Search and Destroy™
Intelligent MIP and Injection Integration For In Situ Treatment
In-Situ Remediation Success

Success is enough reagent cost effectively delivered in contact with contaminant for a long enough period of time to react effectively.

“contact with contaminant”
Contact - Basic Remediation

Monitoring Well Data

No Identification of Mass Distribution In Relation to Lithology

No Targeting of Contaminant Mass/lithology
Contact – Solid and DNAPL Challenges

- HARDEST TO TREAT
- EASIER TO TREAT
- HARDER TO TREAT

- DNAPL
- AIR
- WATER
- SOLID
- REBOUND
## Contact – Mass vs. Lithology Difficulty To Treat Matrix

### Contaminant Mass

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Hydrogeology</th>
<th>Mobile Dissolved (Degrades/Volatilizes)</th>
<th>Mobile Dissolved</th>
<th>Strongly Sorbed, Dissolved (Degrades/Volatilizes)</th>
<th>Separately LNAPL</th>
<th>Separately DNAPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous, Single Layer</td>
<td>1</td>
<td>1-2</td>
<td>2</td>
<td>2-3</td>
<td>2-3</td>
<td>3</td>
</tr>
<tr>
<td>Homogeneous, Multiple Layers</td>
<td>1</td>
<td>1-2</td>
<td>2</td>
<td>2-3</td>
<td>2-3</td>
<td>3</td>
</tr>
<tr>
<td>Heterogeneous, Single Layer</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Heterogeneous, Multiple Layers</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fractured Bedrock</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

1 = Least Difficult   4 = Most Difficult
Search and Destroy™ Remediation
Making Contact / Minimizing Costs

- Identify Contaminant Mass Location Vertically and Horizontally
- Identify Contaminant Mass Location In Relation To Lithology
- Contact Delivery
- Full Scale Performance

Search ➔ Destroy
Search and Destroy™ Stages

SEARCH

- Site Characterization
- Data Gap Analysis
- MIP Characterization

Technology Selection

- Target Injection Plan and Cost
- Pilot Testing

DESTROY

- 1st Full Scale Optimized Event
- MIP Rebound Trouble Shooting
- Additional Events

Risk Reduction 0% → x%
Delivery Systems / Pressure

Direct Push
- Bottom-Up or Top-Down tools (screens 1 to 5 feet) targeting of discrete lithologies

Injection Wells
- Injection wells
- Packer isolation of open bore holes

Fracturing
- Fracturing of tight formations

Injection Pressure
- Low to Moderate
- Low
- Low to High
- Moderate to High
Depth/Soils/Pressure/GPM

$IP = \text{Injection Pressure}$

$IGPM = \text{Injection Rate}$

$PV_I = \% \text{pore volume to be injected}$

$L = \text{Lithology}$

$DC = \text{Depth To Contamination}$

$R_{SP} = \text{Reagent Surfacing Potential}$

<table>
<thead>
<tr>
<th>$PV_I$</th>
<th>$L$</th>
<th>$DC$</th>
<th>$R_{SP}$</th>
<th>$IP$</th>
<th>$IGPM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>Sand</td>
<td>Deep</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>20%</td>
<td>Sand</td>
<td>Shallow</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>5%</td>
<td>Clay</td>
<td>Deep</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>5%</td>
<td>Clay</td>
<td>Shallow</td>
<td>High</td>
<td>Moderate</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
# Targeted DPT Delivery

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Tooling</th>
<th>Screen Lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous Sands</td>
<td>Bottom-Up</td>
<td>5 Feet</td>
</tr>
<tr>
<td>Heterogeneous Sands, Silts and Clays</td>
<td>Bottom- Up</td>
<td>1 Foot</td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>Bottom-Up or Top Down</td>
<td>1 Foot</td>
</tr>
<tr>
<td>Sands Over Clays</td>
<td>Bottom-Up</td>
<td>1 Foot</td>
</tr>
<tr>
<td>Clays Over Sand</td>
<td>Top -Down</td>
<td>1 Foot</td>
</tr>
</tbody>
</table>
Targeted DPT Delivery
MIP Integration
Into Targeted Injection Design
**Radius of Influence (ROI)**

\[
\text{ROI} = P_{\text{ROI}} + A/D_{\text{ROI}}
\]

ROI = pore volume ROI (ft) + advection/dispersion ROI (ft)

9 feet = 2 feet + 7 feet @ 60 days
ROI Realities

<table>
<thead>
<tr>
<th>Pore Volume ROI</th>
<th>Advection / Dispersion ROI</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent Per Location</td>
<td>Injection Volume as a % of Effective Pore Volume</td>
<td>Pore Volume ROI</td>
</tr>
<tr>
<td>500 gals</td>
<td>50%</td>
<td></td>
</tr>
</tbody>
</table>

- Additional ROI from Advection / Dispersion (Feet)
- Time Frame To Achieve Advection / Dispersion ROI (Days)
- 7 feet | 60 Days | 9 feet

- 60 days

Tight Soils
- Low Injection Pore Volumes
- Tighter Spacing
- Higher Reagent Concentrations

Permeable Soils / Flat Gradient
- Reagent Persistence
- May Exceed Fracture Pressure

Permeable Soils / Steep Gradient
- Requires High Injection Pore Volume
- Lower Residence Time
- Stay Below Fracture Pressure
Search and Destroy™ Stages

- Site Characterization
  - Data Gap Analysis
  - MIP Characterization
- Technology Selection
  - Target Injection
    - Plan and Cost
  - Pilot Testing
- 1st Full Scale Optimized Event
  - MIP Rebound
  - Trouble Shooting
  - Additional Events

Graph:
- X-axis: Risk Reduction
- Y-axis: Search and Destroy™ $
Destroy - Pilot Testing

- Ability To Get To Depth
- Injection Rates / Pressures
- Injection Volumes
- Mixing Rates
- Surfacings Identification / Mitigation
Destroy - Pilot Testing ROI Confirmation

- Core samples to verify pore volume ROI ($P_{ROI}$)
- Monitoring well sampling to determine ROI
Re-Search – Post Application Investigation

- Advanced Site Characterization Tools can be used after the remediation event to:
  - Trouble Shoot
  - Confirm Influence
  - Confirm Remediation
MIP Rebound Troubleshooting

Maximum PID Response

Contaminant Mass

PID Response vs Depth (ft)

MIP-1-CA  MIP-2-CA  MIP-3-CA
MIP Rebound Troubleshooting

Conductivity Response

- **Silts**
- **Sands**
- **Contaminant Mass**

Graph shows conductivity response over depth with lines representing MIP-1-CA, MIP-2-CA, and MIP-3-CA.
MIP Rebound Troubleshooting

Maximum PID Response

Depth (ft)

PID Response

TCE Treatment From Preferential Flow

Injection Well Screen

DPT Targeting of Remaining Contaminant Mass

MIP-1-CA

MIP-2-CA

From Preferential Flow

Injection Well Screen

DPT Targeting of Remaining Contaminant Mass

MIP-1-CA

MIP-2-CA

From Preferential Flow

Injection Well Screen

DPT Targeting of Remaining Contaminant Mass

MIP-1-CA

MIP-2-CA

From Preferential Flow

Injection Well Screen

DPT Targeting of Remaining Contaminant Mass
Search and Destroy™ Case Study

Vandenberg AFB, CA
Site 24
PCE Source Area
Versar / Irvine, CA
Site 24 – Vandenberg AFB
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Risk Reduction
- 0%
- x%

Search and Destroy™ $
Conductivity Response

MIP-4 at 25.5
South East ECD Greater than 7.6+E6, PID Greater than 3.6+E5
Top View ECD Greater than 7.6+E6, PID Greater than 3.6+E5
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Risk Reduction

Search and Destroy™ $
Pilot Testing
Destroy Full Scale Injection

Injection Data:
02/12/07 (pilot) 8,887 gals
04/30-06/04/07 (full scale – 28,334 gals
3% KMnO₄
Post Injection Results
Search and Destroy™ In Practice

- MWH – Denver, CO MIP/Pmag/TCE
- ADEQ - Holbrook AZ MIP/Persulfate / BTEX, DCA
- Mactec – Lowry AFB, CO MIP/Persulfate/ Carbon Tet
- Malcolm Pirnie – Kauffman Minteer Superfund, NJ MIP/Pmag/TCE
- URS – Dover AFB, DE MIP/EVO/TCE
- Tetra Tech – Denver, CO MIP/Pmag/TCE
- Battelle, North Island NAS MIP/Soybean Oil/TCE
- Arcadis, Sarasota FL – MIP/Persulfate / TCE
Questions

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