VARSKIN – How and When to Use It, Why Not to Always Trust It

W. John Chase, CHP
Sr. Technical Expert, External Dosimetry
Ontario Power Generation

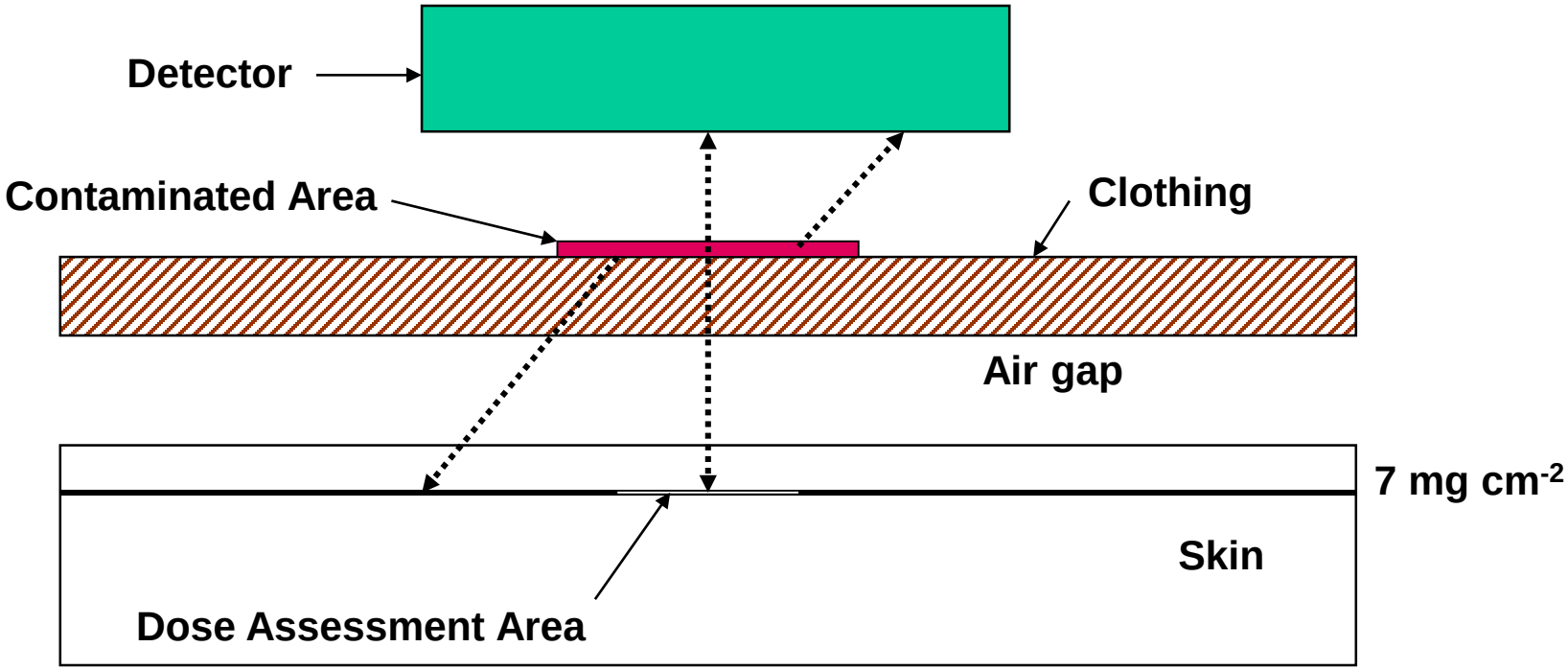
RAMP Meeting, Ottawa
October 2018

Outline

- Basics of Skin Dose Calculations
- History of VARSKIN
- Essentials of Modeling
- VARSKIN Mod 2, SADDE Mod 2
- DOSESKIN, YSADDE
- VARSKIN 3
- VARSKIN 4
- VARSKIN 5
- VARSKIN 6
- The Future: 2019 and beyond

Skin Dose Calculations

Problem Description



History of VARSKIN (Hamby)

- **VARSKIN (Traub et al, 1987)**
- **VARSKIN Mod 2, SADDE Mod 2 (Durham, 1992)**
- **DOSESKIN, YSADDE (Chase et al, 2004)**
- **VARSKIN 3, 3.1 (Durham, 2006)**
- **VARSKIN 4 (Hamby et al, 2011 [NUREG/CR-6918, Rev 1])**
- **VARSKIN 5.3 (Hamby et al, 2014 [NUREG/CR-6918, Rev 2])**
- **VARSKIN 6 (Hamby et al, 2017 [NUREG/CR-6918, Rev 3])**

Essentials of Modeling, Modeling Software

- Attempts to model physical reality, provide insight
- Accurate
- Generally applicable; covers full/wide range of scenarios

- Limitations known
- Really complicated models, transitions
- Adequate numerical methods, precision
- Easy to use
- Tested and reviewed
- Compared to other models or measurements
- Fast
- Works “as advertised”

Features of VARSKIN Mod 2

- Point, 2D disk, 3D disk, sphere and slab
- Models presence of materials between source and target
- Backscatter correction for point and 2D disk
- Gamma dose calculation
- Dose to 1 cm^2 at 7 mg cm^{-2}
- Dose at other depths, and over other areas
- Volume averaging

Reasons to Use VARSKIN Mod 2

- **Easy to use**
- **Flexible, models different shapes of particles, multiple layers of protective clothing, air gaps, etc.**
- **Fast**
- **Wide range of radionuclides**
- **Check of other calculations and measurements**
- **“Extensively peer-reviewed and validated”**

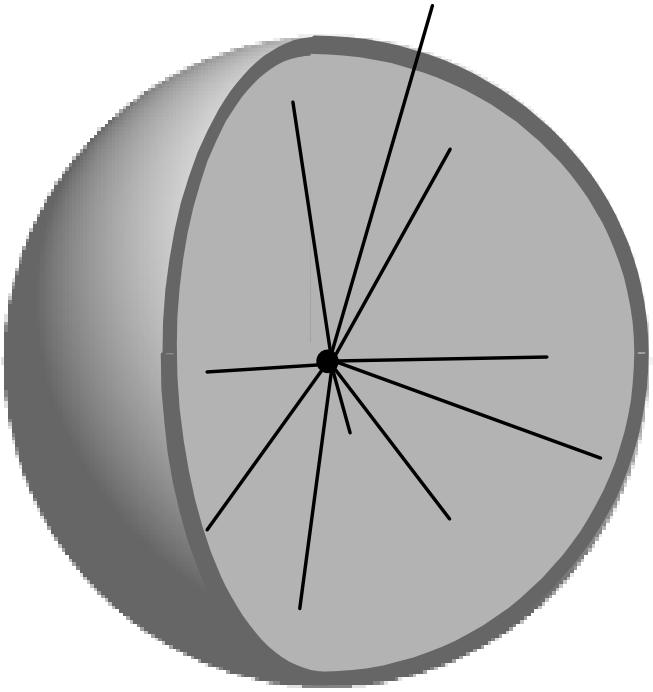
How does VARSKIN Mod 2 Work

- **Berger point kernel**
- **Scaled Absorbed Dose Distribution**
- **X_{90} Distance**
- **Numerical integration in 3 dimensions**

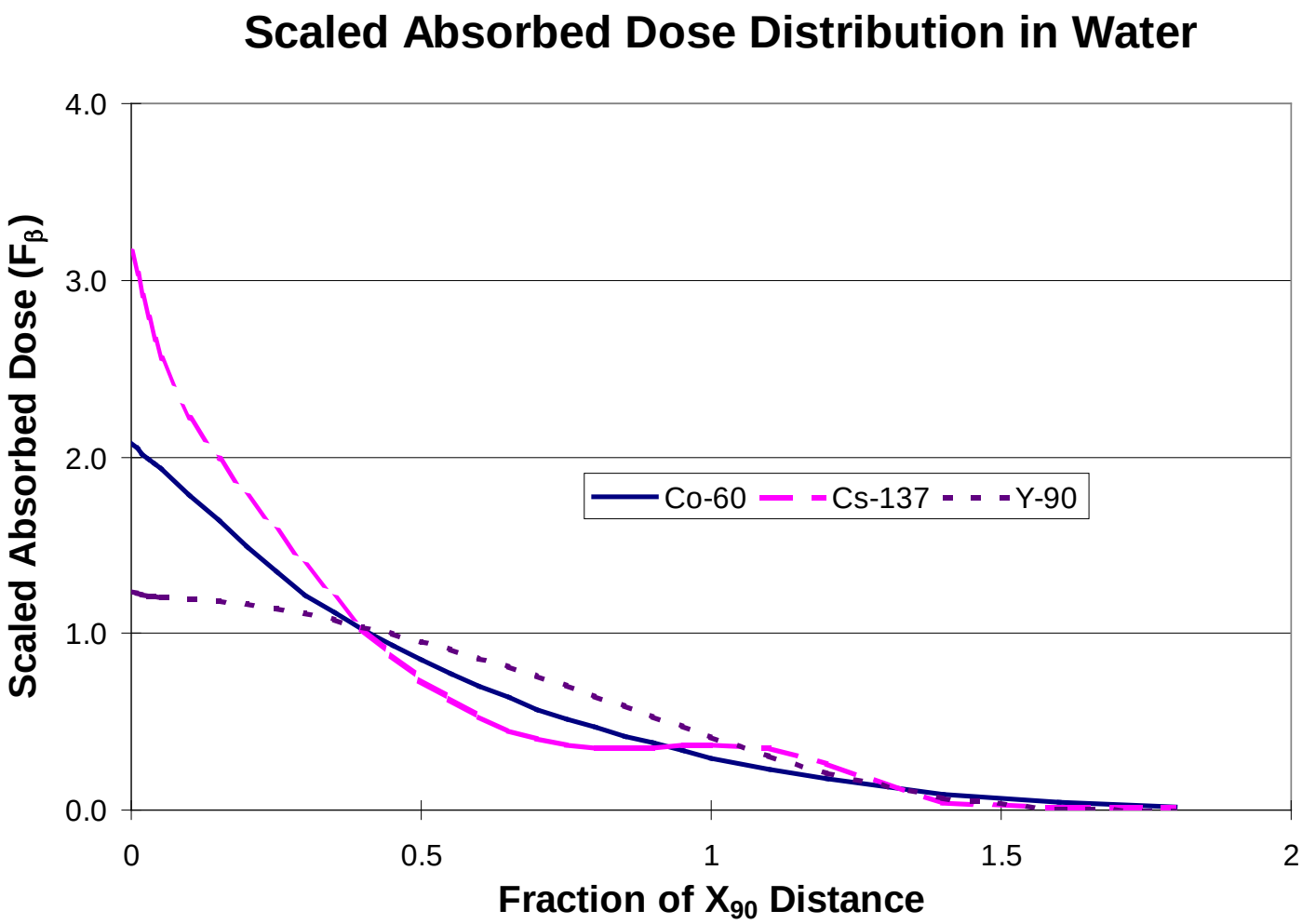
Berger Point Kernel

$$B(r) = \frac{k E_\beta Y F_\beta (r_1 / X_{90})}{4\pi \rho r^2 X_{90}}$$

X_{90} Distance



Scaled Absorbed Dose Distribution



VARSKIN Mod 2: The Trigger

- **Beta Dose Rate for 1 μCi ^{60}Co = 3.81 rad/h**
- **Test Case: 3D disk source**
- **Beta Dose Rate for 1 μCi ^{60}Co = 3.70 rad/h**

VARSKIN 2, SADDE 2 to DOSESKIN, YSADDE

- Source Density
- Backscatter Correction Factor
- Loss of Dose for Small Sources
- Fluctuations at Shallow Skin Depths
- Fluctuations in Volume Averaging
- Variations in Radial Dose Rate
- Gamma Dose Rate Calculation
- Beta yield applied twice (SADDE)

VARSKIN 2, SADDE 2 to DOSESKIN, YSADDE

Causes and Contributing Factors

- Coding logic errors
- Results not checked over full range of data
- Single precision
- Too few calculation points (e.g. radial dose distribution points) to ensure accuracy
- Even distribution of dose calculation points
- Source – target geometry errors
- Lack of self-checking
- Lack of detailed independent testing (review of coding, results; use of independent method (MC))

DOSESKIN, YSADDE

- **Use same (mostly) models as VARSKIN 2 and SADDE 2**
- **Same overall functionality**
- **Corrects all known code logic errors**
- **Increases number of dose calculation points**
- **Changes position of radial distribution points to increase density near source edge**
- **Gamma dose calculation corrected for density**
- **Fixes errors in SADDE 2**
- ***Maintains printing of radial dose distribution***

VARSKIN 3, 3.1

- First Windows™ VARSKIN program
- Uses DOSESKIN Fortran source code as starting point
- More flexible user interface, multiple cover calculator
- Default dose averaging area of 10 cm^2
- Syringe geometry added
- Easy addition of radionuclides to User library from ICRP 38 Radionuclide database
- Simple photon model for particles < 1 mm
- Terminology change: $X_{99} = 1.8\ X_{90}$

VARSKIN 3, 3.1

Identified Issues

- **For photon dose, VARSKIN 3 calculated CPE fraction based on photon energy in keV, but photon energy supplied in MeV => CPE reached too quickly**
- **Photon dose model does not attenuate low energy photons, and calculates higher CPE value than MCNP**
- **No longer prints or displays radial dose distribution**
- **Validation check using limited methods (Delacroix, Rohloff and Heinzelmann, Kocher and Eckerman, Chabot et al, Piechkowski)**

Good Practice

- **Beta dose rates checked using MCNP; good results for HP on skin; MCNP often > VARSKIN 3 for other geometries**

VARSKIN 4

- **Beta dose calculation same as VARSKIN 3**
- **New photon calculation:**
  - **Point kernel method**
  - **Better model for buildup of CPE**
  - **Photon attenuation**
  - **Off-axis scatter**
  - **Numerical integration**

VARSKIN 4 Photon Calculation

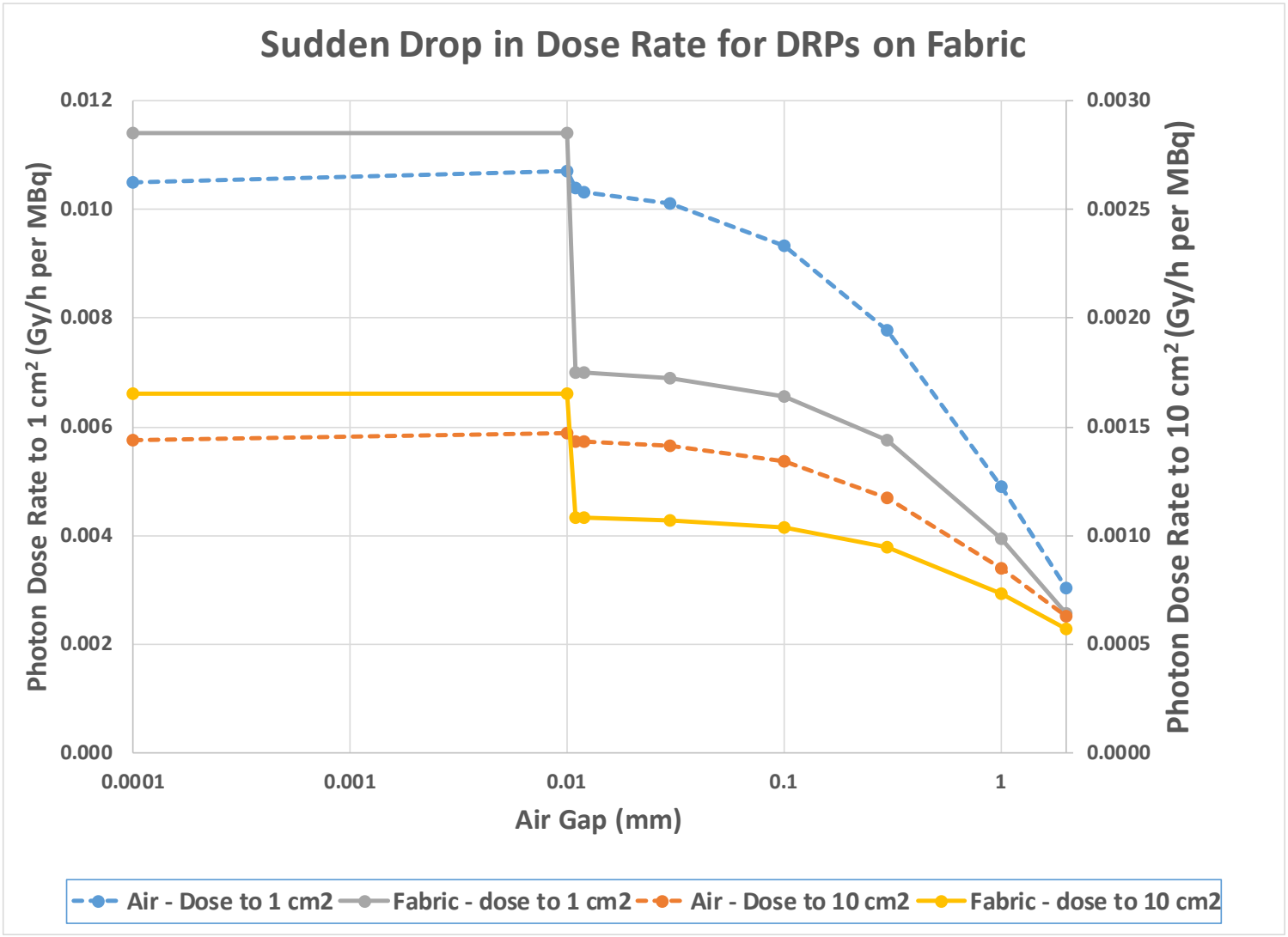
COG TN-10-3006

- 6 radionuclides (Am-241, Co-57, Cr-51, Ba-137m, Co-60, and Na-24)
- For DRPs on Skin, VARSKIN 4 to MCNAP4 ratio ranged from 0.97 to 1.18
- For DRP on cover with a 2 mm air gap, VARSKIN 4 to MCNAP4 ratio ranged from 1.03 to 3.44
- Results better than VARSKIN 3.1 for lower energy photons, worse for higher energy photons

Other Results

- On covers, large drop in dose rate for small change in distance

VARSKIN 4 Photon Calculation



VARSKIN 5 – Changes from VARSKIN 4

- **Photon Model unchanged from VARSKIN 4**
- **Uses Berger point kernel**
- **New Specific Absorbed Dose Distribution values based on EGSnrc Monte Carlo calculations that extended to further distances than the previous calculations**
- **Two SADD scaling models**
- **Effective Z for source material**
- **Comprehensive Monte Carlo backscatter model**
- **Backscatter factors applied to each dose kernel**

VARSKIN 5 – Testing and Issues

Anspach and Hamby (VARSKIN 5.3 Electron Model)

- Primarily testing contamination directly on skin: VARSKIN 5.3 results in mostly good agreement
- For contamination on clothing (Taylor et al) agreement not so good

Dubeau et al (VARSKIN 5.3 vs. MCNP)

- For contamination on skin, good agreement at lower beta energies (Co-60), V 5.3 < MCNP for higher energies
- With clothing and/or air gaps, V 5.3/MCNP in range of 0.52 to 0.95

VARSKIN 6

- **Selection of Radionuclide Database (ICRP 38 or ICRP 107)**
  - **N-16**
- **Option to include decay progeny**
  - **Only the total dose rates printed**
- **Minor bug fixes**

VARSKIN – Remaining Issues

- **Beta contamination on skin at higher energies, and on clothing with or without air gaps**
- **Sudden decrease in photon dose rate with particle on cover and air gap going from 0.01 to 0.011 mm**
- **For photons, dealing with change from no air gap to air gap**
- **Radial dose distribution information**

Kinds of Errors

- Model doesn't cover full range of possible values
- Software does not adequately code model
- Inaccurate numerical methods (too few averaging points, single precision)
- Testing tests only/largely functionality
- Self-checking not rigorous
- Point kernel methods/results used to test VARSKIN point kernel – method not independent
- Lack of independent software coding review

When to Use or Not Use VARSKIN

- **VARSKIN ideal for rapid evaluation of many scenarios, quick guide for evaluating big doses**
- **Caution required, especially for cases with clothing and air gaps**
- **Good check for Monte Carlo results**
- **Acceptable for contamination directly on skin, but apply caution**

Conclusions

- VARSKIN has had issues obtaining accurate results in past, better now
- VARSKIN very easy to use
  - Beware of it being a crutch
  - “It has been tested, so it must be OK”
- VARSKIN useful for benchmarking other results, especially Monte Carlo results
- VARSKIN 7

Acknowlegments

- **Dr. Jacques Dubeau, DETEC**
- **Dr. Ken Garrow, Bruce Power**
- **Dr. David Hamby, Oregon State**
- **All past developers and testers of the VARSKIN/DOSESKIN series of codes**