THE NEW *var*SKIN+ WOUND MODEL

RENAISSANCE CODE DEVELOPMENT

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OUTLINE

- Historical Wound Experience
- Wound Types
  - absorption by type
- Shallow and Local Dosimetry
- NCRP 156 Biokinetic Wound Model
  - default transfer rates
  - examples of biokinetic modeling results
  - dose coefficients for systemic uptake
- First glimpse of Wound Dose 1.0

THE NCRP 156/ISO 20031 "WOUND MODEL" CONSISTS OF THREE CALCULATIONS TO BE EXECUTED GIVEN THE INTRODUCTION OF RADIOACTIVITY INTO THE BODY DUE TO A SKIN WOUND

(1) SHALLOW DOSE EQUIVALENT (@ 7 mg/cm^2)

(2) LOCAL DOSE EQUIVALENT (TO TISSUE)

(3) ORGAN/EFFECTIVE DOSE EQUIVALENT (SYSTEMIC UPTAKE)

HISTORICAL WOUND EXPERIENCE

- Industrial
  - vast majority of contaminated wounds involved actinides
  - > 90% occur in hands and arms, primarily fingers
  - ~ 90% involve punctures and chemical burns
- Military
  - embedded U and Pu compounds/fragments
- Medical
  - needle sticks in radiopharmaceutical labs
  - accidental injections of Thorotrast® (^{232}Th)

WOUND TYPES & POST-INJURY (1 DAY) % ABSORPTION

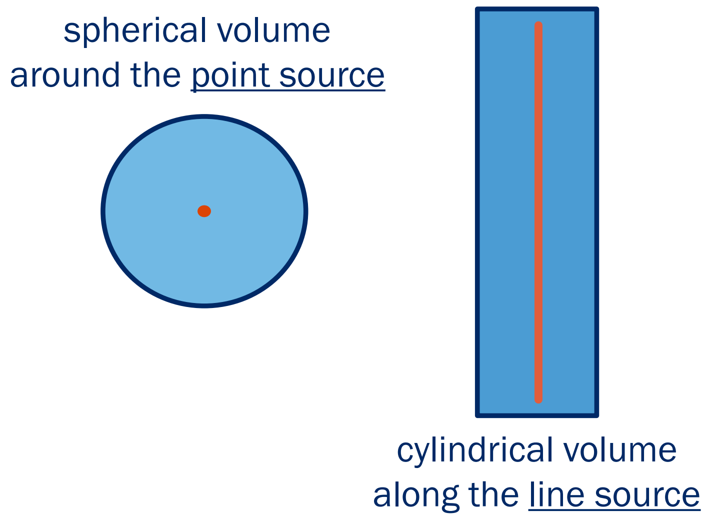
- Intact skin
- Burns
  - thermal
  - chemical
  - radiological
- Abrasions
- Lacerations
- Punctures
  - subcutaneous (s.c.)
  - intramuscular (i.m.)
- i.v. Injections

Radionuclide	Intact skin	Abrasion	Laceration	s.c. Puncture	i.m. Puncture
I-131	2.5	80	93	-	90
Cs-137	2.1	92	95	98	92
Sr-85	2.4	35	49	-	-
Ba-140	-	-	-	95	96
Ce-144	0.15	3.0	2.0	9.0	28
Am-241	0.014	6.0	6.0	44	15
Po-210	0.013	0.5	10	-	26
Pu-239	0.017	-	0.7	-	22

NCRP 156 MODEL INCORPORATION

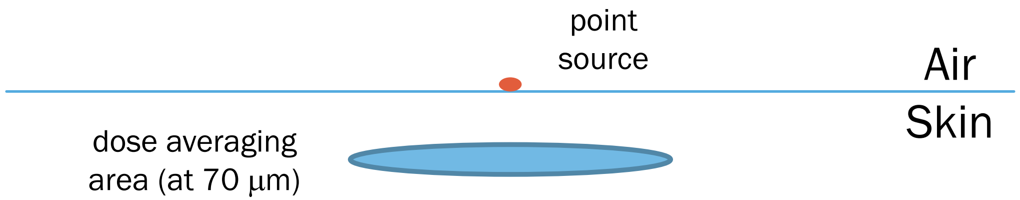
- INPUTS
  - nuclide, database (38 or 107) and activity
  - source geometry (point or line)
  - dose averaging depth (0.007 cm) and dose area (10 cm^2)
  - abraded thickness and wound depth
  - retention classification for the source term
    - weak, moderate, strong, avid, colloid, particle, fragment
- OUTPUTS
  - shallow, local and systemic committed dose equivalent

Source geometry options:



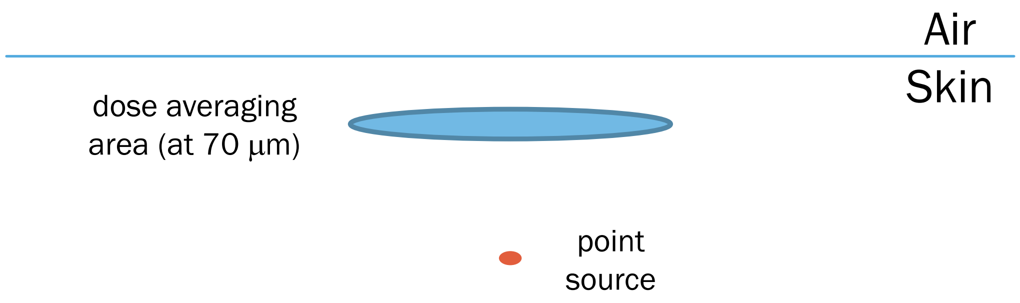
SHALLOW DOSIMETRY FOR A SURFACE SOURCE

This model would be retained for sources associated with burns or abrasions where the source essentially remains on the surface (wound depth = 0). The dosimetry is executed using current models/features of VARSKIN. As long as the source is not embedded beneath the skin surface, there is no alteration necessary to VARSKIN for determining *shallow dose equivalent*.



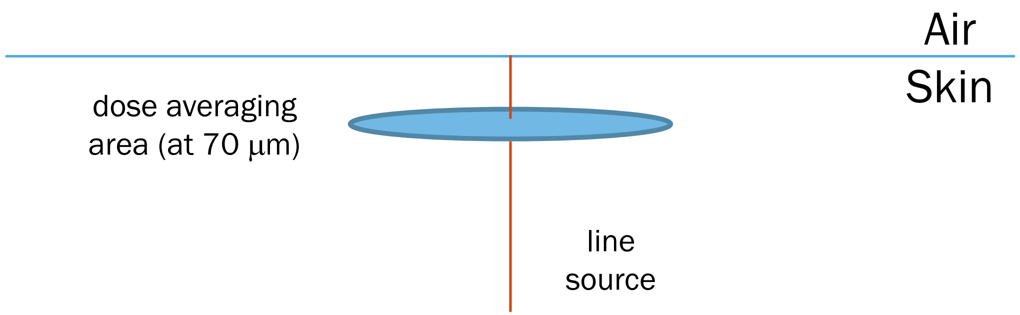
SHALLOW DOSIMETRY FOR AN EMBEDDED POINT SOURCE

This dosimetry is rather easily executed, as well. The VARSKIN calculation is modified by setting backscatter correction factors to unity (1). This results in a dose scenario of a homogeneous water medium. The source could be above or below the dose depth but is always beneath the skin surface.



SHALLOW DOSIMETRY FOR AN EMBEDDED LINE SOURCE

The dosimetry for a penetrating wound (i.e., line source) is a bit more complicated. The source is assumed to start at the surface and extend to the wound depth. This time, the point-source calculation from the previous slide is modified by integrating the point-dosimetry along the line source. Backscatter correction is based on proximity to the surface for each point integration. Depending on its length, the line source may or may not penetrate the dose averaging area at 70 microns.



LOCAL DOSIMETRY

- Local wound dosimetry is straightforward … energy absorbed per unit mass
- NCRP 156 states, "If the activity in the wound is known, … dose calculations may be limited to the volume [mass] of tissue actually irradiated …"
- But, "irradiated mass" can be ambiguous
- For radioactivity in the liver, the mass of liver is assumed to be uniformly irradiated
- If radioactivity were localized in skin, the irradiated mass is that which absorbs energy (range)

- For example, ^{32}P electrons have a range (95%) of about 0.54 cm in tissue, i.e., $\rho V = 6.7 \times 10^{-1}$ g

  whereas, ^{150}Gd alphas have a range of about 18 microns in tissue, i.e., $\rho V = 2.4 \times 10^{-8}$ g

LOCAL DOSIMETRY

- Dose for a 1 kBq point source of ^{32}P (E_{avg} = 0.695 MeV): LDE = 0.60 mSv/h
- And, a 1 kBq point source of ^{150}Gd (E_{α} = 2.75 MeV): LDE = 1.3 MSv/h
- But, a wound with both nuclides (i.e., using larger volume): LDE = 48 mSv/h

- However, with a standard volume (1 cm^3, r = 0.62 cm):
  - 1 kBq ^{150}Gd LDE = 31.7 mSv/h
  - 1 kBq ^{32}P LDE = 0.4 mSv/h
  - 1 kBq ^{150}Gd + 1 kBq ^{32}P LDE = 32.1 mSv/h

- All alpha and electron energy is assumed deposited with 1 cm^3
  - good assumption for 95% absorption until about E_e > 2 MeV

LOCAL DOSIMETRY FOR AN EMBEDDED SOURCE

Electron dosimetry:

$$D_e = k\frac{A\,\tau\,w_{r_e}}{\rho V}\int_0^{E_{max}} N_e(E)dE \qquad where\ \tau = residence\ time$$

Alpha dosimetry:

$$D_\alpha = k\frac{A\,\tau\,w_{r_\alpha}}{\rho V}\sum_i Y_i\,E_i \qquad including\ recoil\ energy$$

Photon dosimetry:

$$D_\gamma = k\frac{A\,\tau\,w_{r_\gamma}}{\rho V}\sum_i Y_i\,E_i\,f_i \qquad where\ \ f_i = \frac{\mu_{en_i}}{\mu_i}(1 - e^{-\mu_i r})$$

$$V_{point} = \pi r^3 = 1\ cm^3$$

$$V_{line} = \pi r^2\left(L + \frac{4}{3}r\right)$$

$$r = 0.62\ cm$$
$$L = wound\ depth$$

BIOLOGICAL RESIDENCE TIME BY RETENTION CLASS

Class	Biological Half-life (d)	Biological Residence Time* (d)	Biological Residence Time (yr)
Weak	0.40	0.58	
Moderate	4.0	5.7	
Strong	150	210	0.58
Avid	560	810	2.2
Colloid	760	1,100	3.0
Particle	1,700	2,400	6.6
Fragment	110,000	150,000	410**

*time integral of triple-exponential wound retention; derived from NCRP 156 Table 4.11
**50-year maximum

BIOKINETIC MODELING RESULTS*

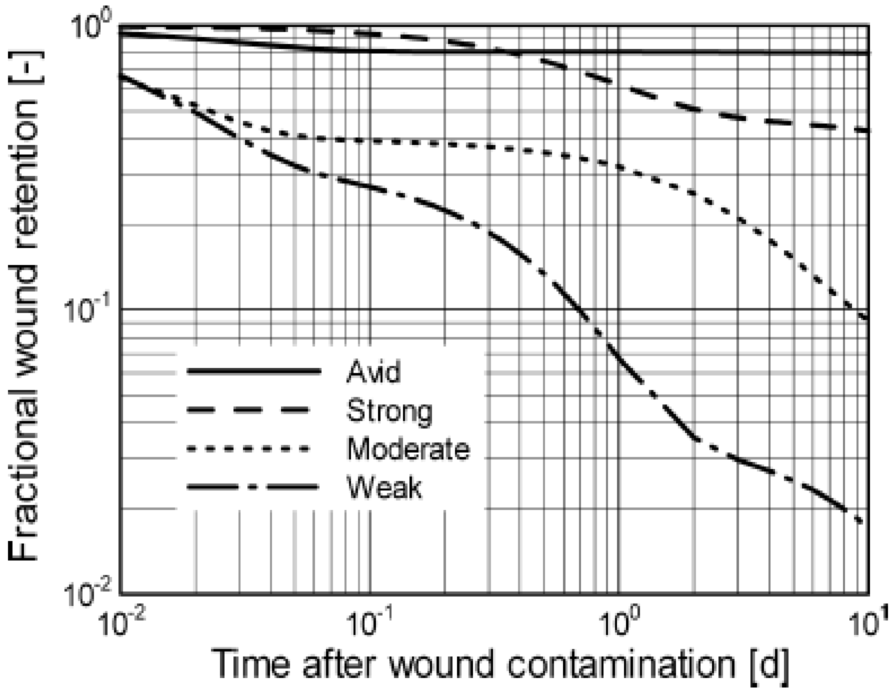


Fig. 2. Predicted wound retention of substances in four categories of soluble forms.

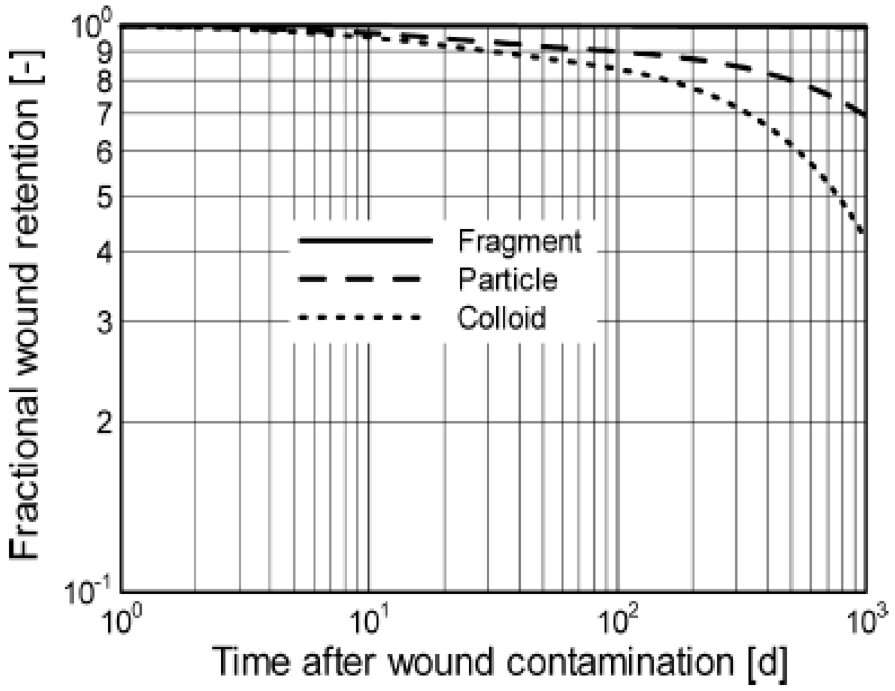
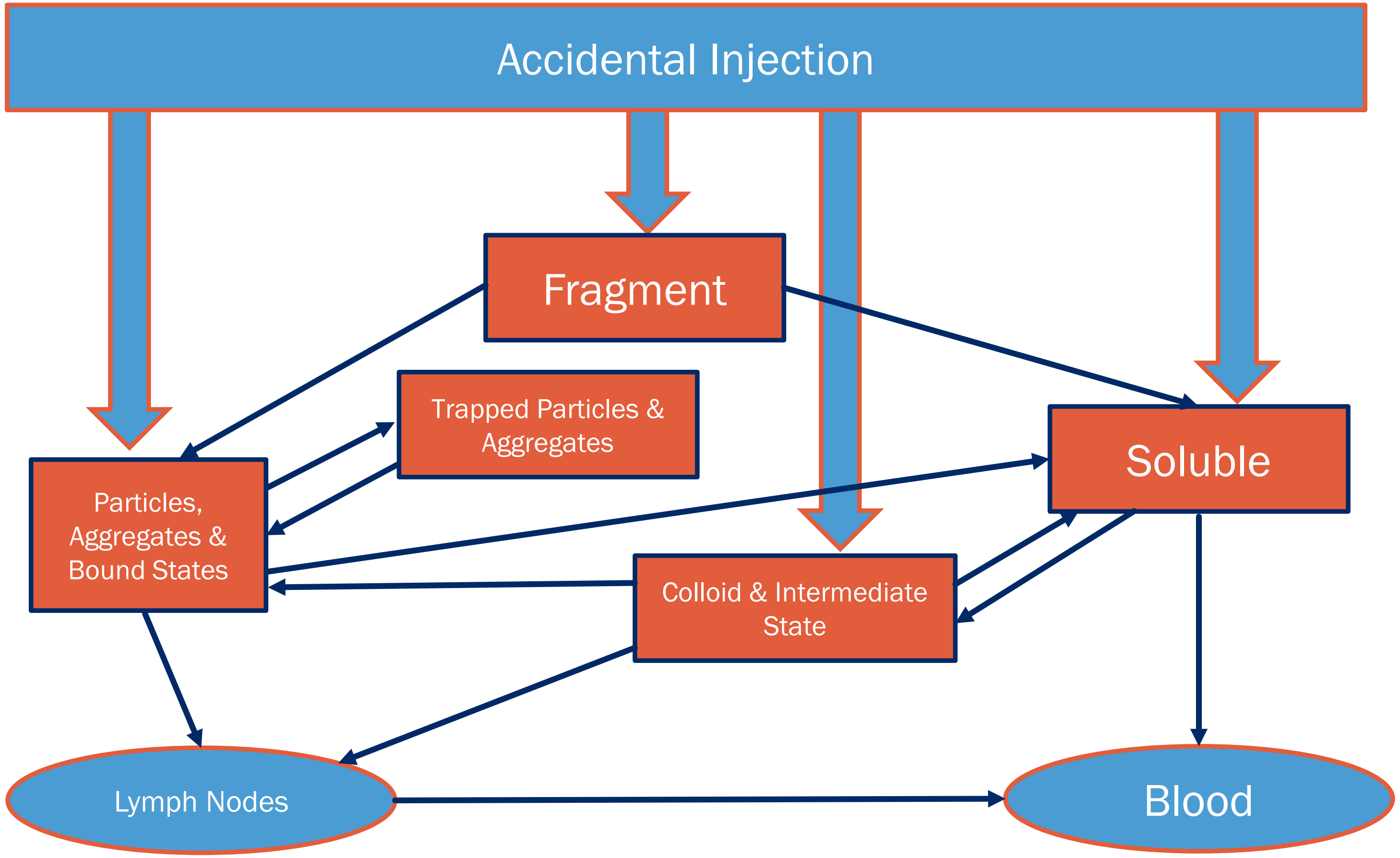


Fig. 3. Predicted wound retention of substances in Colloid, Particle and Fragment categories.

*Ishigure, N. Implementation of the NCRP wound model for interpretation of bioassay data for intake of radionuclides through contaminated wounds. *Journal of Radiation Research*. 50(3): 267-276; 2009.

RETENTION CATEGORIES OF NCRP 156 (2007) SYSTEMIC UPTAKE



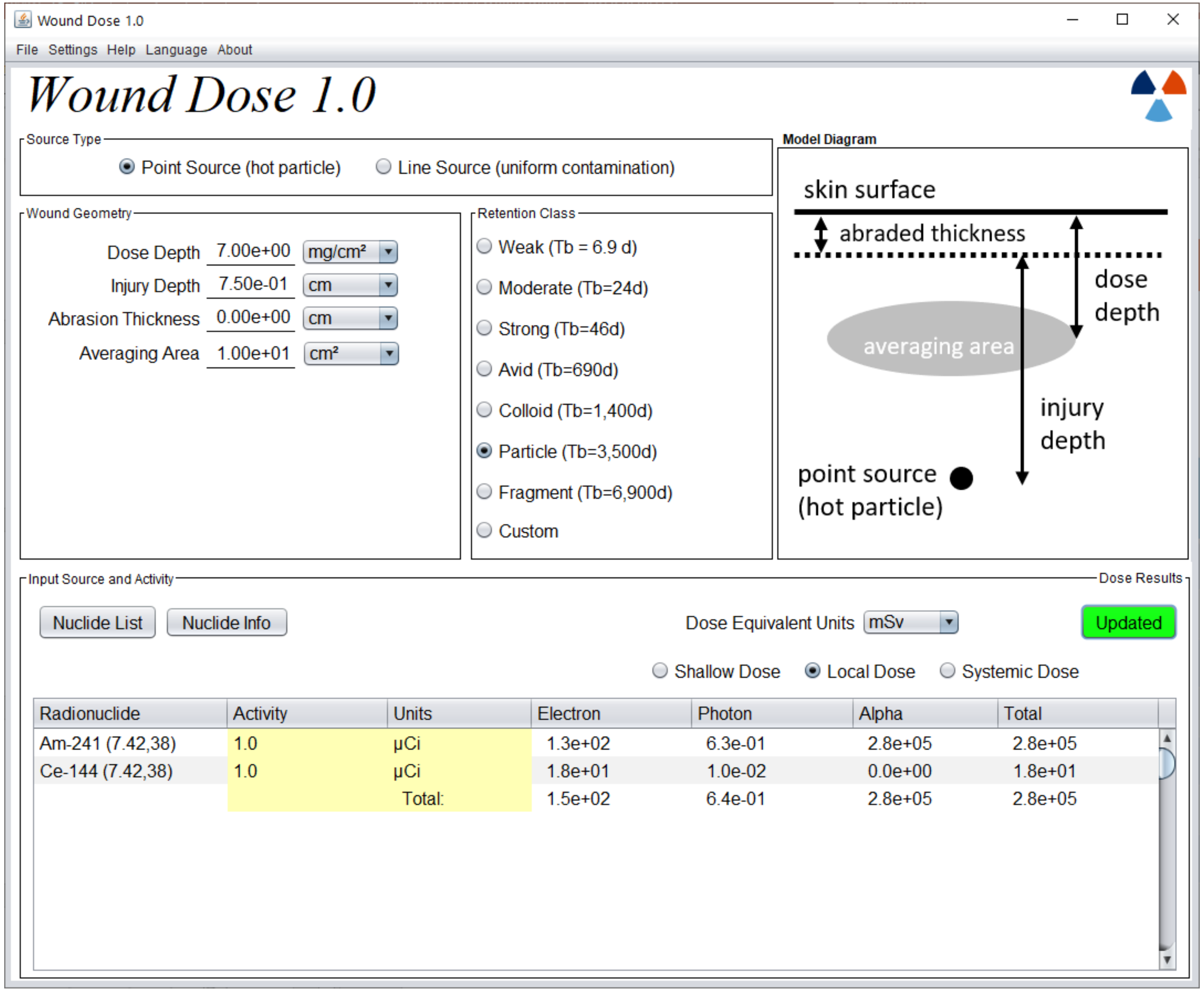
NCRP 156 SYSTEMIC MODEL DEFAULT TRANSFER RATES

Transfer Rates (d^{-1})	Weak	Moderate	Strong	Avid	Colloids	Particles	Fragments
Soluble to blood	45	45	0.67	7.0	0.5	100	-
Soluble to CIS	20	30	0.6	30	2.5	-	-
CIS to soluble	2.8	0.4	0.024	0.03	0.025	-	-
CIS to PABS	0.25	0.065	0.01	10	0.05	-	-
CIS to lymph nodes	0.00002	0.00002	0.00002	0.00002	0.002	-	-
PABS to soluble	0.08	0.02	0.0013	0.005	0.0015	0.0002	-
PABS to lymph nodes	0.00002	0.00002	0.00002	0.00002	0.0004	0.0036	0.004
PABS to TPA	-	-	-	-	-	0.04	0.7
TPA to PABS	-	-	-	-	-	0.0036	0.0005
Lymph nodes to blood	-	-	-	-	0.03	0.0006	0.03
Fragment to soluble	-	-	-	-	-	-	-
Fragment to PABS	-	-	-	-	-	-	0.008

WOUND DOSE COEFFICIENTS FOR SYSTEMIC UPTAKE

- For 38 radionuclides, Toohey et al. (2014)* contains tables of:
  - compartment transfer rates by retention class
  - ODE coefficients by retention class
  - EDE coefficients by retention class
  - derived regulatory guides and clinical decision guides for a subset of radionuclides
- For example, each nuclide (^{241}Am in this case) has 7 effective dose coefficients [x10^{-4} Sv/Bq]:
  - Soluble 3.97 (weak) 3.96 (moderate) 3.91 (strong) 3.79 (avid)
  - Insoluble 3.80 (colloid) 2.23 (particle) 0.141 (fragment)

*Toohey, R.E; Bertelli, L.; Sugarman, S.L.; Wiley, A.L.; Christensen, D.M. Dose coefficients for intakes of radionuclides via contaminated wounds. *Oak Ridge Institute for Science and Education*. US DOE Contract No. DE-AC05-06OR23100. Oak Ridge, TN; Ver. 2, August 2014.


Wound Dose 1.0
File Settings Help Language About
Wound Dose 1.0
Source Type
Point Source (hot particle)
Line Source (uniform contamination)
Model Diagram
skin surface
abraded thickness
dose depth
averaging area
injury depth
point source (hot particle)
Wound Geometry
Dose Depth 7.00e+00 mg/cm²
Injury Depth 7.50e-01 cm
Abrasion Thickness 0.00e+00 cm
Averaging Area 1.00e+01 cm²
Retention Class
Weak (Tb = 6.9 d)
Moderate (Tb=24d)
Strong (Tb=46d)
Avid (Tb=690d)
Colloid (Tb=1,400d)
Particle (Tb=3,500d)
Fragment (Tb=6,900d)
Custom
Input Source and Activity
Dose Results
Nuclide List
Nuclide Info
Dose Equivalent Units mSv
Updated
Shallow Dose
Local Dose
Systemic Dose
Radionuclide | Activity | Units | Electron | Photon | Alpha | Total
Am-241 (7.42,38) | 1.0 | µCi | 1.3e+02 | 6.3e-01 | 2.8e+05 | 2.8e+05
Ce-144 (7.42,38) | 1.0 | µCi | 1.8e+01 | 1.0e-02 | 0.0e+00 | 1.8e+01
Total: | 1.5e+02 | 6.4e-01 | 2.8e+05 | 2.8e+05