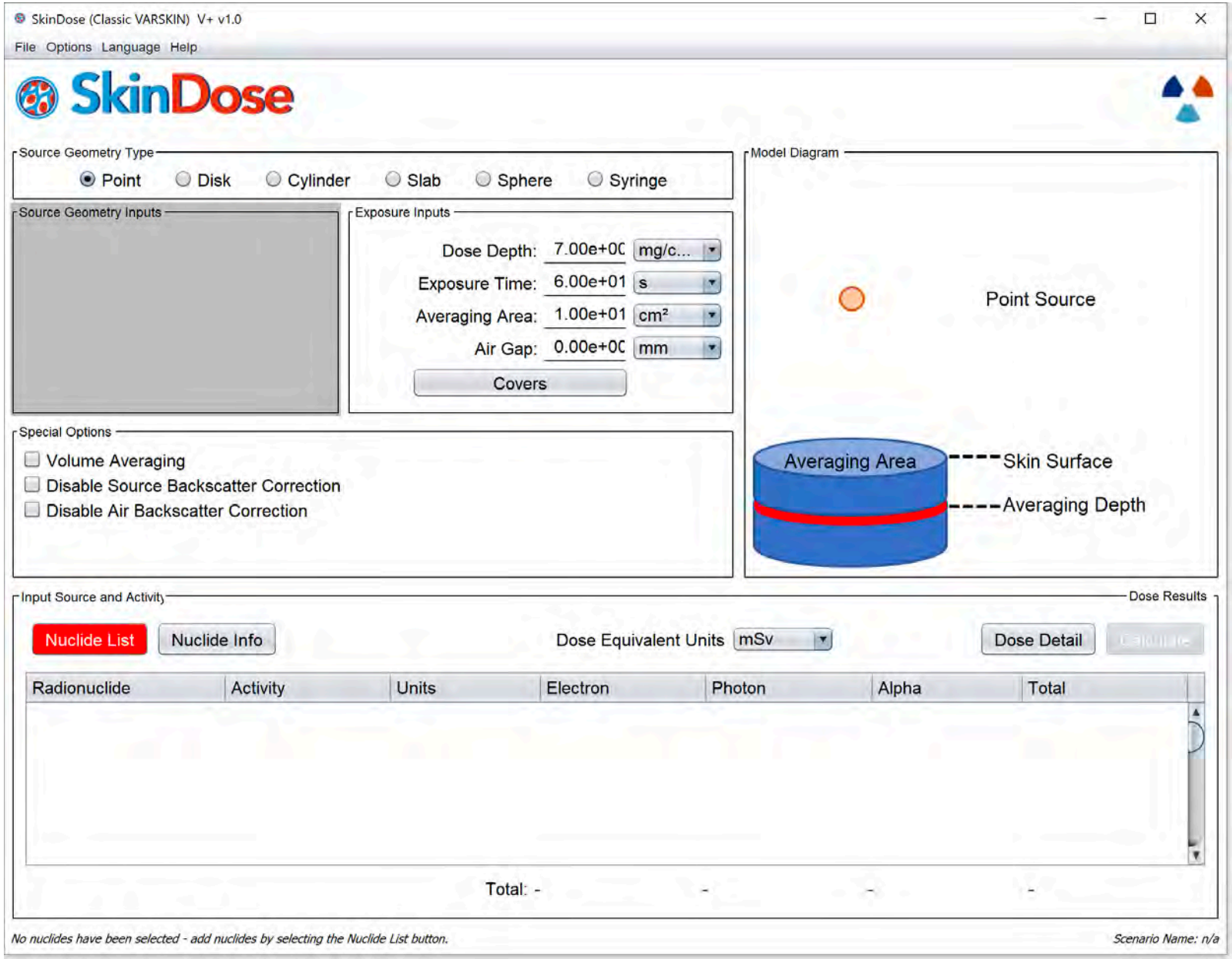


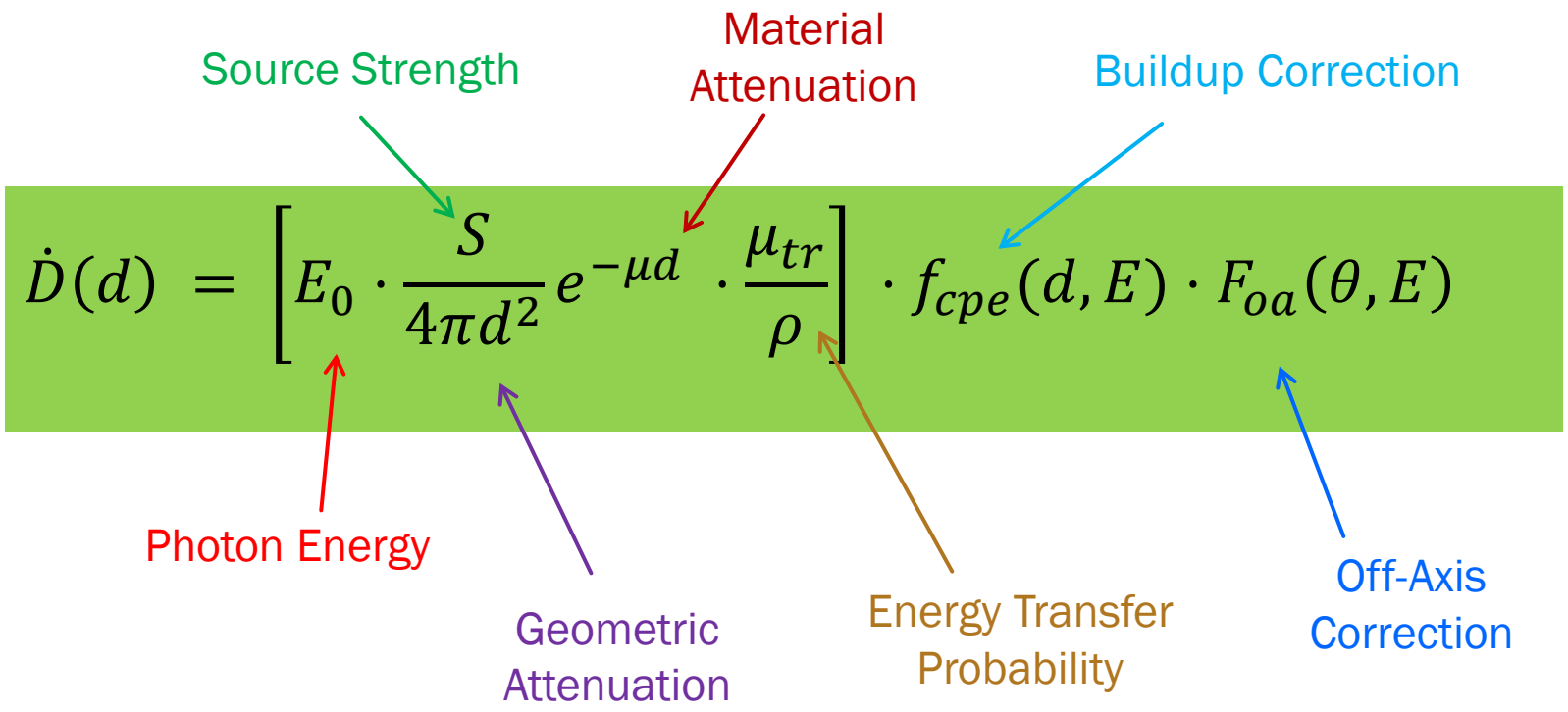
varSKIN+
SKIN DOSE

RENAISSANCE CODE DEVELOPMENT
Colby Mangini, PhD. CHP

OUTLINE

- Overview of new SkinDose GUI
- Gamma Model
  - Brief Theory
  - Correction Factors
- Electron Model
  - Brief Theory
  - Scaling Model
  - Backscatter Correction
- Examples

GAMMA MODEL: BASIC 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)

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

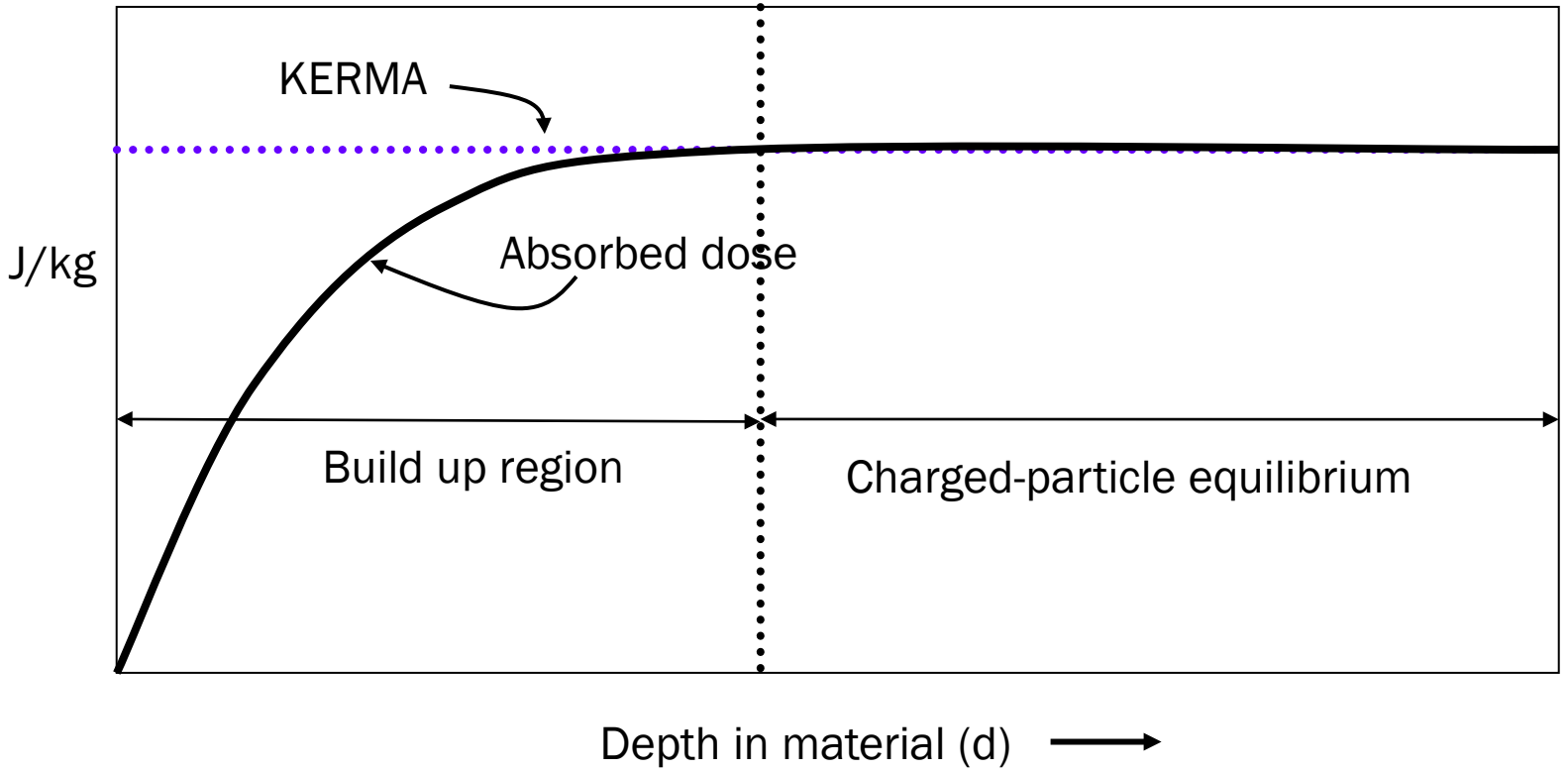
$$D = K \cdot \frac{\mu_{en}}{\mu_{tr}}$$

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

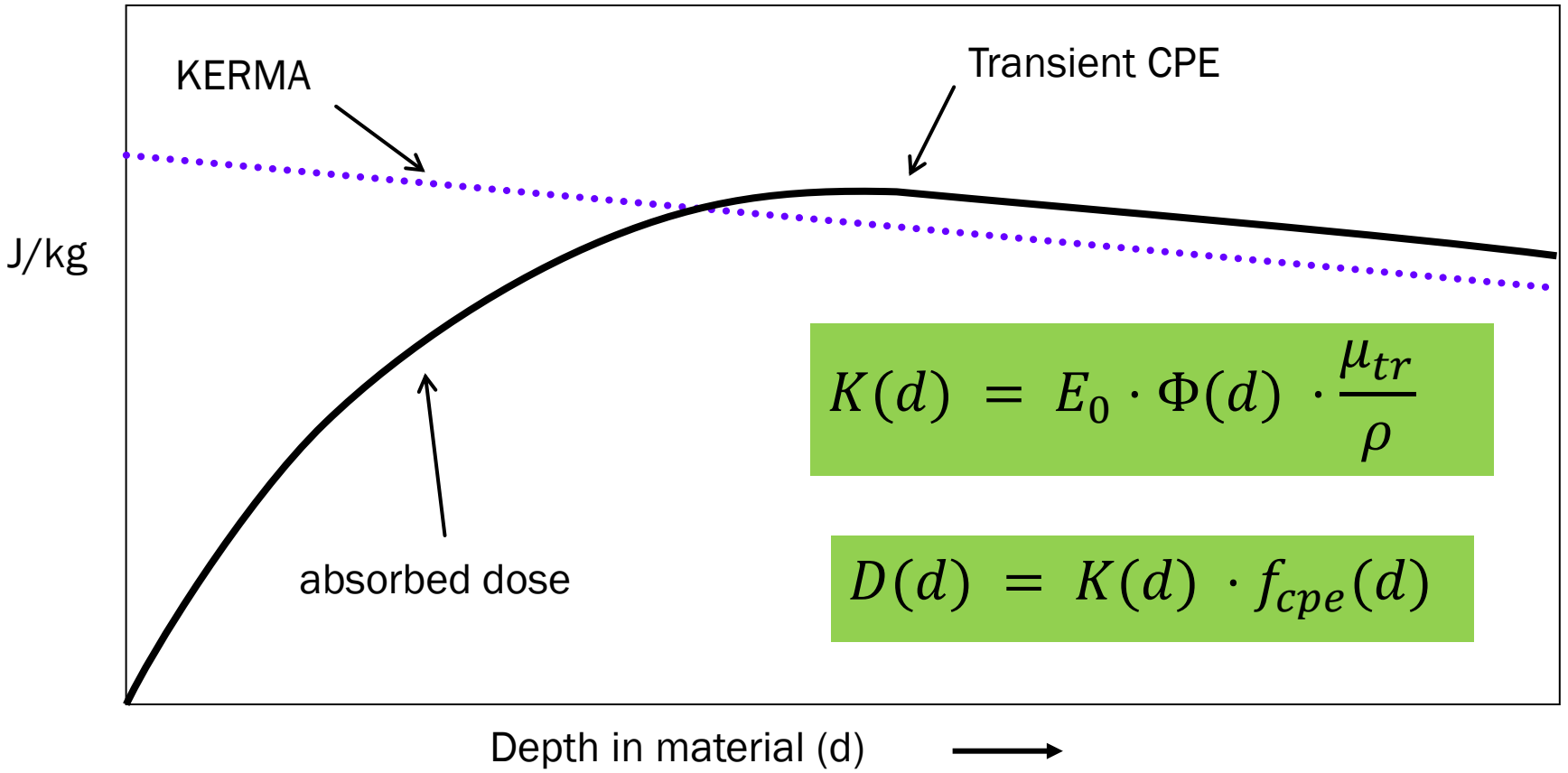
CHARGED-PARTICLE EQUILIBRIUM

- 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

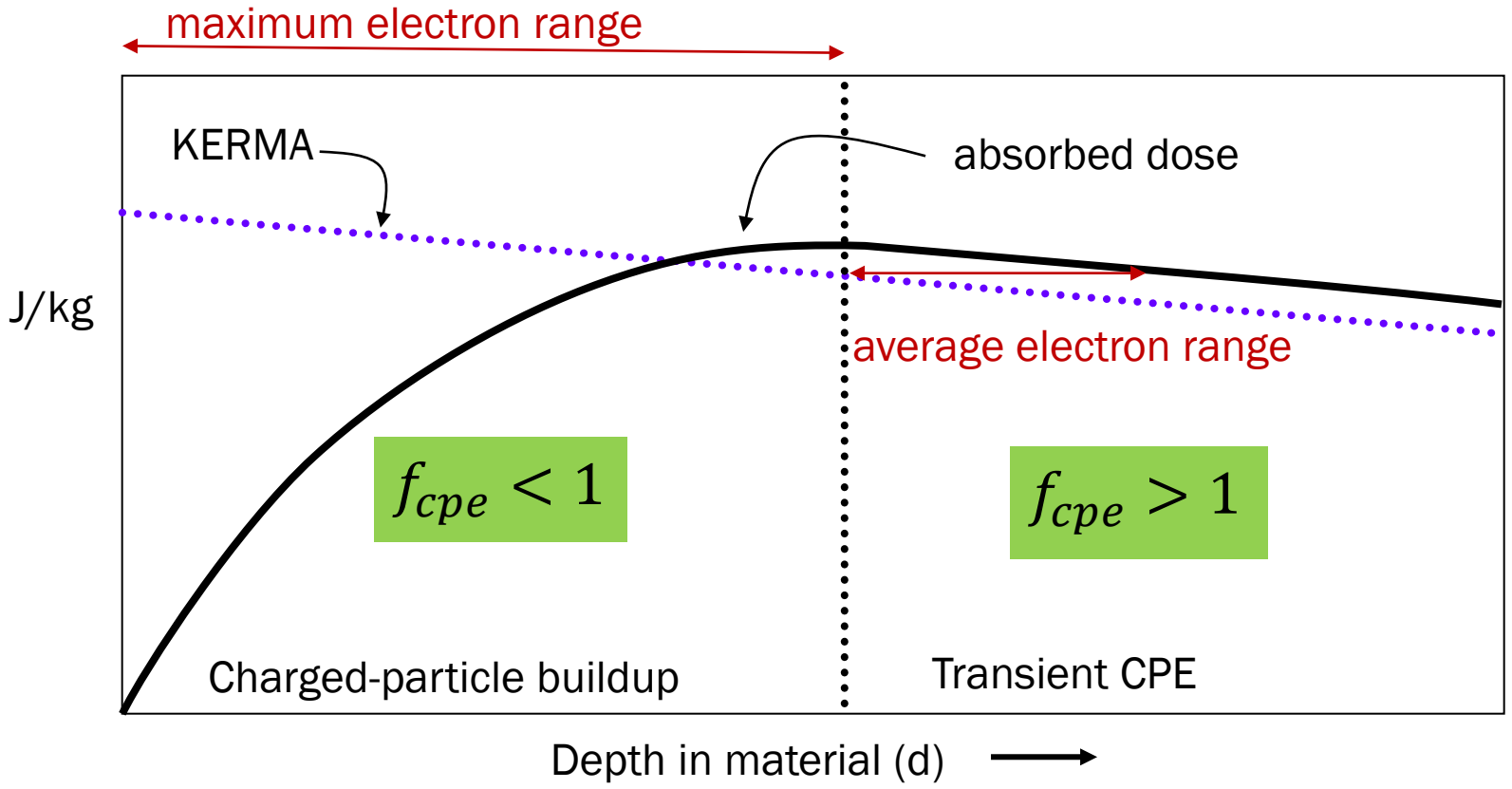


KERMA AND DOSE BUILDUP



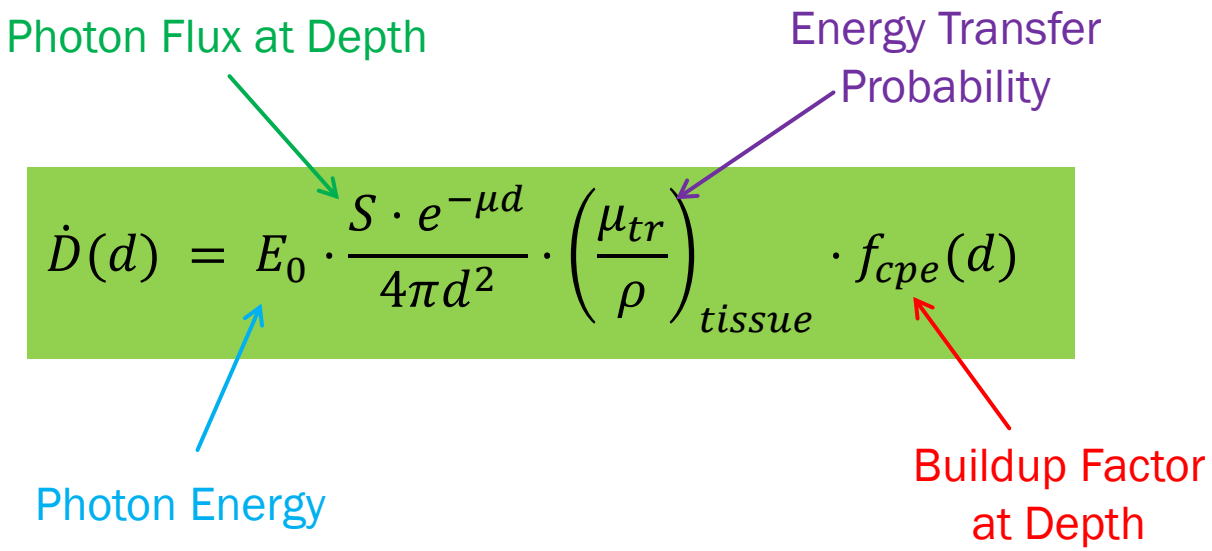
DETAILS

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



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:

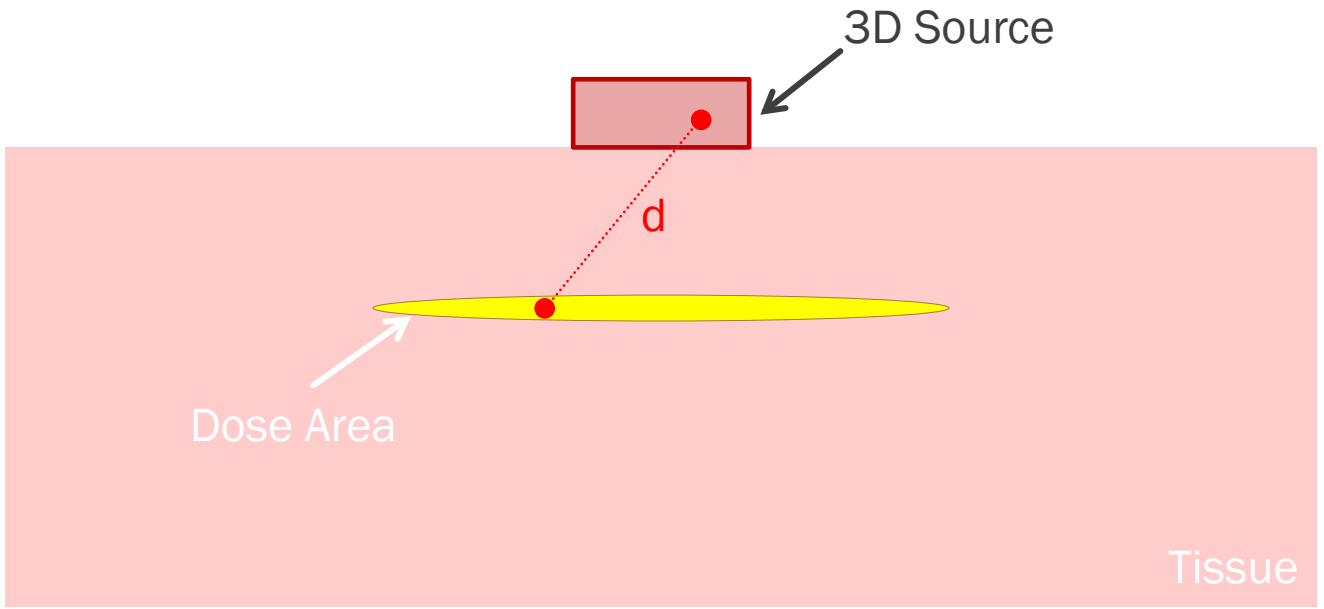


VARSKIN+ PHOTON DOSIMETRY

- The VARKSIN+ SKIN DOSE photon dosimetry model introduced considers:
  - photon point-kernel methodology
  - charge-particle buildup; attenuation; off-axis scatter
  - numerical integration of 300 dose points for each source point
  - 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)

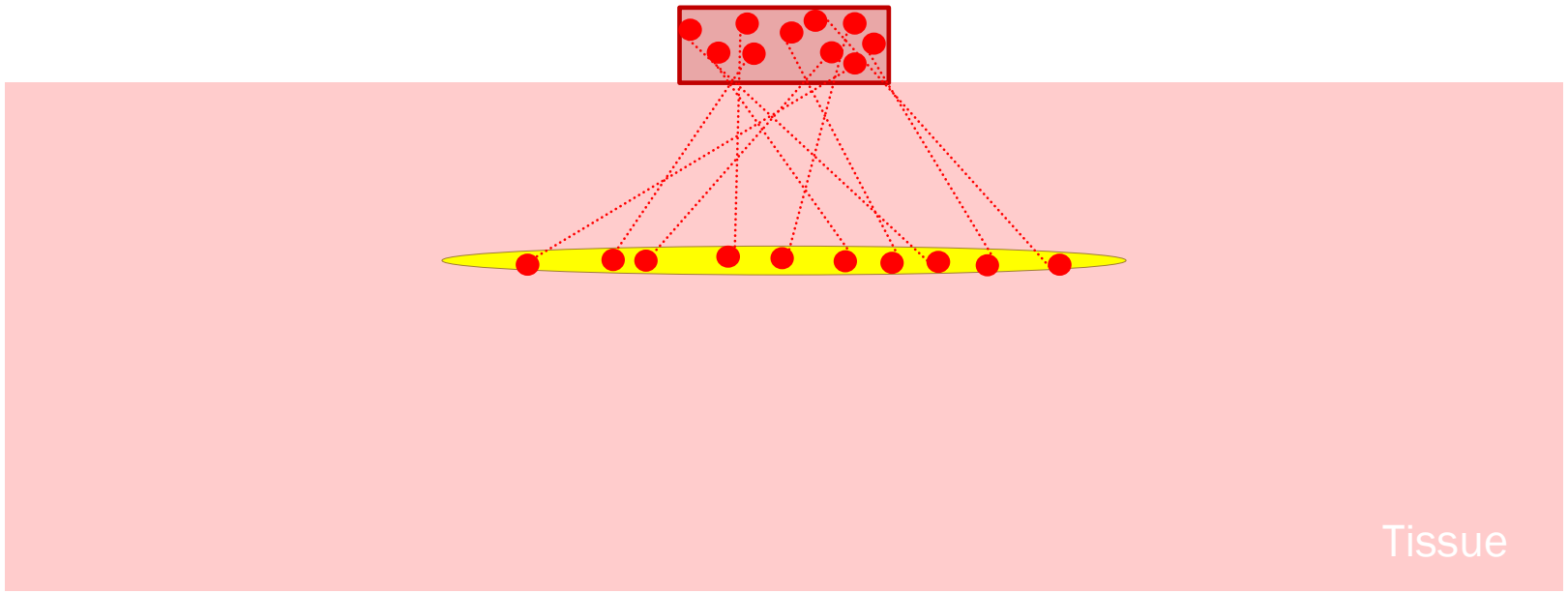
"POINT KERNEL" CONCEPT

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



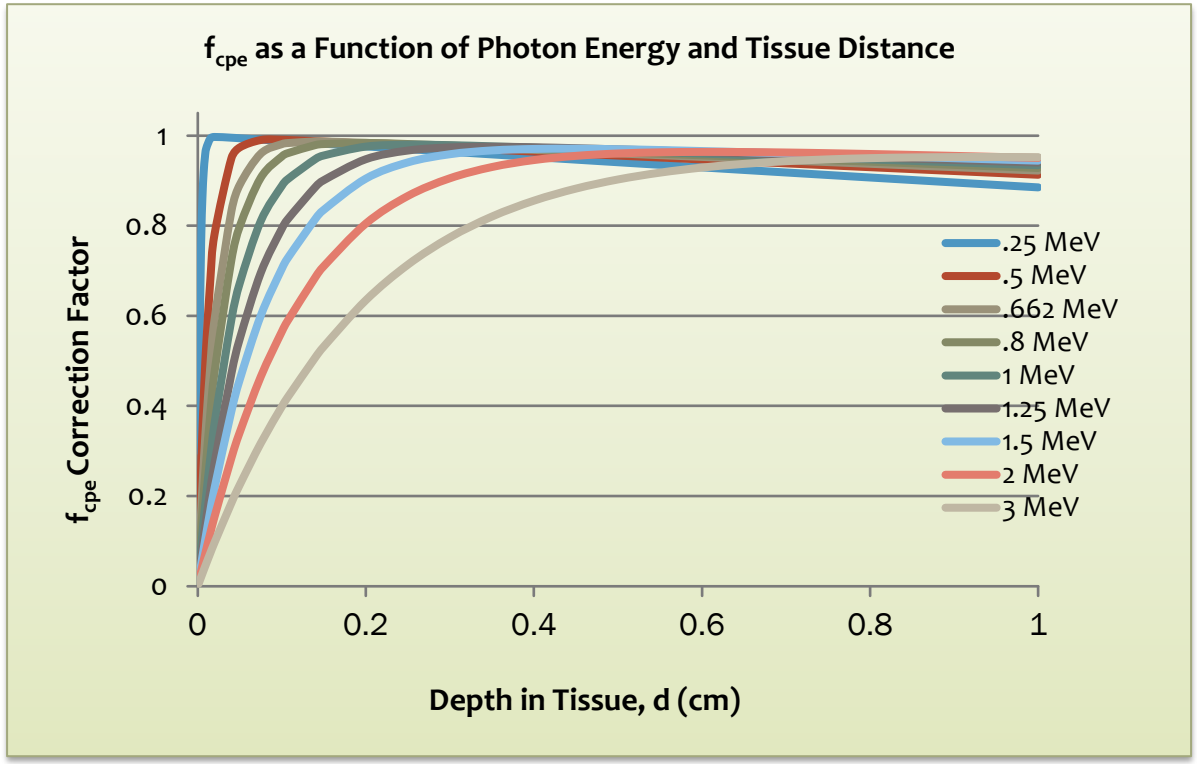
INTEGRATE POINT KERNELS OVER SOURCE/DOSE VOLUME

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



CHARGED-PARTICLE

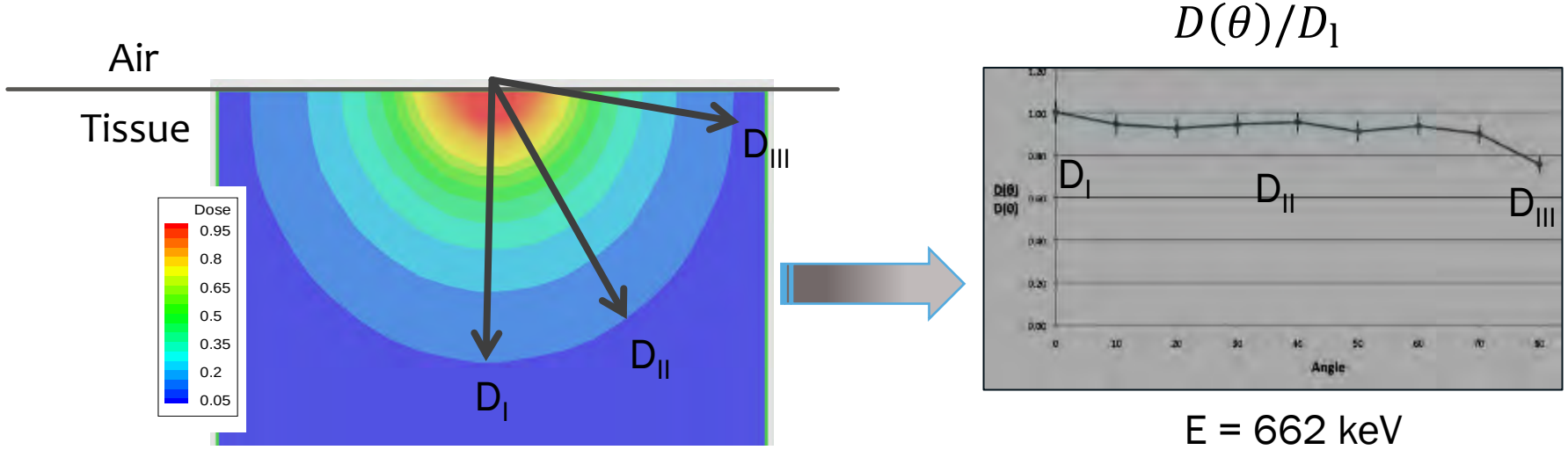
- Using Monte Carlo simulation, the buildup correction factors were found to fit the general form:



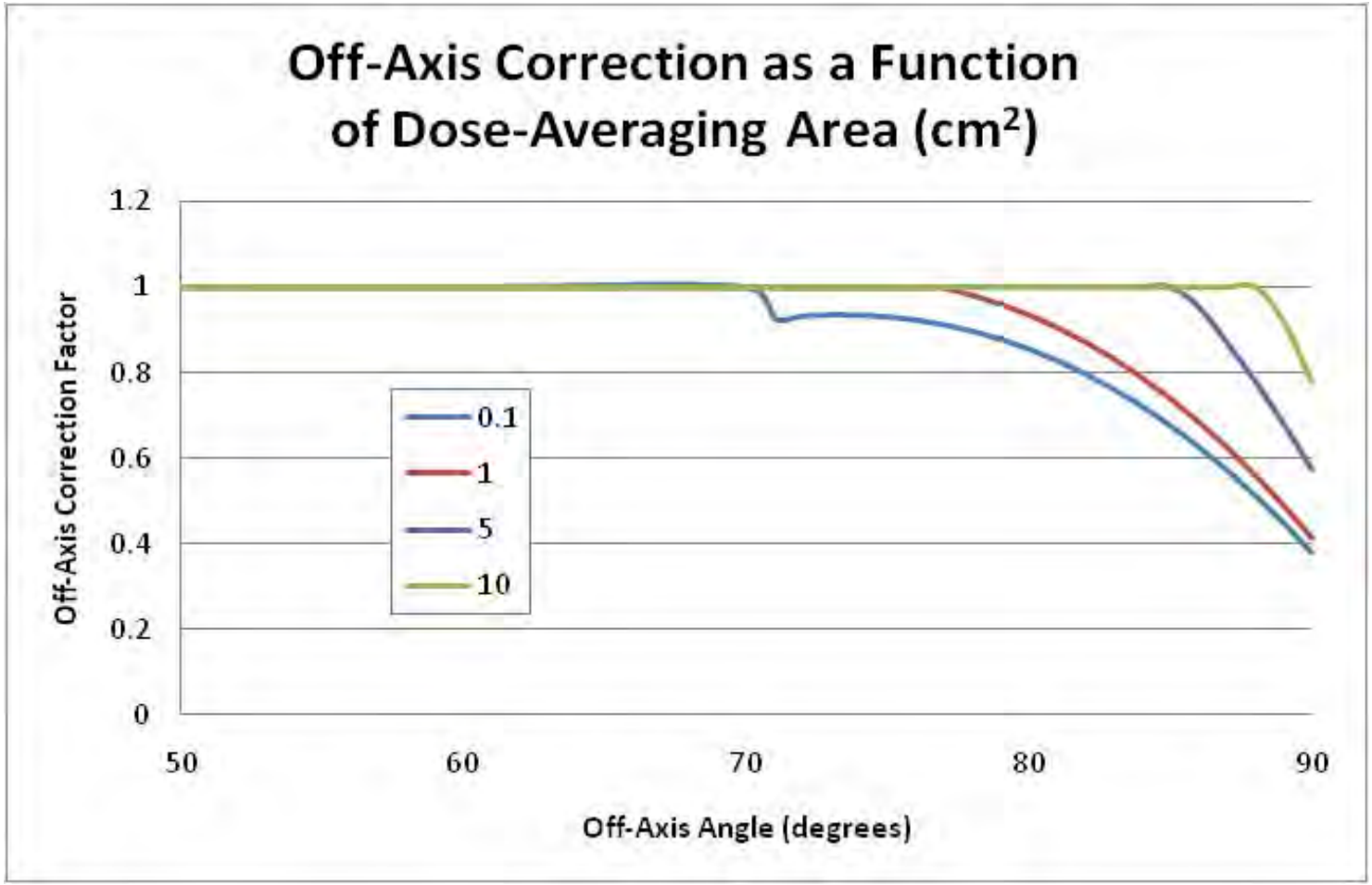
$$\frac{1}{f_{cpe}(d,E)} = a + b\ln(d) + \frac{c}{\sqrt{d}}$$

OFF-AXIS CORRECTION

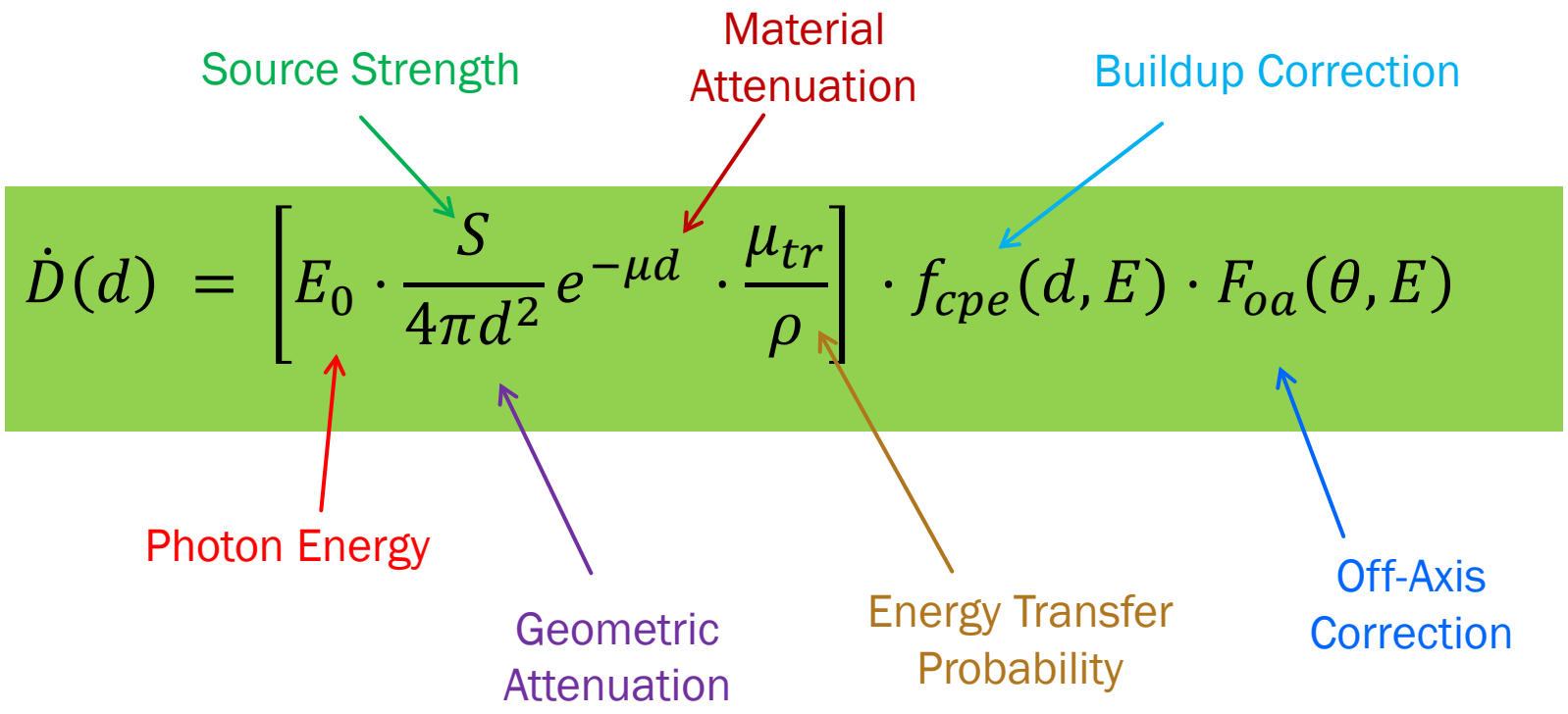
- CPE factors were determined at various depths on-axis in an infinite medium
  - thus, photon/electron loss at tissue-air interface is not considered
- Previous calculations assumed $D_I = D_{II} = D_{III}$
  - additional simulations performed to consider electron loss
- Ratio of off-axis dose to perpendicular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



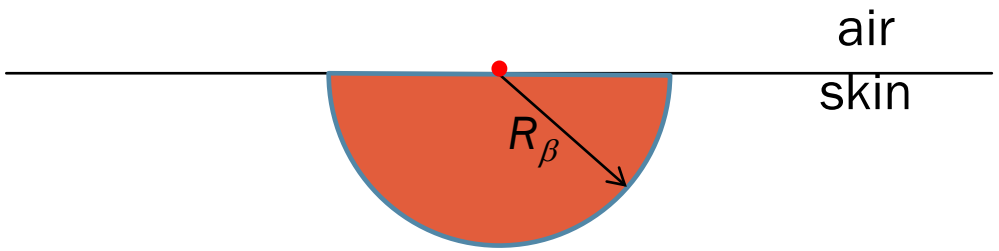
OFF-AXIS CORRECTION FACTORS IMPLEMENTED FOR 4 DOSE AVERAGING AREAS

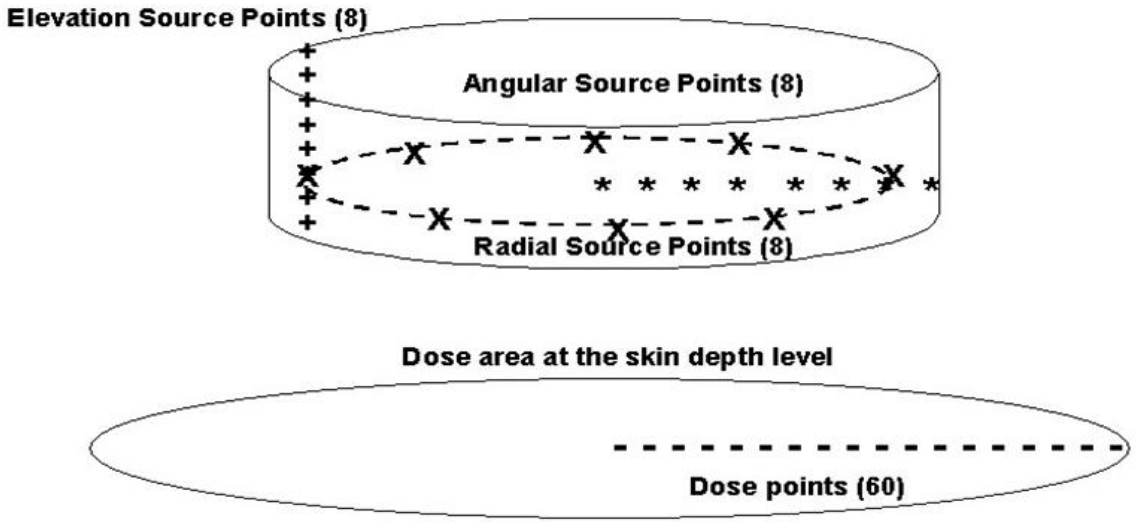


ELEMENTS OF THE DOSE CALCULATION



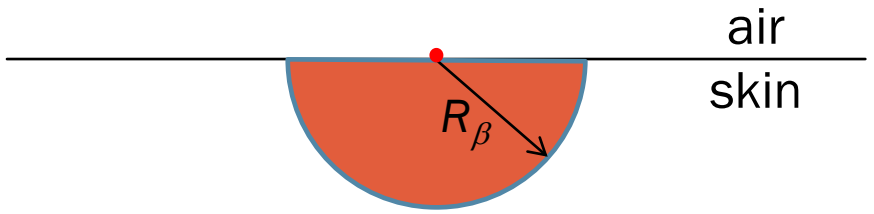
ELECTRON MODEL: BASIC THEORY





ELECTRON INTERACTIONS

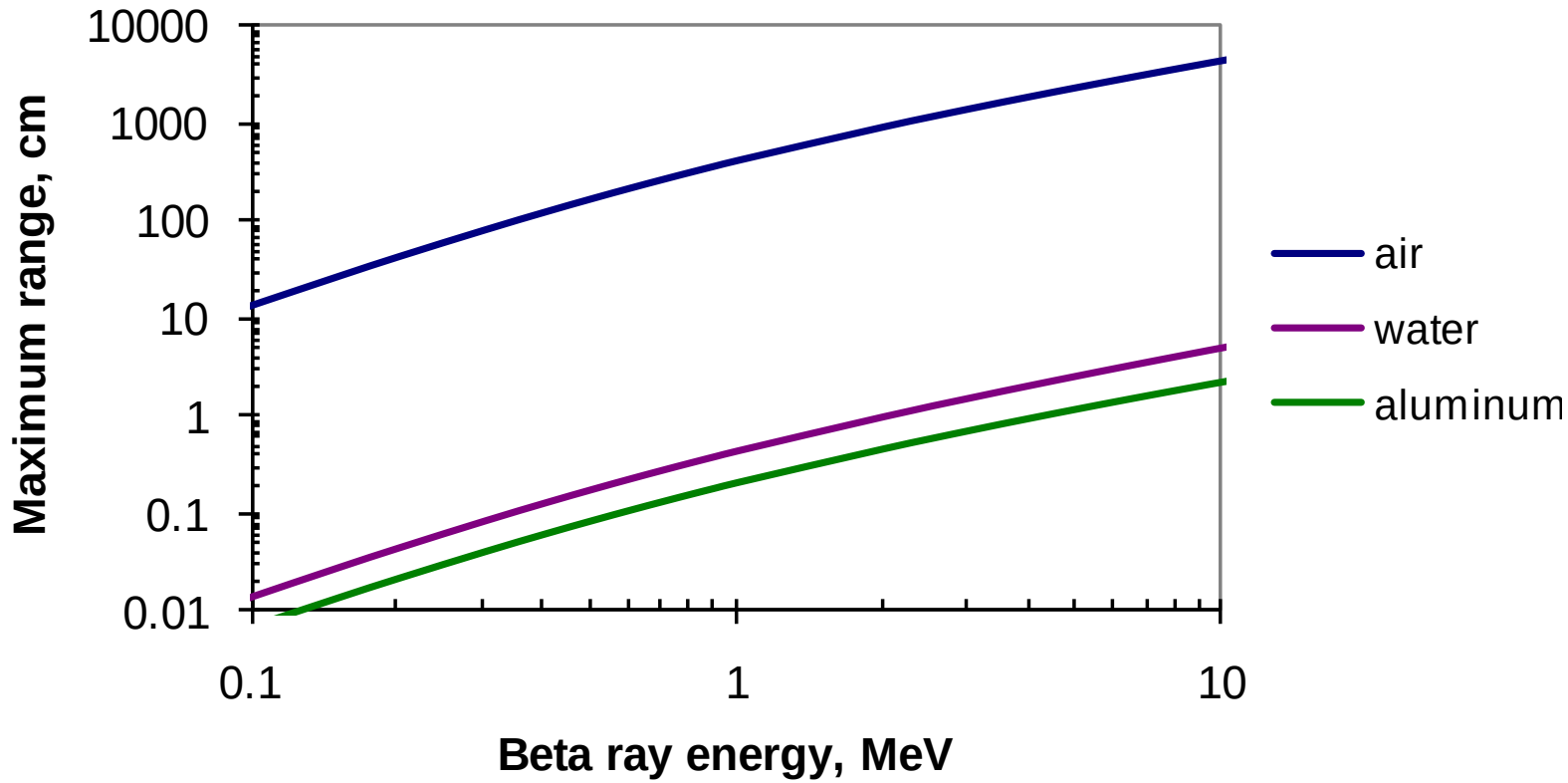
- As energetic electrons pass through material, they transfer energy
  - primarily via “soft collisions”, i.e., Coulombic interactions
  - or, “hard” collisions with orbital electrons
- Energy loss is a function of KE & charge density
- Energy loss can result in:
  - excitation – characteristic X-rays
  - 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



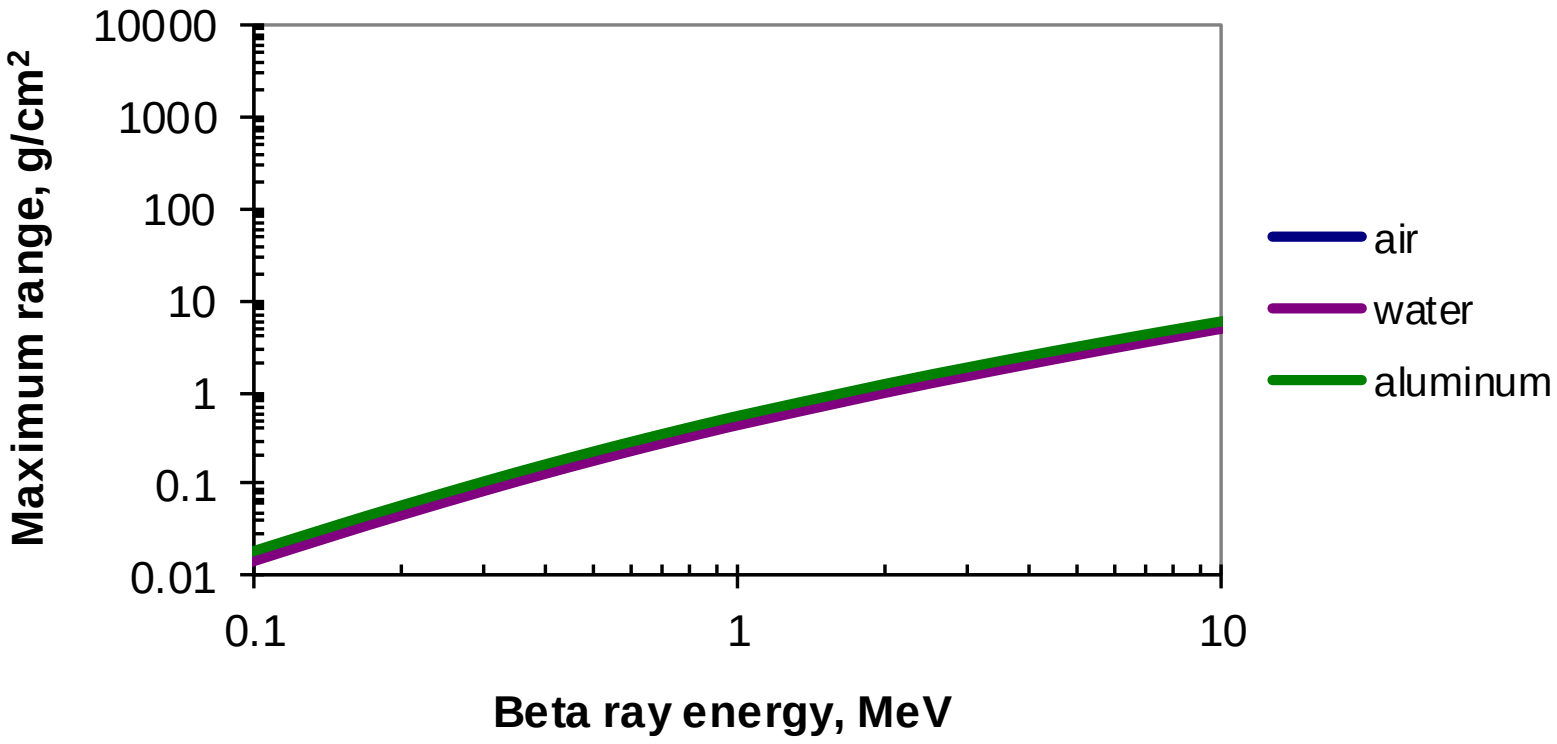
RANGE-ENERGY OBSERVATIONS

- 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

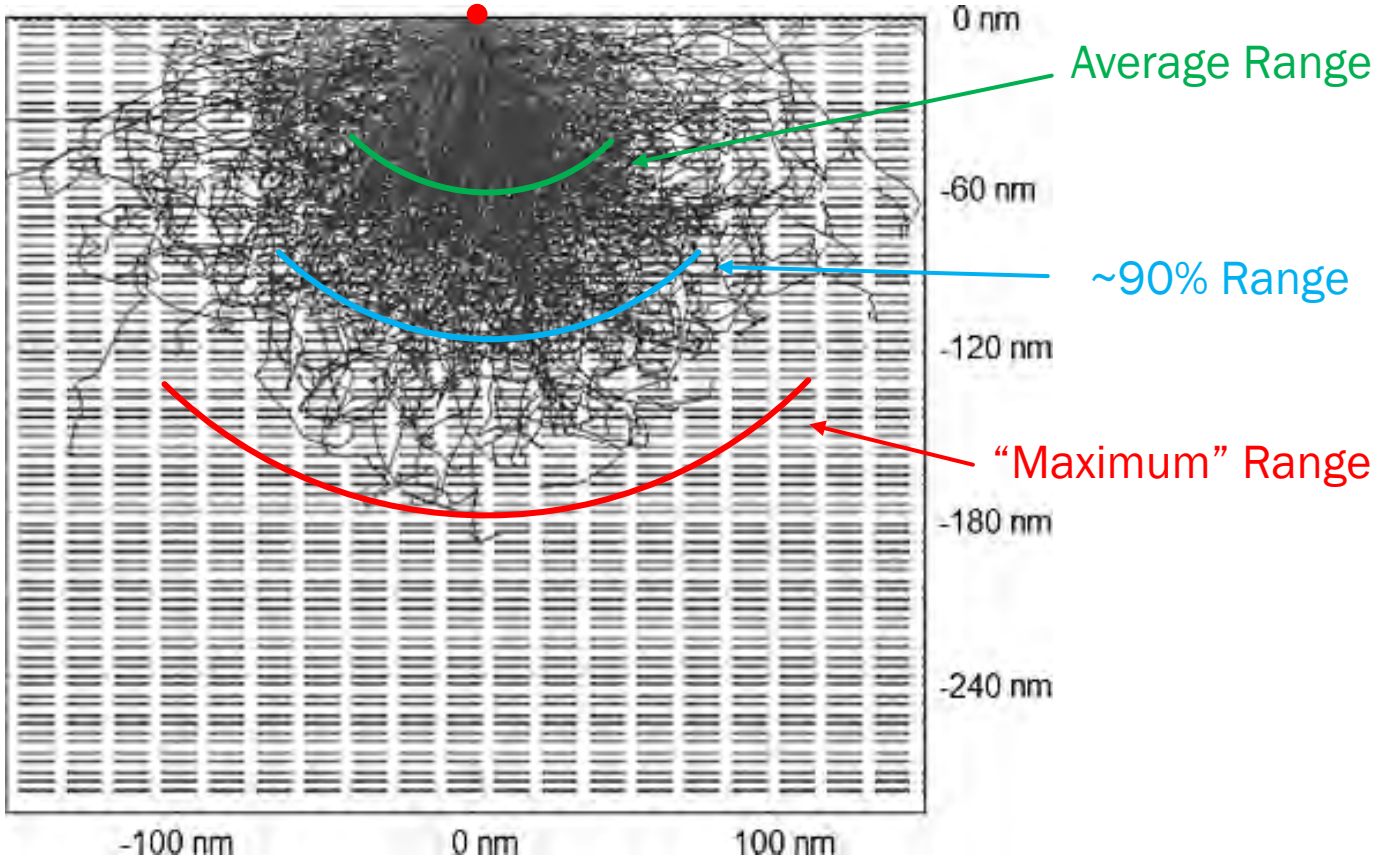
RANGE-ENERGY RELATIONSHIP FOR ELECTRONS



ADVANTAGE OF DENSITY THICKNESS



ELECTRON TRACK SIMULATION



SIMPLIFIED ELECTRON DOSIMETRY

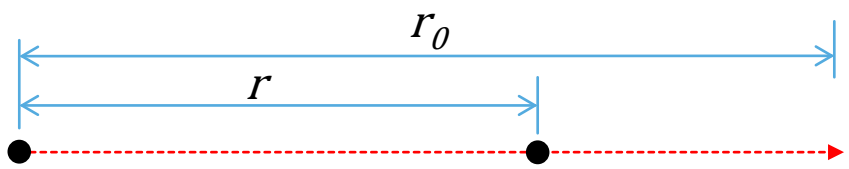
In thin slices that are uniformly exposed, the dose rate from charged particles can be expressed simply as the product of particle flux and mass stopping power:

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

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:

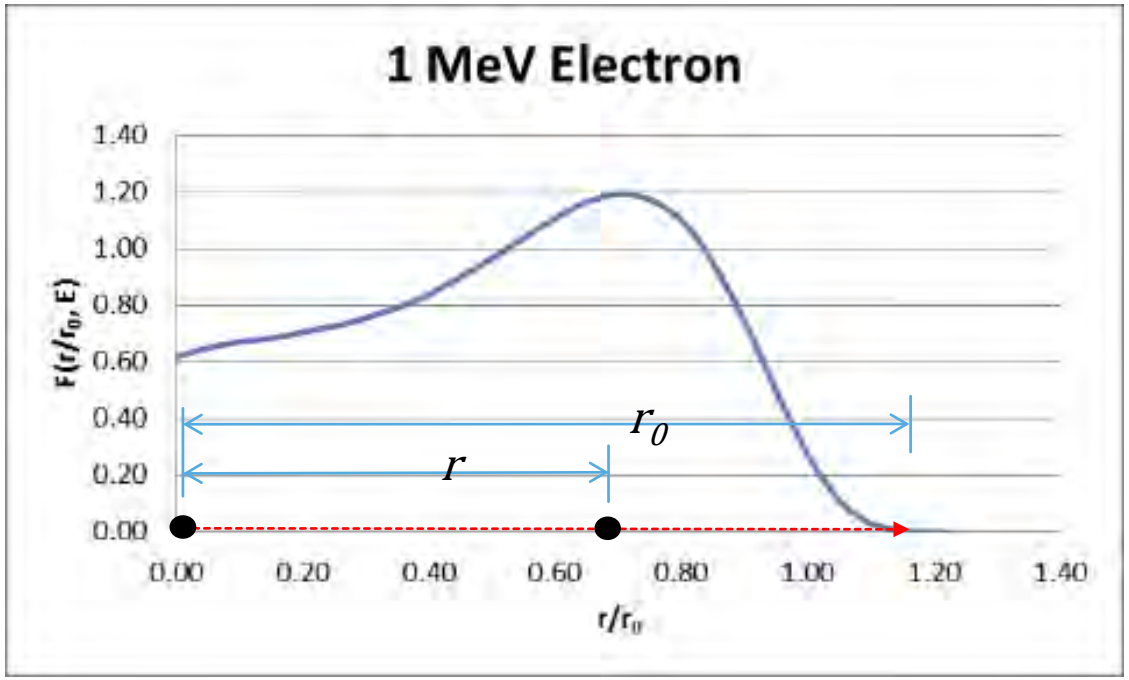
$$G(r,E)=\frac{E}{4\pi r^2 \rho r_0}F(r/r_0,E)$$

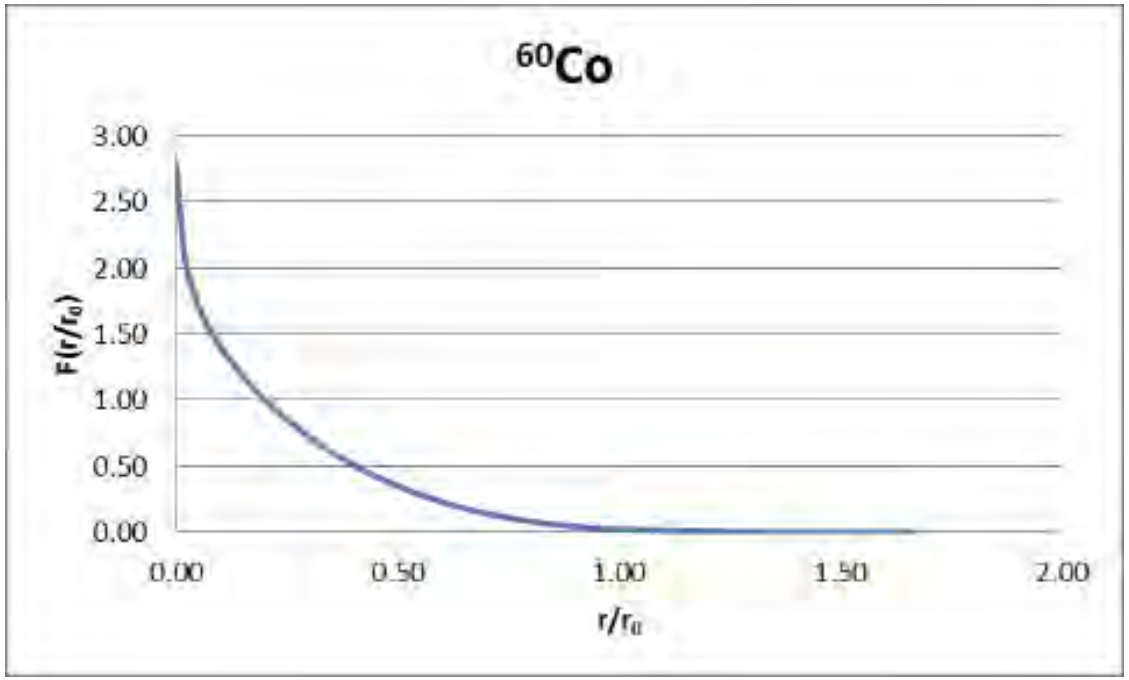


- The function $F(r/r_0,E)$ is a "scaled absorbed dose distribution" (essentially a normalized Bragg curve) that is dependent on the electron initial energy and the fraction of *maximum* range (r/r_0) that the electron has achieved by the time it reaches the dose location.

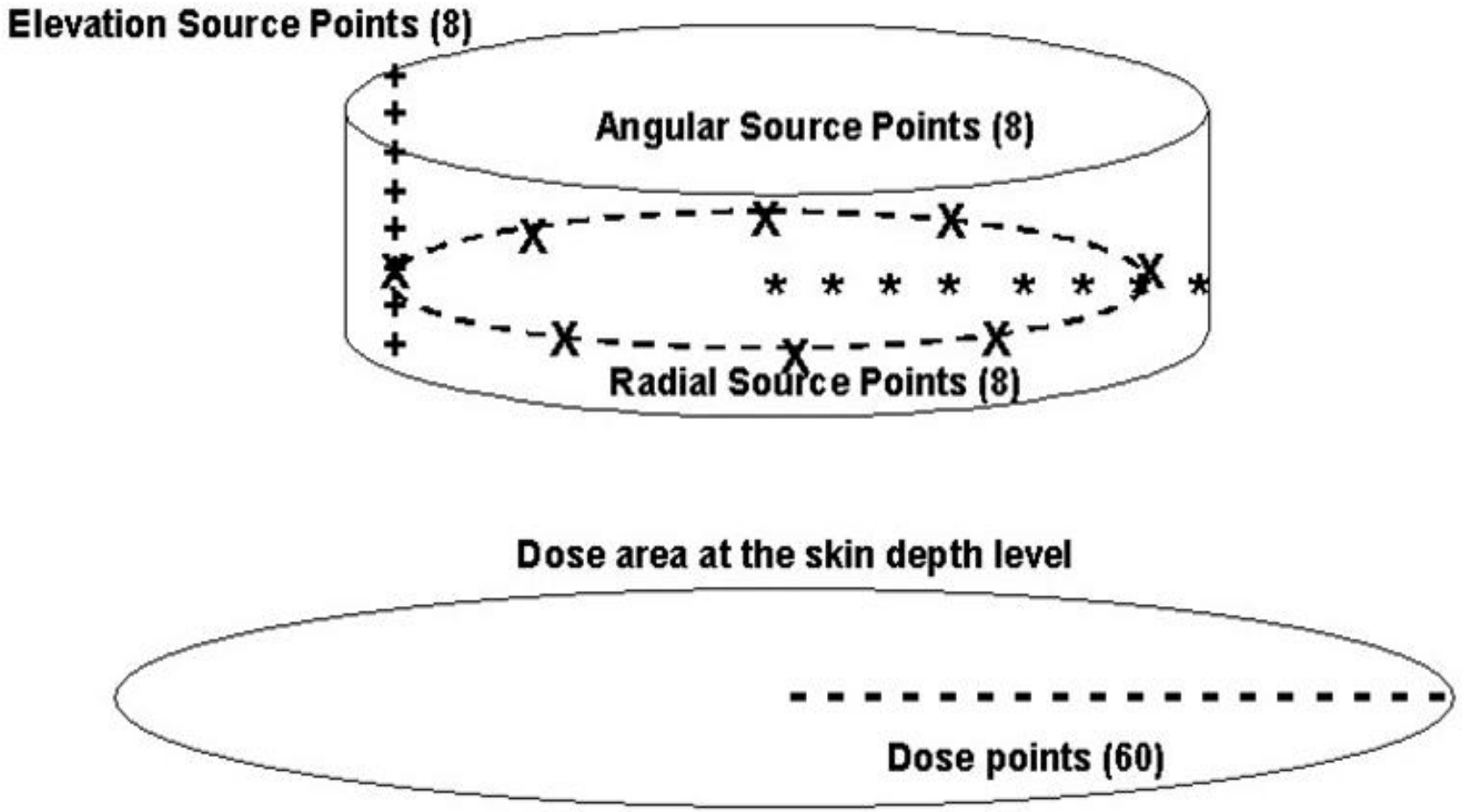
SCALED ABSORBED DOSE DISTRIBUTIONS

- 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



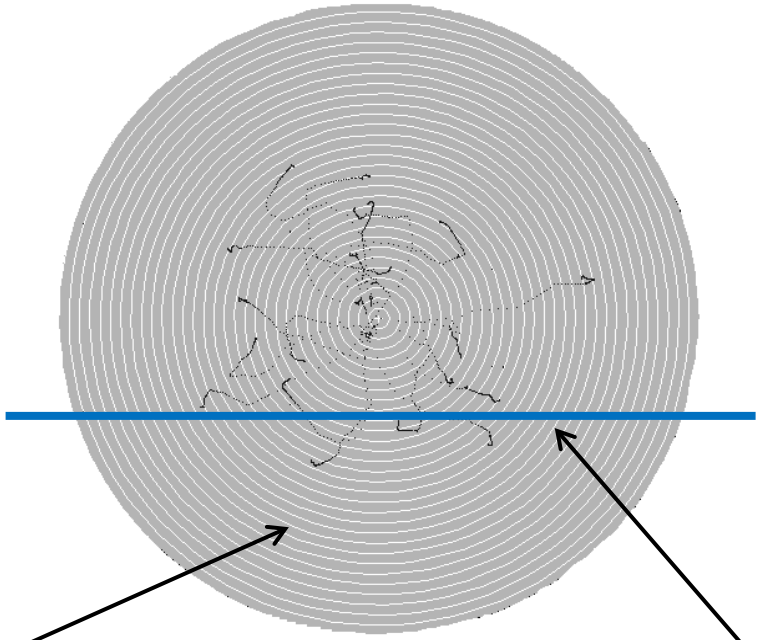


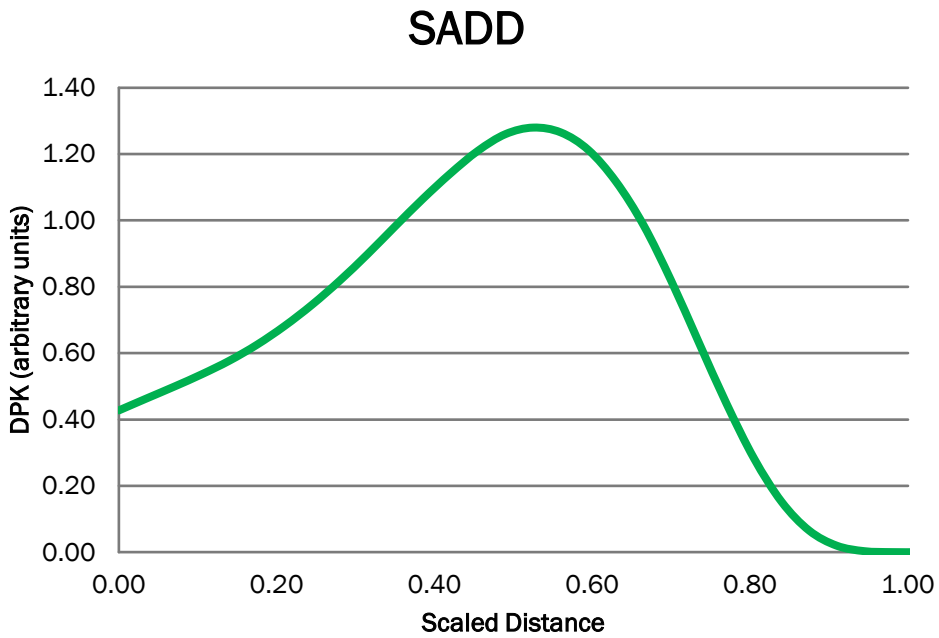
SYMMETRIC-SOURCE DOSE CALCULATION



CORRECTIONS TO DOSE-POINT KERNEL

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

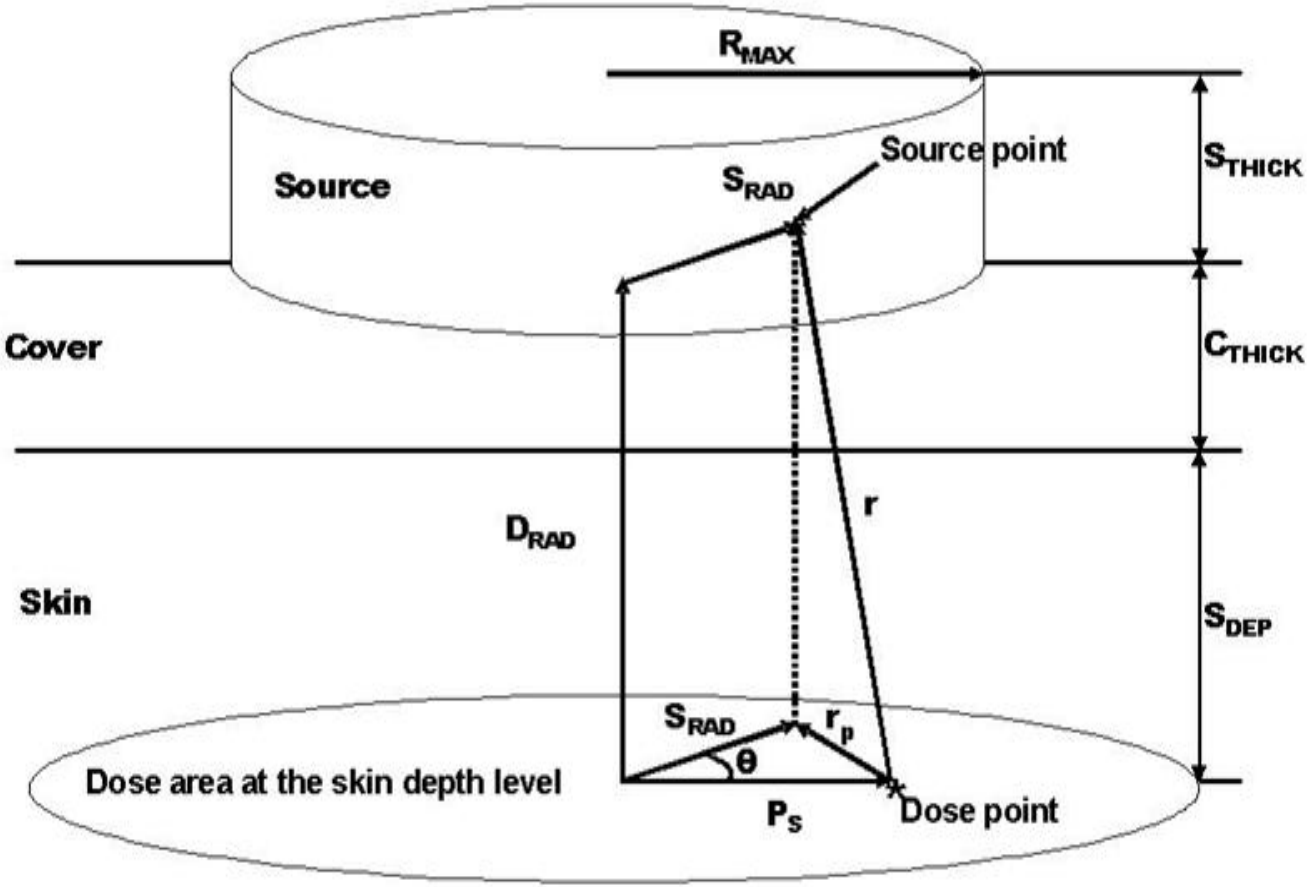




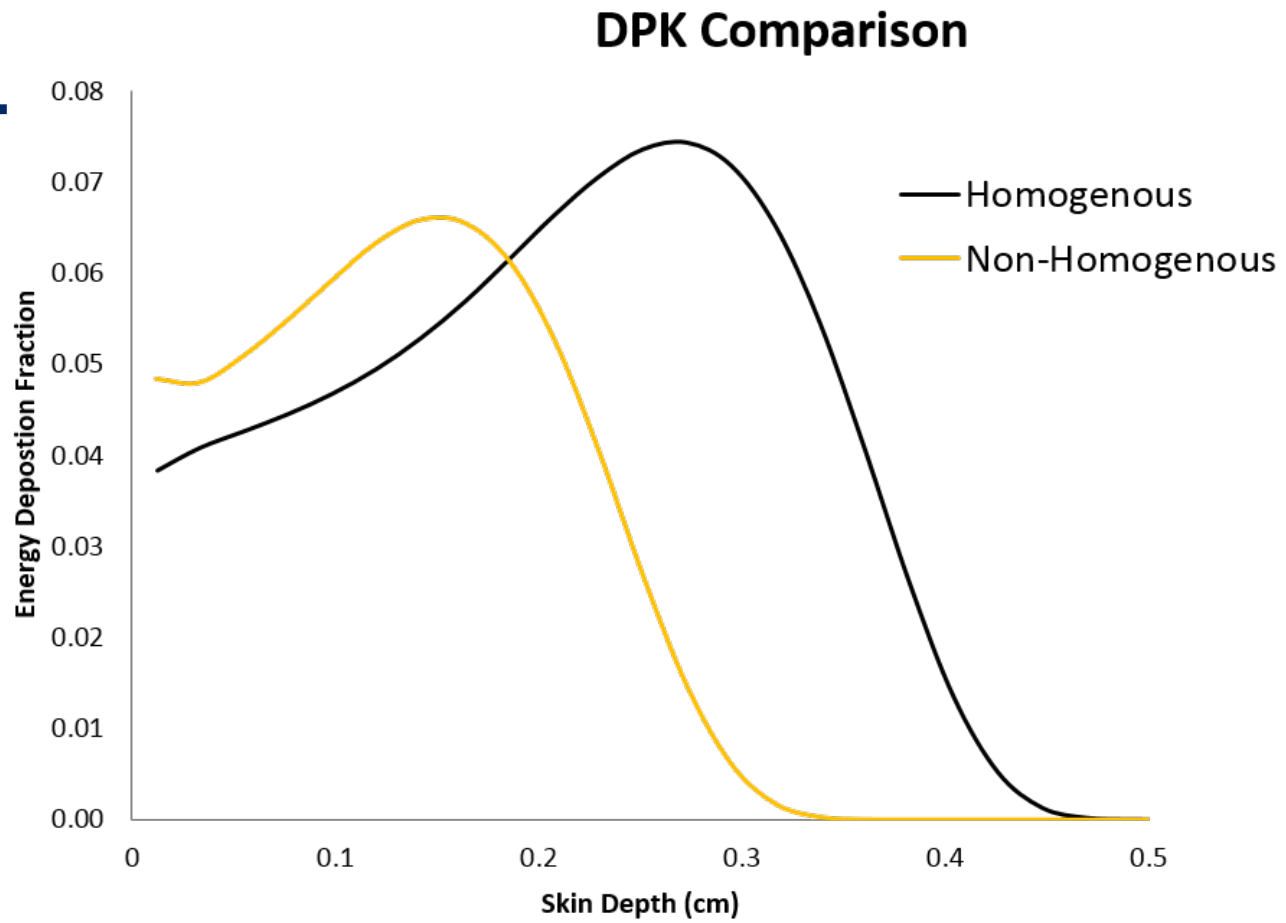
DENSITY CORRECTION MODEL

Fails for typical Hot Particles

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

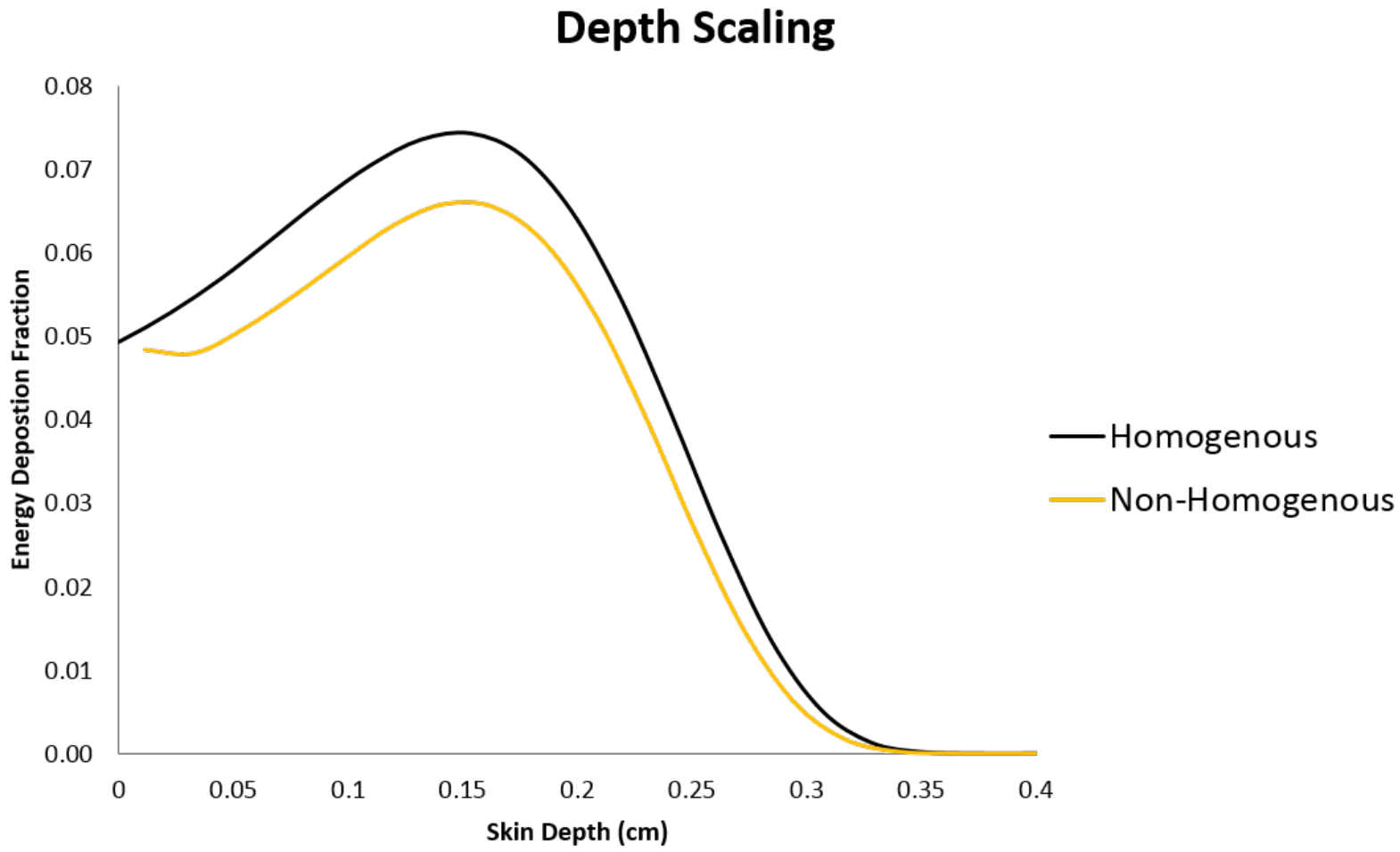


SCALING MODEL



- 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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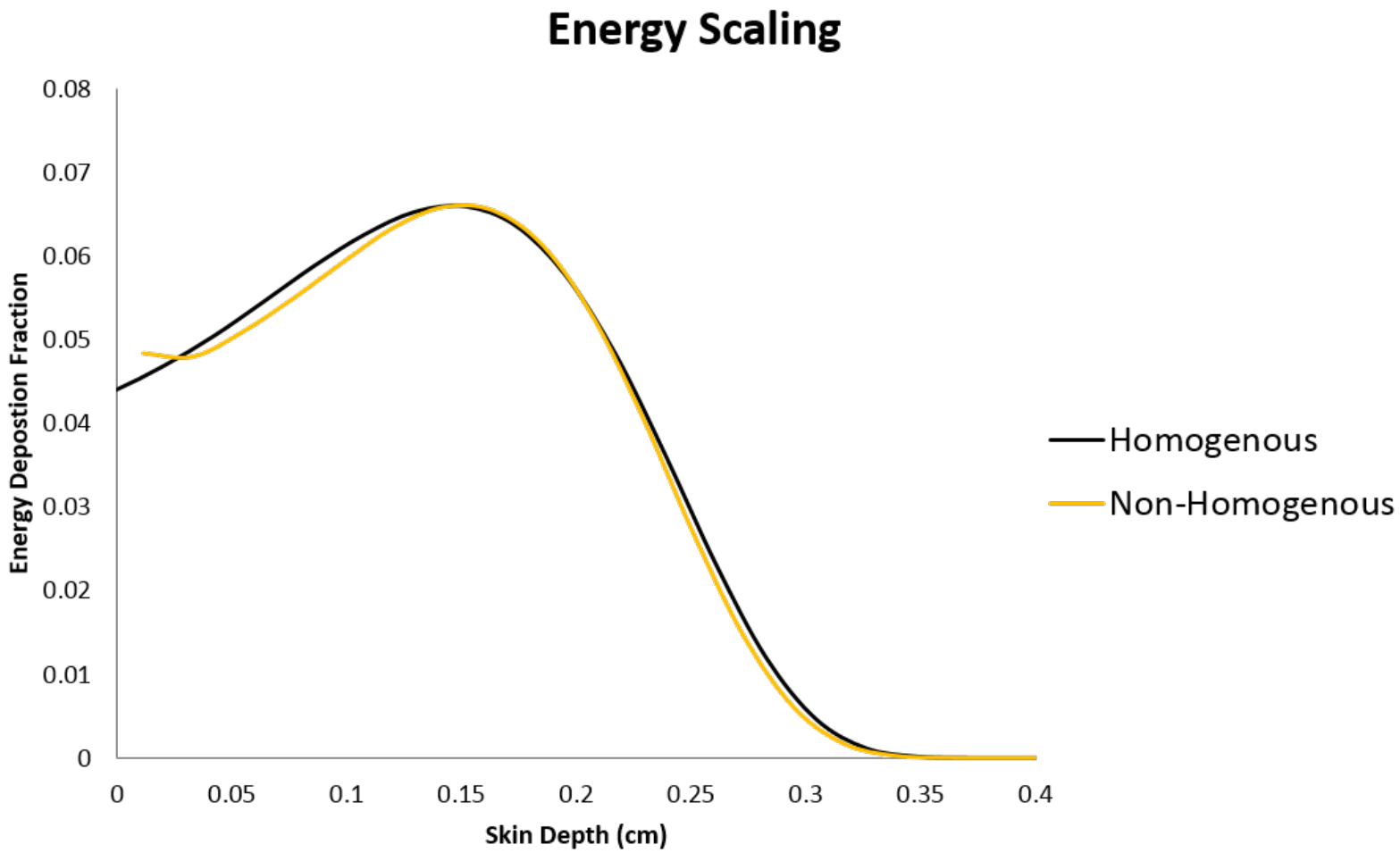
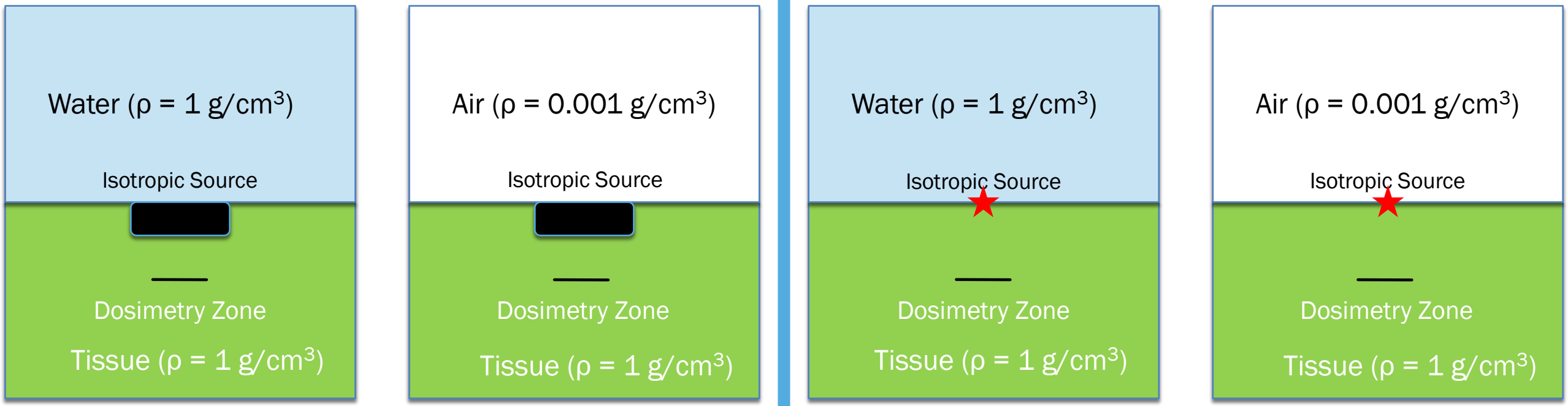
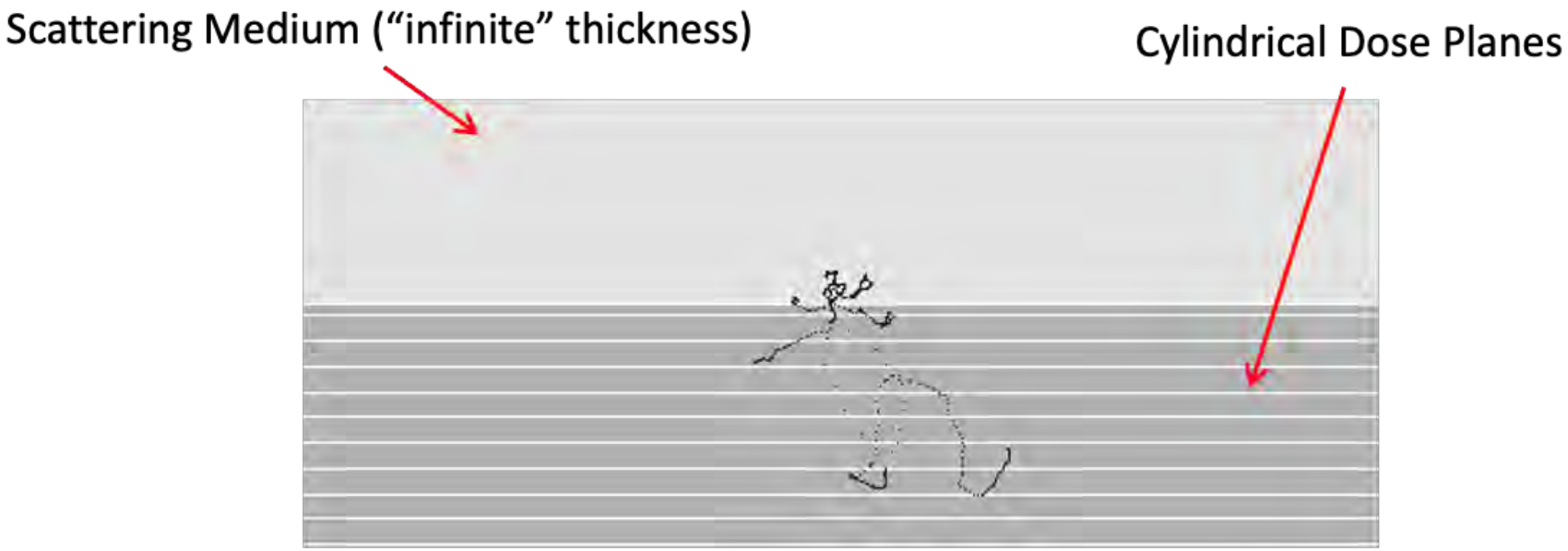


- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

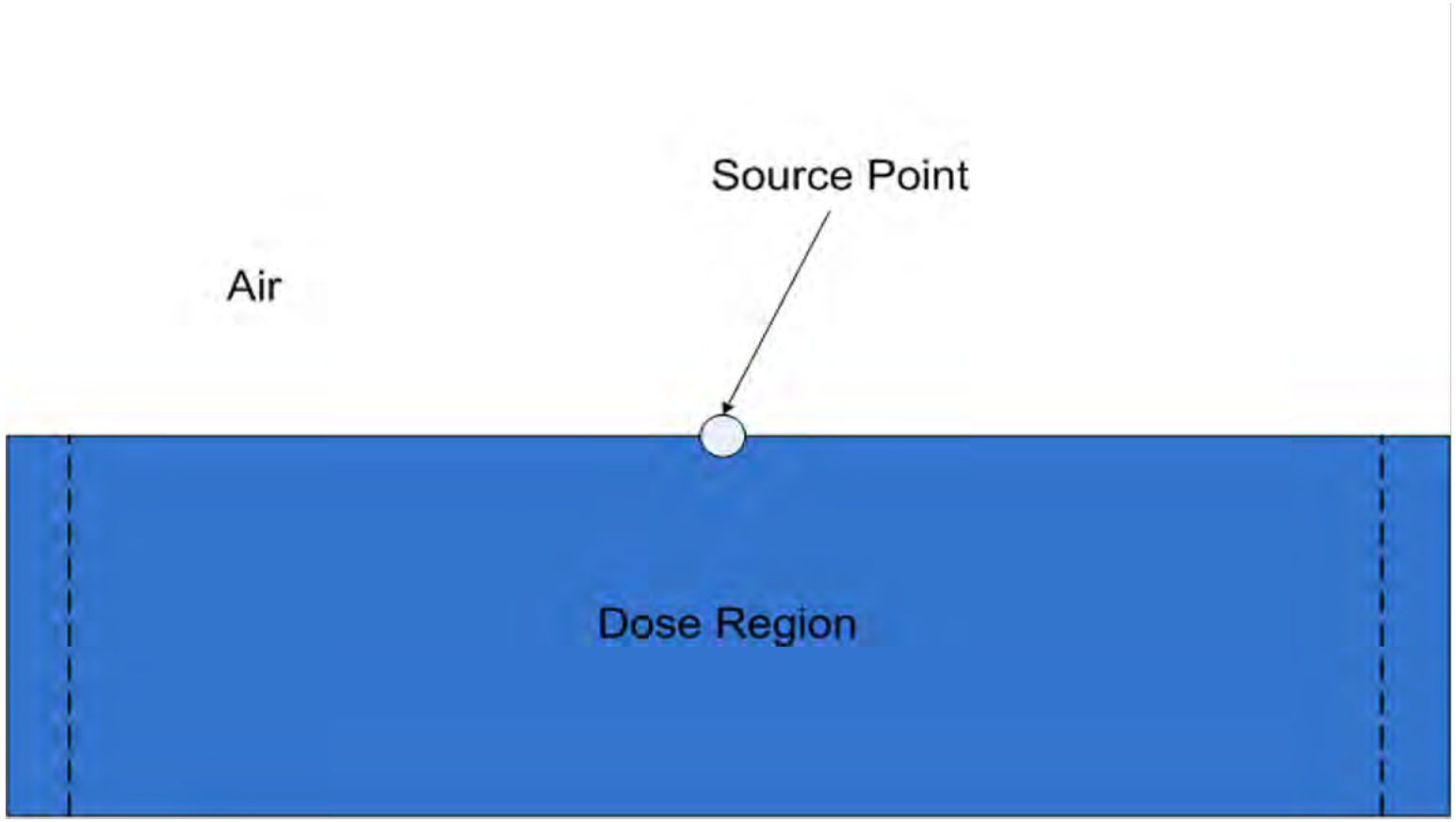
BACKSCATTER CORRECTION FACTORS



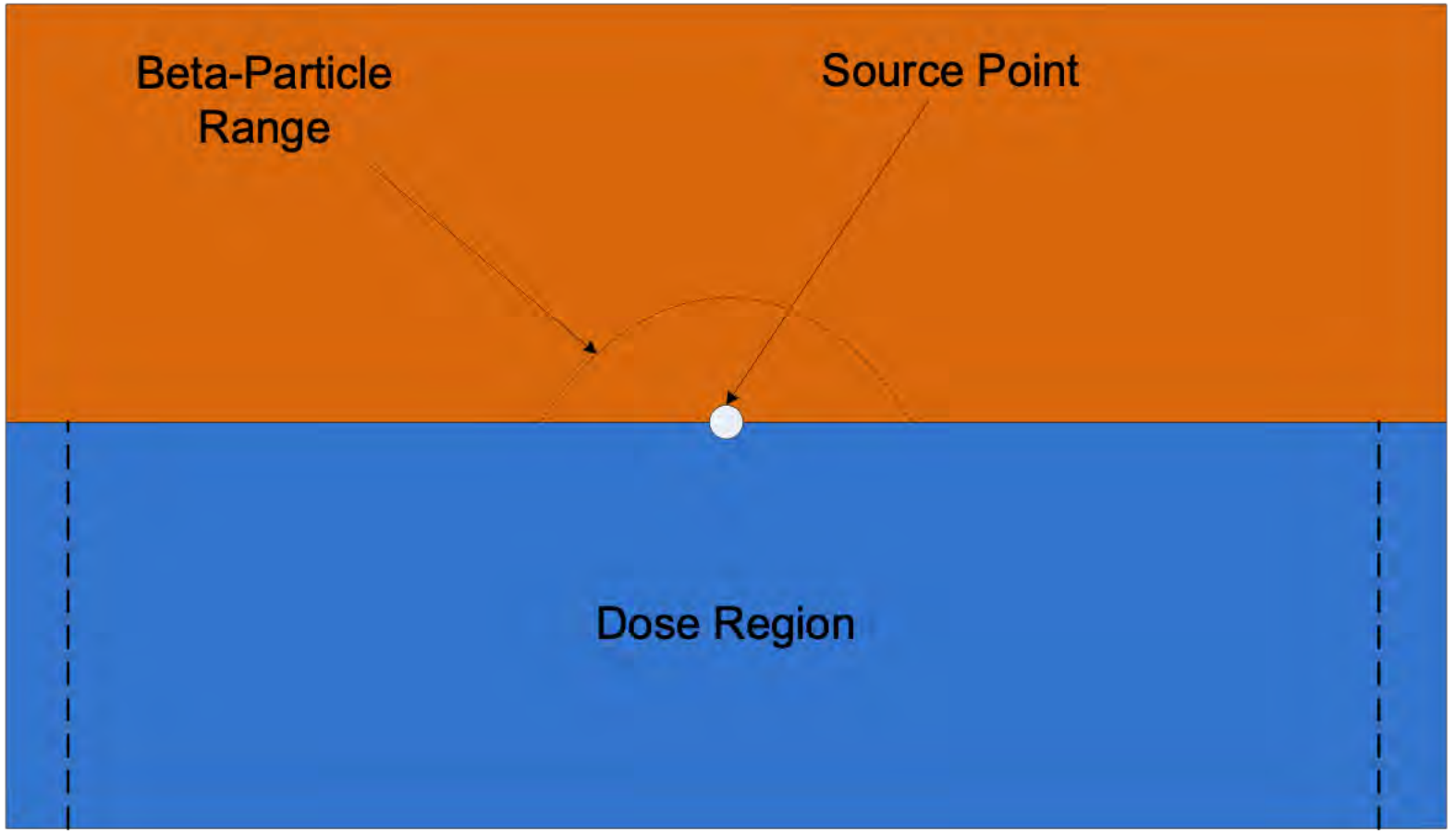
BACKSCATTER CORRECTION FACTORS



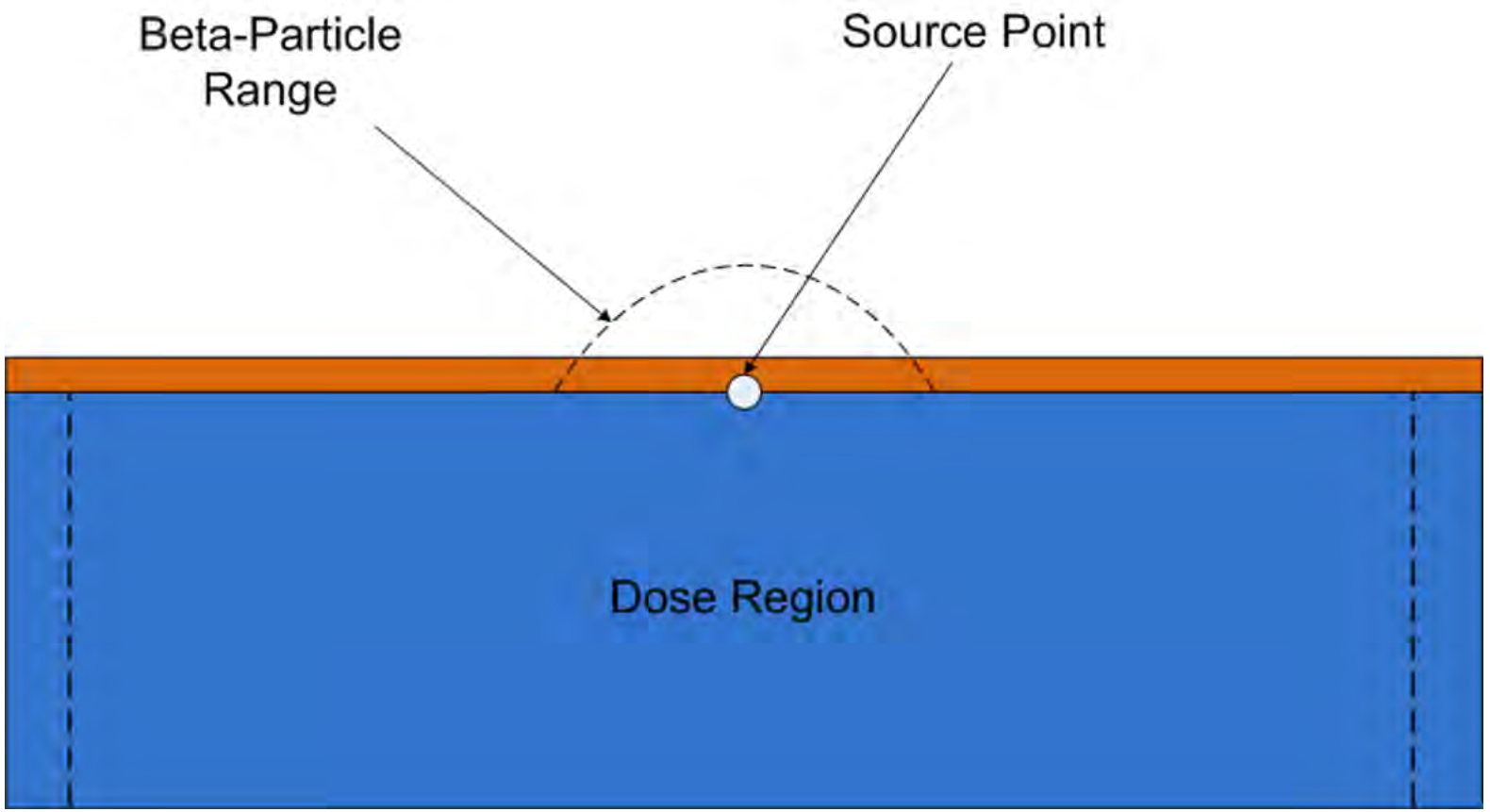
BACKSCATTER CORRECTION FACTORS



BACKSCATTER CORRECTION FACTORS

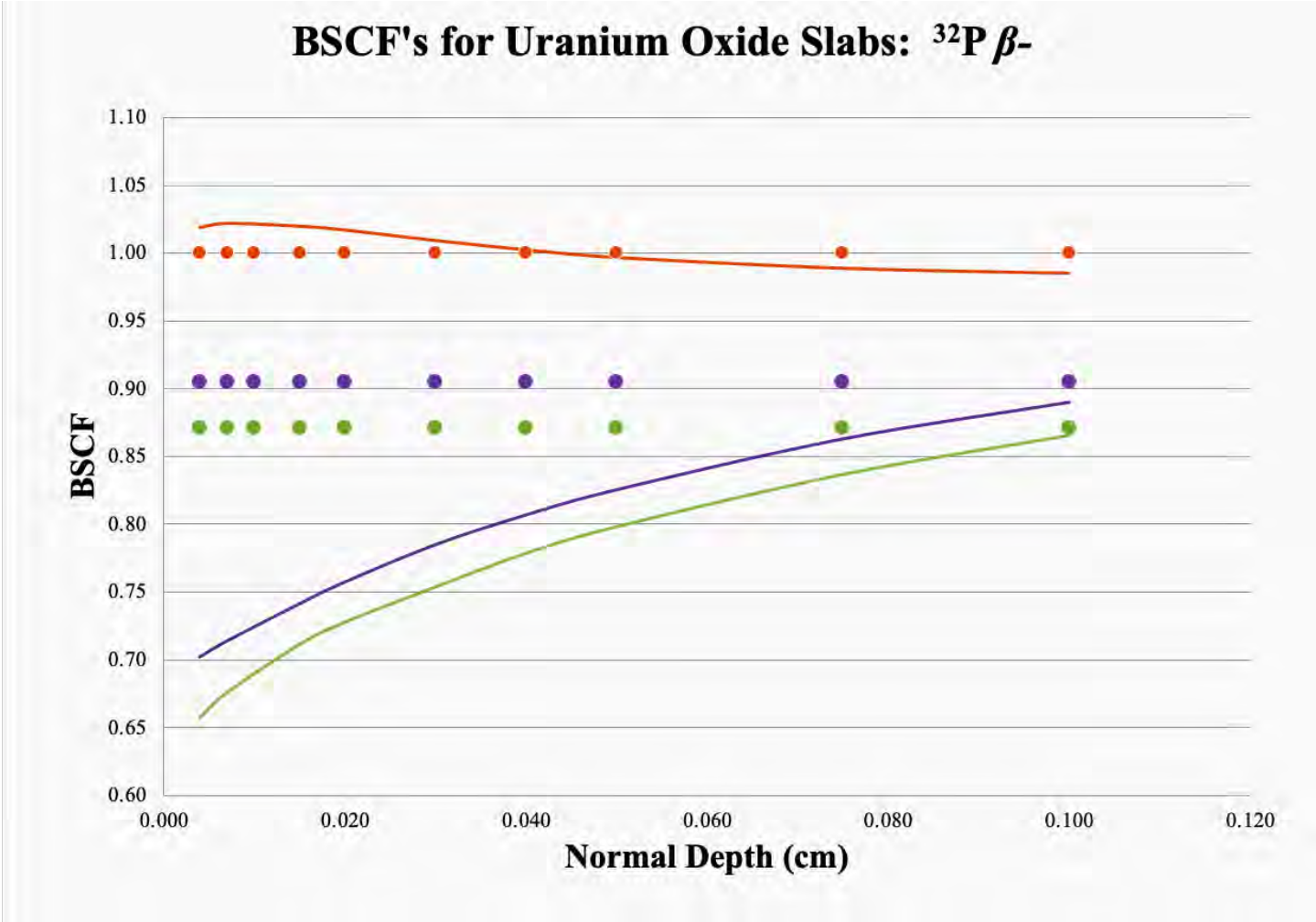


BACKSCATTER CORRECTION FACTORS



BACKSCATTER CORRECTION FACTORS

- Dots = VARSKIN 5
- Lines = VARSKIN 6 and up
- Orange = 0.1 cm source
- Purple = 0.02 cm source
- Green = 0.02 cm source



TO SKINDOSE…

SKINDOSE CAPABILITIES AND LIMITATIONS

- Calculates dose equivalent for Photon, Electron, and Alpha radiation for more than 1200 radionuclides
  - Uses either ICRP 38 or 107 decay data and accounts for decay products
- Dose is averaged over an area ranging from 0.01 cm^2 to 100 cm^2
- Allows for an airgap of up to 20 cm between the source and the skin surface and for source covers
- Source materials are defined by atomic number and density with geometries of:
  - Point source
  - Disk source
  - Spherical source
  - Cylindrical source
  - Slab source
  - Syringe source

SKINDOSE SENSITIVITIES

Direct Propagators	Regulatory Defined Values	Parametric Uncertainty
Exposure time Source activity Distributed activity	Volume averaging depth Skin averaging area Skin thickness	Airgap thickness Cover thickness and density Source geometry

- **Direct propagators** – Uncertainty in these parameters propagates completely through the model to the dose estimate (twice the activity will yield twice the dose)
- **Regulatory Defined Values** – While these inputs can be manipulated in VARSKIN, the regulations call for dose averaged over 10 cm2 at a depth of 7mg/cm2
- **Parametric Uncertainty** – Variations in these inputs will affect dose output, however, the effect is not as intuitive as compared to the direct propagators

ELECTRON DOSE

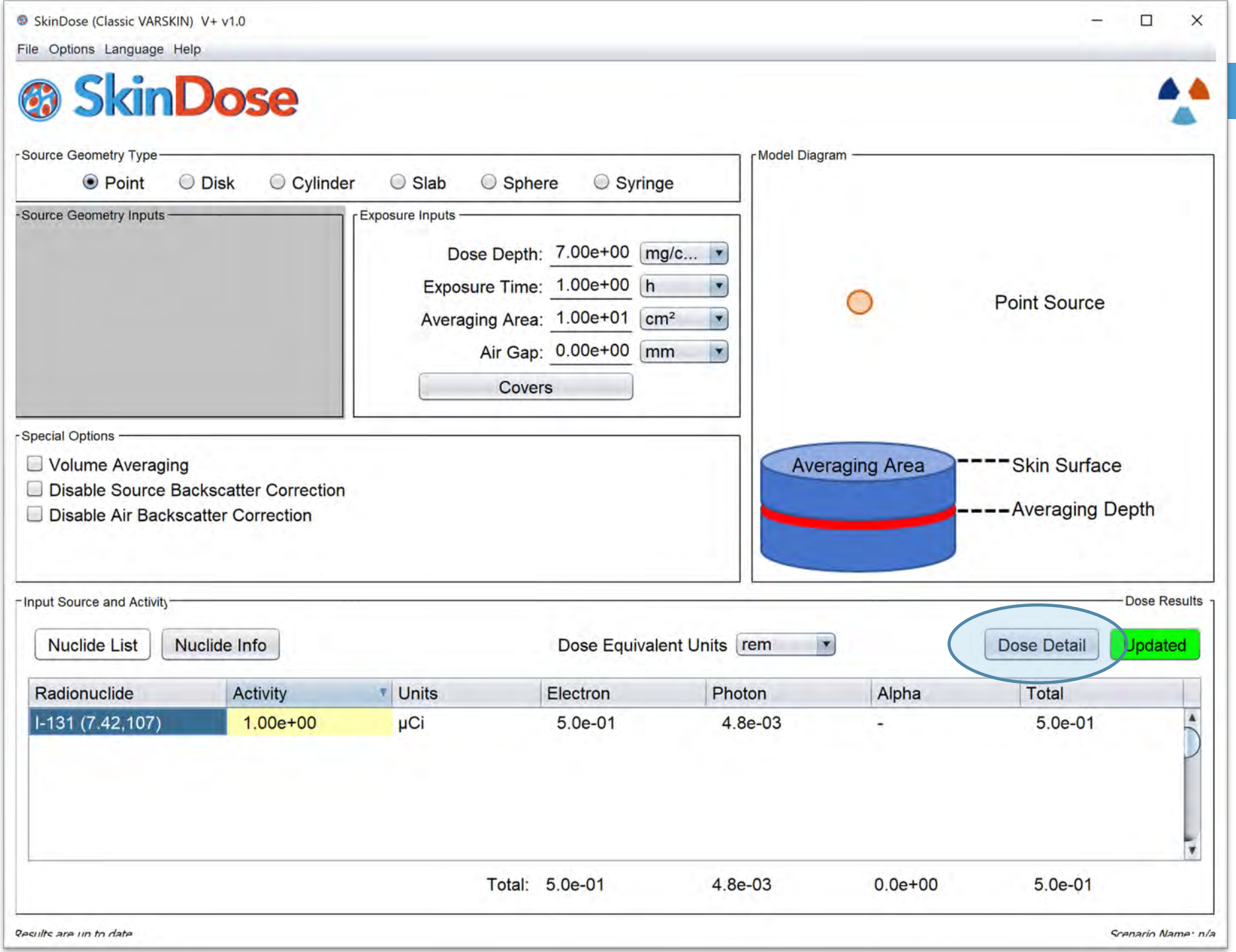
Parameter	E < 200 keV	200 keV – 2 MeV	E > 2 MeV
3D Geometry	LOW	LOW	LOW
3D Source volume	HIGH	HIGH/MODERATE	MODERATE
3D Source density	HIGH	HIGH/MODERATE	MODERATE
2D Source area (relative to avg area)	LOW	LOW/MODERATE	LOW/MODERATE
Cover density	MODERATE	MODERATE	LOW
Cover thickness	HIGH	LOW	LOW
Airgap thickness	LOW	MODERATE	MODERATE

GAMMA DOSE

Parameter	E < 20 keV	20 keV - 500 keV	E > 500 keV
3D Geometry	LOW	LOW	LOW
3D Source volume	MODERATE	LOW	LOW
3D Source density (assumed to be air)	LOW	LOW	LOW
2D Source area*	LOW	LOW/MODERATE	LOW/MODERATE
Cover density	LOW	LOW	LOW
Cover thickness	LOW	MODERATE	MODERATE
Airgap thickness	LOW	MODERATE	MODERATE

BASIC DEMONSTRATION

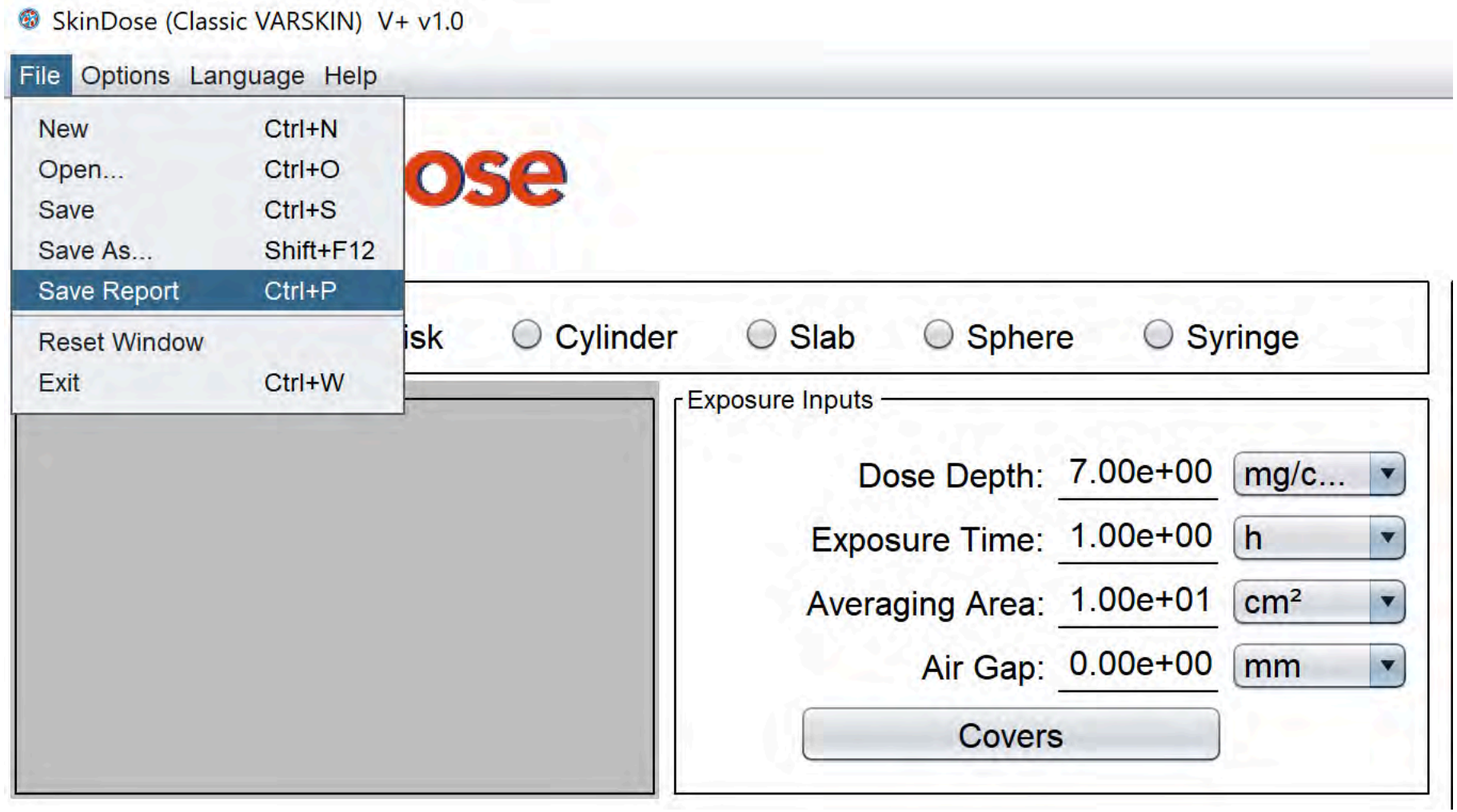
- Assume a 1 uCi I-131 point source
- Use ICRP 107 decay data with Z_{eff} of 7.42 (water)
  - 107 = no decay products accounted for
  - 107D = decay products accounted for
- 1 hr exposure time
- No air gap and no cover
- Dose to a 10 cm^2 averaging area at a depth of 7 mg cm^{-2}


SkinDose (Classic VARSKIN) V+ v1.0
File Options Language Help
SkinDose
Source Geometry Type
Point Disk Cylinder Slab Sphere Syringe
Source Geometry Inputs
Exposure Inputs
Dose Depth: 7.00e+00 mg/c...
Exposure Time: 1.00e+00 h
Averaging Area: 1.00e+01 cm²
Air Gap: 0.00e+00 mm
Covers
Special Options
Volume Averaging
Disable Source Backscatter Correction
Disable Air Backscatter Correction
Model Diagram
Point Source
Averaging Area
Skin Surface
Averaging Depth
Input Source and Activity
Dose Results
Nuclide List
Nuclide Info
Dose Equivalent Units rem
Dose Detail
Updated
Radionuclide Activity Units Electron Photon Alpha Total
I-131 (7.42,107) 1.00e+00 µCi 5.0e-01 4.8e-03 - 5.0e-01
Total: 5.0e-01 4.8e-03 0.0e+00 5.0e-01
Results are up to date
Scenario Name: n/a

varSKIN+

Detailed Results (I-131 (7.42,107))

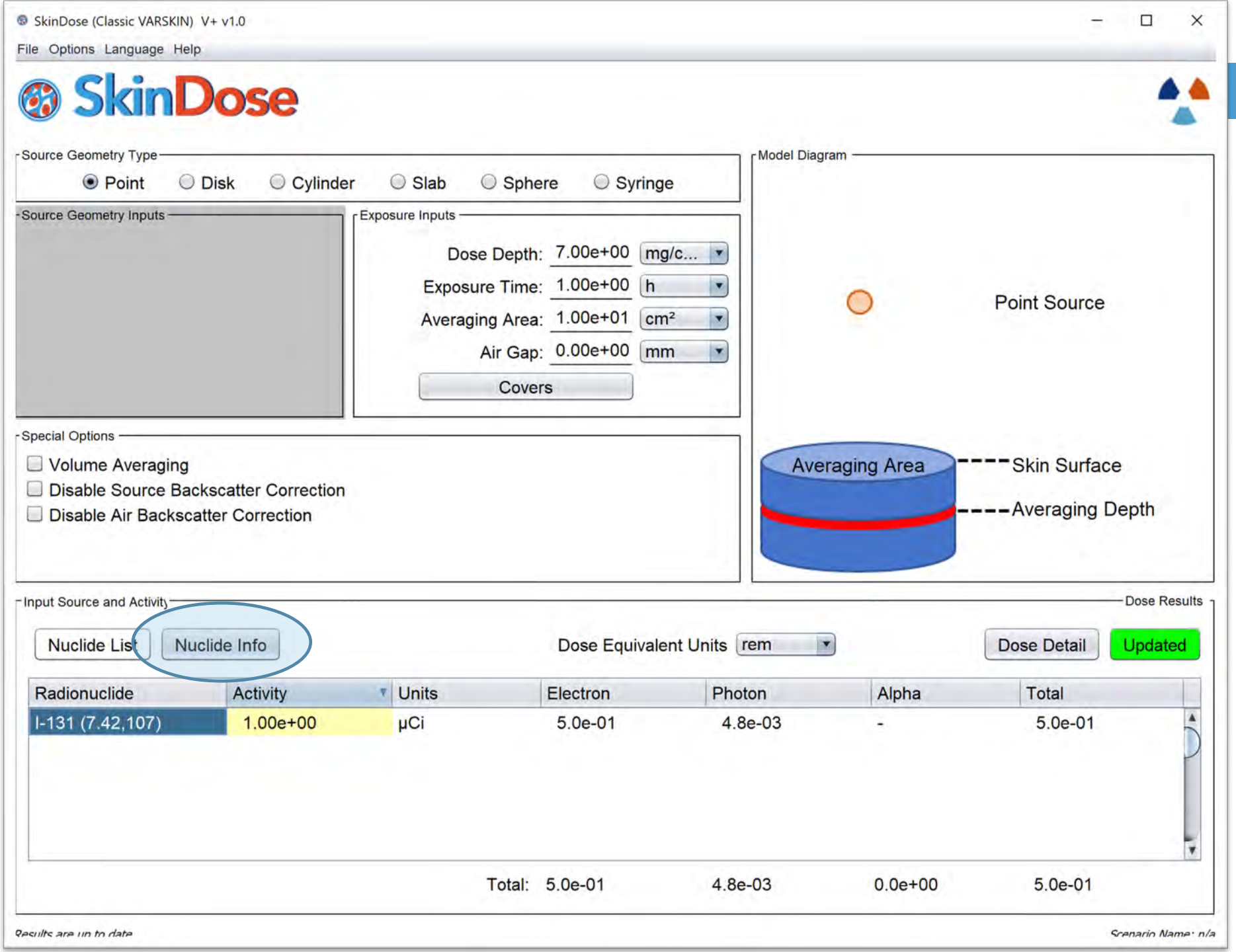
Nuclide:	I-131	
Database:	ICRP107	
Half Life:	8.02e+00	d
Initial Electron Dose Rate:	4.99e-01	rem/h
Initial Gamma Dose Rate:	4.86e-03	rem/h
Initial Alpha Dose Rate:	-	rem/h
Total Initial Dose Rate:	5.04e-01	rem/h
Electron Dose (No Decay Correction):	4.99e-01	rem
Gamma Dose (No Decay Correction):	4.86e-03	rem
Alpha Dose (No Decay Correction):	-	rem
Total Dose (No Decay Correction):	5.04e-01	rem


SkinDose (Classic VARSKIN) V+ v1.0
File
Options
Language
Help
New Ctrl+N
Open... Ctrl+O
Save Ctrl+S
Save As... Shift+F12
Save Report Ctrl+P
Reset Window
Exit Ctrl+W
ose
isk
Cylinder
Slab
Sphere
Syringe
Exposure Inputs
Dose Depth: 7.00e+00 mg/c...
Exposure Time: 1.00e+00 h
Averaging Area: 1.00e+01 cm²
Air Gap: 0.00e+00 mm
Covers

DoseReport_SkinDose - Notepad

File Edit Format View Help

```
Source Geometry Type:                    point

-------------------------------------------------------------------------
Exposure Information
-------------------------------------------------------------------------
                Dose Depth:        7.000     mg/cm²
           Exposure Time:          1.000         h
      Dose Averaging Area:        10.000       cm²
        Air Gap Thickness:         0.000        mm

-------------------------------------------------------------------------
Cover Information
-------------------------------------------------------------------------
Number of Covers:                        0

-------------------------------------------------------------------------
Volume Averaging Information
-------------------------------------------------------------------------
Volume Averaging Active:                 false

-------------------------------------------------------------------------
Nuclide Information
-------------------------------------------------------------------------
     Nuclide    Database    Source Z    Activity       Units
       I-131     ICRP107        7.42   1.000e+00         µCi

*************************************************************************
Results
*************************************************************************

-------------------------------------------------------------------------
Shallow Dose Equivalent (rem)
-------------------------------------------------------------------------
   Nuclide  Database      Electrons    Photons     Alphas     Total
     I-131   ICRP107      4.973e-01  4.844e-03 -0.000e+00  5.021e-01

              Total:      4.973e-01  4.844e-03  0.000e+00  5.021e-01

Note: -0 values indicate instances where a particle is not present
 for the decay chain.

*************************************************************************
End of Report
```


SkinDose (Classic VARSKIN) V+ v1.0
File Options Language Help
SkinDose
Source Geometry Type
Point Disk Cylinder Slab Sphere Syringe
Source Geometry Inputs
Exposure Inputs
Dose Depth: 7.00e+00 mg/c...
Exposure Time: 1.00e+00 h
Averaging Area: 1.00e+01 cm²
Air Gap: 0.00e+00 mm
Covers
Special Options
Volume Averaging
Disable Source Backscatter Correction
Disable Air Backscatter Correction
Model Diagram
Point Source
Averaging Area
Skin Surface
Averaging Depth
Input Source and Activity
Nuclide List
Nuclide Info
Dose Equivalent Units rem
Dose Results
Dose Detail
Updated
Radionuclide Activity Units Electron Photon Alpha Total
I-131 (7.42,107) 1.00e+00 µCi 5.0e-01 4.8e-03 - 5.0e-01
Total: 5.0e-01 4.8e-03 0.0e+00 5.0e-01
Results are up to date
Scenario Name: n/a

varSKIN+

Nuclide Information (I-131 (7.42,107))

Nuclide: I-1

Database: ICR

Half Life: 8.

X90 Distance: 8.

Average Electron Energy: 1.

Average Electron Yield: 10

Beta Spectrum | Electron Em

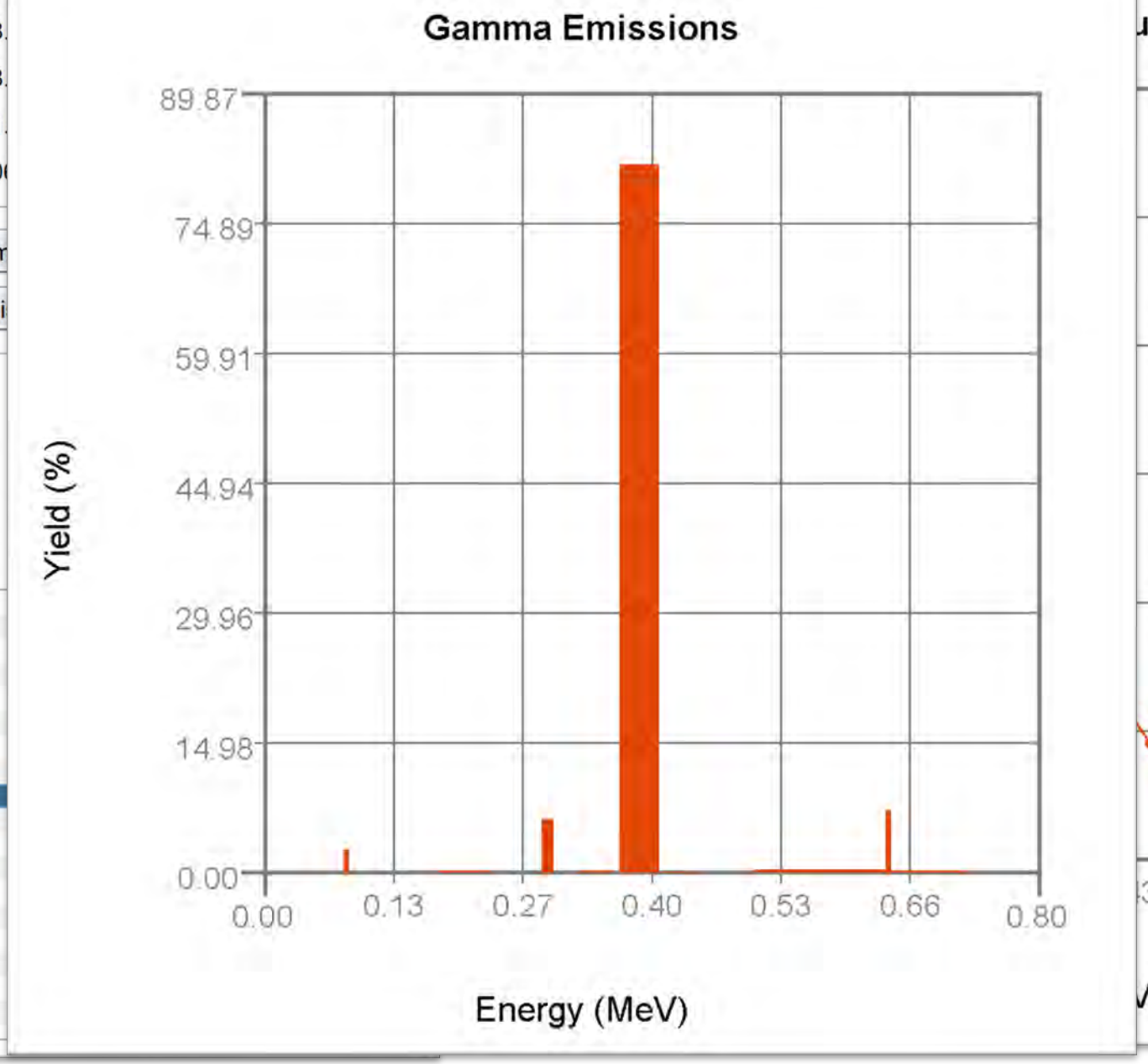
Gamma Emissions | X-Ray Emi

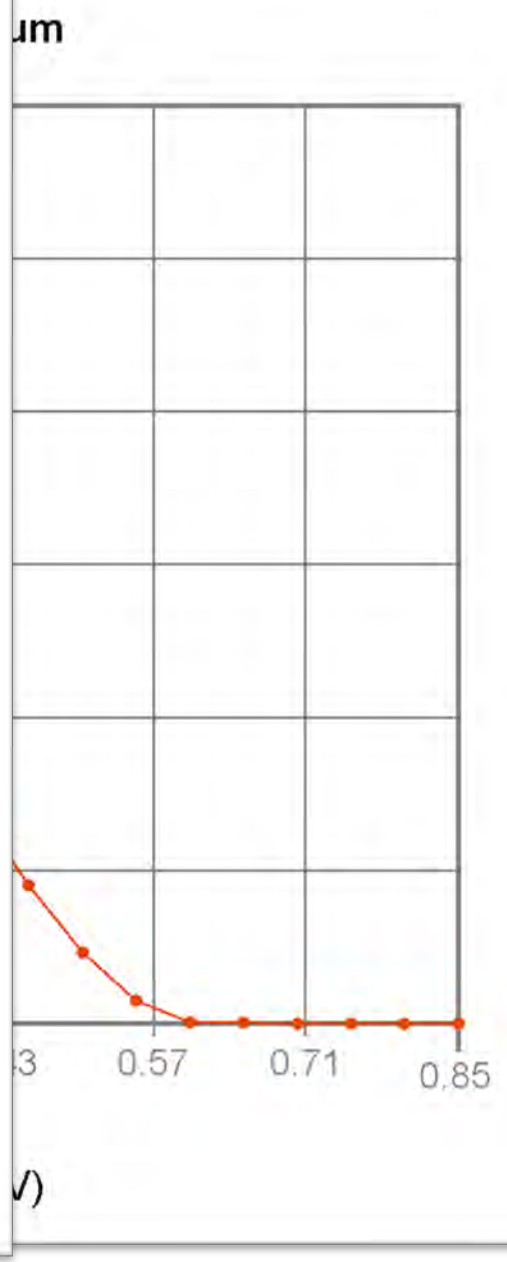
Emissions Key

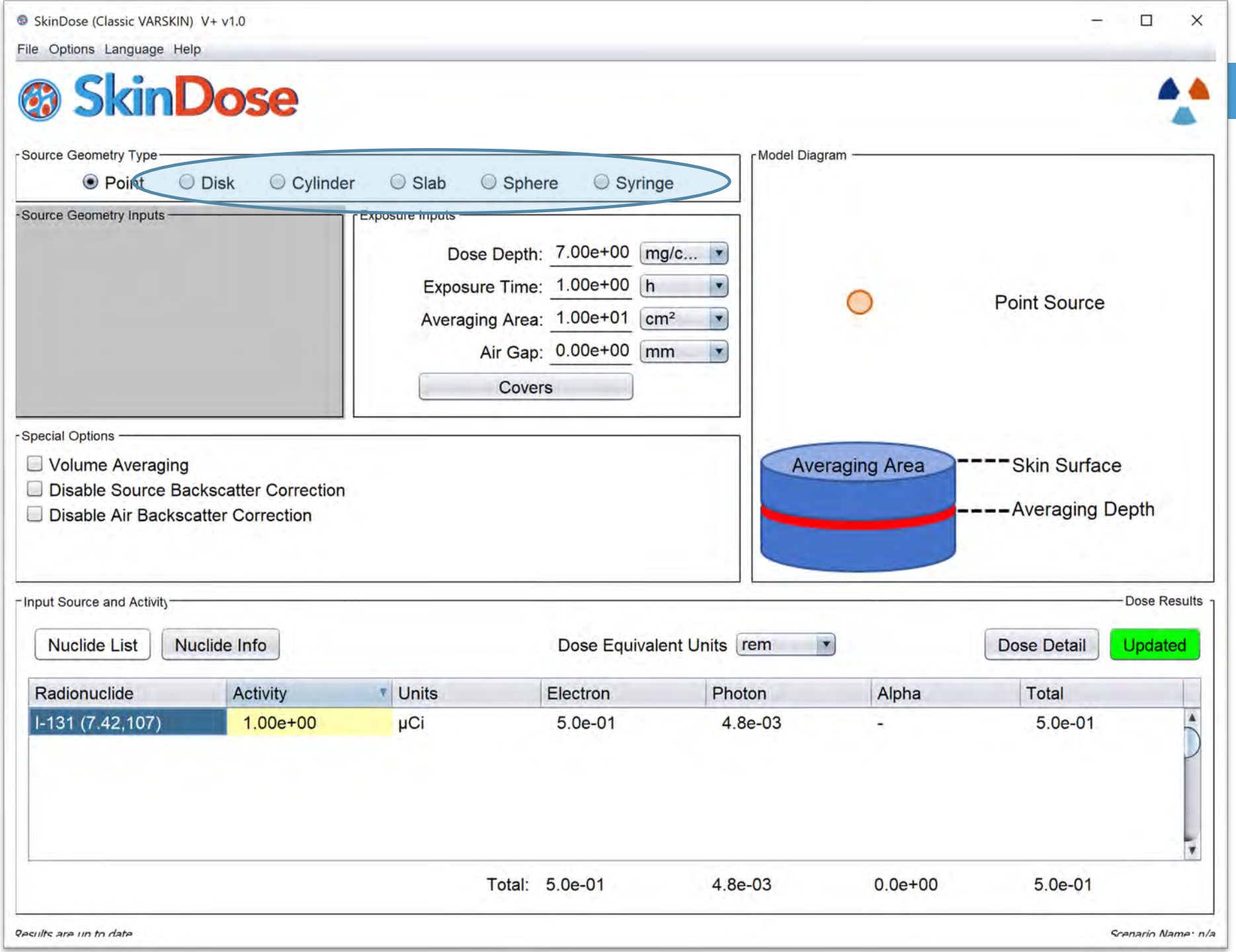
G (1): Gamma	*X (2): X-Ray*
B+ (4): Beta +	*B- (5): Beta -*
AE (7): Auger Electron	*A (8): Alpha*
FF (10): Fission Fragment	*N (11): Neutron*

Emission Type	Yield (%)
X (2)	2.59418
X (2)	0.243522
X (2)	0.472116
G (1)	2.62257
G (1)	0.26961
G (1)	6.13567
G (1)	0.273695
G (1)	81.7
G (1)	0.360297
G (1)	7.17326
G (1)	0.217322
G (1)	1.77289
B- (5)	2.09057
B- (5)	0.648077
B- (5)	7.23736
B- (5)	89.4964
B- (5)	0.0497755

Gamma Emissions I-131 (7.42,107)






SkinDose (Classic VARSKIN) V+ v1.0
File Options Language Help
SkinDose
Source Geometry Type
Point Disk Cylinder Slab Sphere Syringe
Source Geometry Inputs
Exposure Inputs
Dose Depth: 7.00e+00 mg/c...
Exposure Time: 1.00e+00 h
Averaging Area: 1.00e+01 cm²
Air Gap: 0.00e+00 mm
Covers
Special Options
Volume Averaging
Disable Source Backscatter Correction
Disable Air Backscatter Correction
Model Diagram
Point Source
Averaging Area
Skin Surface
Averaging Depth
Input Source and Activity
Dose Results
Nuclide List
Nuclide Info
Dose Equivalent Units rem
Dose Detail
Updated
Radionuclide Activity Units Electron Photon Alpha Total
I-131 (7.42,107) 1.00e+00 µCi 5.0e-01 4.8e-03 - 5.0e-01
Total: 5.0e-01 4.8e-03 0.0e+00 5.0e-01
Results are up to date
Scenario Name: n/a

varSKIN+

SkinDose (Classic VARSKIN) V+ v1.0

File Options Language Help

SkinDose

Source Geometry Type

Point Disk Cylinder Slab Sphere Syringe

Source Geometry Inputs

Diameter: 1.00e+00 cm

Length: 1.00e+01 cm

Exposure Inputs

Dose Depth: 7.00e+00 mg/c...

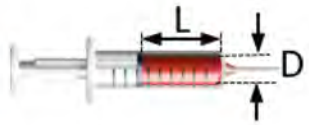
Exposure Time: 1.00e+00 h

Averaging Area: 1.00e+01 cm²

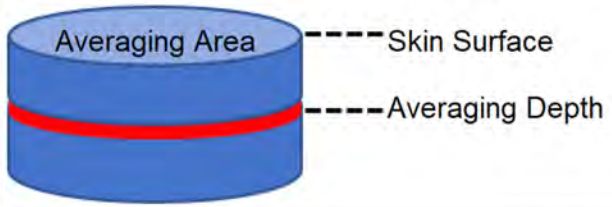
Air Gap: 0.00e+00 mm

Covers

Model Diagram



Syringe Source



Special Options

Volume Averaging

Disable Source Backscatter Correction

Disable Air Backscatter Correction

Input Source and Activity

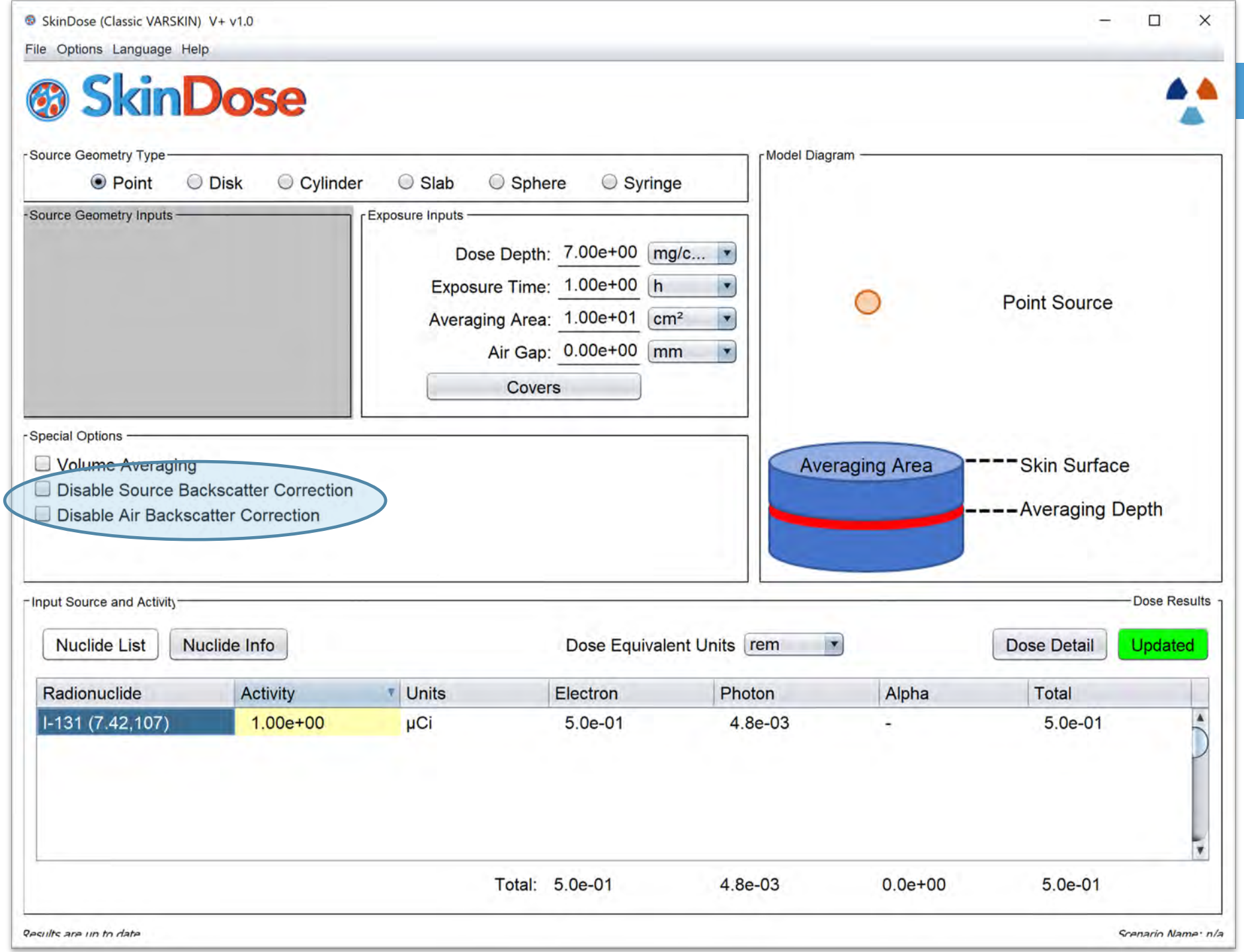
Nuclide List Nuclide Info Distributed Source

Dose Results

Dose Equivalent Units rem

Dose Detail Updated

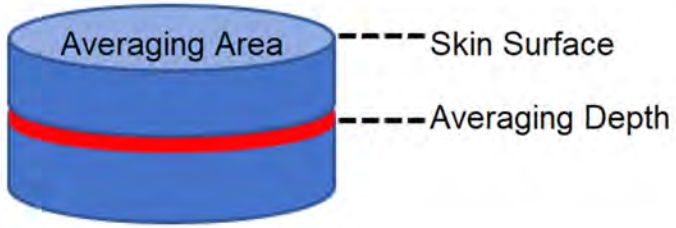
Radionuclide	Activity	Units	Electron	Photon	Alpha	Total
I-131 (7.42,107)	1.00e+00	µCi	8.2e-03	8.1e-04	-	9.0e-03
Total:			8.2e-03	8.1e-04	0.0e+00	9.0e-03


SkinDose (Classic VARSKIN) V+ v1.0
File Options Language Help
SkinDose
Source Geometry Type
Point Disk Cylinder Slab Sphere Syringe
Source Geometry Inputs
Exposure Inputs
Dose Depth: 7.00e+00 mg/c...
Exposure Time: 1.00e+00 h
Averaging Area: 1.00e+01 cm²
Air Gap: 0.00e+00 mm
Covers
Special Options
Volume Averaging
Disable Source Backscatter Correction
Disable Air Backscatter Correction
Model Diagram
Point Source
Averaging Area
Skin Surface
Averaging Depth
Input Source and Activity
Dose Results
Nuclide List
Nuclide Info
Dose Equivalent Units rem
Dose Detail
Updated
Radionuclide Activity Units Electron Photon Alpha Total
I-131 (7.42,107) 1.00e+00 µCi 5.0e-01 4.8e-03 - 5.0e-01
Total: 5.0e-01 4.8e-03 0.0e+00 5.0e-01
Results are up to date
Scenario Name: n/a

varSKIN+

Special Options

- [ ] Volume Averaging
- [ ] Disable Source Backscatter Correction
- [ ] Disable Air Backscatter Correction



varSKIN+

Input Source and Activity

Dose Results

Nuclide List | Nuclide Info | Dose Equivalent Units: rem | Dose Detail | Updated

Radionuclide	Activity	Units	Electron	Photon	Alpha	Total
I-131 (7.42,107)	1.00e+00	µCi	5.0e-01	4.8e-03	-	5.0e-01

Special Options

- [ ] Volume Averaging
- [ ] Disable Source Backscatter Correction
- [x] Disable Air Backscatter Correction

Input Source and Activity

Dose Results

Nuclide List | Nuclide Info | Dose Equivalent Units: rem | Dose Detail | Updated

Radionuclide	Activity	Units	Electron	Photon	Alpha	Total
I-131 (7.42,107)	1.00e+00	µCi	6.5e-01	4.8e-03	-	6.5e-01
Total:			6.5e-01	4.8e-03	0.0e+00	6.5e-01

Results are up to date

Scenario Name: n/a

QUESTIONS

EXAMPLES…