varskin V5

EXAMPLES

Scenario (test case) #1

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

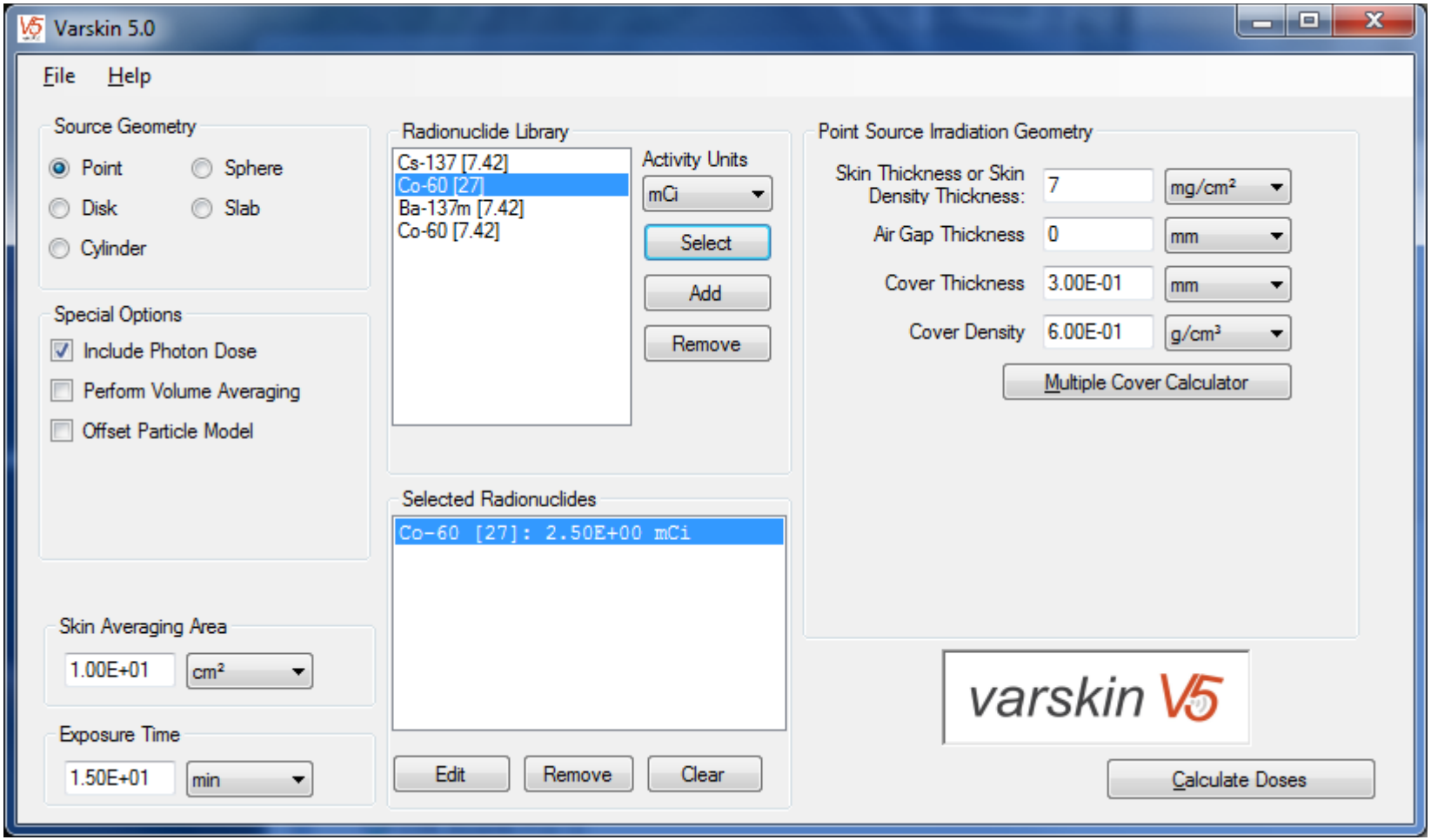
summary

	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

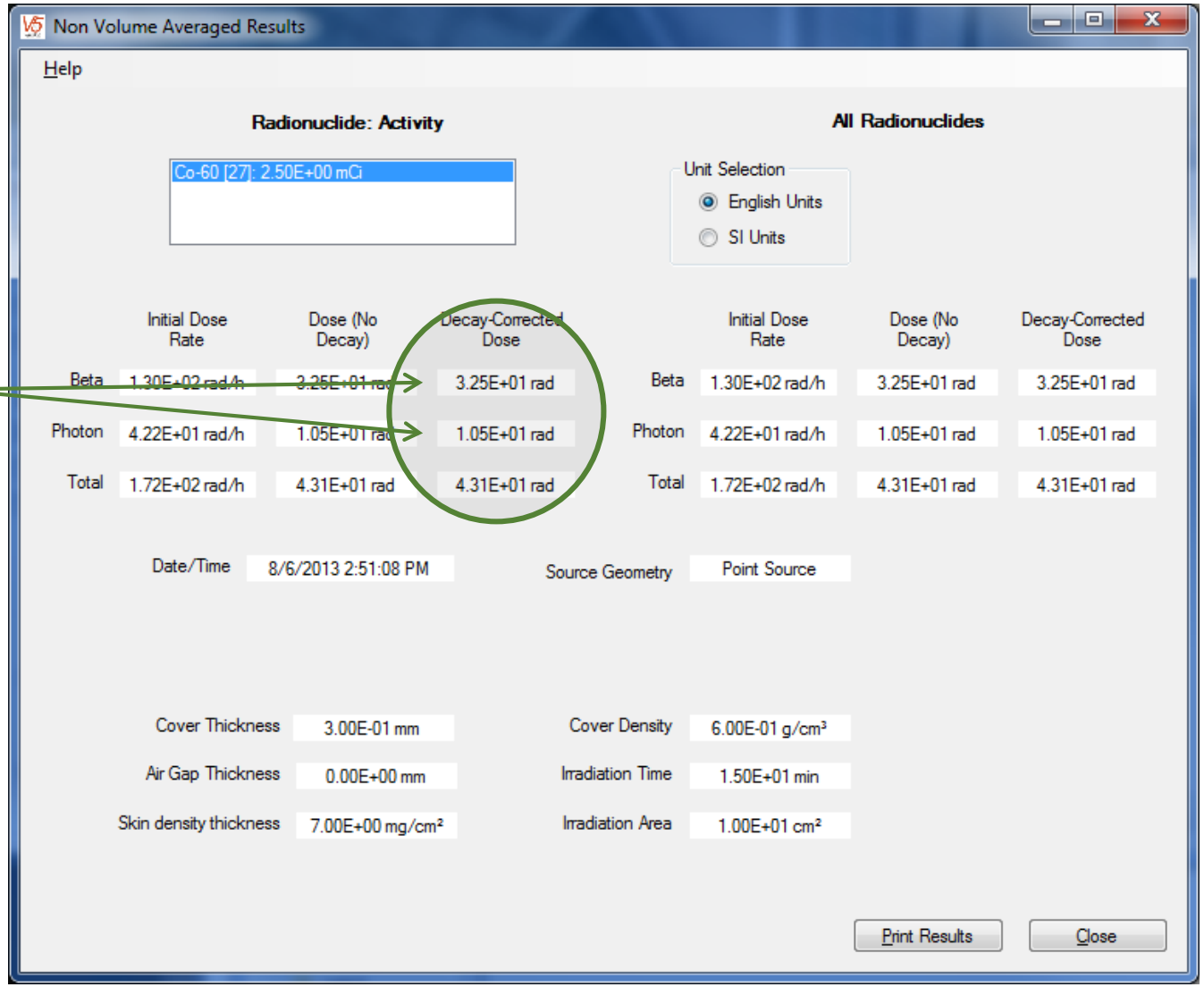
- Radiation worker in reactor containment
- ^{60}Co hot particle (2.5 mCi; 15 min) on gloved hand
- 50 μm @ 8.3 g/cm^3 (Z=27)
- 80 x 70 μm
- Glove characteristics: 0.3 mm and 0.6 g/cm^3
- Initially, point-source geometry
- Then, refine for more realism …

Point source



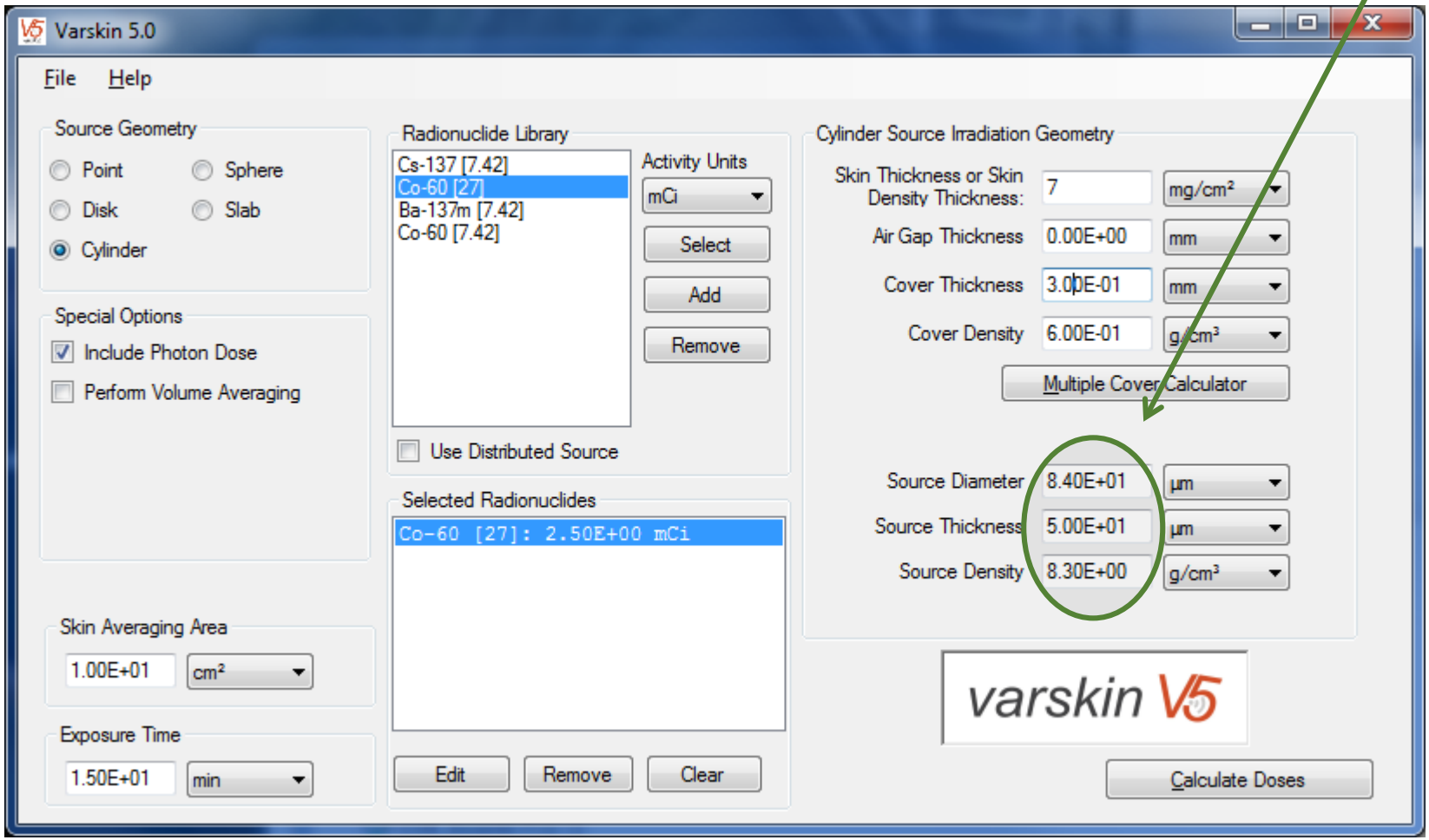
results

Note β/γ contribution

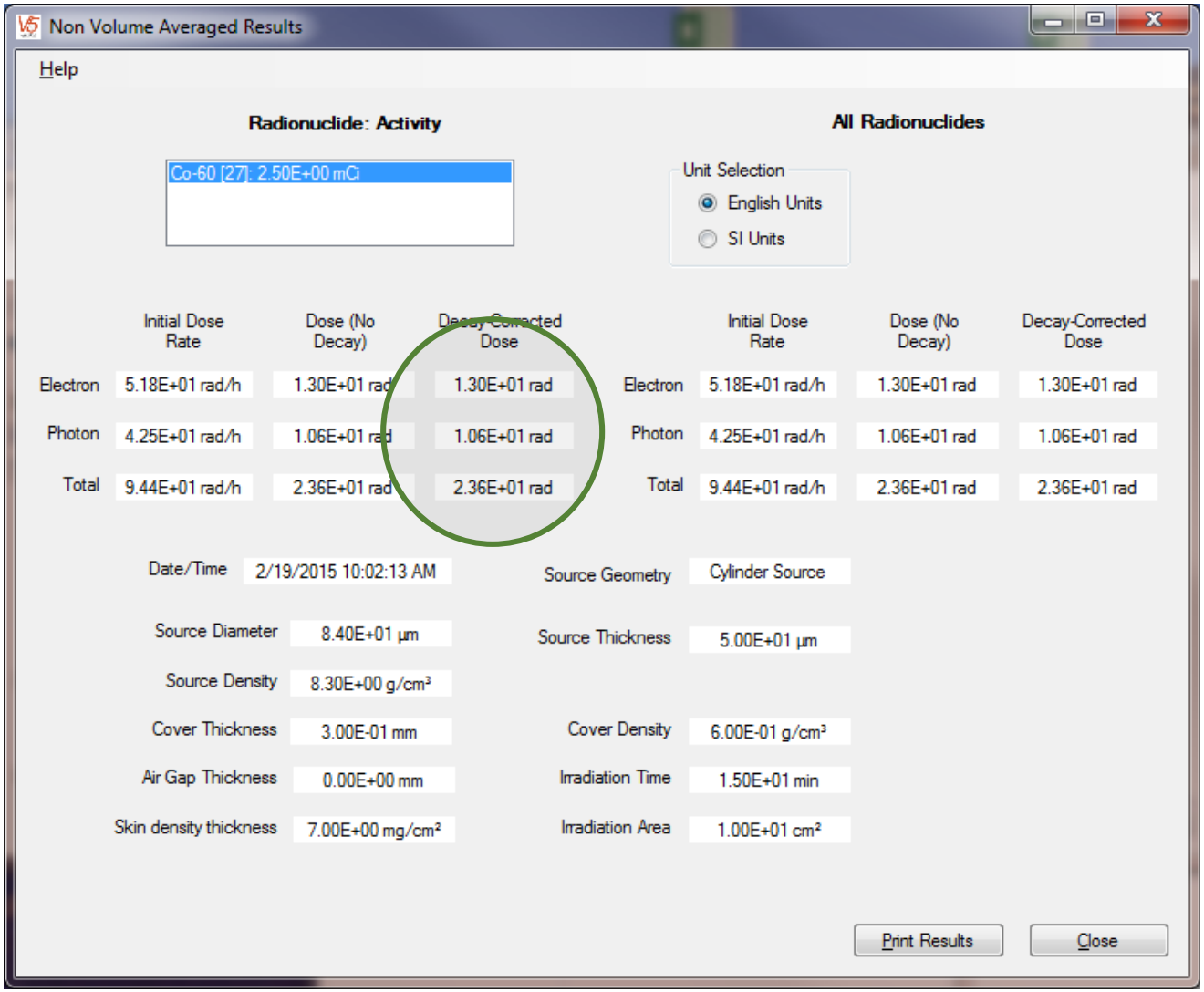


Cylindrical equivalent source

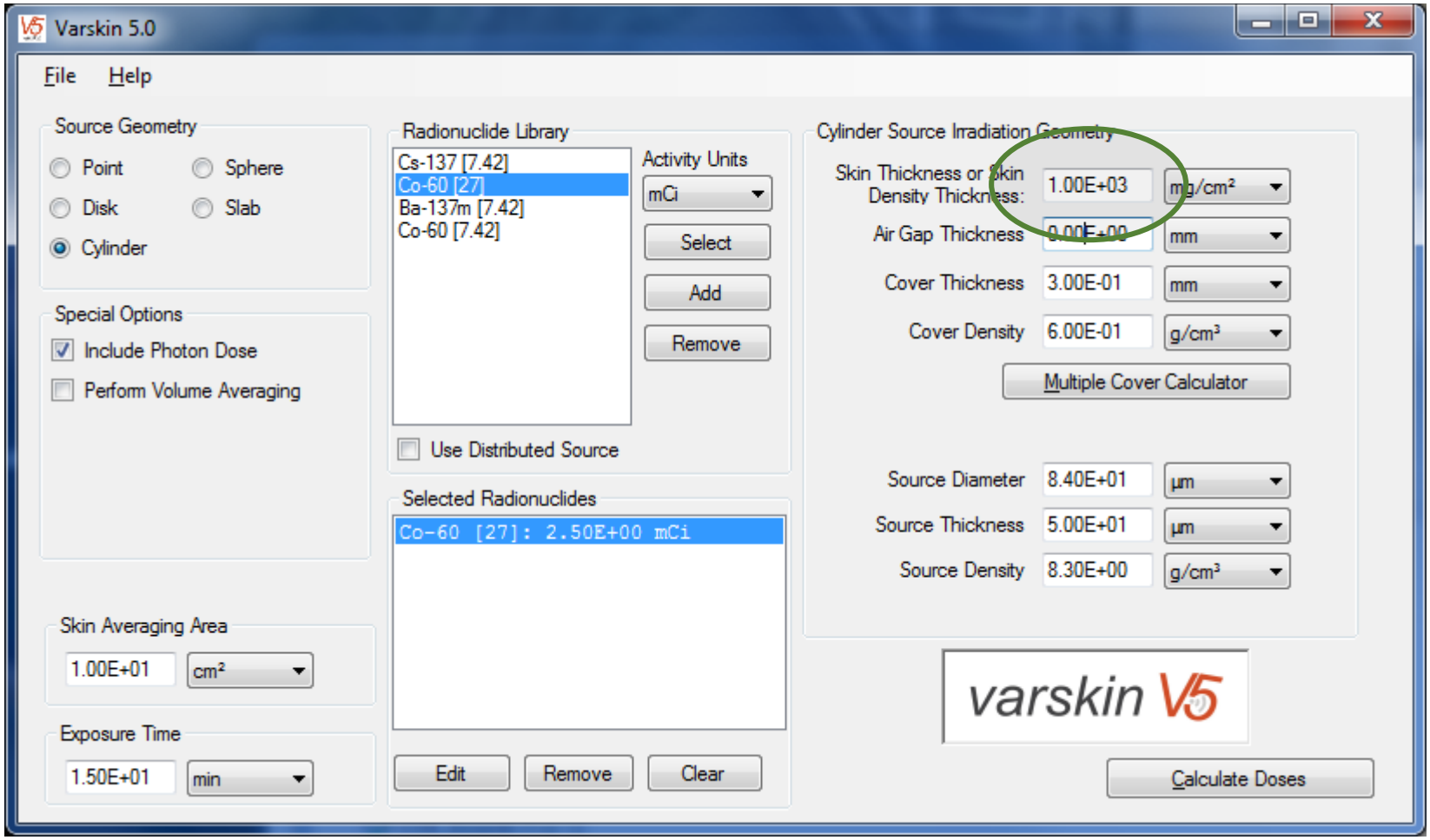
$$d = 2\sqrt{\frac{X \cdot Y}{\pi}} = 2\sqrt{\frac{80\mu m \cdot 70\mu m}{\pi}} = 84\ \mu m$$



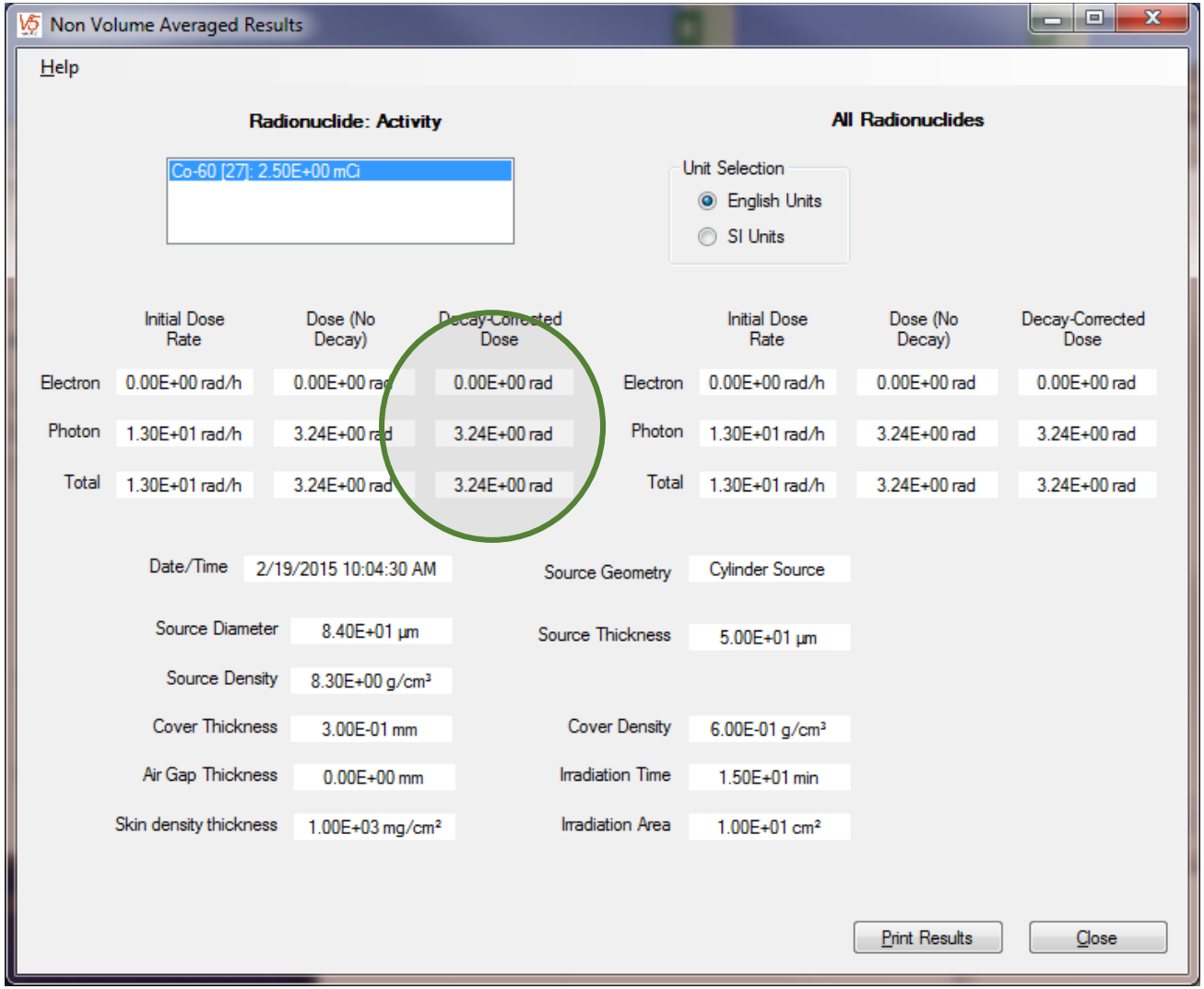
results


Non Volume Averaged Results
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
Electron 5.18E+01 rad/h 1.30E+01 rad 1.30E+01 rad
Photon 4.25E+01 rad/h 1.06E+01 rad 1.06E+01 rad
Total 9.44E+01 rad/h 2.36E+01 rad 2.36E+01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 5.18E+01 rad/h 1.30E+01 rad 1.30E+01 rad
Photon 4.25E+01 rad/h 1.06E+01 rad 1.06E+01 rad
Total 9.44E+01 rad/h 2.36E+01 rad 2.36E+01 rad
Date/Time 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/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 7.00E+00 mg/cm²
Irradiation Area 1.00E+01 cm²
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
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
Electron 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Photon 1.30E+01 rad/h 3.24E+00 rad 3.24E+00 rad
Total 1.30E+01 rad/h 3.24E+00 rad 3.24E+00 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Photon 1.30E+01 rad/h 3.24E+00 rad 3.24E+00 rad
Total 1.30E+01 rad/h 3.24E+00 rad 3.24E+00 rad
Date/Time 2/19/2015 10:04:30 AM
Source Geometry Cylinder Source
Source Diameter 8.40E+01 µm
Source Thickness 5.00E+01 µm
Source Density 8.30E+00 g/cm³
Cover Thickness 3.00E-01 mm
Cover Density 6.00E-01 g/cm³
Air Gap Thickness 0.00E+00 mm
Irradiation Time 1.50E+01 min
Skin density thickness 1.00E+03 mg/cm²
Irradiation Area 1.00E+01 cm²
Print Results
Close

summary

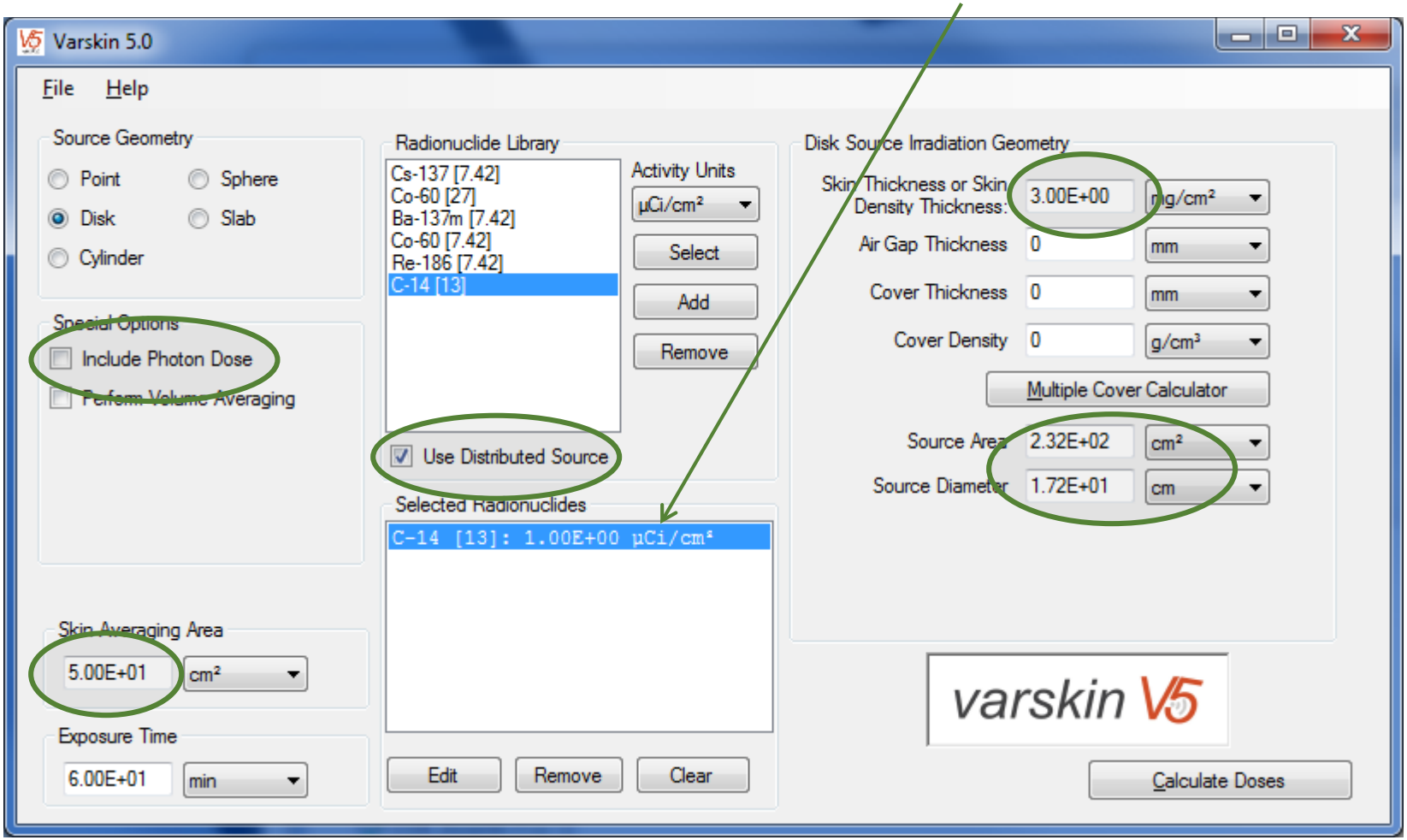
	Beta Dose	Photon Dose	Total Dose (rad)
Point Source	32.5	10.5	43.1
Cylindrical Equivalent	13.0	10.6	23.6
Deep Dose	0	3.24	3.24

Scenario (test case) #3

- Contaminated aluminum plate
- Known to be ^{14}C, but activity must be determined
- 6” x 6” (232 cm^2) uniformly contaminated
- Detector of 50 cm^2 with 3 mg/cm^2 window
  - measured dose rate of 190 mrad/hr on contact
  - 60 mrad/hr at 1 inch
- Using VARSKIN to estimate activity …

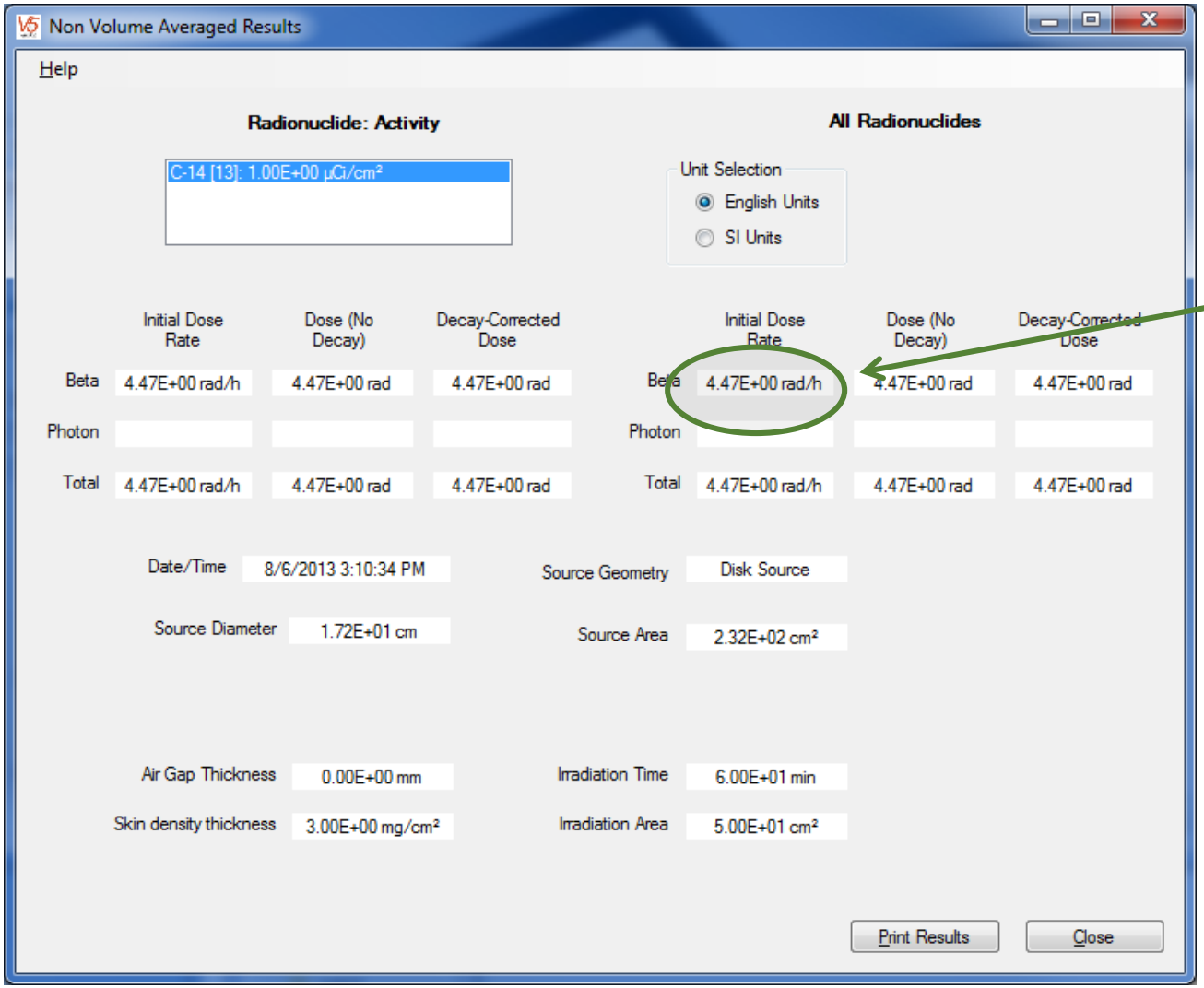
Reverse calculations

Unit concentration to start



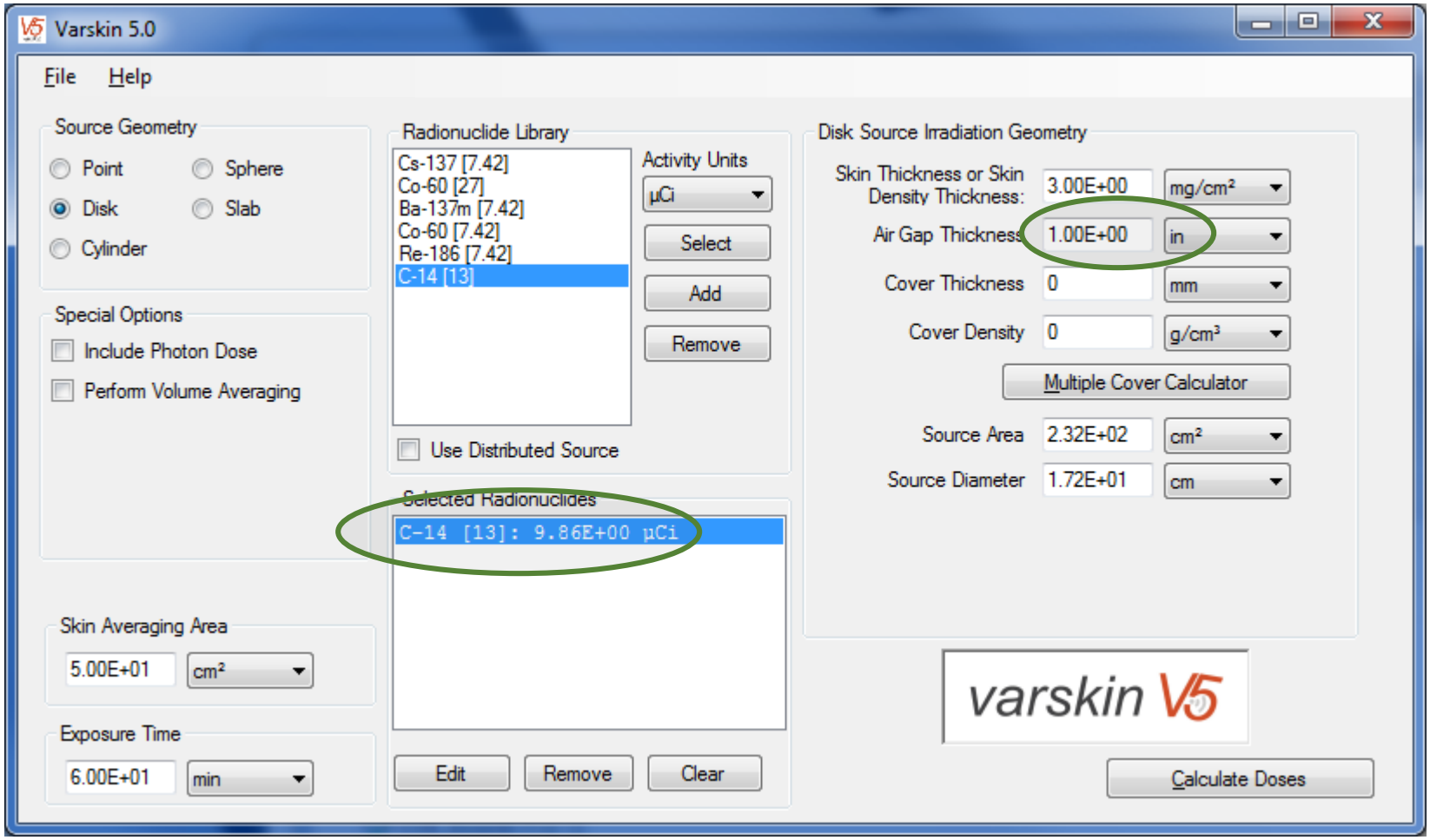
Results

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

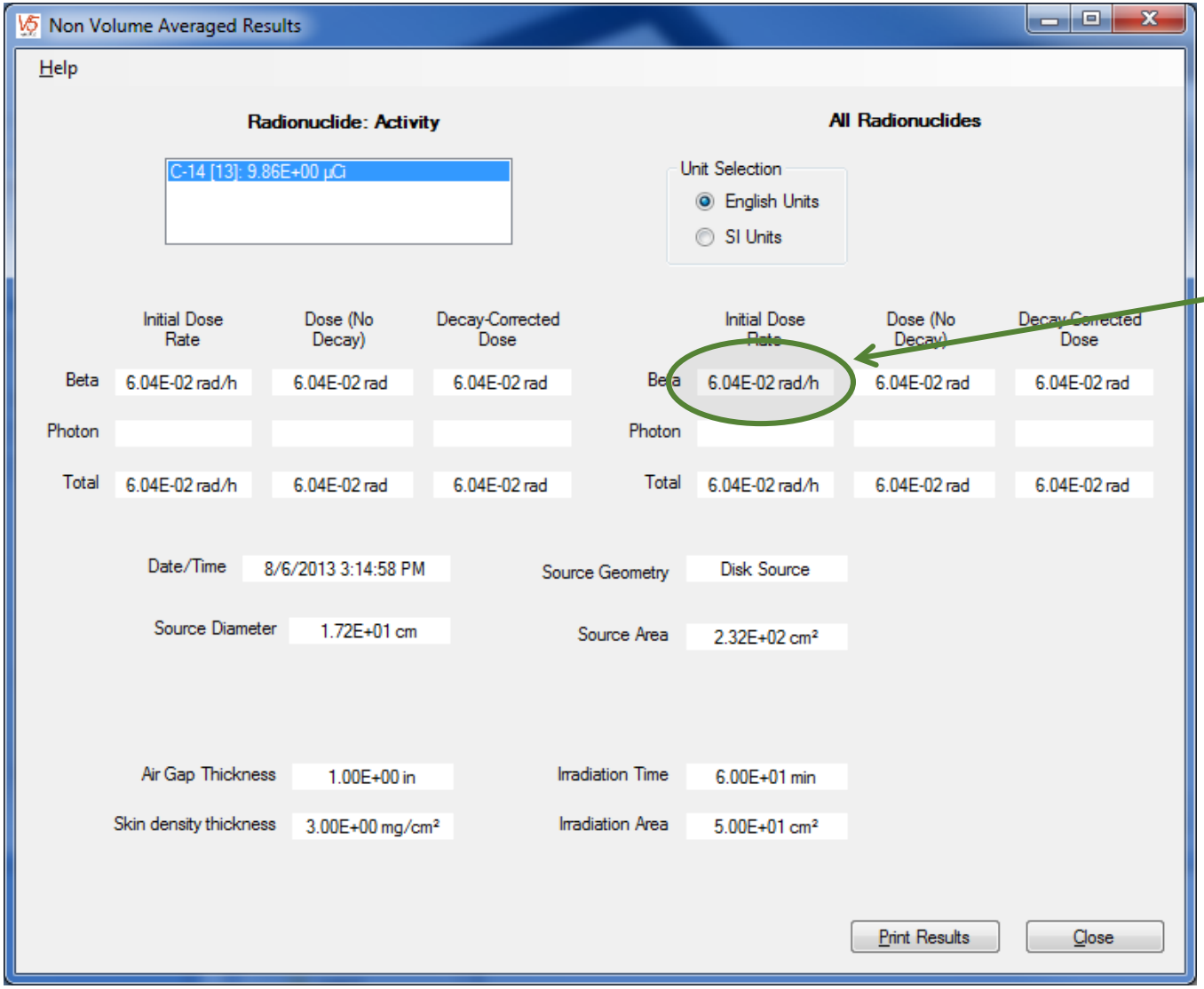


Scales to a source strength of 0.0425 µCi/cm², and a total activity of 9.86 µCi.

Confirmation using air gap



results



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

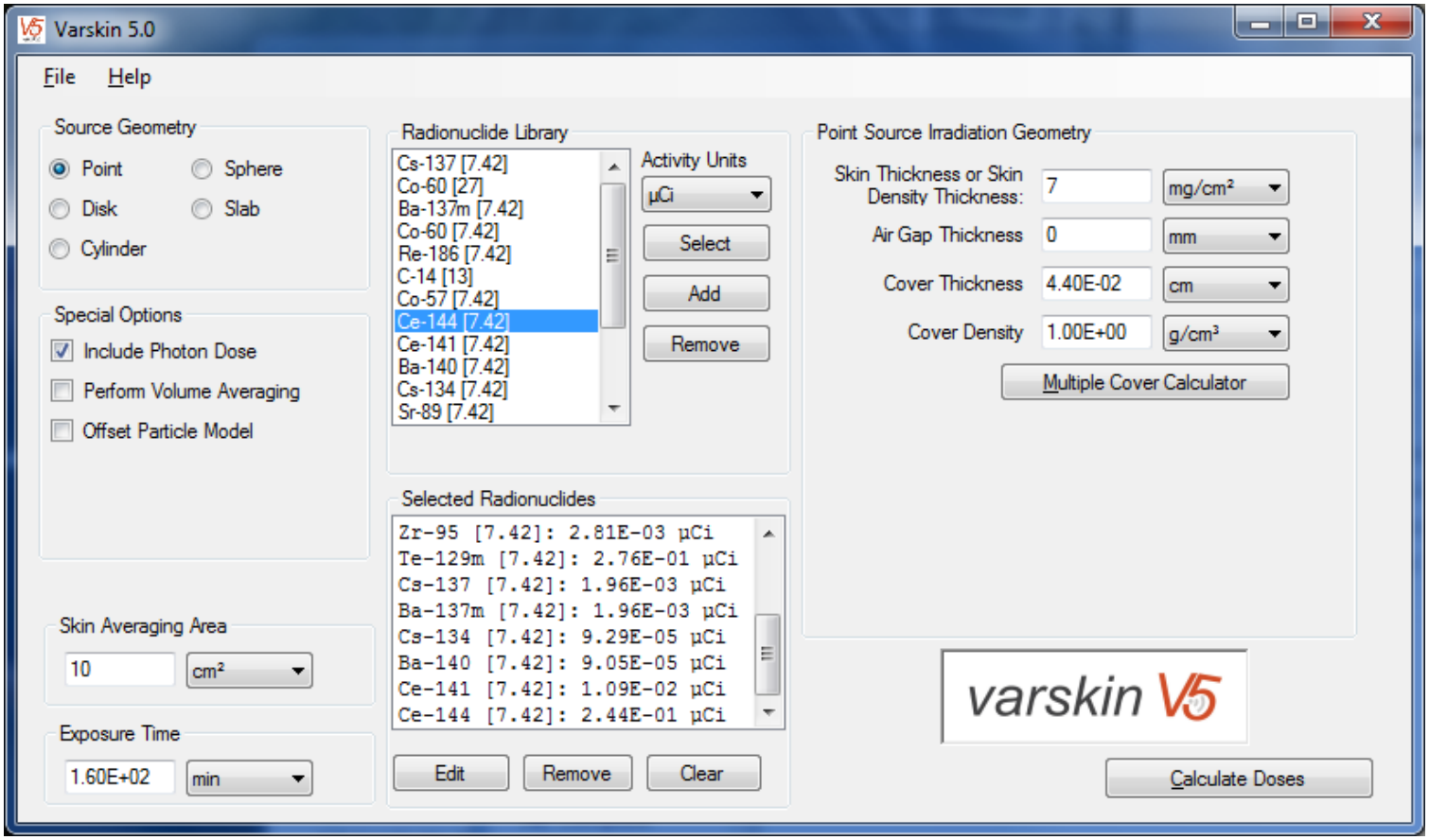
scenario #4

- 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/cm^3

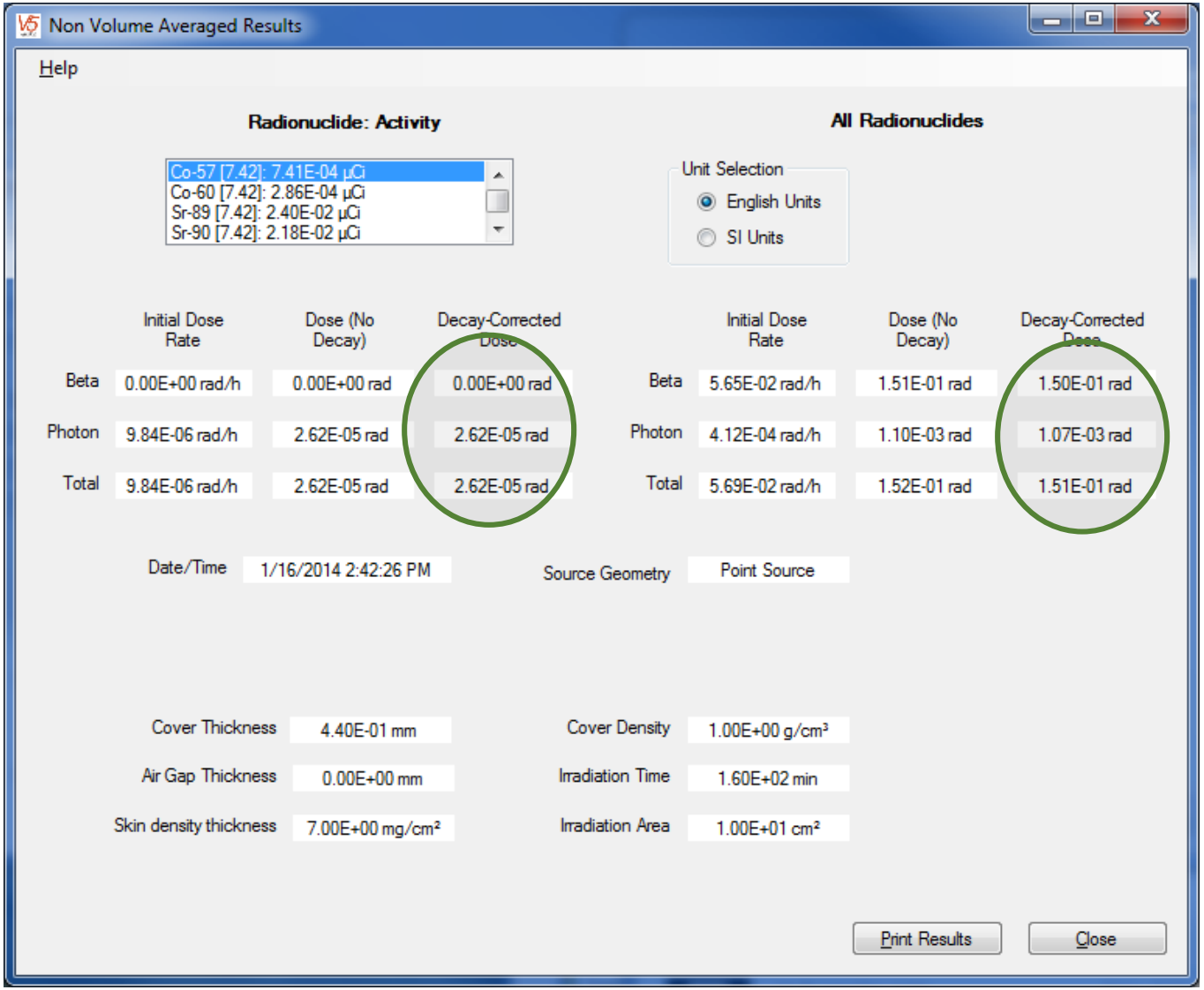
source term

NUCLIDE	ACTIVITY (uCi)
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



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
Beta 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Photon 9.84E-06 rad/h 2.62E-05 rad 2.62E-05 rad
Total 9.84E-06 rad/h 2.62E-05 rad 2.62E-05 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 5.65E-02 rad/h 1.51E-01 rad 1.50E-01 rad
Photon 4.12E-04 rad/h 1.10E-03 rad 1.07E-03 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
Air Gap Thickness 0.00E+00 mm
Skin density thickness 7.00E+00 mg/cm²
Cover Density 1.00E+00 g/cm³
Irradiation Time 1.60E+02 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

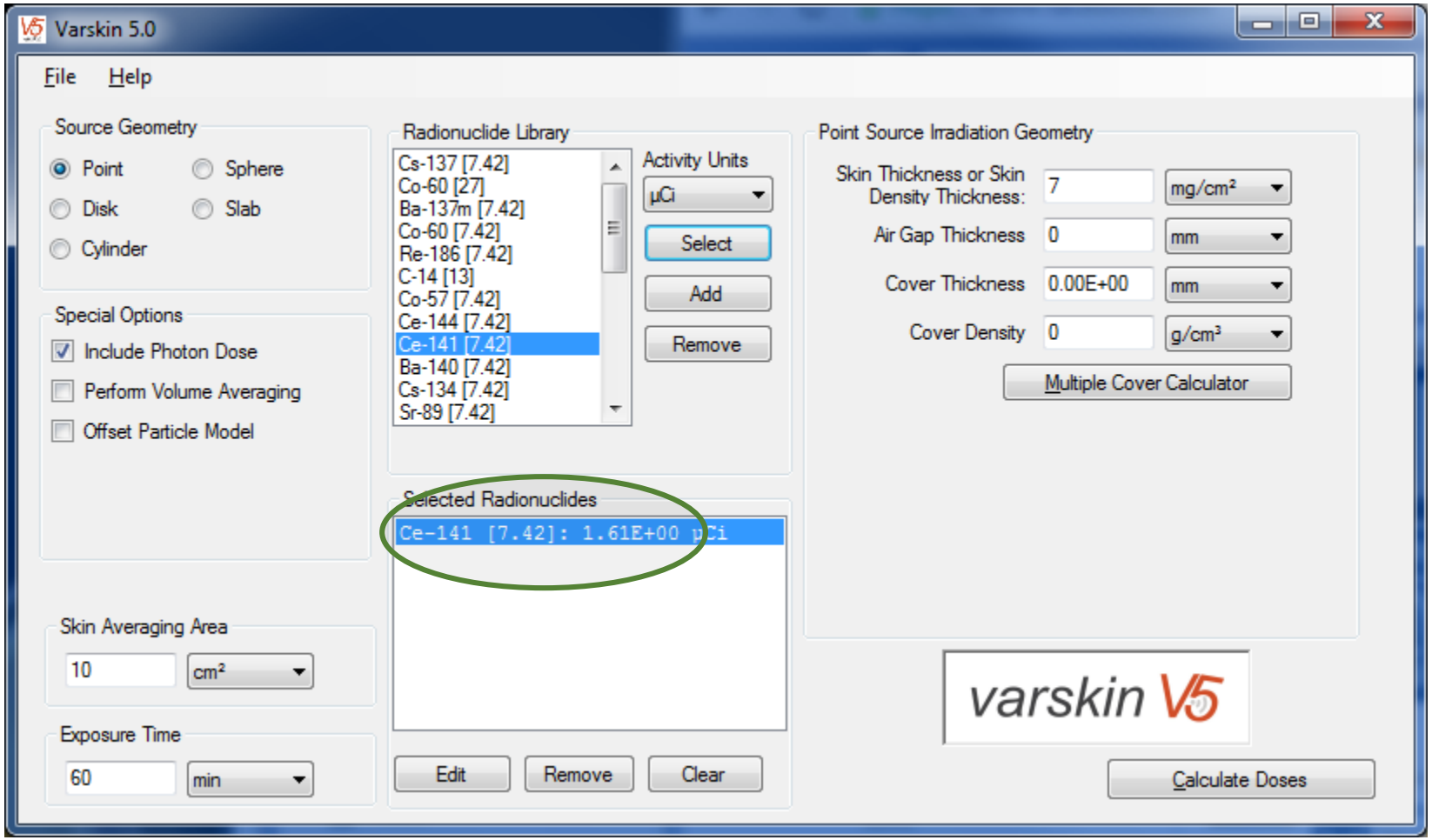
beta/gamma dose

Nuclide	Activity (uCi)	Beta Dose (mrad)	Photon Dose (mrad)
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	9.20E-1	1.85E-1
		1.50E+2	1.07E+0

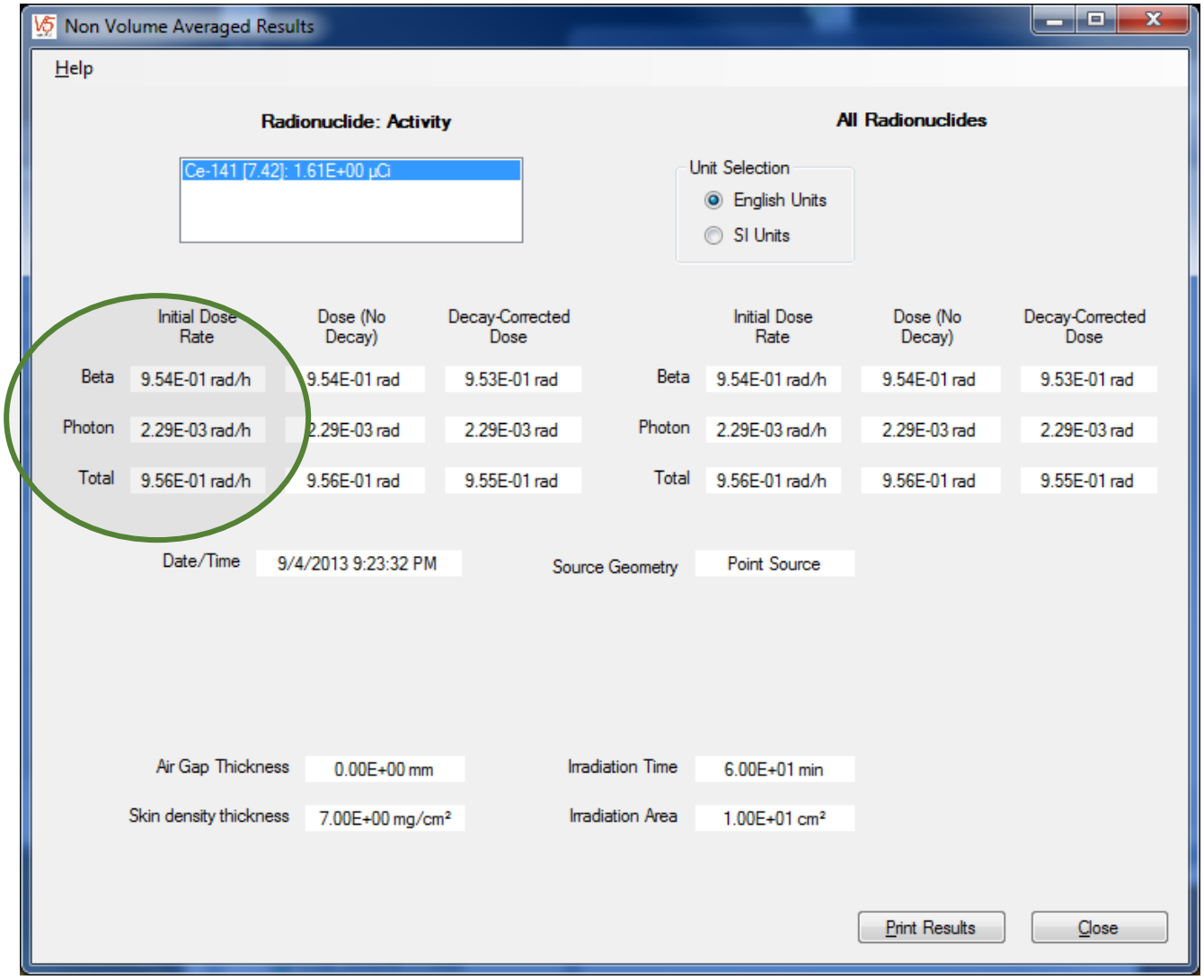
scenario #5

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

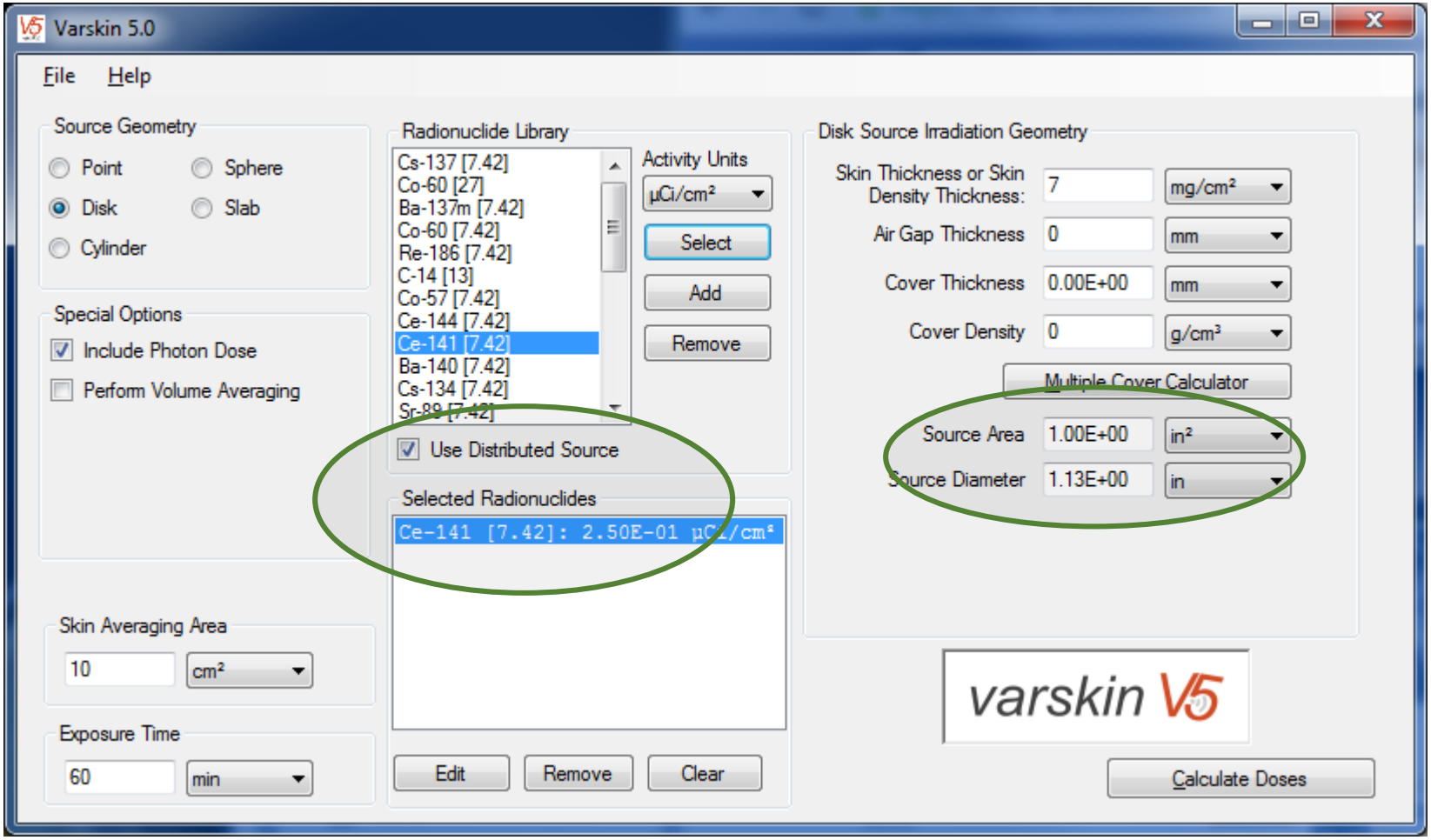
Point source



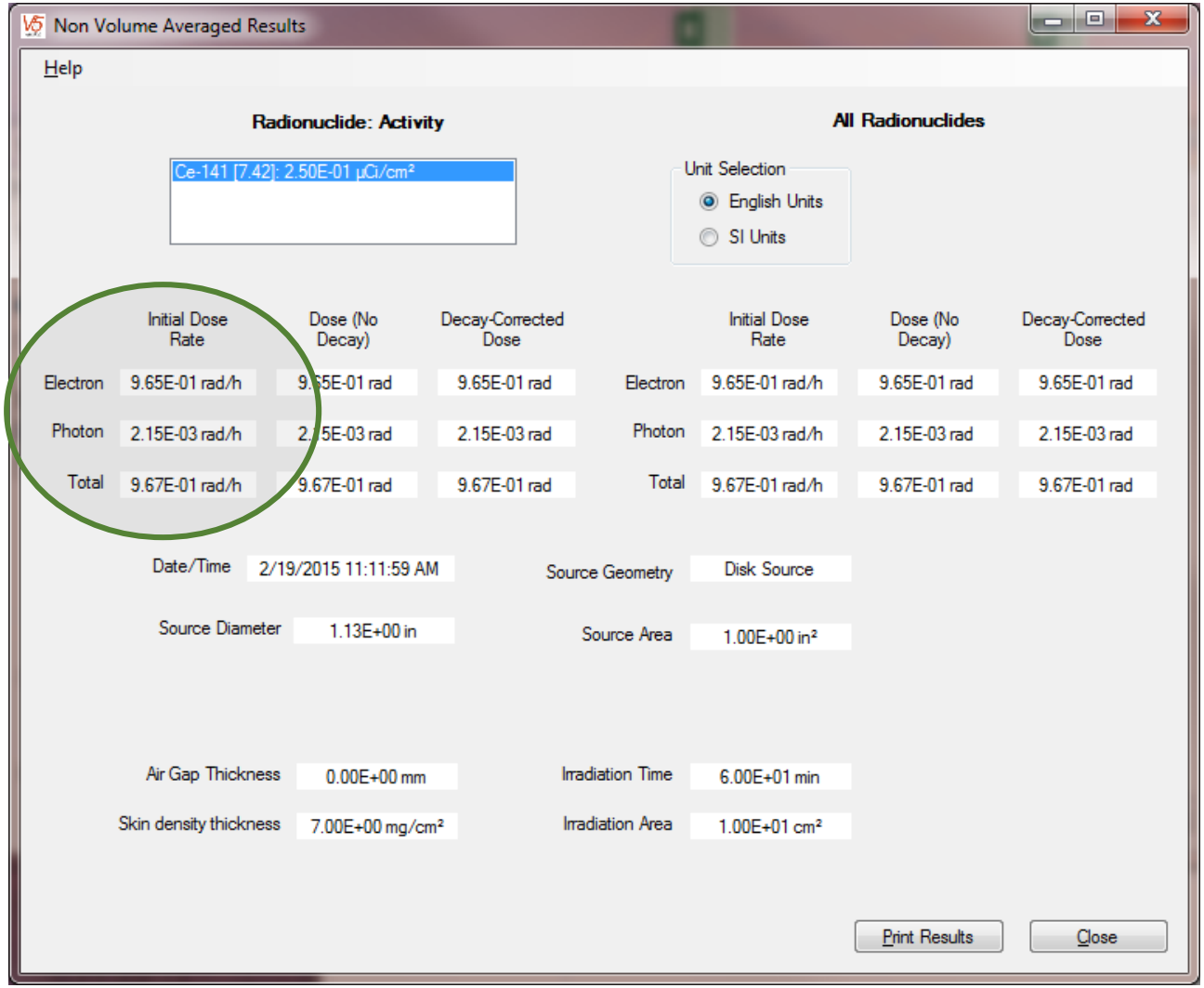
results


Non Volume Averaged Results
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
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
Total 9.56E-01 rad/h 9.56E-01 rad 9.55E-01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
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
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
Skin density thickness 7.00E+00 mg/cm²
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

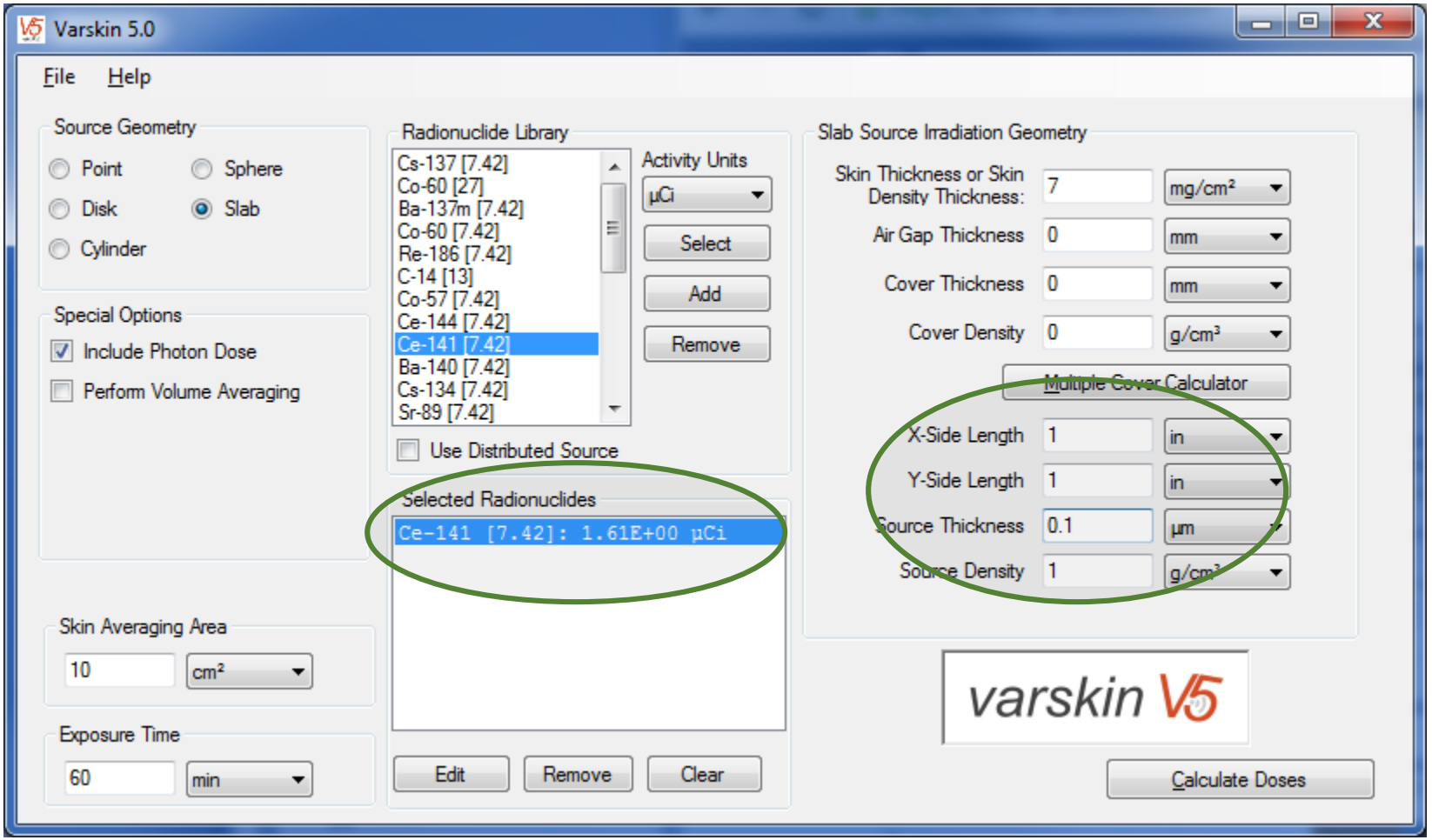
2D Disk source



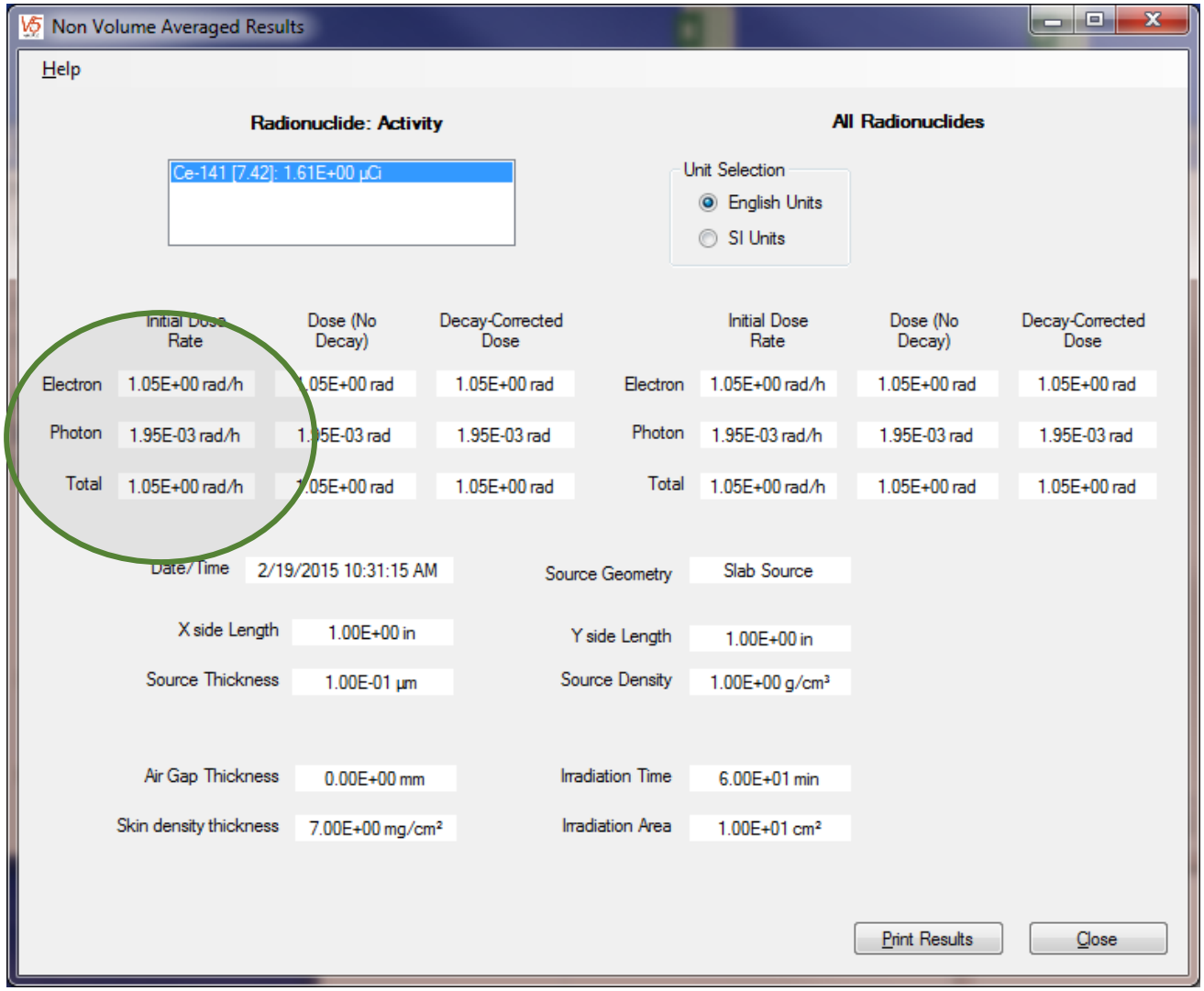
results


Non Volume Averaged Results
Help
Radionuclide: Activity
Ce-141 [7.42]: 2.50E-01 µCi/cm²
All Radionuclides
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.65E-01 rad/h 9.65E-01 rad 9.65E-01 rad
Photon 2.15E-03 rad/h 2.15E-03 rad 2.15E-03 rad
Total 9.67E-01 rad/h 9.67E-01 rad 9.67E-01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.65E-01 rad/h 9.65E-01 rad 9.65E-01 rad
Photon 2.15E-03 rad/h 2.15E-03 rad 2.15E-03 rad
Total 9.67E-01 rad/h 9.67E-01 rad 9.67E-01 rad
Date/Time 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

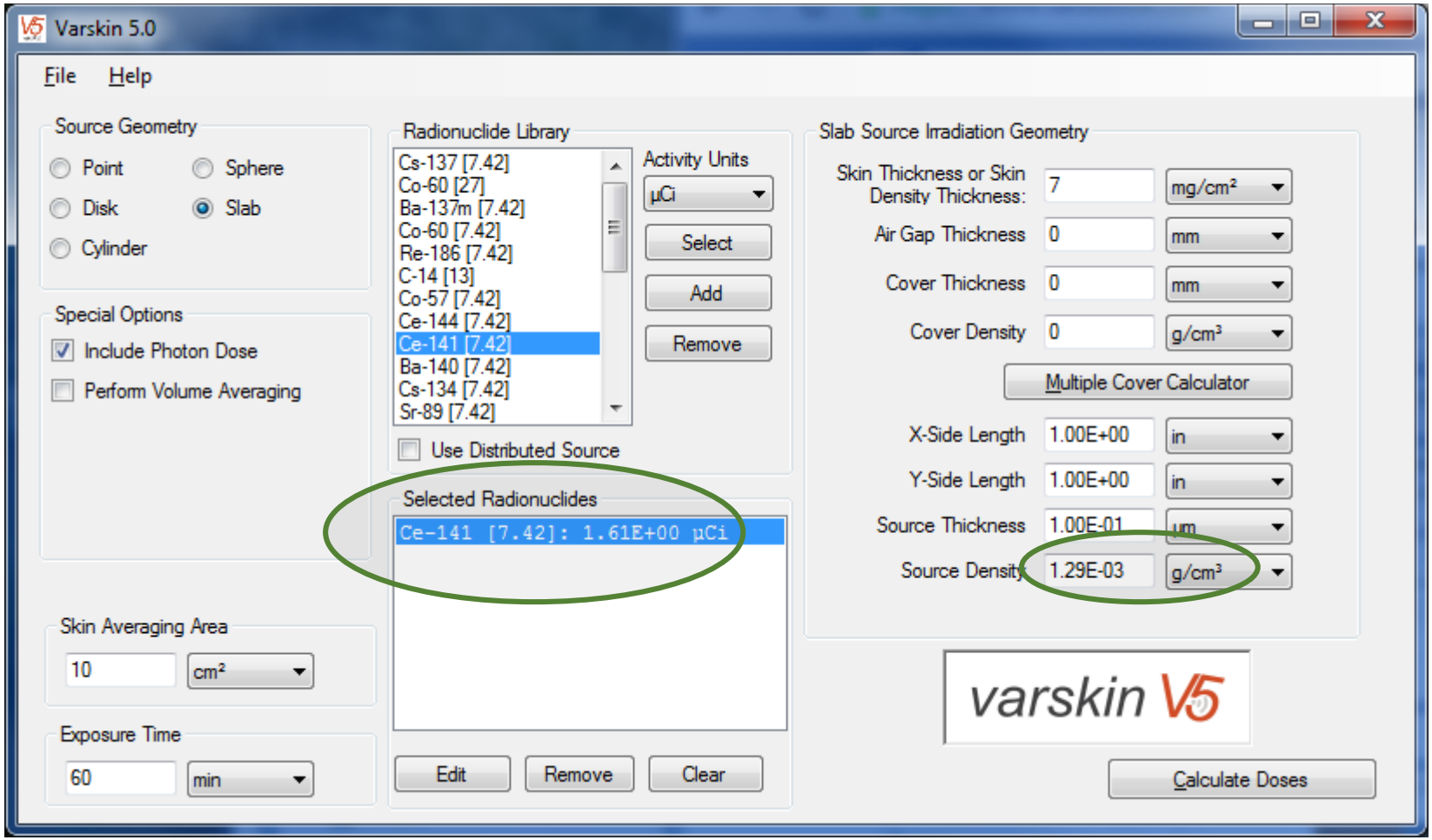
Slab source


Varskin 5.0
File
Help
Source Geometry
Point
Sphere
Disk
Slab
Cylinder
Special Options
Include Photon Dose
Perform Volume Averaging
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
Ce-141 [7.42]: 1.61E+00 µCi
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
in
Y-Side Length
1
in
Source Thickness
0.1
µm
Source Density
1
g/cm³
varskin V5
Calculate Doses

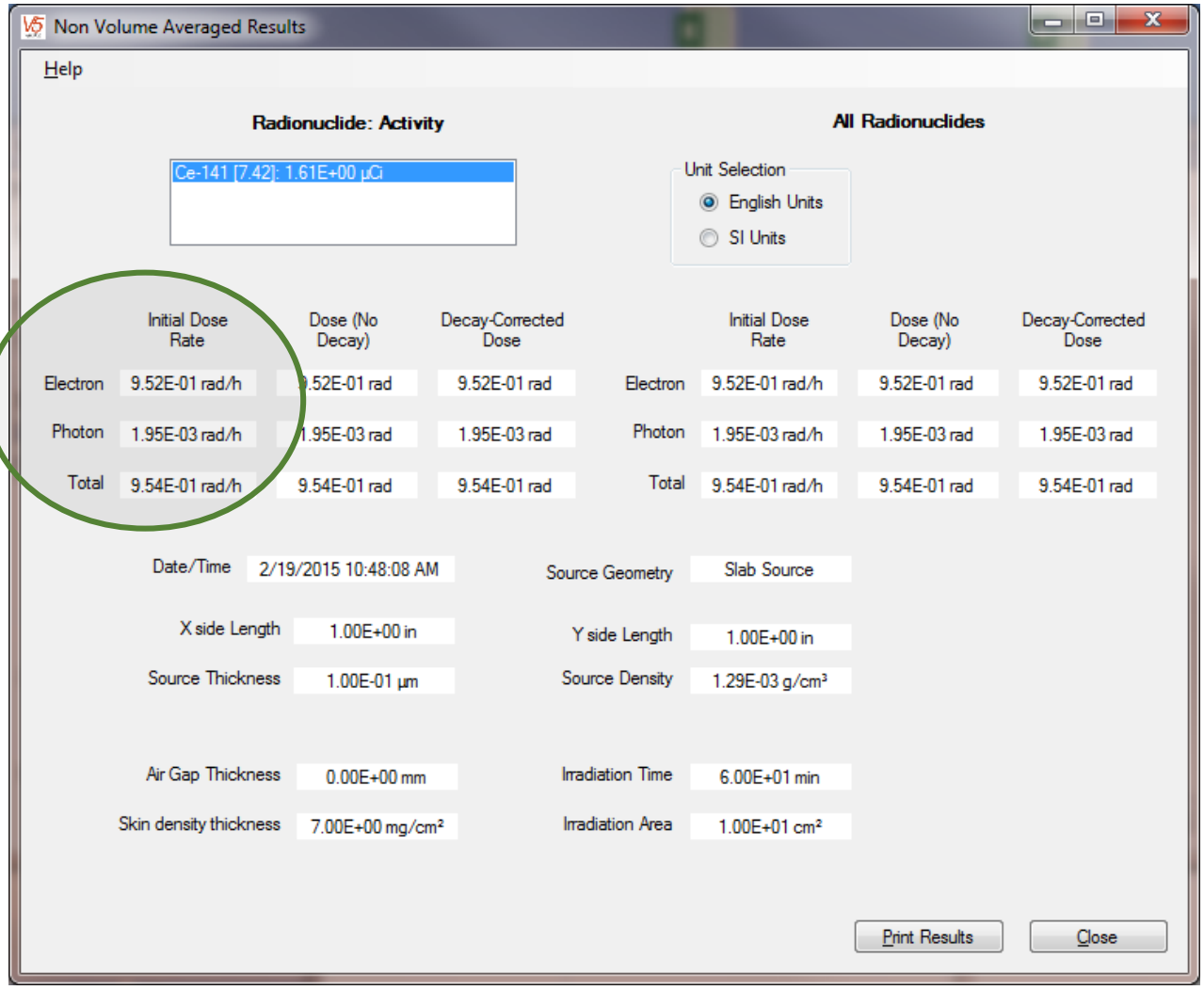
results


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
Electron 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 1.05E+00 rad/h 1.05E+00 rad 1.05E+00 rad
Date/Time 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 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+01 cm²
Print Results
Close

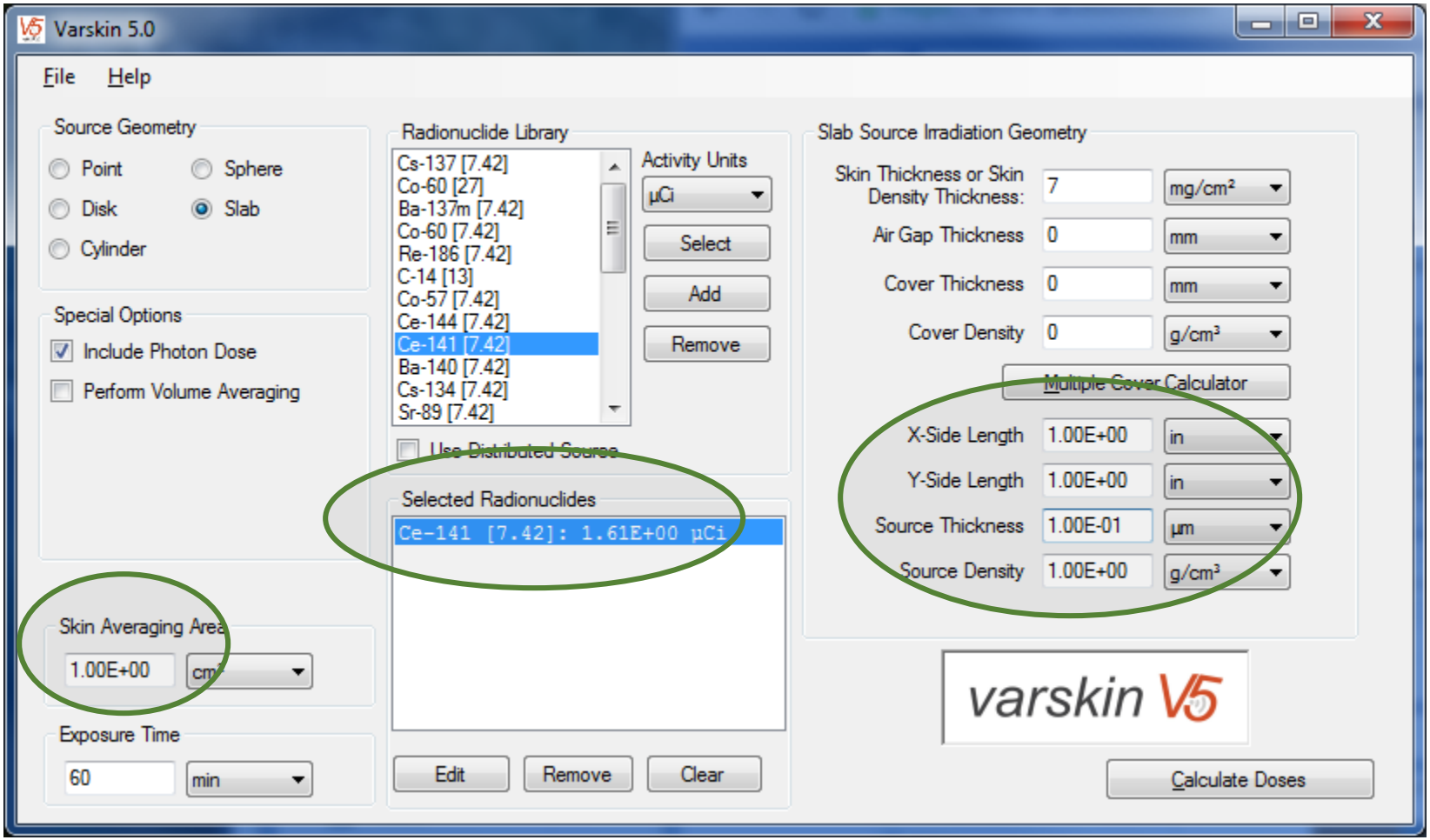
Slab source (low density)



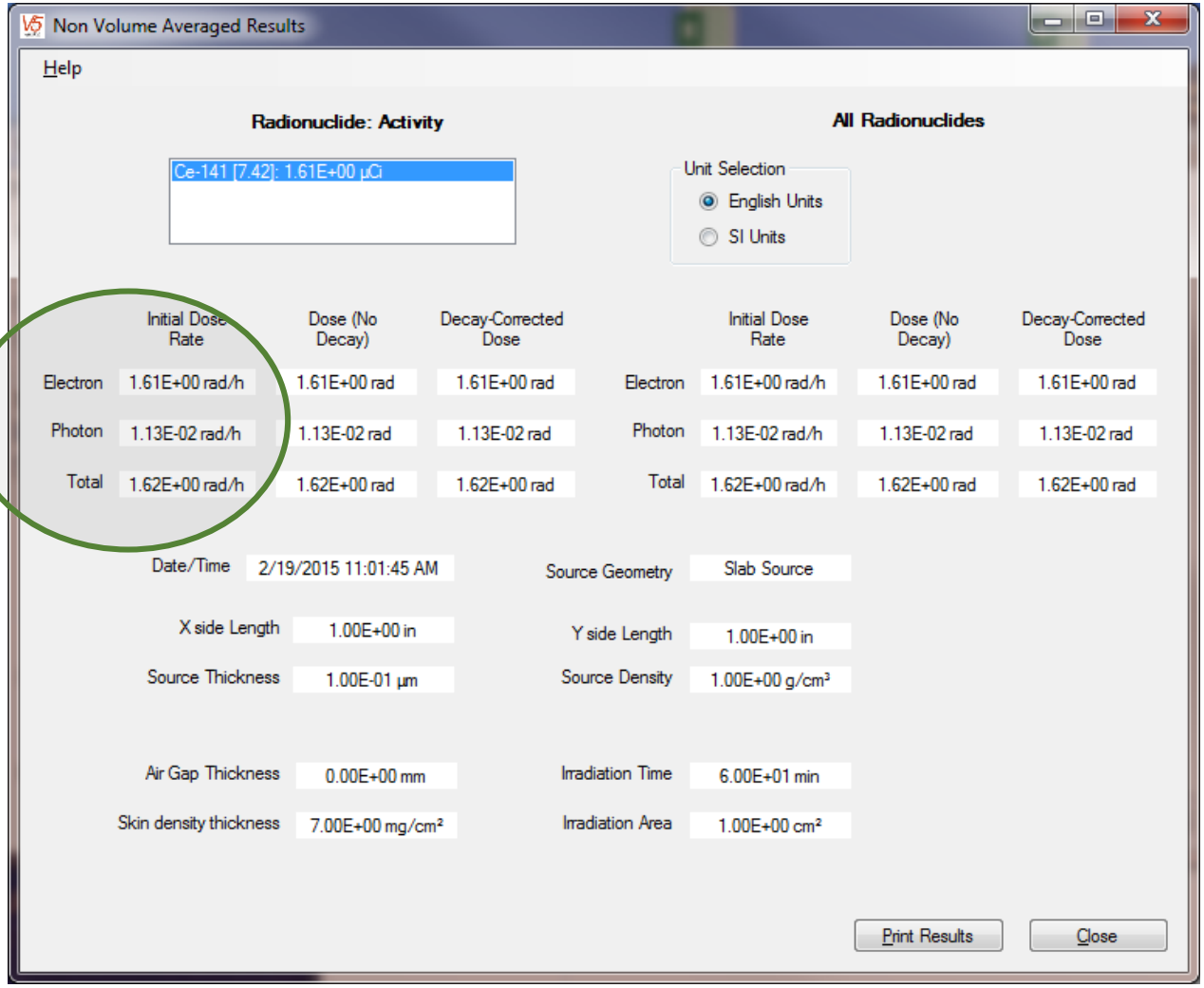
results


Non Volume Averaged Results
Help
Radionuclide: Activity
All Radionuclides
Ce-141 [7.42]: 1.61E+00 µCi
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.52E-01 rad/h 9.52E-01 rad 9.52E-01 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 9.54E-01 rad/h 9.54E-01 rad 9.54E-01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 9.52E-01 rad/h 9.52E-01 rad 9.52E-01 rad
Photon 1.95E-03 rad/h 1.95E-03 rad 1.95E-03 rad
Total 9.54E-01 rad/h 9.54E-01 rad 9.54E-01 rad
Date/Time 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 µm
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 cm^2)



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
Electron 1.61E+00 rad/h 1.61E+00 rad 1.61E+00 rad
Photon 1.13E-02 rad/h 1.13E-02 rad 1.13E-02 rad
Total 1.62E+00 rad/h 1.62E+00 rad 1.62E+00 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 1.61E+00 rad/h 1.61E+00 rad 1.61E+00 rad
Photon 1.13E-02 rad/h 1.13E-02 rad 1.13E-02 rad
Total 1.62E+00 rad/h 1.62E+00 rad 1.62E+00 rad
Date/Time 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

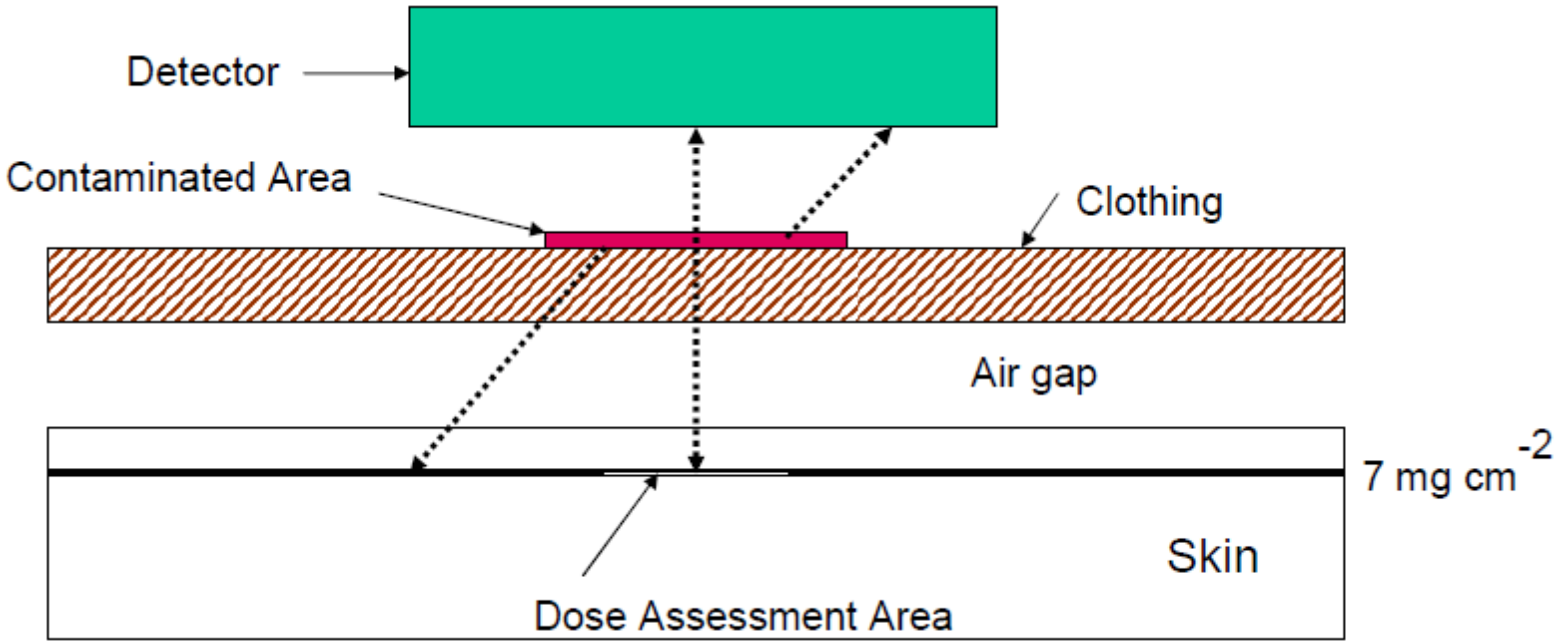
summary

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

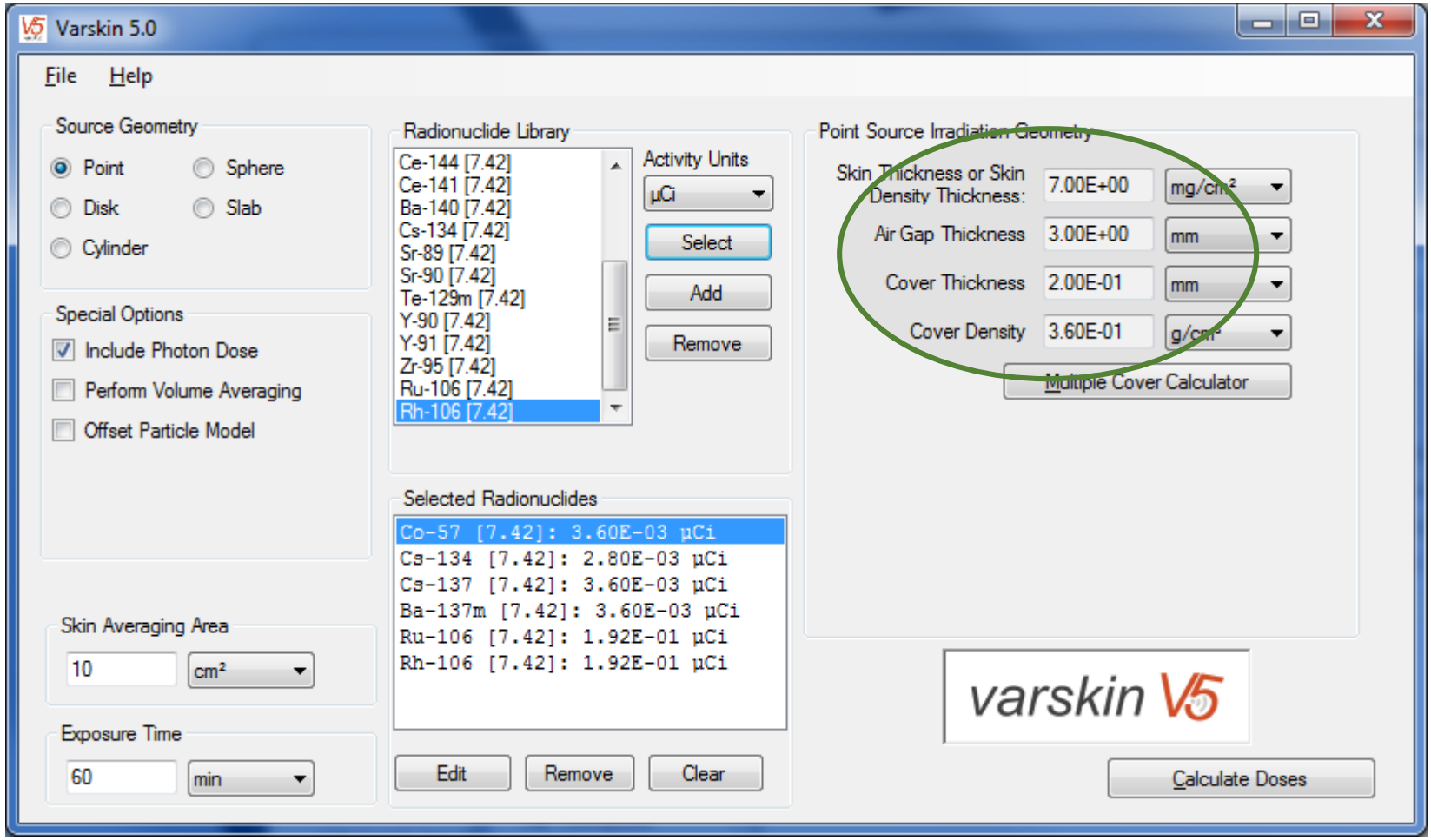
scenario #6

- 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/cm^3
- Source measurements indicate:
  - 0.0036 μCi of Co-57
  - 0.1920 μCi of Ru-106 (Rh-106)
  - 0.0028 μCi of Cs-134
  - 0.0036 μCi of Cs-137 (Ba-137m)
- Modeled as a point source
- Interested in a beta and gamma depth-dose profile

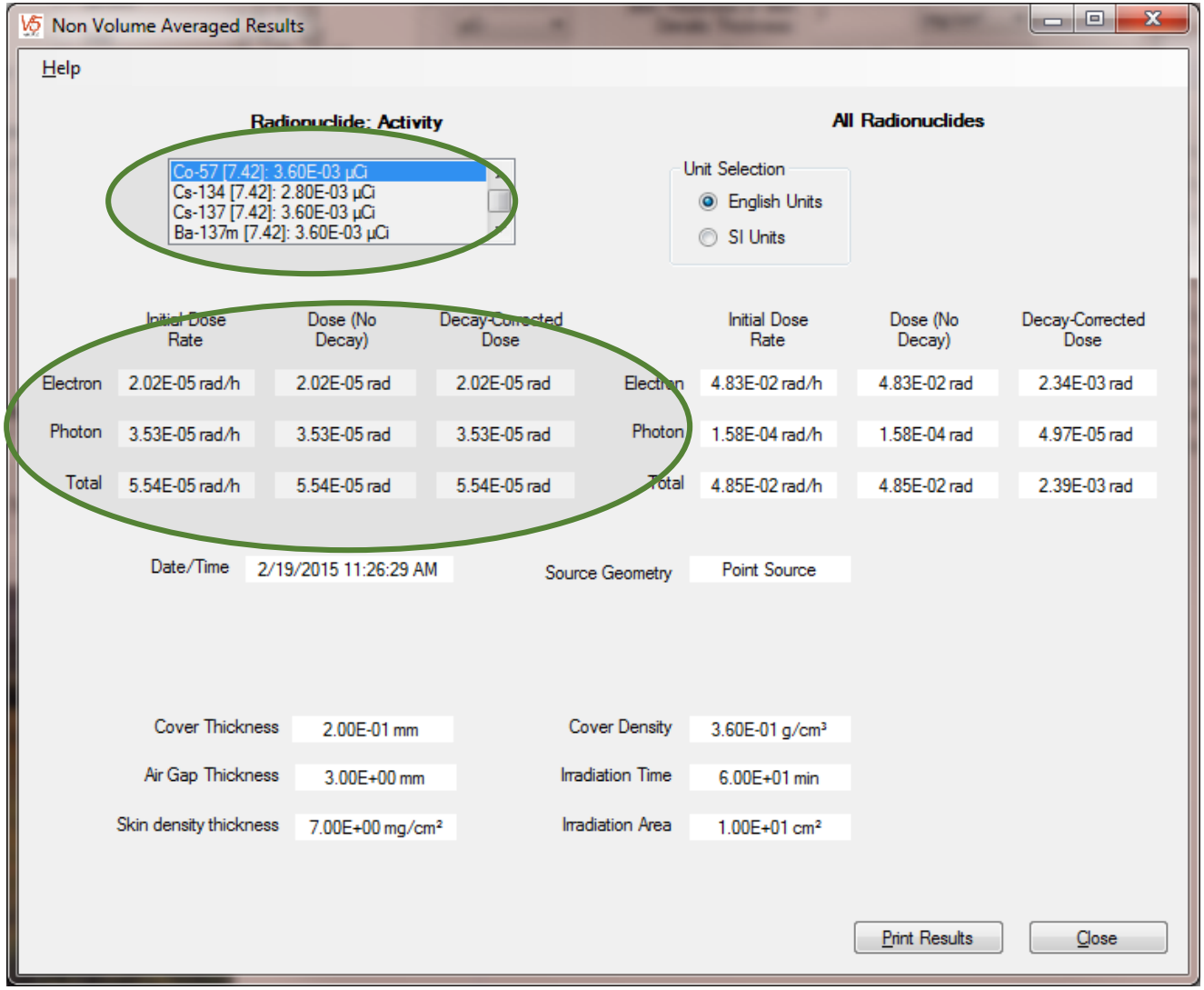
Beta activity determination



Varskin input



results

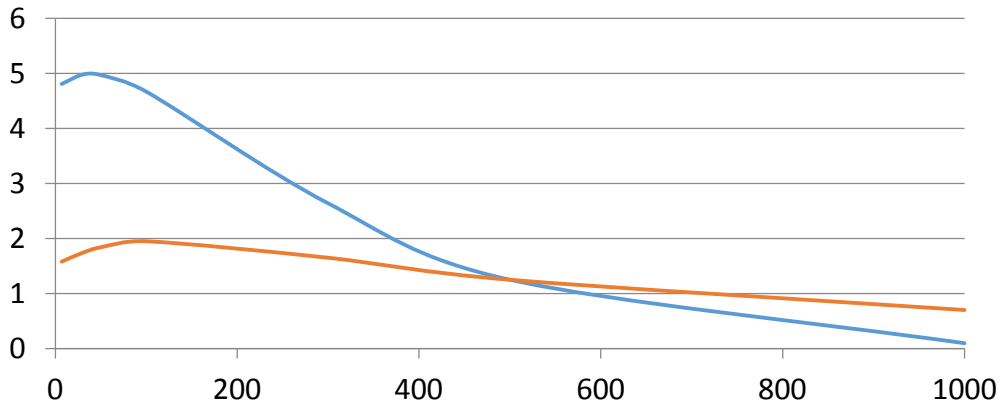

Non Volume Averaged Results
Help
Radionuclide: Activity
Co-57 [7.42]: 3.60E-03 µCi
Cs-134 [7.42]: 2.80E-03 µCi
Cs-137 [7.42]: 3.60E-03 µCi
Ba-137m [7.42]: 3.60E-03 µCi
All Radionuclides
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 2.02E-05 rad/h 2.02E-05 rad 2.02E-05 rad
Photon 3.53E-05 rad/h 3.53E-05 rad 3.53E-05 rad
Total 5.54E-05 rad/h 5.54E-05 rad 5.54E-05 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Electron 4.83E-02 rad/h 4.83E-02 rad 2.34E-03 rad
Photon 1.58E-04 rad/h 1.58E-04 rad 4.97E-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
Air Gap Thickness 3.00E+00 mm
Skin density thickness 7.00E+00 mg/cm²
Cover Density 3.60E-01 g/cm³
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

Results by nuclide

@ 7 mg/cm^2	Beta Dose Rate	Photon Dose Rate	Total Dose Rate (rad/hr)
Co-57	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**

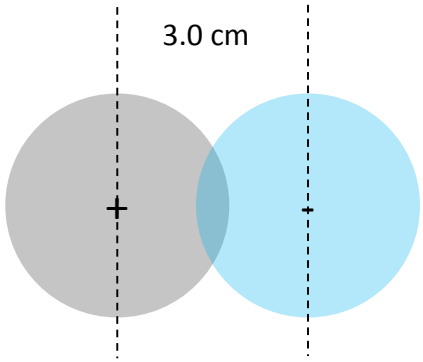
Results by depth

	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

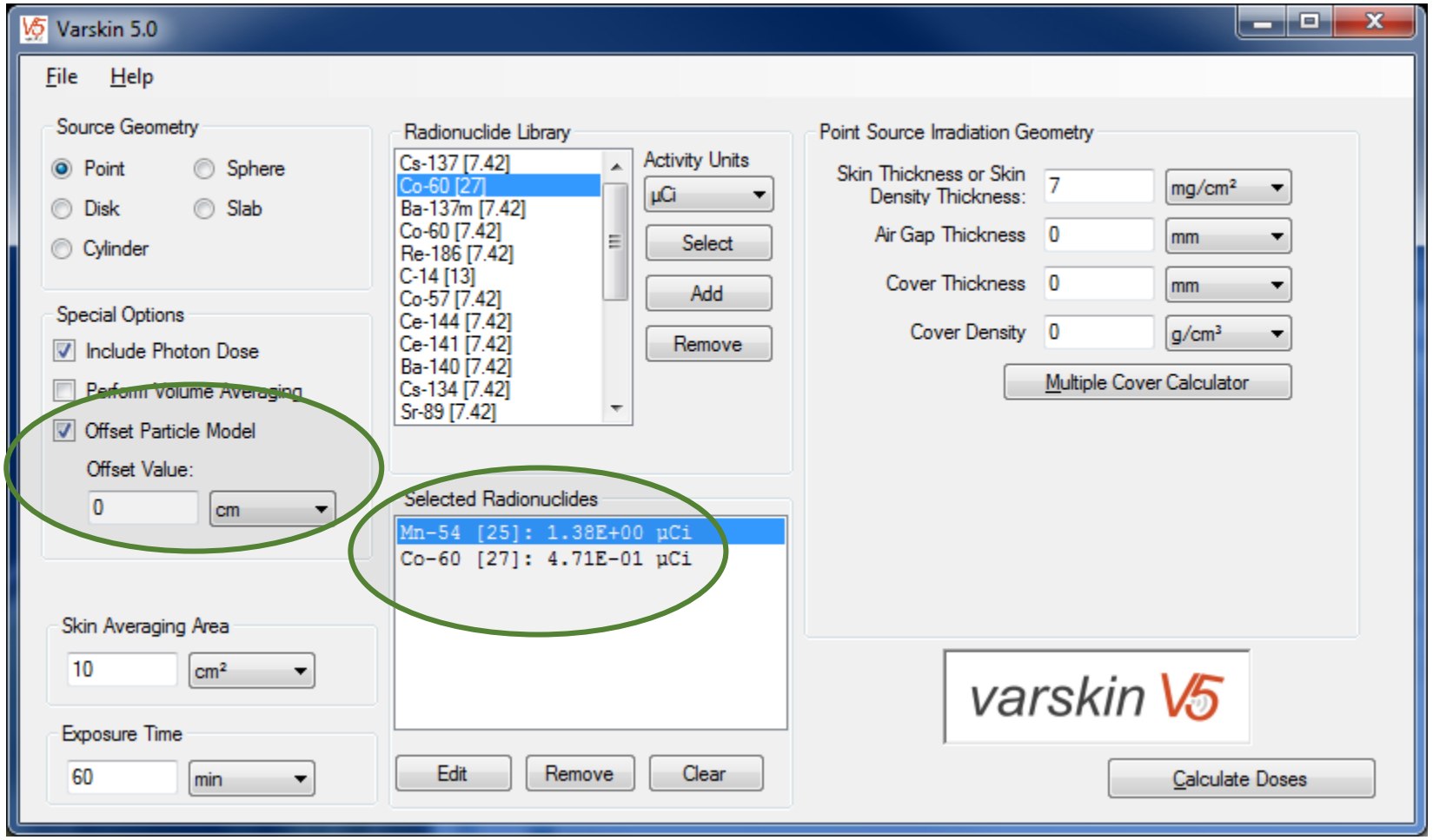


scenario #7 (offset model)

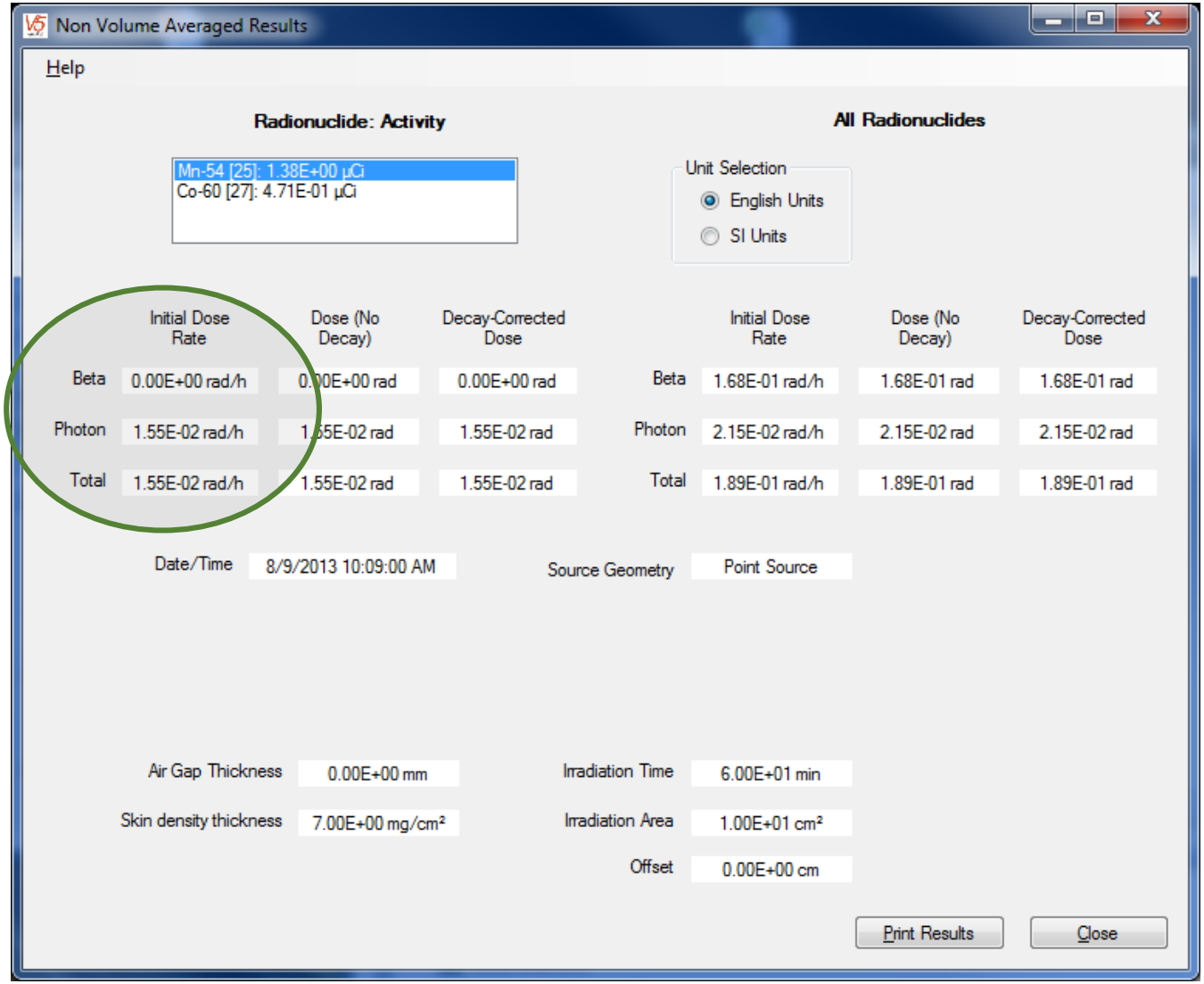
- Two particles on skin
  - separated by 3.0 cm
- Particle #1:
  - 1.38 μCi of Mn-54 (Z=25)
- Particle #2:
  - 0.471 μCi of Co-60 (Z=27)
- Modeled as two offset point sources
- Offset model only works for photon dosimetry
- Need maximum dose rate to 10 cm^2 disk @ 7 mg/cm^2



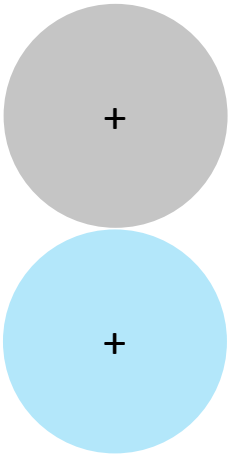
Point source input



results

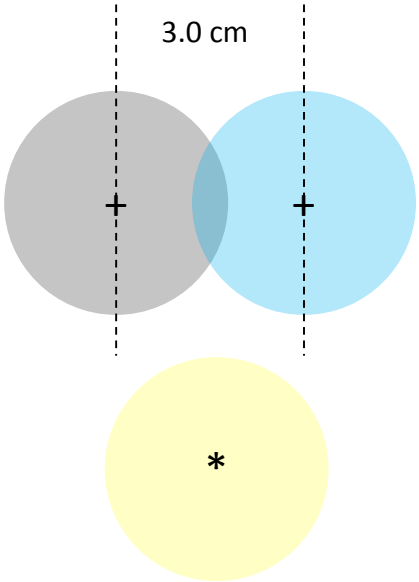

Non Volume Averaged Results
Help
Radionuclide: Activity
Mn-54 [25]: 1.38E+00 µCi
Co-60 [27]: 4.71E-01 µCi
All Radionuclides
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Photon 1.55E-02 rad/h 1.55E-02 rad 1.55E-02 rad
Total 1.55E-02 rad/h 1.55E-02 rad 1.55E-02 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 2.15E-02 rad/h 2.15E-02 rad 2.15E-02 rad
Total 1.89E-01 rad/h 1.89E-01 rad 1.89E-01 rad
Date/Time 8/9/2013 10:09:00 AM
Source Geometry Point Source
Air Gap Thickness 0.00E+00 mm
Skin density thickness 7.00E+00 mg/cm²
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Offset 0.00E+00 cm
Print Results
Close

Photon dose rate from each source



Mn-54
15.5 mrad/hr

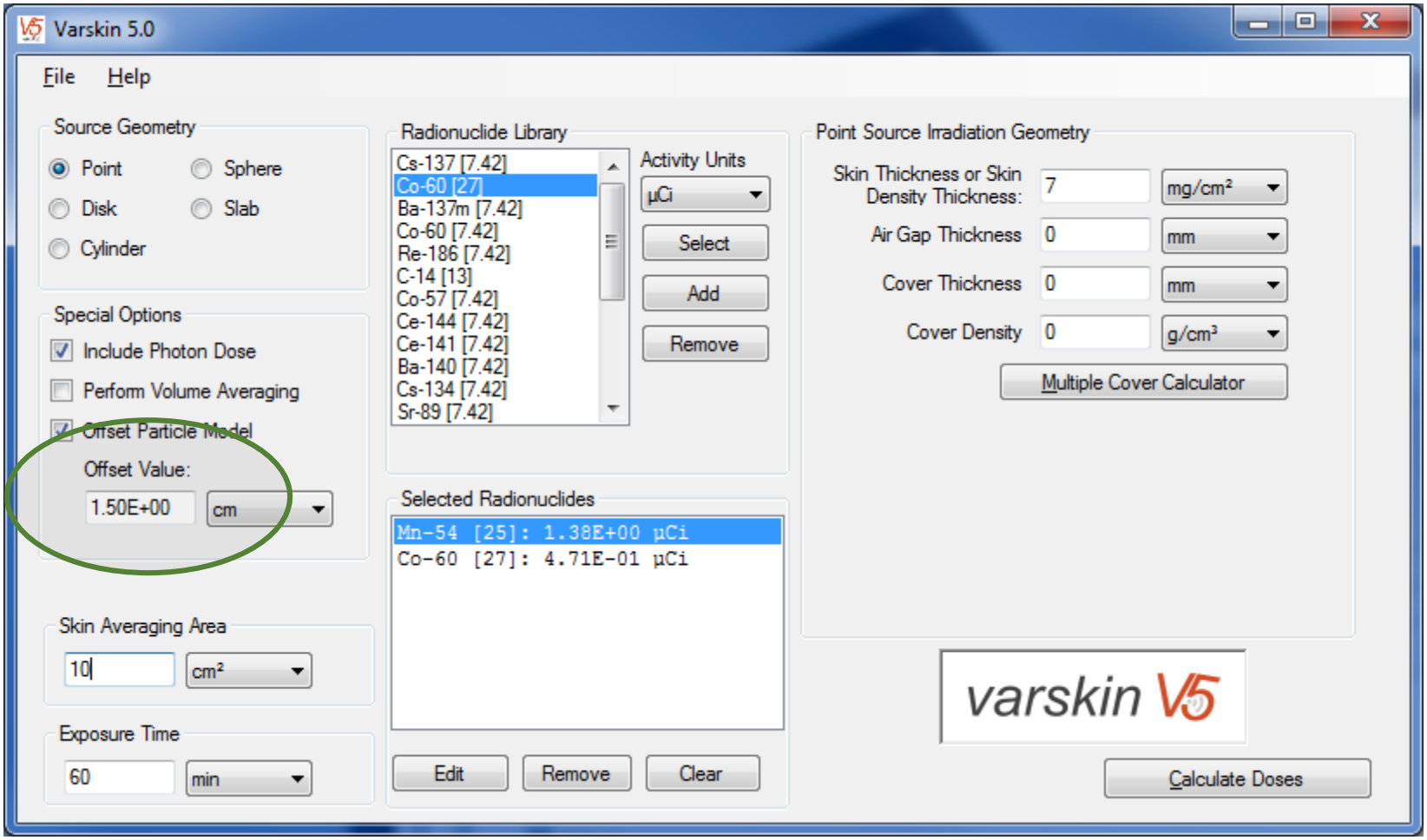
Co-60
6.01 mrad/hr



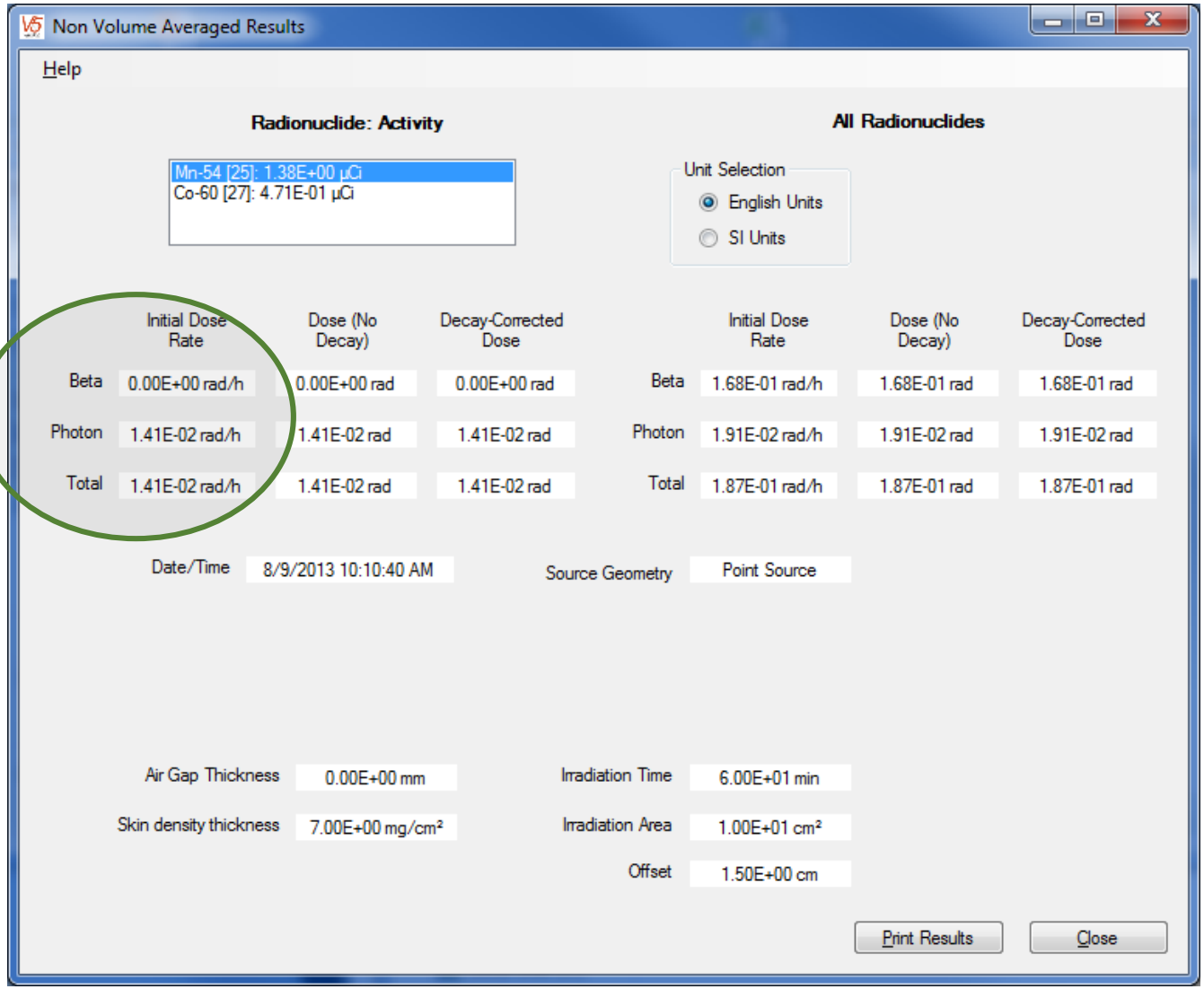
Where do we place a single averaging disk in order to maximize dose?

r = 1.784 cm

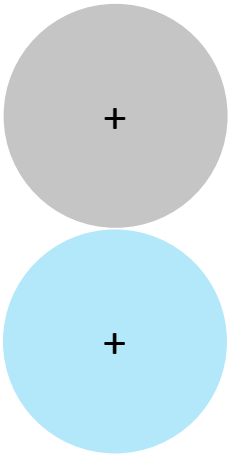
Offset particle model input



results

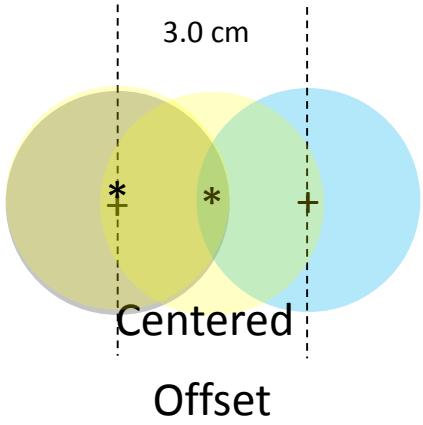

Non Volume Averaged Results
Help
Radionuclide: Activity
All Radionuclides
Mn-54 [25]: 1.38E+00 µCi
Co-60 [27]: 4.71E-01 µCi
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 0.00E+00 rad/h 0.00E+00 rad 0.00E+00 rad
Photon 1.41E-02 rad/h 1.41E-02 rad 1.41E-02 rad
Total 1.41E-02 rad/h 1.41E-02 rad 1.41E-02 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 1.68E-01 rad/h 1.68E-01 rad 1.68E-01 rad
Photon 1.91E-02 rad/h 1.91E-02 rad 1.91E-02 rad
Total 1.87E-01 rad/h 1.87E-01 rad 1.87E-01 rad
Date/Time 8/9/2013 10:10:40 AM
Source Geometry Point Source
Air Gap Thickness 0.00E+00 mm
Skin density thickness 7.00E+00 mg/cm²
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Offset 1.50E+00 cm
Print Results
Close

Dose to single averaging disk



Mn-54
15.5 mrad/hr

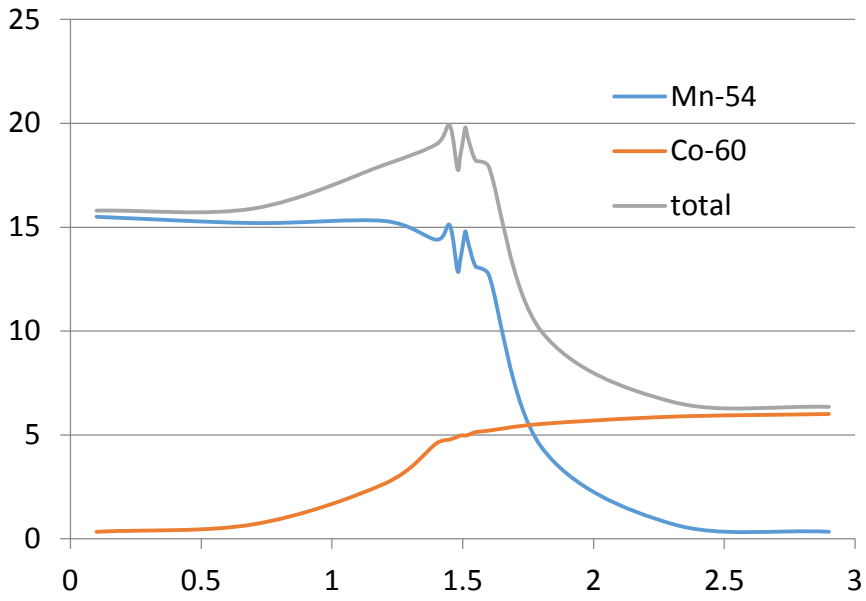
Co-60
6.01 mrad/hr



r = 1.784 cm

Placement to maximize photon dose

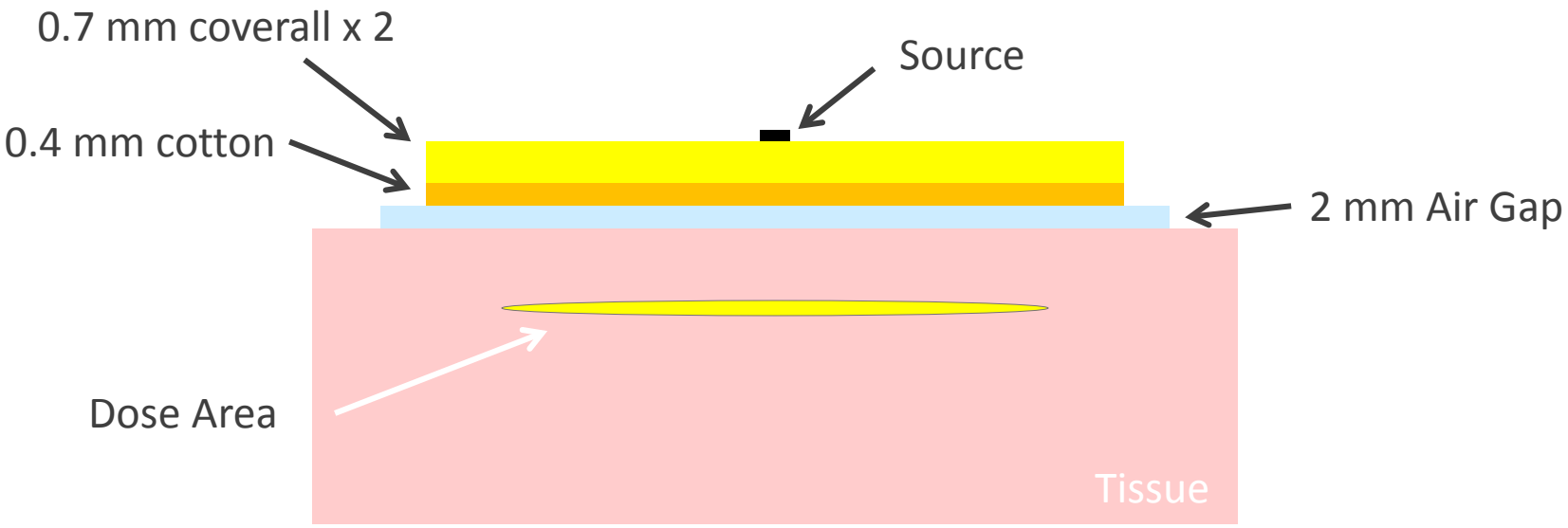
Dose Rate (mrad/hr)	Mn-54	Co-60	Total
Each on-axis (stacked)	15.5	6.01	21.5
0.1 cm from Mn-54	15.5	0.34	15.8
0.7 cm	15.2	0.70	15.9
1.2 cm	15.3	2.65	18.0
1.4 cm	14.4	4.60	19.0
1.45 cm	15.1	4.78	19.9
1.48 cm	12.9	4.91	17.8
1.49 cm	13.4	4.97	18.4
1.5 cm (centered)	14.1	4.98	19.1
1.51 cm	14.8	4.97	19.8
1.52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



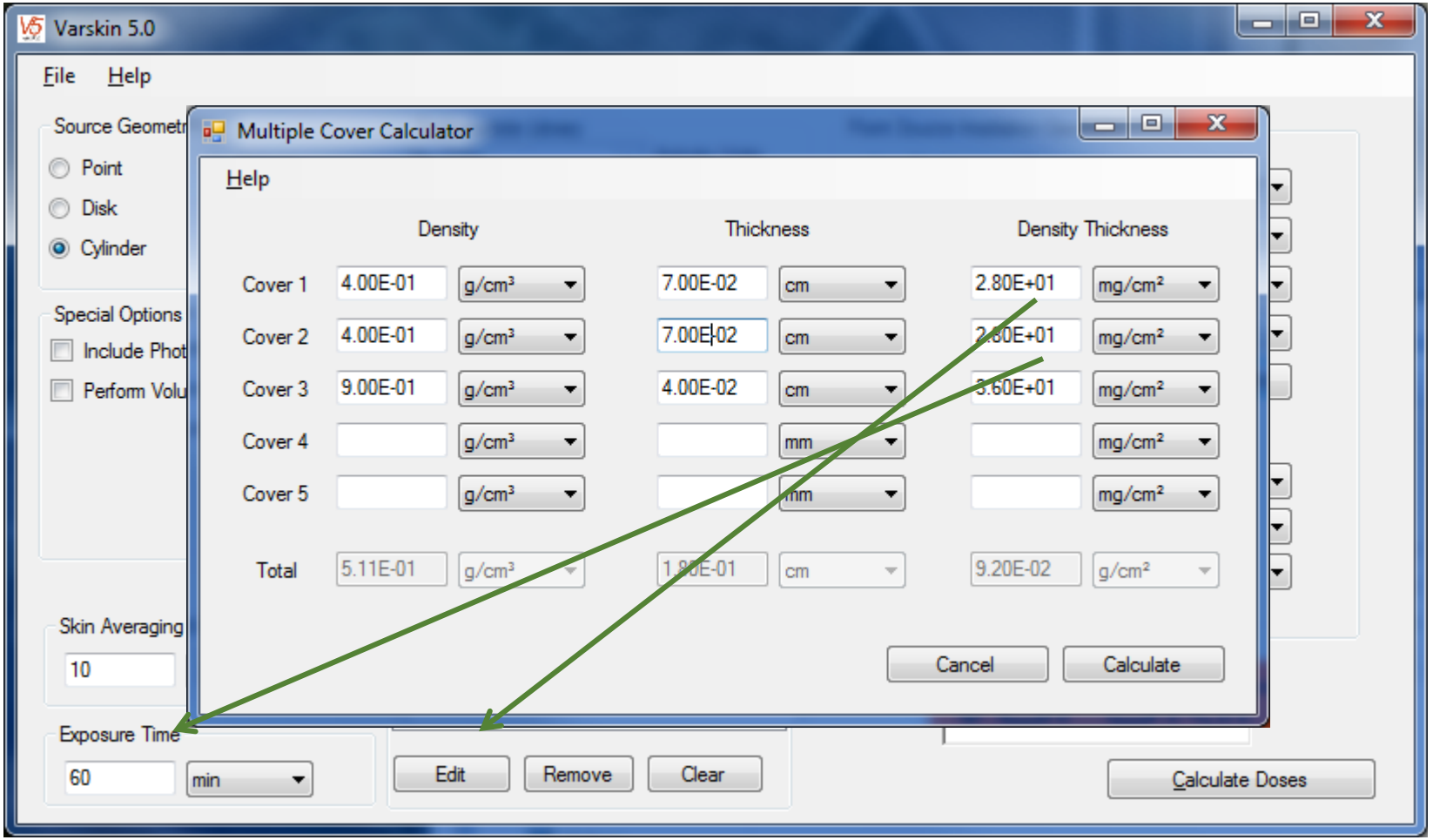
scenario #8 (multiple cover)

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

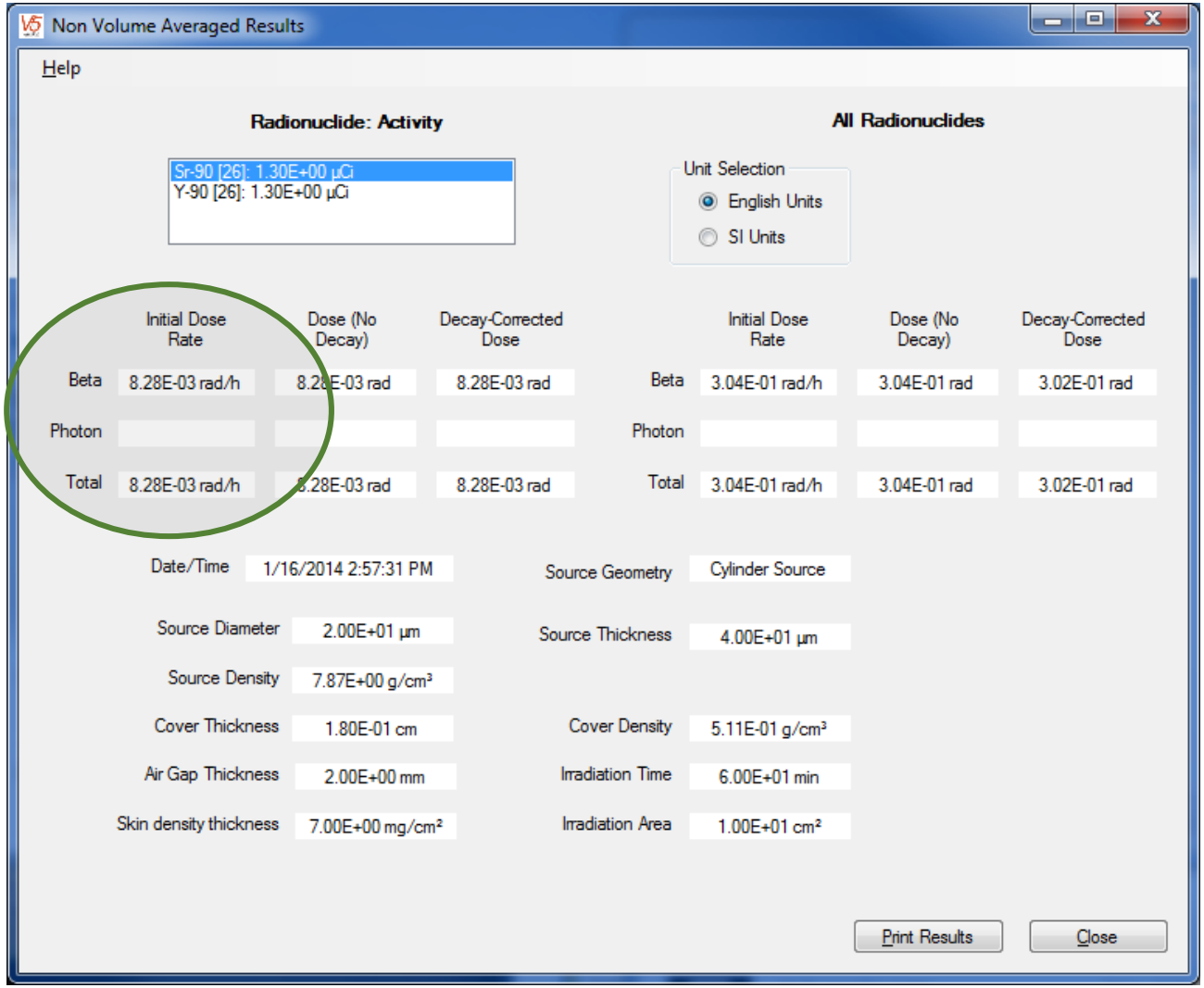
Cover model


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

Multiple cover input



results


Non Volume Averaged Results
Help
Radionuclide: Activity
Sr-90 [26]: 1.30E+00 µCi
Y-90 [26]: 1.30E+00 µCi
All Radionuclides
Unit Selection
English Units
SI Units
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 8.28E-03 rad/h 8.28E-03 rad 8.28E-03 rad
Photon
Total 8.28E-03 rad/h 8.28E-03 rad 8.28E-03 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
Beta 3.04E-01 rad/h 3.04E-01 rad 3.02E-01 rad
Photon
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 µm
Source Thickness 4.00E+01 µm
Source Density 7.87E+00 g/cm³
Cover Thickness 1.80E-01 cm
Cover Density 5.11E-01 g/cm³
Air Gap Thickness 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

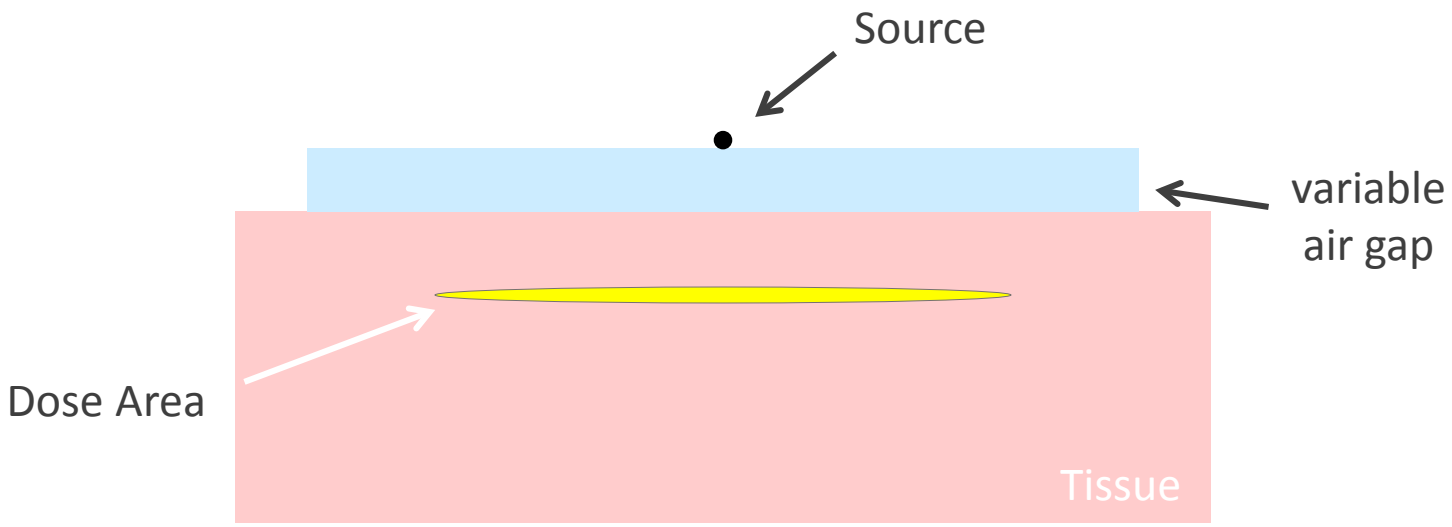
Depth-dose summary

	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

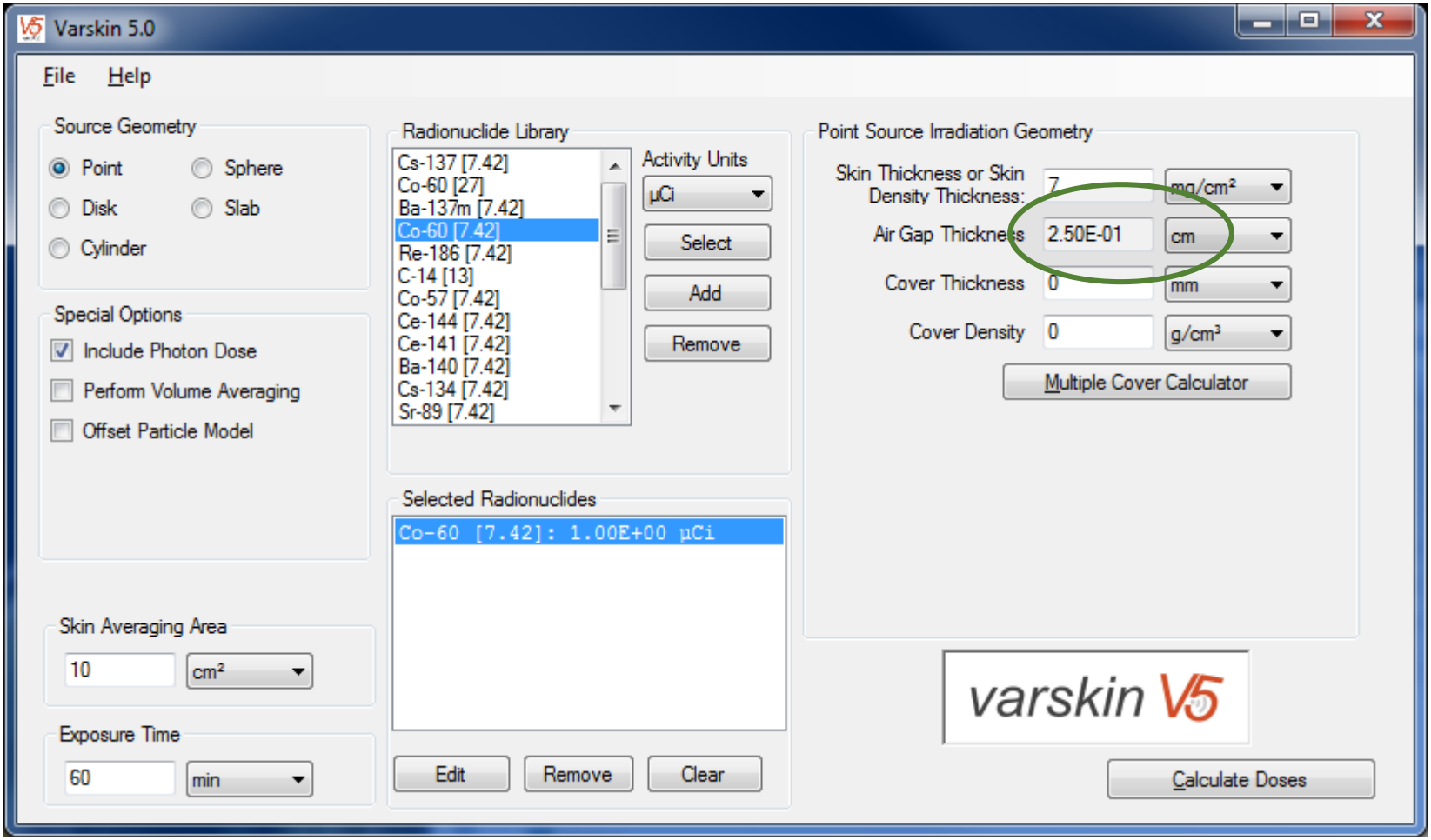
scenario #9 (air gap)

- 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?

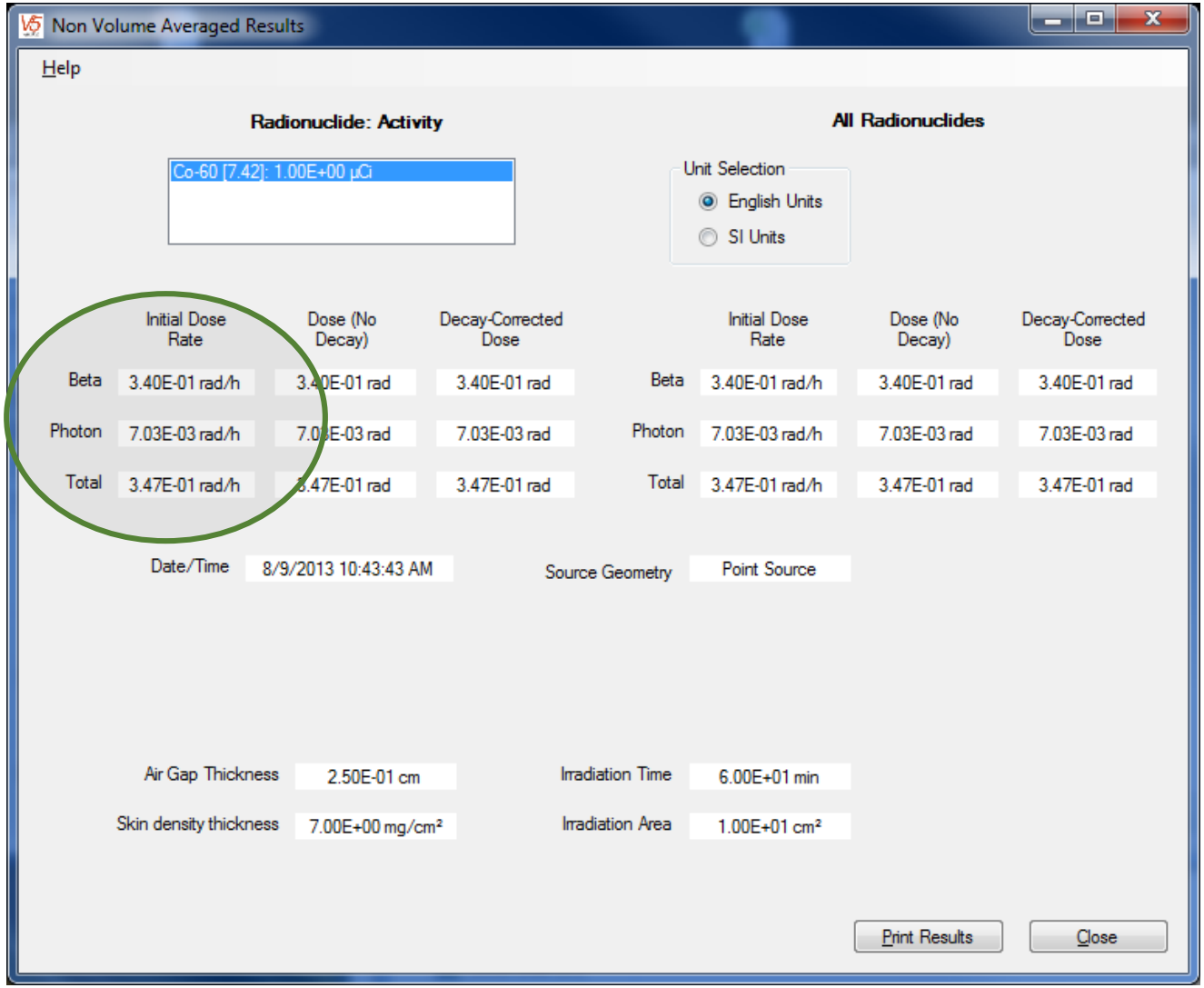
Air gap model



Air gap model input

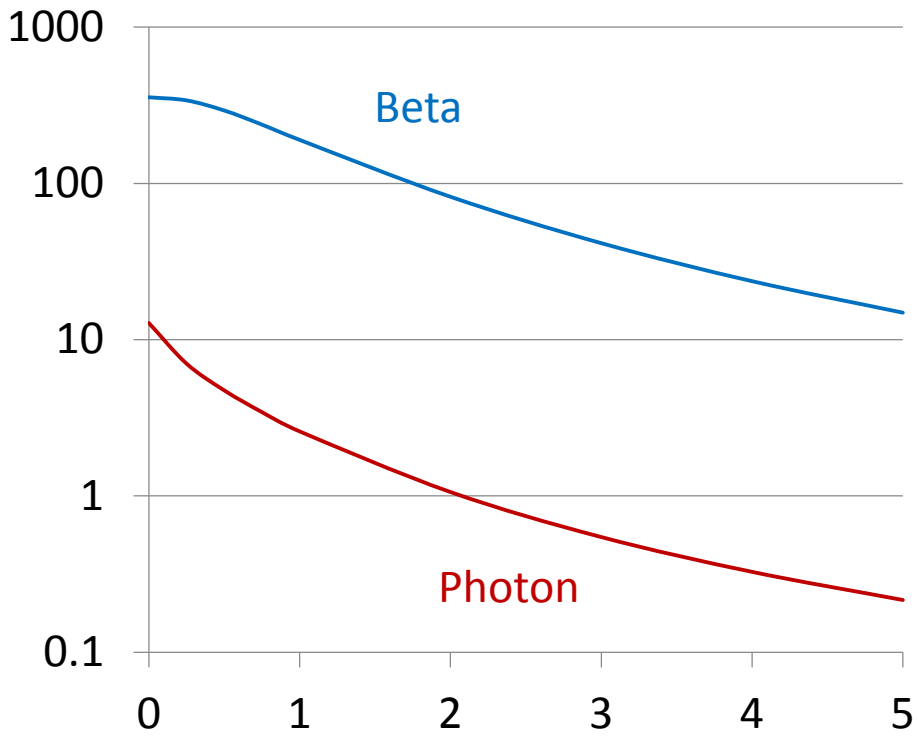


results


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
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
Total 3.47E-01 rad/h 3.47E-01 rad 3.47E-01 rad
Initial Dose Rate
Dose (No Decay)
Decay-Corrected Dose
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
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
Skin density thickness 7.00E+00 mg/cm²
Irradiation Time 6.00E+01 min
Irradiation Area 1.00E+01 cm²
Print Results
Close

Air gap impact on dose

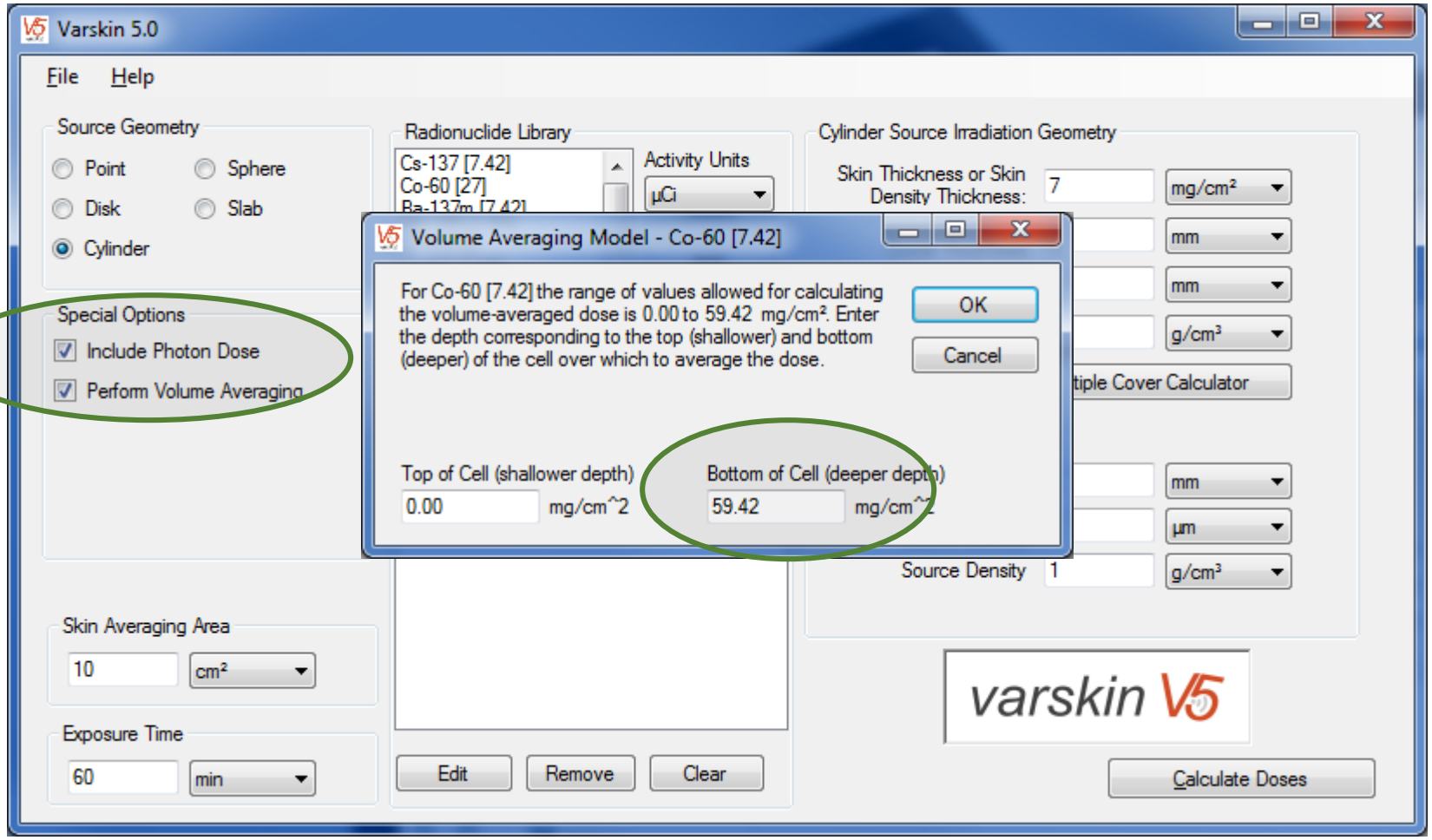
Air Gap (cm)	Beta	Photon	Total
0	356	12.8	369
0.25	340	7.03	347
0.50	293	4.74	298
0.75	238	3.44	241
1	190	2.59	192
2	82.2	1.06	83.3
3	41.5	0.546	42.0
4	23.7	0.327	24.1
5	14.9	0.216	15.1



scenario #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

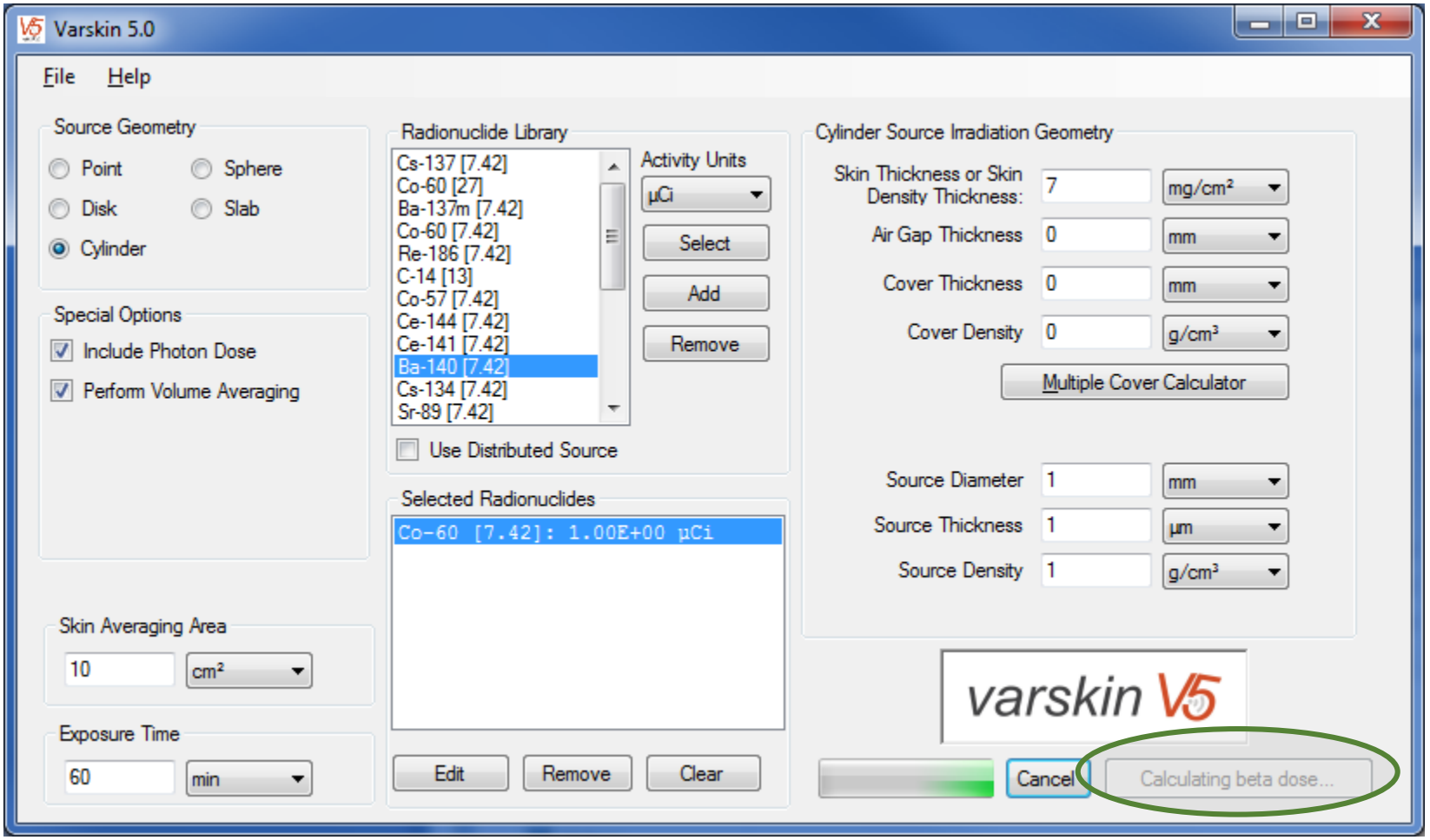
3D source and Volume averaging



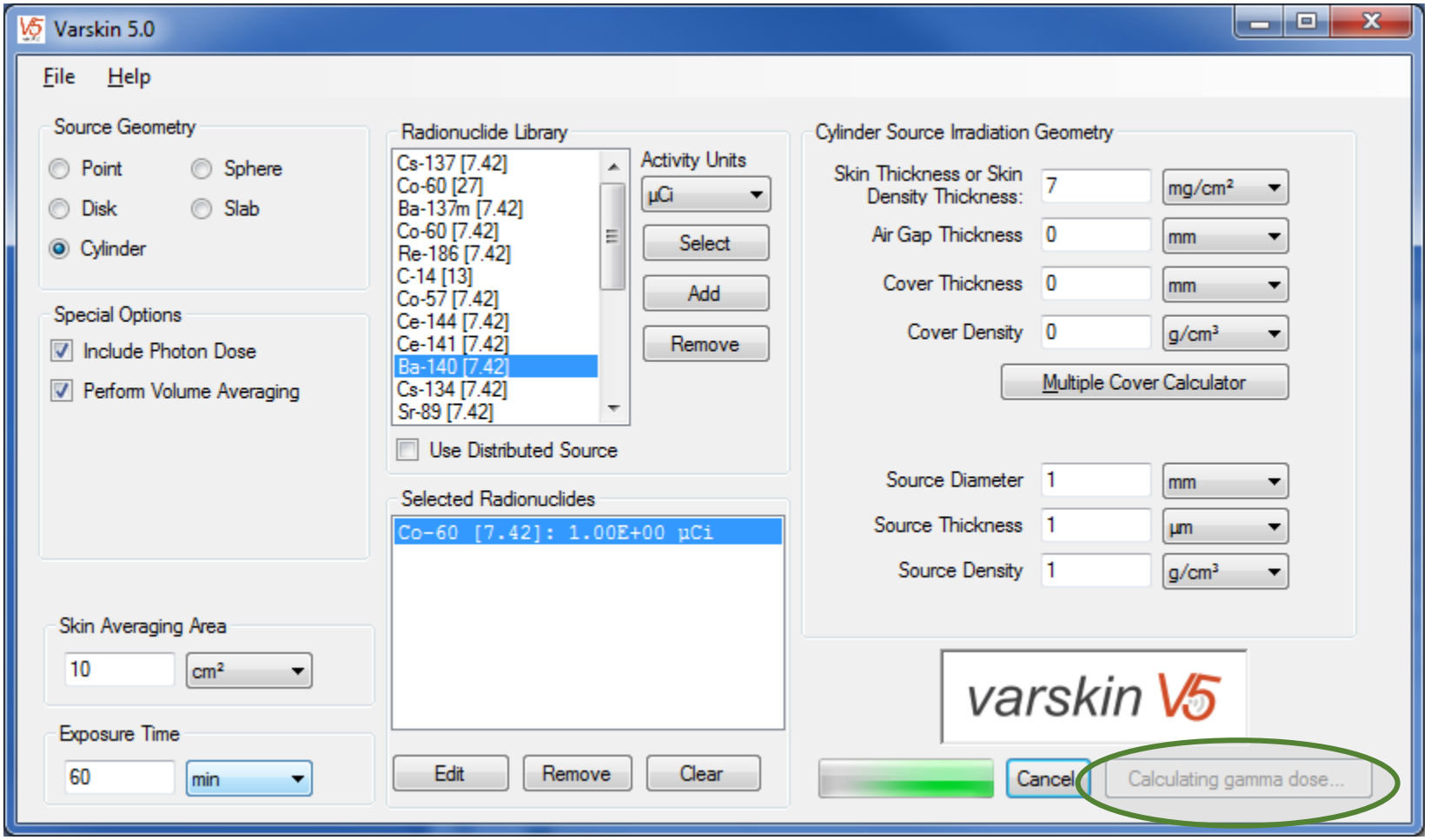
Maximum volume averaging depth

	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



Calculating gamma dose



Time (sec) to calculate dose

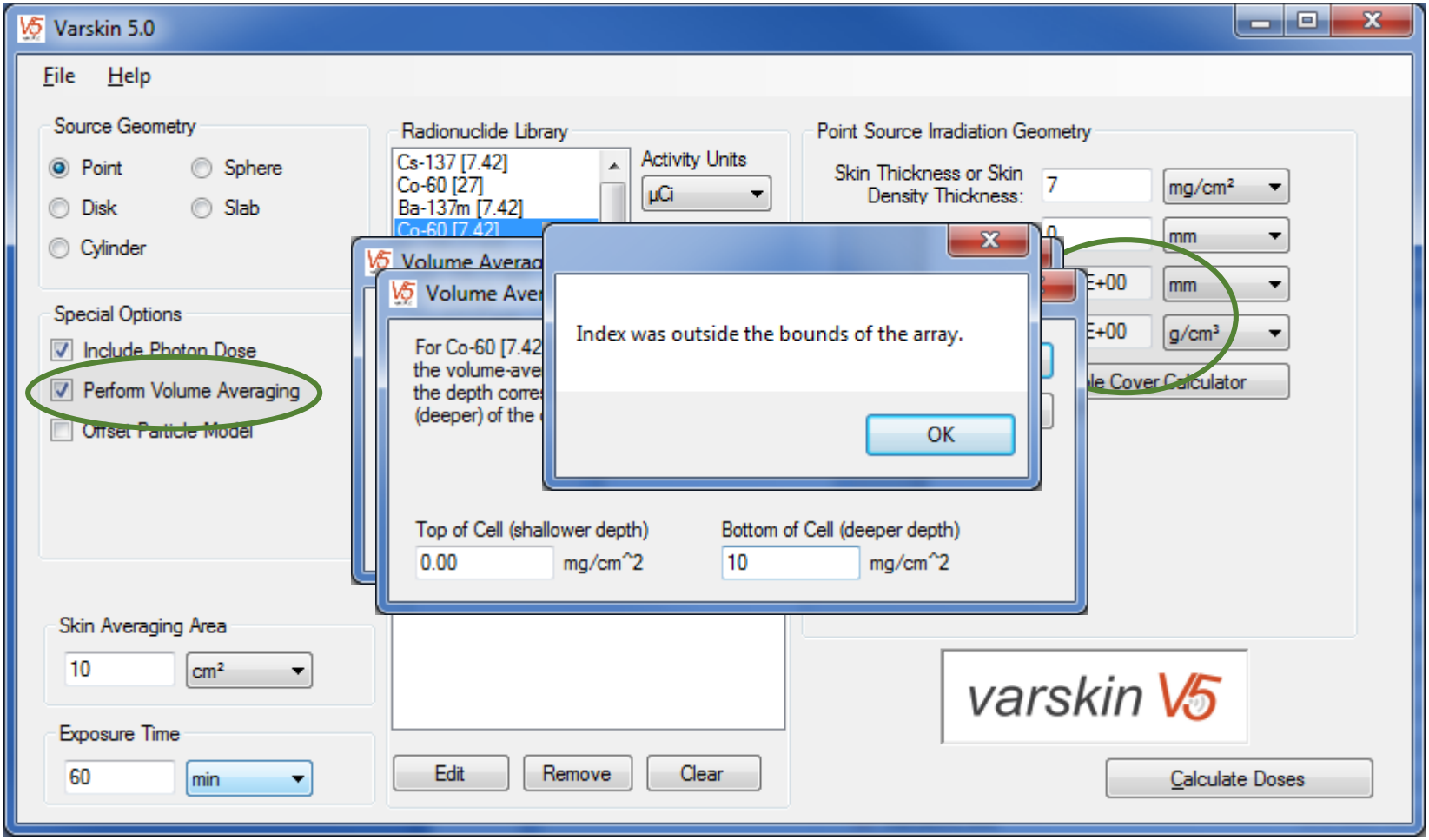
	Beta	Gamma	Volume Avg Beta	Volume Avg Gamma
Co-60	---	6	6	59
Cs-134	---	28	4	288
Ba-137m	---	10	4	87
Cs-137	---	---	4	---
Ba-140	---	38	4	368
Y-91	---	---	3	---

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

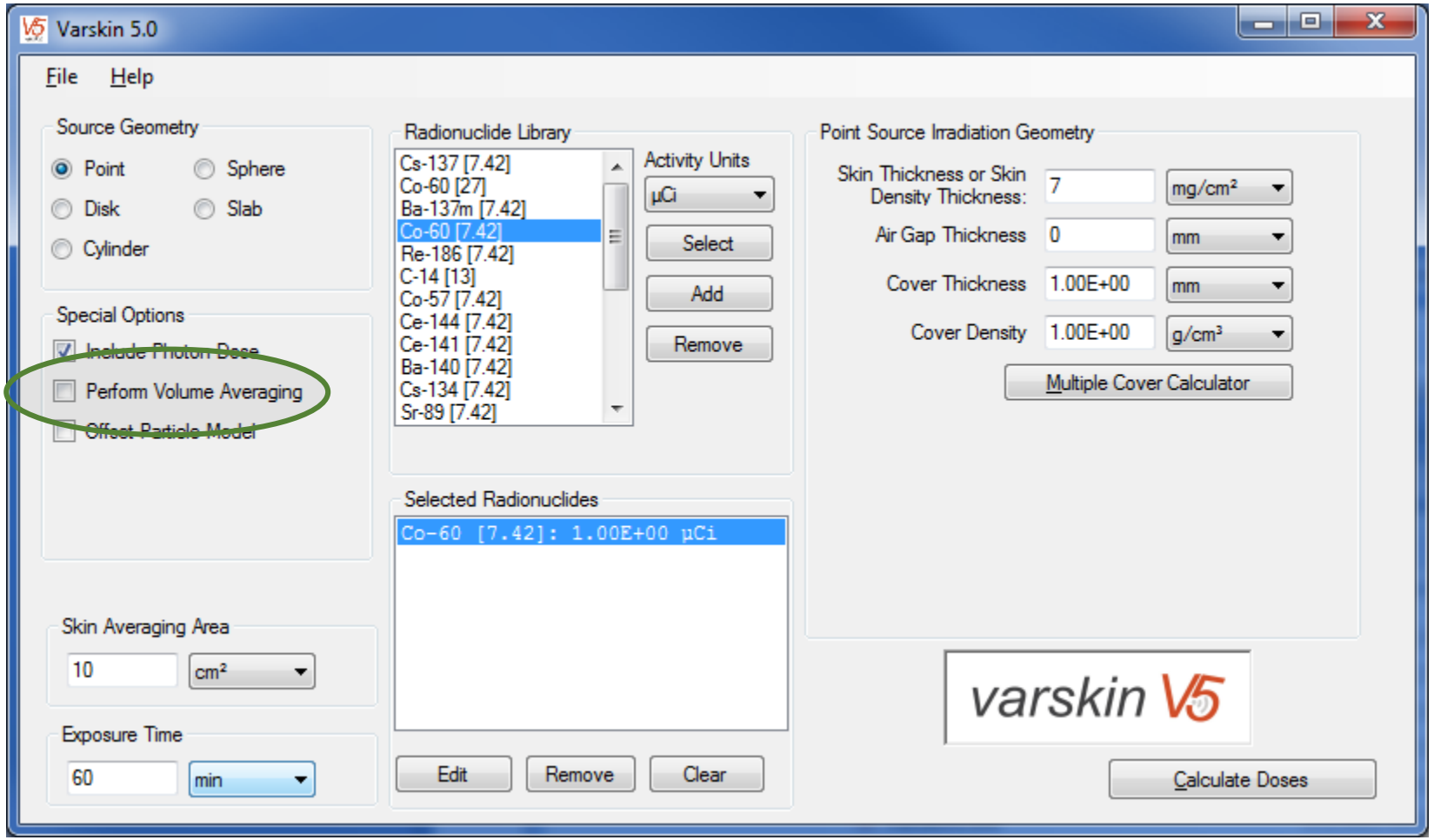
scenario #11

- 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, even if the maximum depth is changed to a non-negative value, because the cover material is preventing any beta dose (glitch in beta dosimetry)

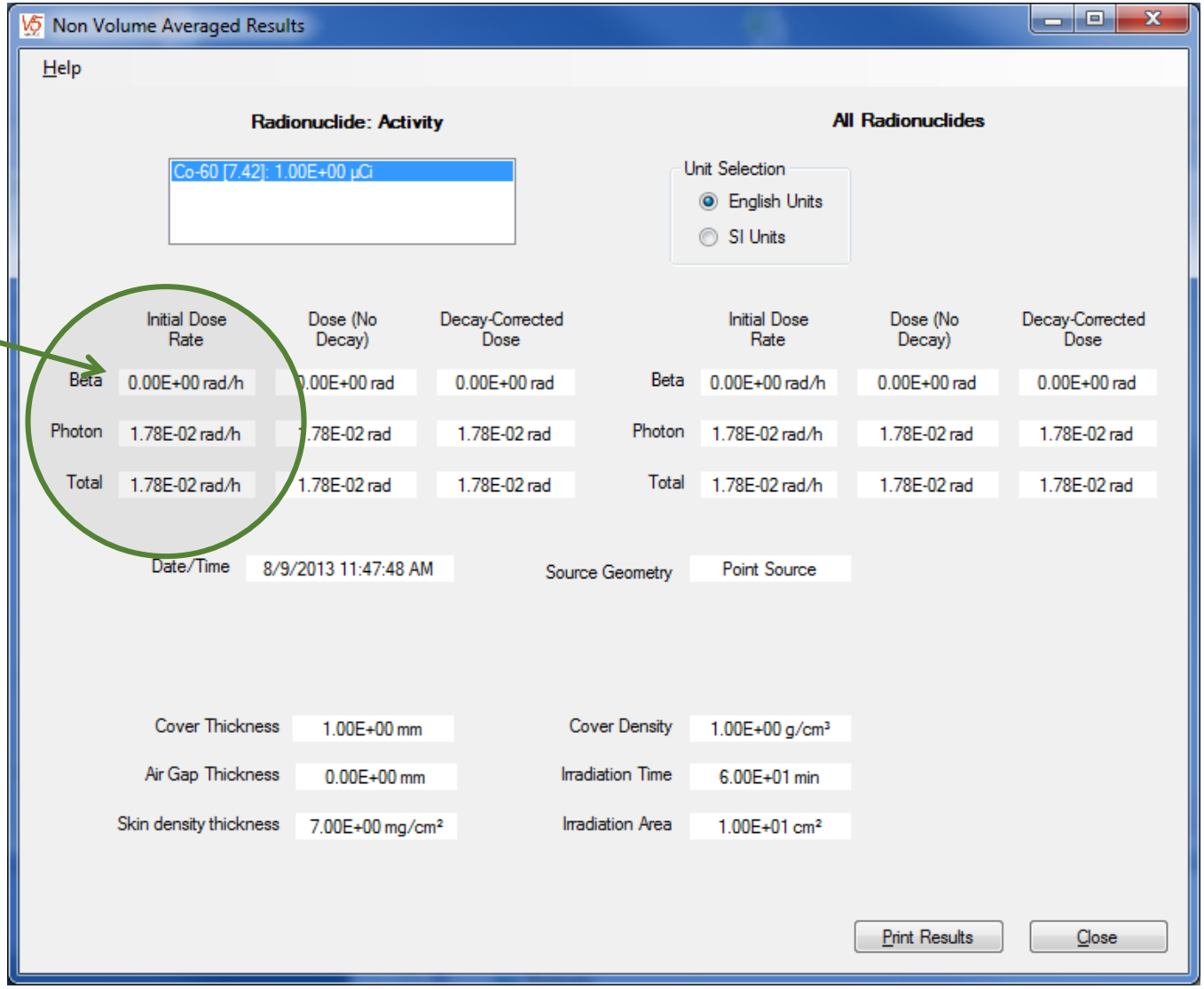
Volume averaging option



w/o volume averaging



Zero beta dose

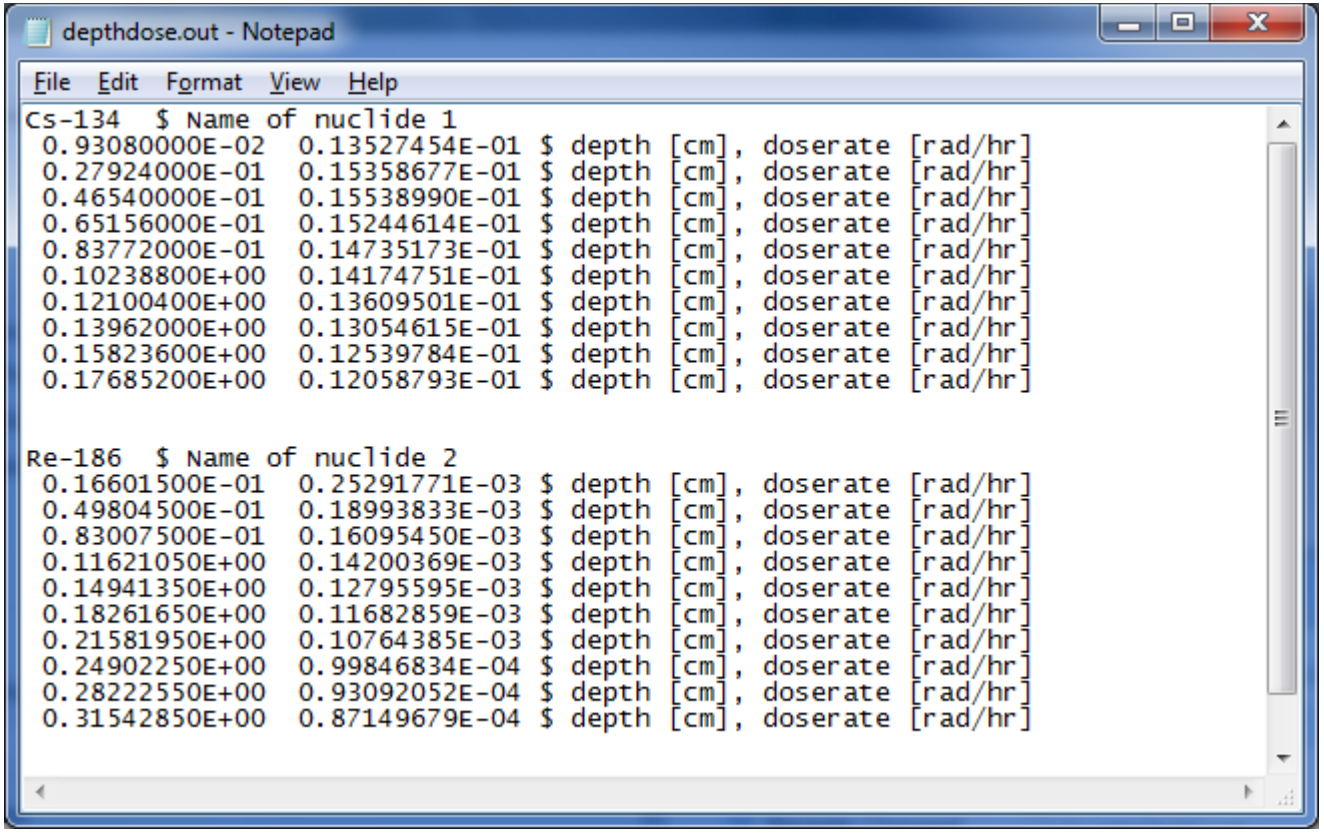


“Hidden” output files

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

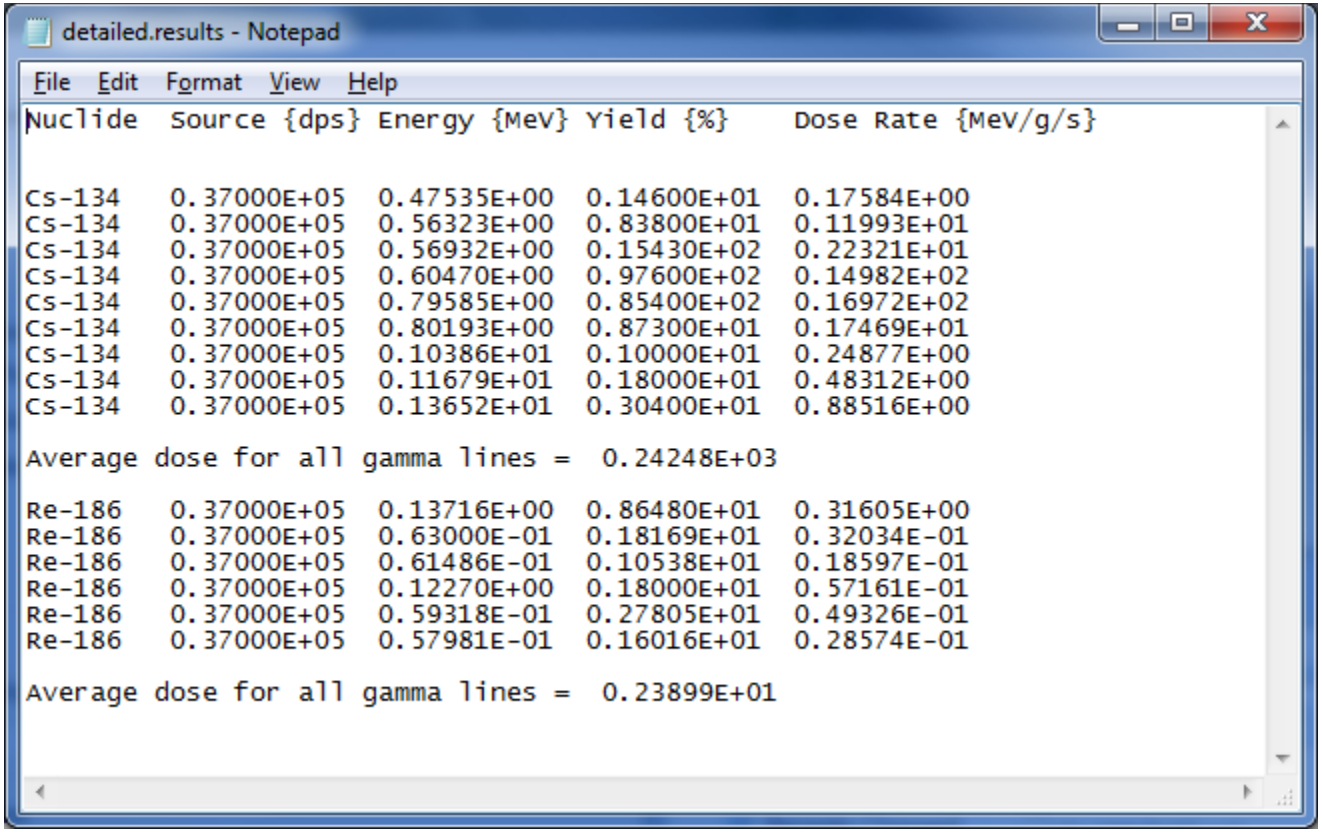
File “Depthdose”

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



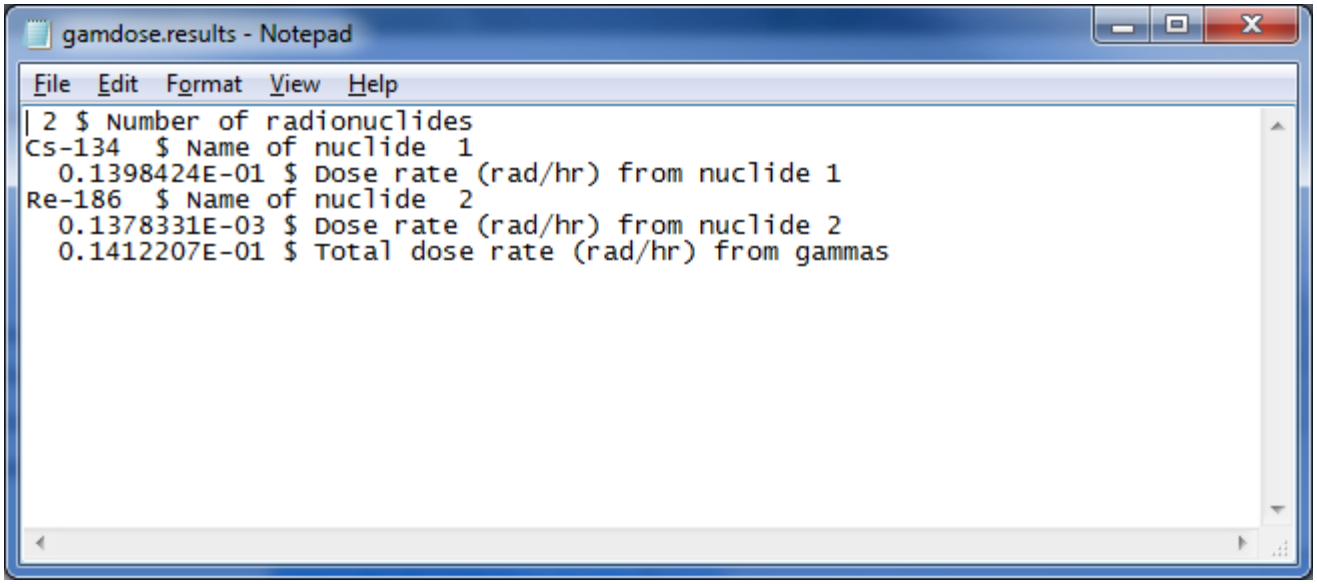
File “Detailed”

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



File “gamdose”

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



File “gaminput”

- Provides data for each gamma emission of selected nuclides

GamInput - Notepad

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 cm^2
- 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

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 (^{137m}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 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
    - (however, as requested, v 5.3 will allow air gap up to 20 cm)
  - 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
  - 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 Source Locations
  - 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 cm^2 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 CHANGED < 20 cm
- Clothing and air gap cause issues with electronic buildup
- Include daughter products (Ga-68 was point out)
- Include ICRP 107 data
- Web-based operation
- 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, errors will occur in the calculation of lens volume REPAIRED
- 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) REPAIRED