The Starting Point

- Innovative Treatment Technologies: Technologies whose routine use is inhibited by lack of data on performance and cost.
- 1990 Mandates/Drivers
  - Preference for treatment (Superfund Amendments and Reauthorization Act or SARA)
  - Move away from “dig and haul” capping
  - Permanence
  - Land Disposal Restrictions – In Situ
  - Very limited menu of treatment options
  - Soil: Incineration, maybe solidification
  - Groundwater: Pump and treat

Early Cleanups in Superfund

- Superfund Law Enacted in 1980 in response to a need to protect citizens from the dangers posed by abandoned or uncontrolled hazardous waste sites
- Superfund was a powerful law that resulted in immediate action at many priority sites
- The challenge was new, and the need for action prevailed
- Technical solutions were few, and we applied what we knew

Technology Innovation Directions: c 1990

- Treatment, soil (surface, vadose zone)
- Groundwater treatment, very limited options
- Characterization, not so much
- Bioremediation
  - Exxon-Valdez
  - Natural attenuation, hmm...
- Ex-situ treatments
  - Soil washing
  - Solvent extraction
  - Thermal desorption
  - Bioreactors

RD&D: Many Options

- U.S. EPA: Superfund Innovative Technology Evaluation (SITE) Program
- Department of Energy, EM-50
- Department of Defense
- State programs
- Non-profit, private sector
  - NETAC
  - PERF
- Cost and performance information at a premium

<table>
<thead>
<tr>
<th>The Starting Point</th>
<th>Containment</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Remedies</td>
<td>75%</td>
<td>25%</td>
</tr>
<tr>
<td>Groundwater Remedies</td>
<td>90%</td>
<td>1%</td>
</tr>
</tbody>
</table>
FRTR Direction: 1990’s
- Sharing information, information resources
- Better information for decision makers
- Demonstration projects
- Information exchange
- Public-private partnerships
  - Remediation Technology Development Forum
  - Clean Sites
- Technology testing centers
- Leveraging investment
- Biggest focus on remediation

Evolution of Technology: 1995-2005
- Treatment trains
- Platforms vs. individual technologies
- Greater focus on groundwater, broader use of alternative technologies
- RD&D money, a shrinking pie
- Emerging concepts
  - Triad
  - Optimization
  - Reuse, land revitalization
  - Building library of cost and performance information, case studies

Evolution of Technology: 2005-Present
- Big growth in Brownfields, land revitalization directions
- Maturation of Triad concepts: approach vs. technologies
- Maturation of optimization
  - Beyond RSE, LTMO
  - Beyond pump and treat
- Growth and maturation in source treatment
  - Thermal approaches
  - Oxidation
- Leveraging investment
- Biggest focus on remediation

Superfund Remedies for Sources
- Remedies often selected and applied in combination
- For example, over 30% of treatment remedies were selected with other types of remedies
- We now have a rich mix of remedies available and mature consulting and engineering sector to implement them

In Situ Source Treatment Technologies at Superfund Sites
- About 45% of treatment remedies for source control are currently in situ (in place)
- We are seeing fewer developments in new technologies, and more innovation in design, construction and operation of commercial technologies
- More aggressive remedies used to tackle source areas (such as in situ thermal treatment, chemical oxidation)
- Often coupled with groundwater remedies, treatment and non-treatment

In Situ Source Treatment Technologies at Superfund Sites

<table>
<thead>
<tr>
<th>Technology</th>
<th>Total</th>
<th>Percent 2009-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Vapor Extraction</td>
<td>25</td>
<td>14%</td>
</tr>
<tr>
<td>Chemical Treatment</td>
<td>17</td>
<td>10%</td>
</tr>
<tr>
<td>Stabilization/Stabilization</td>
<td>11</td>
<td>6%</td>
</tr>
<tr>
<td>Multi-Phase Extraction</td>
<td>9</td>
<td>5%</td>
</tr>
<tr>
<td>In Situ Thermal Treatment</td>
<td>7</td>
<td>4%</td>
</tr>
<tr>
<td>Rejuvenation</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>Subaqueous Reactive Cap</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Flushing</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Fracturing</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Phytoremediation</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total for In Situ</strong></td>
<td>79</td>
<td><strong>45%</strong></td>
</tr>
</tbody>
</table>

- Total Groundwater Decision Documents = 1,912
25 Years of Technology Innovation: 1990-2015

Dan Powell-3

Groundwater Remedy Types Recently Selected in Superfund

<table>
<thead>
<tr>
<th>Remedy Type and Technologies</th>
<th>Total (FY04-10)</th>
<th>Percent (FY04-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Pump and Treat</td>
<td>46</td>
<td>12%</td>
</tr>
<tr>
<td>In Situ Treatment of Groundwater</td>
<td>78</td>
<td>21%</td>
</tr>
<tr>
<td>Bioremediation</td>
<td>49</td>
<td>13%</td>
</tr>
<tr>
<td>Chemical Treatment</td>
<td>27</td>
<td>7%</td>
</tr>
<tr>
<td>Air Sparging</td>
<td>14</td>
<td>4%</td>
</tr>
<tr>
<td>Permeable Reactive Barrier</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>In-Situ Air Sparging</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>Multi-Phase Extraction</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>MINP of Groundwater</td>
<td>56</td>
<td>15%</td>
</tr>
<tr>
<td>Groundwater Containment (VEB)</td>
<td>6</td>
<td>2%</td>
</tr>
<tr>
<td>Engineering (constructed)</td>
<td>9</td>
<td>2%</td>
</tr>
<tr>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Groundwater</td>
<td>177</td>
<td>49%</td>
</tr>
<tr>
<td>Institutional Controls</td>
<td>175</td>
<td>48%</td>
</tr>
<tr>
<td>Alternative Water Supply</td>
<td>13</td>
<td>4%</td>
</tr>
<tr>
<td>Engineering Control</td>
<td>2</td>
<td>1%</td>
</tr>
</tbody>
</table>

- Groundwater pump and treat still common, but we see more in situ treatment remedies.
- Monitored natural attenuation is used either alone or in combination
- Concept of “adaptive management” gaining ground. Actively monitoring operating systems to determine optimal transition time and place between remedy components

U.S. Contaminated Site Programs: We Still a Lot of Remediation Work to Do

- We have made great progress cleaning up contaminated sites but...
- National Academies of Sciences estimates 126,000 sites across U.S. still have contaminated groundwater, and their closure expected to cost at least $110 billion to $127 billion
- We continue to invest over $8 billion a year in remediation (USEPA, EBJ)
- We have opportunity to take lessons learned over the past decades, and apply innovations and best management practices to future sites

Moving Forward

- Focusing and pursuing site cleanup needs
  - Specifics are important
  - Beyond contaminant/media
  - Clearly stating need
  - Providing performance metrics in statement of need
  - Characterization tools – focus on decisions, decisionmakers
  - Need a path forward
    - If we decide we need it, what are we going to do about it?
    - Funding options
    - Map
    - Leverage
    - Path to site use

Evolution of Technology: Moving Forward

- High resolution site characterization approaches
  - Many data points
  - An evolving conceptual site model
- Data management tools and visualization of data
- Green and Sustainable Remediation
  - Approaches
  - Components
  - Energy use, GHGs and climate change adaptation
  - Addressing complexity of sites/“big” sites
  - Bioavailability

Example of Needs Statement

Monitoring Technologies c. 2007

- Air Emissions Monitoring - Continuous emissions monitors for thermal hazardous waste treatment systems; remote sensing for fugitive monitoring of fugitive emissions
- Characterizing and Monitoring Mining Sites - Monitoring technologies for mining waste sites
- Contaminated Sediment Characterization - Sampling and analytical technologies for potentially contaminated sediments
- Field Methods - Screening for dissolved contaminant detection of perchlorate in groundwater
- Indoor Air Quality - Monitoring vapor intrusion into buildings
- In-Situ Monitoring Systems - Sensor technologies for long term monitoring of groundwater; treatment system performance; leak detection for small municipal landfills
- Laboratory Analytical Methods - New monitoring methods for total cyanide and cyanide speciation
- Monitoring Effectiveness of In-Situ Remedies - Monitors of natural attenuation and other in-situ systems
- Non-invasive Subsurface Chemical Detection Systems - Technologies for locating and monitoring DNAPL contamination; technologies for mercury and heavy metals in soils
- Underground Storage Tanks - Leak detection methods for underground storage tanks and pipes