



OSU

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VARSKIN

A software package to estimate ionizing radiation dose to layers of the skin resulting from hot-particle exposure.




10 CFR 20.1201 Occupational dose limits for adults.

(a) The licensee shall control the occupational dose to individual adults ...


(2) The annual limits ... are:

- (i) A lens dose equivalent of 15 rem (0.15 Sv), and
- (ii) A shallow-dose equivalent [to skin] of 50 rem (0.5 Sv) ...

(c) ... The assigned shallow-dose equivalent must be the dose averaged over the contiguous 10 square centimeters of skin receiving the highest exposure. The deep-dose equivalent, lens-dose equivalent, and shallow-dose equivalent may be assessed from surveys or other radiation measurements for the purpose of demonstrating compliance ...

[56 FR 23396, May 21, 1991, as amended at 60 FR 20185, Apr. 25, 1995; 63 FR 39482, July 23, 1998; 67 FR 16304, Apr. 5, 2002; 72 FR 68059, Dec. 4, 2007]

Regulation



- VARSKIN was originally developed nearly 30 years ago (1987) to allow the NRC to confirm skin-dosimetry submitted by licensees
 - intended as a tool for calculating tissue dose at depth resulting from radiological contamination of skin
- The highest localized skin dose will be realized when a “hot particle” exposes the various layers of skin tissue
- Five different source configurations are available
- Electron and photon dose calculations for 838 nuclides

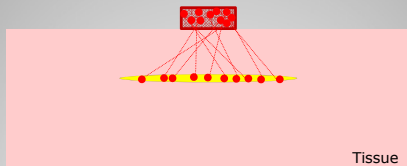
Development



- VARSKIN (1987)
- VARSKIN Mod 2 (1992)
 - → SADDE calculations added
- VARSKIN 3 (2006)
 - → volumetric-source backscatter factors
 - → basic photon model added
- VARSKIN 3.1 (2009)
 - → correction of error in photon energy database
- VARSKIN 4 (2011) varskin v4
 - → rigorous treatment of photon dosimetry
 - → no longer a need for code “installation”
- VARSKIN 5 (2014) varskin v5
 - → overhaul of energy-loss assumptions for electron dosimetry

History





Tissue

Point kernel



- Photon dosimetry considers:
 - point-kernel methodology
 - with secondary charge buildup, attenuation, and off-axis scatter
 - multiple source geometries
 - point, disk, cylinder, sphere, slab
 - skin dose calculated to an infinitely thin disk at a user-specified depth
 - averaging areas between 0.01 and 100 cm²
 - variable dose averaging techniques
 - 2D averaging areas (regulatory compliance)
 - 3D averaging volumes (detector simulation)

Photon model



The VARSKIN point-kernel photon dosimetry model:

$$\dot{D}(d, \theta) = E_0 \cdot \frac{S}{4\pi d^2} e^{-\mu d} \cdot \frac{\mu_{tr}}{\rho} \cdot f_{cpo}(d, E) F_{oa}(\theta, E)$$

Source Strength (S), Material Attenuation (μ), Buildup Correction (f_{cpo}), Photon Energy (E_0), Geometric Attenuation ($4\pi d^2$), Probability of Energy Transfer (μ_{tr}/ρ), Off-axis Correction (F_{oa})

Elements of the photon model



- Electron dosimetry considers:
 - Point-kernel methodology
 - Energy absorption distributions from the original beta emission spectrum
 - including conversion electrons and Auger electrons at their proper energy
 - no use of the "dummy" tritium distribution
 - resulting in a more appropriate electron energy spectrum incident on the skin
 - Kinetic energy loss is better estimated through enhanced
 - energy scaling
 - range/depth scaling
 - A new backscatter correction model

Electron model




The VARSKIN point-kernel electron dosimetry model:

$$\dot{D}_\beta \left[\frac{\text{Gy}}{\text{sec}} \right] = \frac{A \left[\frac{\text{dis}}{\text{sec}} \right] \cdot Y \bar{E} \left[\frac{\text{J}}{\text{dis}} \right] \cdot F_\beta}{4\pi \cdot \rho \left[\frac{\text{kg}}{\text{cm}^3} \right] \cdot r^2 \left[\text{cm}^2 \right] \cdot X_{90} \left[\text{cm} \right] \cdot BSCF}$$

Labels in the diagram:

- Source Strength: A
- Electron Energy Distribution: $Y \bar{E}$
- Normalized Depth-Dose Distribution: F_β
- Tissue Density: ρ
- Dose Depth: r^2
- 90% of Electron Range: X_{90}
- Backscatter Correction: $BSCF$


Elements of the electron model



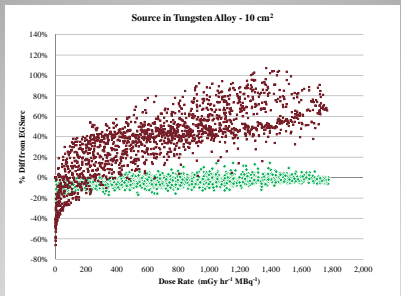
- Hot particle on the skin:
 - Slab geometry assumed
 - 999 x 150 x 14 μm thick
 - density of 7.2 g/cm^3
 - 156 kBq of ^{60}Co
- Dose rate over 1 cm^2 @ 7 mg/cm^2

	Electrons	Photons	Total (rad/hr)
VARSKIN Mod 2	9.77	-	9.77
VARSKIN 3	8.65	1.53	10.2
VARSKIN 3.1	8.65	0.840	9.49
VARSKIN 4	8.65	0.364	9.01
VARSKIN 5	10.5	0.364	10.9

Results by version




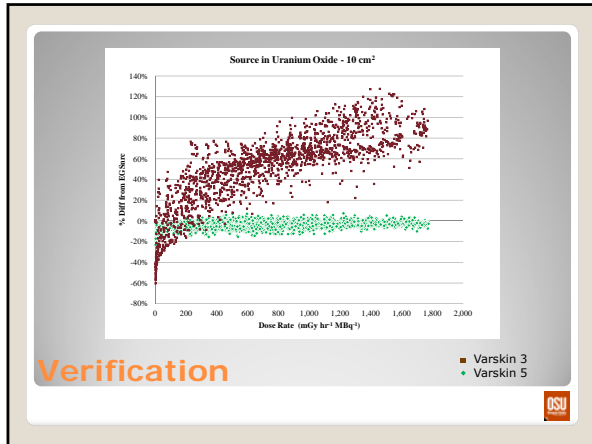
Source in Tungsten Alloy - 10 cm^2



Verification

- Varskin 3
- Varskin 5



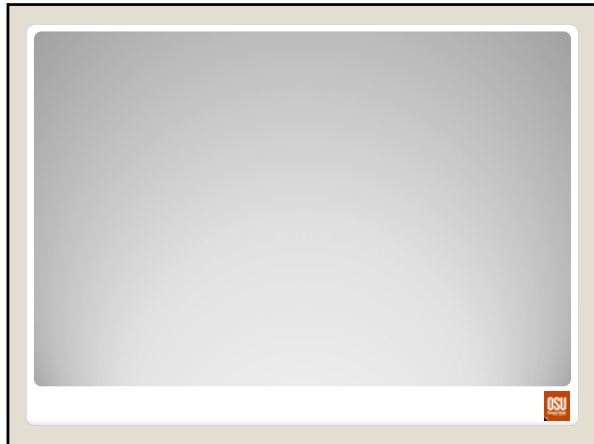


- A User's Group is being initiated, and ... with continued funding, will include:
 - FAQs
 - Issue tracking
 - News/documentation
 - User wiki
 - Topical forums
 - Webinars
 - VARSKIN will become part of the RAMP
 - Currently working out:
 - software distribution protocol
 - software support, maintenance, etc.
 - And, on the side ...
- Next steps**
- OSU

... we have developed a skin dosimeter that will conduct simultaneous dose estimation at 3 tissue depths.

US Patent No. 7,964,848
(85% to completion)

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Nuclide	Depth in Tissue, cm											
	0.004				0.005				0.007			
	V5	V4	M	K	V5	V4	M	H	V5	V4	M	K
Co-57					0.318	0.00	0.360	0.320	0.266	0.00	0.290	0.29
Ga-67	2.97	0.00	3.34	3.21					1.14	0.00	1.19	1.09
Tc-99m	0.988	0.00	1.25	1.22	0.921	0.00	1.12	1.14	0.780	0.00	0.900	0.890
In-111									1.10	0.00	1.36	1.39
I-123									1.13	0.00	1.33	1.35
I-131									4.87	5.10	6.30	6.33
Tl-201	2.01	0.00	2.20	2.24					0.886	0.00	1.27	0.970

Note: Dose rates in rad/hr. (M) McGuire and Dalrymple; (H) Henson; and (K) Kocher.
 McGuire; Dalrymple. Beta and electron dose calculations to skin due to contamination by common nuclear medicine radionuclides. Health Phys. 1990.
 Henson, P. W. A note on some aspects of skin contamination by certain radionuclides in common use. Br. J. Radiol. 45: 938-943; 1972
 Kocher, D. C.; Eckerman, K. F. Electron dose-rate conversion factors for external exposure of the skin from uniformly deposited activity on the body surface. Health Phys. 53:135-141; 1987

Depth dose comparisons


Nuclide	0.008				0.01			
	V5	V4	M	K	V5	V4	M	H
Co-57					0.180	0.00	0.190	0.170
Ga-67	0.622	0.00	0.530	0.590				
Tc-99m	0.703	0.00	0.790	0.760	0.537	0.00	0.580	0.630
In-111								
I-123								
I-131								
Tl-201	0.624	0.00	0.970	0.680				

Note: Dose rates in rad/hr. (M) McGuire and Dalrymple; (H) Henson; and (K) Kocher.
 McGuire; Dalrymple. Beta and electron dose calculations to skin due to contamination by common nuclear medicine radionuclides. Health Phys. 1990.
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... continued

Averaging area:		1 cm ²	Nuclide: Co-60		0.05 cm water sphere
Depth (cm)	MCNP5 Water Dose (mGy/hr/MBq)	VARSKIN 5 Water Dose (mGy/hr/MBq)	VARSKIN 4 Water Dose (mGy/hr/MBq)		
0.003	396	385	375		
0.005	297	281	271		
0.007	238	216	205		
0.01	167	153	142		
0.012	133	122	112		
0.015	96.9	85.1	75.2		
0.02	58.0	46.6	39.1		
0.03	18.1	14.0	9.97		
0.05	1.67	0.961	0.168		
0.1	0.00	0.00	0.00		

Water Sphere



Averaging area:		1 cm ²	Nuclide: Co-60		0.05 cm iron sphere
Depth (cm)	MCNP5 Iron Dose (mGy/hr/MBq)	VARSKIN 5 Iron Dose (mGy/hr/MBq)	VARSKIN 4 Iron Dose (mGy/hr/MBq)		
0.003	59.2	58.7	48.7		
0.005	46.9	42.9	35.0		
0.007	38.7	32.9	26.6		
0.01	26.7	23.2	18.4		
0.012	21.8	18.6	14.5		
0.015	15.9	12.9	9.70		
0.02	9.77	7.04	5.04		
0.03	3.12	2.10	1.28		
0.05	0.479	0.144	0.0213		
0.1	0.00	7.64E-06	0.00		

Iron Sphere

