Overview of Remediation Technologies for Radionuclides in Soil and Groundwater

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Remediation technologies operate at the intersection of:
- radionuclide characteristics
- the target problem
- remedy functionality
- remediation objectives
Outline

- Radionuclide characteristics related to remediation
- Considering end states and attenuation in remedy decisions
- Remedy technologies and approaches
- Remedy implementation

Discussion focused on
  - Uranium, Tc-99, Sr-90, I-129, tritium
  - Groundwater protection and groundwater remediation
Radionuclide Characteristics (Friend or Foe)

- **Half-life**
  - Shorter is better (when exposure is controlled)
    - Sr-90 or tritium compared to uranium, I-129, or Tc-99

- **Mobility (sorption)**
  - Very low mobility generally good
  - Medium or high mobility - depends on the situation
    - Attenuated transport can be helpful (vadose zone contamination) or problematic (P&T)
    - Secondary sources are problematic unless balanced by attenuation
Radionuclide Characteristics (Friend or Foe)

► Biogeochemical interactions

■ Helpful
  - Uranium and Sr-90 interactions with phosphate
  - Uranium silicate precipitates

■ Mixed
  - Uranium and I-129 (and Cr) interactions with carbonate
    ◆ Depends on location/extent
  - I-129 species transformation
    ◆ Depends on change in mobility and potential for attenuation/sequestration
  - Uranium and Tc-99 redox
    ◆ Depends on setting and role in a remedy

■ No interactions
  - tritium
Disposal Chemistry

Szecsody et al. 2013
Truex et al. 2014
Radionuclide Characteristics (Friend or Foe)

The Conceptual Site Model helps us decide:
- Friend or foe for risk and transport
- Friend or foe for remediation

Truex et al. 2017a
Considering End States and Attenuation in Remedy Selection

Site Data

Source Terms

Conceptual Model (nature and extent)

Systems-Based Assessment

MNA-style investigation (Attenuation/transport processes)

Refined Conceptual Model

Assess risk and appropriate end state

Remedial Strategy

Minimal impact

MNA?

Full remedy

Partial remedy

Enhancements and targeted actions
Remedy Technologies and Approaches

- Vadose zone
  - Attenuation
    - Consider transport processes in the vadose zone
  - Flux control (enhanced attenuation)
    - Physical stabilization
    - Hydraulic control
    - Biogeochemical stabilization
  - Extraction (e.g., excavation, soil flushing)
    - Cost/benefit
  - Groundwater treatment (e.g., phosphate)
    - Consider vadose zone source characteristics for groundwater impact

Dresel et al. 2011
Attenuation

Source and Natural Attenuation

Flux to Groundwater Resulting Plume

MNA in Groundwater
Source Source Flux Natural Attenuation Capacity

MNA for Vadose Zone/ Groundwater Systems

Vadose Zone Natural Attenuation
Source Source Flux Natural Attenuation Capacity

Adapted from Dresel et al., 2011

Truex and Carroll 2013
Truex et. al 2015a
Oostrom et al., 2016
Desiccation

Desiccation as hydraulic control

No action

Surface barrier only

Desiccation (40t-45d)/Surface barrier

Truex et al. 2017b
Geochemical stabilization - vadose zone

- Ammonia gas for uranium sequestration

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
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<tbody>
<tr>
<td>inject NH$_3$ and increase pH</td>
<td>dissolve minerals</td>
<td>precipitate and bind U</td>
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Almost all NH$_3$ partitions to water
95% N$_2$
5% NH$_3$

NH$_3$+NH$_4^+$+OH$^-$
pH $\sim$ 11.5
Dissolved, adsorbed, and carbonate mobile U

Ion exchange and mineral dissolution (including silicates)

pH decreases from buffering/loss of NH$_3$, stable precipitates bind/coat U so it is much less mobile

Cumulative uranium leached (µg)

- Untreated Sediment
- 5% Ammonia Treated

- 80% of total
- 20% of total

Szecsody et al. 2012
Uranium source zone

- Periodically rewetted zone
Geochemical stabilization - periodically rewetted zone

▶ Phosphate treatment for uranium
Remedy Technologies and Approaches

Groundwater

- Attenuation
  - EPA guidance

- Enhanced Attenuation and Source Control
  - Physical stabilization
  - Hydraulic control
  - Biogeochemical stabilization

- Extraction (P&T)
  - Cost/benefit

- Volumetric Treatment/Permeable Reactive Barriers
  - Scale, transport, attenuation
Carbonate interactions

- Uranium, iodate, and chromate co-precipitates with calcite

Cr-calcite observed in a Hanford field sediment

Truex et al. 2015b
Only near-river strontium is a risk to the river

Monitoring linked to remedy approach
Remedy Implementation

- Amendment distribution
  - Vadose zone gas phase
  - Phosphate mobility
  - Particles
  - Bioremediation amendments
Reductants

- ZVI
- SMI

Truex et al. 2011a
Truex et al. 2011b
Remedy Implementation

- Adaptive Site Management
  - National Research Council
  - ITRC
    - Remediation Management of Complex Sites
    - http://rmcs-1.itrcweb.org/

- Exit Strategies (P & T)
  - http://bioprocess.pnnl.gov/Pump-and-Treat.htm
References


