THE NCRP WOUND MODEL: DEVELOPMENT AND APPLICATION

Raymond A. Guilmette\textsuperscript{1}
Patricia W. Durbin\textsuperscript{2}
Richard E. Toohey\textsuperscript{3}
Luiz Bertelli\textsuperscript{1}

\textsuperscript{1}Los Alamos National Laboratory
\textsuperscript{2}Lawrence Berkeley National Laboratory
\textsuperscript{3}Oak Ridge Associated Universities
Learning Objectives

• Describe the structure and use of the NCRP Wound Model
• Identify sources for wound model dose coefficients and retention factors
NEED FOR A WOUND MODEL

- Wounds relatively common in specialized plants in U.S.A. and Russia
  - 136 Pu wounds at Hanford by 1969
  - 429 Pu wounds at Rocky Flats Plant by 1967
  - 248 wounds at Mayak PA by 1994

- Relatively little reported biokinetic information on untreated workers in literature

- Can expect more wounds from decommissioning activities
PERSIAN GULF WAR AND DU

• “Friendly Fire” incidents involving DU (depleted uranium) penetrators and armored vehicles
• 39 soldiers on long-term follow up for DU contamination (12 in high DU group)
• Questions about the dosimetry and risk from embedded DU fragments
RADIOGRAPH OF VETERAN WITH EMBEDDED DU FRAGMENTS
DU FRAGMENT REMOVED SURGICALLY
STRATEGY FOR WOUND MODEL DESIGN

- Scientifically and mechanistically based
- Can extrapolate to elements without data
- Can couple to systemic models for bioassay
- Pragmatic and easy to implement

DESIGN BASIS

- Source characteristics
  - Physical
  - Chemical
- Wound characteristics
  - Foreign body reaction
THE NCRP WOUND MODEL

Accidental Injection

- Fragment
- Trapped Particles & Aggregates
- Soluble
- Colloid & Intermediate State
- Particles Aggregates & Bound State
- Lymph Nodes
- Blood
DEVELOPMENT OF DEFAULT CATEGORIES FOR SOLUBLE RADIONUCLIDES IN WOUNDS

• Data from 48 radionuclides injected as initially soluble radionuclides (mostly from studies at Crocker Labs, now LBNL)

• Retention classified according to chemical properties
  – Tendency for hydrolysis
  – Relationship with solubility product $K_{sp}$ (depends on chemical, pH, concentration/mass)

• In general, retention roughly proportional to hydrolysis potential
  – $1^{-} < 1^{+} < 2^{+} < 3^{+} < 4^{+}$
CATEGORIES OF WOUND RETENTION FOR SOLUBLE RADIONUCLIDES

• Weakly retained
  – Simple anions (I), oxo- and chloro-anions (Sb, Tc, As, W, Sb)
  – Monovalent cations (Rb, Cs)
  – Divalent cations (Ca, Sr, Ba, UO$_2^{2+}$)

• Moderately retained
  – Chemical analogs of above
  – Ag, Ra, V, Te, Os, Pt
CATEGORIES (continued)

• **Strongly retained**
  – Trivalent cations (Y, La, Ga, In, Cr, Nb)
  – Trivalent lanthanides
  – Ac, Pu (small masses < 0.2 µg), Am, Cm
  – Be, Po

• **Avidly retained**
  – Tetravalent cations (Zr, Sn, Th, Pu > 10 µg)
  – Pentavalent Pa
DEFAULT RETENTION GROUPS FOR SOLUBLE RADIONUCLIDES IN WOUNDS

<table>
<thead>
<tr>
<th>Weak</th>
<th>Moderate</th>
<th>Strong</th>
<th>Avid</th>
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Fraction Retained in Wound (%)

Time after Injection (days)
COMPARTMENTAL MODEL OF STRONG DATA

Fractional Retention (%)

Time after Injection (days)
BIOKINETICS OF RADIOACTIVE PARTICLES AND FRAGMENTS

- Few studies provide useful data for modeling
  - PuO$_2$ particles in rats (*Harrison et al.* 1978)
    - Avid retention - 97% at 28 d
  - Polymeric Pu in rats and mice (*Brues et al.* 1965)
    - Avid retention – 80% at 6 mo
  - PuO$_2$ in dogs (*Bistline* 1973)
  - Pu metal wire in rats and rabbits (*Lisco and Kisieleski* 1953)
    - Wire rapidly disintegrated into fragments
    - Accompanied by significant tissue reaction
  - DU fragments in rats (*Hahn et al.* 2001)
    - Fragments corroded and disintegrated with time
RETENTION OF COLLOIDAL Pu NITRATE IN DOGS (data from Bistline 1973)

The graph illustrates the fraction retained (%) over time after injection (days) for various data points, including Blood data, LN data, Wound data, Soluble, CIS, PABS, Wound fit, LN fit, and Blood fit. The data shows a significant decrease in retention over time, with the fraction retained decreasing exponentially.
MODEL FIT OF AIR-OXIDIZED Pu PARTICLES IN DOGS (CSU)

Fractional Retention (%) vs. Time after Injection (days)

- LN Data
- Systemic Data
- Wound Data
- Particles
- Trapped Particles
DU METAL FRAGMENTS IMPLANTED IN RAT MUSCLE
APPLICATION OF WOUND MODEL TO BIOASSAY INTERPRETATION

• Select $^{238}_{\text{U}}$ and three relevant default categories
• Couple wound model to ICRP 69 systemic biokinetic model
• Solve using AIDE dose assessment software (v.4; Bertelli)
U RETENTION IN WOUND SITE

![Graph showing the retention of U in wound site over time, with three curves labeled Weak, Particle, and Fragment.](Image)
U RETENTION IN KIDNEY

![Graph showing the retention of U in kidney over time. The graph plots kidney content (fraction of intake) against time (days) on a logarithmic scale. Three curves are shown: Weak, Particle, and Fragment. The Weak curve starts high and decreases rapidly, the Particle curve starts lower and increases before decreasing, and the Fragment curve starts lower and remains relatively constant.]
U EXCRETION IN URINE

![Graph showing the excretion of U in urine over time for different forms: Weak, Particle, and Fragment.](image-url)
SUMMARY AND CONCLUSIONS

• Wound model describes radionuclide behavior for:
  – Range of physical and chemical forms
  – Large number (48) of solubles
  – Fewer (4) insolubles
• Sound scientific basis in chemistry and biology
• Easy to use for bioassay interpretation
• Model proposed by INDOS/DOCAL for implementation in ICRP revision of occupation guidance on radiation protection from intakes of radionuclides
• Model report published as NCRP report 156 (2006)
Follow-on Tasks

• The Radiation Emergency Assistance Center/Training Site (REAC/TS) at ORISE has coupled the NCRP wound model to the ICRP biokinetic models for other elements to generate dose coefficients and intake retention/excretion factors.

• Data for 38 selected radionuclides were published in the May 2011 issue of Health Physics journal (Toohey et al., Health Phys. 100(5), 508-514, 2011.)

• Complete data tables are available online at http://orise.ornl.gov/reacts/resources/retention-intake-publication.aspx