Comparison of Varskin Mod 2 and VARSKIN 6.2.1 Dose Conversion Factors

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Outline

- Introduction – how VARSKIN is being used by Safety and Licensing at Canadian Nuclear Laboratories Chalk River Site.
- Previous Approach to Skin Dose
- Comparison of dose rates from RRPDH (Varskin Mod 2) to VARSKIN 6.2.1.
  - General trends
  - Increases
  - Decreases
  - Library selection (ICRP38/107)
- Conclusion

Introduction

VARSKIN is used by Safety and Licensing Branch to quantify dose consequences for hypothetical accident scenarios. Safety analysis supports the licensing basis for the site.

Thermalhydraulics

Surface Science

Fuel/Actinides

Biological Research

ZED-2 Reactor

Hot Cells

CRL History & Legacy

- Birthplace of Canada's nuclear industry
- First sustained nuclear criticality outside USA
- Supplied Cobalt-60 for first cancer treatment in Canada.
- More than one billion people benefited from life-saving medical procedures worldwide
- Developed CANDU power reactor technology which has provided clean energy
- Major international facility for physics and health research
- Supported numerous Nobel Prize winning research activities


SWITCHYARD
CNL SUPPORT FACILITY
BUSINESS HUB
PHASE 1
PARKING LOT A
PLANT RD
700
CAFETERIA
300
350
114
137
S&T
FUTURE

Previous Approach to Skin Dose

Published dose conversion factors:

$$Equivalent\ Skin\ Dose = \sum_i C_{s,i} \left(\frac{Bq}{cm^2}\right) * CF_i \left(\frac{mSv}{h} per \frac{Bq}{cm^2}\right) * T\ (h)$$

Where:

$C_{s,i}$ = Average surface concentration of radionuclide, i

CF_i = Dose conversion factor for radionuclide, i.

T = Time of exposure (h)

Two dose conversion factors available:

- 0.05 cm^3 droplet, and
- Uniform deposit on the skin.

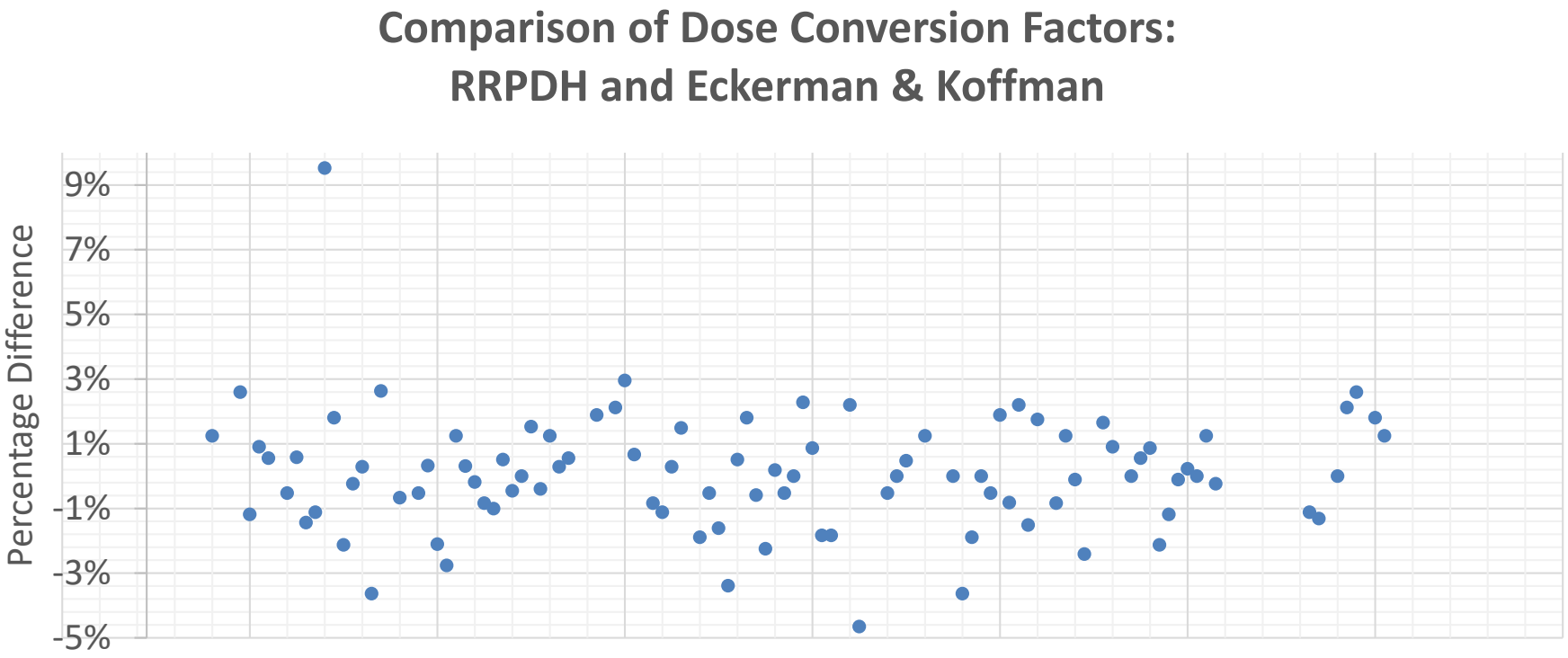
Previous Approach to Skin Dose

Two Main Data Sources:

- Delacroix, D, et al., Radionuclide and Radiation Protection Data Handbook (RRPDH) 2002, ISBN 1 870965 87 6.
- D.C. Kocher & K.F. Eckerman, Electron Dose-rate Conversion Factors for External Exposure of the skin from Uniformly Deposited Activity on the Body Surface. Health Physics Vol. 53, No. 2, 1987.

Berger point kernel methodology formed the basis of both data sources.

Comparison – Dose Conversion Data Sources



Previous Approach to Skin Dose

Data from Kocher and Eckerman has been reproduced in:

- Canadian Nuclear Safety Commission (CNSC) Radionuclide Information Booklet, April 2018.
- International Atomic Energy Agency (IAEA) TECHDOC-1162, August 2000.
- Jensen, P.H., Atmospheric Dispersion and Environmental Consequences — Exposure from Radioactive Plume Pathways, Rep. Risø-M-2849, Risø National Laboratory, Roskilde, Denmark, 1992.

Previous Approach to Skin Dose

The first calculations using VARSKIN 6.2 and the previous dose conversion factors was a hypothetical scenario involving a skin contamination event involving aged Plutonium.

Values were different, different enough to change the conclusions of the safety analysis.

What are the implications of using VARSKIN 6.2.1 in future safety analysis, and when updating existing safety analysis?

Comparison - RRPDH/VARSKIN

Progeny only included when included in RRPDH.

Uniform deposit

- Disc geometry in VARSKIN 6.2.1
- 1 cm^2 surface area
- 1 cm^2 dose averaging area.

Droplet deposit

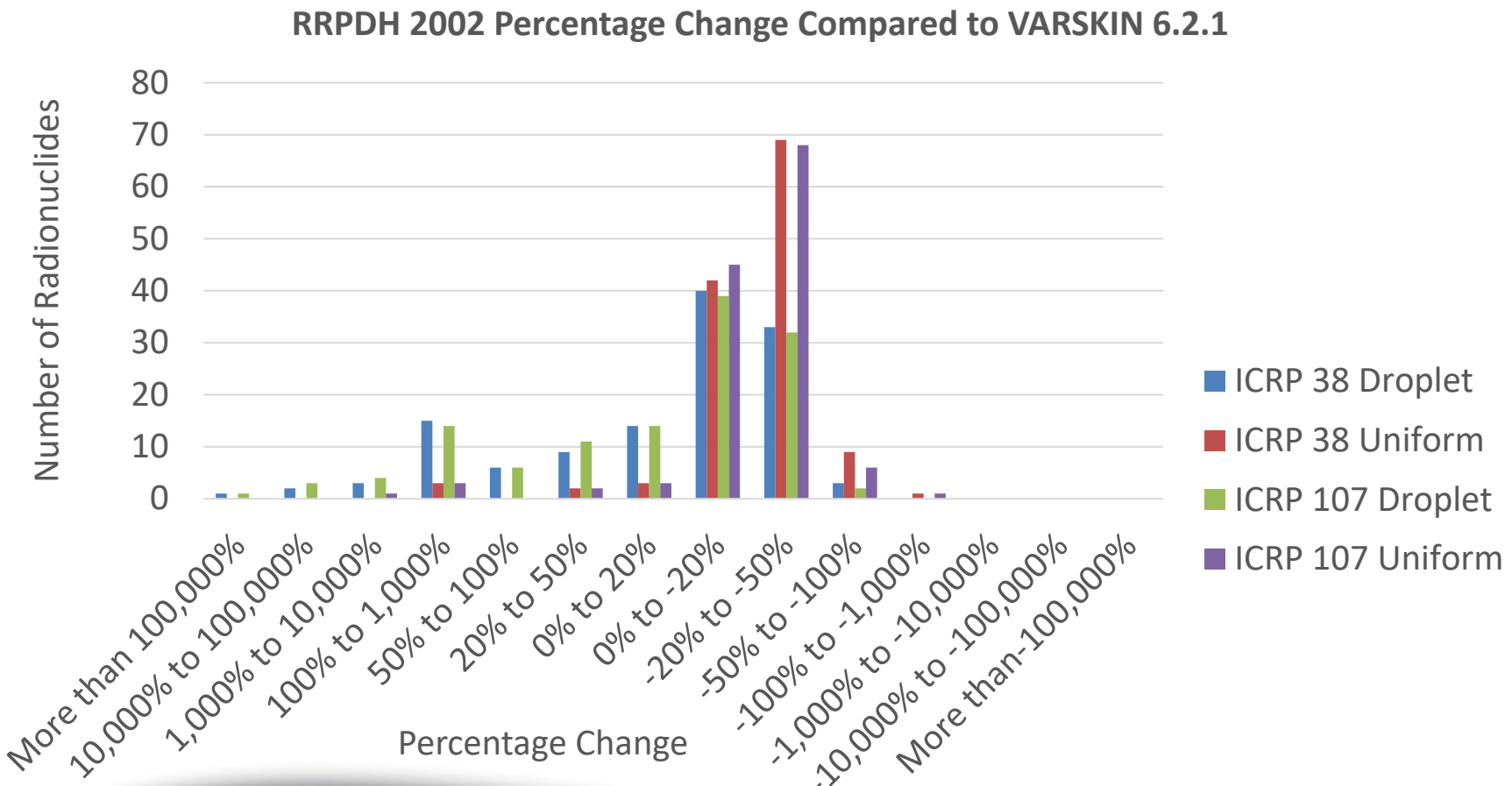
- Cylinder geometry in VARSKIN 6.2.1
- Cross sectional area 1 cm^2
- Height 0.05 cm

Values shown are the dose rates (no decay)

Comparison - RRPDH/VARSKIN

WARNING – Data presented has not been independently checked.

Comparison – RRPDH versus VARSKIN



Comparisons

- Significant increases, performed for both droplet and uniform geometries.
- Zero dose conversion factors in RRPDH who now have a non-zero dose conversion factor.
- Significant decreases, performed for both droplet and uniform geometries.
- Significant differences depending on library selection, ICRP38/ICRP10.

Comparison – Significant Increases

From RRPDH to VARSKIN 6.2.1 using the ICRP 107 library:

- 9/144 radionuclides increased based on a uniform geometry.
- 54/144 radionuclides increased based on a droplet geometry.

Comparison – Significant Increases

Radionuclides with significant increases in both droplet and uniform geometries

Radionuclide	Droplet (mSv/h per kBq)		Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN	RRPDH	VARSKIN
Cf-252	7.08E-04	1.91E-01	3.24E-03	2.75E-01
Am-243	7.10E-05	4.33E-03	4.70E-03	1.34E-02
As-73	2.20E-04	2.93E-02	4.50E-03	4.15E-02
Br-77	9.41E-03	2.94E-02	1.03E-02	6.40E-02

Comparison – Significant Increases Uniform

Other radionuclides that increased in uniform geometry (comprehensive list between both slides).

Radionuclide	Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN
Fe-59	9.73E-01	1.01E+00
Co-60	7.84E-01	9.36E-01
Mo-99	1.89E+00	2.59E+00
Cs-137	1.57E+00	1.90E+00
Eu-156	1.22E+00	1.32E+00

Comparison – Significant Increases Droplet

Radionuclides that increased with droplet geometry Others: Cs^{137}/Ba^{137}, U^{235}, Am^{241}, Co^{60}, Mo^{99}/Tc^{99}, and Fe^{59} (too many to list all here).

Radionuclide	Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN
U-238	1.38E-08	1.16E-03
I-123	5.16E-04	5.55E-02
Co-57	1.62E-03	3.81E-02
Cr-51	5.65E-04	1.10E-02
I-129	2.70E-03	3.10E-02
Hg-197	1.72E-03	1.50E-02
C-14	2.70E-03	2.33E-02

Comparison - Previously Zero Radioisotopes

Radionuclide	Droplet (mSv/h per kBq)	Uniform (mSv/h per kBq)
Pu-240	1.53E-03	3.71E-04
U-233	8.17E-04	0.00E+00
U-234	1.53E-03	8.61E-04
Pu-238	1.62E-03	5.69E-04
Ar-41	9.31E-01	1.45E+00
Pd-103	6.56E-03	0.00E+00
Kr-81	1.10E-02	0.00E+00
Kr-83m	4.57E-03	0.00E+00
Kr-85	6.87E-01	1.36E+00
Kr-85m	6.78E-01	1.29E+00
Fe-55	1.27E-02	0.00E+00
Ar-41	9.31E-01	1.45E+00
Xe-133	2.41E-01	9.80E-01
Tm-171	2.52E-04	1.05E-02

Comparison – Significant Decreases

From RRPDH to VARSKIN 6.2.1 using the ICRP 107 library:

- 120/144 radionuclides decreased based on a uniform geometry,
- 73/144 radionuclides decreased based on a droplet geometry.

Comparison – Significant Decreases Uniform

Significant decreases in both droplet and uniform deposit geometries are observed for the following radionuclides

Radionuclide	Droplet (mSv/h per kBq)		Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN	RRPDH	VARSKIN
Ra-226	8.80E-03	1.49E-04	4.80E-02	2.26E-04
Be-7	1.30E-02	9.47E-04	2.90E-03	1.01E-03
Sr-85	3.32E-02	1.90E-02	5.95E-02	2.29E-02
Ga-66	1.00E+00	5.74E-01	1.62E+00	8.28E-01
Pa-234m	1.50E+00	9.80E-01	2.40E+00	1.42E+00
Pa-234	1.30E+00	8.01E-01	5.40E+00	2.77E+00

Comparison – Significant Decreases Uniform

Radionuclides that significantly decreased in uniform geometry

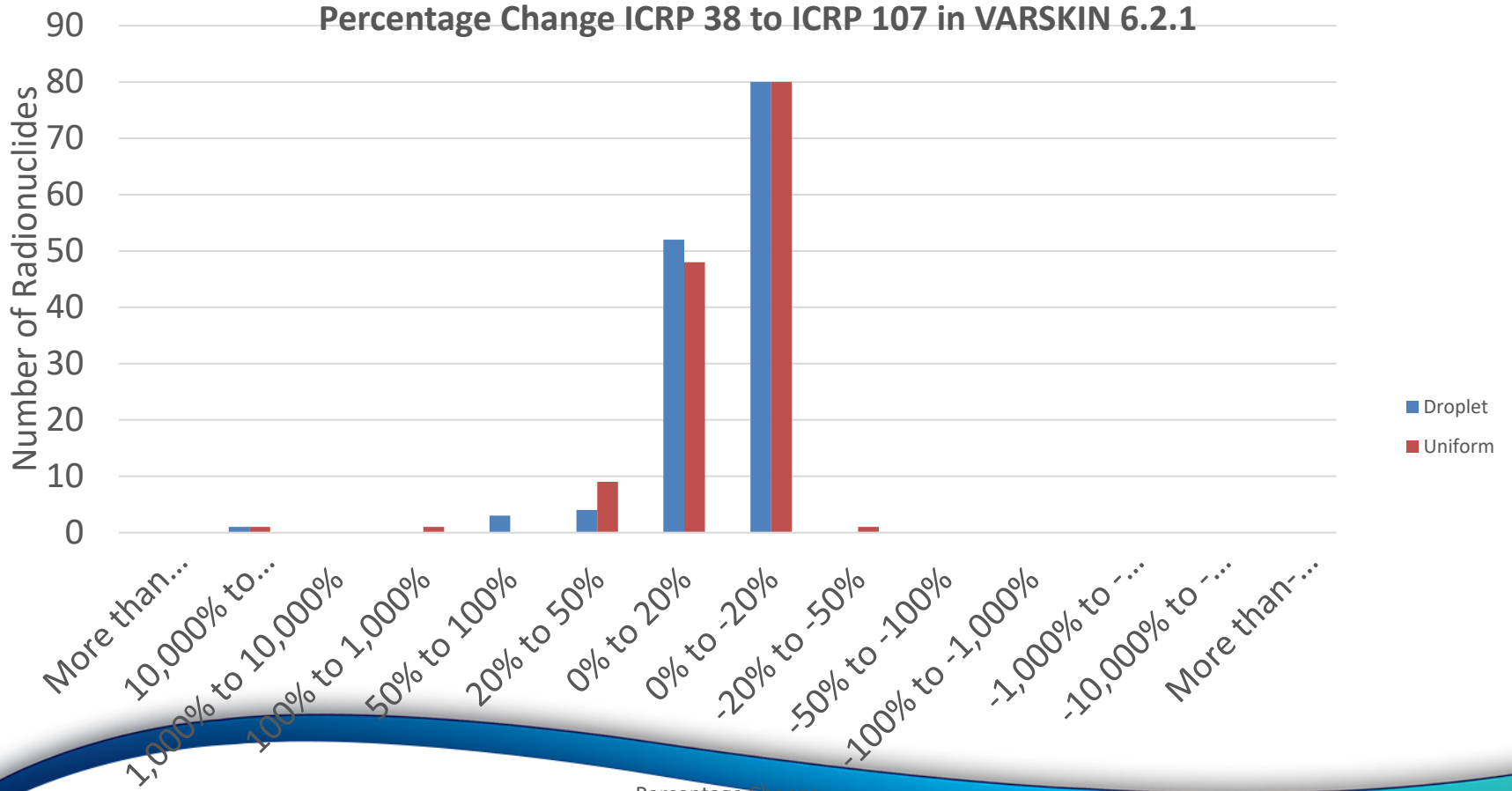
Radionuclide	Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN
Po-210	6.90E-07	0.00E+00
Mn-54	6.22E-02	2.24E-02
U-235	1.78E-01	7.15E-02
Sb-125	2.00E+00	9.26E-01
Sb-124	2.16E+00	1.27E+00

Comparison – Significant Decreases Droplet

Radionuclides that significantly decreased in droplet geometry

Radionuclide	Uniform (mSv/h per kBq)	
	RRPDH	VARSKIN
Mn-56	1.35E+00	9.16E-01
Mn-52m	1.61E+00	1.03E+00
Pr-144	1.42E+00	1.00E+00
Ru-106	1.44E+00	1.01E+00
As-76	1.37E+00	9.82E-01
K-42	1.42E+00	9.98E-01

Comparison – Significant Differences ICRP38/107



Comparison – Significant Differences ICRP38/107

Radionuclides that significantly change depending on library selection include:

Radionuclide	Droplet (mSv/h per kBq)		Uniform (mSv/h per kBq)	
	ICRP38	ICRP107	ICRP38	ICRP107
Cf-252	5.11E-04	1.91E-01	7.24E-04	2.75E-01
Pu-239	4.00E-04	8.83E-04	5.56E-04	1.07E-03
Pu-240	1.03E-03	1.03E-03	1.43E-03	2.28E-03
Cm-244	8.78E-04	1.25E-03	1.23E-03	1.58E-03
Pu-238	1.16E-03	1.62E-03	1.62E-03	2.60E-03
U-233	6.23E-04	8.17E-04	8.54E-04	1.04E-03

Comparison – Conclusion

- Cannot expect the same change for both uniform and droplet geometry.
- For a uniform deposit geometry expect a reduction in the calculated dose from the published RRPDH dose conversion values to those calculated in VARSKIN 6.2.1. Not true for fuels (Pu-238, Pu-240, Am-243, U-233, U-234).
- For a droplet geometry no expectation can really be set.

Comparison – Conclusion

- Library selection is vitally important for Cf-252. Also important for Pu-238, 239, 240, and Cm-244 where energy differences can cause significant changes.
- Main reasons for non-library differences are:
  - Update to photon dosimetry model (VARSKIN 4).
  - Update to the electron dosimetry model (VARSKIN 5).
  - Update to Monte Carlo backscatter model (VARSKIN 5).

Questions?