VARSKIN 6

VARSKIN Examples, Training Modules, Dosimetry Theory

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Nuclear Regulatory Commission

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Outline

- Training Modules Demonstration
- Electron/Photon Dosimetry Theory
- Examples

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VARSKIN Training Modules

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Electron Dosimetry Theory

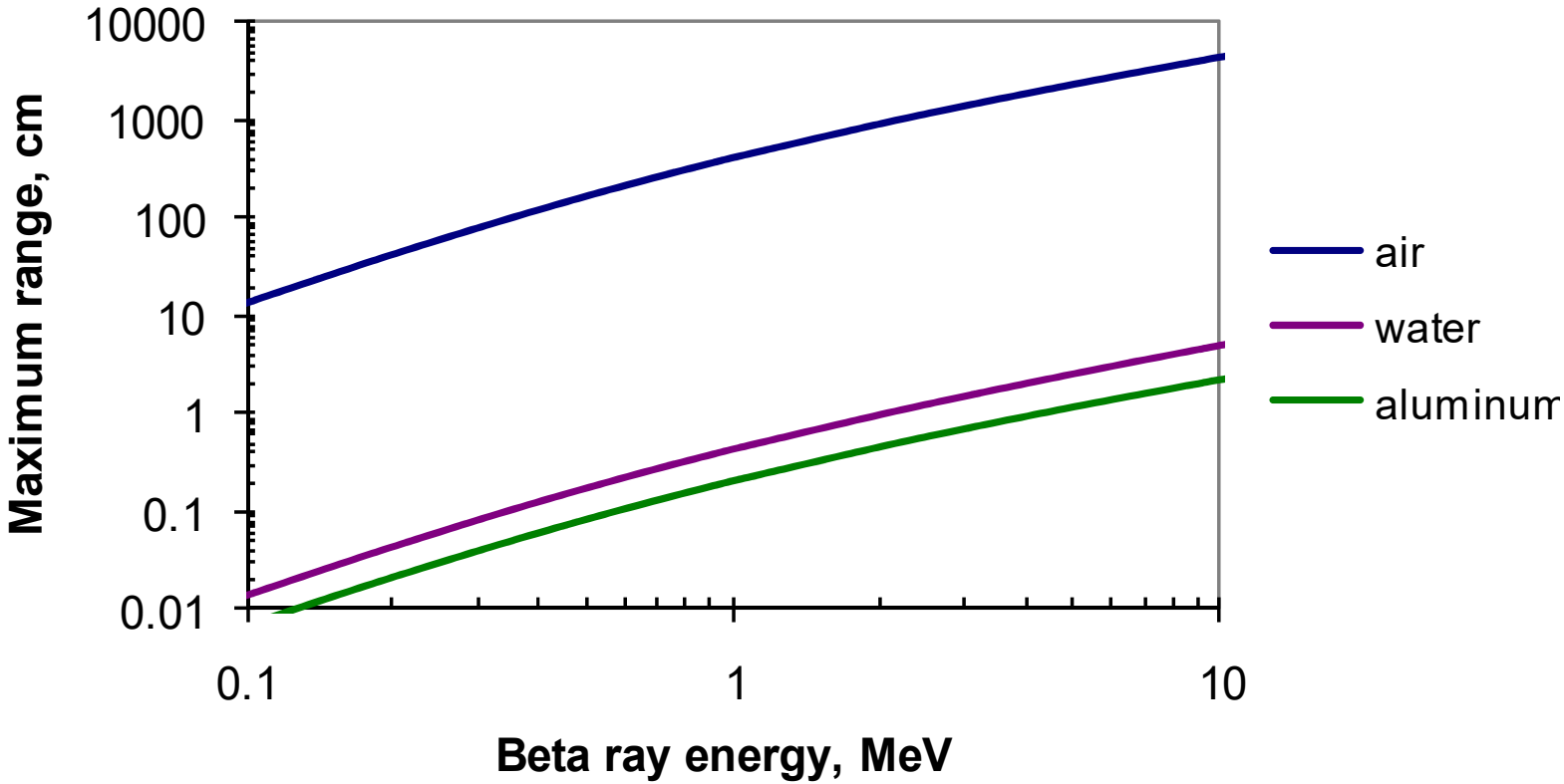
Electron Interactions

- 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

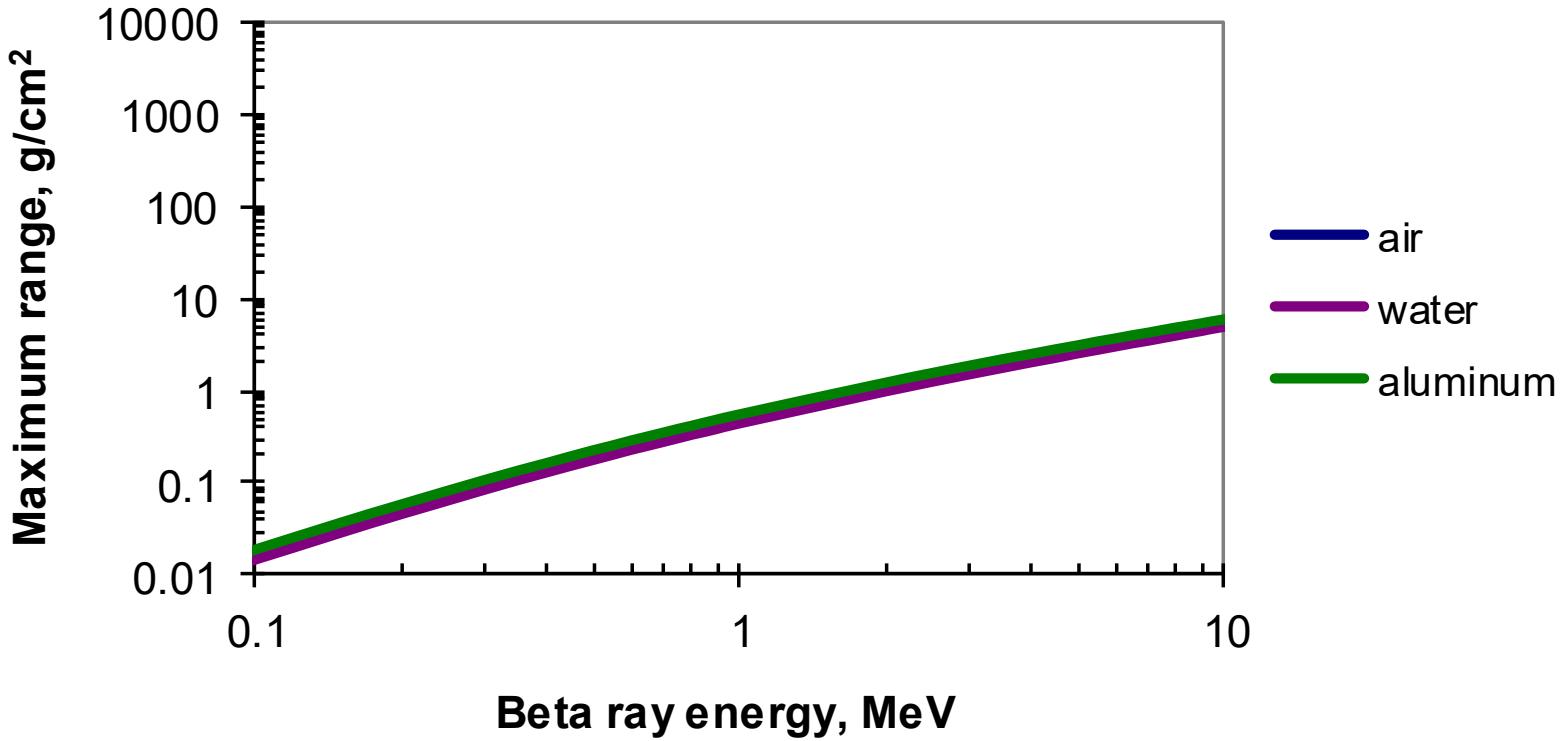
Range-Energy Observations

- 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
  - *density thickness* (mg/cm^2) is best indicator of electron range
  - important tissue depths → 7, 100, 300, 1000 mg/cm^2

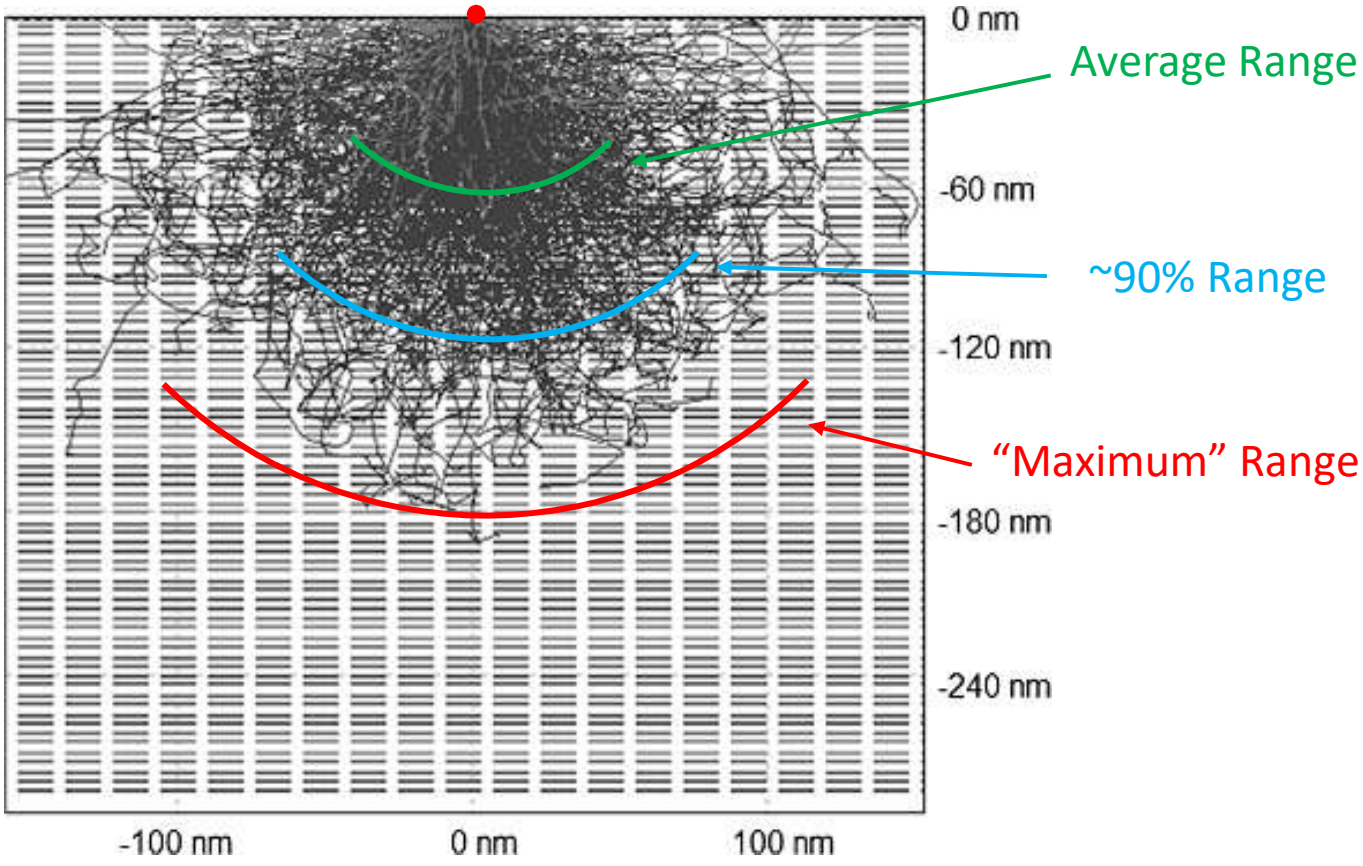
Range-Energy Relationship for Electrons



Advantage of Density Thickness



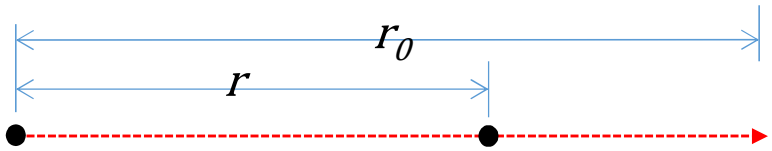
Electron Track Simulation



Electron 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:

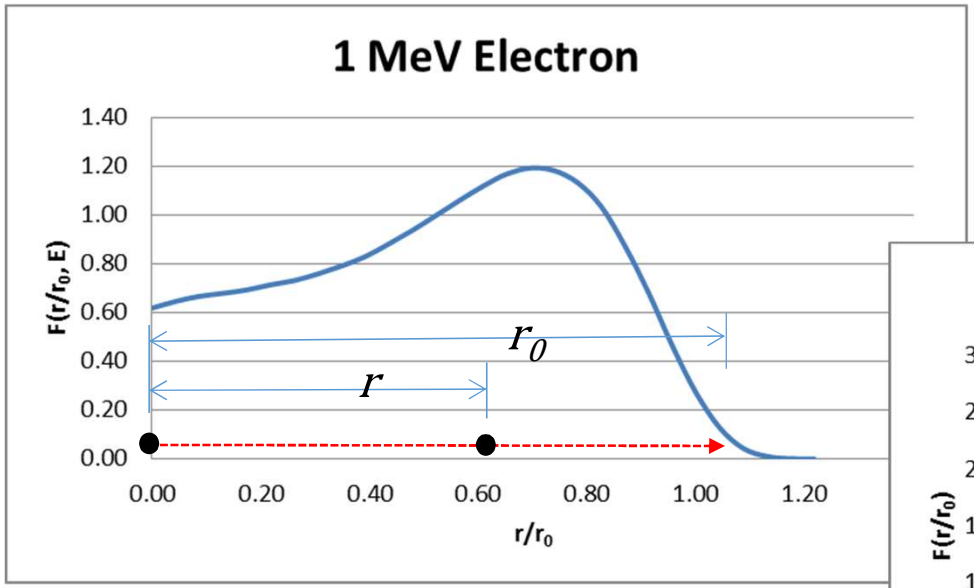
$$G(r,E)=\frac{E}{4\pi r^2 \rho r_0}F(r/r_0,E)$$

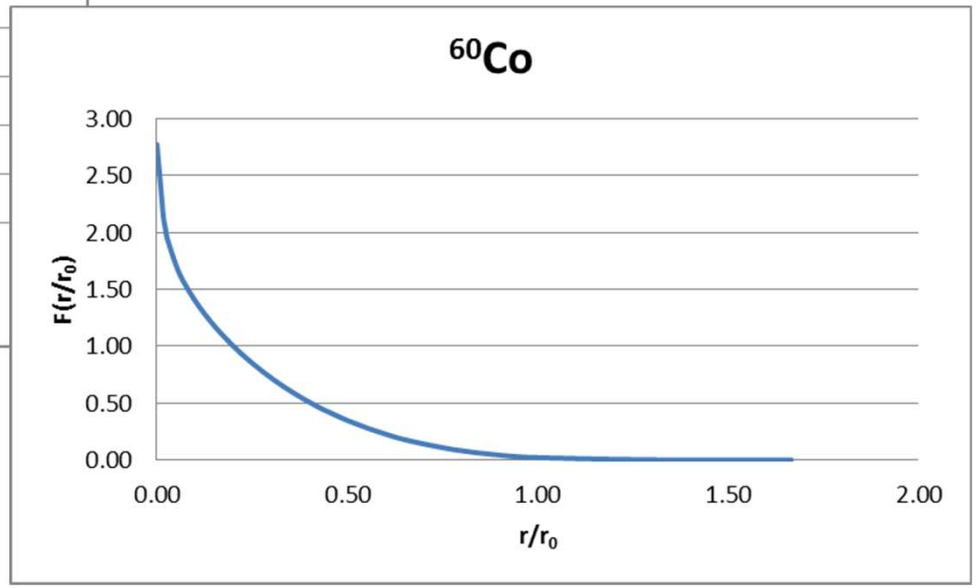


The function $F(r/r_0,E)$ is a "scaled absorbed dose distribution" (essentially a normalized Bragg curve) that is dependent on the electron initial energy and the fraction of *maximum* range (r/r_0) that the electron has achieved by the time it reaches the dose location.

Scaled Absorbed Dose Distributions

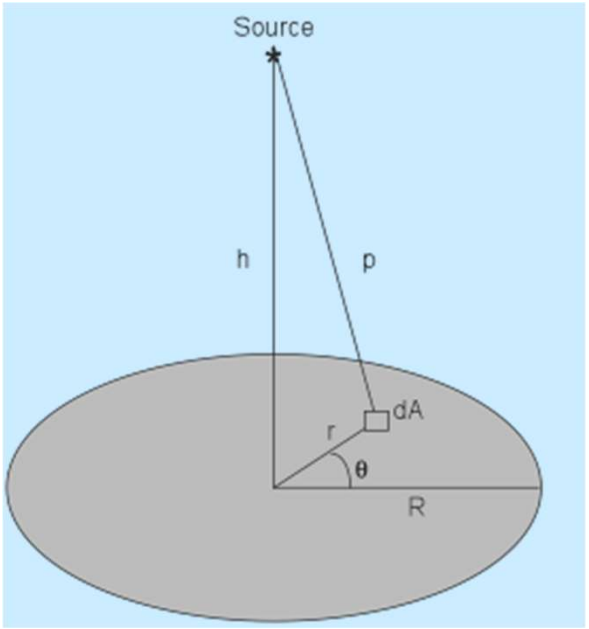
The factor $F(r/r_0,E)$ is shown for electrons of energy E, and for beta particles of distributed E, normalized over their *maximum* range, r_0





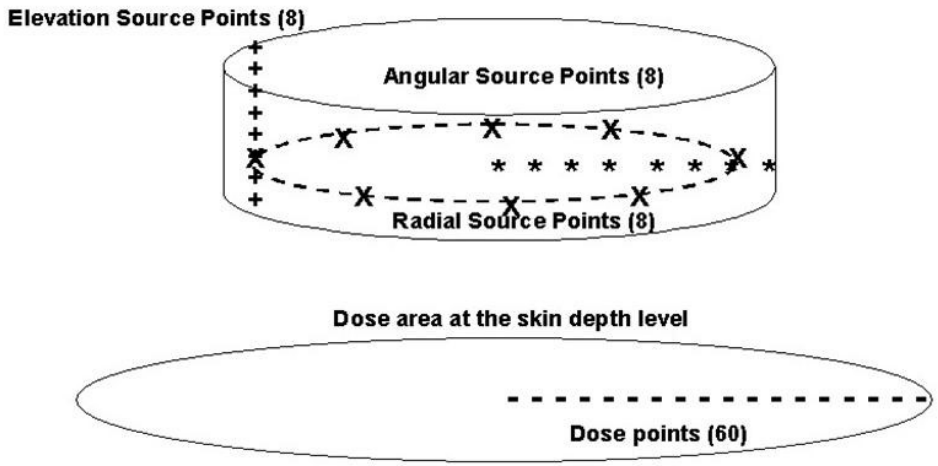
Fundamentally …

- 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)



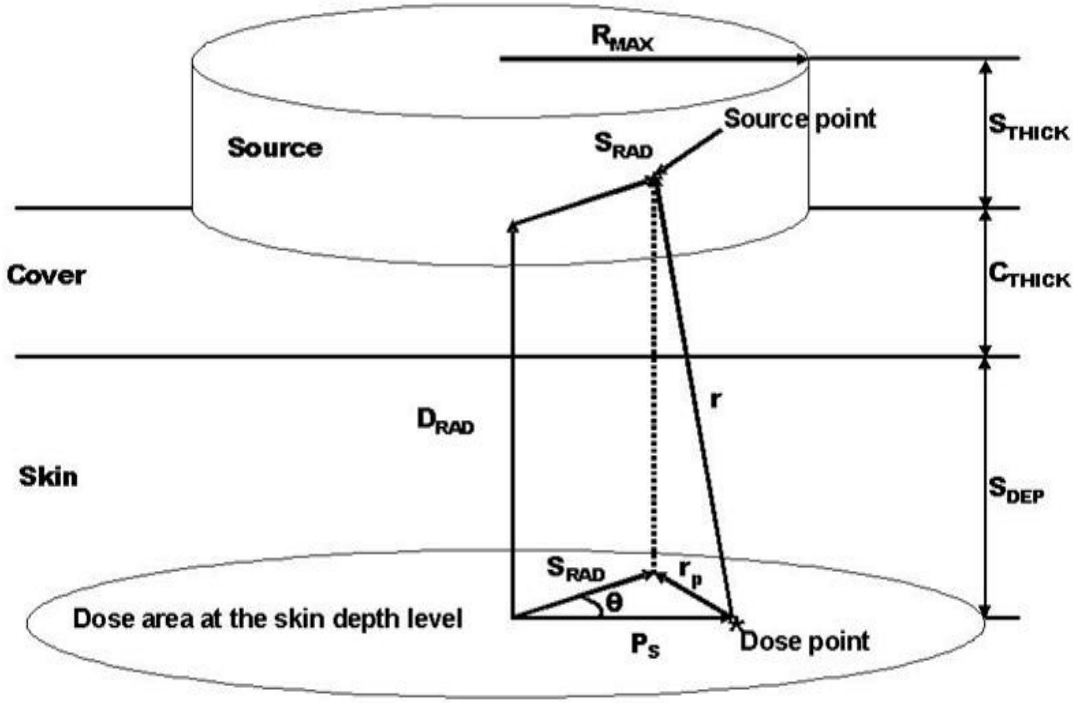
Density Correction Model

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

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

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

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



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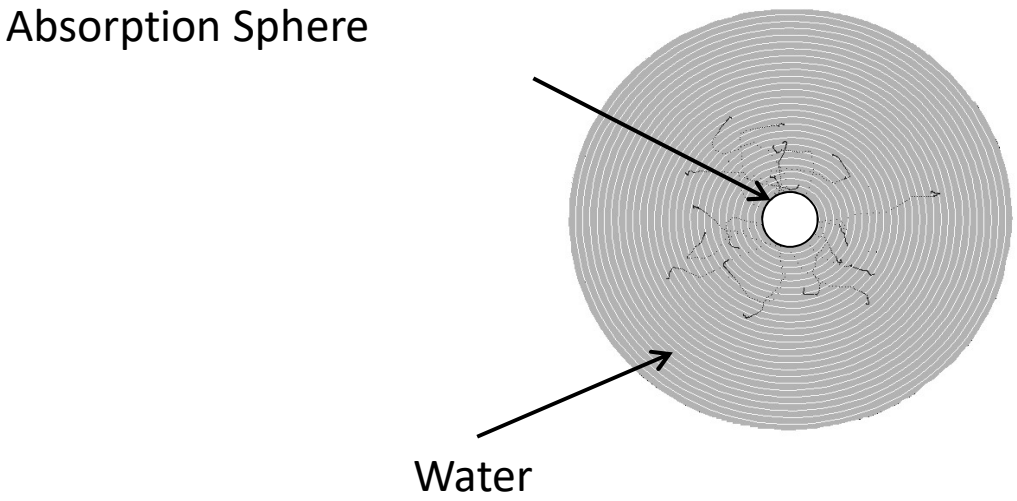
Electron Dosimetry Theory

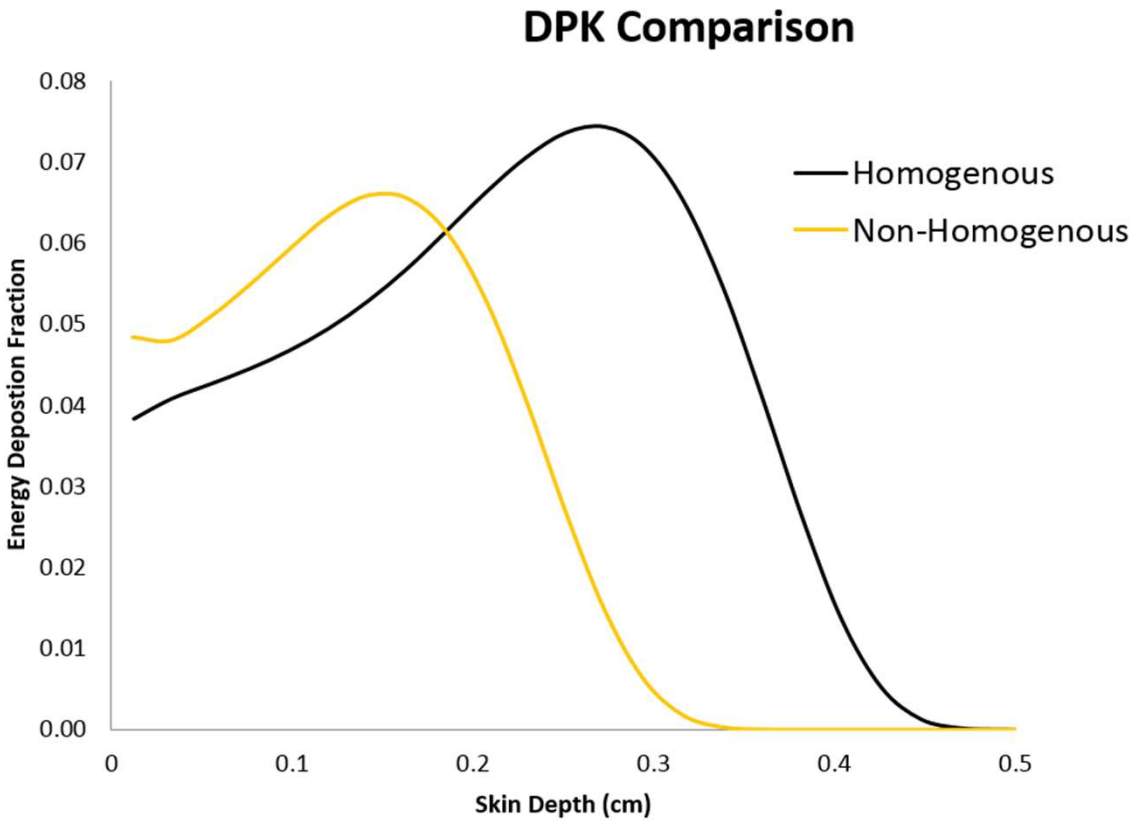
Advanced Scaling Parameters

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

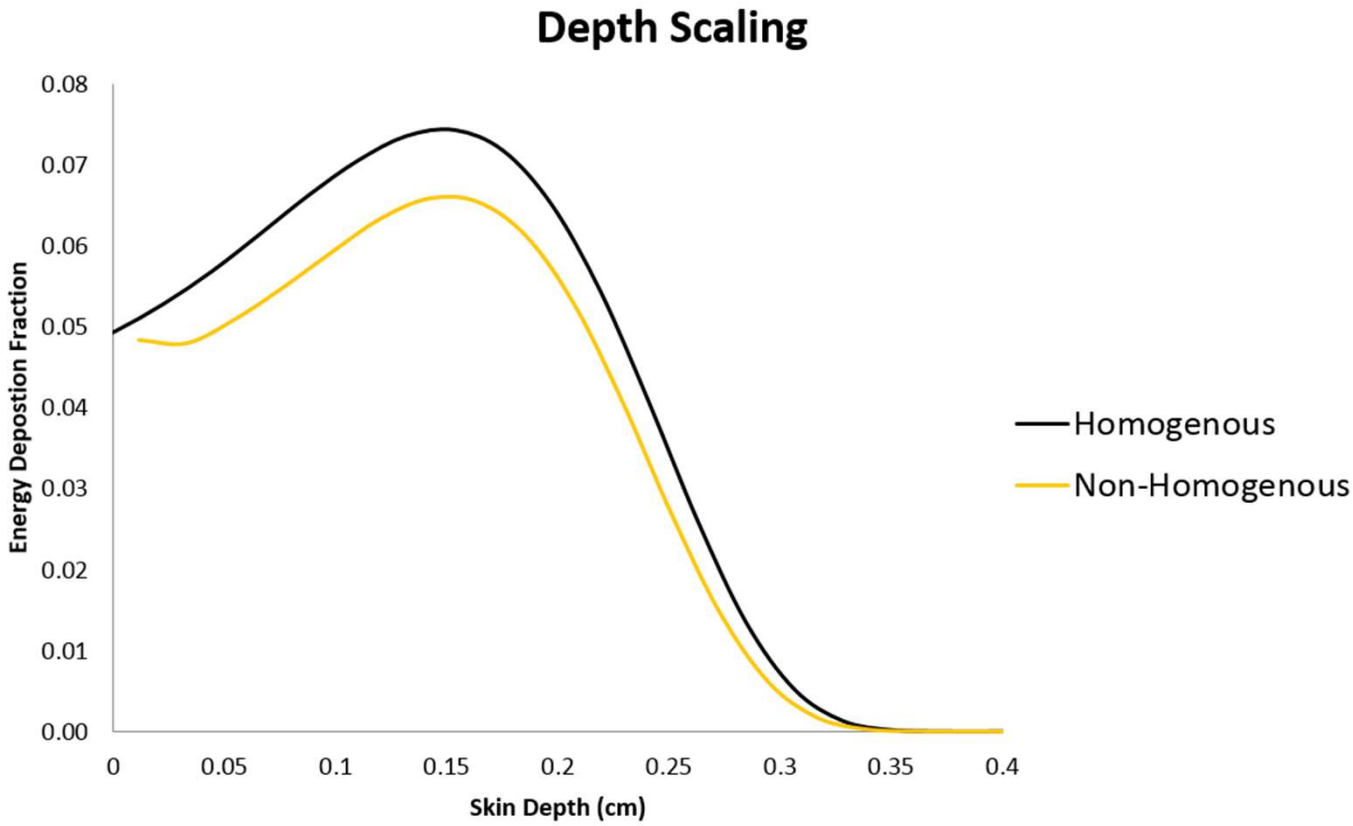


Scaling Model



- 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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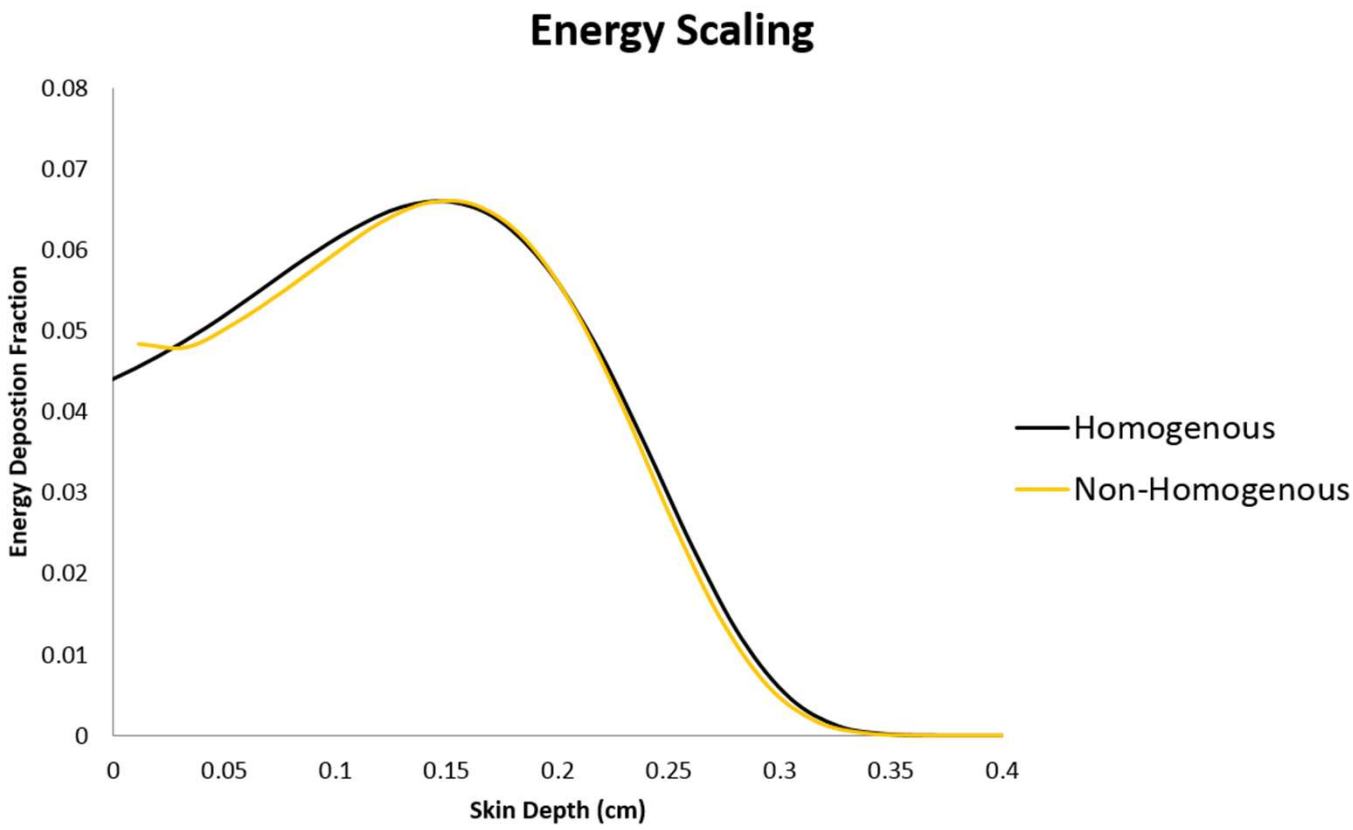
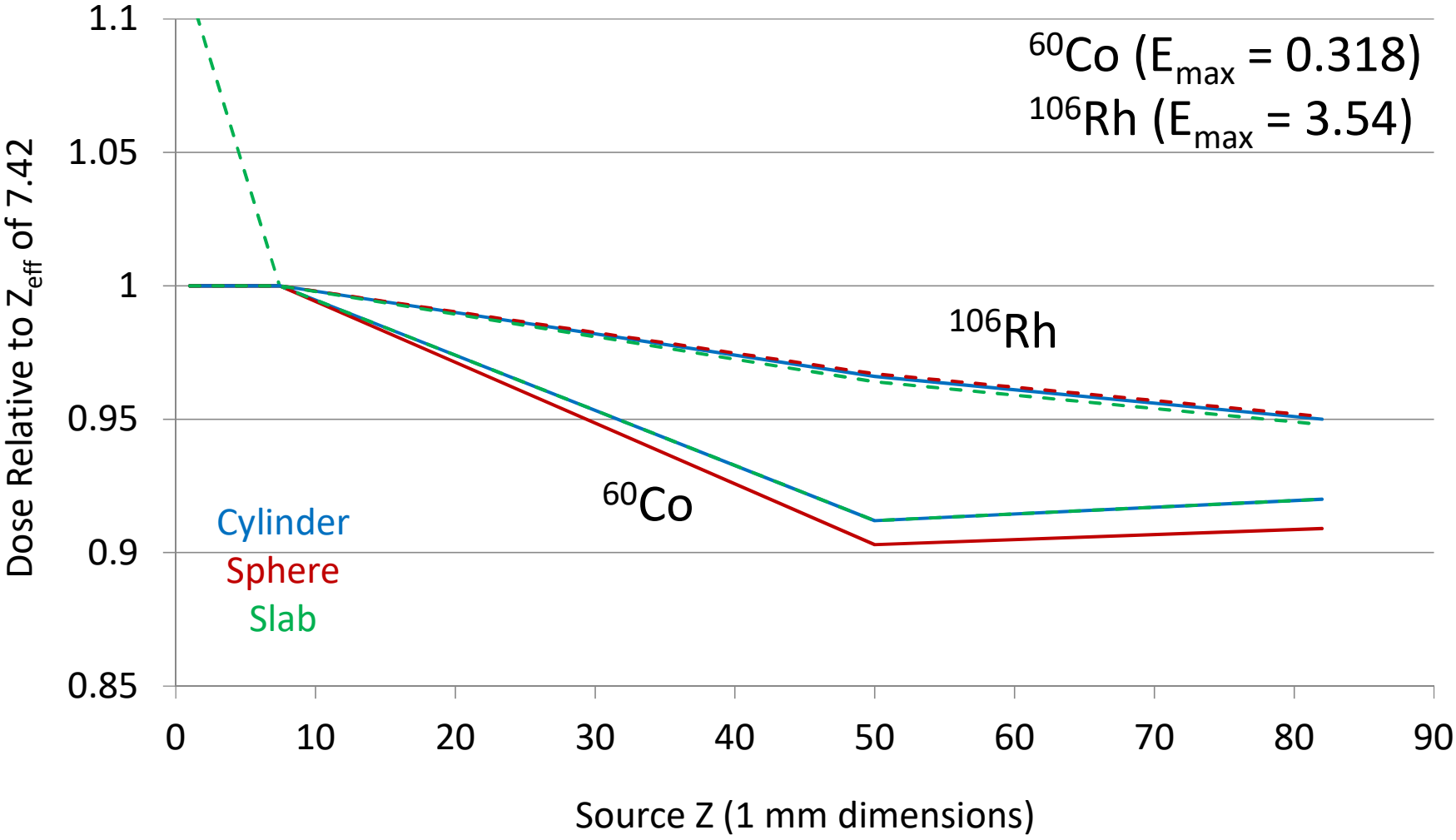
Scaling Model



Volumetric Beta Dose vs Source Z



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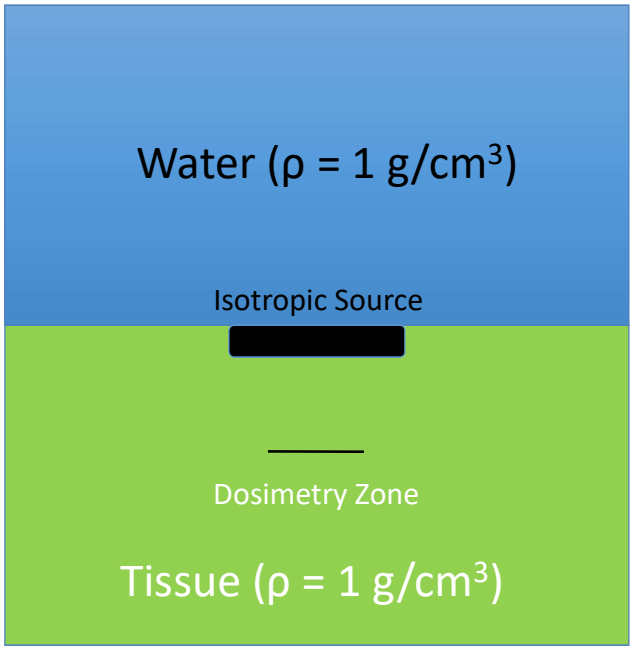
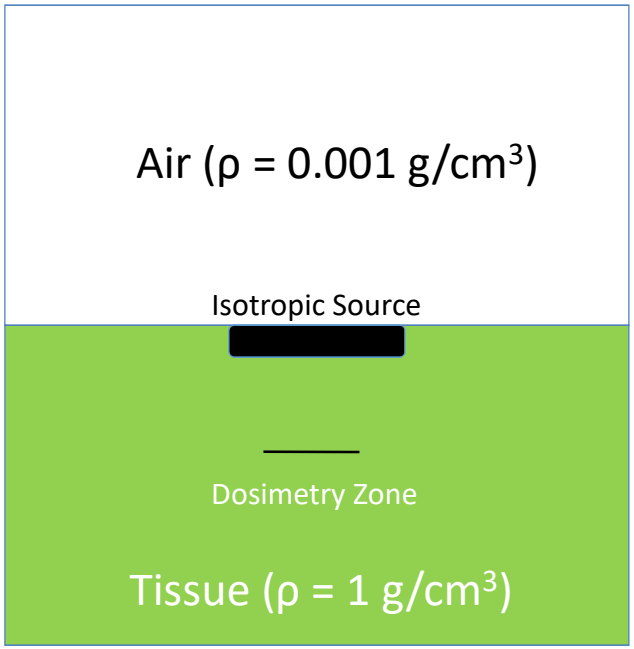
Electron Dosimetry Theory

Backscatter Correction

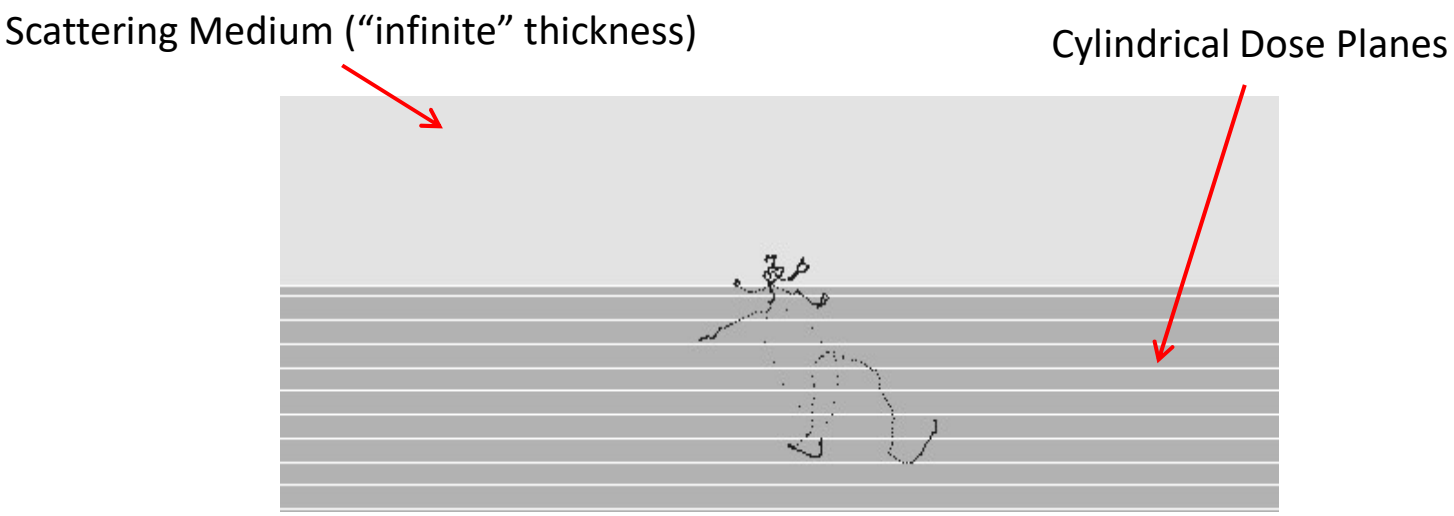
Original Backscatter Determination



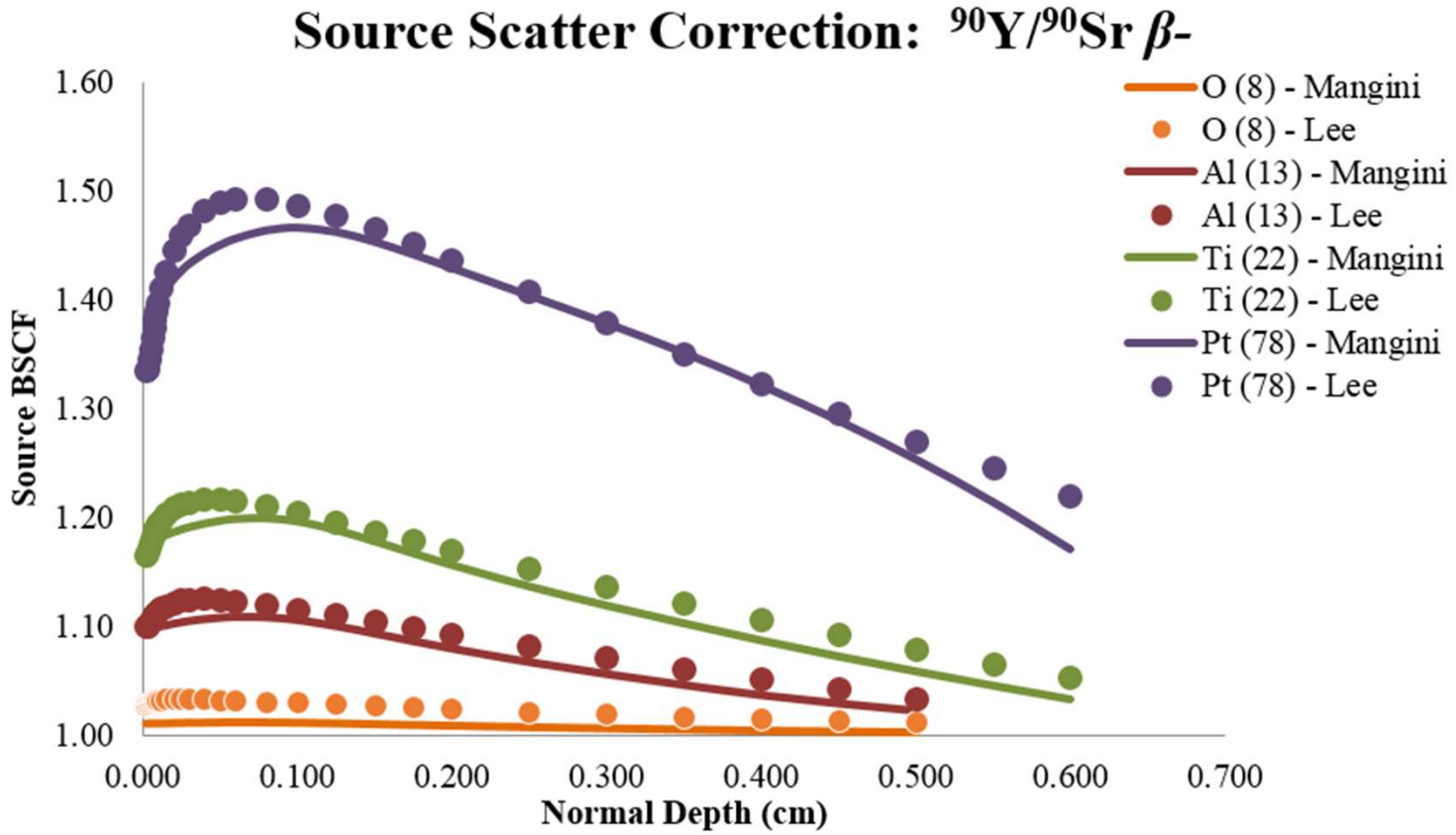


New Backscatter Model

- 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})

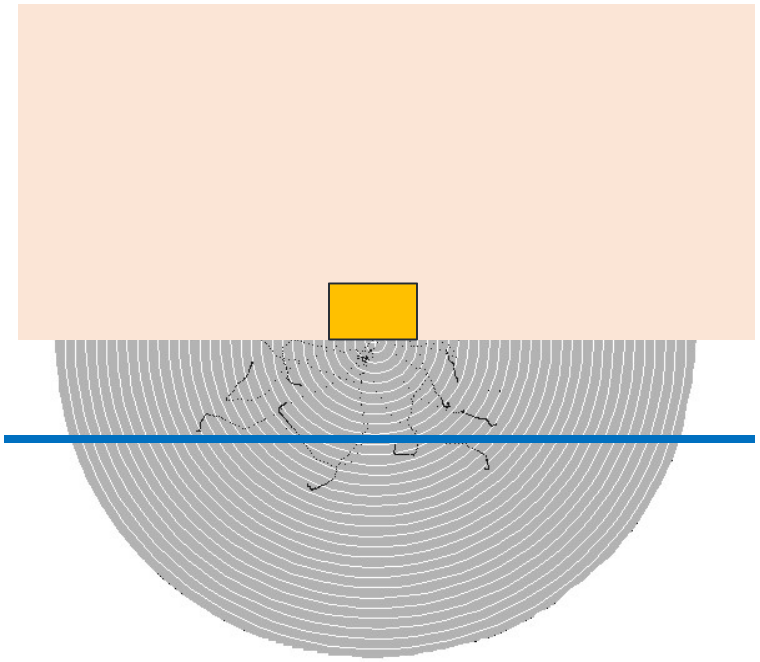


Point-Source BSCF

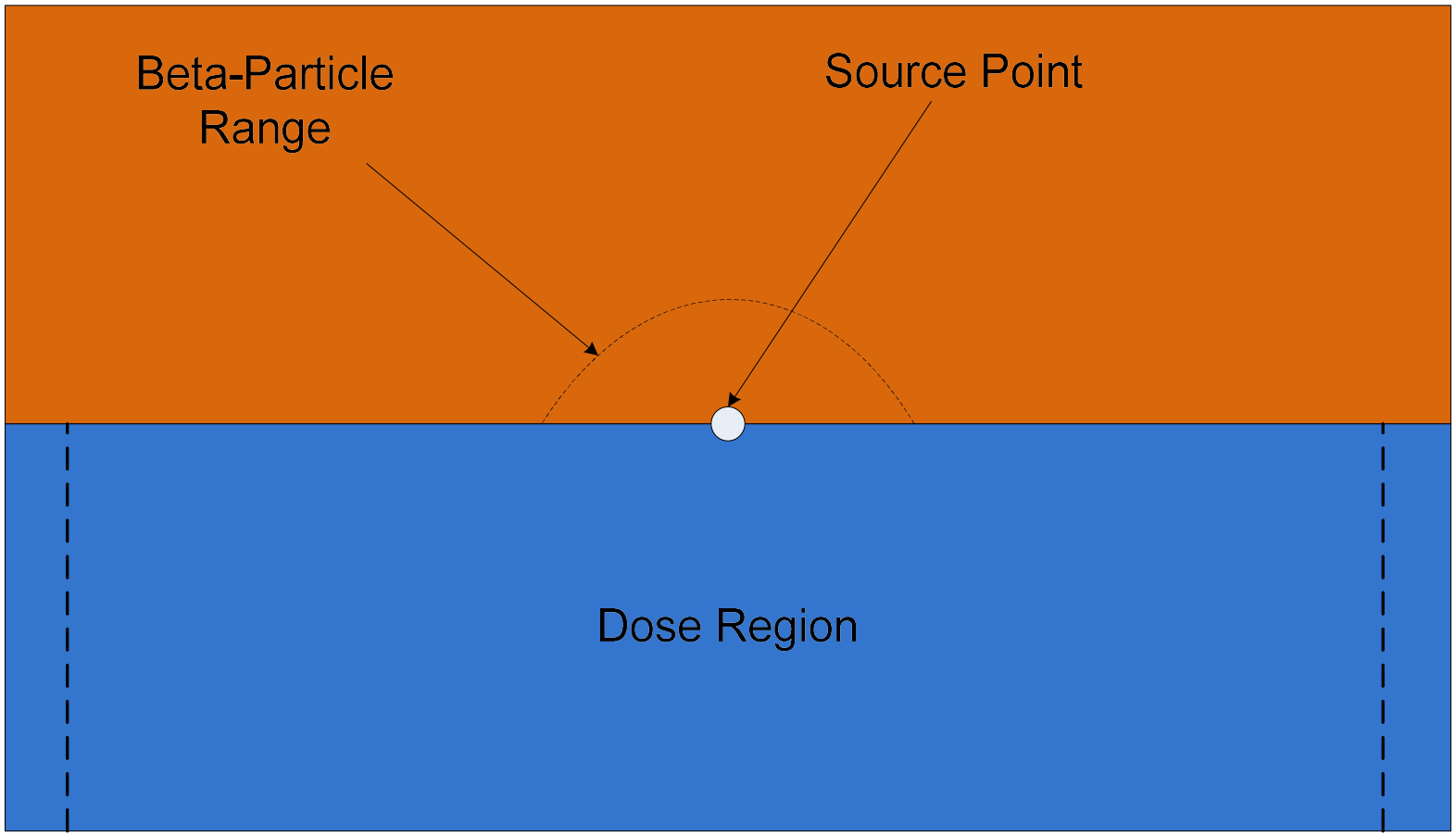


Scatter Scenarios

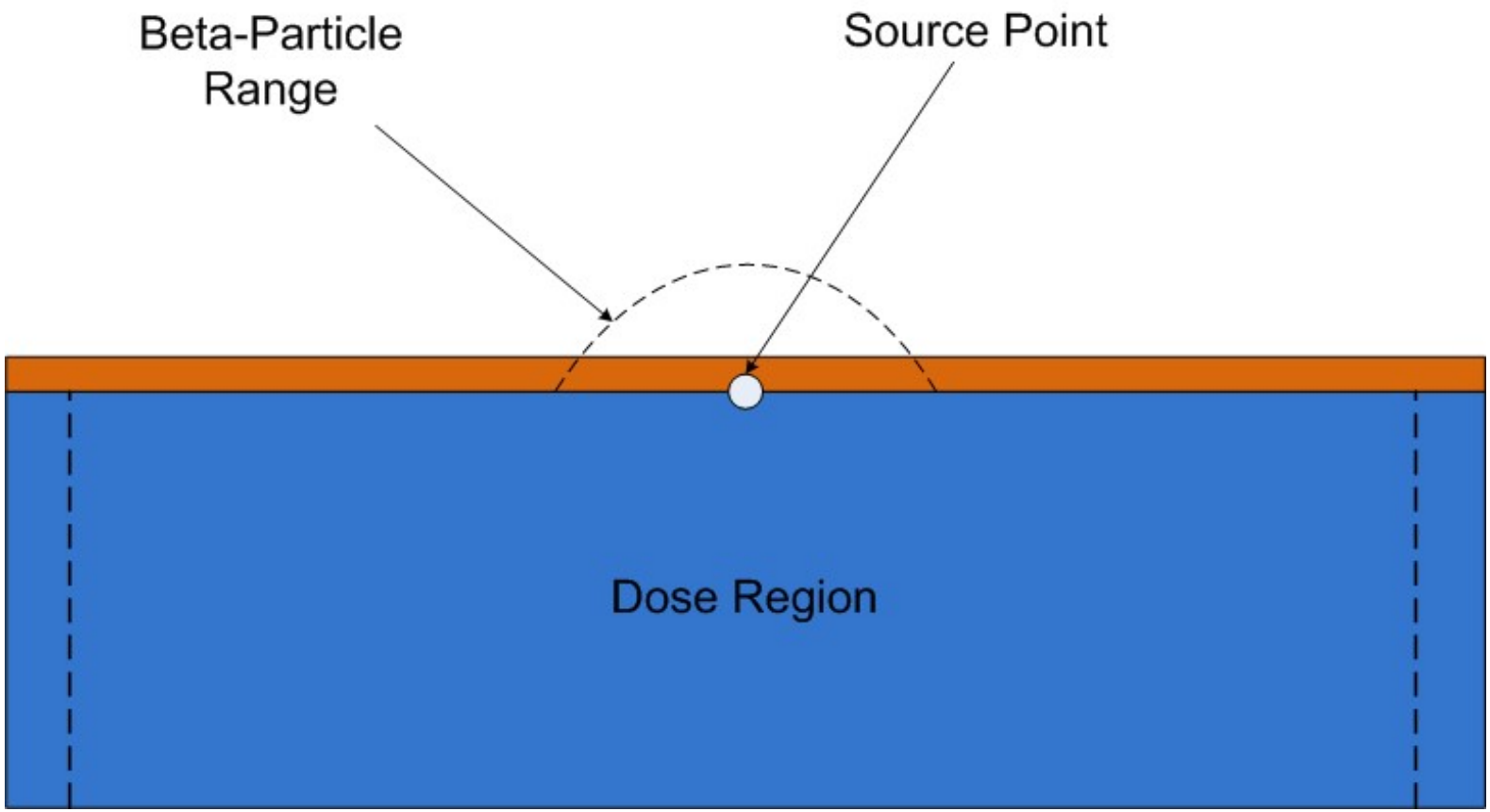
- Source scatter for top/bottom of source
- Source scatter for sides of source
- Air scatter for top/sides of source



Scatter for Top/Bottom of Source



Scatter for Top/Bottom of Source



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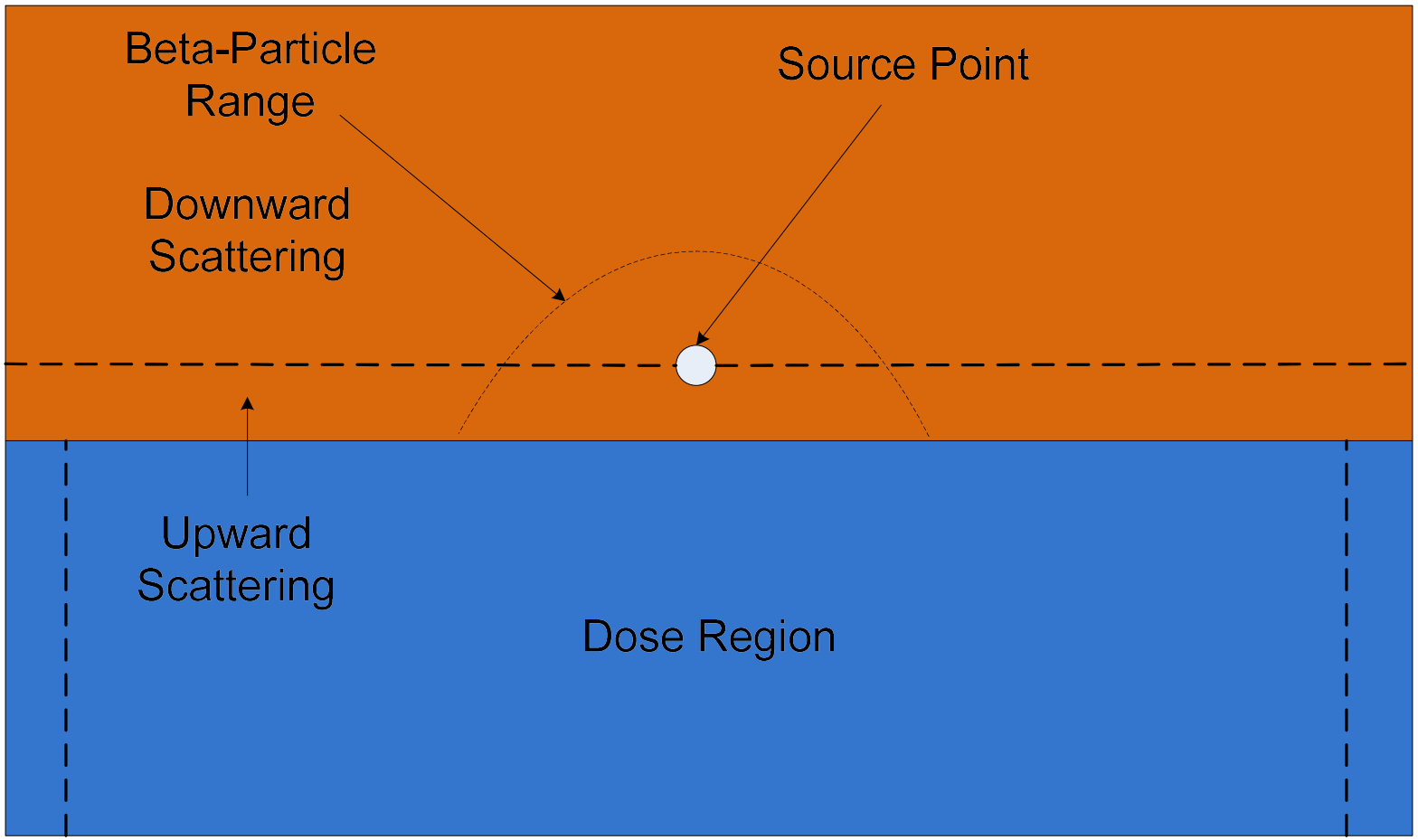
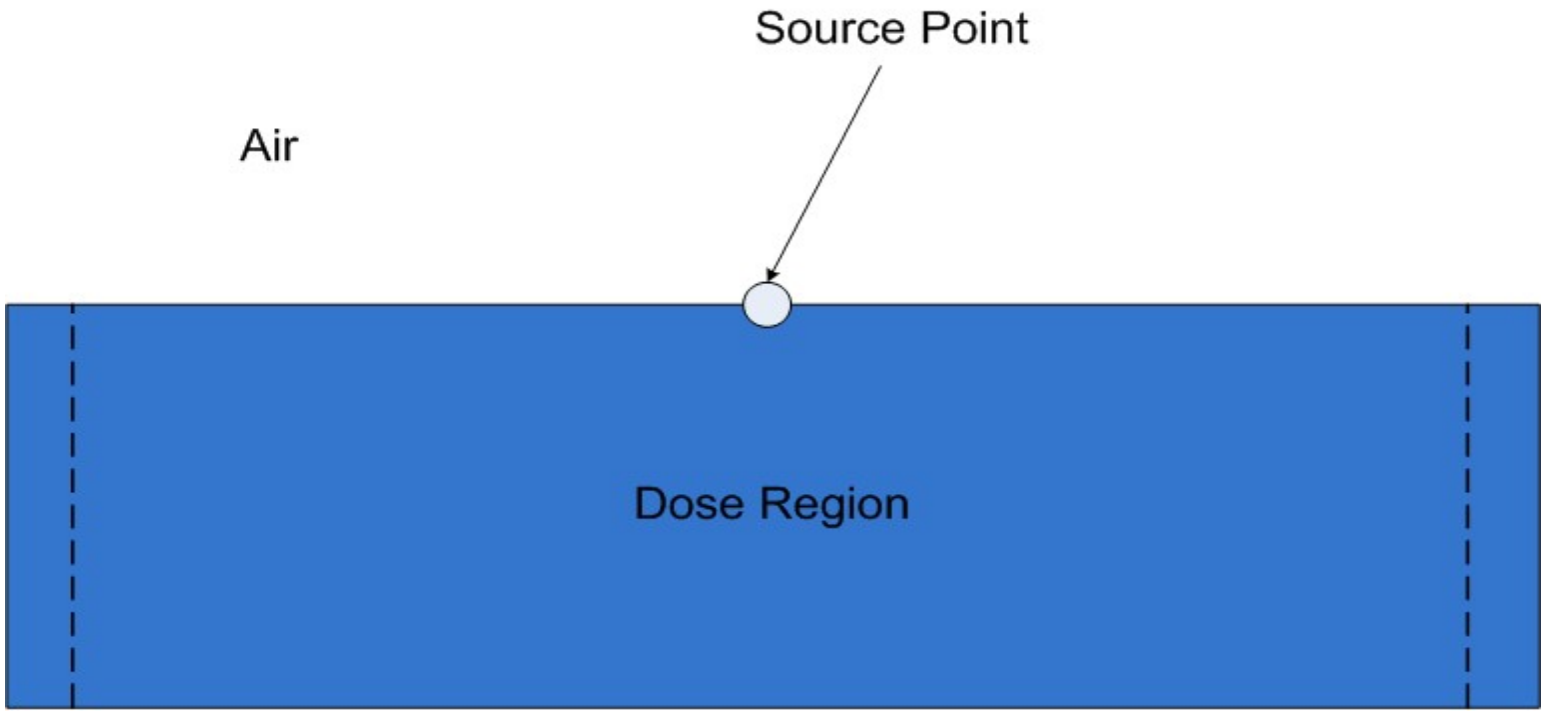
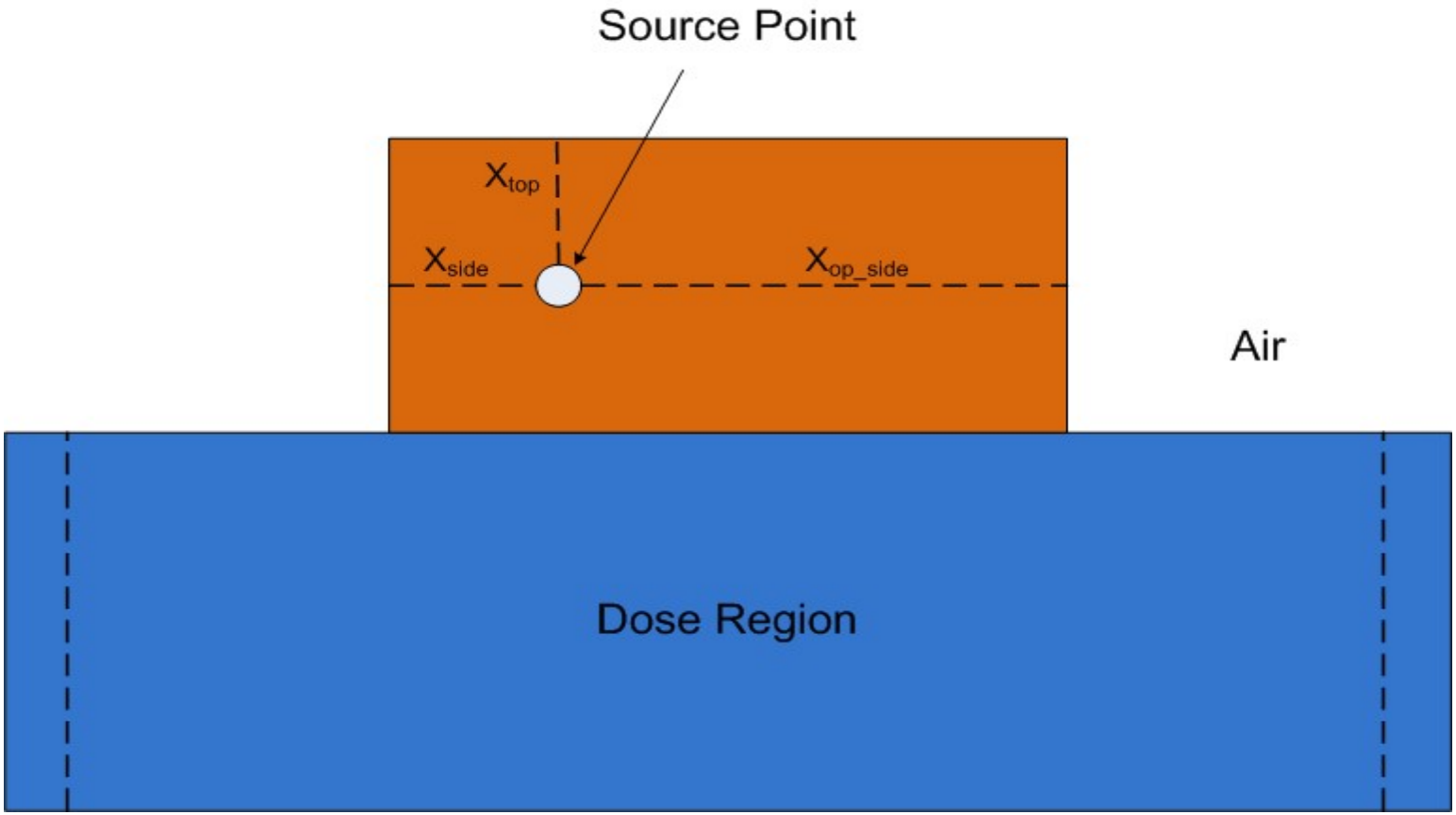


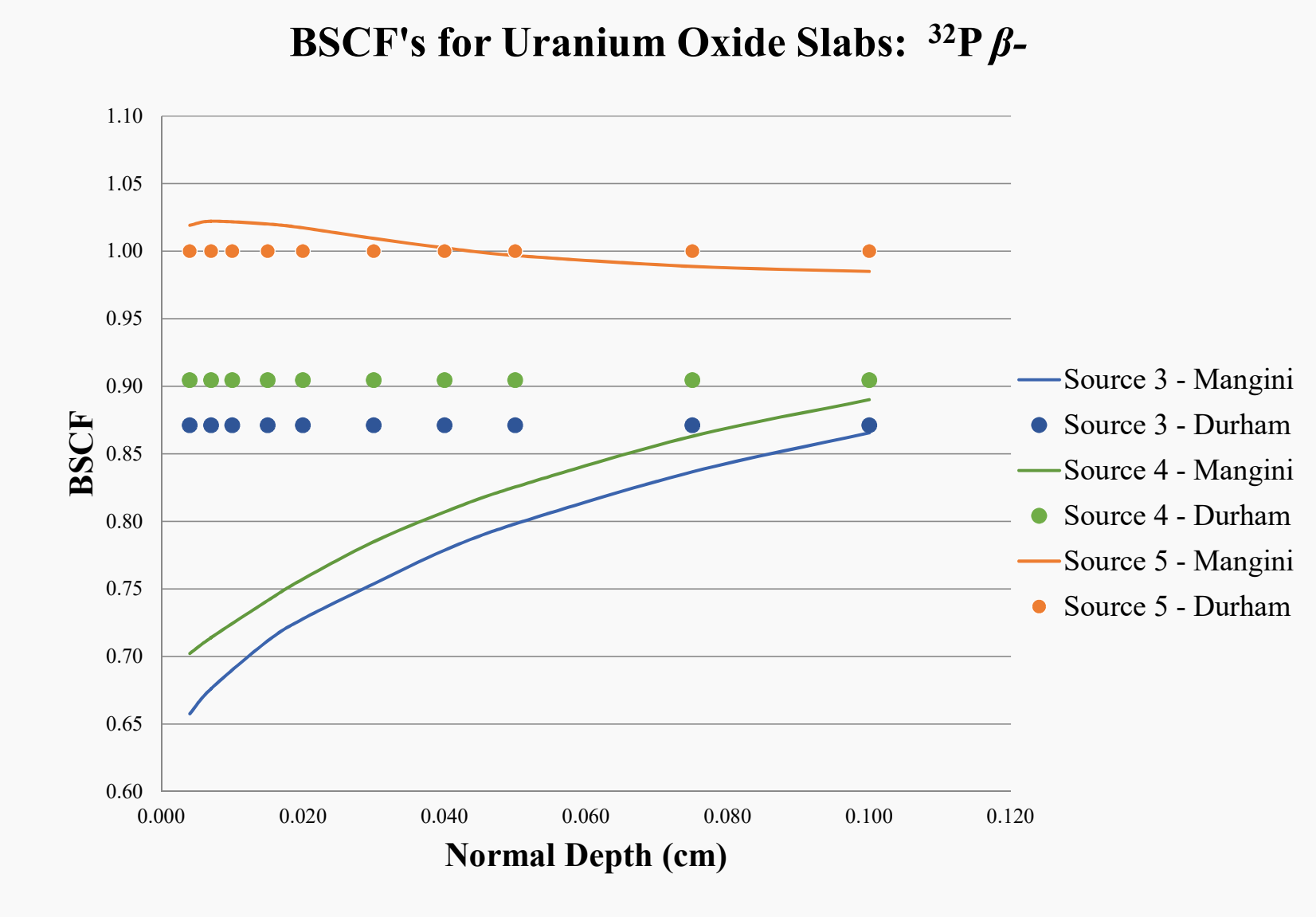
Air Scatter for Top/Sides of Source



Air Scatter for Top/Sides of Source



Volumetric BSCF



SUMMARY

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

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Photon Dosimetry Theory

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)

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

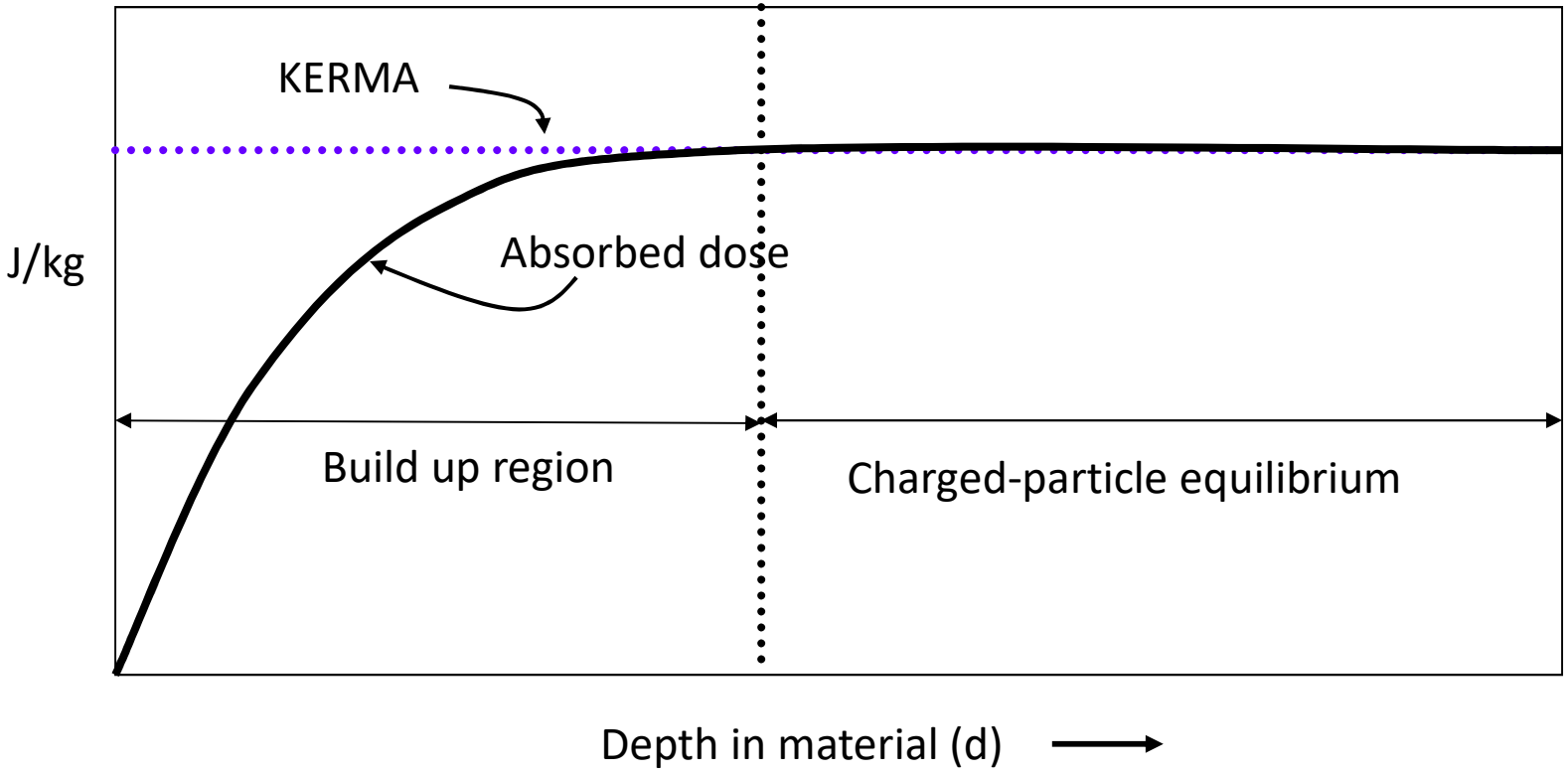
$$D = K \cdot \frac{\mu_{en}}{\mu_{tr}}$$

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

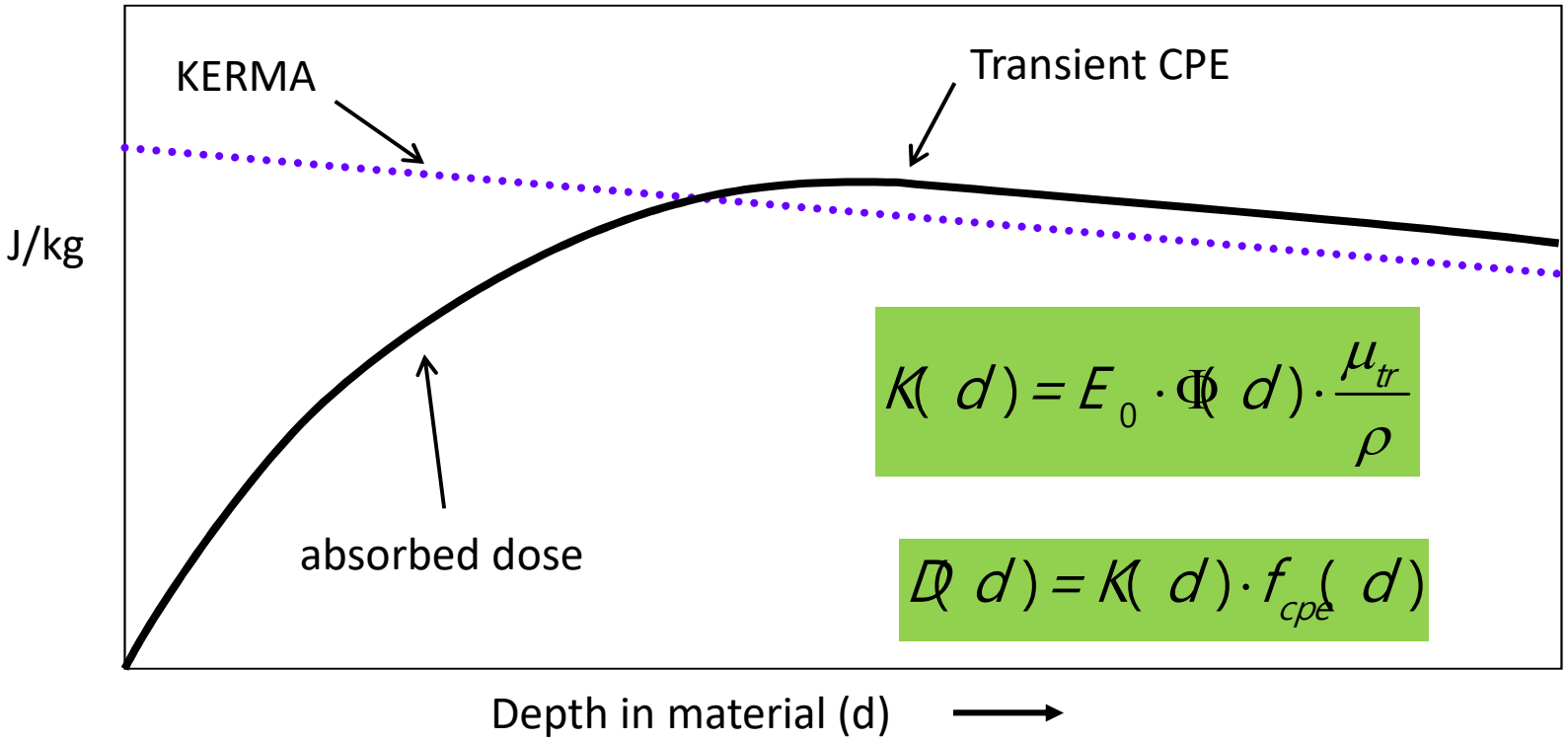
Charged-Particle Equilibrium

- 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

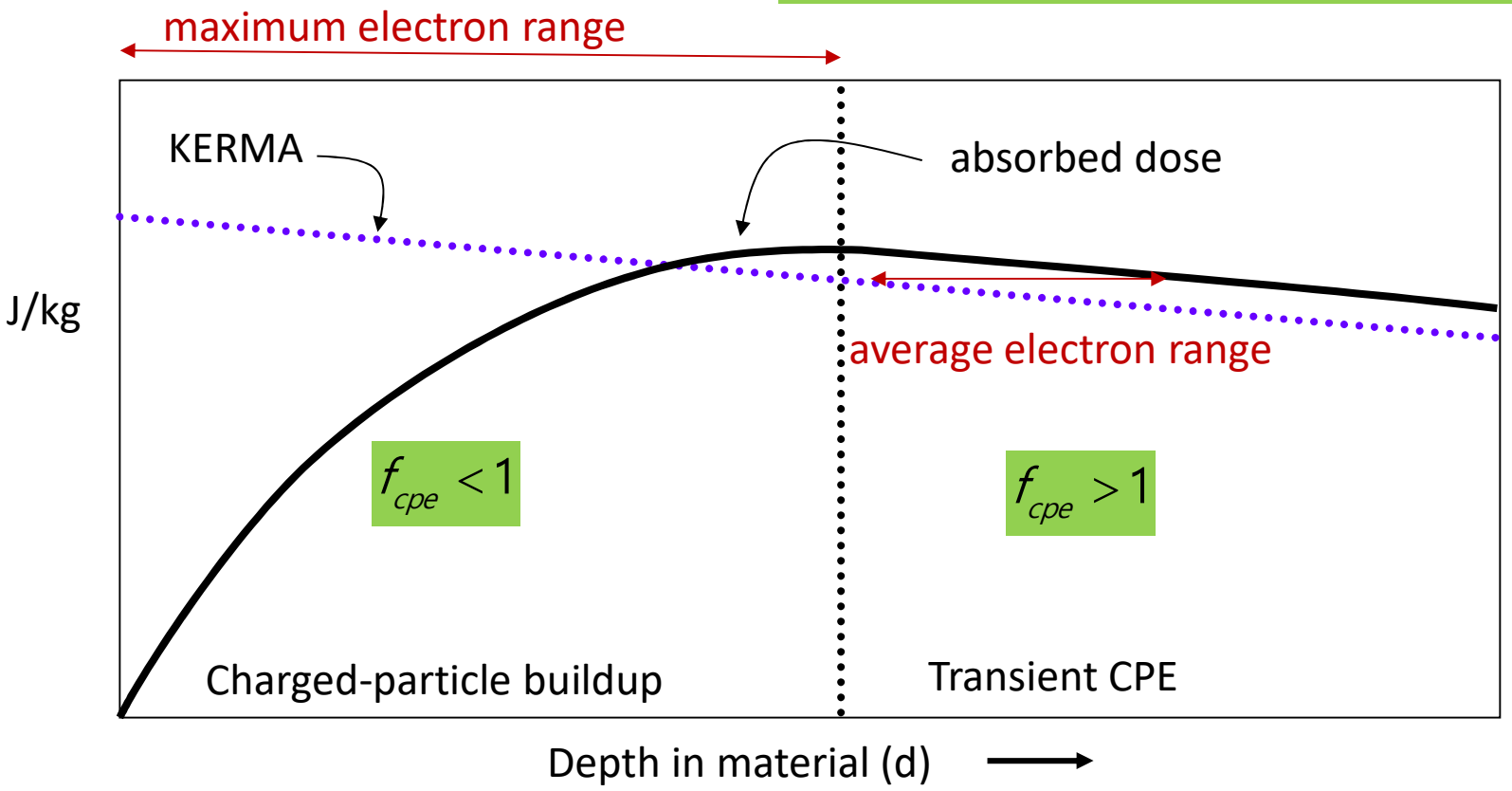


KERMA and Dose Buildup



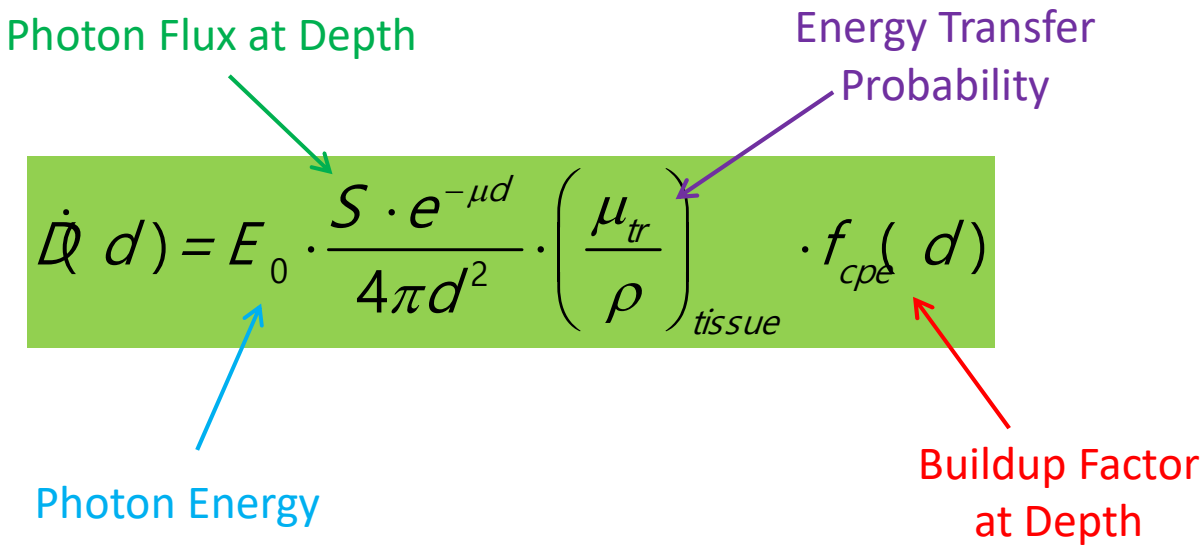
details …

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



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:

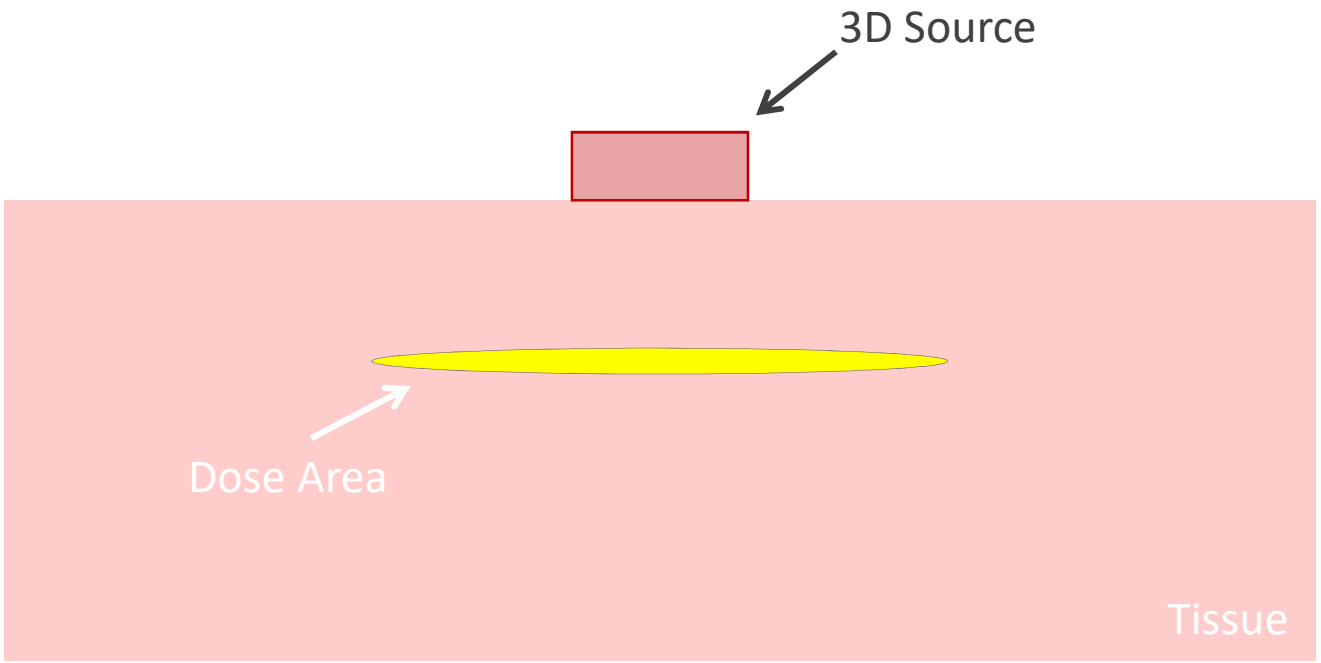


VARSKIN 4/5/6 Photon Dosimetry

- 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)

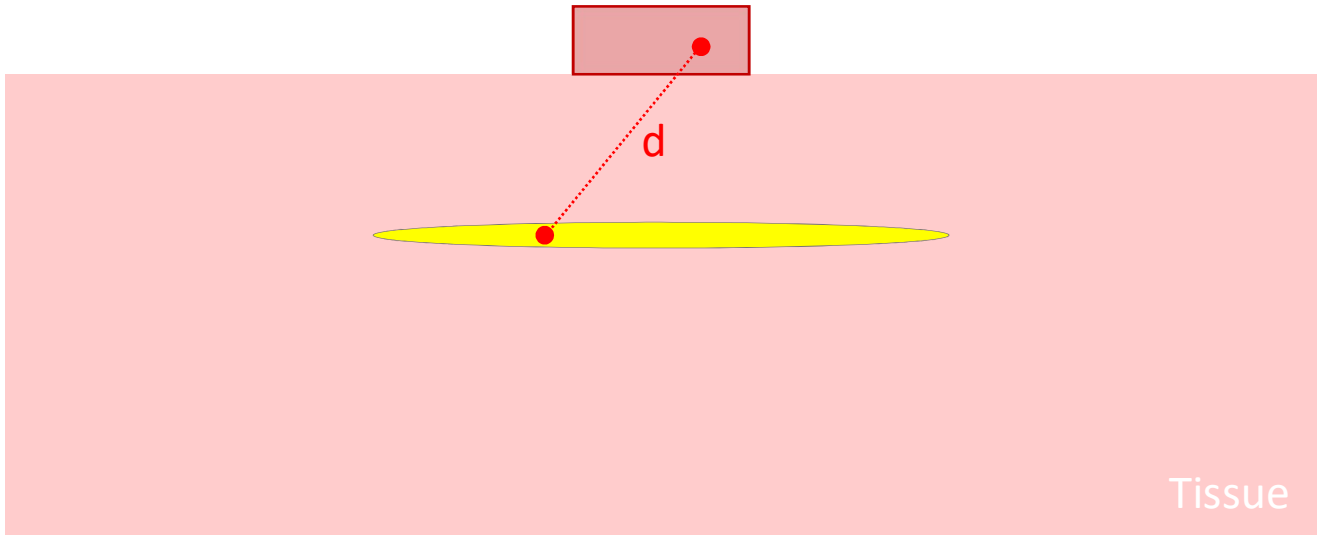
“Point Kernel” Concept

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



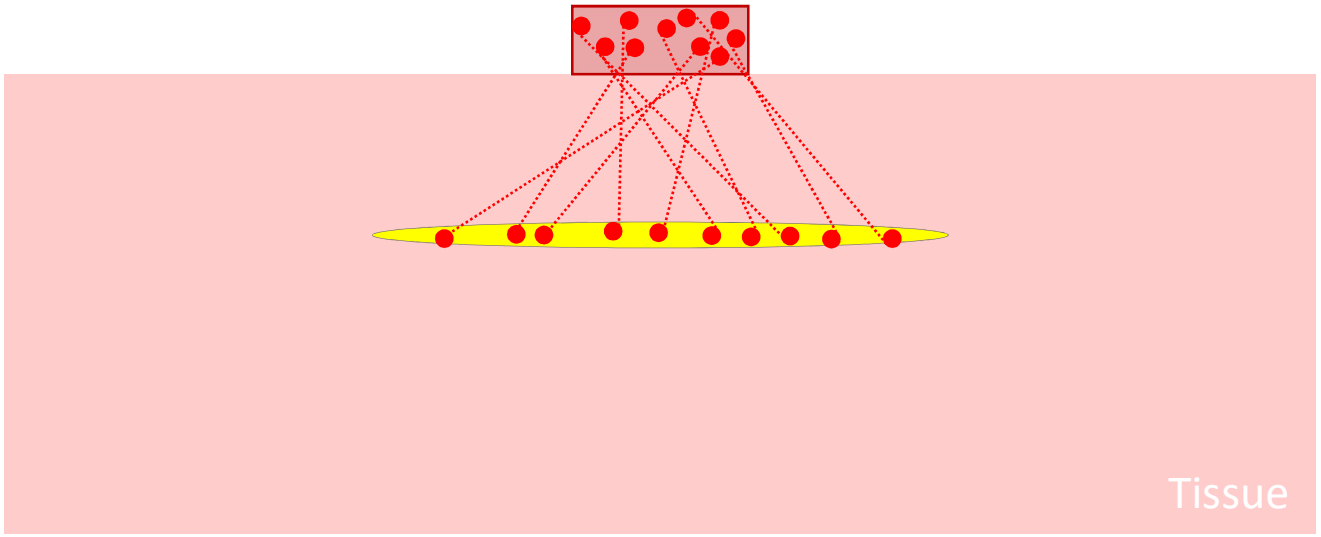
“Point Kernel” Concept

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



Integrate Point Kernels Over Source/Dose Volume

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



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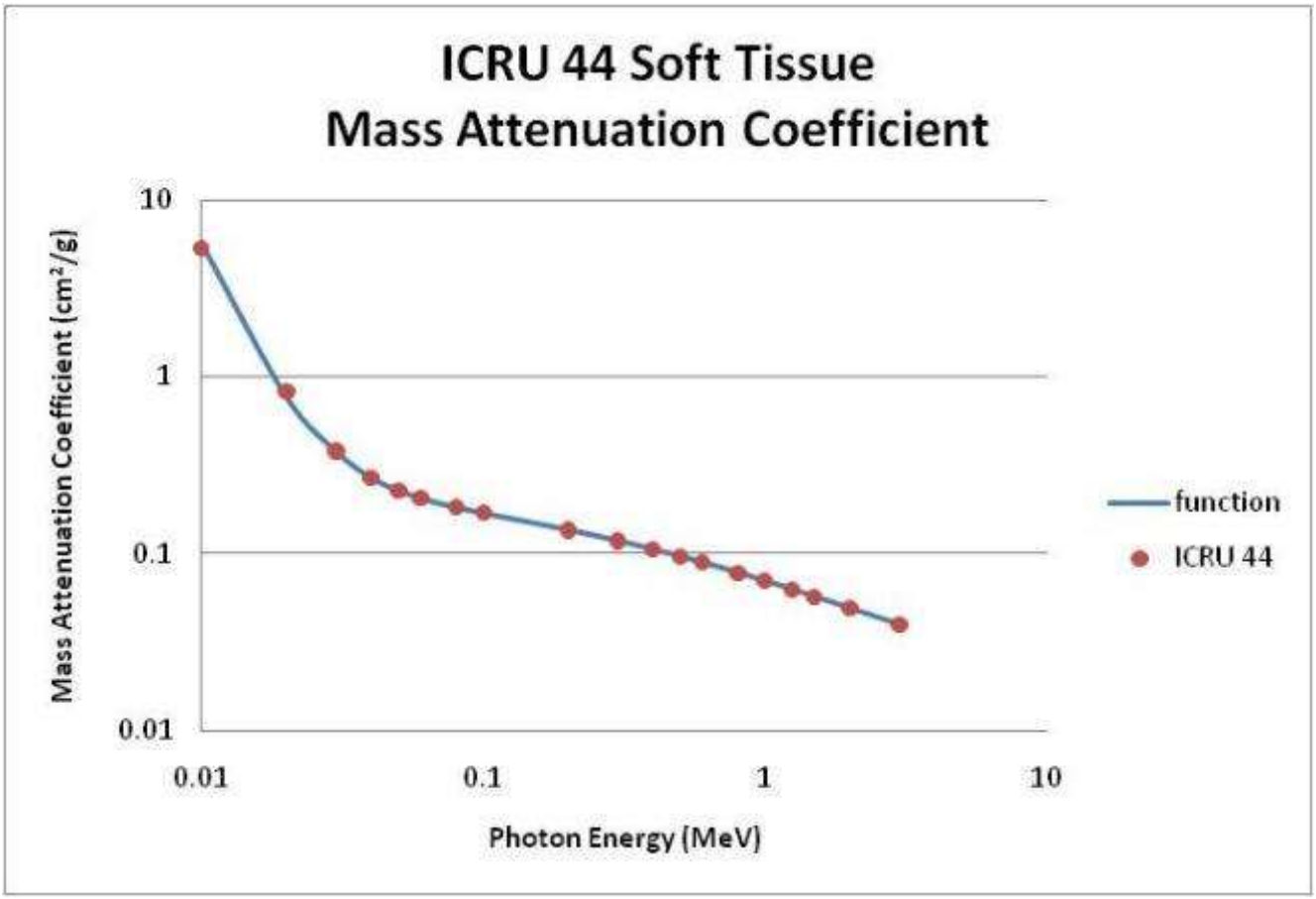
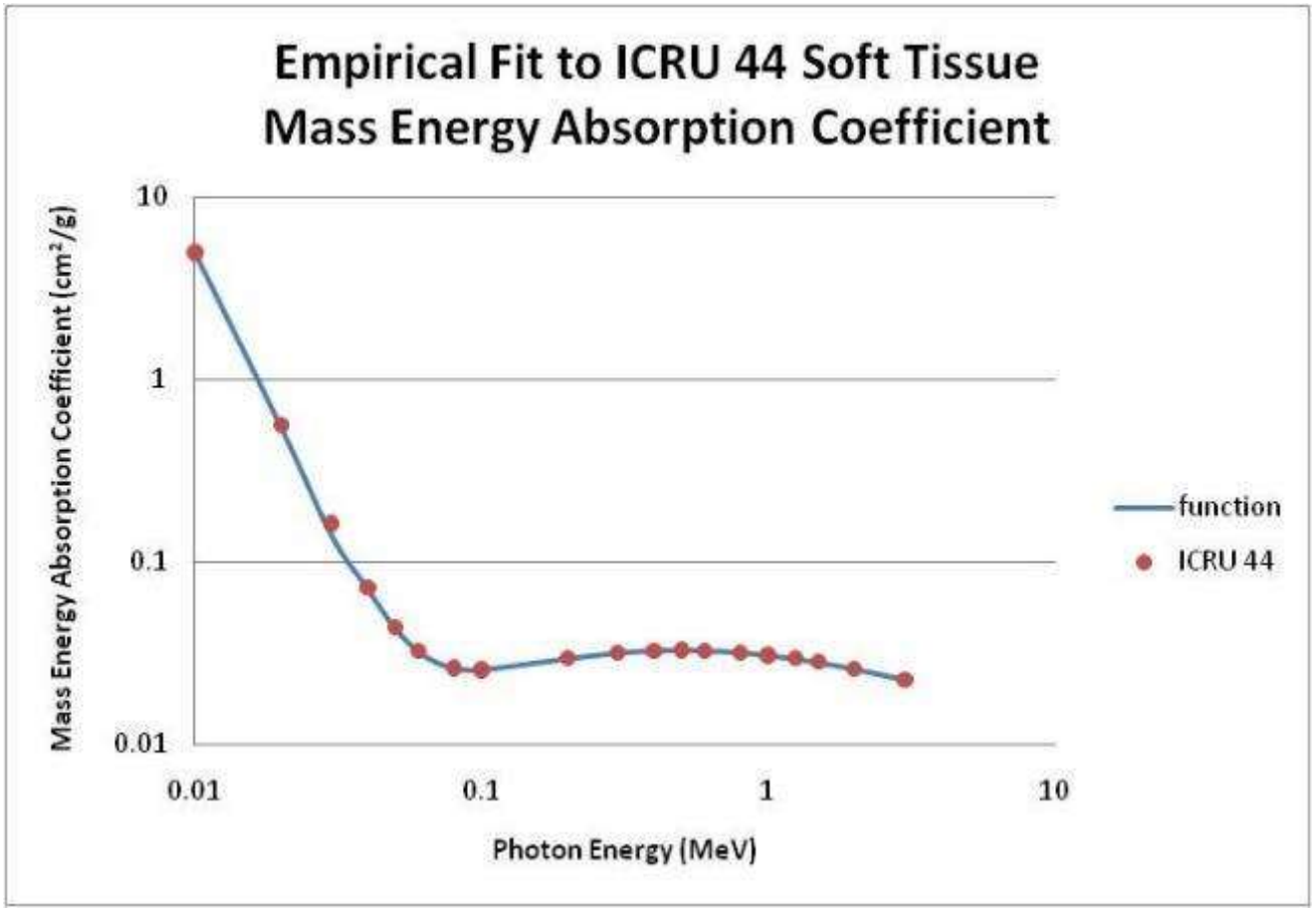
ICRU 44 soft tissue mass attenuation coefficients



ICRU 44 soft tissue mass energy absorption coefficients



Accounting for CPE

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

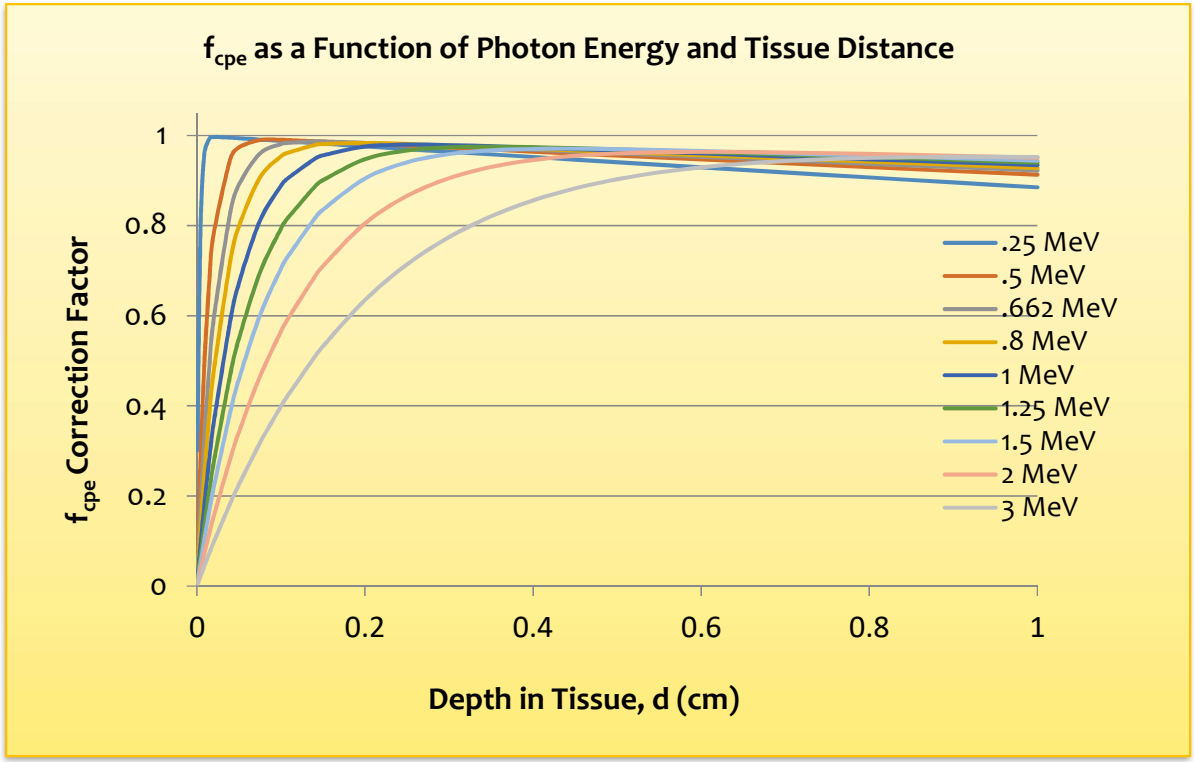
$$D(x) = K(x) \cdot f_{CPE}(x)$$

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

Charged-Particle Buildup

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

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



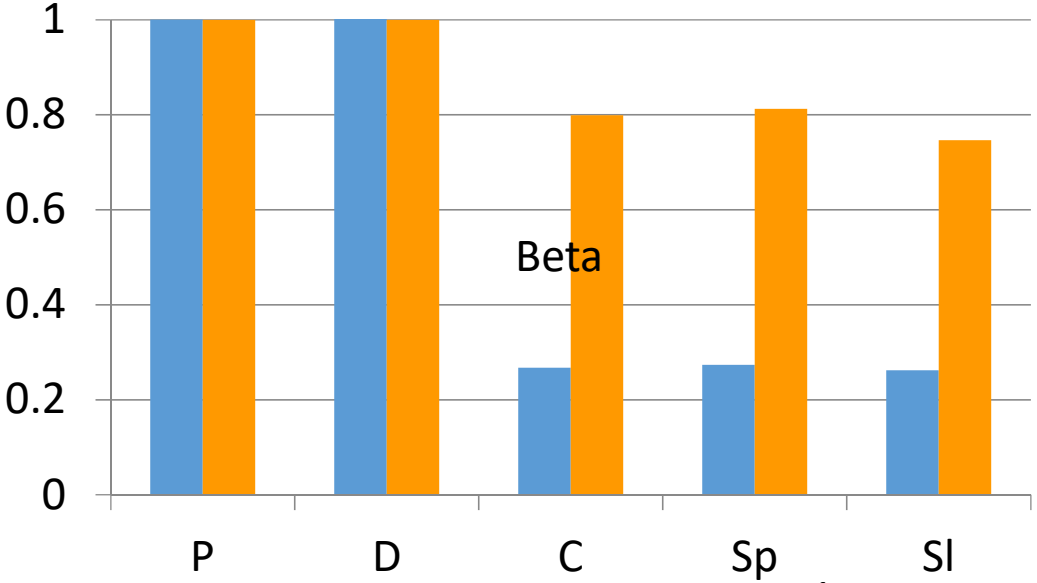
VARSKIN 4/5/6 exposure geometries

- 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

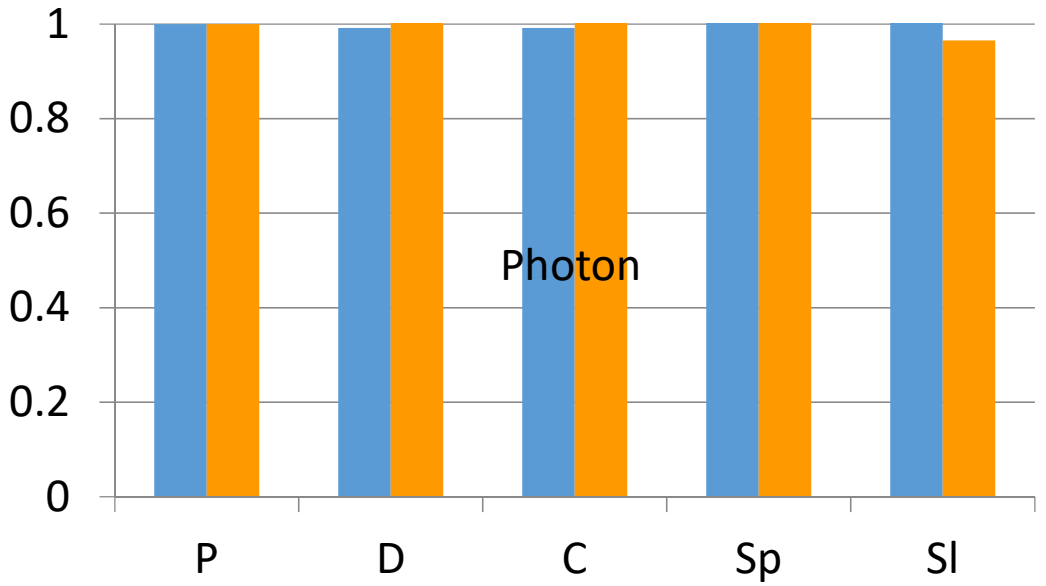
Impact of Source Geometry



^{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

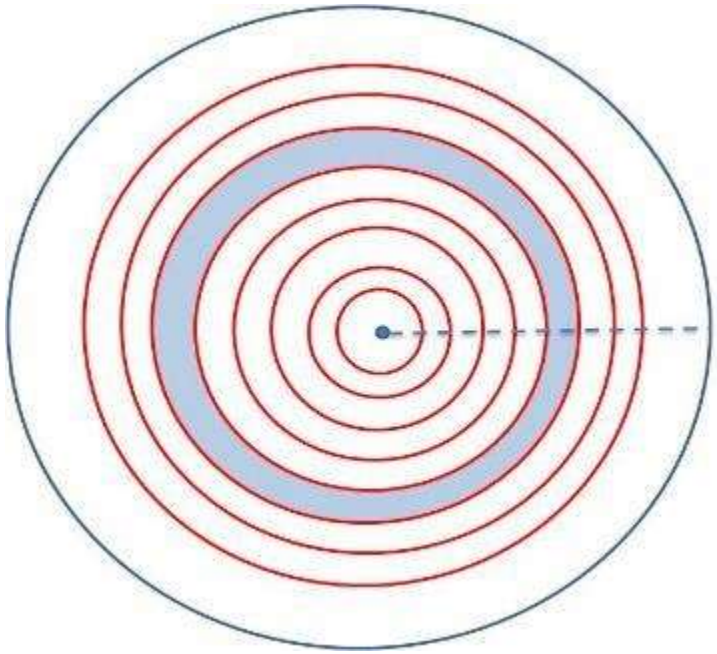


Air-Gap Model

- 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

On-Axis Calculation of Dose

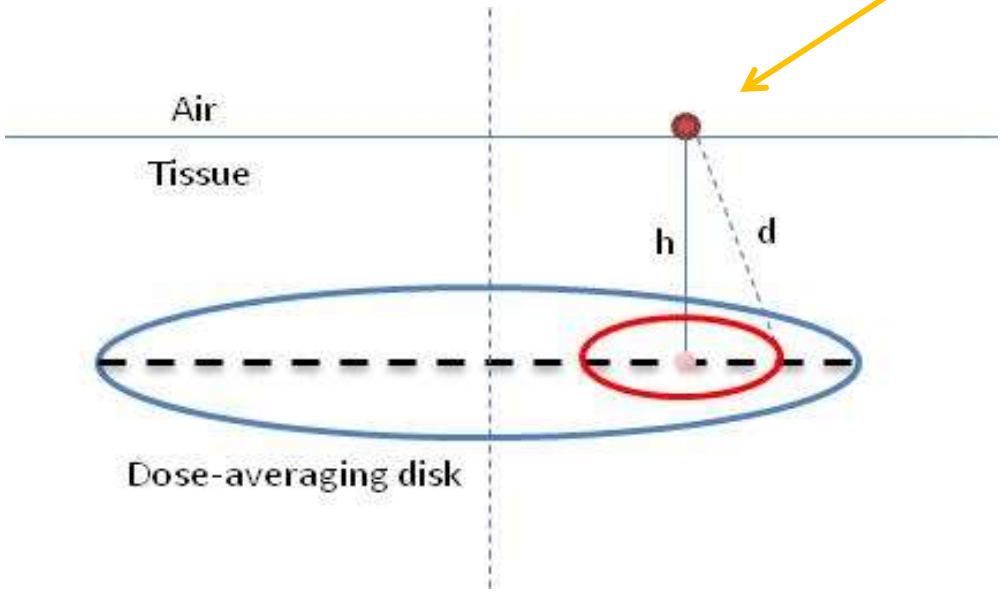
- Varskin 3 calculated dose at 60 locations around the dose-averaging disk
  - Method tends to weight the average such that it provides an over-estimation
- For VARSKIN 4, we assumed the following:
  - Point source is located directly above and on-axis with the averaging disk
  - Presumes symmetry in 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

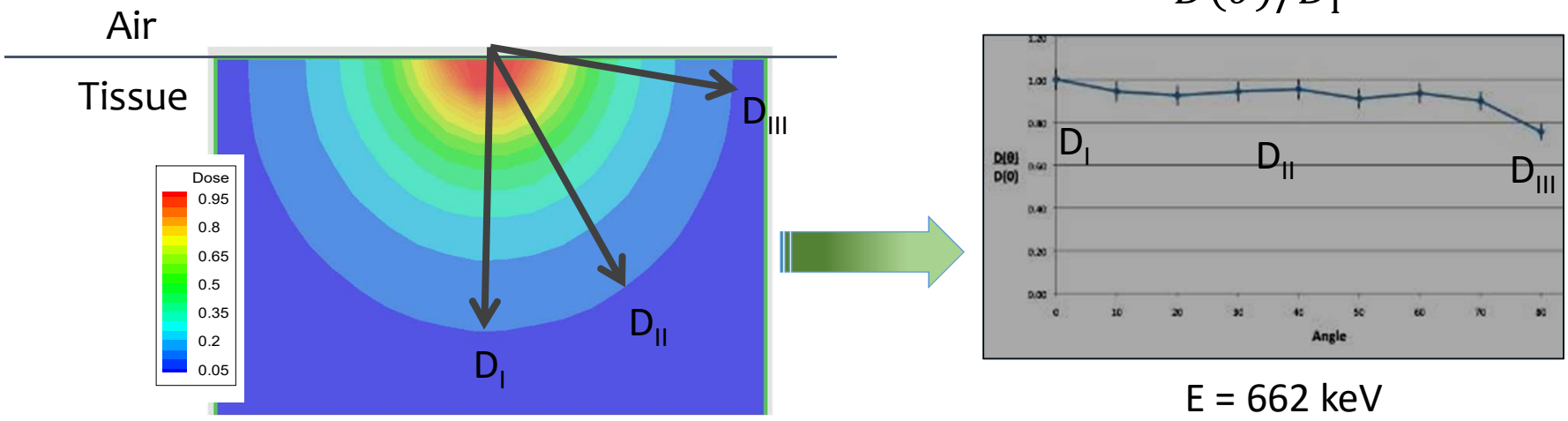


Source is not on axis of dose-averaging disk

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

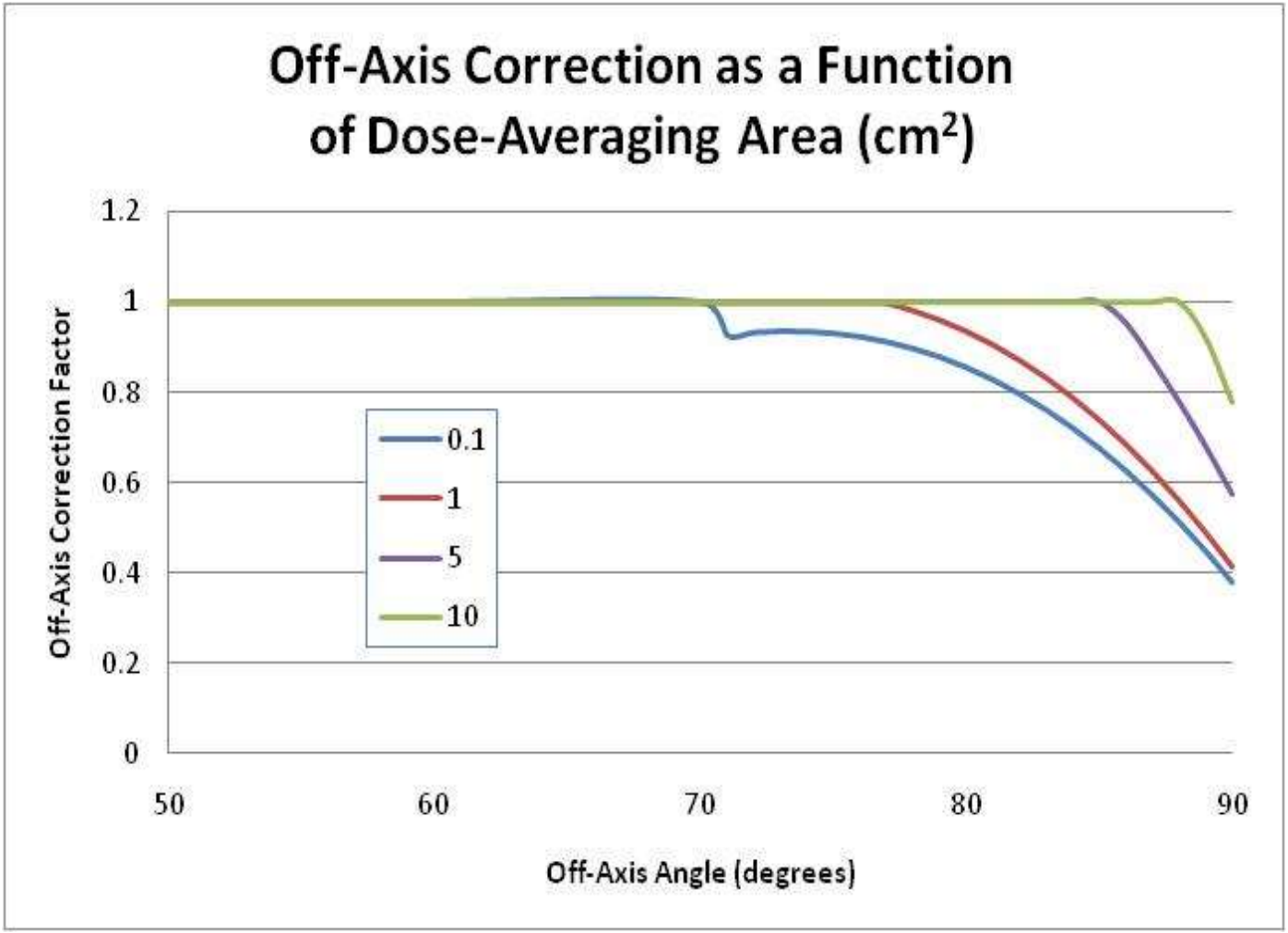
Off-Axis Correction

- 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



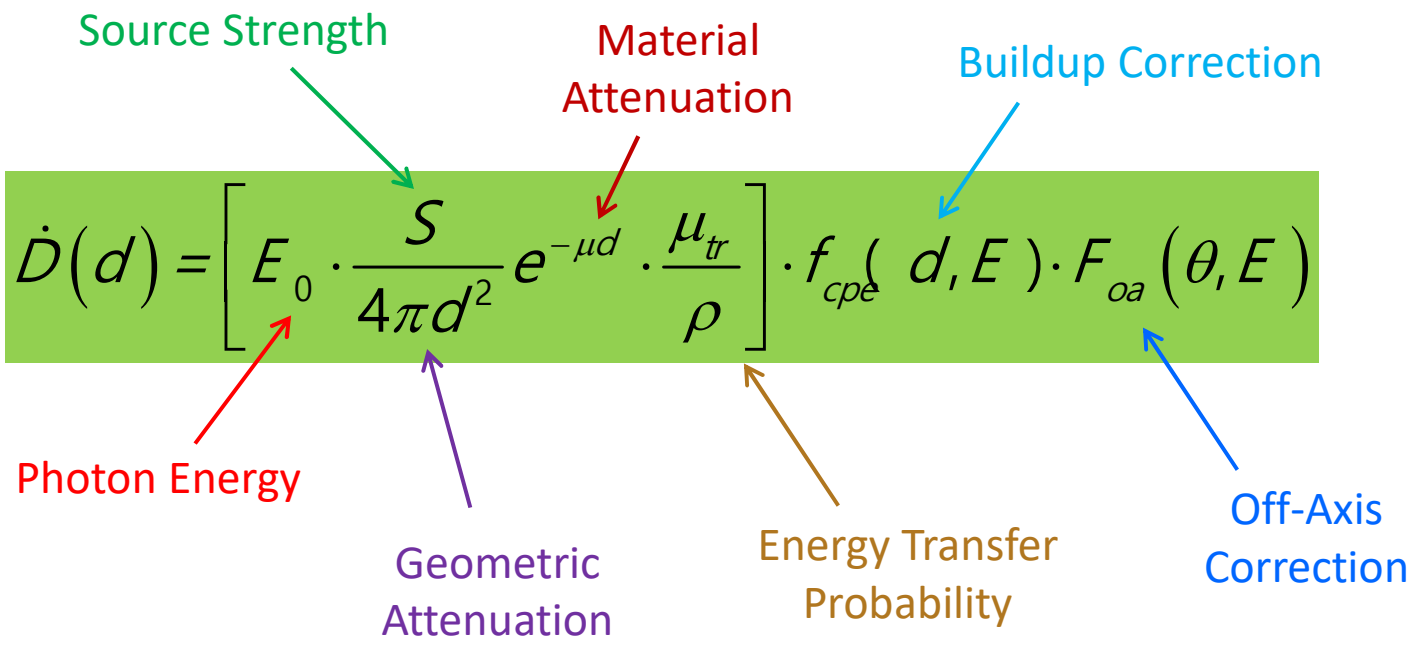
Off-Axis Correction Factors

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:



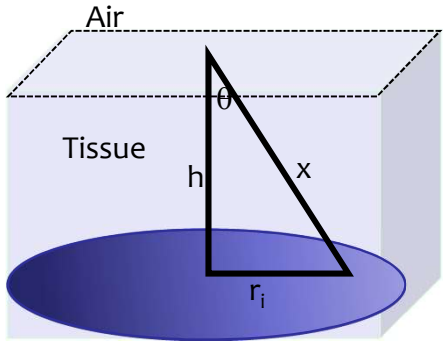
SUMMARIZING the Model

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



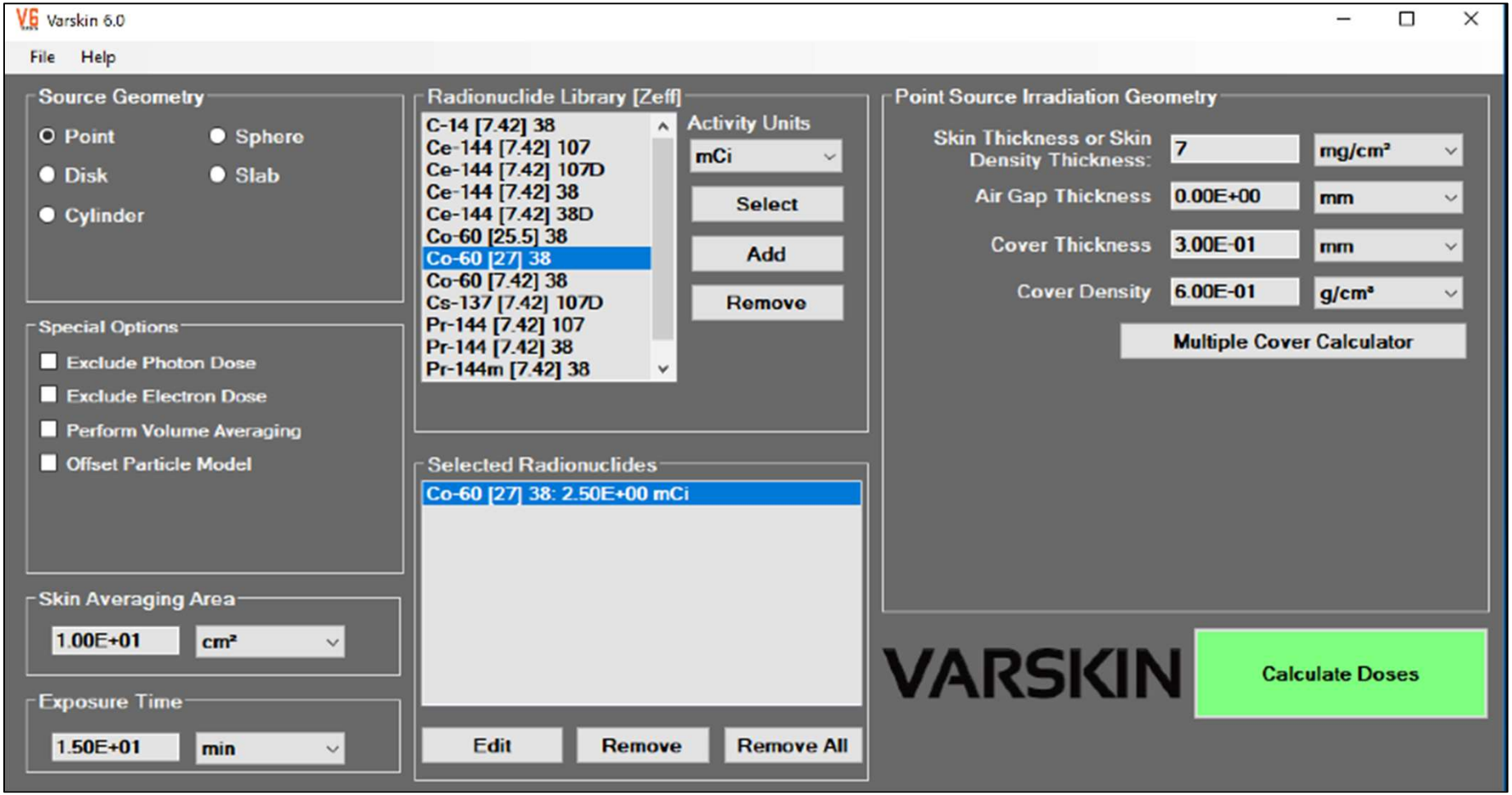
VARSKIN 6

Examples

Scenario #1

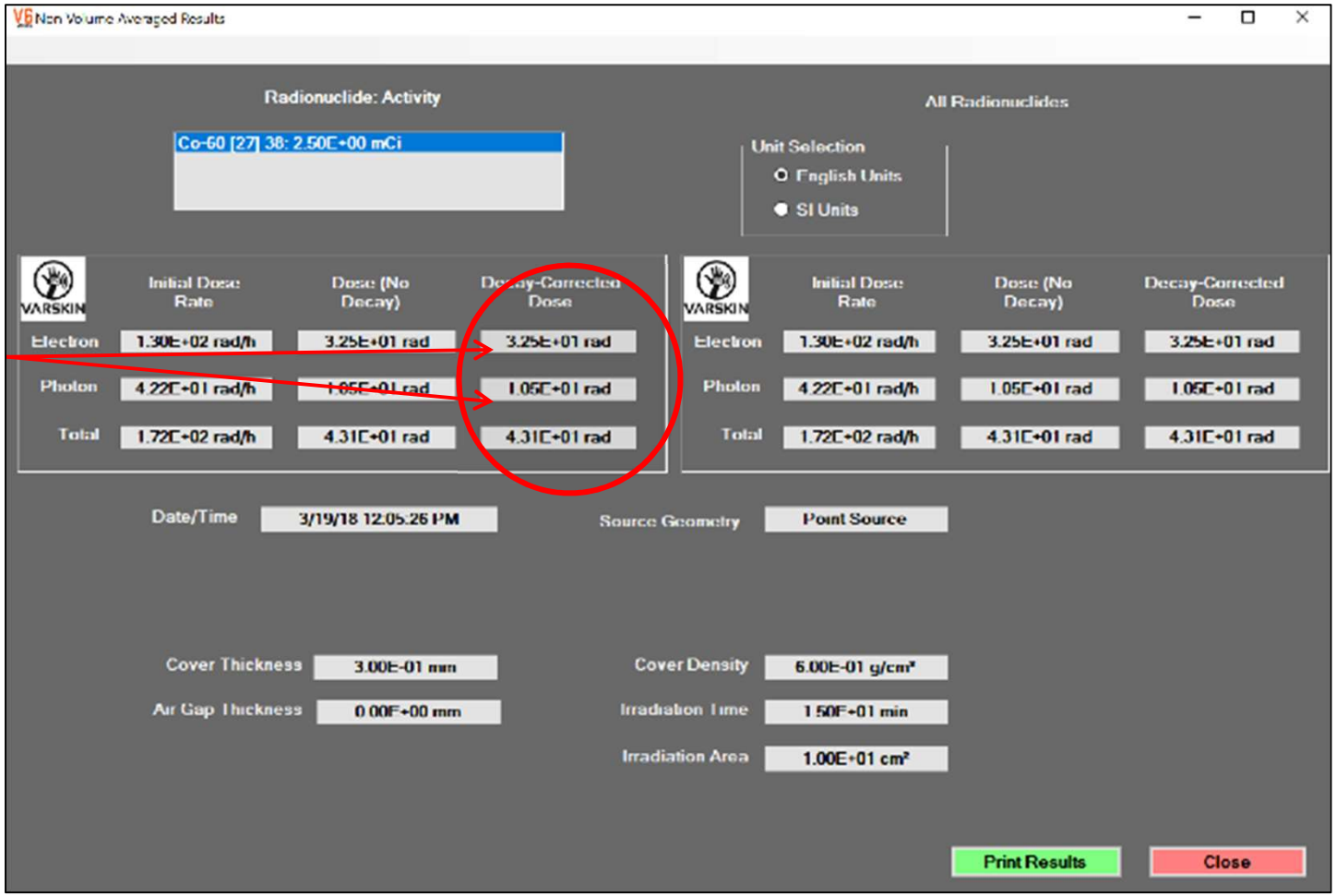
- Radiation worker in reactor containment
- ^{60}Co hot particle (2.5 mCi; 15 min) on gloved hand
- 50 μm @ 8.3 g/cm^3 (Z=27)
- 80 x 70 μm
- Glove characteristics: 0.3 mm and 0.6 g/cm^3
- Initially, point-source geometry
- Then, refine for more realism …

Point source



results

Note β/γ contribution

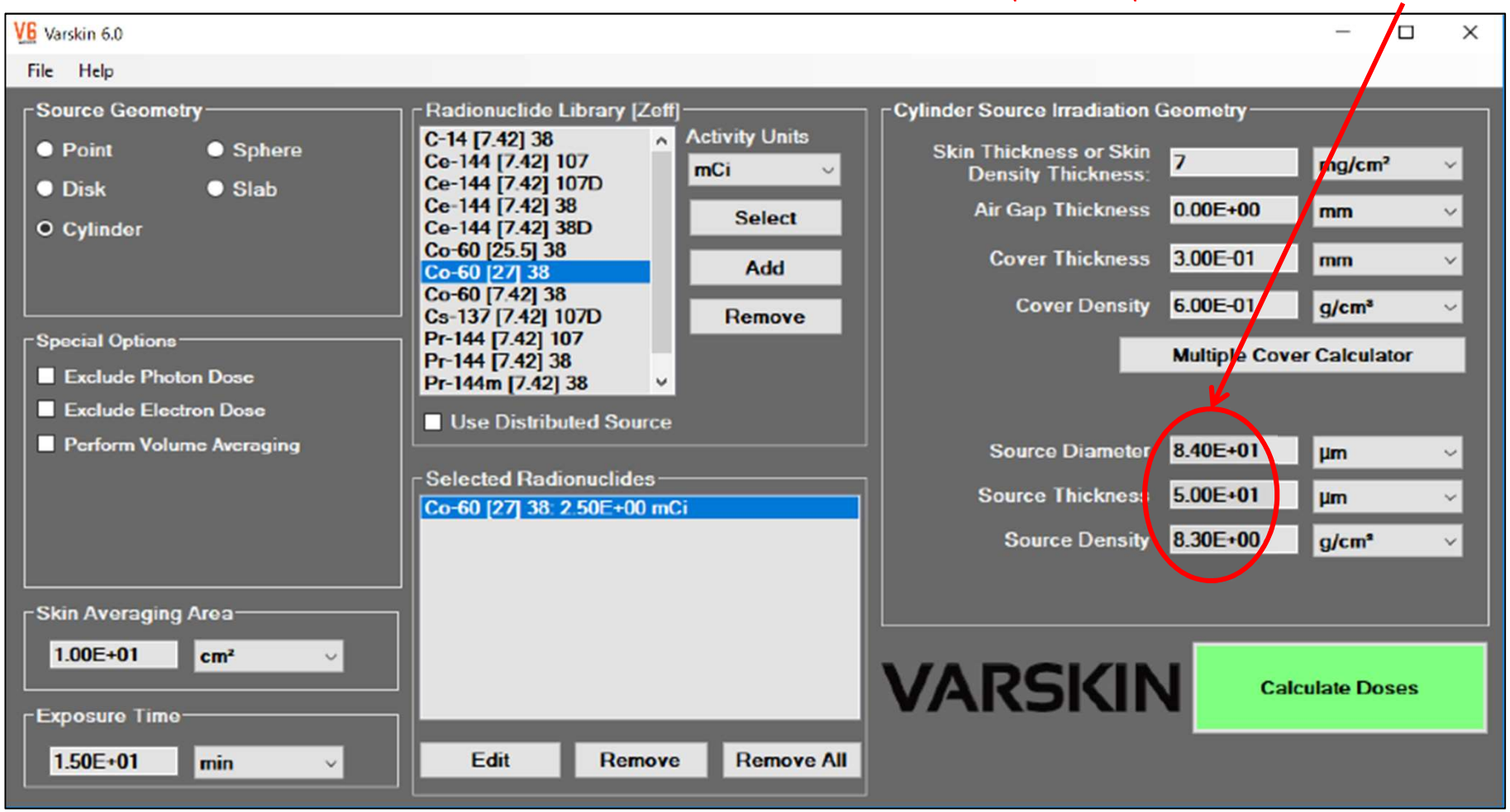


summary

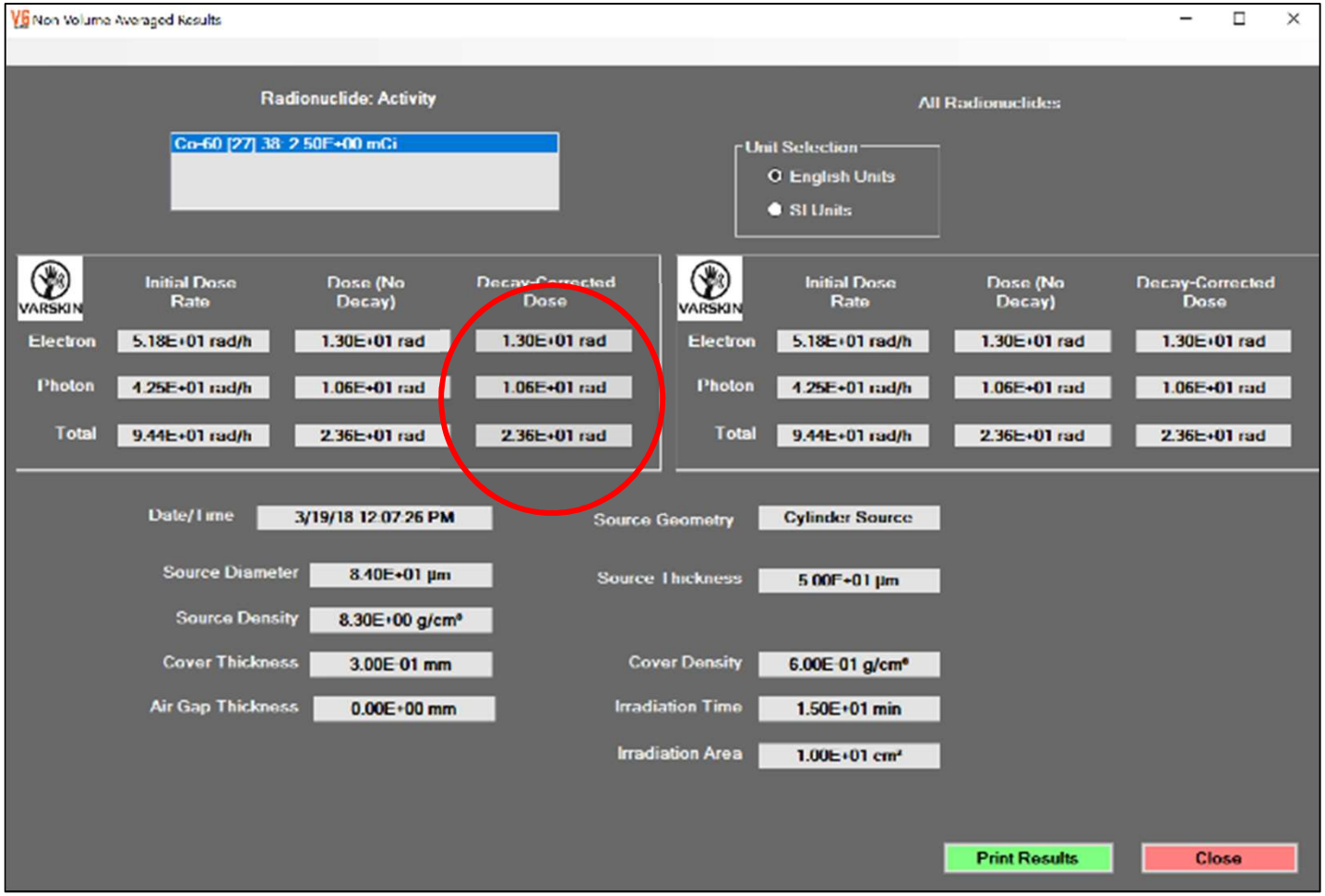
	Beta Dose	Photon Dose	Total Dose (rad)
Point Source	32.5	10.5	43.1
Cylindrical Equivalent			
Deep Dose			

Cylindrical equivalent source

$$d = 2\sqrt{\frac{X \cdot Y}{\pi}} = 2\sqrt{\frac{80\mu m \cdot 70\mu m}{\pi}} = 84\ \mu m$$



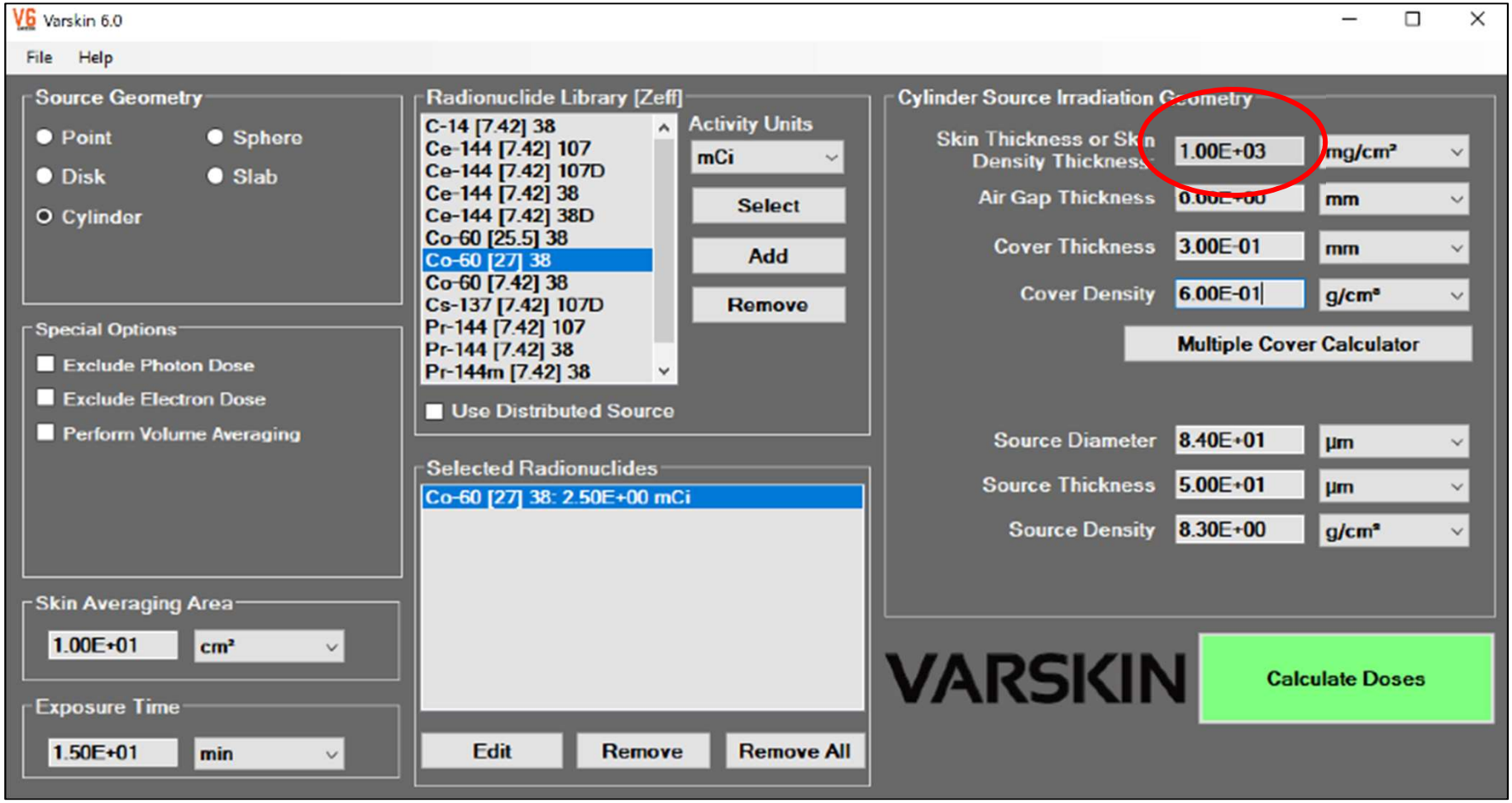
results


Non Volume Averaged Results
Radionuclide: Activity
Co-60 [27] 38.2.50E+00 mCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 5.18E+01 rad/h 1.30E+01 rad 1.30E+01 rad
Photon 4.25E+01 rad/h 1.06E+01 rad 1.06E+01 rad
Total 9.44E+01 rad/h 2.36E+01 rad 2.36E+01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 5.18E+01 rad/h 1.30E+01 rad 1.30E+01 rad
Photon 4.25E+01 rad/h 1.06E+01 rad 1.06E+01 rad
Total 9.44E+01 rad/h 2.36E+01 rad 2.36E+01 rad
Date/Time 3/19/18 12:07:26 PM
Source Geometry Cylinder Source
Source Diameter 8.40E+01 µm
Source Thickness 5.00E+01 µm
Source Density 8.30E+00 g/cm³
Cover Thickness 3.00E-01 mm
Cover Density 6.00E-01 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 1.50E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

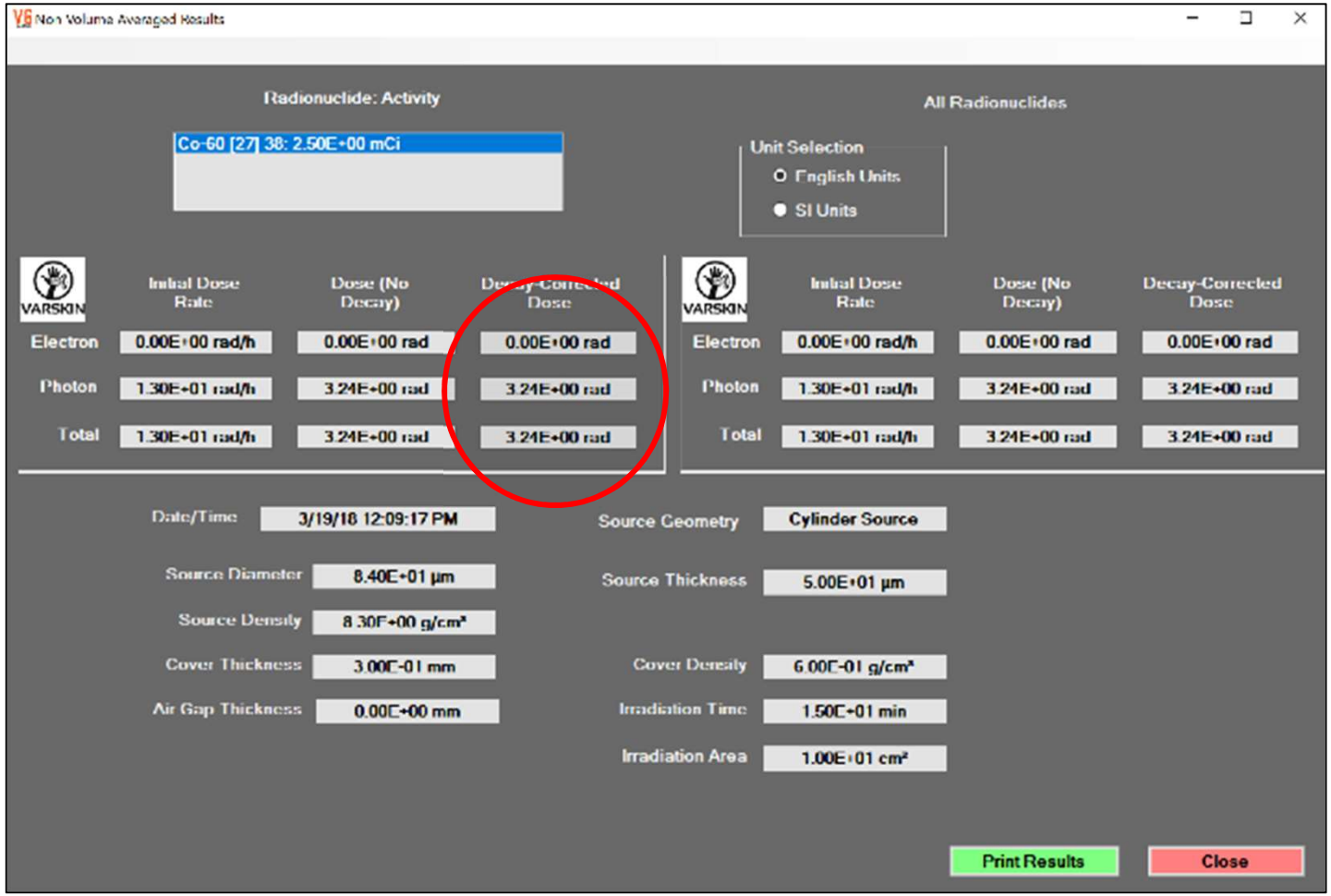
summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point Source	32.5	10.5	43.1
Cylindrical Equivalent	13.0	10.6	23.6
Deep Dose			

Deep dose


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
1.00E+01
cm²
Exposure Time
1.50E+01
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
Co-60 [27] 38
Co-60 [7.42] 38
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Pr-144 [7.42] 38
Pr-144m [7.42] 38
Activity Units
mCi
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Co-60 [27] 38: 2.50E+00 mCi
Edit
Remove
Remove All
Cylinder Source Irradiation Geometry
Skin Thickness or Skin Density Thickness
1.00E+03
mg/cm²
Air Gap Thickness
mm
Cover Thickness
3.00E-01
mm
Cover Density
6.00E-01
g/cm³
Multiple Cover Calculator
Source Diameter
8.40E+01
µm
Source Thickness
5.00E+01
µm
Source Density
8.30E+00
g/cm³
VARSKIN
Calculate Doses

results

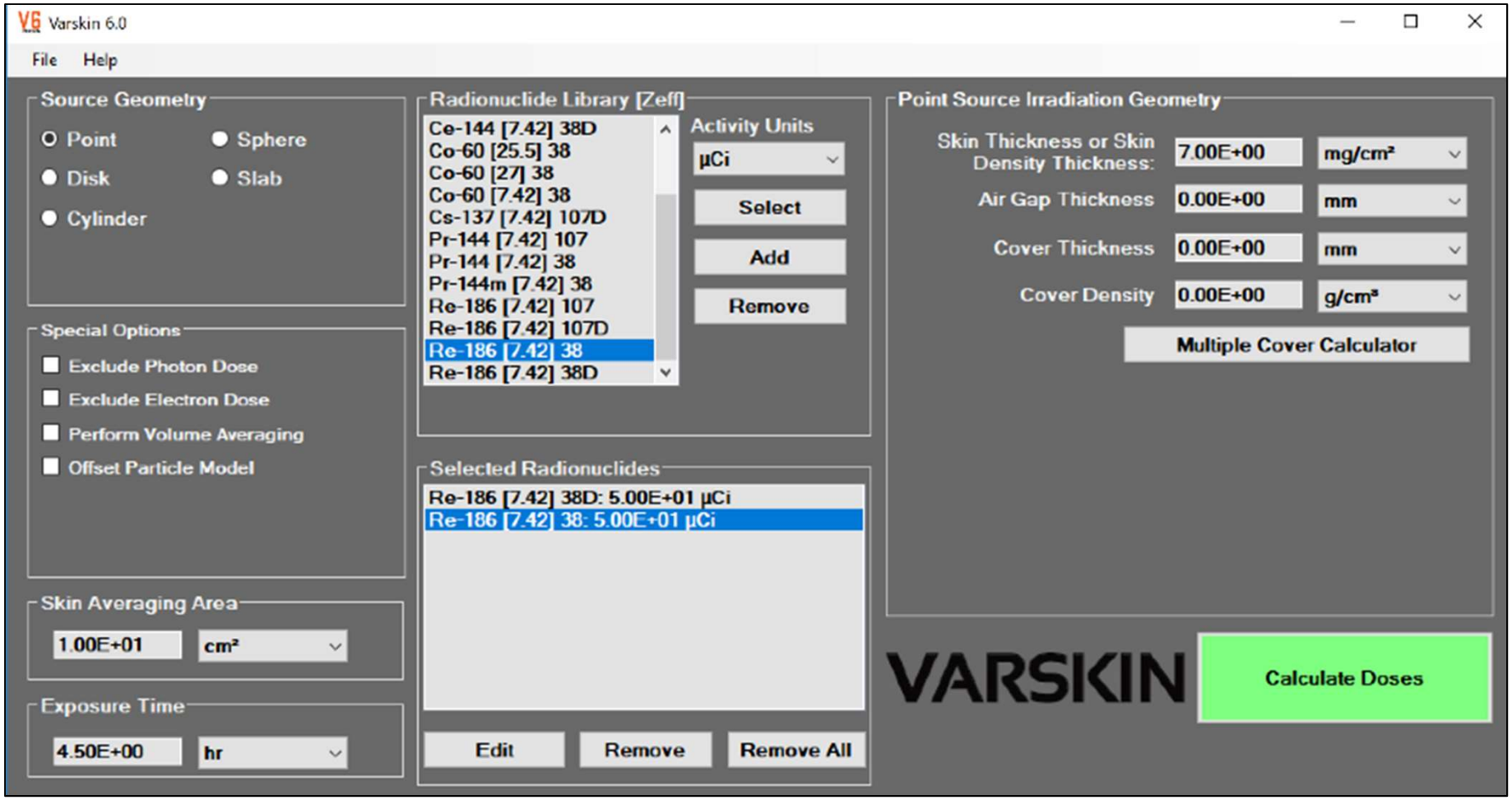

Non Voluma Averaged Results
Radionuclide: Activity
Co-60 [27] 38: 2.50E+00 mCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron
0.00E+00 rad/h
0.00E+00 rad
0.00E+00 rad
Photon
1.30E+01 rad/h
3.24E+00 rad
3.24E+00 rad
Total
1.30E+01 rad/h
3.24E+00 rad
3.24E+00 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron
0.00E+00 rad/h
0.00E+00 rad
0.00E+00 rad
Photon
1.30E+01 rad/h
3.24E+00 rad
3.24E+00 rad
Total
1.30E+01 rad/h
3.24E+00 rad
3.24E+00 rad
Date/Time
3/19/18 12:09:17 PM
Source Geometry
Cylinder Source
Source Diameter
8.40E+01 µm
Source Thickness
5.00E+01 µm
Source Density
8.30E+00 g/cm³
Cover Thickness
3.00E-01 mm
Cover Density
6.00E-01 g/cm³
Air Gap Thickness
0.00E+00 mm
Irradiation Time
1.50E+01 min
Irradiation Area
1.00E+01 cm²
Print Results
Close

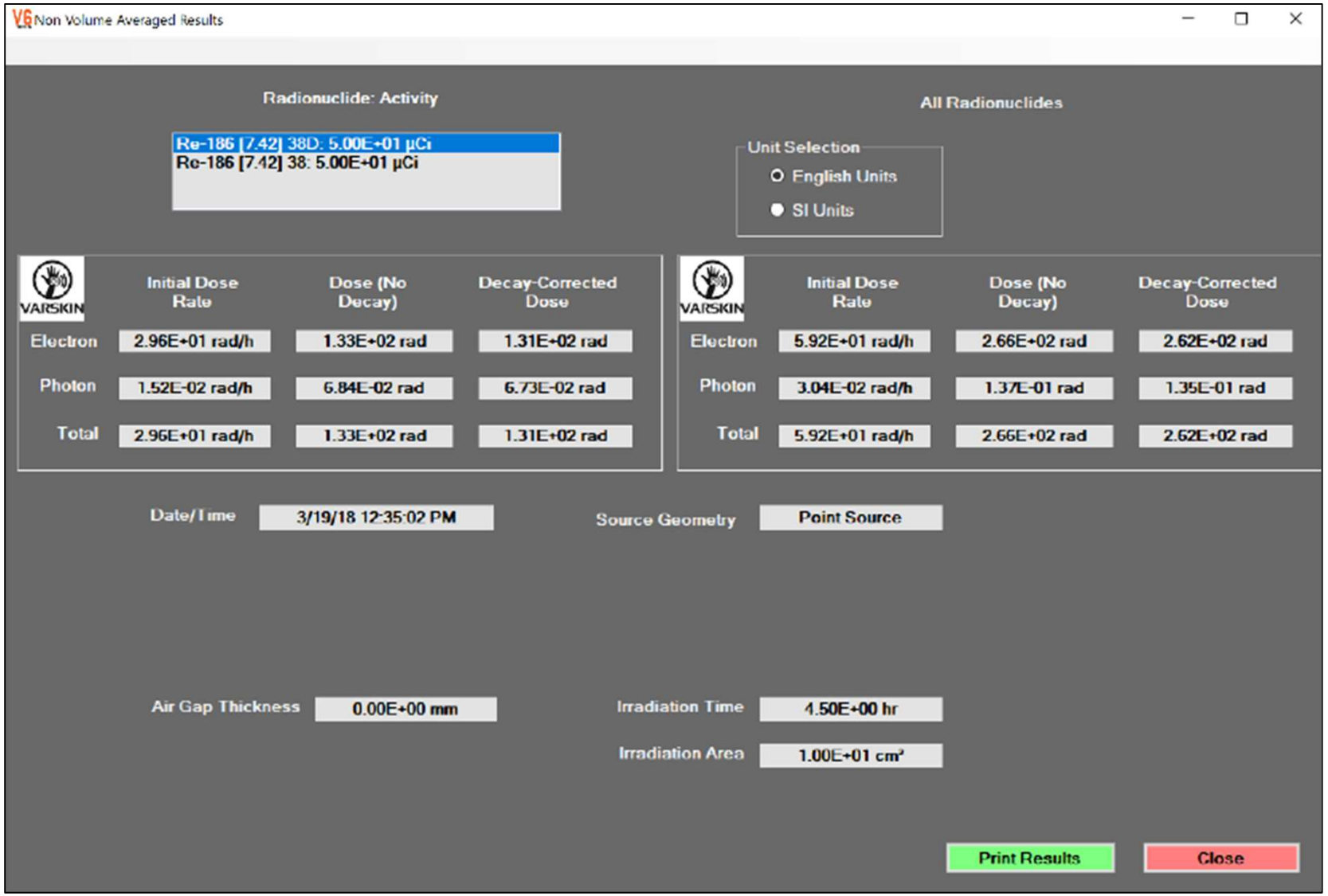
summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point Source	32.5	10.5	43.1
Cylindrical Equivalent	13.0	10.6	23.6
Deep Dose	0	3.24	3.24

Scenario #2

- Nuclear medicine technician
- 10 μCi/mL of ^{186}Re (decays to ^{186}Os and ^{186}W)
- Unknown to tech, 5 mL spills on lab coat
- 50 cm^2 circular shape
- 4.5 hr exposure
- Initially,
  - point-source geometry
  - source in contact with the skin
- Then, refine for more realism
  - coat thickness of 0.4 mm, and density of 0.9 g/cm^3


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
1.00E+01
cm²
Exposure Time
4.50E+00
hr
Radionuclide Library [Zeff]
Ce-144 [7.42] 38D
Co-60 [25.5] 38
Co-60 [27] 38
Co-60 [7.42] 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] 107
Re-186 [7.42] 107D
Re-186 [7.42] 38
Re-186 [7.42] 38D
Activity Units
µCi
Select
Add
Remove
Selected Radionuclides
Re-186 [7.42] 38D: 5.00E+01 µCi
Re-186 [7.42] 38: 5.00E+01 µCi
Edit
Remove
Remove All
Point Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7.00E+00
mg/cm²
Air Gap Thickness
0.00E+00
mm
Cover Thickness
0.00E+00
mm
Cover Density
0.00E+00
g/cm³
Multiple Cover Calculator
VARSKIN
Calculate Doses


Non Volume Averaged Results
Radionuclide: Activity
Re-186 [7.42] 38D: 5.00E+01 µCi
Re-186 [7.42] 38: 5.00E+01 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 2.96E+01 rad/h 1.33E+02 rad 1.31E+02 rad
Photon 1.52E-02 rad/h 6.84E-02 rad 6.73E-02 rad
Total 2.96E+01 rad/h 1.33E+02 rad 1.31E+02 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 5.92E+01 rad/h 2.66E+02 rad 2.62E+02 rad
Photon 3.04E-02 rad/h 1.37E-01 rad 1.35E-01 rad
Total 5.92E+01 rad/h 2.66E+02 rad 2.62E+02 rad
Date/Time 3/19/18 12:35:02 PM
Source Geometry Point Source
Air Gap Thickness 0.00E+00 mm
Irradiation Time 4.50E+00 hr
Irradiation Area 1.00E+01 cm²
Print Results
Close

summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point on Skin	131	0.0673	131
Disk on Skin			
Disk on Coat			
Cylinder in Cloth			

summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point on Skin	131	0.0673	131
Disk on Skin	26.2	0.0149	26.2
Disk on Coat			
Cylinder in Cloth			

summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point on Skin	131	0.0673	131
Disk on Skin	26.2	0.0149	26.2
Disk on Coat	9.21	0.0110	9.23
Cylinder in Cloth			

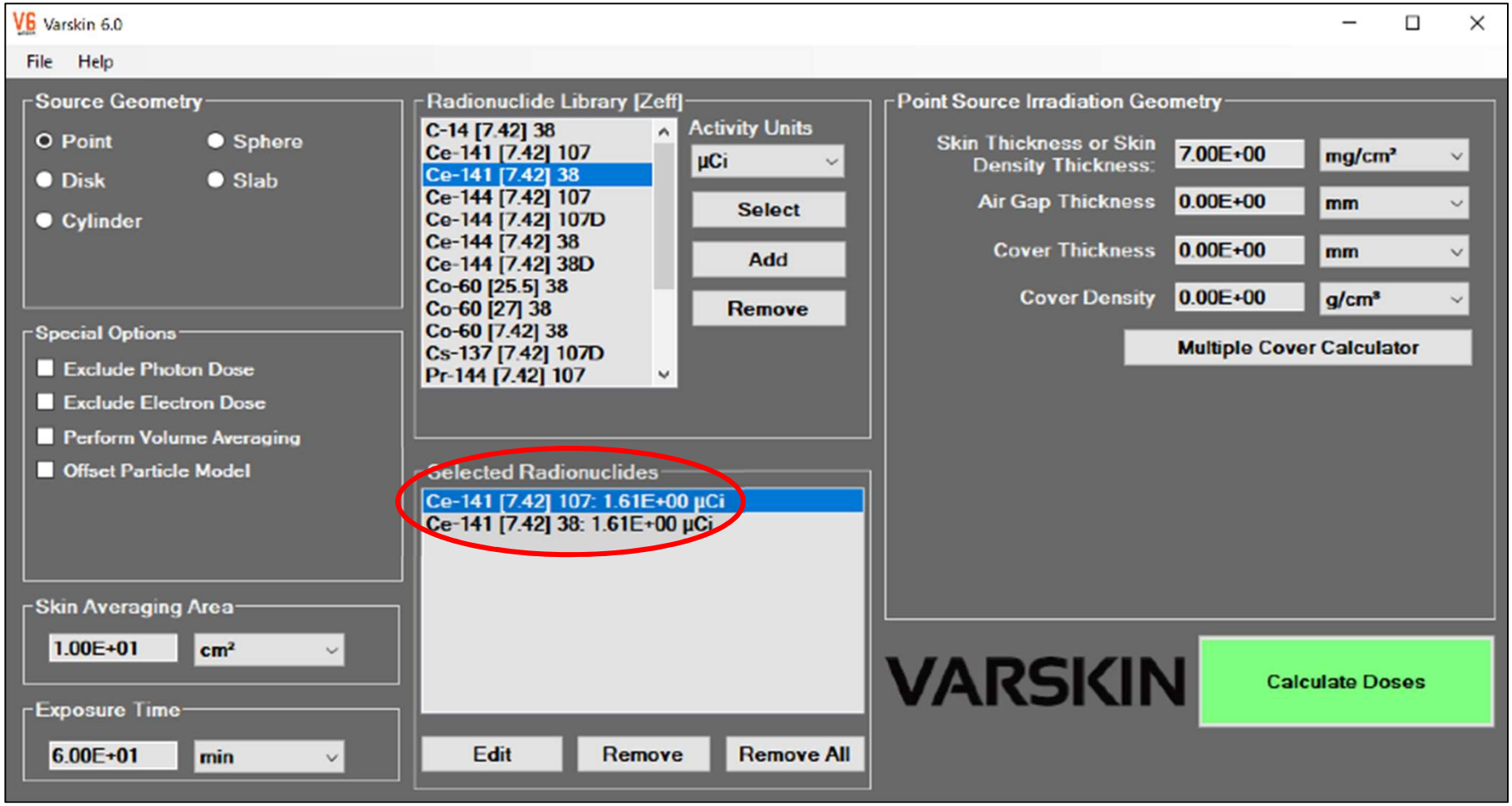
summary

	Beta Dose	Photon Dose	Total Dose (rad)
Point on Skin	131	0.0673	131
Disk on Skin	26.2	0.0149	26.2
Disk on Coat	9.21	0.0110	9.23
Cylinder in Cloth	16.9	0.0126	16.9

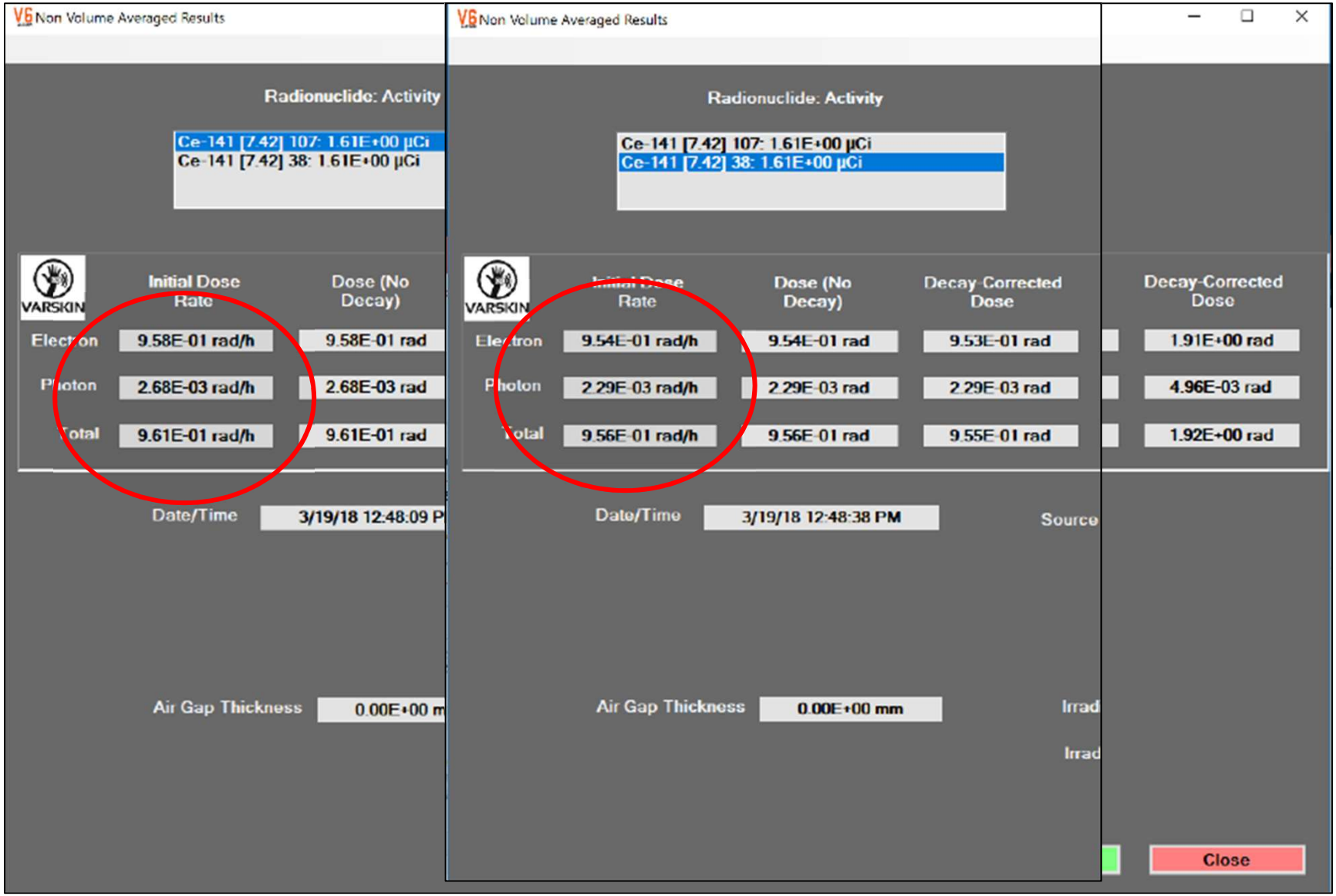
scenario #3

- Dose rate from general contamination
- ^{141}Ce directly on the skin
  - with concentration (0.25 μCi/cm^2)
- 1” x 1” contamination area
- Exposure to 1.61 μCi liquid source
- As before, point-source geometry for a bounding estimate
- … then refine for more realism …

Point source



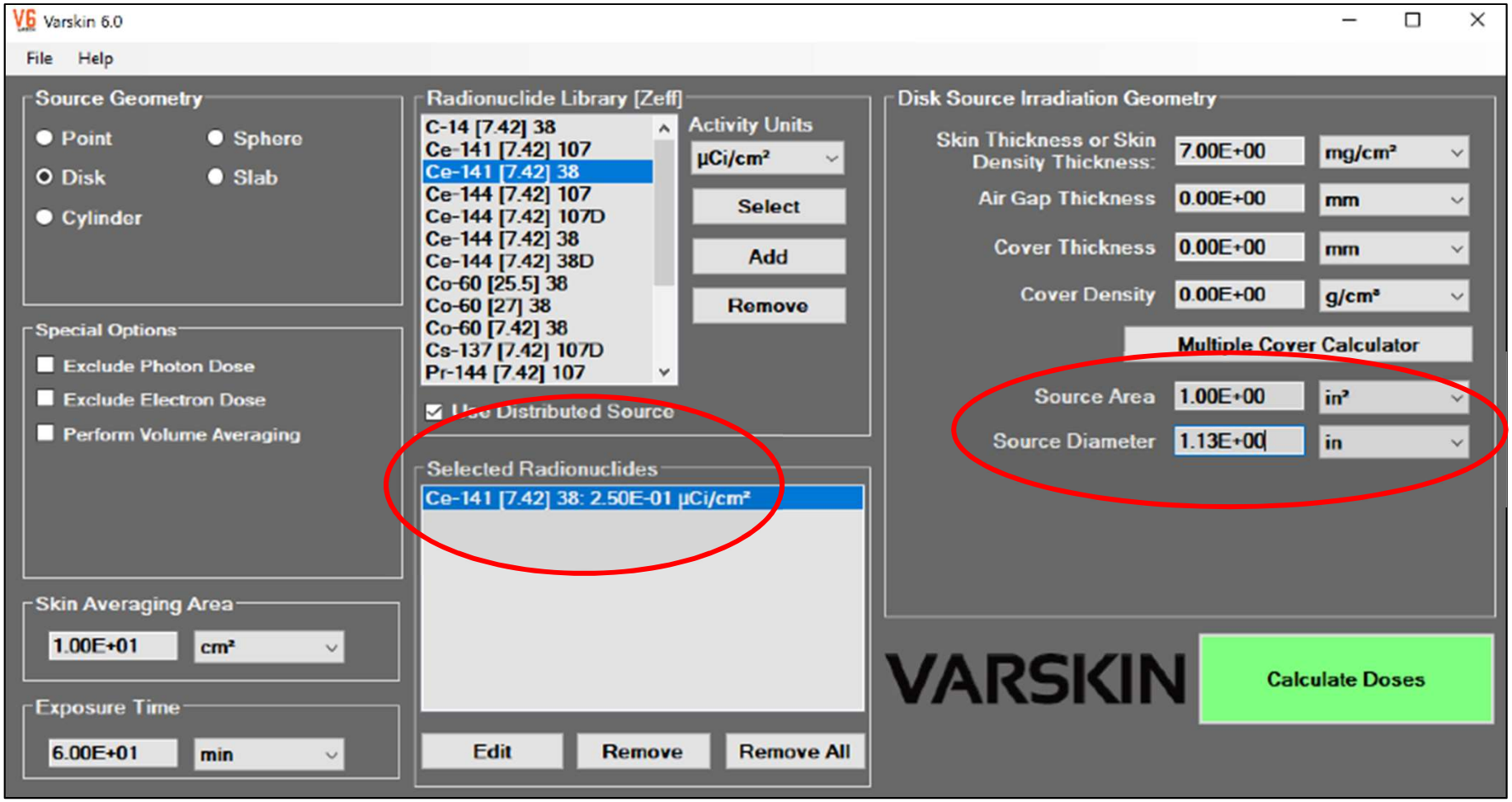
results


Non Volume Averaged Results
Radionuclide: Activity
Ce-141 [7.42] 107: 1.61E+00 µCi
Ce-141 [7.42] 38: 1.61E+00 µCi
VARSKIN
Initial Dose Rate
Dose (No Decay)
Electron 9.58E-01 rad/h 9.58E-01 rad
Photon 2.68E-03 rad/h 2.68E-03 rad
Total 9.61E-01 rad/h 9.61E-01 rad
Date/Time 3/19/18 12:48:09 P
Air Gap Thickness 0.00E+00 m
Non Volume Averaged Results
Radionuclide: Activity
Ce-141 [7.42] 107: 1.61E+00 µCi
Ce-141 [7.42] 38: 1.61E+00 µCi
VARSKIN
Dose (No Decay)
Decay-Corrected Dose
Decay-Corrected Dose
Electron 9.54E-01 rad/h 9.54E-01 rad 9.53E-01 rad 1.91E+00 rad
Photon 2.29E-03 rad/h 2.29E-03 rad 2.29E-03 rad 4.96E-03 rad
Total 9.56E-01 rad/h 9.56E-01 rad 9.55E-01 rad 1.92E+00 rad
Date/Time 3/19/18 12:48:38 PM
Source
Air Gap Thickness 0.00E+00 mm
Irrad
Irrad
Close

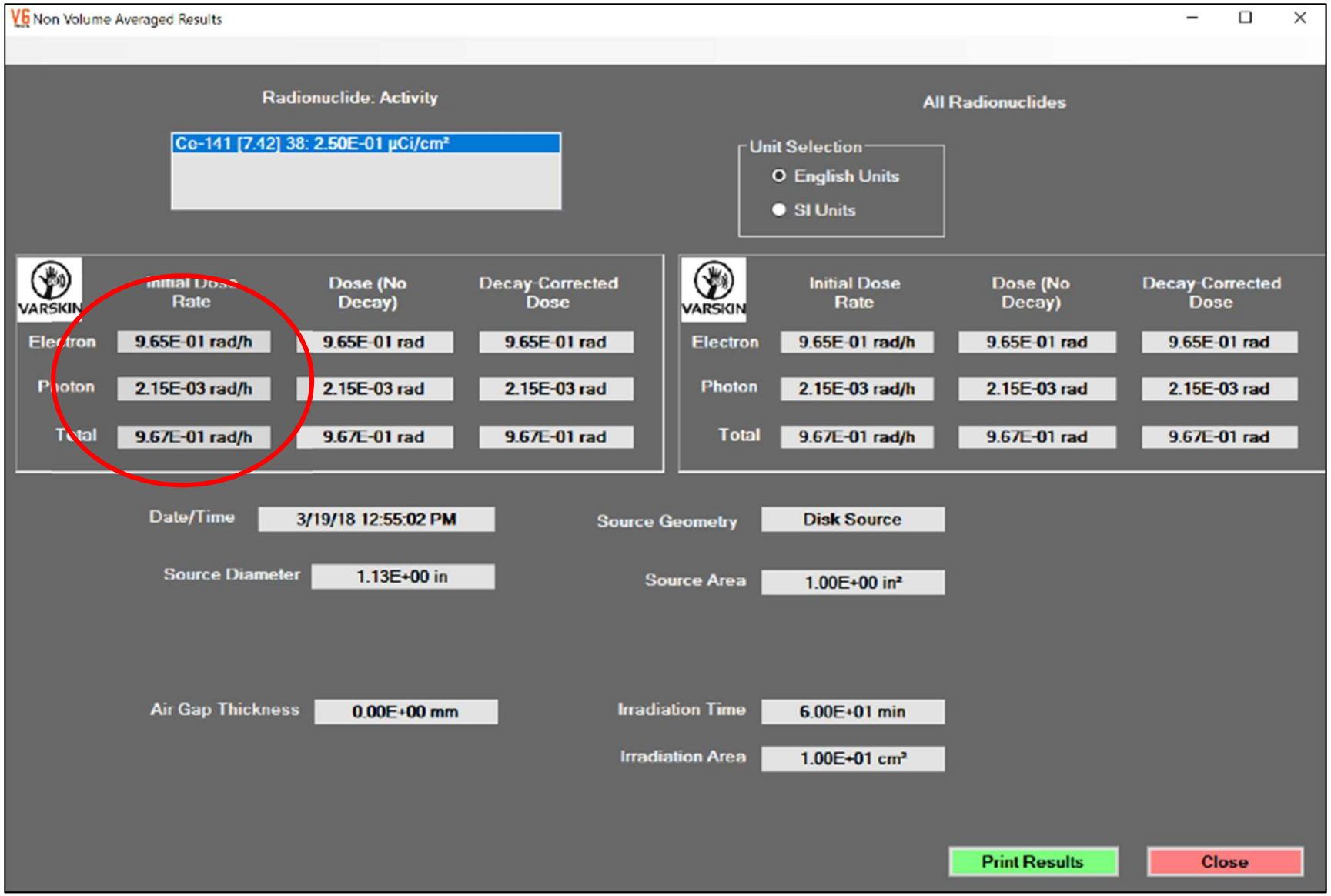
summary

1” x 1”	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Point Source	0.954	0.00229	0.956
2D Disk Source			
Water Slab Source			
Air Slab Source			
Water Slab (1 cm^2)			

2D Disk source



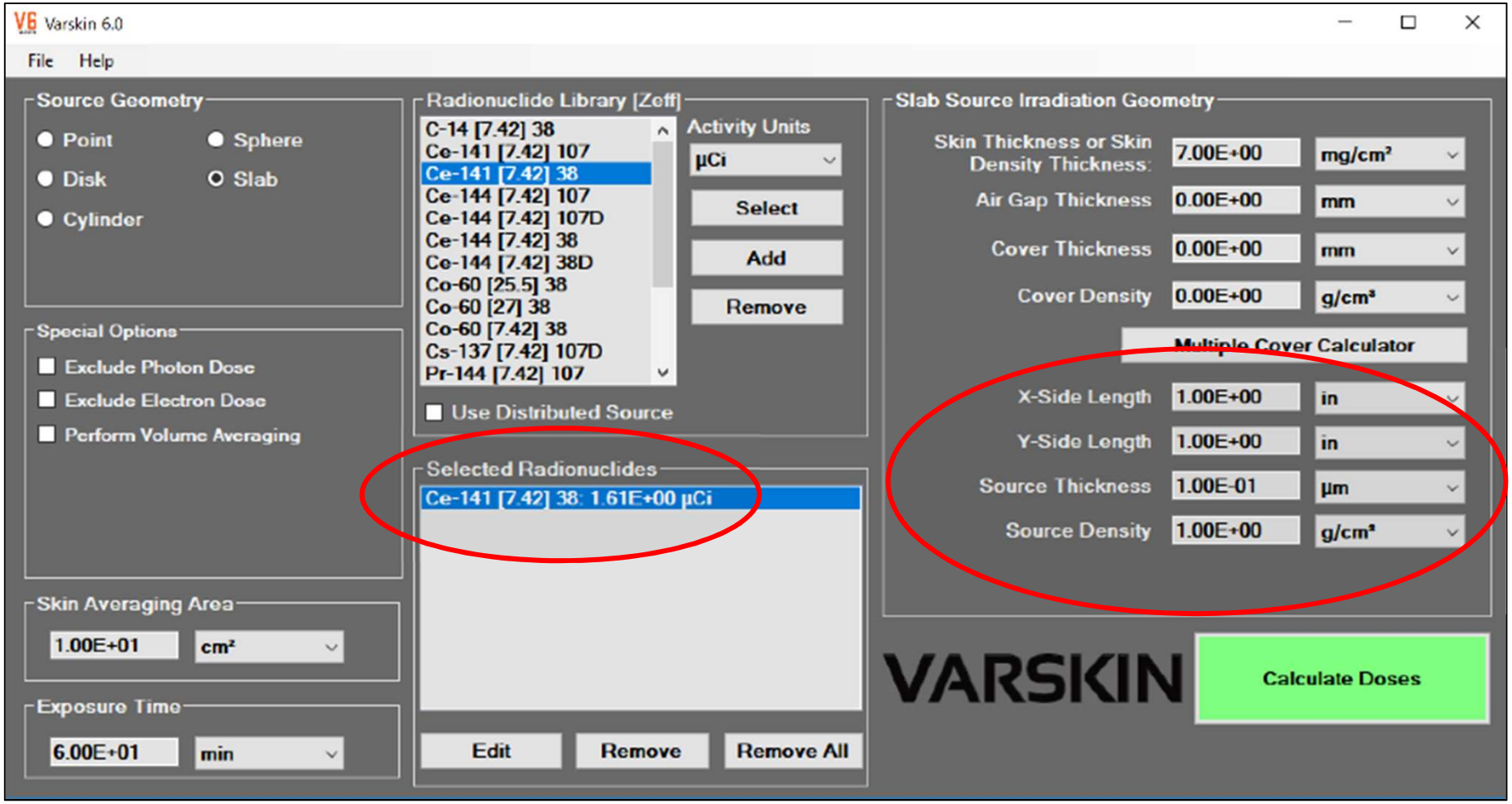
results


Non Volume Averaged Results
Radionuclide: Activity
Co-141 [7.42] 38: 2.50E-01 µCi/cm²
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.65E-01 rad/h 9.65E-01 rad 9.65E-01 rad
Photon 2.15E-03 rad/h 2.15E-03 rad 2.15E-03 rad
Total 9.67E-01 rad/h 9.67E-01 rad 9.67E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.65E-01 rad/h 9.65E-01 rad 9.65E-01 rad
Photon 2.15E-03 rad/h 2.15E-03 rad 2.15E-03 rad
Total 9.67E-01 rad/h 9.67E-01 rad 9.67E-01 rad
Date/Time 3/19/18 12:55:02 PM
Source Geometry Disk Source
Source Diameter 1.13E+00 in
Source Area 1.00E+00 in²
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

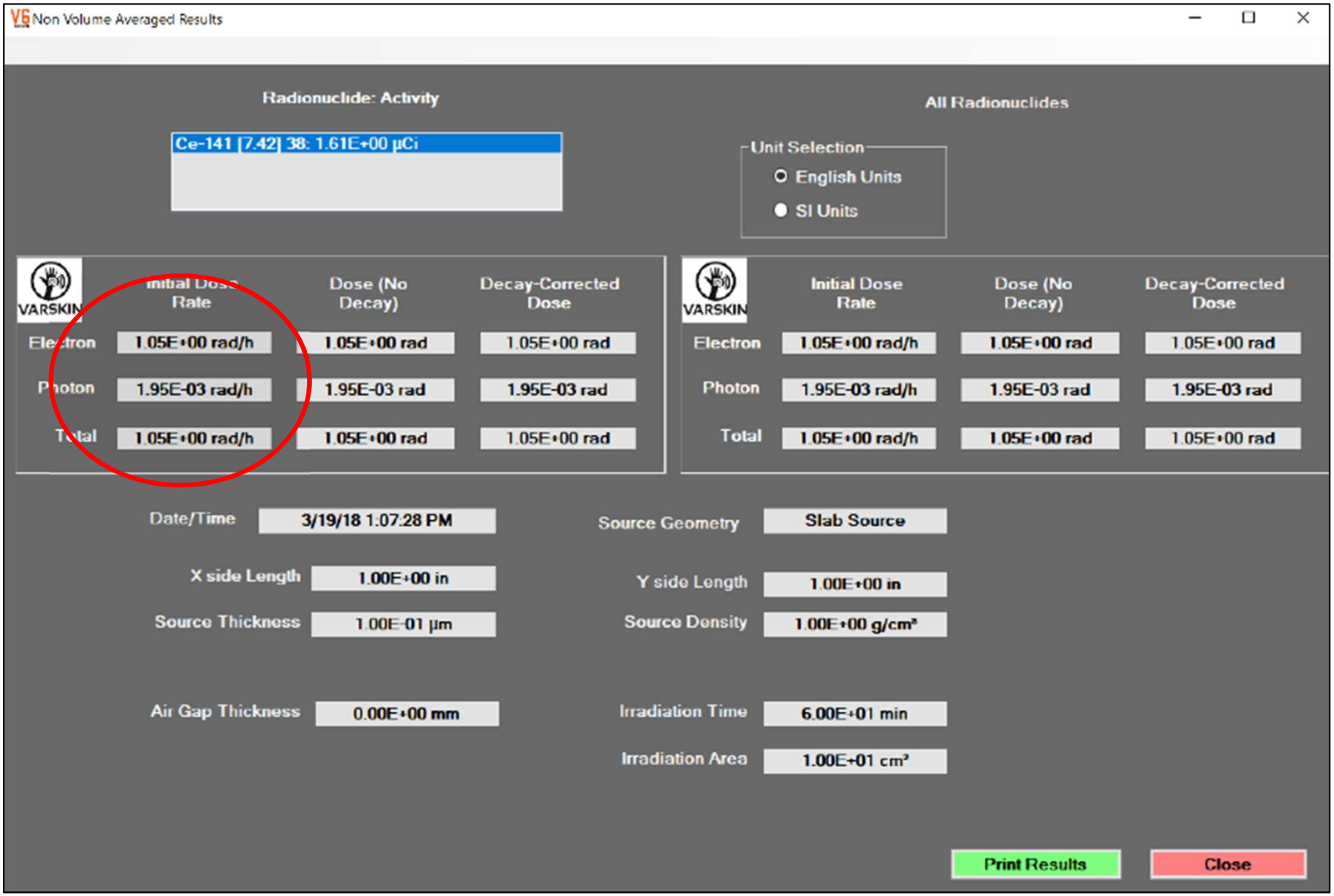
summary

1” x 1”	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Point Source	0.954	0.00229	0.956
2D Disk Source	0.965	0.00215	0.967
Water Slab Source			
Air Slab Source			
Water Slab (1 cm^2)			

Slab source


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
1.00E+01
cm²
Exposure Time
6.00E+01
min
Radionuclide Library [Zeff]
C-14 [7.42] 38
Co-141 [7.42] 107
Ce-141 [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
Co-60 [27] 38
Co-60 [7.42] 38
Cs-137 [7.42] 107D
Pr-144 [7.42] 107
Activity Units
µCi
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Ce-141 [7.42] 38: 1.61E+00 µCi
Edit
Remove
Remove All
Slab Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7.00E+00
mg/cm²
Air Gap Thickness
0.00E+00
mm
Cover Thickness
0.00E+00
mm
Cover Density
0.00E+00
g/cm³
Multiple Cover Calculator
X-Side Length
1.00E+00
in
Y-Side Length
1.00E+00
in
Source Thickness
1.00E-01
µm
Source Density
1.00E+00
g/cm³
VARSKIN
Calculate Doses

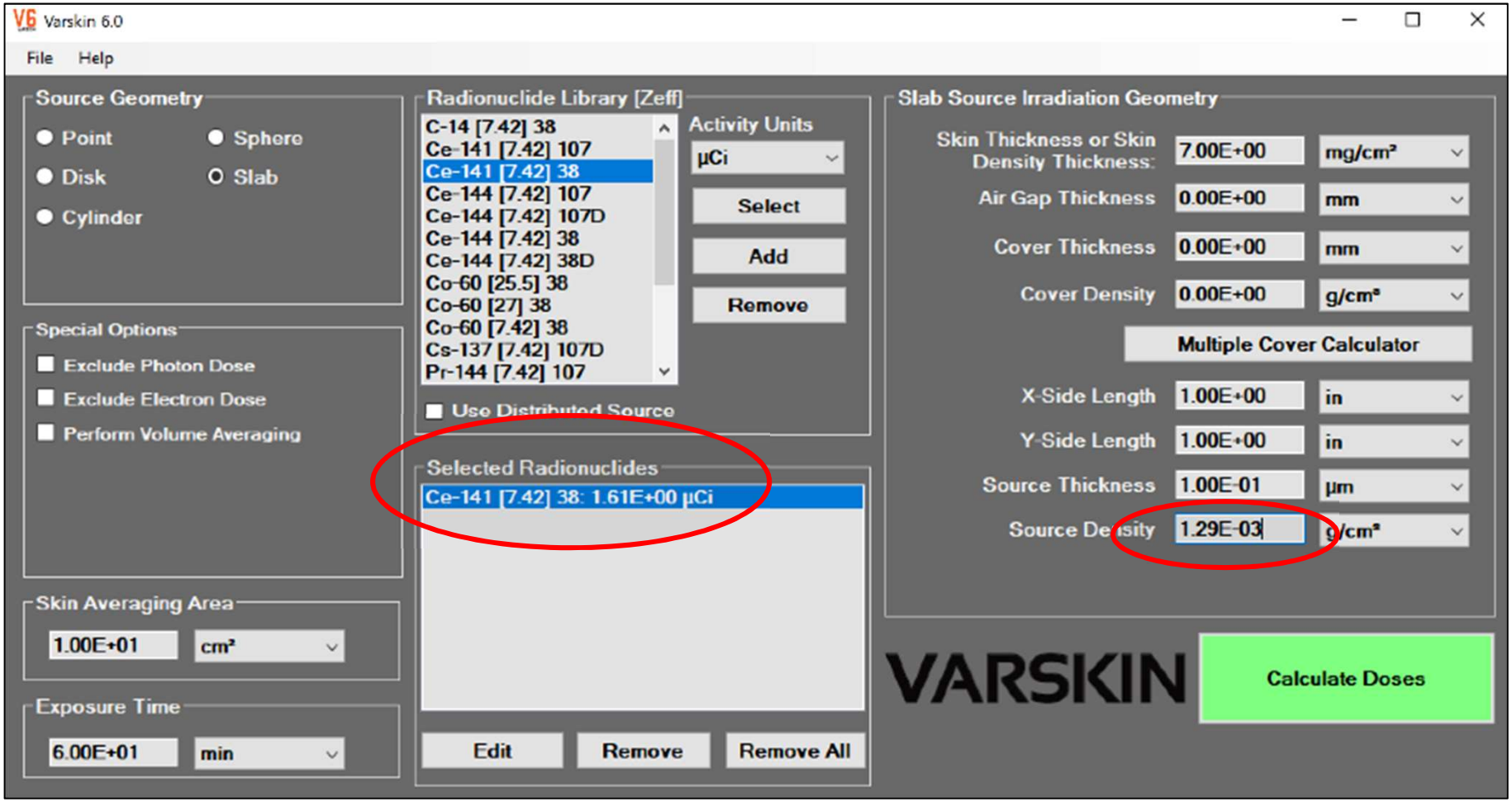
results


Non Volume Averaged Results
Radionuclide: Activity
Ce-141 [7.42] 38: 1.61E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Date/Time 3/19/18 1:07:28 PM
Source Geometry Slab Source
X side Length 1.00E+00 in
Y side Length 1.00E+00 in
Source Thickness 1.00E-01 µm
Source Density 1.00E+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

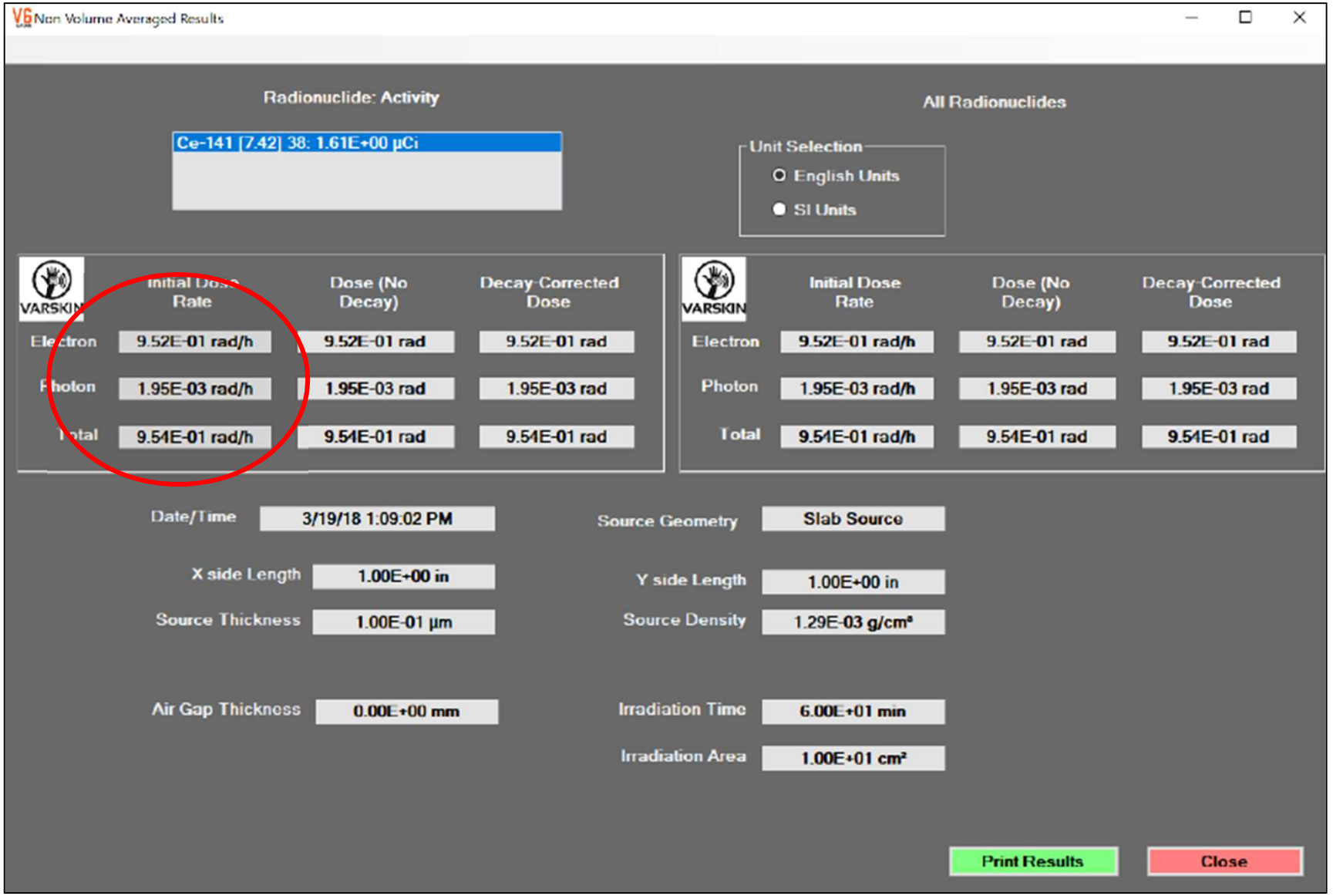
summary

1” x 1”	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Point Source	0.954	0.00229	0.956
2D Disk Source	0.965	0.00215	0.967
Water Slab Source	1.05	0.00195	1.05
Air Slab Source			
Water Slab (1 cm^2)			

Slab source (low density)



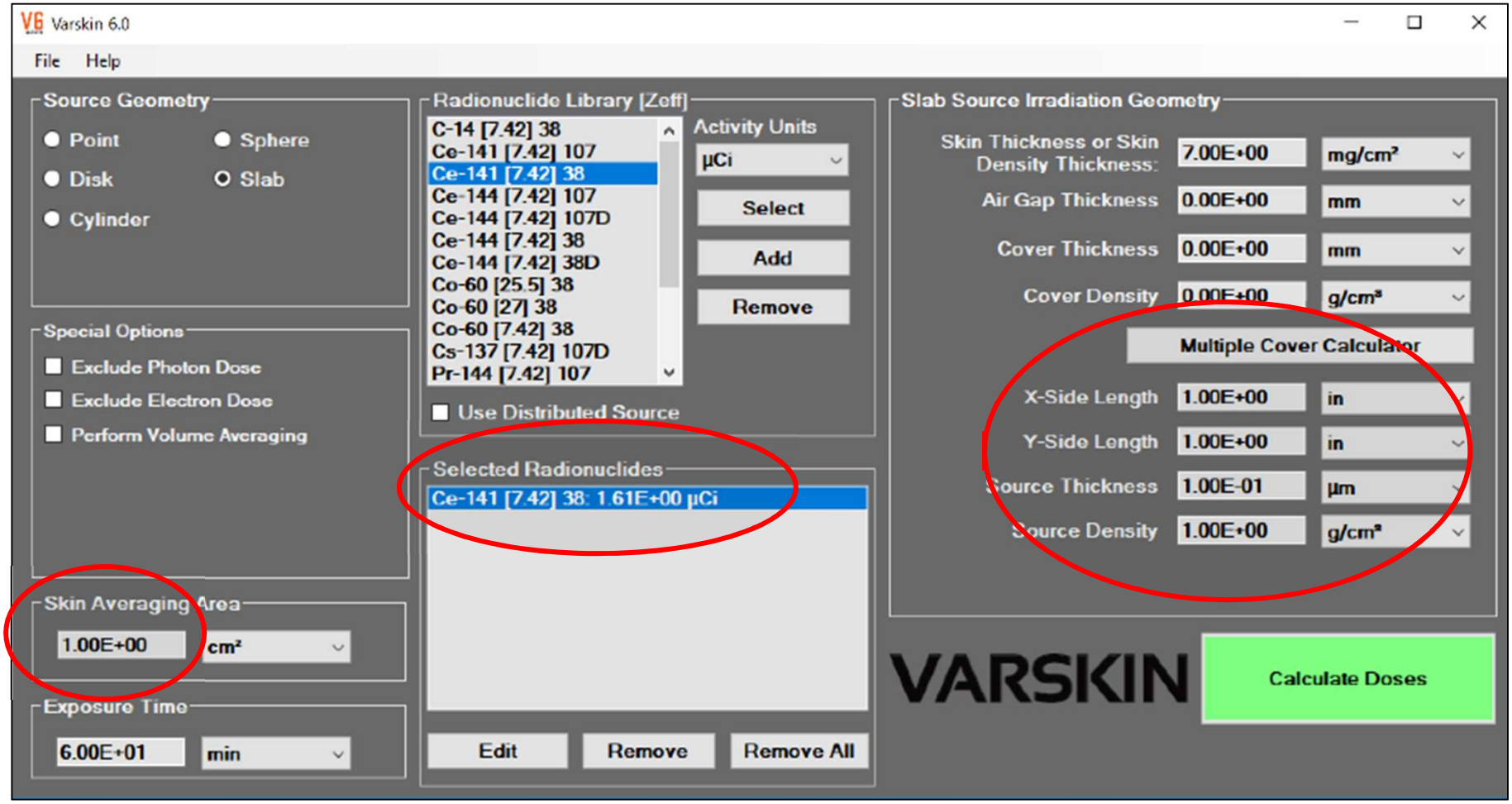
results


Non Volume Averaged Results
Radionuclide: Activity
Ce-141 [7.42] 38: 1.61E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.52E-01 rad/h 9.52E-01 rad 9.52E-01 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 9.54E-01 rad/h 9.54E-01 rad 9.54E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.52E-01 rad/h 9.52E-01 rad 9.52E-01 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 9.54E-01 rad/h 9.54E-01 rad 9.54E-01 rad
Date/Time 3/19/18 1:09:02 PM
Source Geometry Slab Source
X side Length 1.00E+00 in
Y side Length 1.00E+00 in
Source Thickness 1.00E-01 µm
Source Density 1.29E-03 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

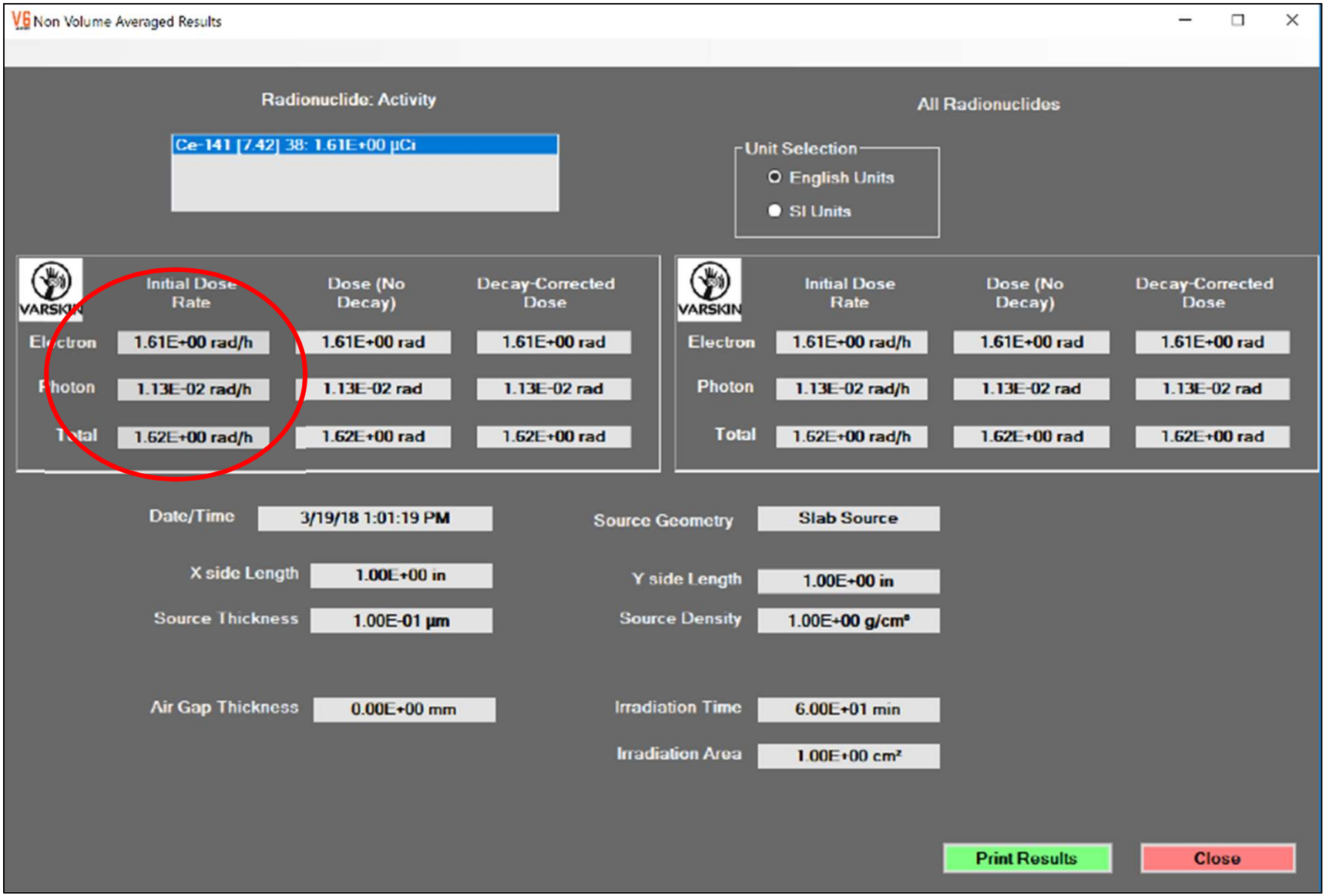
summary

1” x 1”	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Point Source	0.954	0.00229	0.956
2D Disk Source	0.965	0.00215	0.967
Water Slab Source	1.05	0.00195	1.05
Air Slab Source	0.952	0.00195	0.954
Water Slab (1 cm^2)			

Slab source (1 cm^2)



results


Non Volume Averaged Results
Radionuclide: Activity
Ce-141 [7.42] 38: 1.61E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.61E+00 rad/h 1.61E+00 rad 1.61E+00 rad
Photon 1.13E-02 rad/h 1.13E-02 rad 1.13E-02 rad
Total 1.62E+00 rad/h 1.62E+00 rad 1.62E+00 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.61E+00 rad/h 1.61E+00 rad 1.61E+00 rad
Photon 1.13E-02 rad/h 1.13E-02 rad 1.13E-02 rad
Total 1.62E+00 rad/h 1.62E+00 rad 1.62E+00 rad
Date/Time 3/19/18 1:01:19 PM
Source Geometry Slab Source
X side Length 1.00E+00 in
Y side Length 1.00E+00 in
Source Thickness 1.00E-01 µm
Source Density 1.00E+00 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+00 cm²
Print Results
Close

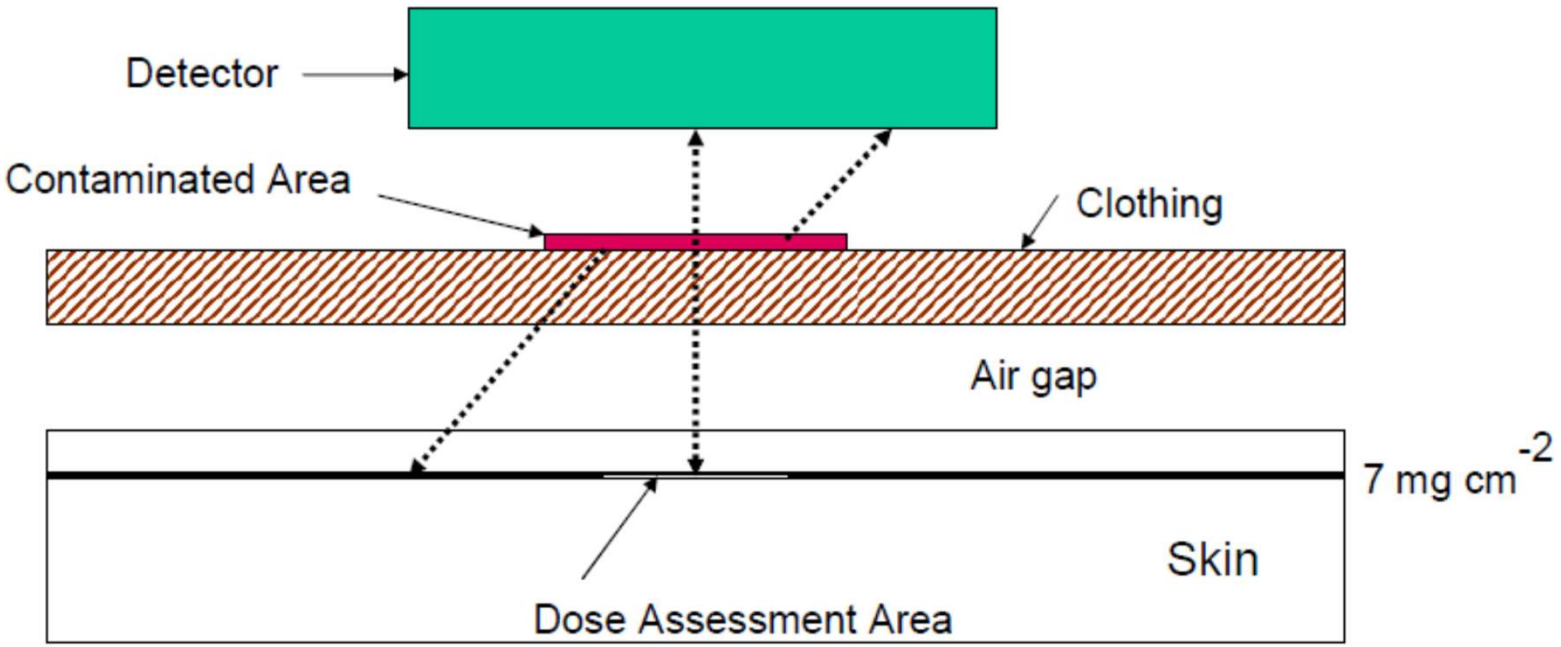
summary

1” x 1”	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Point Source	0.954	0.00229	0.956
2D Disk Source	0.965	0.00215	0.967
Water Slab Source	1.05	0.00195	1.05
Air Slab Source	0.952	0.00195	0.954
Water Slab (1 cm^2)	1.61	0.0113	1.62

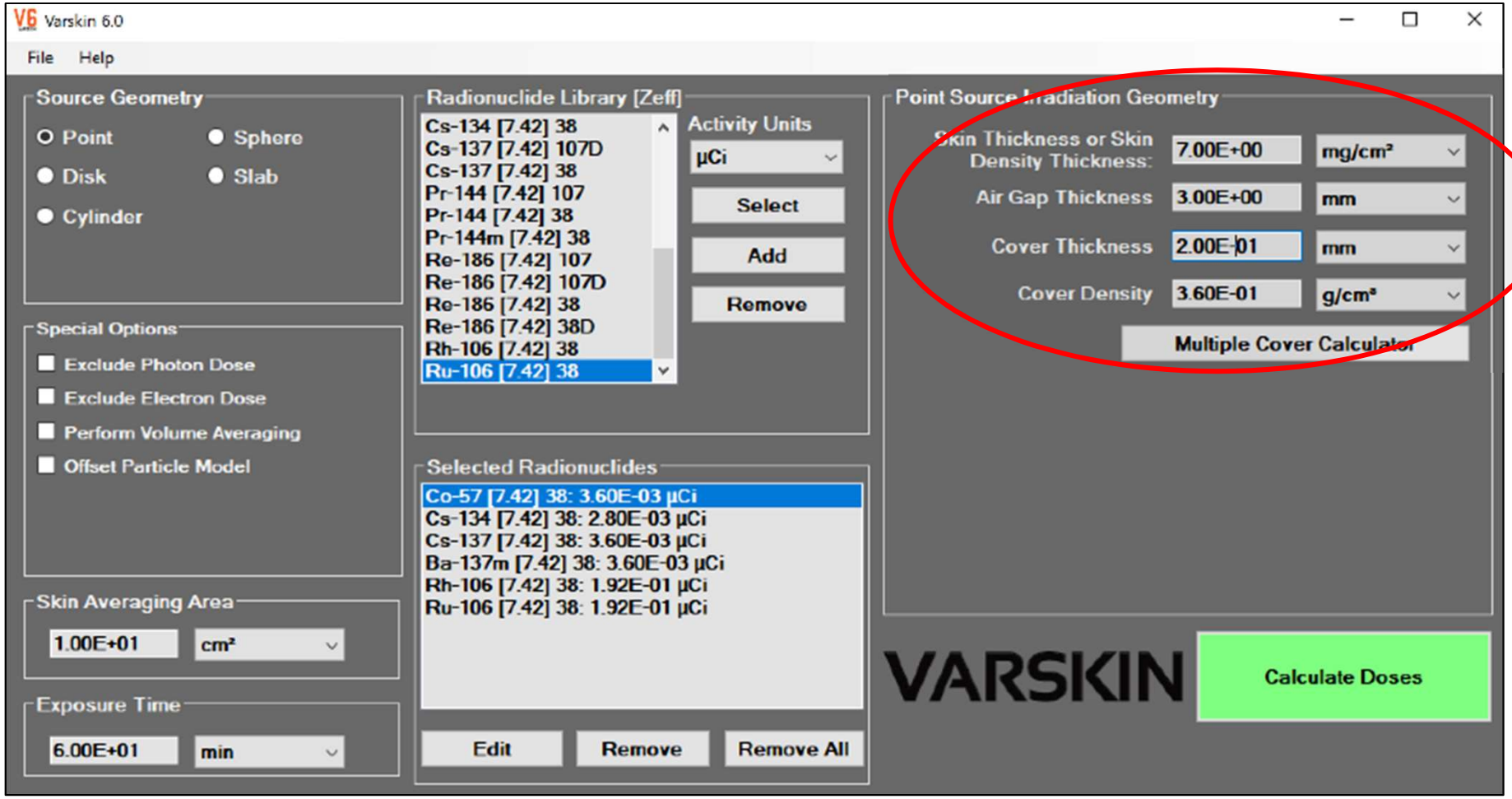
scenario #4

- Particle (not captured) on plastic lab coat
  - will assume 3 mm air gap (very arbitrary)
  - coat thickness of 0.20 mm, and density of 0.36 g/cm^3
- Source measurements indicate:
  - 0.0036 μCi of Co-57
  - 0.1920 μCi of Ru-106 (Rh-106)
  - 0.0028 μCi of Cs-134
  - 0.0036 μCi of Cs-137 (Ba-137m)
- Modeled as a point source
- Interested in a beta and gamma depth-dose profile

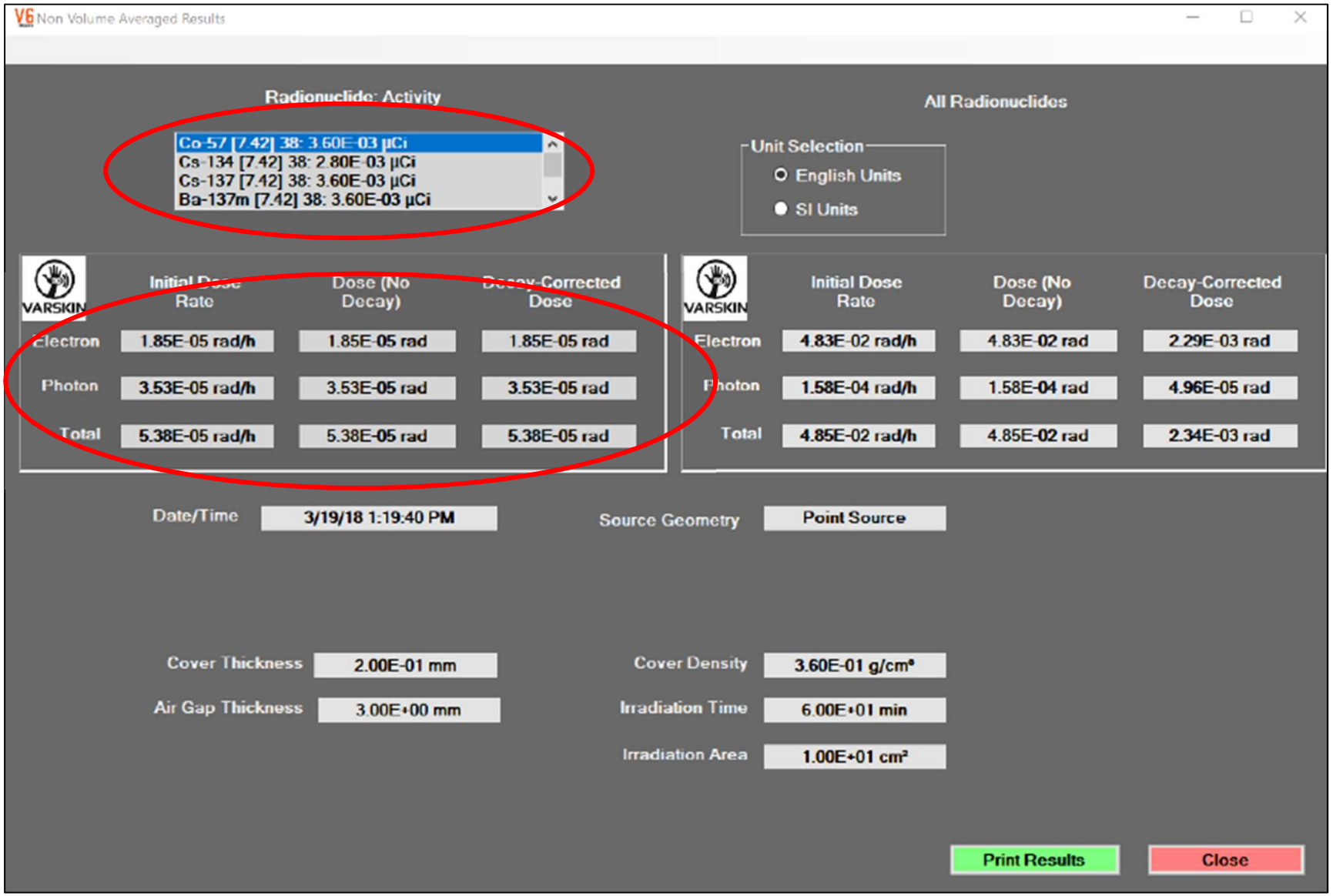
Beta activity determination



Varskin input



results

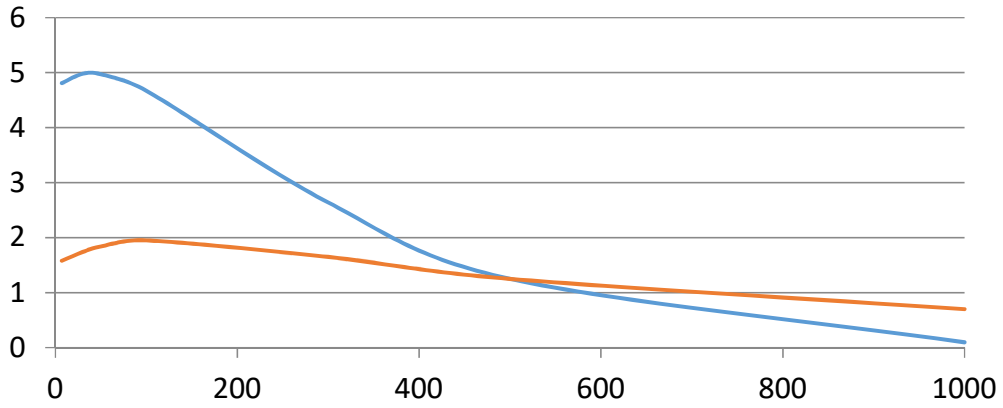

Non Volume Averaged Results
Radionuclide: Activity
Co-57 [7.42] 38: 3.60E-03 µCi
Cs-134 [7.42] 38: 2.80E-03 µCi
Cs-137 [7.42] 38: 3.60E-03 µCi
Ba-137m [7.42] 38: 3.60E-03 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.85E-05 rad/h 1.85E-05 rad 1.85E-05 rad
Photon 3.53E-05 rad/h 3.53E-05 rad 3.53E-05 rad
Total 5.38E-05 rad/h 5.38E-05 rad 5.38E-05 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 4.83E-02 rad/h 4.83E-02 rad 2.29E-03 rad
Photon 1.58E-04 rad/h 1.58E-04 rad 4.96E-05 rad
Total 4.85E-02 rad/h 4.85E-02 rad 2.34E-03 rad
Date/Time 3/19/18 1:19:40 PM
Source Geometry Point Source
Cover Thickness 2.00E-01 mm
Air Gap Thickness 3.00E+00 mm
Cover Density 3.60E-01 g/cm³
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

Results by nuclide

@ 7 mg/cm^2	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Co-57	1.85E-5	3.53E-5	5.38E-5
Ru-106	0	0	0
Rh-106	4.65E-2	1.04E-4	4.66E-2
Cs-134	6.41E-4	1.27E-5	6.54E-4
Cs-137	1.06E-3	0	1.06E-3
Ba-137m	1.02E-4	6.49E-6	1.09E-4
TOTAL	**4.83E-2**	**1.58E-4**	**4.85E-2**

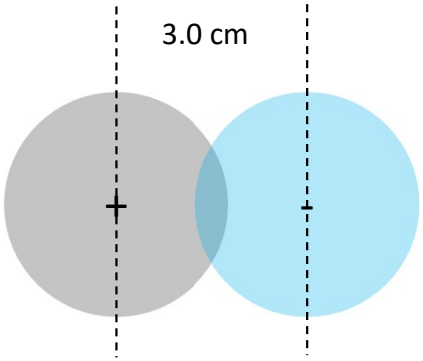
Results by depth

	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
7 mg/cm^2	4.83E-2	1.58E-4	4.85E-2
30	5.00E-2	1.74E-4	5.01E-2
50	4.98E-2	1.84E-4	5.00E-2
100	4.67E-2	1.95E-4	4.69E-2
300	2.64E-2	1.65E-4	2.66E-2
500	1.25E-2	1.25E-4	1.27E-2
1000	9.68E-4	7.00E-5	1.04E-3

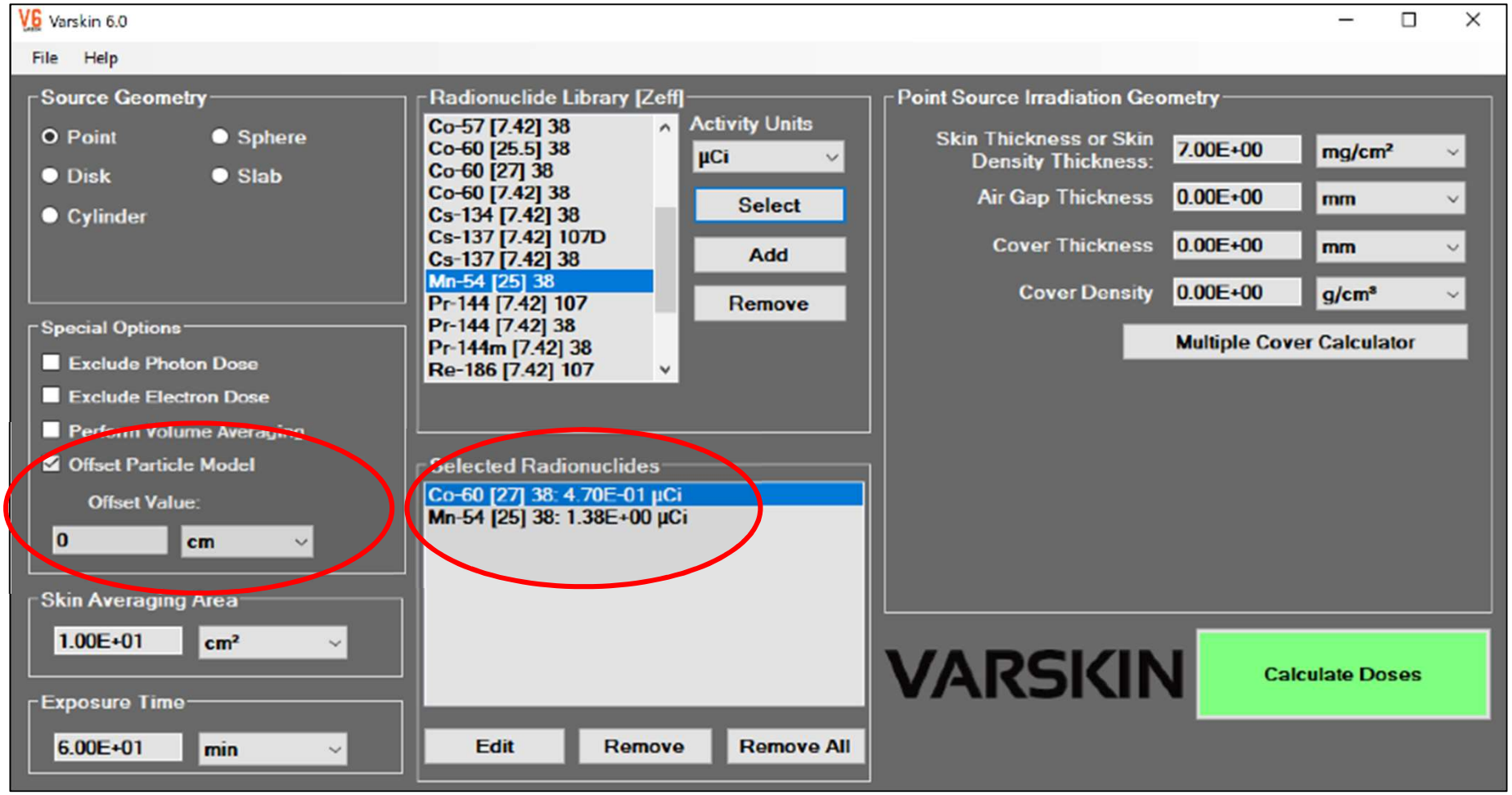


scenario #5 (offset model)

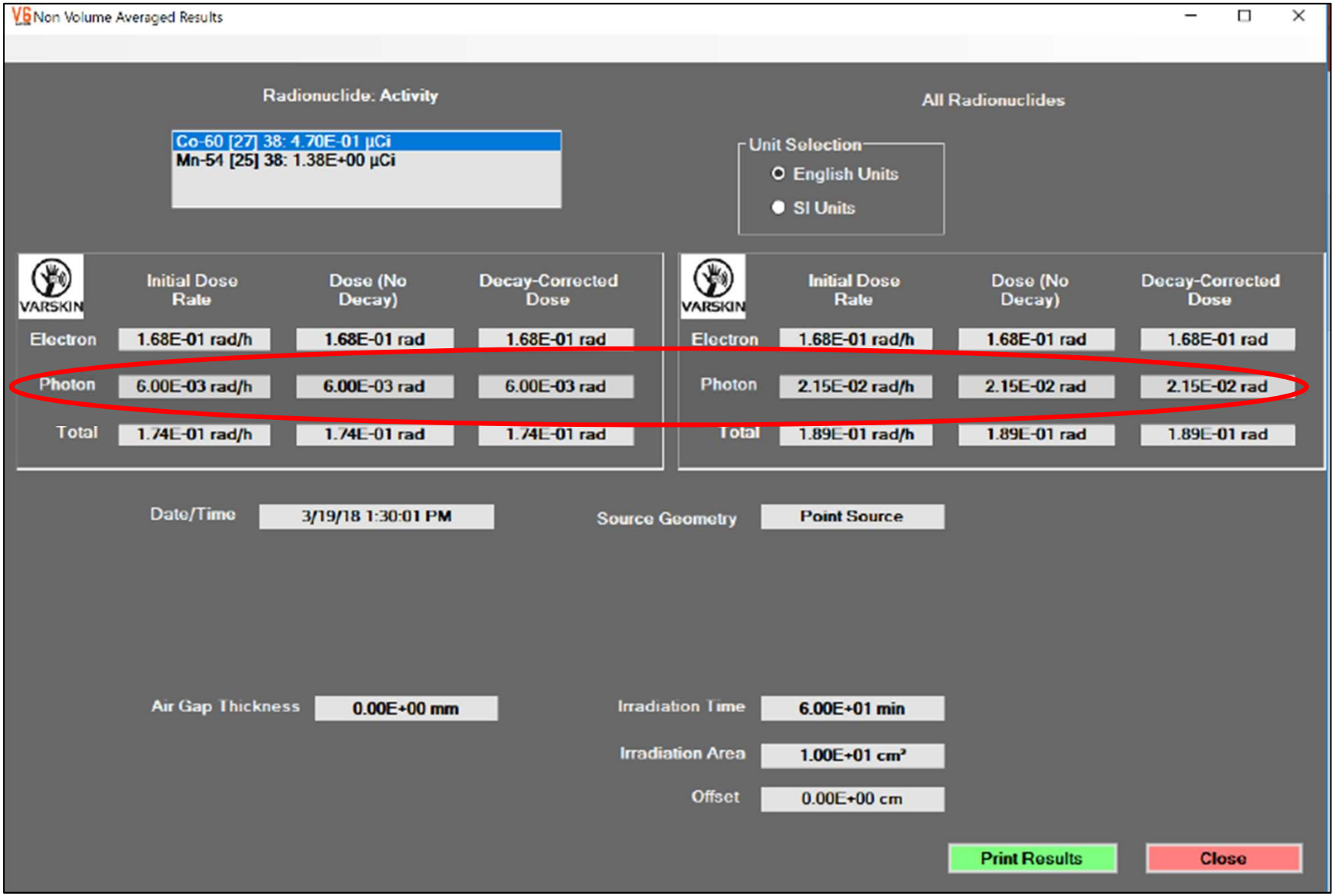
- Two particles on skin
  - separated by 3.0 cm
- Particle #1:
  - 1.38 μCi of Mn-54 (Z=25)
- Particle #2:
  - 0.471 μCi of Co-60 (Z=27)
- Modeled as two offset point sources
- Offset model only works for photon dosimetry
- Need maximum dose rate to 10 cm^2 disk @ 7 mg/cm^2



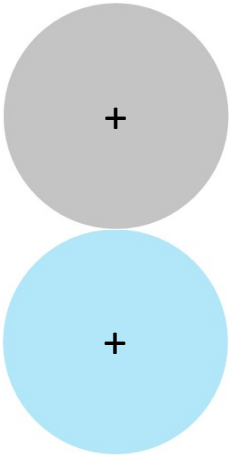
Point source input



results

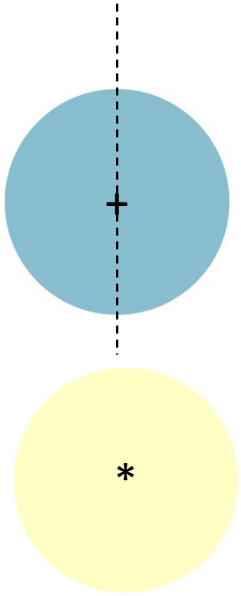

Non Volume Averaged Results
Radionuclide: Activity
Co-60 [27] 38: 4.70E-01 µCi
Mn-54 [25] 38: 1.38E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 6.00E-03 rad/h 6.00E-03 rad 6.00E-03 rad
Total 1.74E-01 rad/h 1.74E-01 rad 1.74E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 2.15E-02 rad/h 2.15E-02 rad 2.15E-02 rad
Total 1.89E-01 rad/h 1.89E-01 rad 1.89E-01 rad
Date/Time 3/19/18 1:30:01 PM
Source Geometry Point Source
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Offset 0.00E+00 cm
Print Results
Close

Photon dose rate from each source



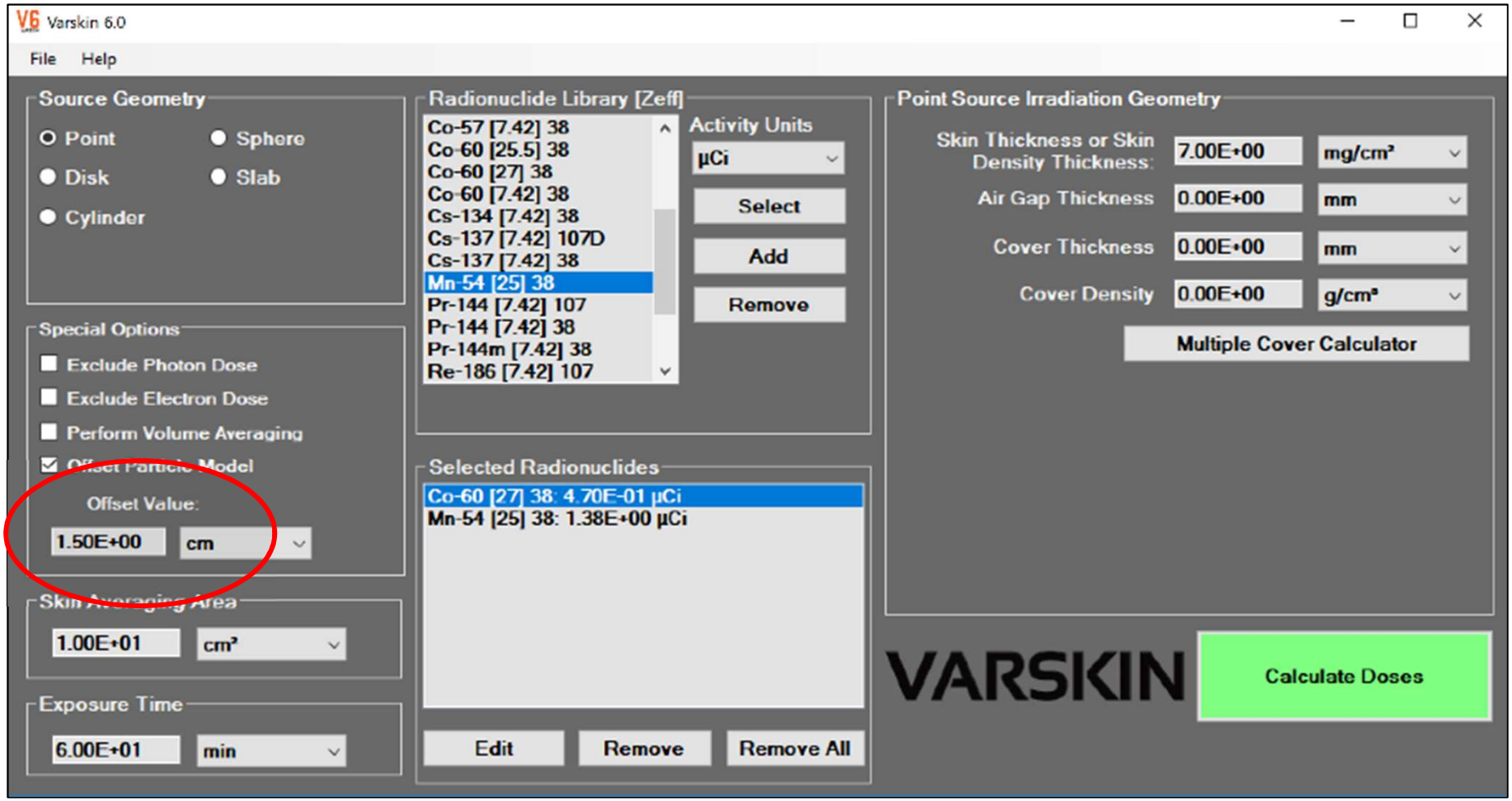
Mn-54
15.5 mrad/hr

Co-60
6.00 mrad/hr

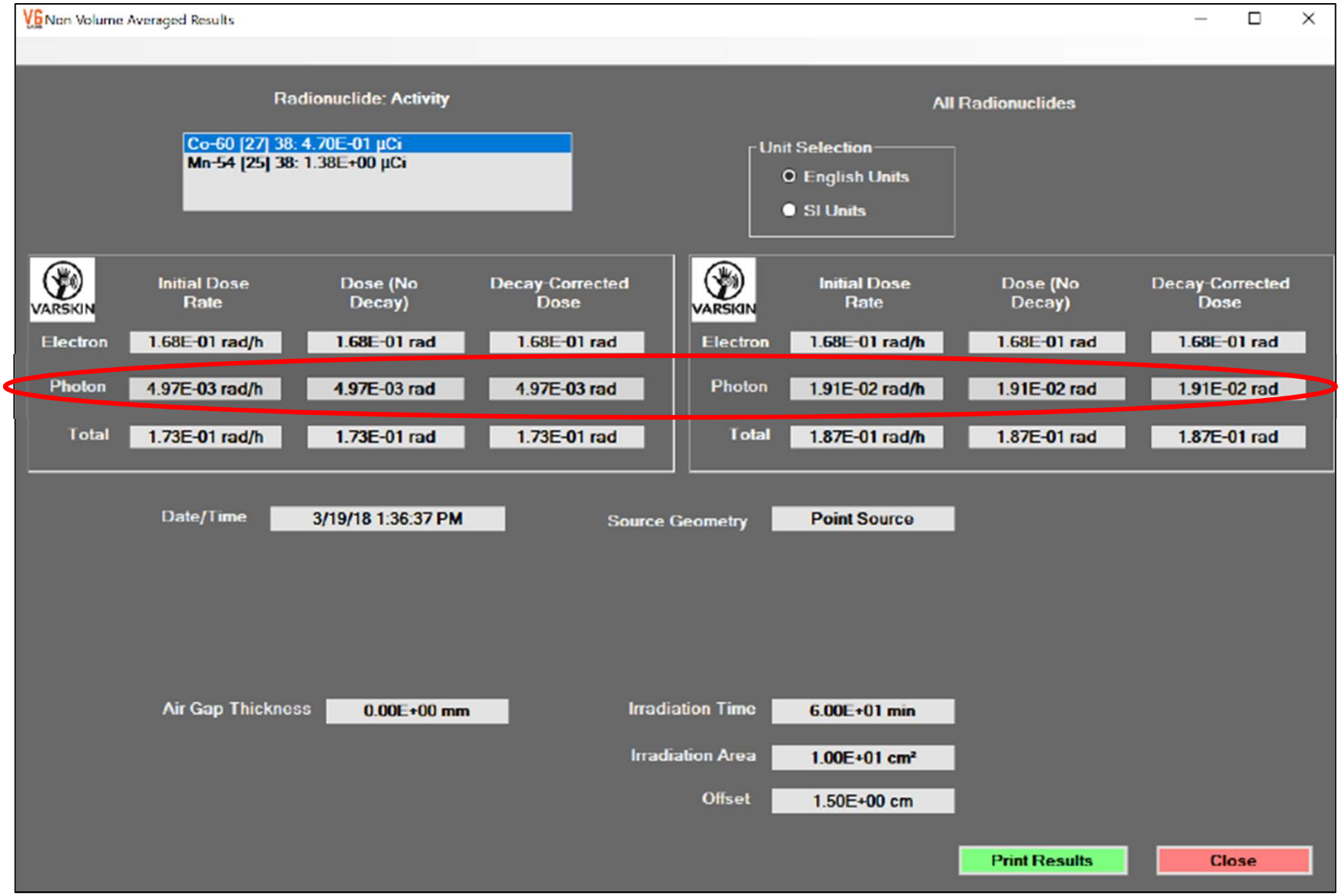


Where do we place a single averaging disk in order to maximize dose?

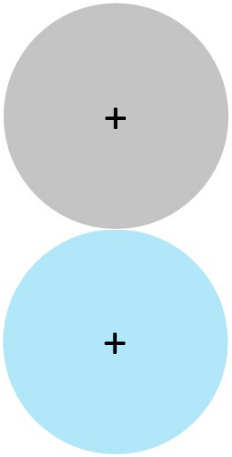
Offset particle model input



results

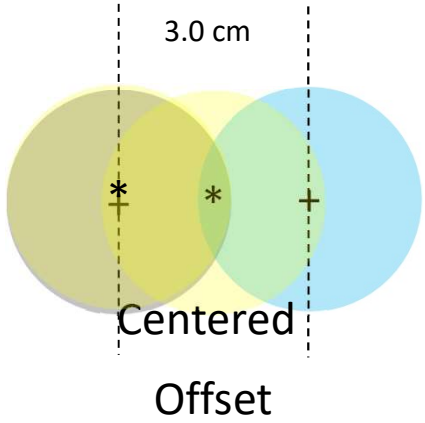

Non Volume Averaged Results
Radionuclide: Activity
Co-60 [27] 38: 4.70E-01 µCi
Mn-54 [25] 38: 1.38E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 4.97E-03 rad/h 4.97E-03 rad 4.97E-03 rad
Total 1.73E-01 rad/h 1.73E-01 rad 1.73E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 1.91E-02 rad/h 1.91E-02 rad 1.91E-02 rad
Total 1.87E-01 rad/h 1.87E-01 rad 1.87E-01 rad
Date/Time 3/19/18 1:36:37 PM
Source Geometry Point Source
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Offset 1.50E+00 cm
Print Results
Close

Dose to single averaging disk



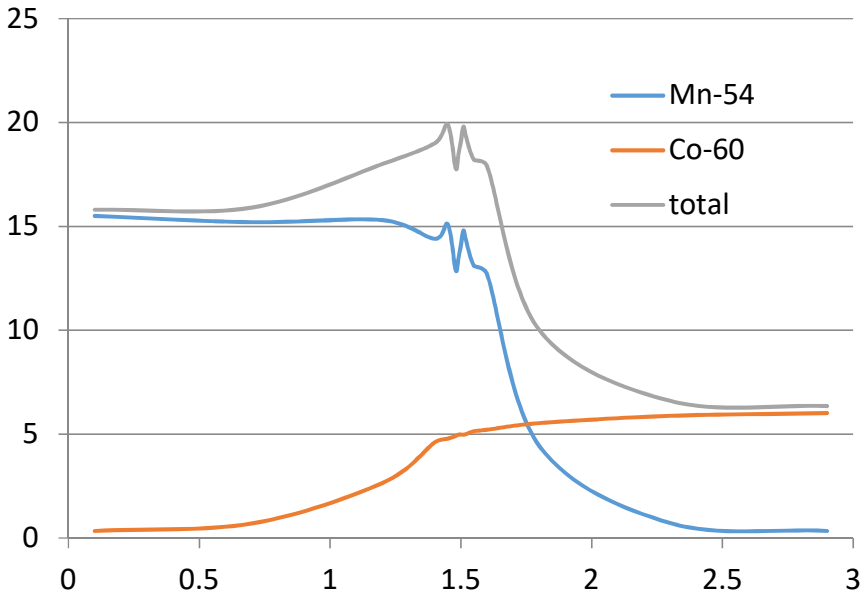
Mn-54
14.1 mrad/hr

Co-60
4.97 mrad/hr



Placement to maximize photon dose

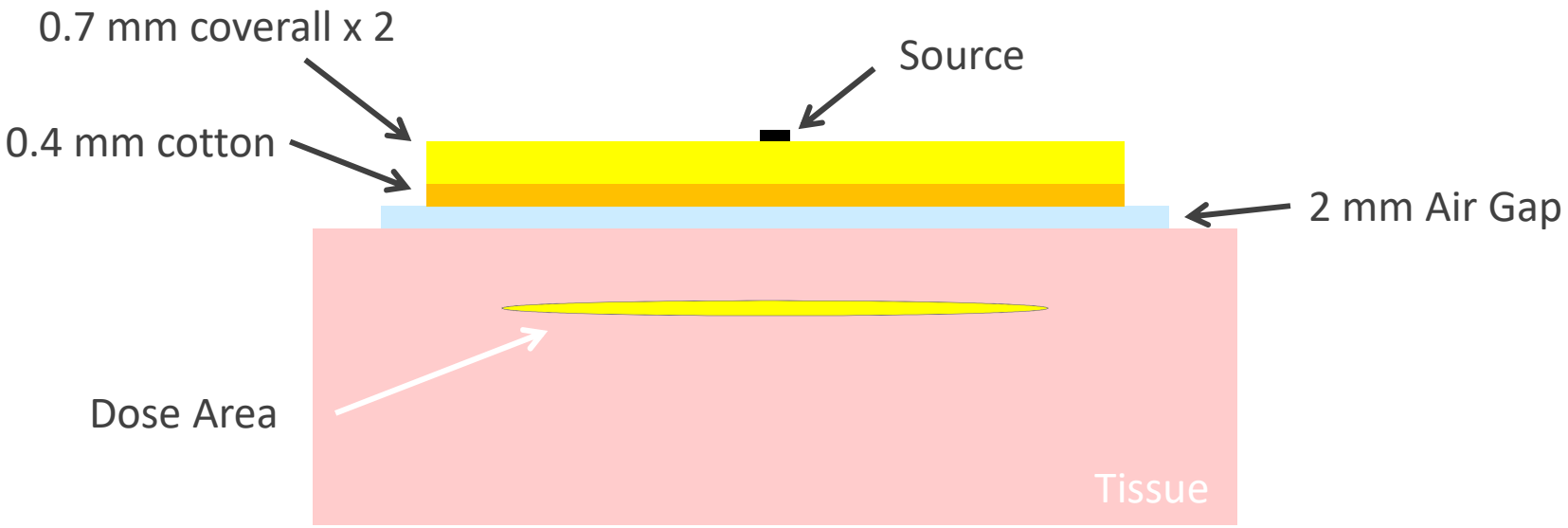
Dose Rate (mrad/hr)	Mn-54	Co-60	Total
Each on-axis (stacked)	15.5	6.00	21.5
0.1 cm from Mn-54	15.5	0.34	15.8
0.7 cm	15.2	0.70	15.9
1.2 cm	15.3	2.65	18.0
1.4 cm	14.4	4.60	19.0
1.45 cm	15.1	4.78	19.9
1.48 cm	12.9	4.91	17.8
1.49 cm	13.4	4.97	18.4
1.5 cm (centered)	14.1	4.97	19.1
1.51 cm	14.8	4.97	19.8
1.52 cm	14.3	5.00	19.3
1.55 cm	13.1	5.14	18.2
1.6 cm	12.7	5.21	17.9
1.8 cm	4.43	5.53	10.0
2.3 cm	0.72	5.88	6.60
2.9 cm (0.1 cm from Co-60)	0.34	6.00	6.35



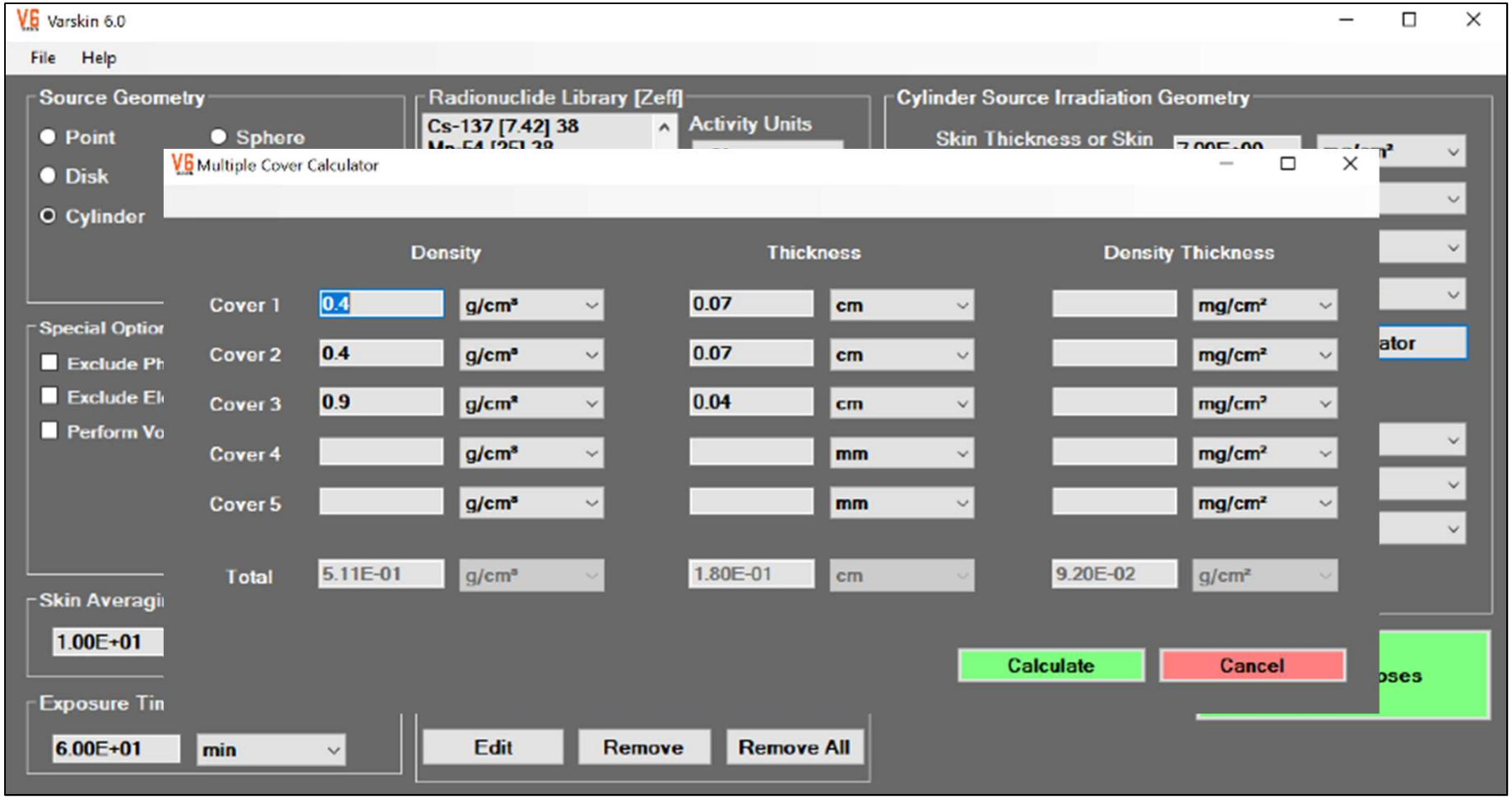
scenario #6 (multiple cover)

- Using the Multiple Cover Calculator
- Hot particle imbedded in two layers of coveralls (0.7 mm; 0.4 g/cm^3), and one heavy cotton shirt (assumed similar to cloth lab coat; 0.4 mm; 0.9 g/cm^3)
- Assume air gap of 1.5 mm + 0.5 mm between coveralls and cotton shirt
- Sr-90 in equilibrium with daughter
- 1.3 μCi in iron (Z=26; 7.87 g/cm^3), cylindrical source, 20 μm diameter x 40 μm length
- Depth-dose profile to 100 mg/cm^2

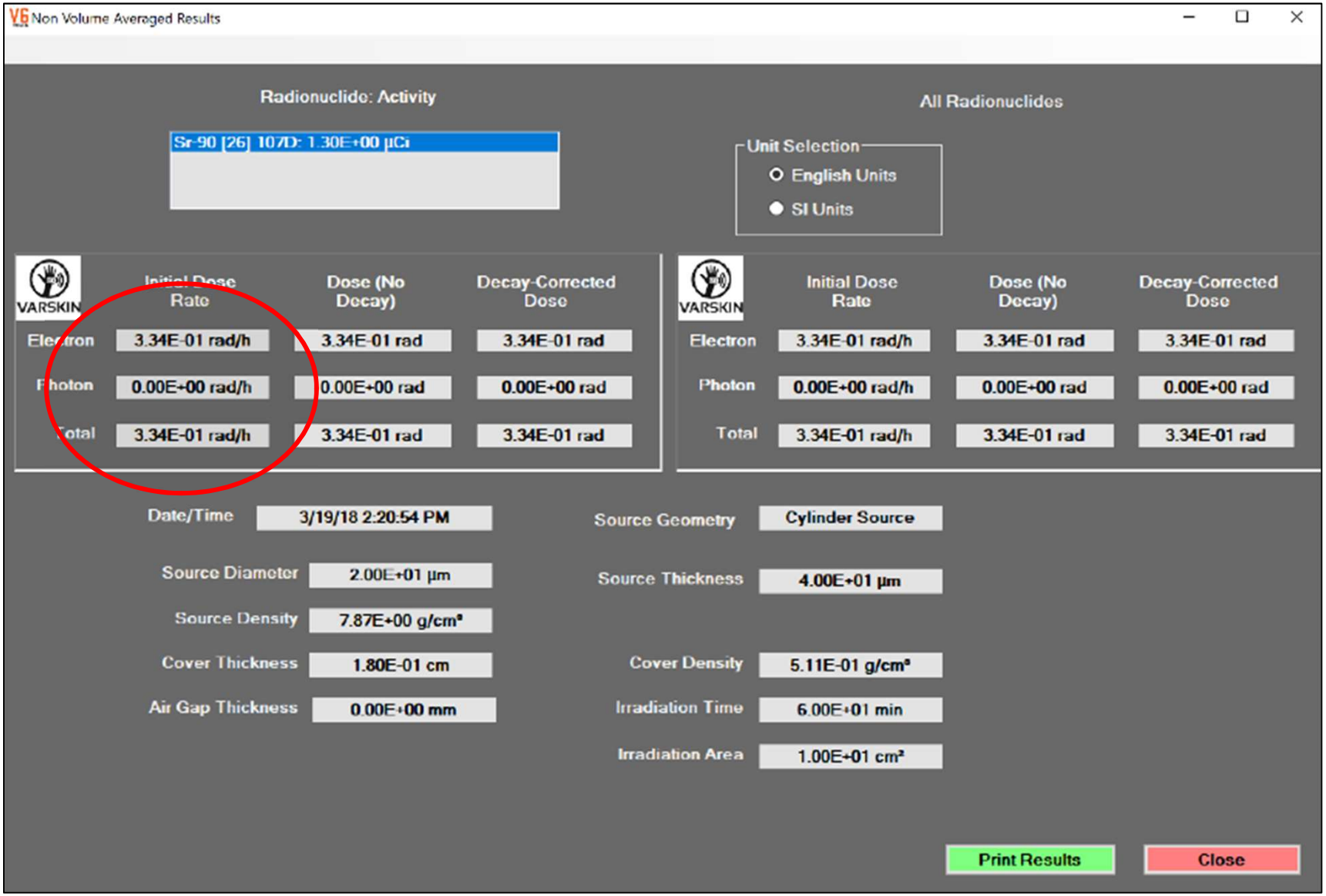
Cover model


0.7 mm coverall x 2
Source
0.4 mm cotton
2 mm Air Gap
Dose Area
Tissue

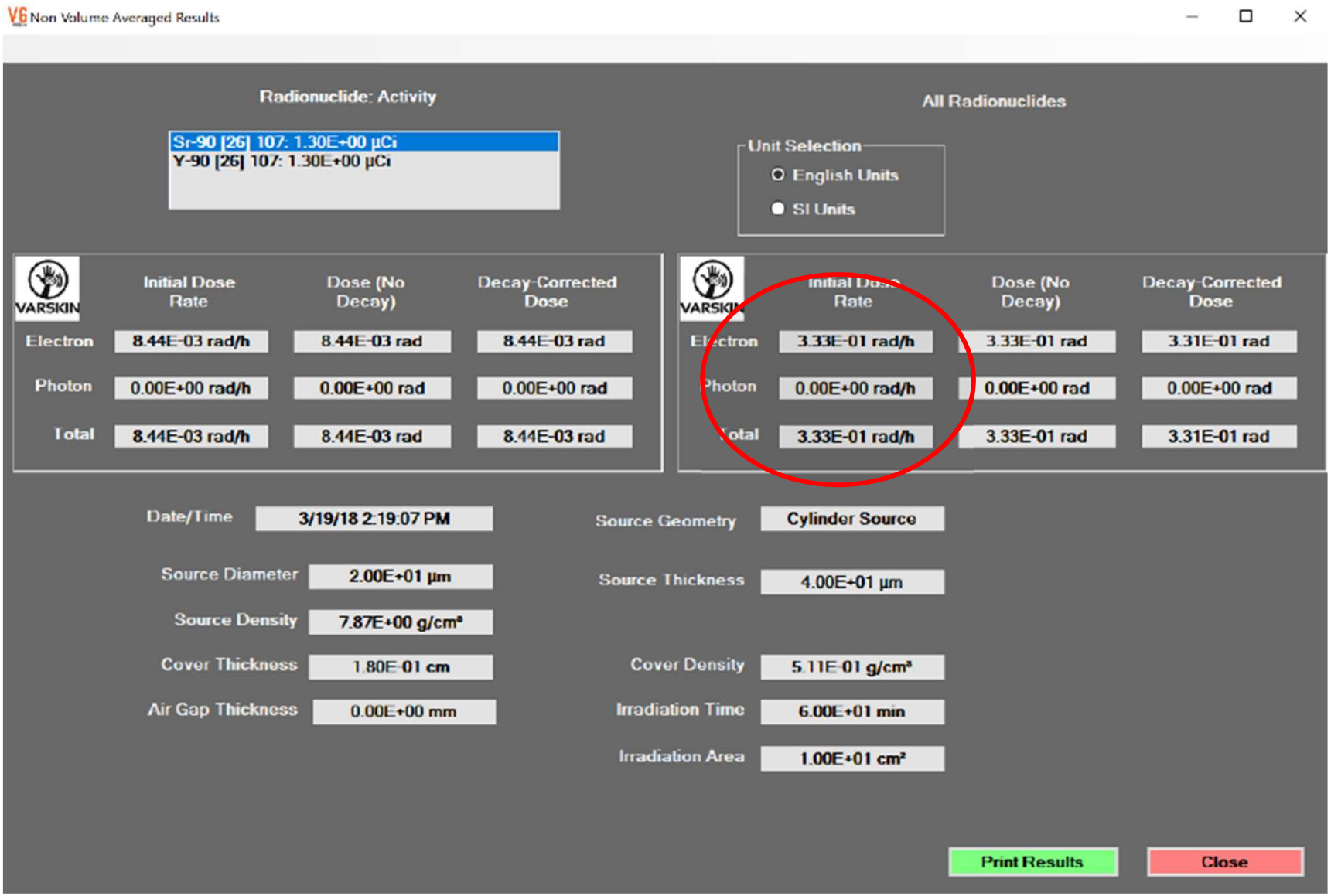
Multiple cover input



results


Non Volume Averaged Results
Radionuclide: Activity
Sr-90 [26] 107D: 1.30E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.34E-01 rad/h 3.34E-01 rad 3.34E-01 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 3.34E-01 rad/h 3.34E-01 rad 3.34E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.34E-01 rad/h 3.34E-01 rad 3.34E-01 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 3.34E-01 rad/h 3.34E-01 rad 3.34E-01 rad
Date/Time 3/19/18 2:20:54 PM
Source Geometry Cylinder Source
Source Diameter 2.00E+01 µm
Source Thickness 4.00E+01 µm
Source Density 7.87E+00 g/cm³
Cover Thickness 1.80E-01 cm
Cover Density 5.11E-01 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

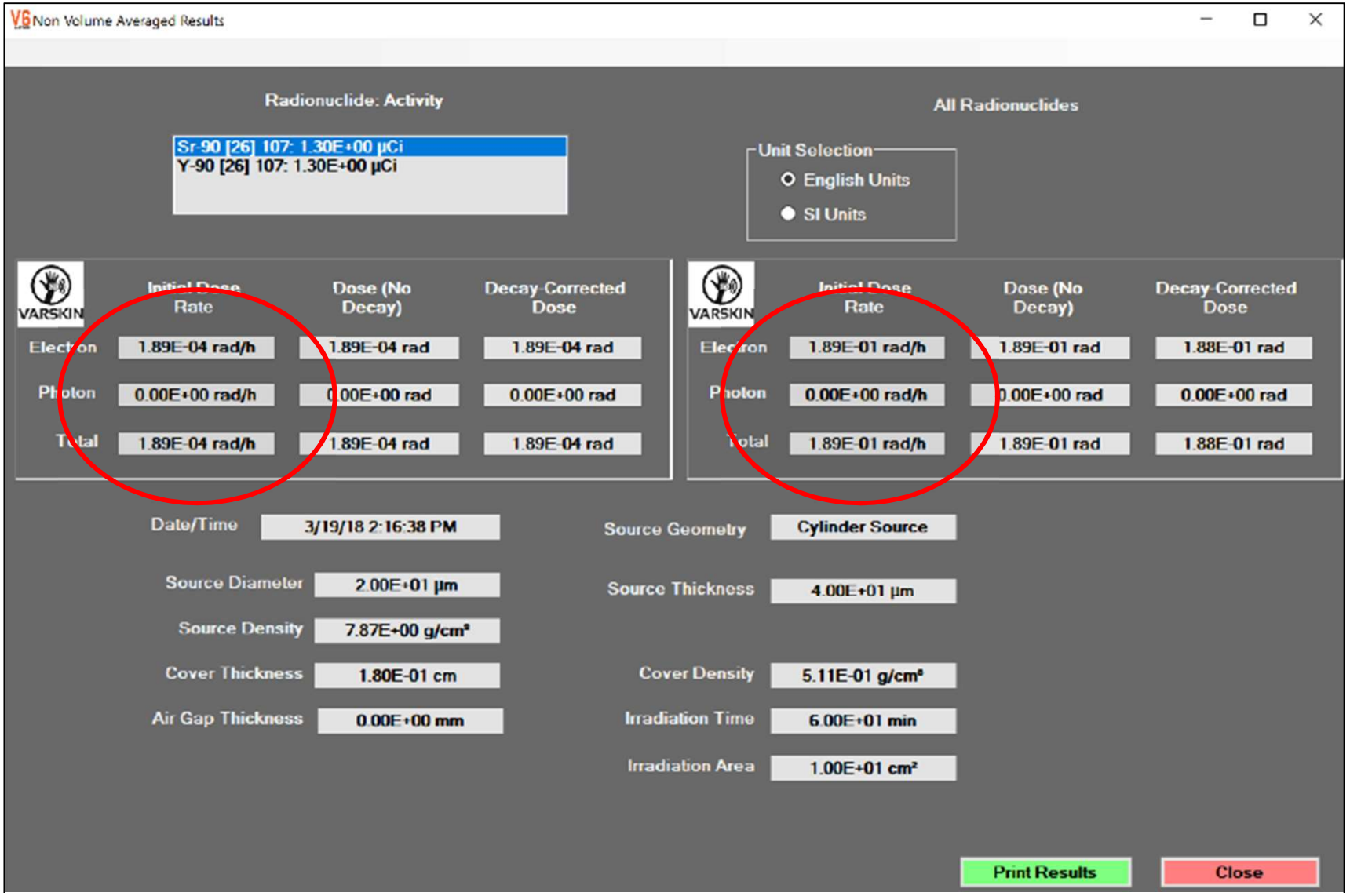
results


V6 Non Volume Averaged Results
Radionuclide: Activity
Sr-90 [26] 107: 1.30E+00 µCi
Y-90 [26] 107: 1.30E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 8.44E-03 rad/h 8.44E-03 rad 8.44E-03 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 8.44E-03 rad/h 8.44E-03 rad 8.44E-03 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.33E-01 rad/h 3.33E-01 rad 3.31E-01 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 3.33E-01 rad/h 3.33E-01 rad 3.31E-01 rad
Date/Time 3/19/18 2:19:07 PM
Source Geometry Cylinder Source
Source Diameter 2.00E+01 µm
Source Thickness 4.00E+01 µm
Source Density 7.87E+00 g/cm³
Cover Thickness 1.80E-01 cm
Cover Density 5.11E-01 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

Depth-dose summary

	Total Dose (mrad/hr)
7 mg/cm^2	334
10	326
20	304
30	285
50	252
100	189

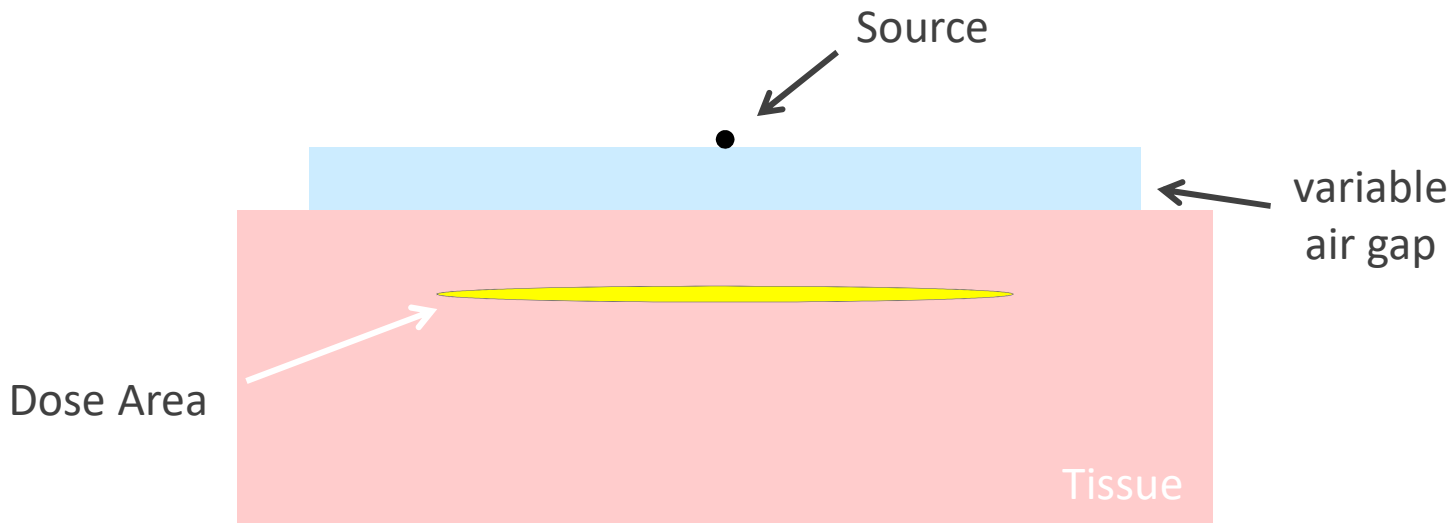
results


Non Volume Averaged Results
Radionuclide: Activity
Sr-90 [26] 107: 1.30E+00 µCi
Y-90 [26] 107: 1.30E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay Corrected Dose
Electron 1.89E-04 rad/h 1.89E-04 rad 1.89E-04 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 1.89E-04 rad/h 1.89E-04 rad 1.89E-04 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay Corrected Dose
Electron 1.89E-01 rad/h 1.89E-01 rad 1.88E-01 rad
Photon 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Total 1.89E-01 rad/h 1.89E-01 rad 1.88E-01 rad
Date/Time 3/19/18 2:16:38 PM
Source Geometry Cylinder Source
Source Diameter 2.00E+01 µm
Source Thickness 4.00E+01 µm
Source Density 7.87E+00 g/cm³
Cover Thickness 1.80E-01 cm
Cover Density 5.11E-01 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

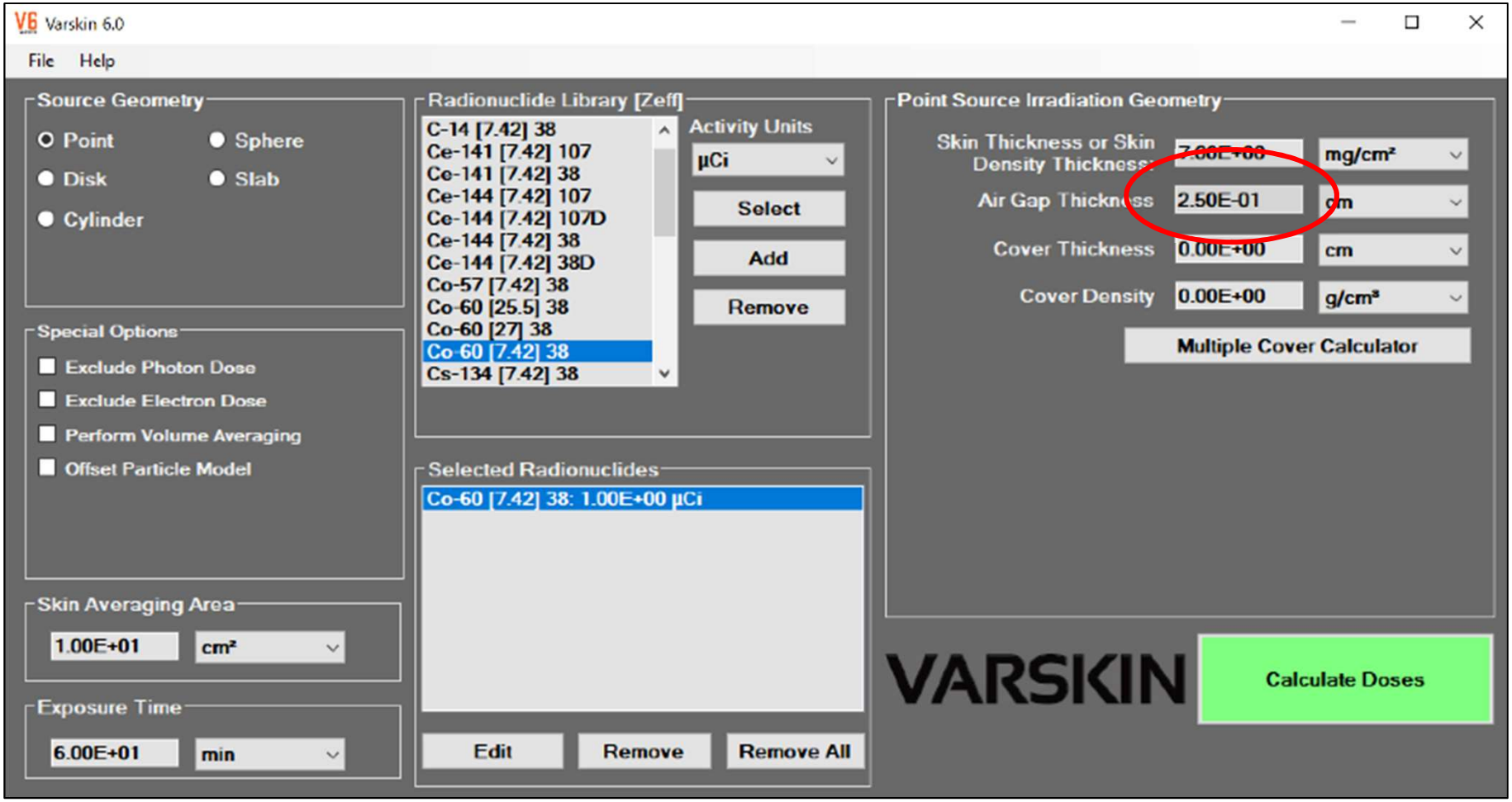
scenario #7 (air gap)

- Using the Air Gap Model
- Co-60 point source (1 μCi)
- 10 cm^2 averaging area
- Tissue depth of 7 mg/cm^2
- How does dose vary with an air gap of zero to 5 cm?

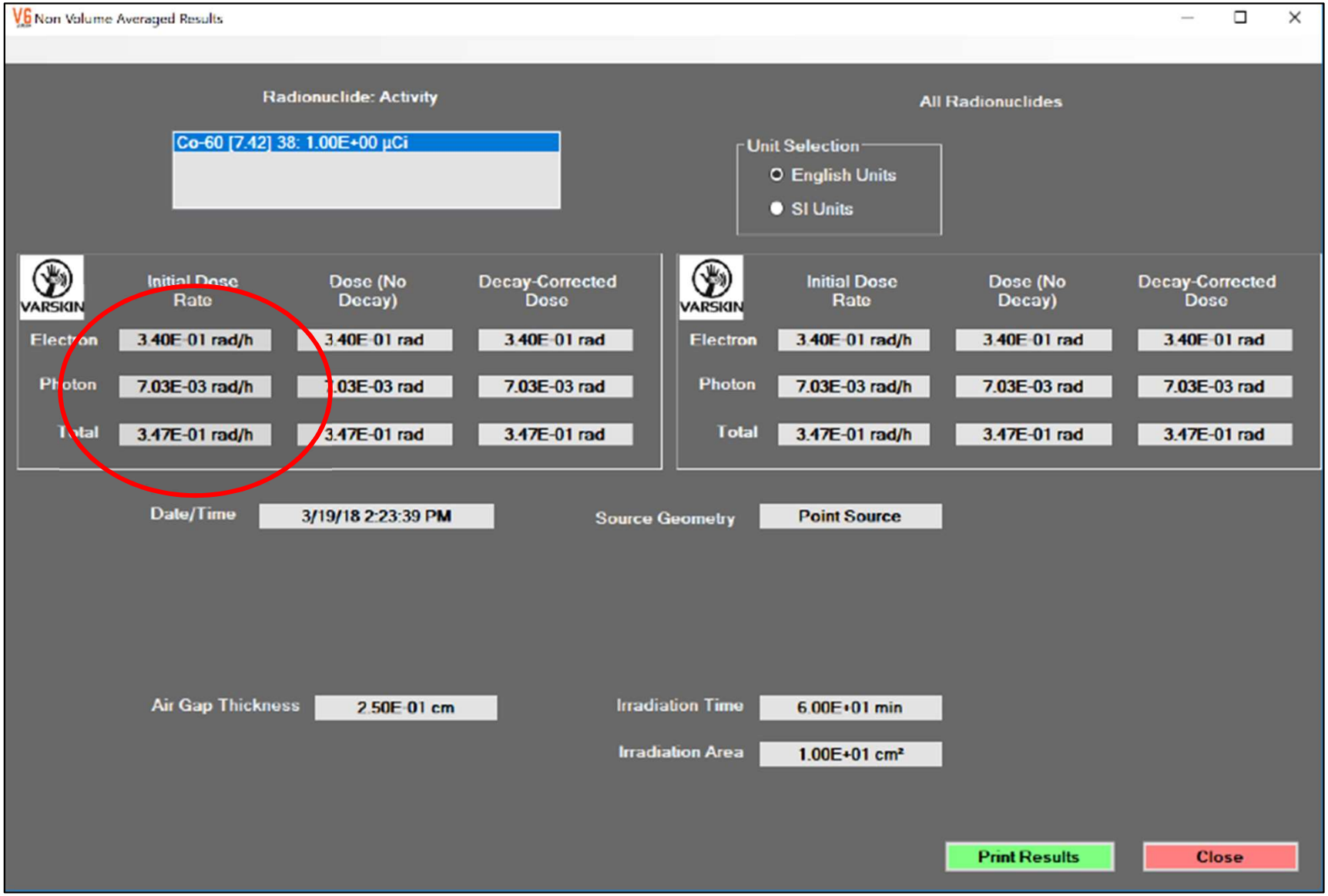
Air gap model



Air gap model input

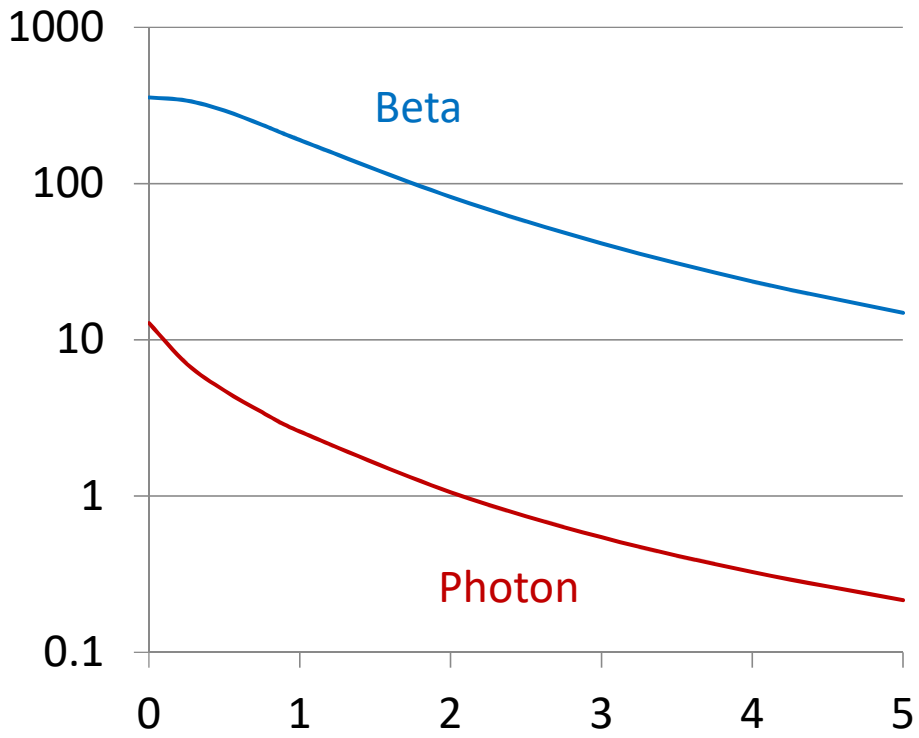


results


Non Volume Averaged Results
Radionuclide: Activity
Co-60 [7.42] 38: 1.00E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.40E-01 rad/h 3.40E-01 rad 3.40E-01 rad
Photon 7.03E-03 rad/h 7.03E-03 rad 7.03E-03 rad
Total 3.47E-01 rad/h 3.47E-01 rad 3.47E-01 rad
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.40E-01 rad/h 3.40E-01 rad 3.40E-01 rad
Photon 7.03E-03 rad/h 7.03E-03 rad 7.03E-03 rad
Total 3.47E-01 rad/h 3.47E-01 rad 3.47E-01 rad
Date/Time 3/19/18 2:23:39 PM
Source Geometry Point Source
Air Gap Thickness 2.50E-01 cm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

Air gap impact on dose

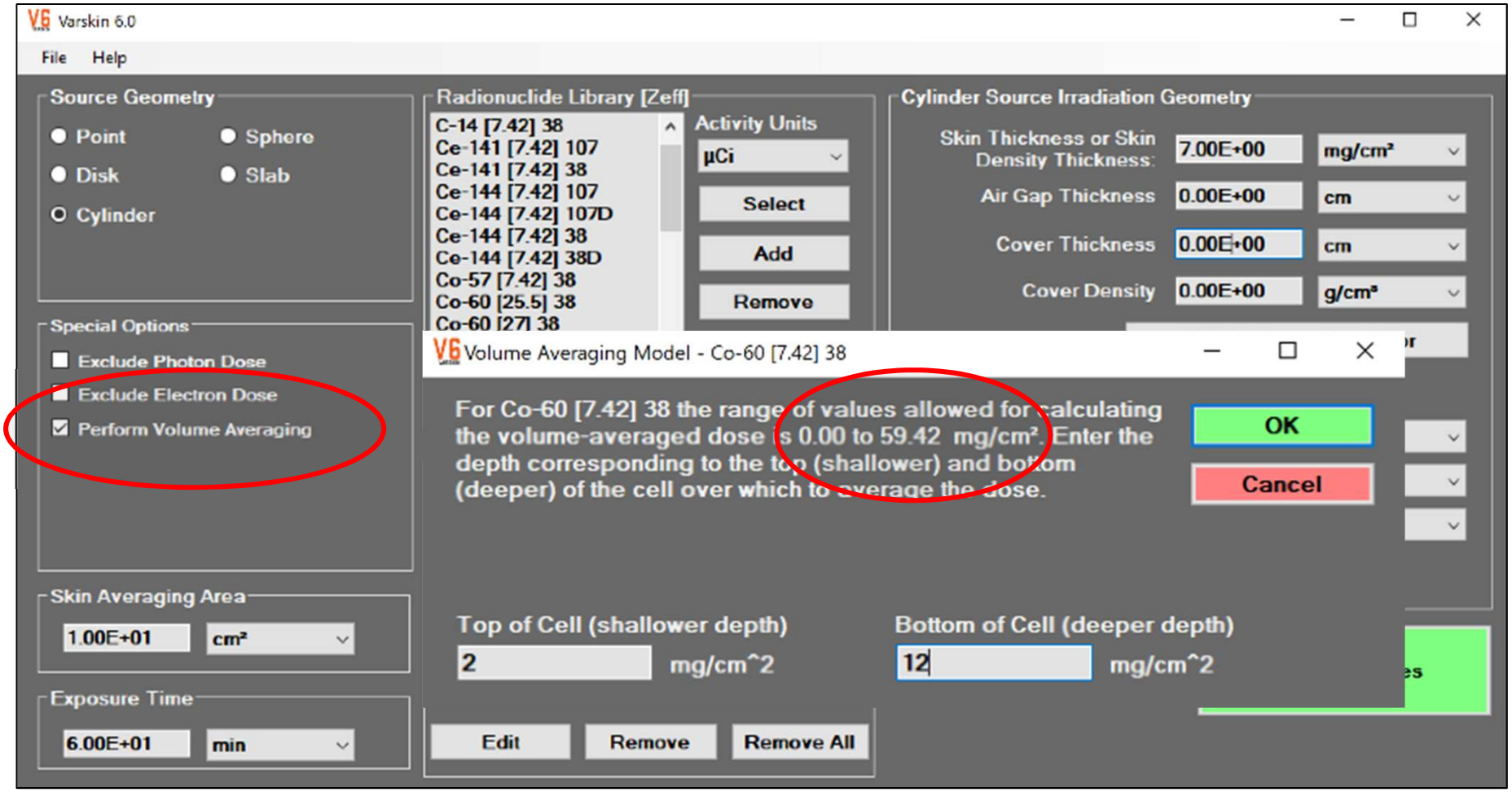
Air Gap (cm)	Beta	Photon	Total
0	356	12.8	369
0.25	340	7.03	347
0.50	293	4.74	298
0.75	238	3.44	241
1	190	2.59	192
2	82.2	1.06	83.3
3	41.5	0.546	42.0
4	23.7	0.327	24.1
5	14.9	0.216	15.1



scenario #8

- 1 μCi of Co-60 on skin
- 3D source
- With photon dose calculations
- With volume averaging (beta and gamma)
- For the purpose of examining run times and picking reasonable volume

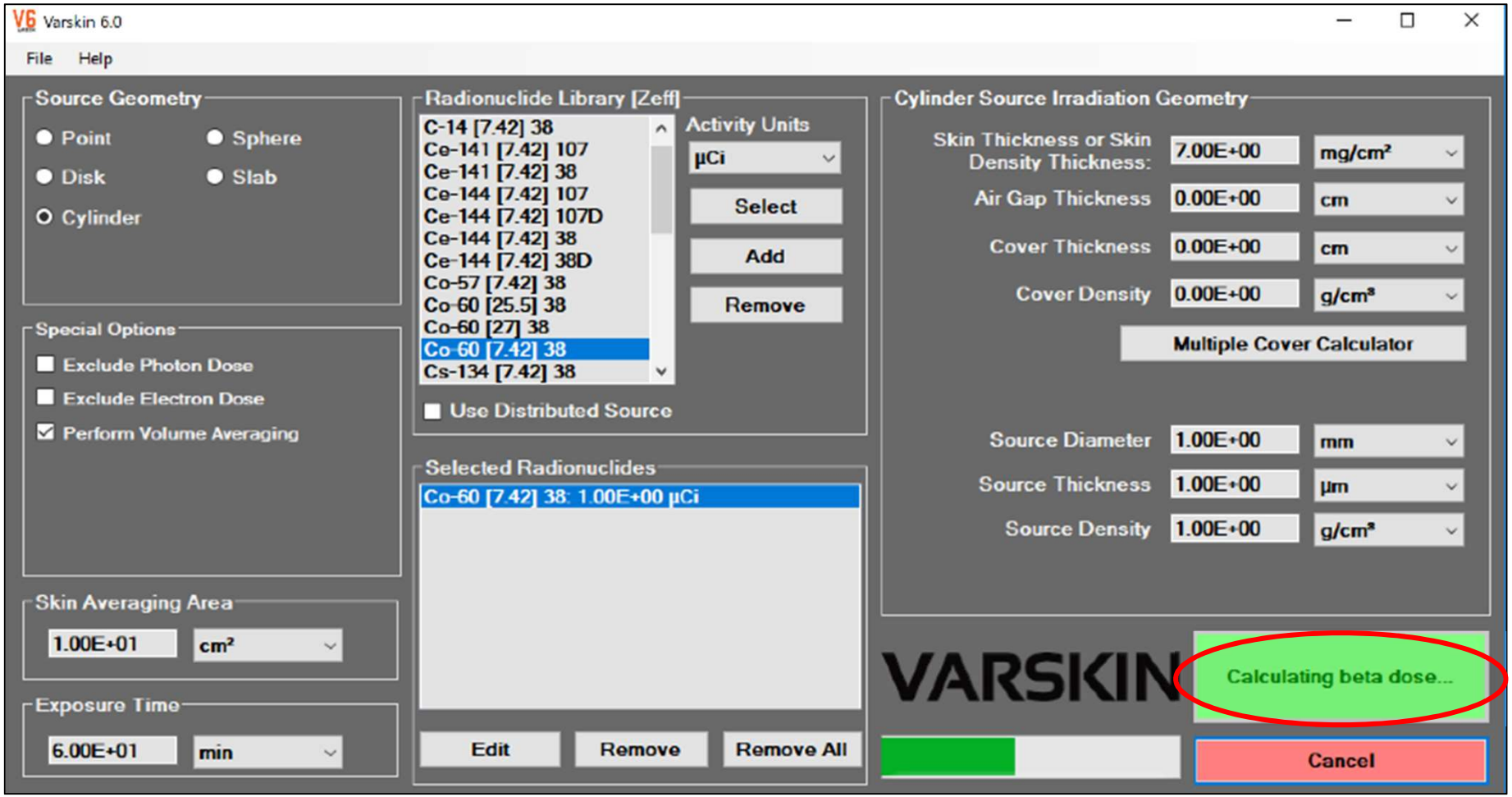
3D source and Volume averaging



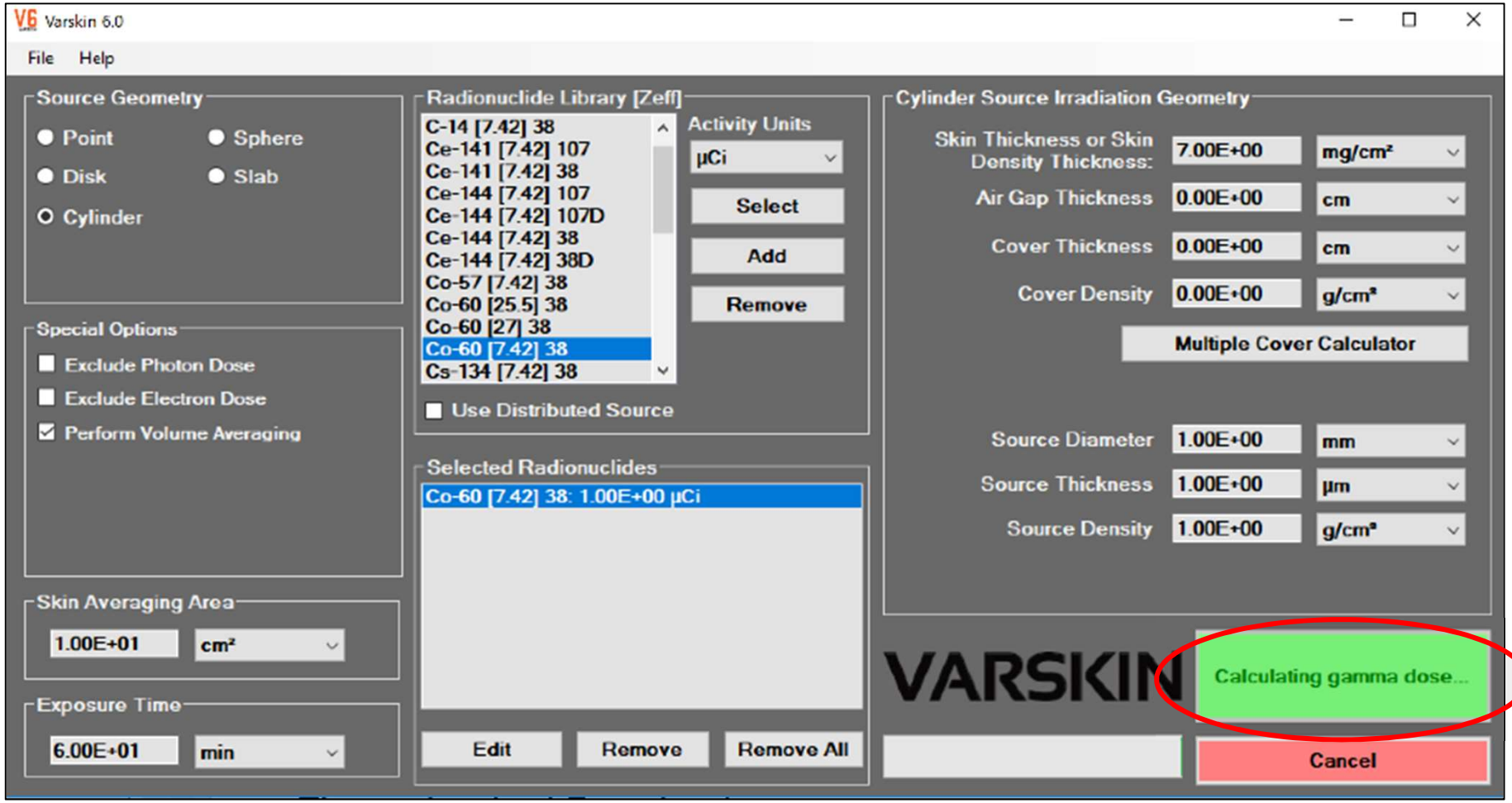
Maximum volume averaging depth

	Max Beta Energy (keV)	Max Depth (mg/cm^2)
Co-60	318	59.09
Cs-137	514	163.8
Cs-134	658	186.2
Ba-140	1020	295.3
Y-91	1540	604.4

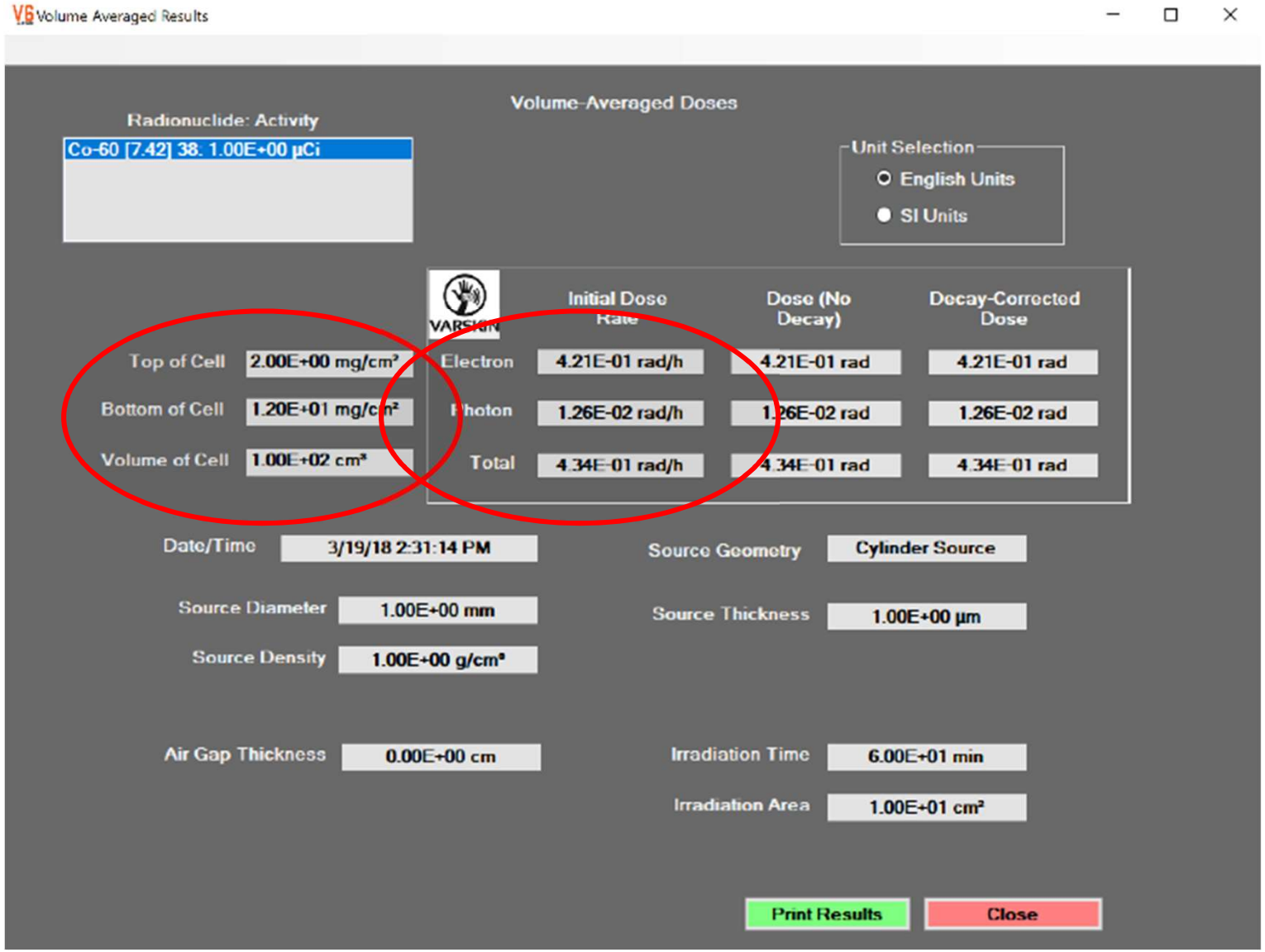
Calculating beta dose



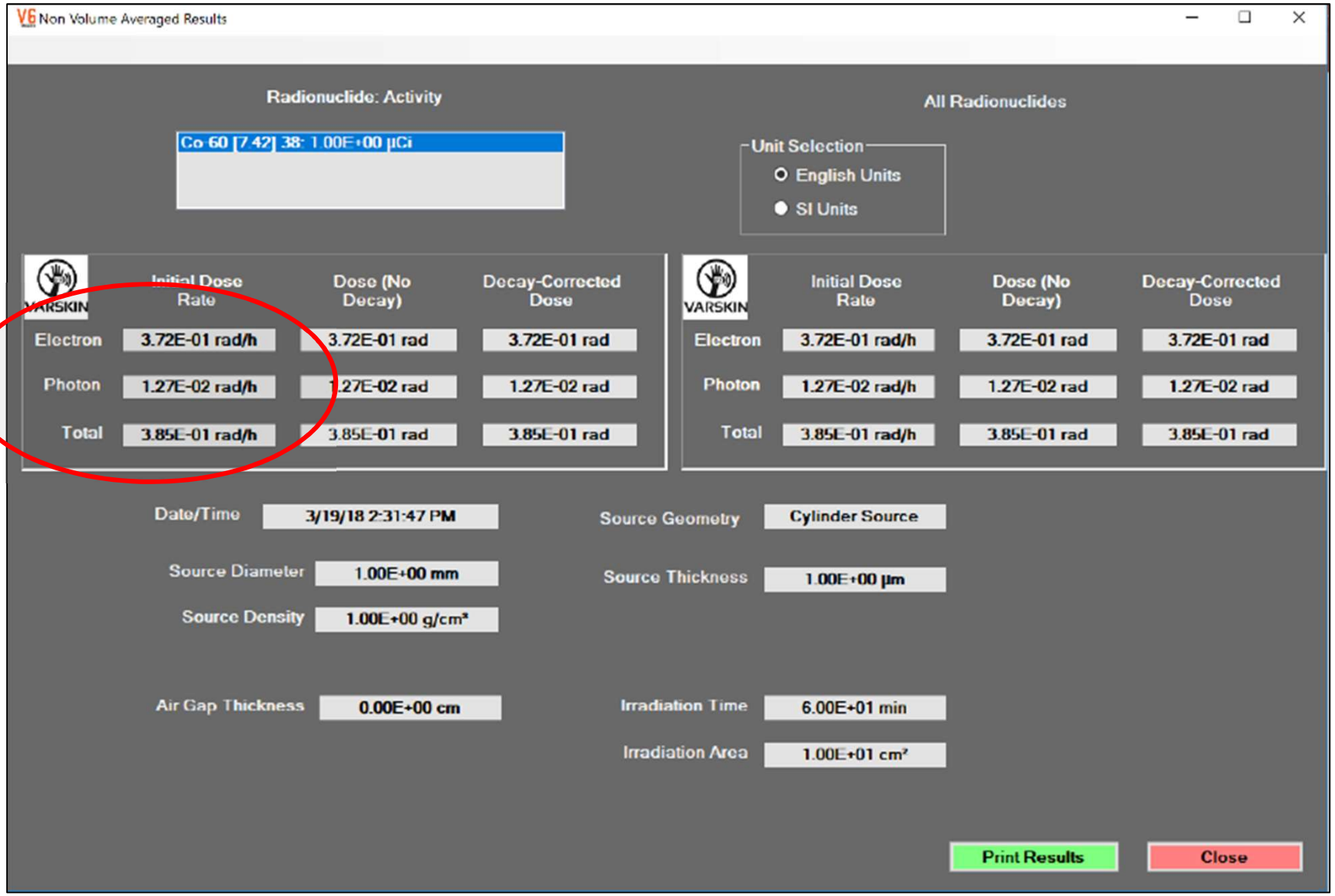
Calculating gamma dose



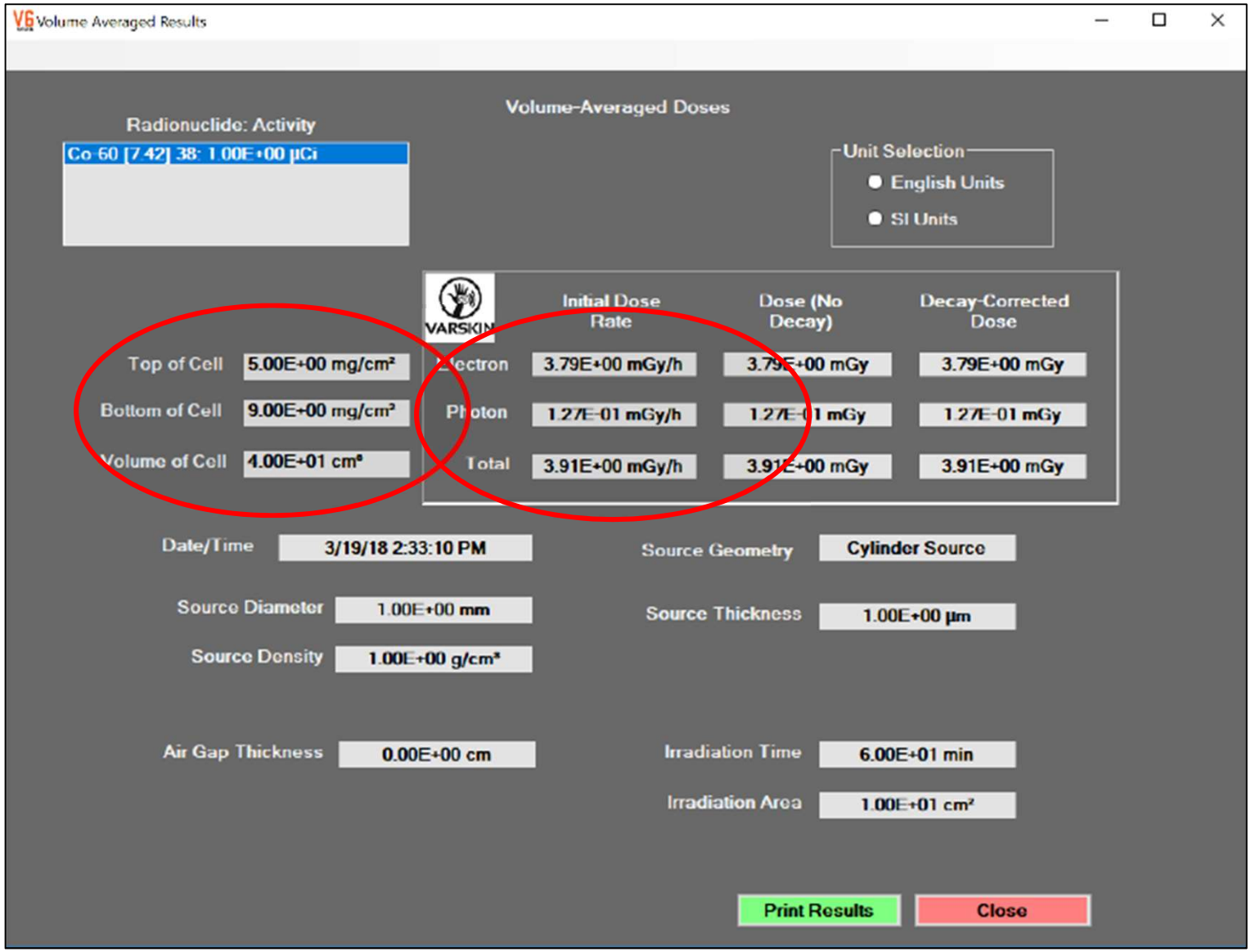
results


V6 Volume Averaged Results
Volume-Averaged Doses
Radionuclide: Activity
Co-60 [7.42] 38. 1.00E+00 µCi
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Top of Cell
2.00E+00 mg/cm²
Bottom of Cell
1.20E+01 mg/cm²
Volume of Cell
1.00E+02 cm³
Electron
4.21E-01 rad/h
4.21E-01 rad
4.21E-01 rad
Photon
1.26E-02 rad/h
1.26E-02 rad
1.26E-02 rad
Total
4.34E-01 rad/h
4.34E-01 rad
4.34E-01 rad
Date/Time
3/19/18 2:31:14 PM
Source Geometry
Cylinder Source
Source Diameter
1.00E+00 mm
Source Thickness
1.00E+00 µm
Source Density
1.00E+00 g/cm³
Air Gap Thickness
0.00E+00 cm
Irradiation Time
6.00E+01 min
Irradiation Area
1.00E+01 cm²
Print Results
Close

results


Non Volume Averaged Results
Radionuclide: Activity
Co-60 [7.42] 38: 1.00E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.72E-01 rad/h 3.72E-01 rad 3.72E-01 rad
Photon 1.27E-02 rad/h 1.27E-02 rad 1.27E-02 rad
Total 3.85E-01 rad/h 3.85E-01 rad 3.85E-01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 3.72E-01 rad/h 3.72E-01 rad 3.72E-01 rad
Photon 1.27E-02 rad/h 1.27E-02 rad 1.27E-02 rad
Total 3.85E-01 rad/h 3.85E-01 rad 3.85E-01 rad
Date/Time 3/19/18 2:31:47 PM
Source Geometry Cylinder Source
Source Diameter 1.00E+00 mm
Source Thickness 1.00E+00 µm
Source Density 1.00E+00 g/cm³
Air Gap Thickness 0.00E+00 cm
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

results


Volume Averaged Results
Volume-Averaged Doses
Radionuclide: Activity
Co-60 [7.42] 38: 1.00E+00 µCi
Unit Selection
English Units
SI Units
VARSKIN
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Top of Cell
5.00E+00 mg/cm²
Bottom of Cell
9.00E+00 mg/cm²
Volume of Cell
4.00E+01 cm³
Electron
3.79E+00 mGy/h
3.79E+00 mGy
3.79E+00 mGy
Photon
1.27E-01 mGy/h
1.27E-01 mGy
1.27E-01 mGy
Total
3.91E+00 mGy/h
3.91E+00 mGy
3.91E+00 mGy
Date/Time
3/19/18 2:33:10 PM
Source Geometry
Cylinder Source
Source Diameter
1.00E+00 mm
Source Thickness
1.00E+00 µm
Source Density
1.00E+00 g/cm³
Air Gap Thickness
0.00E+00 cm
Irradiation Time
6.00E+01 min
Irradiation Area
1.00E+01 cm²
Print Results
Close