Sustainable Remediation Approaches Using a Common-Sense Approach to Enhanced Attenuation

Accelerating Progress and Reducing Cost

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Diverse Stewardship Challenges require...
Attenuation Based Remedies

- **Monitored Natural Attenuation**
  Cleanup strategy that relies on "a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater."

- **Enhanced Attenuation**
  Any type of intervention implemented in a source-plume system to sustainably increase the magnitude of attenuation by natural processes.

- **Diverse contaminants require…**
  - organic contaminants → degradation and mass removal.
  - metals and radionuclides → reduce mobility and/or toxicity
Technical frameworks… a key to success

Focusing Science on the Problem at Hand
Start with what is known
- Nature of source
- Contaminant Distribution
- Biogeochemical Conditions in plume
- Background Biogeochemical Conditions
- Geology and Hydrology
- General Contaminant Chemistry
Often know 80% to 90% of what is needed for Success
**Plume Dynamics**

<table>
<thead>
<tr>
<th>Source</th>
<th>EXPANDING</th>
<th>STABLE</th>
<th>SHRINKING</th>
<th>EXHAUSTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time evolution</td>
<td>I.</td>
<td>II.</td>
<td>III.</td>
<td>IV.</td>
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Time evolution of a plume if it undergoes attenuation

- **Plume status is controlled by the balance of source mass flux and attenuation capacity in plume**
- **Some of the “requirements” for MNA**
  - Source remediation to extent practicable
  - Plume poses minimal risk and remediation goals met in reasonable timeframe
  - Plume is stable or collapsing
  - Monitoring to assure attenuation mechanisms in place and sustainable
  - Triggers to implement contingency plans as needed
Simplified Mass Balance and Natural Attenuation

Chemical attenuation:
- Sorption
- Abiotic degradation

Biological attenuation:
- Aerobic
- Anaerobic

Maximum permissible flux to meet regulatory requirements

Physical attenuation:
- Dispersion
- Diffusion
- Advection

Flux from source zone following primary treatment

Progressive decrease in mass flux

Flux to compliance plane

Flux reduction due to natural attenuation processes
General Enhanced Attenuation Mass Balance Concept

Source treatment:
- Primary treatment
- Enhancements

Chemical attenuation:
- Sorption
- Abiotic degradation

Biological attenuation:
- Aerobic
- Anaerobic

Maximum permissible flux to meet regulatory requirements

Additional flux reduction due to enhancements (EA)

Progressive decrease in mass flux

Flux from source following primary treatment and enhancement

Flux from source following primary treatment

Flux reduction due to natural processes without intervention

Physical attenuation:
- Dispersion
- Diffusion
- Advection

Flux to compliance plane
a) simplified representations of a groundwater plume in space and time

expanding plume

stable / shrinking plume due to attenuation and/or remediation

b) potential remedial technologies

Source Removal and/or Treatment

Interdiction and Active Remediation

Enhanced Attenuation

Monitored Natural Attenuation
Continuum of Remediation Technologies

**Technology Class**

**Source Removal and/or Treatment**
- excavation
- in situ bioremediation
- thermally enhanced removal

**Interdiction & Active Remediation**
- pump and treat
- recirculation wells
- in situ bioremediation

**Enhanced Attenuation**
- in situ bioremediation
- permeable reactive barrier
- phytoremediation
- permeable biotreatment system

**Monitored Natural Attenuation**

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Enhanced Attenuation (EA)

A “Bridge” between Source Treatments and MNA

Developed by a team of the Interstate Technology and Regulatory Council (ITRC)
Enhanced Attenuation Decision Flowchart

Figure 2-1 of the ITRC Technical & Regulatory Guidance Document for Enhanced Attenuation of Chlorinated Organics

Also available on the Enhance Attenuation: Chlorinated Organics Team resource page at http://www.itrcweb.org.
Case Studies

• Mound OU1 (contaminated groundwater from former landfill)

• F-Area Groundwater at the Savannah River Site (contaminated groundwater from former seepage basins)

• Brainstorming for Tuba City (former uranium mill and tailings disposal site)
Mound OU1 Groundwater

- Source removal “complete” ✓
- Operating groundwater pump and treat ✓

- Transition groundwater remedy to Enhanced Attenuation using Structured Geochemical Zones
  - Relies on groundwater flow through succession of anaerobic and aerobic zones
  - Anaerobic zones stimulate rapid parent-compound degradation
  - Aerobic areas encourage rapid daughter-products degradation
  - Basis for using structured zones: relative degradation rate of various cVOCs under anaerobic and aerobic conditions
Mound Results

- Enhanced attenuation accelerated progress toward remedial objectives and reduced costs
- The “Core Team” of DOE and regulators will meet to consider the questions:

  ... “has the EA remedy effectively transitioned the site into monitored natural attenuation?” and “is attenuation likely to continue to be effective, timely, and sustainable?”

  If these criteria are met, then the site will be formally transitioned to MNA.
**SRS F Area Groundwater**

**Enhanced Attenuation – Using a Wall and Gate System**

### Basic Geochemistry
- Study of inter-related topics: solution-solid-contaminant interactions, potential treatment amendments, and long term stability of in-situ stabilized phases.

### Applied Lab and Field Studies
- Focus on natural and plume induced facies and the chemical dynamics at the leading and trailing edges of the plume.
- Confirmatory field studies.

### System Design and Optimization
- Development of innovative treatment reagents.

### Deployment
- In Situ Treatment using Wall and Gate for Combined Hydrologic and Geochemical Control.
- Installed barriers ("walls") to block plume and force water through treatment zones ("gates").
- Alkaline treatment solution periodically injected into the gate area to create permeable reactive treatment zone to immobilize contaminants.

### Problem: Groundwater Contamination from Seepage Basins
- 40 years of seepage basin operation resulted in low pH groundwater plume containing radionuclides and metals. 10 years of pump and treat had limited impact on the plume and cost over $12 million per year to operate.

### Tobacco Road “Sand”
- Refined geological conceptual model and identified target areas of opportunity for in situ treatment deployment.
- Active work with stakeholders and regulators to facilitate transition from baseline pump & treat system to innovative in situ treatment.

### Savings:
- $300M
Tuba City Mill Site

Where do contaminants go?
Linkage of hydrological and geochemical framework...

Where does water go?
Hydrological framework in an arid terraced setting – Tuba City Mill/Tailings.
Tuba City Mill Site – Brainstorming Ideas…

Groundwater Bypass?
Key Points

• Enhanced Attenuation Remedies represent a powerful strategy to address the diversity of DOE environmental challenges.
• Enhanced Attenuation Remedies support formulation of alternative end states and foster creative options for long term monitoring
• Enhanced Attenuation Remedies need to consider (and be consistent with) the biology, chemistry, geology, hydrology and other conditions and the projected biogeochemical evolution over time
• Many examples:
  – Hydrological and geochemical controls in arid environments that work together to limit the size of groundwater plumes and can extend plume flushing times
  – Geochemical conditions at the trailing edge of the plume that help stabilize contaminants
  – …