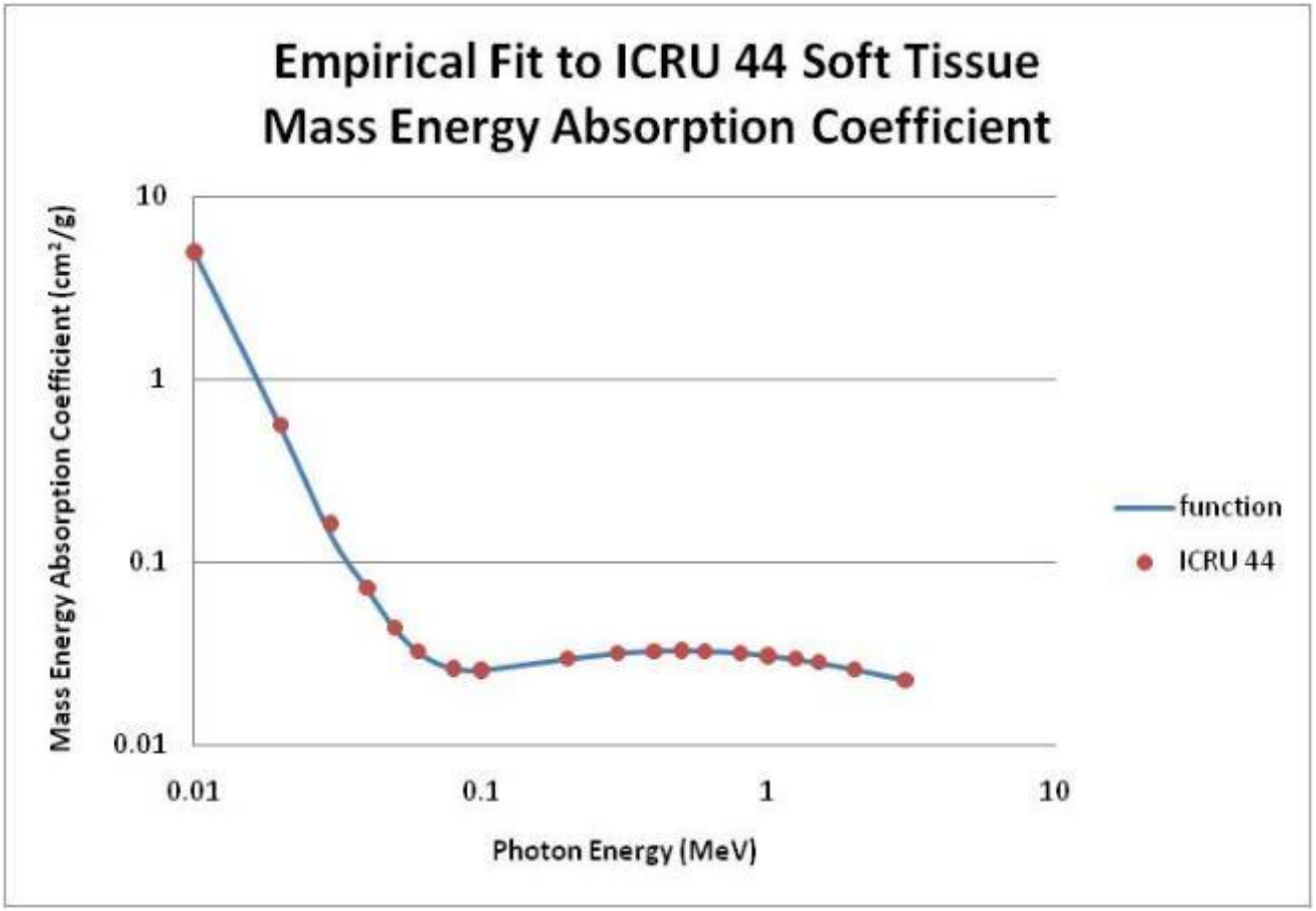
Estimating Tissue Energy Absorption Coefficients

- A function was developed to approximate the energy-dependent value of μ_{en}/ρ for tissue:

$$\frac{\mu_{en}}{\rho}(E) = \frac{a + clnE + e(lnE)^2 + g(lnE)^3 + i(lnE)^4}{1 + blnE + d(lnE)^2 + f(lnE)^3 + h(lnE)^4 + j(lnE)^5}$$

- This function has a different set of coefficients for energies less than or equal to 30 keV and energies greater than 30 keV.

ICRU 44 soft tissue mass energy absorption coefficients



Accounting for CPE

CPE buildup correction factors, f_{CPE}, is defined as:

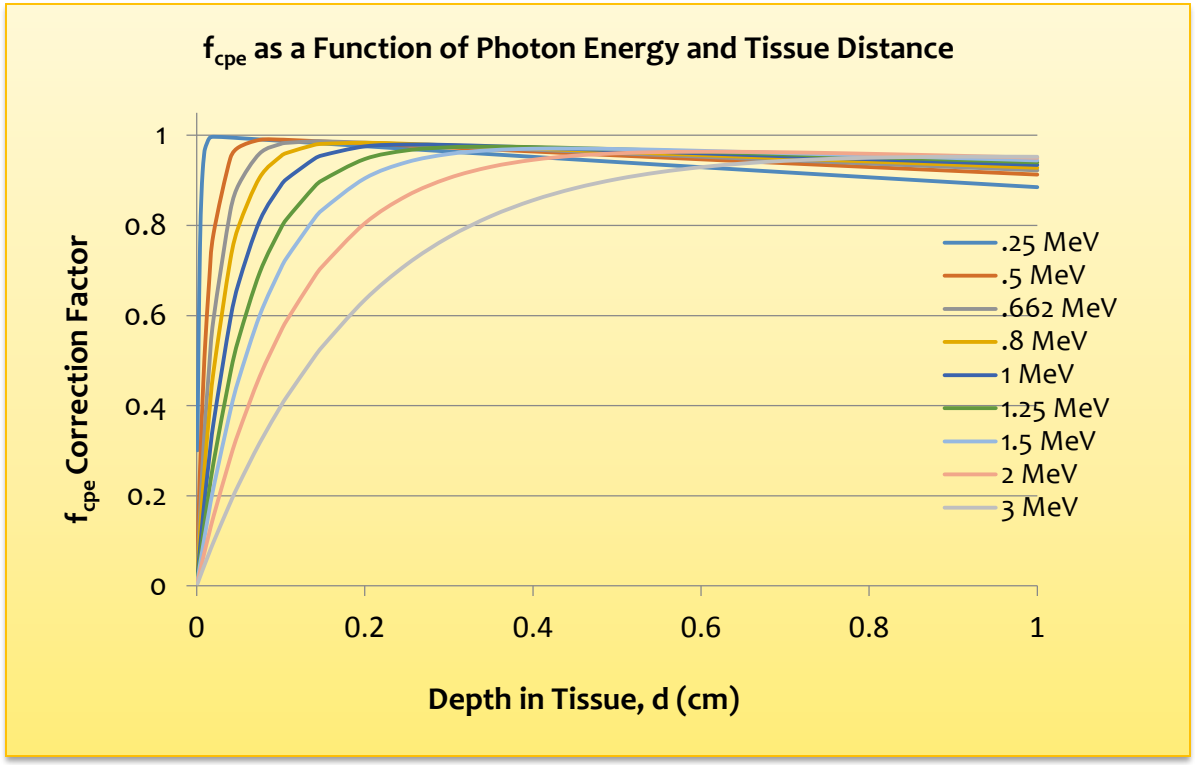
$$D(x) = K(x) \cdot f_{CPE}(x)$$

$$f_{CPE}(x) = \frac{D(x)}{K(x)} \rightarrow \frac{\sum * f8(x)}{f6(x)}$$

Charged-Particle Buildup

- Using Monte Carlo simulation, the buildup correction factors were found to fit the general form:

$$\frac{1}{f_{cpe}(d,E)} = a + b\ln(d) + c/\sqrt{d}$$



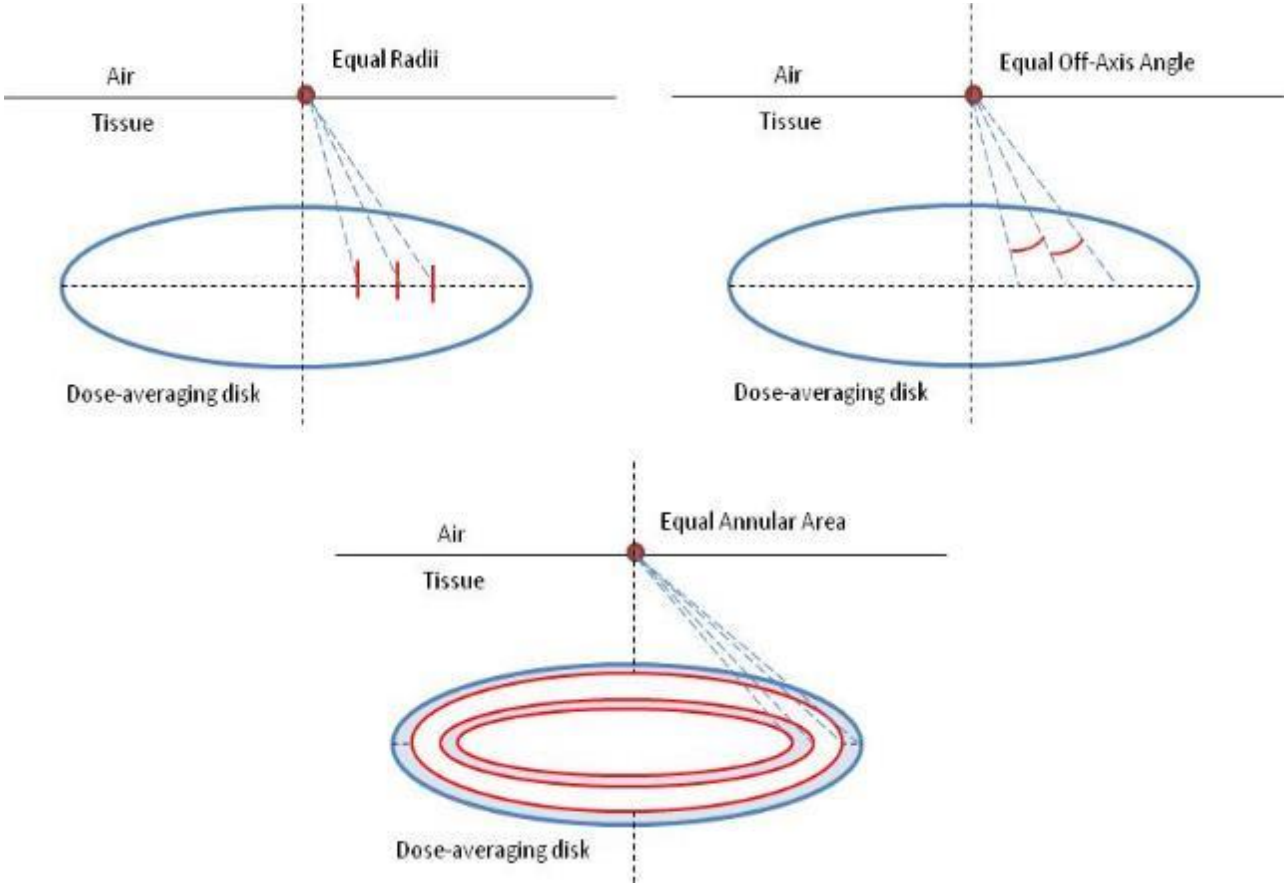
Numerical Integration Method

- Numerical integration provides
  - Average of point kernel dose over combination of photon emission locations
  - Within volume of source, and
  - Dose point locations
- Within infinitely thin disk of tissue
  - Depth h from the surface

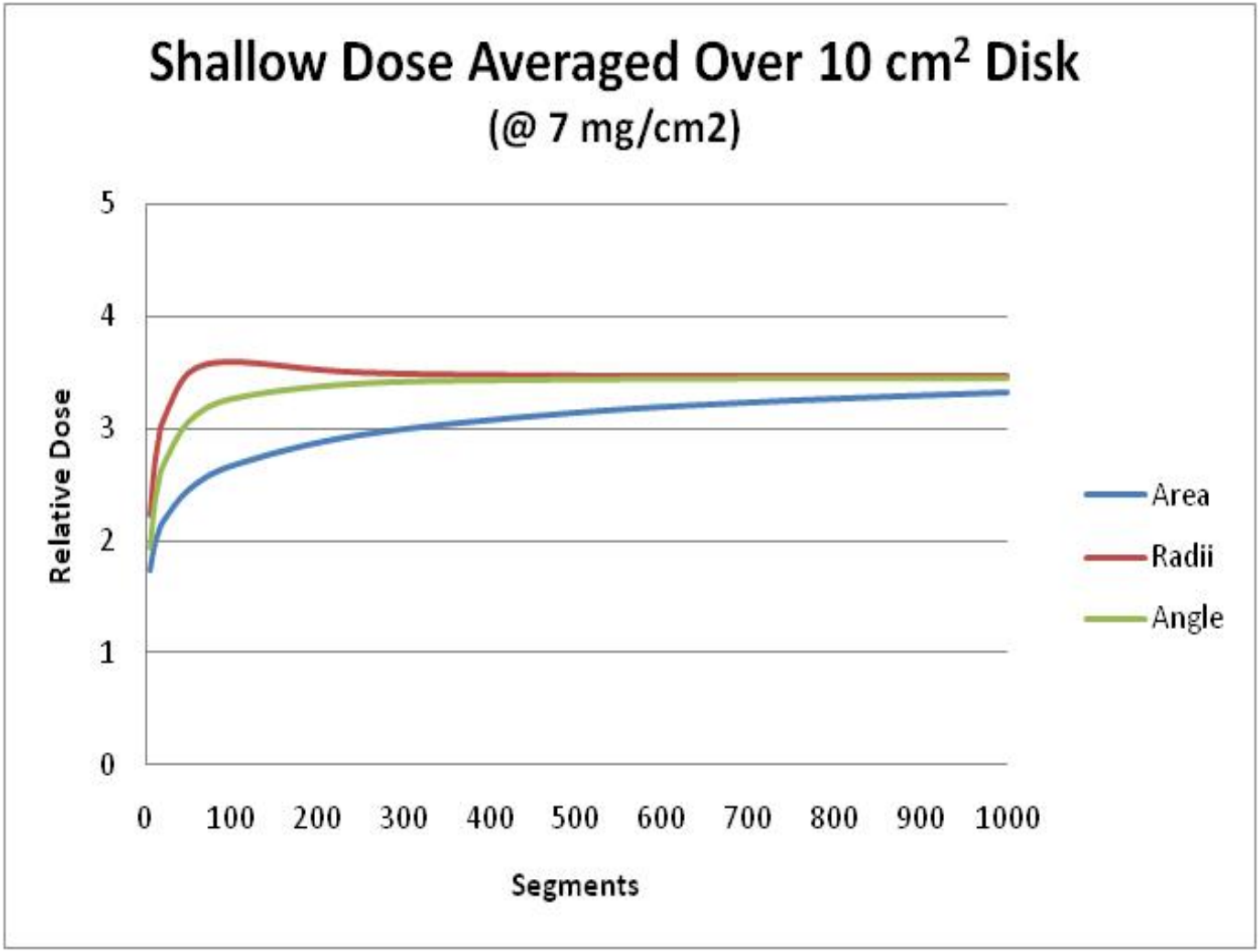
Approach to calculation

- Convergence studies conducted
- Dose averaging disk divided into segments
- Three segmenting methods examined
  - equal radii (quickest)
  - equal off-axis angle
  - equal annular area (slowest)

Methods used to select integration method



Relative dose as a function of the number of segments in a numerical integration (iterations), by method



VARSKIN 4 numerical integration utilizes 300 segments along the radius for the averaging disk. Convergence achieved with fewer segments for smaller disk

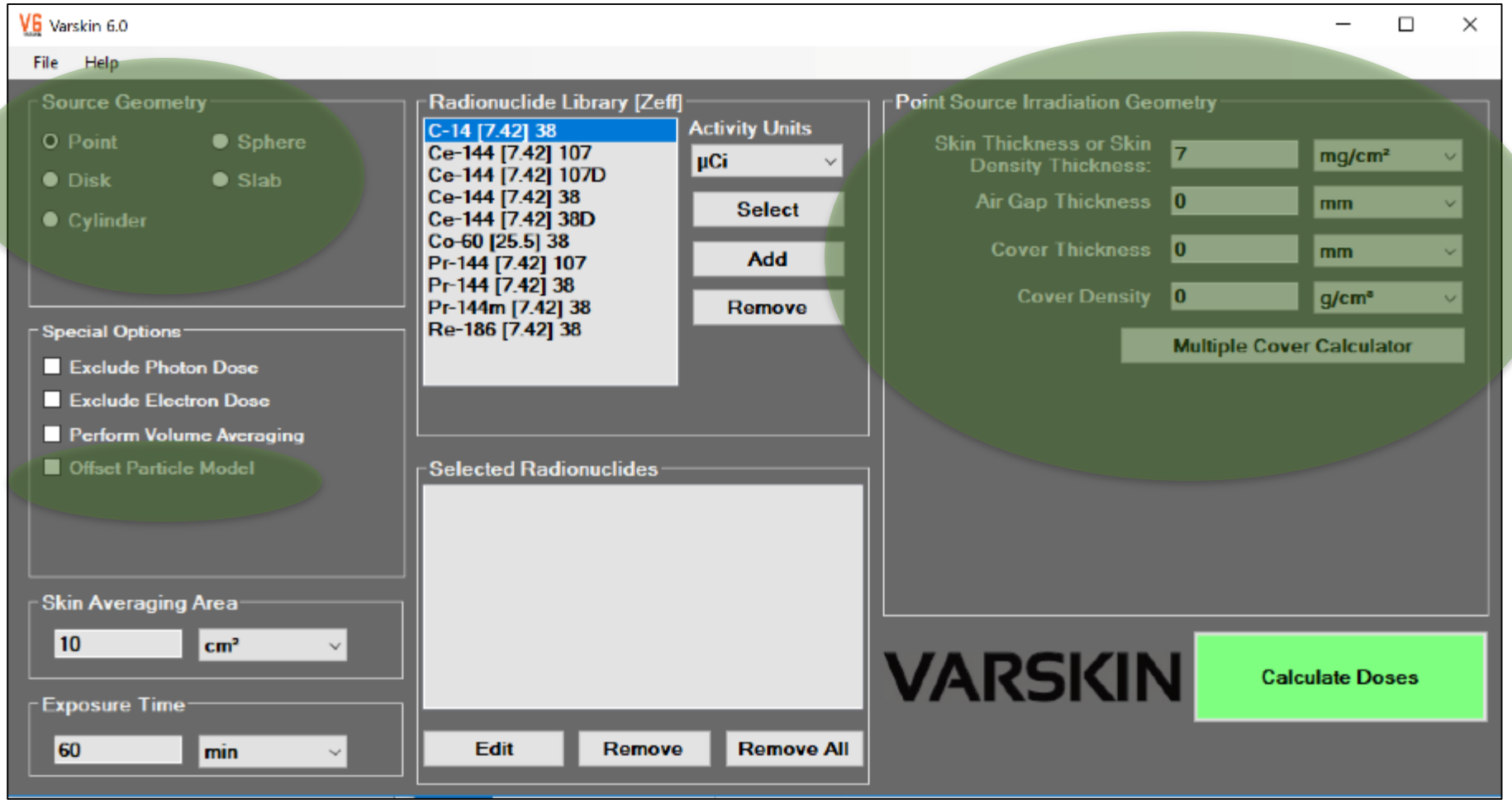
VARSKIN 4/5/6 exposure geometries

- Source Geometries
  - Point ← Offset Particle Model
  - Disk
  - Cylinder
  - Sphere
  - Slab

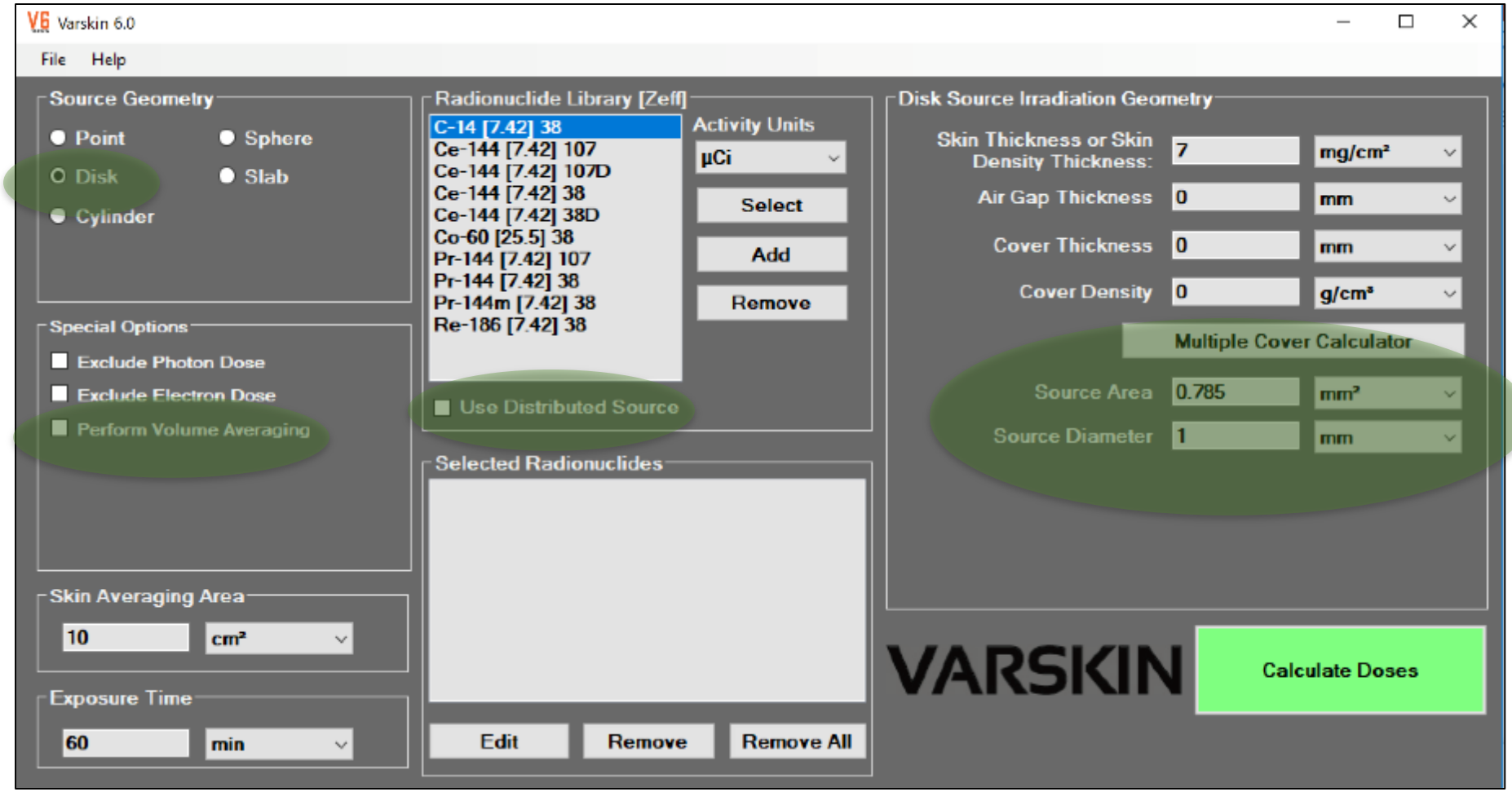
  ← Distributed Source Option
  - Syringe ← Geometry eliminated

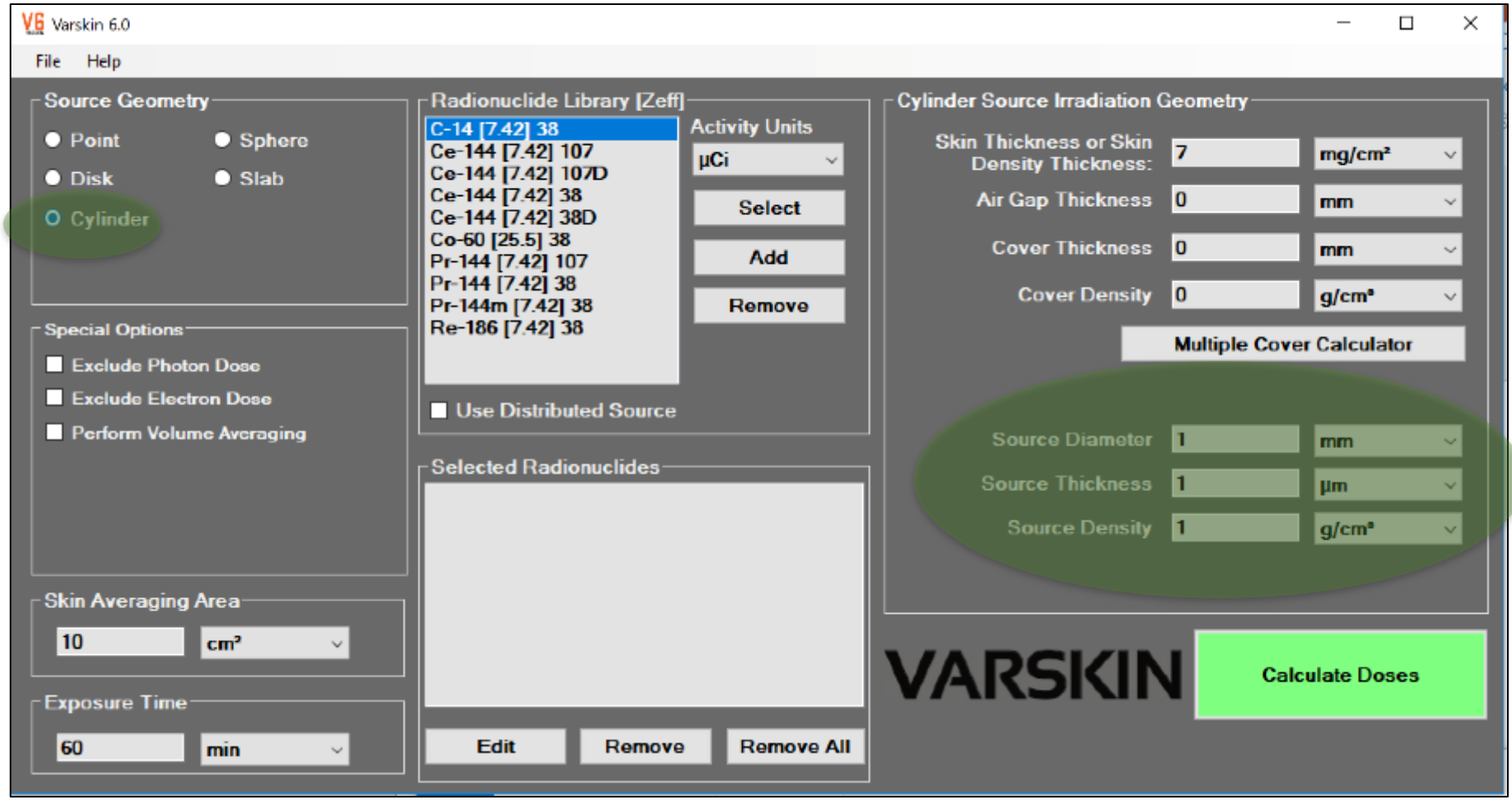
VARSKIN 4/5/6 exposure options

- User specifies:
  - Source & Geometry
  - Dose depth
  - Dose averaging area
  - Volume averaging option
  - Air and cover thicknesses
- Multiple cover calculator
- Option to turn off photon dose calculations
- “Reset” feature to re-initialize parameters



air gap (5 cm max) is always adjacent to the skin


Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Skin Averaging Area
10
cm²
Exposure Time
60
min
Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Edit
Remove
Remove All
Disk Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
Source Area
0.785
mm²
Source Diameter
1
mm
VARSKIN
Calculate Doses


Varskin 6.0
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Source Geometry
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Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Skin Averaging Area
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cm²
Exposure Time
60
min
Radionuclide Library [Zeff]
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Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
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Use Distributed Source
Selected Radionuclides
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Remove
Remove All
Cylinder Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
Source Diameter
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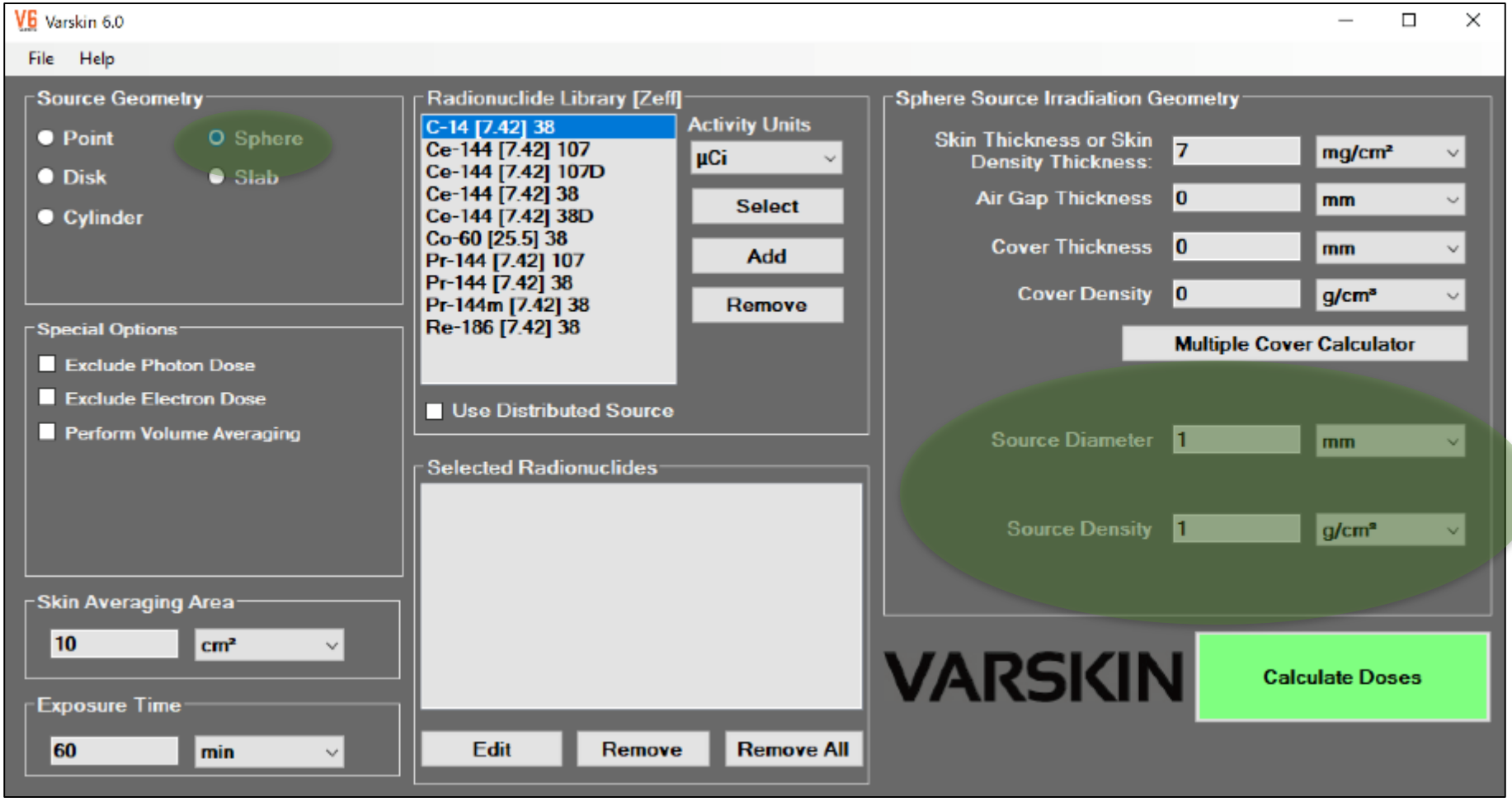
mm
Source Thickness
1
µm
Source Density
1
g/cm³
VARSKIN
Calculate Doses


Varskin 6.0
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Source Geometry
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Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Skin Averaging Area
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cm²
Exposure Time
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Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
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Use Distributed Source
Selected Radionuclides
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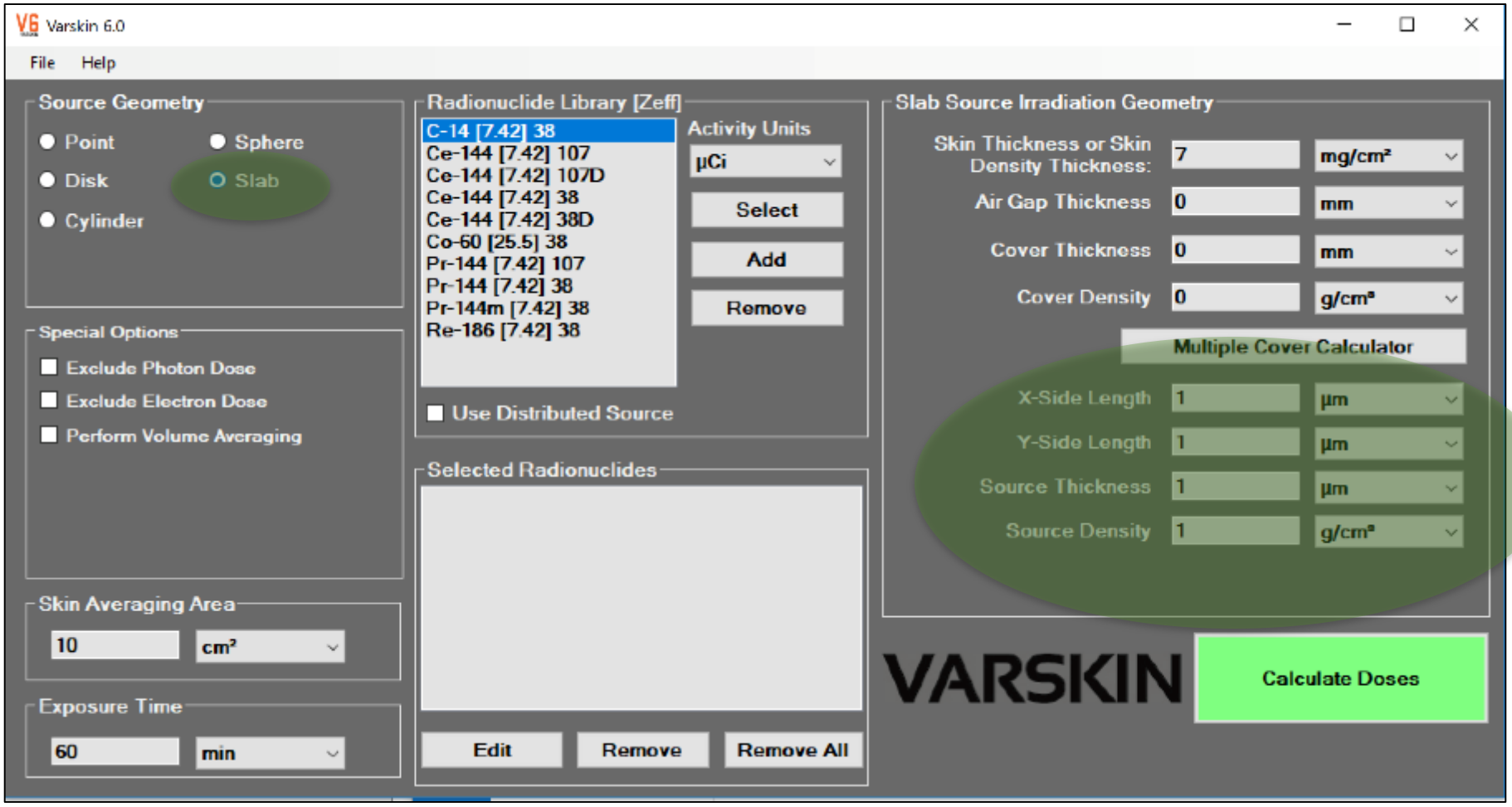
Remove
Remove All
Sphere Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
Source Diameter
1
mm
Source Density
1
g/cm³
VARSKIN
Calculate Doses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Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Skin Averaging Area
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cm²
Exposure Time
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min
Radionuclide Library [Zeff]
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Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
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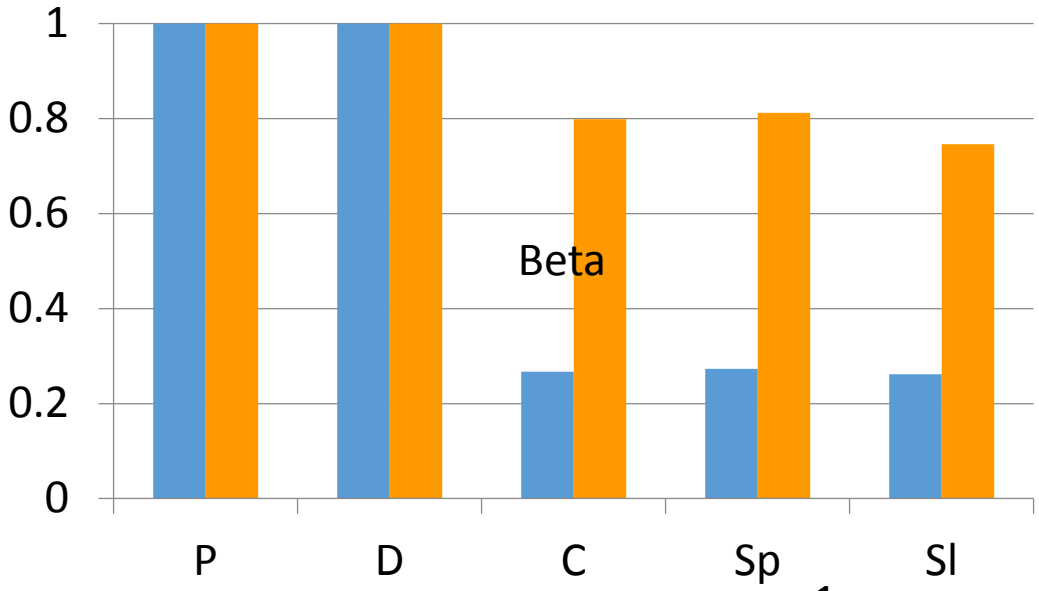
Use Distributed Source
Selected Radionuclides
Edit
Remove
Remove All
Slab Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
X-Side Length
1
µm
Y-Side Length
1
µm
Source Thickness
1
µm
Source Density
1
g/cm³
VARSKIN
Calculate Doses

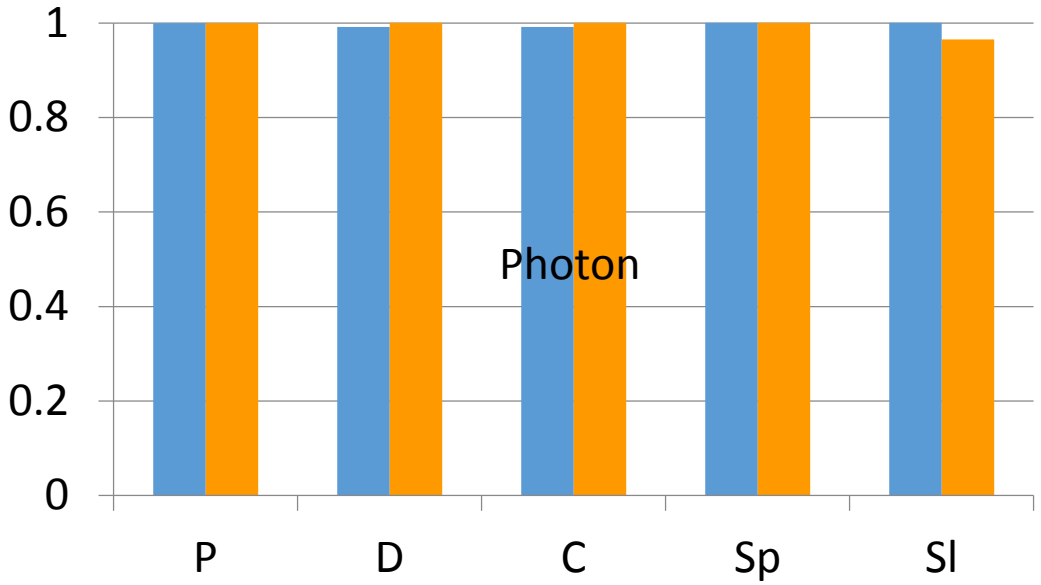
Impact of Source Geometry



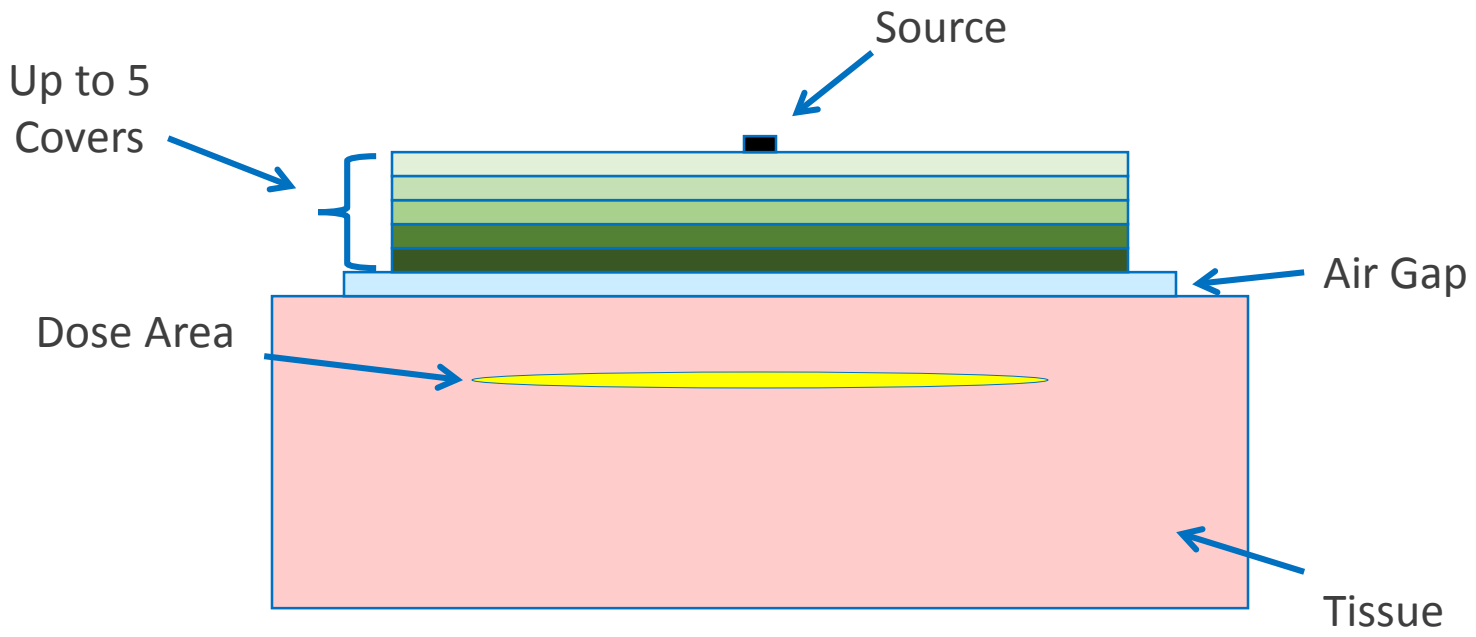
^{60}Co (0.318; 1.25)

^{106}Rh (3.54; 0.512)

Dose relative to point geometry
1 mm dimensions
10 cm^2 area
Shallow dose



Cover model



Cover Materials

- Up to 5 layers above the skin are allowed (air next to skin, if present)
- Attenuation in cover materials is considered

For Photons…

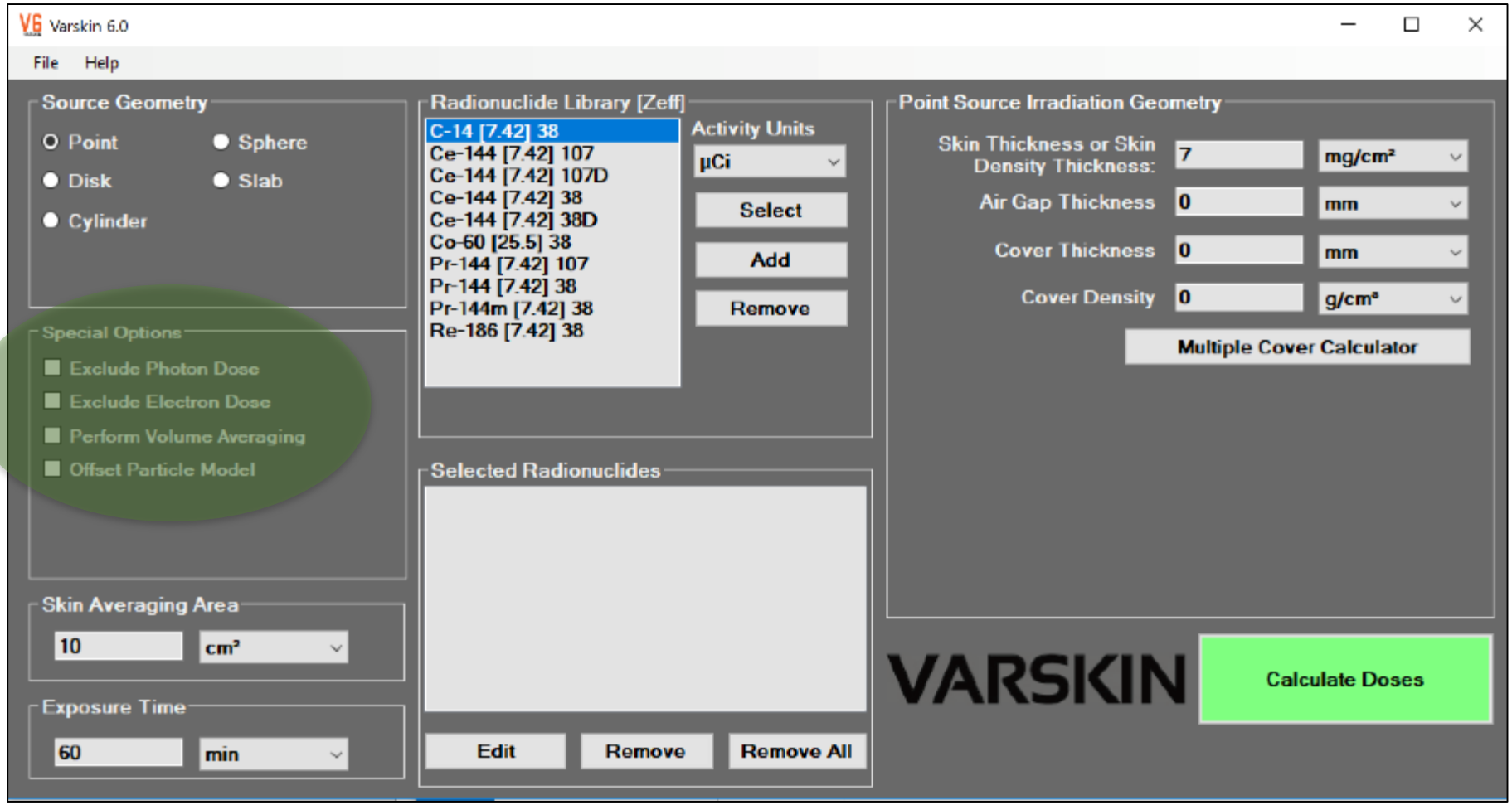
- The presence of cover materials
  - disrupts CPE, adds depth, and alters off-axis geometry
- Material layers are restricted to “cotton” or “latex”
- Cotton or latex attenuation is energy dependent
  - if $\rho > 1.25$ g/cm^2 (cotton assumed)
  - if $\rho < 1.25$ g/cm^2 (latex assumed)
- For photon attenuation, the cover material is assumed to be air
  - insignificant for very small volumetric sources and for photon energies above ~50 keV

Air-Gap Model

- The presence of air between source and skin
  - disrupts charged-particle buildup
  - adds depth to dose calculation
  - alters off-axis geometry
- The air layer can be model only as being in contact with the skin surface
- Attenuation in air is considered

Special Options

- Exclude Photon Dose (off)
- Exclude Electron Dose (off)
- Perform Volume Averaging (off)
  - errors possible with large values
- Offset Particle Model (off)
  - available only for point source geometry and only for photon dosimetry


Varskin 6.0
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Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Skin Averaging Area
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cm²
Exposure Time
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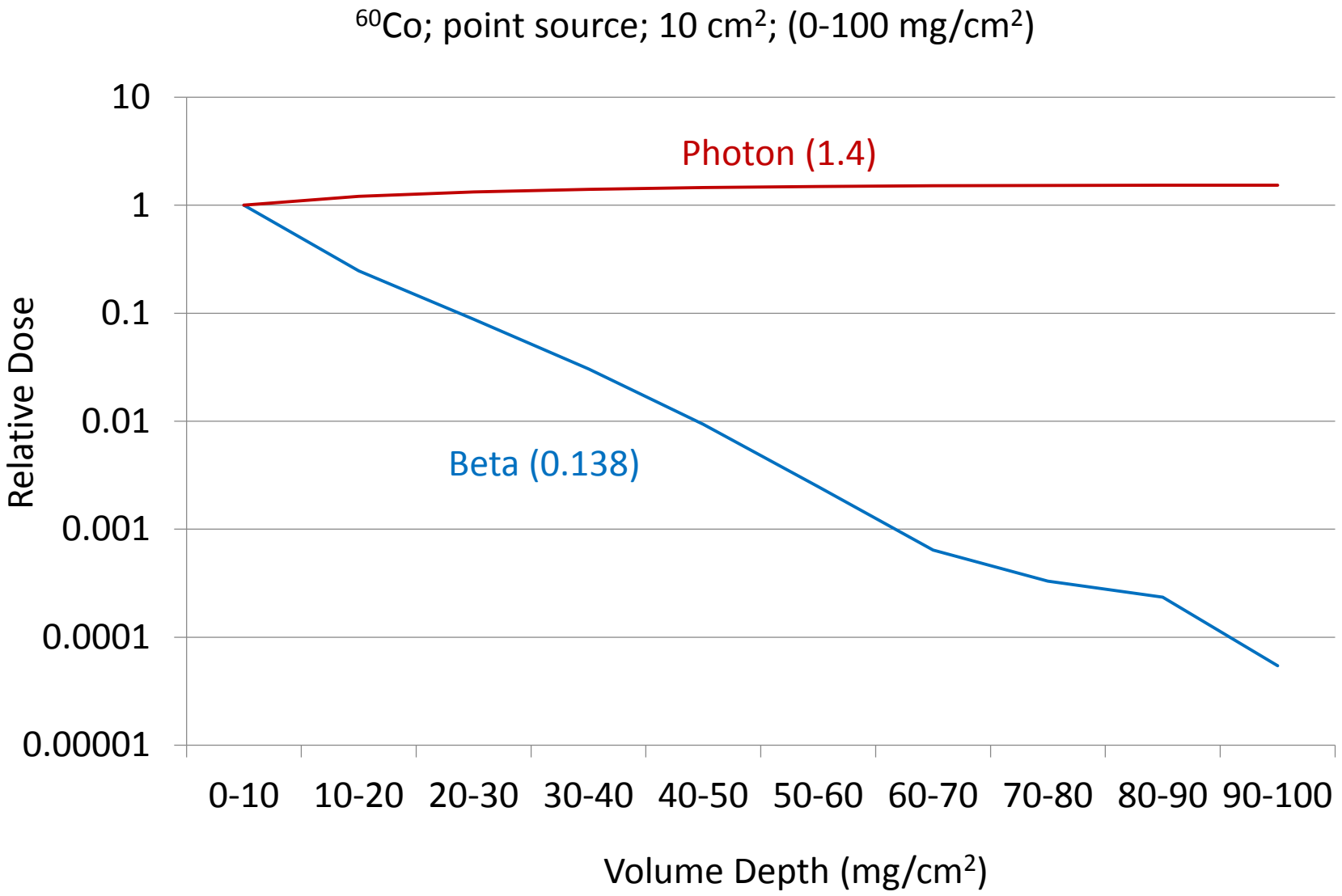
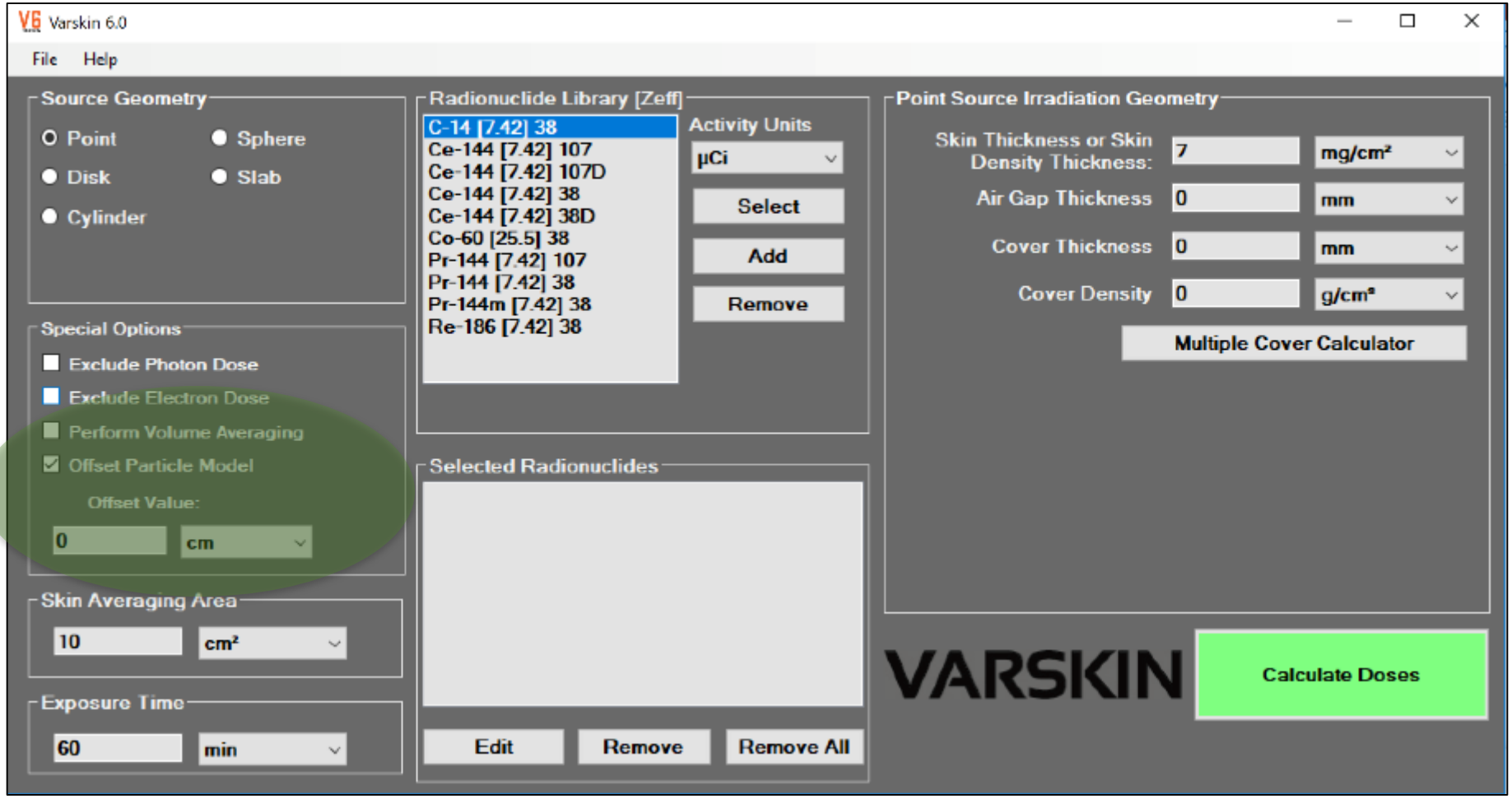
min
Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remove
Selected Radionuclides
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses

Volume Averaging

- Averaging cell is a cylinder defined laterally by the skin averaging area, with a user-specified top and bottom
- As defaults, the “top” of the cell is assumed to be the skin surface (0 mg/cm^2) and the “bottom” is assumed to be equal to the range of the maximum energy electron for the chosen radionuclide (not to exceed 1500 mg/cm^2)

Volume Averaging




Varskin 6.0
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Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Offset Value:
0
cm
Skin Averaging Area
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cm²
Exposure Time
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min
Radionuclide Library [Zeff]
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Ce-144 [7.42] 107D
Ce-144 [7.42] 38
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Pr-144m [7.42] 38
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Activity Units
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Select
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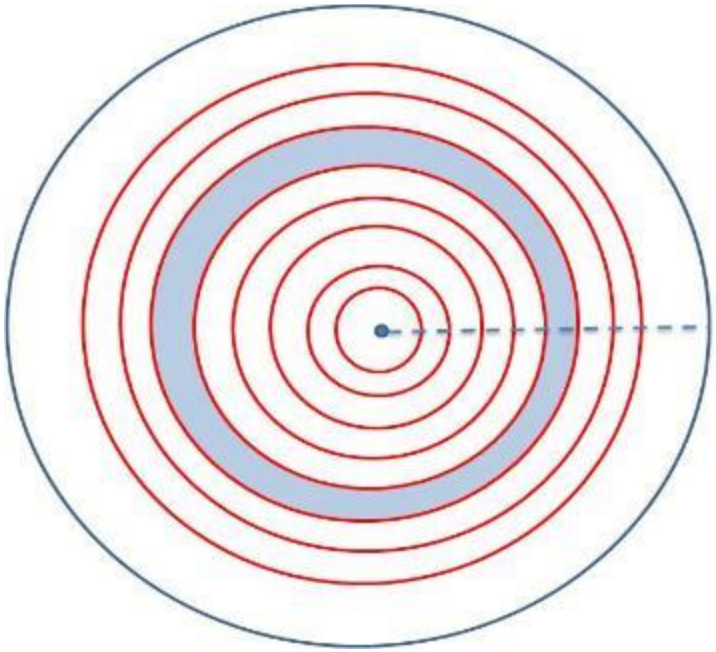
Selected Radionuclides
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses

On-Axis Calculation of Dose

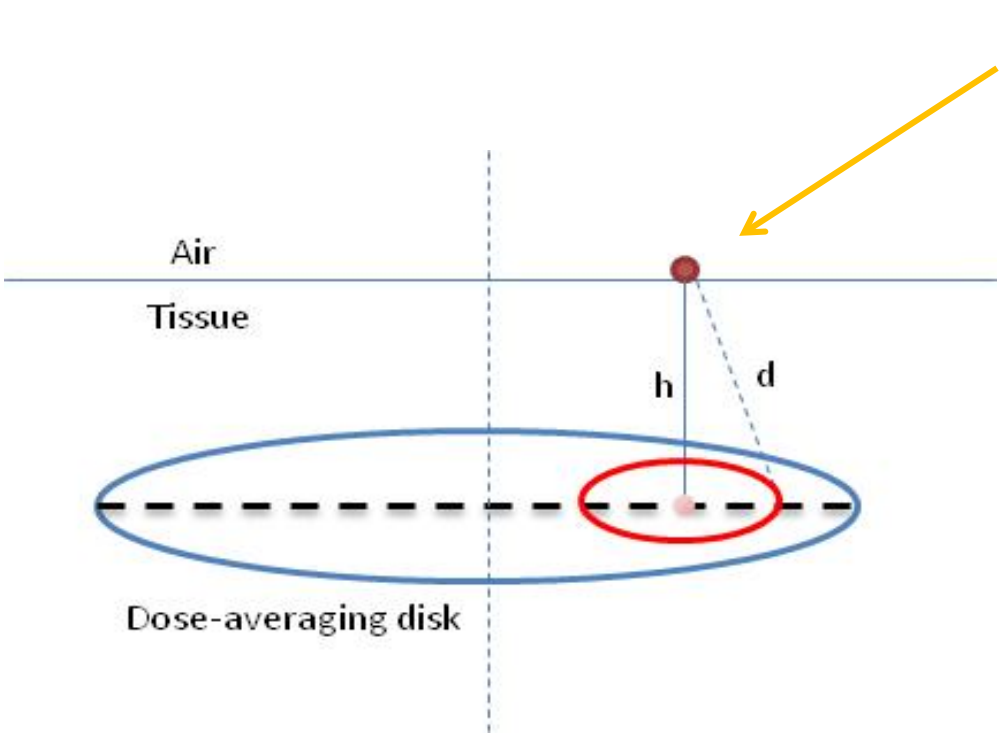
- Varskin 3 calculated dose at 60 locations around the dose-averaging disk
  - Method tends to weight the average such that it provides an over-estimation
- For VARSKIN 4, we assumed the following:
  - Point source is located directly above and on-axis with the averaging disk
  - Presumes symmetry in calculations along a radius of the dose-averaging disk
  - Weighted by the fractional area of each annulus
  - Provides a better estimate of average dose to the entire disk



Offset Particle Model

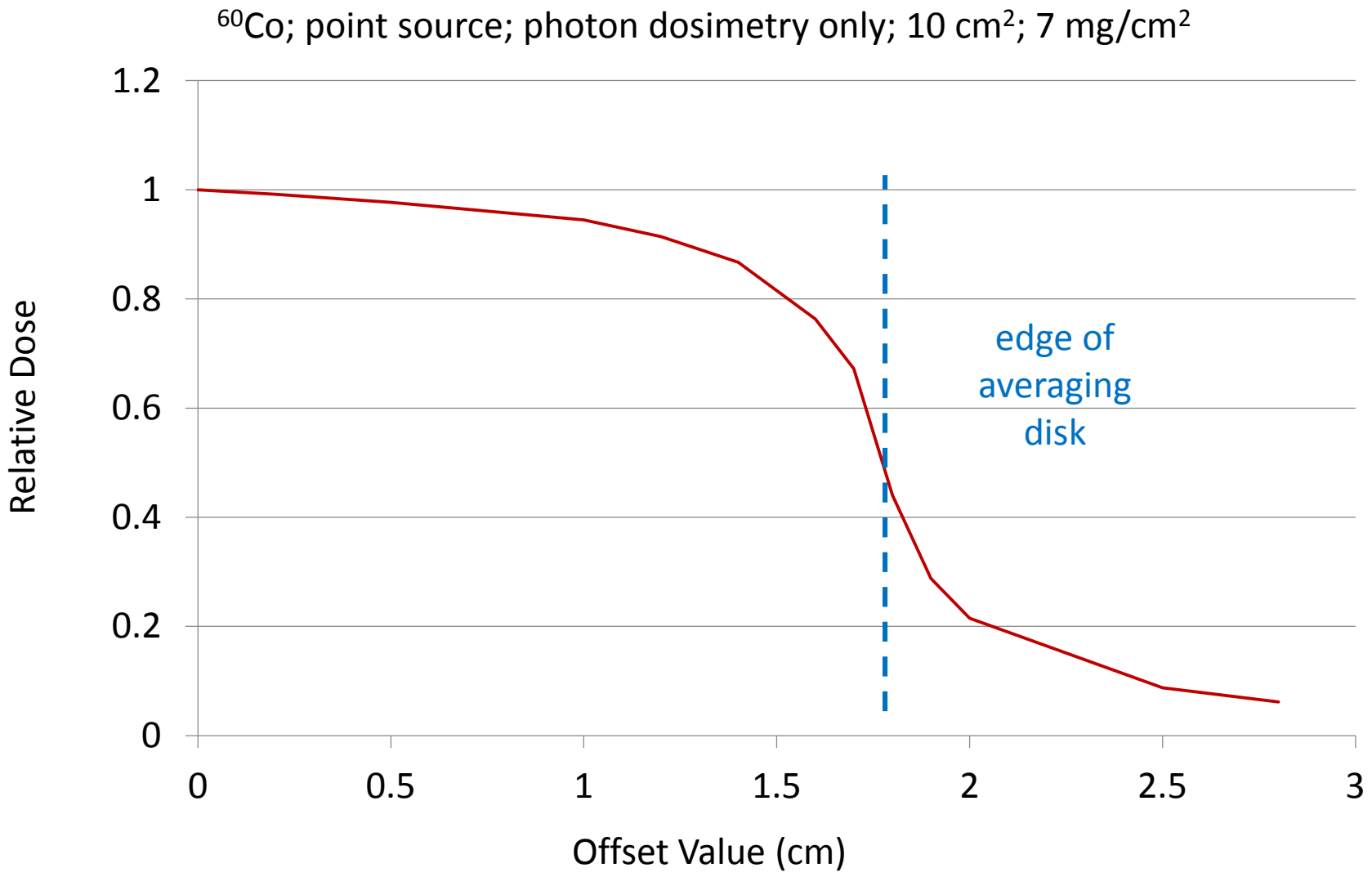
- For point source, photon dosimetry
- To estimate the greatest dose to a single averaging area beneath multiple sources
- Used when two (or more) hot particles are in proximity to each other (when separation is less than the diameter of the averaging area)
- On selection, user must enter the Offset Value (0 cm)

Offset-particle model



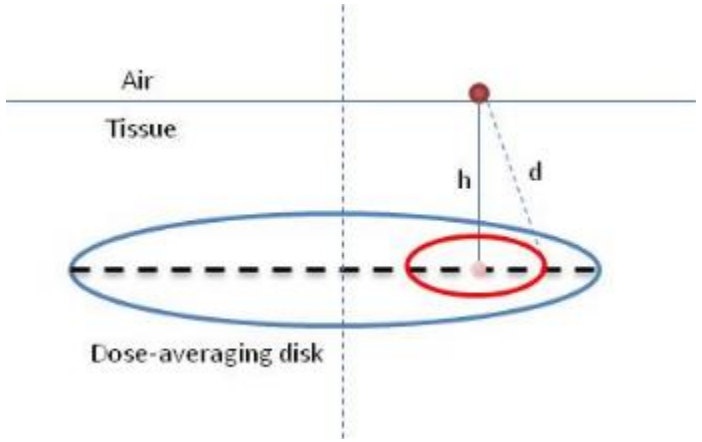
This feature allows for the calculation of photon dose from multiple hot particles to a single dose-averaging disk

Offset Particle



Dose Calculation for Offset Particles

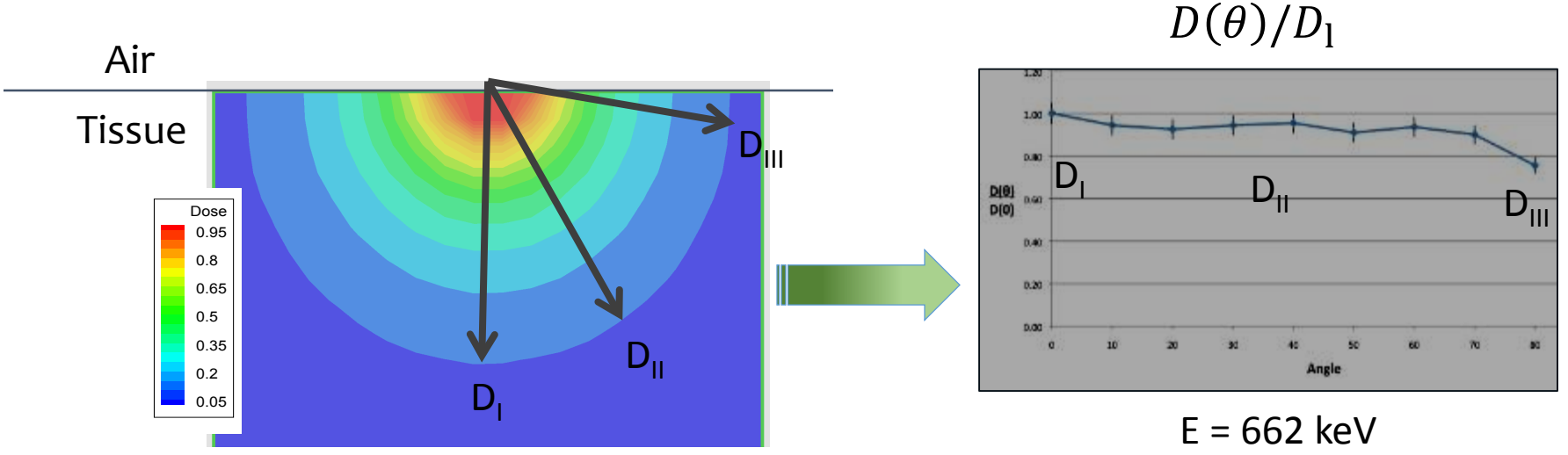
- Also, necessary for volumetric sources
  - essentially all of source volume will be offset
  - 15 x 15 x 15 source points
  - 300 dose points along the symmetric diameter
  - weighted by the fractional area of each annulus (red circle) that resides within the averaging disk



Offset (10 cm^2) r = 1.78 cm	Relative Dose Rate
0.0 cm	1.28
0.1	1.28
0.2	1.27
0.3	1.27
0.5	1.25
0.7	1.25
0.9	1.23
1.1	1.19
1.3	1.13
1.5	1.06
1.7	0.86
1.8	0.56
1.9	0.37

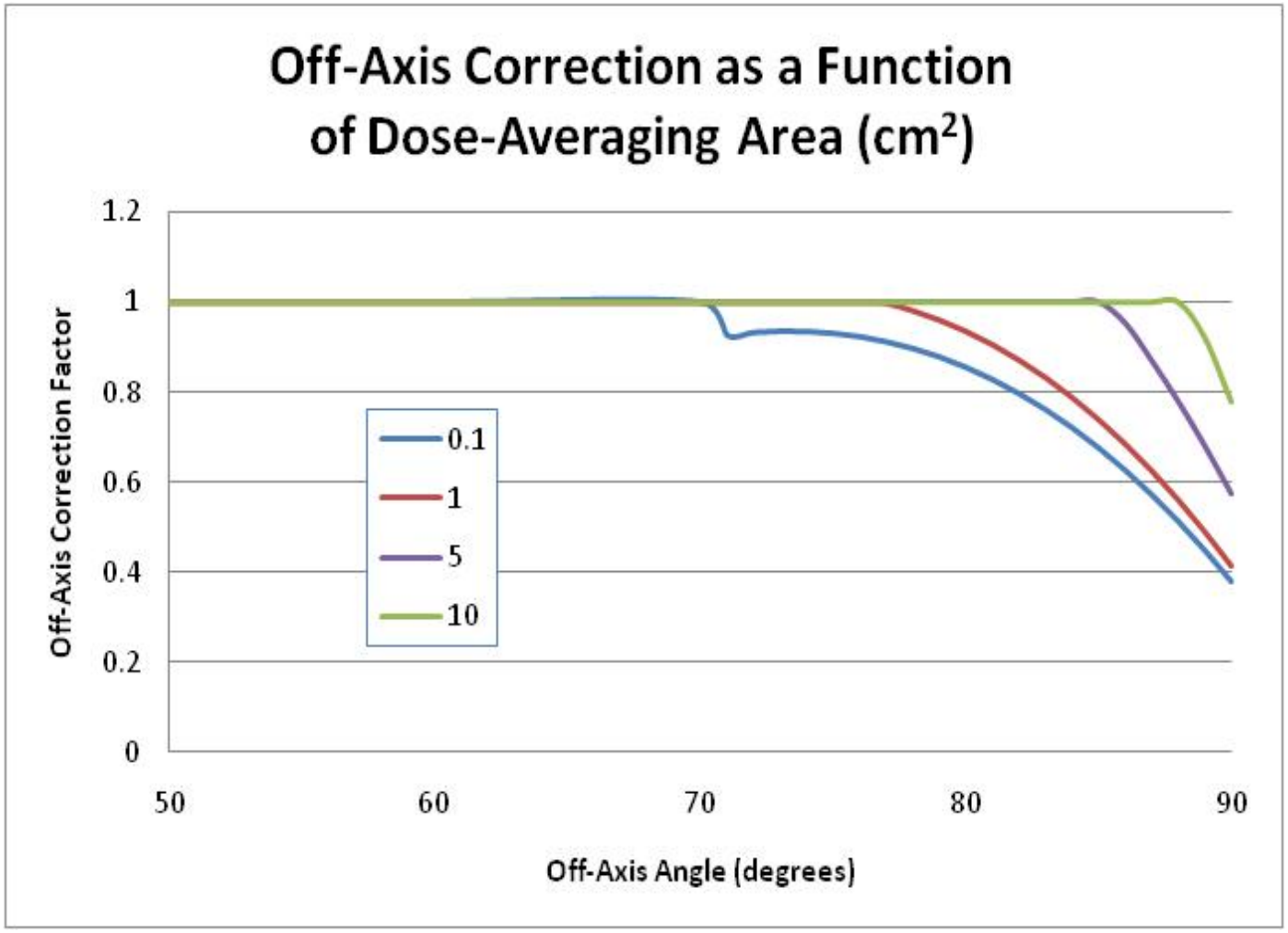
Off-Axis Correction

- CPE factors were determined at various depths <u>on-axis</u> in an infinite medium
  - thus, photon/electron loss at tissue-air interface is not considered
- Previous calculations assumed $D_I = D_{II} = D_{III}$
  - additional simulations performed to consider electron loss
- Ratio of off-axis dose to perpendicular dose at depth is plotted



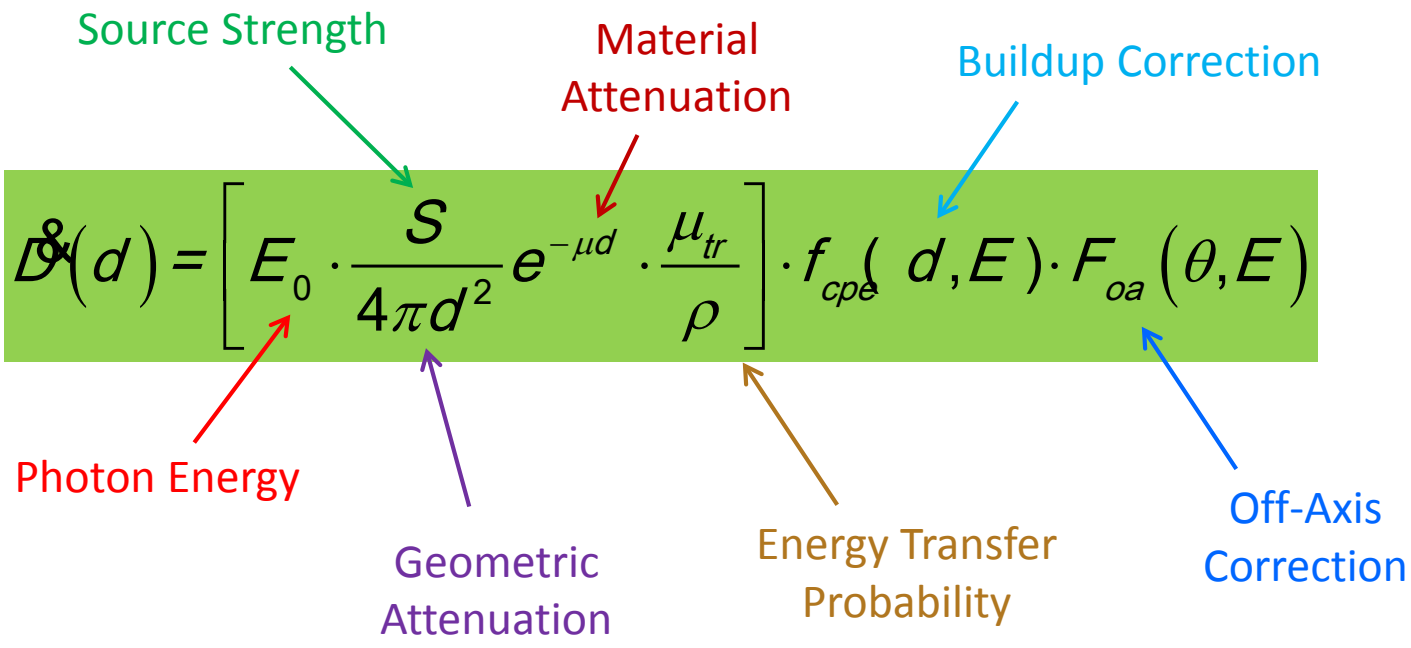
Off-Axis Correction Factors

Implemented for 4 Dose Averaging Areas



Elements of the dose calculation

- So, this leaves us with a point-kernel photon dosimetry model that contains these elements:



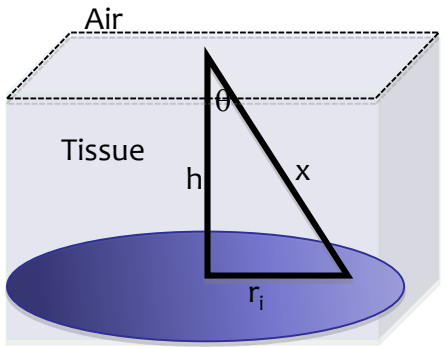
SUMMARIZING the Model

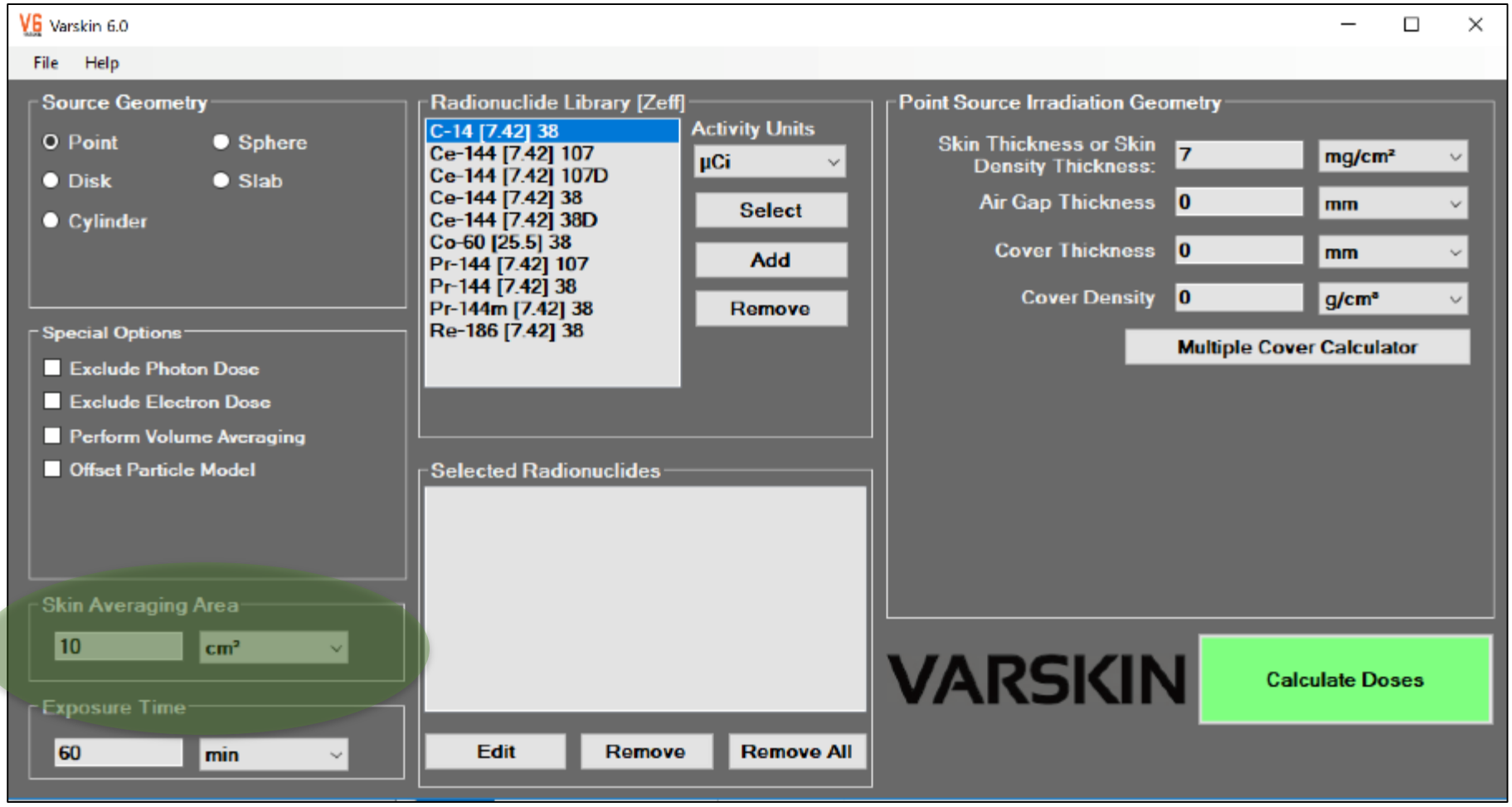
Effort to improve accuracy, simplify, and provide continuity

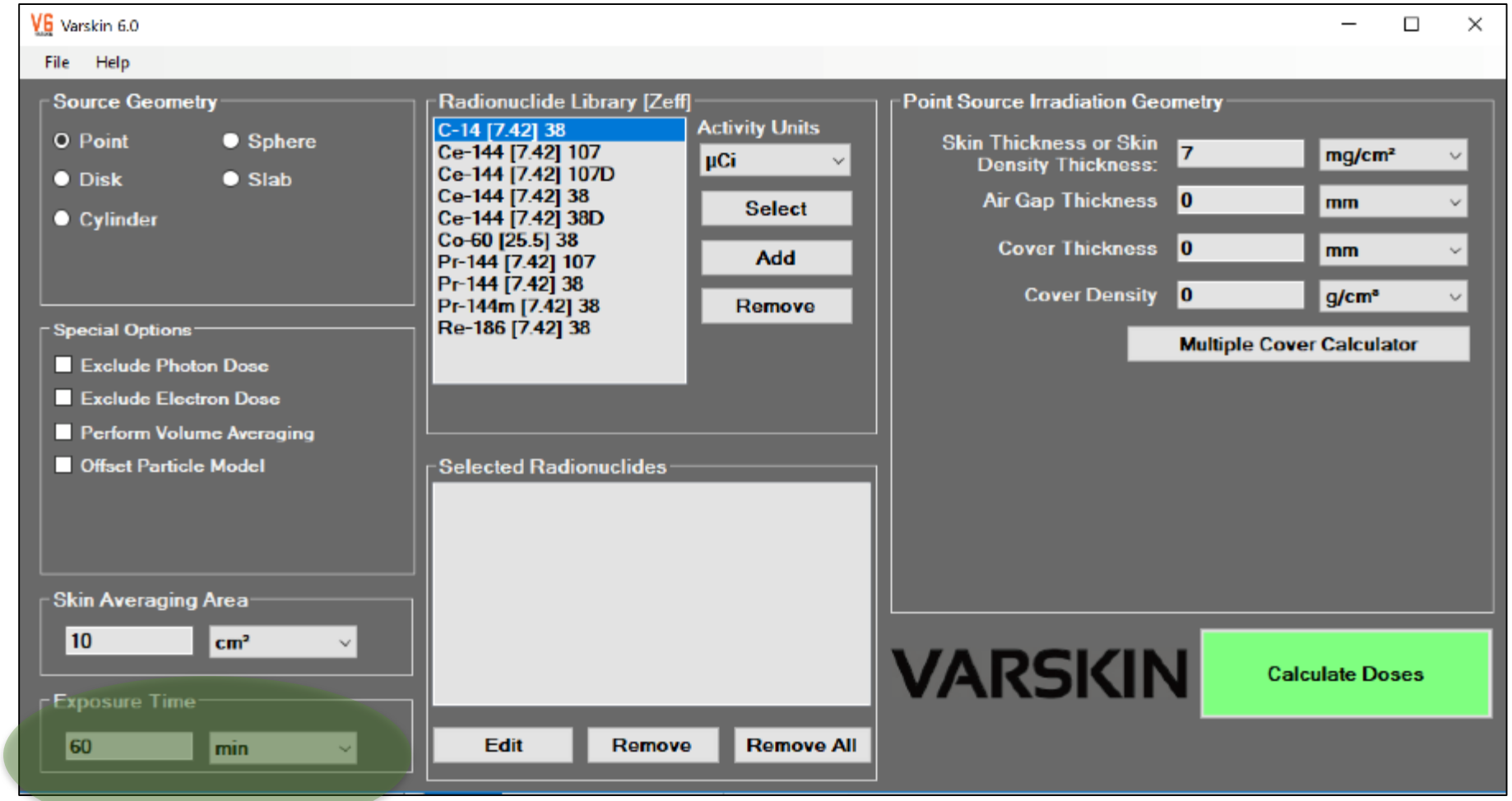
$$\dot{D}_{disc}(h,A) = \frac{\int f_{CPE}(x) \cdot \dot{K}(x) \cdot F_{oa} \cdot e^{-\mu\sqrt{h^2+r^2}}\, dA}{\int dA}$$

Model Components

- Attenuation Coefficient
  - improve accuracy
- Buildup Region – f_{cpe}
  - improve accuracy
  - simplify –function of E
- Off-Axis Factors – F_{oa}
  - analytical fit




Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Skin Averaging Area
10
cm²
Exposure Time
60
min
Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remove
Selected Radionuclides
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses


Varskin 6.0
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Help
Source Geometry
Point
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Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
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Exposure Time
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Air Gap Thickness
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Cover Thickness
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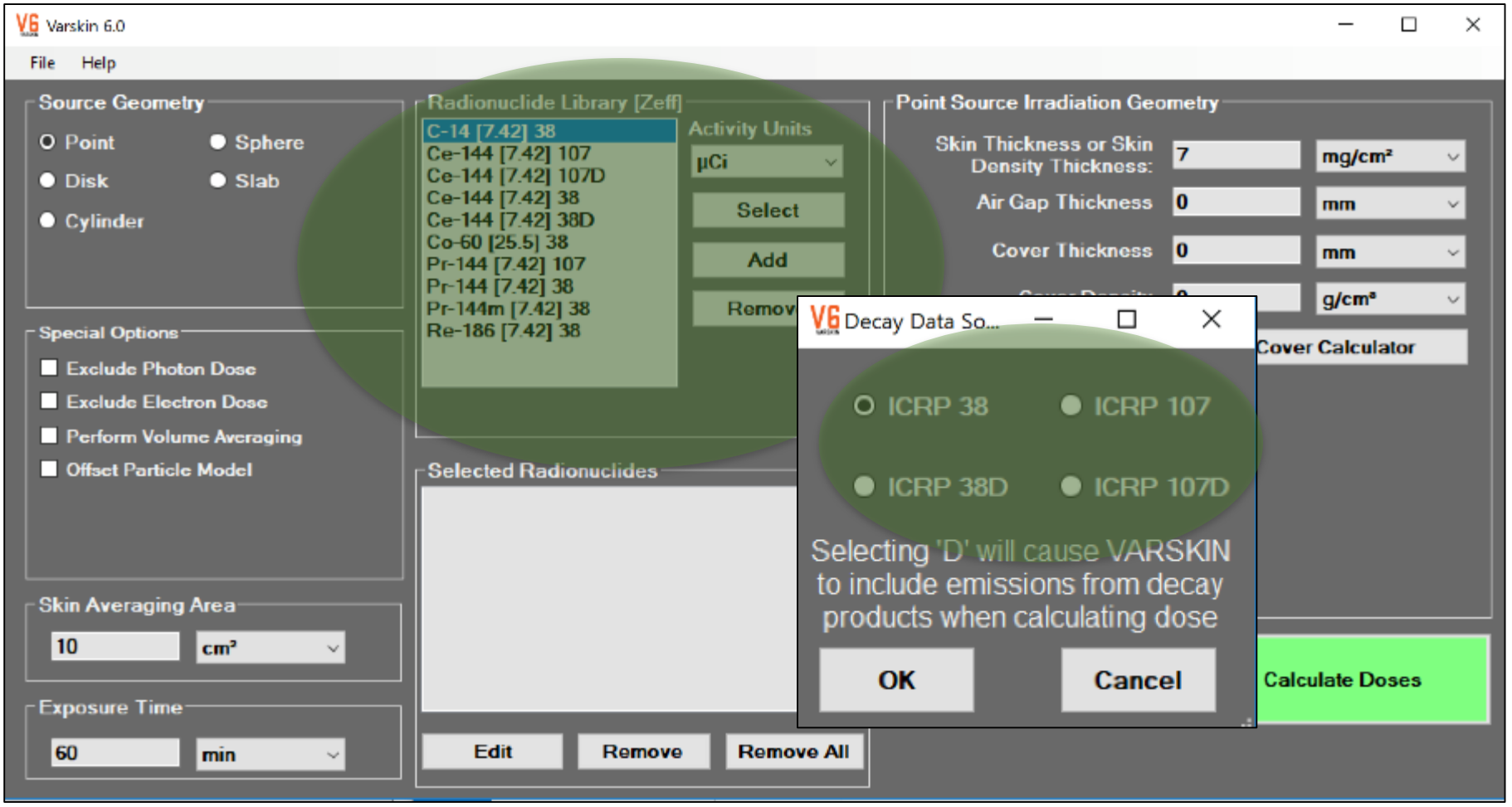
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses


Varskin 6.0
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Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Skin Averaging Area
10
cm²
Exposure Time
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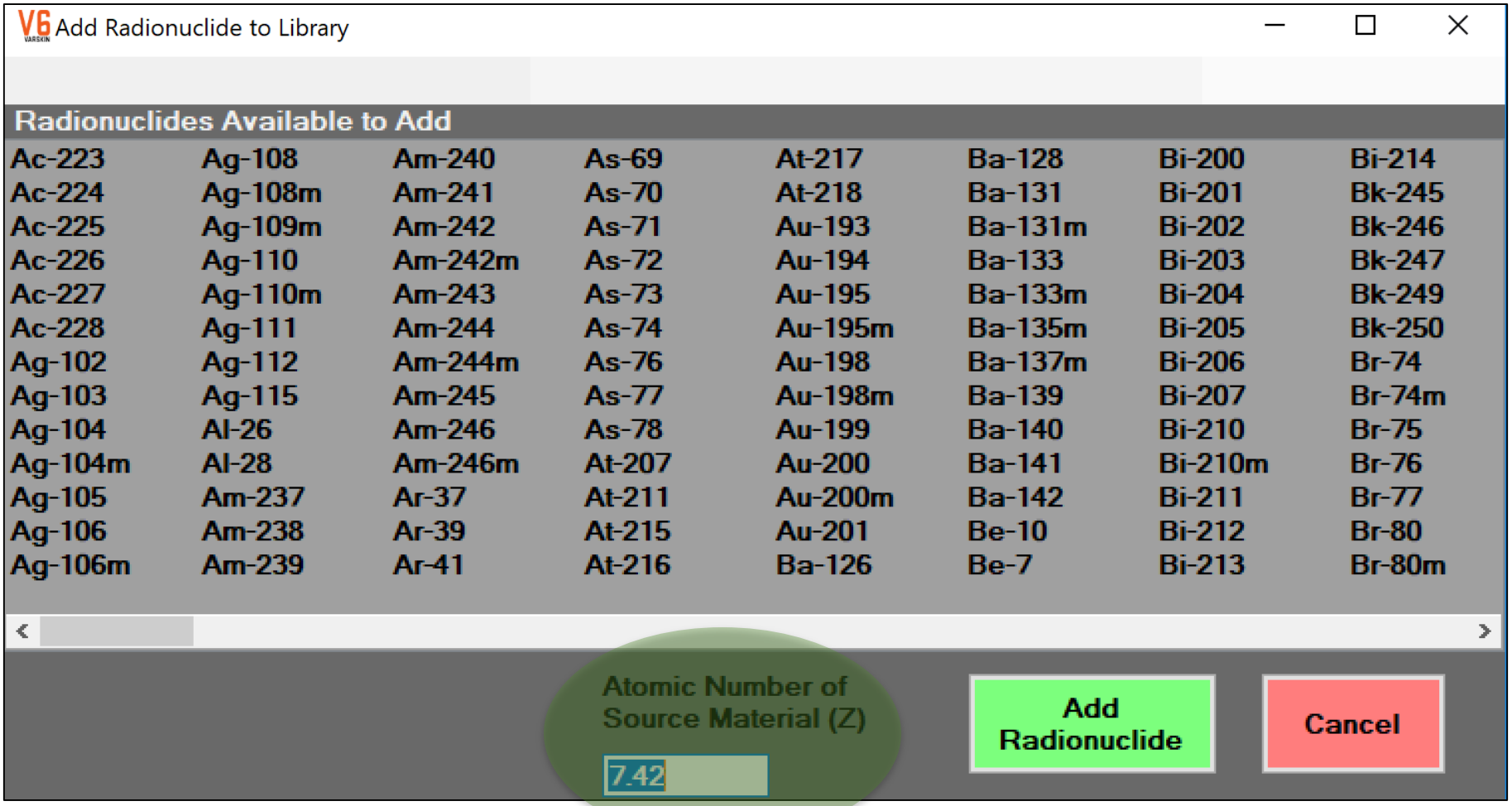
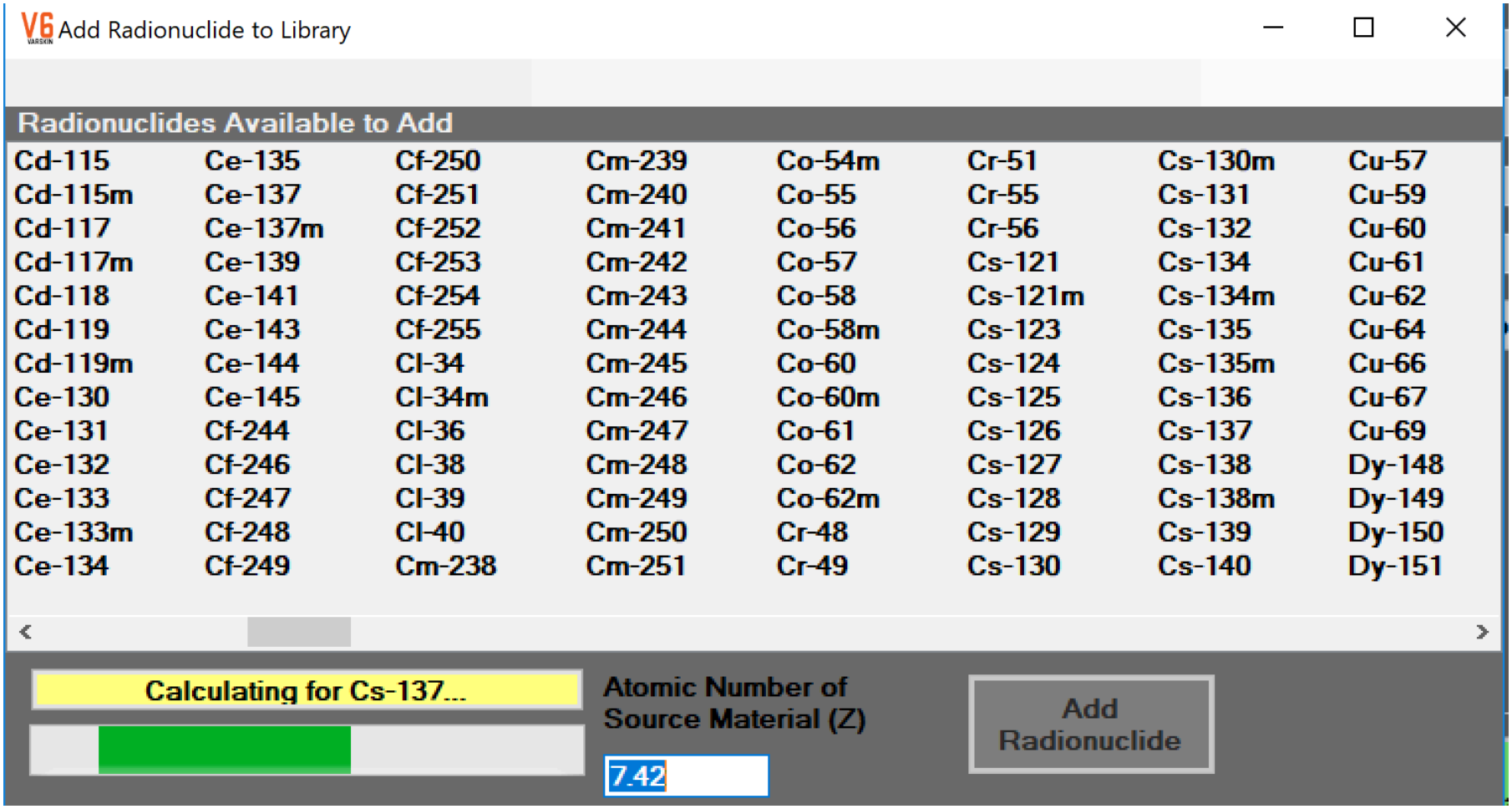
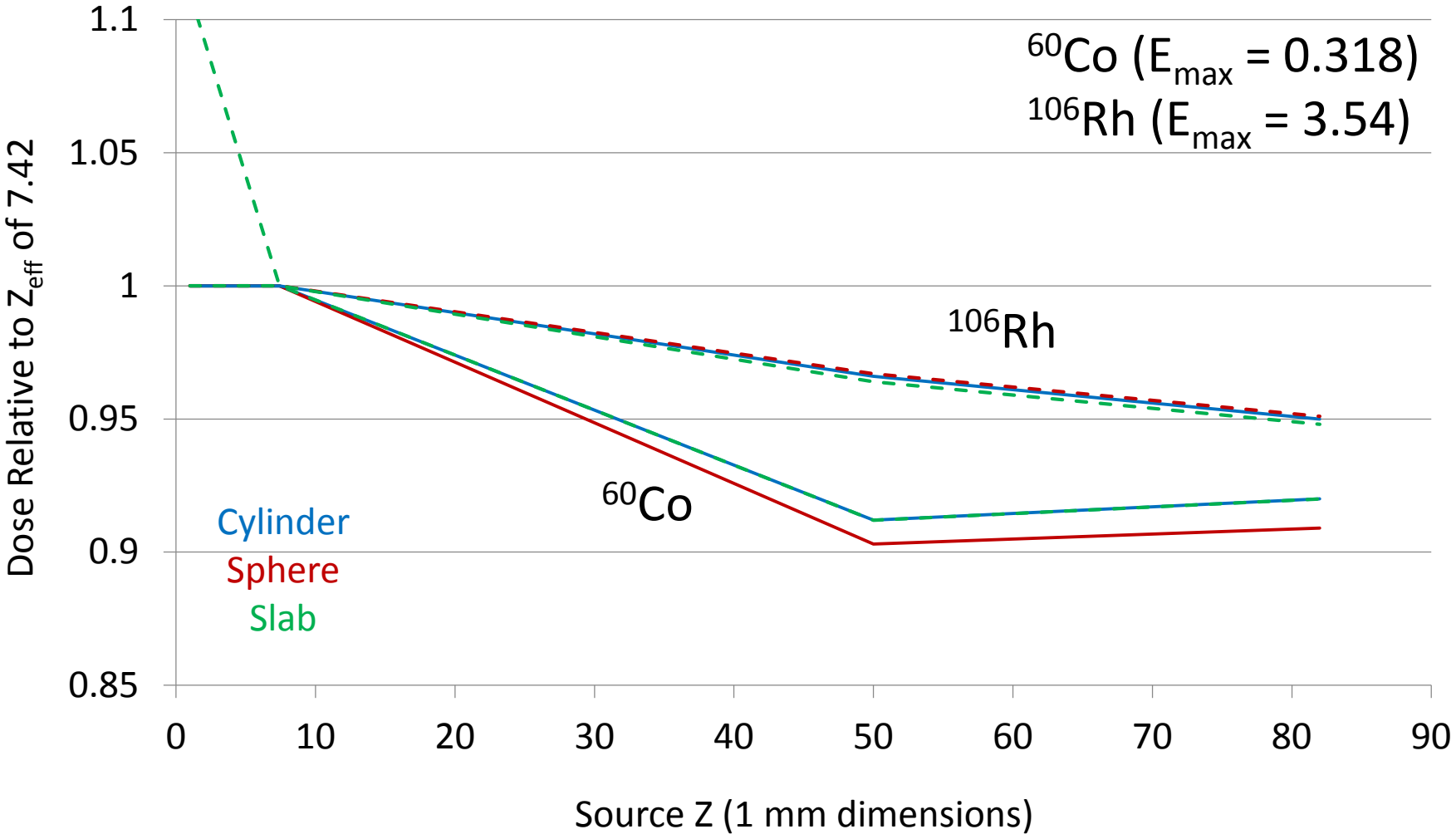
Co-60 [25.5] 38
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remov
Selected Radionuclides
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
g/cm³
Cover Calculator
Calculate Doses
Decay Data So...
ICRP 38
ICRP 107
ICRP 38D
ICRP 107D
Selecting 'D' will cause VARSKIN to include emissions from decay products when calculating dose
OK
Cancel


Add Radionuclide to Library
Radionuclides Available to Add
Ac-223 Ac-224 Ac-225 Ac-226 Ac-227 Ac-228 Ag-102 Ag-103 Ag-104 Ag-104m Ag-105 Ag-106 Ag-106m
Ag-108 Ag-108m Ag-109m Ag-110 Ag-110m Ag-111 Ag-112 Ag-115 Al-26 Al-28 Am-237 Am-238 Am-239
Am-240 Am-241 Am-242 Am-242m Am-243 Am-244 Am-244m Am-245 Am-246 Am-246m Ar-37 Ar-39 Ar-41
As-69 As-70 As-71 As-72 As-73 As-74 As-76 As-77 As-78 At-207 At-211 At-215 At-216
At-217 At-218 Au-193 Au-194 Au-195 Au-195m Au-198 Au-198m Au-199 Au-200 Au-200m Au-201 Ba-126
Ba-128 Ba-131 Ba-131m Ba-133 Ba-133m Ba-135m Ba-137m Ba-139 Ba-140 Ba-141 Ba-142 Be-10 Be-7
Bi-200 Bi-201 Bi-202 Bi-203 Bi-204 Bi-205 Bi-206 Bi-207 Bi-210 Bi-210m Bi-211 Bi-212 Bi-213
Bi-214 Bk-245 Bk-246 Bk-247 Bk-249 Bk-250 Br-74 Br-74m Br-75 Br-76 Br-77 Br-80 Br-80m
Atomic Number of Source Material (Z)
7.42
Add Radionuclide
Cancel


Add Radionuclide to Library
Radionuclides Available to Add
Cd-115 Cd-115m Cd-117 Cd-117m Cd-118 Cd-119 Cd-119m Ce-130 Ce-131 Ce-132 Ce-133 Ce-133m Ce-134
Ce-135 Ce-137 Ce-137m Ce-139 Ce-141 Ce-143 Ce-144 Ce-145 Cf-244 Cf-246 Cf-247 Cf-248 Cf-249
Cf-250 Cf-251 Cf-252 Cf-253 Cf-254 Cf-255 Cl-34 Cl-34m Cl-36 Cl-38 Cl-39 Cl-40 Cm-238
Cm-239 Cm-240 Cm-241 Cm-242 Cm-243 Cm-244 Cm-245 Cm-246 Cm-247 Cm-248 Cm-249 Cm-250 Cm-251
Co-54m Co-55 Co-56 Co-57 Co-58 Co-58m Co-60 Co-60m Co-61 Co-62 Co-62m Cr-48 Cr-49
Cr-51 Cr-55 Cr-56 Cs-121 Cs-121m Cs-123 Cs-124 Cs-125 Cs-126 Cs-127 Cs-128 Cs-129 Cs-130
Cs-130m Cs-131 Cs-132 Cs-134 Cs-134m Cs-135 Cs-135m Cs-136 Cs-137 Cs-138 Cs-138m Cs-139 Cs-140
Cu-57 Cu-59 Cu-60 Cu-61 Cu-62 Cu-64 Cu-66 Cu-67 Cu-69 Dy-148 Dy-149 Dy-150 Dy-151
Calculating for Cs-137...
Atomic Number of Source Material (Z)
7.42
Add Radionuclide

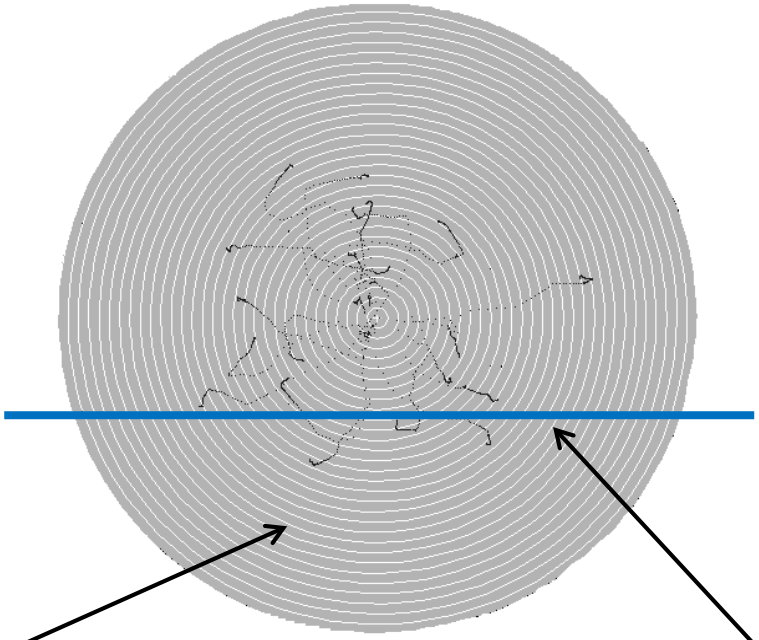
Why do I need the source atomic number?

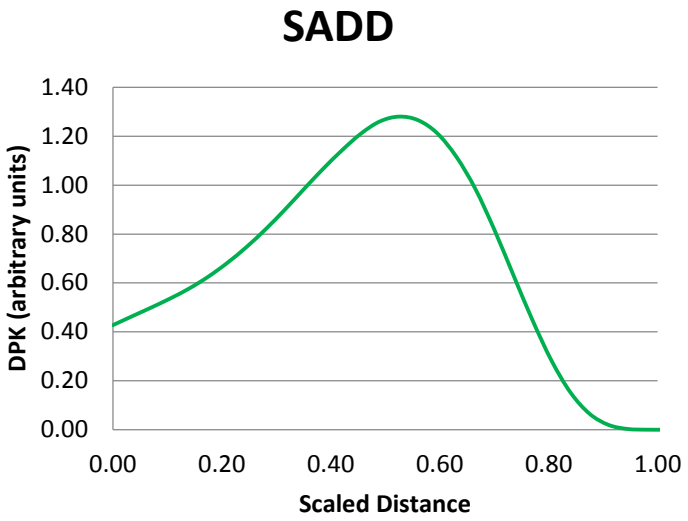
Volumetric Beta Dose vs Source Z



Corrections to Dose-Point Kernel

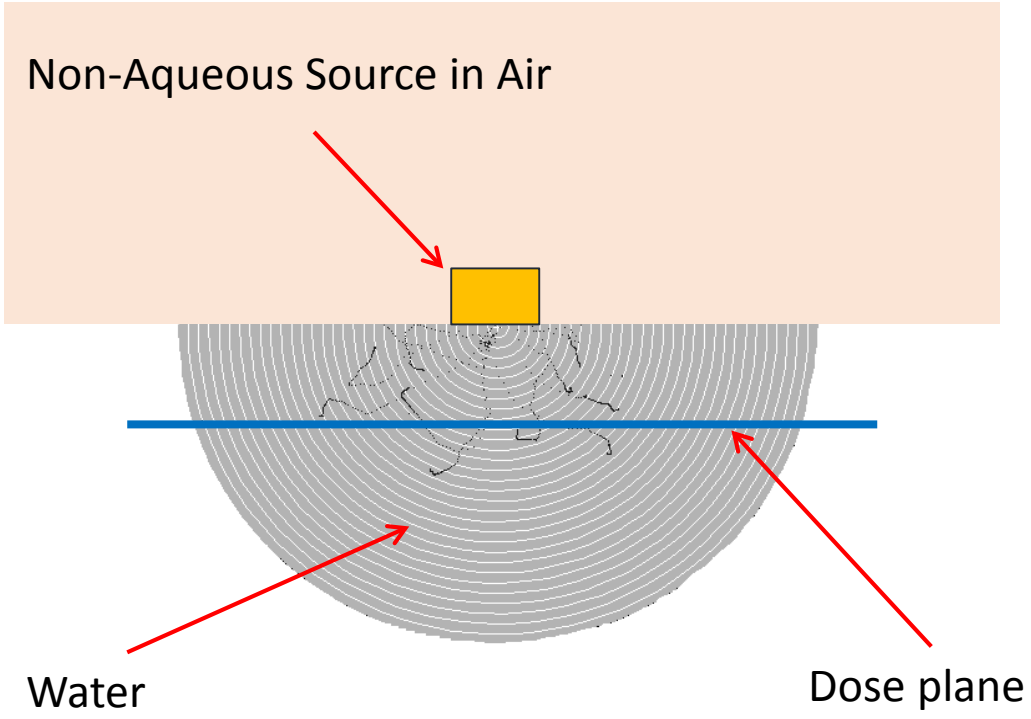
- Spatial distribution of energy absorption from electron emission sources is the basic physical information required for electron dosimetry





Corrections to Dose-Point Kernels

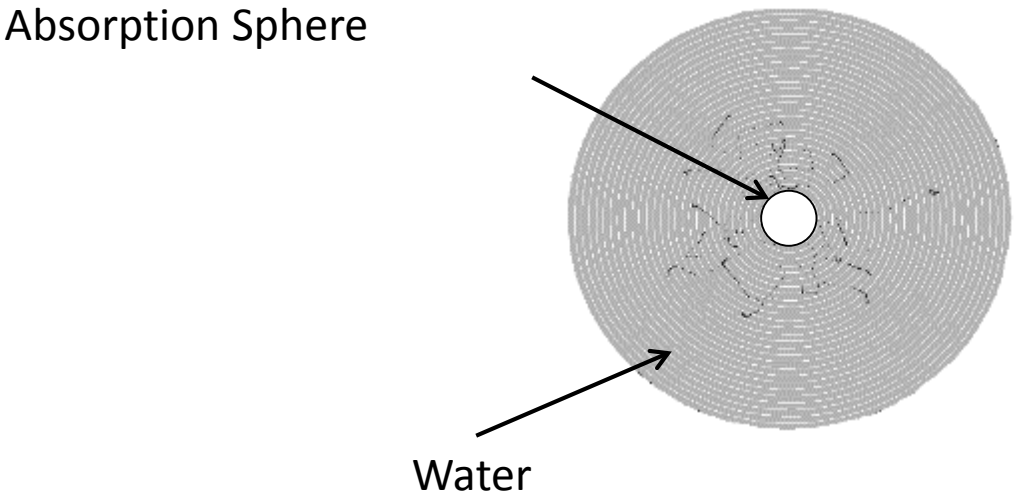
- Develop an electron energy-absorption scaling model for source materials with $7.42 < Z \leq 94$
- Develop a volumetric backscatter model for typical hot particle geometries
  - to predict dose perturbations due to both source and atmospheric backscattering



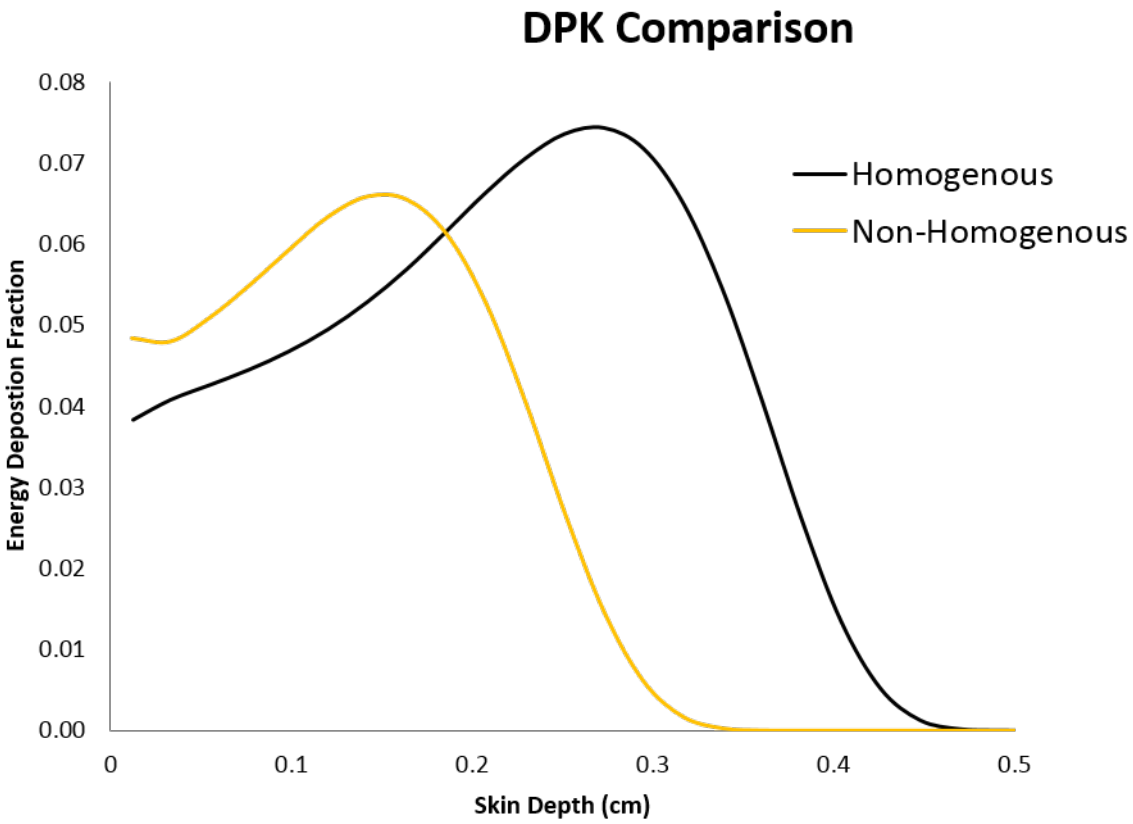
the handling of
kinetic energy loss (SADD)

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

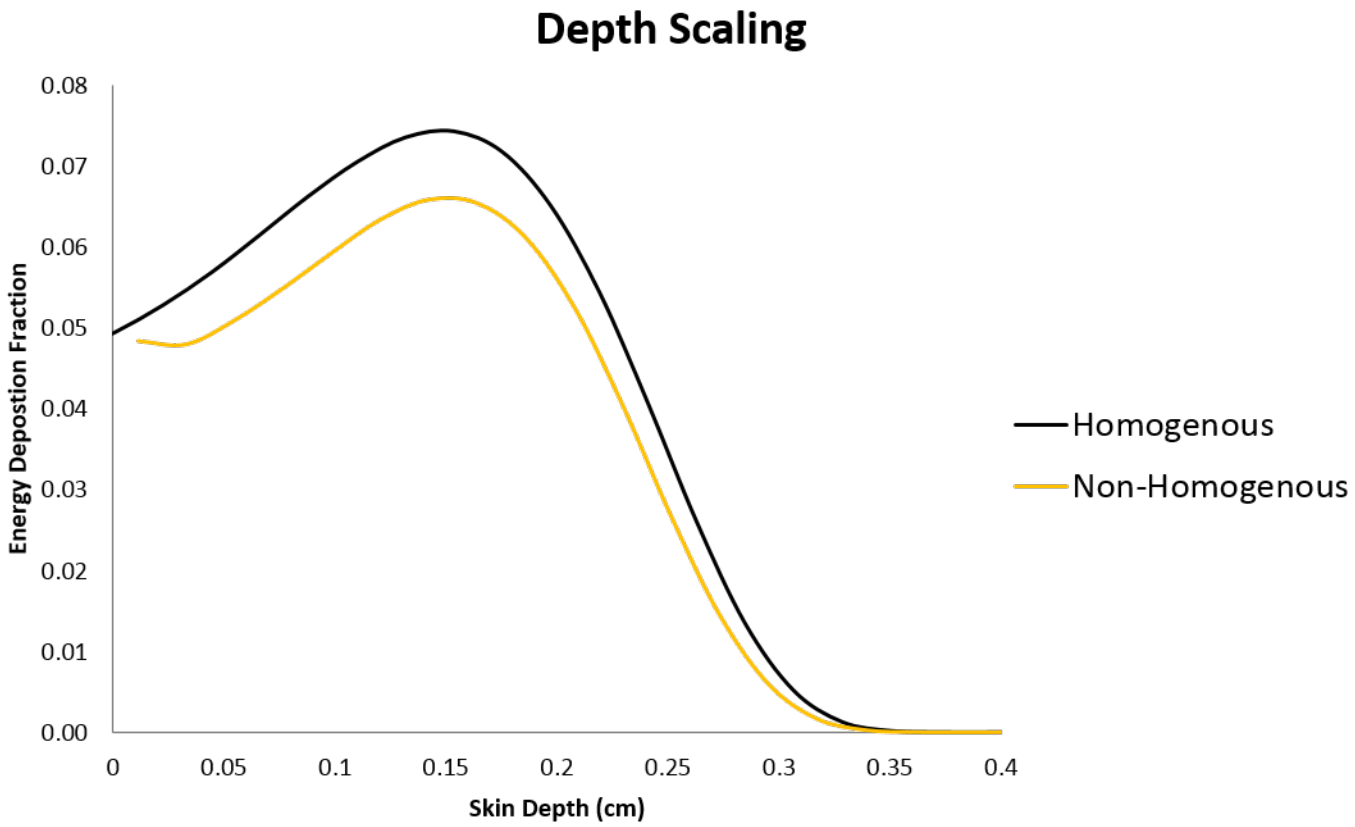


Scaling Model



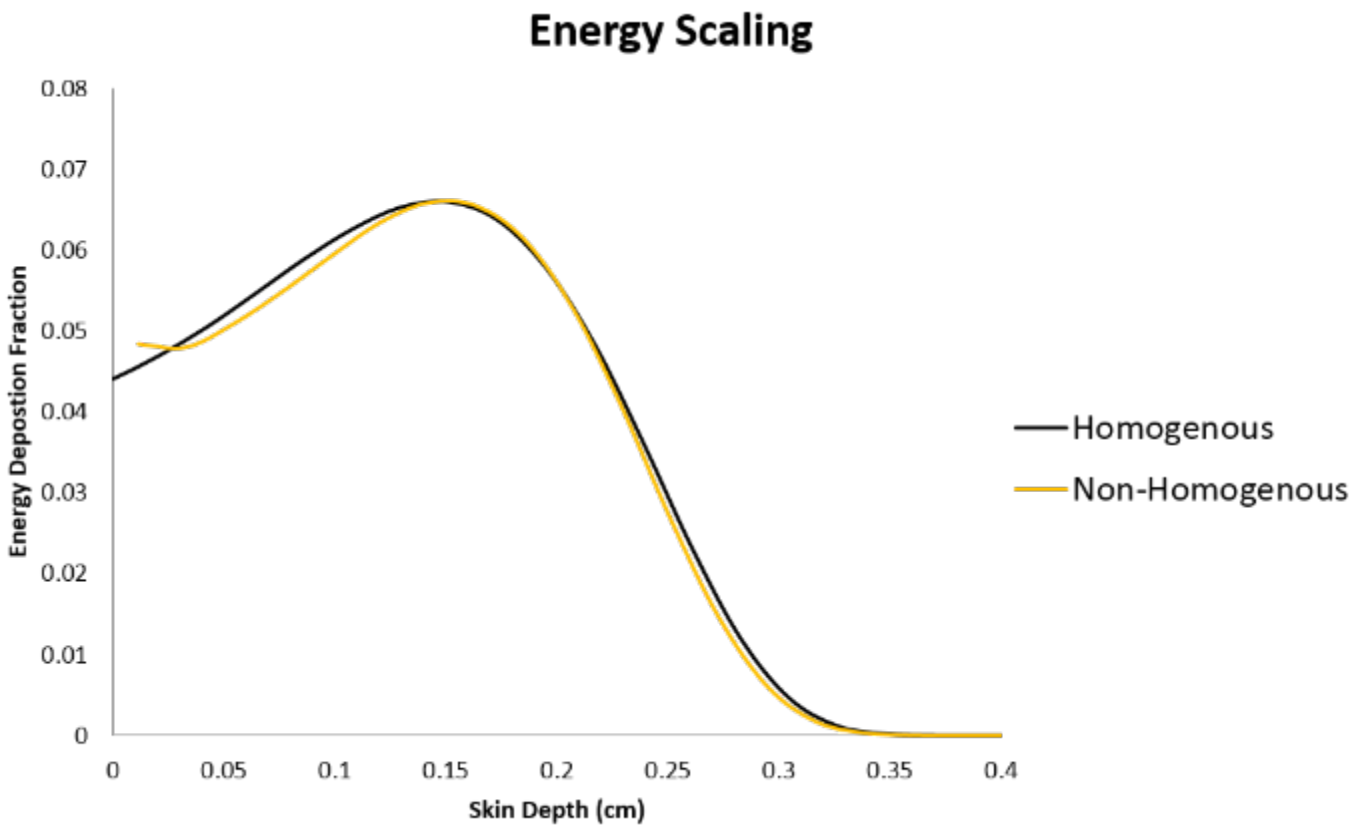
- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

Scaling Model

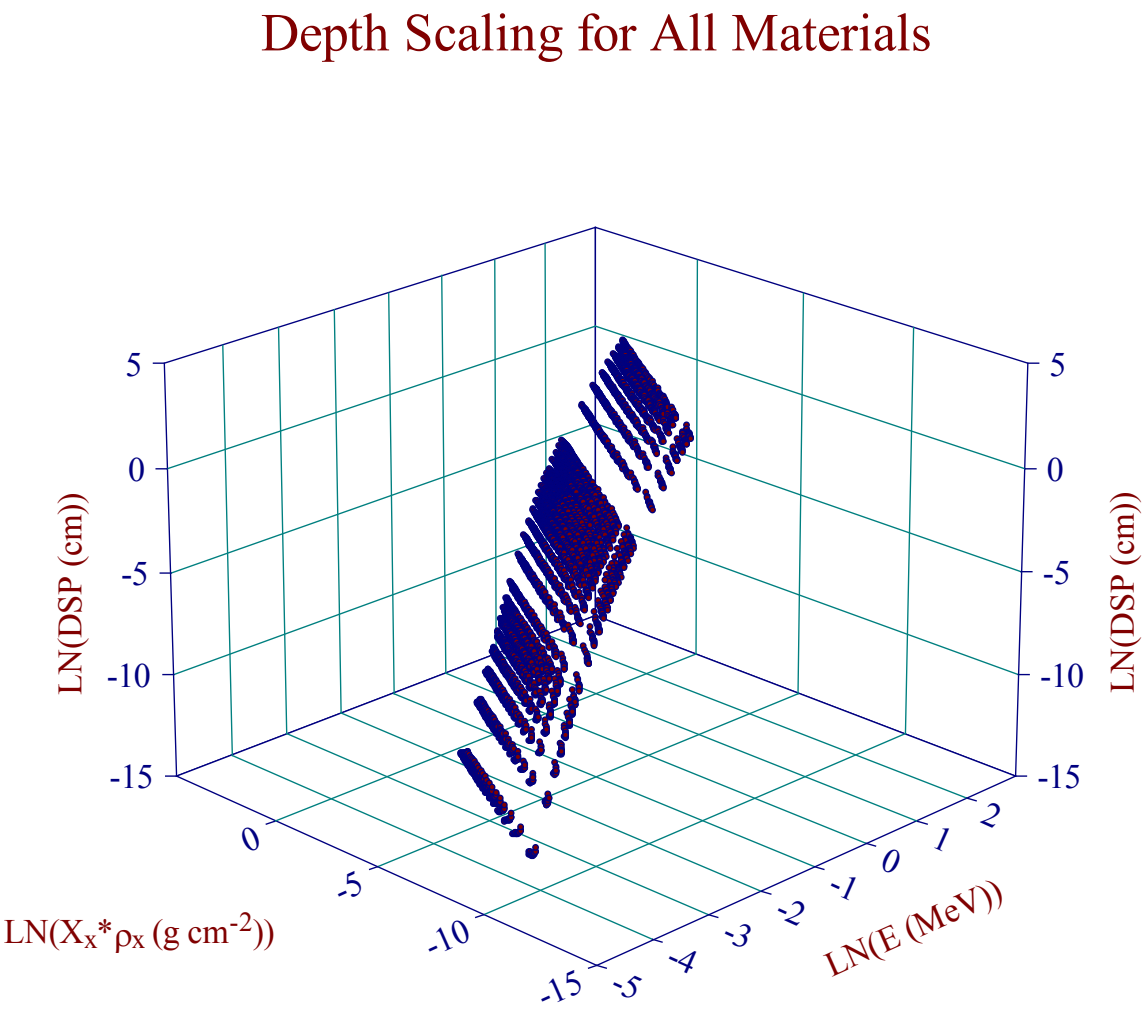


- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

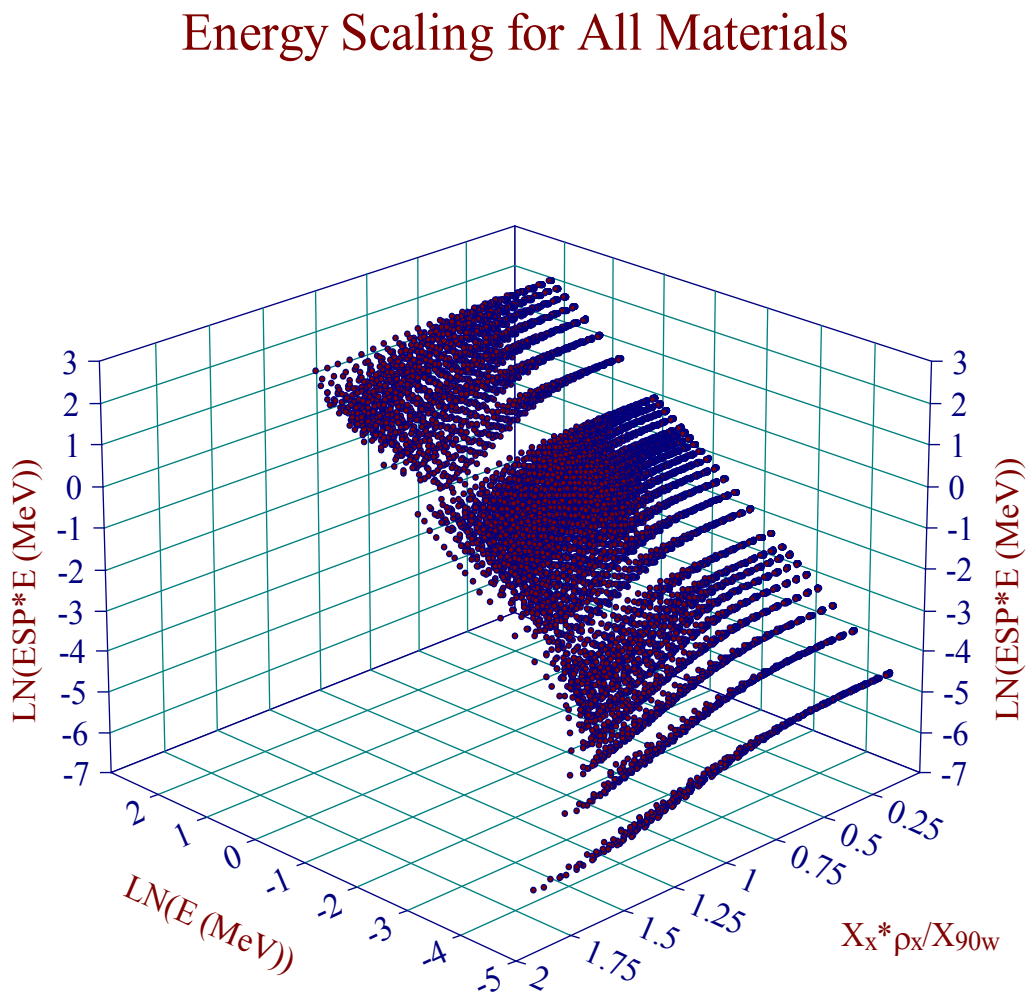
Scaling Model



Scaling Results

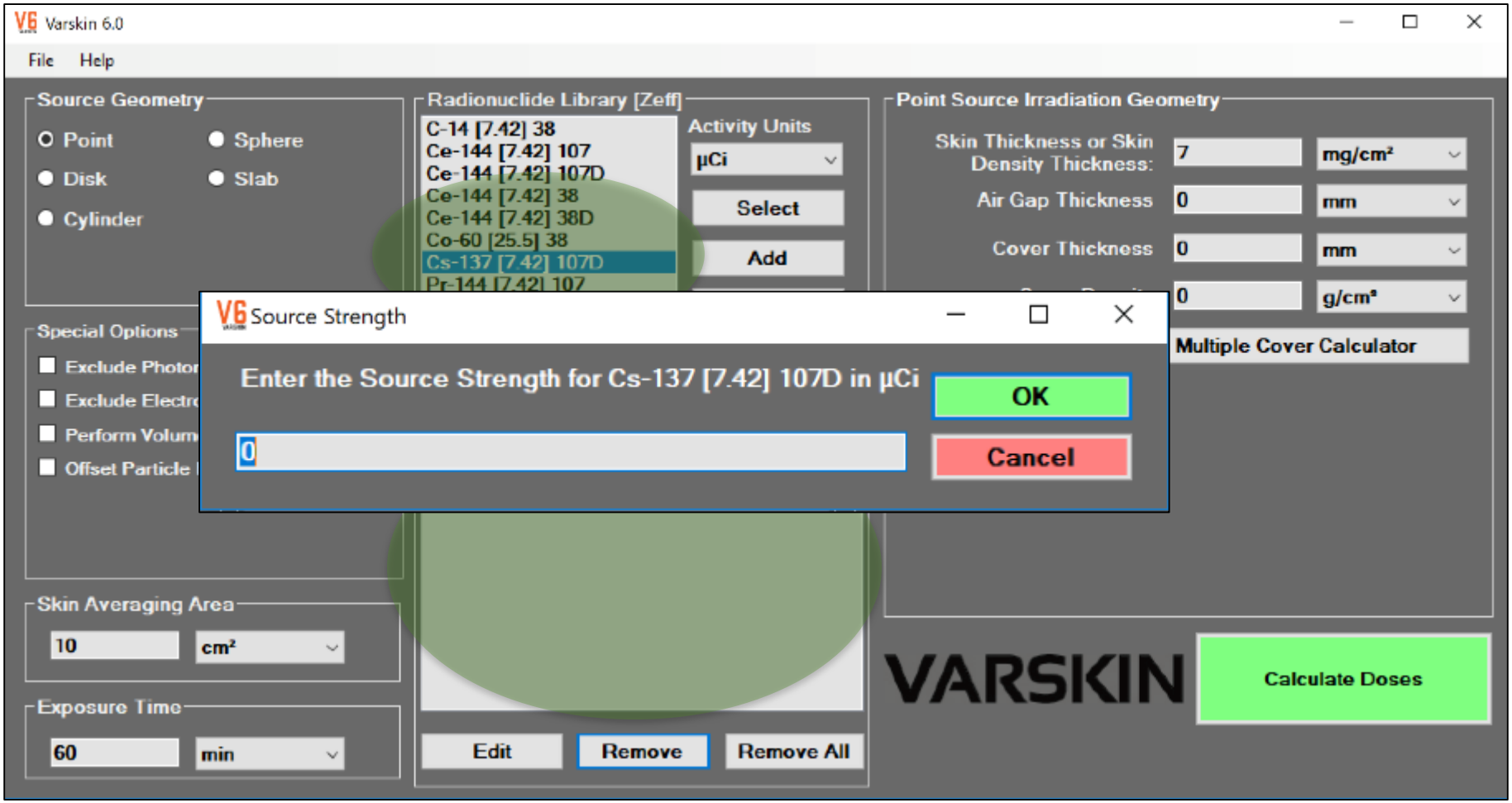


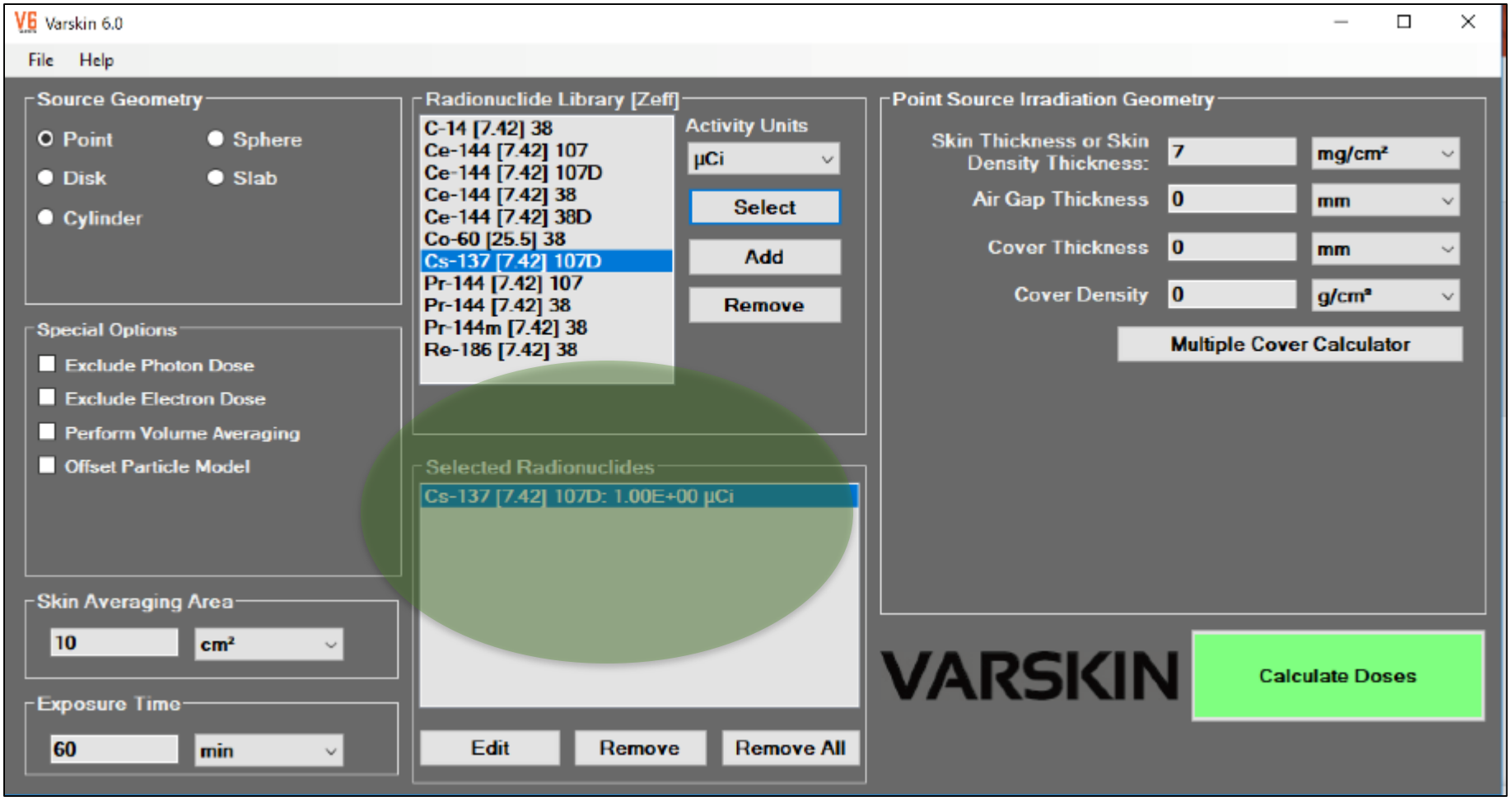
Scaling Results



Radionuclide Library

- Current database taken from ICRP 38
- Contains > 800 radionuclides
- Parent/daughter relationships NOT incorporated
- Emissions include:
  - photons (gamma; X-ray; annihilation)
  - electrons (beta; positron; conversion; Auger)
- Source atomic number (Z) affects electron energy loss prior to skin entry


Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Activity Units
µCi
Select
Add
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
0
g/cm³
Multiple Cover Calculator
Special Options
Exclude Photon
Exclude Electron
Perform Volume
Offset Particle
Source Strength
Enter the Source Strength for Cs-137 [7.42] 107D in µCi
OK
0
Cancel
Skin Averaging Area
10
cm²
Exposure Time
60
min
Edit
Remove
Remove All
VARSKIN
Calculate Doses


Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Skin Averaging Area
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cm²
Exposure Time
60
min
Radionuclide Library [Zeff]
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Ce-144 [7.42] 107D
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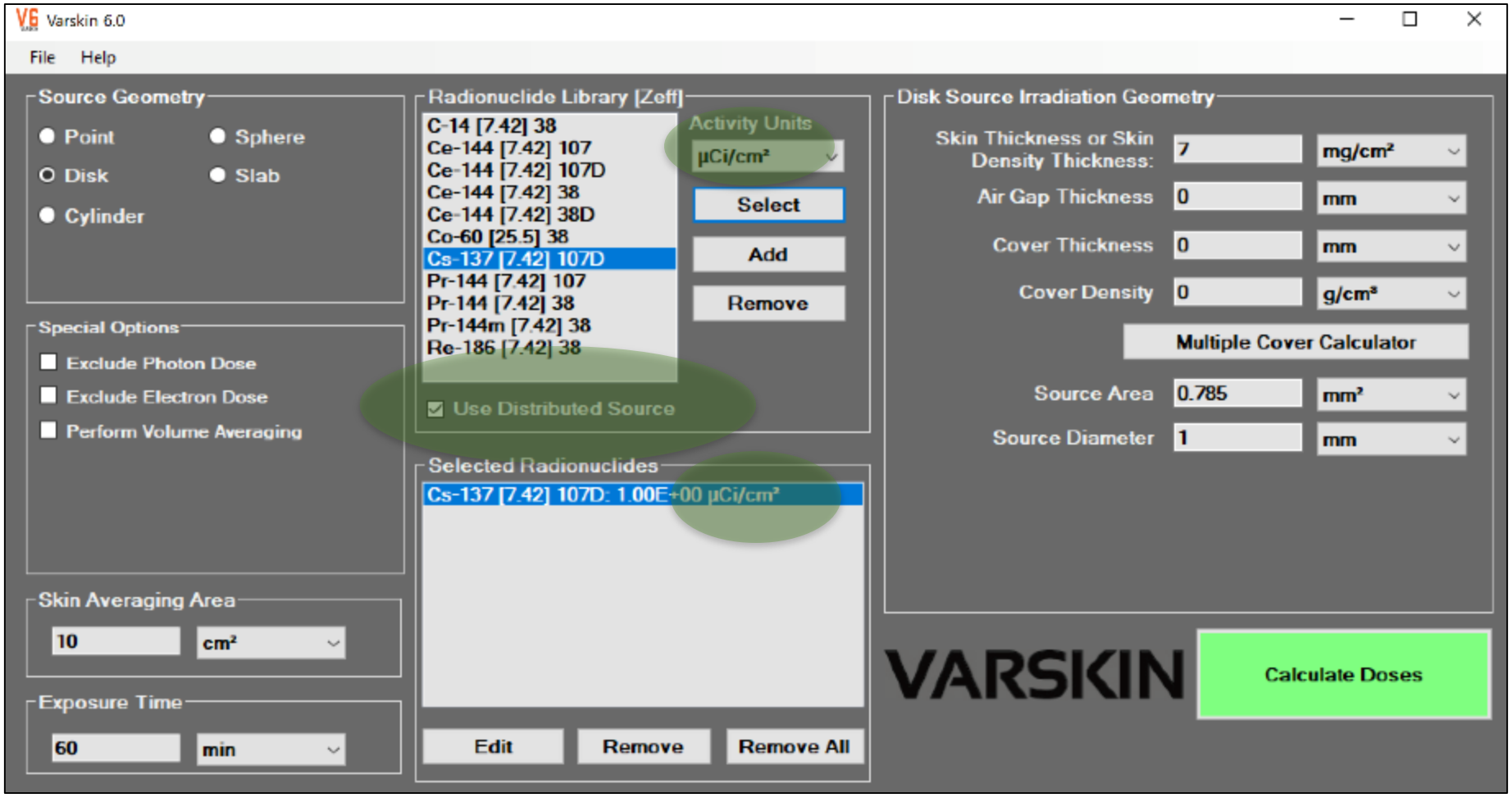
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remove
Selected Radionuclides
Cs-137 [7.42] 107D: 1.00E+00 µCi
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses


Varskin 6.0
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Disk
Slab
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Special Options
Exclude Photon Dose
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Perform Volume Averaging
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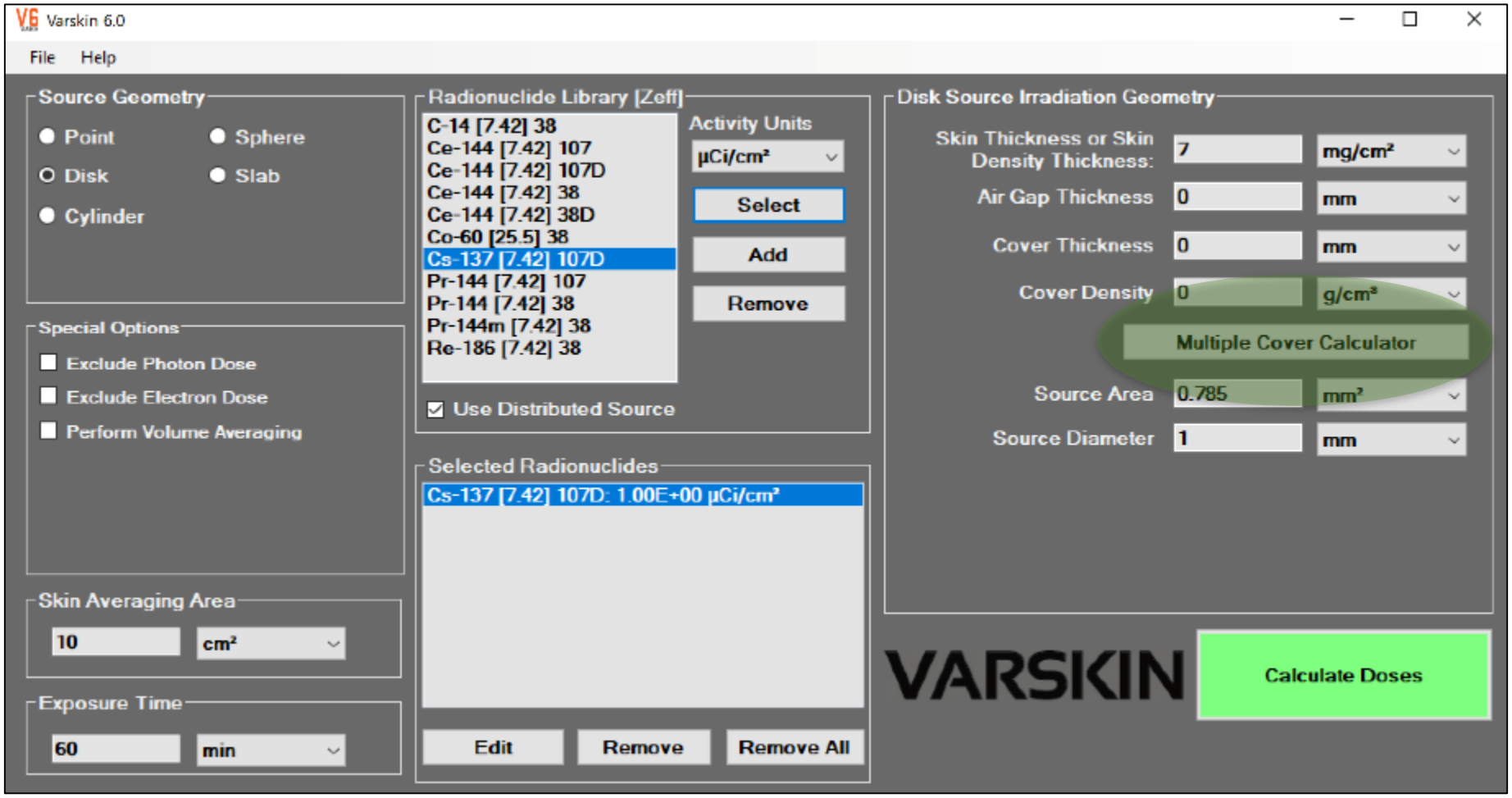
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi/cm²
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Cs-137 [7.42] 107D: 1.00E+00 µCi/cm²
Edit
Remove
Remove All
Disk Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
Source Area
0.785
mm²
Source Diameter
1
mm
VARSKIN
Calculate Doses

Distributed Source

- For all geometries except point
- The selected radionuclide is always distributed throughout the source area or volume
- This option simply gives the user the ability to enter the volumetric equivalent of activity, as opposed to total activity
- On selection:
  - source units change from activity to activity per unit area ($\mu Ci/cm^2$) or volume ($\mu Ci/cm^3$)
  - user must remove and re-select radionuclide(s)


Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Skin Averaging Area
10
cm²
Exposure Time
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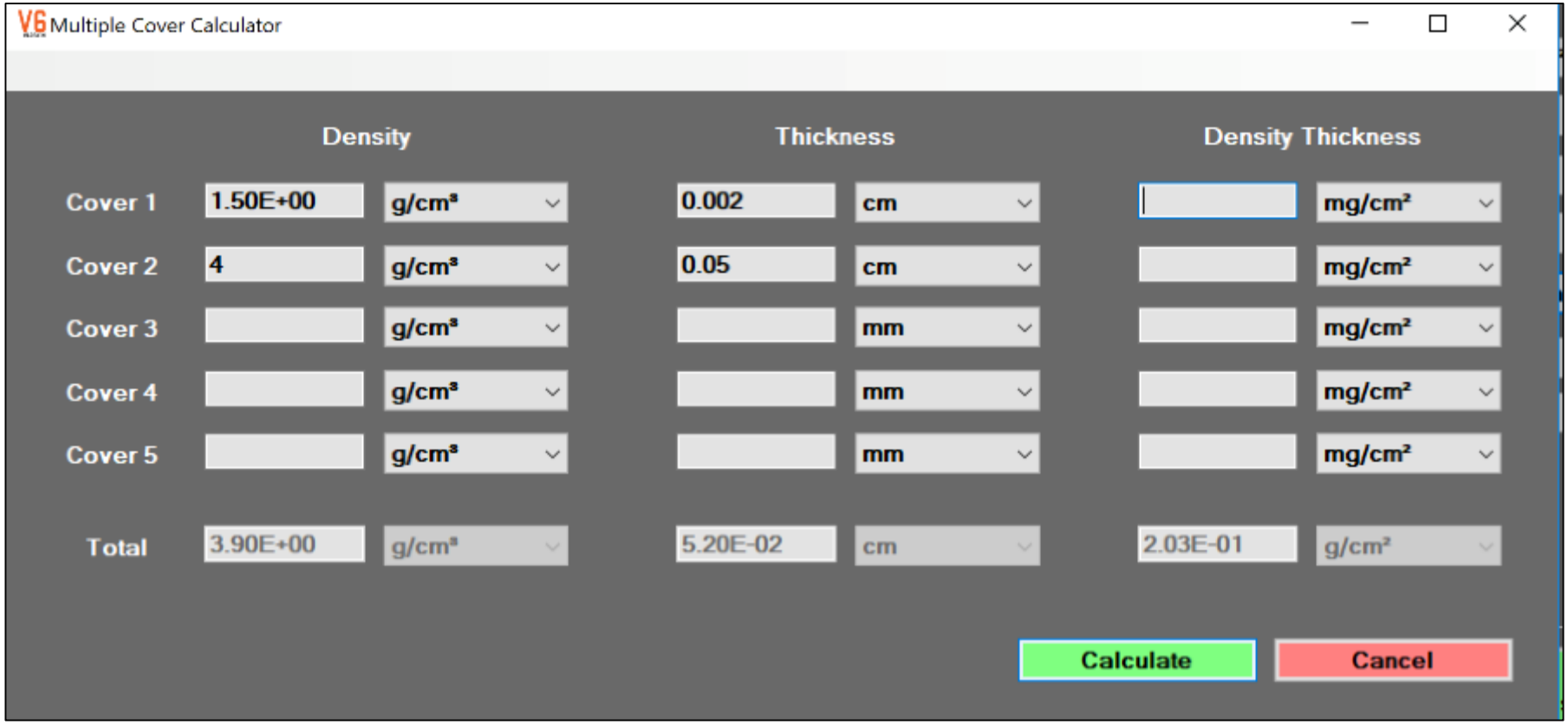
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi/cm²
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Cs-137 [7.42] 107D: 1.00E+00 µCi/cm²
Edit
Remove
Remove All
Disk Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
Source Area
0.785
mm²
Source Diameter
1
mm
VARSKIN
Calculate Doses

Multiple Cover Calculator

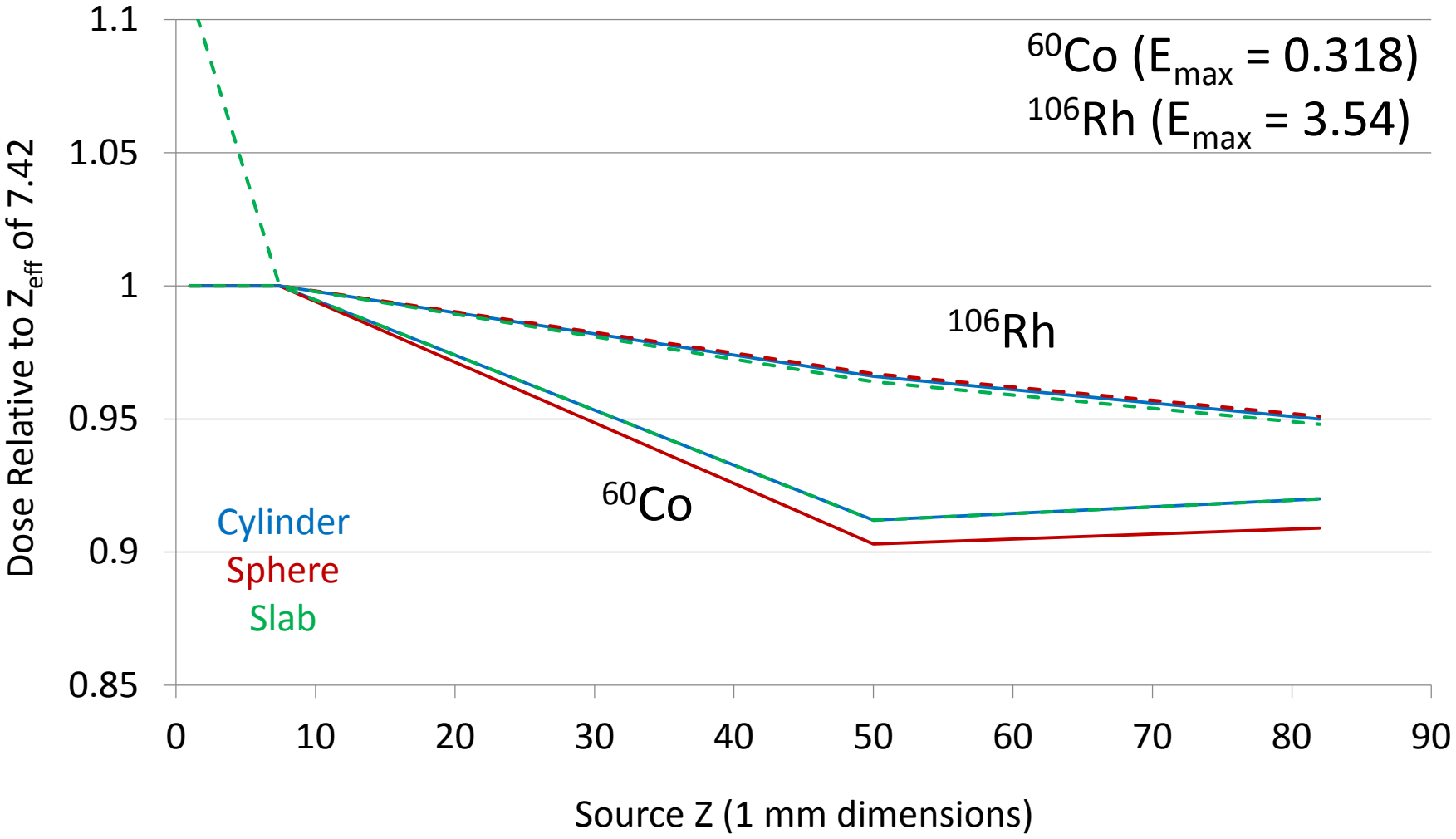
- For each cover material, user enters <u>two</u> of:
  - density (g/cm^3)
  - thickness (mm)
  - density thickness (mg/cm^2)

- Then, total thickness and effective density are used as inputs describing the total cover:

$$\rho_{eff}\ \left(\frac{g}{cm^3}\right) = \frac{\sum \rho x\ \left(\frac{g}{cm^2}\right)}{\sum x\ (cm)}$$


Multiple Cover Calculator
Density
Thickness
Density Thickness
Cover 1
1.50E+00
g/cm³
0.002
cm
mg/cm²
Cover 2
4
g/cm³
0.05
cm
mg/cm²
Cover 3
g/cm³
mm
mg/cm²
Cover 4
g/cm³
mm
mg/cm²
Cover 5
g/cm³
mm
mg/cm²
Total
3.90E+00
g/cm³
5.20E-02
cm
2.03E-01
g/cm²
Calculate
Cancel

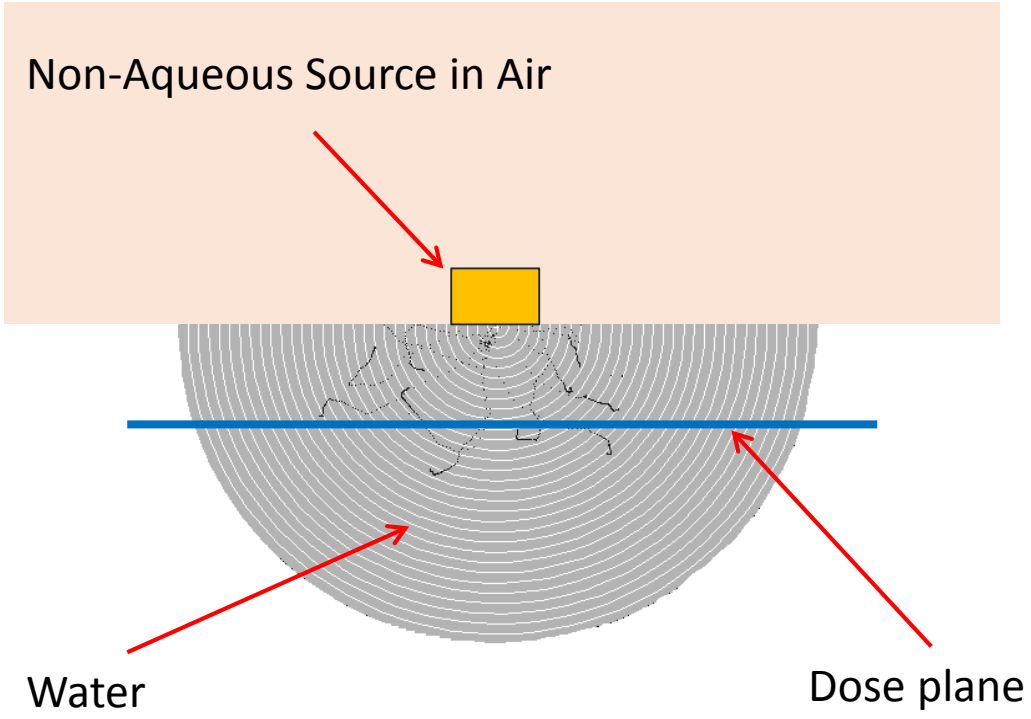
Volumetric Beta Dose vs Source Z



Why would dose increase as Z increases >50?

Corrections to Dose-Point Kernels

- Develop an electron energy-absorption scaling model for source materials with $7.42 < Z \leq 94$
- Develop a volumetric backscatter model for typical hot particle geometries
  - to predict dose perturbations due to both source and atmospheric backscattering

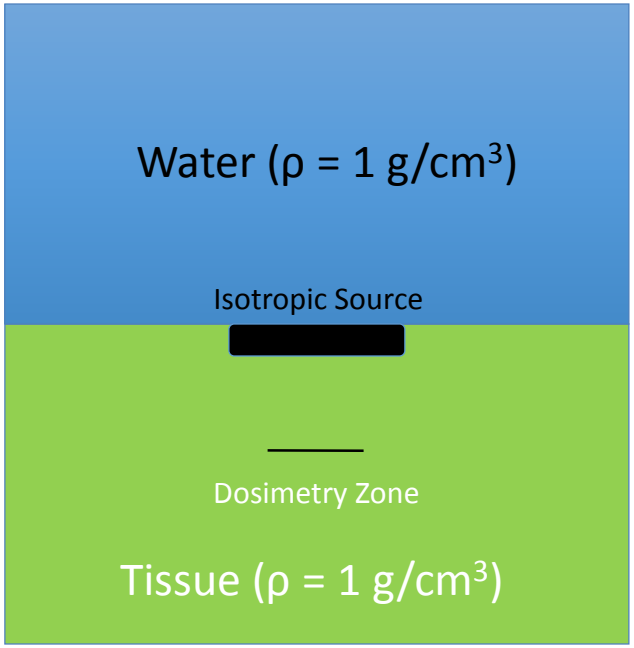


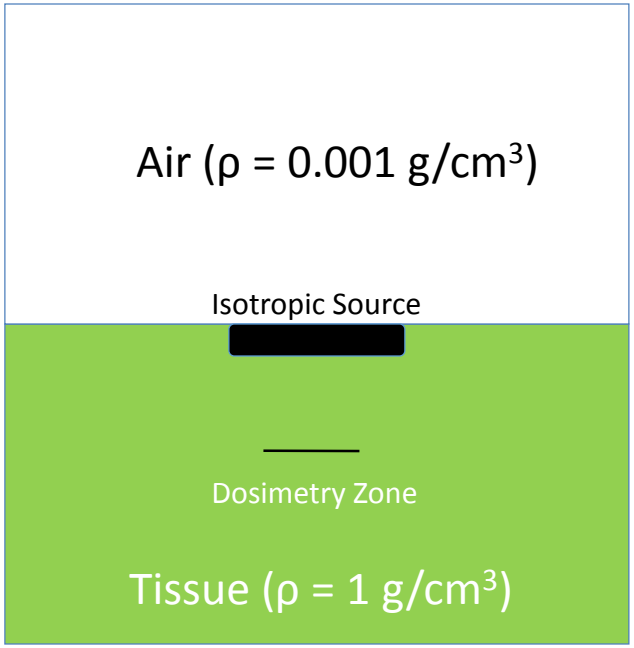
backscatter correction

Backscatter Correction

- Cross (1991b, 1992c) developed atmospheric point-source factors
- Source material point-source factors for medical physics by Buffa (2004), Cho (1999), and Lee (2004)
- Durham (2006) developed backscatter factors for volumetric sources with dimensions < beta-particle range
  - accounts only for atmospheric scattering above the source

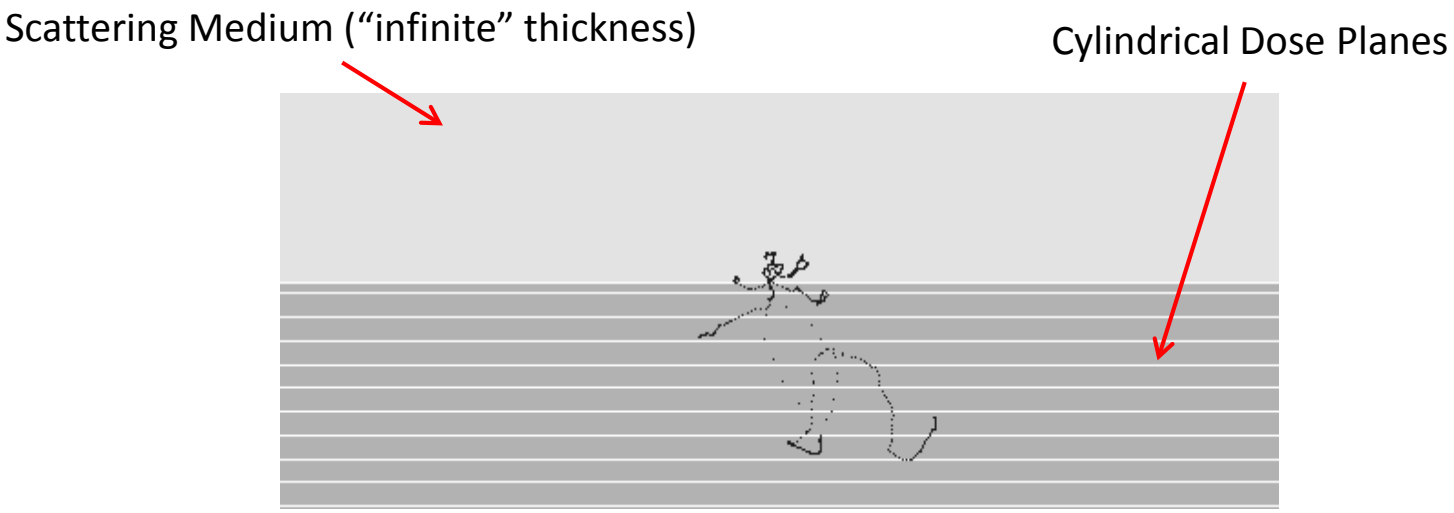
Original Backscatter Determination



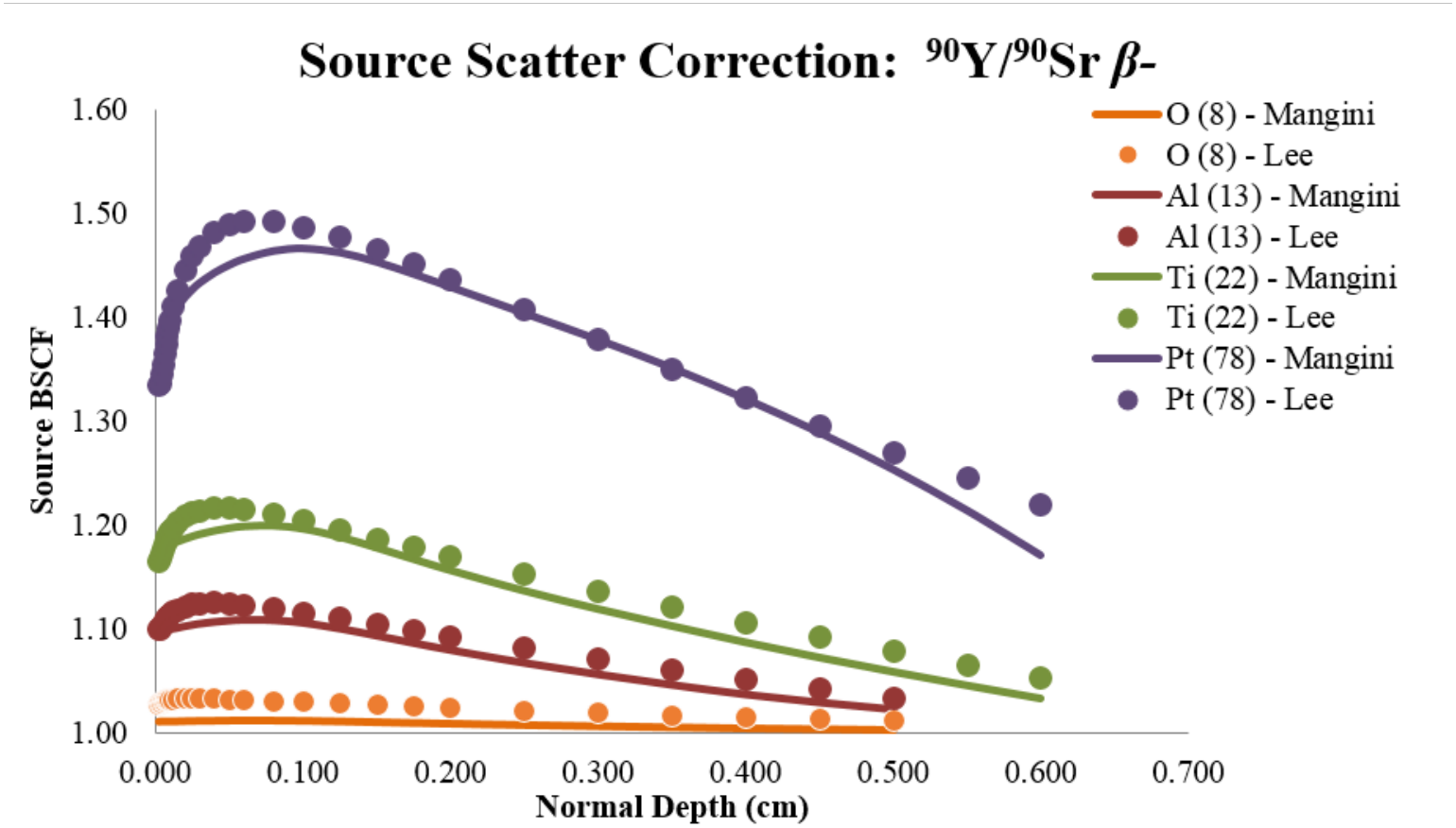


New Backscatter Model

- 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})

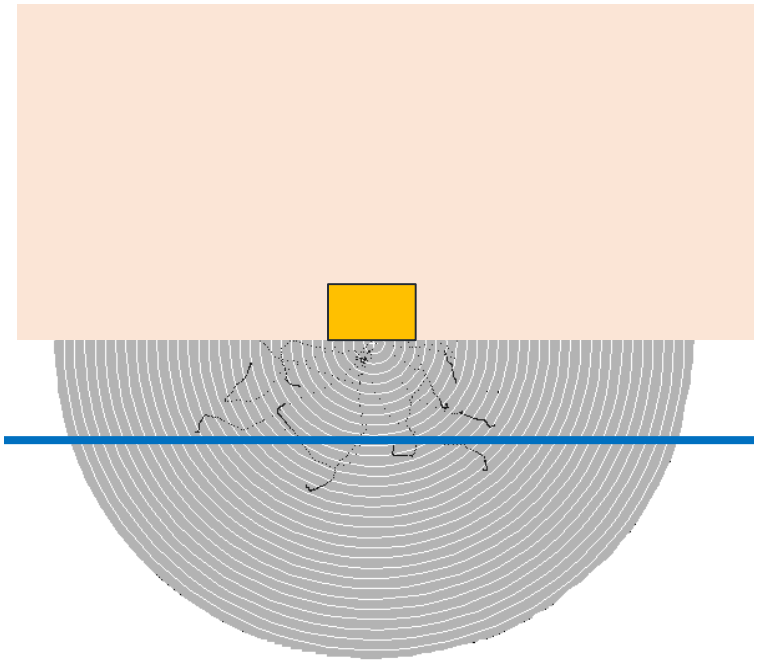


Point-Source BSCF

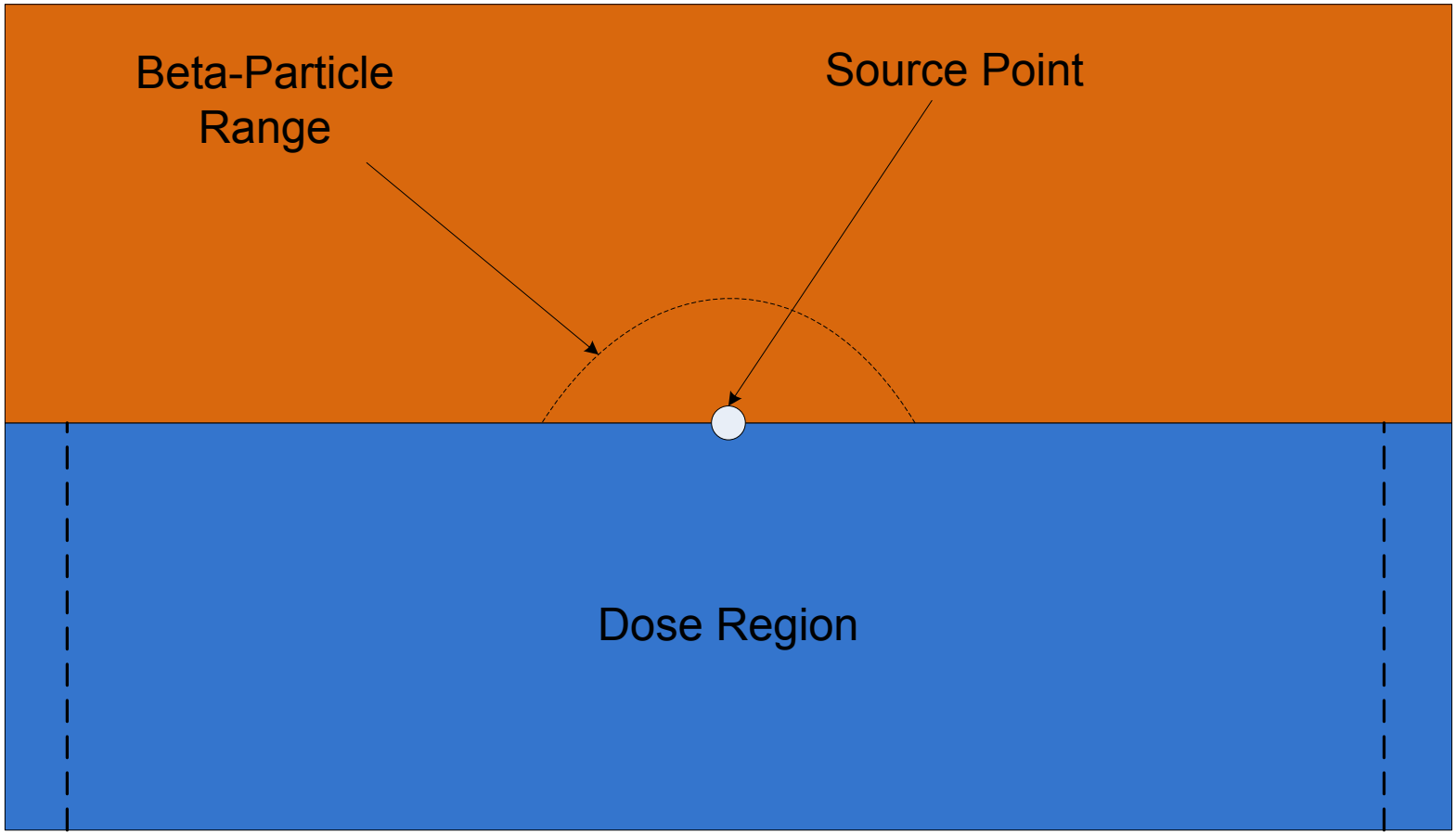


Scatter Scenarios

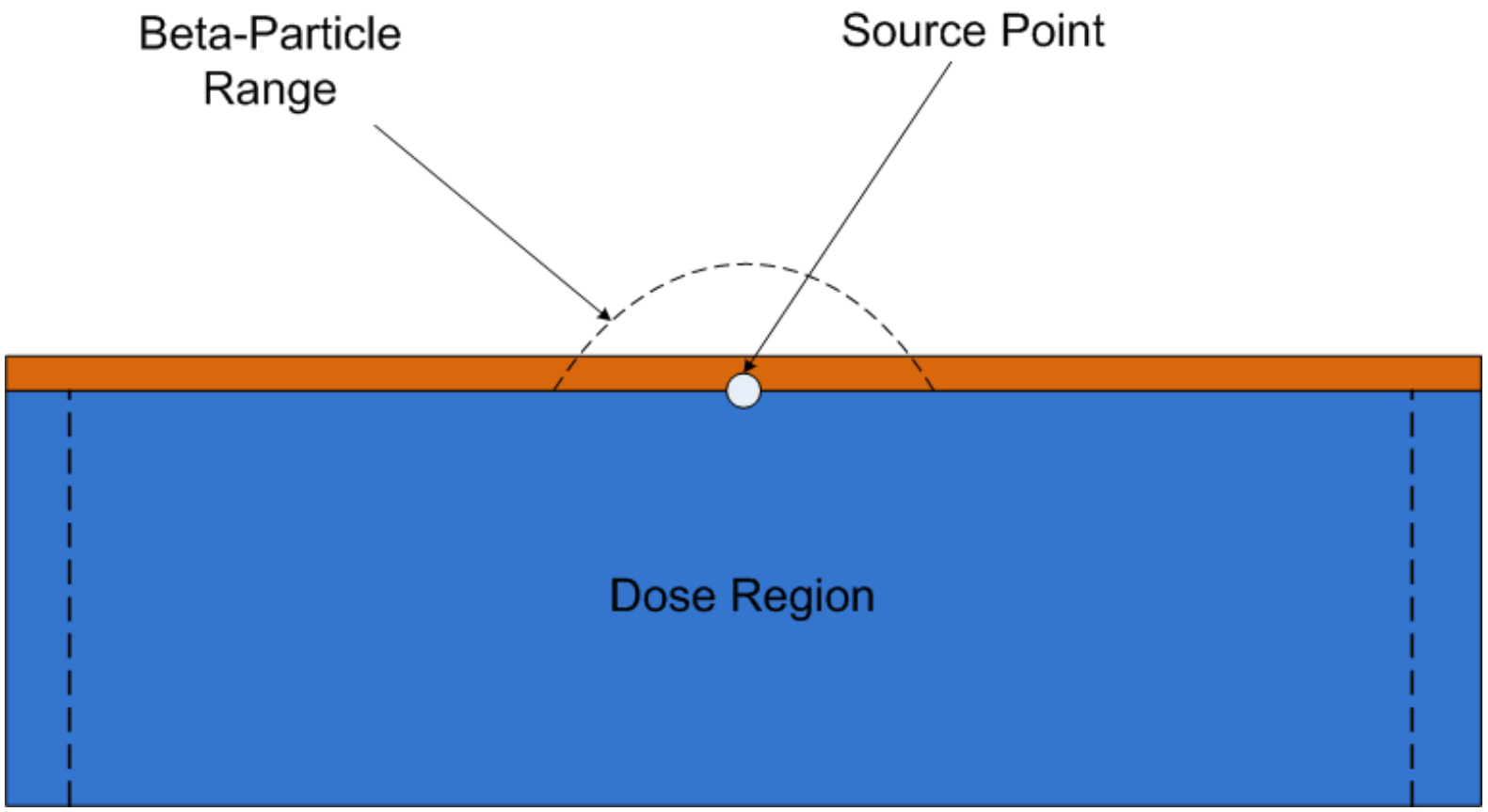
- Source scatter for top/bottom of source
- Source scatter for sides of source
- Air scatter for top/sides of source



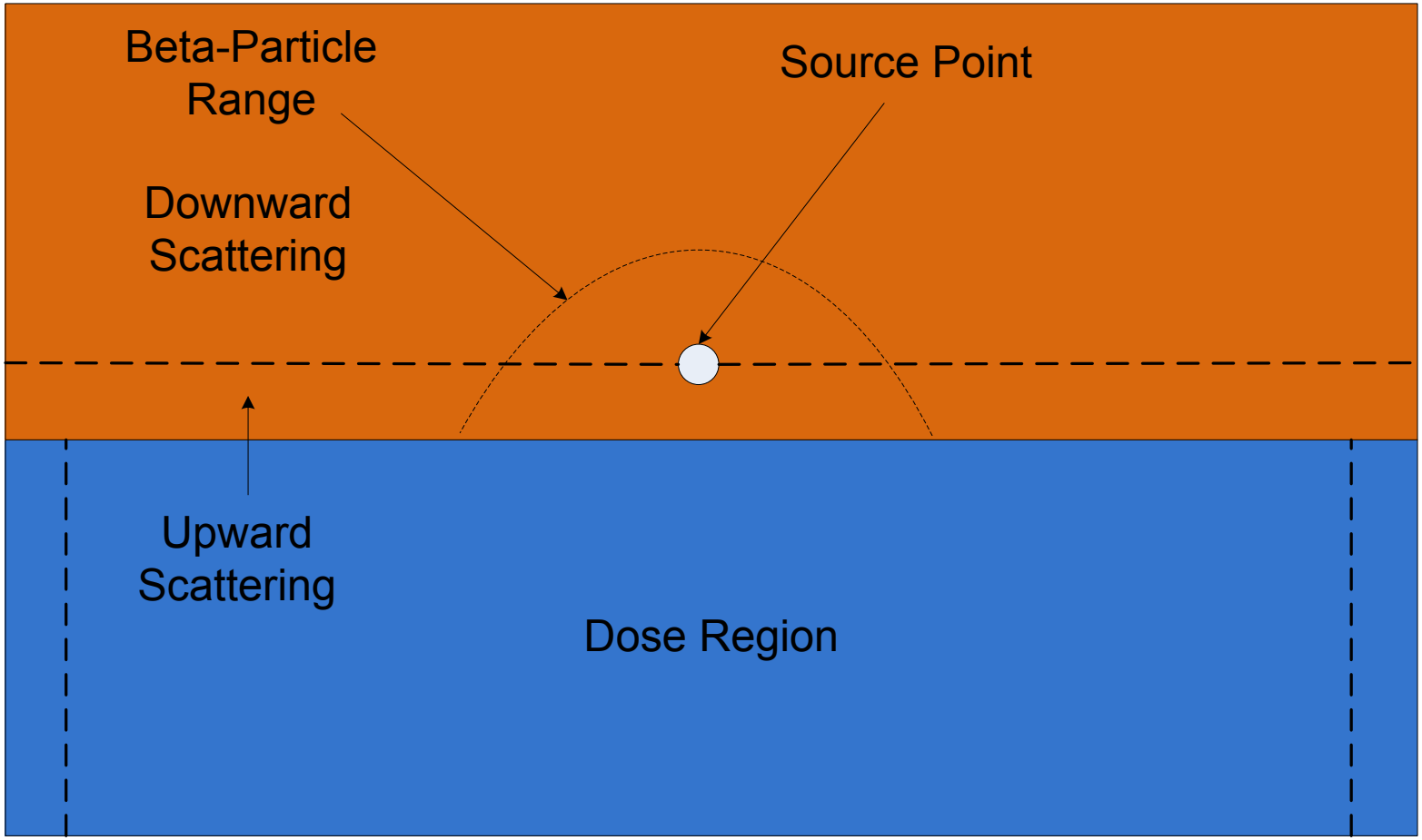
Scatter for Top/Bottom of Source



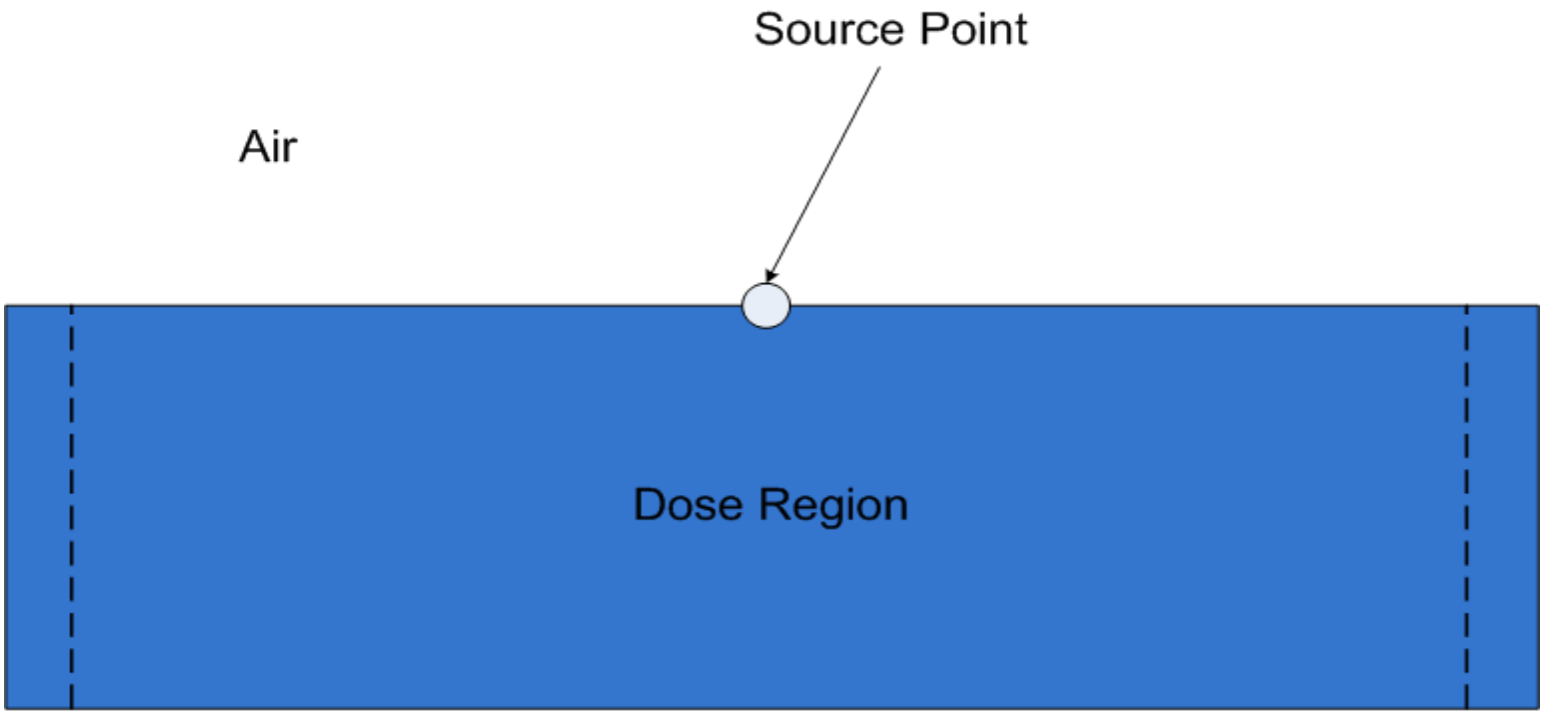
Scatter for Top/Bottom of Source



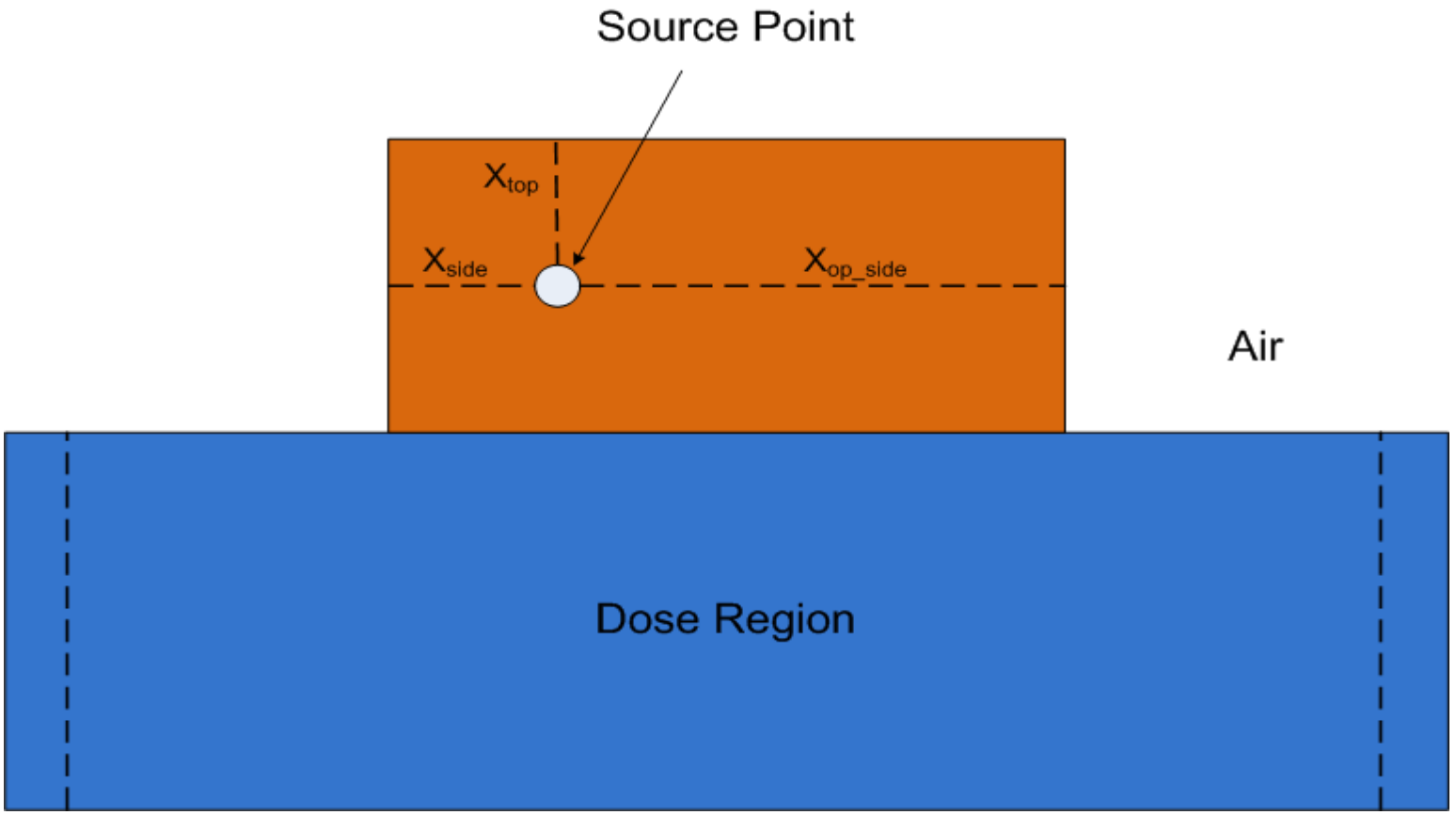
Scatter for Top/Bottom of Source



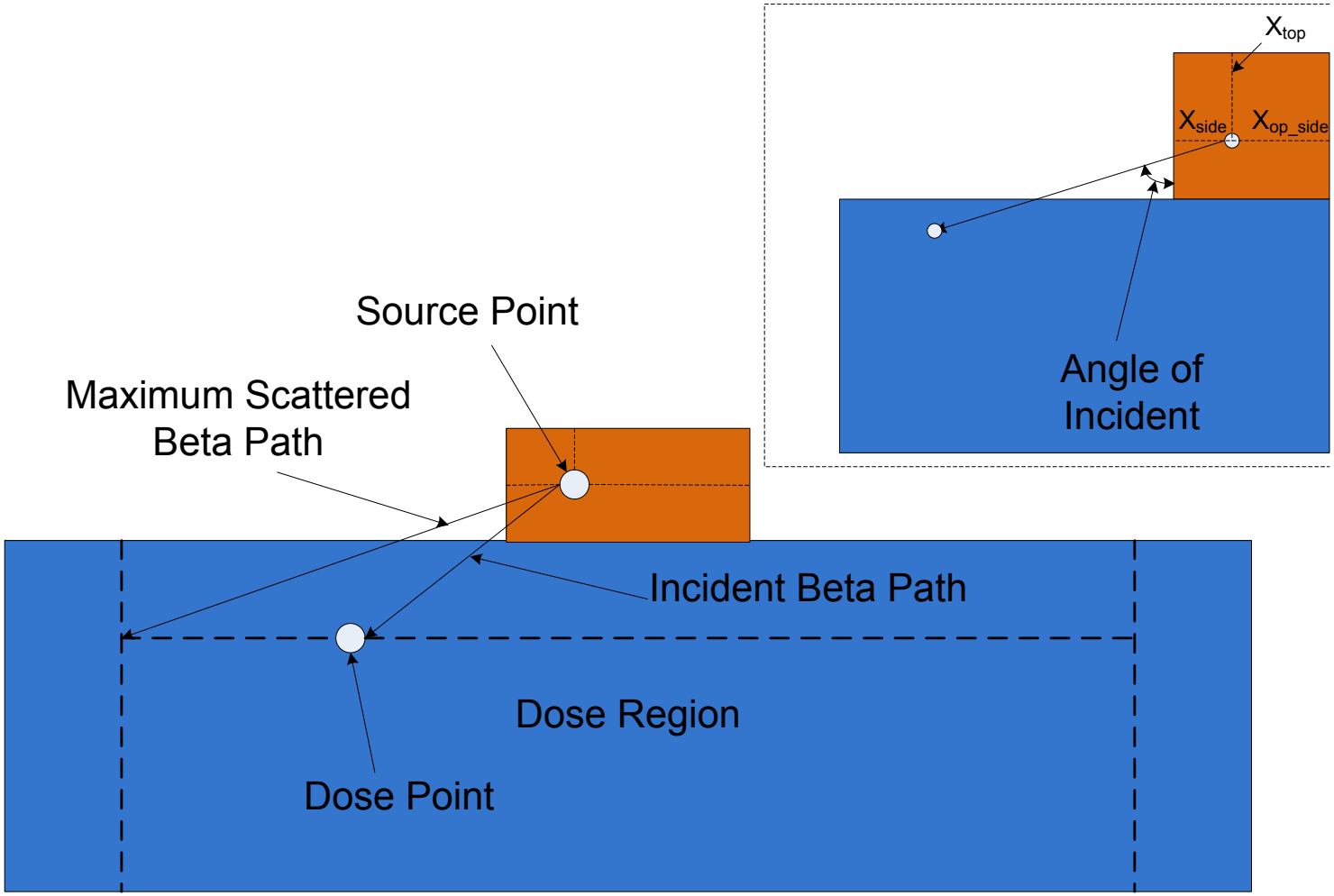
Air Scatter for Top/Sides of Source



Air Scatter for Top/Sides of Source



Scatter for Sides of Source



Selective Integration

- Source Scatter for Top/Bottom of Source

$$Source\ BSCF_{top/bottom} = SW(SE_{top} - SE_{bottom})$$

- Source Scatter for Sides of Source

$$Source\ BSCF_{side} = SA\frac{X_{top}}{0.5}(X_{op\_side} - X_{side})$$

SW = source/water scatter correction for point sources

SE = scattering effectiveness (i.e., finite backscatter factor)

SA = source/air scatter correction for point sources

AW = air/water scatter correction for point sources

X = distance dimension

Selective Integration

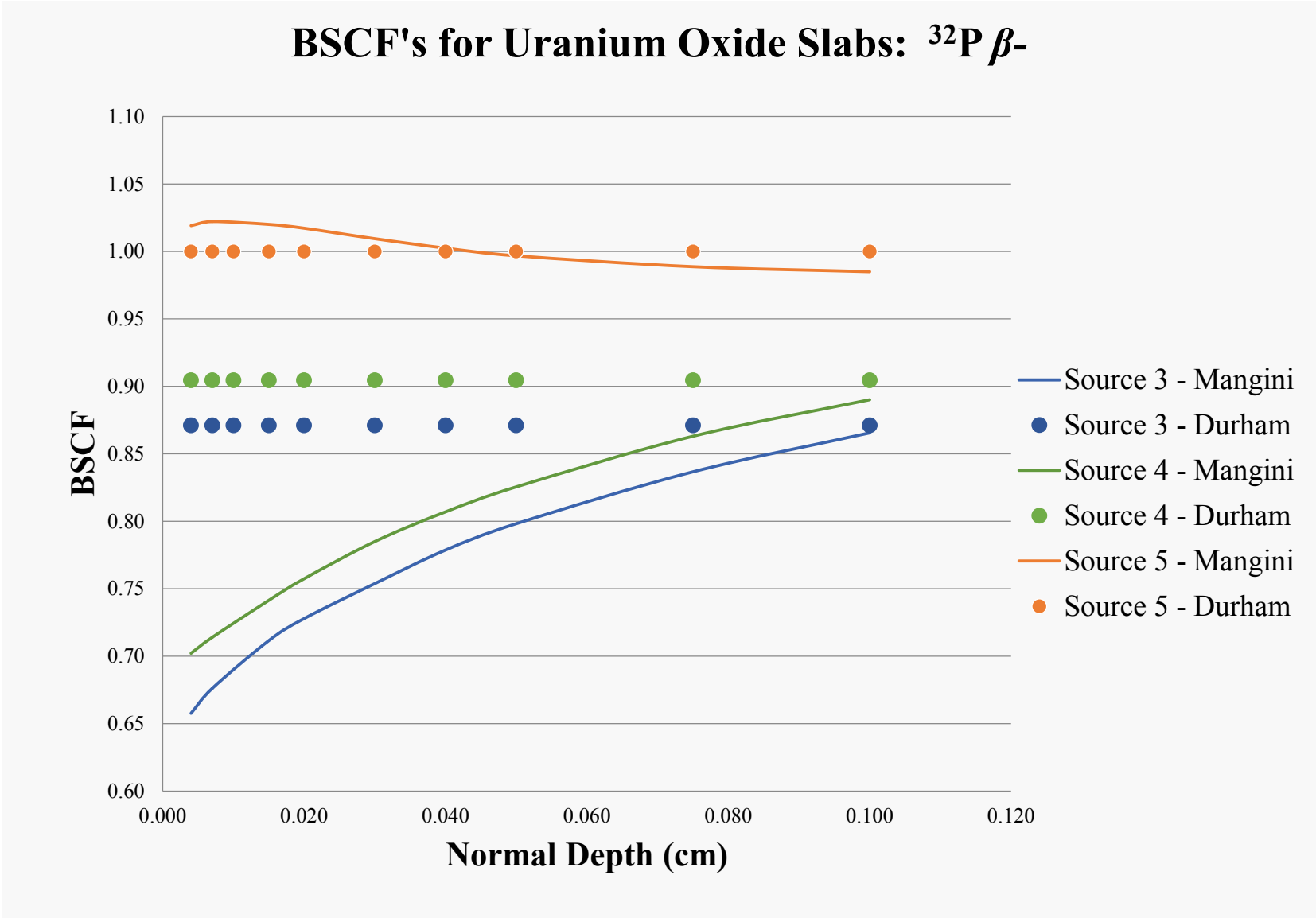
- Air Scatter for Top/Sides of Source

$$Air\ BSCF_{top} = AW\ \frac{1.8 - X_{top}}{1.8} 0.5$$

$$Air\ BSCF_{side} = AW\ \frac{1.8 - X_{side}}{1.8} 0.25$$

$$Air\ BSCF_{op\_side} = AW\ \frac{1.8 - X_{op\_side}}{1.8} 0.25$$

Volumetric BSCF



One other important improvement…

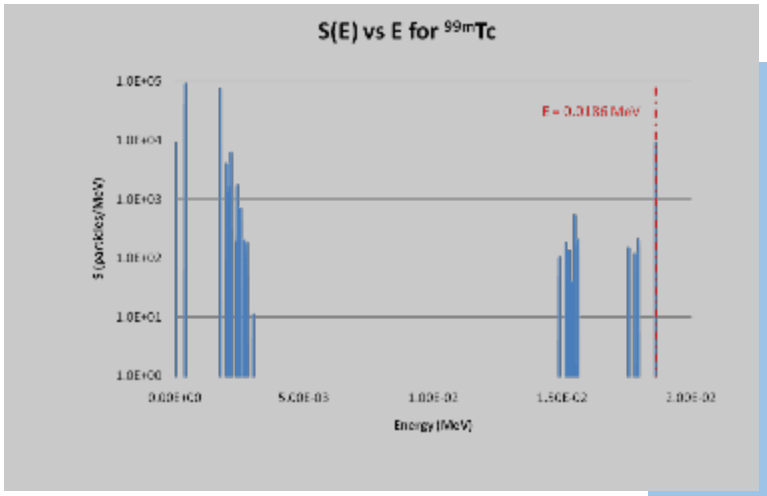
Electron Energy Distribution

- Nuclides were first processed in SADCALC.f
  - calculation of the SADD when adding a radionuclide to the User library
  - electron emission data imported from ICRP38.BET
- For beta emitters:
  - an energy distribution, S(E), was developed by interpolating 1500 points from 0.0 to E_{max}
  - average energy of S(E) calculated
  - conversion/Auger electrons added to *S(E)*
    - but, if $S(E)_e > S(E_{max})$ then $S(E)_e$ was added to $S(E_{max})$
- For non-beta emitters:
  - electron yields were added to a "dummy" ^{3}H spectrum with a yield of 0.1%, with E_{max} = 0.0186 MeV
- This resulted in errors depending on max electron energy

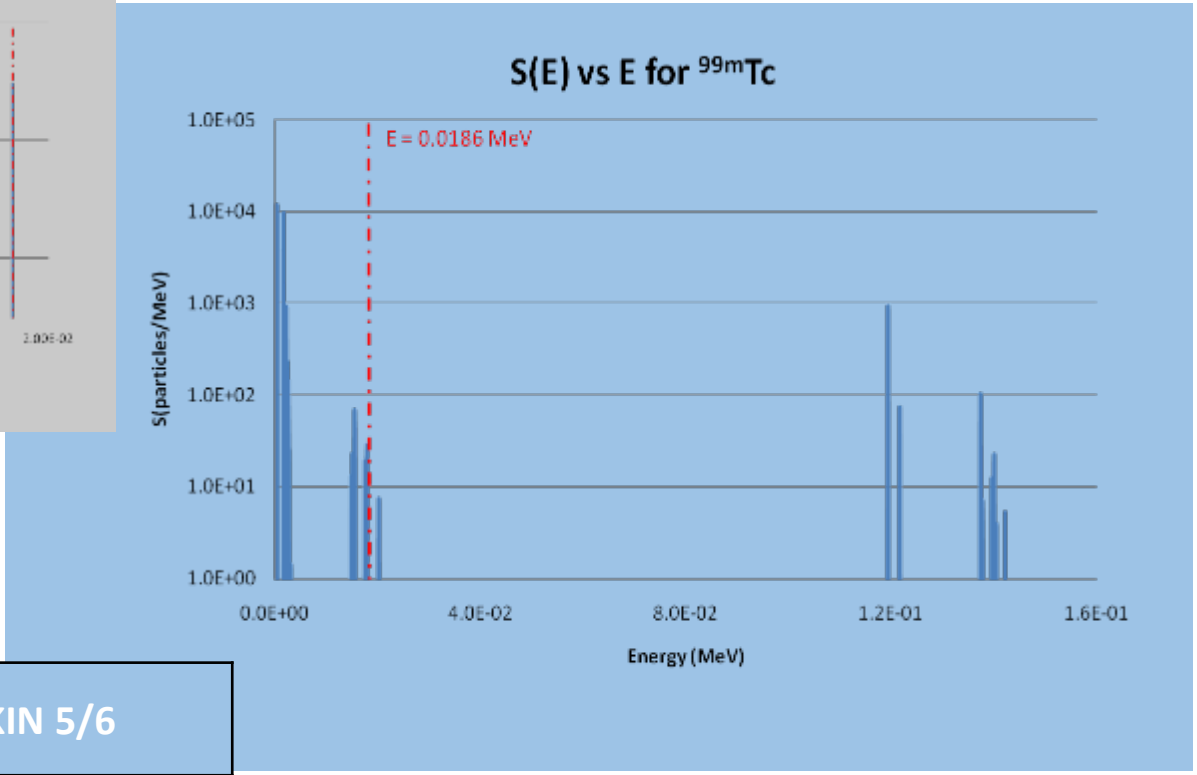
Electron Energy Distribution

- The new SADCALC routine constructs S(E) from the original beta emission spectrum
- … and, includes conversion electrons and Auger electrons at their proper energy
- Results in a more appropriate average electron energy incident on the skin

ELECTRON ENERGY – V3/4 vs V5/6



^{99m}Tc as the example



VARSKIN 3/4		VARSKIN 5/6	
X_{90} (mm)	E_{avg} (keV)	X_{90} (mm)	E_{avg} (keV)
0.0055	1.99	0.15	6.67

VARSKIN 5/6 Electron Model

- Integrated dose point-kernel over source and dose volumes
- Improved handling of electron energy distribution
- Modified energy loss (SADD) functions, (F_β)
  - relative to the X_{90} range
- New backscatter characteristics (BSCF)

$$\dot{D}_\beta \left[\frac{Gy}{sec}\right] = \frac{A\left[{}^{dis}/_{sec}\right] \cdot Y\bar{E}\left[{}^{J}/_{dis}\right] \cdot F_\beta}{4\pi\rho\left[{}^{kg}/_{cm^3}\right] \cdot x^2[cm^2] \cdot X_{90}[cm] \cdot BSCF}$$

Comparison with literature

- “Beta and Electron Dose Calculations to Skin Due to Contamination by Common Nuclear Medicine Radionuclides.”
  - McGuire and Dalrymple, *Health Physics,* 1990
- “Electron dose-rate conversion factors for external exposure of the skin from uniformly deposited activity on the body surface.”
  - Kocher, D. C.; Eckerman, K. F., *Health Physics,* 1987
- ^{99m}Tc, ^{51}Cr, ^{57}Co, ^{67}Ga, ^{111}In, ^{123}I, ^{131}I, and ^{201}Tl
- 1 μCi cm^{-2} source uniform contamination, averaged over a 1 cm^2
- 0.004 cm to 0.010 cm skin depths

Depth dose comparisons

	Depth in Tissue, cm											
	0.004				0.005				0.007			
Nuclide	V5/6	V4	M	K	V5/6	V4	M	K	V5/6	V4	M	K
Co-57(EC)					0.32	0.00	0.36	0.32	0.27	0.00	0.29	0.29
Ga-67(EC)	2.97	0.00	3.34	3.21					1.14	0.00	1.19	1.09
Tc-99m(γ)	0.99	0.00	1.25	1.22	0.92	0.00	1.12	1.14	0.78	0.00	0.90	0.89
In-111(EC)									1.10	0.00	1.36	1.39
I-123(EC)									1.13	0.00	1.33	1.35
I-131(β)									4.87	5.10	6.30	6.33
Tl-201(EC)	2.01	0.00	2.20	2.24					0.90	0.00	1.27	0.97

Note: Dose rates in rad/hr. (M) McGuire and Dalrymple, and (K) Kocher.

McGuire; Dalrymple. Beta and electron dose calculations to skin due to contamination by common nuclear medicine radionuclides. Health Phys. 1990.
Kocher, D. C.; Eckerman, K. F. Electron dose-rate conversion factors for external exposure of the skin from uniformly deposited activity on the body surface. Health Phys. 53:135-141: 1987

… continued

	0.008				0.01			
Nuclide	V5/6	V4	M	K	V5/6	V4	M	K
Co-57					0.18	0.00	0.19	0.17
Ga-67	0.62	0.00	0.53	0.59				
Tc-99m	0.70	0.00	0.79	0.76	0.54	0.00	0.58	0.63
In-111								
I-123								
I-131								
Tl-201	0.62	0.00	0.97	0.68				

Note: Dose rates in rad/hr. (M) McGuire and Dalrymple, and (K) Kocher.

McGuire; Dalrymple. Beta and electron dose calculations to skin due to contamination by common nuclear medicine radionuclides. Health Phys. 1990.
Kocher, D. C.; Eckerman, K. F. Electron dose-rate conversion factors for external exposure of the skin from uniformly deposited activity on the body surface. Health Phys. 53:135-141: 1987

Water Sphere

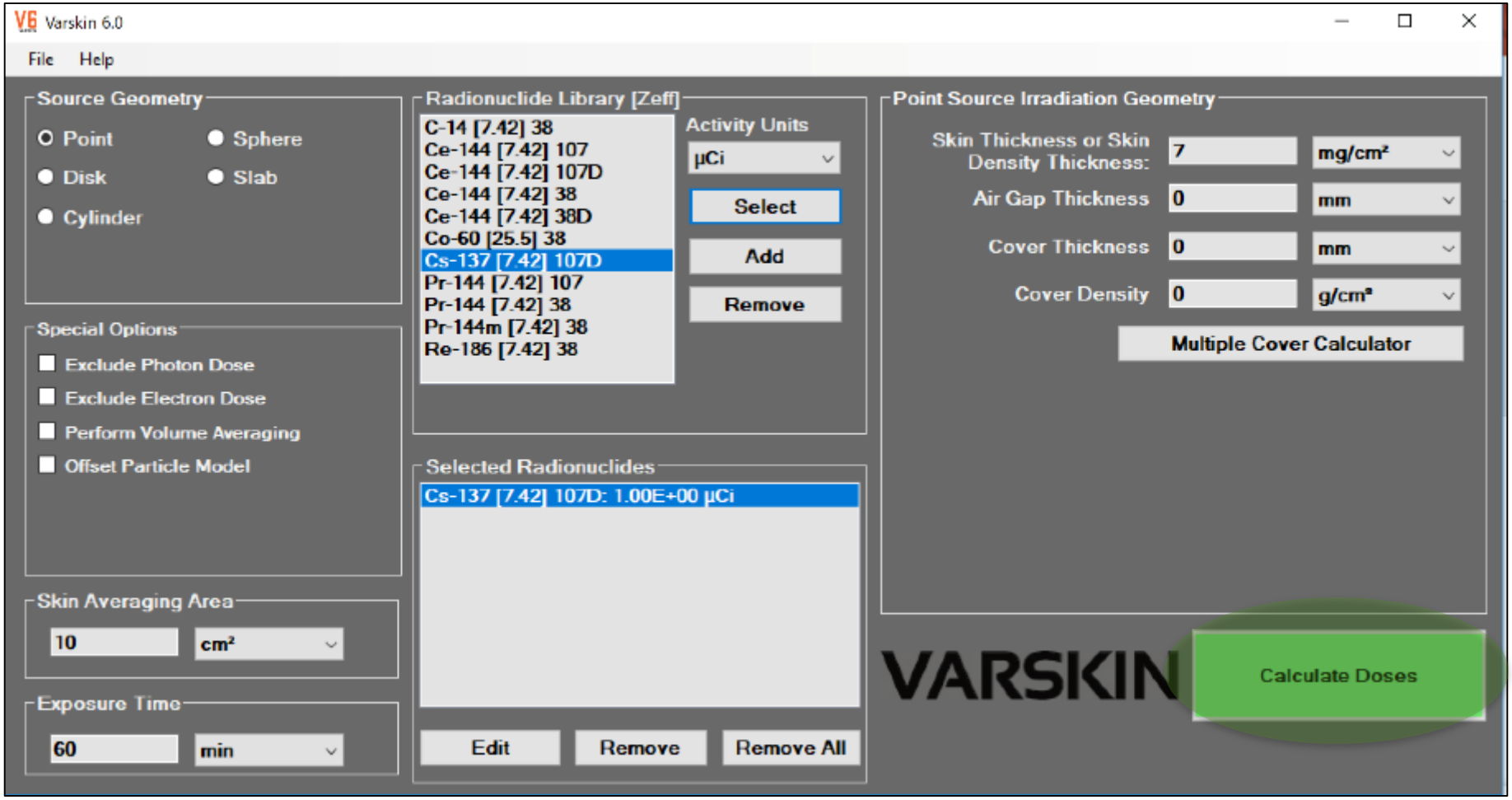
Averaging area:	1 cm^2	Nuclide: Co-60	0.05 cm water sphere
Depth (μm)	MCNP5 Dose Rate (mGy/hr/MBq)	VARSKIN 5/6 Dose Rate (mGy/hr/MBq)	VARSKIN 4 Dose Rate (mGy/hr/MBq)
30	396	385	375
50	297	281	271
70	238	216	205
100	167	153	142
120	133	122	112
150	96.9	85.1	75.2
200	58.0	46.6	39.1
300	18.1	14.0	9.97
500	1.67	0.961	0.168
1000	0	0	0

Iron Sphere

Averaging area:	1 cm^2	Nuclide: Co-60	0.05 cm iron sphere
Depth (μm)	MCNP5 Dose Rate (mGy/hr/MBq)	VARSKIN 5/6 Dose Rate (mGy/hr/MBq)	VARSKIN 4 Dose Rate (mGy/hr/MBq)
30	59.2	58.7	48.7
50	46.9	42.9	35.0
70	38.7	32.9	26.6
100	26.7	23.2	18.4
120	21.8	18.6	14.5
150	15.9	12.9	9.70
200	9.77	7.04	5.04
300	3.12	2.10	1.28
500	0.479	0.144	0.0213
1000	0	0.000008	0

SUMMARY

- Electron energy distribution
- Energy scaling model
- Range scaling model
- Backscatter correction factors
- Comparisons brought closer in line with literature


Varskin 6.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Exclude Photon Dose
Exclude Electron Dose
Perform Volume Averaging
Offset Particle Model
Skin Averaging Area
10
cm²
Exposure Time
60
min
Radionuclide Library [Zeff]
C-14 [7.42] 38
Ce-144 [7.42] 107
Ce-144 [7.42] 107D
Ce-144 [7.42] 38
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Re-186 [7.42] 38
Activity Units
µCi
Select
Add
Remove
Selected Radionuclides
Cs-137 [7.42] 107D: 1.00E+00 µCi
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness
0
mm
Cover Thickness
0
mm
Cover Density
0
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses

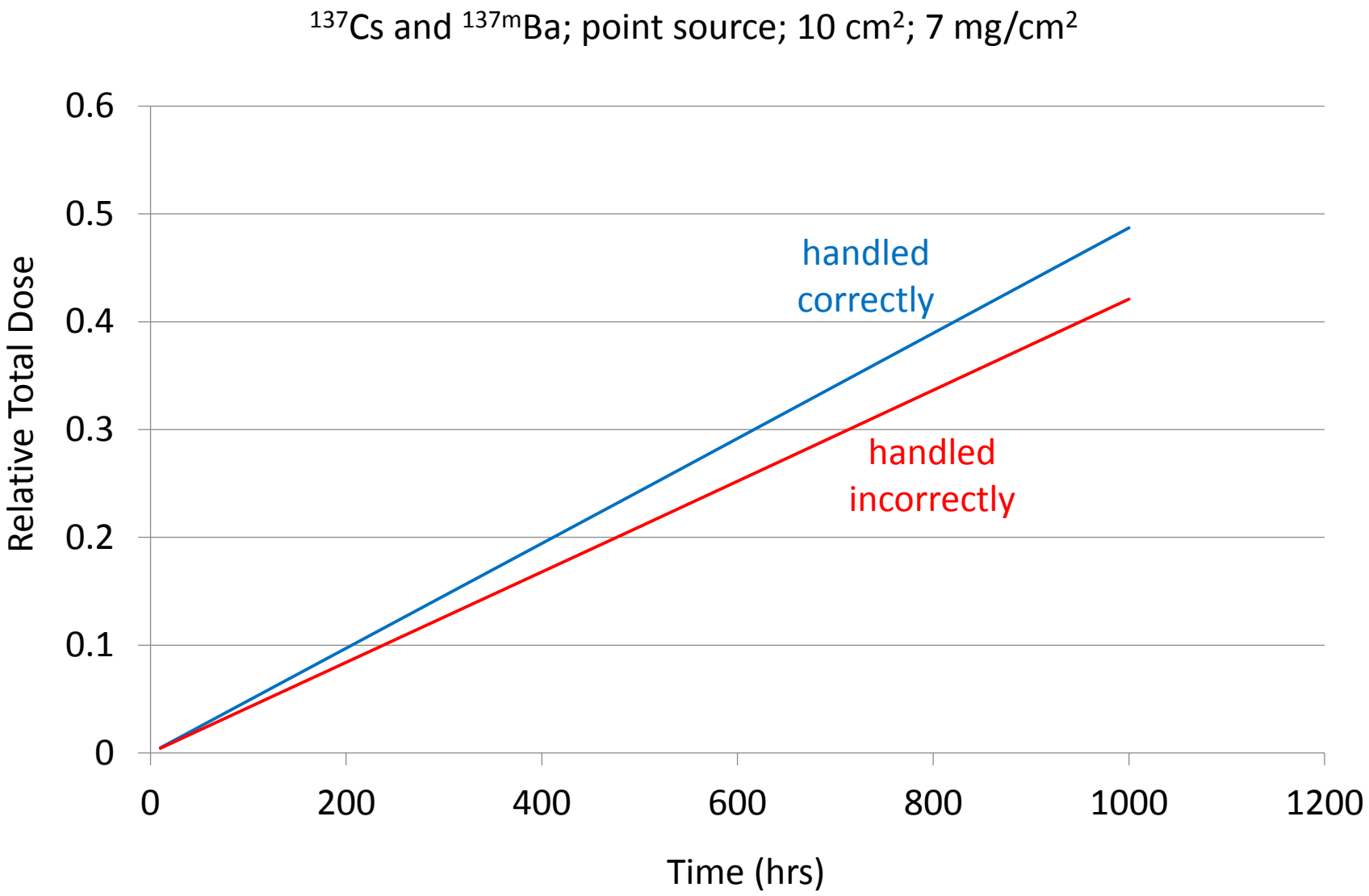
VARSKIN Output

- English or SI units
- For each radionuclide (and total), the following doses are provided:
  - Beta, Photon & Total:
    - initial dose rate
    - dose (no decay)
    - decay-corrected dose
- Date/time
- Geometry summary
- Print option (to html file)

$$D = \dot{D}(0) \cdot t$$

$$D_{dc} = \int_0^t \dot{D}(t)dt = \dot{D}(0) \int_0^t e^{-\lambda t} dt$$

Decay-Corrected Dose




Non Volume Averaged Results
Radionuclide: Activity
Cs-137 [7.42] 107D: 1.00E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron
2.55E-03 rad/h
2.55E-03 rad
2.55E-03 rad
Photon
4.99E-03 rad/h
4.99E-03 rad
4.99E-03 rad
Total
7.54E-03 rad/h
7.54E-03 rad
7.54E-03 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron
2.55E-03 rad/h
2.55E-03 rad
2.55E-03 rad
Photon
4.99E-03 rad/h
4.99E-03 rad
4.99E-03 rad
Total
7.54E-03 rad/h
7.54E-03 rad
7.54E-03 rad
Date/Time
3/19/18 11:29:50 AM
Source Geometry
Disk Source
Source Diameter
1.00E+00 mm
Source Area
7.85E-01 mm²
Cover Thickness
5.20E-02 cm
Cover Density
3.90E+00 g/cm³
Air Gap Thickness
0.00E+00 mm
Irradiation Time
6.00E+01 min
Irradiation Area
1.00E+01 cm²
Print Results
Close