

varskin V5



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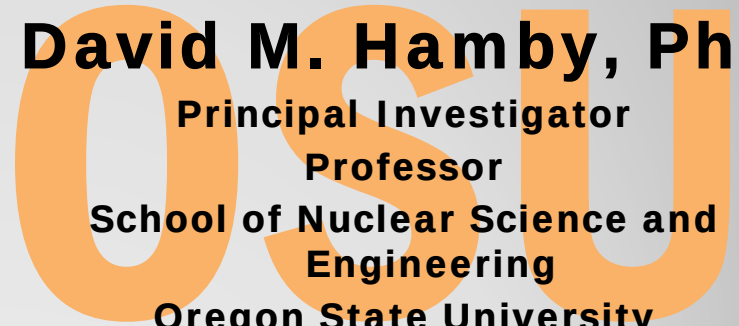
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*Work conducted under NRC Contract Nos. NRC-04-08-137, NRC-HQ-11-C-04-0011, and NRC-HQ-60-15-C-0011
with Oregon State University*

International RAMP VARSKIN Workshop

April 27th, 2017

8:00 – 8:15	Overview and Objectives
8:15 – 9:45	Intro to VARSKIN and Dose Calcs
9:45 – 10:00	Break
10:00 – 11:30	Exploring the GUI
11:30 – 1:00	Lunch
1:00 – 2:30	Recent VARSKIN Improvements
2:30 – 2:45	Break
2:45 – 5:00	Start Examples

Thursday's schedule

International RAMP VARSKIN Workshop

April 28, 2017

8:00 – 9:45	Finish Examples and Discuss V & V
9:45 – 10:00	Break
10:00 – 11:00	VARSKIN Code Discussions

Friday's schedule

- The NRC oversees licensee compliance with regulatory requirements specified in 10 CFR 20.1201(c)
- VARSKIN was first developed in 1987 to allow the NRC independent confirmation of skin dose estimates submitted by licensees
 - the code is intended to be used as a tool for calculating tissue dose at depth resulting from radiological contamination of skin
- The current version is VARSKIN 5.3

Overview

- VARSKIN (Traub et al., 1987)
- VARSKIN Mod 2 (Durham, 1992)
 - → SADDE calculations added (Reece et al., 1989)
- VARSKIN 3 (Durham, 2006)
 - → volumetric-source backscatter factors
 - → basic photon model added
 - → syringe geometry added
- VARSKIN 3.1 (Durham, 2009)
 - → correction of error in photon energy database
- VARSKIN 4 (Hamby et al., 2011)
 - → more rigorous treatment of photon dosimetry
 - → no need for code “installation”
 - → syringe model deleted
- VARSKIN 5 (Hamby et al., 2013)
 - → enhancements to electron dosimetry

— varskin 4.0

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VARSKIN history

- To become knowledgeable of the general models used for skin dosimetry
- To become knowledgeable of the VARSKIN models employed for photon and electron skin dosimetry
- To gain experience executing the VARSKIN software for skin dosimetry estimation
- To become knowledgeable of VARSKIN's limitations

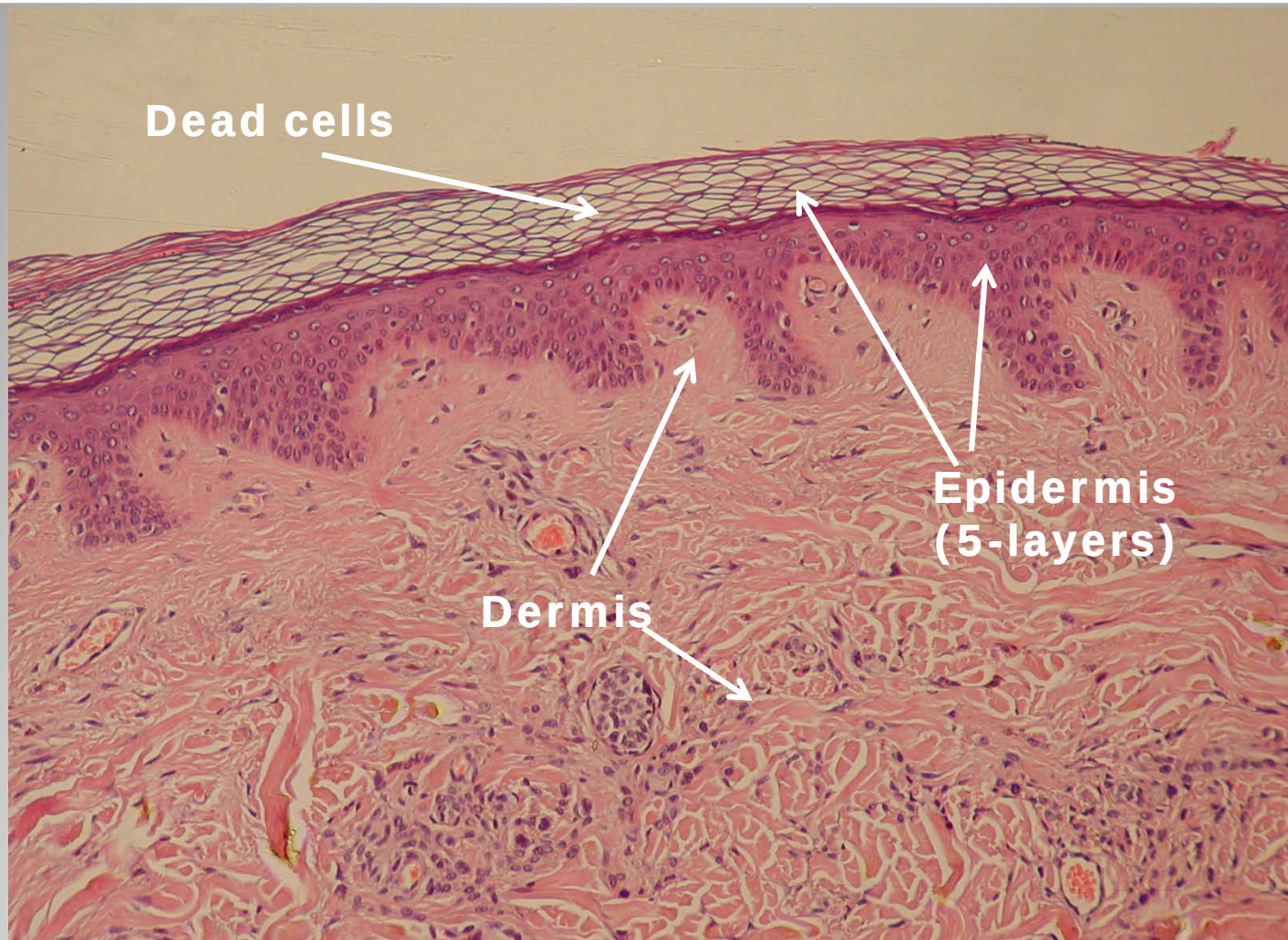
Objectives

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Skin physiology and skin dose limits

- The skin is the largest human organ/tissue
 - accounts for about 15% of adult body weight
- Human skin is similar to that of pigs
- Skin provides ...
 - physical barrier
 - to protect against external agents
 - to prevent excess water loss
 - thermo-regulation
- Serves a significant role in maintaining homeostasis
- Dead layer is about 70 μm thick
 - i.e., 7 mg/cm^2 for unit-density material
- Three fundamental living layers:
 - epidermis
 - dermis
 - subcutaneous fat (hypodermis)

Human skin



Skin layers

- The epidermis is a continually renewing layer
- It is a dynamic tissue in which cells are in unsynchronized continuous motion, making their way toward the surface
- Epidermis contains proliferating basal cells
 - undulating thickness from ~100 to ~1500 microns
- Epidermal stem cells in the basal layer are generally long-lived with slow cell cycles
- Wounding, however, can stimulate stem-cell division
- DNA damage can mutate stem cells
- Basal-layer cells migrate to the surface in about 30 days

Human skin - Epidermis

- Skin thickness (total) ranges between about 500 μm and 14,000 μm
- The energy deposition of most significance will be heavily impacted by hot-particle location
- Thus, calculated dose may or may not provide a true indication of radiation damage to that particular area of exposed skin
- Skin dose is generally limited by the potential for deterministic effects

Dosimetry implications

- ICRP 1 (1954) – 600 mR/wk
 - @ 70 μm
- ICRP 9 (1966) – 30 rem/yr
 - averaged over 1 cm^2
- ICRP 26 (1977) – 50 rem/yr
 - 50 – 100 μm
- ICRP 59 (1992) – 30 Gy/lifetime
 - averaged over 1 cm^2
 - deterministic (dermal effects): 300 – 500 μm
 - acute transient ulceration: 100 – 150 μm
 - stochastic (epidermal effects): 20 – 100 μm

Historical limits on skin dose

- ICRP 60 (1991) – 20 Gy/lifetime; 0.5 Sv/yr
 - averaged over 1 cm² @ 70 μm
 - deterministic (dermal effects): 300 – 500 μm
 - stochastic (epidermal effects): 20 – 100 μm
- 10 CFR 20 (1991) – 0.5 Sv/yr
 - averaged over 1 cm² @ 70 μm
- 10 CFR 20 (2002) – 0.5 Sv/yr
 - averaged over 10 cm² @ 70 μm

Historical limits on skin dose

- NCRP 106 (1989) – source limitations
 - to limit acute deep ulceration
 - 10^{10} beta particles emitted
 - equivalent to: ~ 5 Sv, over 1 cm^2 @ $100 - 150\text{ }\mu\text{m}$
- ICRP 60 (1991) – 0.5 Sv/yr
 - averaged over 1 cm^2 @ $70\text{ }\mu\text{m}$
- NCRP 130 (1999) – 5 Sv/yr
 - averaged over 1 cm^2 @ $70\text{ }\mu\text{m}$
 - $0.5\text{ Sv}/10\text{ cm}^2$ for particle on clothing

Limits on HOT particle skin dose

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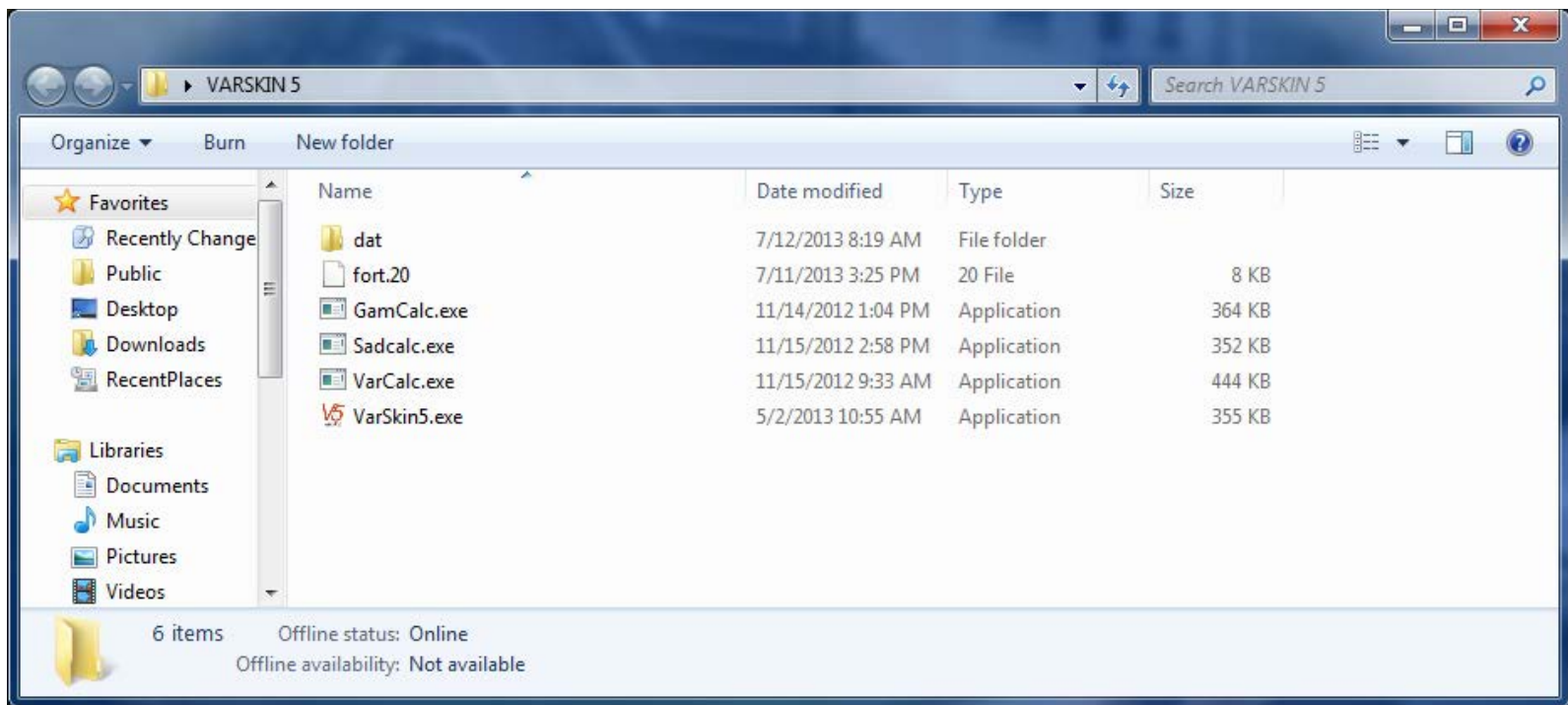
USING VARSKIN

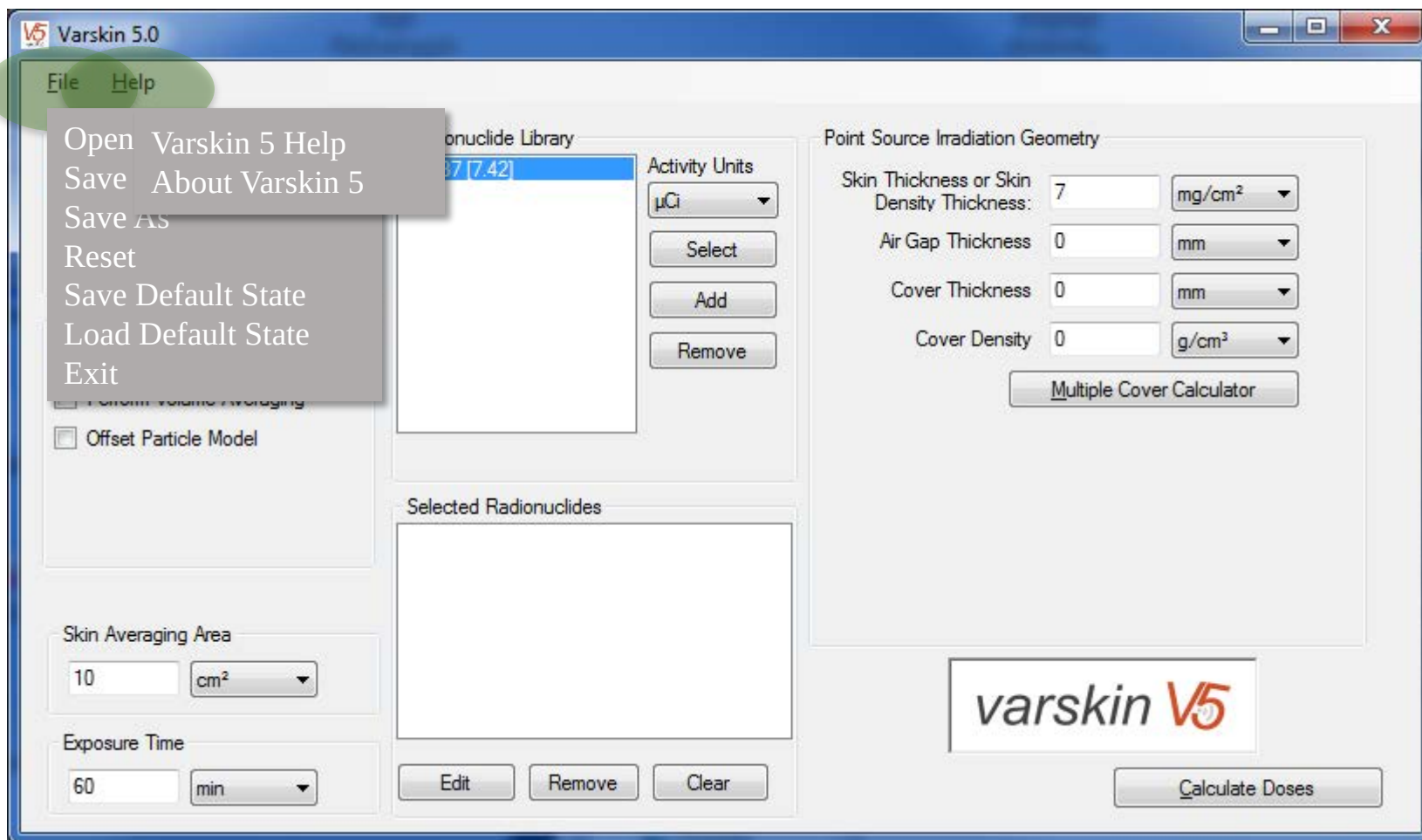
CODING structure

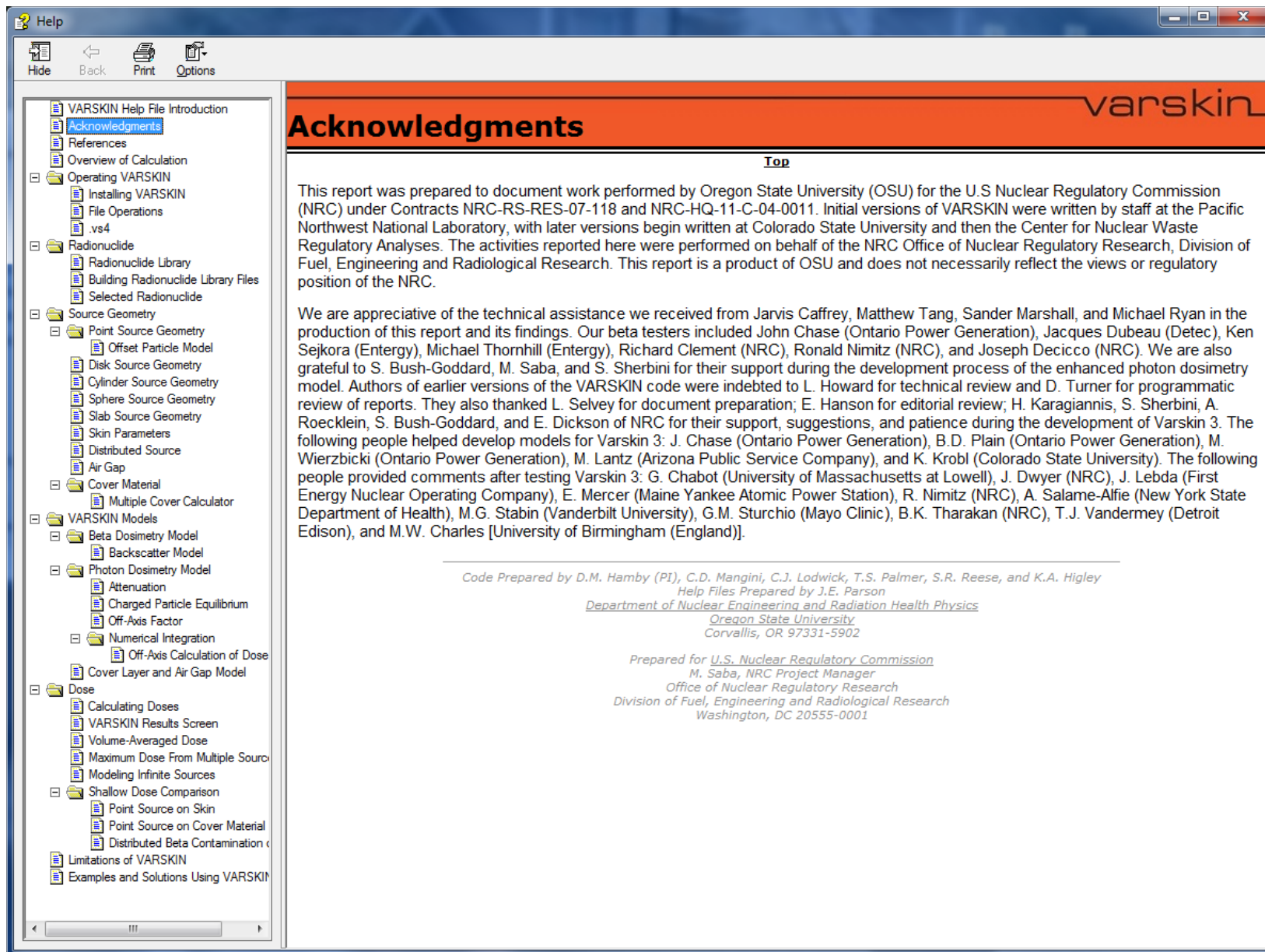
- GUI written in C#
 - controls I/O functions and executables
- Three modules written in FORTRAN
 - SadCalc.exe; VarCalc.exe; GamCalc.exe
- GamCalc.exe file written to execute photon dose model
- No need to “install” the code
 - simply double-click the VARSKIN 5 executable file



VARSKIN 5







Acknowledgments

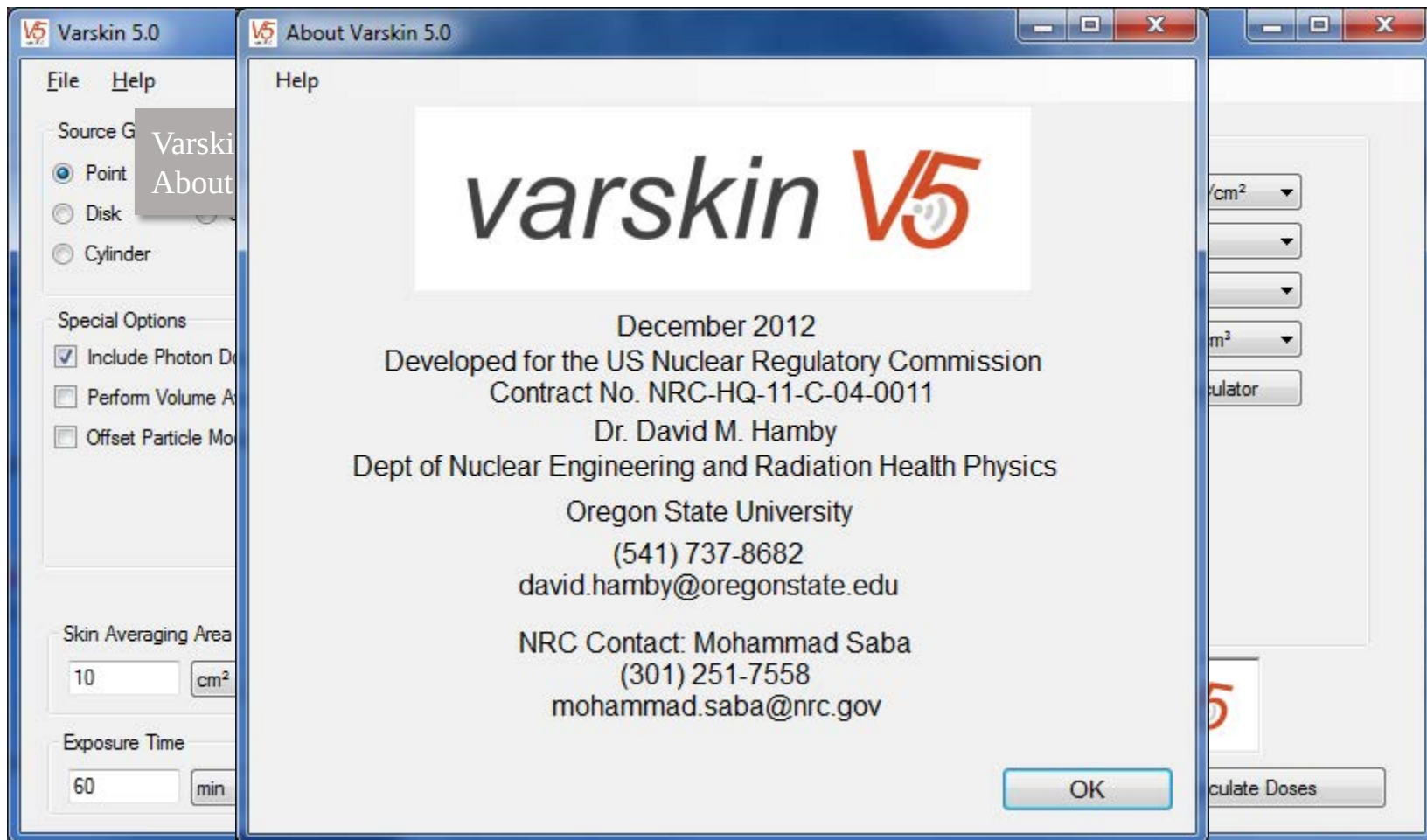
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This report was prepared to document work performed by Oregon State University (OSU) for the U.S Nuclear Regulatory Commission (NRC) under Contracts NRC-RS-RES-07-118 and NRC-HQ-11-C-04-0011. Initial versions of VARSKIN were written by staff at the Pacific Northwest National Laboratory, with later versions begin written at Colorado State University and then the Center for Nuclear Waste Regulatory Analyses. The activities reported here were performed on behalf of the NRC Office of Nuclear Regulatory Research, Division of Fuel, Engineering and Radiological Research. This report is a product of OSU and does not necessarily reflect the views or regulatory position of the NRC.

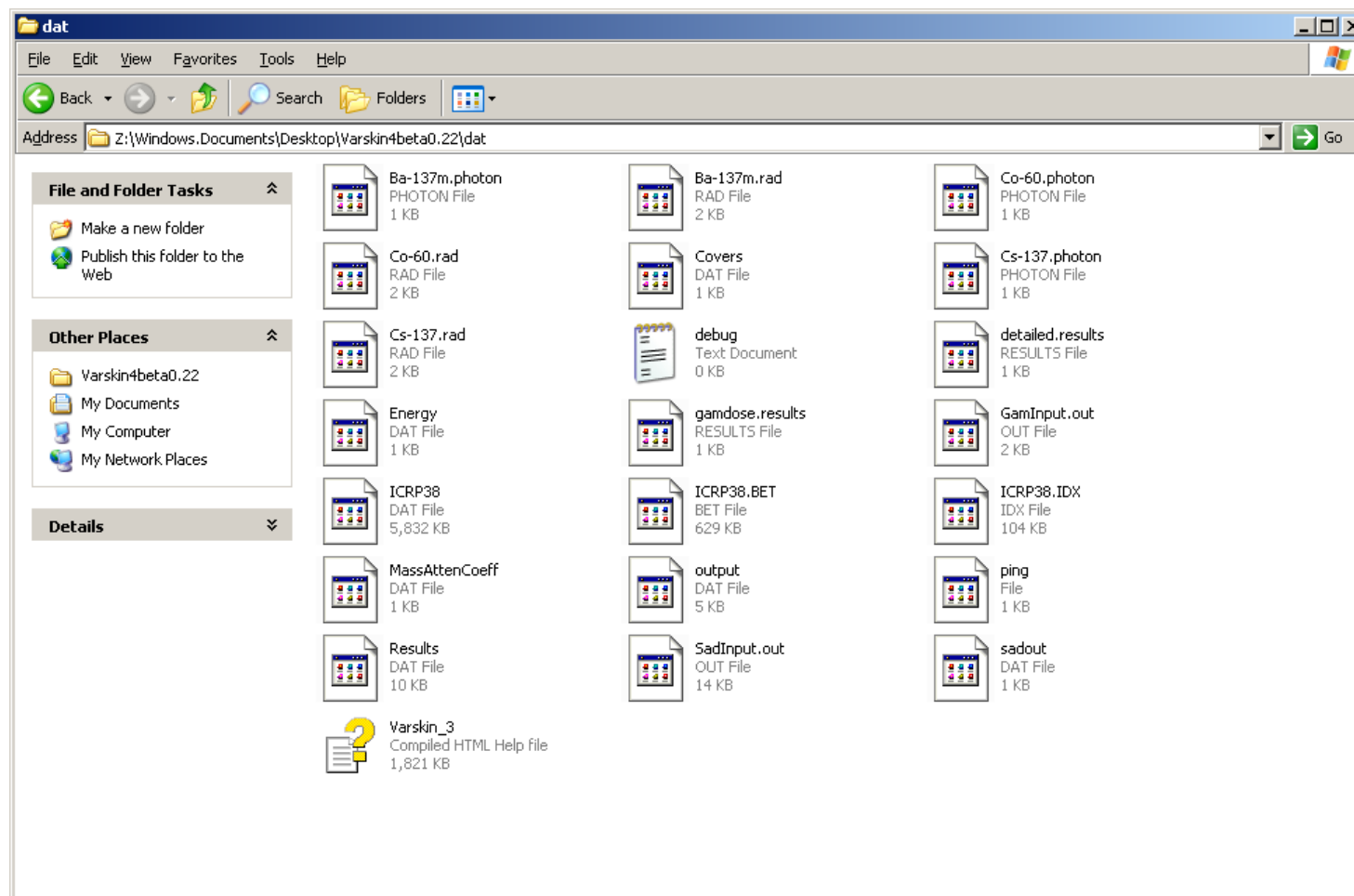
We are appreciative of the technical assistance we received from Jarvis Caffrey, Matthew Tang, Sander Marshall, and Michael Ryan in the production of this report and its findings. Our beta testers included John Chase (Ontario Power Generation), Jacques Dubeau (Detec), Ken Sejkora (Entergy), Michael Thornhill (Entergy), Richard Clement (NRC), Ronald Nimitz (NRC), and Joseph Decicco (NRC). We are also grateful to S. Bush-Goddard, M. Saba, and S. Sherbini for their support during the development process of the enhanced photon dosimetry model. Authors of earlier versions of the VARSKIN code were indebted to L. Howard for technical review and D. Turner for programmatic review of reports. They also thanked L. Selvey for document preparation; E. Hanson for editorial review; H. Karagiannis, S. Sherbini, A. Roecklein, S. Bush-Goddard, and E. Dickson of NRC for their support, suggestions, and patience during the development of Varskin 3. The following people helped develop models for Varskin 3: J. Chase (Ontario Power Generation), B.D. Plain (Ontario Power Generation), M. Wierzbicki (Ontario Power Generation), M. Lantz (Arizona Public Service Company), and K. Krobl (Colorado State University). The following people provided comments after testing Varskin 3: G. Chabot (University of Massachusetts at Lowell), J. Dwyer (NRC), J. Lebda (First Energy Nuclear Operating Company), E. Mercer (Maine Yankee Atomic Power Station), R. Nimitz (NRC), A. Salame-Alfie (New York State Department of Health), M.G. Stabin (Vanderbilt University), G.M. Sturchio (Mayo Clinic), B.K. Tharakan (NRC), T.J. Vandermeij (Detroit Edison), and M.W. Charles [University of Birmingham (England)].

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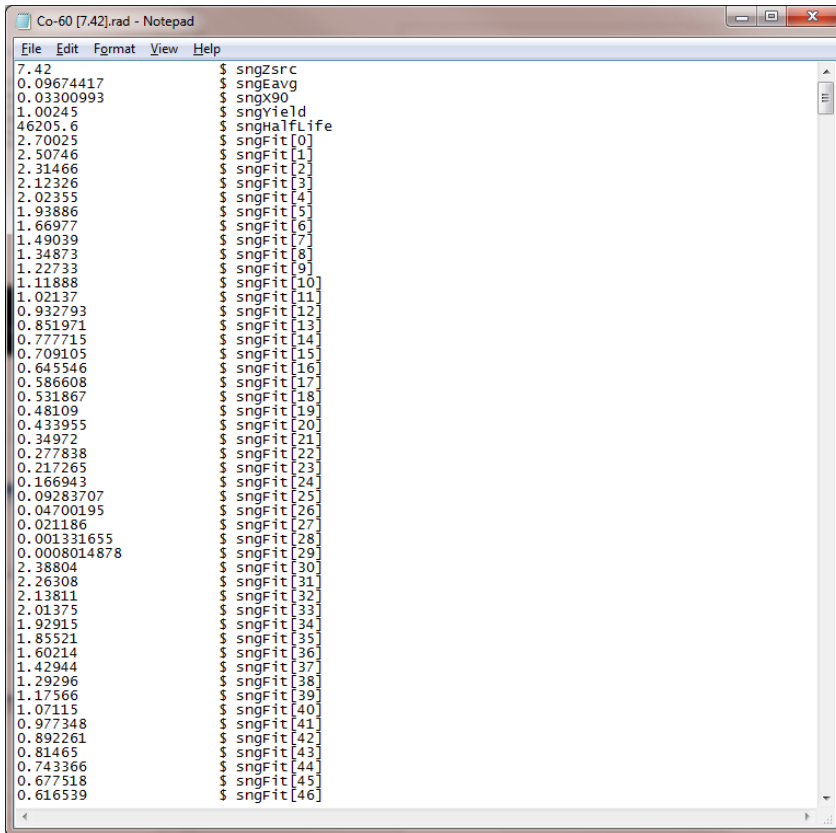
Prepared for U.S. Nuclear Regulatory Commission
M. Saba, NRC Project Manager
Office of Nuclear Regulatory Research
Division of Fuel, Engineering and Radiological Research
Washington, DC 20555-0001



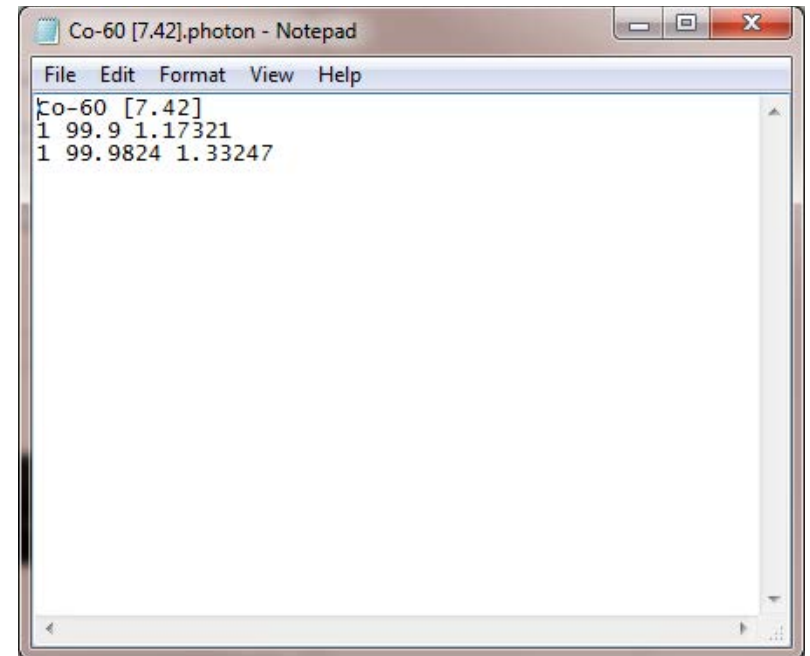
Dat folder



.rad and .photon dat files



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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

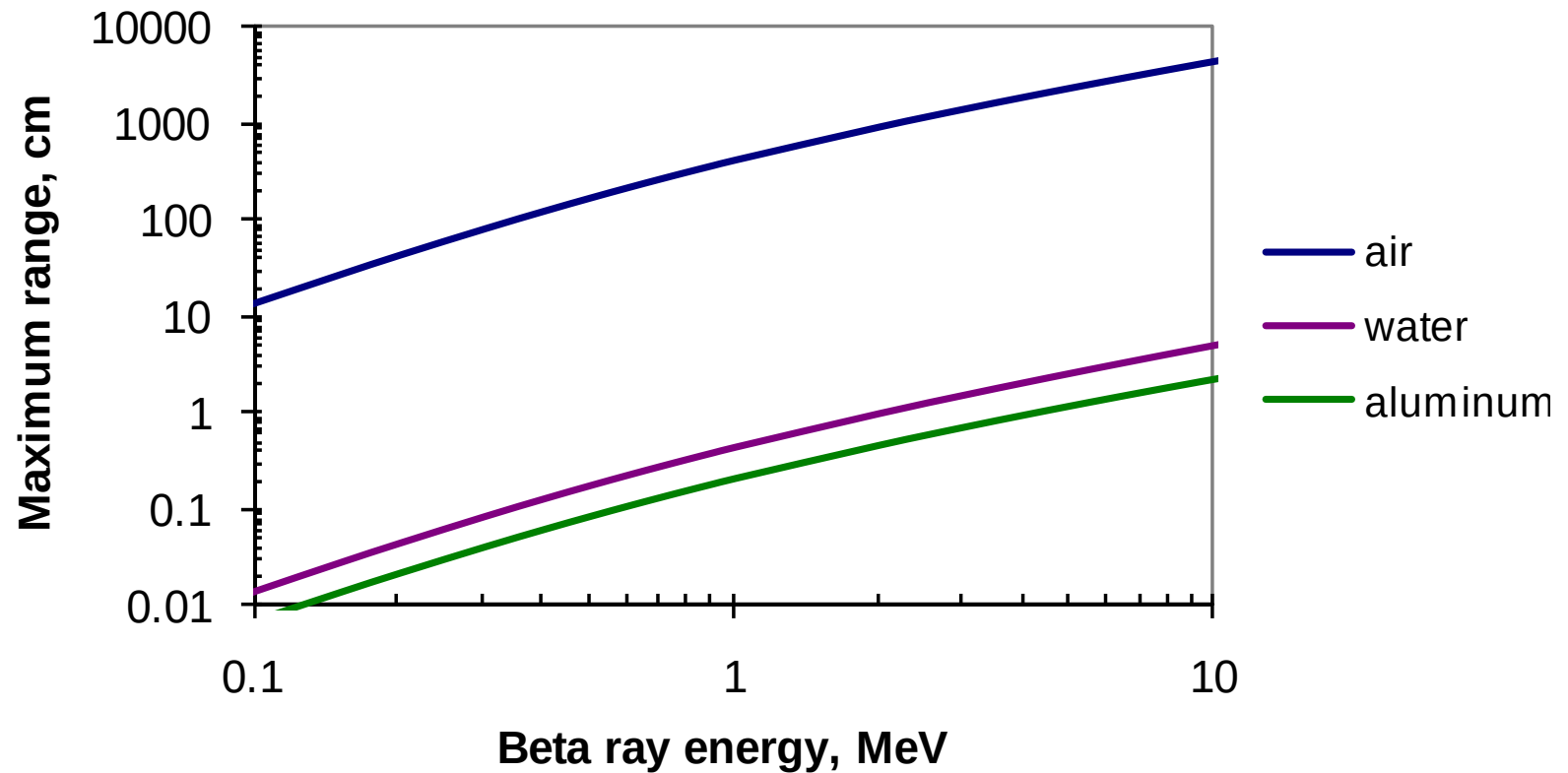
Characteristics Important for Dosimetry

- 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

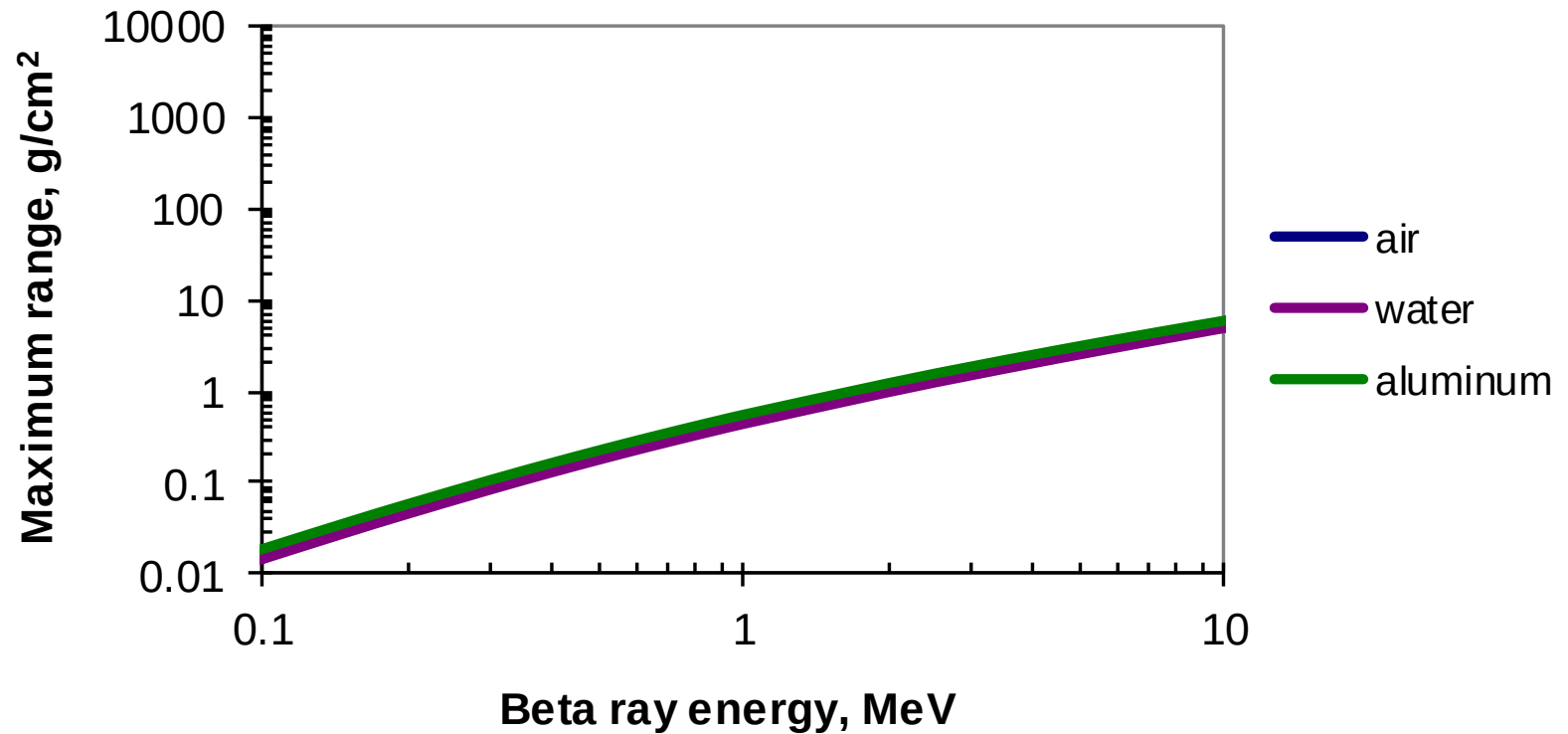
Range-Energy Observations

- 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 $\rightarrow$ 7, 100, 300, 1000 mg/cm^2

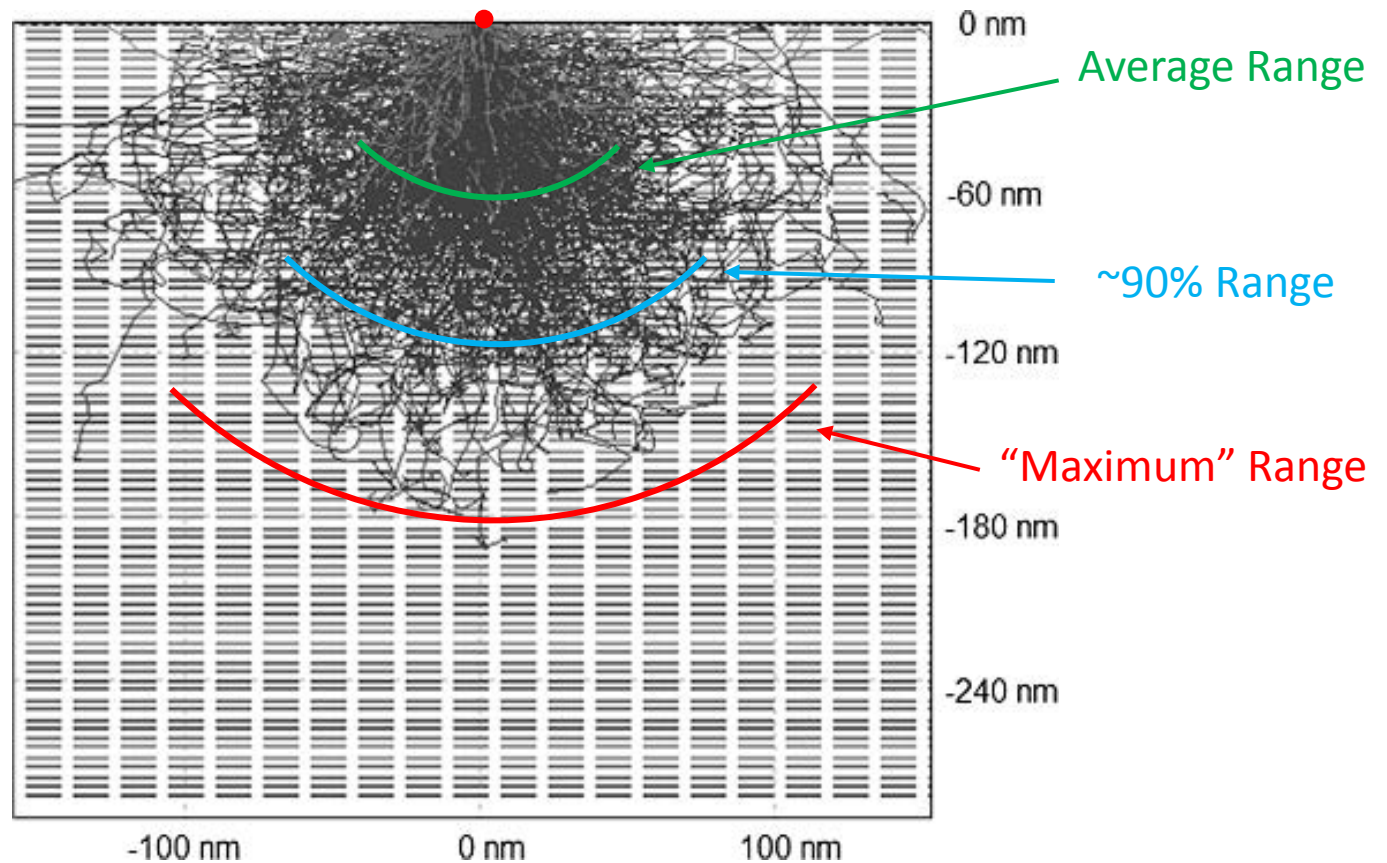
Range-Energy Relationship for Electrons



Advantage of Density Thickness



Electron Track Simulation



Electron “Attenuation”

Method assumes that electrons attenuate similar to photons:

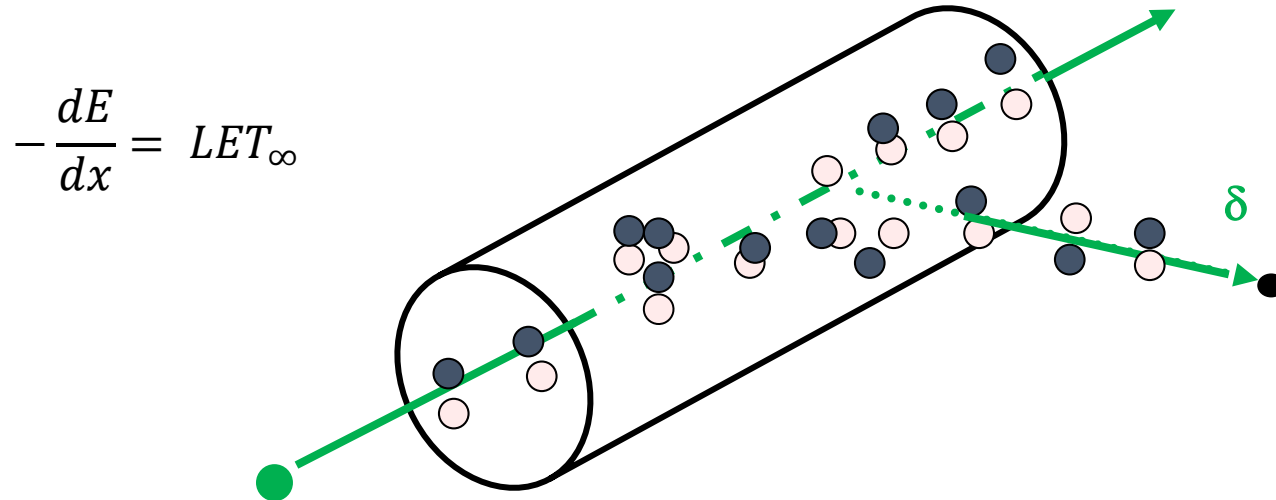
$$\phi_{\beta}(x) = \phi_{\beta,0}(x) \cdot e^{-\mu_{\beta}(\rho x)}$$

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 locally
 - 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”)

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

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

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

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

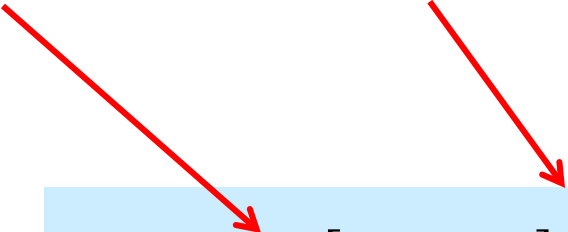
- ✗ Because electrons are interacting with other electrons, the phenomenon of “backscatter” is an important issue
- ✗ In thin foils, backscatter isn’t significant to dosimetry
- ✗ In thick materials, however, some portion of the electron energy flux is redirected in the reverse direction and the average 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

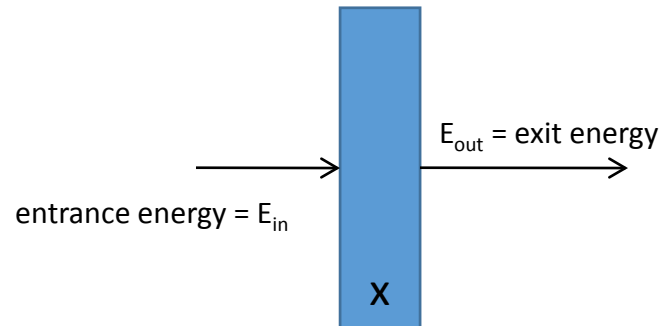
Simplified Electron Dosimetry

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

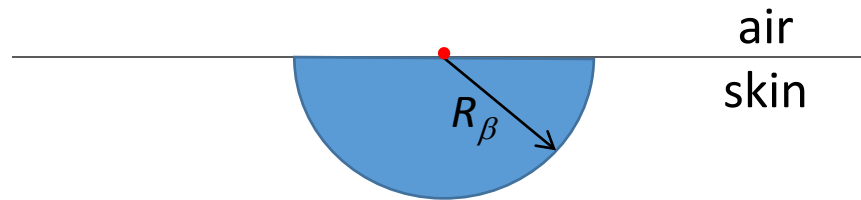
And, in thick materials (uniformly exposed), the average dose rate from charged particles can be determined from estimates of the particle range and related energy loss:



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

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):

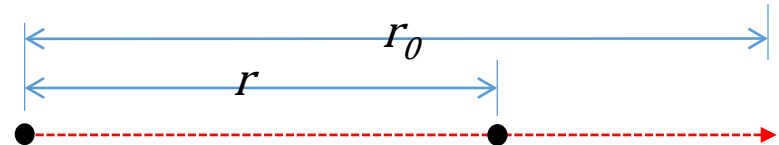


$$\dot{D}_\beta \left[\frac{\text{Gy}}{\text{sec}} \right] = \frac{\frac{1}{2} \cdot A \left[\frac{\text{dis}}{\text{sec}} \right] \cdot Y \left[\frac{\beta}{\text{dis}} \right] \cdot \bar{E}_\beta \left[\frac{\text{J}}{\beta} \right]}{\frac{1}{2} \cdot \frac{4}{3} \pi \cdot R_\beta^3 \left[\text{cm}^3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

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:

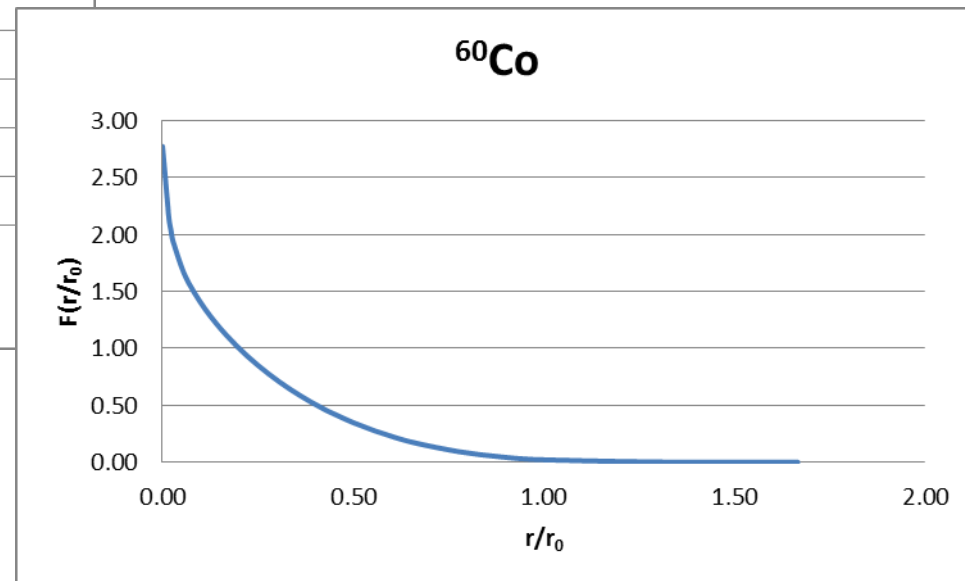
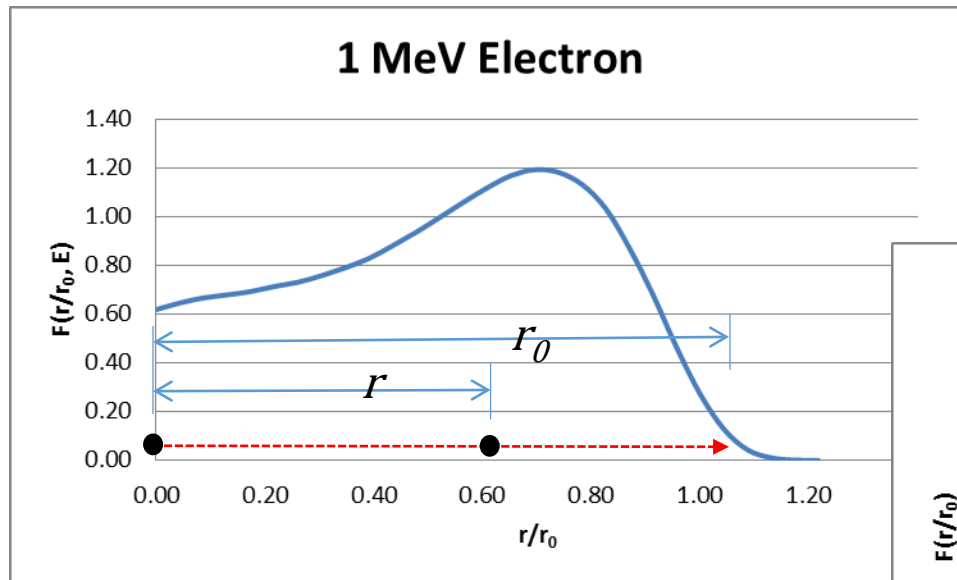
$$G(r, E) = \frac{E}{4\pi r^2 \rho r_0} F(r/r_0, E)$$



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

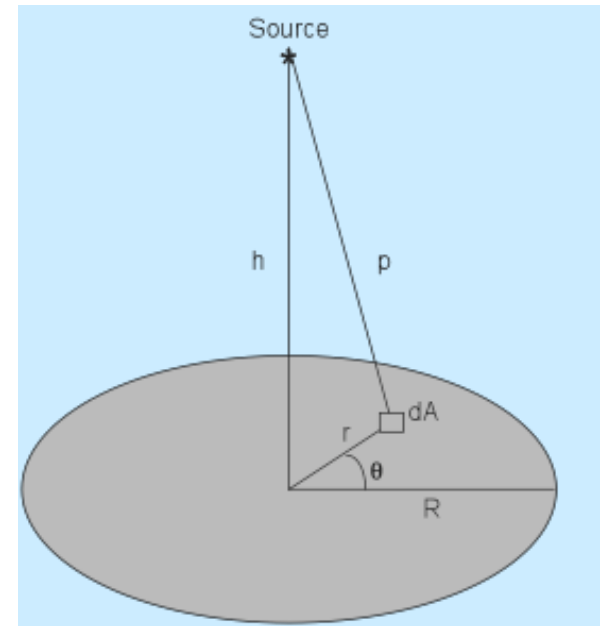




A Brief Review of the
Original VARSKIN Beta Dosimetry

Fundamentally ...

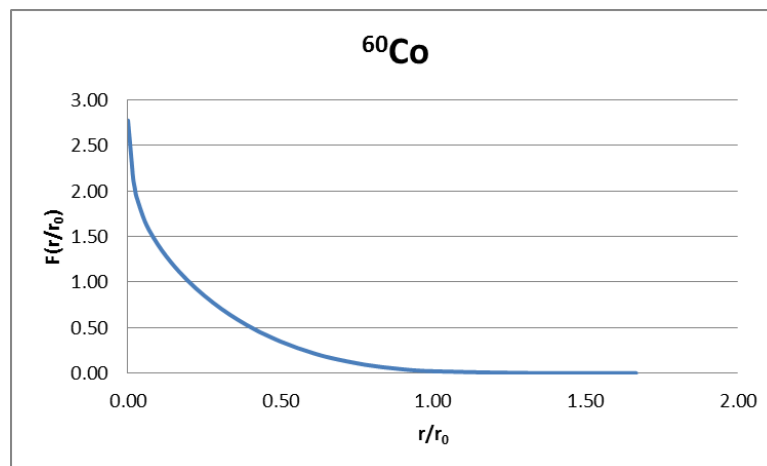
- Point-kernel method employed
- Source on skin surface
- Dose calculated to a given averaging area at the user-specified depth
- Energy absorption based on calculated stopping power at depth



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}

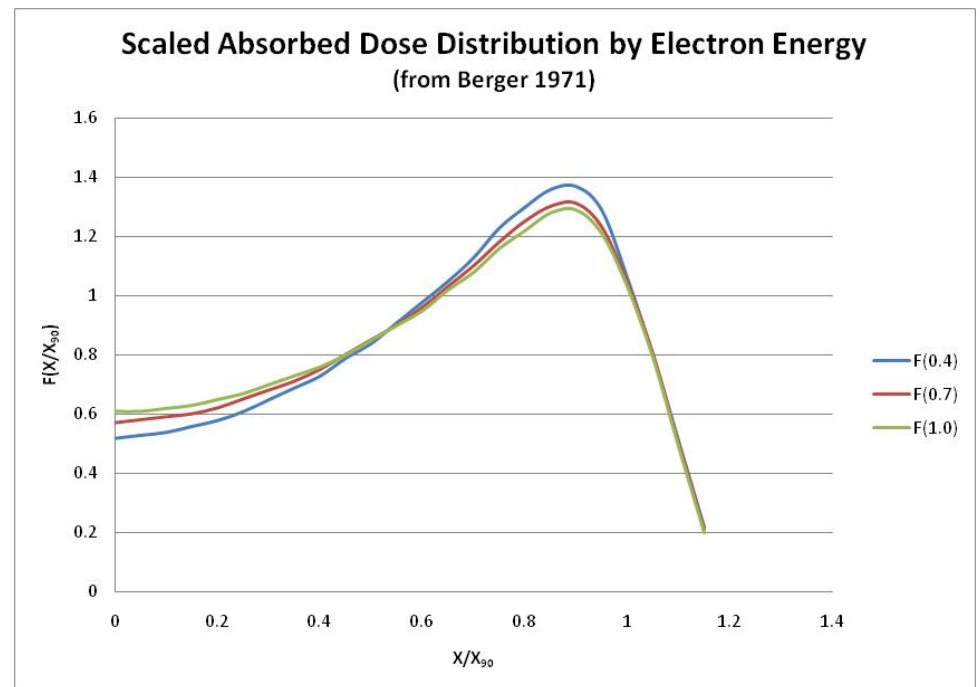
$$B(r) = \frac{kY\bar{E}F_{\beta}(r_1/r_0)}{\pi r^2 \rho r_0}$$



Scaled Absorbed Dose Distribution

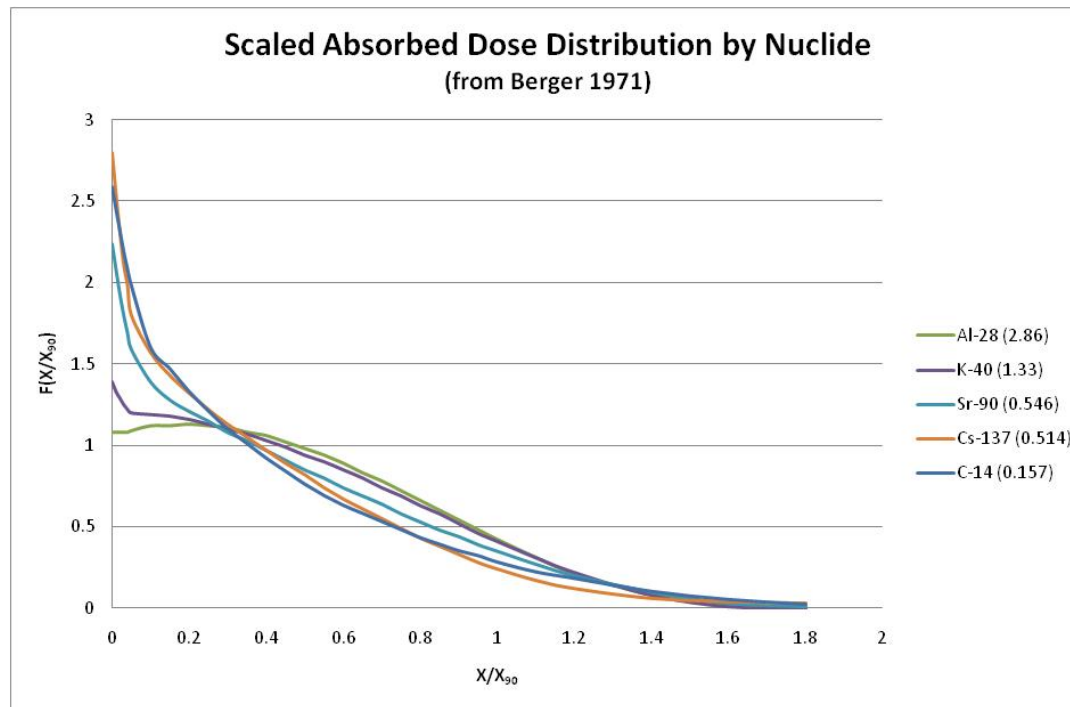
Berger determined the absorbed dose distribution for electrons of a given energy and depth of penetration (X); this is essentially a Bragg curve for monoenergetic electrons traveling through the absorber (water in this case).

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

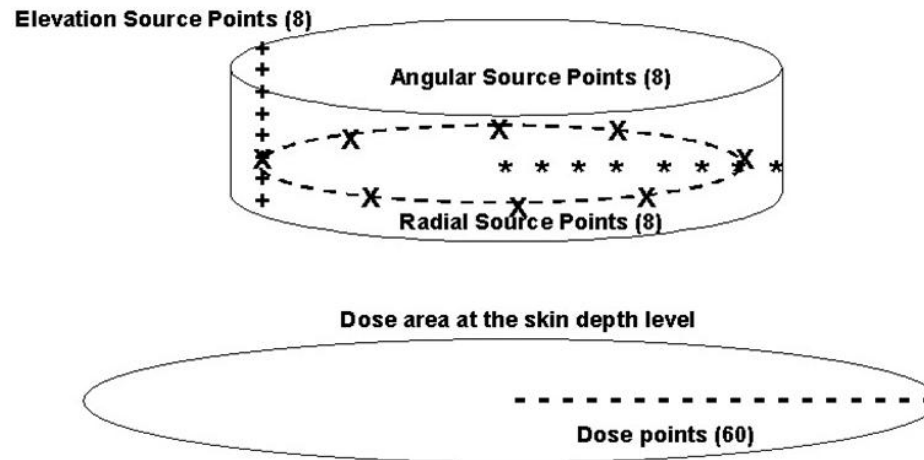
The beta energy emission spectra is folded with the energy-dependent scaled absorbed dose distribution to derive the nuclide-specific SADD.



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:

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

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”

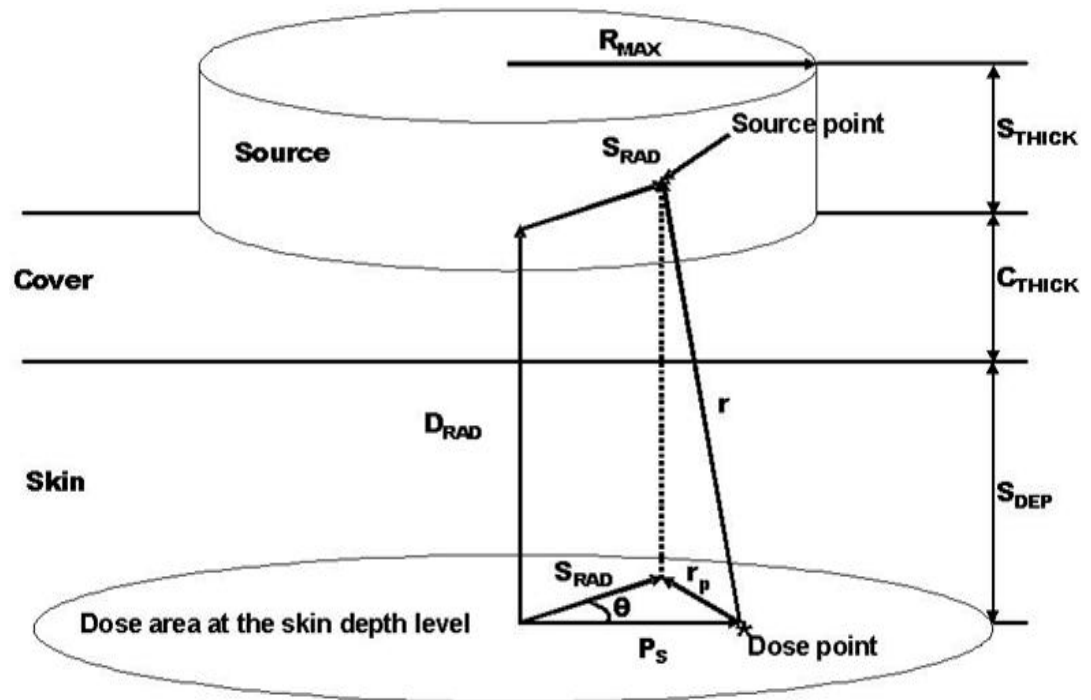
Density Correction Model

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

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

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

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



How is Gamma Dose Determined?

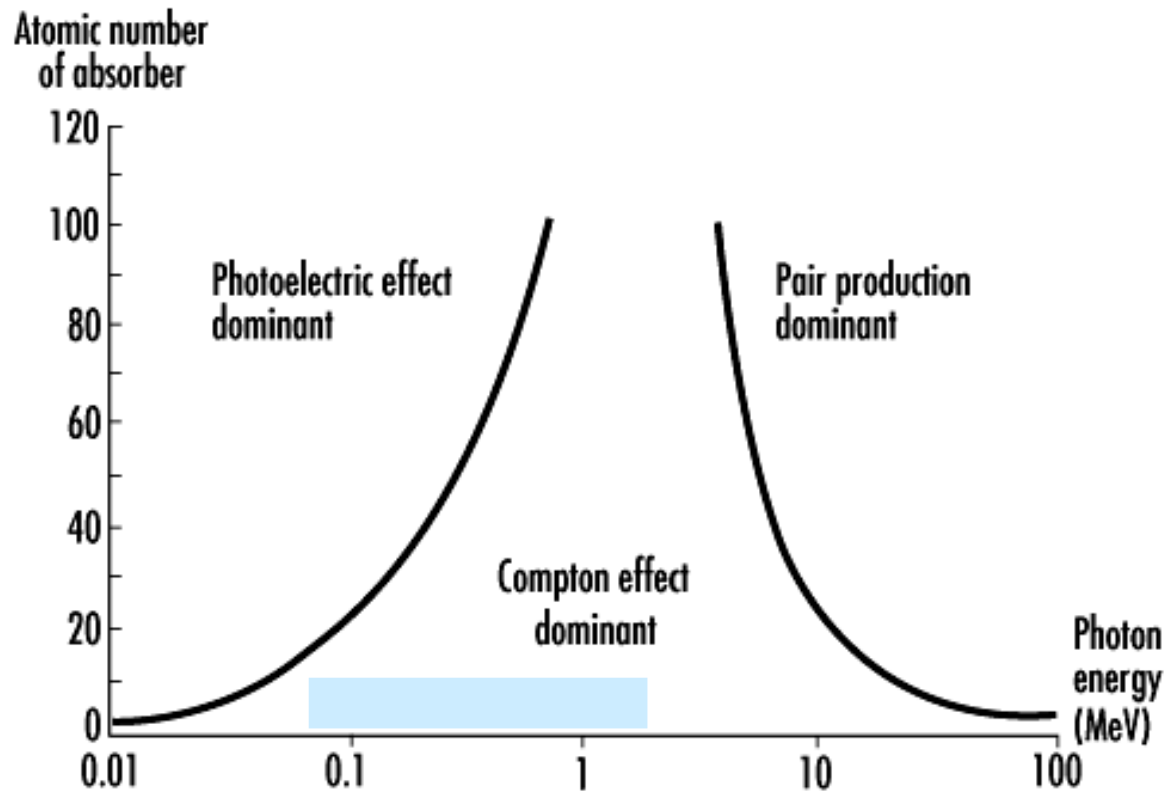
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Photon Interactions and Dosimetry

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:

$$I = I_0 e^{-\mu x}$$

- 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 Relaxed 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

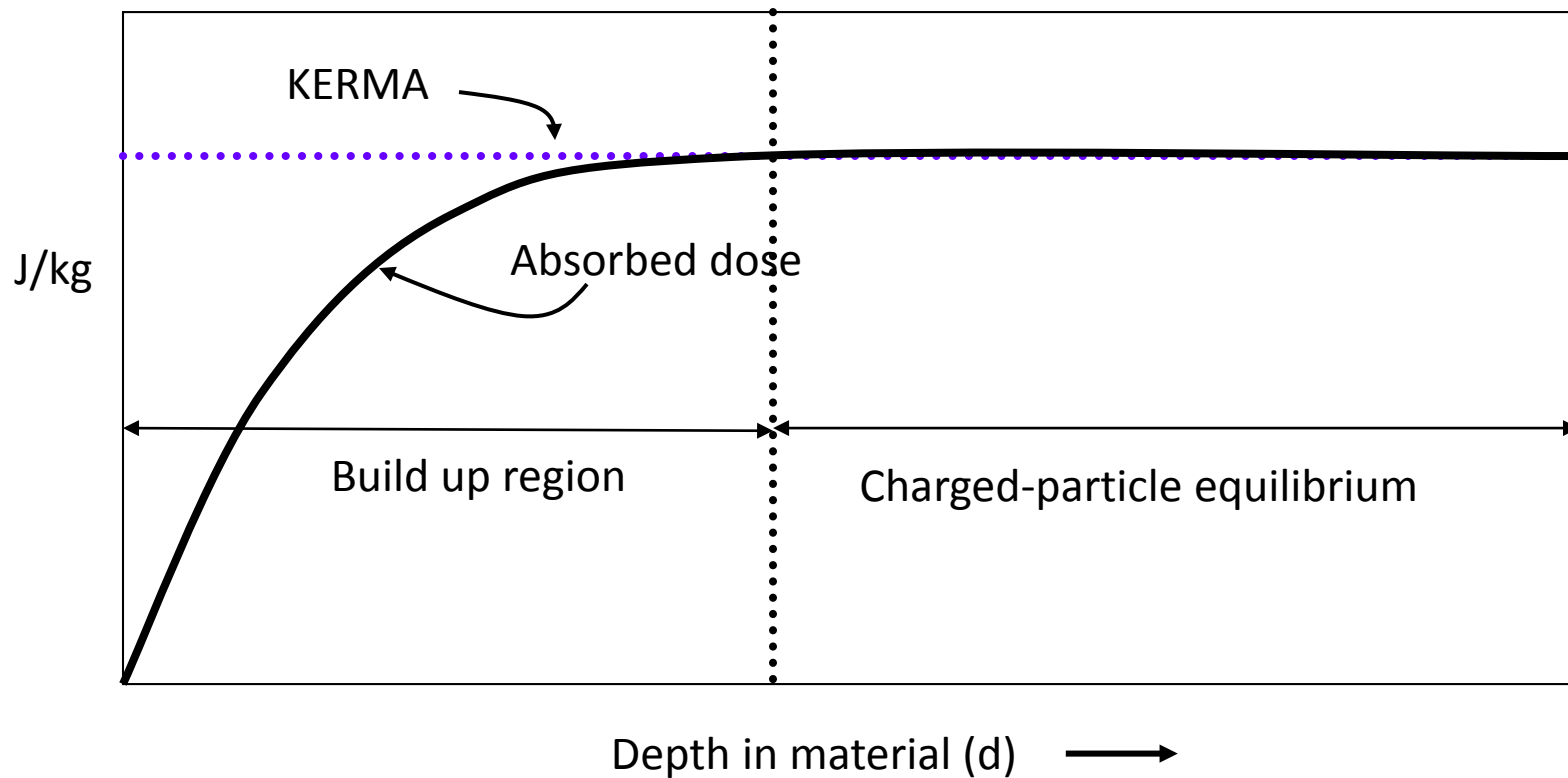
$$D = K \cdot \frac{\mu_{en}}{\mu_{tr}}$$

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

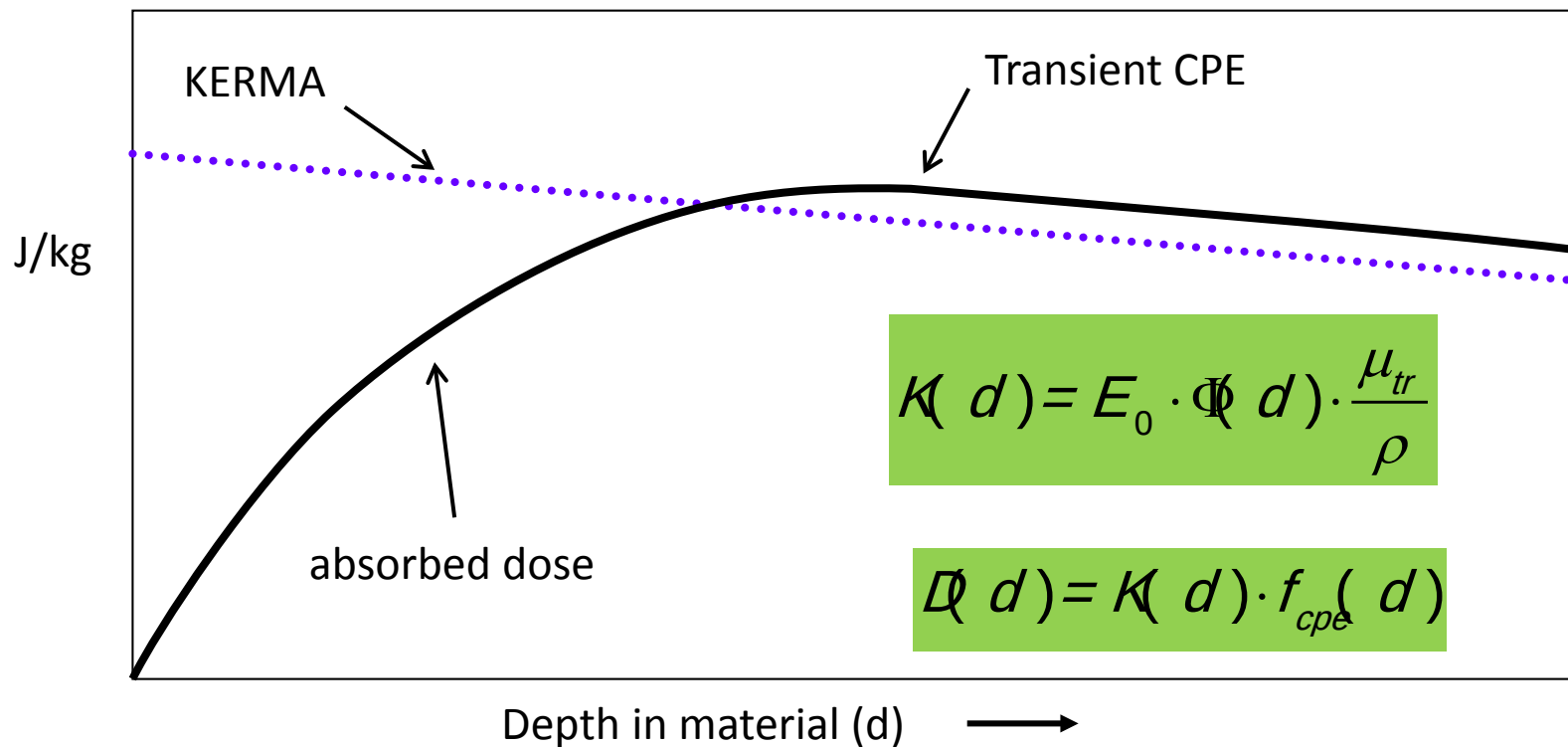
Charged-Particle Equilibrium

- 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

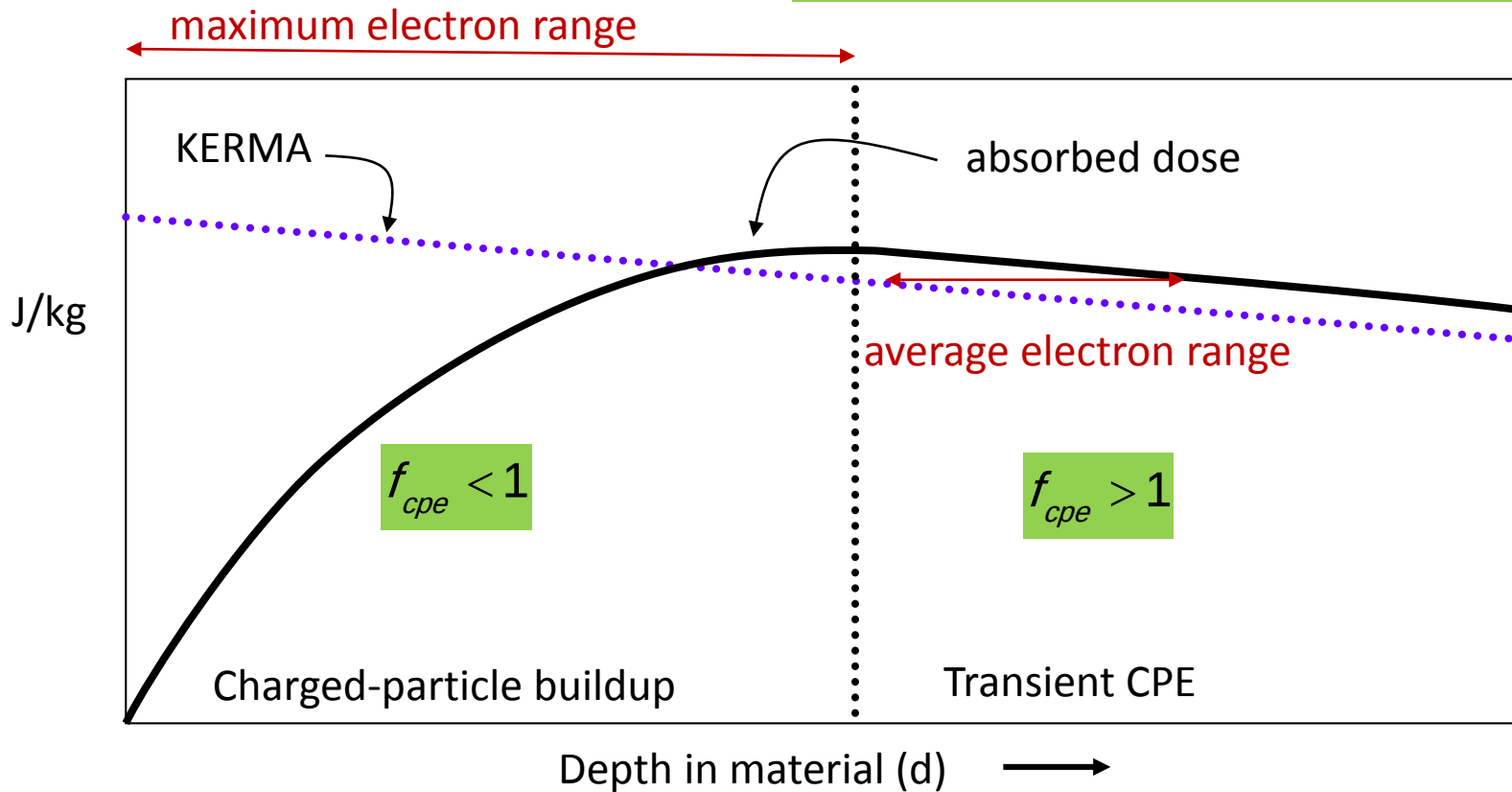


KERMA and Dose Buildup



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:

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

Photon Flux at Depth

Energy Transfer Probability

Photon Energy

Buildup Factor at Depth

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:

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

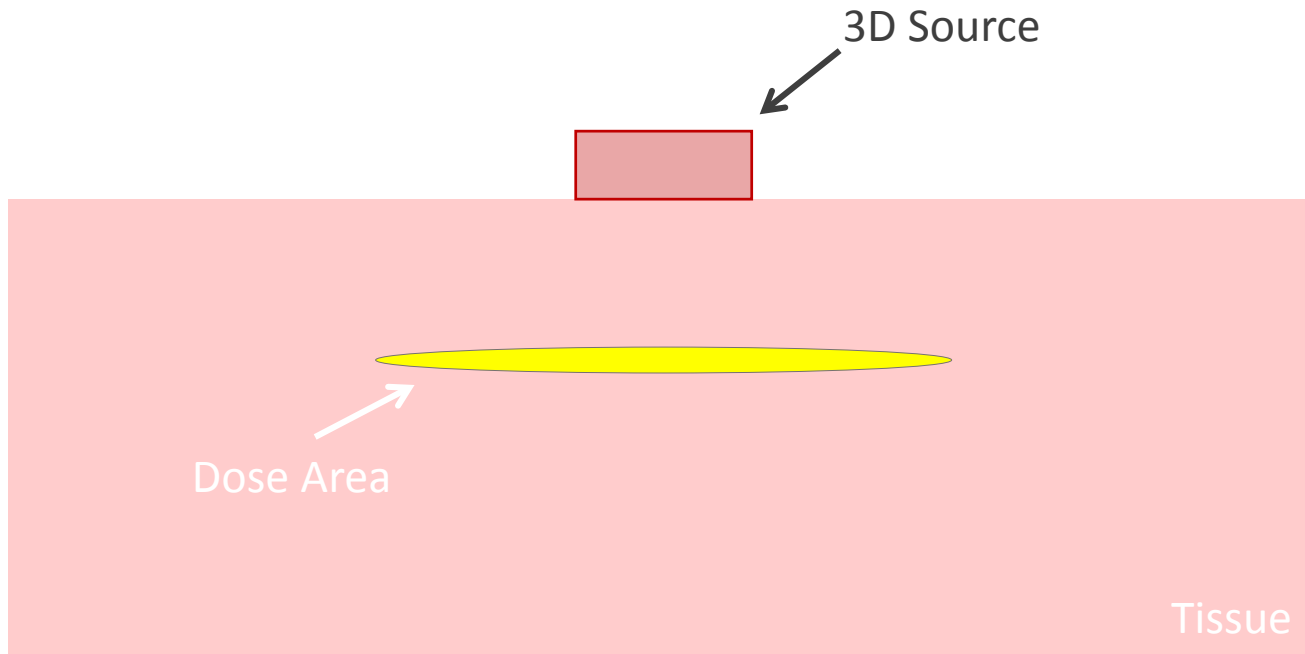
- Relevant data obtained from NIST, ICRU-44, and NUCDECAY files

VARSKIN 4/5 Photon Dosimetry

- The new VARSKIN 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 cm²) beneath skin at user specified depth
 - variable dose averaging
 - 2D averaging areas (regulatory compliance)
 - 3D averaging volumes (detector simulation)

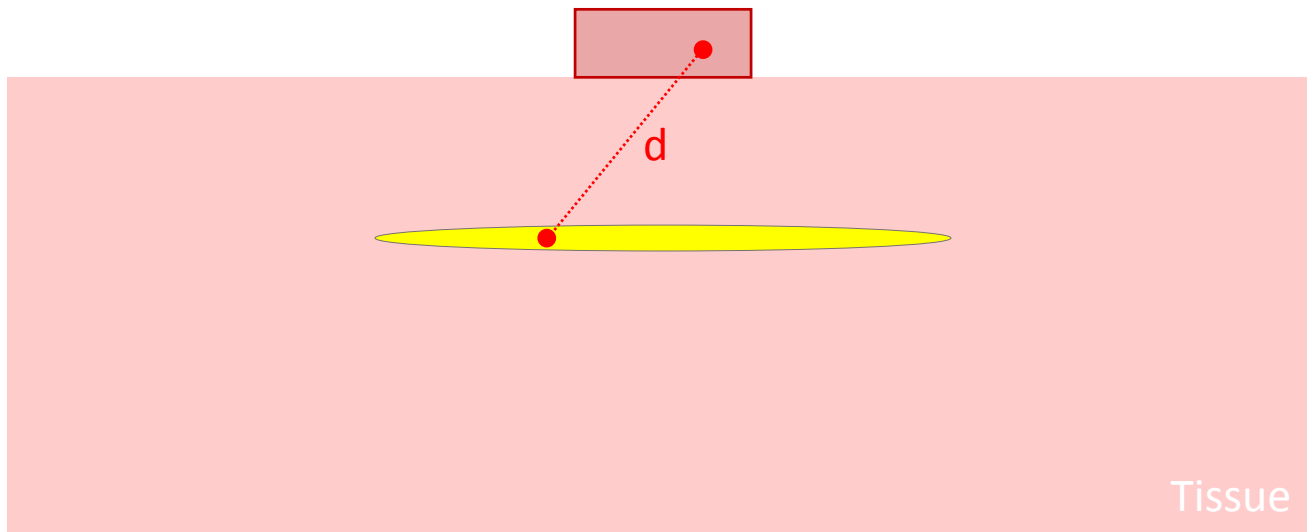
“Point Kernel” Concept

Now, let's put the dose equation to use ...



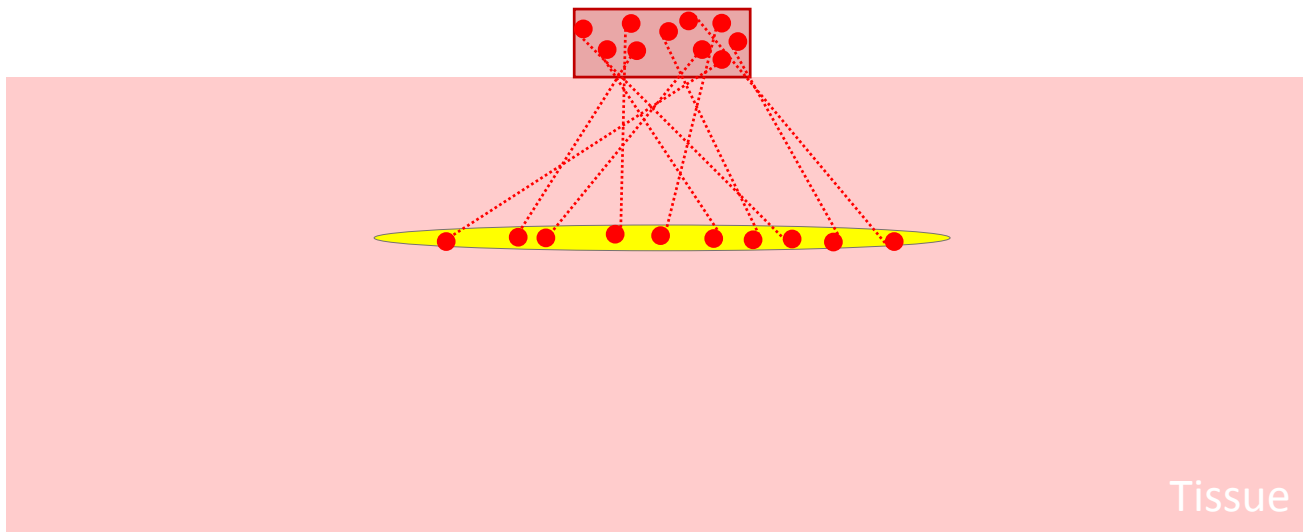
“Point Kernel” Concept

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



Integrate Point Kernels Over Source/Dose Volume

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



Estimating Tissue Mass Attenuation Coefficients

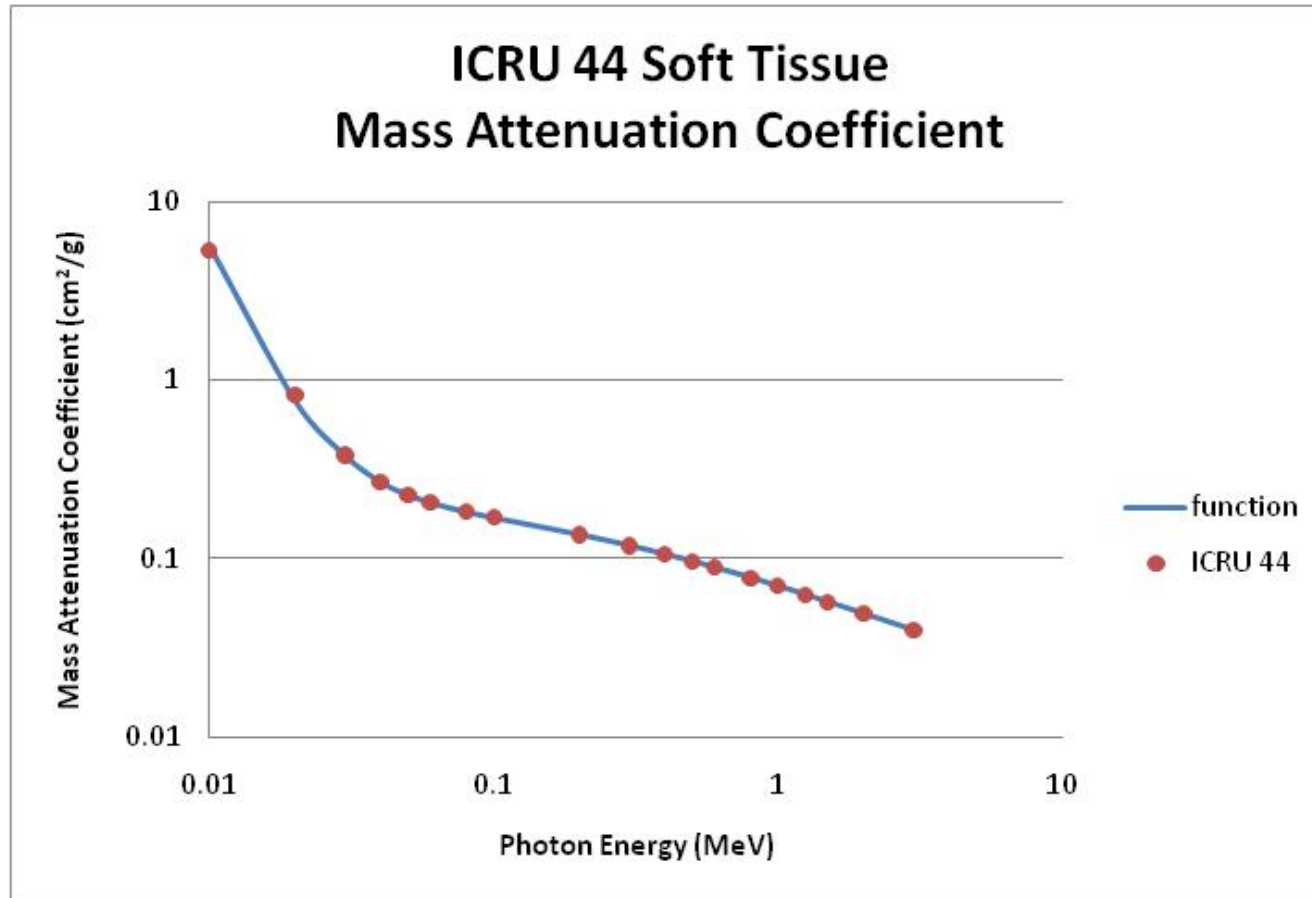
- As used in VARSKIN 4/5, an empirical relationship to estimate μ/ρ for tissue as a function of incident photon energy (in MeV) is given below.
- For energies less than or equal to 20 keV,

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

- and for energies greater than 20 keV,

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

ICRU 44 soft tissue mass attenuation coefficients



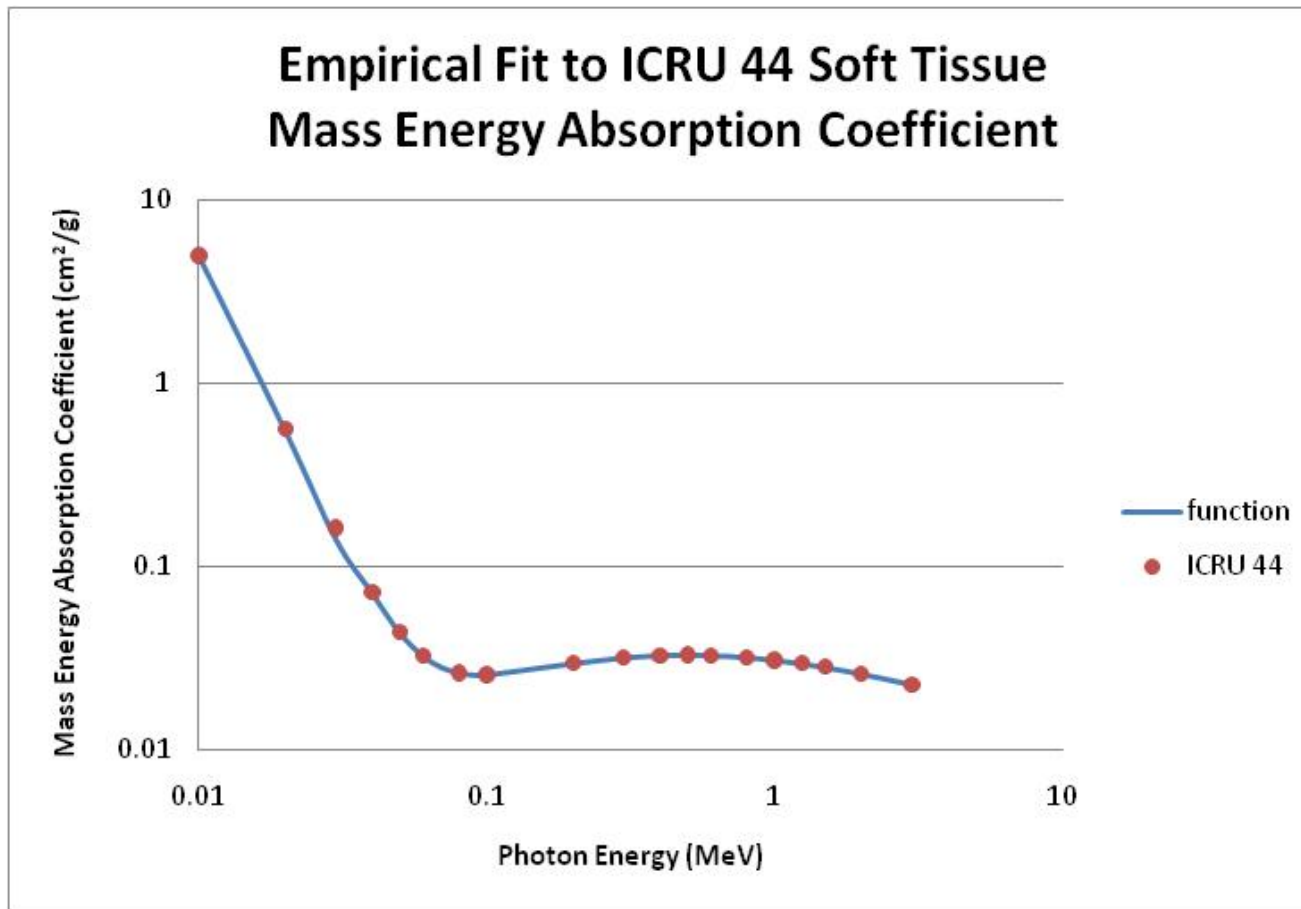
Estimating Tissue Energy Absorption Coefficients

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

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

- 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:

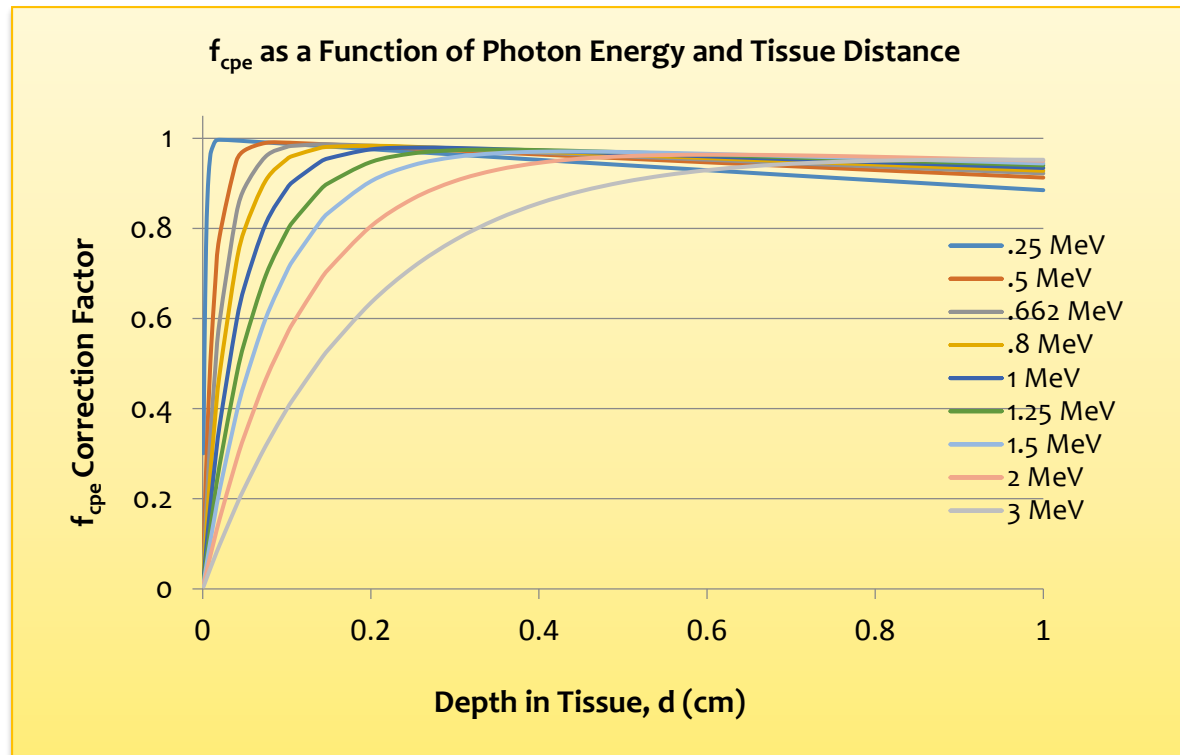
$$D(x) = K(x) \cdot f_{CPE}(x)$$

$$f_{CPE}(x) = \frac{D(x)}{K(x)} \rightarrow \frac{\sum^* f_8(x)}{f_6(x)}$$

Charged-Particle Buildup

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

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



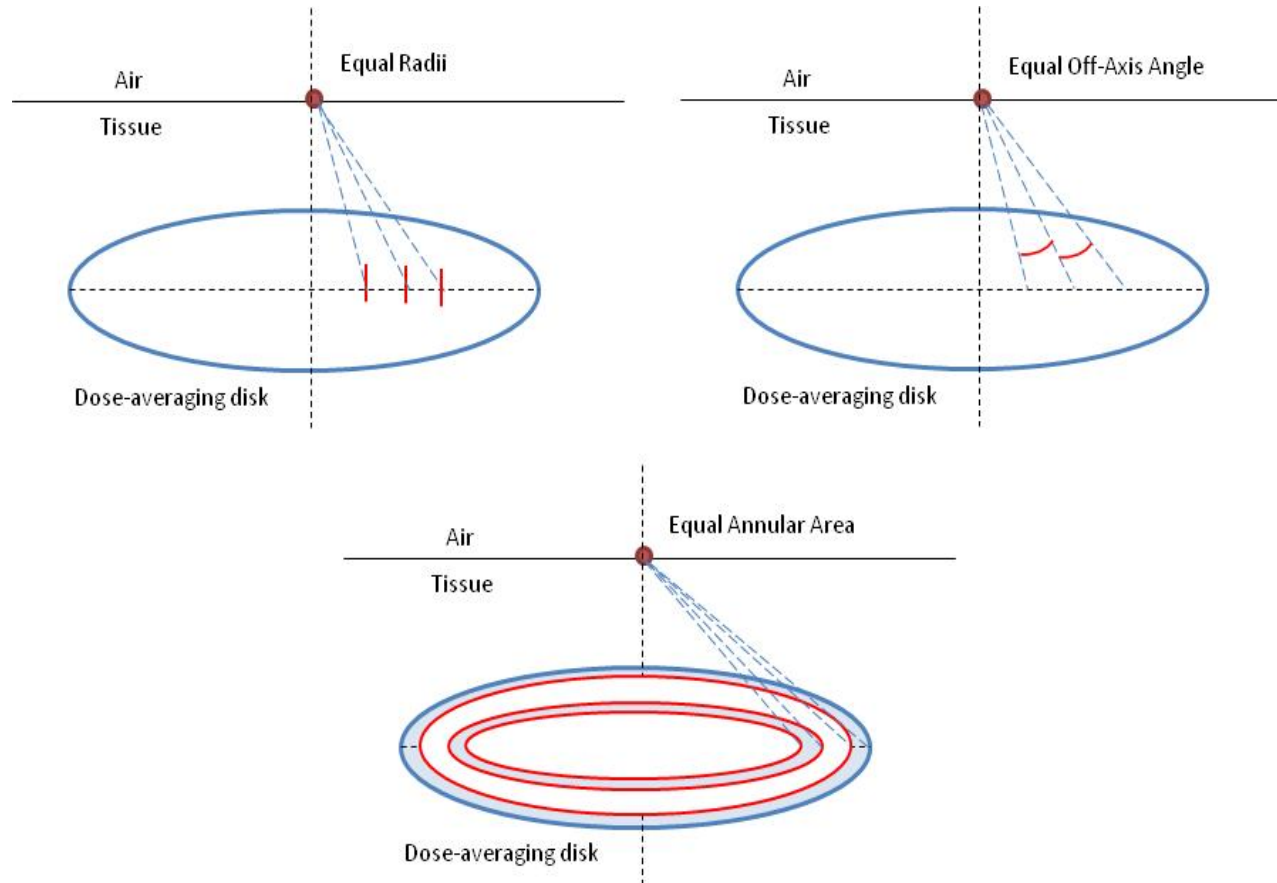
Numerical Integration Method

- 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

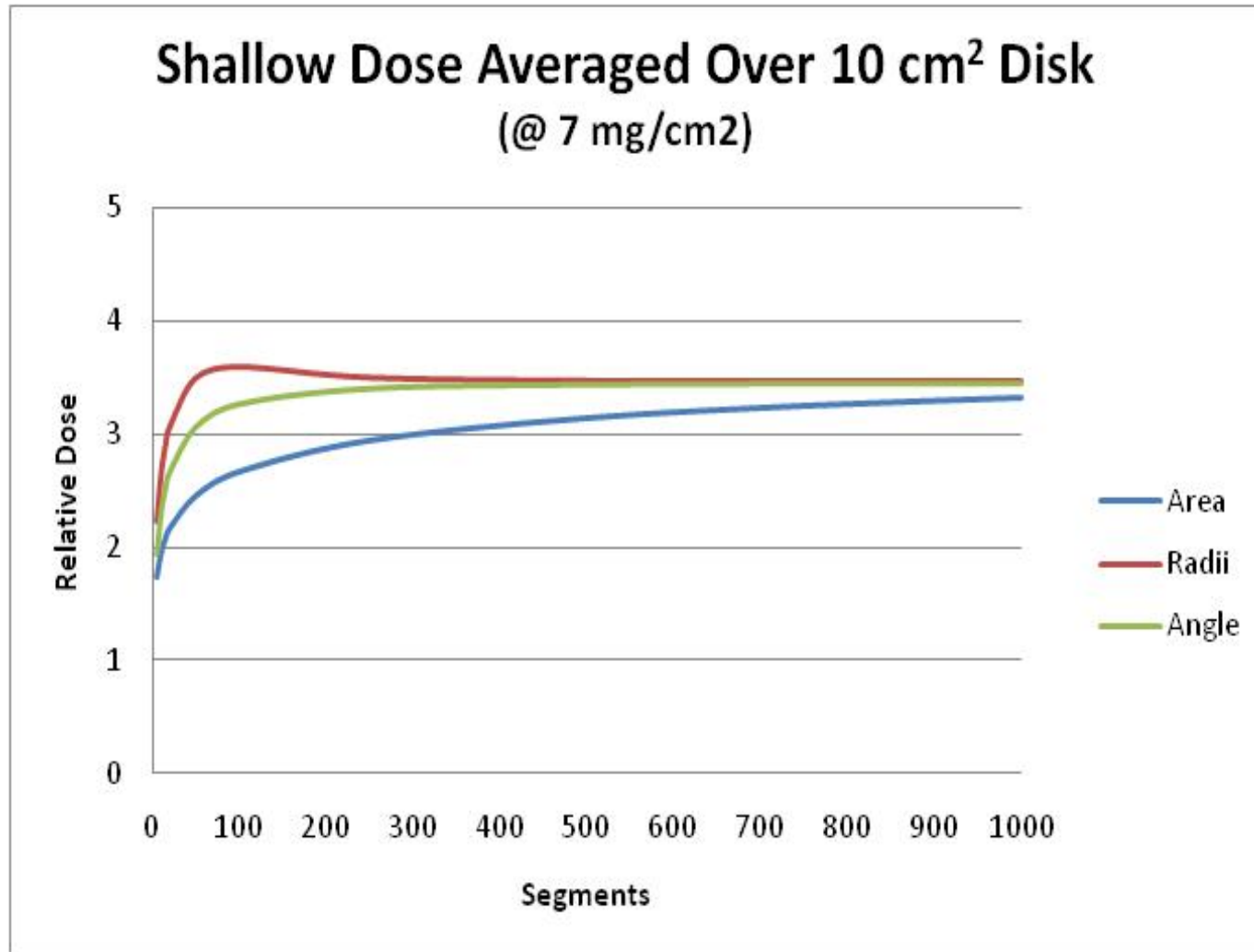
Approach to calculation

- 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



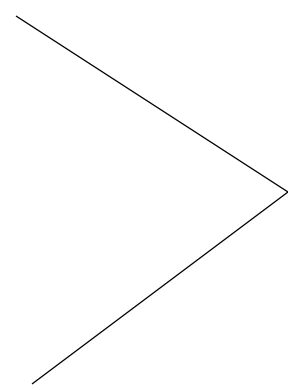
Relative dose as a function of the number of segments in a numerical integration (iterations), by method



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 exposure geometries

•Source Geometries

- Point ← Offset Particle Model
 - Disk
 - Cylinder
 - Sphere
 - Slab
 - Syringe
- ← Distributed Source Option
- ← Geometry eliminated
- 

VARSKIN 4/5 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

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere

☐ Disk ☐ Slab

☐ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select

Add

Remove

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

Selected Radionuclides

Edit Remove Clear

varskin V5

Calculate Doses

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

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☒ Disk ☐ Slab

☐ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select

Add

Remove

Use Distributed Source

Selected Radionuclides

Edit Remove Clear

Skin Averaging Area

10 cm^2

Exposure Time

60 min

Disk Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2

Air Gap Thickness 0 mm

Cover Thickness 0 mm

Cover Density 0 g/cm^3

Multiple Cover Calculator

Source Area 0.785 mm^2

Source Diameter 1 mm

varskin V5

Calculate Doses

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☐ Disk ☐ Slab

☒ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select

Add

Remove

☐ Use Distributed Source

Selected Radionuclides

Edit Remove Clear

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 1 mm

Source Thickness 1 μm

Source Density 1 g/cm³

varskin V5

Calculate Doses

Varskin 5.0

File Help

Source Geometry

☐ Point ☒ Sphere ☐ Disk ☐ Slab ☐ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select

Add

Remove

☐ Use Distributed Source

Selected Radionuclides

Edit Remove Clear

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 V5

Calculate Doses

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☐ Disk ☒ Slab

☐ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select

Add

Remove

☐ Use Distributed Source

Selected Radionuclides

Edit Remove Clear

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

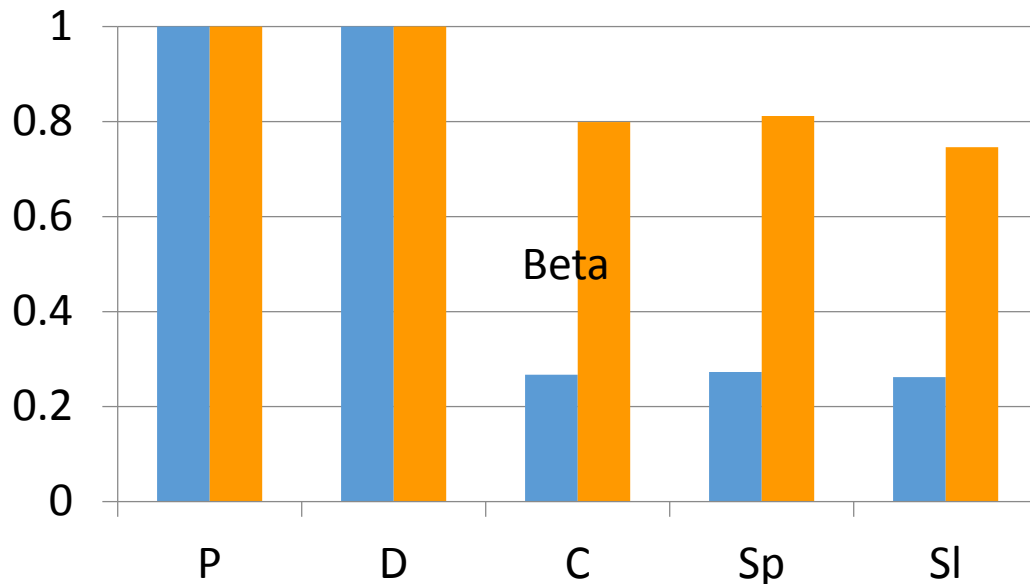
Source Thickness 1 μm

Source Density 1 g/cm³

varskin V5

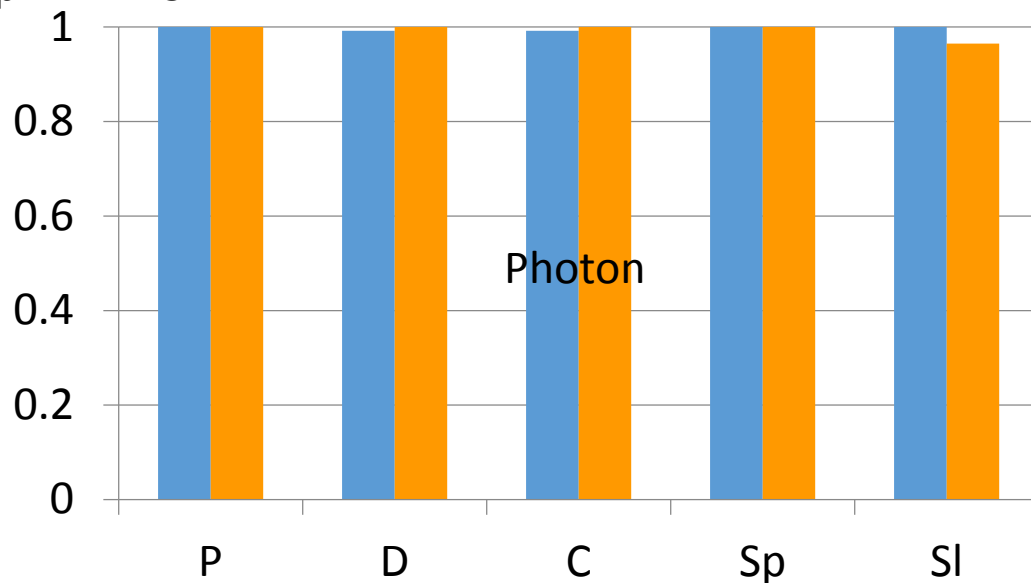
Calculate Doses

Impact of Source Geometry



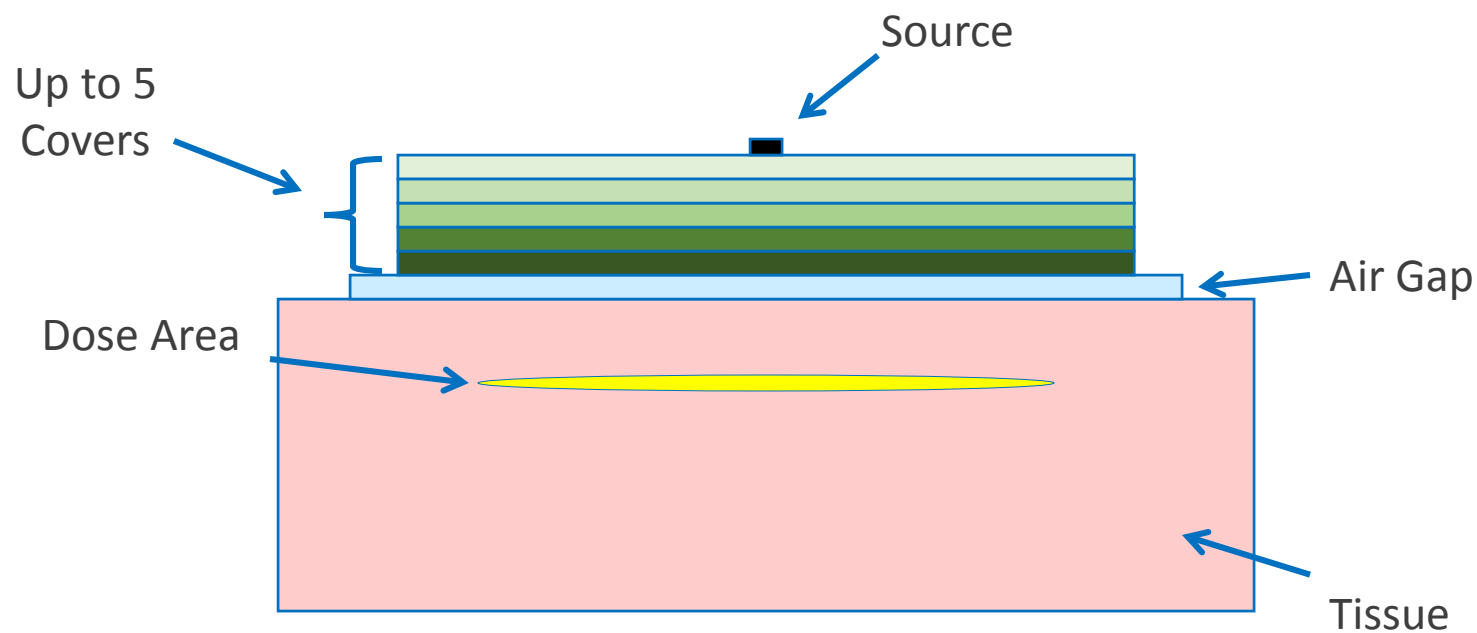
^{60}Co (0.318; 1.25)
 ^{106}Rh (3.54; 0.512)

Dose relative to point geometry
1 mm dimensions
10 cm² area
Shallow dose



Photon

Cover model



Cover Materials

- The presence of cover materials
 - disrupts CPE, adds depth, and alters off-axis geometry
- Up to 5 layers above the skin are allowed (air next to skin, if present)
- Attenuation in cover materials is considered
- Material layers are restricted to “cotton” or “latex”
- Cotton or latex attenuation is energy dependent
 - if $\rho > 1.25 \text{ g/cm}^2$ (cotton assumed)
 - if $\rho < 1.25 \text{ g/cm}^2$ (latex assumed)
- For photon attenuation, the cover material is assumed to be air
 - insignificant for very small volumetric sources and for photon energies above $\sim 50 \text{ keV}$

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

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select
Add
Remove

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

Selected Radionuclides

Edit Remove Clear

varskin V5

Calculate Doses

Special Options

- Include Photon Dose (on)
 - choice is likely to be removed with next version
- 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 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☒ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units

μCi

Select
Add
Remove

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

Selected Radionuclides

Edit Remove Clear

varskin V5

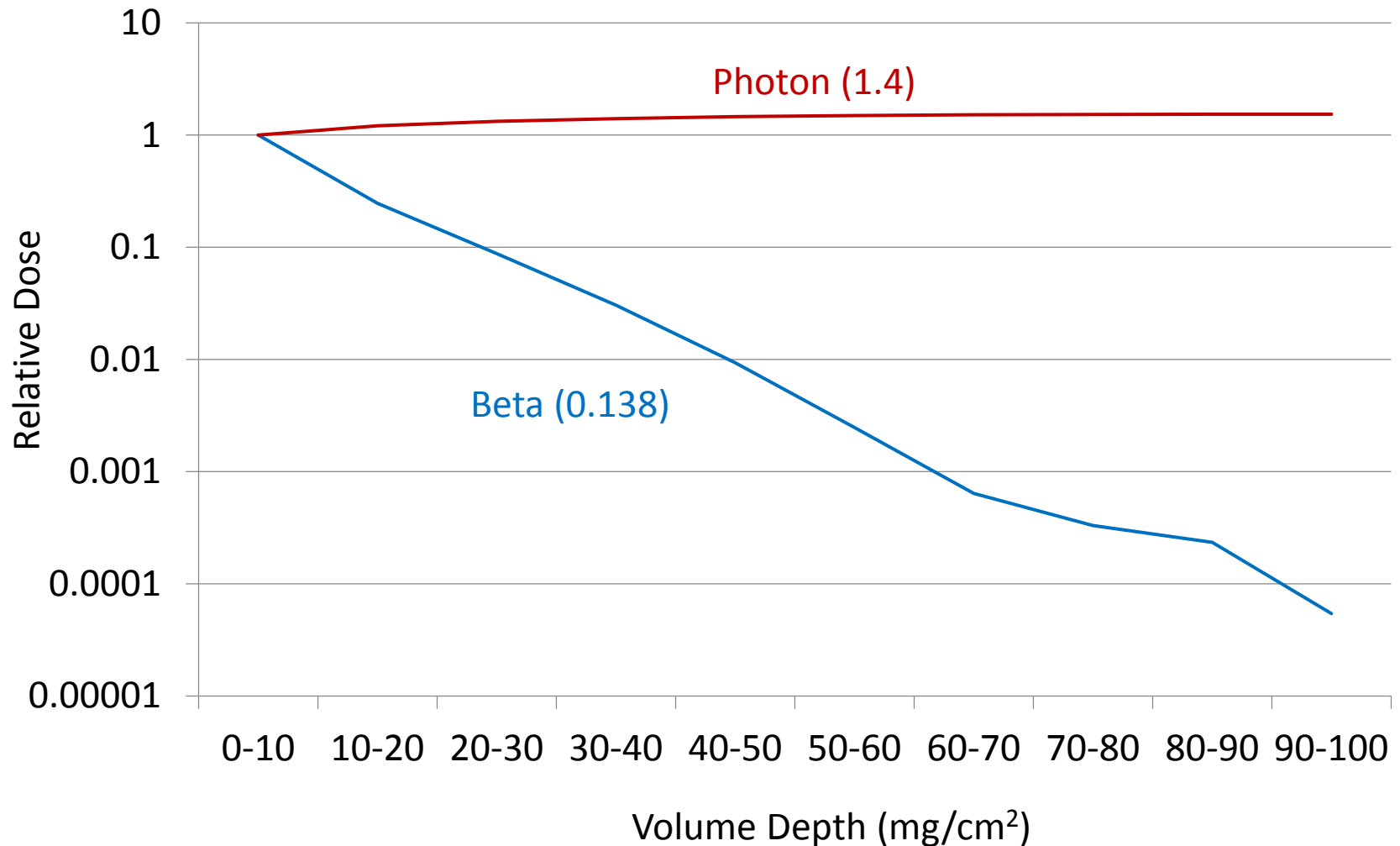
Calculate Doses

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/cm²) 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/cm²)

Volume Averaging

^{60}Co ; point source; 10 cm^2 ; $(0-100\text{ mg/cm}^2)$



Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☒ Offset Particle Model
Offset Value:
0 cm

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]

Activity Units
μCi

Select
Add
Remove

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

Selected Radionuclides

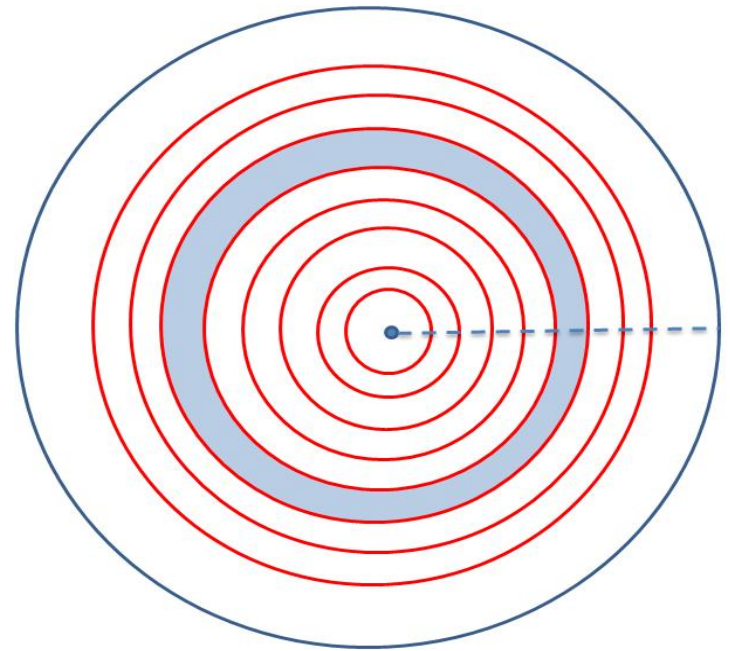
Edit Remove Clear

varskin V5

Calculate Doses

On-Axis Calculation of Dose

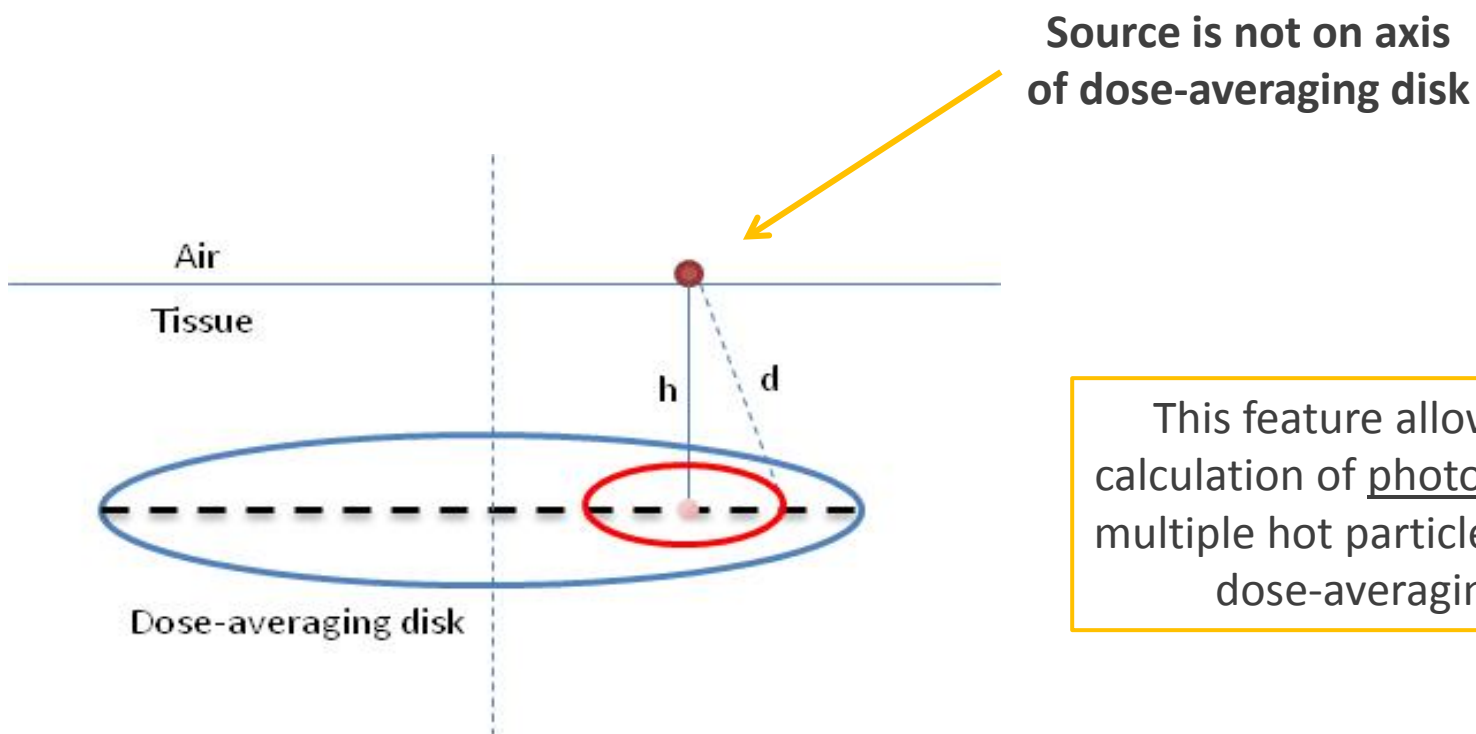
- Varskin 3 calculated dose at 60 locations around the dose-averaging disk
 - Method tends to weight the average such that it provides an over-estimation
- For VARSKIN 4, we assumed the following:
 - Point source is located directly above and on-axis with the averaging disk
 - Presumes symmetry in calculations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

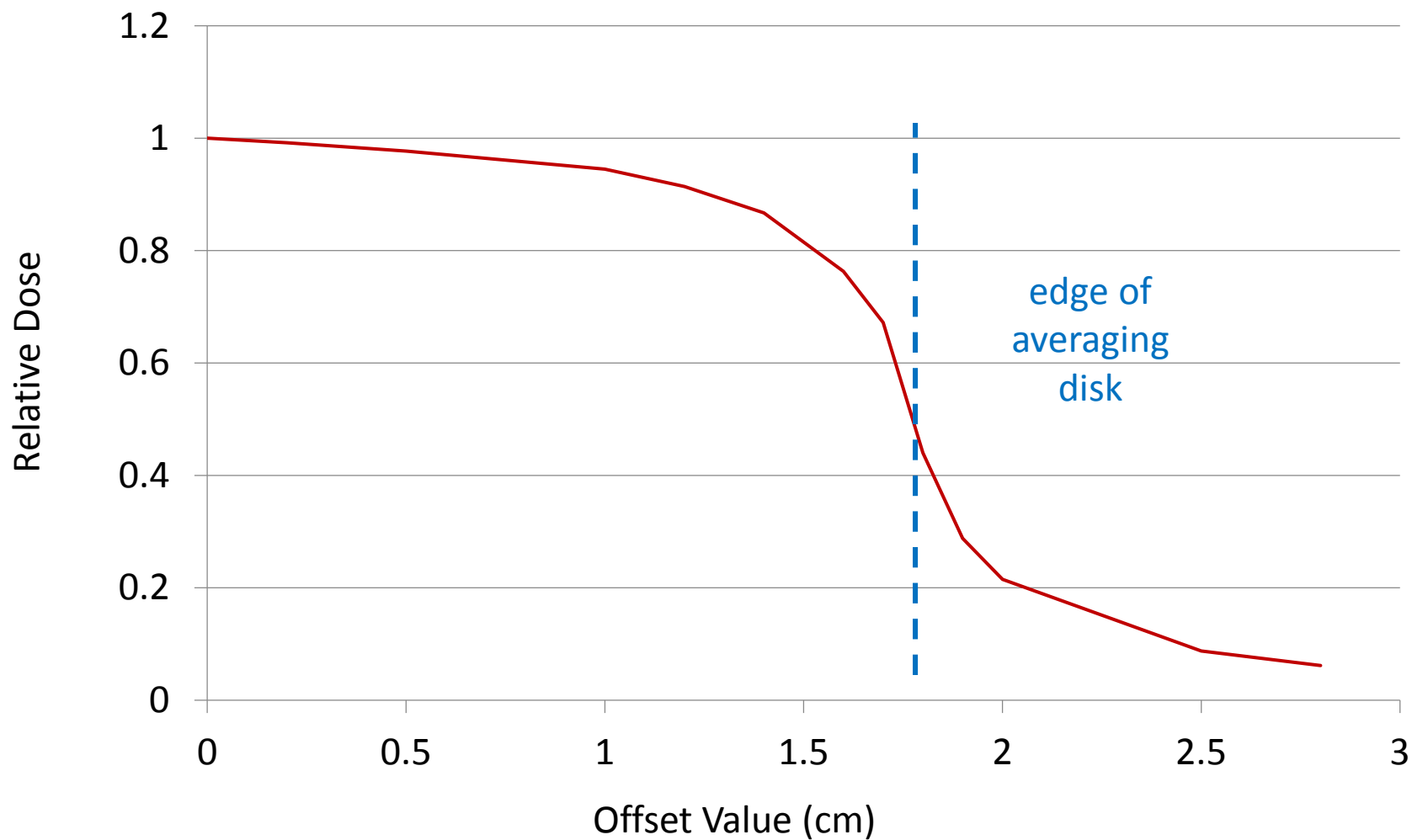
Offset-particle model



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

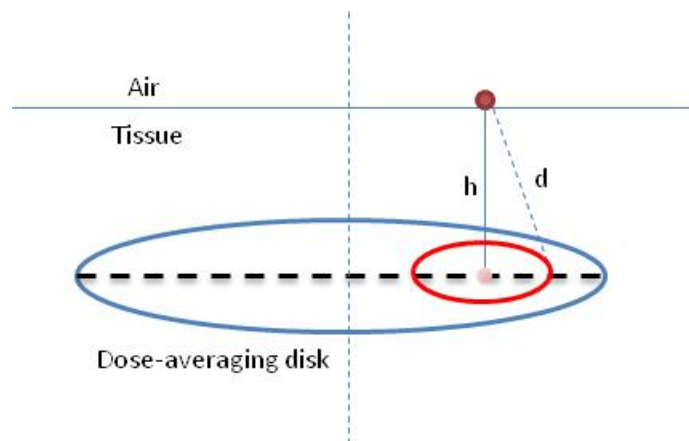
Offset Particle

^{60}Co ; point source; photon dosimetry only; 10 cm^2 ; 7 mg/cm^2



Dose Calculation for Offset Particles

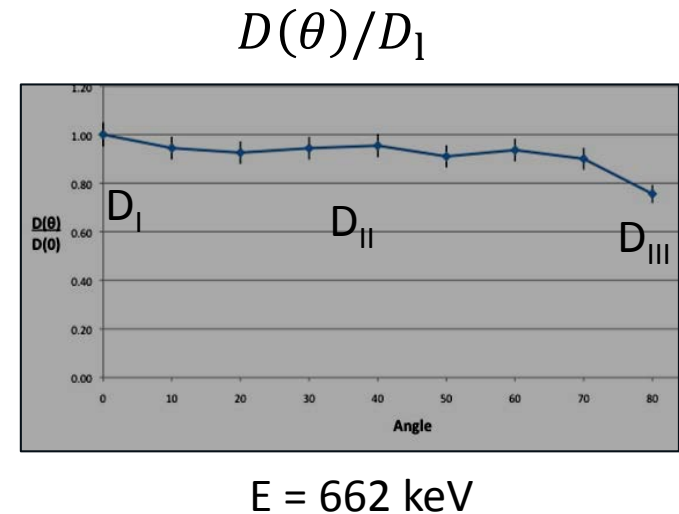
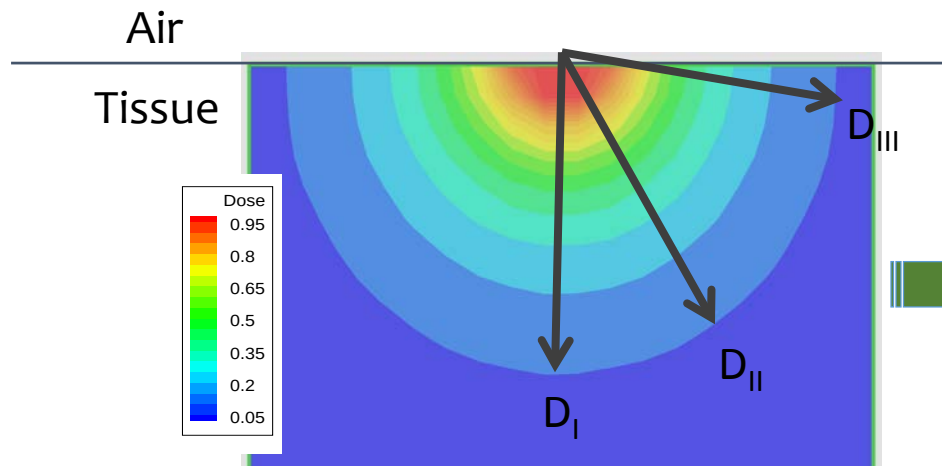
- Also, necessary for volumetric sources
 - essentially all of source volume will be offset
 - 15 x 15 x 15 source points
 - 300 dose points along the symmetric diameter
 - weighted by the fractional area of each annulus (red circle) that resides within the averaging disk



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

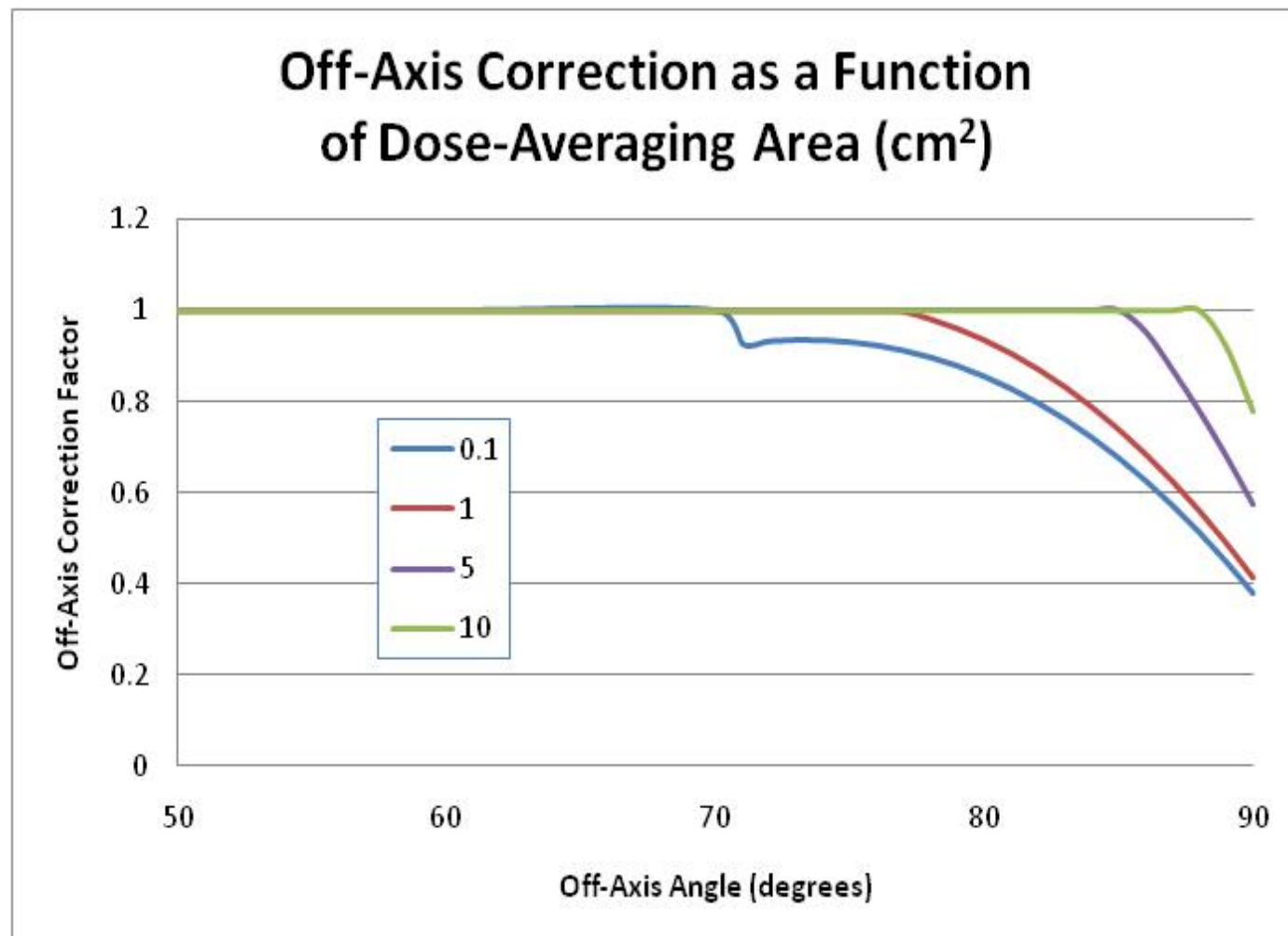
Off-Axis Correction

- CPE factors were determined at various depths 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

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

The diagram shows the equation for the dose rate $\dot{D}(d)$ as a function of distance d . The equation is presented within a green rectangular box. Various components of the equation are labeled with colored text and arrows pointing to their respective parts in the formula:

- Source Strength** (green text, green arrow) points to the variable S .
- Photon Energy** (red text, red arrow) points to the variable E_0 .
- Geometric Attenuation** (purple text, purple arrow) points to the term $4\pi d^2$.
- Material Attenuation** (red text, red arrow) points to the exponential term $e^{-\mu d}$.
- Energy Transfer Probability** (brown text, brown arrow) points to the term $\frac{\mu_{tr}}{\rho}$.
- Buildup Correction** (light blue text, light blue arrow) points to the function $f_{cpe}(d, E)$.
- Off-Axis Correction** (blue text, blue arrow) points to the function $F_{oa}(\theta, E)$.

$$\dot{D}(d) = \left[E_0 \cdot \frac{S}{4\pi d^2} e^{-\mu d} \cdot \frac{\mu_{tr}}{\rho} \right] \cdot f_{cpe}(d, E) \cdot F_{oa}(\theta, E)$$

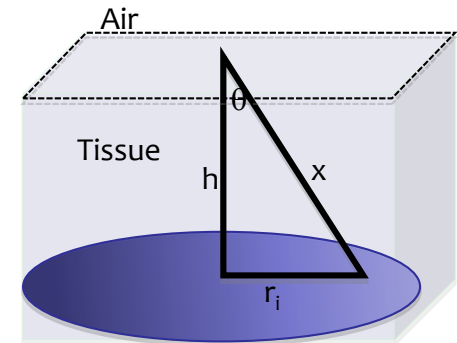
SUMMARIZING the Model

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 4 Dose Model

- Therefore, accounting for charged-particle buildup; material and geometric attenuation; and off-axis scatter
- Calculation of dose over the averaging area requires a numerical approach since the integration of the exponential results in imaginary components
 - at depth h ; averaging radius R ; unit conv k ; j^{th} integration step; and i^{th} radiation emitted

$$\dot{D}(h, R) \left[\frac{\text{Gy}}{\text{nt}} \right] = \frac{k}{4\pi} \sum_{j=1}^N \frac{W_j}{d_j^2} \left[\sum_i \left[y_i E_i \left(\frac{\mu_{tr}}{\rho} \right)_i (f_{cpe})_{i,j} (F_{oa})_{i,j} e^{-\mu_i d_j} \right] \right]$$

Summarizing Photon Dosimetry Enhancements

- Point-kernel model
- Multiple geometry options
- More User parameter specification
- Accounting for buildup of charged-particle equilibrium
- Full consideration of photon attenuation
 - no longer are there photon-energy issues
- Off-axis energy-loss estimation
- Cover attenuation
- Numerical integration scheme with greatest convergence

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Radionuclide Library

Cs-137 [7.42]

Activity Units
 μCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2
Air Gap Thickness: 0 mm
Cover Thickness: 0 mm
Cover Density: 0 g/cm^3

Multiple Cover Calculator

Skin Averaging Area
10 cm^2

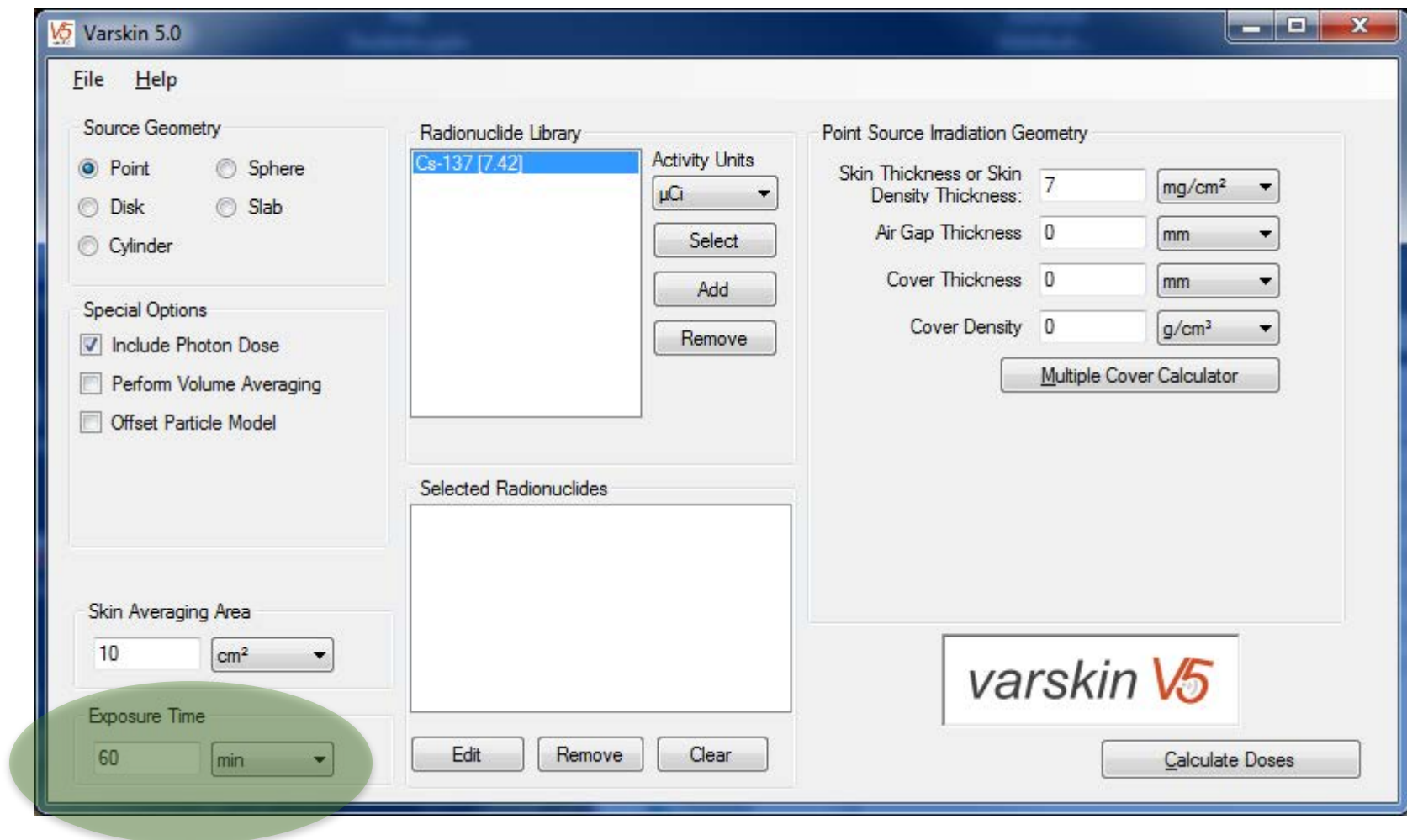
Exposure Time
60 min

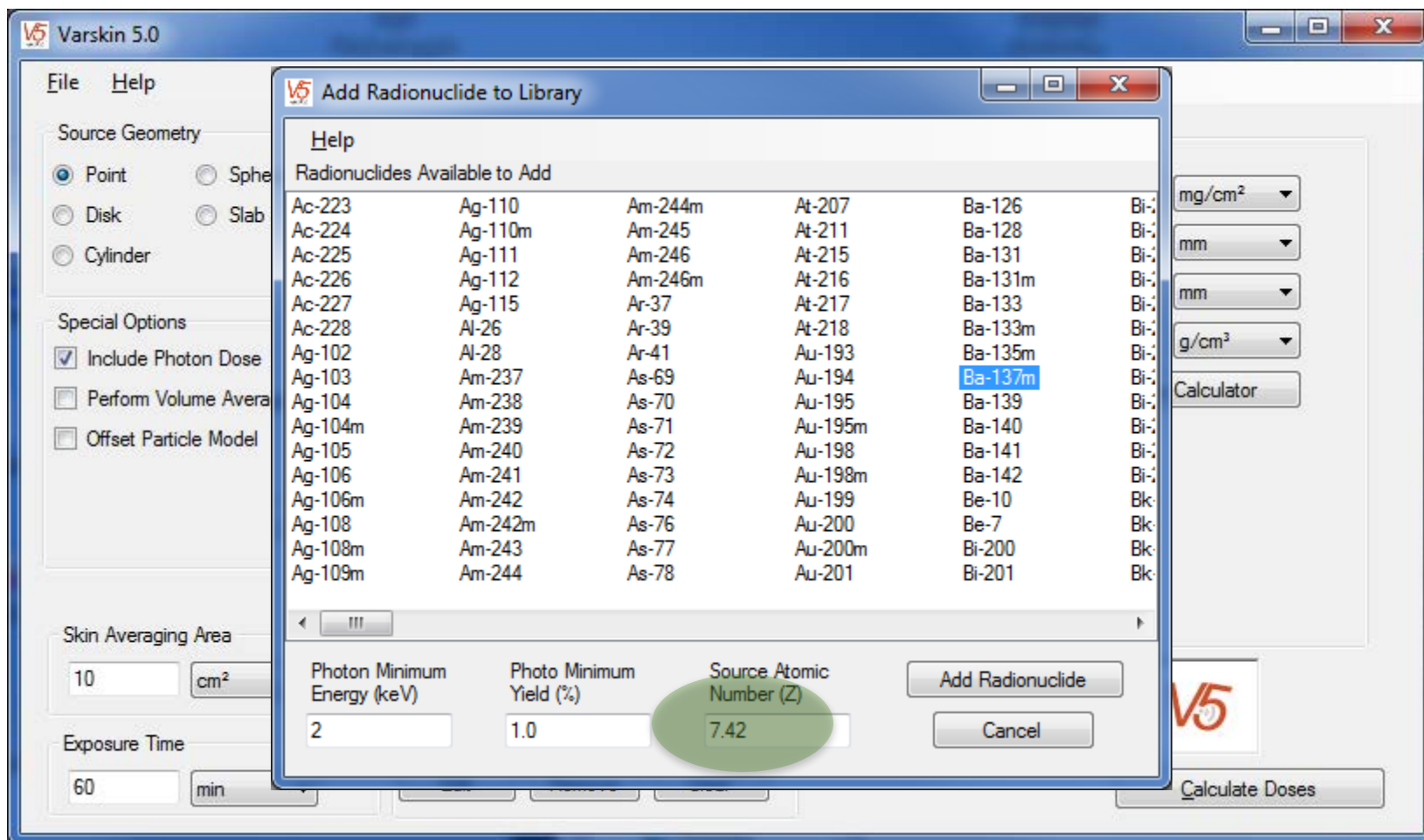
Selected Radionuclides

Edit Remove Clear

varskin V5

Calculate Doses

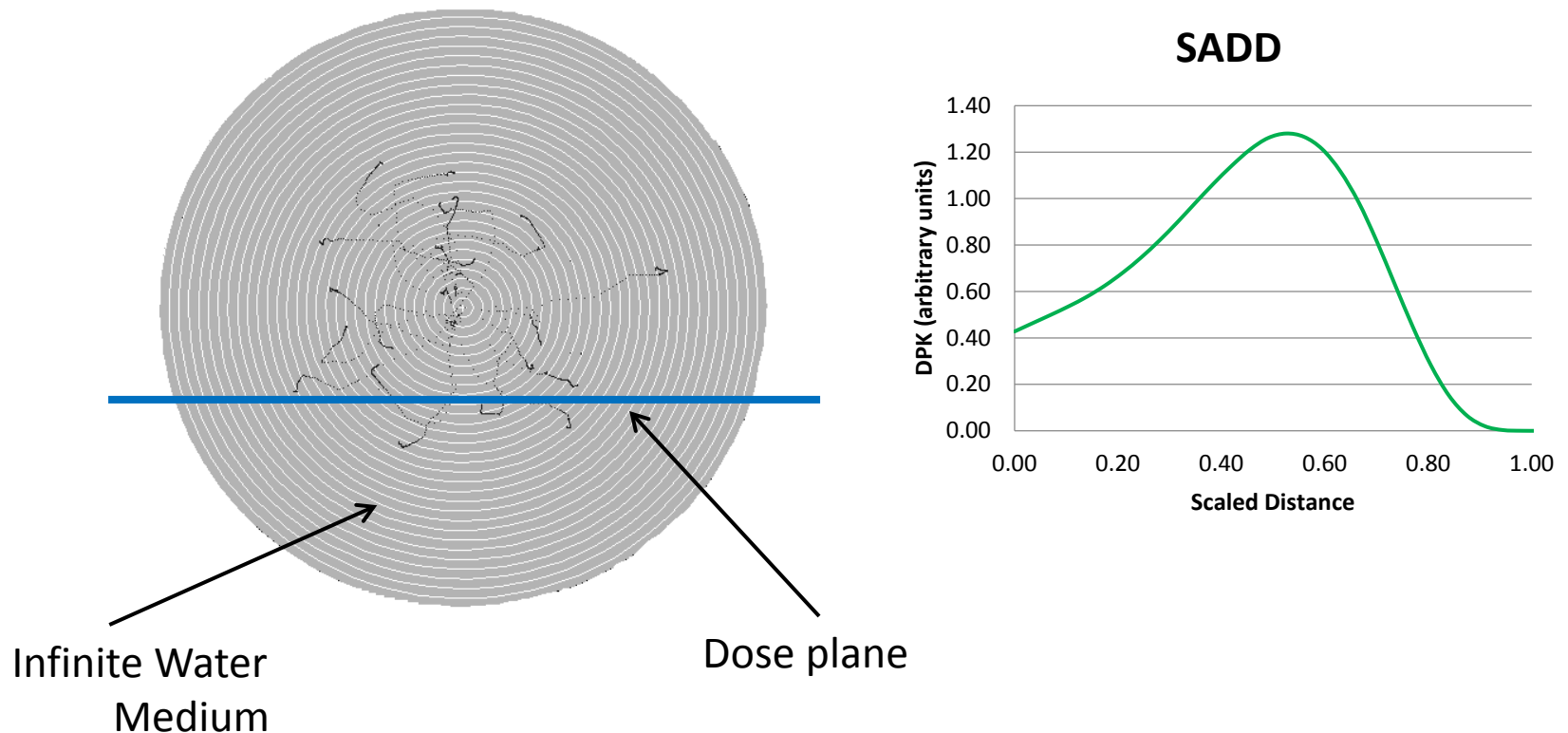




Why do I need the source atomic number?

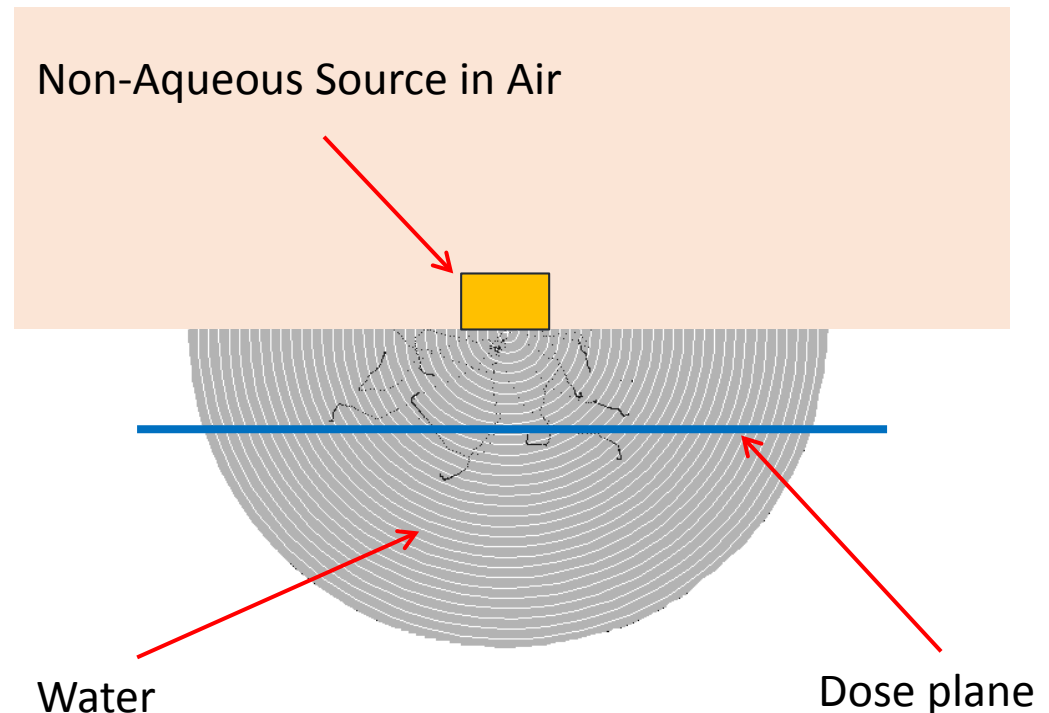
Corrections to Dose-Point Kernel

- 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

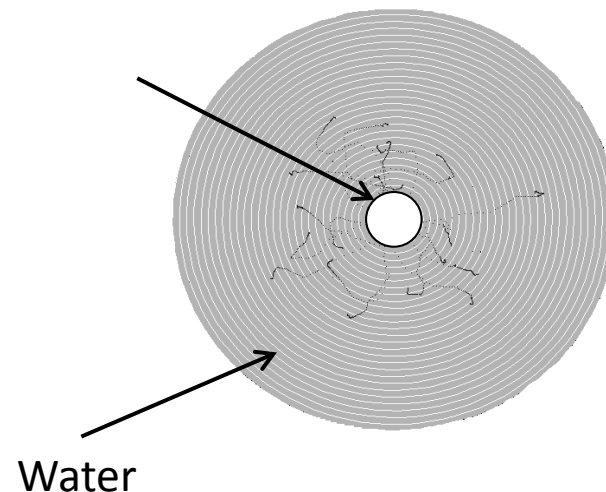


the handling of
kinetic energy loss (SADD)

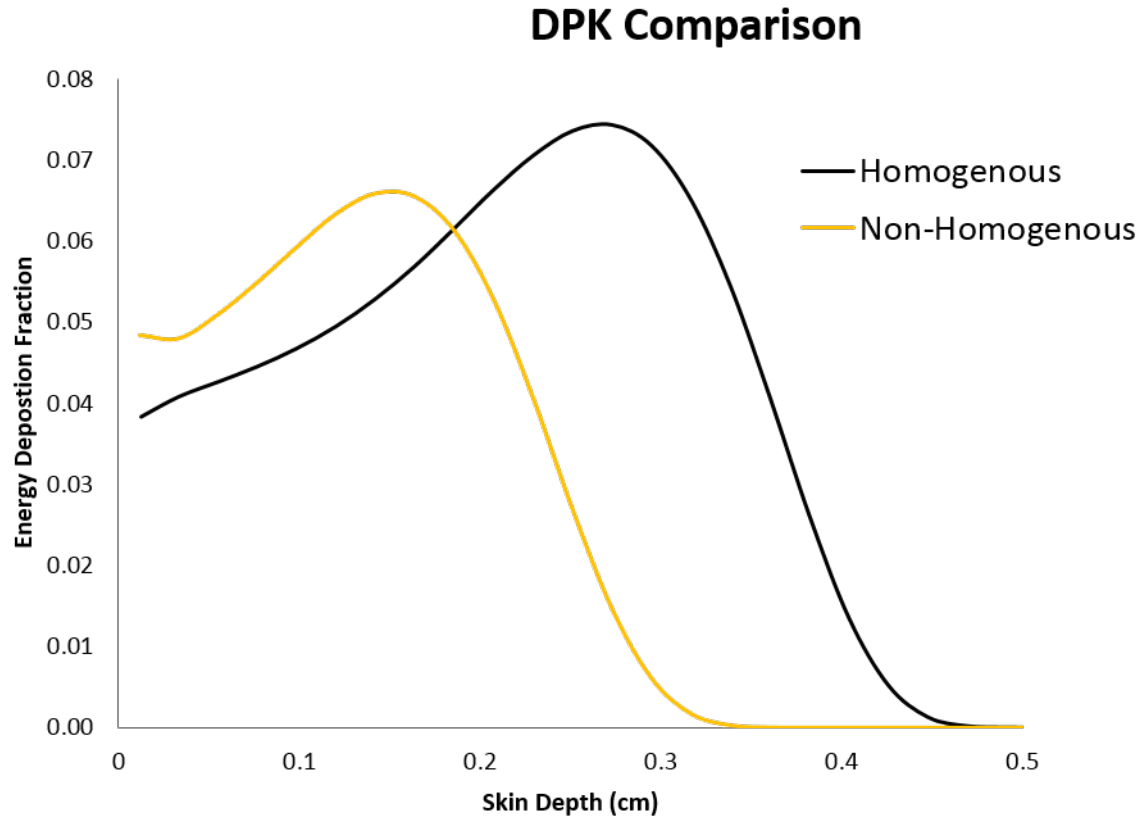
Methods: Scaling Model

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

Absorption Sphere

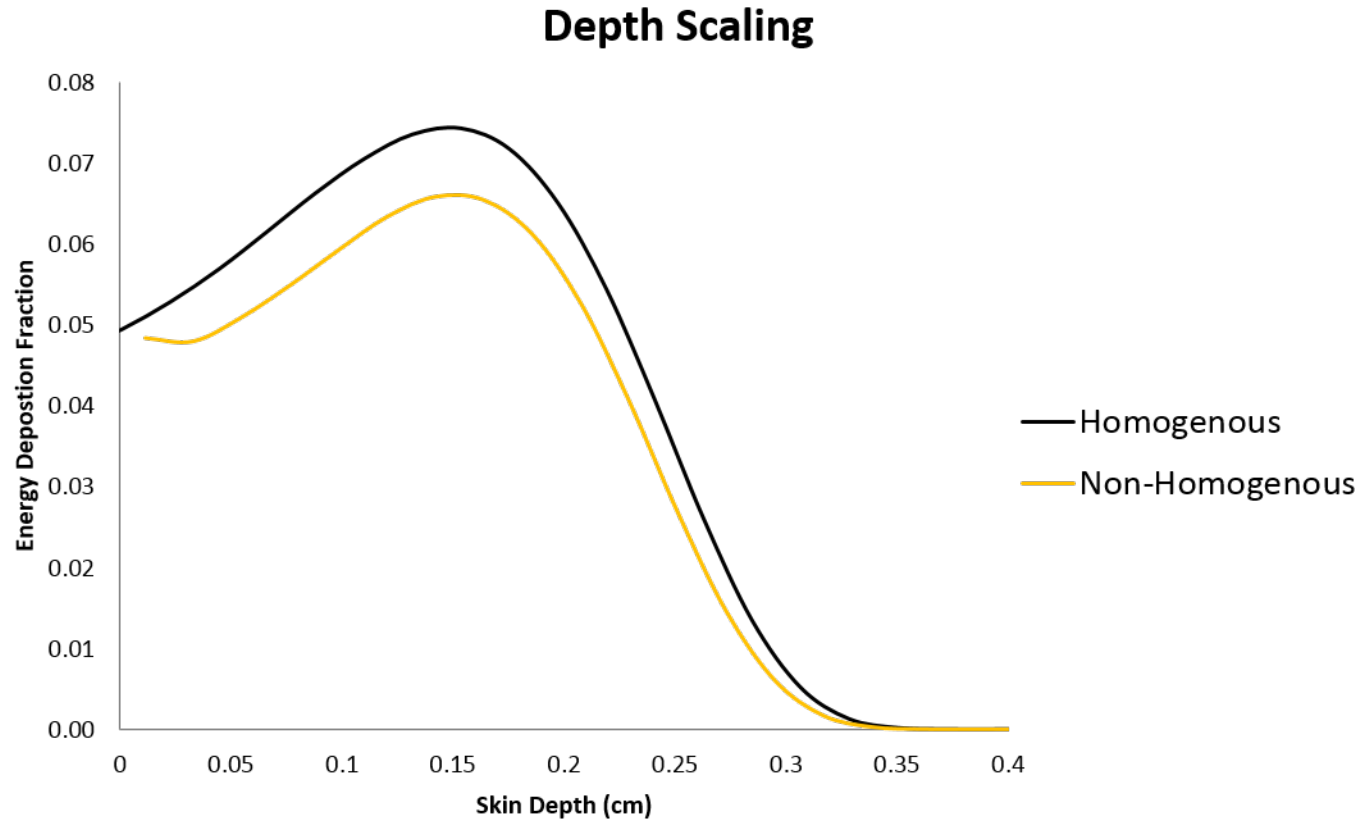


Scaling Model



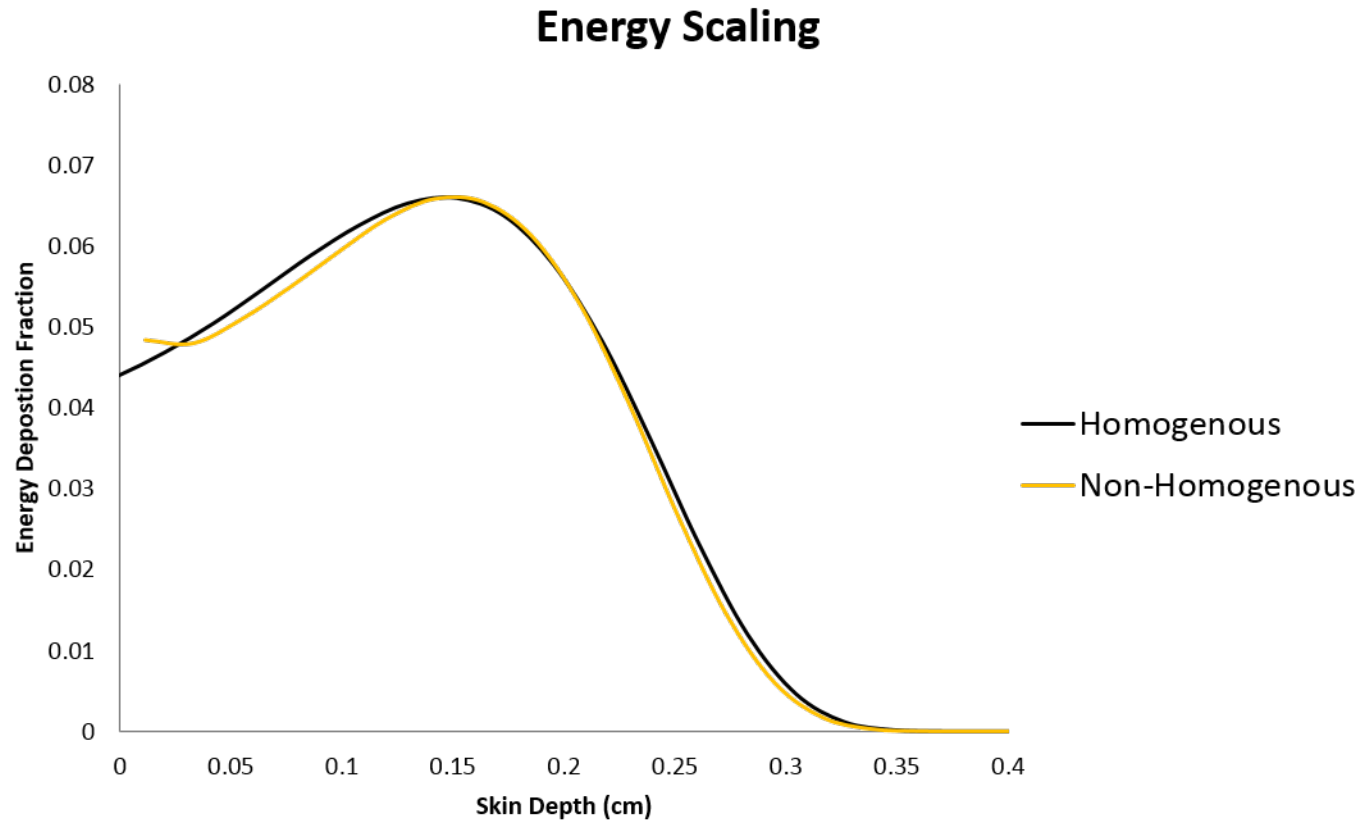
- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

Scaling Model



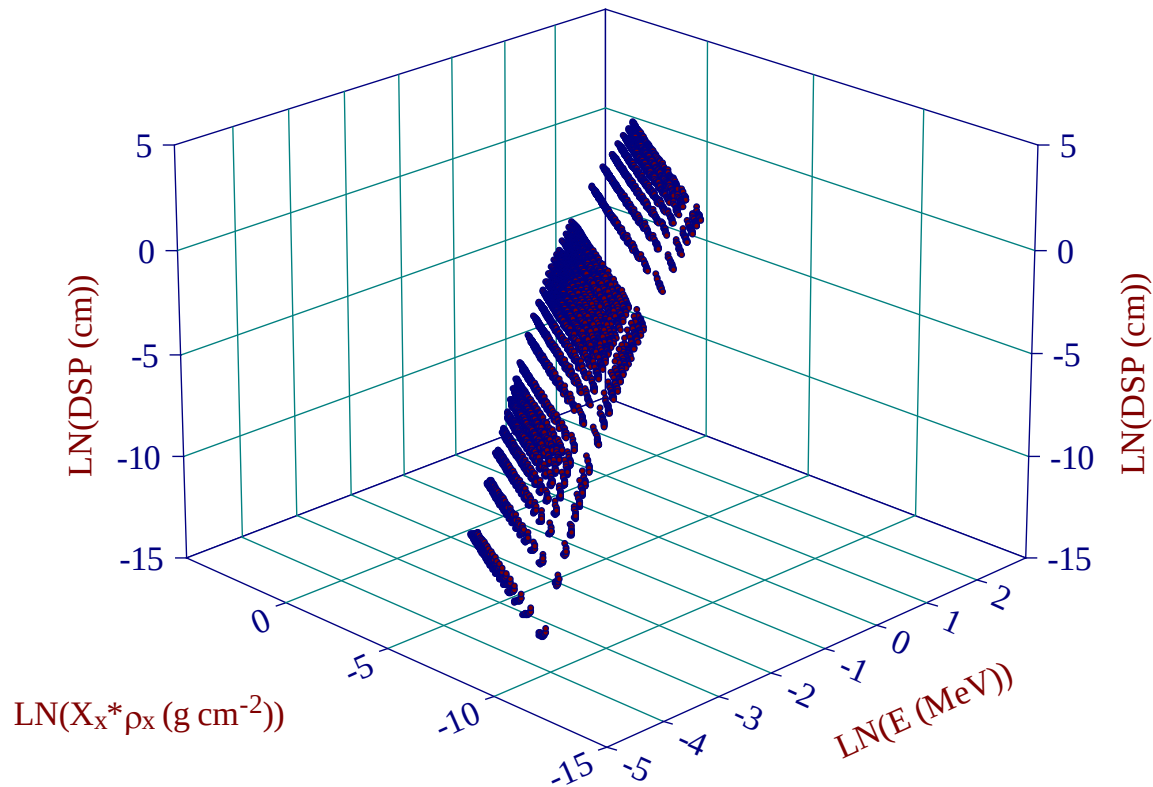
- 1 MeV electron DPK's for the case of a homogenous medium (water) and the case of a non-homogeneous medium (for example, air over the skin with a source material of iron)

Scaling Model



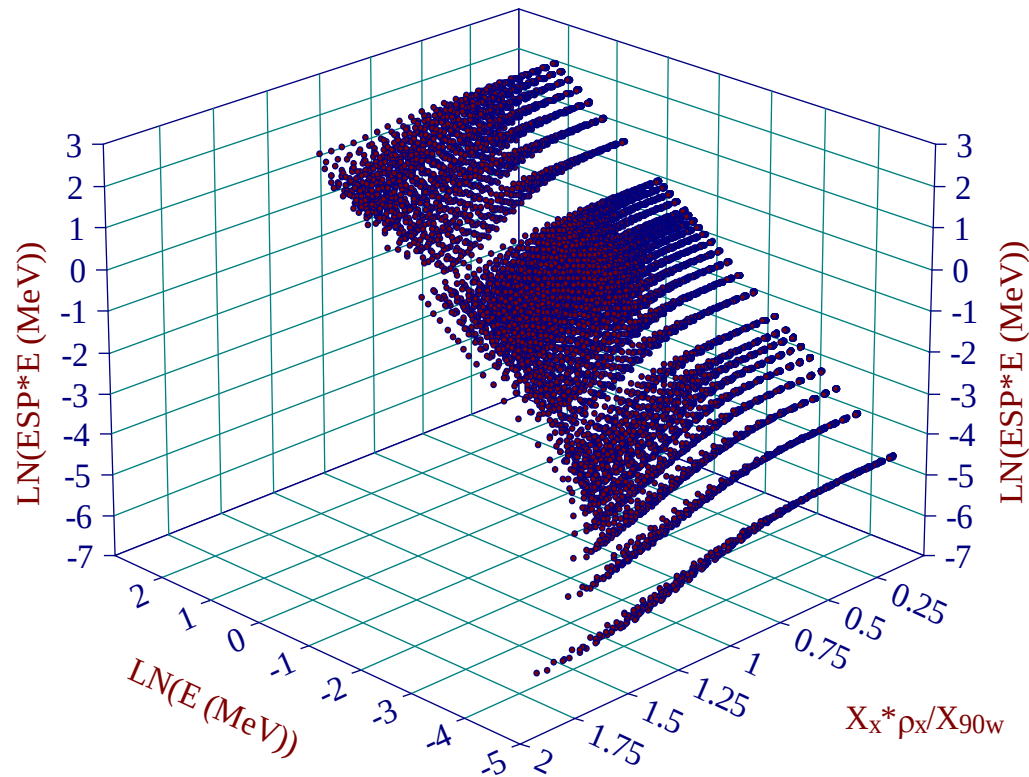
Scaling Results

Depth Scaling for All Materials



Scaling Results

Energy Scaling for All Materials



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 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Ba-137m [7.42]

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

Source Strength

Enter the Source Strength for Cs-137 [7.42] in μCi

1

OK

Cancel

Edit Remove Clear

varskin V5

Calculate Doses

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Radionuclide Library

Cs-137 [7.42]
Ba-137m [7.42]

Activity Units
 μCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2
Air Gap Thickness: 0 mm
Cover Thickness: 0 mm
Cover Density: 0 g/cm^3

Multiple Cover Calculator

Skin Averaging Area
10 cm^2

Exposure Time
60 min

Selected Radionuclides

Cs-137 [7.42]: 1.00E+00 μCi
Ba-137m [7.42]: 1.00E+00 μCi

Edit Remove Clear

varskin V5

Calculate Doses

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☒ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]
Ba-137m [7.42]

Activity Units
 $\mu\text{Ci}/\text{cm}^2$

Select
Add
Remove

☒ Use Distributed Source

Selected Radionuclides

Cs-137 [7.42]: $1.00\text{E}+00 \mu\text{Ci}/\text{cm}^2$
Ba-137m [7.42]: $1.00\text{E}+00 \mu\text{Ci}/\text{cm}^2$

Edit Remove Clear

Disk Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2
Air Gap Thickness 0 mm
Cover Thickness 0 mm
Cover Density 0 g/cm^3
Multiple Cover Calculator
Source Area 0.785 mm^2
Source Diameter 1 mm

varskin V5

Calculate Doses

Skin Averaging Area

10 cm^2

Exposure Time

60 min

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 ($\mu\text{Ci}/\text{cm}^2$) or volume ($\mu\text{Ci}/\text{cm}^3$)
 - user must remove and re-select radionuclide(s)

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Ba-137m [7.42]

Activity Units
μCi

Select
Add
Remove

Selected Radionuclides

Cs-137 [7.42]: 1.00E+00 μCi
Ba-137m [7.42]: 1.00E+00 μCi

Edit Remove Clear

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 V5

Calculate Doses

Multiple Cover Calculator

- For each cover material, user enters two 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:

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

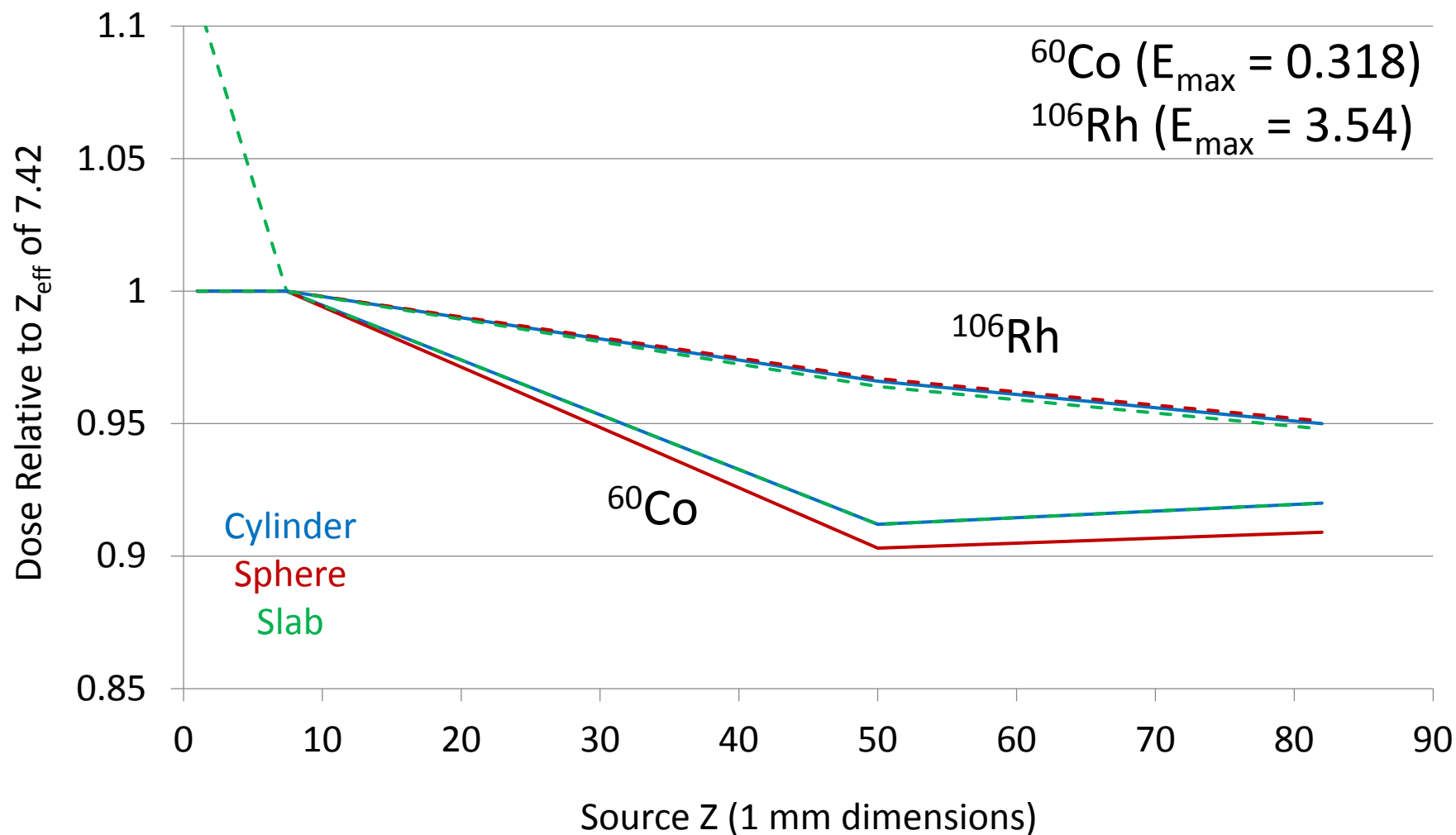
 Multiple Cover Calculator

Help

	Density	Thickness	Density Thickness
Cover 1	1.5 g/cm ³	0.02 cm	3.00E+01 mg/cm ²
Cover 2	4 g/cm ³	0.005 cm	2.00E+01 mg/cm ²
Cover 3	g/cm ³	mm	mg/cm ²
Cover 4	g/cm ³	mm	mg/cm ²
Cover 5	g/cm ³	mm	mg/cm ²
Total	2.00E+00 g/cm ³	2.50E-02 cm	5.00E-02 g/cm ²

Cancel Calculate

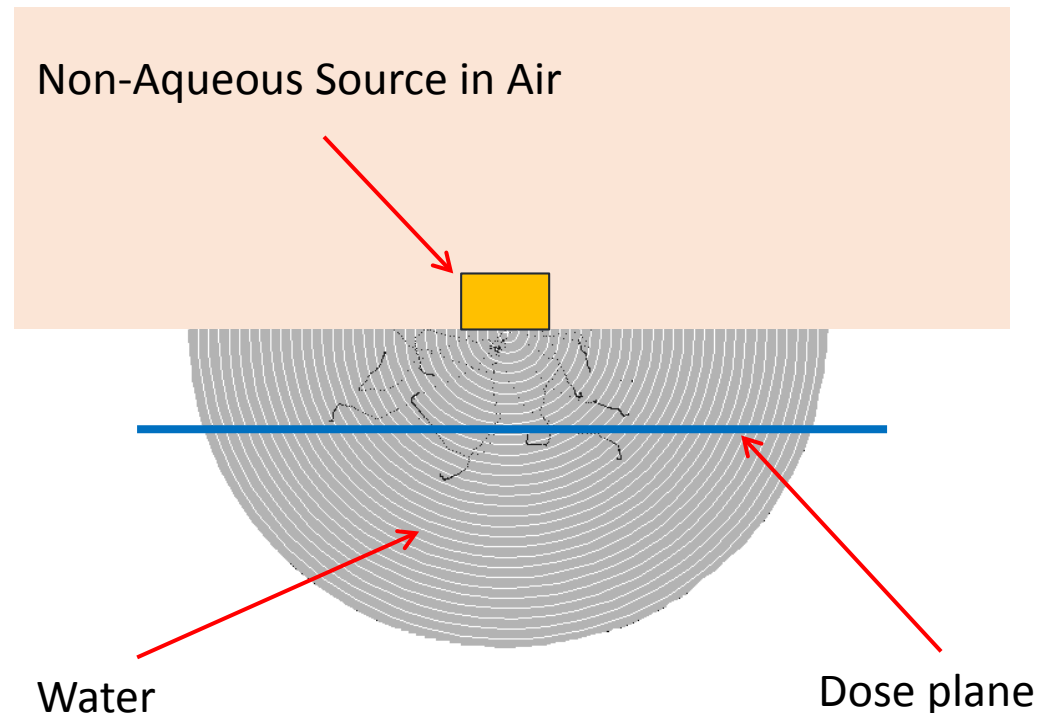
Volumetric Beta Dose vs Source Z



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

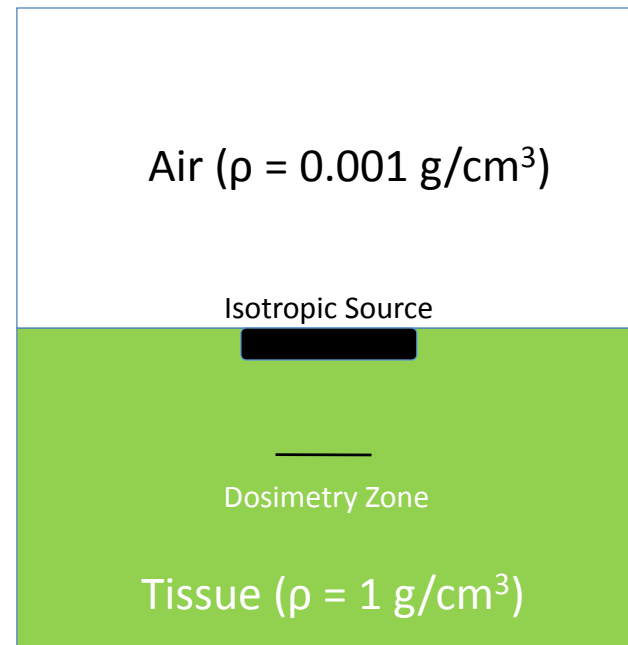
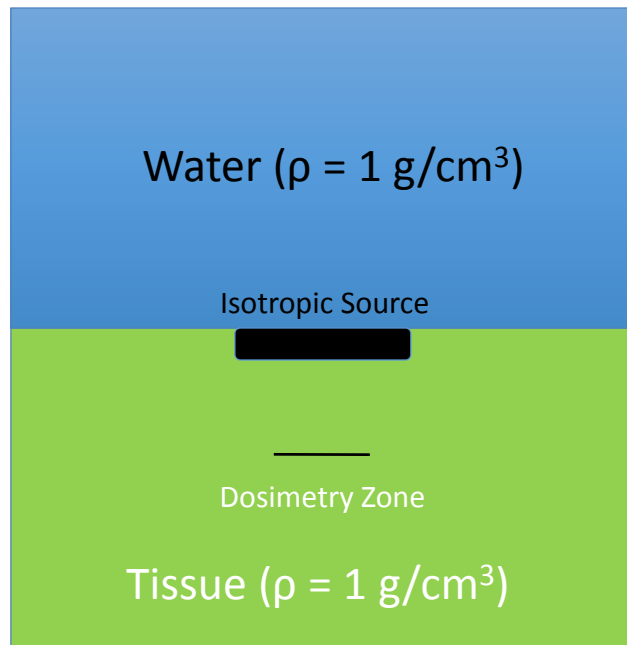


backscatter correction

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

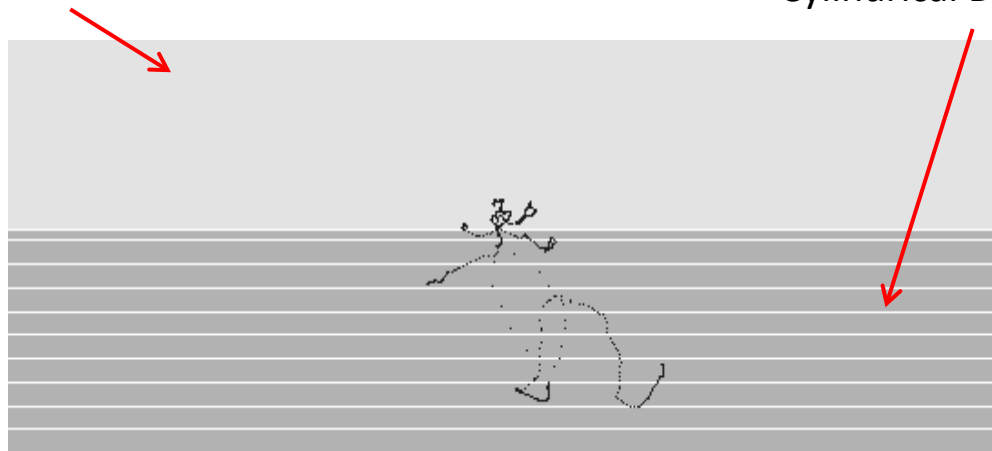


New Backscatter Model

- 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})

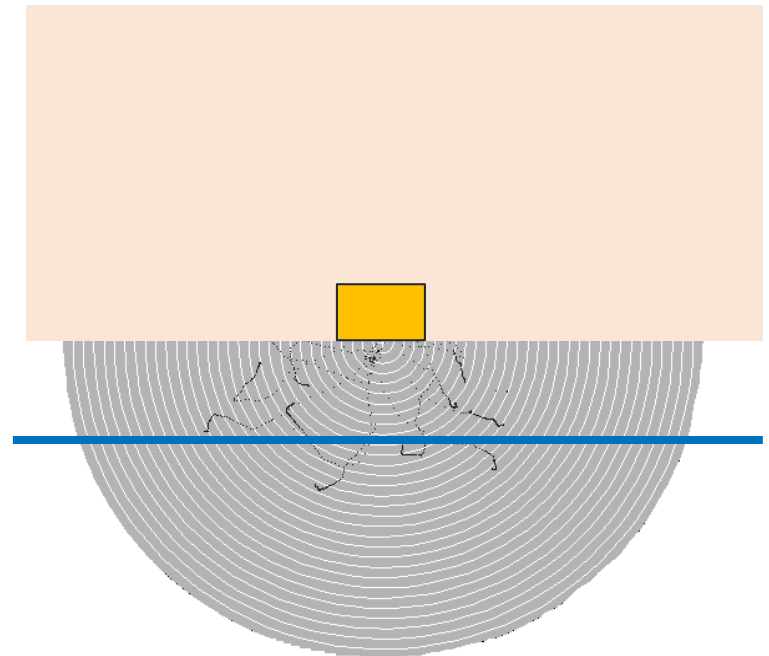
Scattering Medium (“infinite” thickness)

Cylindrical Dose Planes

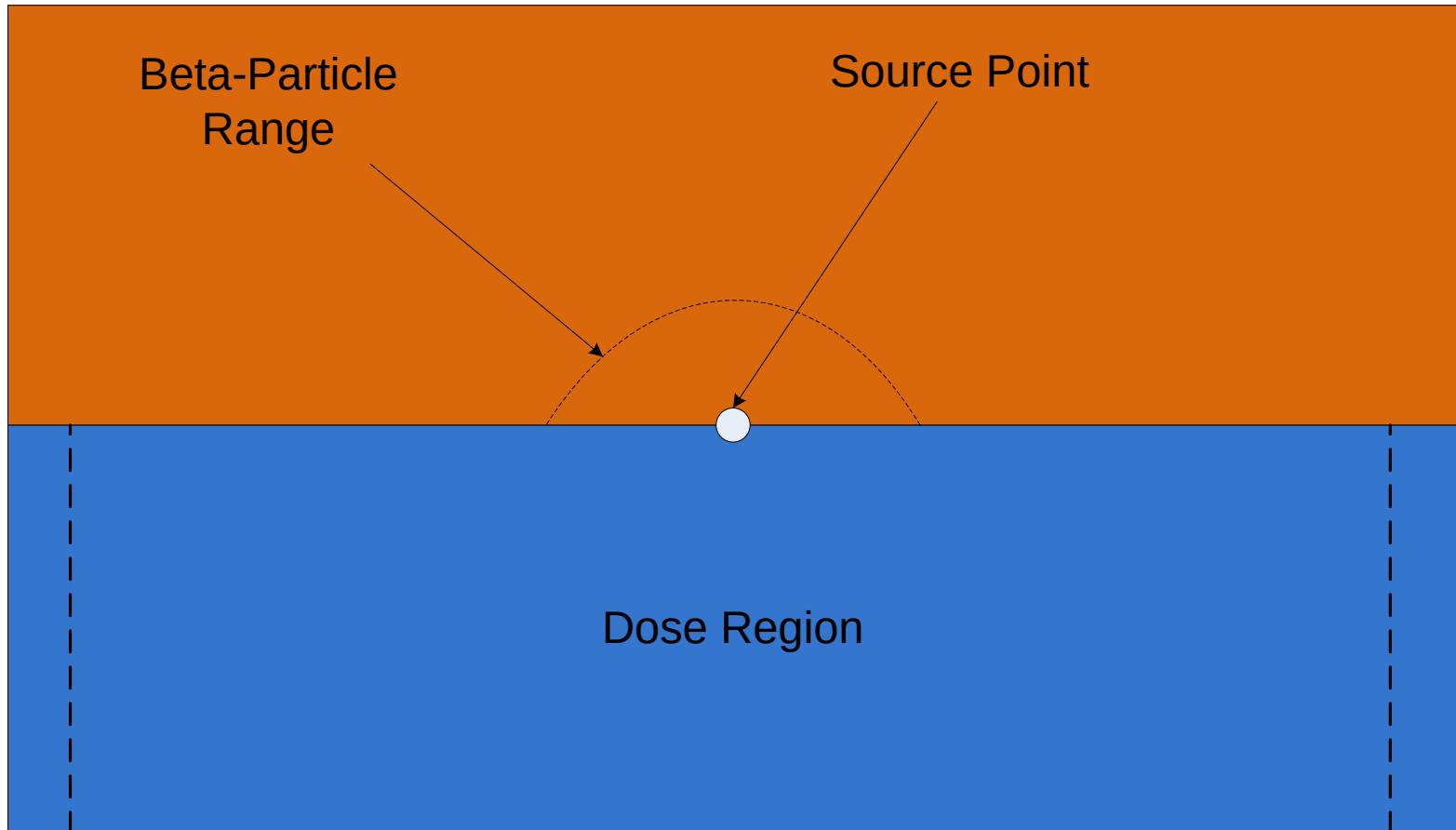


Scatter Scenarios

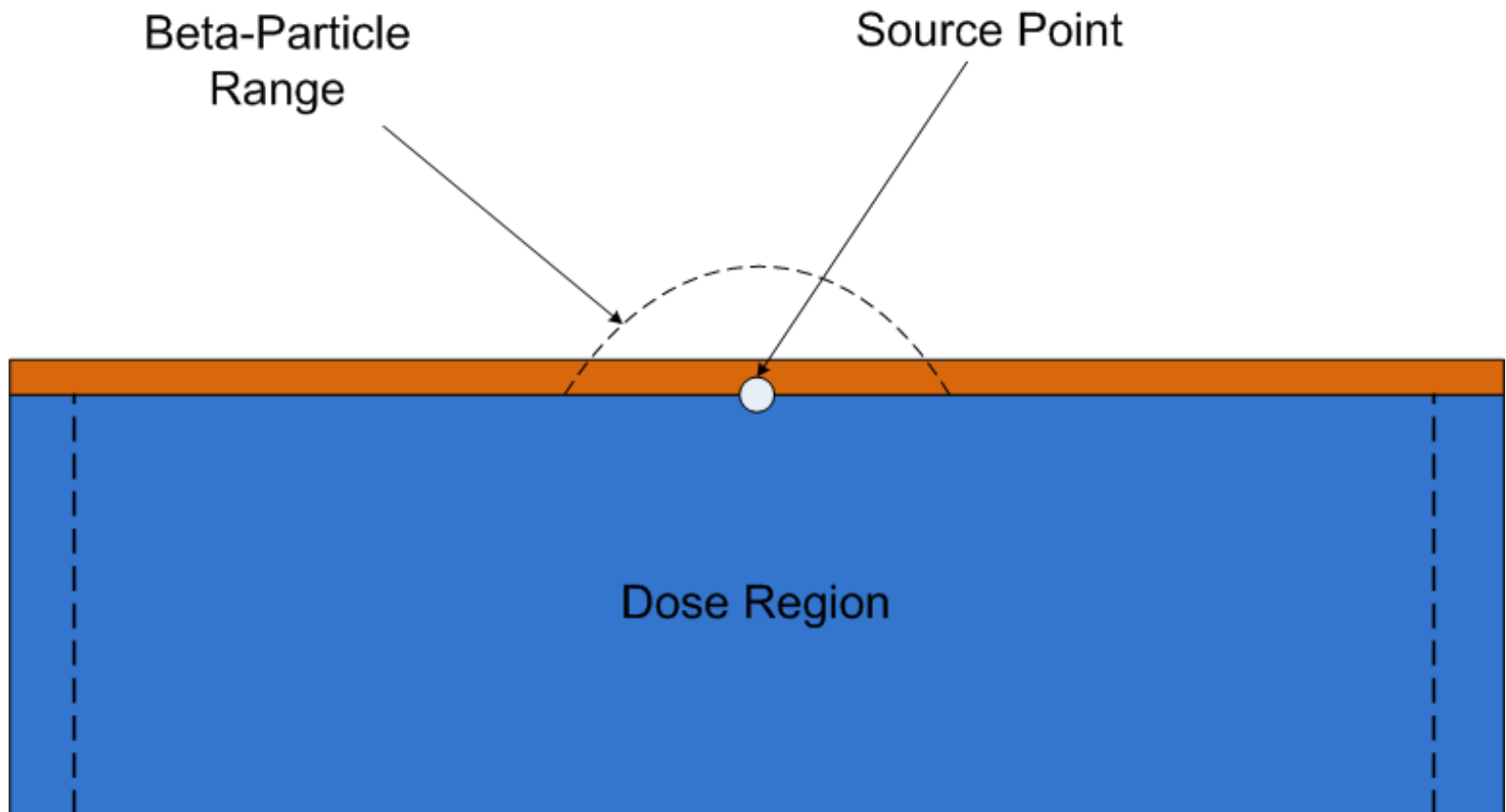
- Source scatter for top/bottom of source
- Source scatter for sides of source
- Air scatter for top/sides of source



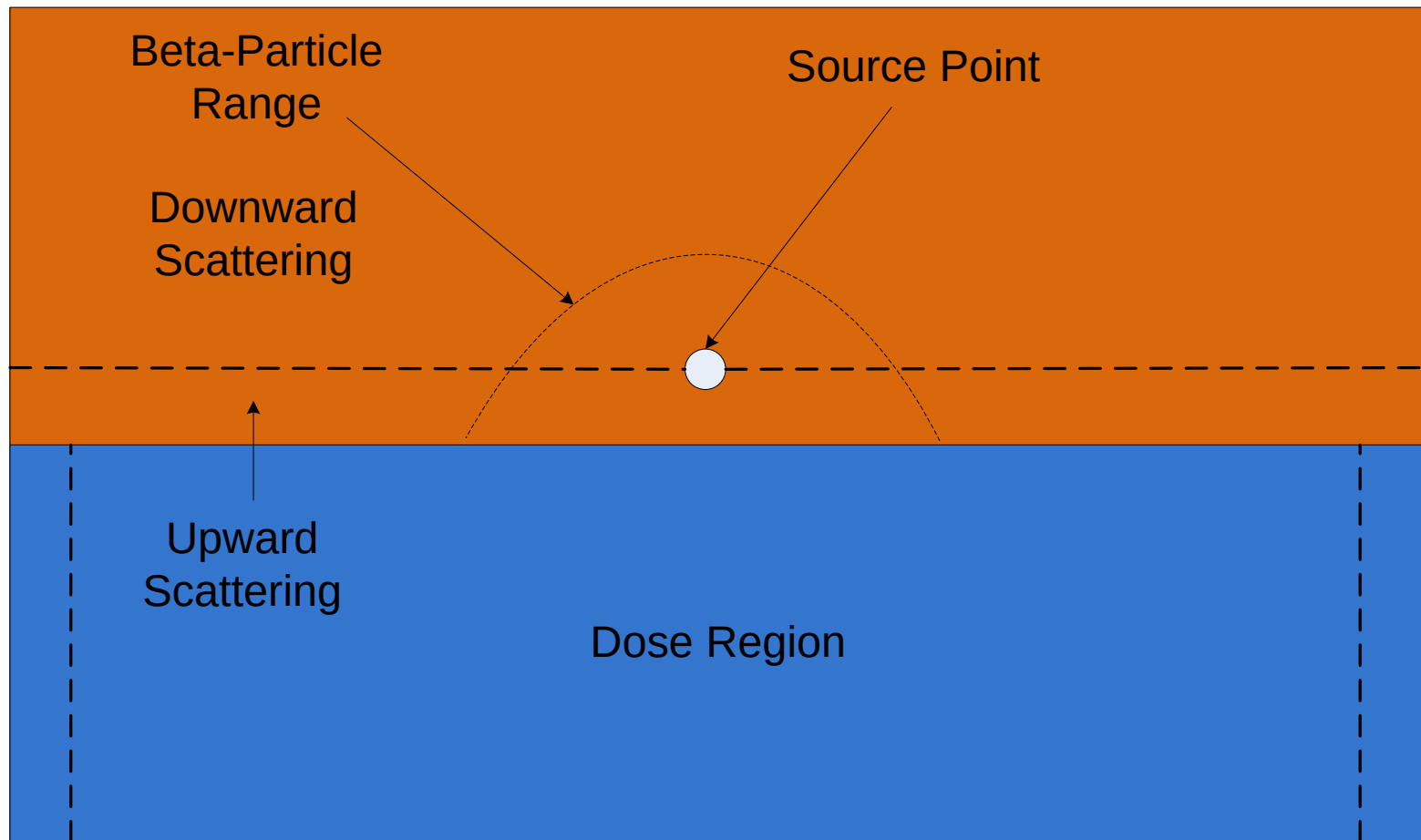
Scatter for Top/Bottom of Source



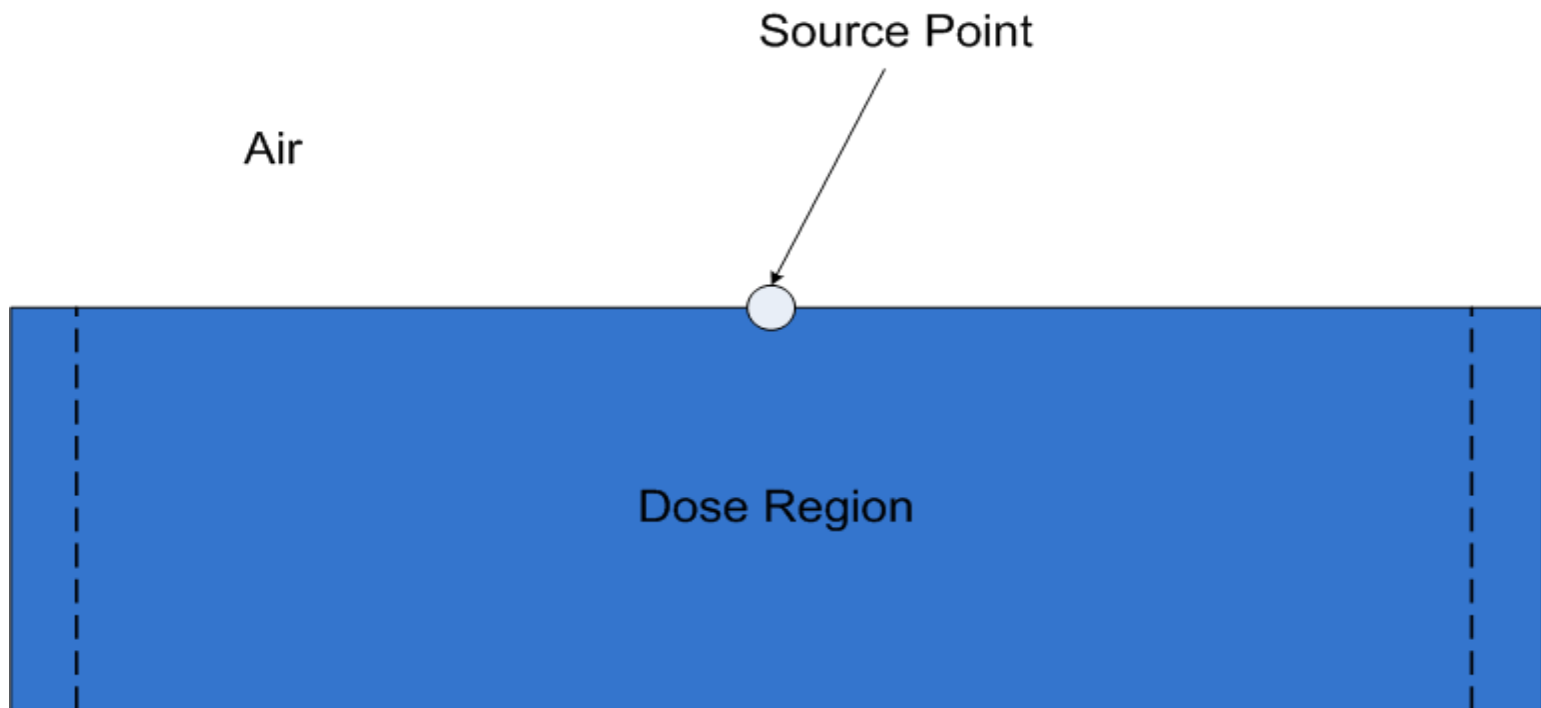
Scatter for Top/Bottom of Source



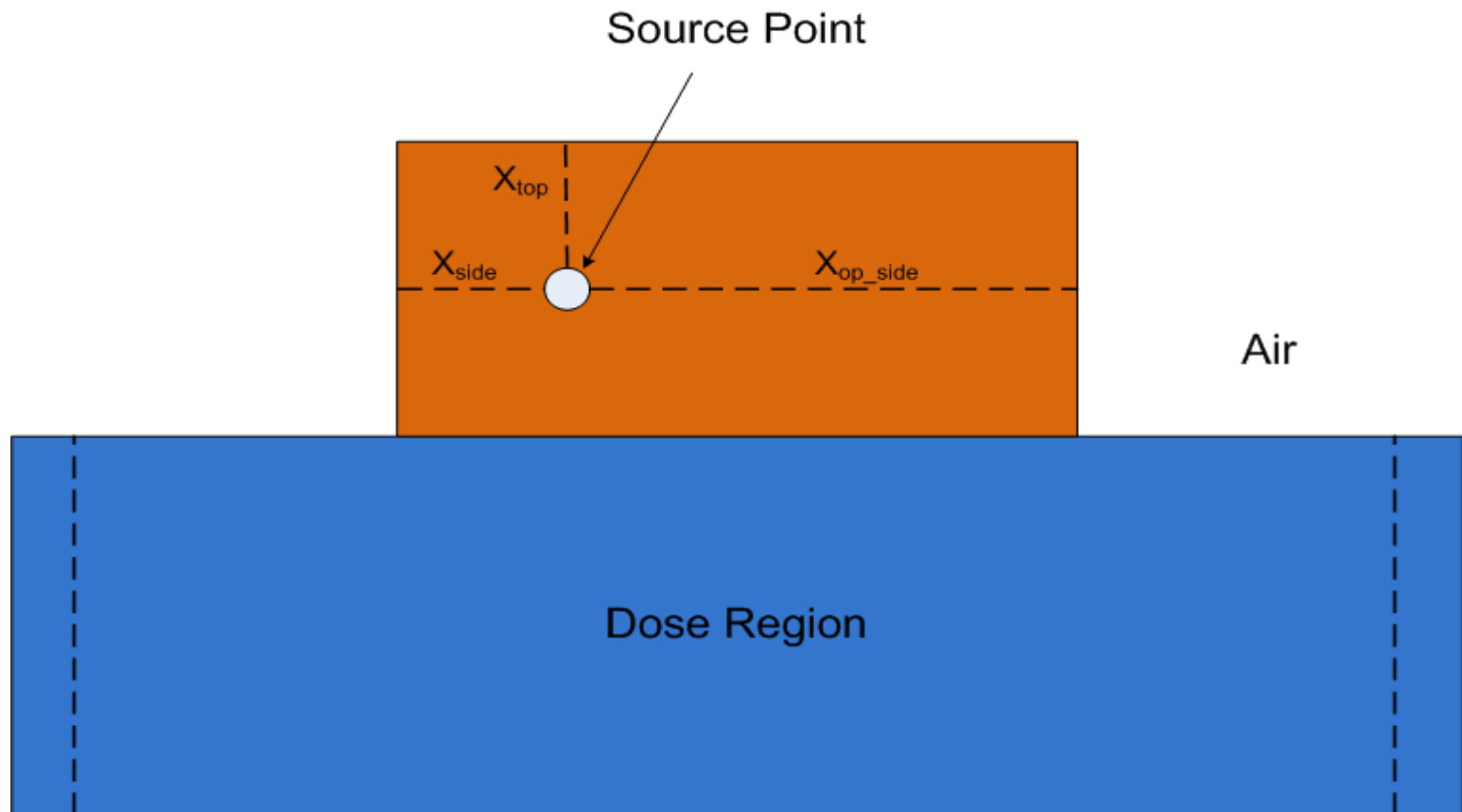
Scatter for Top/Bottom of Source



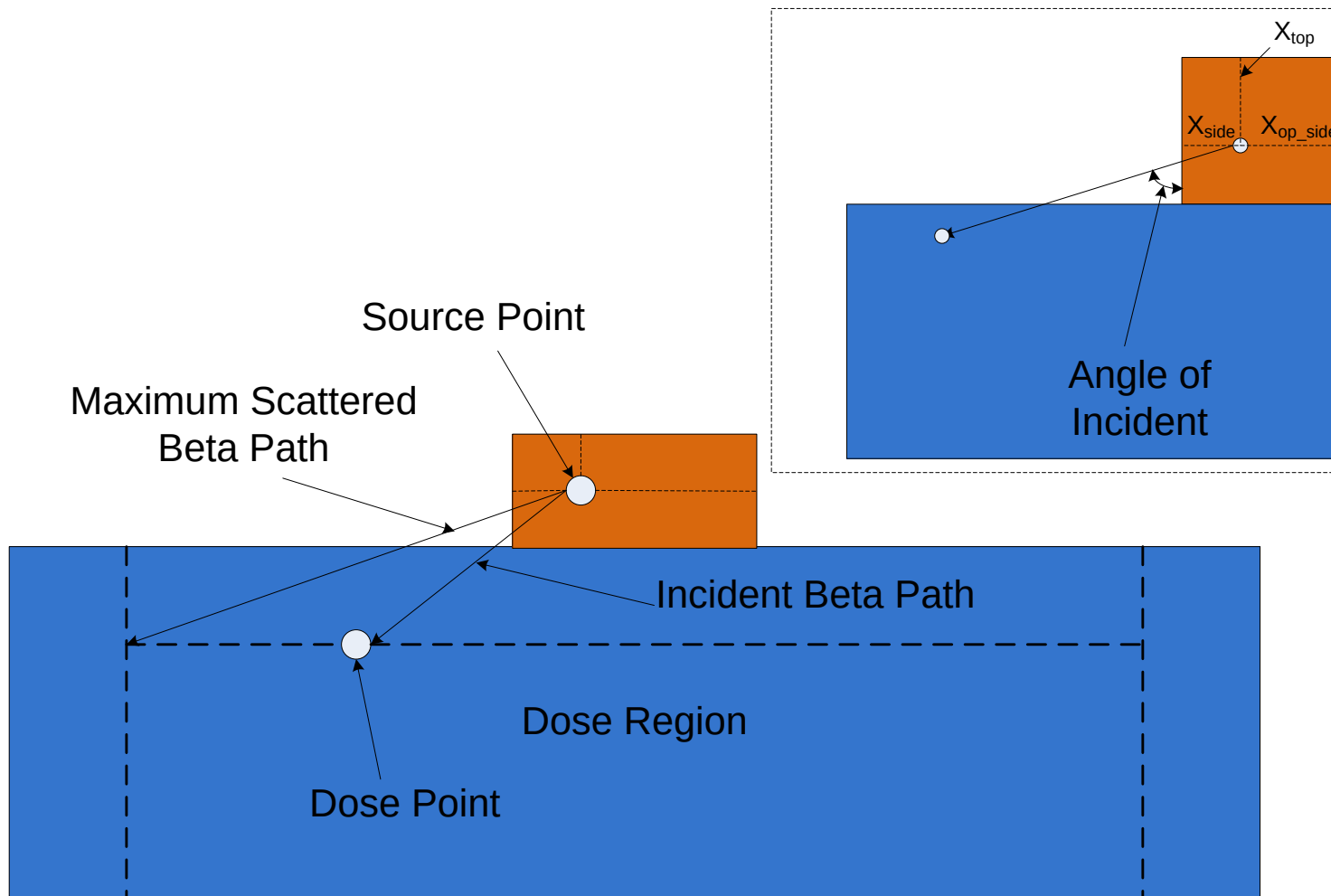
Air Scatter for Top/Sides of Source



Air Scatter for Top/Sides of Source



Scatter for Sides of Source



Selective Integration

- Source Scatter for Top/Bottom of Source

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

- Source Scatter for Sides of Source

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

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

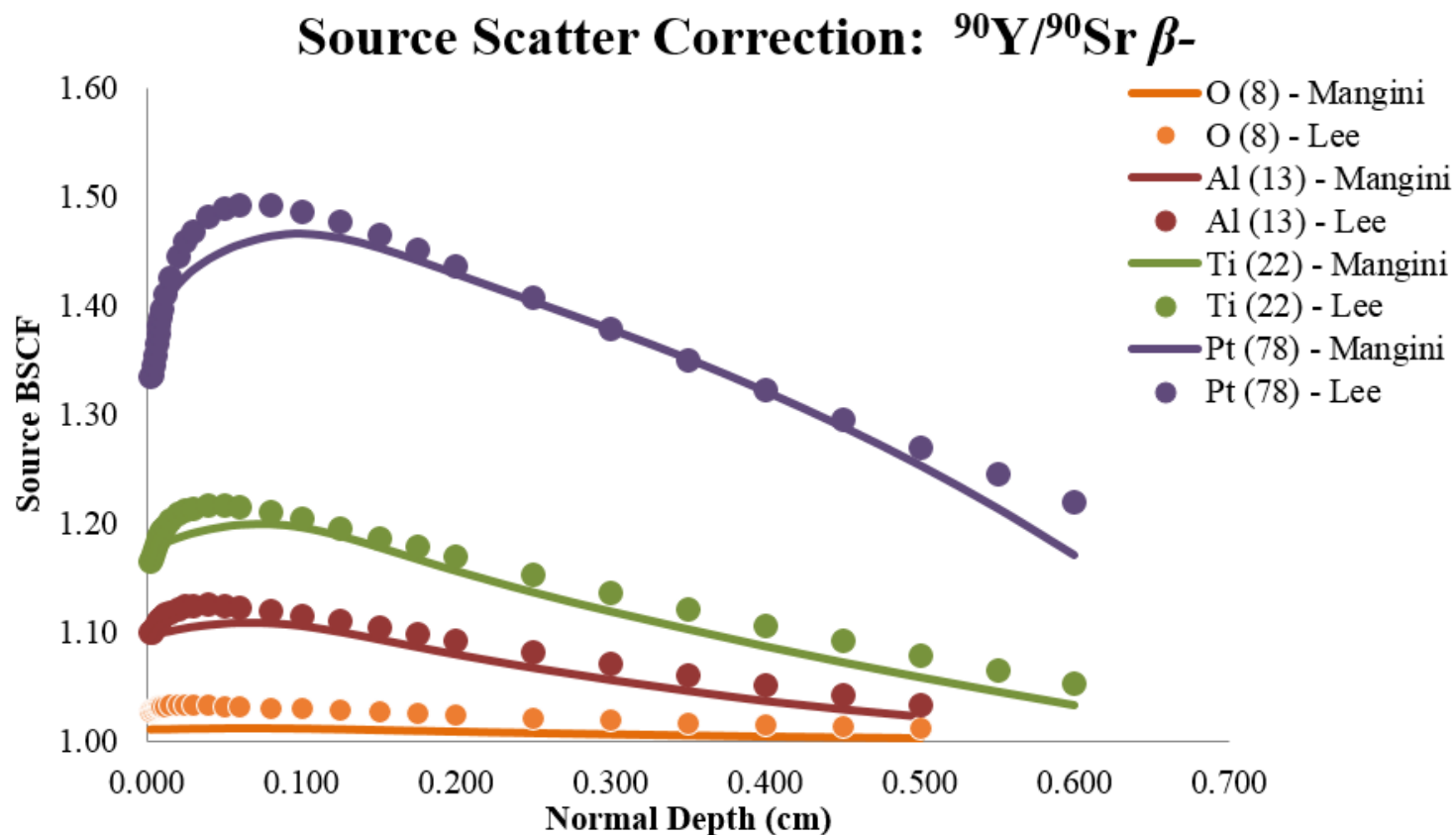
- Air Scatter for Top/Sides of Source

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

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

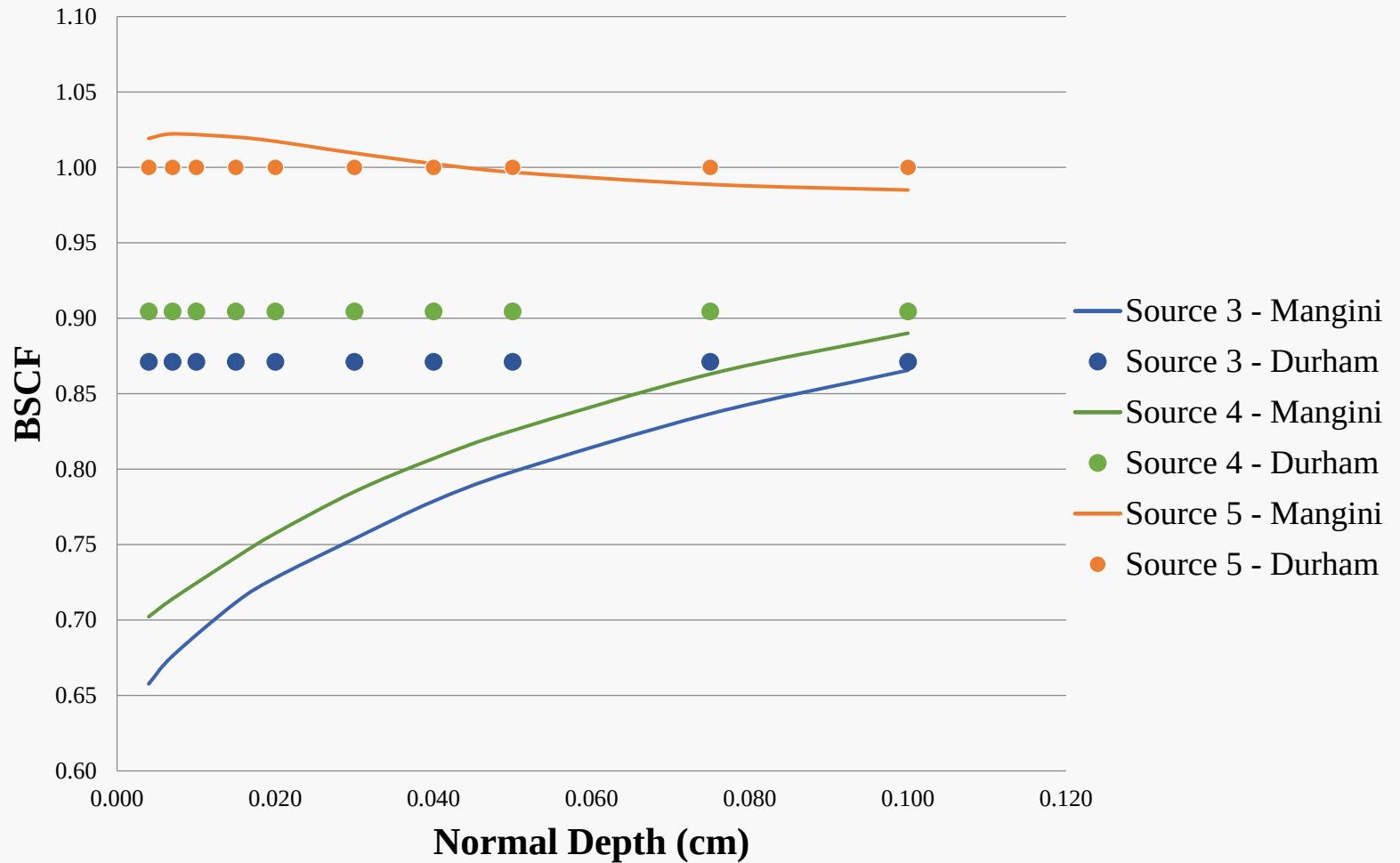
$$Air\ BSCF_{op\_side} = AW \frac{1.8 - X_{op\_side}}{1.8} 0.25$$

Point-Source BSCF



Volumetric BSCF

BSCF's for Uranium Oxide Slabs: ^{32}P β -



One other important improvement...

Electron Energy Distribution

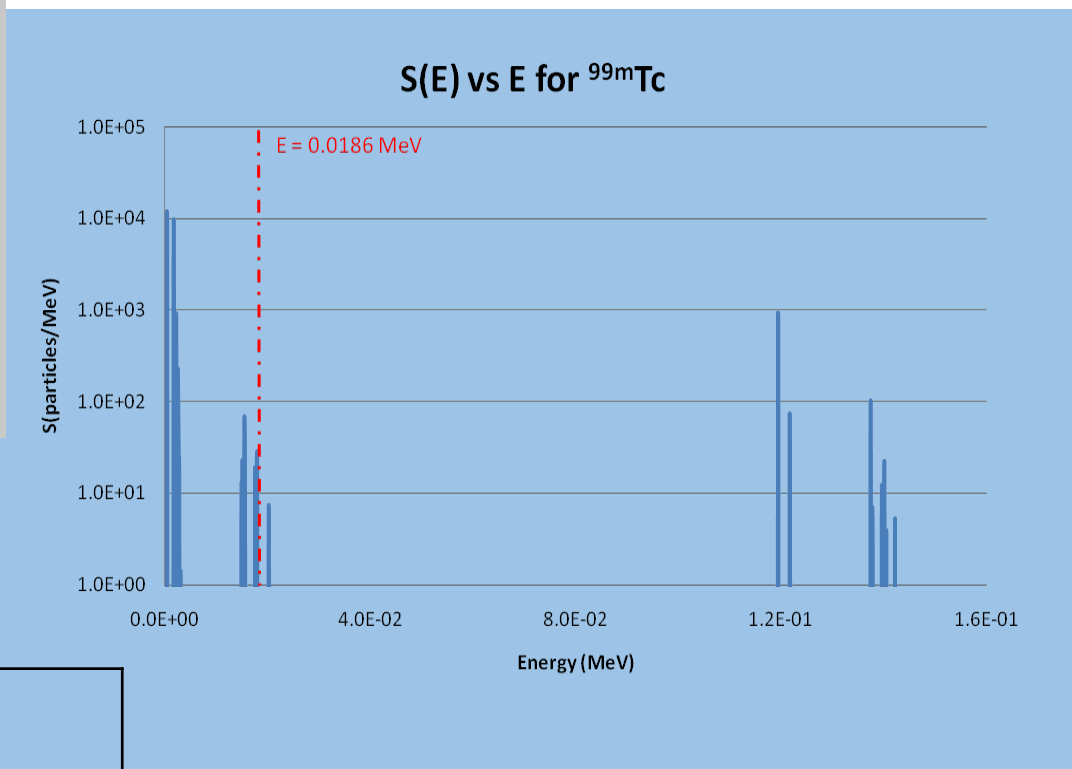
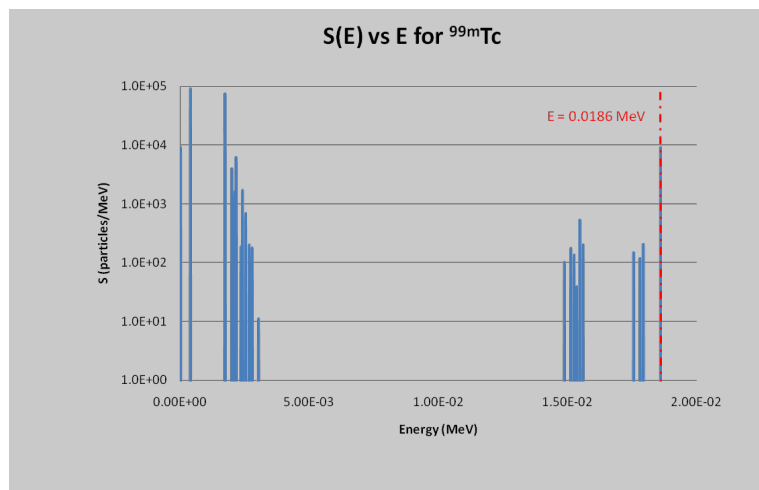
- Nuclides were first processed in SADCALC.f
 - calculation of the SADD when adding a radionuclide to the User library
 - electron emission data imported from ICRP38.BET
- For beta emitters:
 - an energy distribution, $S(E)$, was developed by interpolating 1500 points from 0.0 to E_{max}
 - average energy 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” ^3H spectrum with a yield of 0.1%, with $E_{max} = 0.0186 \text{ MeV}$
- 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
- It does not use the “dummy” tritium distribution
- Results in a more appropriate average electron energy incident on the skin

ELECTRON ENERGY – V3/4 vs V5

^{99m}Tc as the example



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

VARSKIN 5 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)

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

Comparison to experiment

- “Beta and Electron Dose Calculations to Skin Due to Contamination by Common Nuclear Medicine Radionuclides.”
 - McGuire and Dalrymple, *Health Physics*, 1990
- ^{99m}Tc , ^{51}Cr , ^{57}Co , ^{67}Ga , ^{111}In , ^{123}I , ^{131}I , and ^{201}Tl
- $1 \mu\text{Ci cm}^{-2}$ 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	V4	M	K	V5	V4	M	H	V5	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	V4	M	K	V5	V4	M	H
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 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 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 experiment

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Ba-137m [7.42]

Activity Units

μCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²
Air Gap Thickness: 0 mm
Cover Thickness: 0.025 cm
Cover Density: 2 g/cm³

Multiple Cover Calculator

Selected Radionuclides

Cs-137 [7.42]: 1.00E+00 μCi
Ba-137m [7.42]: 1.00E+00 μCi

Edit Remove Clear

varskin V5

Calculate Doses

VARSKIN Output

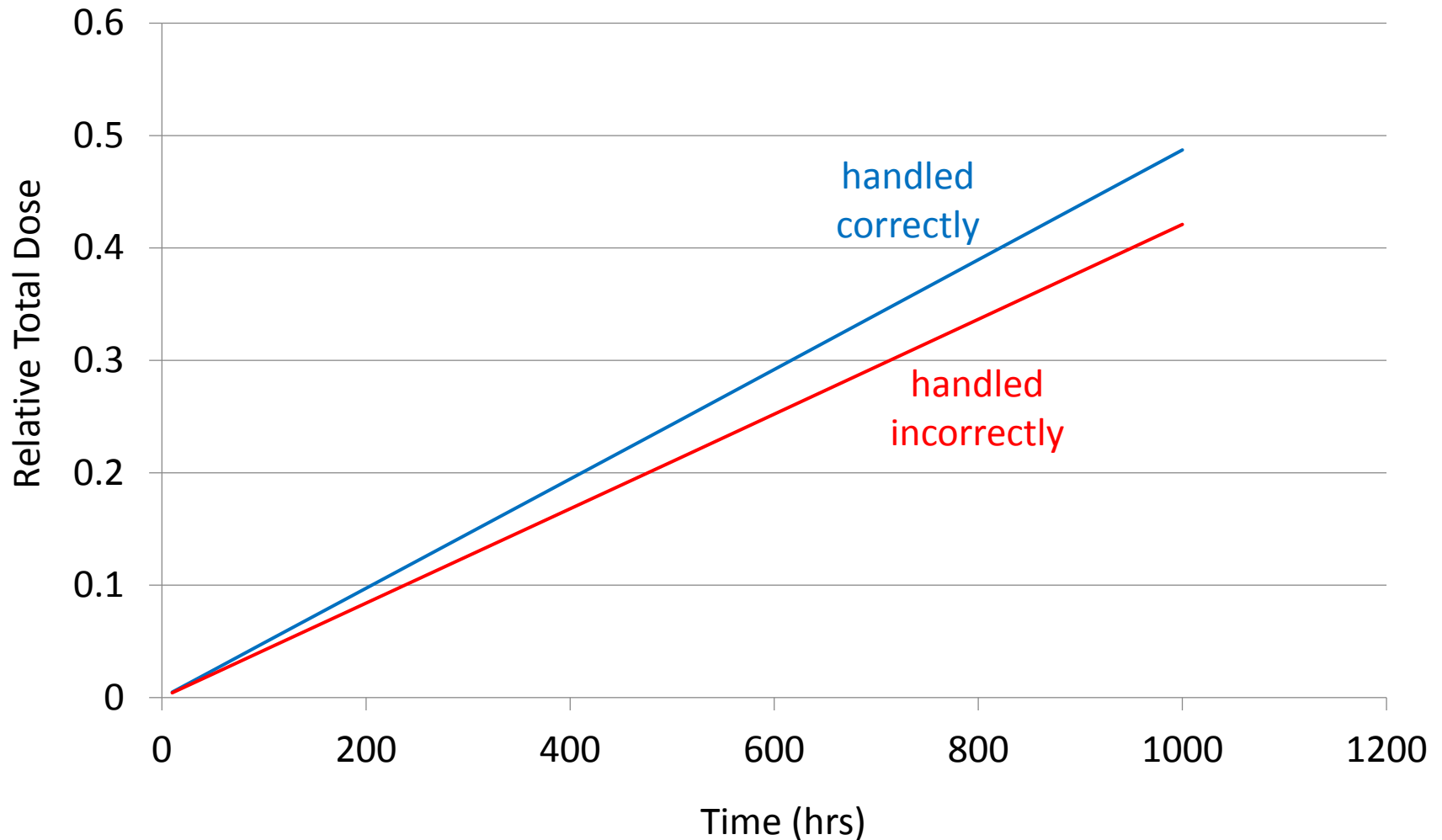
- English or SI units
- For each radionuclide (and total), the following doses are provided:
 - Beta, Photon & Total:
 - initial dose rate
 - dose (no decay)
 - decay-corrected dose
- Date/time
- Geometry summary
- Print option (to html file)

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

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

Decay-Corrected Dose

^{137}Cs and $^{137\text{m}}\text{Ba}$; point source; 10 cm^2 ; 7 mg/cm^2



[Help](#)**Radionuclide: Activity**

Cs-137 [7.42]: 1.00E+00 μ Ci
Ba-137m [7.42]: 1.00E+00 μ Ci

All Radionuclides

Unit Selection

- ☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	4.74E-02 rad/h	4.74E-02 rad	4.74E-02 rad
Photon	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad
Total	4.74E-02 rad/h	4.74E-02 rad	4.74E-02 rad

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	8.42E-02 rad/h	8.42E-02 rad	4.97E-02 rad
Photon	5.85E-03 rad/h	5.85E-03 rad	3.65E-04 rad
Total	9.00E-02 rad/h	9.00E-02 rad	5.00E-02 rad

Date/Time 7/12/2013 3:06:41 PM

Source Geometry Point Source

Cover Thickness	2.50E-02 cm	Cover Density	2.00E+00 g/cm ³
Air Gap Thickness	0.00E+00 mm	Irradiation Time	6.00E+01 min
Skin density thickness	7.00E+00 mg/cm ²	Irradiation Area	1.00E+01 cm ²

[Print Results](#)[Close](#)

varskin V5

EXAMPLES

Scenario (test case) #1

- Nuclear medicine technician
- 10 $\mu\text{Ci/mL}$ 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

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 (test case) #2

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

Point source

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

1.00E+01 cm²

Exposure Time

1.50E+01 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]

Activity Units

mCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²
Air Gap Thickness 0 mm
Cover Thickness 3.00E-01 mm
Cover Density 6.00E-01 g/cm³

Multiple Cover Calculator

Selected Radionuclides

Co-60 [27]: 2.50E+00 mCi

Edit Remove Clear

varskin V5

Calculate Doses

results

Note β/γ
contribution

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-60 [27]: 2.50E+00 mCi

Unit Selection

☒ English Units
☐ SI Units

All Radionuclides

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	1.30E+02 rad/h	3.25E+01 rad	3.25E+01 rad	Beta	1.30E+02 rad/h	3.25E+01 rad
Photon	4.22E+01 rad/h	1.05E+01 rad	1.05E+01 rad	Photon	4.22E+01 rad/h	1.05E+01 rad
Total	1.72E+02 rad/h	4.31E+01 rad	4.31E+01 rad	Total	1.72E+02 rad/h	4.31E+01 rad

Date/Time 8/6/2013 2:51:08 PM Source Geometry Point Source

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

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

Cylindrical equivalent source

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

The screenshot shows the Varskin 5.0 software interface. The 'Source Geometry' section on the left has 'Cylinder' selected. The 'Radionuclide Library' in the center lists 'Co-60 [27]' as the selected radionuclide. The 'Cylinder Source Irradiation Geometry' section on the right shows the following values: Skin Thickness or Skin Density Thickness: 7 mg/cm², Air Gap Thickness: 0.00E+00 mm, Cover Thickness: 3.00E-01 mm, Cover Density: 6.00E-01 g/cm³, Source Diameter: 8.40E+01 µm, Source Thickness: 5.00E+01 µm, and Source Density: 8.30E+00 g/cm³. A green circle highlights the 'Source Diameter' and 'Source Thickness' fields, and a green arrow points from the equation above to the 'Source Diameter' field. The 'Calculate Doses' button is at the bottom right.

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☐ Disk ☐ Slab

☒ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Skin Averaging Area

1.00E+01 cm²

Exposure Time

1.50E+01 min

Radionuclide Library

Cs-137 [7.42]

Co-60 [27]

Ba-137m [7.42]

Co-60 [7.42]

Activity Units

mCi

Select

Add

Remove

Use Distributed Source

Selected Radionuclides

Co-60 [27]: 2.50E+00 mCi

Cylinder Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²

Air Gap Thickness: 0.00E+00 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 V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-60 [27]: 2.50E+00 mCi

All Radionuclides

Unit Selection

☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.18E+01 rad/h	1.30E+01 rad	1.30E+01 rad	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	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	Total	9.44E+01 rad/h	2.36E+01 rad	2.36E+01 rad

Date/Time 2/19/2015 10:02:13 AM Source Geometry Cylinder Source

Source Diameter 8.40E+01 μm Source Thickness 5.00E+01 μm

Source Density 8.30E+00 g/cm^3

Cover Thickness 3.00E-01 mm Cover Density 6.00E-01 g/cm^3

Air Gap Thickness 0.00E+00 mm Irradiation Time 1.50E+01 min

Skin density thickness 7.00E+00 mg/cm^2 Irradiation Area 1.00E+01 cm^2

Print Results Close

Deep dose

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☐ Slab
☒ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging

Skin Averaging Area

1.00E+01 cm²

Exposure Time

1.50E+01 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]

Activity Units

mCi

Select
Add
Remove

Use Distributed Source

Selected Radionuclides

Co-60 [27]: 2.50E+00 mCi

Edit Remove Clear

Cylinder Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 1.00E+03 mg/cm²

Air Gap Thickness 0.00E+00 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 V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-60 [27]: 2.50E+00 mCi

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad	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	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	Total	1.30E+01 rad/h	3.24E+00 rad	3.24E+00 rad

Date/Time 2/19/2015 10:04:30 AM Source Geometry Cylinder Source

Source Diameter 8.40E+01 μ m Source Thickness 5.00E+01 μ m

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

Skin density thickness 1.00E+03 mg/cm² 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 (test case) #3

- Contaminated aluminum plate
- Known to be ^{14}C , but activity must be determined
- 6" x 6" (232 cm²) uniformly contaminated
- Detector of 50 cm² with 3 mg/cm² window
 - measured dose rate of 190 mrad/hr on contact
 - 60 mrad/hr at 1 inch
- Using VARSKIN to estimate activity ...

Reverse calculations

Unit concentration to start

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☒ Disk ☐ Slab

☐ Cylinder

Special Options

☐ Include Photon Dose

☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]

Co-60 [27]

Ba-137m [7.42]

Co-60 [7.42]

Re-186 [7.42]

C-14 [13]

Activity Units

$\mu\text{Ci}/\text{cm}^2$

Select

Add

Remove

Use Distributed Source

Selected Radionuclides

C-14 [13]: $1.00\text{E}+00 \mu\text{Ci}/\text{cm}^2$

Skin Averaging Area

$5.00\text{E}+01 \text{ cm}^2$

Exposure Time

$6.00\text{E}+01 \text{ min}$

Disk Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: $3.00\text{E}+00 \text{ mg}/\text{cm}^2$

Air Gap Thickness 0 mm

Cover Thickness 0 mm

Cover Density 0 g/cm^3

Multiple Cover Calculator

Source Area $2.32\text{E}+02 \text{ cm}^2$

Source Diameter $1.72\text{E}+01 \text{ cm}$

varskin V5

Calculate Doses

Edit Remove Clear

Results

$$1 \frac{\mu\text{Ci}}{\text{cm}^2} \cdot \frac{0.19 \text{ rad/hr}}{4.47 \text{ rad/hr}} = 0.0425 \frac{\mu\text{Ci}}{\text{cm}^2} \cdot 232 \text{ cm}^2 = 9.86 \mu\text{Ci}$$

Non Volume Averaged Results

Help

Radionuclide: Activity

C-14 [13]: 1.00E+00 $\mu\text{Ci}/\text{cm}^2$

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	4.47E+00 rad/h	4.47E+00 rad	4.47E+00 rad	Beta	4.47E+00 rad/h	4.47E+00 rad	4.47E+00 rad
Photon				Photon			
Total	4.47E+00 rad/h	4.47E+00 rad	4.47E+00 rad	Total	4.47E+00 rad/h	4.47E+00 rad	4.47E+00 rad

Date/Time 8/6/2013 3:10:34 PM Source Geometry Disk Source

Source Diameter 1.72E+01 cm Source Area 2.32E+02 cm^2

Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 3.00E+00 mg/cm^2 Irradiation Area 5.00E+01 cm^2

Print Results Close

Scales to a source strength of 0.0425 $\mu\text{Ci}/\text{cm}^2$, and a total activity of 9.86 μCi .

Confirmation using air gap

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☒ Disk ☐ Slab

☐ Cylinder

Special Options

☐ Include Photon Dose

☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]

Co-60 [27]

Ba-137m [7.42]

Co-60 [7.42]

Re-186 [7.42]

C-14 [13]

Activity Units

μCi

Select

Add

Remove

Use Distributed Source

Selected Radionuclides

C-14 [13]: 9.86E+00 μCi

Skin Averaging Area

5.00E+01 cm^2

Exposure Time

6.00E+01 min

Disk Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 3.00E+00 mg/cm^2

Air Gap Thickness: 1.00E+00 in

Cover Thickness 0 mm

Cover Density 0 g/cm^3

Multiple Cover Calculator

Source Area 2.32E+02 cm^2

Source Diameter 1.72E+01 cm

varskin V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

C-14 [13]: 9.86E+00 μCi

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	6.04E-02 rad/h	6.04E-02 rad	6.04E-02 rad	Beta	6.04E-02 rad/h	6.04E-02 rad	6.04E-02 rad
Photon				Photon			
Total	6.04E-02 rad/h	6.04E-02 rad	6.04E-02 rad	Total	6.04E-02 rad/h	6.04E-02 rad	6.04E-02 rad

Date/Time 8/6/2013 3:14:58 PM Source Geometry Disk Source

Source Diameter 1.72E+01 cm Source Area 2.32E+02 cm^2

Air Gap Thickness 1.00E+00 in Irradiation Time 6.00E+01 min

Skin density thickness 3.00E+00 mg/cm^2 Irradiation Area 5.00E+01 cm^2

Print Results Close

Compares to the measured value of 60 mrad/hr at 1 inch.

scenario #4

- Contamination found on the outside of a boot
- 160 minute exposure
- Contains 14 nuclides (fission products)
- Conservatively modeled as a point source
- Boot has thickness of 0.44 mm, and density of 1 g/cm³

source term

<u>NUCLIDE</u>	<u>ACTIVITY (uCi)</u>
Co-57	7.41E-4
Co-60	2.86E-4
Sr-89	2.40E-2
Sr-90	2.18E-2
Y-90	2.18E-2
Y-91	4.69E-2
Zr-95	2.81E-3
Te-129m	2.76E-1
Cs-134	9.29E-5
Cs-137	1.96E-3
Ba-137m	1.96E-3
Ba-140	9.05E-5
Ce-141	1.09E-2
Ce-144	2.44E-1

point source

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

1.60E+02 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units

μCi

Select
Add
Remove

Selected Radionuclides

Zr-95 [7.42]: 2.81E-03 μCi
Te-129m [7.42]: 2.76E-01 μCi
Cs-137 [7.42]: 1.96E-03 μCi
Ba-137m [7.42]: 1.96E-03 μCi
Cs-134 [7.42]: 9.29E-05 μCi
Ba-140 [7.42]: 9.05E-05 μCi
Ce-141 [7.42]: 1.09E-02 μCi
Ce-144 [7.42]: 2.44E-01 μCi

Edit Remove Clear

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²

Air Gap Thickness: 0 mm

Cover Thickness: 4.40E-02 cm

Cover Density: 1.00E+00 g/cm³

Multiple Cover Calculator

varskin V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-57 [7.42]: 7.41E-04 μCi
Co-60 [7.42]: 2.86E-04 μCi
Sr-89 [7.42]: 2.40E-02 μCi
Sr-90 [7.42]: 2.18E-02 μCi

All Radionuclides

Unit Selection
☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad	Beta	5.65E-02 rad/h	1.51E-01 rad	1.50E-01 rad
Photon	9.84E-06 rad/h	2.62E-05 rad	2.62E-05 rad	Photon	4.12E-04 rad/h	1.10E-03 rad	1.07E-03 rad
Total	9.84E-06 rad/h	2.62E-05 rad	2.62E-05 rad	Total	5.69E-02 rad/h	1.52E-01 rad	1.51E-01 rad

Date/Time 1/16/2014 2:42:26 PM Source Geometry Point Source

Cover Thickness 4.40E-01 mm Cover Density 1.00E+00 g/cm³

Air Gap Thickness 0.00E+00 mm Irradiation Time 1.60E+02 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

beta/gamma dose

<u>Nuclide</u>	<u>Activity (uCi)</u>	<u>Beta Dose (mrad)</u>	<u>Photon Dose (mrad)</u>
Co-57	7.41E-4	---	2.62E-2
Co-60	2.86E-4	1.88E-3	1.34E-2
Sr-89	2.40E-2	1.80E+1	---
Sr-90	2.18E-2	4.58E+0	---
Y-90	2.18E-2	2.03E+1	---
Y-91	4.69E-2	3.58E+1	---
Zr-95	2.81E-3	8.75E-2	5.36E-2
Te-129m	2.76E-1	6.93E+1	7.56E-1
Cs-134	9.29E-5	1.75E-2	3.76E-3
Cs-137	1.96E-3	3.53E-1	---
Ba-137m	1.96E-3	2.02E-1	3.19E-2
Ba-140	9.05E-5	3.34E-2	1.06E-3
Ce-141	1.09E-2	1.02E+0	2.74E-2
Ce-144	2.44E-1	<u>9.20E-1</u> 1.50E+2	<u>1.85E-1</u> 1.07E+0

scenario #5

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

Point source

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units

μCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²

Air Gap Thickness 0 mm

Cover Thickness 0.00E+00 mm

Cover Density 0 g/cm³

Multiple Cover Calculator

Selected Radionuclides

Ce-141 [7.42]: 1.61E+00 μCi

Edit Remove Clear

varskin V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Ce-141 [7.42]: 1.61E+00 μ Ci

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	9.54E-01 rad/h	9.54E-01 rad	9.53E-01 rad	Beta	9.54E-01 rad/h	9.54E-01 rad	9.53E-01 rad
Photon	2.29E-03 rad/h	2.29E-03 rad	2.29E-03 rad	Photon	2.29E-03 rad/h	2.29E-03 rad	2.29E-03 rad
Total	9.56E-01 rad/h	9.56E-01 rad	9.55E-01 rad	Total	9.56E-01 rad/h	9.56E-01 rad	9.55E-01 rad

Date/Time 9/4/2013 9:23:32 PM Source Geometry Point Source

Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

2D Disk source

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere

☒ Disk ☐ Slab

☐ Cylinder

Special Options

☒ Include Photon Dose

☐ Perform Volume Averaging

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Activity Units

$\mu\text{Ci}/\text{cm}^2$

Select

Add

Remove

Selected Radionuclides

Ce-141 [7.42]: 2.50E-01 $\mu\text{Ci}/\text{cm}^2$

Use Distributed Source

Disk Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²

Air Gap Thickness: 0 mm

Cover Thickness: 0.00E+00 mm

Cover Density: 0 g/cm³

Multiple Cover Calculator

Source Area: 1.00E+00 in²

Source Diameter: 1.13E+00 in

varskin V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Ce-141 [7.42]: 2.50E-01 $\mu\text{Ci}/\text{cm}^2$

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	9.65E-01 rad/h	9.65E-01 rad	9.65E-01 rad	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	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	Total	9.67E-01 rad/h	9.67E-01 rad	9.67E-01 rad

Date/Time 2/19/2015 11:11:59 AM 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

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

Slab source

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☒ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units
 μCi

Select
Add
Remove

☐ Use Distributed Source

Selected Radionuclides

Ce-141 [7.42]: 1.61E+00 μCi

Skin Averaging Area
10 cm^2

Exposure Time
60 min

Slab Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2
Air Gap Thickness 0 mm
Cover Thickness 0 mm
Cover Density 0 g/cm^3
Multiple Cover Calculator
X-Side Length 1 in
Y-Side Length 1 in
Source Thickness 0.1 μm
Source Density 1 g/cm^3

varskin V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Ce-141 [7.42]: 1.61E+00 μ Ci

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.05E+00 rad/h	1.05E+00 rad	1.05E+00 rad	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	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	Total	1.05E+00 rad/h	1.05E+00 rad	1.05E+00 rad

Date/Time 2/19/2015 10:31:15 AM

Source Geometry Slab Source

X side Length 1.00E+00 in

Y side Length 1.00E+00 in

Source Thickness 1.00E-01 μ m

Source Density 1.00E+00 g/cm³

Air Gap Thickness 0.00E+00 mm

Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm²

Irradiation Area 1.00E+01 cm²

Print Results

Close

Slab source (low density)

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☒ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units
 μCi

Select
Add
Remove

☐ Use Distributed Source

Selected Radionuclides

Ce-141 [7.42]: 1.61E+00 μCi

Skin Averaging Area
10 cm^2

Exposure Time
60 min

Slab Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2

Air Gap Thickness 0 mm

Cover Thickness 0 mm

Cover Density 0 g/cm^3

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 1.29E-03 g/cm^3

varskin V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Ce-141 [7.42]: 1.61E+00 μ Ci

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	9.52E-01 rad/h	9.52E-01 rad	9.52E-01 rad	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	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	Total	9.54E-01 rad/h	9.54E-01 rad	9.54E-01 rad

Date/Time 2/19/2015 10:48:08 AM Source Geometry Slab Source

X side Length 1.00E+00 in Y side Length 1.00E+00 in

Source Thickness 1.00E-01 μ m Source Density 1.29E-03 g/cm³

Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

Slab source (1 cm²)

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☒ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units

Select
Add
Remove

Use Distributed Source

Selected Radionuclides

Ce-141 [7.42]: 1.61E+00 μCi

Skin Averaging Area
 cm²

Exposure Time
 min

Slab Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: mg/cm²
Air Gap Thickness mm
Cover Thickness mm
Cover Density g/cm³
Multiple Cover Calculator

X-Side Length in
Y-Side Length in
Source Thickness μm
Source Density g/cm³

varskin V5

Calculate Doses

Edit Remove Clear

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Ce-141 [7.42]: 1.61E+00 µCi

All Radionuclides

Unit Selection

☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.61E+00 rad/h	1.61E+00 rad	1.61E+00 rad	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	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	Total	1.62E+00 rad/h	1.62E+00 rad	1.62E+00 rad

Date/Time 2/19/2015 11:01:45 AM 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

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+00 cm²

Print Results Close

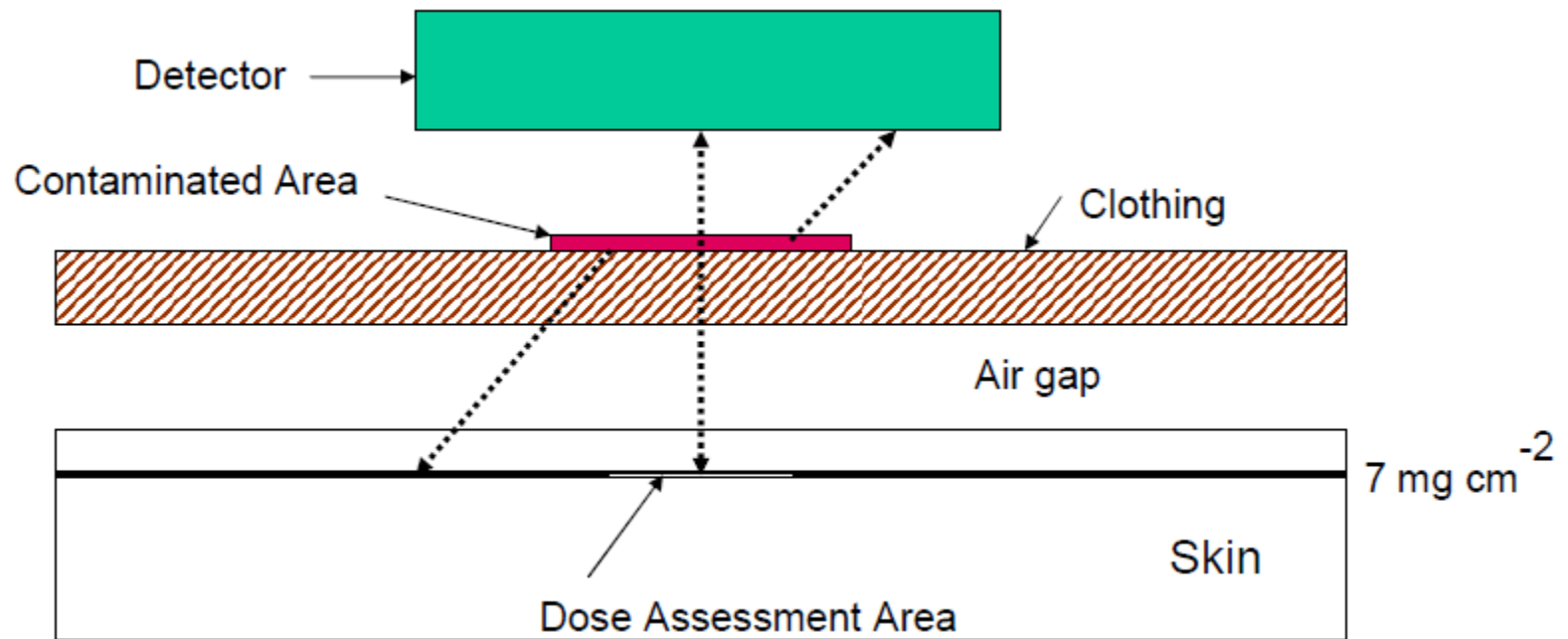
summary

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 #6

- 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/cm³
- Source measurements indicate:
 - 0.0036 μ Ci of Co-57
 - 0.1920 μ Ci of Ru-106 (Rh-106)
 - 0.0028 μ Ci of Cs-134
 - 0.0036 μ Ci of Cs-137 (Ba-137m)
- Modeled as a point source
- Interested in a beta and gamma depth-dose profile

Beta activity determination



Varskin input

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Activity Units: μCi

Select Add Remove

Selected Radionuclides

Co-57 [7.42]: 3.60E-03 μCi
Cs-134 [7.42]: 2.80E-03 μCi
Cs-137 [7.42]: 3.60E-03 μCi
Ba-137m [7.42]: 3.60E-03 μCi
Ru-106 [7.42]: 1.92E-01 μCi
Rh-106 [7.42]: 1.92E-01 μCi

Edit Remove Clear

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7.00E+00 mg/cm²
Air Gap Thickness: 3.00E+00 mm
Cover Thickness: 2.00E-01 mm
Cover Density: 3.60E-01 g/cm³

Multiple Cover Calculator

varskin V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-57 [7.42]: 3.60E-03 μ Ci
Cs-134 [7.42]: 2.80E-03 μ Ci
Cs-137 [7.42]: 3.60E-03 μ Ci
Ba-137m [7.42]: 3.60E-03 μ Ci

All Radionuclides

Unit Selection
☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.02E-05 rad/h	2.02E-05 rad	2.02E-05 rad	Electron	4.83E-02 rad/h	4.83E-02 rad	2.34E-03 rad
Photon	3.53E-05 rad/h	3.53E-05 rad	3.53E-05 rad	Photon	1.58E-04 rad/h	1.58E-04 rad	4.97E-05 rad
Total	5.54E-05 rad/h	5.54E-05 rad	5.54E-05 rad	Total	4.85E-02 rad/h	4.85E-02 rad	2.39E-03 rad

Date/Time 2/19/2015 11:26:29 AM Source Geometry Point Source

Cover Thickness 2.00E-01 mm Cover Density 3.60E-01 g/cm³

Air Gap Thickness 3.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

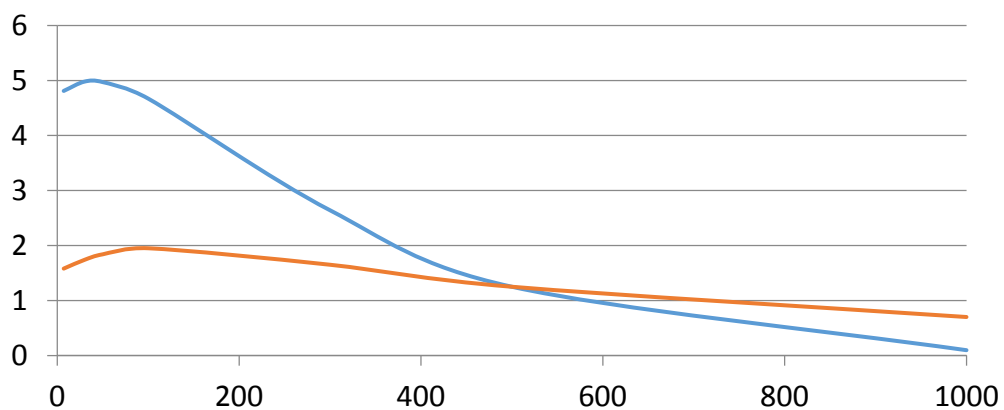
Print Results Close

Results by nuclide

@ 7 mg/cm ²	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Co-57	2.02E-5	3.53E-5	5.54E-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

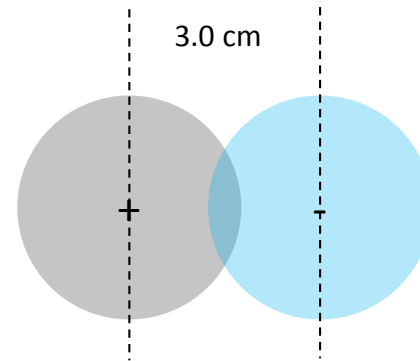
Results by depth

	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 #7 (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

The screenshot displays the Varskin 5.0 software window. The interface is divided into several sections:

- Source Geometry:** Includes radio buttons for Point (selected), Sphere, Disk, Slab, and Cylinder.
- Special Options:** Includes checkboxes for Include Photon Dose (checked), Perform Volume Averaging (unchecked), and Offset Particle Model (checked). Below this is an Offset Value field set to 0 with a unit dropdown set to cm.
- Radionuclide Library:** A list of radionuclides with their half-lives. Co-60 [27] is highlighted. To the right are buttons for Select, Add, and Remove, and an Activity Units dropdown set to μCi .
- Selected Radionuclides:** A list showing the selected radionuclides and their activities: Mn-54 [25]: $1.38\text{E}+00 \mu\text{Ci}$ and Co-60 [27]: $4.71\text{E}-01 \mu\text{Ci}$.
- Point Source Irradiation Geometry:** Includes input fields for Skin Thickness or Skin Density Thickness (7 mg/cm^2), Air Gap Thickness (0 mm), Cover Thickness (0 mm), and Cover Density (0 g/cm^3). A Multiple Cover Calculator button is also present.
- Bottom Section:** Includes Skin Averaging Area (10 cm^2), Exposure Time (60 min), and buttons for Edit, Remove, Clear, and Calculate Doses.

Two green circles highlight the 'Offset Particle Model' checkbox and the 'Selected Radionuclides' list.

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Mn-54 [25]: 1.38E+00 µCi
Co-60 [27]: 4.71E-01 µCi

All Radionuclides

Unit Selection
☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad	Beta	1.68E-01 rad/h	1.68E-01 rad	1.68E-01 rad
Photon	1.55E-02 rad/h	1.55E-02 rad	1.55E-02 rad	Photon	2.15E-02 rad/h	2.15E-02 rad	2.15E-02 rad
Total	1.55E-02 rad/h	1.55E-02 rad	1.55E-02 rad	Total	1.89E-01 rad/h	1.89E-01 rad	1.89E-01 rad

Date/Time 8/9/2013 10:09:00 AM Source Geometry Point Source

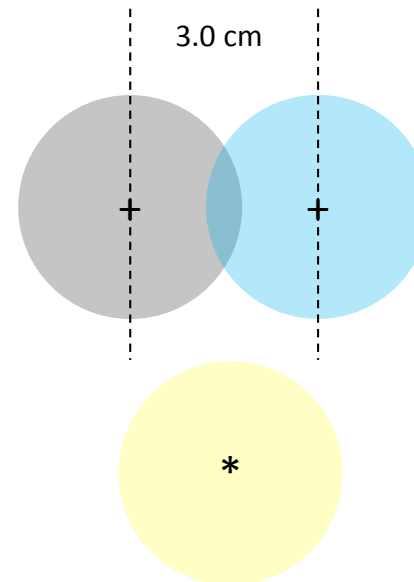
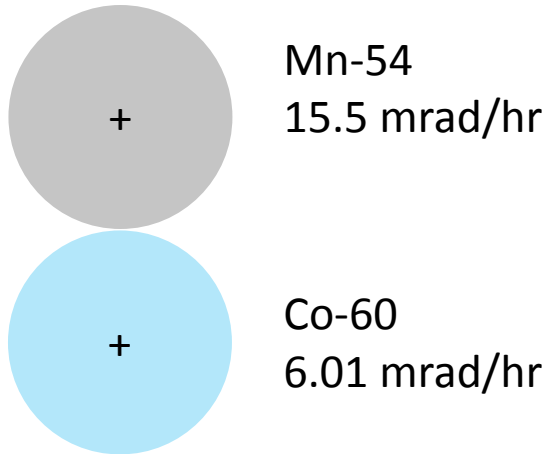
Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Offset 0.00E+00 cm

Print Results Close

Photon dose rate from each source



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

Offset particle model input

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☒ Offset Particle Model

Offset Value:
1.50E+00 cm

Skin Averaging Area
10 cm²

Exposure Time
60 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units
μCi

Select
Add
Remove

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

Selected Radionuclides

Mn-54 [25]: 1.38E+00 μCi
Co-60 [27]: 4.71E-01 μCi

Edit Remove Clear

varskin V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Mn-54 [25]: 1.38E+00 μ Ci
Co-60 [27]: 4.71E-01 μ Ci

All Radionuclides

Unit Selection
☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad	Beta	1.68E-01 rad/h	1.68E-01 rad	1.68E-01 rad
Photon	1.41E-02 rad/h	1.41E-02 rad	1.41E-02 rad	Photon	1.91E-02 rad/h	1.91E-02 rad	1.91E-02 rad
Total	1.41E-02 rad/h	1.41E-02 rad	1.41E-02 rad	Total	1.87E-01 rad/h	1.87E-01 rad	1.87E-01 rad

Date/Time 8/9/2013 10:10:40 AM Source Geometry Point Source

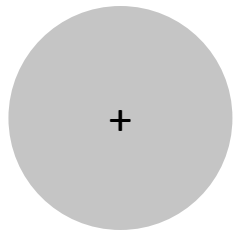
Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

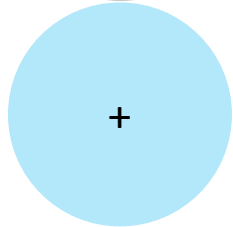
Offset 1.50E+00 cm

Print Results Close

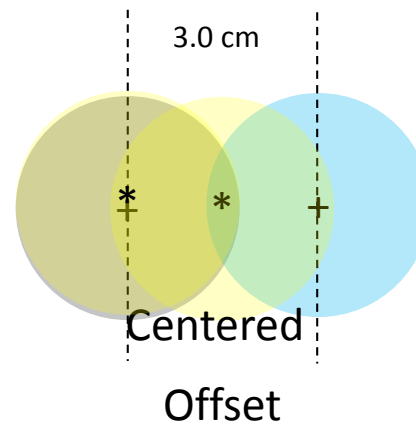
Dose to single averaging disk



Mn-54
15.5 mrad/hr

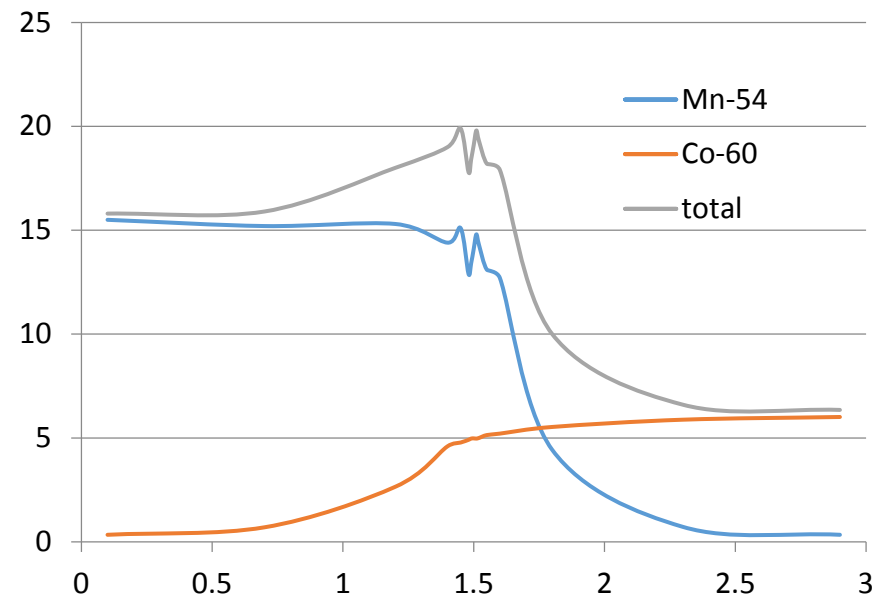


Co-60
6.01 mrad/hr



Placement to maximize photon dose

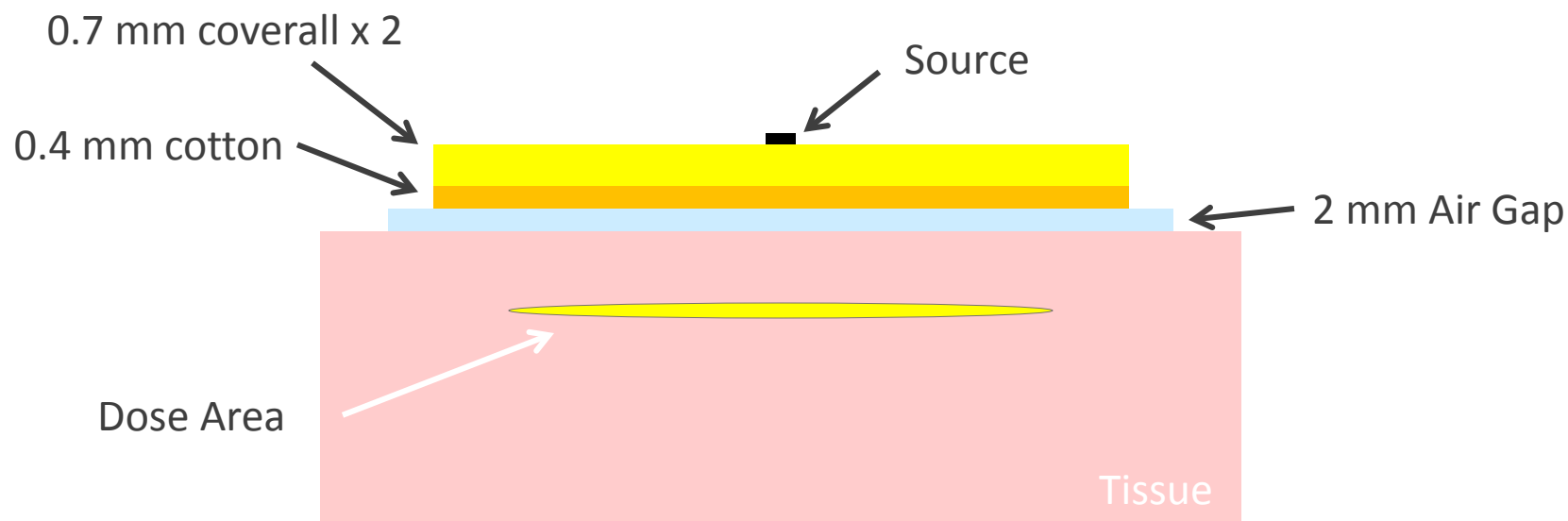
Dose Rate (mrad/hr)	Mn-54	Co-60	Total
Each on-axis (stacked)	15.5	6.01	21.5
0.1 cm from Mn-54	15.5	0.34	15.8
0.7 cm	15.2	0.70	15.9
1.2 cm	15.3	2.65	18.0
1.4 cm	14.4	4.60	19.0
1.45 cm	15.1	4.78	19.9
1.48 cm	12.9	4.91	17.8
1.49 cm	13.4	4.97	18.4
1.5 cm (centered)	14.1	4.98	19.1
1.51 cm	14.8	4.97	19.8
1.52 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	6.01	6.35



scenario #8 (multiple cover)

- Using the Multiple Cover Calculator
- Hot particle imbedded in two layers of coveralls (0.7 mm; 0.4 g/cm³), and one heavy cotton shirt (assumed similar to cloth lab coat; 0.4 mm; 0.9 g/cm³)
- 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/cm³), cylindrical source, 20 µm diameter x 40 µm length
- Depth-dose profile to 100 mg/cm²

Cover model



Multiple cover input

Varskin 5.0

File Help

Source Geometry

- ☐ Point
- ☐ Disk
- ☒ Cylinder

Special Options

- ☐ Include Photo
- ☐ Perform Volume

Skin Averaging

10

Exposure Time

60 min

Multiple Cover Calculator

Help

	Density	Thickness	Density Thickness
Cover 1	4.00E-01 g/cm ³	7.00E-02 cm	2.80E+01 mg/cm ²
Cover 2	4.00E-01 g/cm ³	7.00E-02 cm	2.80E+01 mg/cm ²
Cover 3	9.00E-01 g/cm ³	4.00E-02 cm	3.60E+01 mg/cm ²
Cover 4	g/cm ³	mm	mg/cm ²
Cover 5	g/cm ³	mm	mg/cm ²
Total	5.11E-01 g/cm ³	1.80E-01 cm	9.20E-02 g/cm ²

Cancel Calculate

Edit Remove Clear Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Sr-90 [26]: 1.30E+00 μ Ci
Y-90 [26]: 1.30E+00 μ Ci

All Radionuclides

Unit Selection
☒ English Units
☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	8.28E-03 rad/h	8.28E-03 rad	8.28E-03 rad	Beta	3.04E-01 rad/h	3.04E-01 rad	3.02E-01 rad
Photon				Photon			
Total	8.28E-03 rad/h	8.28E-03 rad	8.28E-03 rad	Total	3.04E-01 rad/h	3.04E-01 rad	3.02E-01 rad

Date/Time 1/16/2014 2:57:31 PM Source Geometry Cylinder Source

Source Diameter 2.00E+01 μ m Source Thickness 4.00E+01 μ m

Source Density 7.87E+00 g/cm³

Cover Thickness 1.80E-01 cm Cover Density 5.11E-01 g/cm³

Air Gap Thickness 2.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

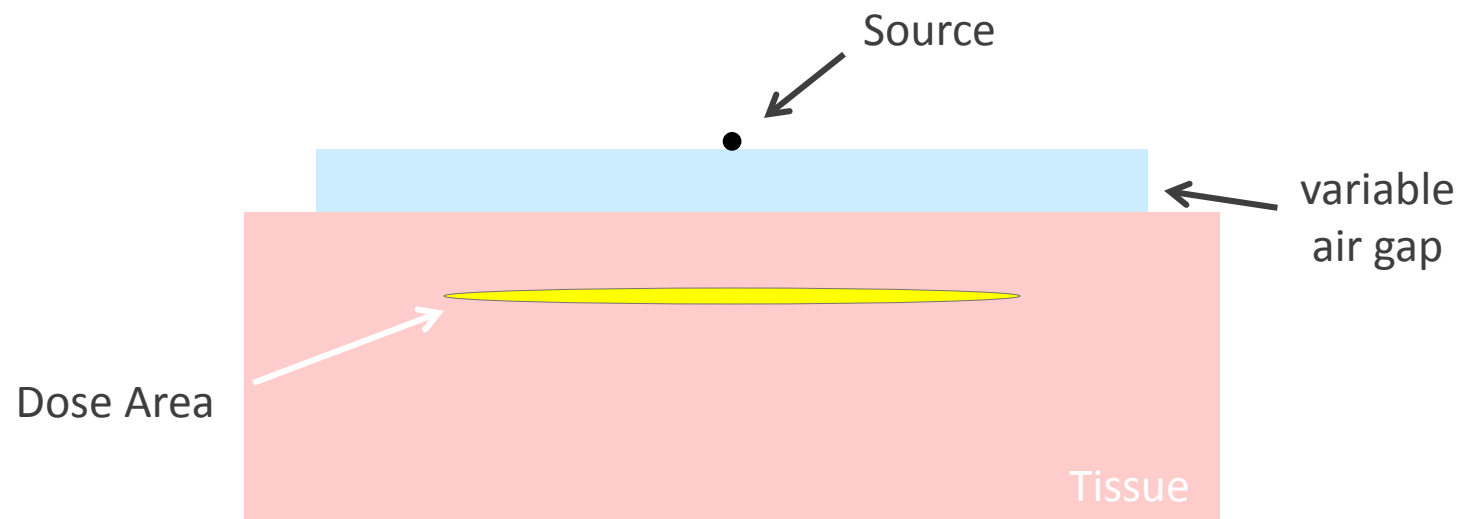
Depth-dose summary

	Sr-90 Beta	Y-90 Beta	Total Dose (mrad/hr)
7 mg/cm ²	8.28	296	304
10	6.91	292	298
20	3.67	279	282
30	1.86	267	269
50	0.413	242	242
100	0.185	187	187

scenario #9 (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

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Activity Units
μCi

Select
Add
Remove

Selected Radionuclides

Co-60 [7.42]: 1.00E+00 μCi

Edit Remove Clear

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²

Air Gap Thickness: 2.50E-01 cm

Cover Thickness: 0 mm

Cover Density: 0 g/cm³

Multiple Cover Calculator

varskin V5

Calculate Doses

results

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-60 [7.42]: 1.00E+00 μ Ci

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	3.40E-01 rad/h	3.40E-01 rad	3.40E-01 rad	Beta	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	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	Total	3.47E-01 rad/h	3.47E-01 rad	3.47E-01 rad

Date/Time 8/9/2013 10:43:43 AM Source Geometry Point Source

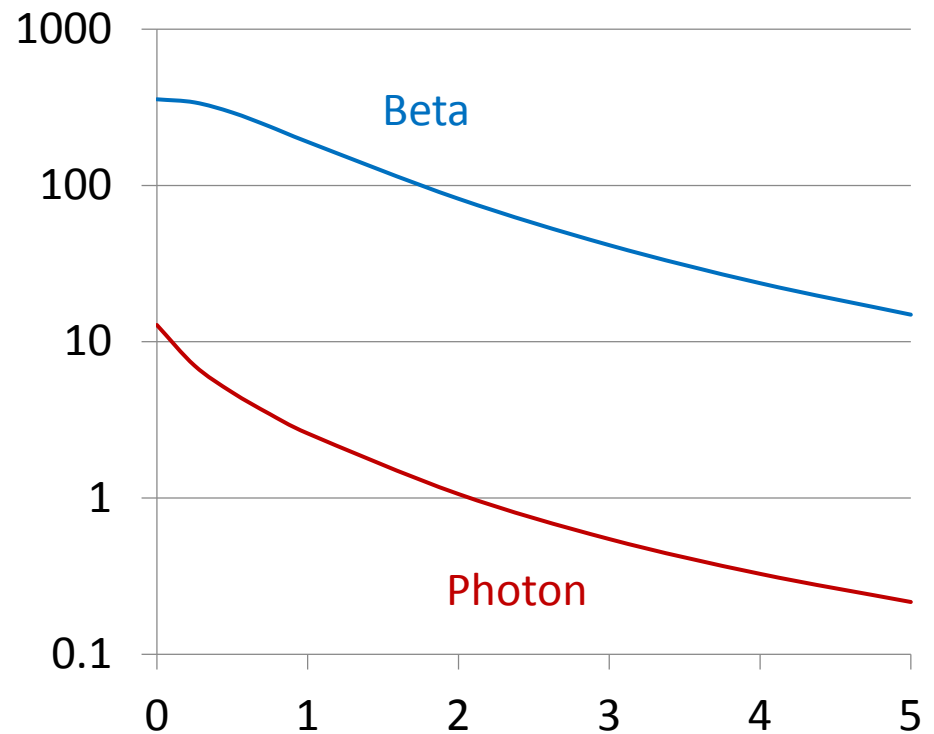
Air Gap Thickness 2.50E-01 cm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

Print Results Close

Air gap impact on dose

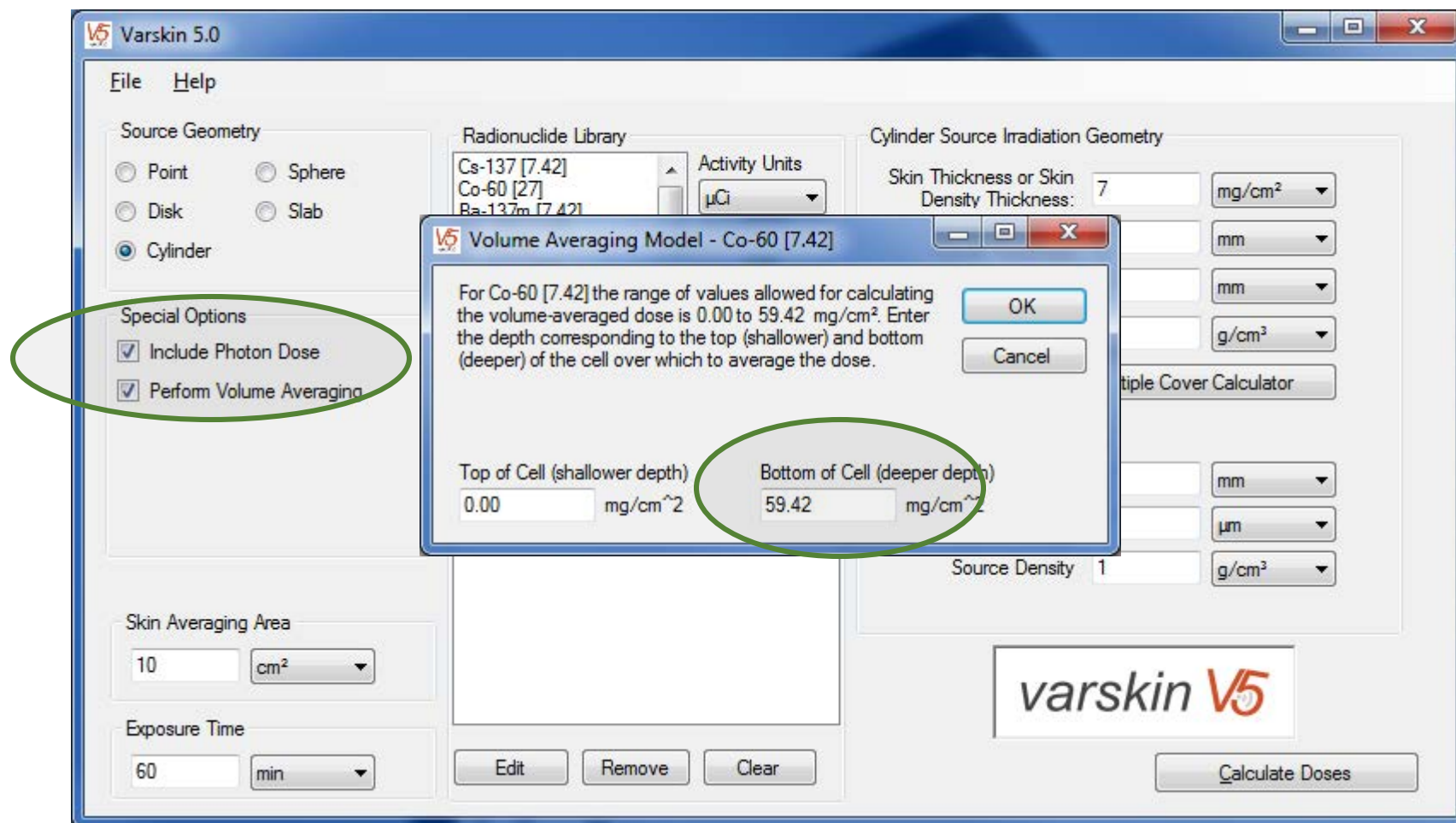
Air Gap (cm)	Beta	Photon	Total
0	356	12.8	369
0.25	340	7.03	347
0.50	293	4.74	298
0.75	238	3.44	241
1	190	2.59	192
2	82.2	1.06	83.3
3	41.5	0.546	42.0
4	23.7	0.327	24.1
5	14.9	0.216	15.1



scenario #10

- 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

3D source and Volume averaging



Maximum volume averaging depth

	Max Beta Energy (keV)	Max Depth (mg/cm ²)
Co-60	318	59.42
Cs-137	514	163.8
Cs-134	658	186.2
Ba-140	1020	295.3
Y-91	1540	604.4

Calculating beta dose

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☐ Slab
☒ Cylinder

Special Options

☒ Include Photon Dose
☒ Perform Volume Averaging

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units

μCi

Select
Add
Remove

☐ Use Distributed Source

Selected Radionuclides

Co-60 [7.42]: 1.00E+00 μCi

Edit Remove Clear

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 1 mm

Source Thickness 1 μm

Source Density 1 g/cm³

varskin V5

Cancel Calculating beta dose...

Calculating gamma dose

Varskin 5.0

File Help

Source Geometry

☐ Point ☐ Sphere
☐ Disk ☐ Slab
☒ Cylinder

Special Options

☒ Include Photon Dose
☒ Perform Volume Averaging

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units
 μCi

Select
Add
Remove

☐ Use Distributed Source

Selected Radionuclides

Co-60 [7.42]: 1.00E+00 μCi

Edit Remove Clear

Skin Averaging Area

10 cm^2

Exposure Time

60 min

Cylinder Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm^2
Air Gap Thickness 0 mm
Cover Thickness 0 mm
Cover Density 0 g/cm^3
Multiple Cover Calculator

Source Diameter 1 mm
Source Thickness 1 μm
Source Density 1 g/cm^3

varskin V5

Cancel Calculating gamma dose...

Time (sec) to calculate dose

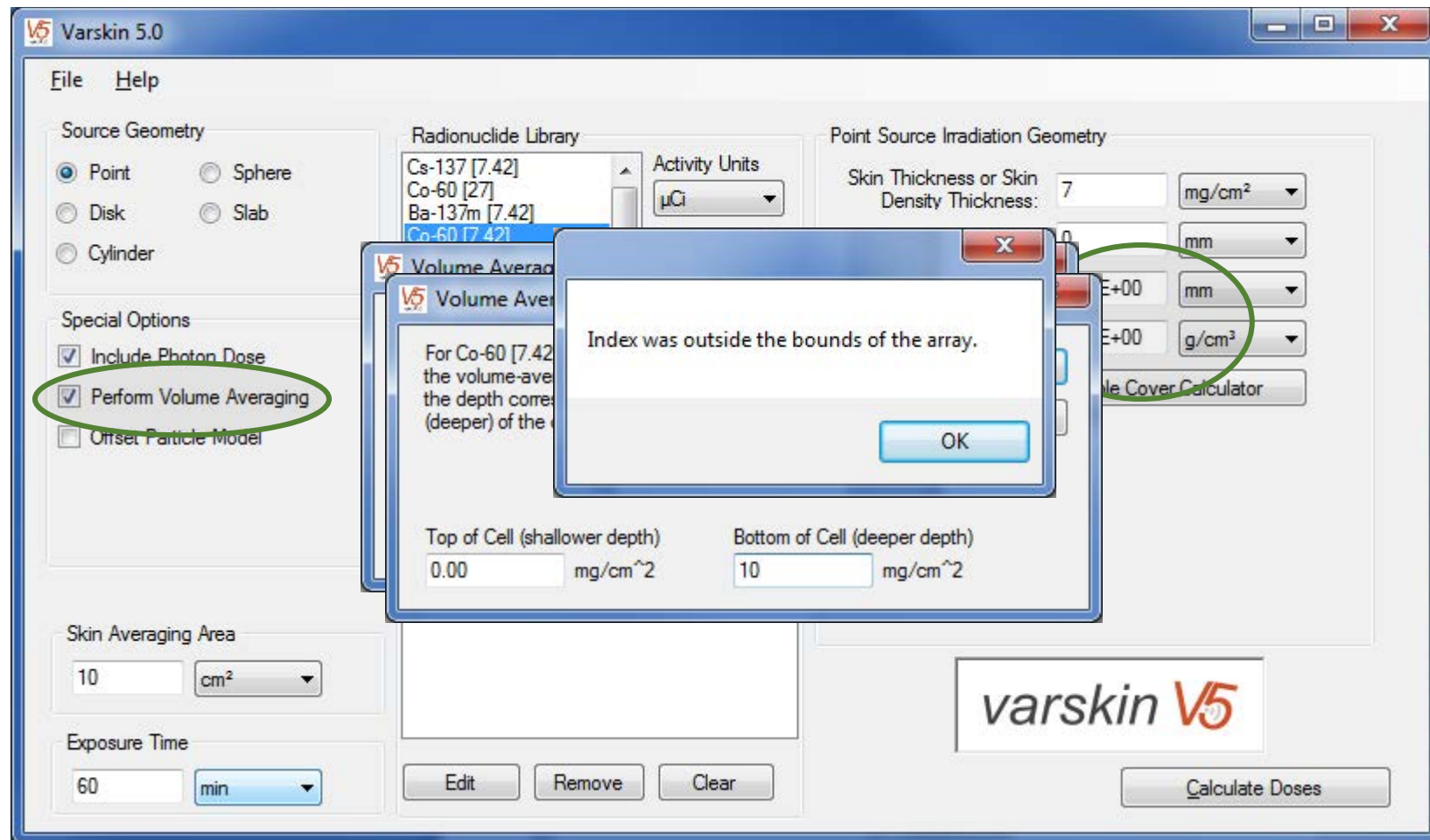
	Beta	Gamma	Volume Avg Beta	Volume Avg Gamma
Co-60 (2)	---	6	6	59
Cs-134 (9)	---	28	4	288
Ba-137m (3)	---	10	4	87
Cs-137 (2)	---	---	4	---
Ba-140 (10)	---	38	4	368
Y-91 (1)	---	---	3	---

*Using default cylindrical source geometry (--- indicates <1 second).

scenario #11

- Using the volume-averaging option w/ the cover model
- If the cover is too thick/dense for the selected beta emitter, the maximum beta range is shown as NEGATIVE
- The code will not run unless the maximum depth is changed to a non-negative value
 - and then, the code will provide an error message

Volume averaging option



w/o volume averaging

Varskin 5.0

File Help

Source Geometry

☒ Point ☐ Sphere
☐ Disk ☐ Slab
☐ Cylinder

Special Options

☒ Include Photon Dose
☐ Perform Volume Averaging
☐ Offset Particle Model

Skin Averaging Area

10 cm²

Exposure Time

60 min

Radionuclide Library

Cs-137 [7.42]
Co-60 [27]
Ba-137m [7.42]
Co-60 [7.42]
Re-186 [7.42]
C-14 [13]
Co-57 [7.42]
Ce-144 [7.42]
Ce-141 [7.42]
Ba-140 [7.42]
Cs-134 [7.42]
Sr-89 [7.42]

Activity Units

μCi

Select
Add
Remove

Point Source Irradiation Geometry

Skin Thickness or Skin Density Thickness: 7 mg/cm²
Air Gap Thickness: 0 mm
Cover Thickness: 1.00E+00 mm
Cover Density: 1.00E+00 g/cm³

Multiple Cover Calculator

Selected Radionuclides

Co-60 [7.42]: 1.00E+00 μCi

Edit Remove Clear

varskin V5

Calculate Doses

Zero beta dose

Non Volume Averaged Results

Help

Radionuclide: Activity

Co-60 [7.42]: 1.00E+00 μCi

All Radionuclides

Unit Selection

☒ English Units

☐ SI Units

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose		Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Beta	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad	Beta	0.00E+00 rad/h	0.00E+00 rad	0.00E+00 rad
Photon	1.78E-02 rad/h	1.78E-02 rad	1.78E-02 rad	Photon	1.78E-02 rad/h	1.78E-02 rad	1.78E-02 rad
Total	1.78E-02 rad/h	1.78E-02 rad	1.78E-02 rad	Total	1.78E-02 rad/h	1.78E-02 rad	1.78E-02 rad

Date/Time 8/9/2013 11:47:48 AM Source Geometry Point Source

Cover Thickness 1.00E+00 mm Cover Density 1.00E+00 g/cm³

Air Gap Thickness 0.00E+00 mm Irradiation Time 6.00E+01 min

Skin density thickness 7.00E+00 mg/cm² Irradiation Area 1.00E+01 cm²

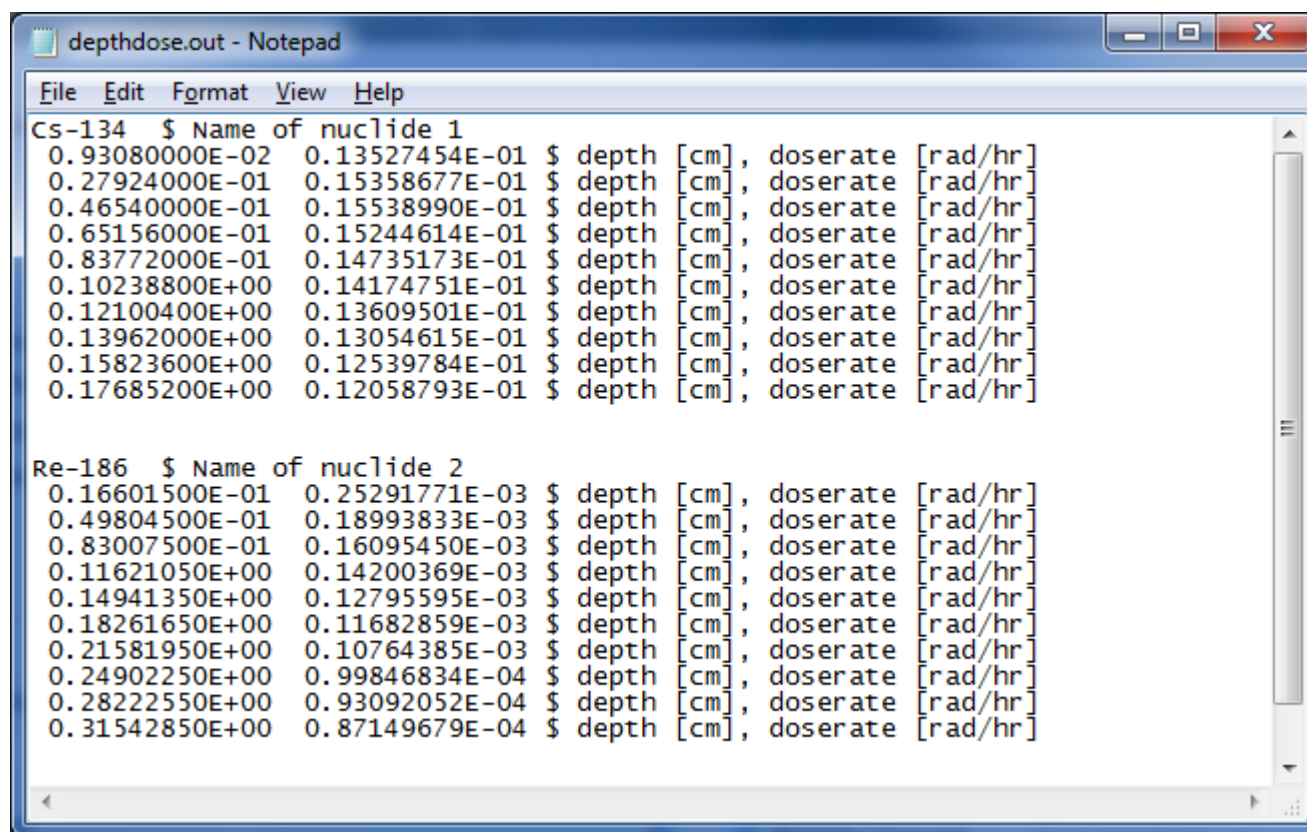
Print Results Close

“Hidden” output files

- These files could be helpful to you ...
 - depthdose
 - detailed
 - gamdose
 - gaminput
- Developed for photon-model debugging
- They’re found in the “dat” folder

File “Depthdose”

- Provides gamma dose rate at 10 depths (to max beta depth) when “perform volume averaging” is selected

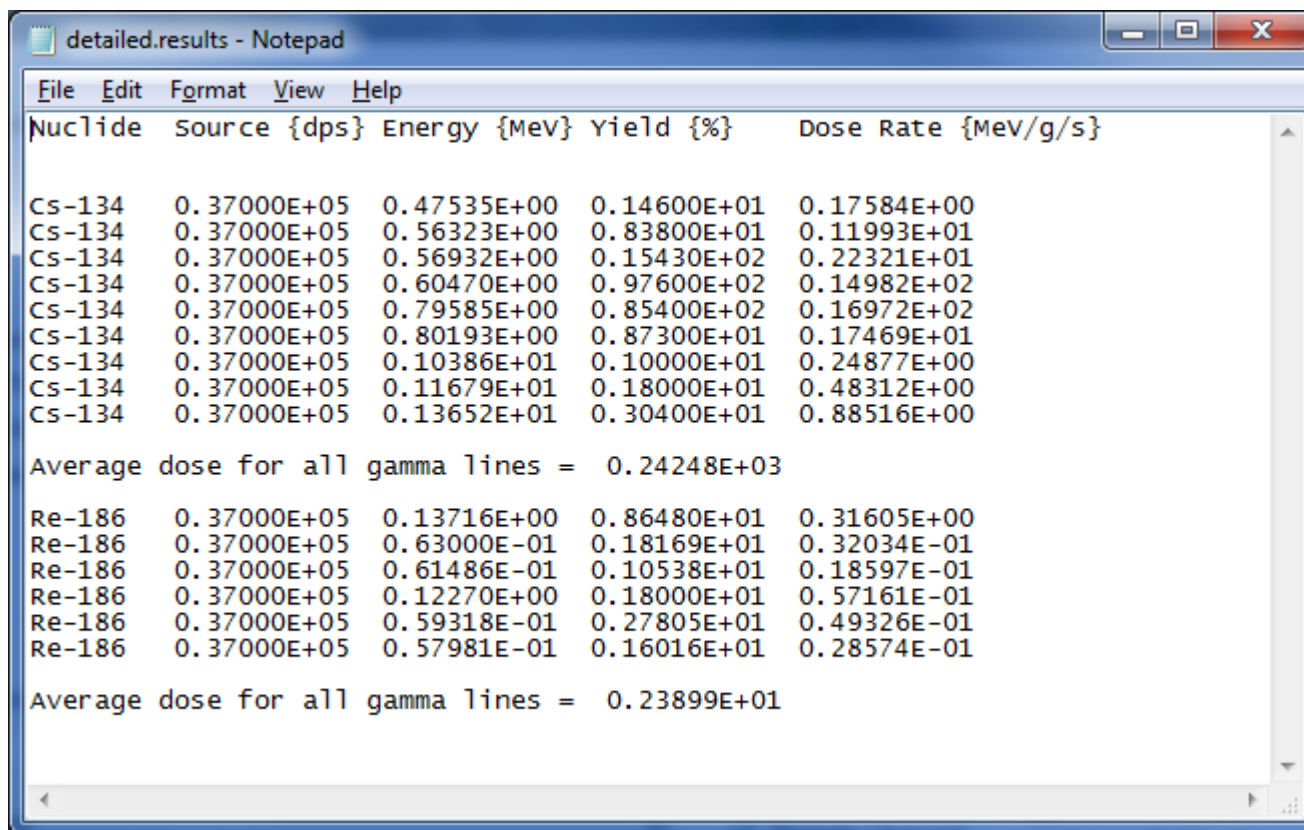


```
depthdose.out - Notepad
File Edit Format View Help
Cs-134 $ Name of nuclide 1
0.93080000E-02 0.13527454E-01 $ depth [cm], doserate [rad/hr]
0.27924000E-01 0.15358677E-01 $ depth [cm], doserate [rad/hr]
0.46540000E-01 0.15538990E-01 $ depth [cm], doserate [rad/hr]
0.65156000E-01 0.15244614E-01 $ depth [cm], doserate [rad/hr]
0.83772000E-01 0.14735173E-01 $ depth [cm], doserate [rad/hr]
0.10238800E+00 0.14174751E-01 $ depth [cm], doserate [rad/hr]
0.12100400E+00 0.13609501E-01 $ depth [cm], doserate [rad/hr]
0.13962000E+00 0.13054615E-01 $ depth [cm], doserate [rad/hr]
0.15823600E+00 0.12539784E-01 $ depth [cm], doserate [rad/hr]
0.17685200E+00 0.12058793E-01 $ depth [cm], doserate [rad/hr]

Re-186 $ Name of nuclide 2
0.16601500E-01 0.25291771E-03 $ depth [cm], doserate [rad/hr]
0.49804500E-01 0.18993833E-03 $ depth [cm], doserate [rad/hr]
0.83007500E-01 0.16095450E-03 $ depth [cm], doserate [rad/hr]
0.11621050E+00 0.14200369E-03 $ depth [cm], doserate [rad/hr]
0.14941350E+00 0.12795595E-03 $ depth [cm], doserate [rad/hr]
0.18261650E+00 0.11682859E-03 $ depth [cm], doserate [rad/hr]
0.21581950E+00 0.10764385E-03 $ depth [cm], doserate [rad/hr]
0.24902250E+00 0.99846834E-04 $ depth [cm], doserate [rad/hr]
0.28222550E+00 0.93092052E-04 $ depth [cm], doserate [rad/hr]
0.31542850E+00 0.87149679E-04 $ depth [cm], doserate [rad/hr]
```

File “Detailed”

- Provides gamma dose-rate (note units!) by gamma energy and average dose by nuclide

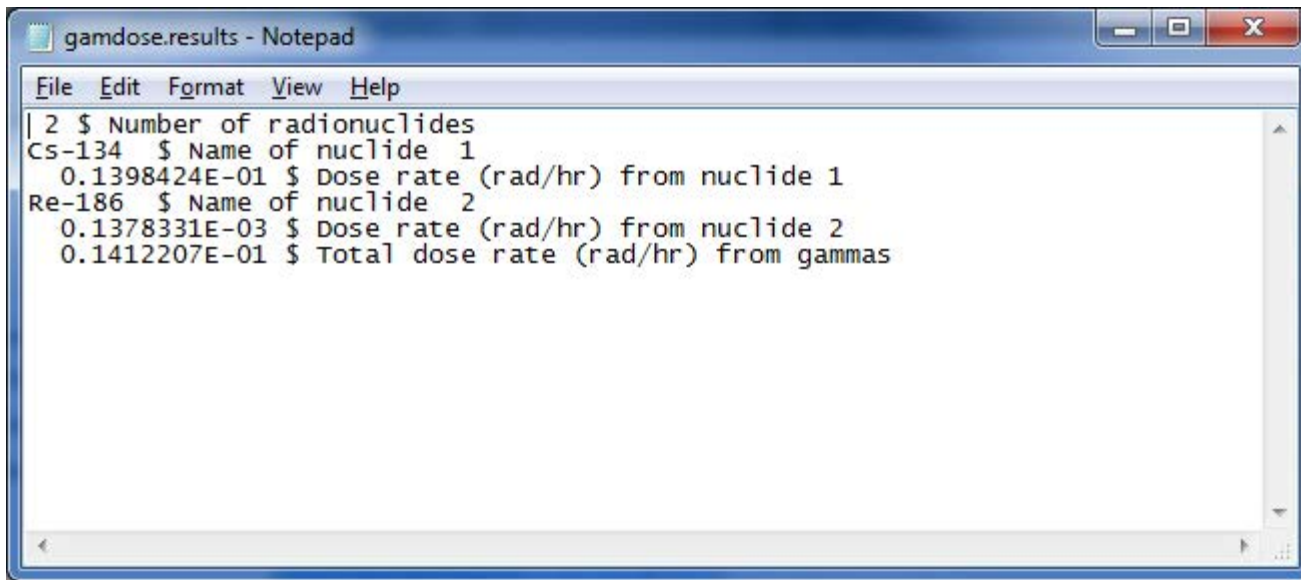


The screenshot shows a Notepad window with the title 'detailed.results - Notepad'. The window contains a table of gamma dose-rate data. The table has five columns: Nuclide, Source {dps}, Energy {MeV}, Yield {%, and Dose Rate {MeV/g/s}. The data is organized into two sections, one for Cs-134 and one for Re-186. Each section lists eight gamma lines with their respective energy, yield, and dose rate. Below each list of gamma lines, there is a summary line: 'Average dose for all gamma lines ='. The dose rate values are in scientific notation.

Nuclide	Source {dps}	Energy {MeV}	Yield {%	Dose Rate {MeV/g/s}
Cs-134	0.37000E+05	0.47535E+00	0.14600E+01	0.17584E+00
Cs-134	0.37000E+05	0.56323E+00	0.83800E+01	0.11993E+01
Cs-134	0.37000E+05	0.56932E+00	0.15430E+02	0.22321E+01
Cs-134	0.37000E+05	0.60470E+00	0.97600E+02	0.14982E+02
Cs-134	0.37000E+05	0.79585E+00	0.85400E+02	0.16972E+02
Cs-134	0.37000E+05	0.80193E+00	0.87300E+01	0.17469E+01
Cs-134	0.37000E+05	0.10386E+01	0.10000E+01	0.24877E+00
Cs-134	0.37000E+05	0.11679E+01	0.18000E+01	0.48312E+00
Cs-134	0.37000E+05	0.13652E+01	0.30400E+01	0.88516E+00
Average dose for all gamma lines = 0.24248E+03				
Re-186	0.37000E+05	0.13716E+00	0.86480E+01	0.31605E+00
Re-186	0.37000E+05	0.63000E-01	0.18169E+01	0.32034E-01
Re-186	0.37000E+05	0.61486E-01	0.10538E+01	0.18597E-01
Re-186	0.37000E+05	0.12270E+00	0.18000E+01	0.57161E-01
Re-186	0.37000E+05	0.59318E-01	0.27805E+01	0.49326E-01
Re-186	0.37000E+05	0.57981E-01	0.16016E+01	0.28574E-01
Average dose for all gamma lines = 0.23899E+01				

File “gamdose”

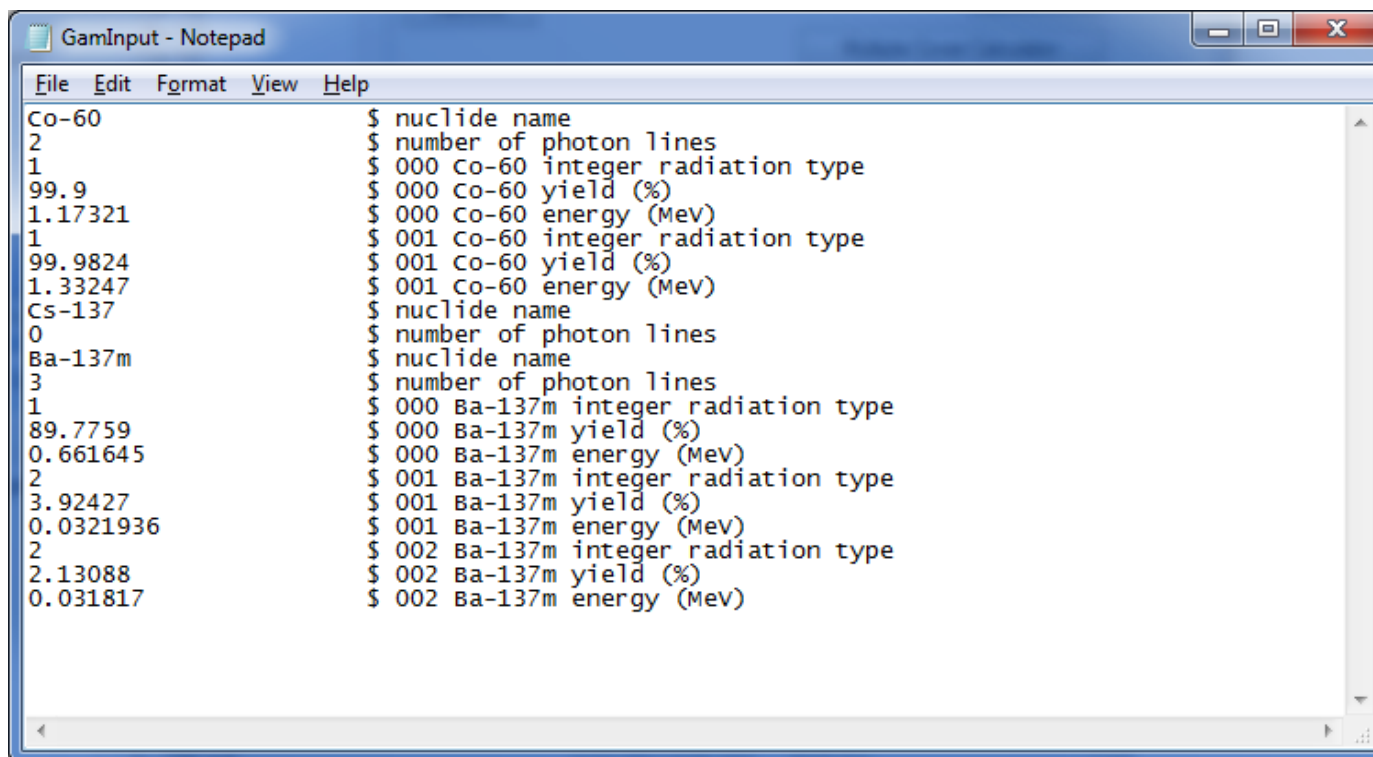
- Provides gamma dose-rate contribution by nuclide and total gamma dose rate



```
gamdose.results - Notepad
File Edit Format View Help
| 2 $ Number of radionuclides
Cs-134 $ Name of nuclide 1
0.1398424E-01 $ Dose rate (rad/hr) from nuclide 1
Re-186 $ Name of nuclide 2
0.1378331E-03 $ Dose rate (rad/hr) from nuclide 2
0.1412207E-01 $ Total dose rate (rad/hr) from gammas
```

File “gaminput”

- Provides data for each gamma emission of selected nuclides



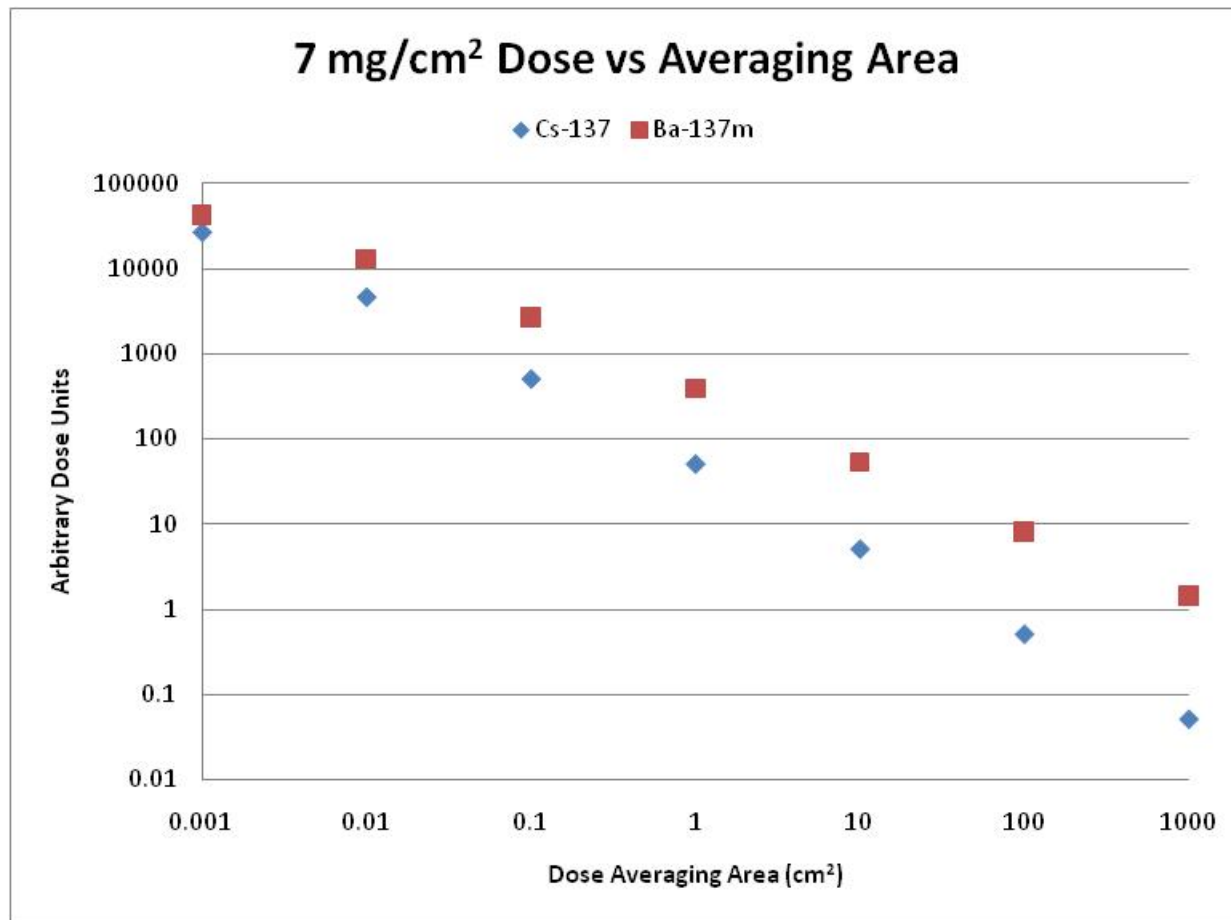
```
File Edit Format View Help
Co-60          $ nuclide name
2             $ number of photon lines
1             $ 000 Co-60 integer radiation type
99.9          $ 000 Co-60 yield (%)
1.17321       $ 000 Co-60 energy (Mev)
1             $ 001 Co-60 integer radiation type
99.9824       $ 001 Co-60 yield (%)
1.33247       $ 001 Co-60 energy (Mev)
Cs-137        $ nuclide name
0             $ number of photon lines
Ba-137m       $ nuclide name
3             $ number of photon lines
1             $ 000 Ba-137m integer radiation type
89.7759       $ 000 Ba-137m yield (%)
0.661645      $ 000 Ba-137m energy (Mev)
2             $ 001 Ba-137m integer radiation type
3.92427       $ 001 Ba-137m yield (%)
0.0321936     $ 001 Ba-137m energy (Mev)
2             $ 002 Ba-137m integer radiation type
2.13088       $ 002 Ba-137m yield (%)
0.031817      $ 002 Ba-137m energy (Mev)
```

Varskin Limitations

Input limits

- Skin averaging area: 0.01 – 100 cm²
- Air gap thickness: 5 cm
- Covers: Up to 5
- Volume averaging: non-negative
 - and “deeper” must be greater than “shallower” depth
- Large source dimensions results in a warning, but code is still executed
 - possible error w/ small-area dose averaging

Impact of dose averaging area



Modeling limitations

- Radionuclide selection
- Source dimensions
- Air gap model
- Cover model
- Multiple sources

Modeling limitations

- Source/geometry
 - Calculates dose to skin from skin contamination
 - uses should be restricted to this application
 - Radioactive progeny are not included in parent nuclides
 - must be selected explicitly ($^{137\text{m}}\text{Ba}$ for example)
 - but, be careful of decay-corrected dose!
 - Reliable for particulate sources with dimensions up to 8x nuclide beta range in tissue
 - Not tested extensively for dose areas $> 10 \text{ cm}^2$
 - but, our quick study indicates that linearity exists for photons with averaging areas between 10^{-3} cm^2 and 10^3 cm^2

Modeling limitations

- Infinite sources (e.g., enveloping cloud)
 - Choosing very large source dimensions will result in inaccurate or zero doses because integration routine becomes unstable
 - Correct approach is to determine maximum penetration distance (X_{99}) and set source dimensions accordingly
 - Essentially use dimensions to allow betas to expose the skin, while considering self absorption and backscatter
 - Again, this scenario may mean that the code is being applied outside its intended use

Modeling limitations

- Photon model limited to an air gap < 5 cm
 - A large air gap means that skin contamination isn't the proper scenario; not proper code usage
 - Large air gap will likely result in errors due to multiple scattering events in air
 - Code will not allow calculations for air gap > 5 cm, and a warning is displayed
 - Preliminary results indicate that a disruption in electronic equilibrium with air gaps could make deterministic modeling quite difficult

Modeling limitations

- Cover model allows 5 layers of covering
 - User enters up to 5 cover thickness/density combinations
 - Code will calculate “equivalent” (single) cover
 - Source assumed to sit on top of cover
 - If air is present, it is assumed to be between skin and cover
 - Current model does not consider alterations in charged-particle buildup caused by cover

Modeling limitations

- Multiple Contamination Sources
 - Determining the maximum dose to a given dose-averaging area for multiple contaminations requires multiple calculations
 - The calculations require elements that are not available in VARSKIN 4, but that can be accomplished manually
 - Based on the orientation of particles on the skin, sketch dose-averaging areas (e.g., 10 cm² circles) centered on each radioactive particle
 - Determine average dose to a common averaging area for each source particle
 - Use the offset particle model to perform dose calculation
 - VARSKIN 4/5 only allows off-axis dose calculations for a point source

A few tips

- Set exposure time to 1 second and use an activity of 1 Bq; resulting dose will be a “dose conversion factor” with units of dose per decay.
- Calculate dose for point source first, then refine in several steps changing geometry in each step. This provides an indication of the sensitivity of your geometry choice and a boundary of possible dose values.
- Use the “Save/Load Default State” option to run common scenarios.

User input to date

Users would like to see ...

- Calculation for a particle trapped under the skin
- Increase the 5 cm limit on air gap
- Clothing and air gap cause issues with electronic buildup
- Include positron annihilation photons
- Include daughter products (Ga-68 was point out)
- Include ICRP 107 data
- Smart phone app
- Inclusion of obscure nuclides: V-52, Re-183, Ga-68
- Uncertainty/Sensitivity analysis capability
- IEEE certification

Where will VARSKIN fail?

- If, in dose volume averaging, the user enters a value greater than the X_{99} distance, the dose average is less than the maximum because now the code is averaging zeroes and negative dose values may be calculated.
- In the photon model, if the dose averaging area is small relative to the source cross section on the skin, arc-sine and arc-cosine calculational errors will occur.
- Photon dosimetry with point and disk geometries is excellent, but the air and cover models currently are not reliable.
- Users have found electron dose from Be-7, Y-90, Ho-166m, to be very high (short-lived nuclides)



Quality Assurance - Validation & Verification

Software V & V

- Validation: The process of evaluating software to determine whether it satisfies specified requirements. [IEEE-STD-610]

Are we building the right product?

- Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. [IEEE-STD-610]

Are we building the product right?

Validation

Are we building the right product?

- VARSKIN validation comes in the form of confirmation that the dosimetry models used therein are the models that are appropriate for photon and electron dosimetry
- Is the point-kernel method appropriate for skin-contamination dosimetry?
- We might be biased, but we believe, “YES”. 😊

Verification

Are we building the **product** **right**?

- VARSKIN verification was completed through a comparison of results with probabilistic particle-transport simulation packages:
 - photon dosimetry compared with MCNP5
 - electron dosimetry compared with EGSnrc
- Results were also compared with previous versions of VARSKIN to identify potential coding errors
- All verification work was performed by individuals not involved with the creation of new models

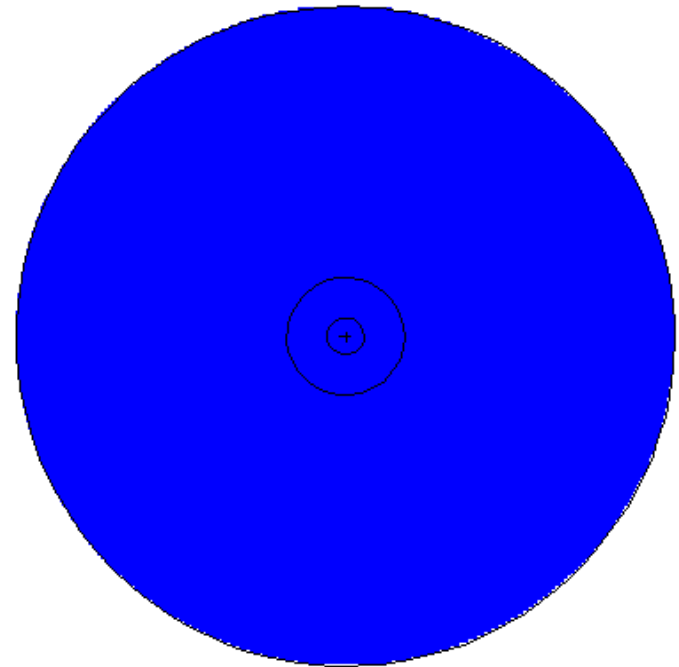
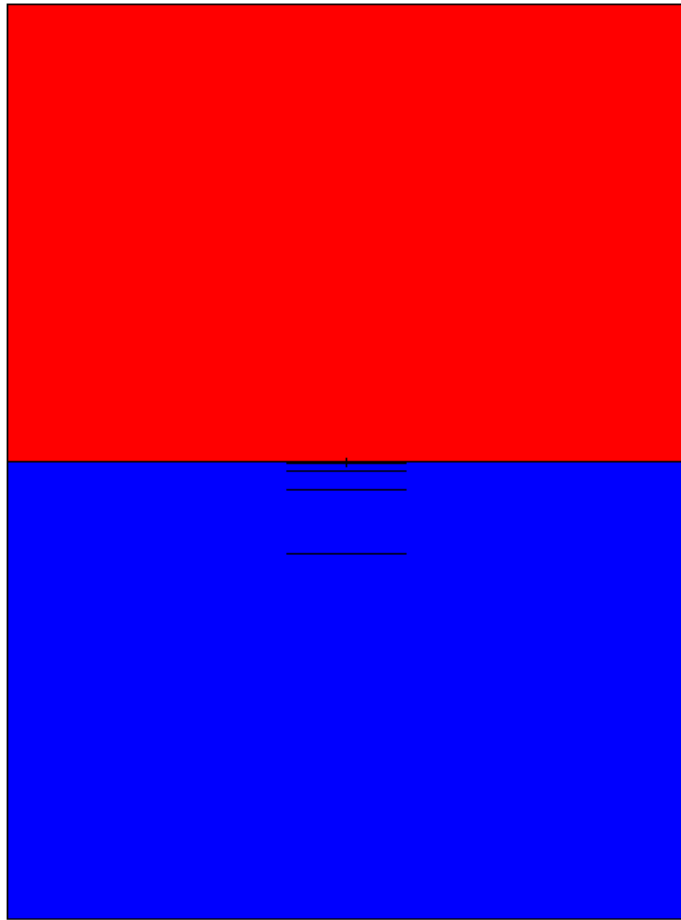
Supplemental Verification

- Examination of fundamental physics:
 - **Energy transfer (KERMA)**
 - **Charged-particle buildup**
 - **Absorption and attenuation coefficients**
 - **Off-axis scatter**
 - **Scaled absorbed dose distributions**
 - **Particle range and stopping power estimates**
 - **Backscatter factors**

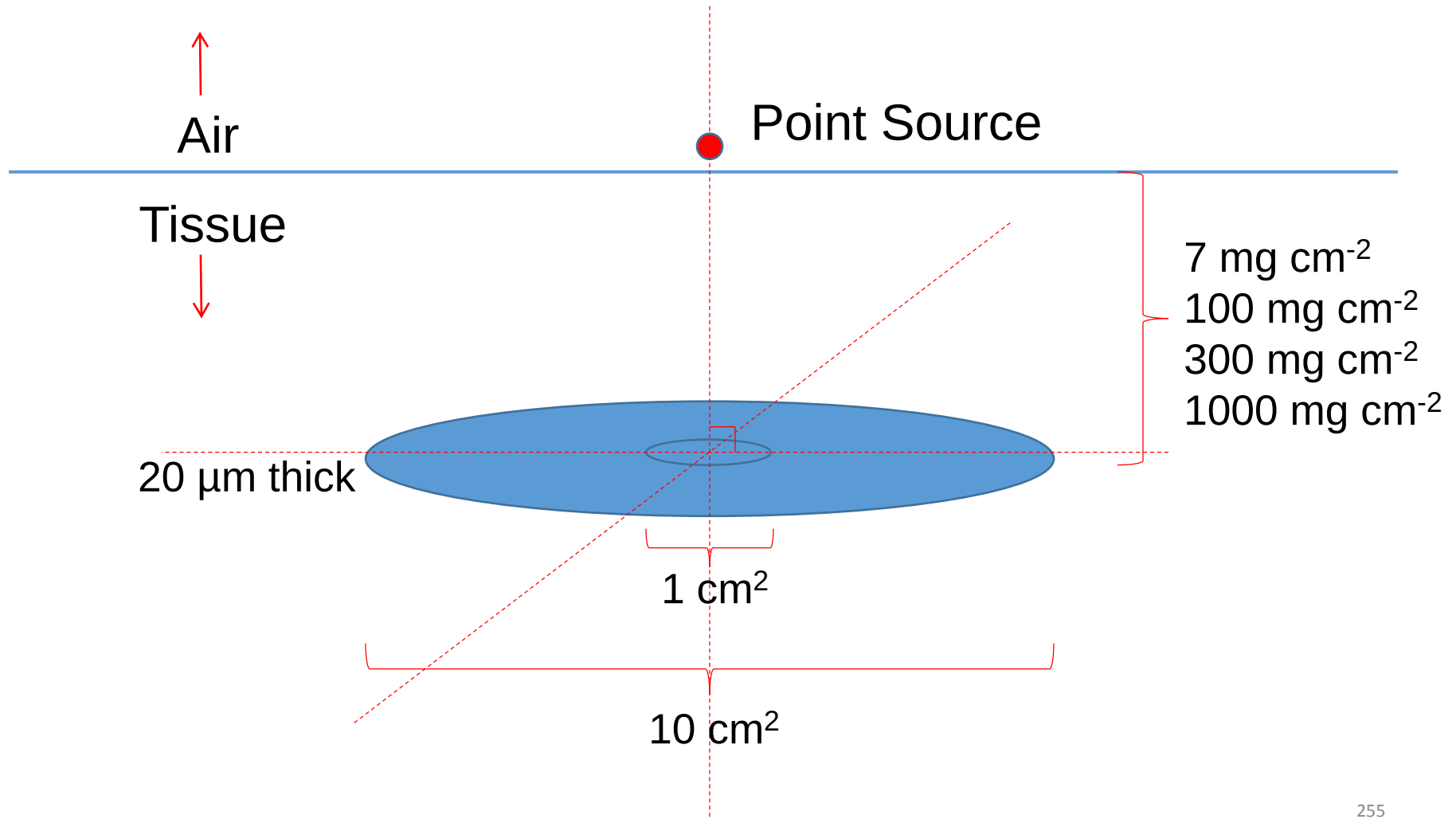
Verification

- The modeled composition of unit-density skin was taken from ICRU
- Two dose-averaging areas were modeled:
 - 1 cm²
 - 10 cm²
- Four tissue depths were modeled:
 - 7 mg cm⁻² (shallow dose)
 - 100 mg cm⁻²
 - 300 mg cm⁻² (lens dose)
 - 1000 mg cm⁻² (deep dose)

The Simulation Universe



Monte Carlo Geometric Model



Modeled Sources

- Since we use the point-kernel method for photon and electron dosimetry, it is important to observe the dose contribution for each particle as a function of initial energy
- Sources, therefore, were simulated to emit single photons and single electrons (100% yield)
- Initial particle energies ranged from 25 keV to 3 MeV
- Unless otherwise stated, it is assumed that no air gap and no covers exist between the source and the skin surface

Statistical Error

- The number of particles was sufficiently high to keep the statistical error to less than 5%
- Standard error was generally greater for lower energies and at deeper tissue depths
- Minimum beta energy (up to a maximum of 3 MeV) was increased when examining dose at depth; energy ranges used:
 - - $E > 0.08 \text{ MeV}$ @ 7 mg/cm^2
 - - $E > 0.40 \text{ MeV}$ @ 100 mg/cm^2
 - - $E > 0.80 \text{ MeV}$ @ 300 mg/cm^2
 - - $E > 2.10 \text{ MeV}$ @ 1000 mg/cm^2

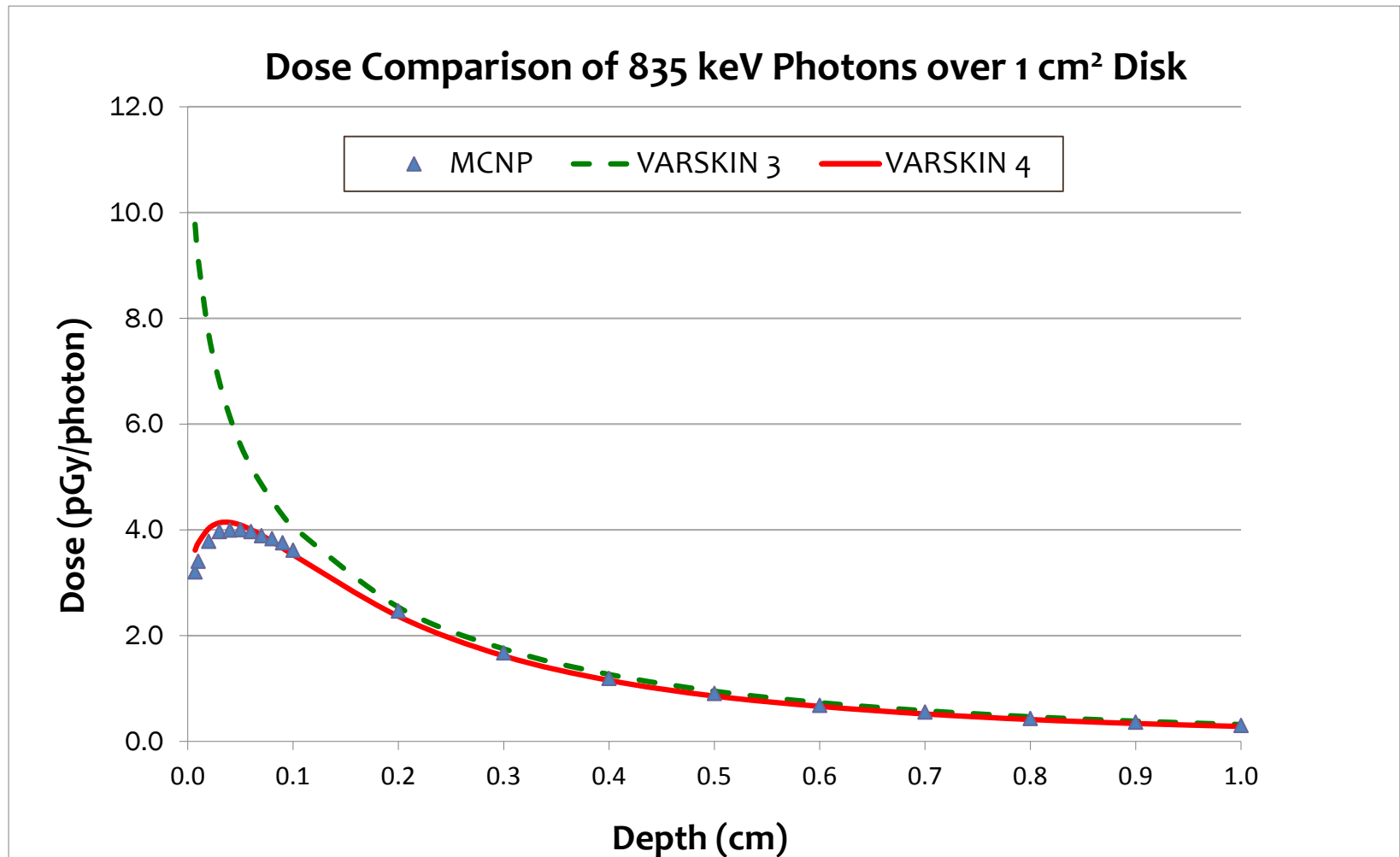


Performance of the photon dosimetry model

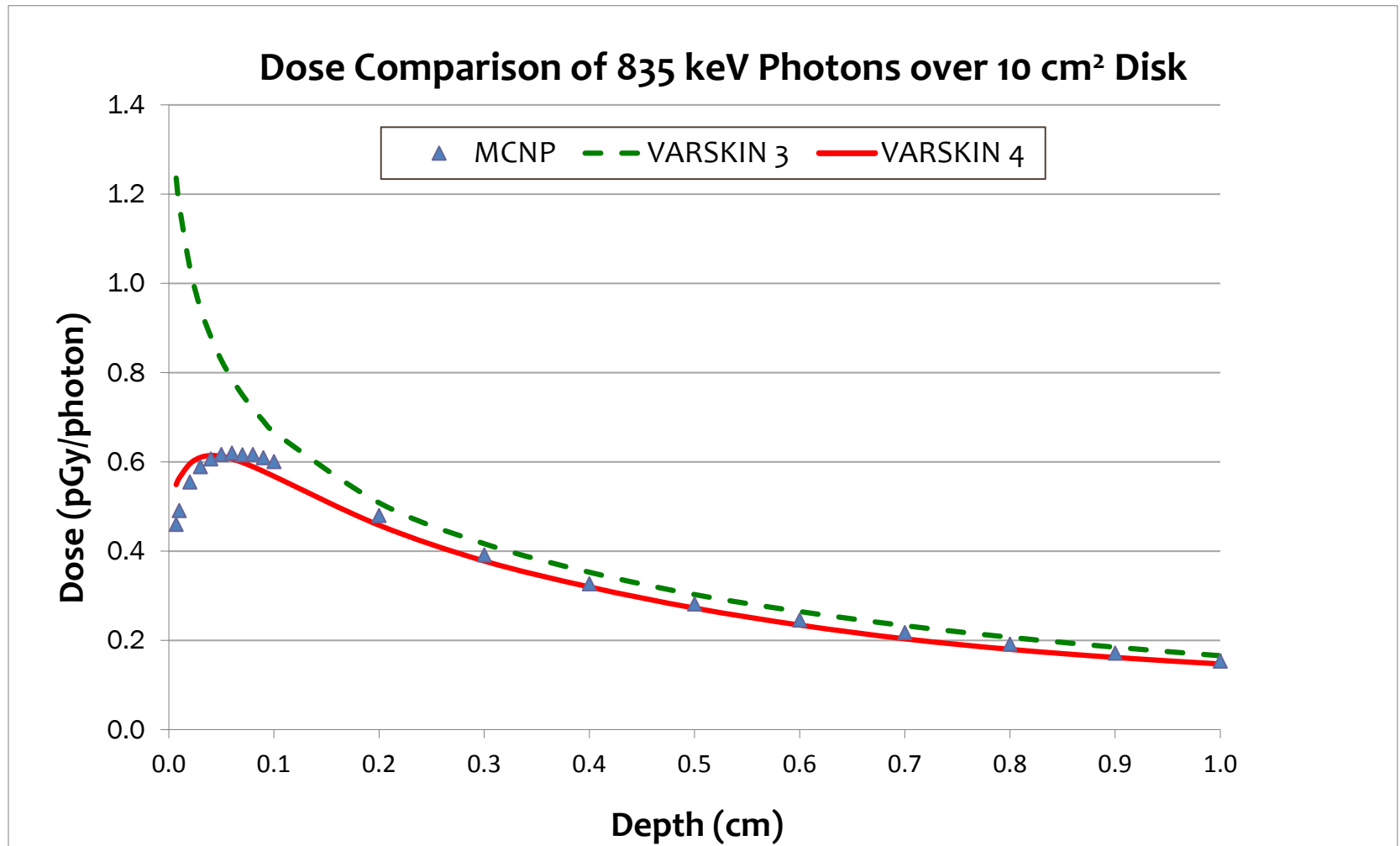
Photon Energy Absorption Simulated with MCNP5

- Five photon-emission geometries modeled:
 - Point
 - Disk (area = 1 cm²)
 - Cylinder (r = 1 cm, h = 0.5 cm)
 - Slab (l = w = 1 cm, h = 0.5 cm)
 - Sphere (r = 1 cm)
- All source geometries located 0.1 nm in air above skin
- Material compositions (other than tissue) were taken from NIST standards for each material
- All sources were assumed to be composed of air
- No model changes between V4 and V5

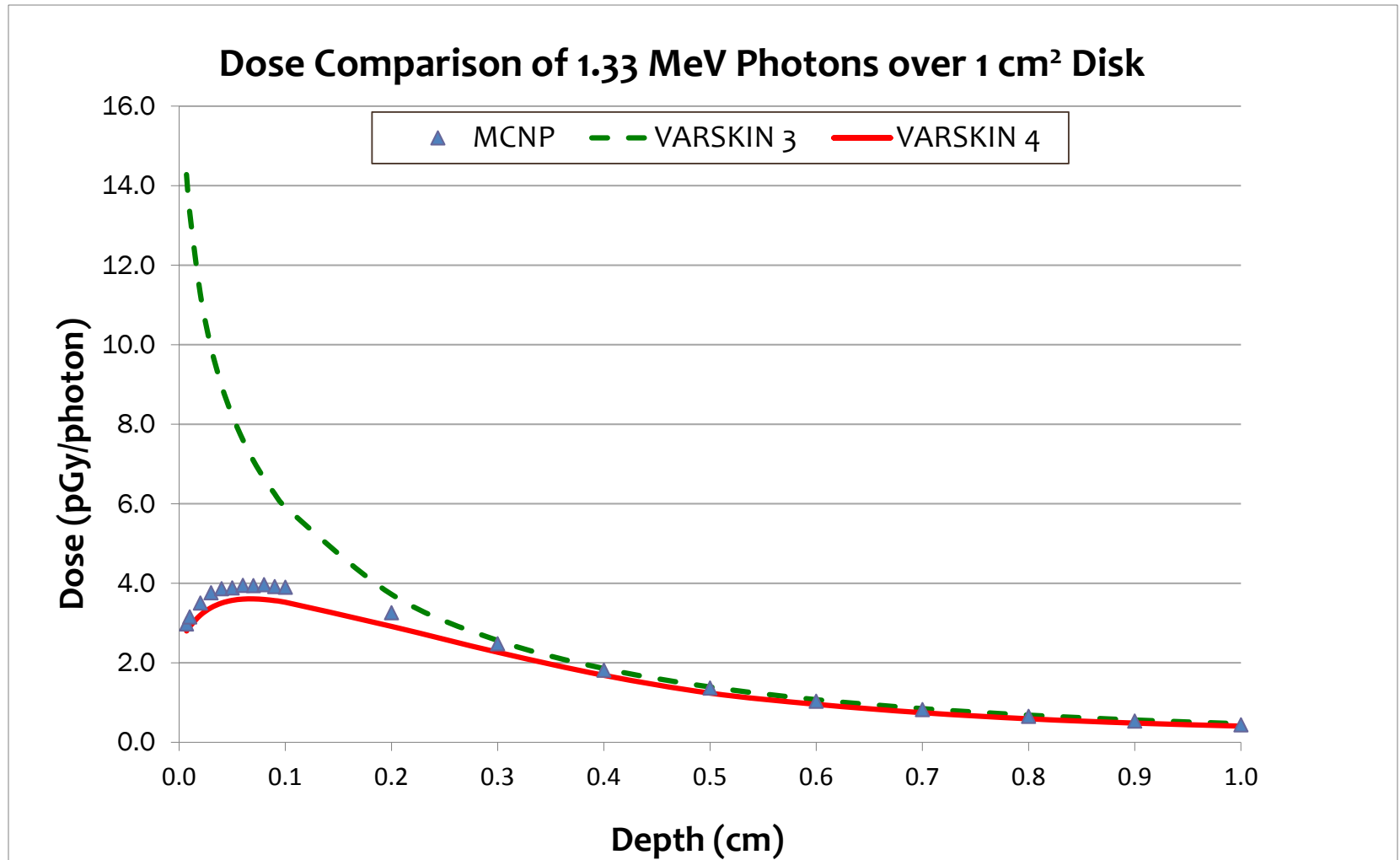
Depth Profile – early CPE demo



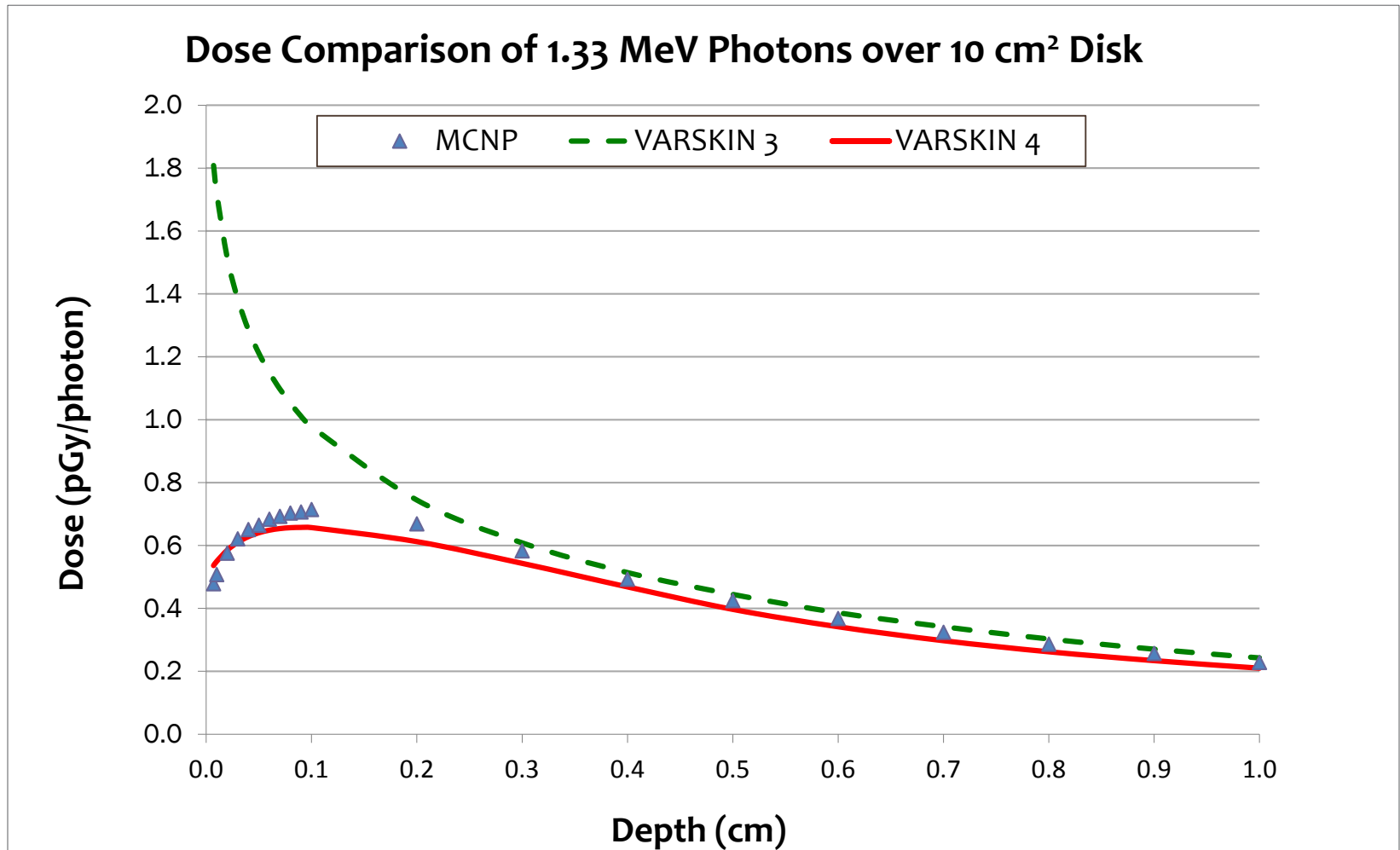
Depth Profile – early CPE demo



Depth Profile – early CPE demo

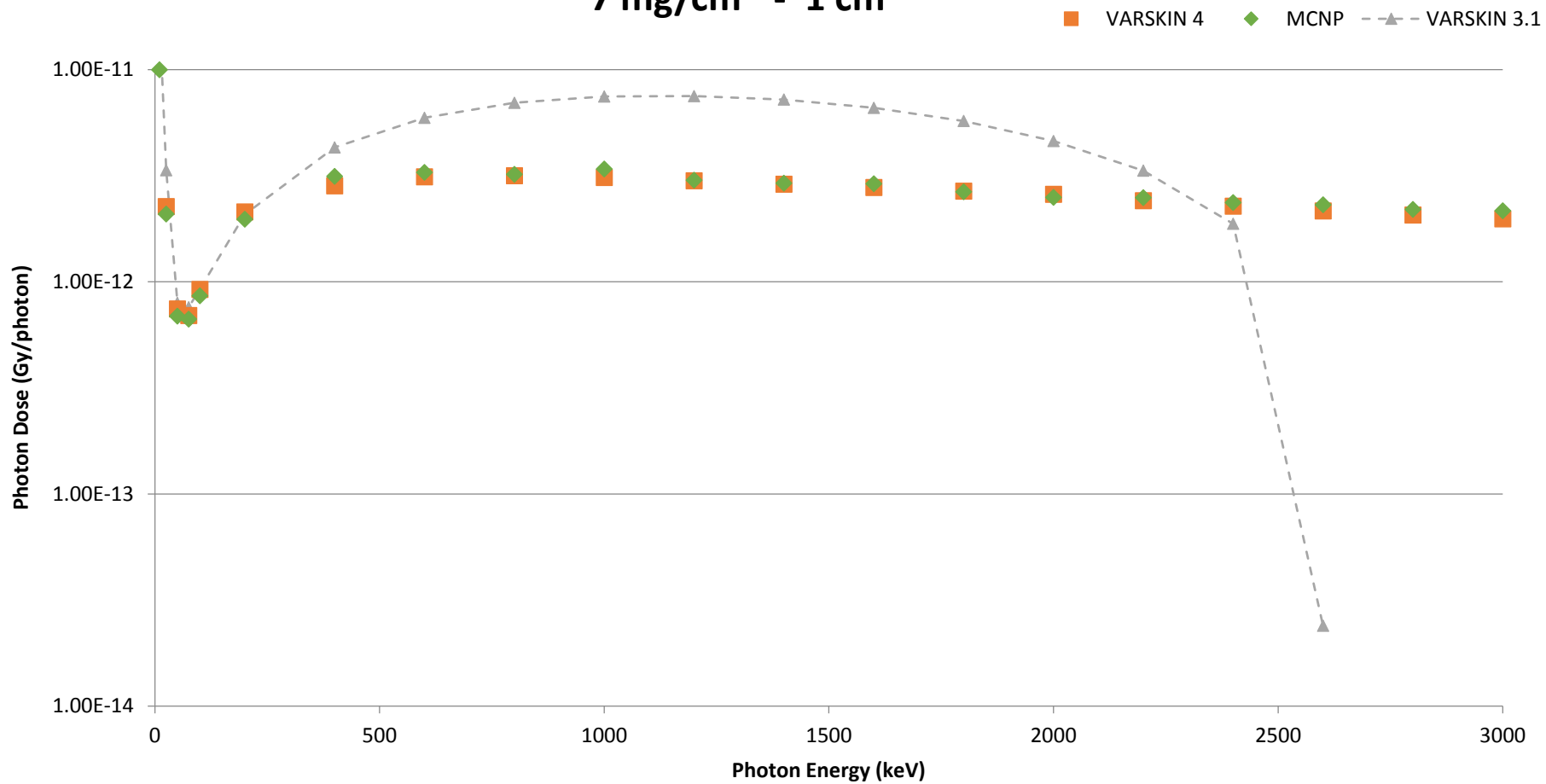


Depth Profile – early CPE demo



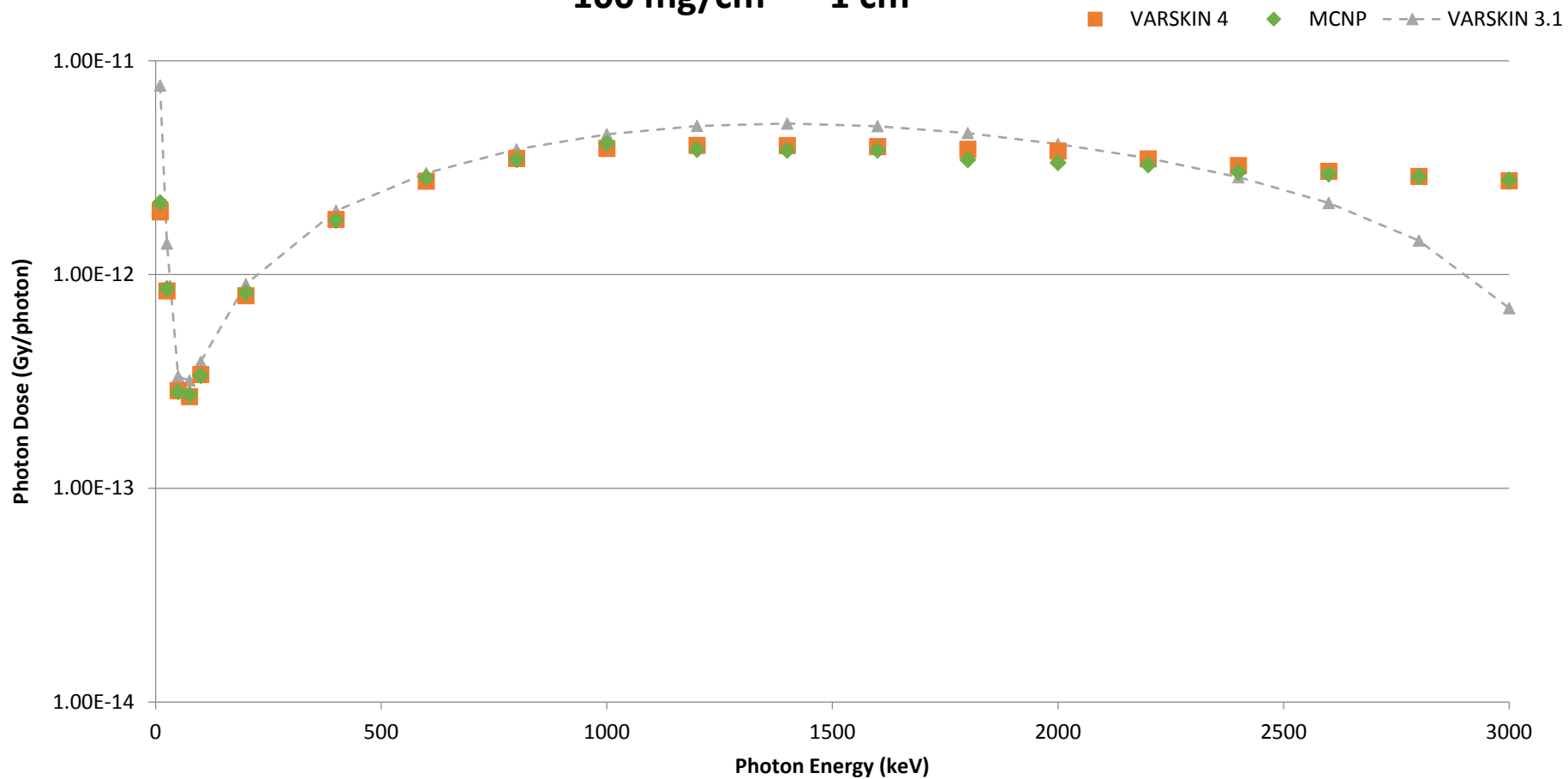
Results – Point Source

7 mg/cm² - 1 cm²



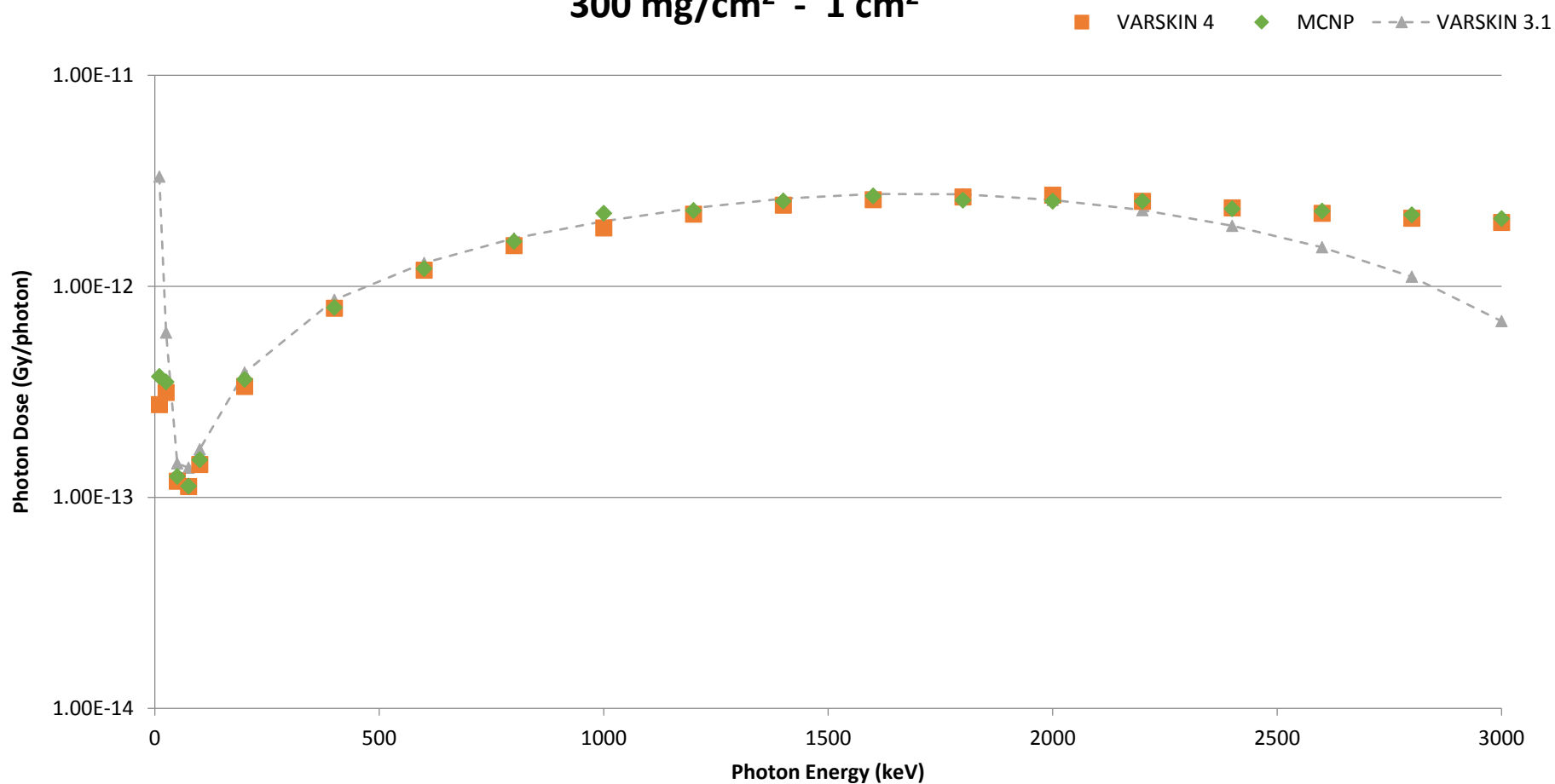
Results – Point Source

100 mg/cm² - 1 cm²



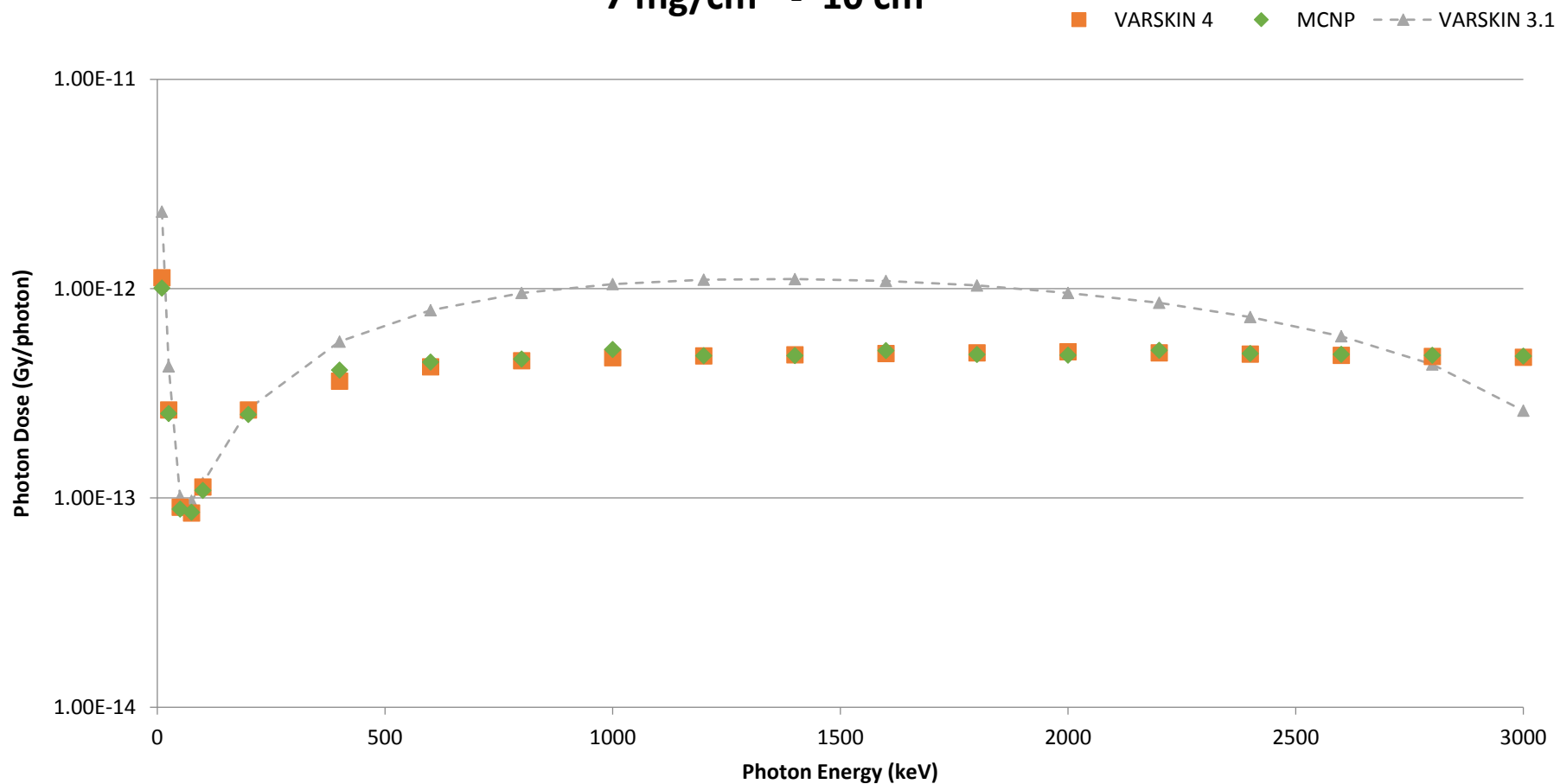
Results – Point Source

300 mg/cm² - 1 cm²



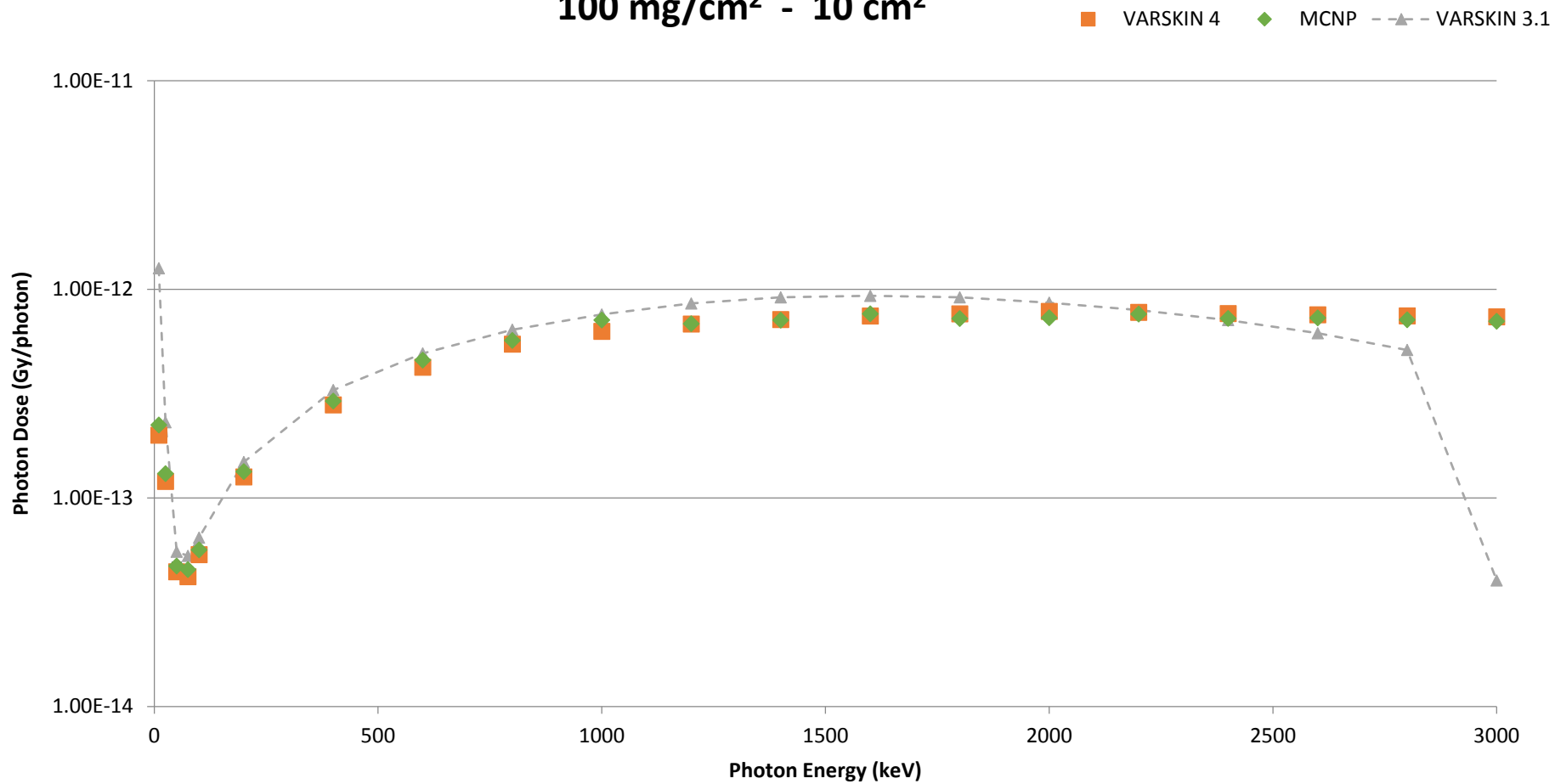
Results – Point Source

7 mg/cm² - 10 cm²



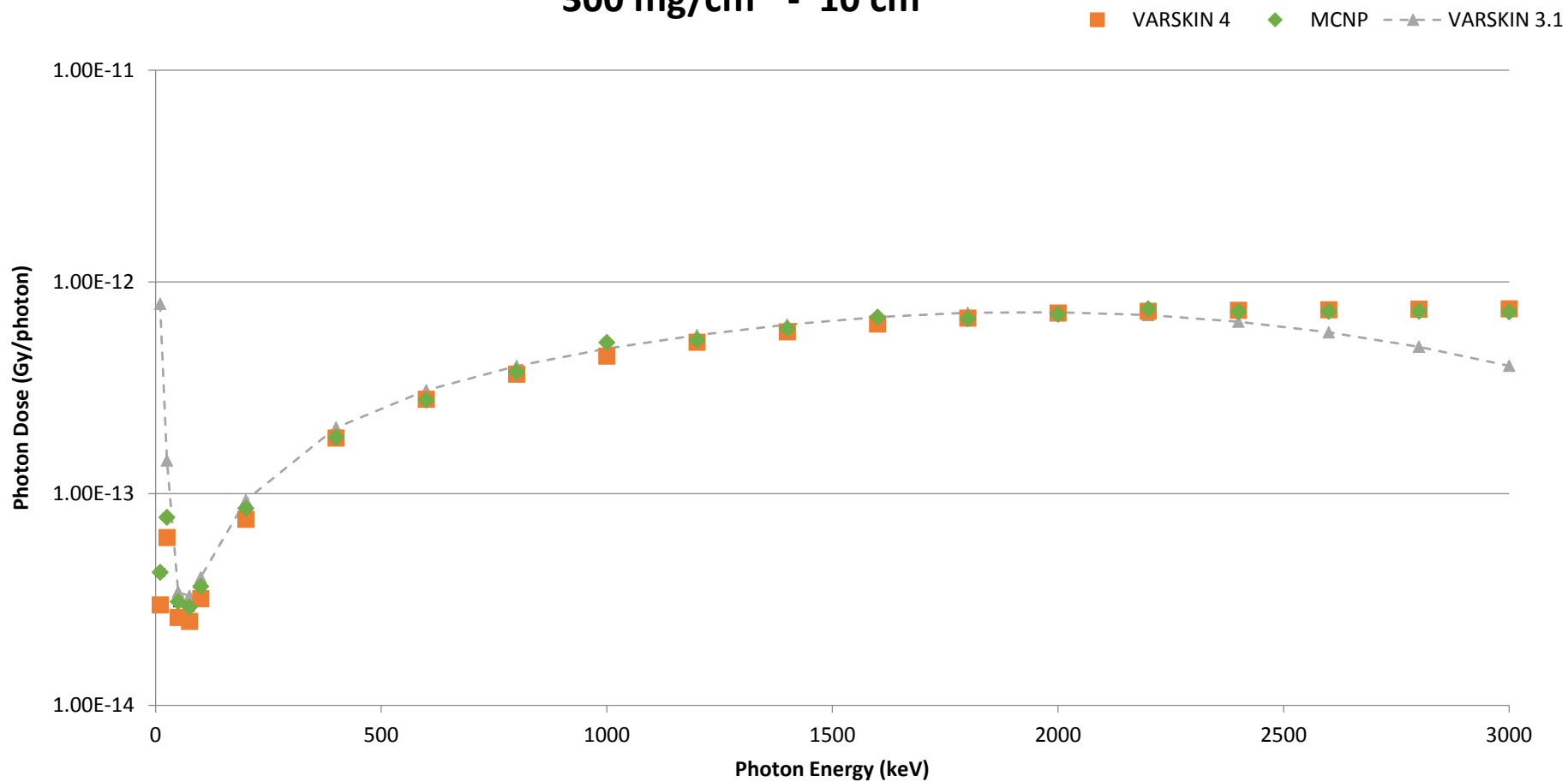
Results – Point Source

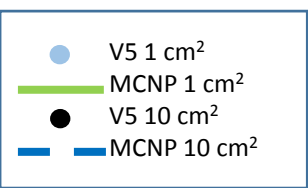
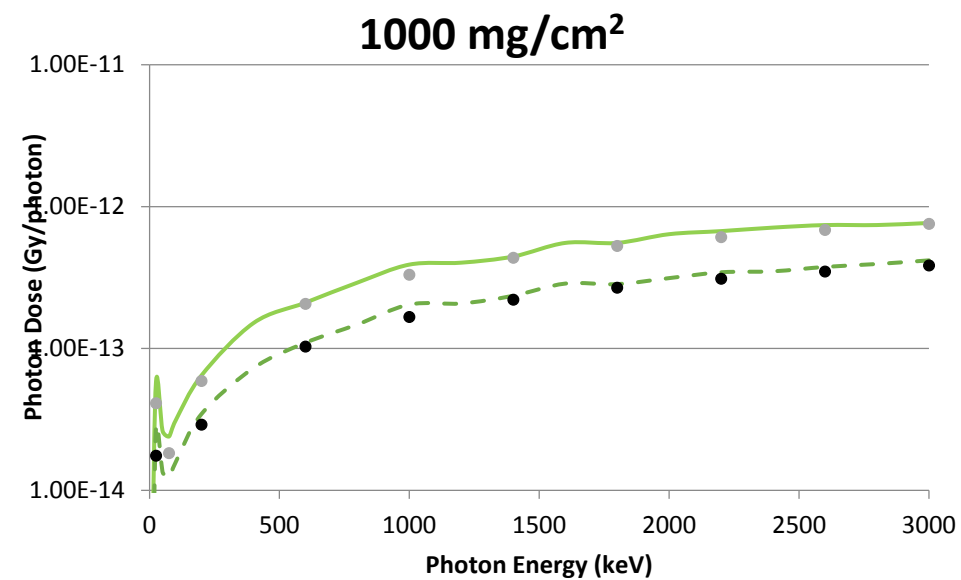
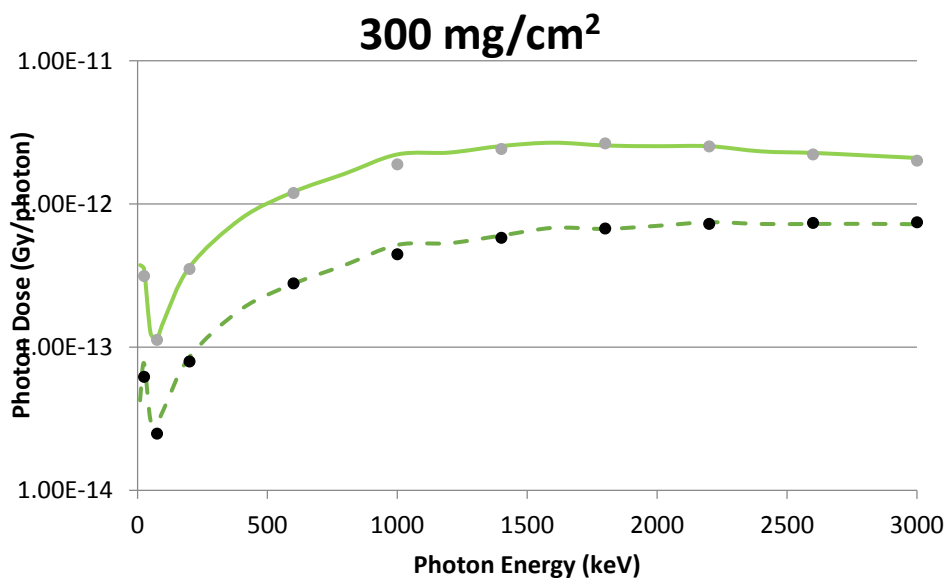
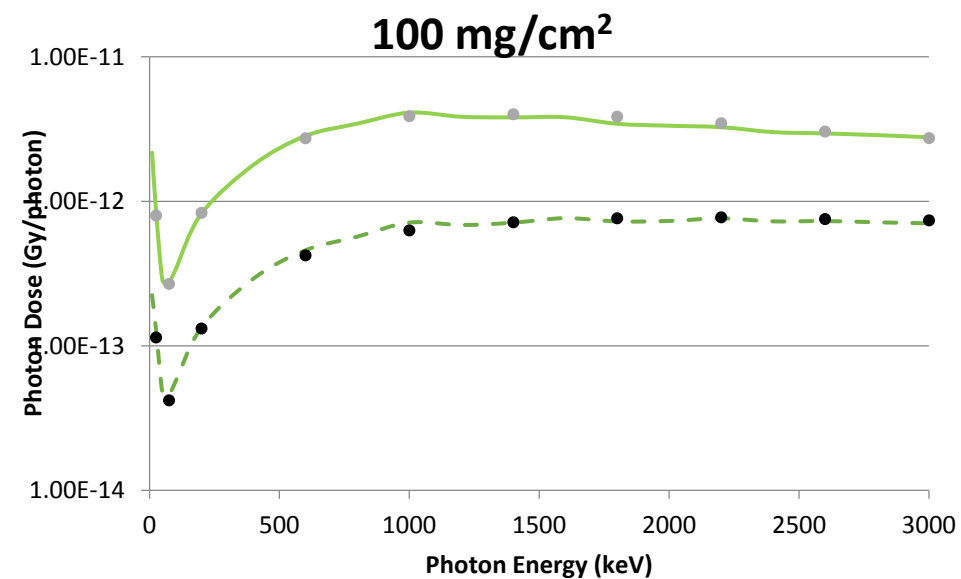
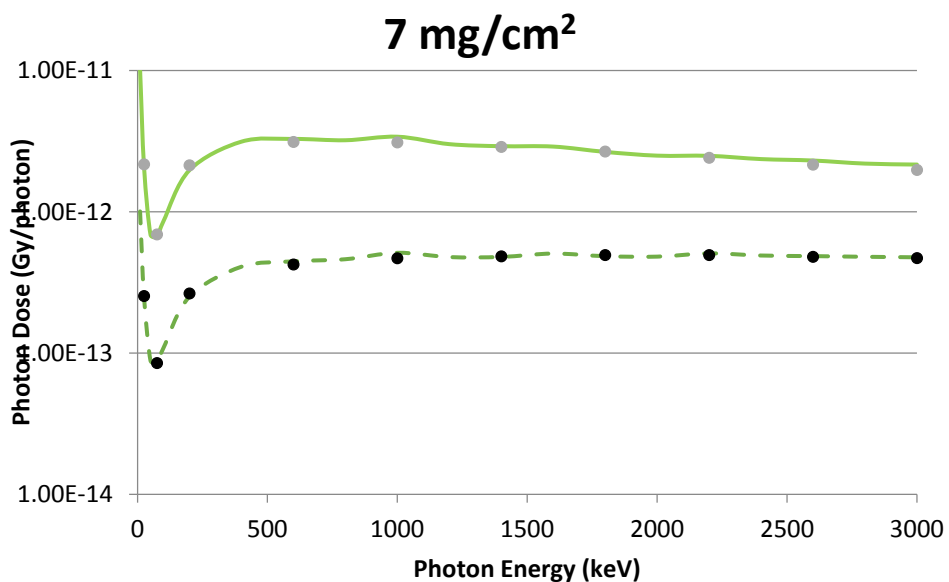
100 mg/cm² - 10 cm²



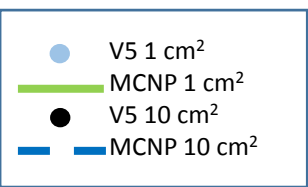
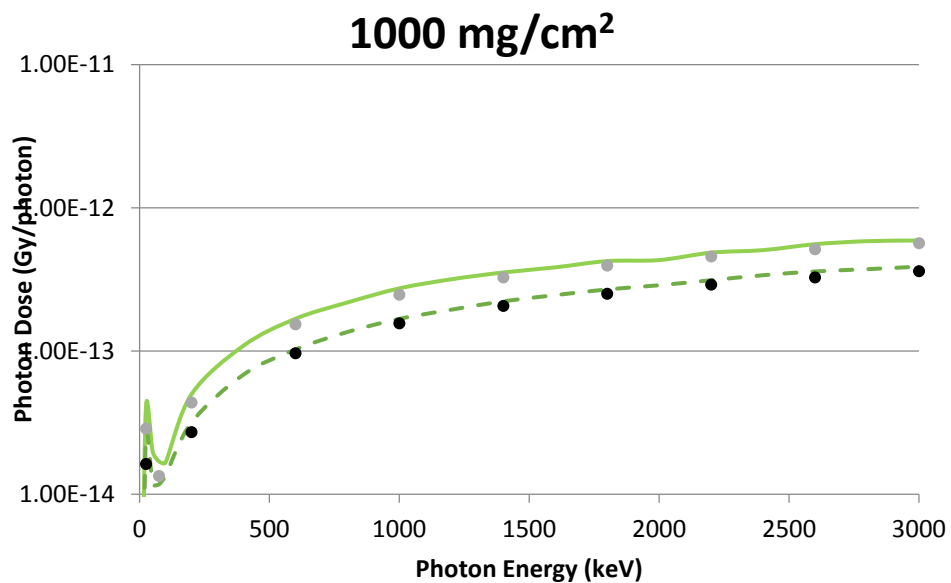
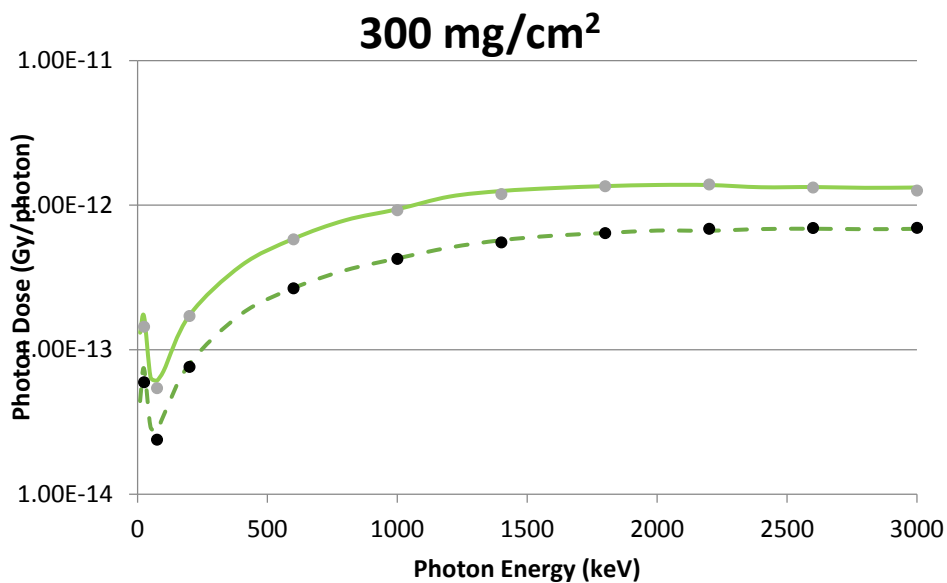
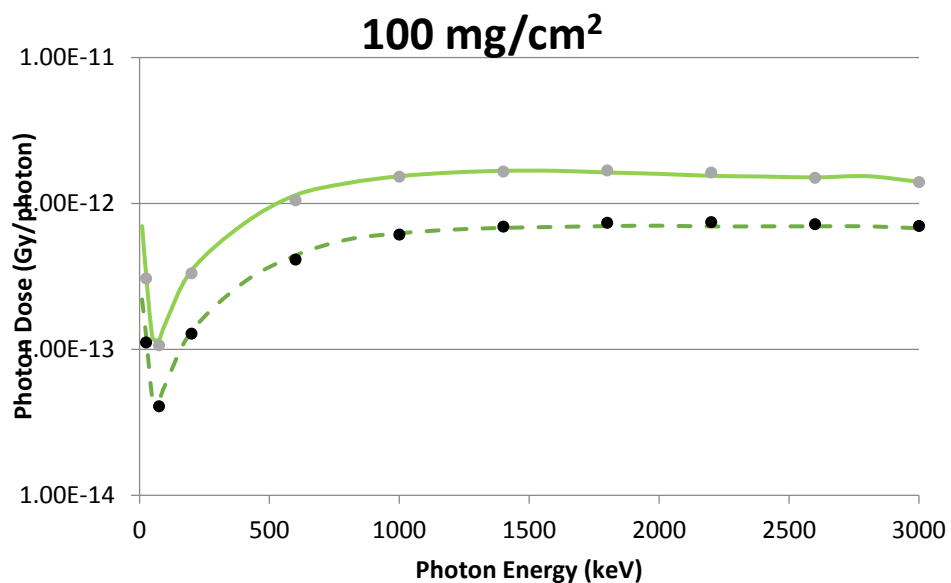
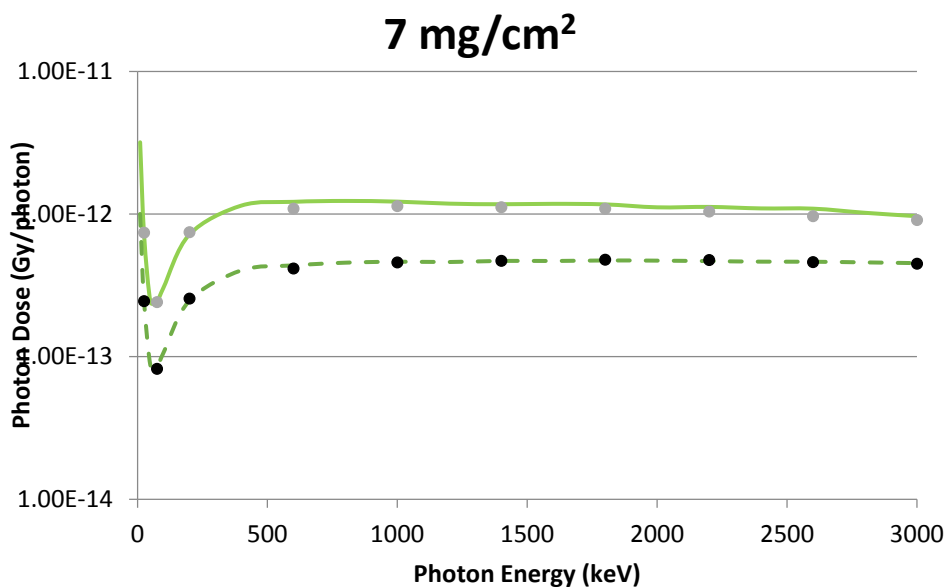
Results – Point Source

300 mg/cm² - 10 cm²

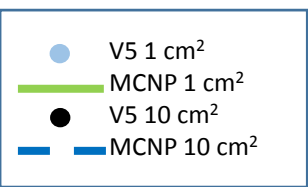
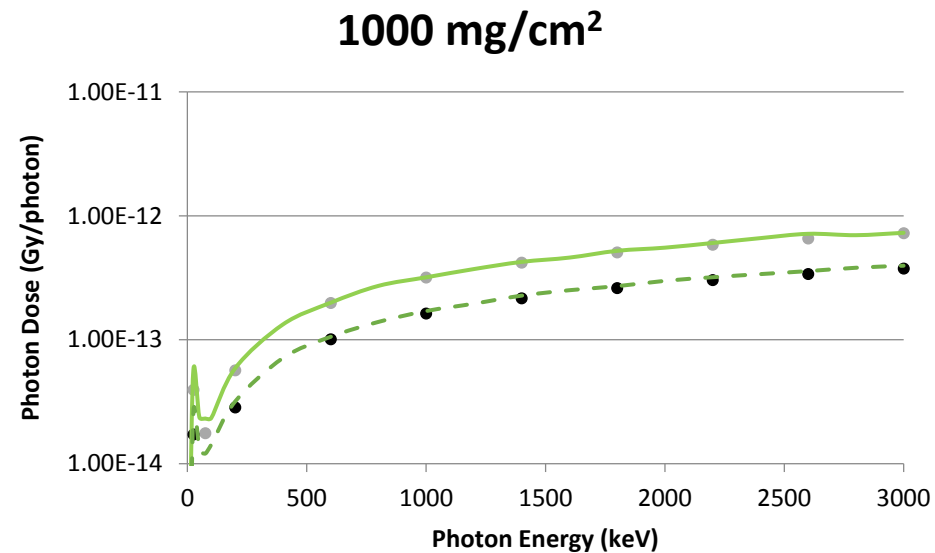
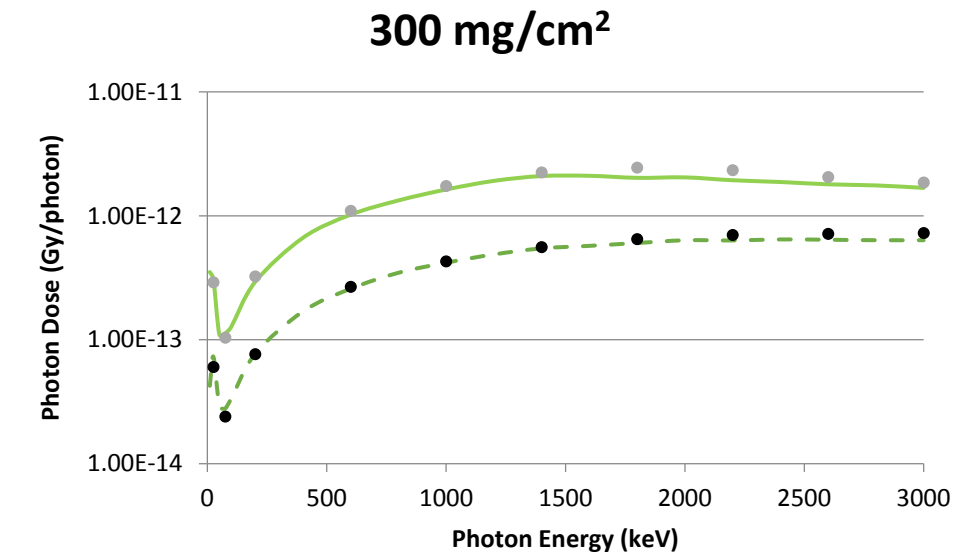
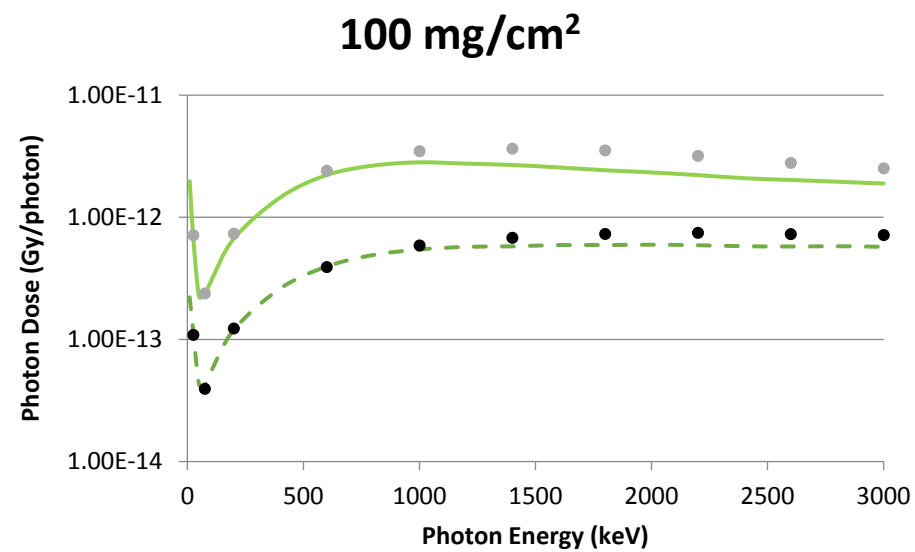
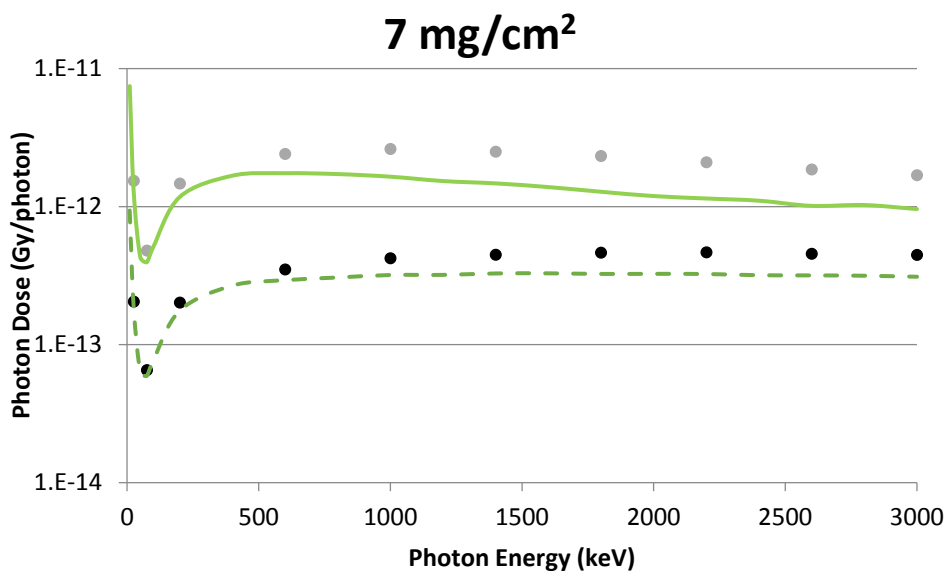




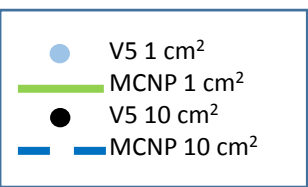
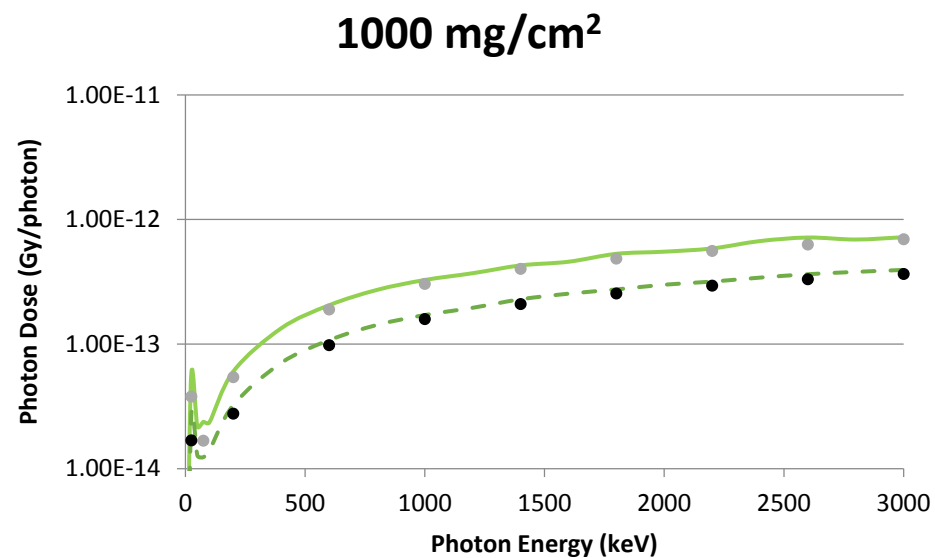
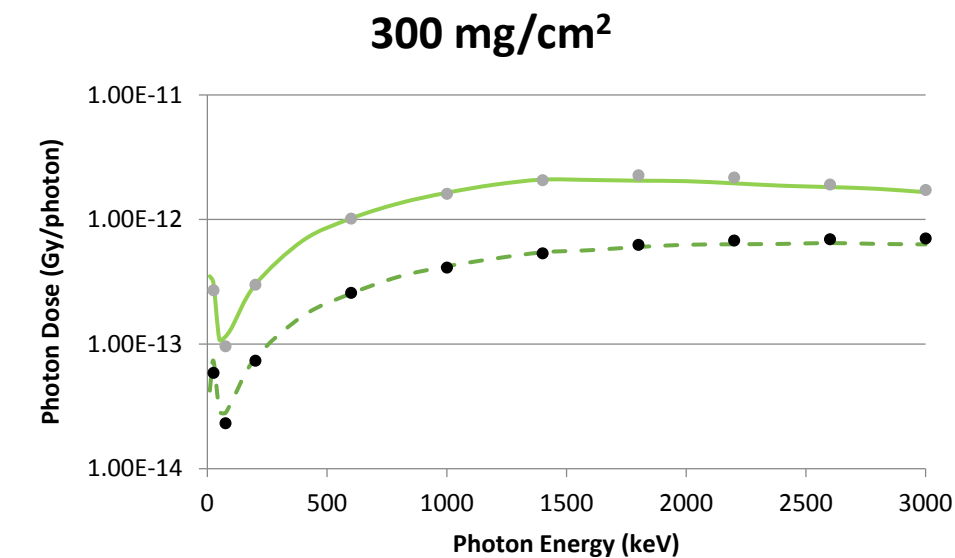
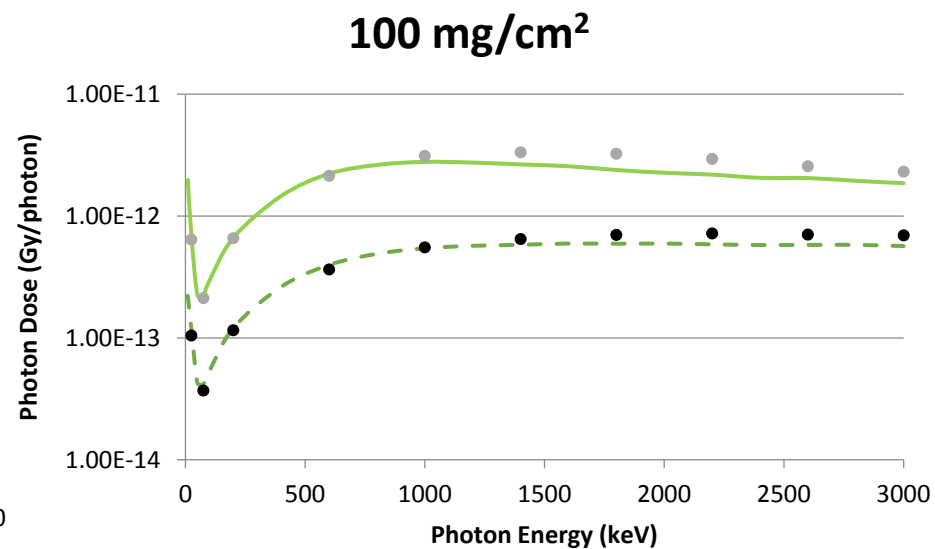
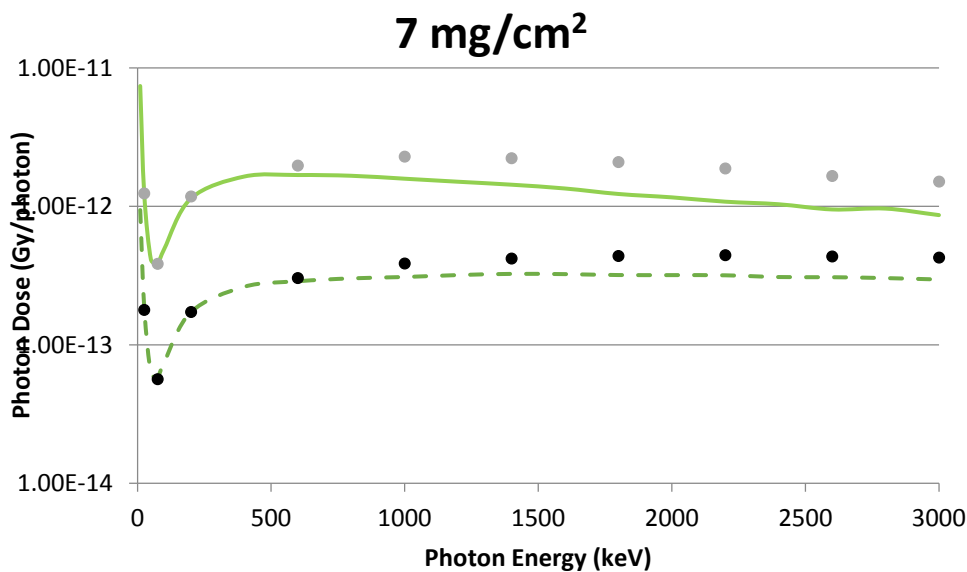
Point source - photon



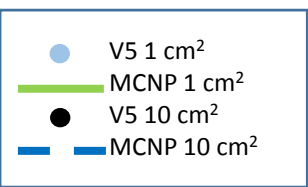
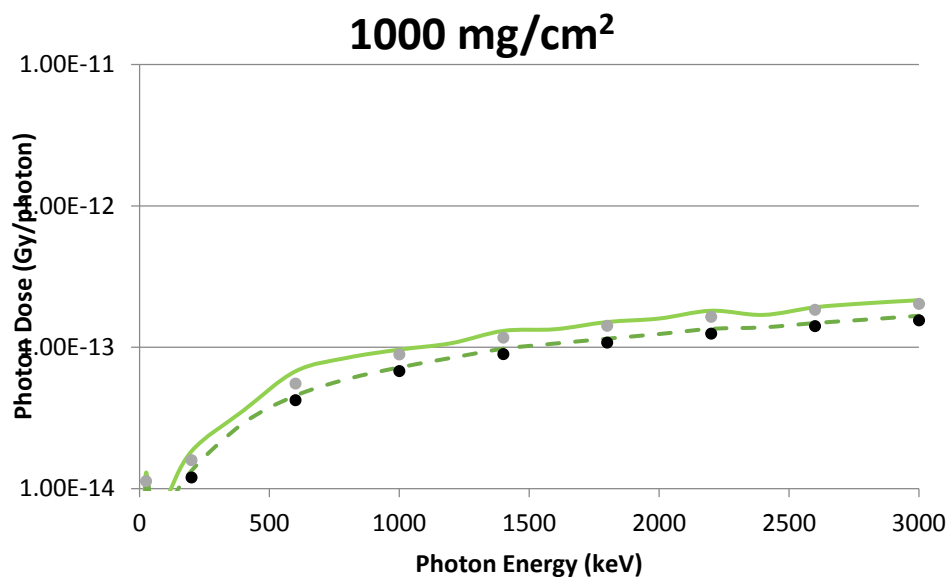
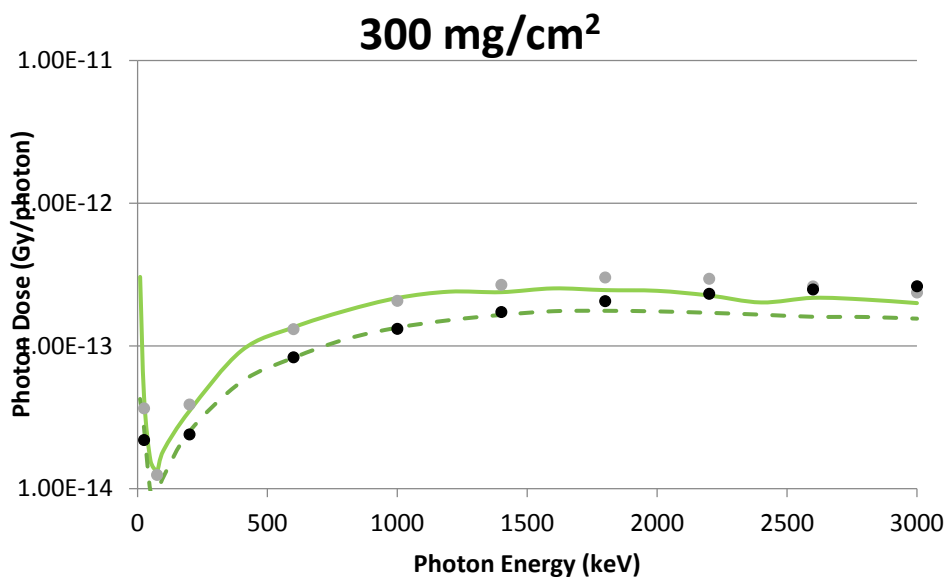
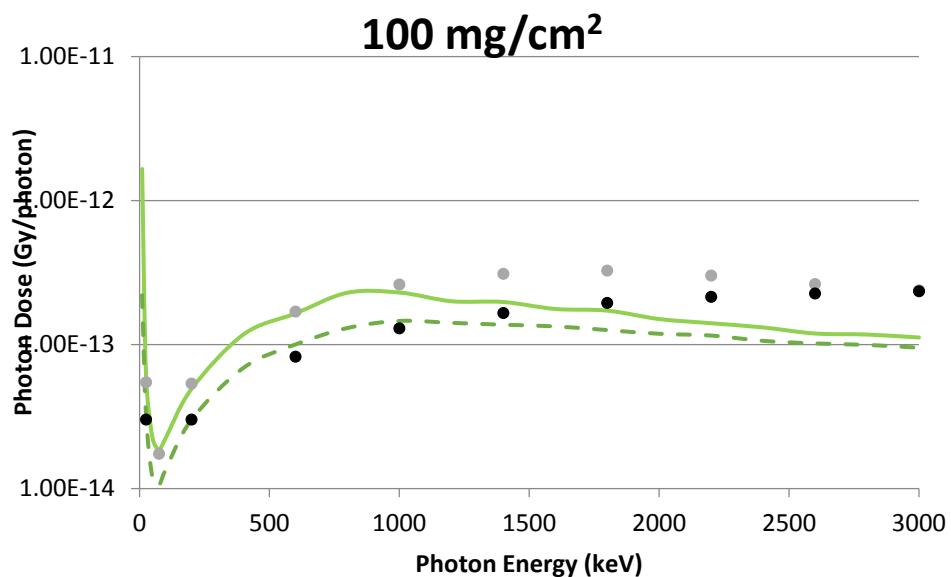
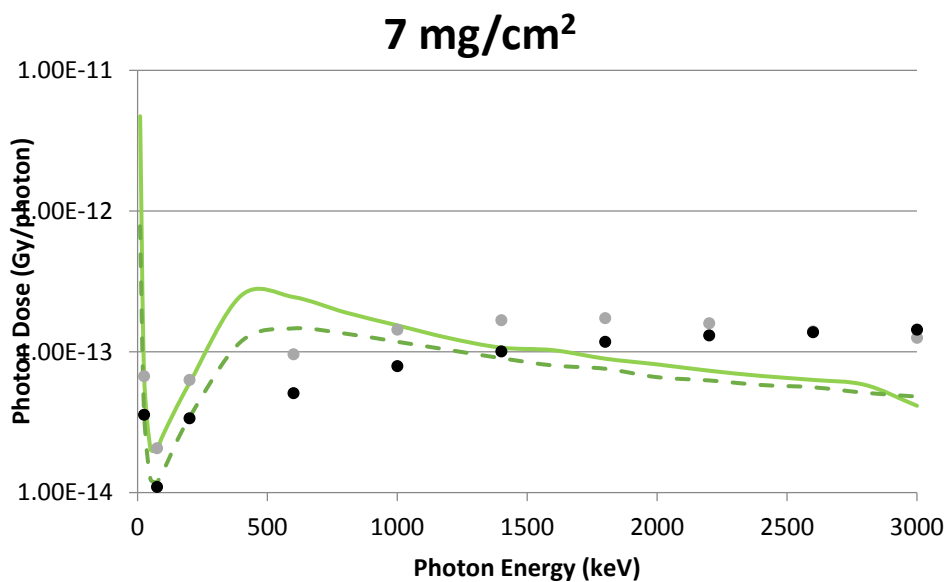
Disk source - photon



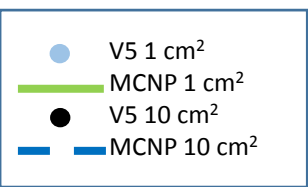
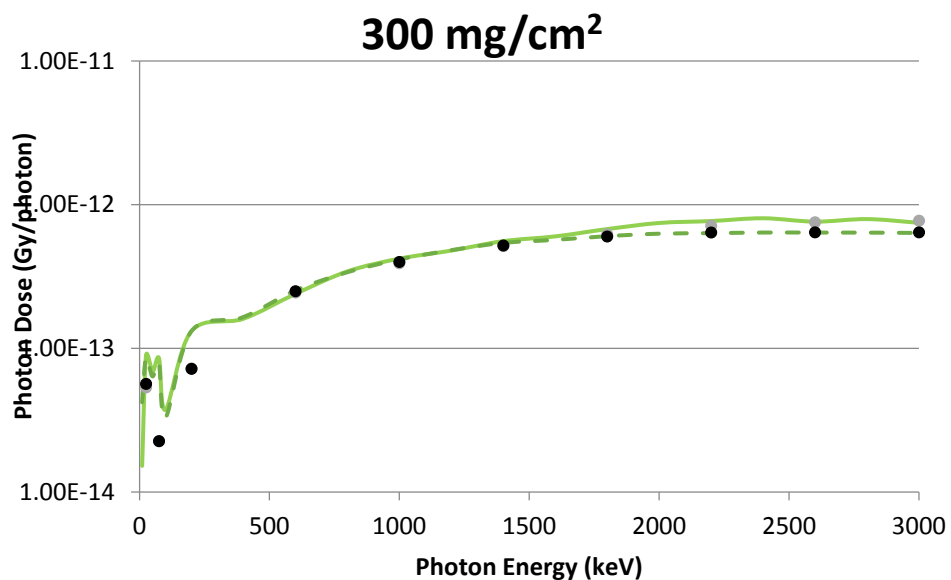
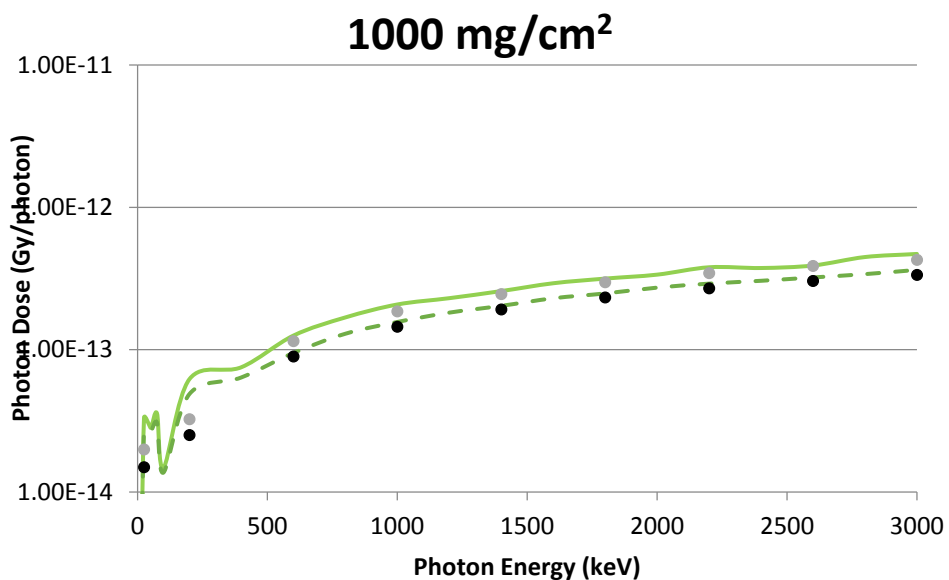
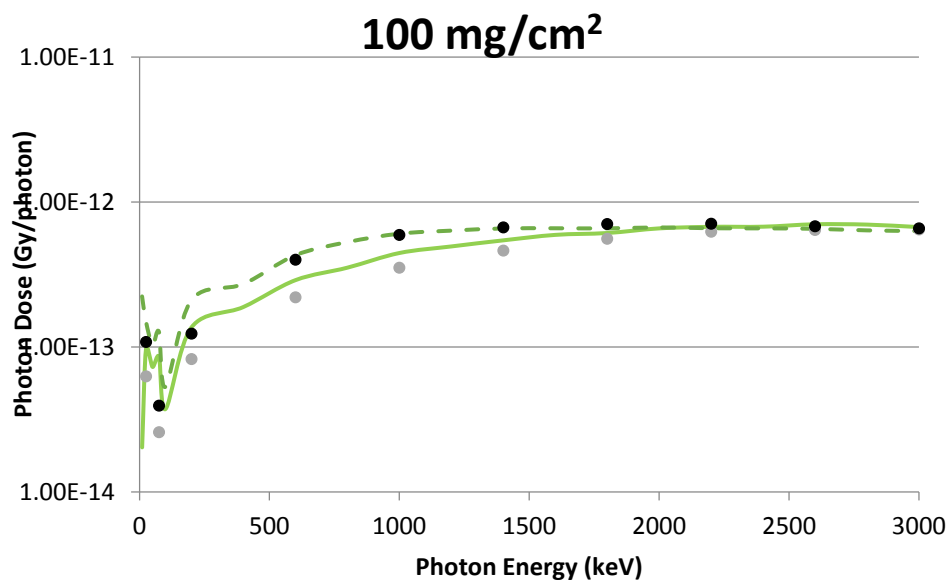
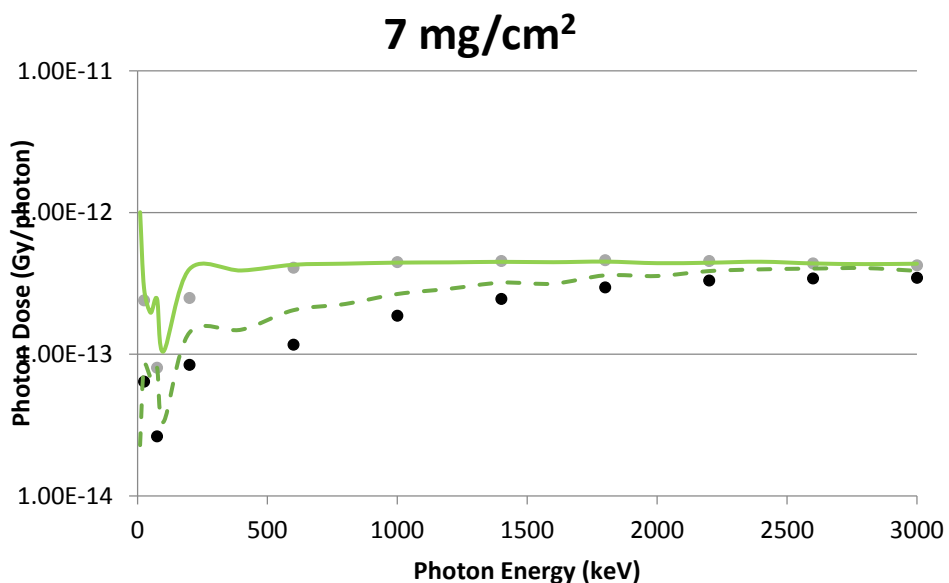
Cylindrical source - photon



Spherical source - photon



Air gap and cotton cover



Off axis by 1 cm

Nuclide	Air Gap (cm)	Cover Material	V3.1 Shallow Dose (mGy)	V5 Shallow Dose (mGy)
Co-60	none	none	3.29	0.790
Co-60	0.2	M ₁	0.571	0.291
Cs-137/ Ba-137m			0.199	0.0965
Sr/Y-90			0	0
Co-60	0.2	M ₁ + M ₁	0.558	0.257
Cs-137/ Ba-137m			0.181	0.0836
Sr/Y-90			0	0
Co-60	1.0	M ₁	0.0797	0.0429
Cs-137/ Ba-137m			0.0277	0.0129
Sr/Y-90			0	0
Co-60	1.0	M ₁ + M ₁	0.0836	0.0402
Cs-137/ Ba-137m			0.0270	0.0121
Sr/Y-90			0	0
Co-60	1.0	M ₁ + M ₂	0.0876	0.0400
Cs-137/ Ba-137m			0.0271	0.0120
Sr/Y-90			0	0
Co-60	5.0	M ₁ + M ₂	0.00453	0.00205
Cs-137/ Ba-137m			0.00138	0.00061
Sr/Y-90			0	0

$$M_1 = 0.37 \text{ mm} \\ 0.70 \text{ g/cm}^3$$

$$M_2 = 0.40 \text{ mm} \\ 1.1 \text{ g/cm}^3$$

Photon point source on cover



performance of the
electron dosimetry model

Electron Energy Absorption Simulated with EGSnrc

- Five geometries modeled:
 - Point
 - Disk ($d = 0.5 \text{ mm}$, 1 mm and 5 mm)
 - Cylinder ($d = 1 \text{ cm}$, $h = 1 \text{ cm}$)
 - Slab ($l = w = h = 1 \text{ cm}$)
 - Sphere ($d = 1 \text{ cm}$)
- Five source dimensions range from $0.005 - 1 \text{ mm}$
- All sources located $0.1 \text{ }\mu\text{m}$ above the skin
- Dose per electron calculated as a function of depth

EGS Simulation

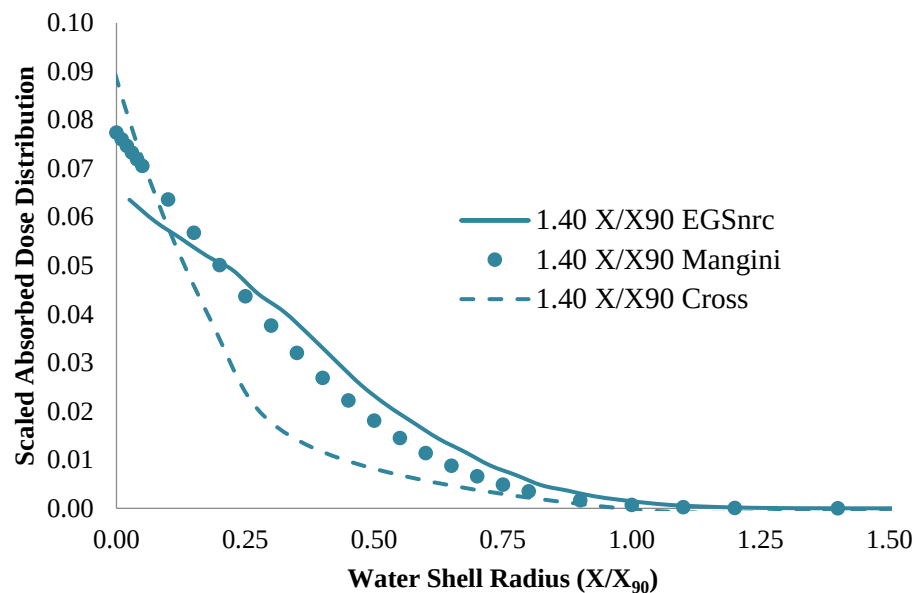
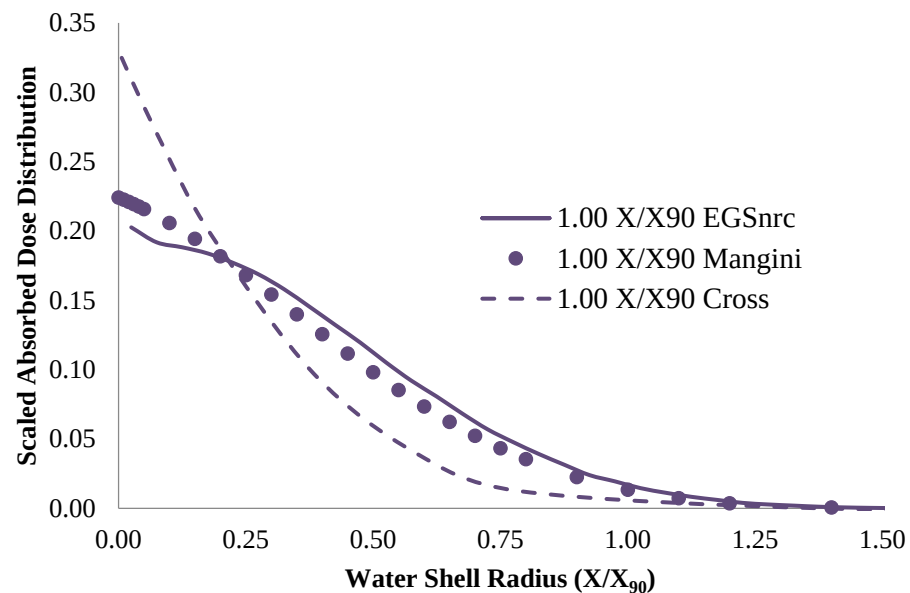
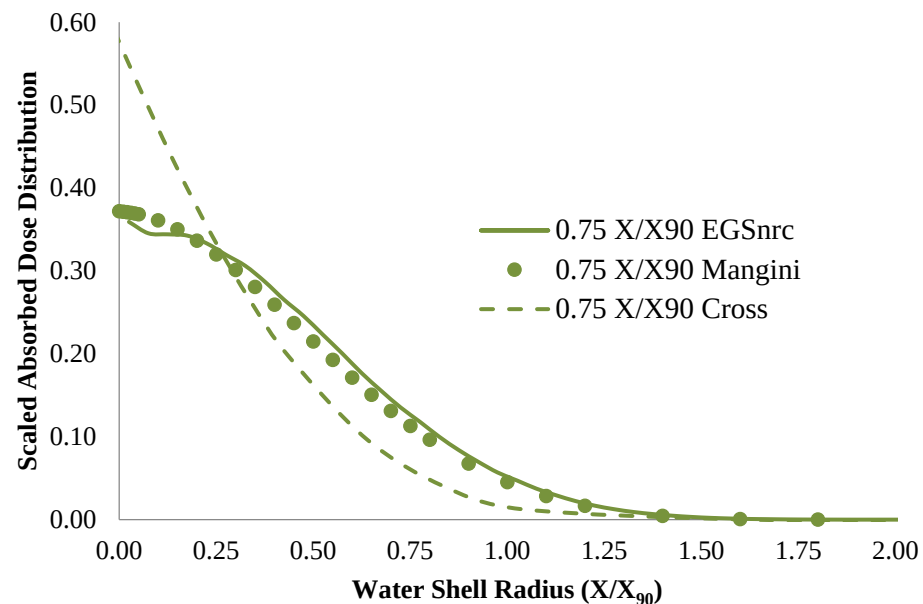
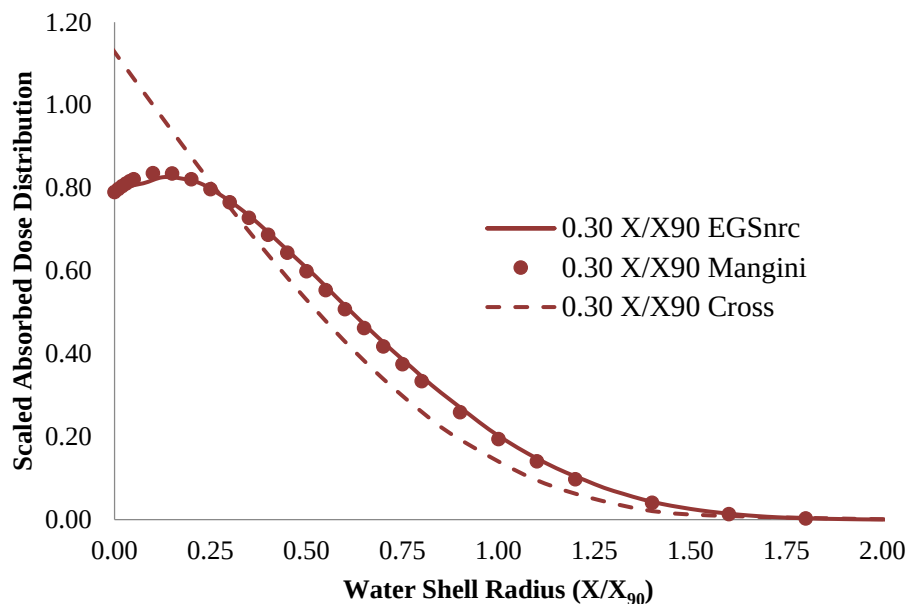
- VARSKIN results were compared to EGS simulations for the same geometrical scenarios
- Volumetric sources investigated:

Alloy	Z_{eff}	Density (g/cm³)	Atomic Wt (g mol⁻¹)
Stainless Steel	25.81	8.06	55.54
Tungsten Alloy	72.79	18.00	177.65
Uranium Oxide	87.88	10.96	211.72

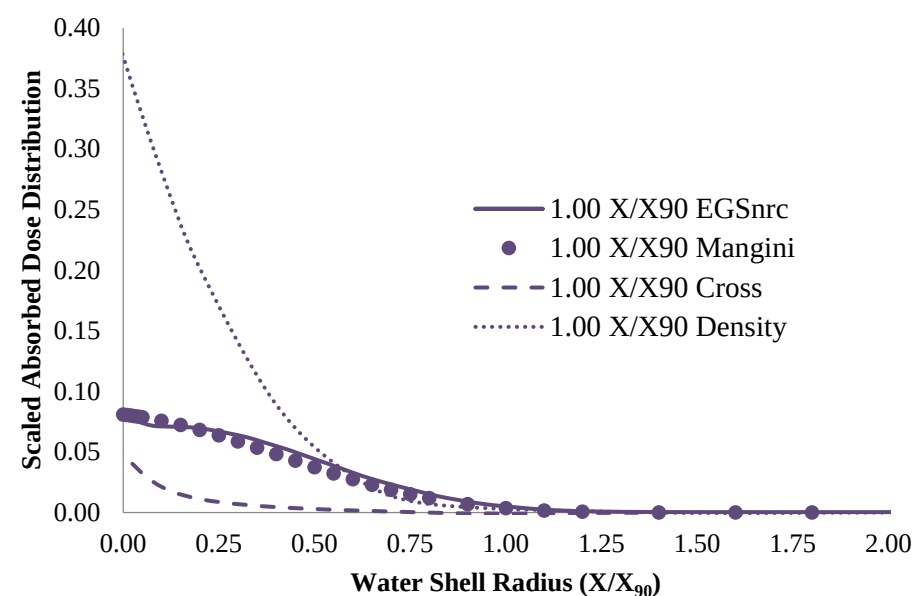
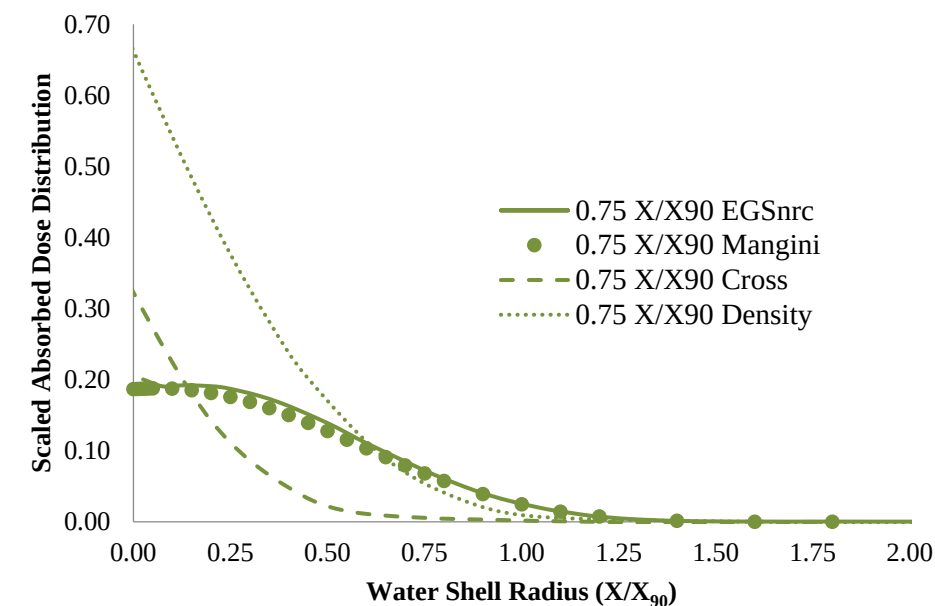
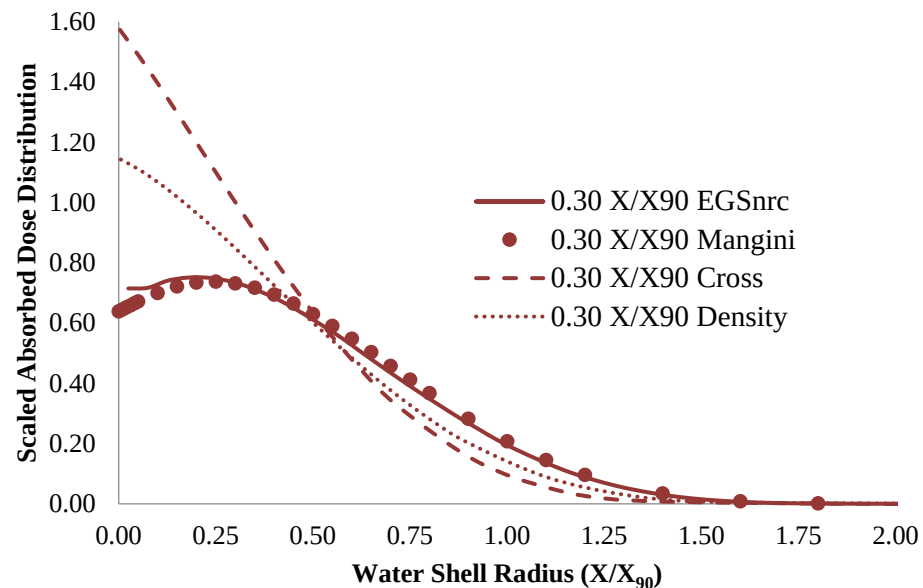
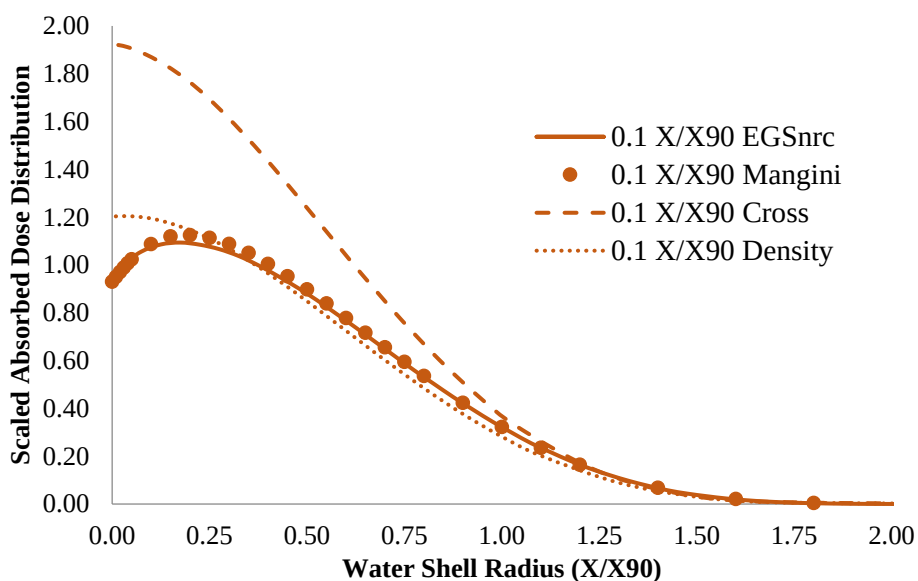
EGS Simulation

- Four nuclides chosen:
 - ^{28}Al ($E_{\text{avg}} = 1.24 \text{ MeV}$; $E_{\text{max}} = 2.86 \text{ MeV}$)
 - ^{42}K ($E_{\text{avg}} = 1.43 \text{ MeV}$; $E_{\text{max}} = 3.52 \text{ MeV}$)
 - ^{66}Cu ($E_{\text{avg}} = 1.07 \text{ MeV}$; $E_{\text{max}} = 2.63 \text{ MeV}$)
 - ^{138}Cs ($E_{\text{avg}} = 1.05 \text{ MeV}$; $E_{\text{max}} = 2.90 \text{ MeV}$)
- Skin depths to 1000 mg/cm^2
- Dose-averaging areas of 1 and 10 cm^2

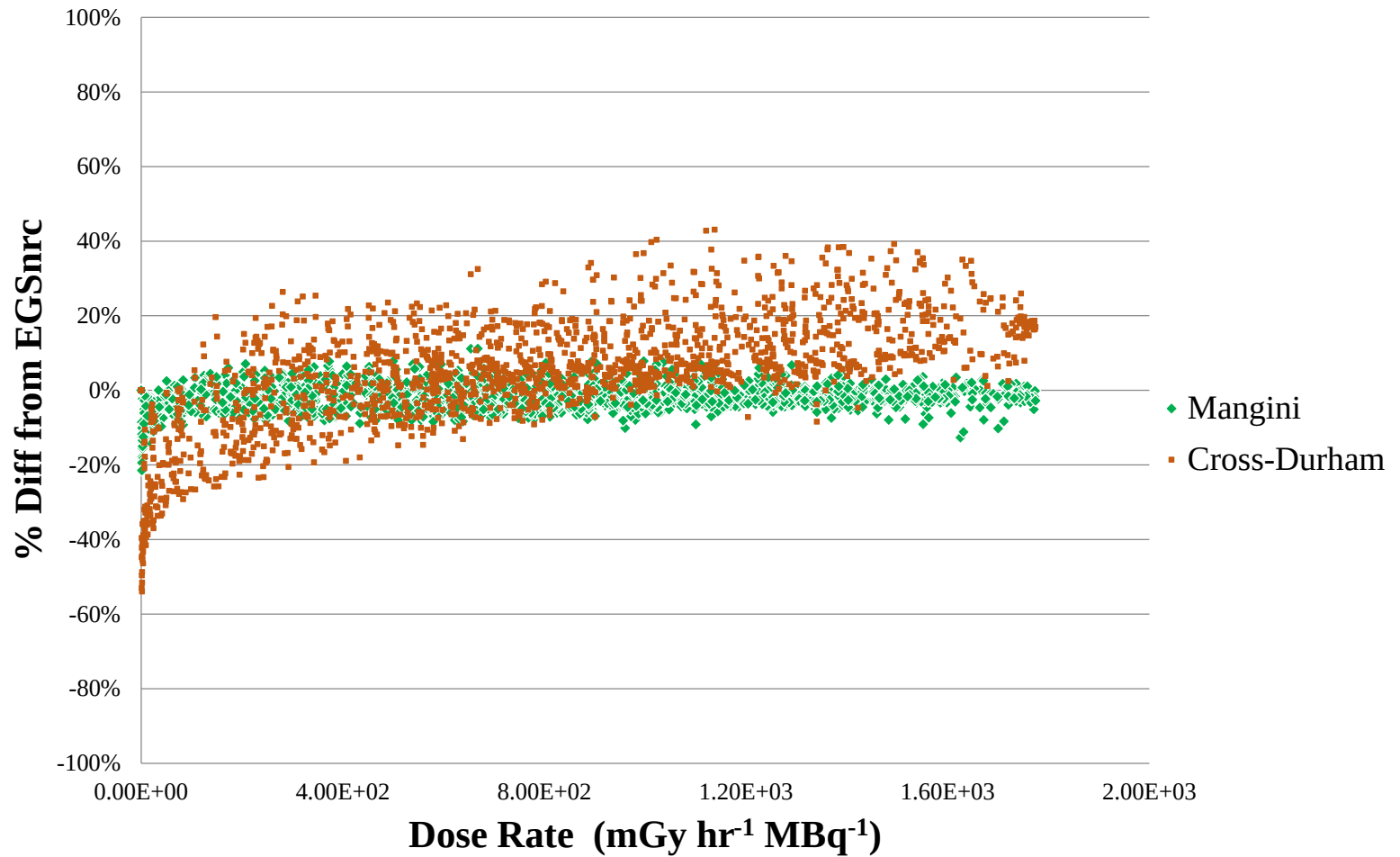
Non-Homogeneous Stainless Steel DPKs: ^{90}Sr



Non-Homogeneous Uranium Oxide DPKs: ^{32}P

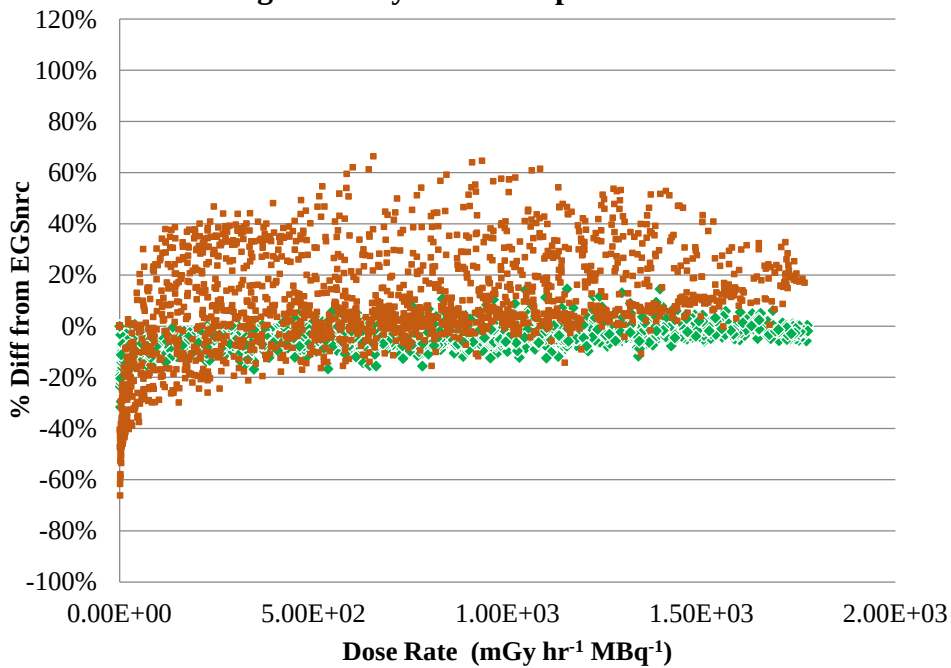


Stainless Steel Dose Comparison - 1 cm²

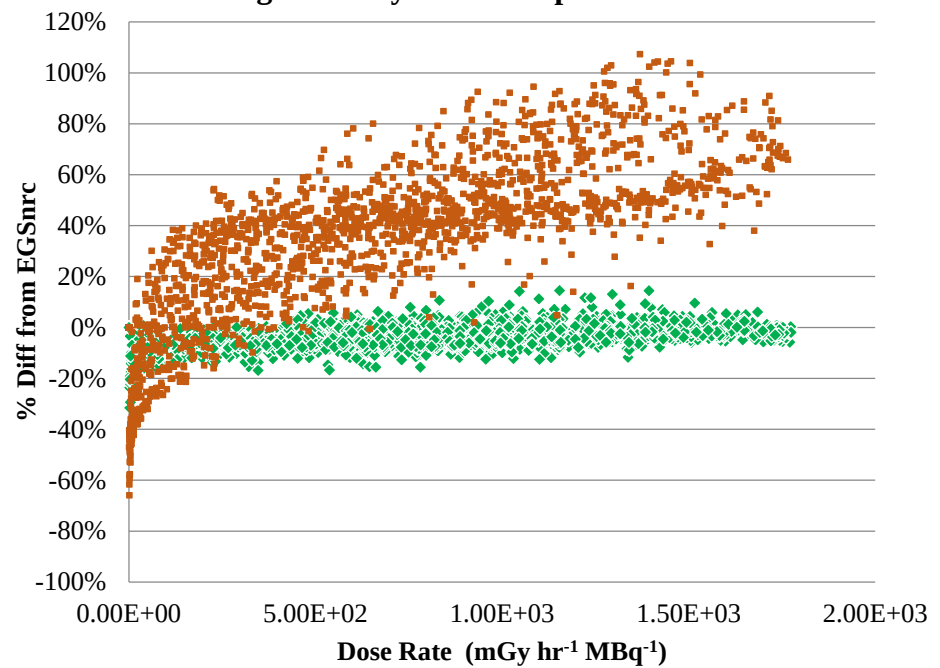


Dose Verification

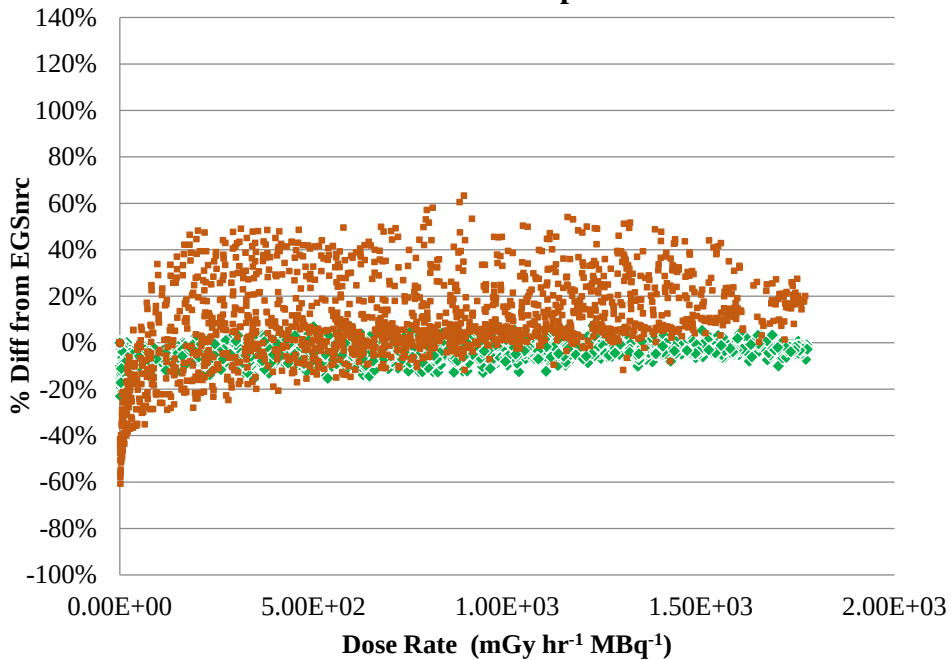
Tungsten Alloy Dose Comparison - 1 cm²



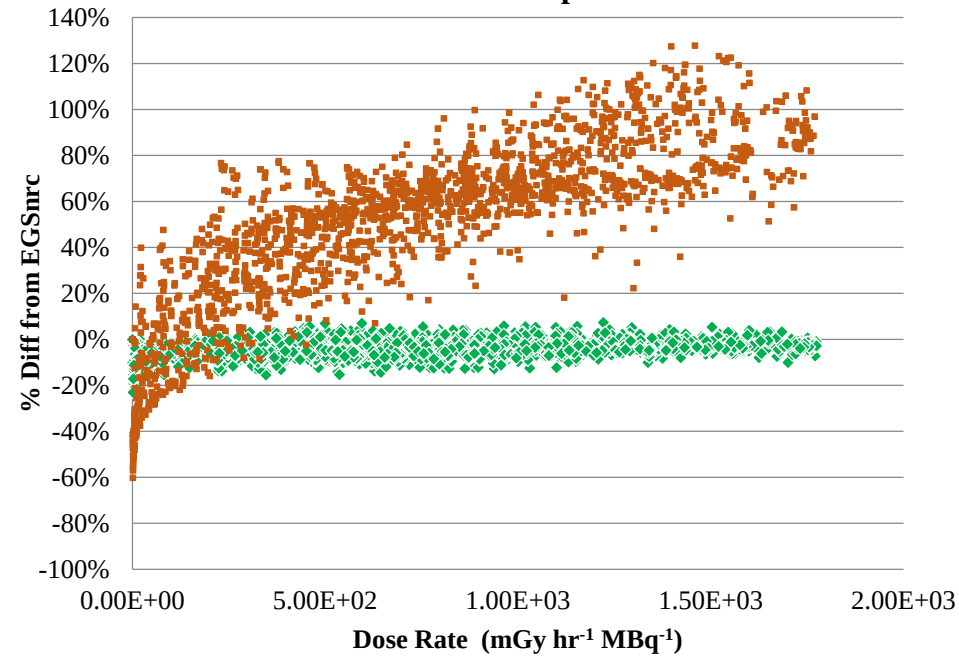
Tungsten Alloy Dose Comparison - 10 cm²



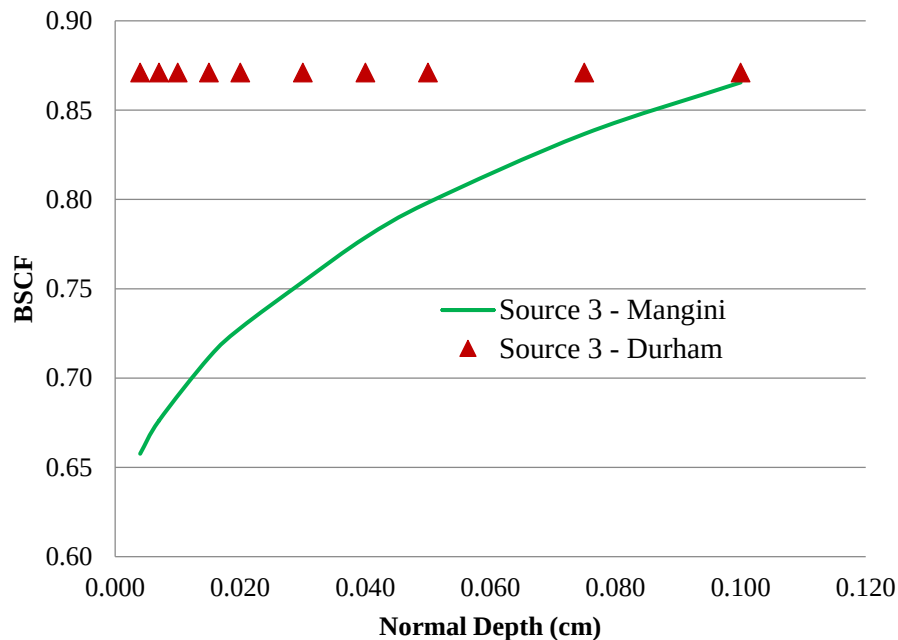
Uranium Oxide Dose Comparison - 1 cm²



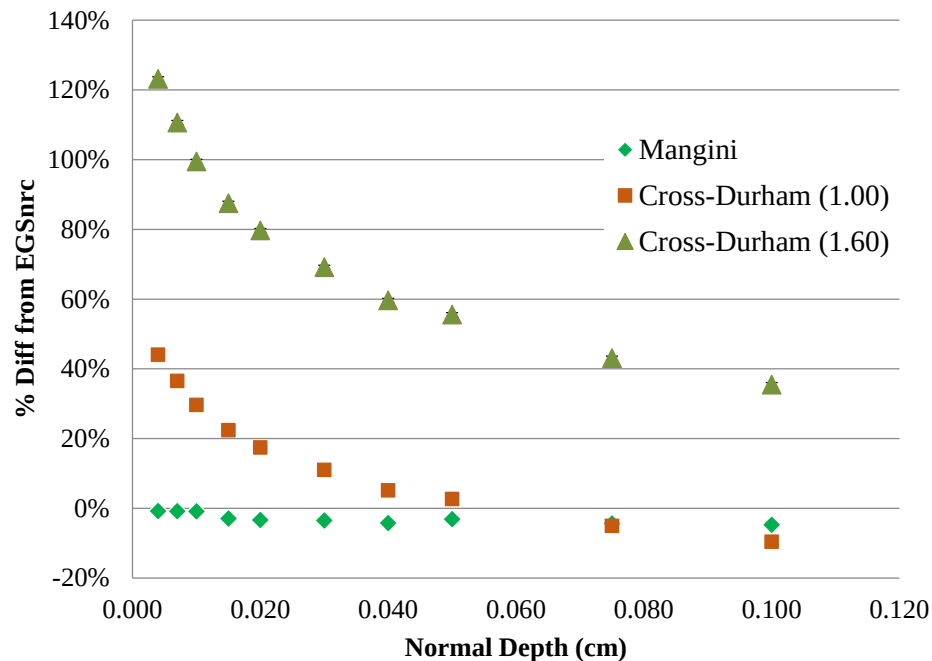
Uranium Oxide Dose Comparison - 10 cm²



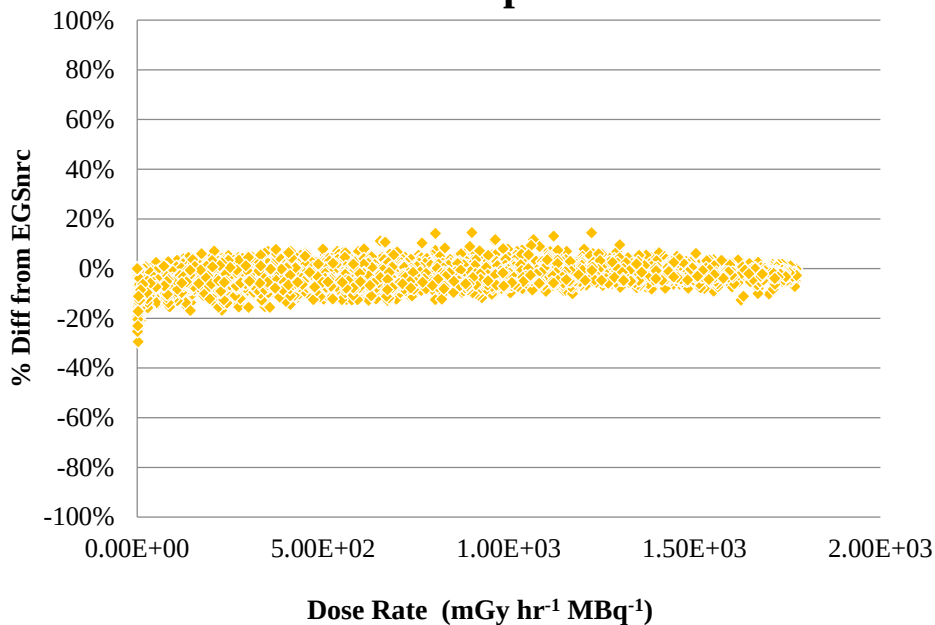
BSCF's for Uranium Oxide Slabs: ^{32}P



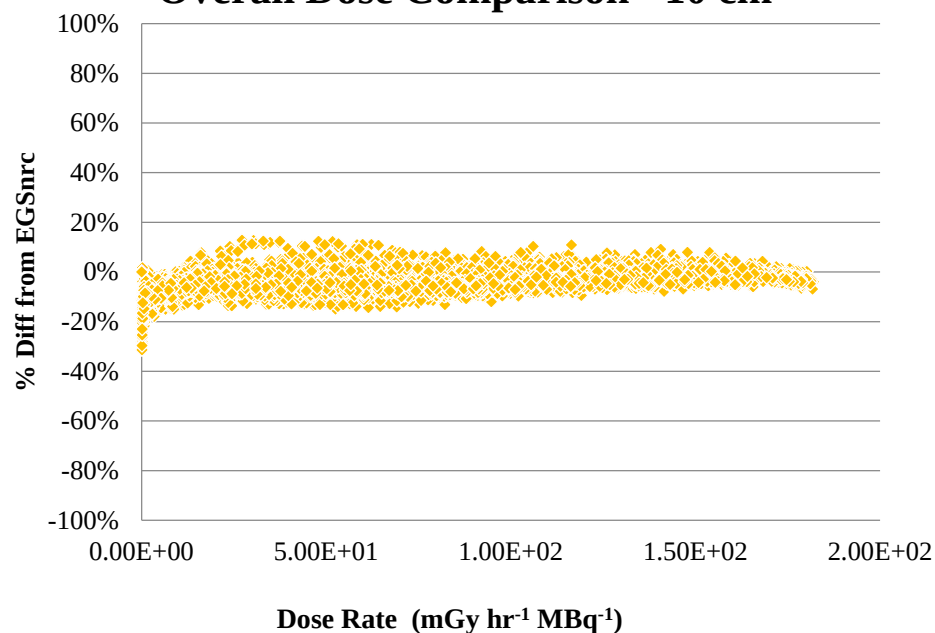
Dose Comparison for ^{32}P Uranium Oxide Slabs



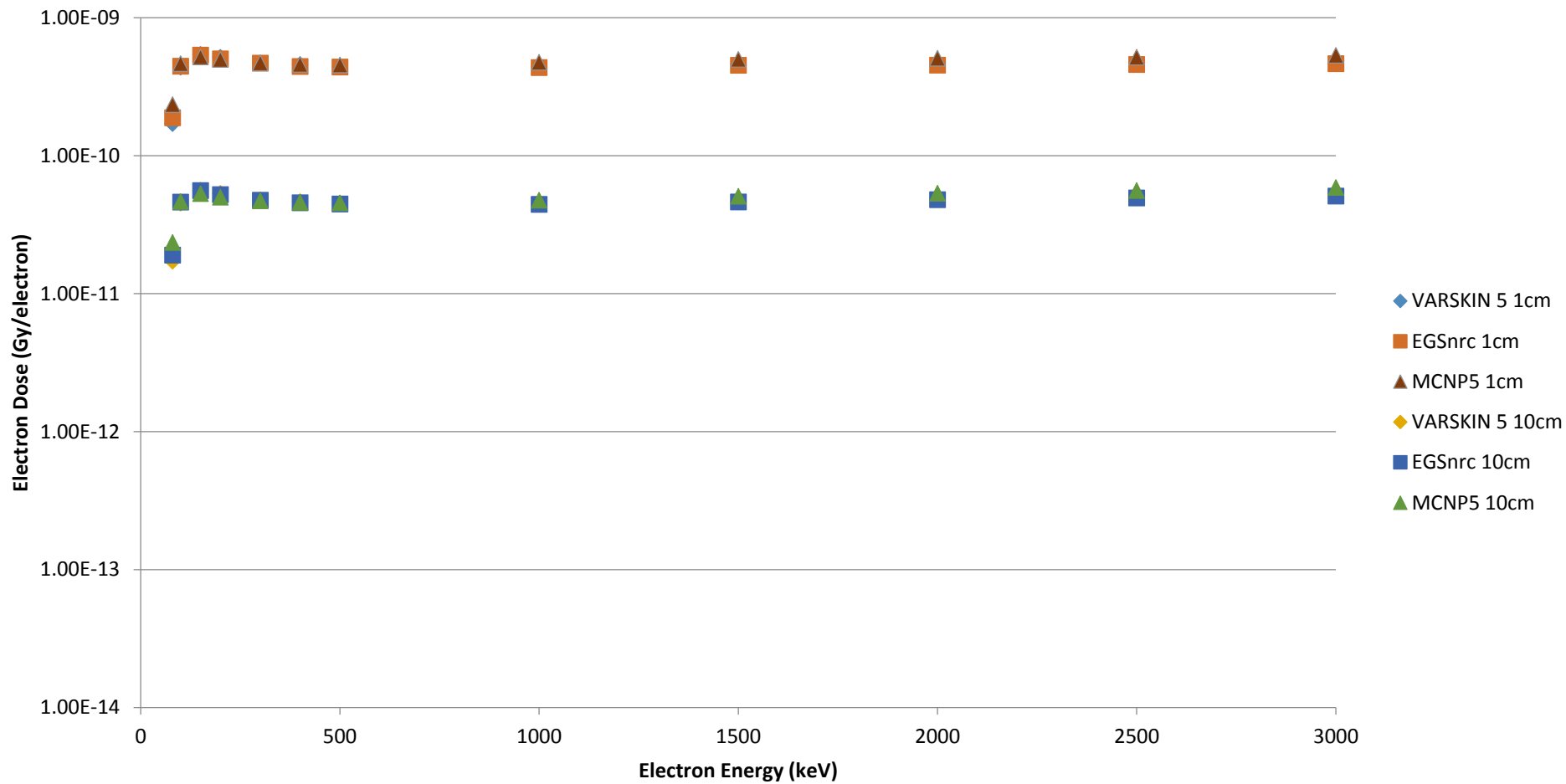
Overall Dose Comparison - 1 cm²



Overall Dose Comparison - 10 cm²

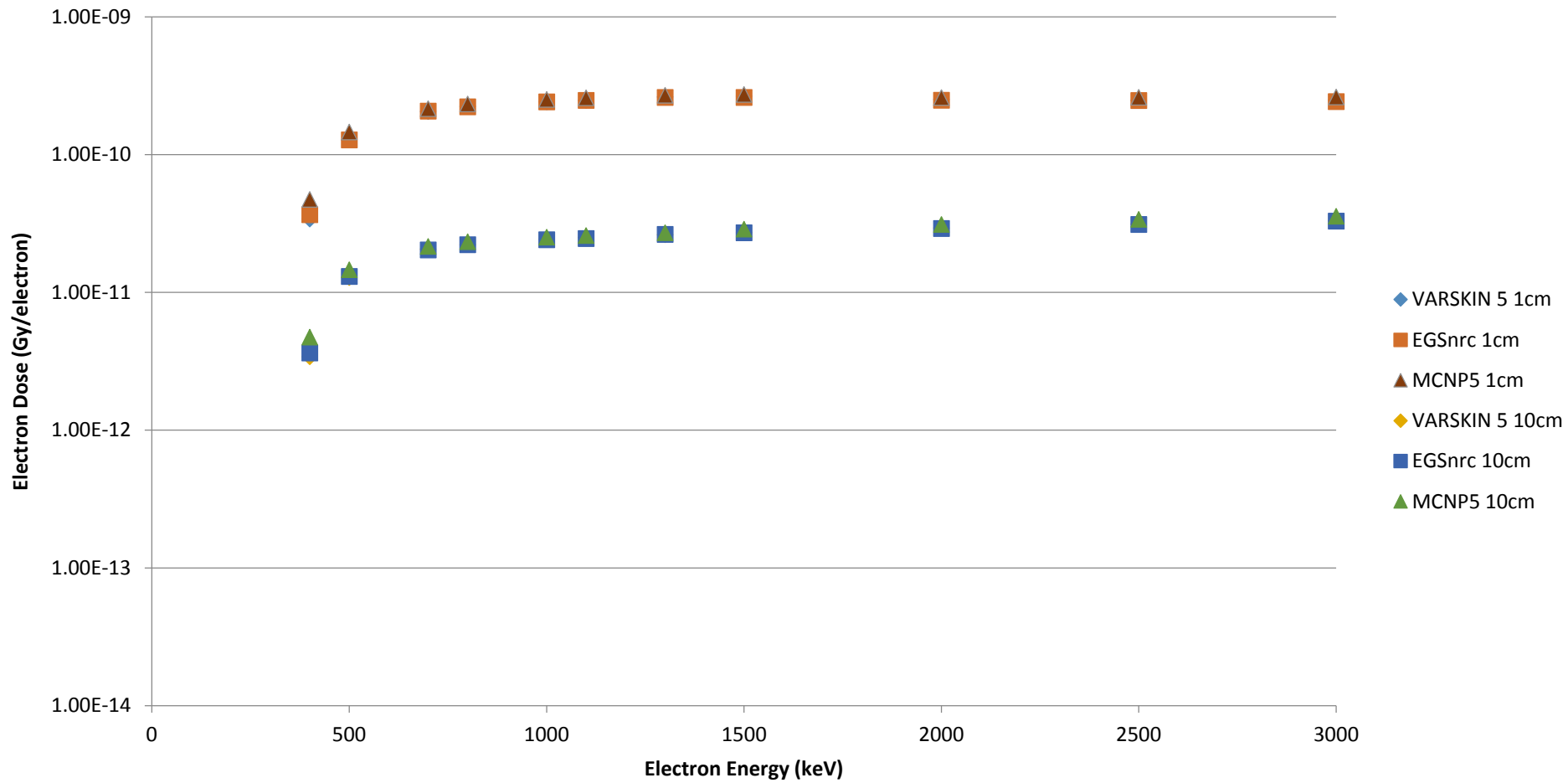


7 mg/cm²



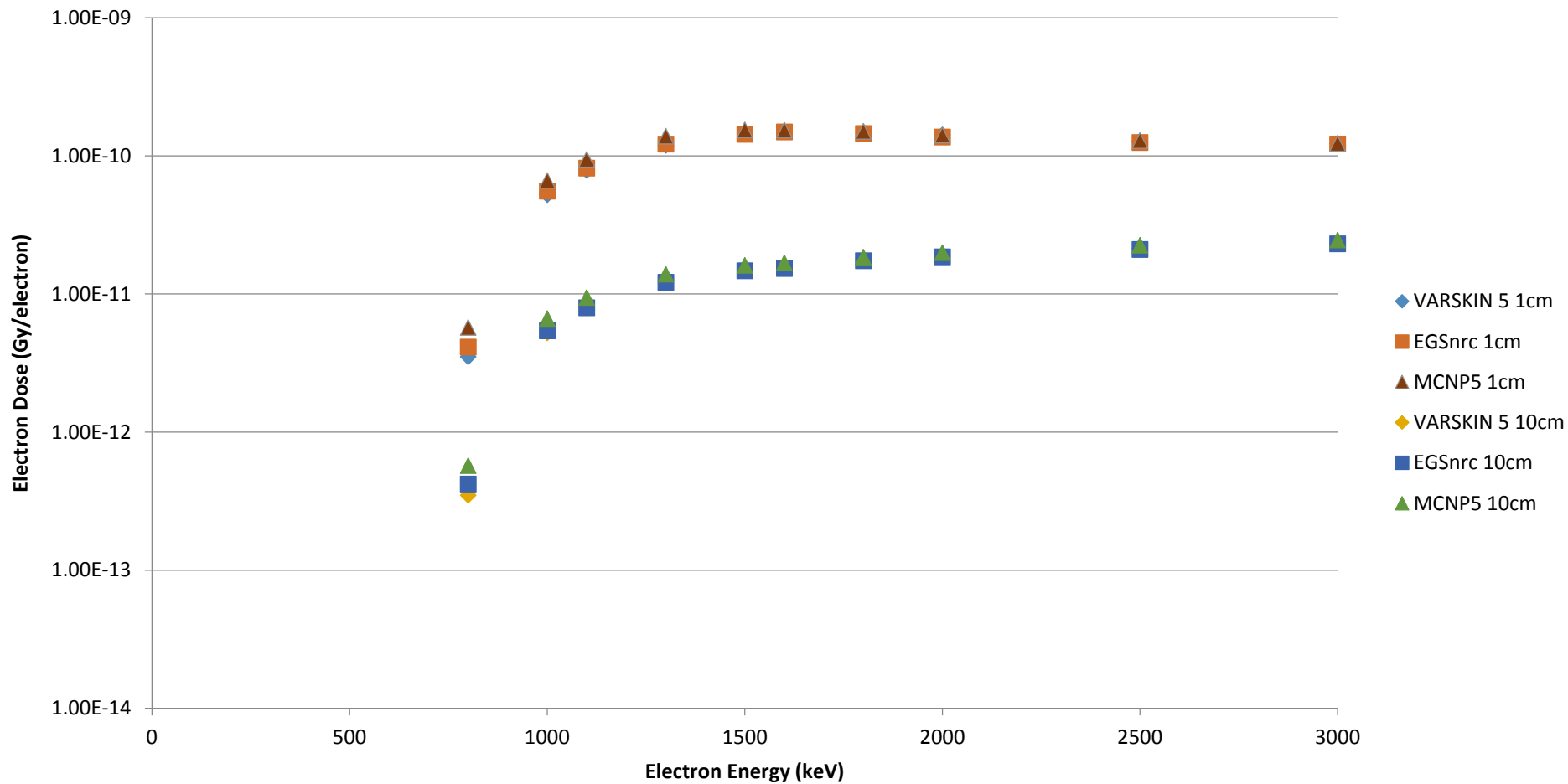
Point Source

100 mg/cm²



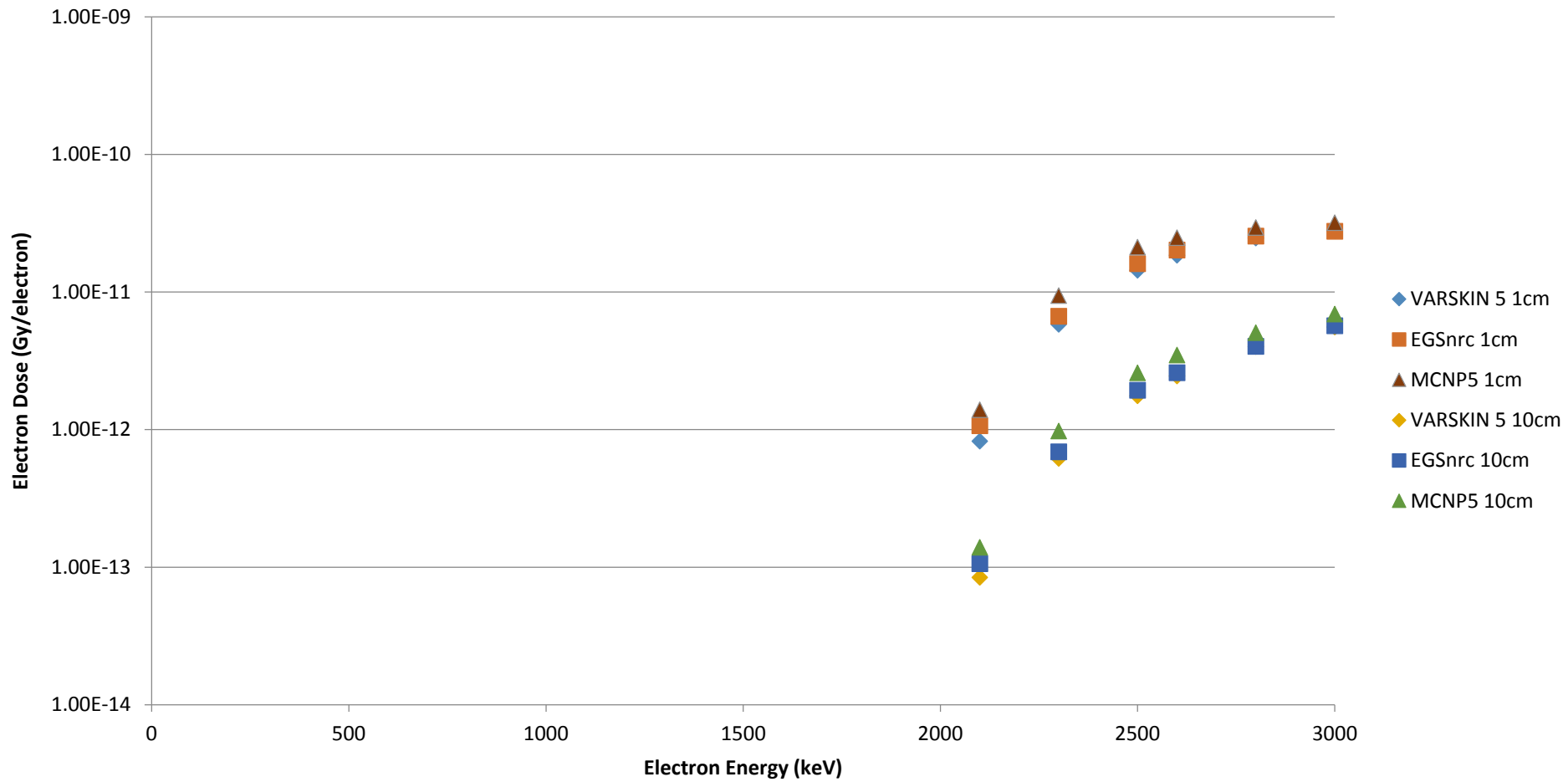
Point Source

300 mg/cm²



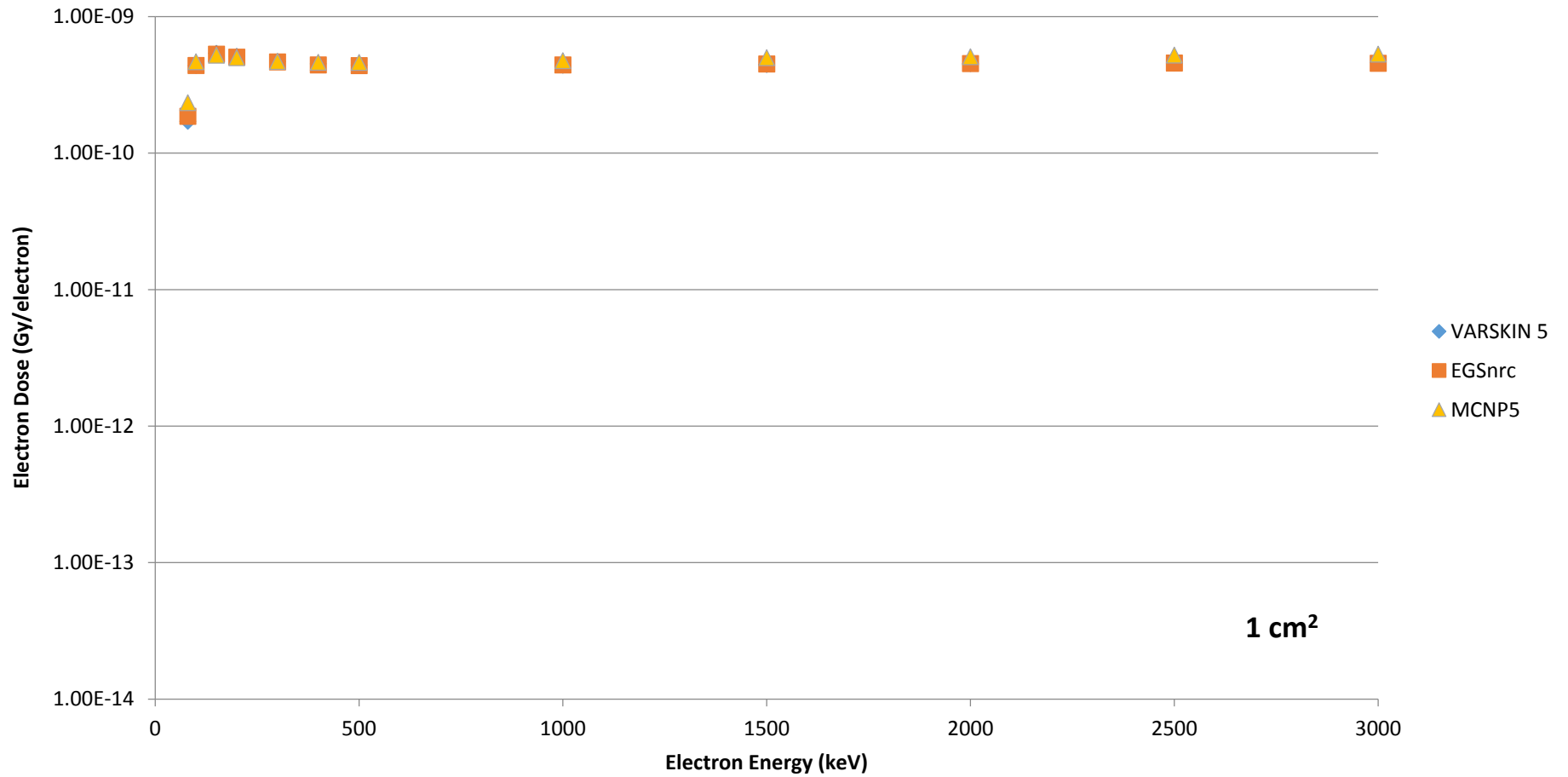
Point Source

1000 mg/cm²



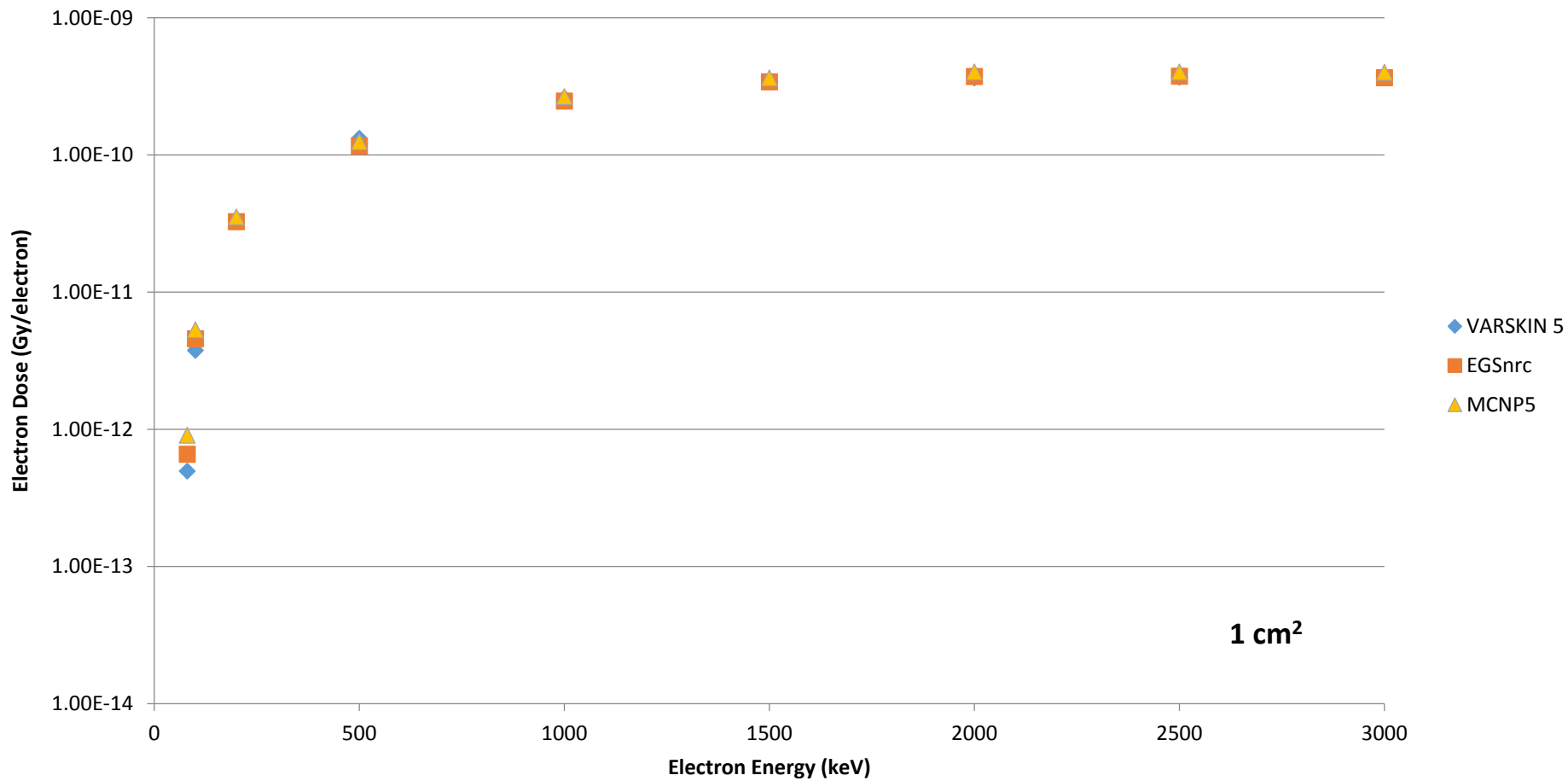
Point Source

7 mg/cm²

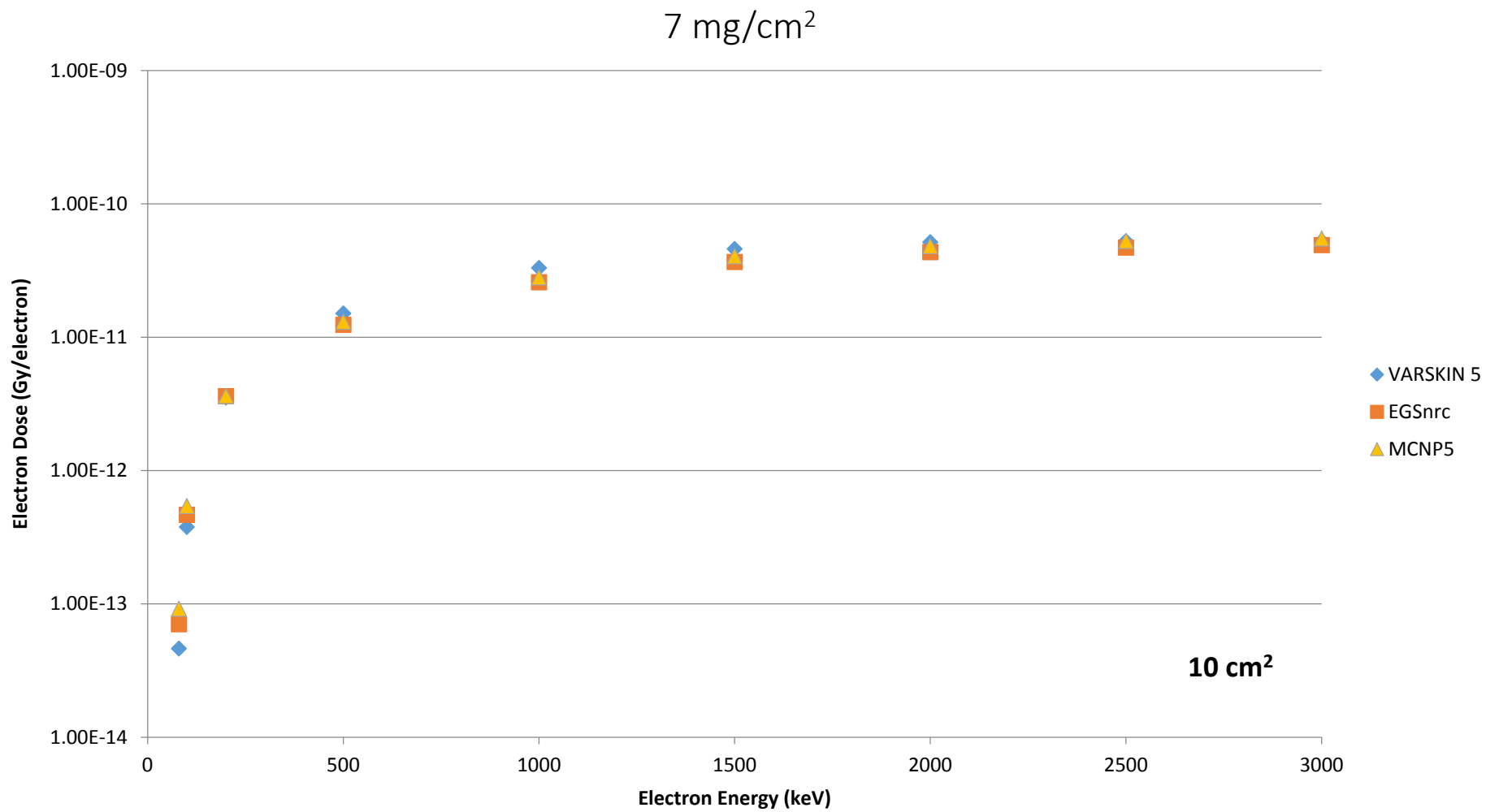


Disk Source

7 mg/cm²

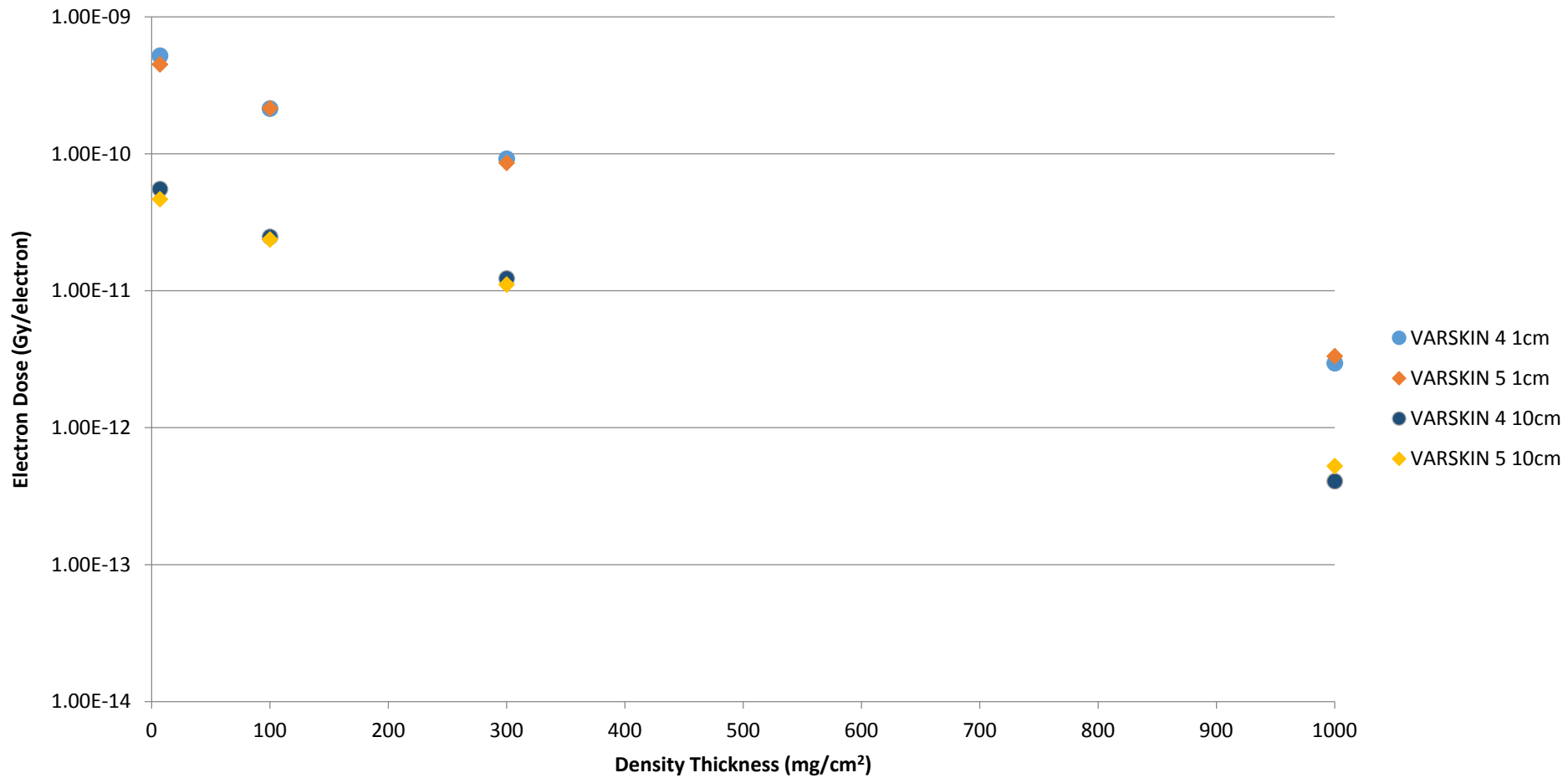


Spherical Source



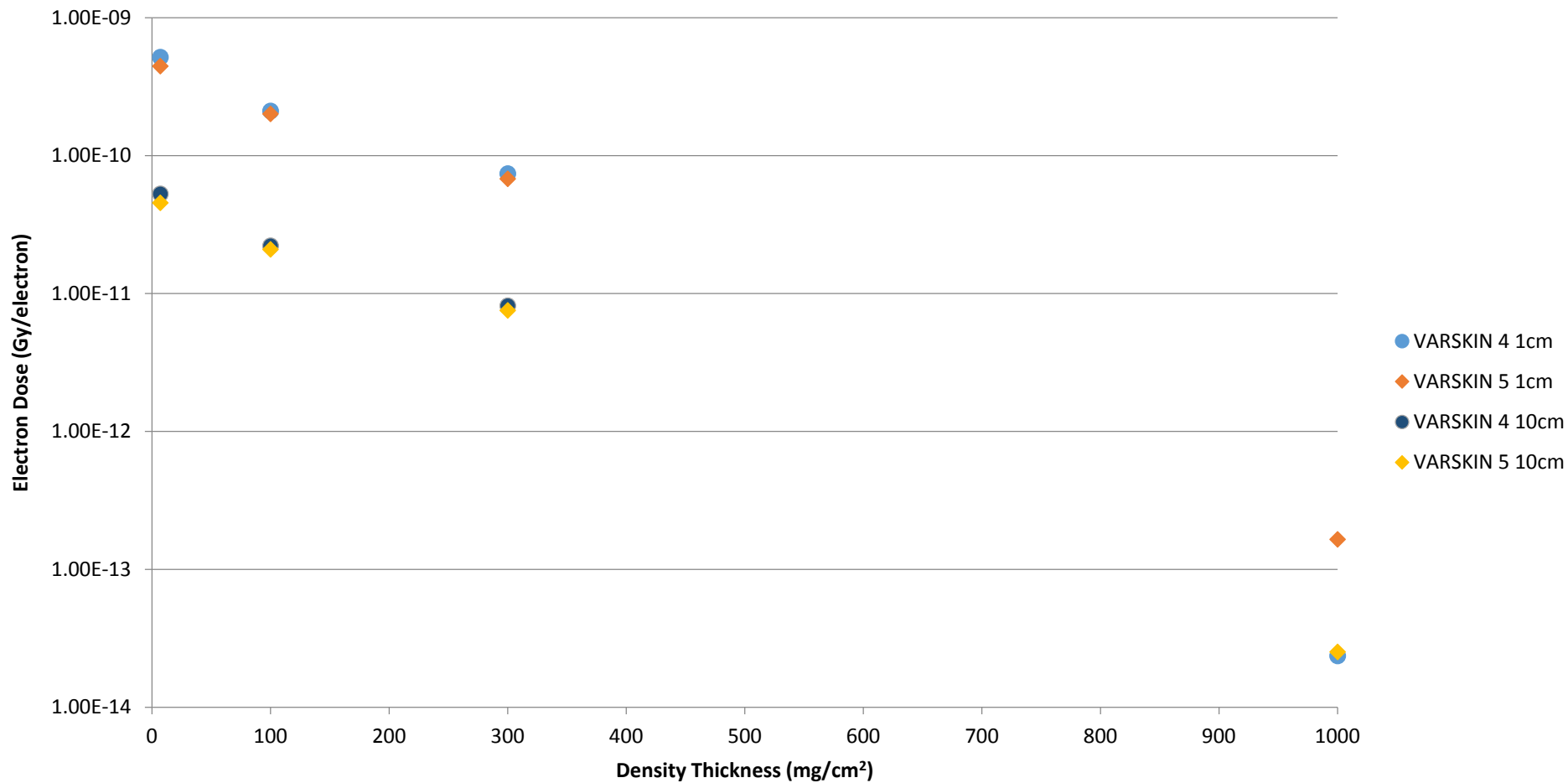
Cylindrical Source

K-42



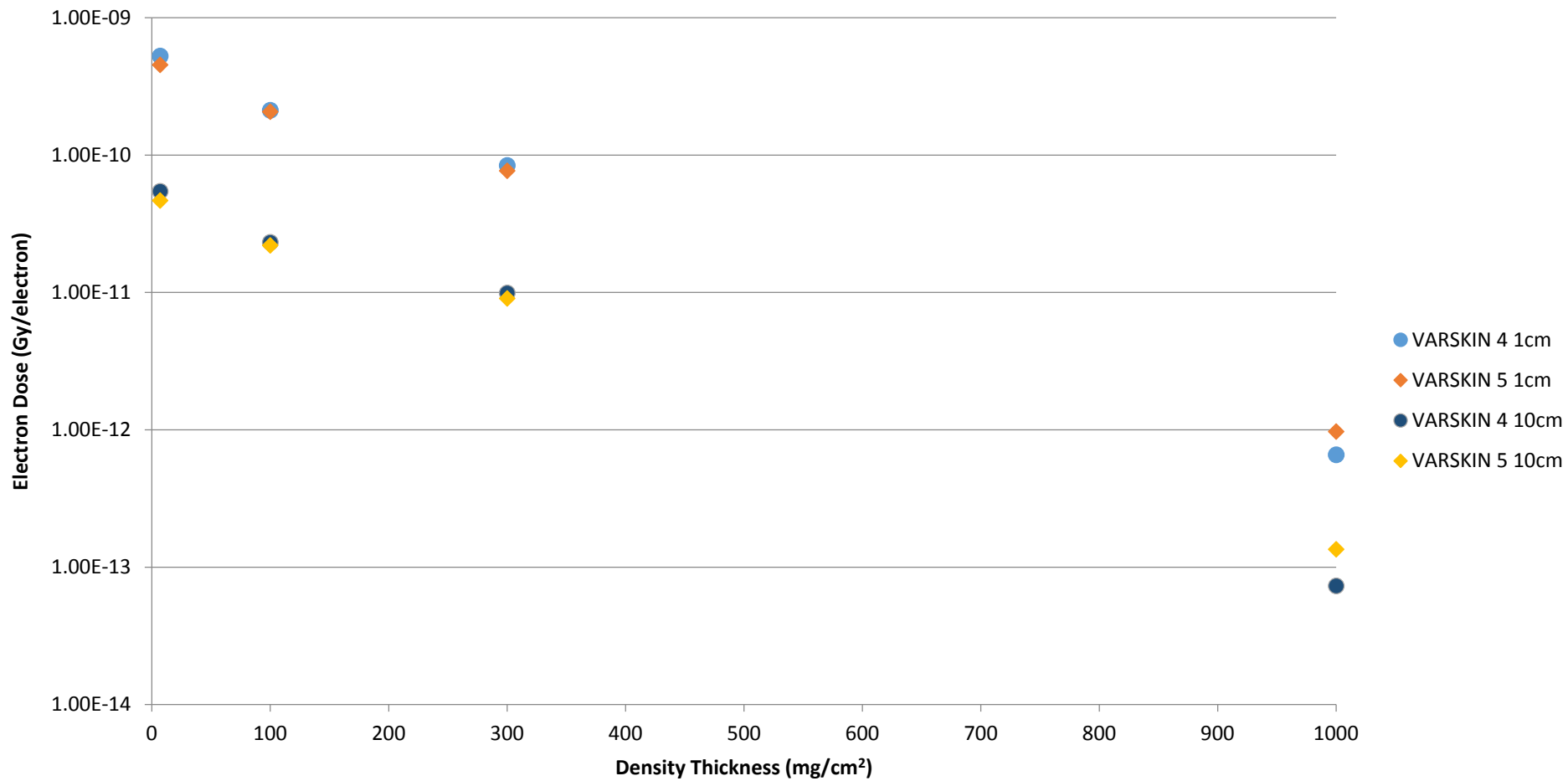
Point Source

Cu-66



Point Source

Cs-138



Point Source

Beta point source on cover

Nuclide	Air Gap (cm)	Cover Material	V4 Shallow Dose (mGy)	V5 Shallow Dose (mGy)
Co-60	none	none	37.6	34.5
Co-60	0.2	M ₁	1.96	2.17
Cs-137/ Ba-137m			14.0	13.8
Sr/Y-90			32.6	29.1
Co-60	0.2	M ₁ + M ₁	0	0.0789
Cs-137/ Ba-137m			4.75	6.64
Sr/Y-90			20.7	19.5
Co-60	1.0	M ₁	0.813	0.813
Cs-137/ Ba-137m			2.79	2.61
Sr/Y-90			5.37	4.74
Co-60	1.0	M ₁ + M ₁	0	0.0409
Cs-137/ Ba-137m			1.40	1.55
Sr/Y-90			3.95	3.66
Co-60	1.0	M ₁ + M ₂	0	0.00838
Cs-137/ Ba-137m			0.770	1.05
Sr/Y-90			3.26	3.11
Co-60	5.0	M ₁ + M ₂	0	0.000452
Cs-137/ Ba-137m			0.0384	0.0532
Sr/Y-90			0.167	0.159

$$M_1 = 0.37 \text{ mm} \\ 0.70 \text{ g/cm}^3$$

$$M_2 = 0.40 \text{ mm} \\ 1.1 \text{ g/cm}^3$$

Beta Disk Source

Nuclide	V4	V5	Rohloff et al. (1986)	Kocher et al. (1987)
Co-60	37.7	34.5	32.4	41.8
Cs-137	51.2	53.8	-	59.1
Sr/Y-90	123	109	121	156

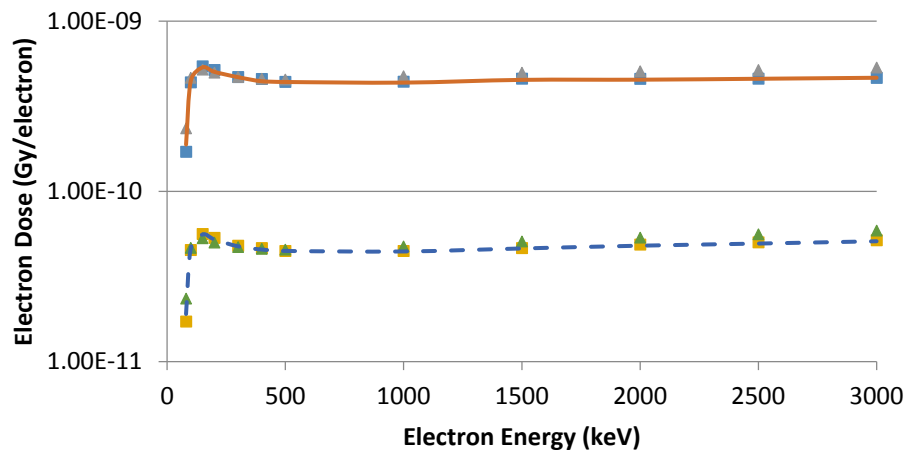
Beta Disk Source

Method	C-14	P-32	I-131	Sr-90	Y-90
VARSKIN 4	11.2	66.3	52.5	54.7	68.2
VARSKIN 5	11.1	58.6	48.4	49.7	59.4
Delacroix (1986)	10.7	91.5	64.2	69.9	91.8
Kocher and Eckerman (1987)	12.2	88.7	63.4	67.6	88.7
Piechowski (1988)	12	70	60	59	75

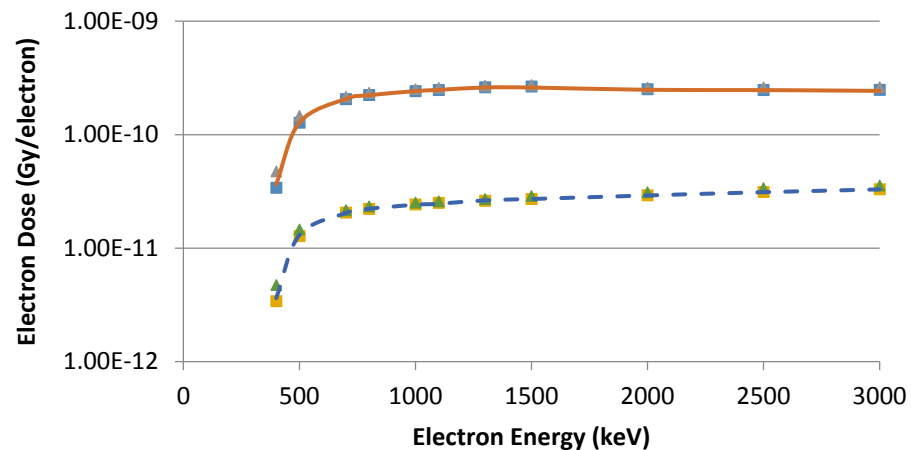
Beta Disk Source

Method	4 mg/cm ²	7 mg/cm ²	10 mg/cm ²	40 mg/cm ²
VARSKIN 4	79.0	68.2	61.4	40.7
VARSKIN 5	65.7	59.4	55.3	38.2
Delacroix (1986)	105	91.8	83.7	52.4
Kocher and Eckerman (1987)	101	88.7	—	50.7

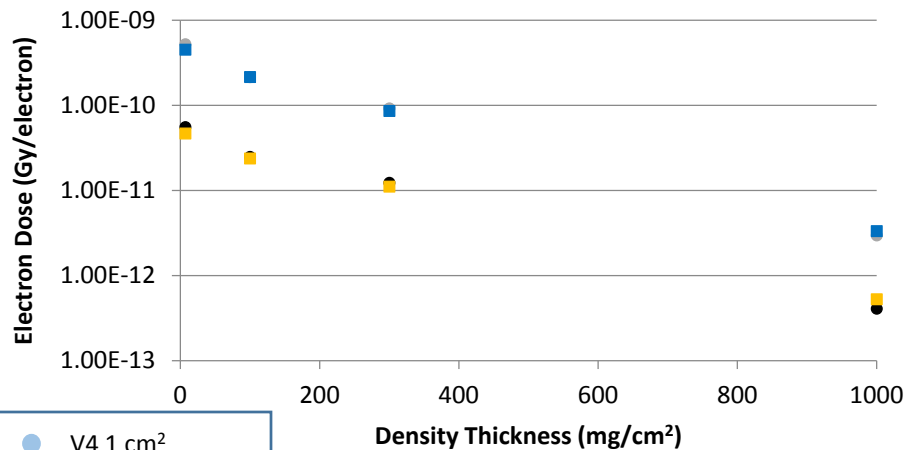
7 mg/cm²



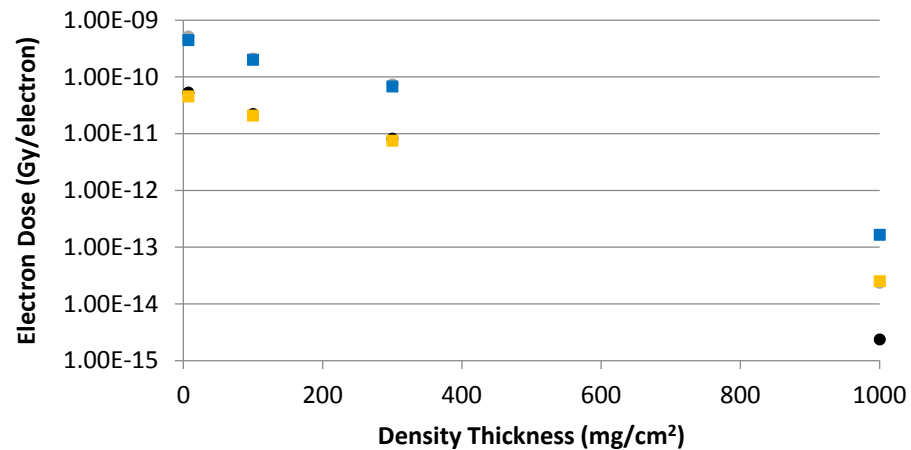
100 mg/cm²



K-42

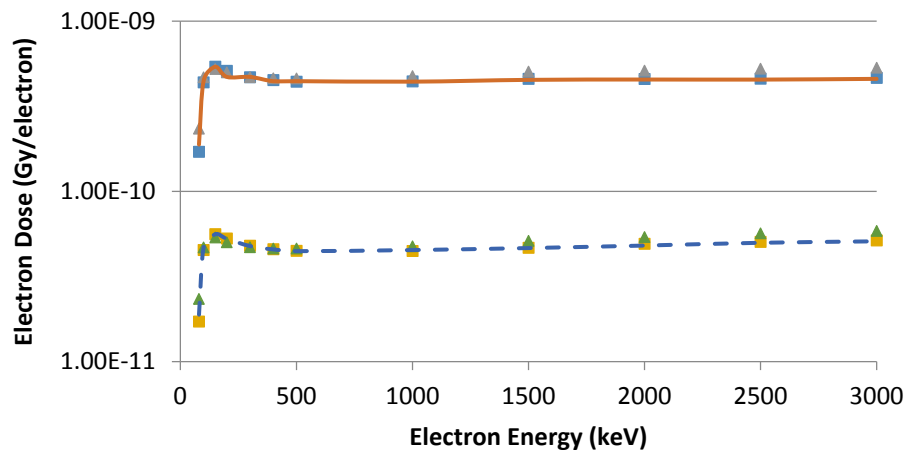


Cu-66

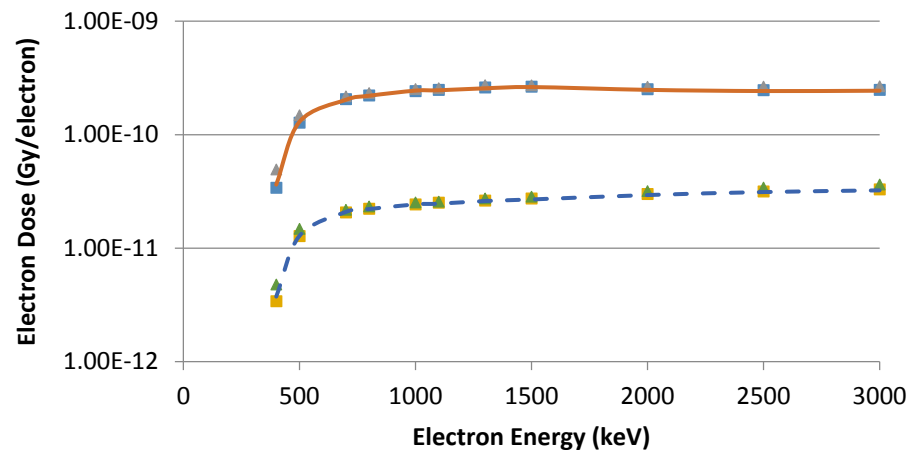


Point source - electron

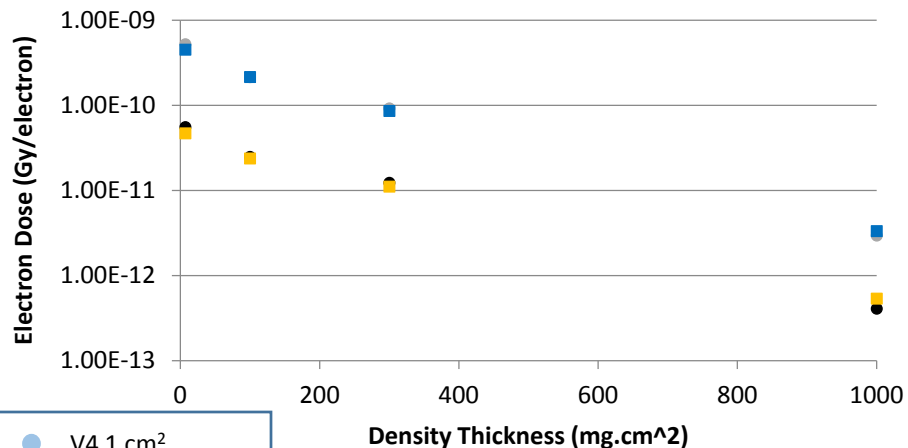
7 mg/cm²



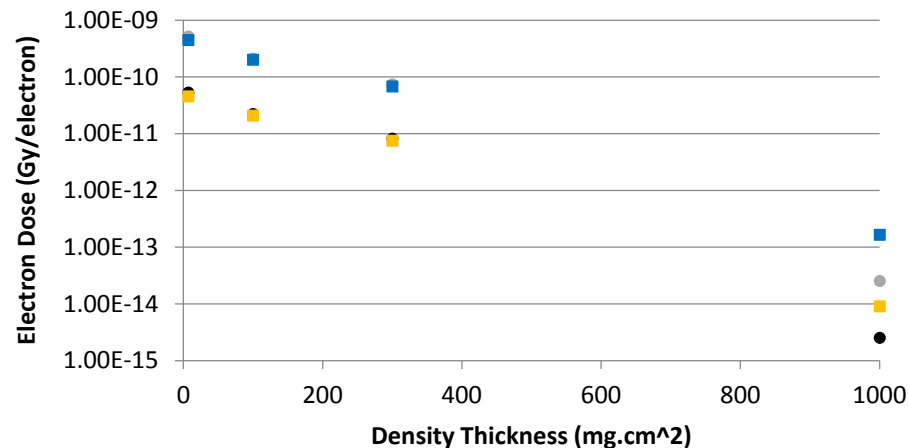
100 mg/cm²



K-42

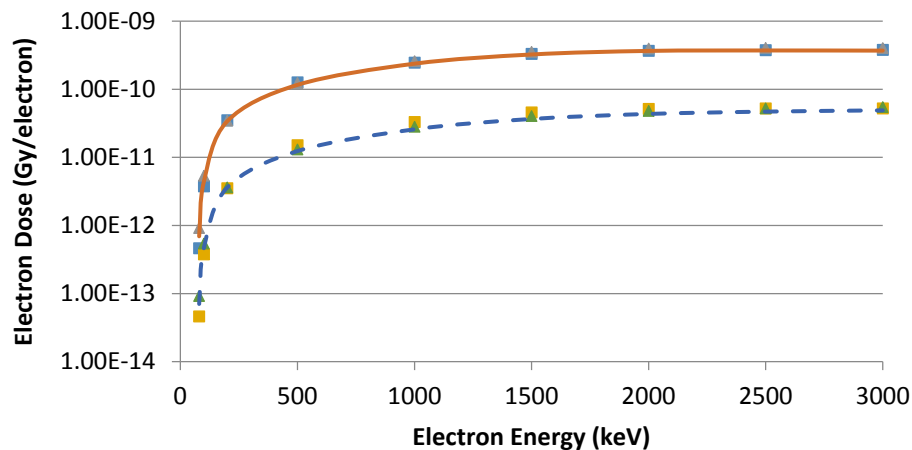


Cu-66

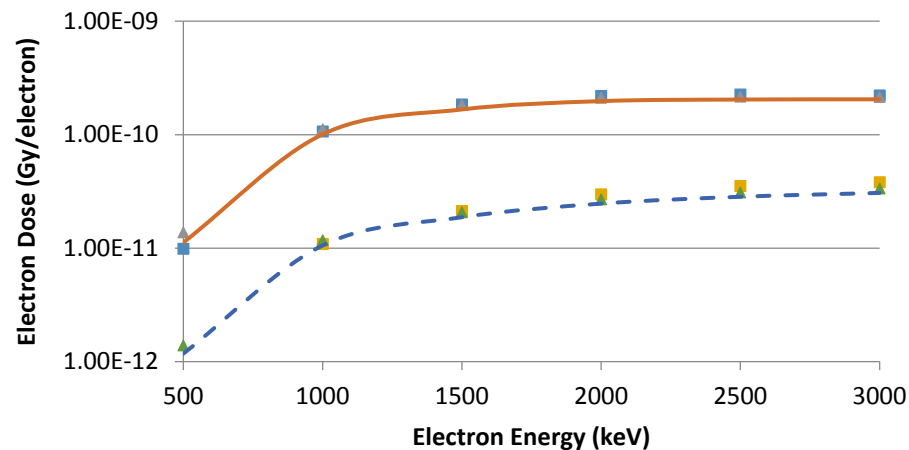


Disk source - electron

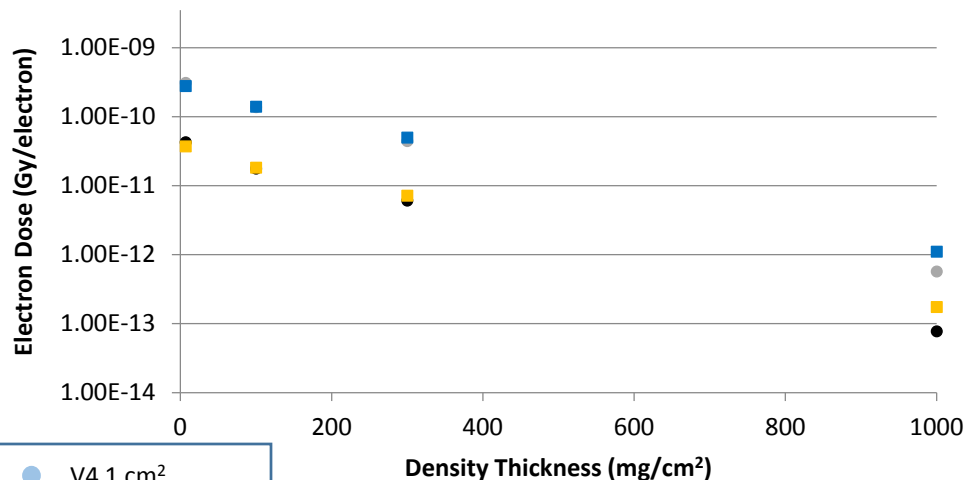
7 mg/cm²



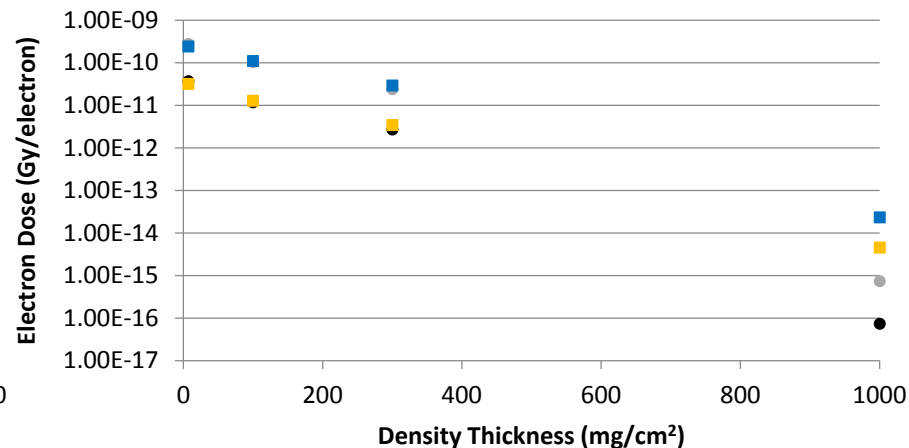
100 mg/cm²



K-42

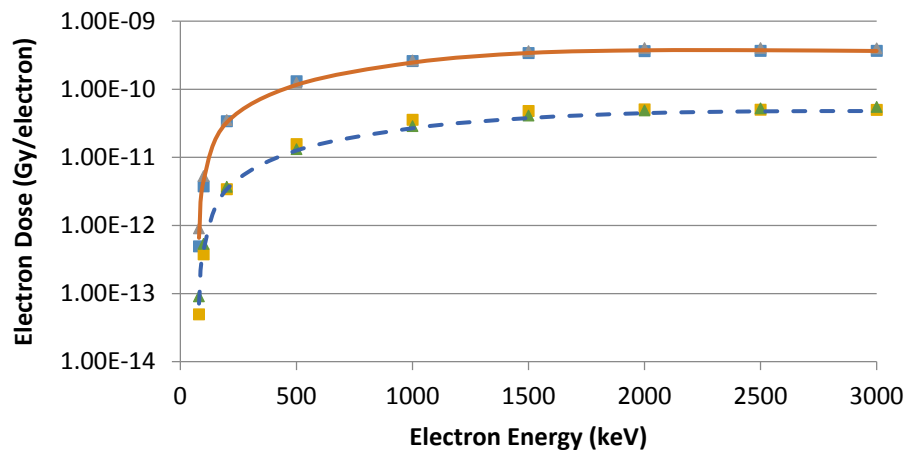


Cu-66

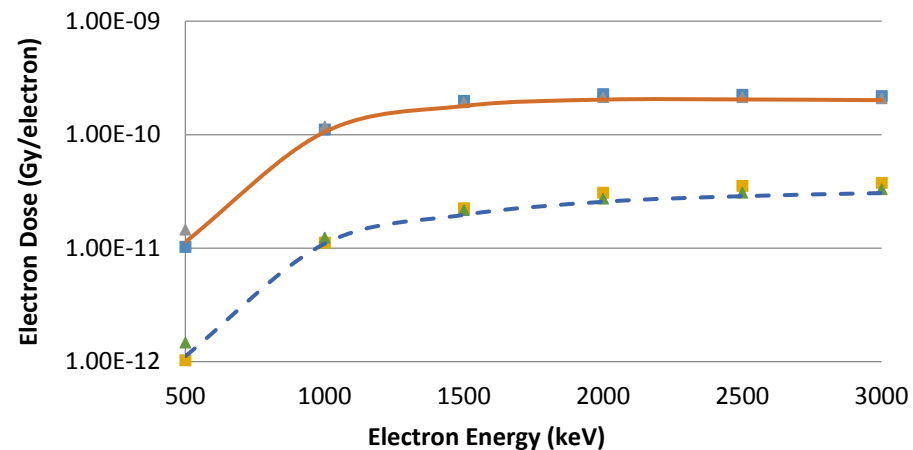


Cylindrical source - electron

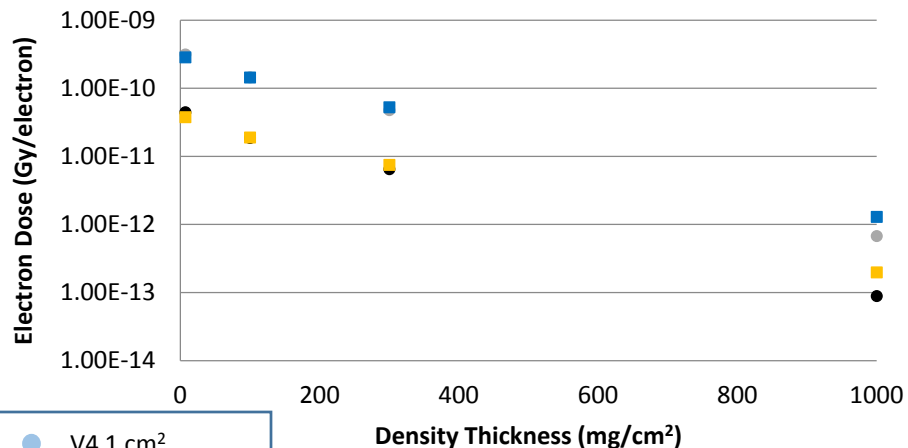
7 mg/cm²



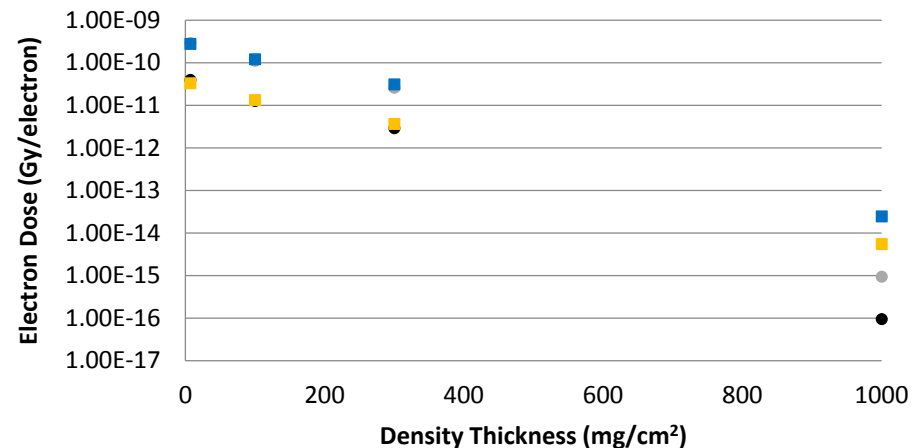
100 mg/cm²



K-42



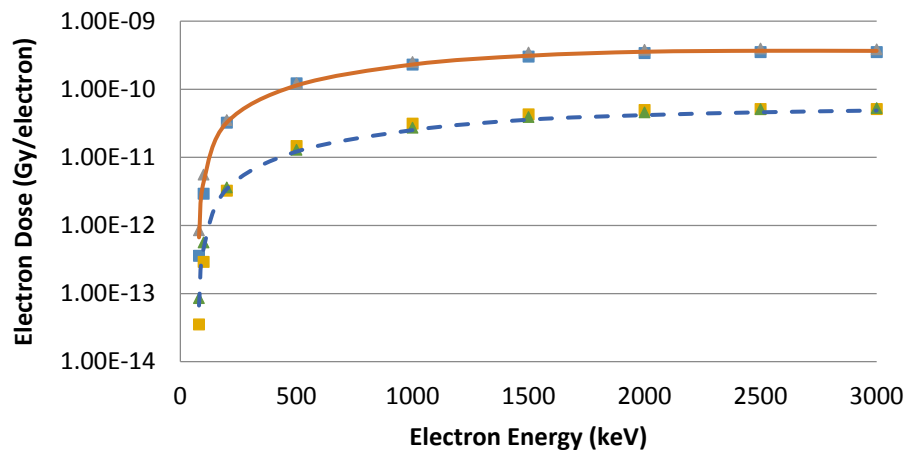
Cu-66



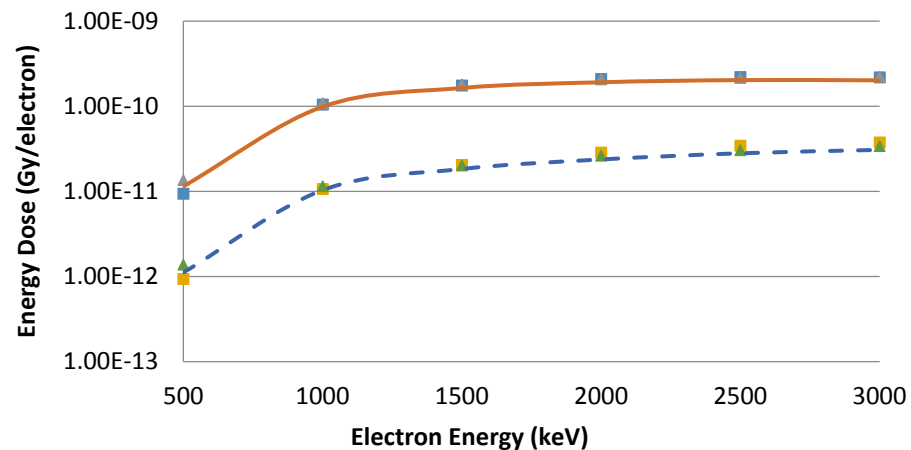
- V4 1 cm²
- V5 1 cm²
- ▲ MCNP 1 cm²
- EGS 1 cm²
- V4 10 cm²
- V5 10 cm²
- ▲ MCNP 10 cm²
- EGS 10 cm²

Spherical source - electron

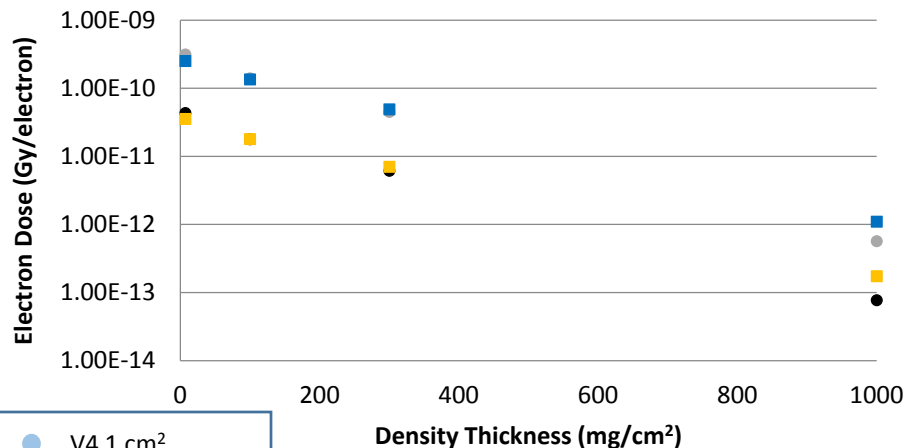
7 mg/cm²



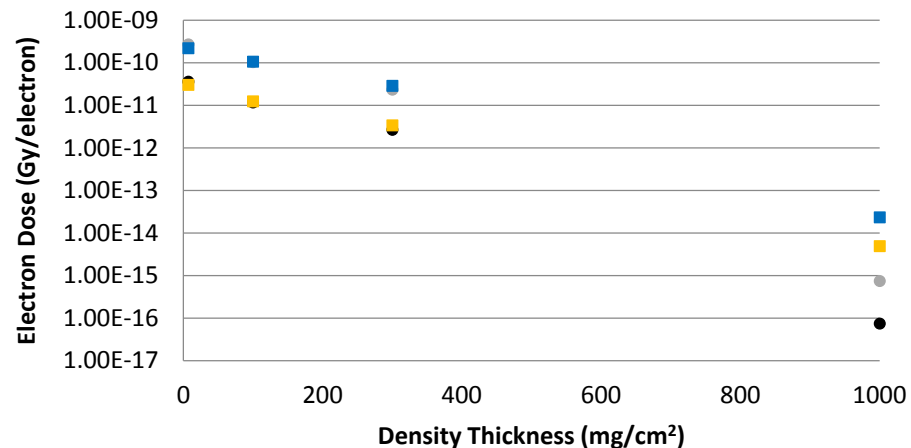
100 mg/cm²



K-42



Cu-66



Slab source - electron

varskin V5

Software QA

Quality Assurance

- Software QA program guidelines (NUREG/BR-0167)
- Acceptance testing on 3 Test Cases, with 10 iterations

**VARSKIN 5: A COMPUTER CODE FOR SKIN
CONTAMINATION DOSIMETRY**

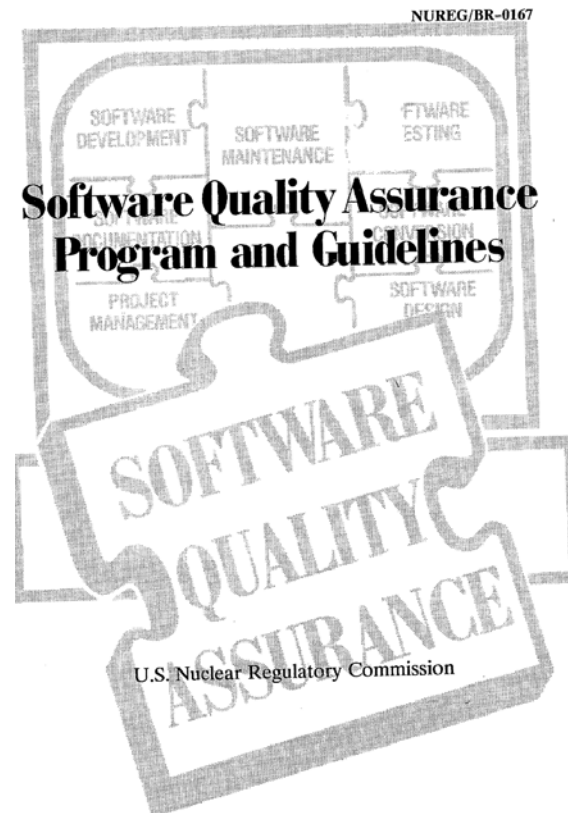
Software Acceptance Test Cases

Prepared by D.M. Hamby

Department of Nuclear Engineering and Radiation Health Physics
Oregon State University
Corvallis, OR 97331-5902

M. Saba, NRC Project Manager

Prepared for
Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission



Software Acceptance Test Cases

- Test Case 1
 - nuclear medicine tech
 - ^{186}Re in solution
 - 50 μCi on lab coat (arm)
- Test Case 2
 - worker in reactor containment
 - hot particle on plastic glove
 - 2.5 mCi of ^{60}Co
- Test Case 3
 - ^{14}C contamination of aluminum plate
 - dose rate estimated by measurement
 - back-calculation of activity present

Test Case Results

¹⁸⁶Re

⁶⁰Co

¹⁴C

VARSKIN 3.0	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.36E+00	0.00E+00	2.71E-01	1.66E-01	1.95E-01	3.25E-01	8.36E-02	0.00E+00	4.68E-02	1.43E-02
gamma	7.22E-04	9.67E-05	0.00E+00	0.00E+00	0.00E+00	2.08E-01	2.08E-01	3.72E-02	0.00E+00	0.00E+00
total	1.36E+00	9.67E-05	2.71E-01	1.66E-01	1.95E-01	5.33E-01	2.92E-01	3.72E-02	4.68E-02	1.43E-02
VARSKIN 3.1	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.36E+00	0.00E+00	2.71E-01	1.66E-01	1.95E-01	3.25E-01	8.36E-02	0.00E+00	4.68E-02	1.43E-02
gamma	7.10E-04	9.67E-05	0.00E+00	0.00E+00	0.00E+00	1.58E-01	1.58E-01	3.72E-02	0.00E+00	0.00E+00
total	1.36E+00	9.67E-05	2.71E-01	1.66E-01	1.95E-01	4.83E-01	2.42E-01	3.72E-02	4.68E-02	1.43E-02
VARSKIN 4.0	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.36E+00	0.00E+00	2.71E-01	1.66E-01	1.95E-01	3.25E-01	8.36E-02	0.00E+00	4.68E-02	1.43E-02
gamma	6.73E-04	7.12E-05	1.49E-04	1.49E-04	1.24E-04	1.05E-01	1.05E-01	3.25E-02	0.00E+00	0.00E+00
total	1.36E+00	7.12E-05	2.71E-01	1.66E-01	1.95E-01	4.30E-01	1.89E-01	3.25E-02	4.68E-02	1.43E-02
VARSKIN 5.0	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.31E+00	0.00E+00	2.62E-01	1.69E-01	1.86E-01	3.25E-01	1.30E-01	0.00E+00	4.47E-02	6.04E-04
gamma	6.73E-04	7.12E-05	1.49E-04	1.49E-04	1.24E-04	1.05E-01	1.05E-01	3.25E-02	0.00E+00	0.00E+00
total	1.31E+00	7.12E-05	2.62E-01	1.69E-01	1.86E-01	4.31E-01	2.35E-01	3.25E-02	4.47E-02	6.04E-04
VARSKIN 5.1	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.31E+00	0.00E+00	2.62E-01	1.69E-01	1.86E-01	3.25E-01	1.22E-01	0.00E+00	4.47E-02	6.04E-04
gamma	6.73E-04	7.12E-05	1.49E-04	1.49E-04	1.24E-04	1.05E-01	1.05E-01	3.25E-02	0.00E+00	0.00E+00
total	1.31E+00	7.12E-05	2.62E-01	1.69E-01	1.86E-01	4.31E-01	2.28E-01	3.25E-02	4.47E-02	6.04E-04
VARSKIN 5.2	===== EXAMPLE 1 =====					===== EXAMPLE 2 =====			===== EXAMPLE 3 =====	
Dose (Gy)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 1	Case 2
beta	1.31E+00	0.00E+00	2.62E-01	1.69E-01	1.86E-01	3.25E-01	1.22E-01	0.00E+00	4.47E-02	6.04E-04
gamma	6.73E-04	7.12E-05	1.49E-04	1.26E-04	1.24E-04	1.05E-01	1.06E-01	3.24E-02	0.00E+00	0.00E+00
total	1.31E+00	7.12E-05	2.62E-01	1.69E-01	1.86E-01	4.31E-01	2.29E-01	3.24E-02	4.47E-02	6.04E-04



V&V Conclusions

Conclusions – Photon Dosimetry

- For the point and disk source geometries, MCNP and VARSKIN 5 are in excellent agreement over an energy range from 25 keV to 3 MeV
- 3D source models show good agreement for deep dose, but shallow dose is increasingly over-predicted as energy increases
- The cover/gap models seem to work well at deeper depths, but for shallow depths variability of 2x is shown to exist
- Off-axis model is a fair predictor

Conclusions – Electron Dosimetry

- VARSKIN 5 is in reasonable agreement with EGS over a wide energy range (w deviations for $E < 200$ keV)
- Differences observed at medium energies, medium depths for some volumetric sources
- Depending upon geometry, MCNP usually predicts higher absorbed dose compared to VARSKIN 5 and EGS
- VARSKIN 5 generally predicts higher than its predecessor at deep depths and lower at shallow depths

Conclusions – Electron Dosimetry

- Comparisons have been made between VARSKIN 4 and VARSKIN 5 for several high-energy nuclides
- Data suggests that at shallow depths, V4 and V5 agree reasonably well over most energies
- However, for the same energy, V4 consistently predicts a lower dose than V5 at deep depths