V6 VARSKIN

VARSKIN 6

V6 VARSKIN

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

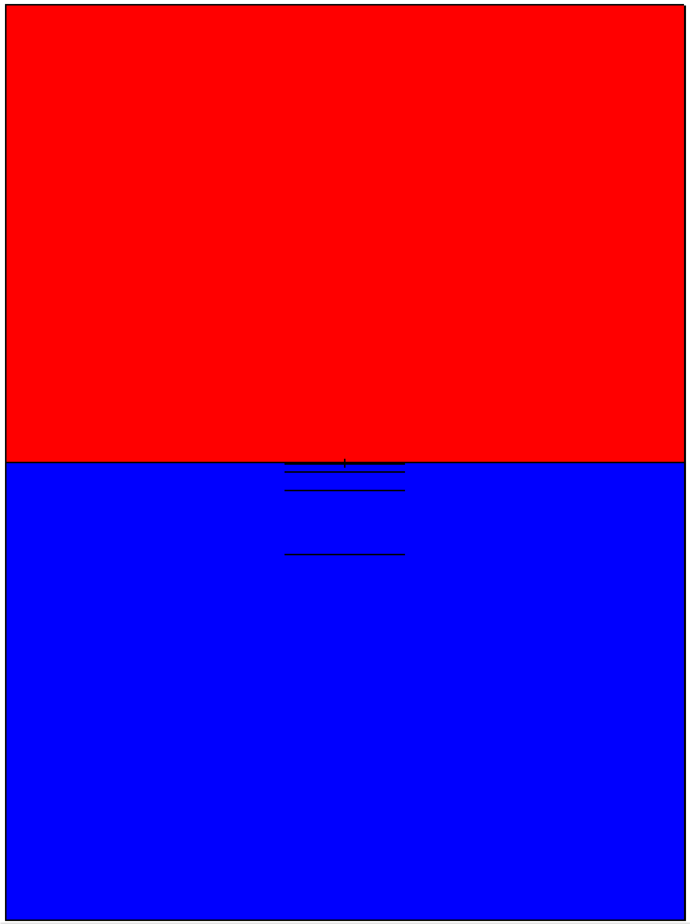
Supplemental Verification

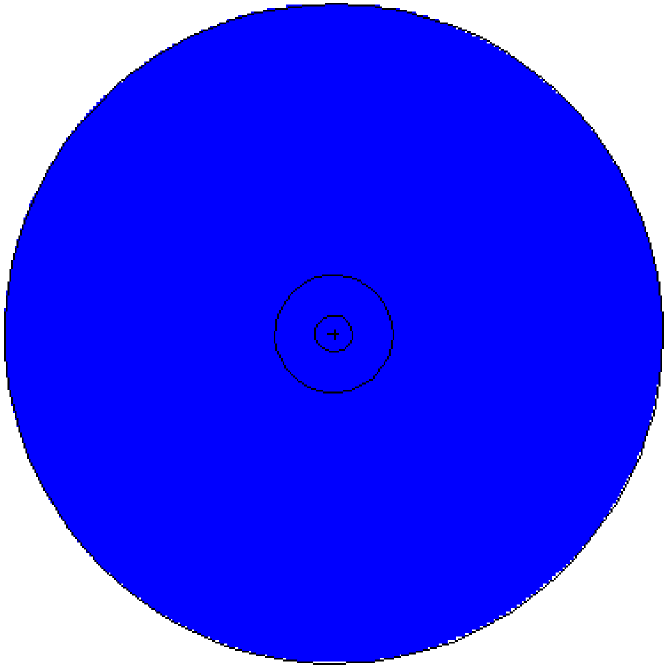
- Examination of fundamental physics:
    - **Energy transfer (KERMA)**
    - **Charged-particle buildup**
    - **Absorption and attenuation coefficients**
    - **Off-axis scatter**
    - **Scaled absorbed dose distributions**
    - **Particle range and stopping power estimates**
    - **Backscatter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

Verification

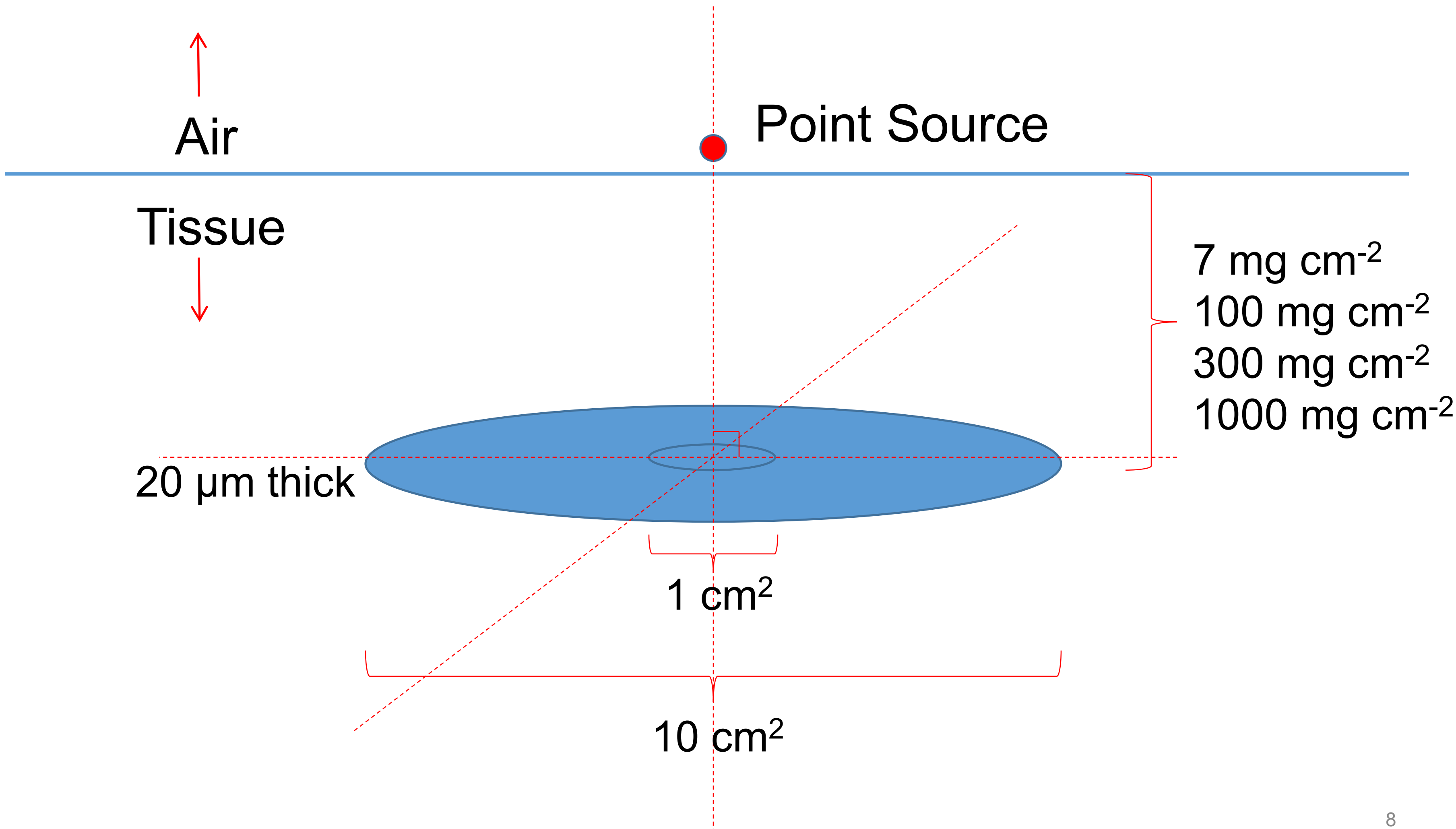
- The modeled composition of unit-density skin was taken from ICRU
- Two dose-averaging areas were modeled:
  - $1\ cm^2$
  - $10\ cm^2$
- Four tissue depths were modeled:
  - $7\ mg\ cm^{-2}$ (shallow dose)
  - $100\ mg\ cm^{-2}$
  - $300\ mg\ cm^{-2}$ (lens dose)
  - $1000\ mg\ cm^{-2}$ (deep dose)

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 MeV @ 7 mg/cm^2
- - E > 0.40 MeV @ 100 mg/cm^2
- - E > 0.80 MeV @ 300 mg/cm^2
- - E > 2.10 MeV @ 1000 mg/cm^2

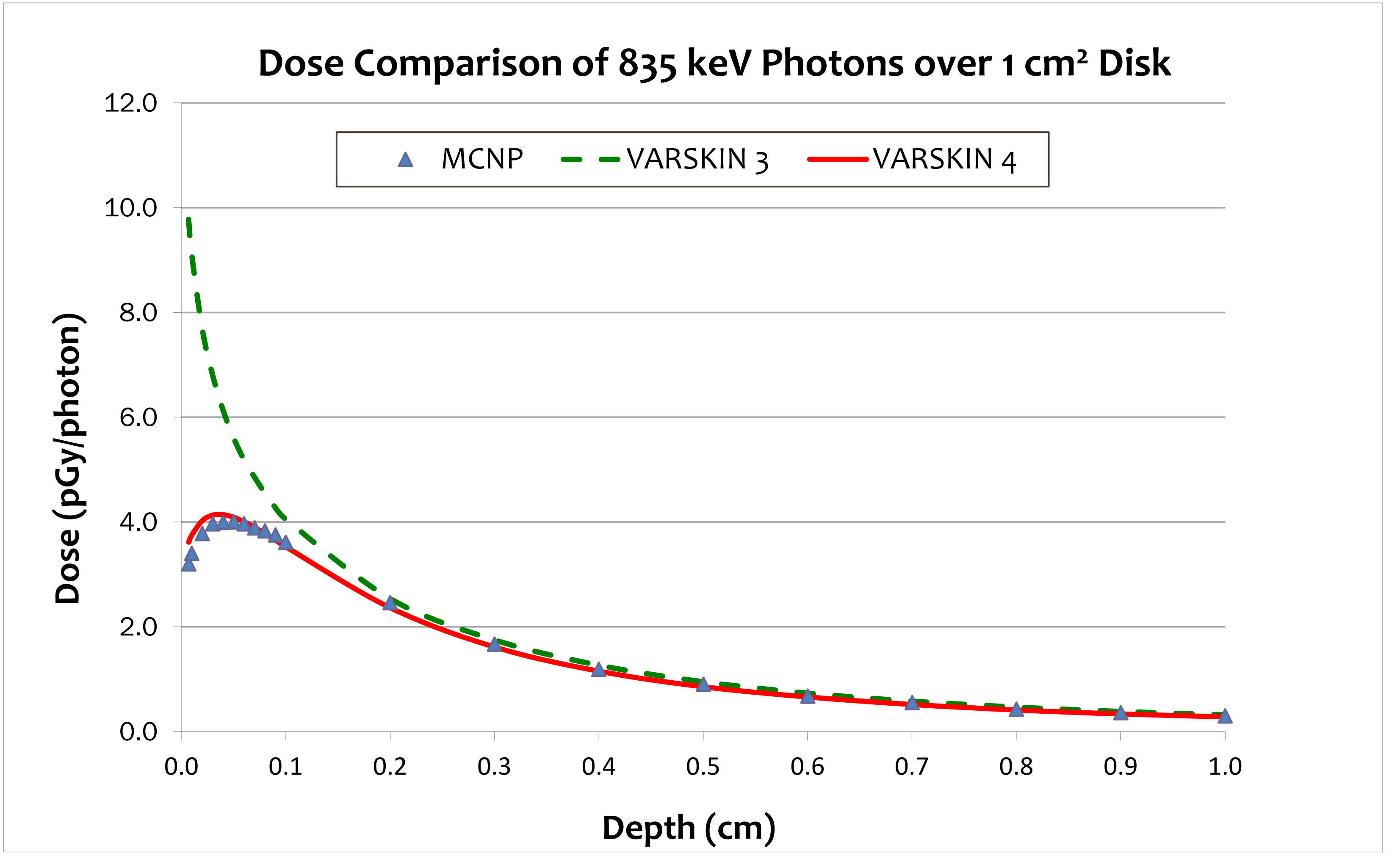
VARSKIN 6

Performance of the photon dosimetry model

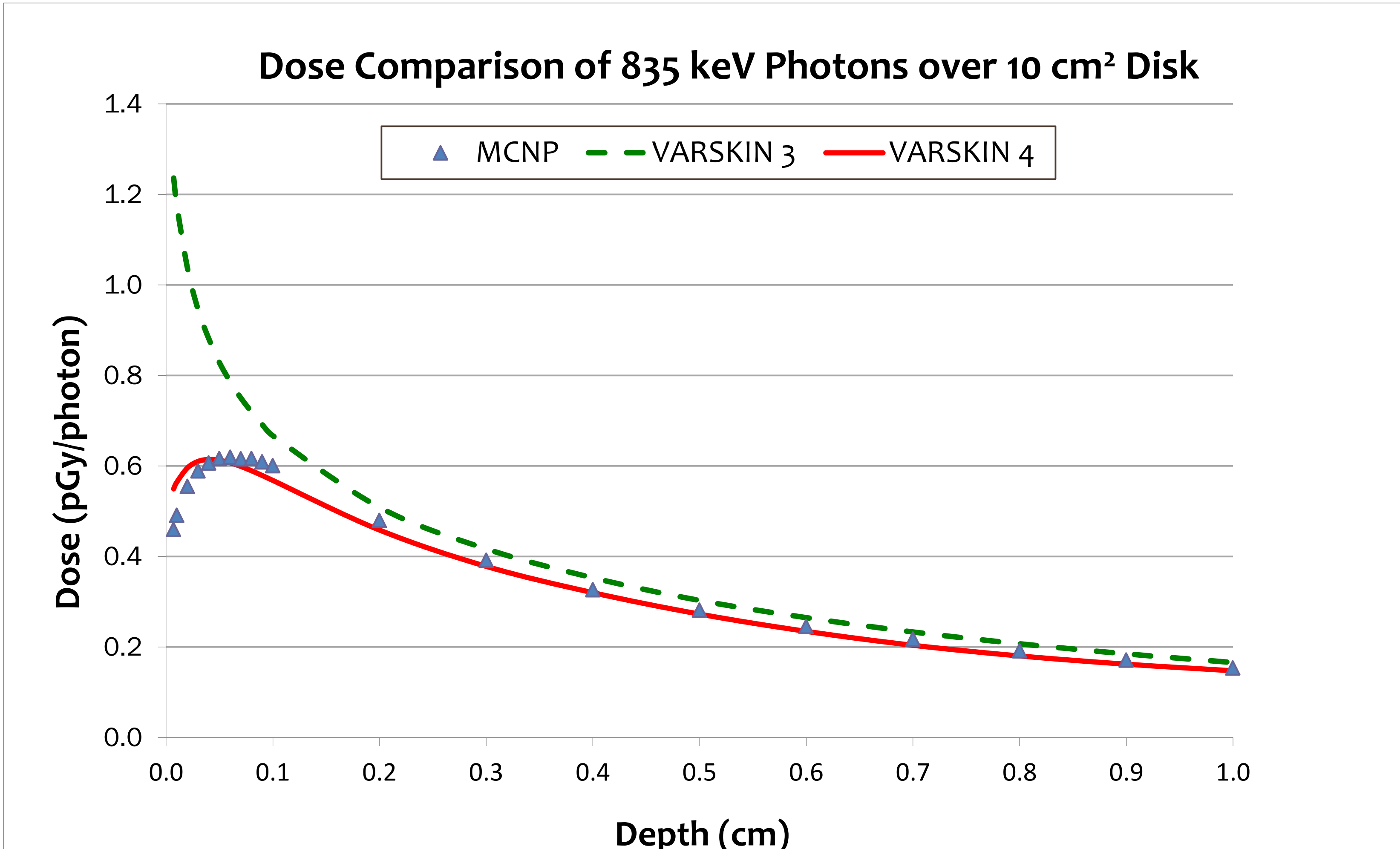
Photon Energy Absorption Simulated with MCNP5

- Five photon-emission geometries modeled:
  - Point
  - Disk (area = 1 cm^2)
  - 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 V6

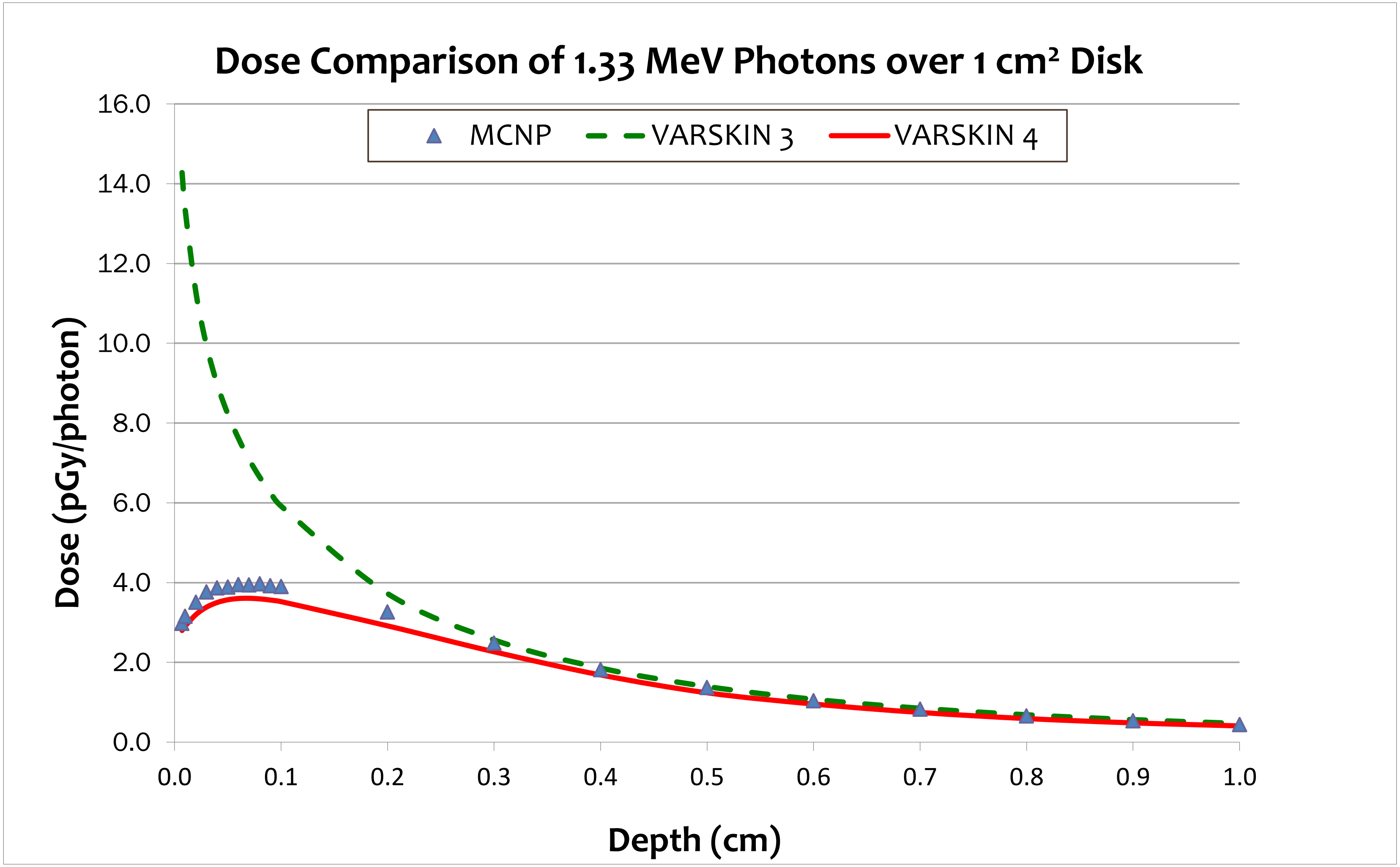
Depth Profile – early CPE demo



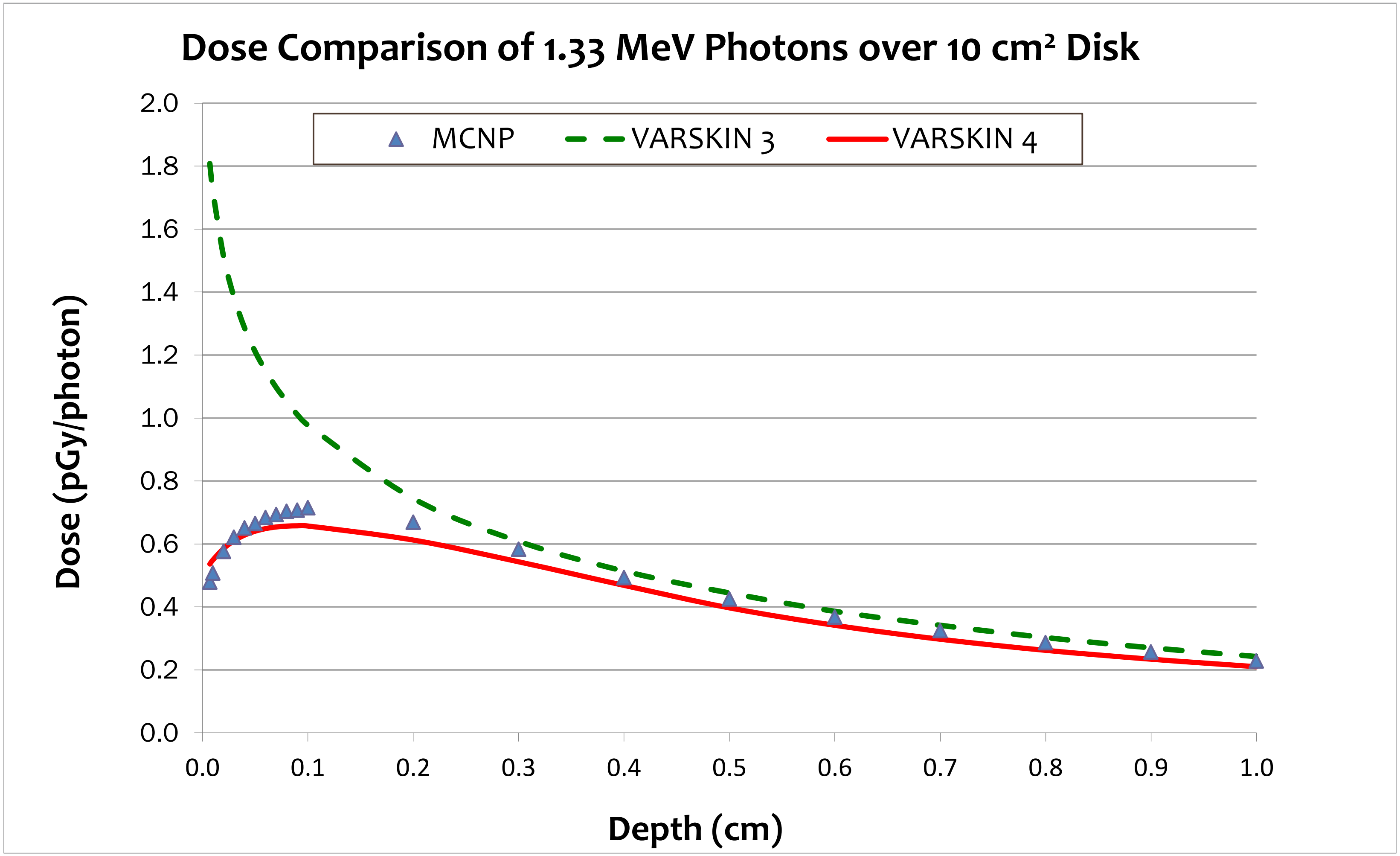
Depth Profile – early CPE demo



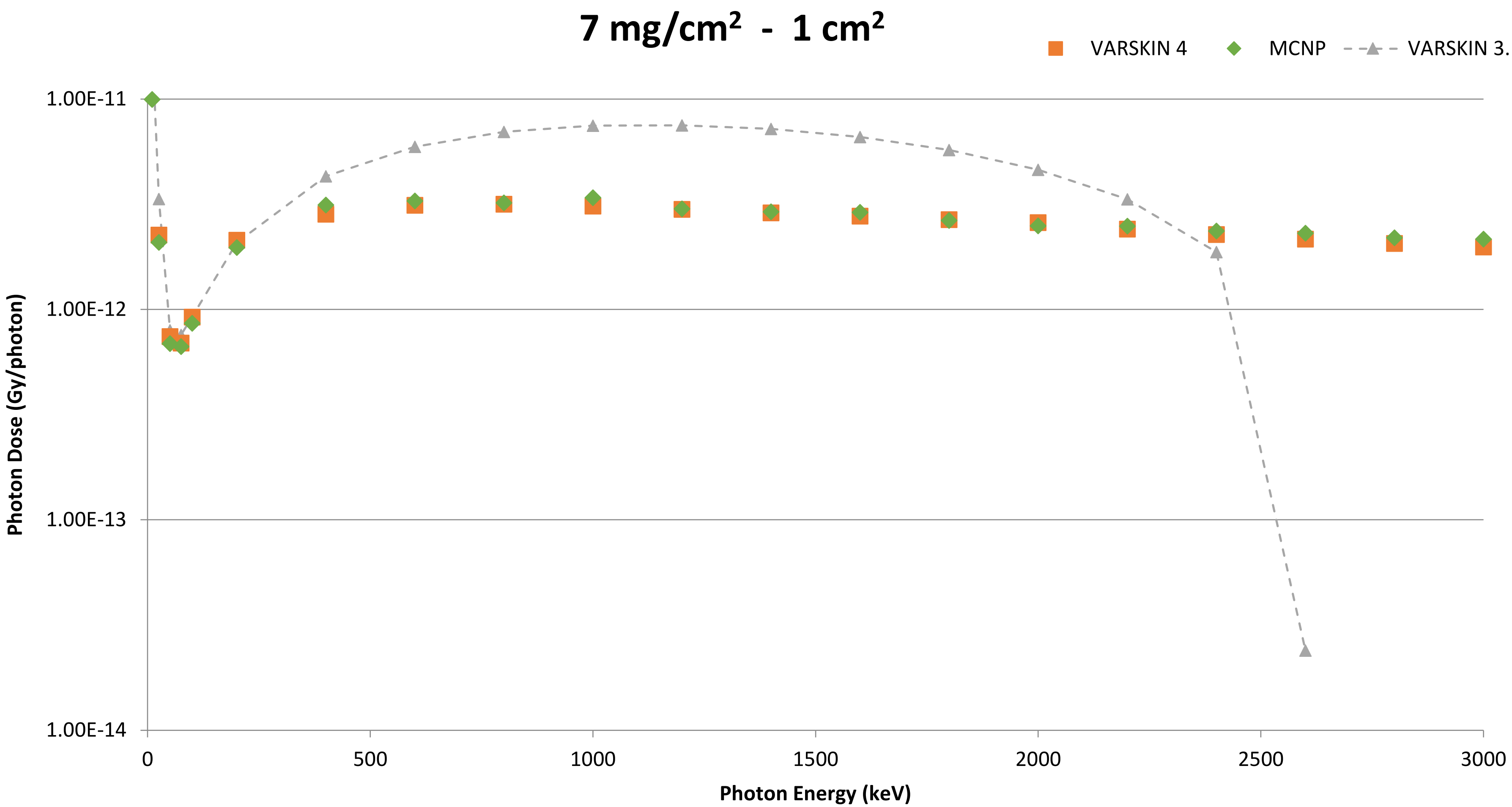
Depth Profile – early CPE demo



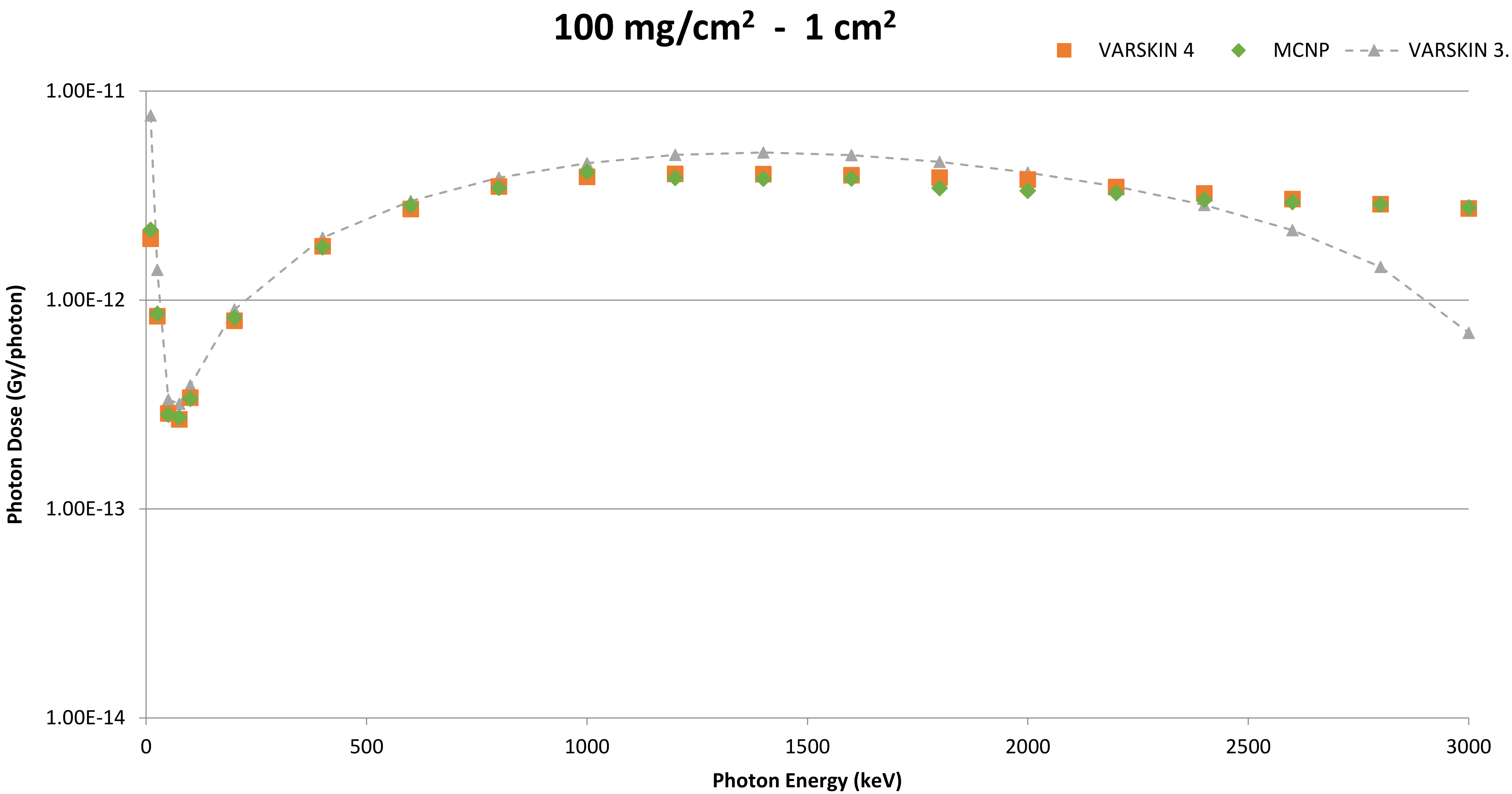
Depth Profile – early CPE demo



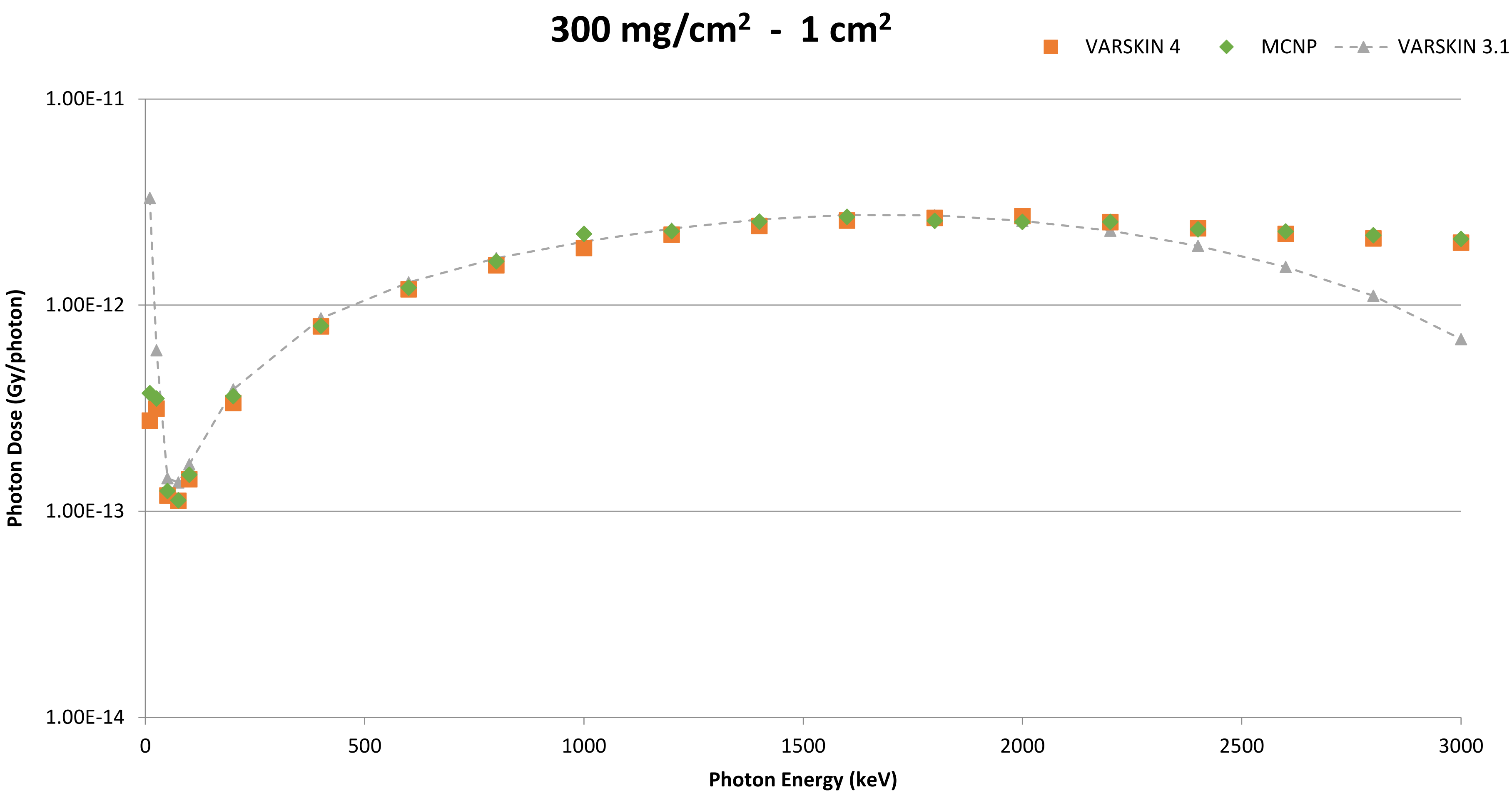
Results – Point Source



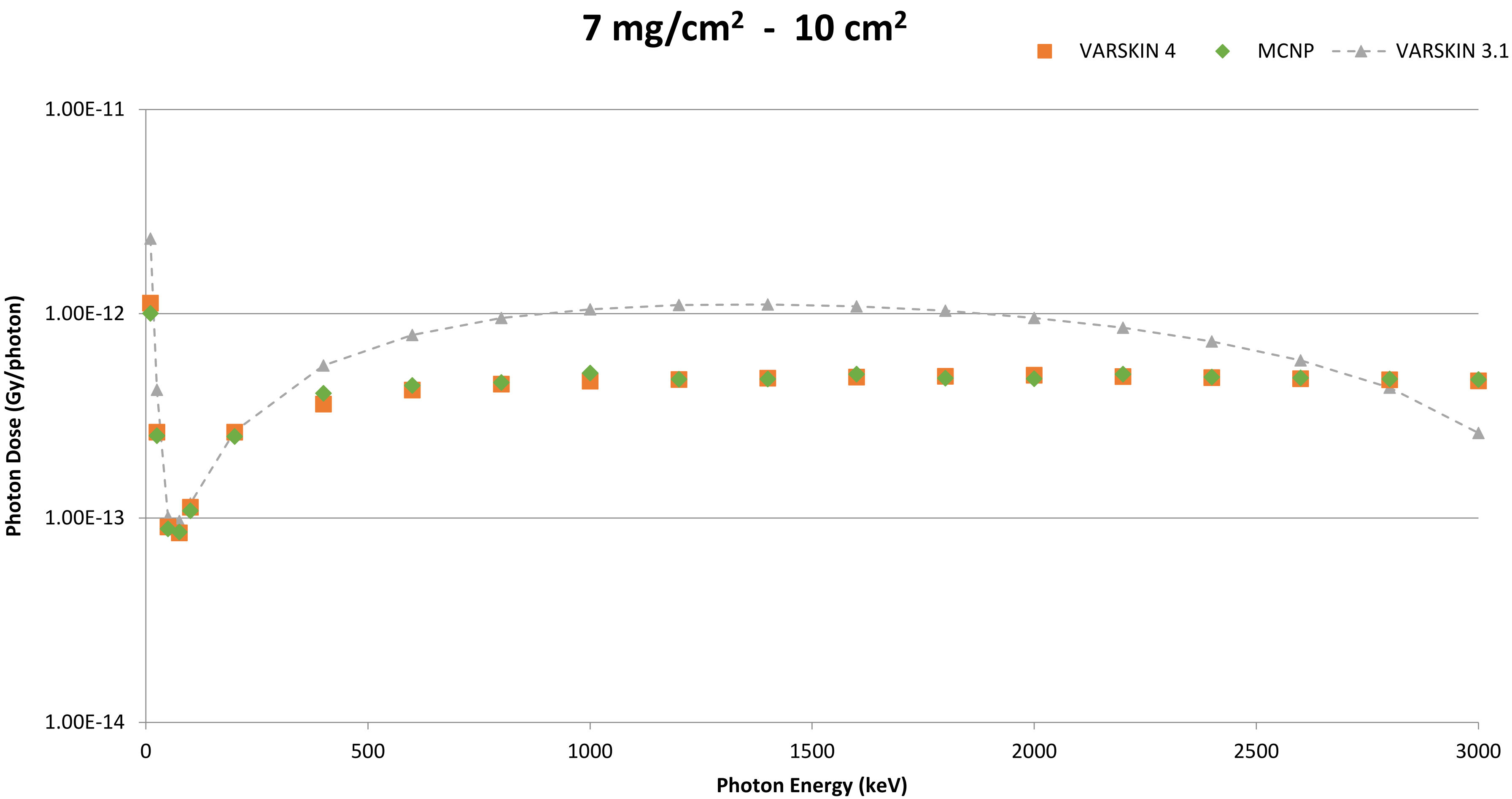
Results – Point Source



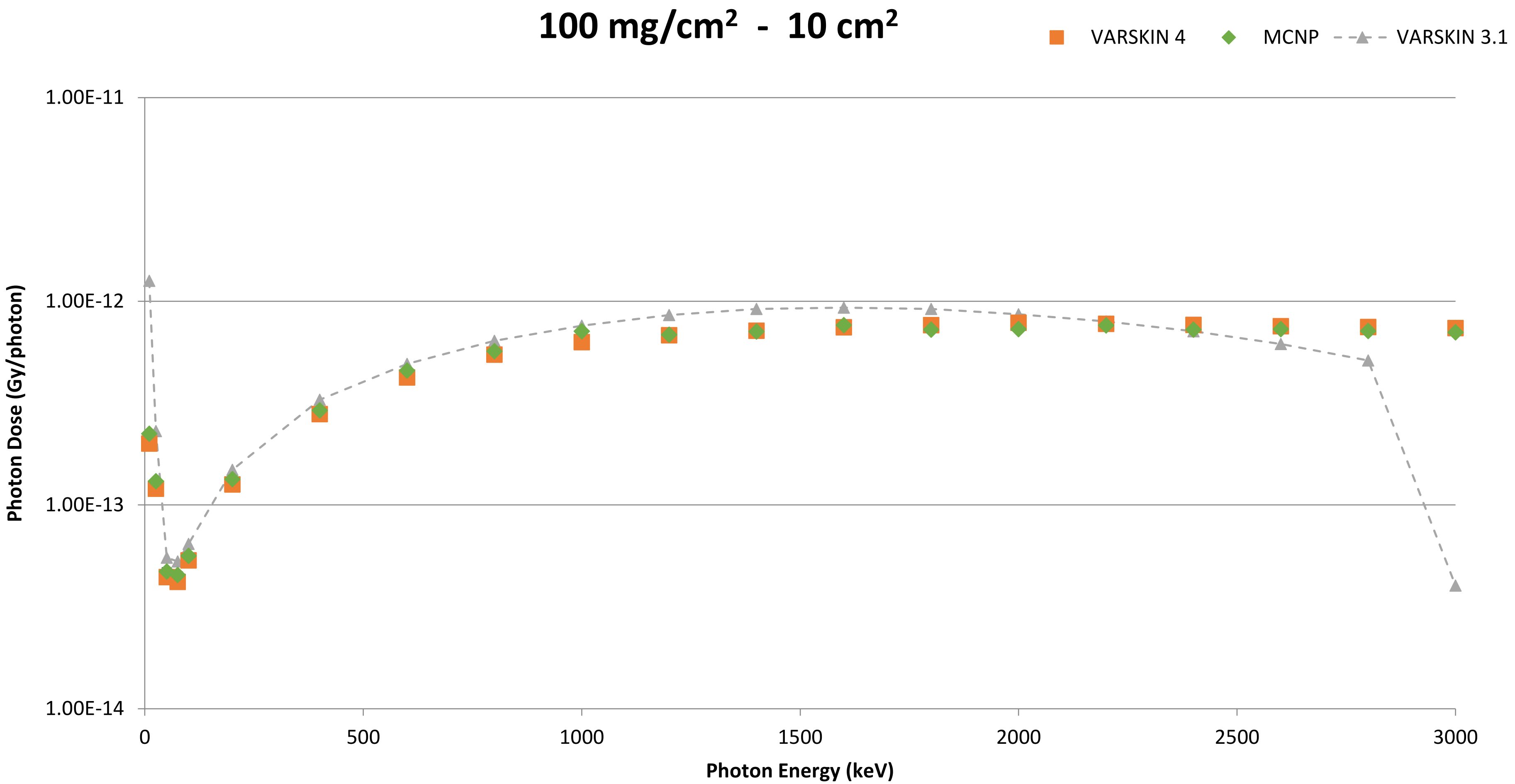
Results – Point Source



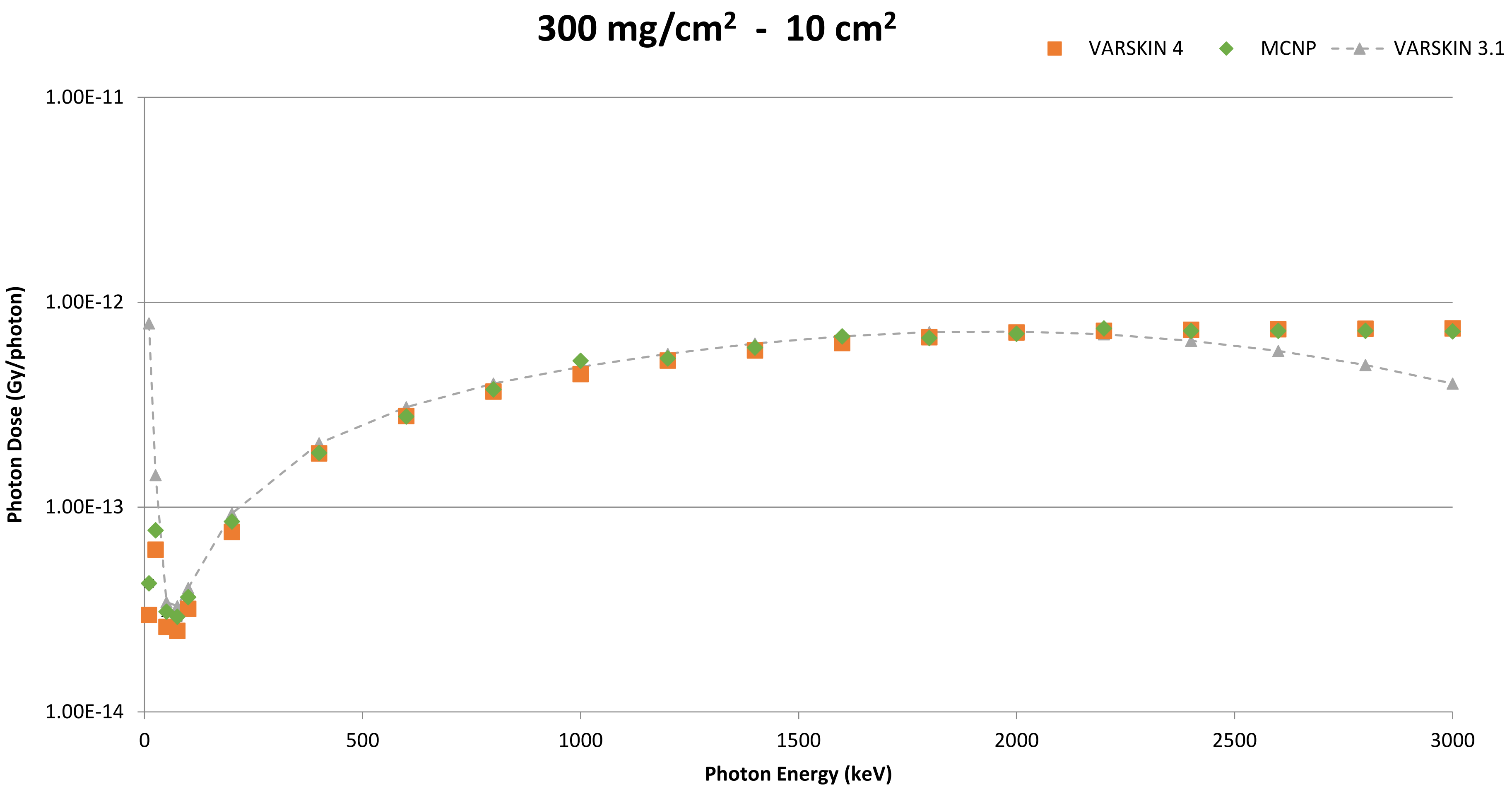
Results – Point Source

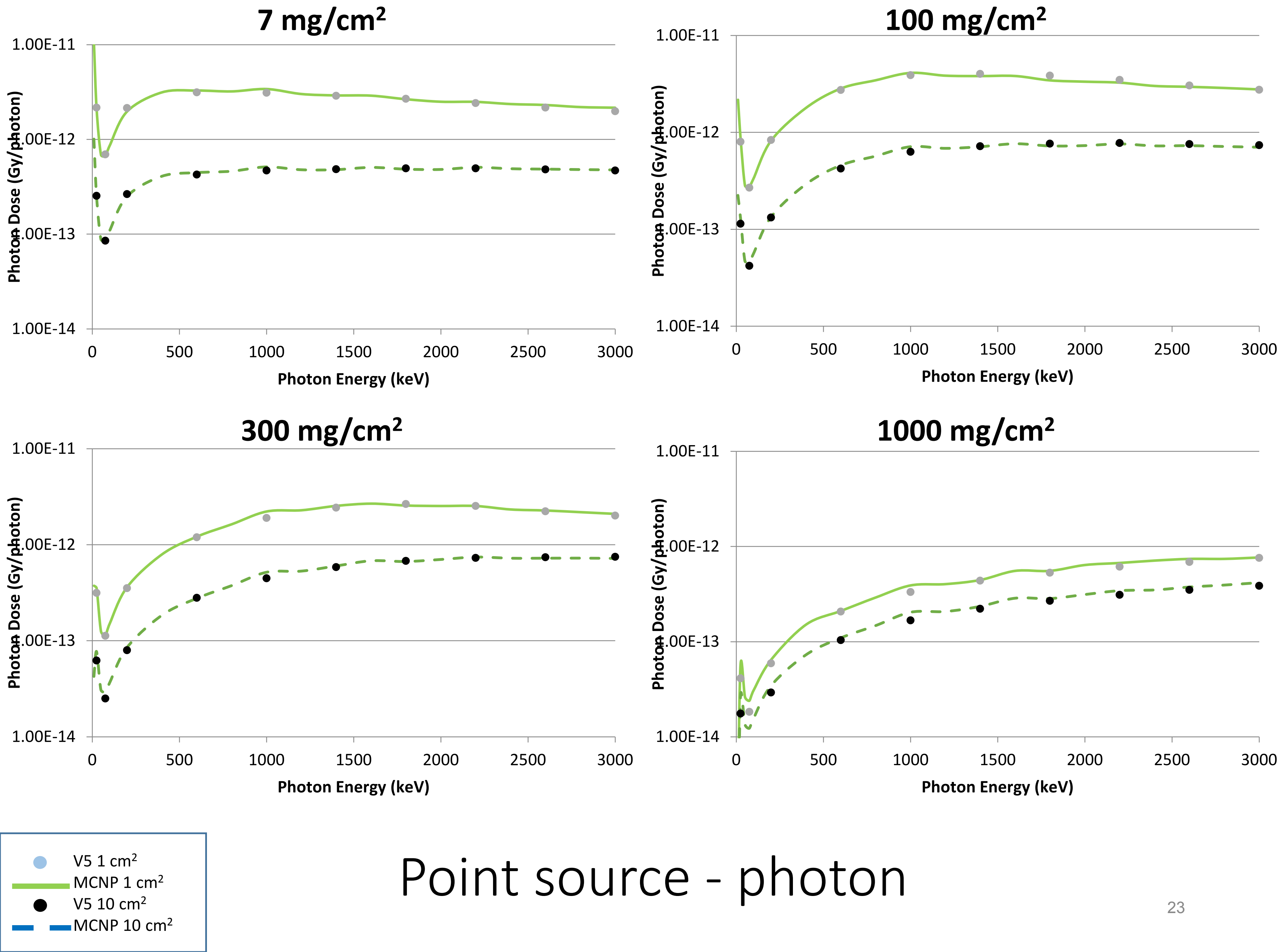


Results – Point Source

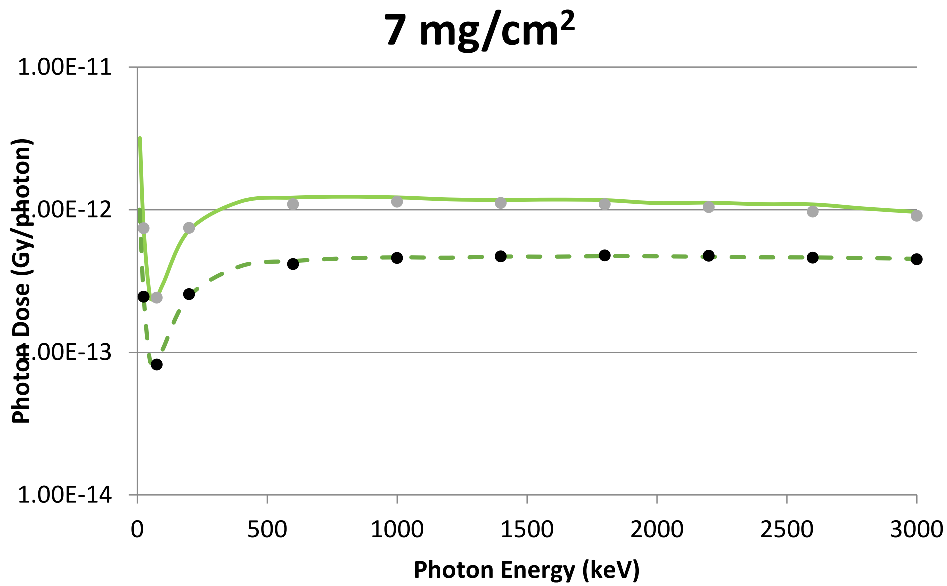


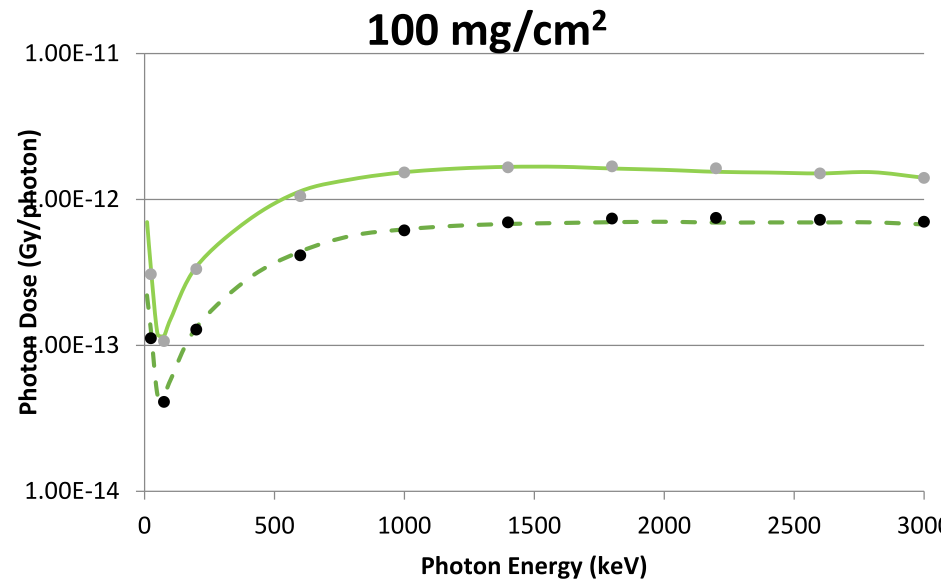
Results – Point Source

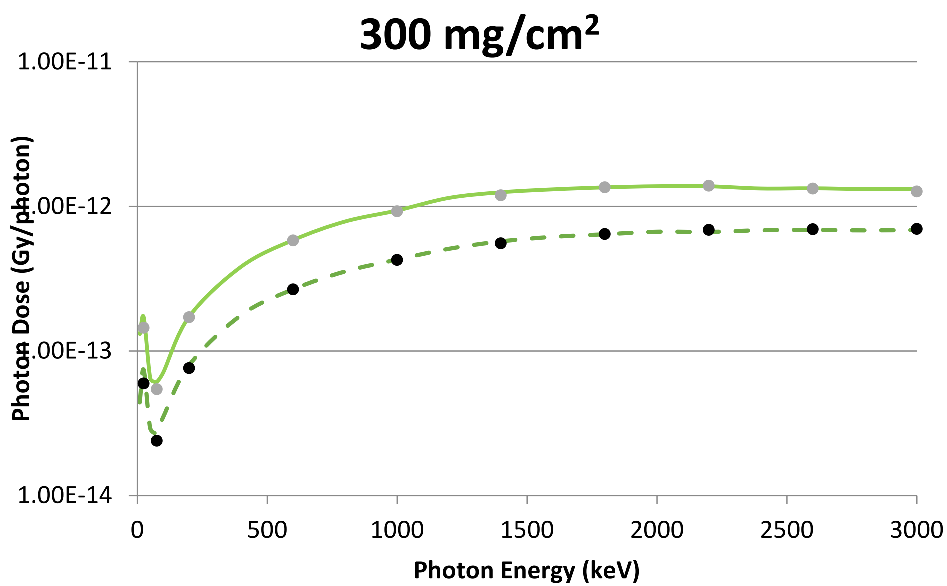


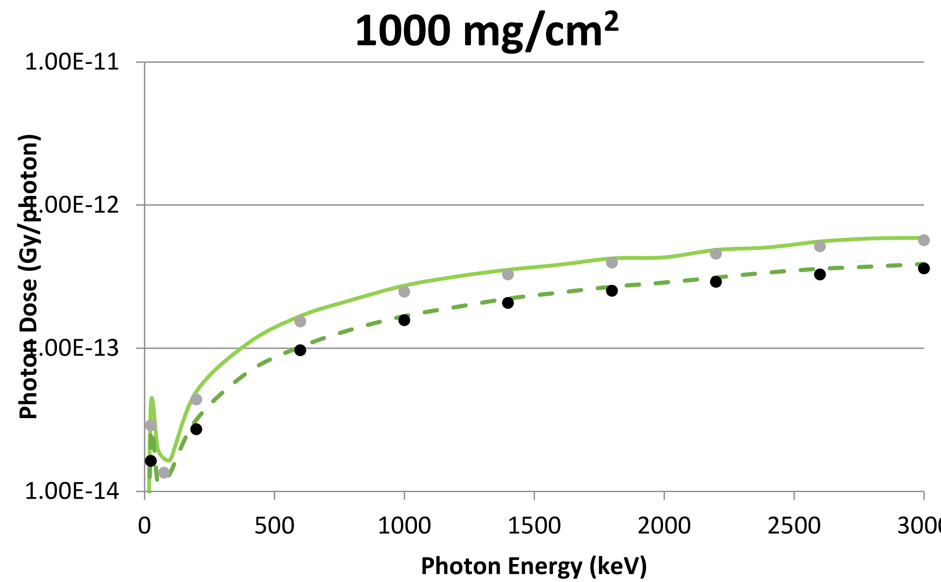


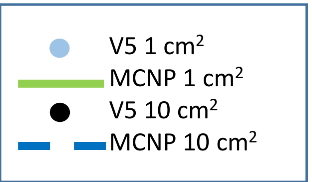
Point source - photon



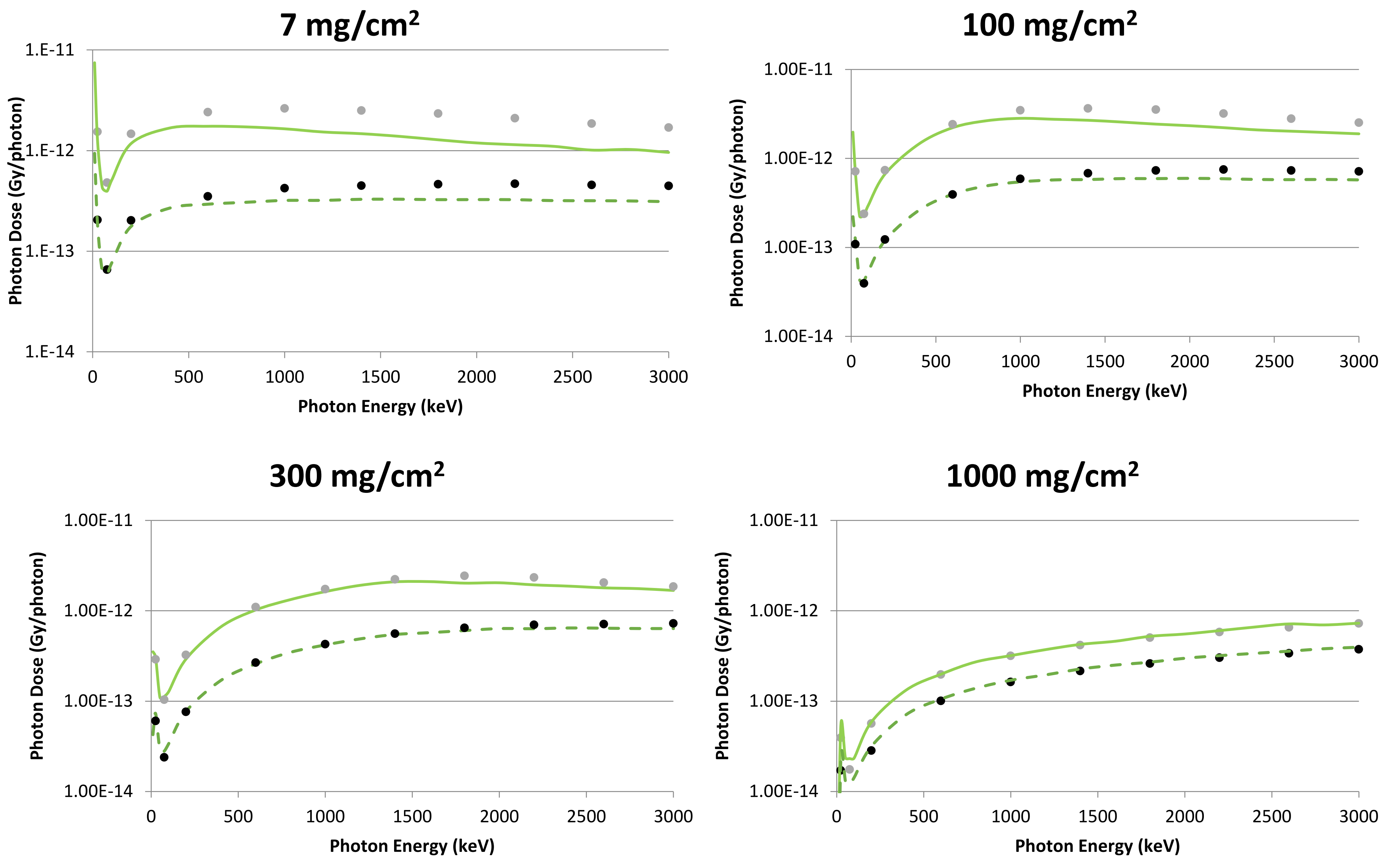


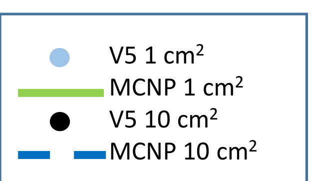






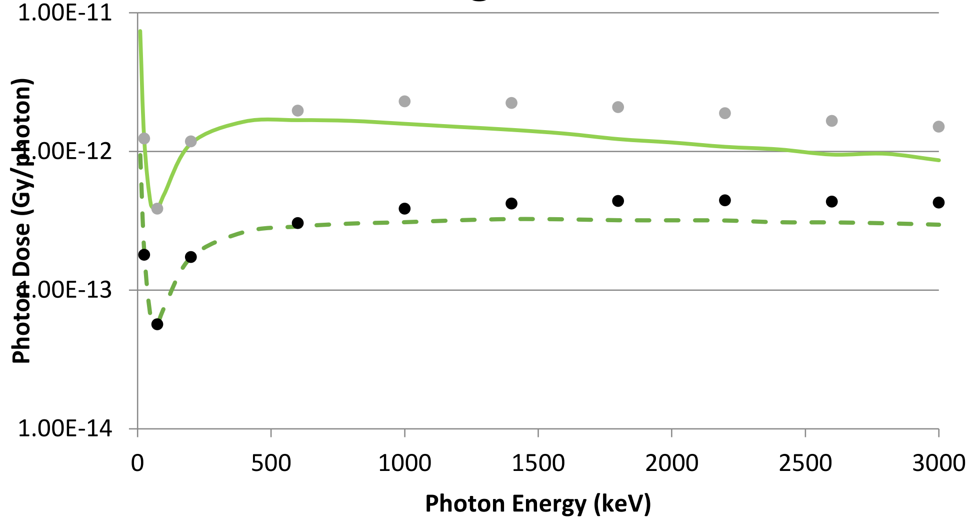
Disk source - photon



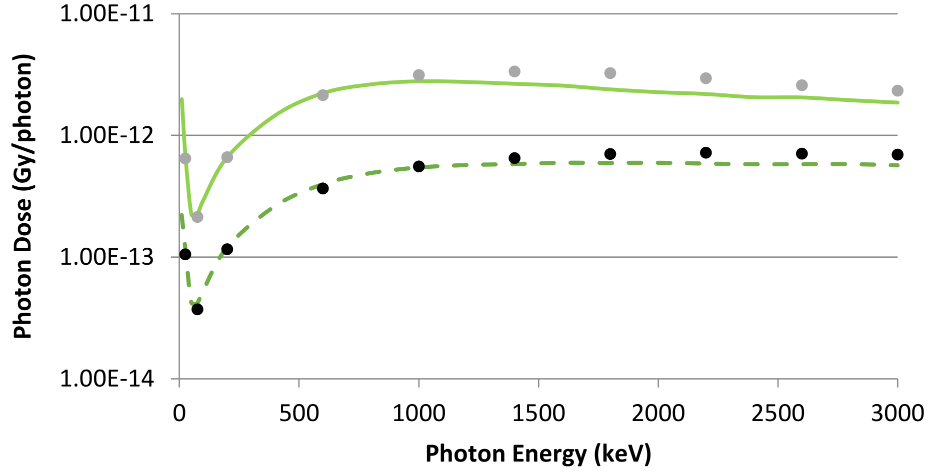


Cylindrical source - photon

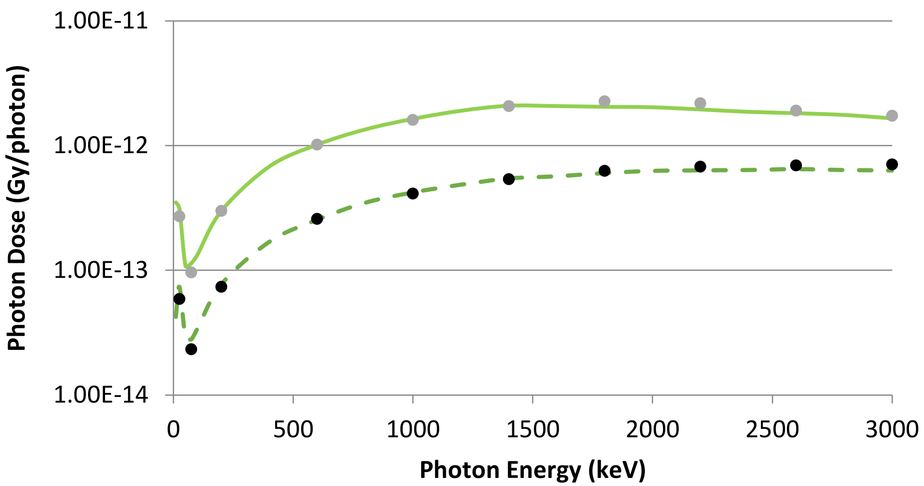
7 mg/cm²



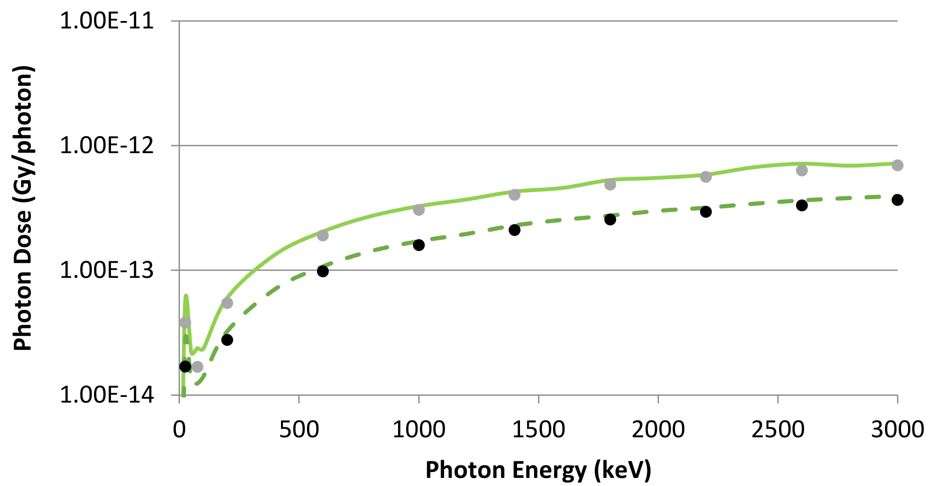
100 mg/cm²

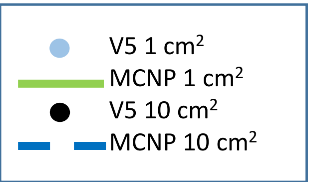


300 mg/cm²

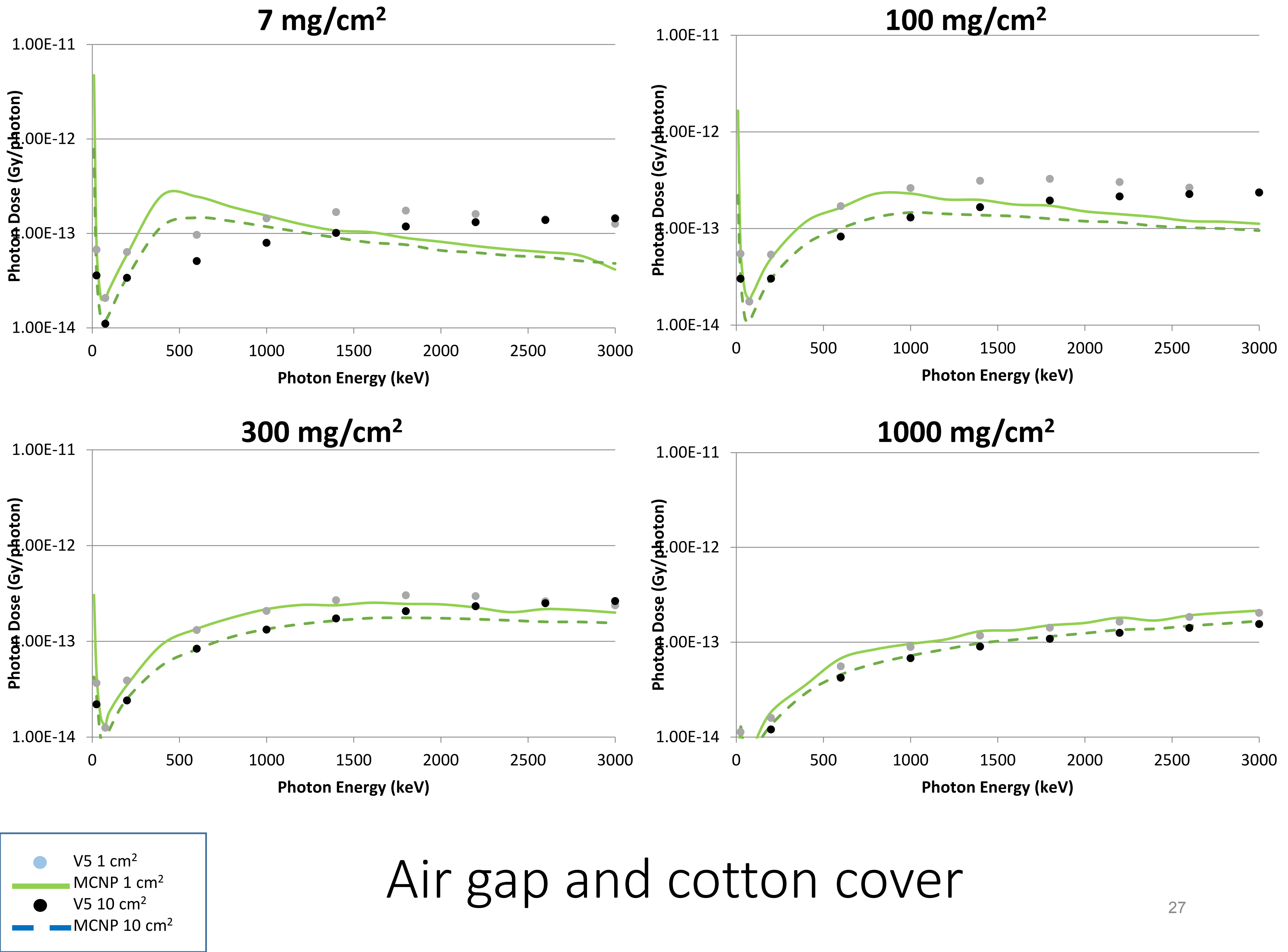


1000 mg/cm²

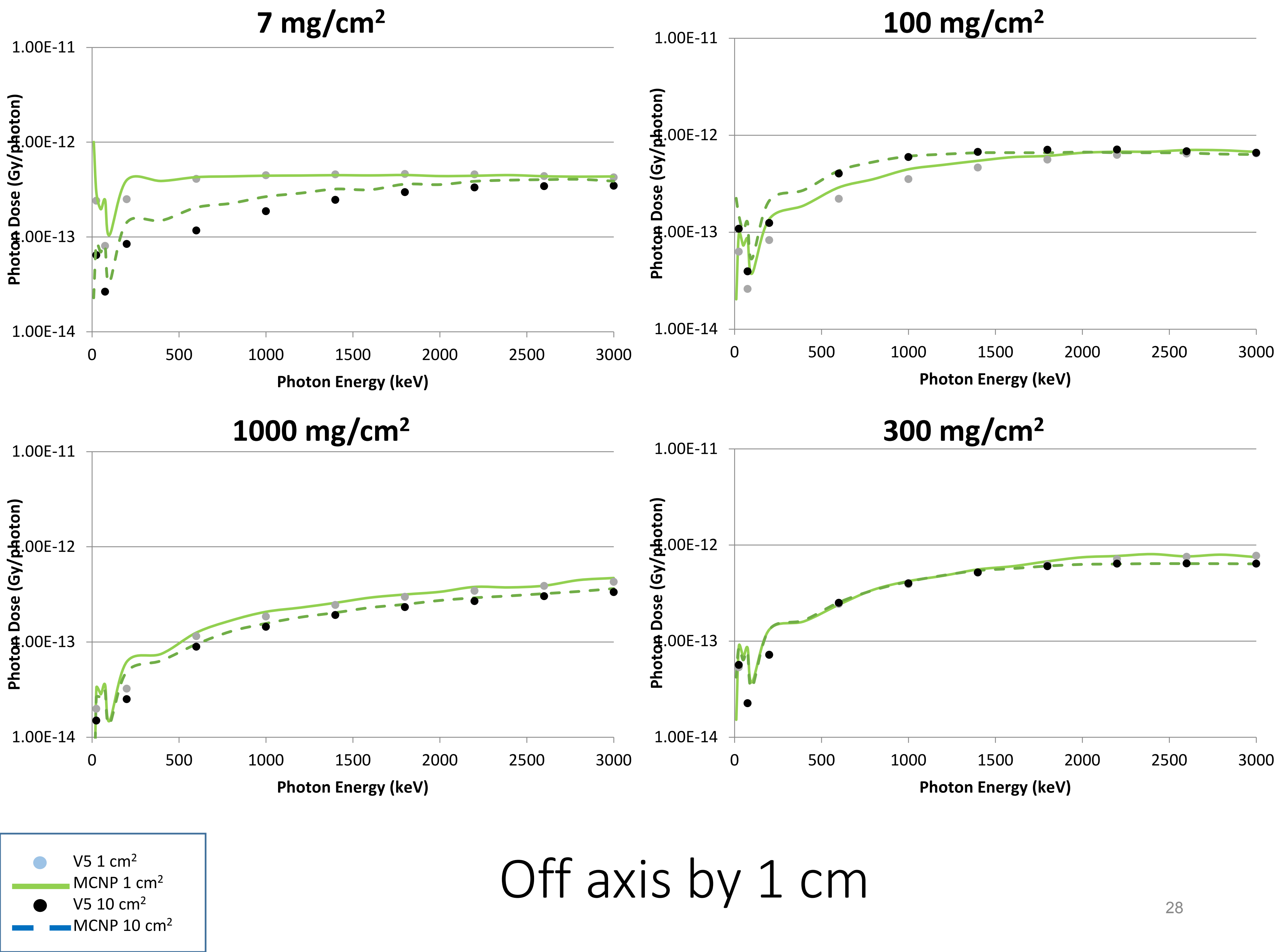




Spherical source - photon



Air gap and cotton cover



Off axis by 1 cm

Comparison of Electron (β) and Photon (γ) Shallow Dose Calculations from VARSKIN 3.1, 4, 5.3, and 6.0 for Various Cover Material Configurations

Nuclide	Air Gap (cm)	Cover Material	V3.1 β Dose (mGy)	V4 β Dose (mGy)	V5.3 β Dose (mGy)	V6.0 β Dose (mGy)	V3.1 γ Dose (mGy)	V4 γ Dose (mGy)	V5.3 γ Dose (mGy)	V6.0 γ Dose (mGy)
Co-60	0.2	M_1	1.96	1.96	2.17	2.17	0.571	0.292	0.290	0.292
Cs-137D	0.2	M_1	14.0	14.0	13.7	13.5	0.199	0.0969	0.0959	0.0917
Sr-90D	0.2	M_1	32.6	32.6	29.1	28.2	0	0	0	0
Co-60	0.2	$2M_1$	0	0	0.0789	0.0789	0.558	0.258	0.257	0.258
Cs-137D	0.2	$2M_1$	4.75	4.75	6.50	6.44	0.181	0.0842	0.0834	0.0797
Sr-90D	0.2	$2M_1$	20.7	20.7	19.5	19.1	0	0	0	0
Co-60	1.0	M_1	0.813	0.813	0.813	0.813	0.0797	0.0429	0.0427	0.0429
Cs-137D	1.0	M_1	2.79	2.79	2.59	2.53	0.0277	0.0129	0.0128	0.0122
Sr-90D	1.0	M_1	5.37	5.37	4.74		0	0	0	0
Co-60	1.0	$2M_1$	0	0	0.0409	0.0409	0.0836	0.0404	0.0402	0.0404
Cs-137D	1.0	$2M_1$	1.40	1.40	1.53	1.49	0.0270	0.0121	0.0121	0.0115
Sr-90D	1.0	$2M_1$	3.95	3.95	3.66	3.51	0	0	0	0
Co-60	1.0	$M_1 + M_2$	0	0	0.00838	0.00838	0.0876	0.0400	0.0400	0.0400
Cs-137D	1.0	$M_1 + M_2$	0.770	0.770	1.03	1.01	0.0271	0.0120	0.0120	0.0114
Sr-90D	1.0	$M_1 + M_2$	3.26	3.26	3.11	3.00	0	0	0	0
Co-60	5.0	$M_1 + M_2$	0	0	0.00045	0.00045	0.0045	0.0020	0.0025	0.0025
Cs-137D	5.0	$M_1 + M_2$	0.0384	0.0384	0.0521	0.0513	0.0013	0.0006	0.0006	0.0006
Sr-90D	5.0	$M_1 + M_2$	0.167	0.167	0.158	0.153	0	0	0	0

Cs-137D includes the progeny ^{137m}Ba; Sr-90D includes the progeny ^{90}Y
M_1 — Cover material = thickness of 0.37 mm, density of 0.70 g/cm^3
$2M_1$ — Cover material = thickness of 0.74 mm, density of 0.70 g/cm^3
M_2 — Cover material = thickness of 0.40 mm, density of 1.1 g/cm^3

Photon point source on cover

VARSKIN 6

performance of the
electron dosimetry model

Electron Energy Absorption Simulated with EGSnrc

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

EGS Simulation

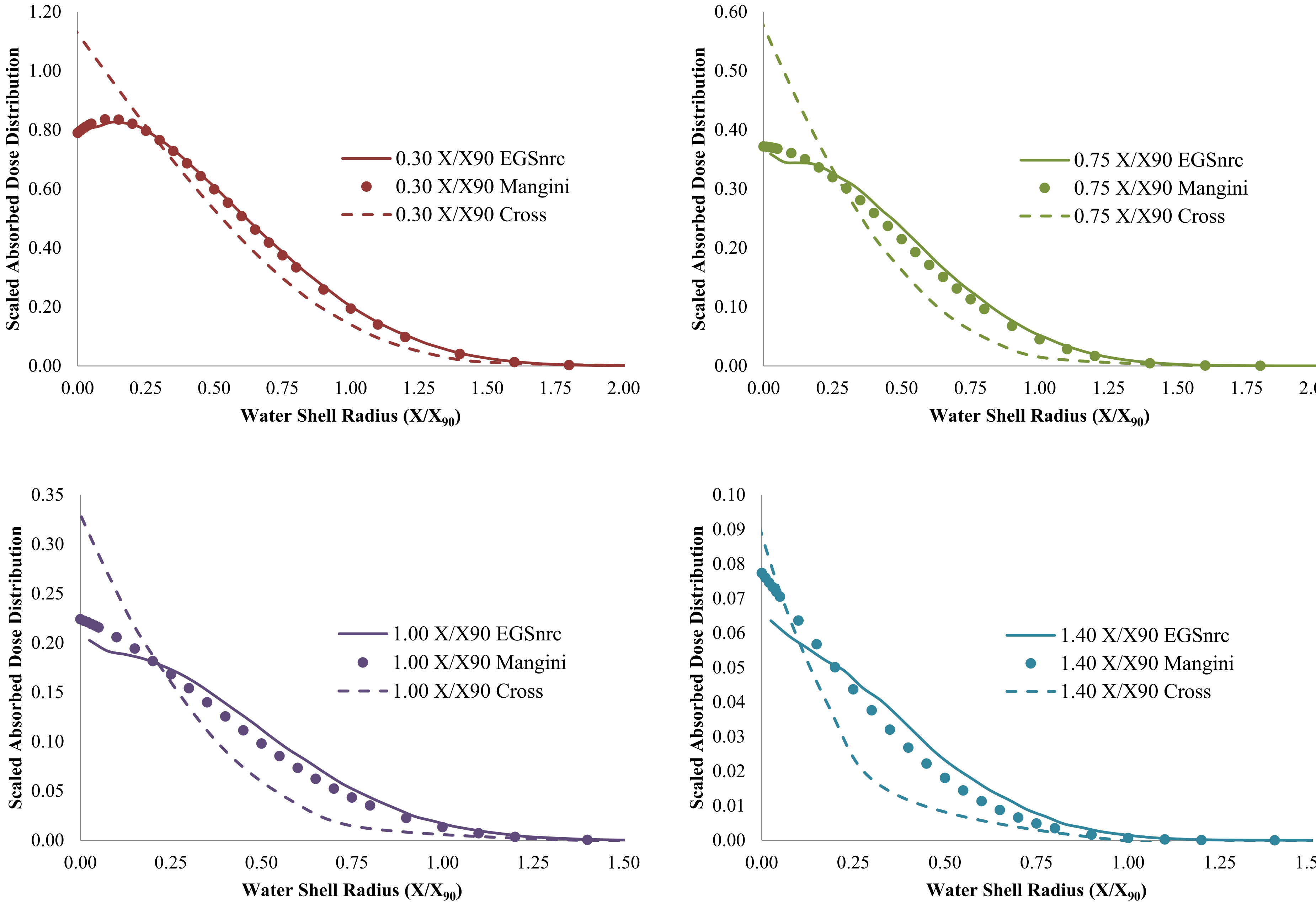
- VARSKIN results were compared to EGS simulations for the same geometrical scenarios
- Volumetric sources investigated:

Alloy	**Z_{eff}**	**Density (g/cm^3)**	**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

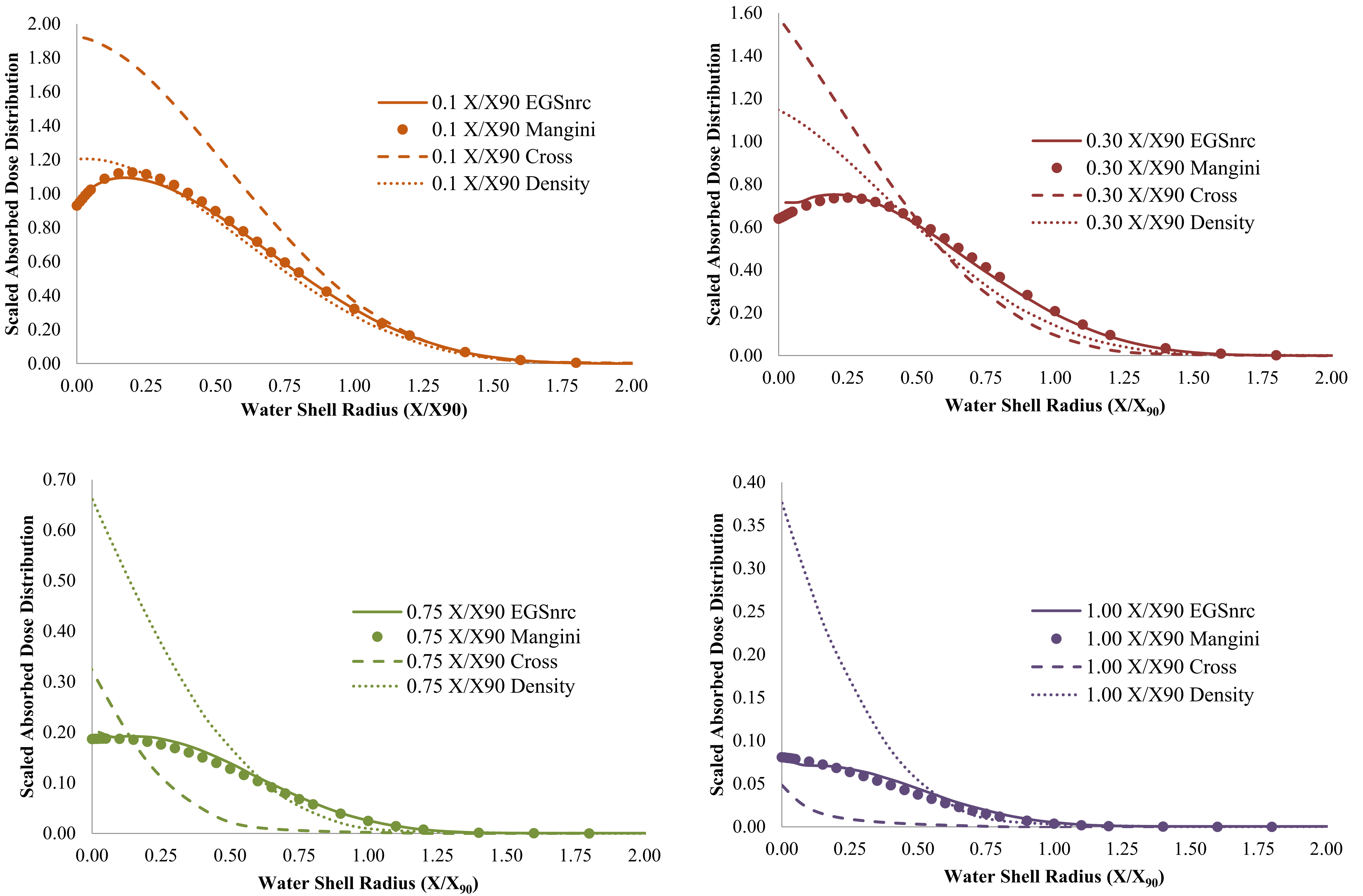
EGS Simulation

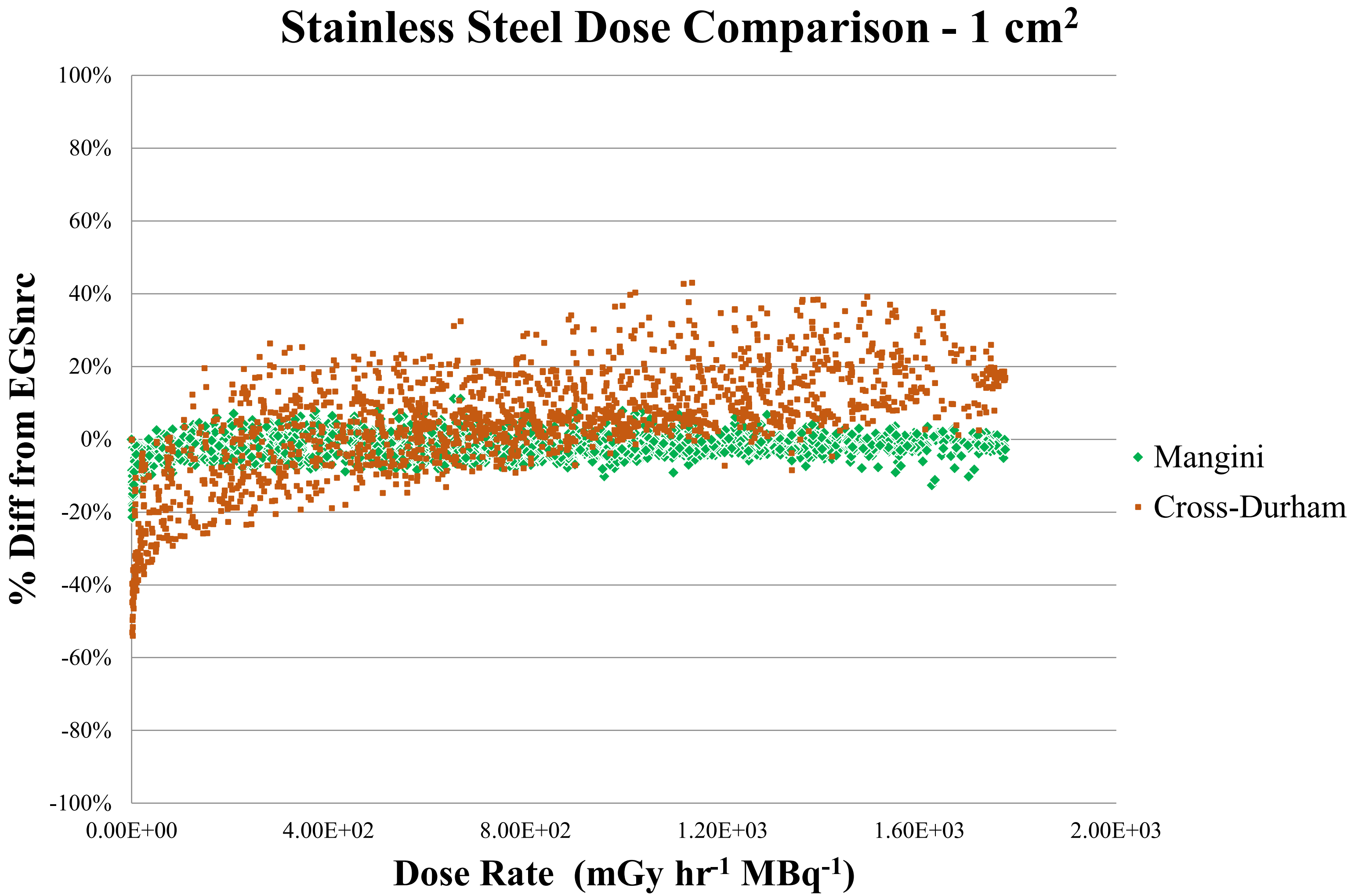
- Four nuclides chosen:
  - ^{28}Al (E_{avg} = 1.24 MeV; E_{max} = 2.86 MeV)
  - ^{42}K (E_{avg} = 1.43 MeV; E_{max} = 3.52 MeV)
  - ^{66}Cu (E_{avg} = 1.07 MeV; E_{max} = 2.63 MeV)
  - ^{138}Cs (E_{avg} = 1.05 MeV; E_{max} = 2.90 MeV)
- Skin depths to 1000 mg/cm^2
- Dose-averaging areas of 1 and 10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

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

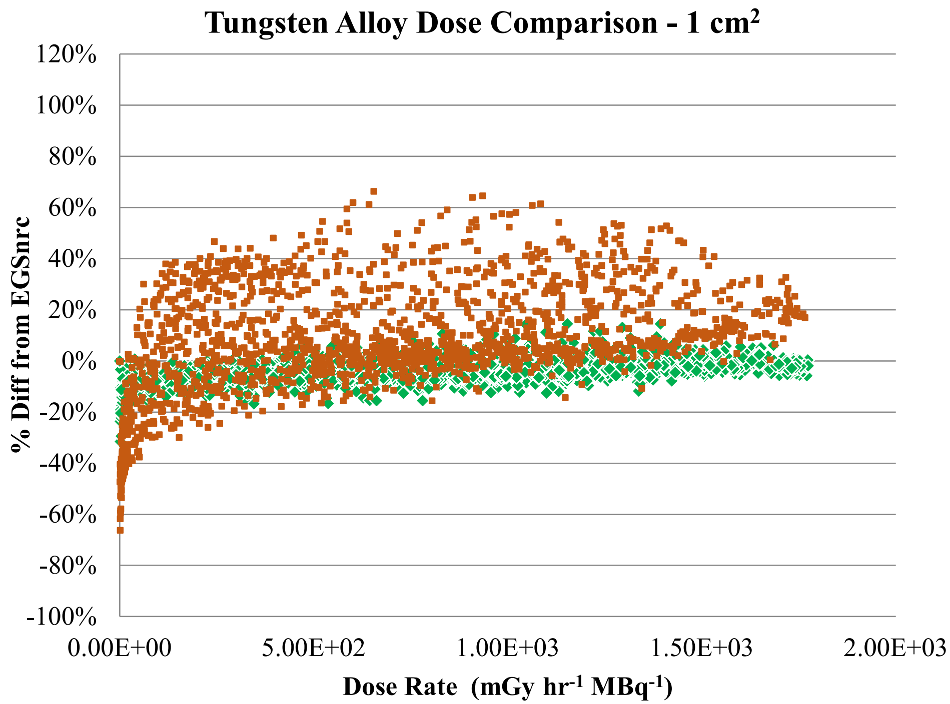


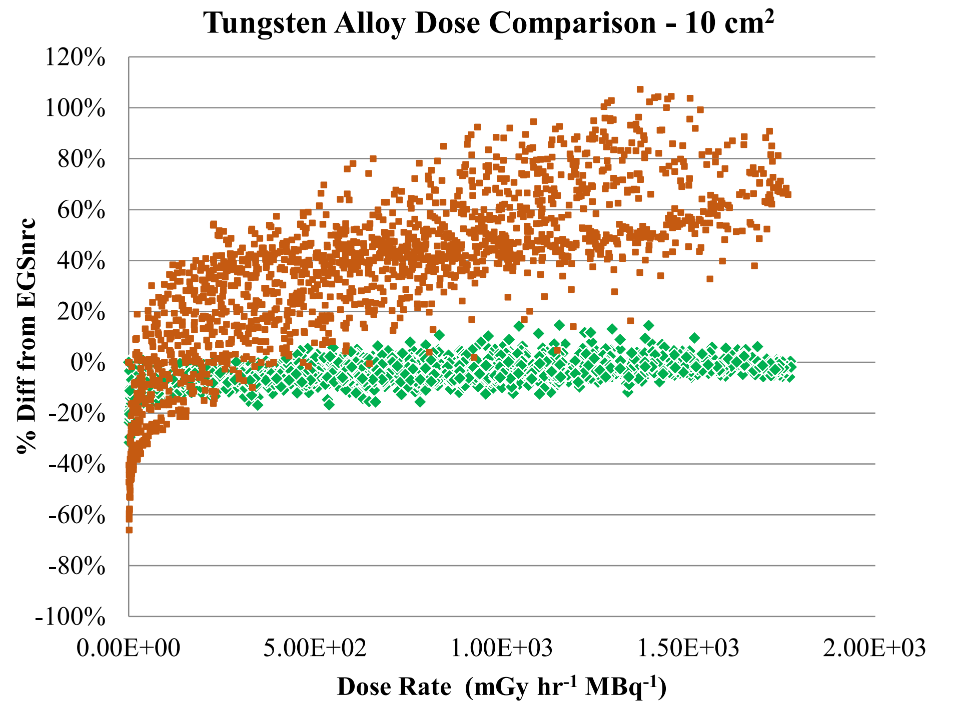
Non-Homogeneous Uranium Oxide DPKs: ^{32}P

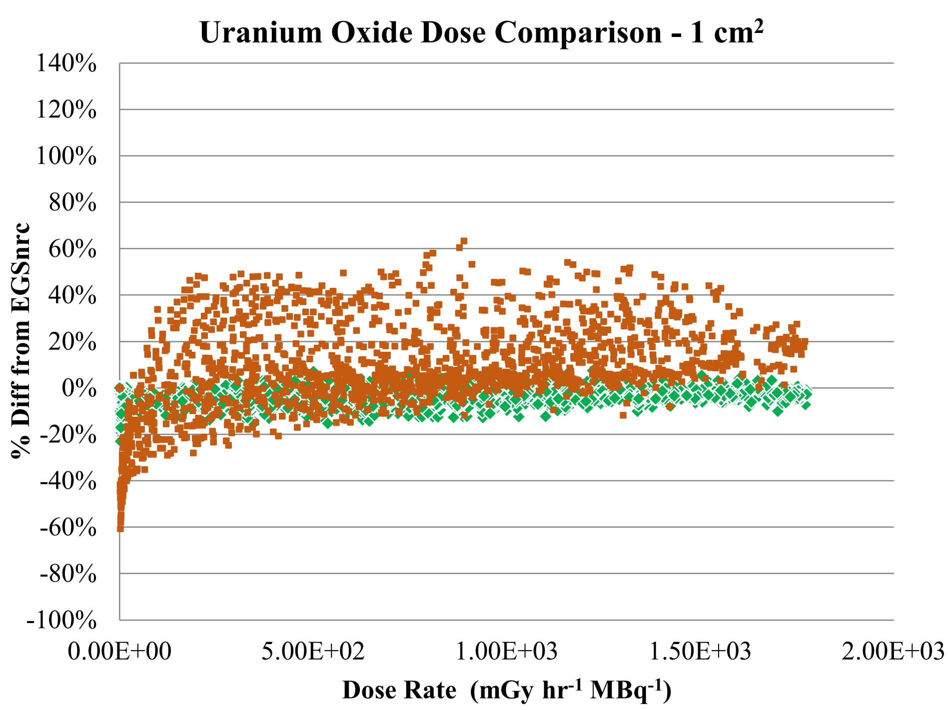


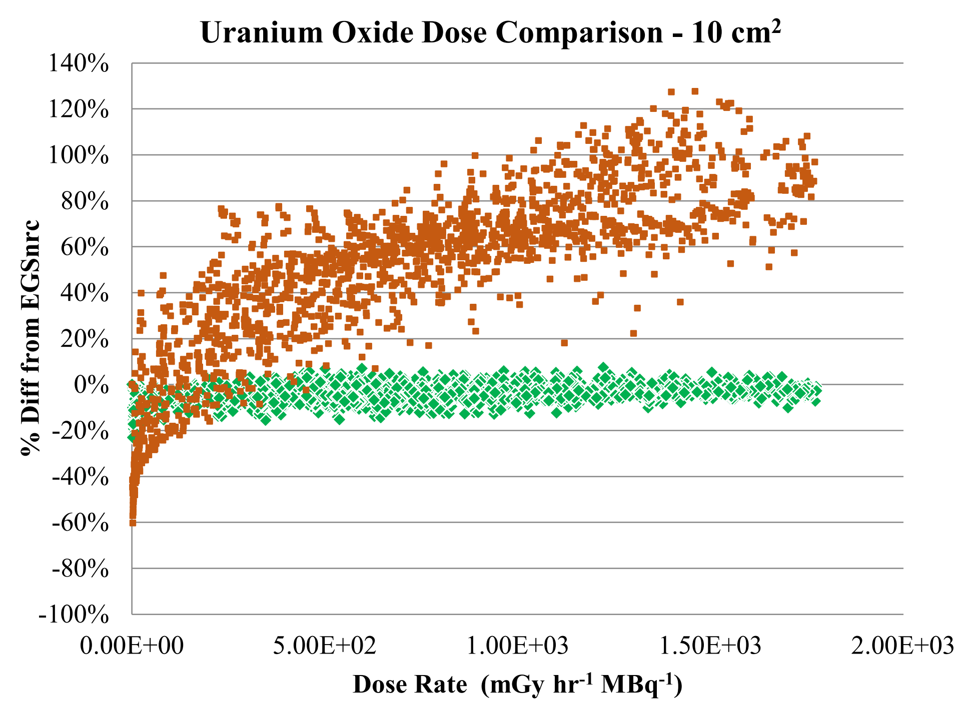


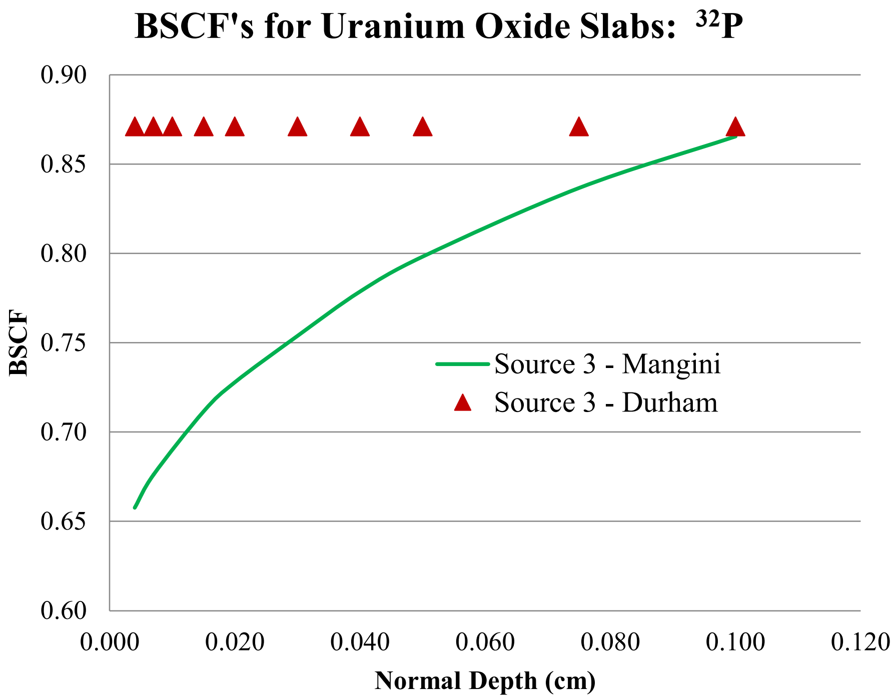
Dose Verification

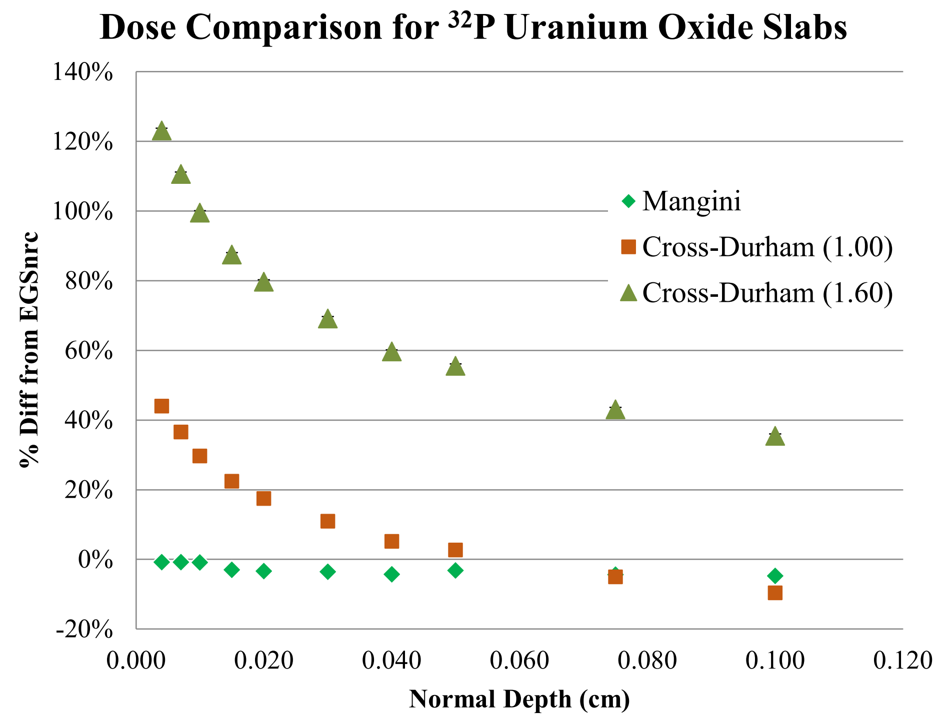

Tungsten Alloy Dose Comparison - 1 cm²
% Diff from EGSnrc
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+02
1.00E+03
1.50E+03
2.00E+03
Dose Rate (mGy hr⁻¹ MBq⁻¹)

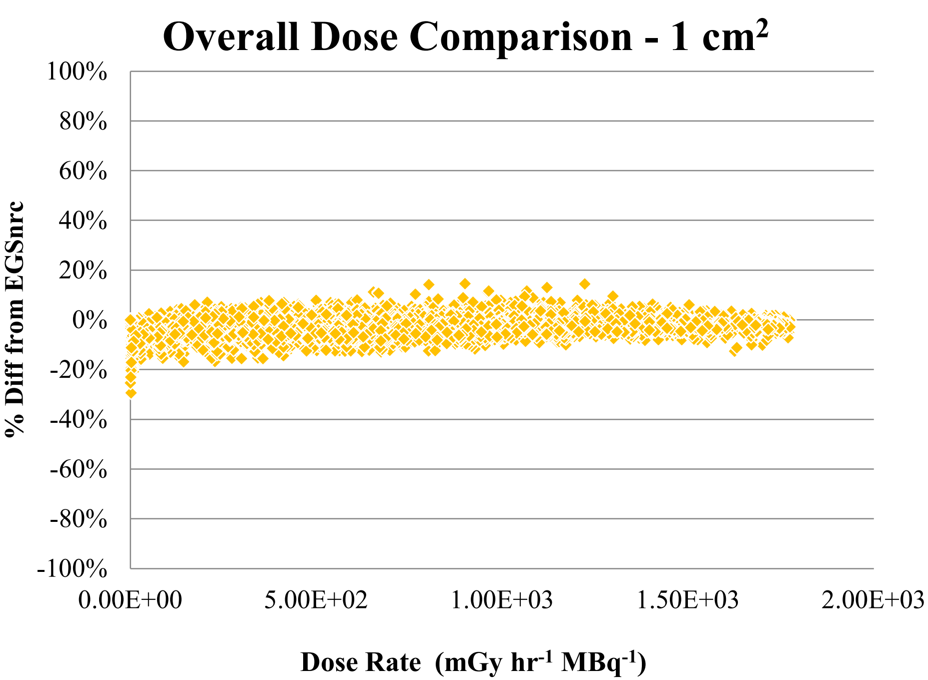

Tungsten Alloy Dose Comparison - 10 cm²
% Diff from EGSnrc
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+02
1.00E+03
1.50E+03
2.00E+03
Dose Rate (mGy hr⁻¹ MBq⁻¹)

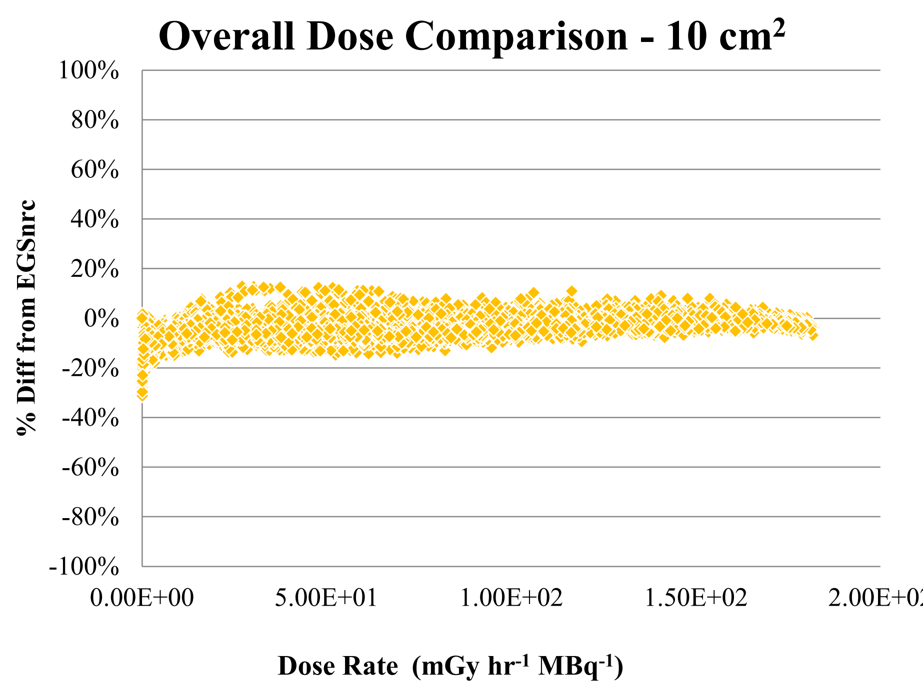

Uranium Oxide Dose Comparison - 1 cm²
% Diff from EGSnrc
140%
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+02
1.00E+03
1.50E+03
2.00E+03
Dose Rate (mGy hr⁻¹ MBq⁻¹)

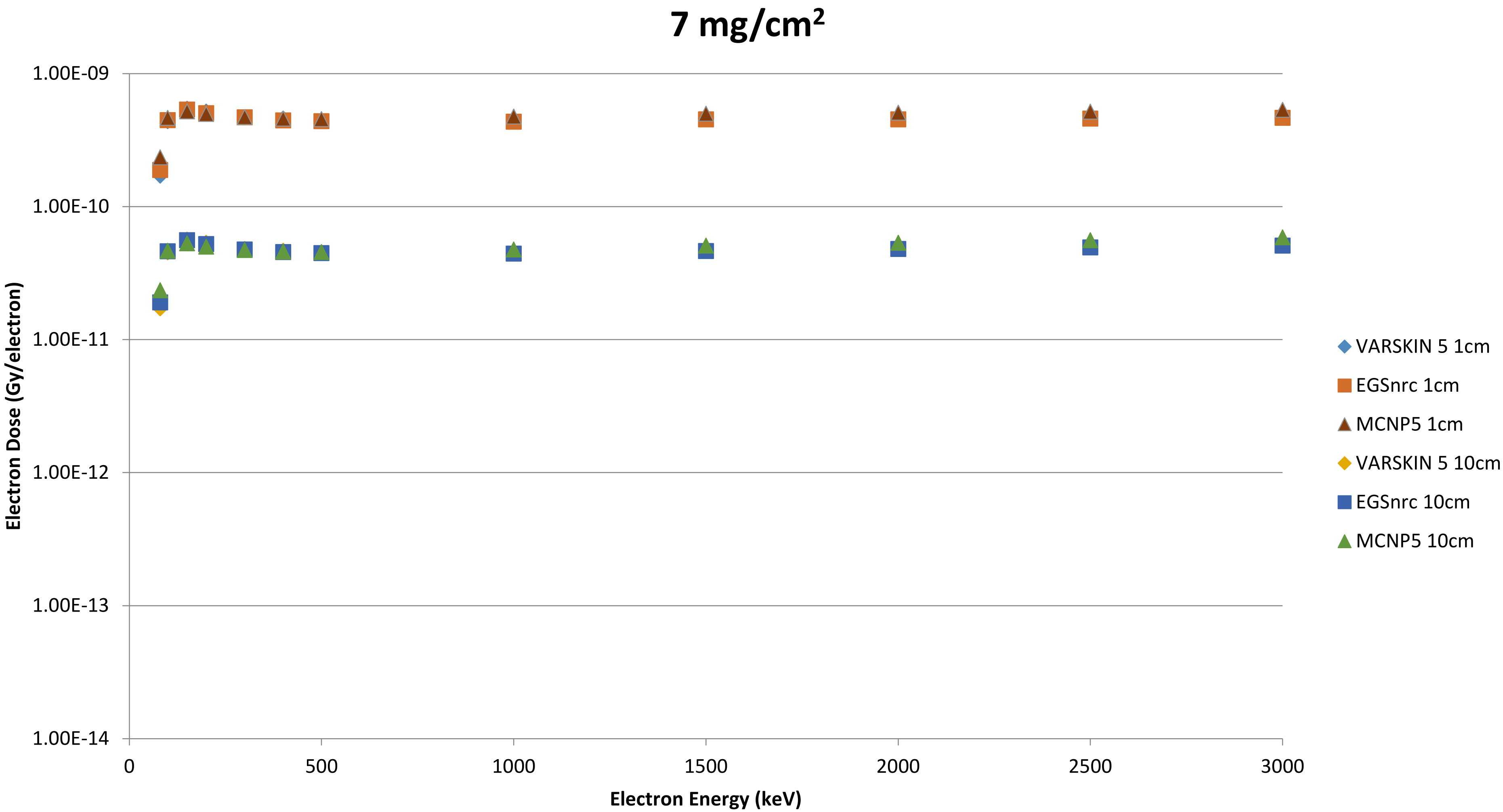

Uranium Oxide Dose Comparison - 10 cm²
% Diff from EGSnrc
140%
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+02
1.00E+03
1.50E+03
2.00E+03
Dose Rate (mGy hr⁻¹ MBq⁻¹)


BSCF's for Uranium Oxide Slabs: 32P
BSCF
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.000
0.020
0.040
0.060
0.080
0.100
0.120
Normal Depth (cm)
Source 3 - Mangini
Source 3 - Durham

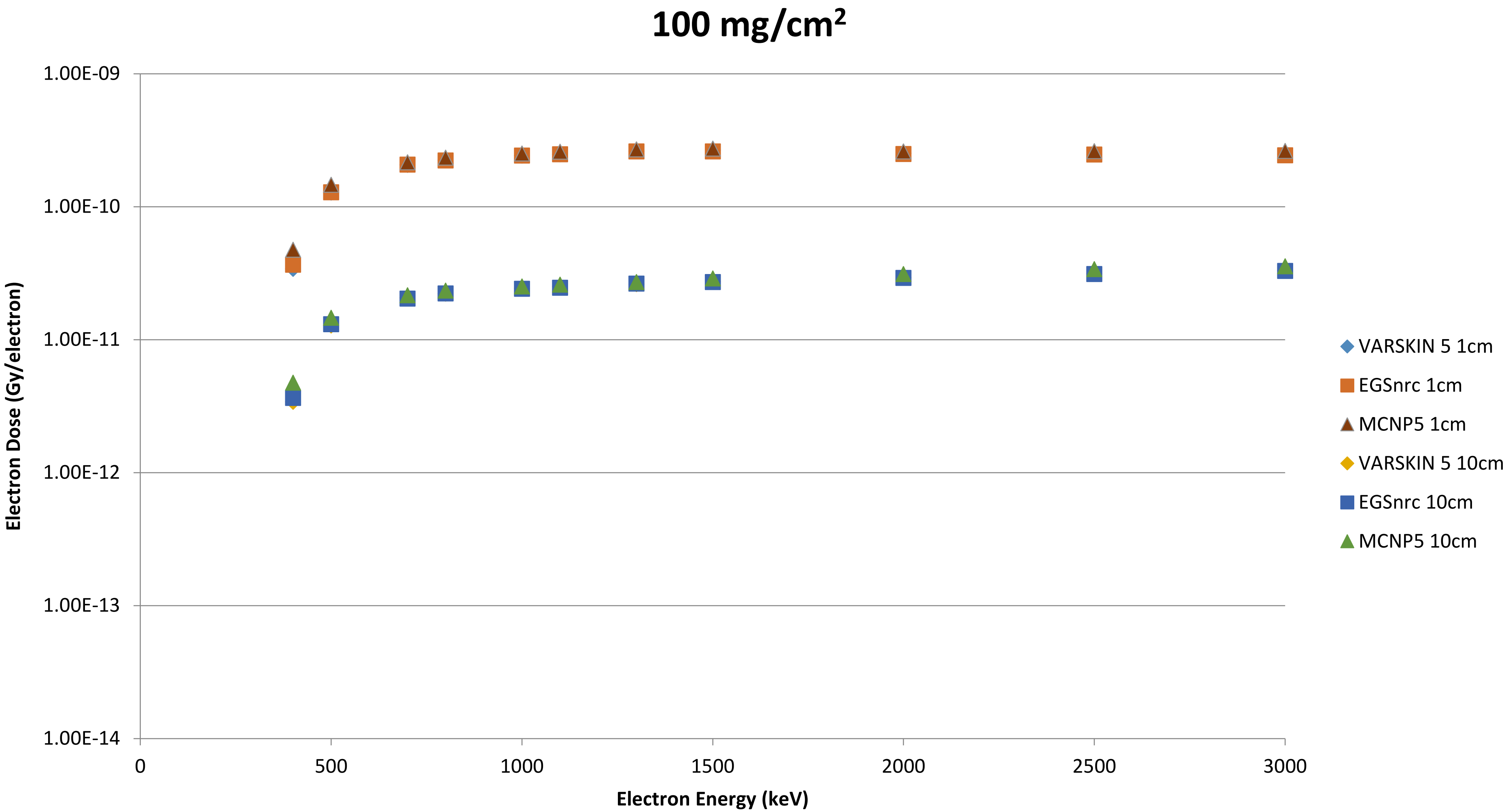

Dose Comparison for 32P Uranium Oxide Slabs
% Diff from EGSnrc
140%
120%
100%
80%
60%
40%
20%
0%
-20%
0.000
0.020
0.040
0.060
0.080
0.100
0.120
Normal Depth (cm)
Mangini
Cross-Durham (1.00)
Cross-Durham (1.60)


Overall Dose Comparison - 1 cm2
% Diff from EGSnrc
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+02
1.00E+03
1.50E+03
2.00E+03
Dose Rate (mGy hr-1 MBq-1)

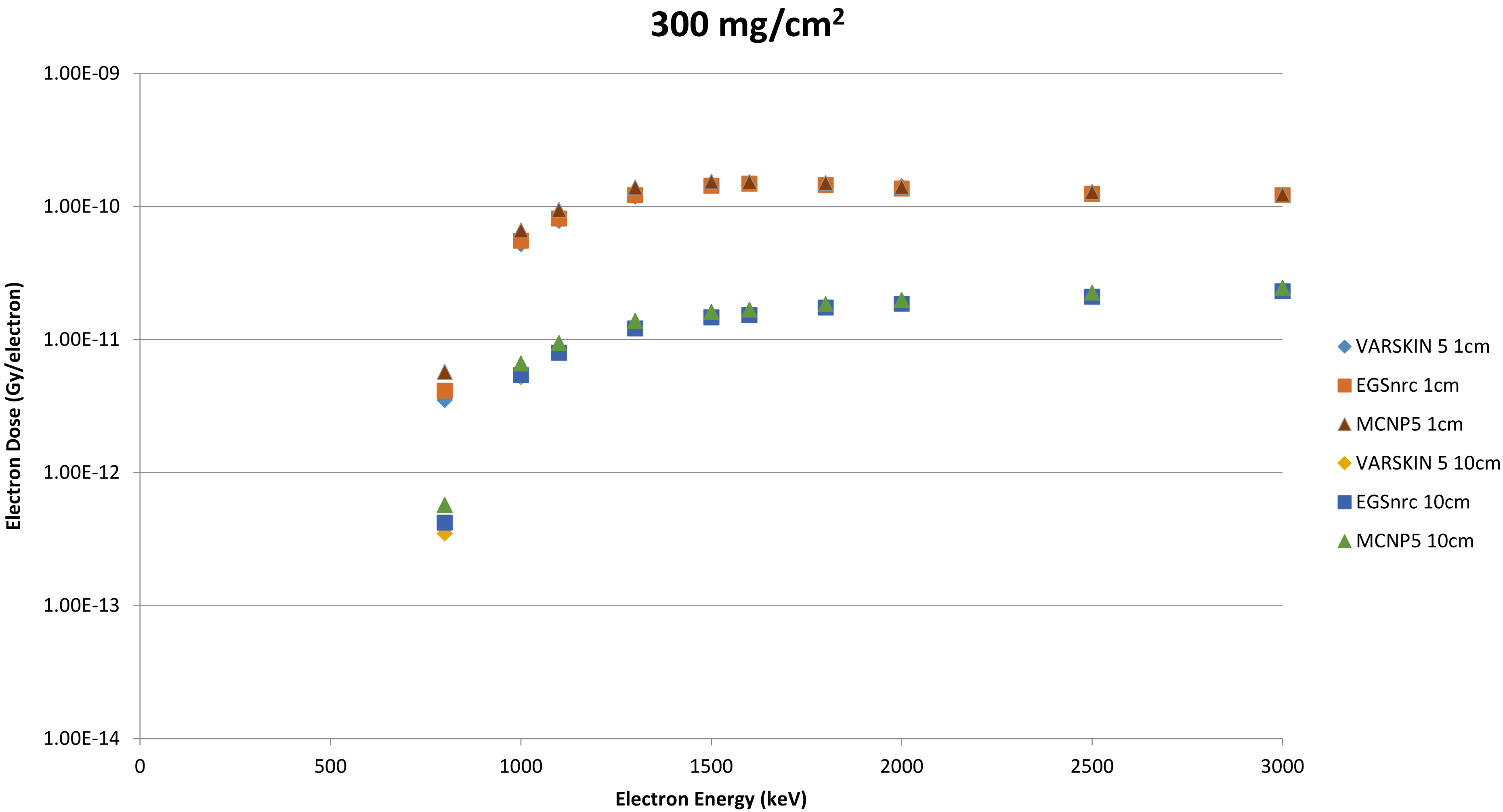

Overall Dose Comparison - 10 cm2
% Diff from EGSnrc
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
0.00E+00
5.00E+01
1.00E+02
1.50E+02
2.00E+02
Dose Rate (mGy hr-1 MBq-1)



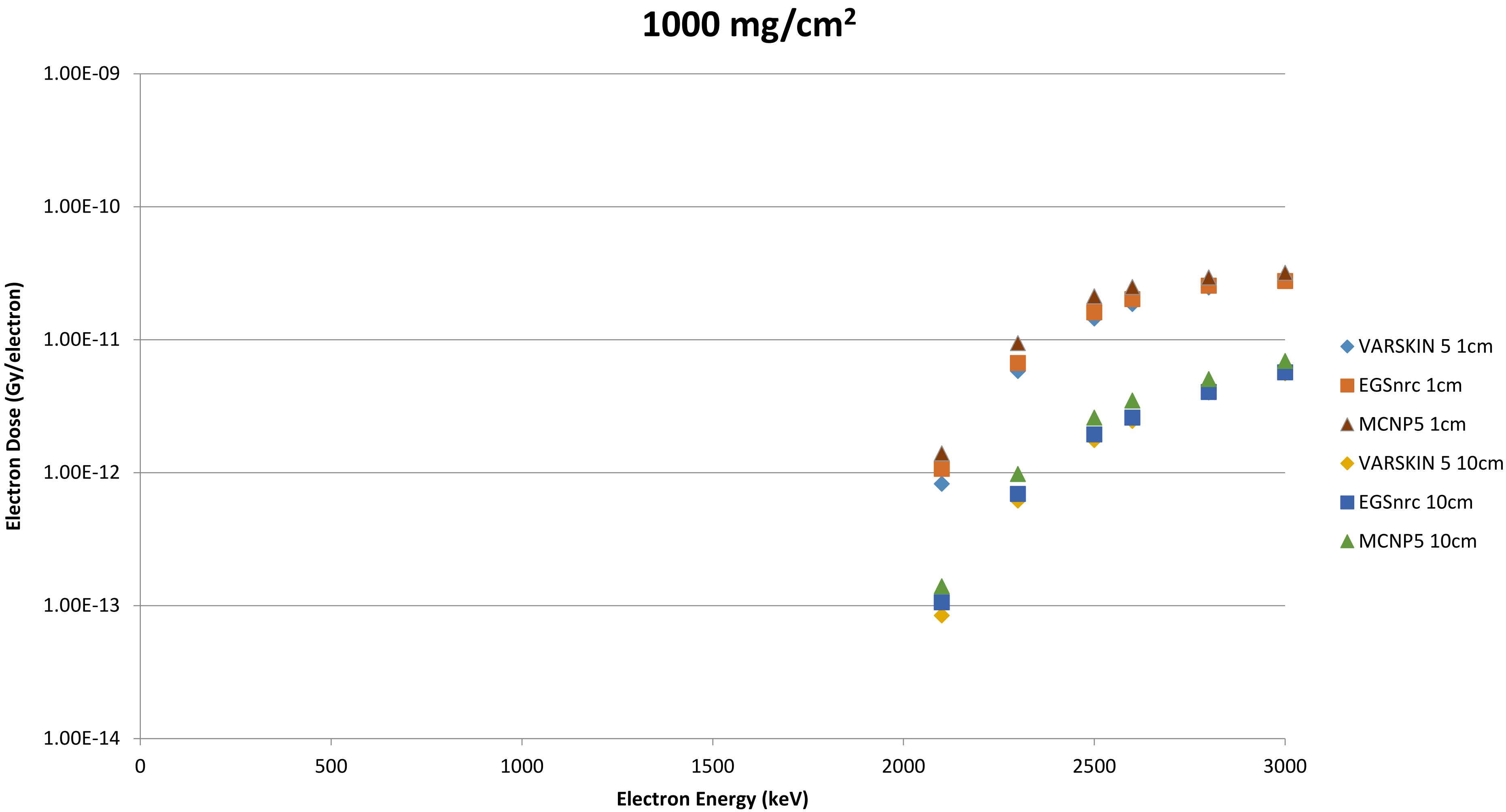
Point Source



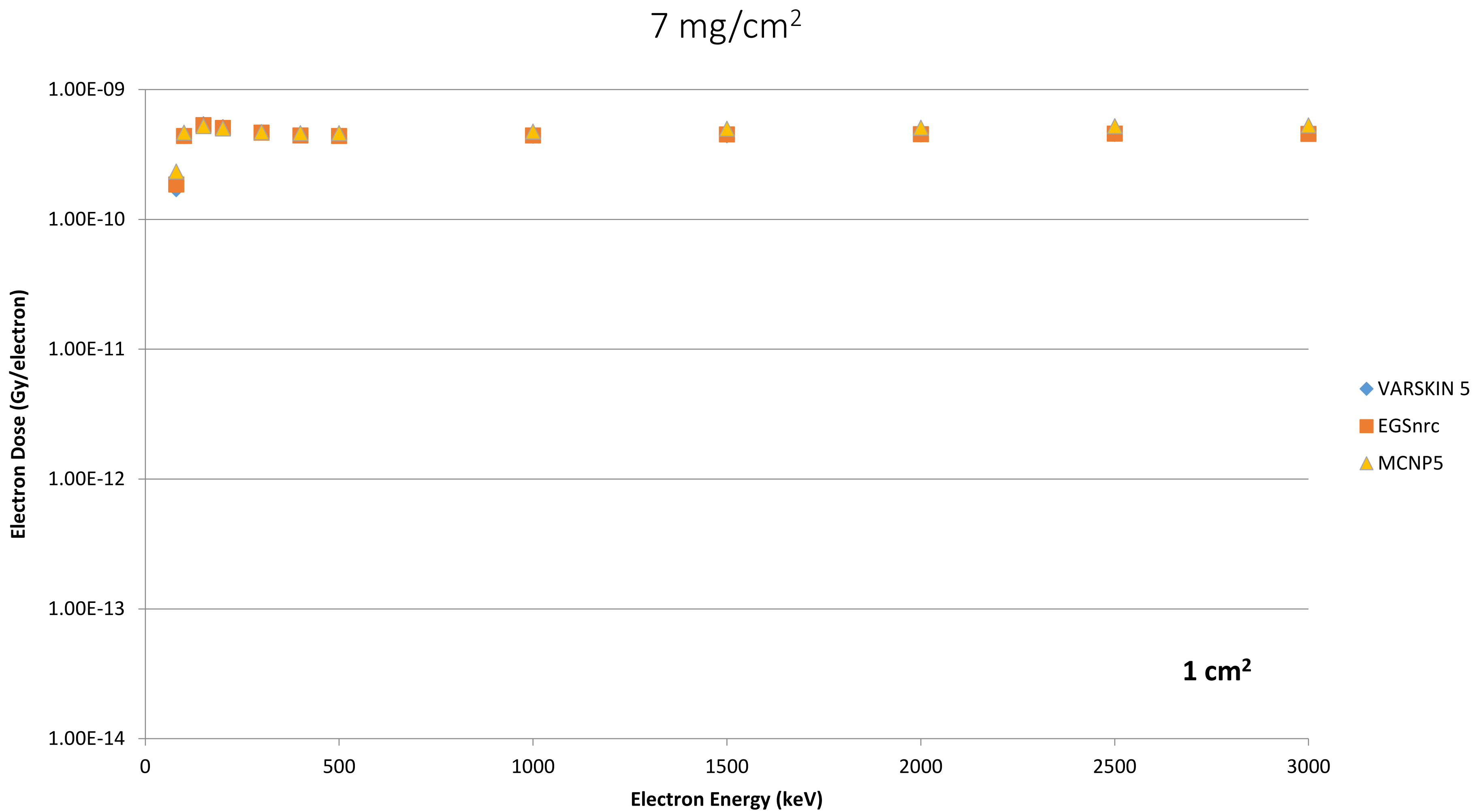
Point Source



Point Source

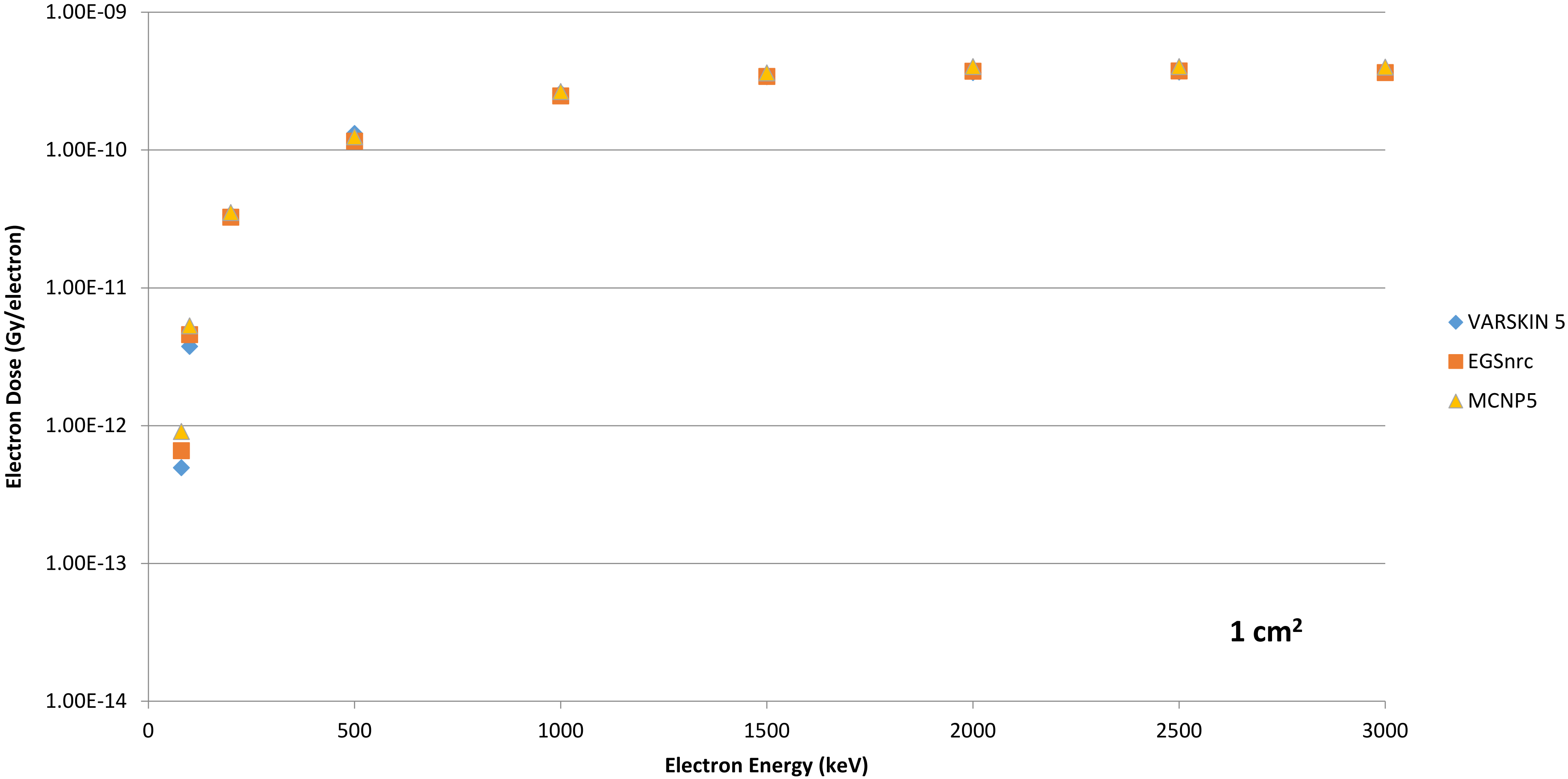


Point Source


7 mg/cm²
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
Electron Dose (Gy/electron)
0
500
1000
1500
2000
2500
3000
Electron Energy (keV)
VARSKIN 5
EGSnrc
MCNP5
1 cm²

Disk Source

7 mg/cm^2



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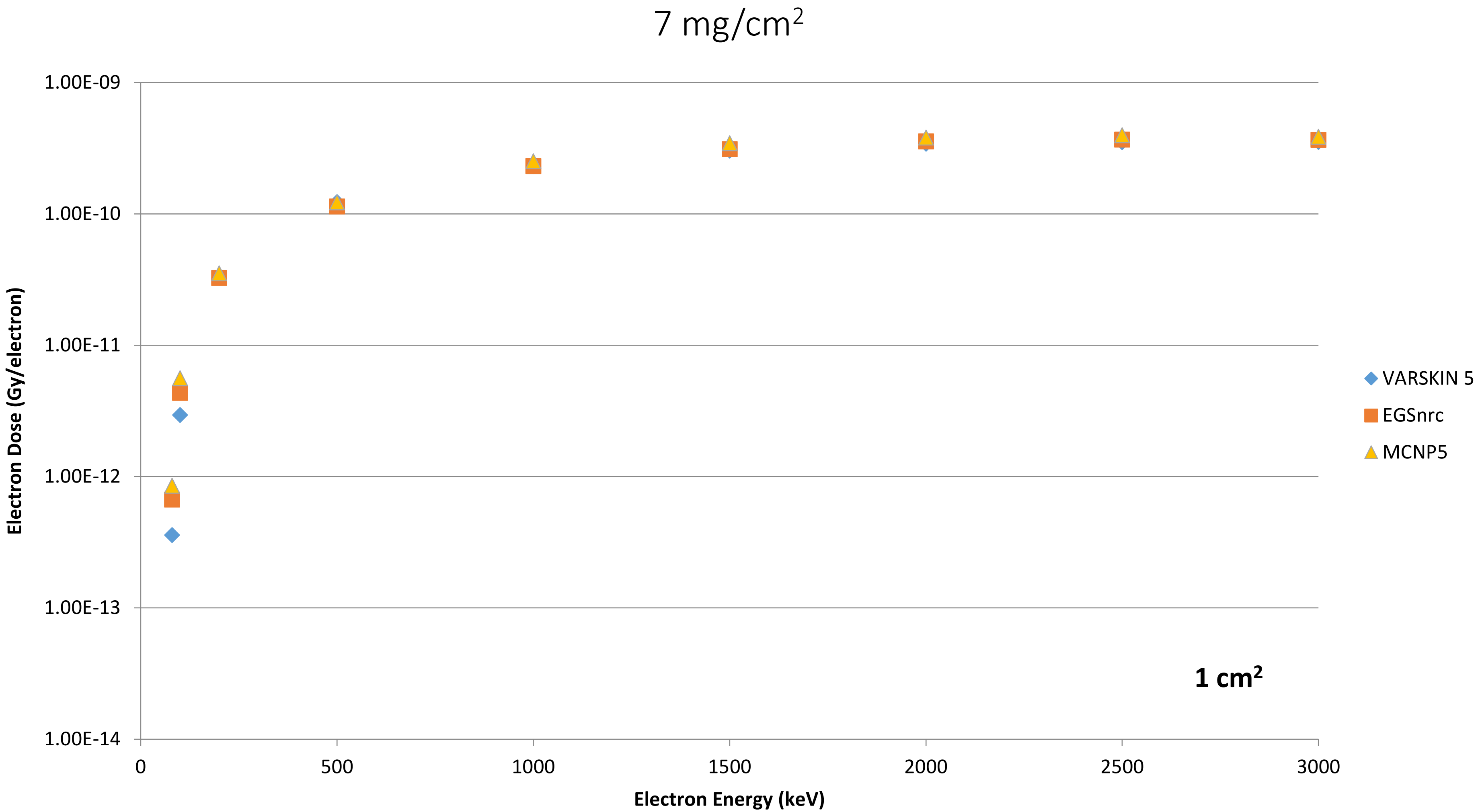
7 mg/cm2
1.00E-09
1.00E-10
1.00E-11
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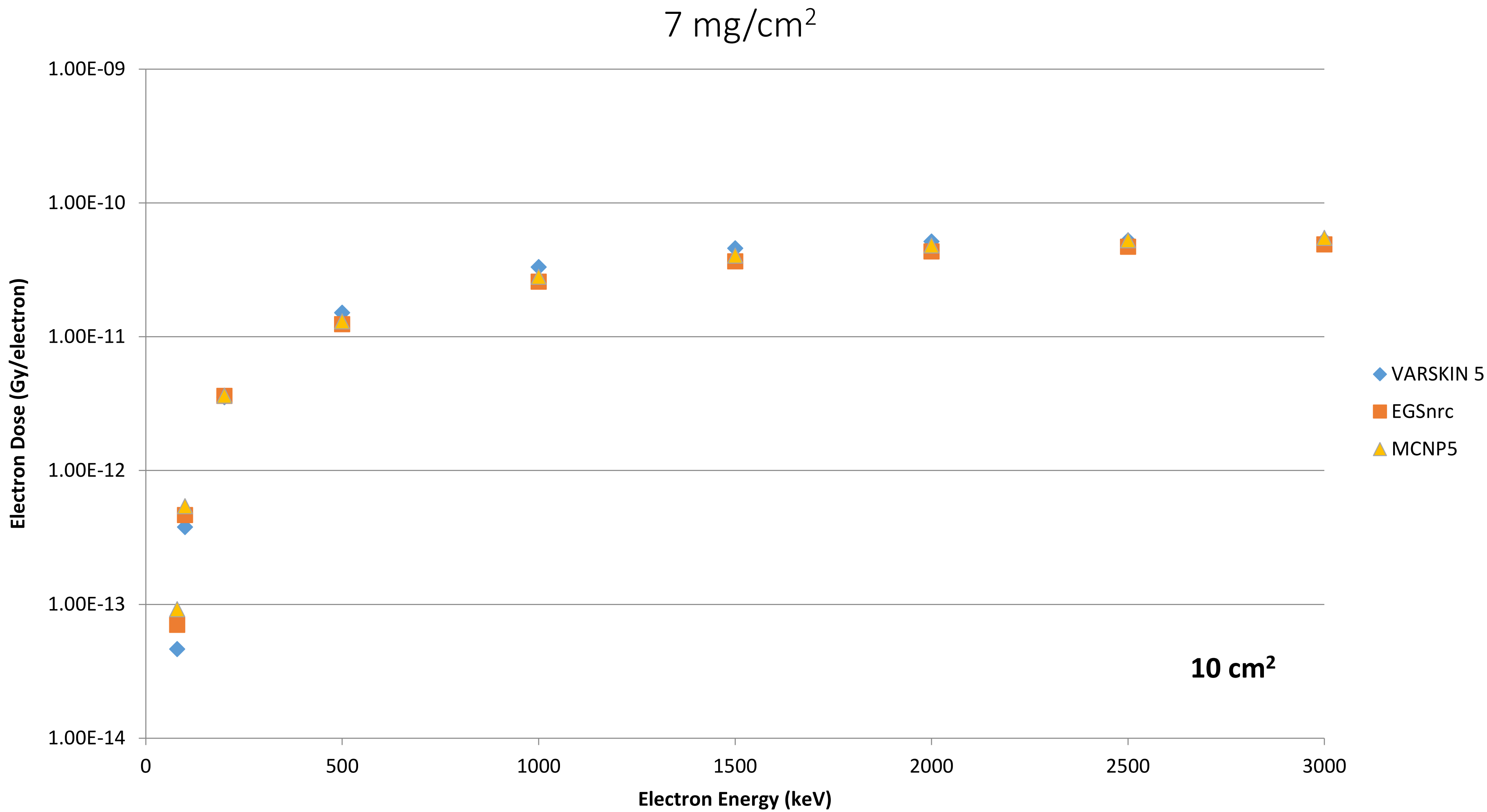
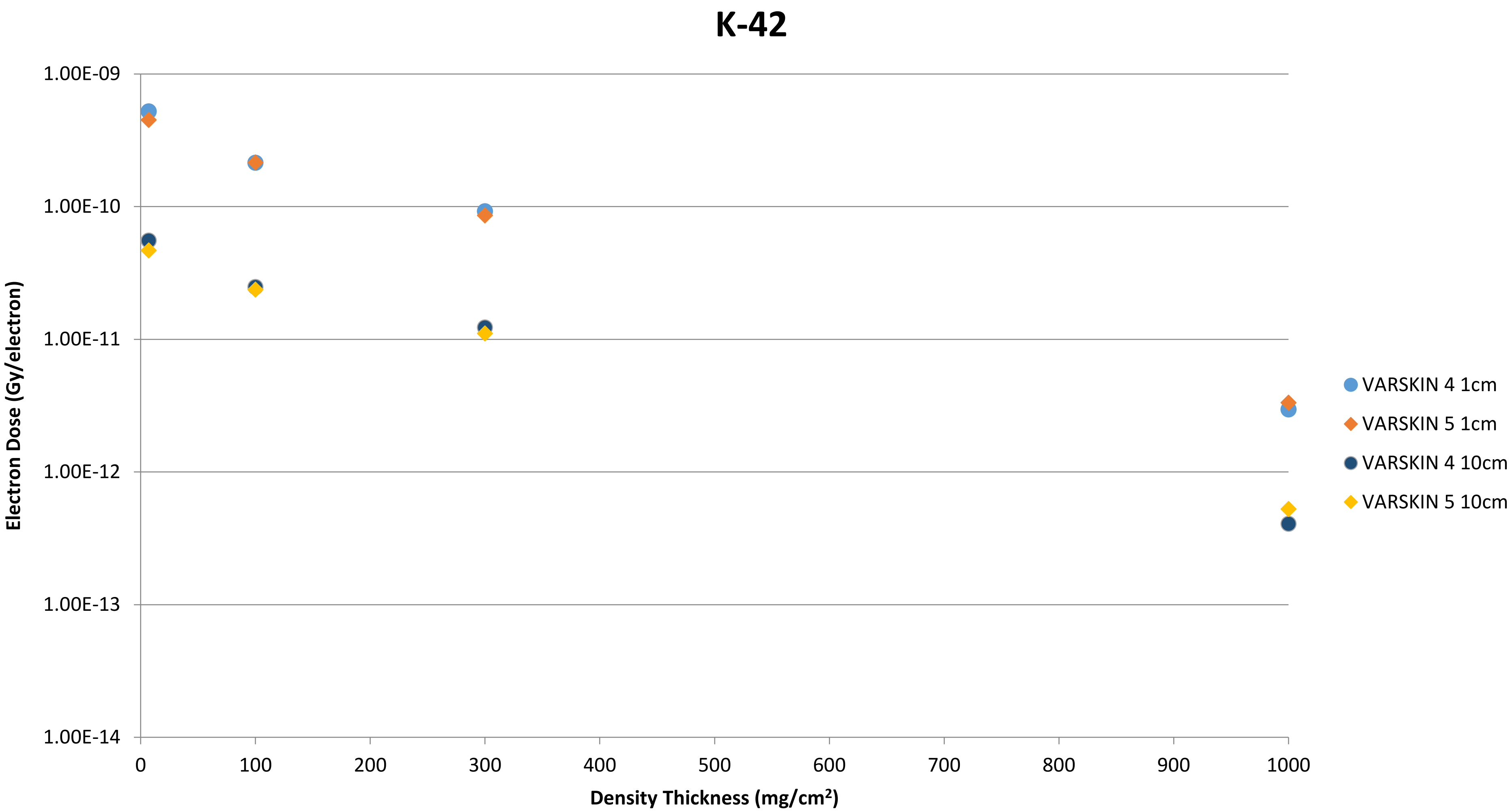
1.00E-14
Electron Dose (Gy/electron)
0
500
1000
1500
2000
2500
3000
Electron Energy (keV)
1 cm2
VARSKIN 5
EGSnrc
MCNP5

Slab Source



Cylindrical Source



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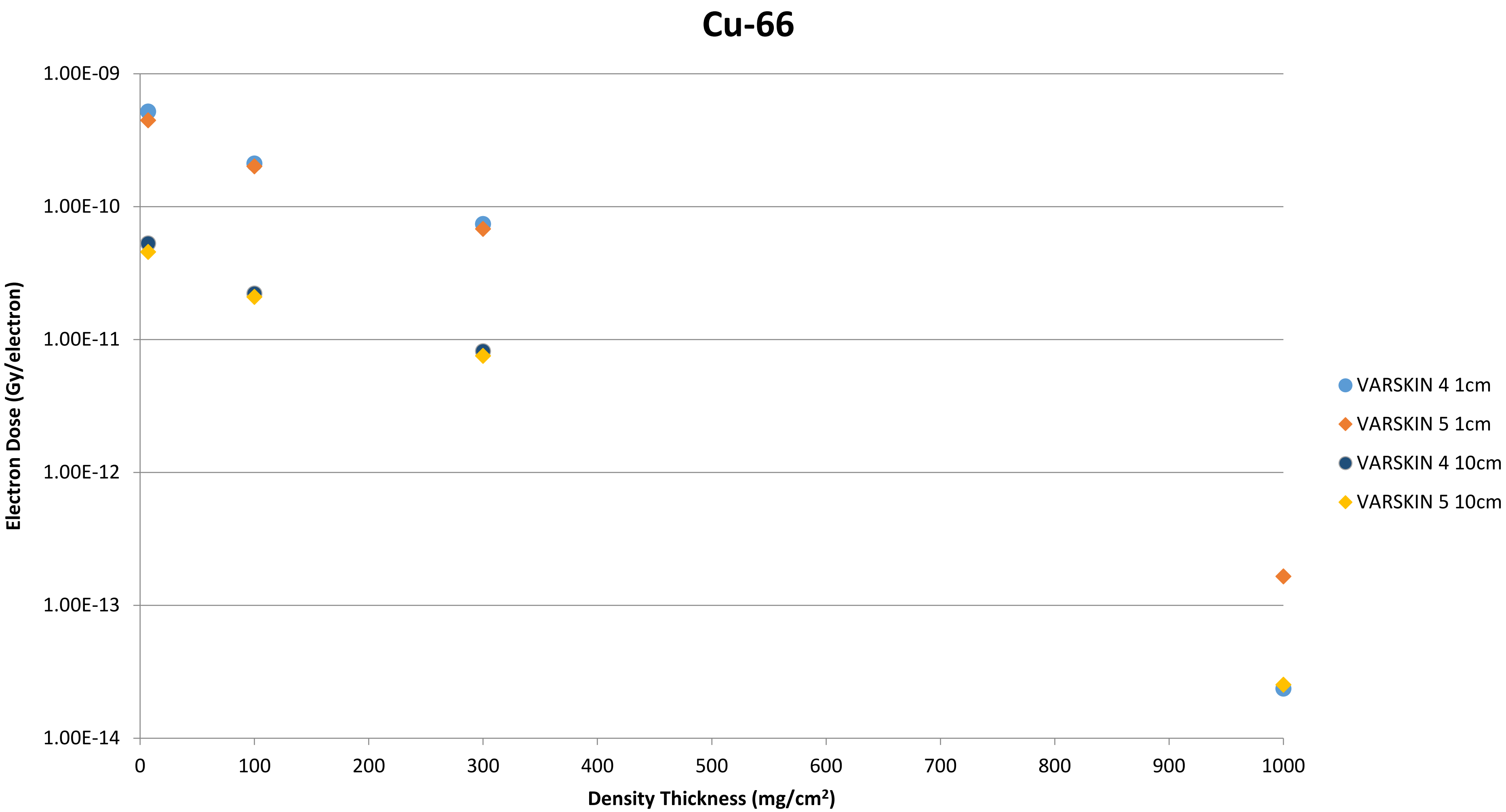

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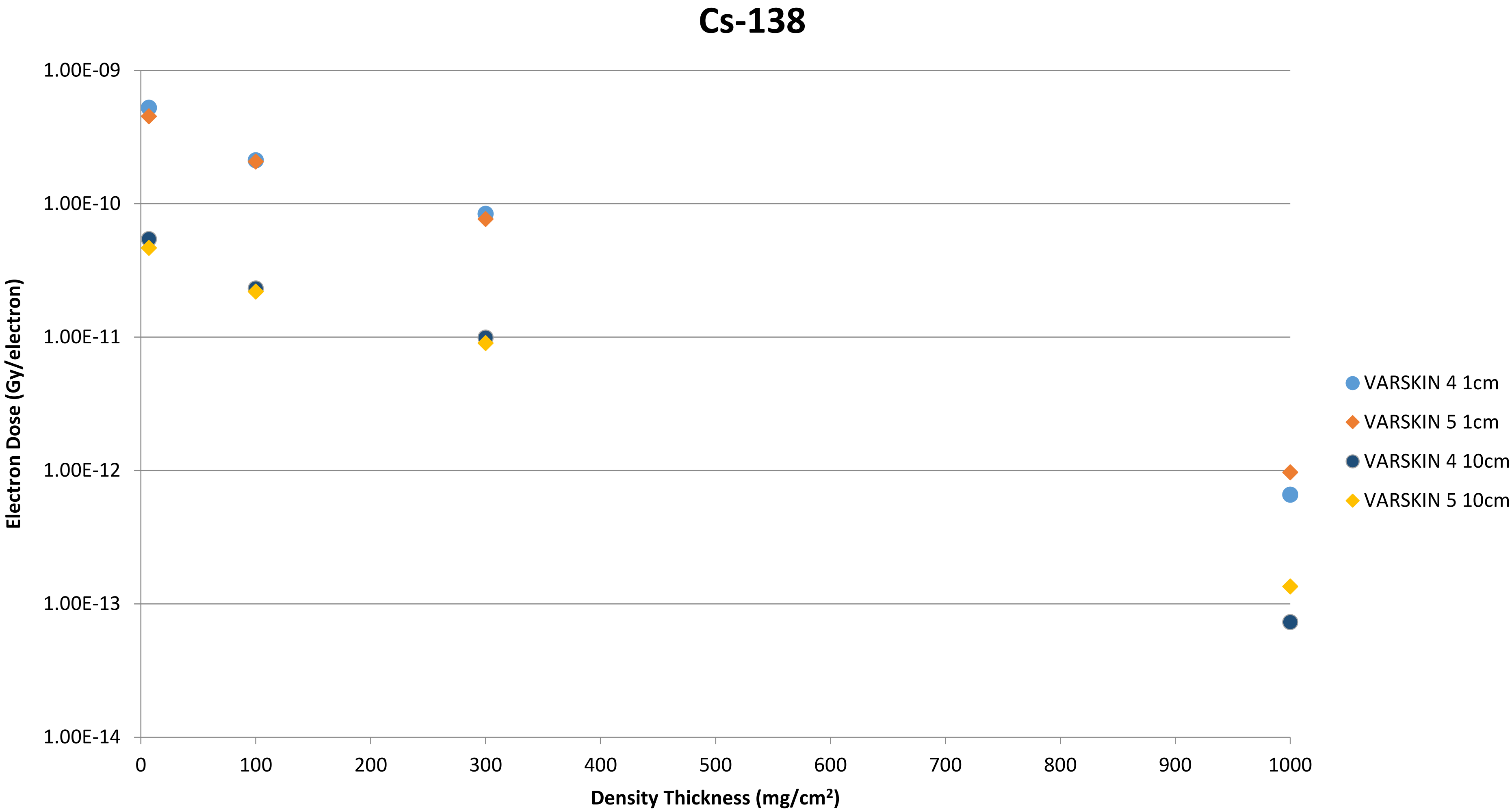


Point Source

Comparison of Electron (β) and Photon (γ) Shallow Dose Calculations from VARSKIN 3.1, 4, 5.3, and 6.0 for Various Cover Material Configurations

Nuclide	Air Gap (cm)	Cover Material	V3.1 β Dose (mGy)	V4 β Dose (mGy)	V5.3 β Dose (mGy)	V6.0 β Dose (mGy)	V3.1 γ Dose (mGy)	V4 γ Dose (mGy)	V5.3 γ Dose (mGy)	V6.0 γ Dose (mGy)
Co-60	0.2	M_1	1.96	1.96	2.17	2.17	0.571	0.292	0.290	0.292
Cs-137D	0.2	M_1	14.0	14.0	13.7	13.5	0.199	0.0969	0.0959	0.0917
Sr-90D	0.2	M_1	32.6	32.6	29.1	28.2	0	0	0	0
Co-60	0.2	$2M_1$	0	0	0.0789	0.0789	0.558	0.258	0.257	0.258
Cs-137D	0.2	$2M_1$	4.75	4.75	6.50	6.44	0.181	0.0842	0.0834	0.0797
Sr-90D	0.2	$2M_1$	20.7	20.7	19.5	19.1	0	0	0	0
Co-60	1.0	M_1	0.813	0.813	0.813	0.813	0.0797	0.0429	0.0427	0.0429
Cs-137D	1.0	M_1	2.79	2.79	2.59	2.53	0.0277	0.0129	0.0128	0.0122
Sr-90D	1.0	M_1	5.37	5.37	4.74		0	0	0	0
Co-60	1.0	$2M_1$	0	0	0.0409	0.0409	0.0836	0.0404	0.0402	0.0404
Cs-137D	1.0	$2M_1$	1.40	1.40	1.53	1.49	0.0270	0.0121	0.0121	0.0115
Sr-90D	1.0	$2M_1$	3.95	3.95	3.66	3.51	0	0	0	0
Co-60	1.0	$M_1 + M_2$	0	0	0.00838	0.00838	0.0876	0.0400	0.0400	0.0400
Cs-137D	1.0	$M_1 + M_2$	0.770	0.770	1.03	1.01	0.0271	0.0120	0.0120	0.0114
Sr-90D	1.0	$M_1 + M_2$	3.26	3.26	3.11	3.00	0	0	0	0
Co-60	5.0	$M_1 + M_2$	0	0	0.00045	0.00045	0.0045	0.0020	0.0025	0.0025
Cs-137D	5.0	$M_1 + M_2$	0.0384	0.0384	0.0521	0.0513	0.0013	0.0006	0.0006	0.0006
Sr-90D	5.0	$M_1 + M_2$	0.167	0.167	0.158	0.153	0	0	0	0

Cs-137D includes the progeny ^{137m}Ba; Sr-90D includes the progeny ^{90}Y

M_1 — Cover material = thickness of 0.37 mm, density of 0.70 g/cm^3

$2M_1$ — Cover material = thickness of 0.74 mm, density of 0.70 g/cm^3

M_2 — Cover material = thickness of 0.40 mm, density of 1.1 g/cm^3

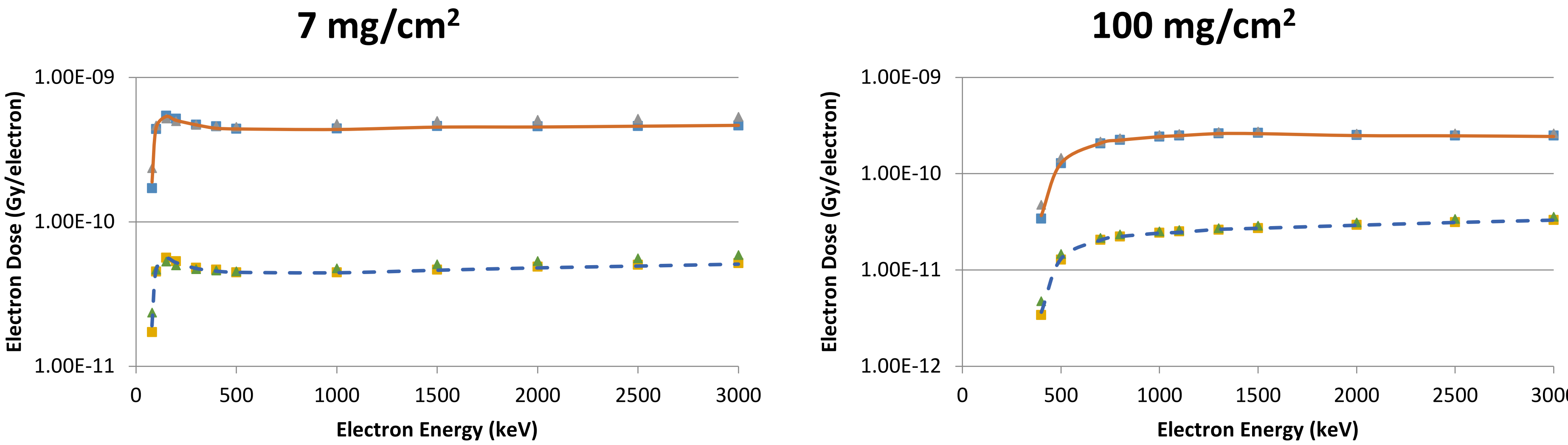
Electron point source on cover

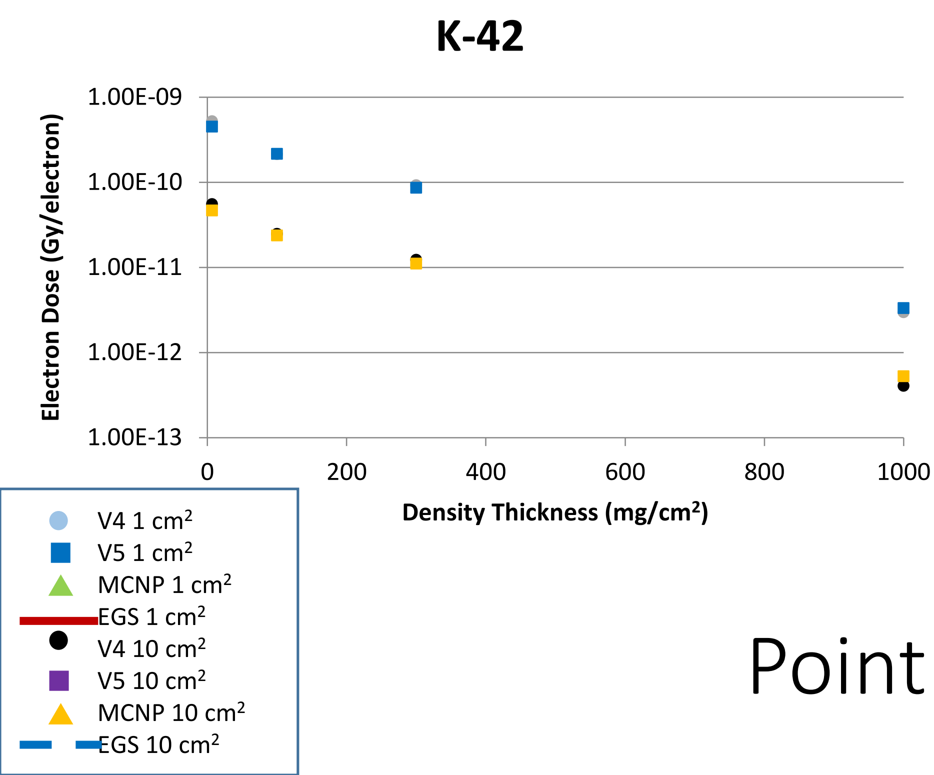
Beta Disk Source

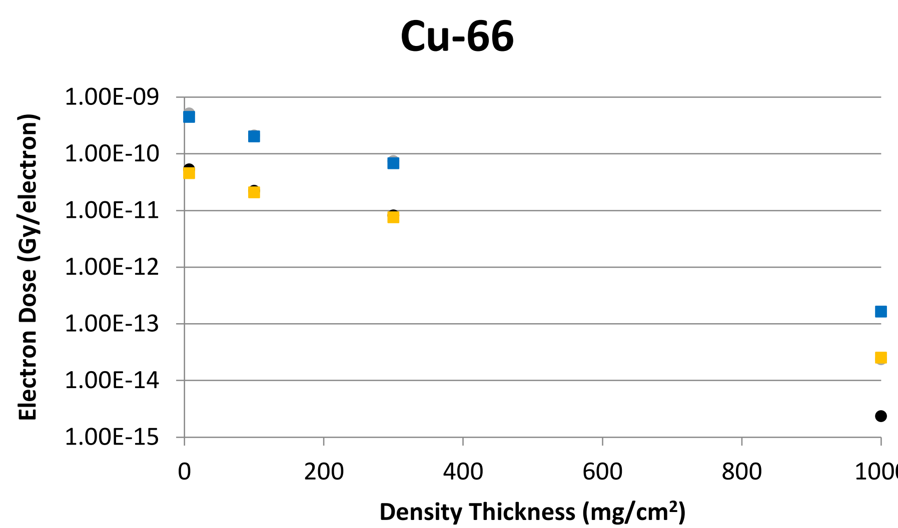
Method	C-14	P-32	I-131	Sr-90	Y-90
VARSKIN 4	11.2	66.3	52.5	54.7	68.2
VARSKIN 5	11.1	58.6	48.4	49.7	59.4
VARSKIN 6	11.1	58.7	48.4	49.7	59.7

Beta Disk Source

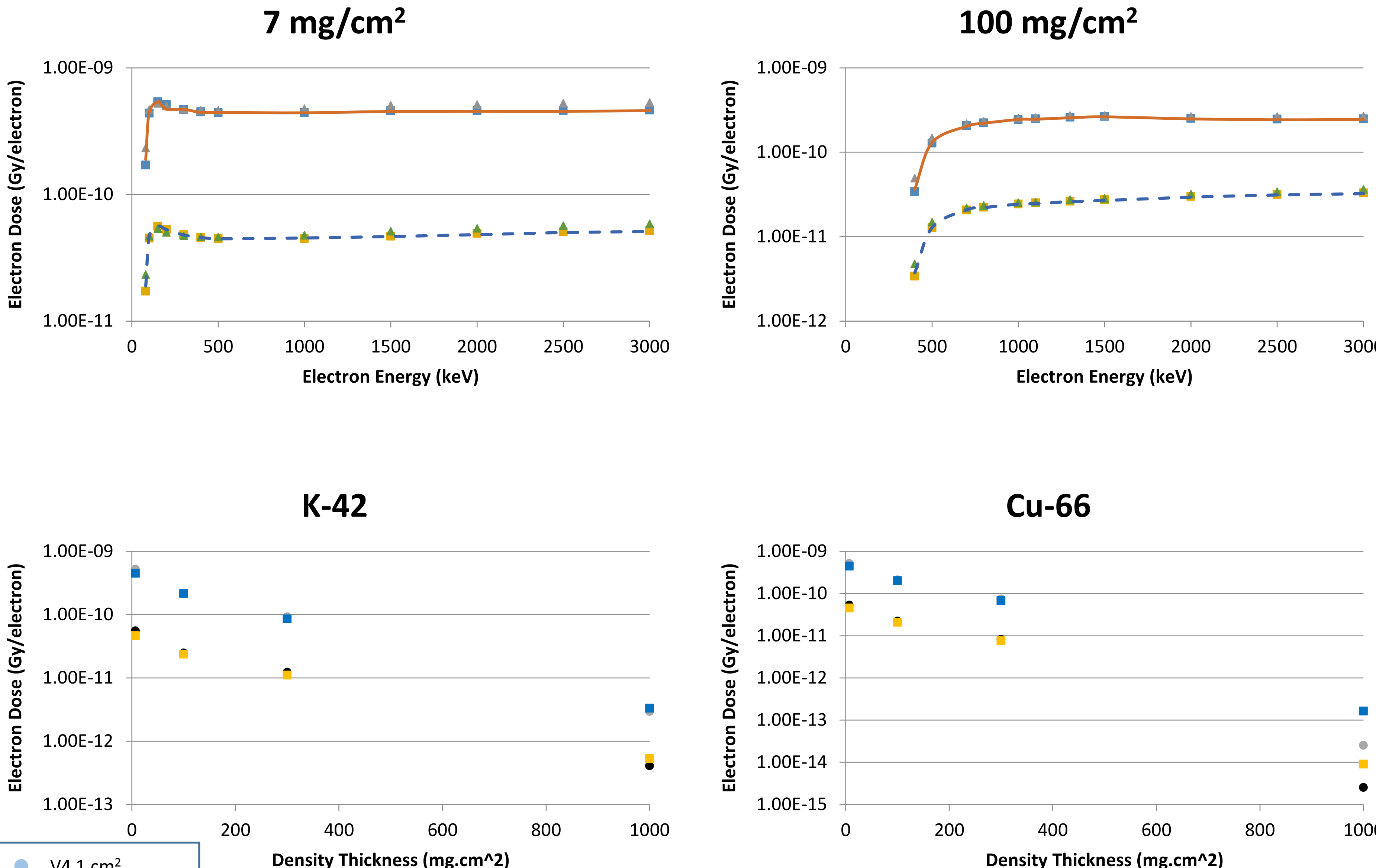
Method	4 mg/cm^2	7 mg/cm^2	10 mg/cm^2	40 mg/cm^2
VARSKIN 4	79.0	68.2	61.4	40.7
VARSKIN 5	65.7	59.4	55.3	38.2
VARSKIN 6	65.9	59.7	55.5	38.4

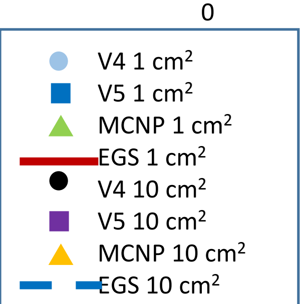




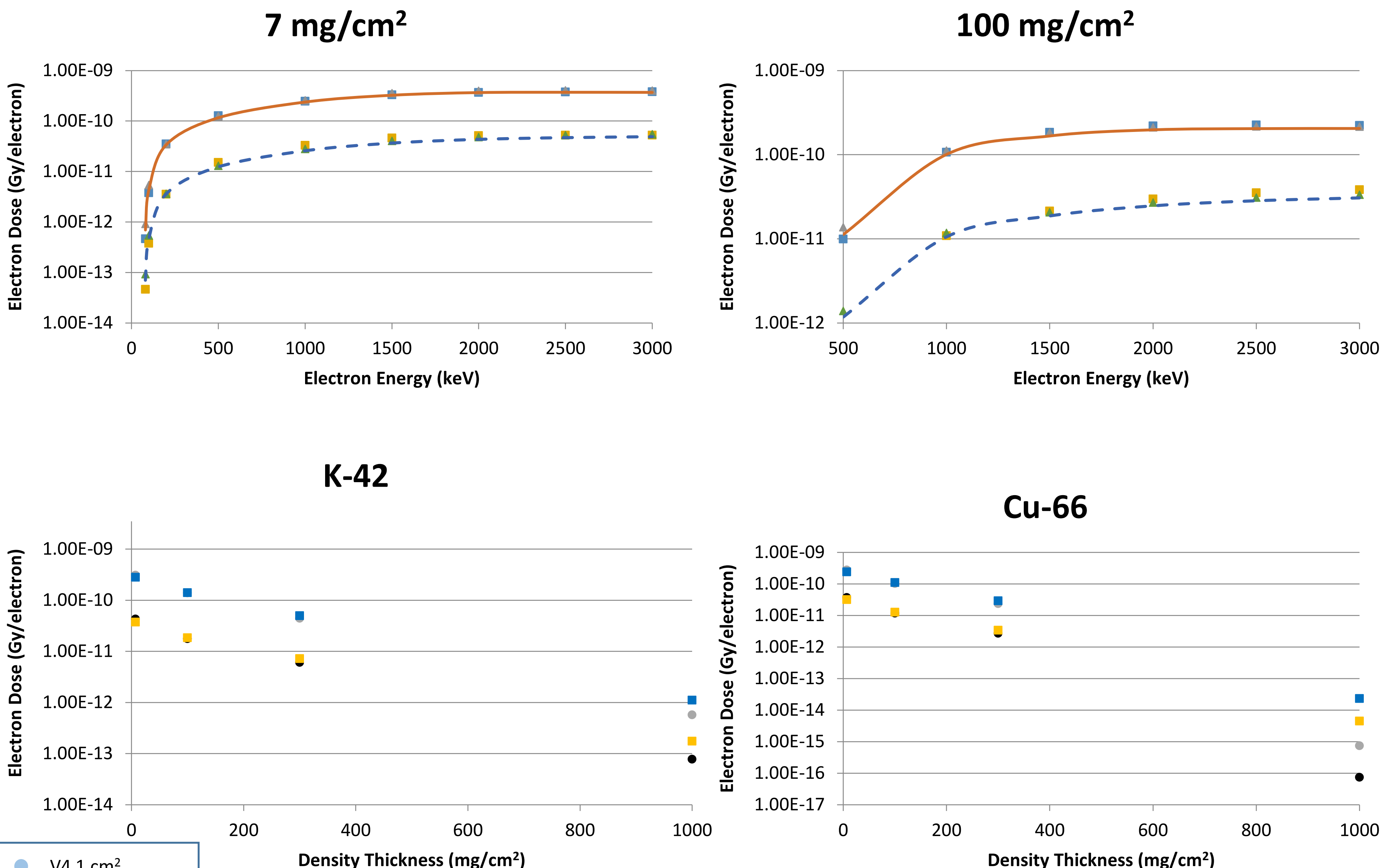


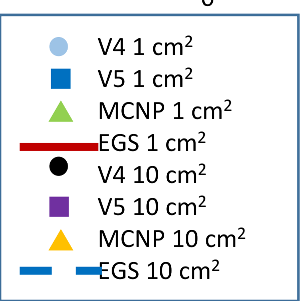
Point source - electron



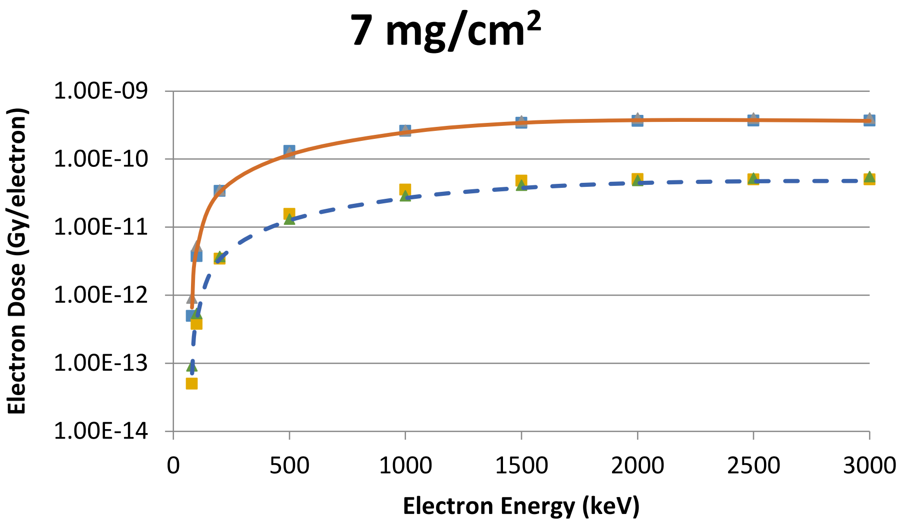


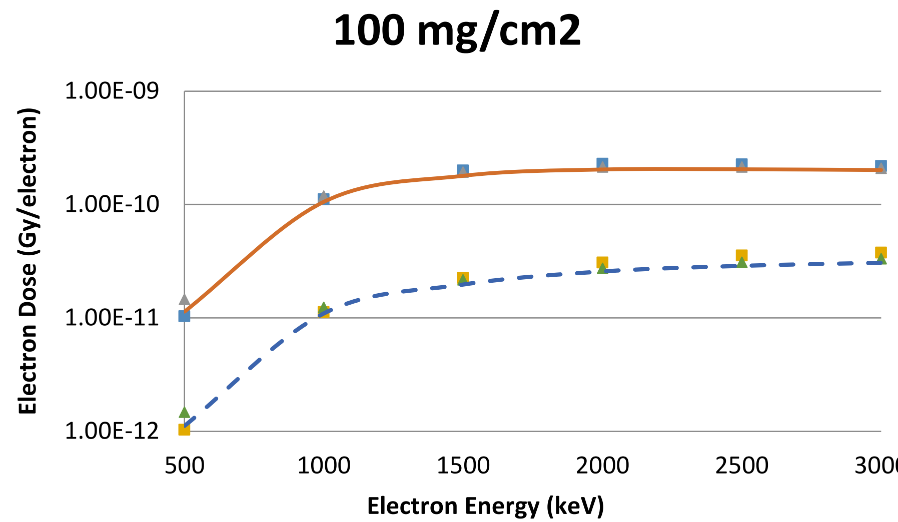
Disk source - electron

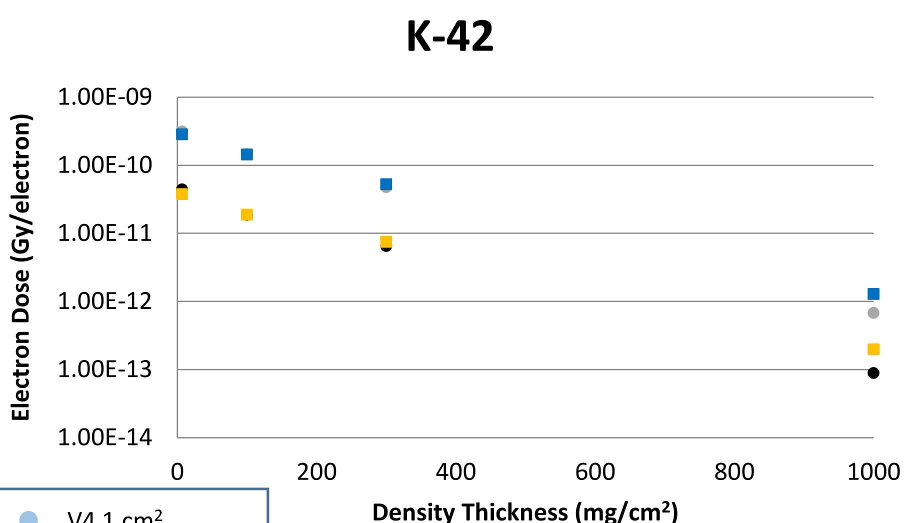


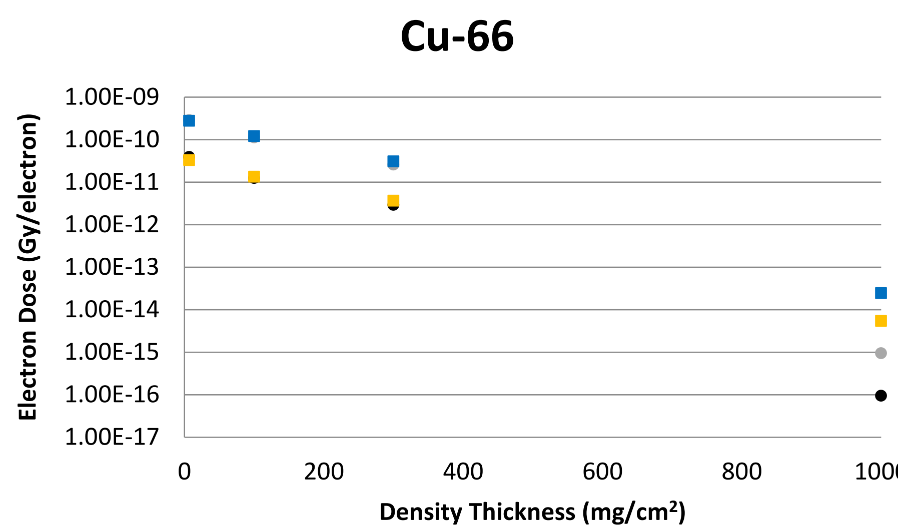


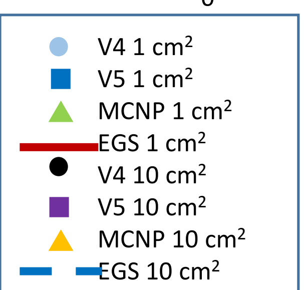
Cylindrical source - electron





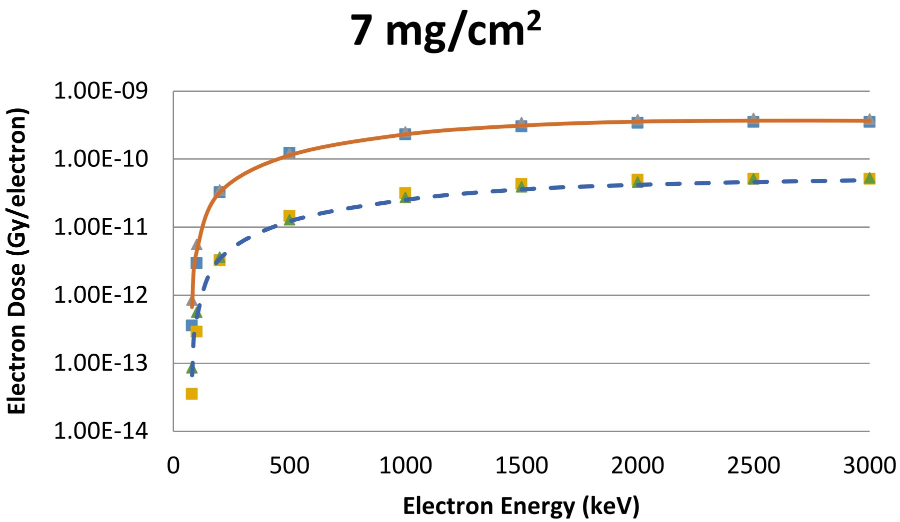


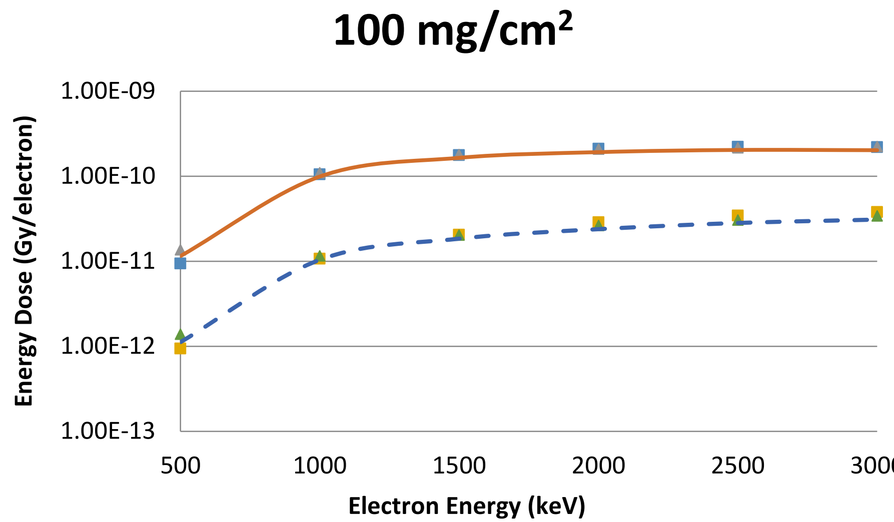


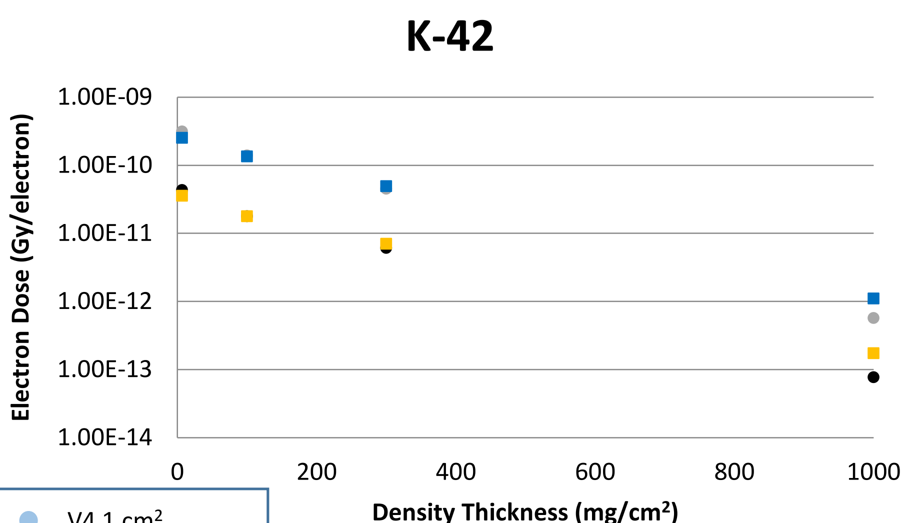


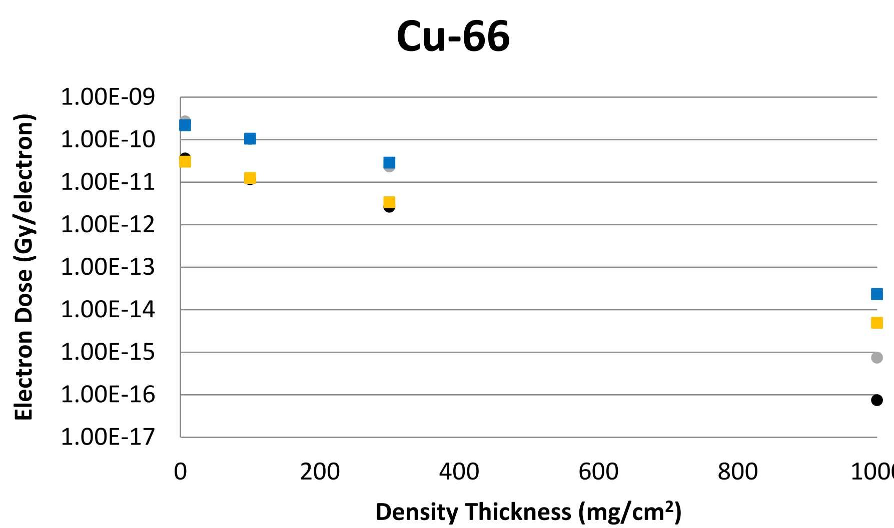
Spherical source - electron

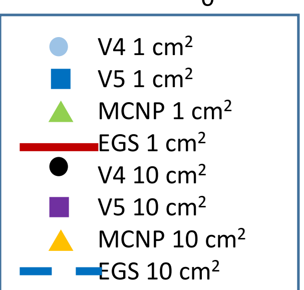
Slab source - electron











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

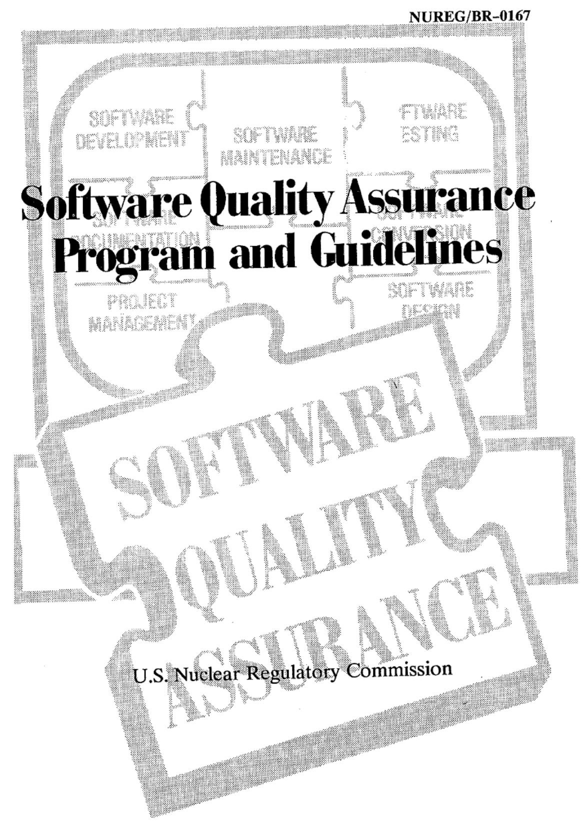
Software Acceptance Test Cases

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

	^{186}Re					^{60}Co			^{14}C	
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

VARSKIN 6

V&V Conclusions

Conclusions – Photon Dosimetry

- For the point and disk source geometries, MCNP and VARSKIN 5/6 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 5/6 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 5/6 and EGS
- VARSKIN 5/6 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

Limitations

VARSKIN Limitations

- Air Gap
  - Dose calculations involving air gaps greater than 20 cm have not been tested
  - It is likely that erroneous results may be obtained for large air gaps because the code does not account for multiple scattering events in air.
  - These events may result in the dose being delivered to an area greater than that determined using VARSKIN and can lead to inaccurate results.
  - VARSKIN is limited such that calculations for air gaps greater than 20 cm are not possible and a warning message is displayed.

VARSKIN Limitations

- Dose Averaging Area
  - VARSKIN has not been tested extensively for dose-averaging areas other than 1 and 10 cm^2.
  - However, because of the nature of the calculations performed by VARSKIN, there is no reason to believe that doses to areas less than or greater than 10 cm^2 will result in errors.
  - A quick and limited study of dose results as a function of averaging disk area shows that the code appears to be stable and linear in this regard from 0.01 to 100 cm^2.

VARSKIN Limitations

- Near complete source absorption
  - VARSKIN has been shown to be reliable for particulate sources that have dimensions less than eight times the X_{99} distance of the radionuclide in tissue.
  - The X_{99} distance is essentially 99 percent of the range of beta particles in tissue emitted by nuclides in the source term. When the physical size of the source approaches this value, VARSKIN may give unreliable results.
  - A user who wants to model sources larger than this limit may wish to begin with smaller sources and increase the source size gradually to ensure that spurious results are not being generated.
  - Modeling a source of this size is generally not necessary, however, as most of the source does not contribute to beta skin dose because of self-shielding.

VARSKIN Limitations

- DPK's and Scaling Model
  - DPK's have always underestimated dose at depths approaching the range of the electron.
  - Monte Carlo is the standard and DPK models begin to fail when energy and range straggling becomes more and more important at greater depths.
  - The effects of straggling are dominant at that part of the electron path.
  - We suspect that the scaling model is not a contributor to the discrepancies noted. In fact, the accuracy of the scaling model is highest towards the end of the electron path.
  - The interface between the source material and water is where the model has its largest deviations. This is likely not the cause, as dose at deeper depths will be dominated by electrons traversing very little of the source material (i.e., 0.25 X/X90); the model is extremely accurate in this case.

VARSKIN Limitations

- Photon Dosimetry
  - The photon dosimetry model assumes that all volume sources are composed of air. This assumption results in greater accuracy when modeling larger, less dense sources (e.g., a gas cloud).
  - However, when modeling volumetric sources of greater density, VARSKIN is optimized for small dimensions (less than about a millimeter).
  - This optimization is the result of a tradeoff between attenuation and charge particle buildup within the source itself.
  - The user should exercise care when modeling large-volume sources (i.e., if the source is large enough to impact self-absorption of photons).

VARSKIN Limitations

- Progeny Inclusion
  - When the user elects to include progeny ("D") in the parent-nuclide dose calculation, the SADD calculations are a bit more involved. For photons, the .photon file simply includes a longer list of photon energies/yields. For electrons, however, a single SADD file is created for all beta/electron emissions from the parent and all of its progeny.
  - This single SADD file contains all the same data, but now based on a combination of beta/electron emissions from all nuclides in the decay chain.
  - Combining the SADD file in this way simply results in a composite emitted electron probability distribution for the chain nuclides.
  - This being the case, dose calculations for parent/progeny electrons may be different from the same dose calculated by summing individual nuclides (rather than relying on the automatic progeny inclusions).
  - These deviations are shown to be the result of the difference in backscatter factors calculated individually, or for the combined decay data (because a singular backscatter factor is applied based on average electron energy rather than on the probability distribution).
  - One example in which this is most prominent is the difference between the sum of ^{90}Sr and its progeny ^{90}Y, versus the combined $^{90}Sr/^{90}Y$ calculation by selecting "D". The difference is generally less than 1% and no more than about 3%, varying by nuclide.

VARSKIN Limitations

- Progeny Inclusion

Dose from individual and combined parent/progeny in cylindrical geometry.

Nuclide Selection	Branching Ratio	Relative electron dose	Relative photon dose
Sr-90		2.12	-
Y-90	1.000	2.74	-
SUM		4.86	-
Sr-90D*		4.71	-
Discrepancy		3%	

*includes dose from Y-90 as calculated in VARSKIN 6.0 with progeny inclusion

Dose from individual and combined parent/progeny in cylindrical geometry.

Nuclide Selection	Branching Ratio	Relative Electron Dose	Relative Photon Dose
I-133		2.77	0.0295
Xe-133	0.971	0.794	0.0270
Xe-133m	0.029	2.33	0.0123
Xe-133	1.000	0.794	0.0107
SUM		3.63	0.0405
I-133D*		3.63	0.0402
Discrepancy		0%	0.9%

*includes dose from Xe-133 and Xe-133m as calculated in VARSKIN 6.0 with progeny inclusion

VARSKIN Limitations

- Progeny Inclusion