VARSKIN 6

Shallow Dose Estimates Using EGS and MCNP

VARSKIN USER'S GROUP MEETING

Oct. 29, 2018; Ottawa, Ontario

as part of the US NRC 4 th Annual RAMP User's Meeting

Colby Mangini, PhD, CHP

VARSKIN Consultant

Paragon Scientific, LLC

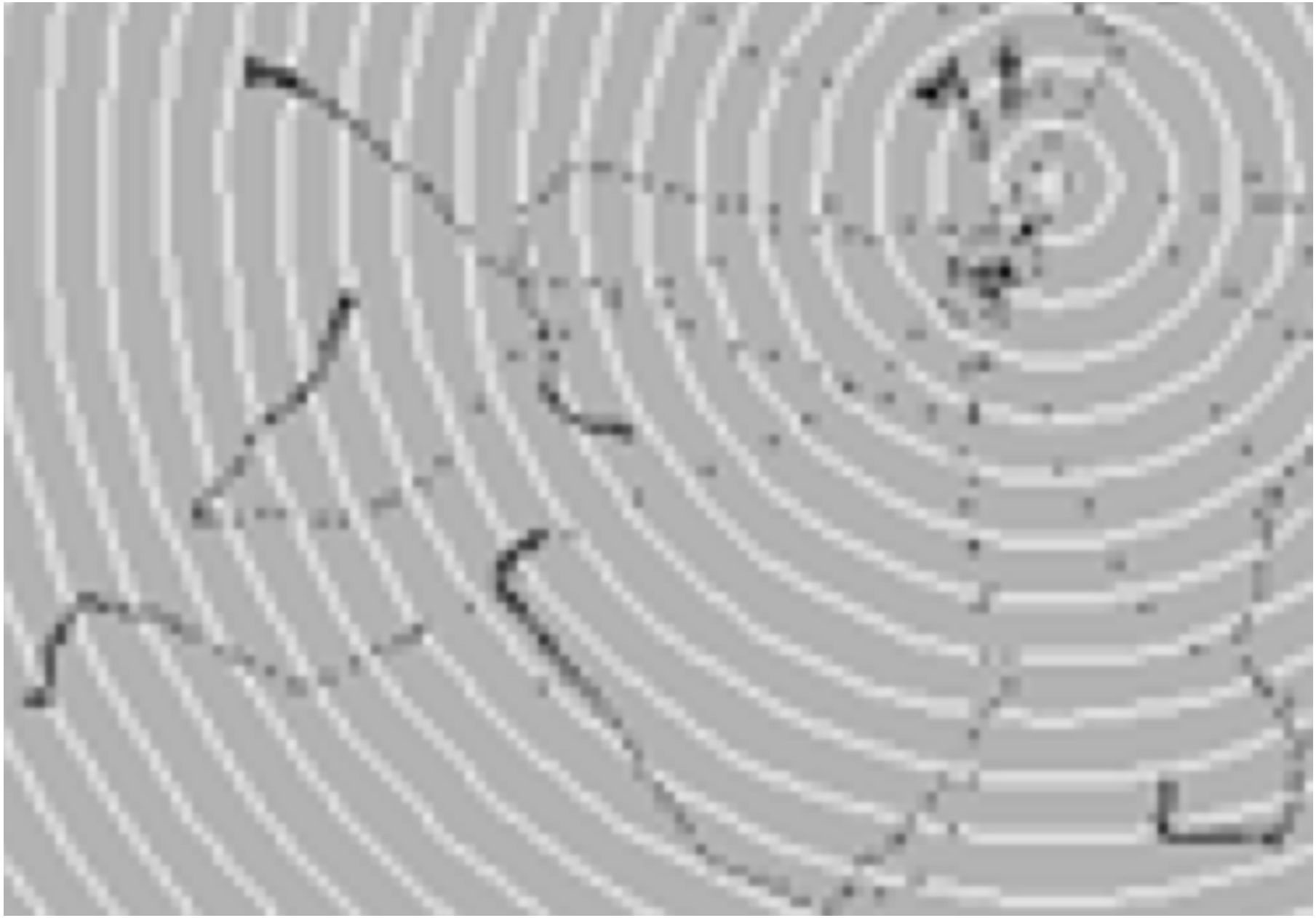
Outline

- Monte Carlo Basics
- MCNP
- EGSnrc
- Monte Carlo Skin Dosimetry
- Monte Carlo Skin Dosimetry Analyses

DISCLAIMER

I have never written a Monte Carlo code, I have only used them

I am not an expert in MCNP or EGSnrc or any other Monte Carlo code



Basic Monte Carlo Process

- Particles are ‘born’ according to a predetermined source distribution
- Travels a given distance to a point of collision
- Loses energy as determined by a probability distribution based on the total interaction cross section
- Scatters at an angle to the next point of collision according to the corresponding differential scatter cross section
- Known as the *random walk*
  - repeated until the particle is absorbed or leaves the defined geometry
- Each birth to ‘death’ process is called a ‘history’

The beginning of Monte Carlo…for electrons

Monte Carlo Calculation of the Penetration and Diffusion of Fast Charged Particles*

MARTIN J. BERGER

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C.

Basic Monte Process for Electrons

- Main issue with electron transport is the number of 'histories' required for tracking the particle as it slows down
  - Undergo hundreds of thousands of interactions before they can be absorbed
  - Plus number of histories required for acceptable statistical uncertainty

insurmountable computing challenge

- Condensed history method proposed by Berger (1963)
- Condenses a large number of transport and collision processes into a single electron 'step'
- Net effect of many interactions in each step is sampled from pertinent multiple scattering theories
- Defined two basic classes of condensed history algorithms: Class 1 schemes and Class 2 schemes
  - secondary electron and bremsstrahlung transport

Class 1 Algorithm

- Individual elastic collisions are grouped together to form a single multiple scattering step
- Groups all the cross sections (energy straggling, multiple scattering, knock-on electrons) and utilizes a predetermined set of path lengths
- Sampling is performed at the end of the step so that energy is conserved
- The condensed random walk is based on the continuous slowing down approximation and is regarded in terms of path lengths and decreasing energy associated with the total stopping power, $-dE/ds$

Class 1 Algorithm

- While range and total energy loss are calculated for each major step, angular deviation and secondary particle production are sampled within a major step by dividing it into smaller substeps

- No correlation between primary and secondary particles
- No correlation is made between angular deviation and secondary particle energy. Consequently, there is no conservation of energy and momentum during the interactions

Class 2 Algorithm

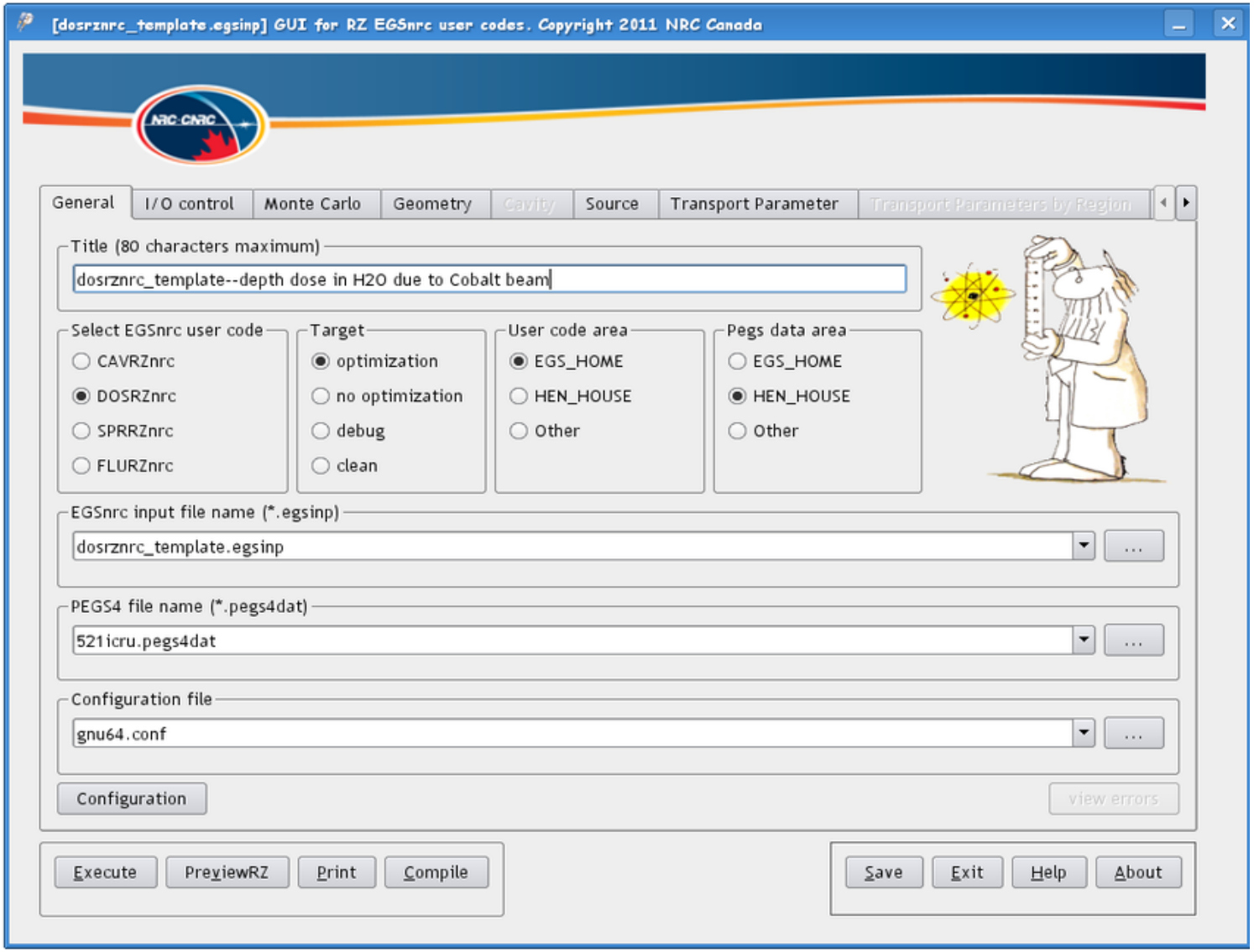
- Models interactions discretely such that primary and secondary particles are always correlated.
- Threshold for energy loss where events above this threshold are simulated explicitly
- Secondary particle energy and scatter angle are then sampled as a correlation so that energy changes are entirely conserved within each step
- Events below the threshold value are accounted for in the CSDA model (Class 1 methodology)

MCNP

MCNP

- Monte Carlo N-Particle
- Class 1 algorithm with electron transport physics based on the ETRAN/ITS platform
- Maintained by a large group at Los Alamos National Laboratory and was originally created for neutron-photon transport in reactor calculations
- Great flexibility - simulation times much larger for electron transport than other more particle-specific codes
- MCNP4, MCNPX, and MCNP5 have been used extensively for electron and beta dose distribution calculations

EGSnrc

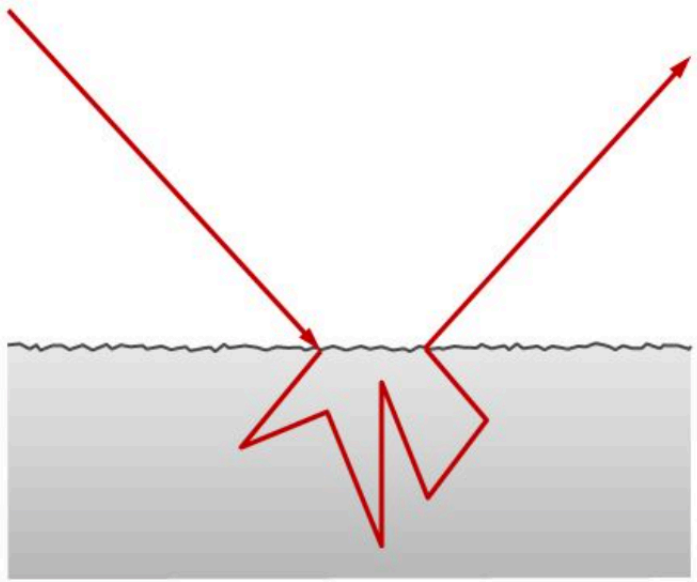

[dosrznrc_template.egsinp] GUI for RZ EGSnrc user codes. Copyright 2011 NRC Canada
NRC·CNRC
General
I/O control
Monte Carlo
Geometry
Cavity
Source
Transport Parameter
Transport Parameters by Region
Title (80 characters maximum)
dosrznrc_template--depth dose in H2O due to Cobalt beam
Select EGSnrc user code
CAVRZnrc
DOSRZnrc
SPRRZnrc
FLURZnrc
Target
optimization
no optimization
debug
clean
User code area
EGS_HOME
HEN_HOUSE
Other
Pegs data area
EGS_HOME
HEN_HOUSE
Other
EGSnrc input file name (*.egsinp)
dosrznrc_template.egsinp
PEGS4 file name (*.pegs4dat)
521icru.pegs4dat
Configuration file
gnu64.conf
Configuration
view errors
Execute
PreviewRZ
Print
Compile
Save
Exit
Help
About

EGSnrc

- **E**lectron **G**amma **S**hower **N**ational **R**esearch **C**ouncil (of Canada)
- Ralph Nelson largely responsible for EGS inception – EGS4 1985
- EGSnrc, is a result of the work by Kawrakow, Rogers, and Bieloajew (2000)
- Both EGS4 and EGSnrc are Class 2 codes
- Kawrakow eliminated multiple scattering at interfaces in EGSnrc
- Transition to single-scatter direct transport at any region within a specified length from a boundary (default is three elastic mean-free paths).
- Simulate energy deposition in the thin walls of an ionization chamber (called the Fano test) to an accuracy level 0.1% (independent of energy step size) when compared to experimental results

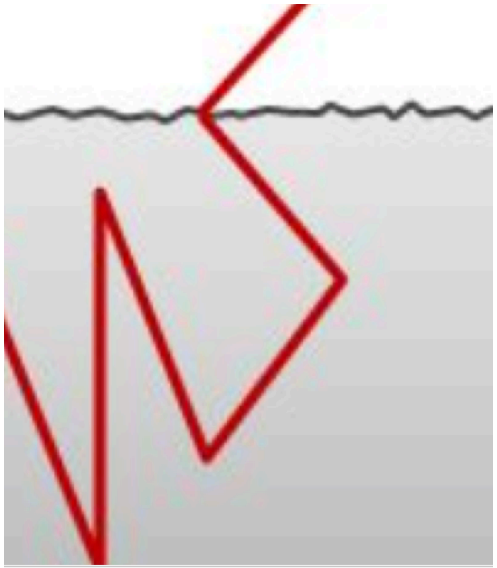
Monte Carlo Skin Dosimetry

- Special case in which dose must be calculated to very thin regions of tissue near the surface of the skin
- Difficult challenge for nearly all Monte Carlo codes due to the systematic errors introduced by boundary crossing



Monte Carlo Skin Dosimetry

- Electron multiple-scattering theory assumes an infinite homogeneous medium
- Energy steps for which the electron crosses a boundary will violate this assumption
- Typical approach has been to simply terminate the electron's major step as it crosses a boundary
  - introduces a systematic error as the average energy loss rate for that step was sampled with the assumption that the electron would in fact traverse the entire step length



Monte Carlo Skin Dosimetry

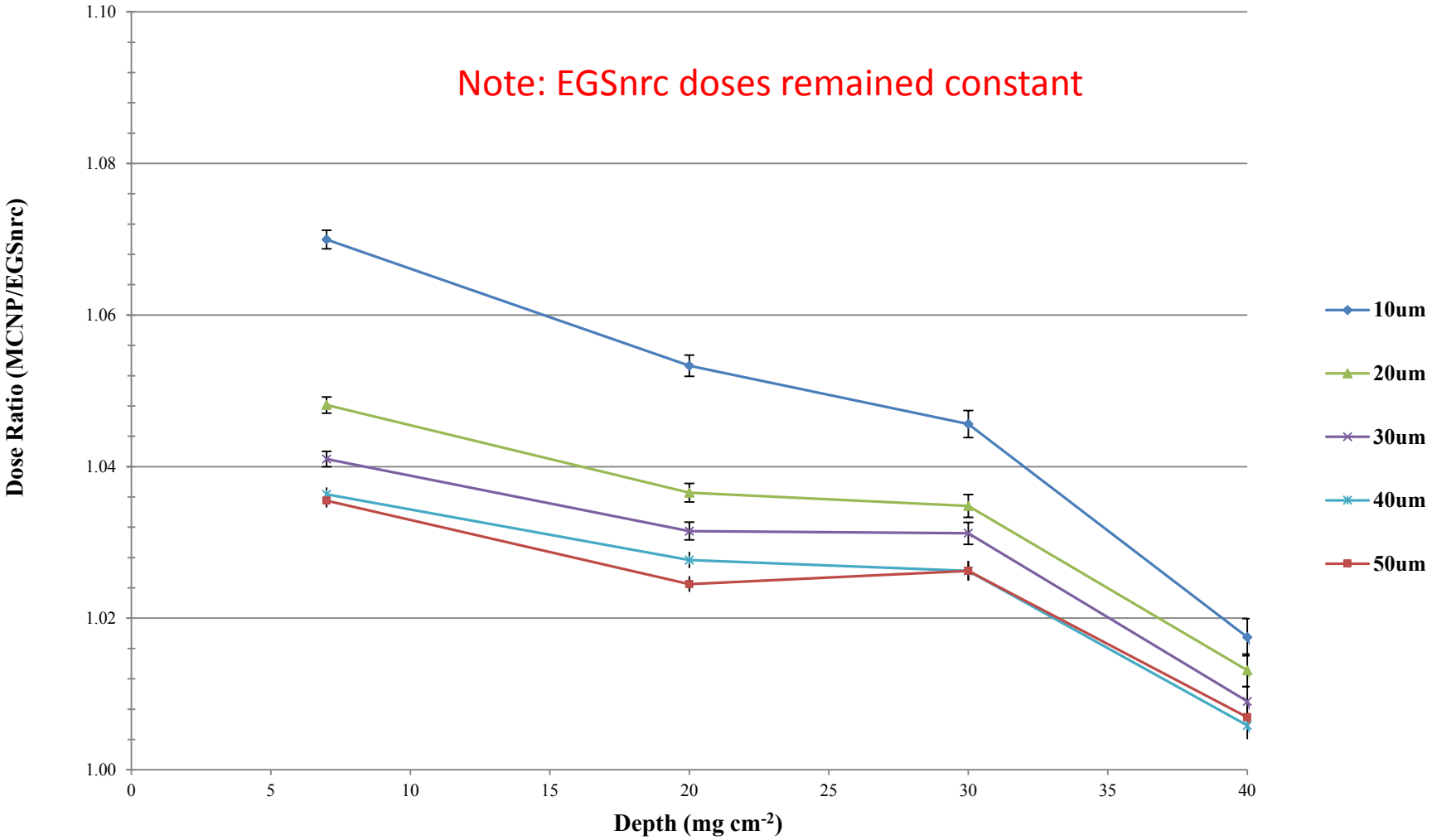
- Little effect on dose volumes of significant size (relative to the particles range), but the impact within such small volumes may be severely exaggerated

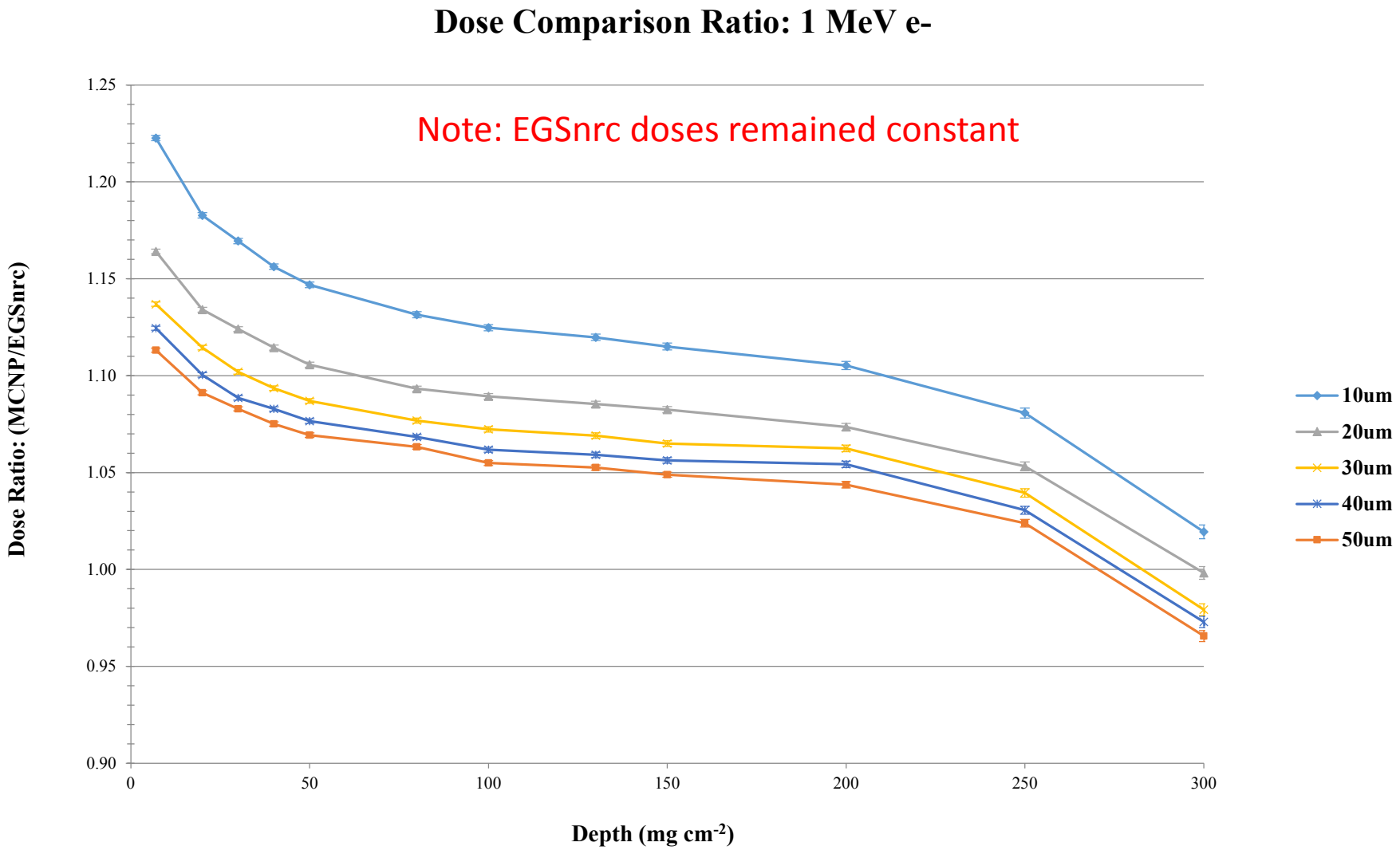
- A new transport method was developed that removed the problem of multiple-scatter boundary crossing errors by eliminating condensed history techniques near boundaries entirely
- Monitors the distance from a particle to a wall and switches the electron transport method into single-scatter calculations until the electron crosses or exits the boundary region

Monte Carlo Skin Dosimetry Analysis

- Examined the dose volume thickness dependence of the Monte Carlo transport codes EGSnrc and MCNPX (Jarvis Caffrey, 2012)
- Estimated dose to volumes segmented within water at various depths beginning at 7 mg cm^{-2} and extending to 1000 mg cm^{-2}
- 1 cm^2 planar area
- Dose volume thickness was treated as an independent variable and set to 10, 20, 30, 40, and 50 µm
- Each dose volume was centered upon the depth of interest, ie: the (10 µm x 1 cm^2) volume at 7 mg cm^{-2} resided between 6.5 mg cm^{-2} and 7.5 mg cm^{-2}
- Mono-energetic source problems using 1 MeV and 250 keV electrons were evaluated separately

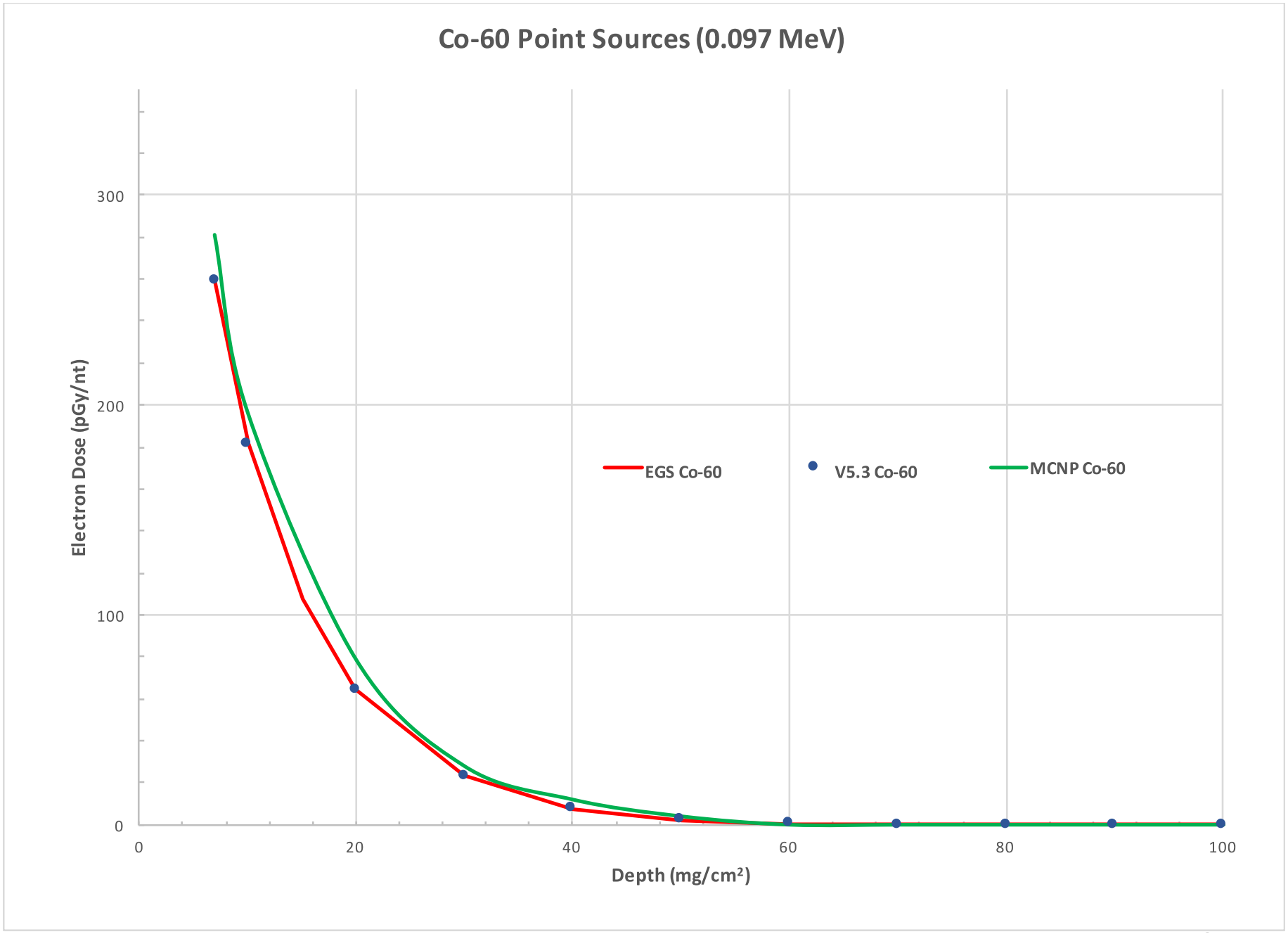
Dose Comparison Ratio: 250 keV e-

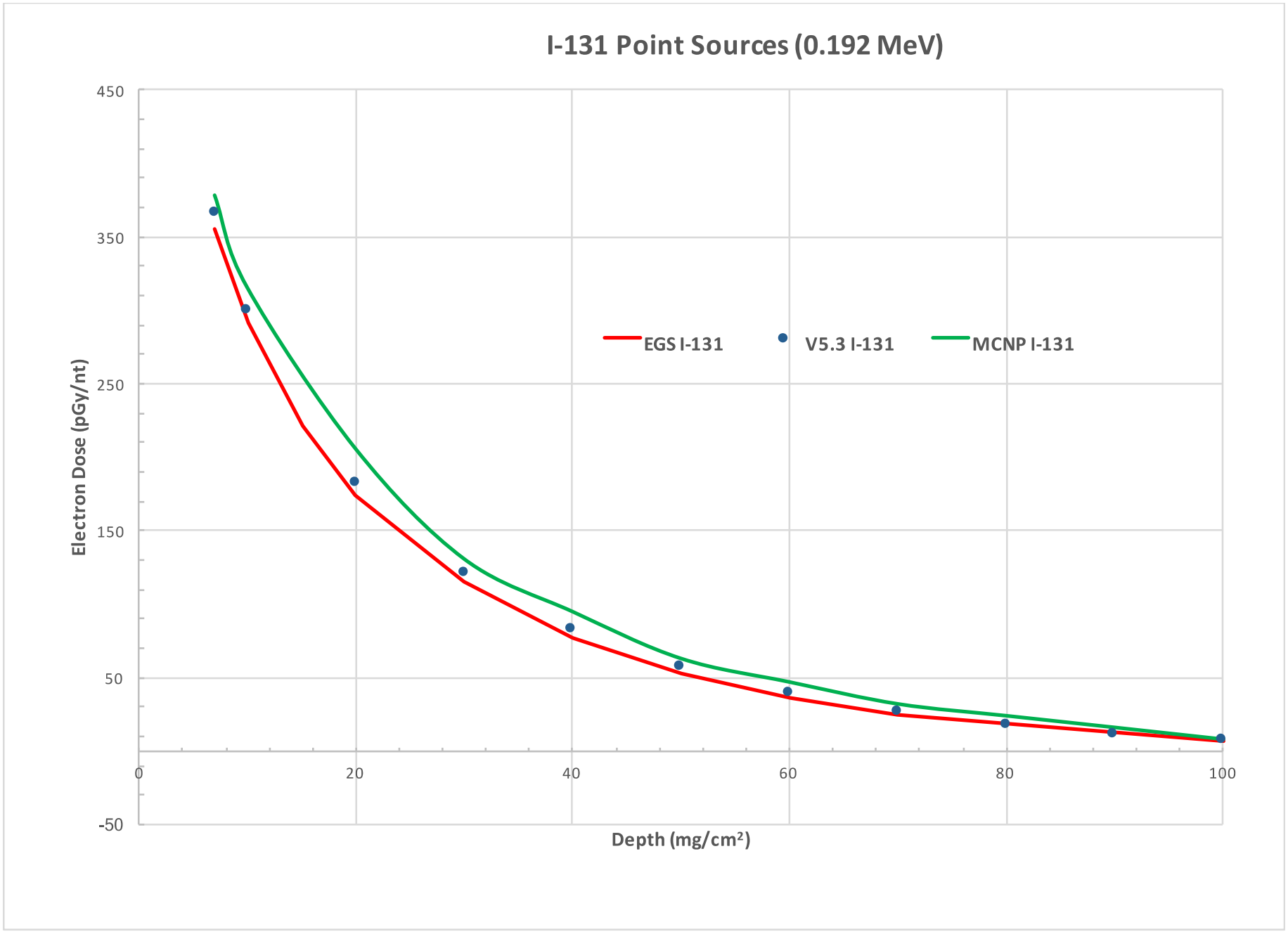


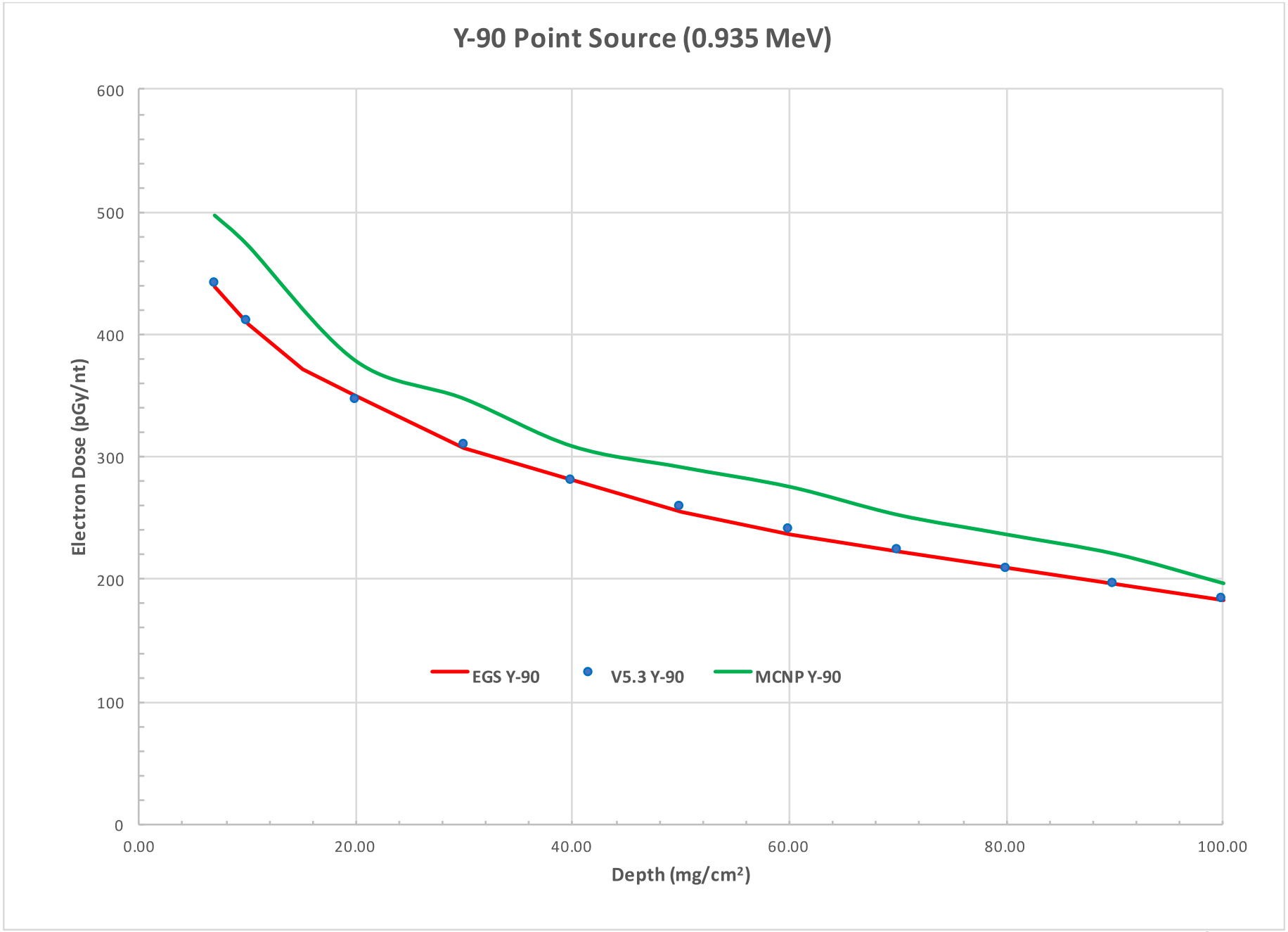

Dose Comparison Ratio: 1 MeV e-
Note: EGSnrc doses remained constant
Dose Ratio: (MCNP/EGSnrc)
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0
50
100
150
200
250
300
Depth (mg cm-2)
10um
20um
30um
40um
50um

Monte Carlo Skin Dosimetry Analysis

- Compared MCNPX and EGSnrc to Varskin 5.3 for a range of beta-emitting point sources
- Co-60 – average energy 0.097 MeV
- I-131 – average energy 0.192 MeV
- Y-90 – average energy 0.935 MeV
- 1 µCi source strength
- Dose volumes of 1 cm^2 x 10 µm


Co-60 Point Sources (0.097 MeV)
Electron Dose (pGy/nt)
300
200
100
0
0
20
40
60
80
100
Depth (mg/cm²)
EGS Co-60
V5.3 Co-60
MCNP Co-60


I-131 Point Sources (0.192 MeV)
Electron Dose (pGy/nt)
450
350
250
150
50
-50
0
20
40
60
80
100
Depth (mg/cm²)
EGS I-131
V5.3 I-131
MCNP I-131


Y-90 Point Source (0.935 MeV)
Electron Dose (pGy/nt)
600
500
400
300
200
100
0
0.00
20.00
40.00
60.00
80.00
100.00
Depth (mg/cm²)
EGS Y-90
V5.3 Y-90
MCNP Y-90

What's all this mean?

- No dependence upon volume size was noted in this investigation for EGSnrc
  - In agreement with existing literature (Kawrakow 1998, 2000)
- MCNPX demonstrated little consistency between calculations of varying dose region thickness
  - Also in agreement with existing literature (Wang 2001; Schaart 2002; Reynaert 2002)
- The systematic errors introduced by boundary crossing in the MCNP algorithm become very prominent as total cell size was reduced
- These effects are present at lower energies and further exaggerated at high energies.
- Changing the number of substeps within each major step by modifying the ESTEP parameter in MCNPX will likely improve agreement to some extent, but this will result in much longer computation times
- Use caution when comparing VARSKIN to MCNP results

Questions

References

- Berger, M. J. (1963) Monte Carlo calculation of the penetration and diffusion of fast charged particles *Methods in Computational Physic,* 1, 135–215. ed Alder, B., Fernbach, S., & Rotenberg, M. New York: Academic.
- Caffrey, J. (2012) Personal correspondence.
- Kawrakow, I. (2000). Accurate condensed history Monte Carlo simulation of electron transport: I. EGSnrc, the new EGS4 version. *Medical Physics, 27,* 485–98
- Kawrakow, I., & Bielajew, A. F. (1998). On the condensed history technique for electron transport. *Nuclear Instruments and Methods B*, *142*, 253–80
- Kawrakow, I., & Rogers, D. W. (2000). The EGSnrc code system: Monte Carlo simulation of electron and photon transport. *Technical Report* PIRS-701. Ottawa, Canada: National Research Council of Canada.
- Nelson,W. R., Hirayama, H. & Rogers, D. W. O. (1985). The EGS4 code system. *Report SLAC-265* Stanford, CA: Stanford Linear Accelerator Center.