Current Performance of the VARSKIN 5.3 Electron Dosimetry Model

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Improvements

VARSKIN 5.3 allows the user to adjust the effective Z and density of the source material.

The SadCalc routine generates a precise account of average electron energy and range, better accounting for decay processes such as Internal Conversion.

A Monte Carlo-based dosimetry method better accounts for electron energy loss and backscatter.

Methods of Analysis:

Generally, comparisons between VARSKIN and other dosimetry tools (MCNP and other Monte Carlo codes) were drawn.

Several methods were employed to modify VARSKIN to perform a task it is not typically capable of doing (monoenergetic electrons and water/water interfaces)

Monoenergetic Electron Routine:

```
H-3         12.35y         1
        5 1.00000E+02 5.68276E-03
        Be-7        53.3d        4
        1 1.03400E+01 4.77605E-01
        6 8.04306E-06 4.77550E-01
        6 1.18019E-07 4.77605E-01
        2 1.63500E-02 5.47500E-05
        Be-10     1.6E6y         1
        5 1.00000E+02 2.52256E-01
        C-11      20.38m         4
        4 9.97600E+01 3.85535E-01
        3 1.99520E+02 5.11000E-01
        2 1.61920E-04 1.83300E-04
        2 8.09600E-05 1.83300E-04
```

```
H-3         12.35y         1
5 1.00000E+02 5.68276E-03
Be-7        53.3d          4
1 0.00000E+00 0.00000E-00
6 1.00000E+00 0.75000E-00
6 0.00000E+00 0.00000E-00
2 0.00000E+00 0.00000E-00
Be-10     1.6E6y           1
5 1.00000E+02 2.52256E-01
C-11      20.38m           4
4 9.97600E+01 3.85535E-01
3 1.99520E+02 5.11000E-01
2 1.61920E-04 1.83300E-04
2 8.09600E-05 1.83300E-04
```

Water/Water Interface Simulation:

Enter the .rad file (located within the dat folder).

Find the final 160 lines of the nuclides of interest.

These lines are backscatter factors, setting them to "1" removes consideration of half-space (air/water interface) and assumes a water/water interface.

Comparisons to Faw (1992):

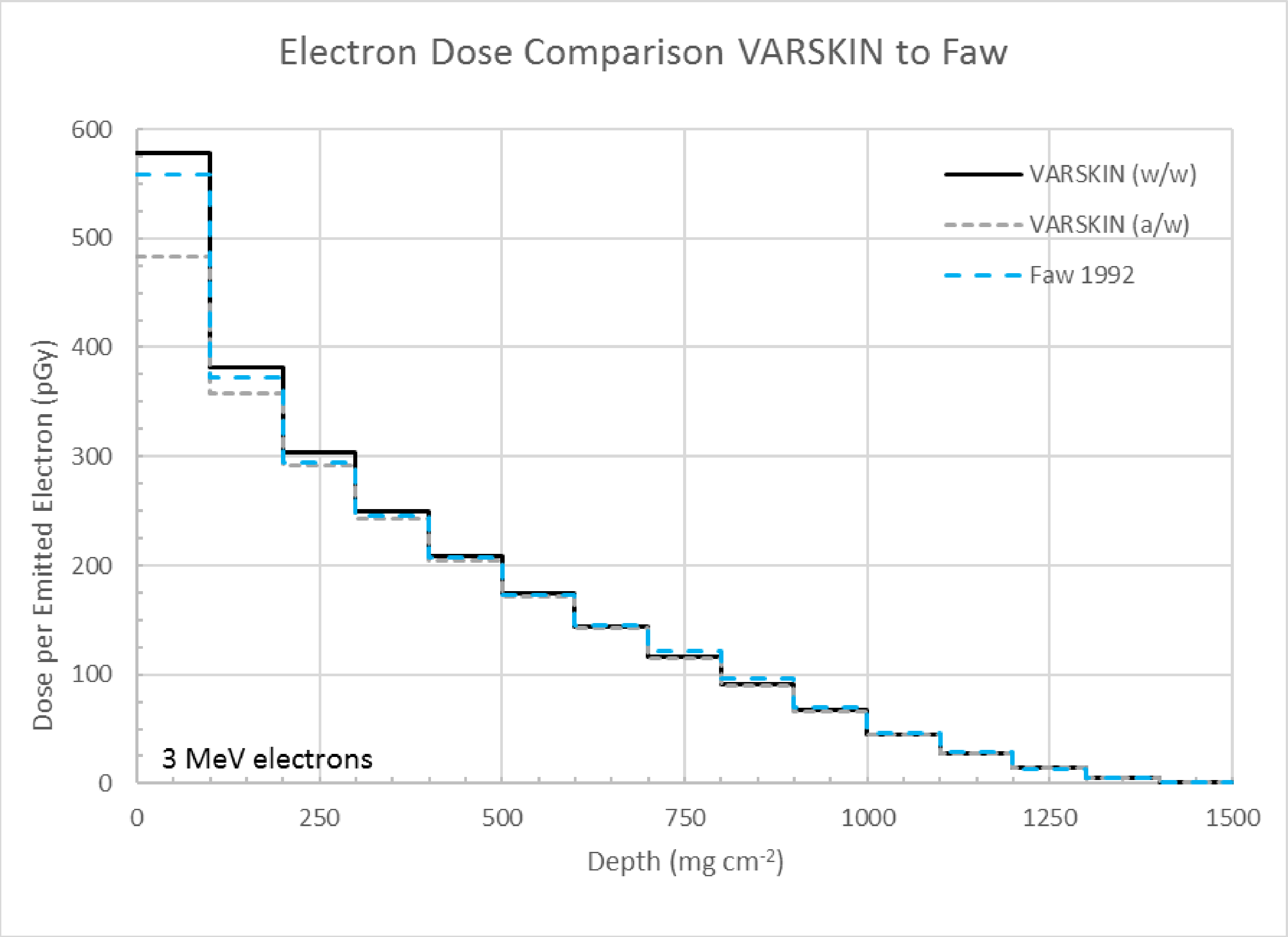
Faw [1992] utilized two Monte Carlo based codes, CYLTRON and TIGER, to calculate dose to skin for isotropic plane sources with mono-energetic electrons of .25 and 3.0 MeV.

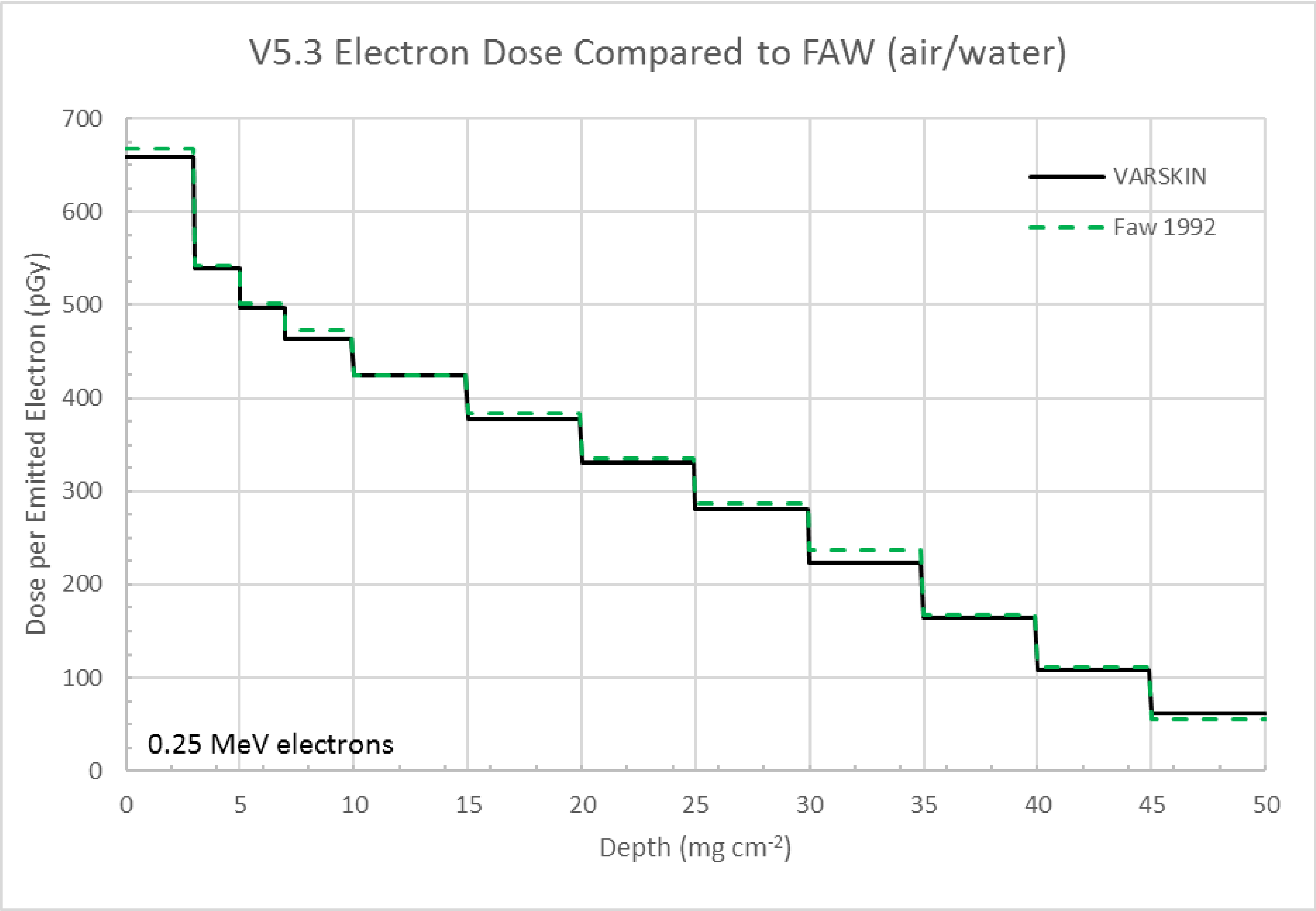
Dose is analyzed for two situations, with and without backscatter. This is interpreted as a water/water and air/water interface, respectively.

This is applied to two scenarios:

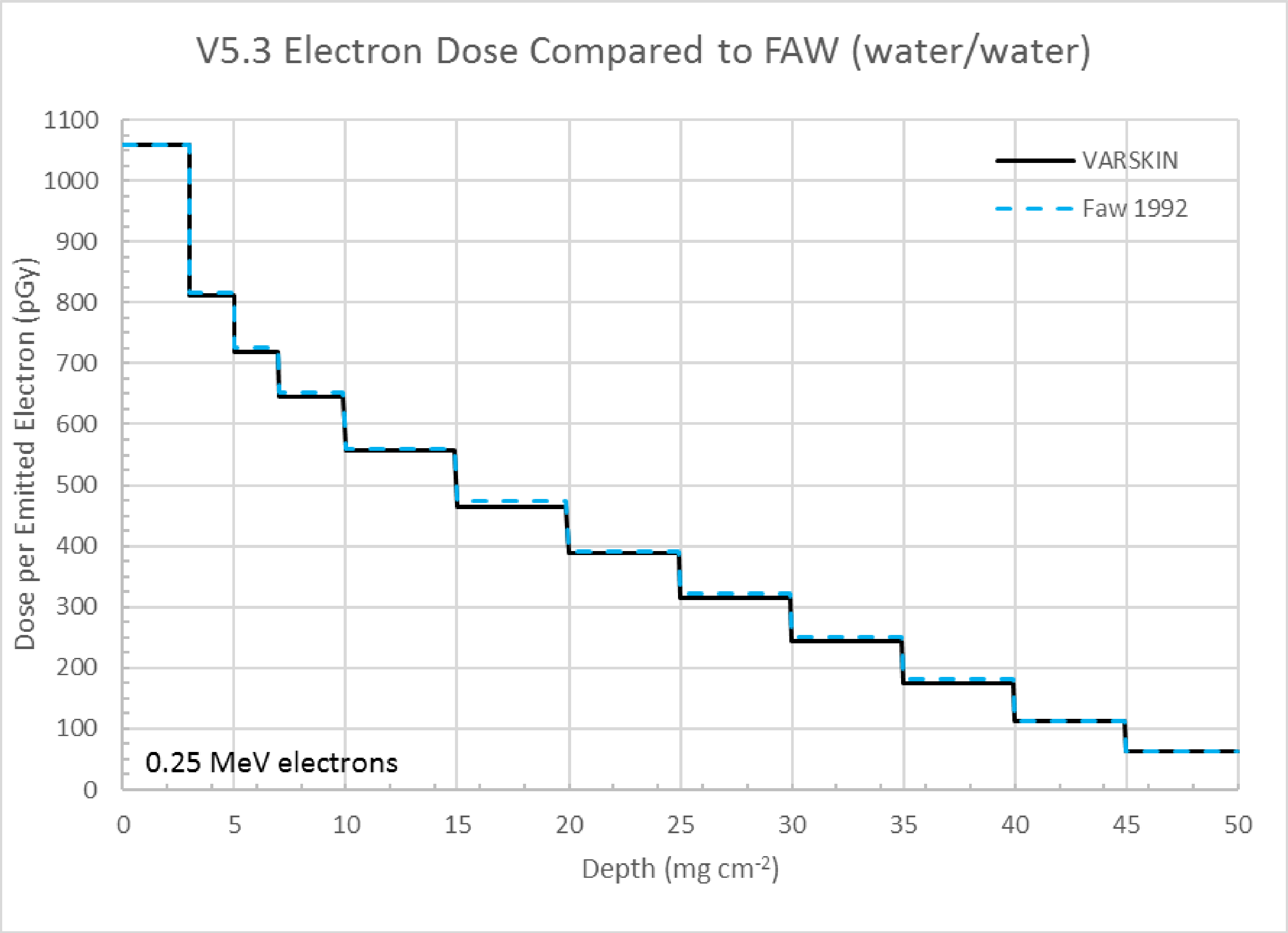
- Dose per Emitted Electron vs Depth at a specified electron energy [.25 or 3 MeV]
- Dose per Emitted Electron vs Electron Energy (MeV) at a specified depth [3-5, 5-10, 30-50 mg cm^{-2}]

VARSKIN and Faw's data are in good agreement.

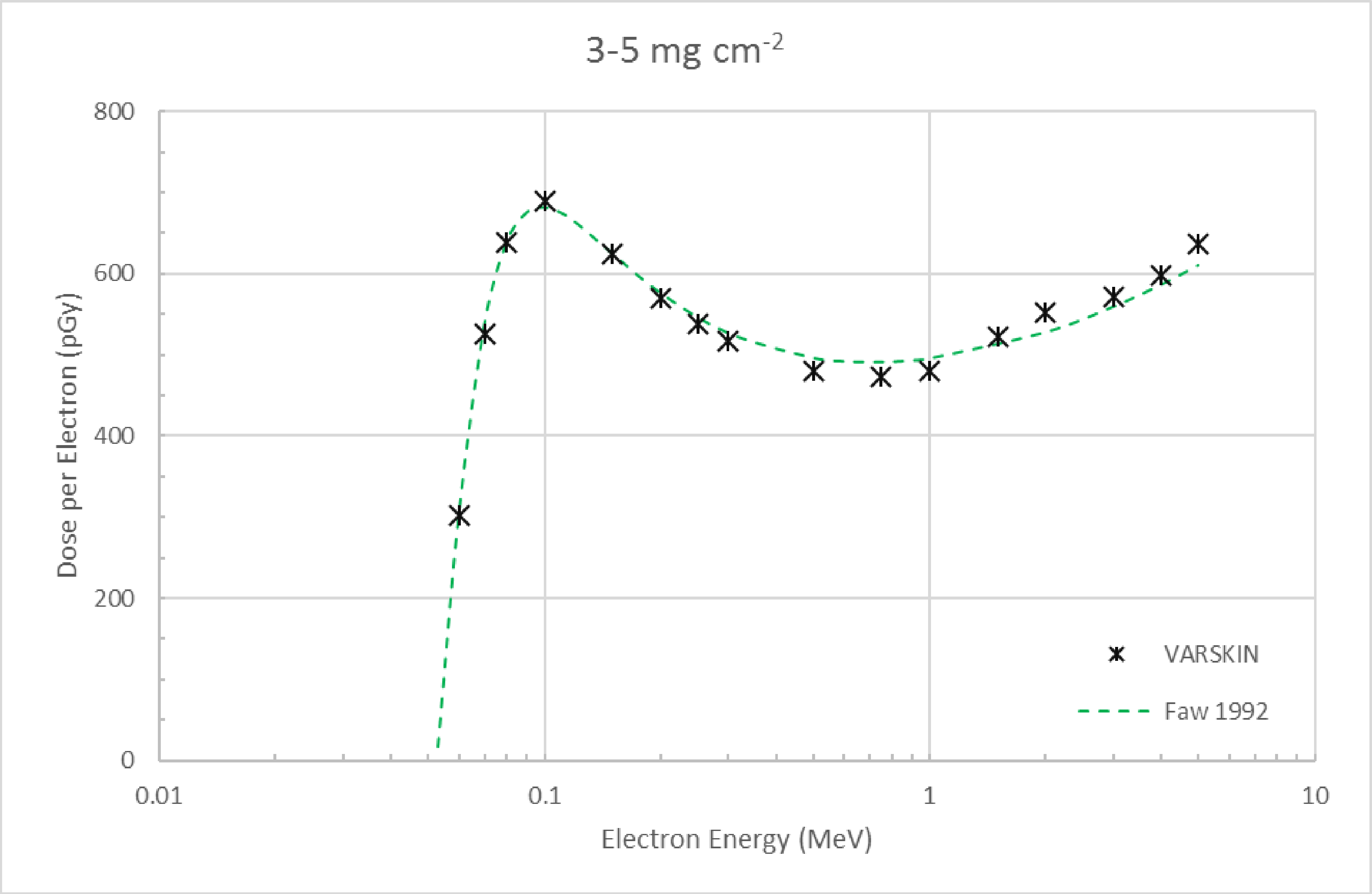

Electron Dose Comparison VARSKIN to Faw
VARSKIN (w/w)
VARSKIN (a/w)
Faw 1992
3 MeV electrons
Dose per Emitted Electron (pGy)
Depth (mg cm-2)
0
100
200
300
400
500
600
0
250
500
750
1000
1250
1500



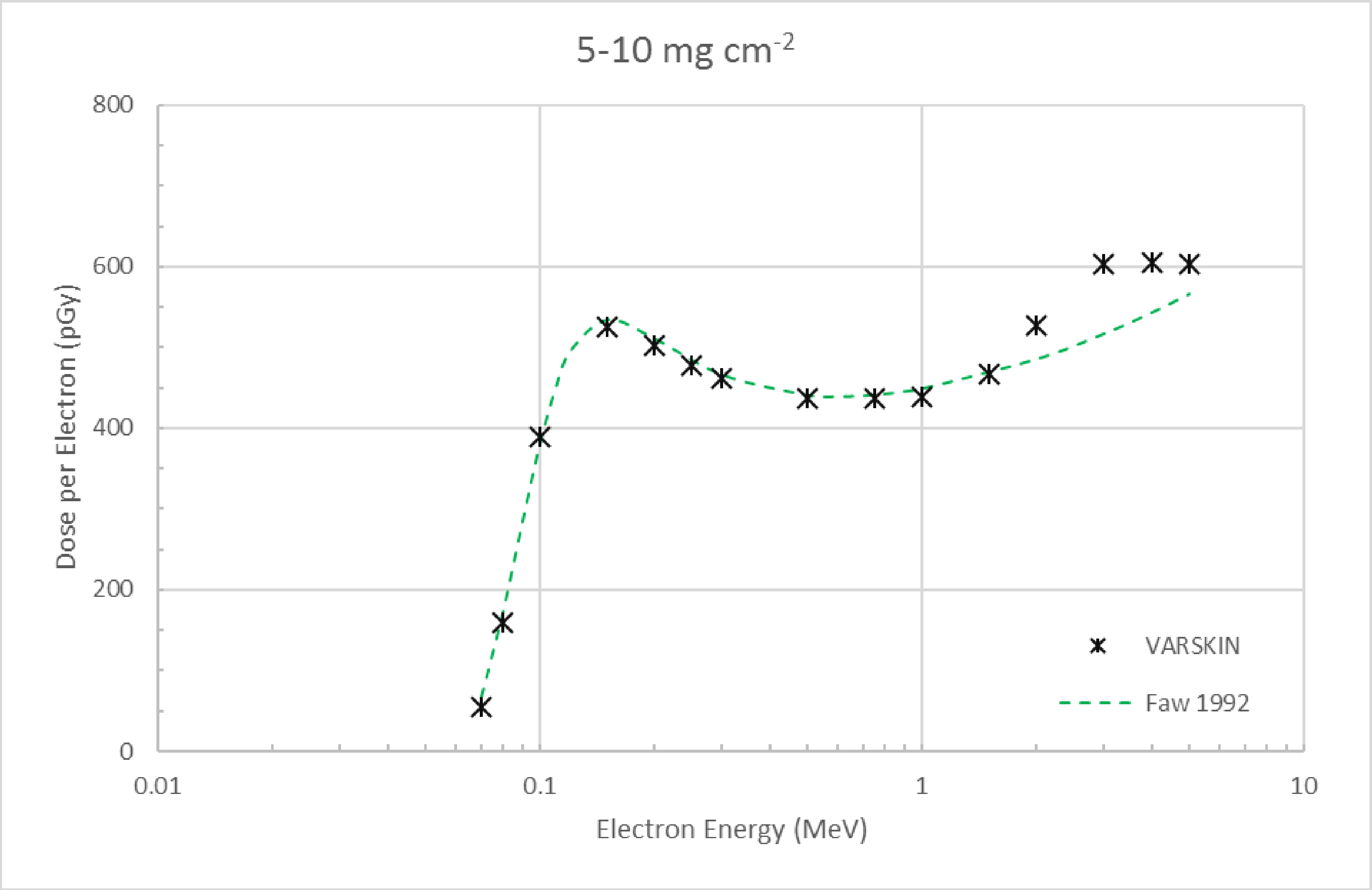
V5.3 Electron Dose Compared to FAW (air/water)
Dose per Emitted Electron (pGy)
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
50
Depth (mg cm-2)
VARSKIN
Faw 1992
0.25 MeV electrons



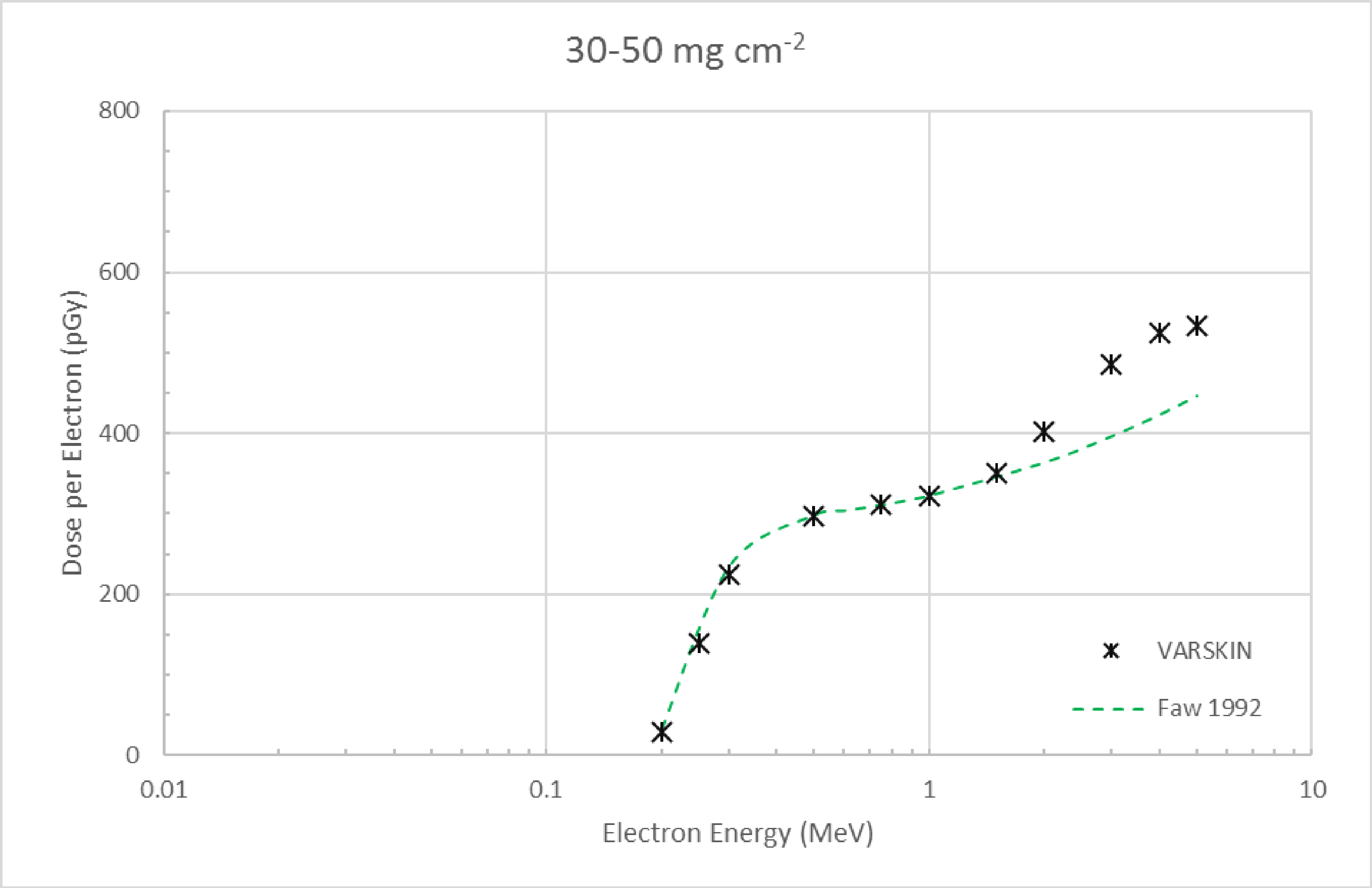
V5.3 Electron Dose Compared to FAW (water/water)
VARSKIN
Faw 1992
Dose per Emitted Electron (pGy)
Depth (mg cm-2)
0.25 MeV electrons
0
100
200
300
400
500
600
700
800
900
1000
1100
0
5
10
15
20
25
30
35
40
45
50



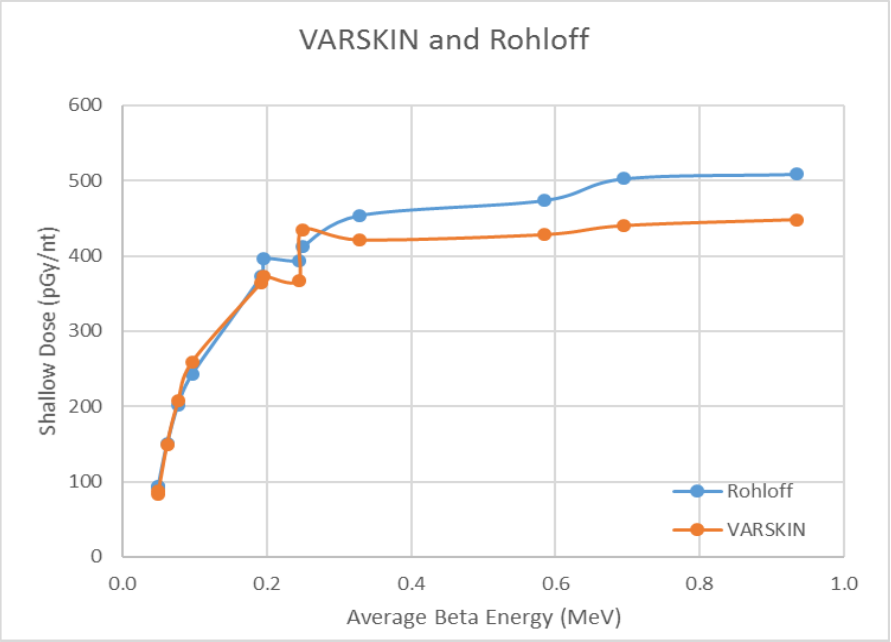
3-5 mg cm-2
800
600
400
200
0
Dose per Electron (pGy)
0.01
0.1
1
10
Electron Energy (MeV)
VARSKIN
Faw 1992

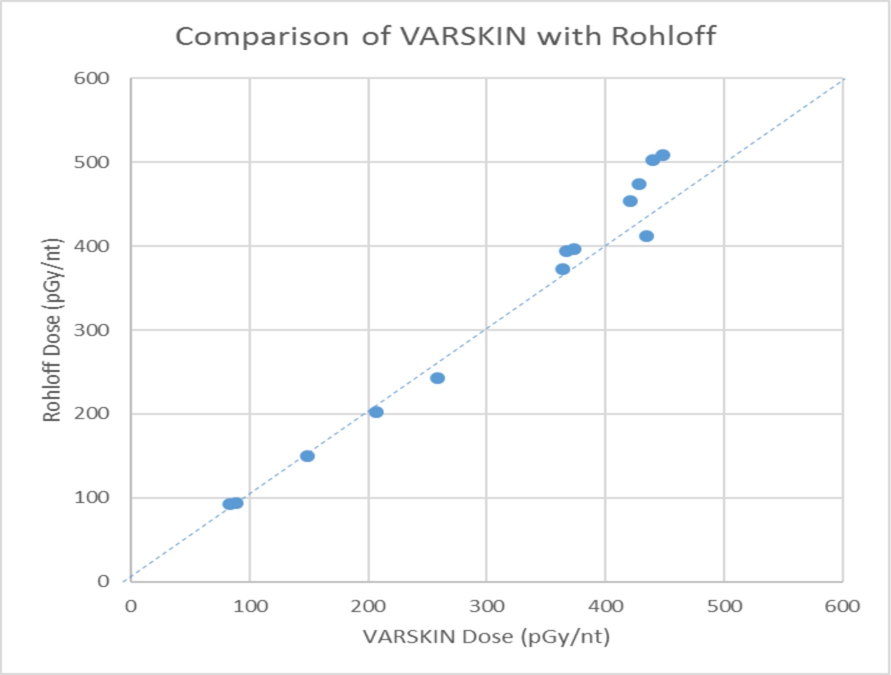


5-10 mg cm-2
800
600
400
200
0
Dose per Electron (pGy)
0.01
0.1
1
10
Electron Energy (MeV)
VARSKIN
Faw 1992



30-50 mg cm-2
Dose per Electron (pGy)
800
600
400
200
0
0.01
0.1
1
10
Electron Energy (MeV)
VARSKIN
Faw 1992





Comparison to Rohloff and Heinzelmann [1986]

Rohloff and Heinzelmann [1986] estimated electron dose to the skin for various beta-emitting nuclides ranging from 49 keV (^{35}S) to 0.935 MeV (^{90}Y).

VARSKIN is in good agreement at low energies, but indicates an under prediction by ~10% at the highest doses.

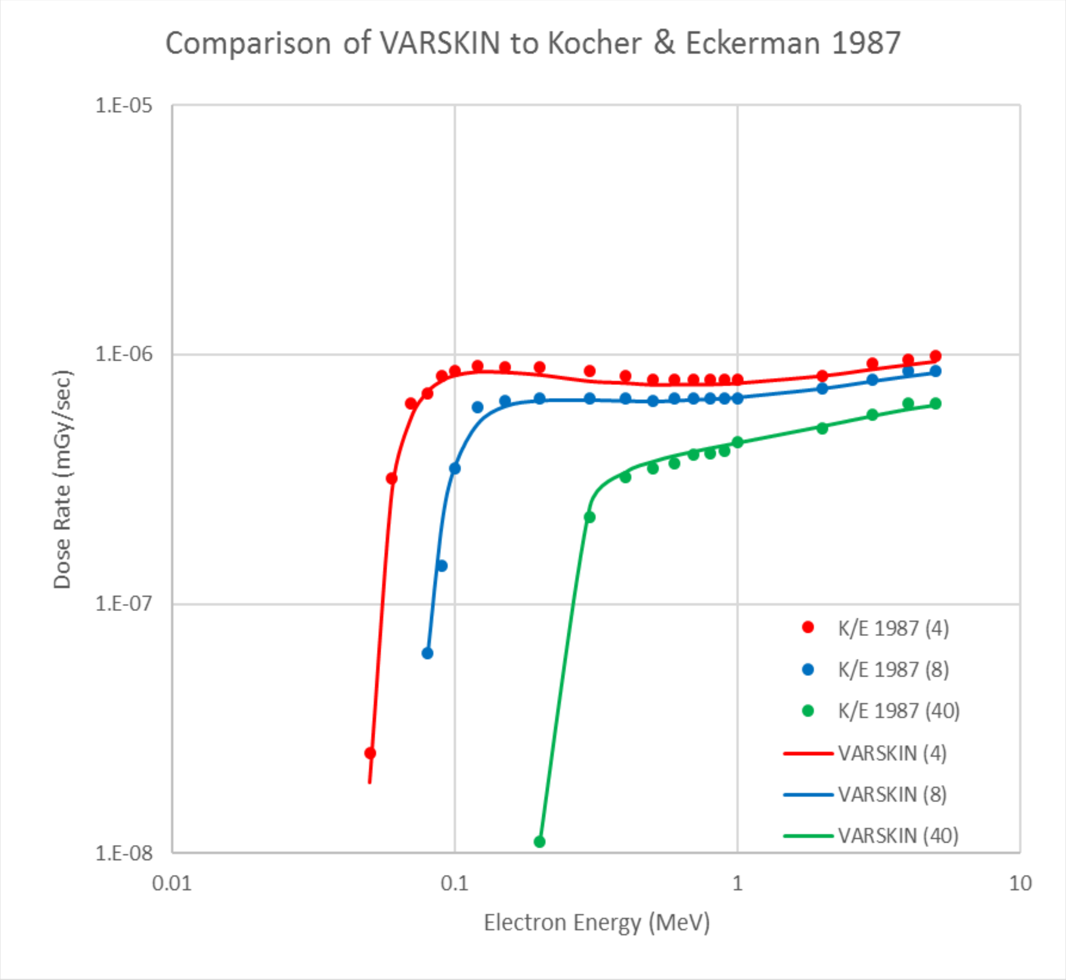
Comparison to Kocher and Eckerman (1987)

Kocher and Eckerman [1987] estimated electron dose-rate factors for mono-energetic sources on the skin. The scaled point-kernel methods of Berger [1971; 1973; 1974], inherently in a homogeneous water medium, were used.

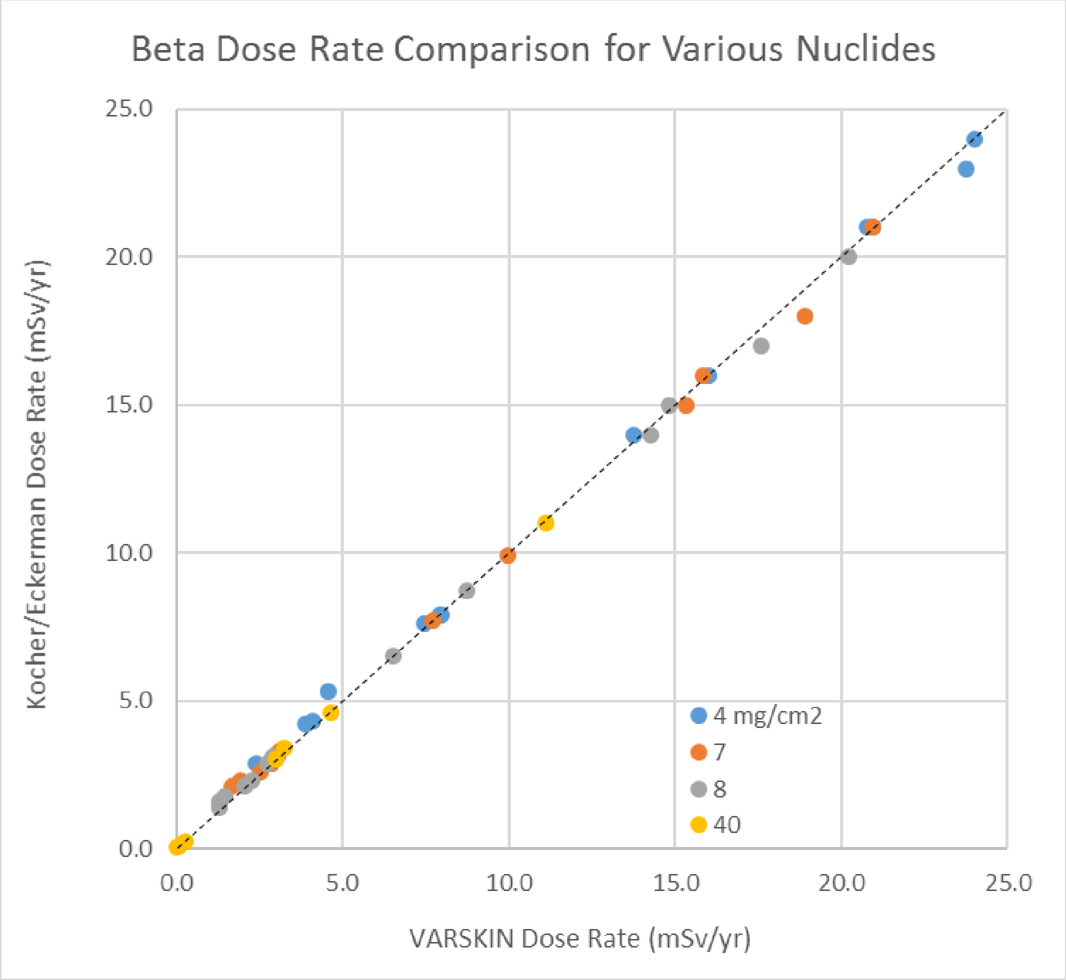
These dose factors were simulated in VARSKIN by assuming an infinitely large 2D disk source (15 cm^2) on the skin surface with a uniformly distributed activity of 1 Bq/cm^2 . This was done for four different depths [4, 7, 8, 40 mg cm^{-2}].

A water/water interface was simulated due to the original use of a homogenous water medium.

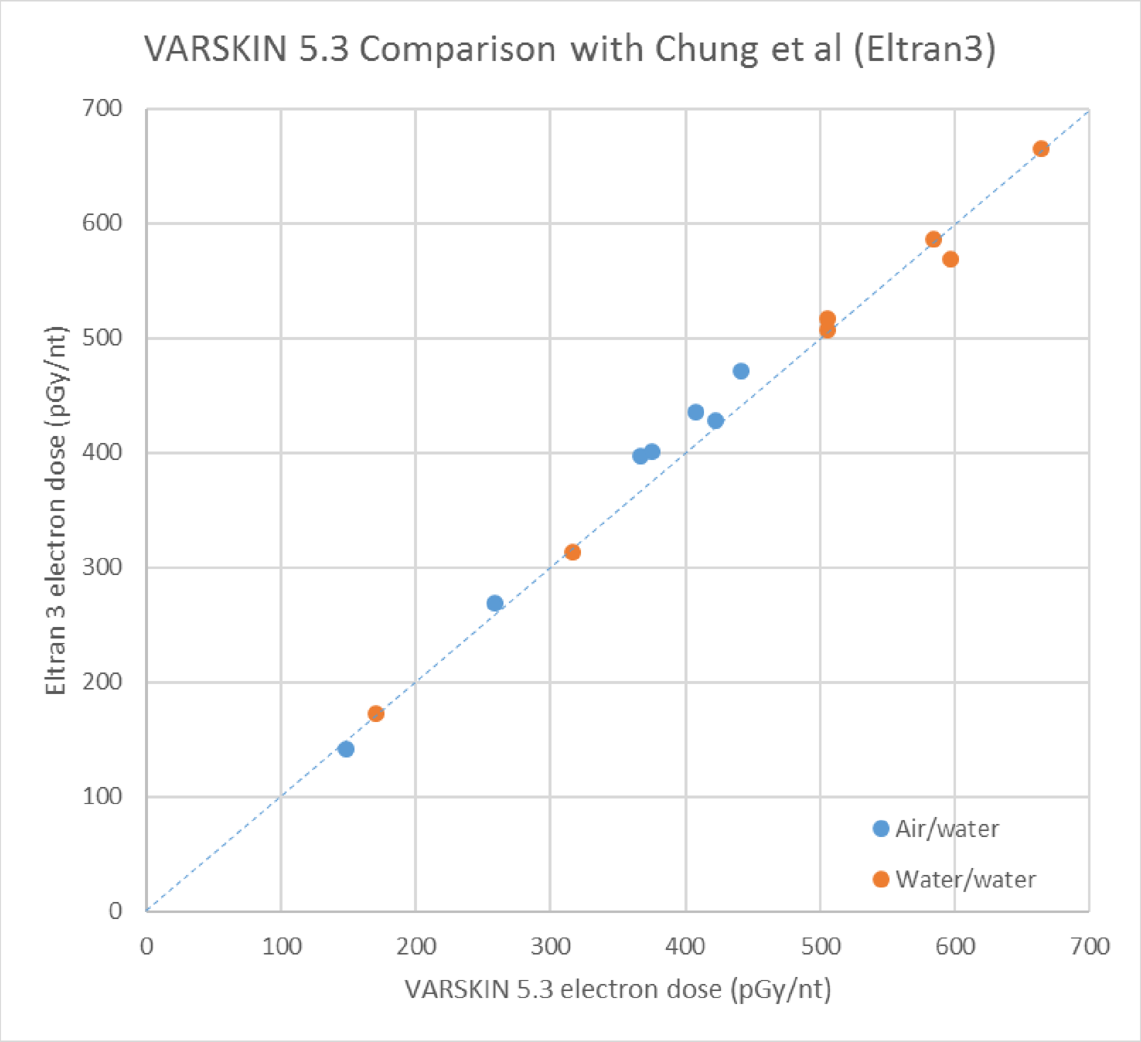
VARSKIN 5.3 and Kocher/Eckerman are in good agreement.



Comparison of VARSKIN to Kocher & Eckerman 1987
1.E-05
1.E-06
1.E-07
1.E-08
0.01
0.1
1
10
Dose Rate (mGy/sec)
Electron Energy (MeV)
K/E 1987 (4)
K/E 1987 (8)
K/E 1987 (40)
VARSKIN (4)
VARSKIN (8)
VARSKIN (40)



Beta Dose Rate Comparison for Various Nuclides
25.0
20.0
15.0
10.0
5.0
0.0
Kocher/Eckerman Dose Rate (mSv/yr)
VARSKIN Dose Rate (mSv/yr)
4 mg/cm2
7
8
40



Comparisons to Chung et al. [1991]

Chung et al. [1991] simulated a point source on the skin for six radionuclides (and considered a 7th 'nuclide' as the sum of Sr-90 and Y-90, in equilibrium) using a 2D Monte Carlo transport code, Eltran3.

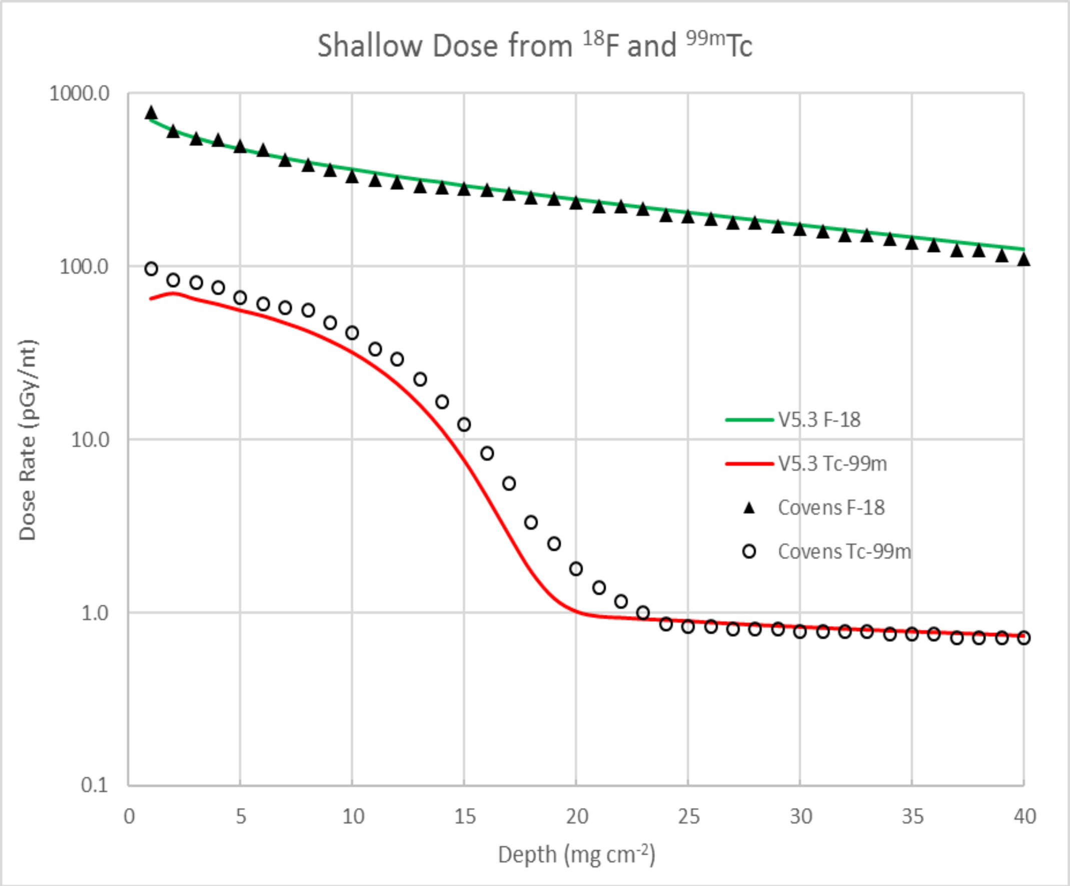
VARSKIN 5.3 results are shown to be in good agreement with their data for both air/water and water/water simulations.

Comparisons to Covens et al. [2013]

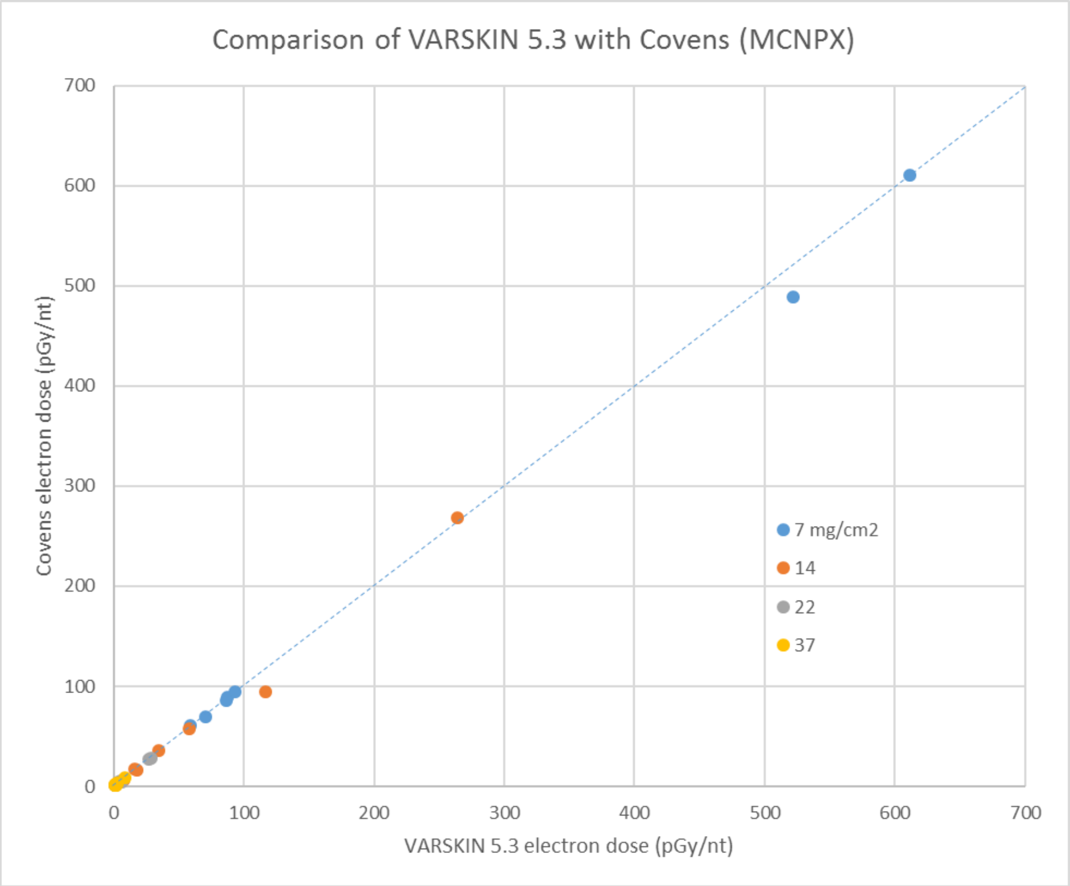
Covens et al. [2013] estimated skin dose at four depths using MCNPX. They assumed an air/water interface with surface contamination areas normalized over 1 cm^2.

Results for seven nuclides are compared to VARSKIN 5.3.

Covens et al. [2013] also calculate skin dose (from photons and electrons) for infinitely thin disk sources (1 cm^2 area) of ^{18}F and ^{99m}Tc.



Shallow Dose from ¹⁸F and ⁹⁹ᵐTc
1000.0
100.0
10.0
1.0
0.1
Dose Rate (pGy/nt)
0
5
10
15
20
25
30
35
40
Depth (mg cm-2)
V5.3 F-18
V5.3 Tc-99m
Covens F-18
Covens Tc-99m



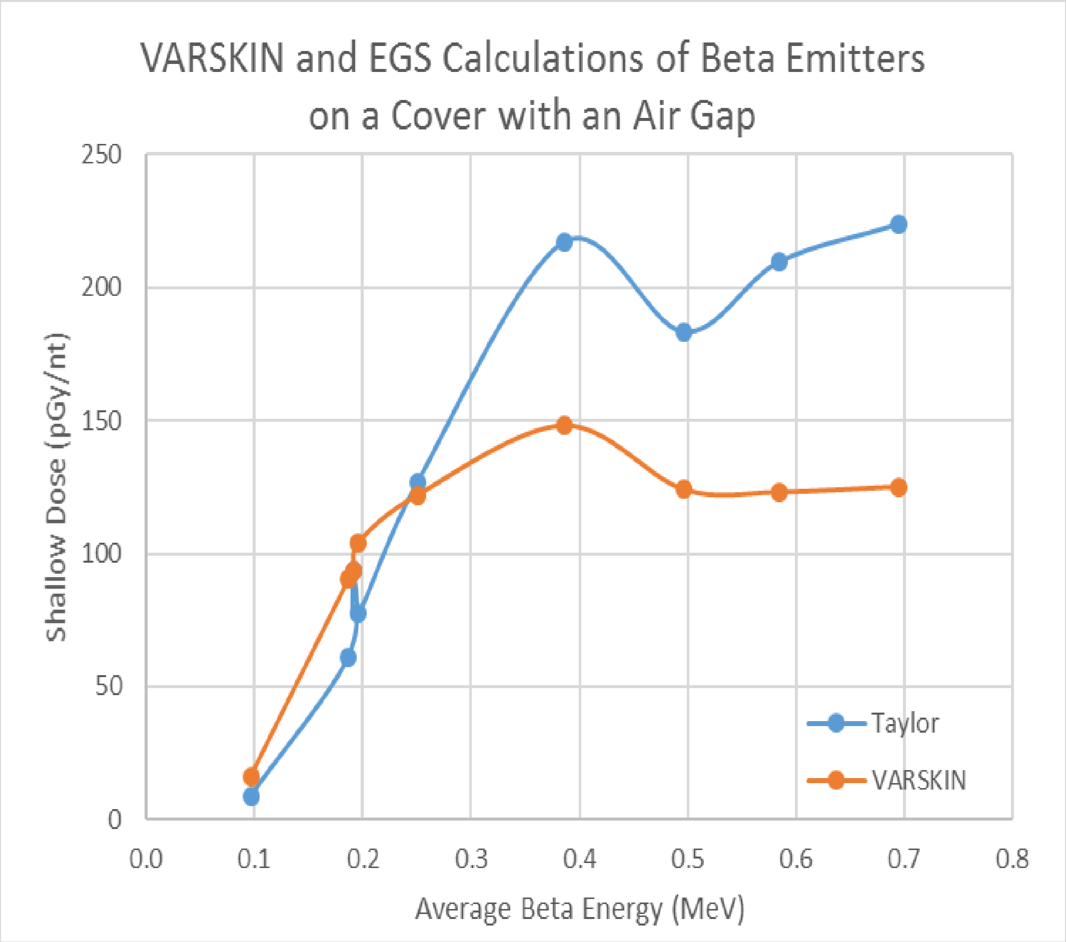
Comparison of VARSKIN 5.3 with Covens (MCNPX)
700
600
500
400
300
200
100
0
Covens electron dose (pGy/nt)
0
100
200
300
400
500
600
700
VARSKIN 5.3 electron dose (pGy/nt)
7 mg/cm2
14
22
37

Comparisons to Taylor et al. [1997]

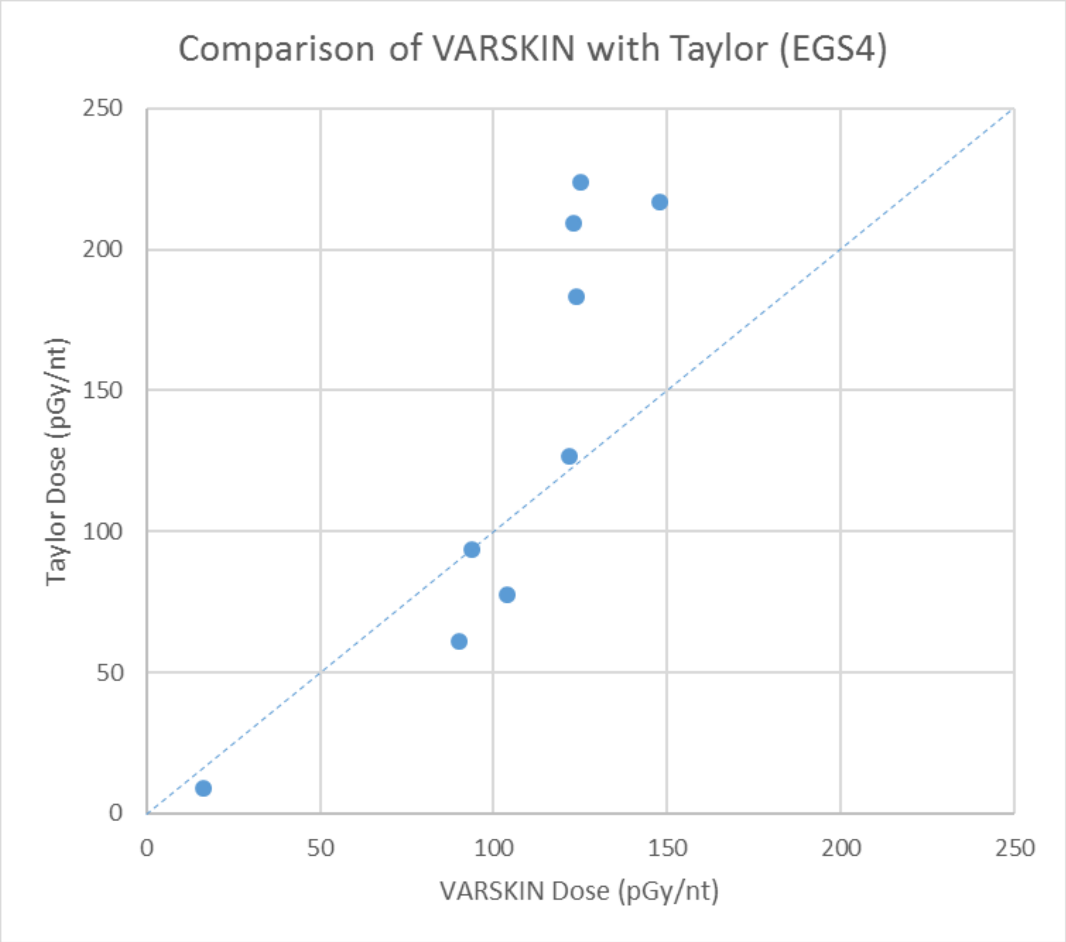
Taylor et al. [1997] calculated dose for mono-energetic electrons and then multiplied by the electron emission spectra to estimate dose for particular radionuclides.

EGS4 was used to simulate beta skin dose for several different nuclides placed on a 26 mg/cm^2 cotton cover ($\rho = 0.7\ g/cm^3$), with a 2 mm air gap over the skin.

VARSKIN 5.3 results do not agree with Taylor's data for the analyzed radionuclides (^{60}Co, ^{137}Cs, ^{131}I, ^{90}Sr, ^{85}Kr, ^{11}C, ^{132}I, ^{89}Sr, and ^{32}P).



VARSKIN and EGS Calculations of Beta Emitters on a Cover with an Air Gap
250
200
150
100
50
0
Shallow Dose (pGy/nt)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Average Beta Energy (MeV)
Taylor
VARSKIN



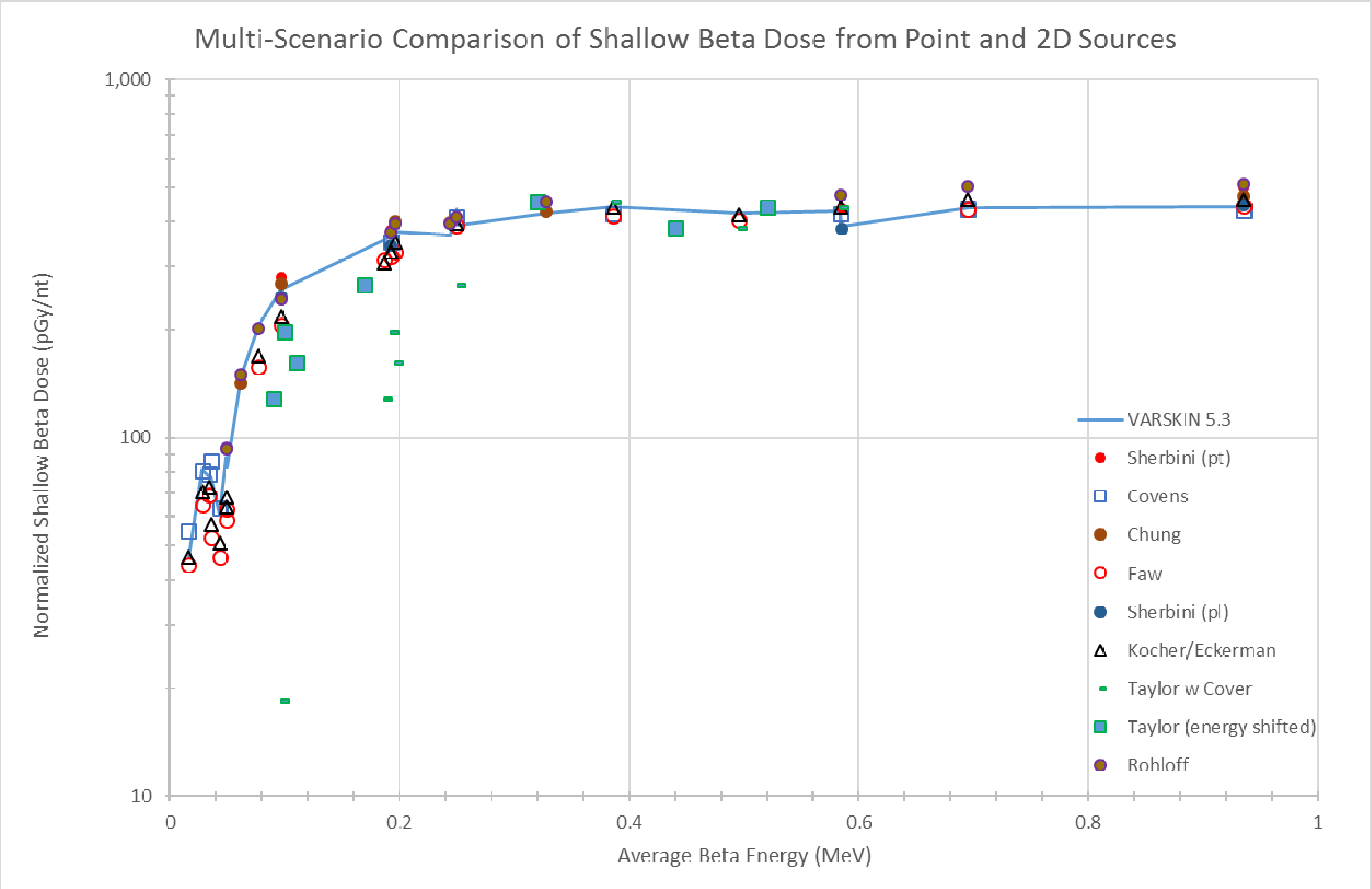
Comparison of VARSKIN with Taylor (EGS4)
250
200
150
100
50
0
Taylor Dose (pGy/nt)
0
50
100
150
200
250
VARSKIN Dose (pGy/nt)

Current Observations and Findings

Through scaling of all scenarios, the same graphical outcome is produced.

Electron shallow dose ranges about an order of magnitude over average electron energies from 16 keV up to about 1 MeV, with the dose plateau reached at approximately 300 keV

A discontinuity in dose at about 30-50 keV is observable in all scenarios that track beta dose from low-energy emitters


Multi-Scenario Comparison of Shallow Beta Dose from Point and 2D Sources
Normalized Shallow Beta Dose (pGy/nt)
1,000
100
10
0
0.2
0.4
0.6
0.8
1
Average Beta Energy (MeV)
VARSKIN 5.3
Sherbini (pt)
Covens
Chung
Faw
Sherbini (pl)
Kocher/Eckerman
Taylor w Cover
Taylor (energy shifted)
Rohloff