Outline

RTCD Overview

Project Summaries

- In Situ Real Time Groundwater Monitor
- In Situ Chemical Oxidation
- In Situ Bioremediation
- Horizontal Multiport Sampling and Injection Well
- High Resolution Site Characterization
Overview

RTCD has been active since May 2010

Purpose:
“...establish and maintain the capability to specifically target reductions in the long-term liability associated with NASA’s most challenging remediation sites.”

Accomplished by:

- Maintaining a database of deployed site remediation processes and conditions
- Researching potential emerging technologies while simultaneously looking for similar situations where these emerging technologies could be used
- Pursuing the most promising technologies with directed research, bench studies, pilot studies and demonstration projects
Overview

Provides independent, unbiased assessment of the current conditions and technologies.

- (Independent from the viewpoint that we are not tasked with any remediation implementation.)

Risks addressed are associated with the long-term environmental liability which includes:

- Cost
- Schedule
- Demonstration of support for technical impracticability (TI) waivers where warranted
Overview

Step I Opportunity Assessment
- Obtain data from HQ Center & Component Facilities Remediation Project Managers (RPMs)
- Standardize and compile data in centralized location (NETS Module)
- Conduct comprehensive evaluation of remedies based on analysis of data
- Identify sites/remedies of interest based on communicated need and/or exceptional remedy success or failure

Step II Planning
- Successful remedies:
  - Facilitate implementation at additional sites throughout NASA (tech transfer)
- Failed remedies and communicated needs:
  - Research alternative/innovative technologies/processes (unbiased screening)
  - Develop field demonstrations, pilot tests, and bench tests of viable alternative/innovative technologies/processes

Step III Partner Commitments
- Disseminate documents, data, ideas, etc. to HQ and RPMs and obtain stakeholder buy-in
- If buy-in is not obtained then return to Step II and develop revised strategy

Step IV Execute
- Coordinate & document the execution of field demonstrations, pilot tests, and bench tests.
- Conduct comprehensive evaluation of new technology/process performance
- Return to Step II

Opportunities to implement innovative site characterization technologies/processes and Green and Sustainable Remediation designs are considered at every step.

ITB’s Remediation Technology Collaboration Development (RTCD) process leads to in-depth understanding of remediation technology applicability to NASA’s most challenging cleanup sites.
Overview

- Screen Shot from the NETS Express RTCD Module
Overview

- RTCD payback is seen immediately in donated engineering services and product vendor materials.

<table>
<thead>
<tr>
<th>Demonstration / Pilot Test</th>
<th>POP</th>
<th>Direct Cost</th>
<th>Cost to NASA</th>
<th>In-Kind Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>In situ real-time measurement of TCE in groundwater (Area D)</td>
<td>9/11 - 11/11</td>
<td>$28,000</td>
<td>$0</td>
<td>($28,000)</td>
</tr>
<tr>
<td>In situ chemical oxidation of TCE in groundwater (Area G)</td>
<td>3/12 - 12/12</td>
<td>$184,300</td>
<td>$112,425</td>
<td>($71,875)</td>
</tr>
<tr>
<td>In situ bioremediation of TCE in groundwater (Area D)</td>
<td>8/13 - 6/14</td>
<td>$17,974</td>
<td>$0</td>
<td>($17,974)</td>
</tr>
<tr>
<td>HDD Installation of Multiport Sampling &amp; Injection Well (Area B)</td>
<td>7/14 - 7/14</td>
<td>$32,500</td>
<td>$24,500</td>
<td>($8,000)</td>
</tr>
<tr>
<td>In situ chemical oxidation of TCE in groundwater using horizontal multiport injection well (Area B)</td>
<td>9/14 - present</td>
<td>$64,750</td>
<td>$0</td>
<td>($64,750)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$327,524</strong></td>
<td><strong>$136,925</strong></td>
<td><strong>($190,599)</strong></td>
</tr>
</tbody>
</table>

- Long term payback will be seen in reduced cleanup times and cost.
In Situ Real Time Groundwater Monitor (September 2011)

Development and implementation of monitor that combines sampling and detection of contaminants in a single step with high sensitivity could reduce NASA’s site characterization and groundwater monitoring costs across all Centers and Component Facilities.

White Sands Test Facility:

- Plume is ~ 4 miles long, 2 miles wide, and up to 800 feet thick
- Over 100 active monitoring wells with 222 discrete zones being used to define the plume
- NDMA is health risk driver with cleanup target 4.2 ppt
- Expected to take at least several decades to a century achieve to cleanup
In Situ Real Time Groundwater Monitor

- Membrane-Extraction Ion-Mobility Groundwater Monitor was being developed by Oak Ridge National Laboratory under SERDP funding (ER1603) – currently unfunded

- Two wells at SSC, including one with low trichloroethylene (TCE) concentration/slow recharge rate (06-11 MW) and one with high TCE concentration/fast recharge rate (06-12 MW) were tested with various water depths and timings

- The monitor demonstrated a clear identification of chlorinated hydrocarbons in the wells and reasonably accurate quantification

- More development is needed to be reliable and totally usable in the field
In Situ Real Time Groundwater Monitor

- The analysis at various water depths suggested three TCE-concentration zones within the well.
- Evidence that where your sample collection tubing inlet is placed within the well matters.
In Situ Chemical Oxidation (March 2012 – December 2012)

- Some P&T systems have been operating for years and based on recent influent concentration data they have reached asymptotic conditions (cannot remove remaining residual contamination to achieve cleanup goals - a.k.a. “flat-lined”) or worse; influent concentrations are still increasing.
Project Summary

In Situ Chemical Oxidation

- Demonstrate and evaluate a commercially-available chemical oxidation system to treat TCE in situ and augment an existing P&T system at Stennis Space Center’s Area G.
In Situ Chemical Oxidation

Why EN Rx?

- EN Rx uses a proprietary sodium-based catalyst instead of iron with peroxide – “modified Fenton’s system” to generate hydroxyl radicals (strongest oxidizer)
- Long-lasting reaction (match mass flux)
- Safe for workers and utilities (slow reaction)
- Works in all subsurface conditions (any pH)
- “Complete package” (consultant and contractor in one - assessment, design, injection, reporting)
- Innovative low-energy delivery process (Continuous Injection System [CIS])
- Very eager and responsive
- Willing to donate in-kind services, materials, and equipment rental for a chance to work with NASA
Project Summary

In Situ Chemical Oxidation

- Innovative low-energy delivery process – Continuous Injection System (CIS)
In Situ Chemical Oxidation

- At the conclusion of the nine month study, levels of TCE and associated daughter products had dropped by more than 50 percent in ground water samples and were non-detect in the treated soils.
- SSC has deemed the demonstration successful and are assessing where the technology may be deployed next.
In Situ Chemical Oxidation

- Limited assessment of the area hydraulically up gradient of the initial pilot test location revealed that the contaminant mass has not been delineated.
- All parties agree that a complete delineation is required before injections resume.
- EN Rx has proposed a Performance Based Remediation (PBR) contract to achieve the project goal of closure levels throughout Area G (TCE to 5 μg/L in groundwater).
- A cost ceiling for the remediation phase will be proposed after the complete delineation of contaminant mass (April 2014).
In Situ Bioremediation (August 2013 – present)

- Some P&T systems have been operating for years and based on historical groundwater monitoring data, they have lost (or never had) containment and control of the contaminated groundwater plume.

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Date</th>
<th>TCE</th>
<th>Cis-1,2 DCE</th>
<th>VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-12MW</td>
<td>2007</td>
<td>69</td>
<td>12</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>1201</td>
<td>233</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>186</td>
<td>16</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>1259</td>
<td>177</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>1893</td>
<td>331</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>10/2012</td>
<td>1017</td>
<td>99</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>5/2013</td>
<td>154</td>
<td>13</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>7/2013</td>
<td>690</td>
<td>198</td>
<td>ND</td>
</tr>
</tbody>
</table>

Monitoring well 06-12MW, screened at 83 to 93 feet below ground surface, in WBZ 3, is not impacted by the extraction system.
In Situ Bioremediation

- Conduct a field demonstration (pilot test) and laboratory treatability study on groundwater from Water Bearing Zone (WBZ) 3 at Area D of SSC (monitoring well 06-12 MW) using bioremediation techniques.

Pilot test site characteristics:
- Anaerobic deep aquifer with dissolved phase TCE
- Little to no apparent residual source mass believed present
- Inaccessible to P&T system

Pilot test strategy:
- Biostimulation of native microbes
- Substrate (proprietary blend of nutrients) in fabric socks lowered into well
- Sampling / replacement about every 45 days
In Situ Bioremediation

- Microbial reductive dechlorination of trichloroethene (TCE) in groundwater often results in the accumulation of dichloroethenes (DCEs).
- Dehalococcoides mccartyi (Dhc) are the only known bacteria capable of dechlorination beyond DCE to non-toxic ethene.
Project Summary
In Situ Bioremediation

- Laboratory treatability study results (in-kind by CB&I, augmented with SDC-9™)

BioStryke® Faster, Safer, Complete Biotransformation of Greater Molar Mass of cVOC contaminants

Lactate did not yield complete biotransformation during evaluation period
In Situ Bioremediation

- Field demonstration resulted in 95% reduction in TCE
- Initial 85% decrease in cis-DCE; followed by 16x increase, confirming TCE biotransformation
- cis-DCE has since decreased 65%
- Vinyl Chloride and/or Ethene yet to be detected
- A larger scale pilot is being considered at Area E
Horizontal Multiport Sampling and Injection Well (July 2014 – present)

- ITB has observed a recurring theme at many of NASA’s cleanup sites; more site assessment/re-assessment is required before realistic expectations of remediation effectiveness can be determined.

Horizontal Directional Drilling (HDD)

- Offers the capability to characterize and treat contaminated soil and groundwater under existing structures with minimal interference to facility operations.
Horizontal Multiport Sampling and Injection Well

- An HDD installed congruent to typical horizontal lithology (e.g., installed just above a clay confining layer). Therefore they are far more useful than traditional monitoring wells or vertical injectors.
- EN Rx is developing a multiport groundwater sampling and injection well called Vertebrae™ and proposed a demonstration to fill in data gaps and potentially treat contamination under a building at SSC Area B.
**Project Summary**

**Horizontal Multiport Sampling and Injection Well**

<table>
<thead>
<tr>
<th>Well Construction Details 18-V1W</th>
<th>Analytical Results (in µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freon</td>
</tr>
<tr>
<td><strong>ID</strong></td>
<td><strong>Color</strong></td>
</tr>
<tr>
<td>18-V11W</td>
<td>white</td>
</tr>
<tr>
<td>18-V10C</td>
<td>cyan</td>
</tr>
<tr>
<td>18-V9T</td>
<td>tan</td>
</tr>
<tr>
<td>18-V8G</td>
<td>green</td>
</tr>
<tr>
<td>18-V7O</td>
<td>orange</td>
</tr>
<tr>
<td>18-V6B</td>
<td>blue</td>
</tr>
<tr>
<td>18-V5R</td>
<td>red</td>
</tr>
<tr>
<td>18-V4L</td>
<td>lime</td>
</tr>
<tr>
<td>18-V3S</td>
<td>silver</td>
</tr>
<tr>
<td>18-V2M</td>
<td>mag</td>
</tr>
<tr>
<td>18-V1Y</td>
<td>yellow</td>
</tr>
</tbody>
</table>

**Stennis Space Center (NAS)**

**ARENA B: VERTEBRAE MAP**

**FIGURE 1**

PO Box 270686
Flower Mound, TX 75022
832-250-1700

CONFIDENTIAL AND PROTECTED INFORMATION

THIS INFORMATION WAS PRODUCED FOR THE EXCLUSIVE USE OF JACOBS TECHNOLOGIES. REPRODUCTION BEYOND THESE LIMITS REQUIRES WRITTEN PERMISSION. COPYRIGHT © 2014.
Project Summary
Horizontal Multiport Sampling and Injection Well
High Resolution Site Characterization

- ITB has observed a recurring theme at many of NASA’s cleanup sites; more site assessment/re-assessment is required before realistic expectations of remediation effectiveness can be determined.

EPA Definition:

- Strategies and techniques use scale-appropriate measurement and sample density to define contaminant distributions, and the physical context in which they reside, with greater certainty, supporting faster and more effective site cleanup.
Project Summary

High Resolution Site Characterization

- Sample Density (one mobilization)
Membrane Interface Probe (MIP)

- Percussion-tolerant down-hole VOC sensor
- Continuously logs VOCs vs. depth
- Photoionization Detector (PID)
- Flame Ionization Detector (FID)
- Electron Capture Detector (ECD)

<table>
<thead>
<tr>
<th>Detector</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECD</td>
<td>Primary: Total CVOCs (including TCE, PCE)</td>
</tr>
<tr>
<td>PID</td>
<td>Primary: Aromatic Compounds (e.g. BTEX); Secondary: CVOCs at higher contamination levels</td>
</tr>
<tr>
<td>FID</td>
<td>Primary: Ethane, Methane, Ethene; Secondary: CVOCs &amp; Aromatic Compounds at higher contamination levels</td>
</tr>
</tbody>
</table>
### Project Summary

**High Resolution Site Characterization**

- MIP Results lead to more useful lab sample locations, less mobilizations

---

#### Table of Sample Data

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Analysis Date</th>
<th>Sample Time</th>
<th>Matrix</th>
<th>Dilution Factor</th>
<th>Vinyl chloride</th>
<th>Freon113</th>
<th>1,1-Dichloroethene</th>
<th>trans-1,2-Dichloroethene</th>
<th>cis-1,2-Dichloroethene</th>
<th>Trichloroethene</th>
<th>Tetrachloroethene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method Blank</td>
<td>9/16/2014</td>
<td>00:00</td>
<td>Water</td>
<td>1</td>
<td>0.16 U</td>
<td>1.0 U</td>
<td>0.15 U</td>
<td>0.16 U</td>
<td>0.16 U</td>
<td>0.17 U</td>
<td>0.23 U</td>
</tr>
<tr>
<td>CPT002 8-12'</td>
<td>9/16/2014</td>
<td>08:10</td>
<td>Water</td>
<td>5000</td>
<td>1400 J</td>
<td>62000</td>
<td>750 U</td>
<td>800 U</td>
<td>1800 U</td>
<td>180000</td>
<td>1200 U</td>
</tr>
<tr>
<td>Method Blank</td>
<td>9/17/2014</td>
<td>00:00</td>
<td>Water</td>
<td>1</td>
<td>0.16 U</td>
<td>1.0 U</td>
<td>0.15 U</td>
<td>0.16 U</td>
<td>0.16 U</td>
<td>0.17 U</td>
<td>0.23 U</td>
</tr>
<tr>
<td>CPT001 10-14'</td>
<td>9/17/2014</td>
<td>07:57</td>
<td>Water</td>
<td>10000</td>
<td>1600 U</td>
<td>14000</td>
<td>1500 U</td>
<td>1600 U</td>
<td>1600 U</td>
<td>41000</td>
<td>2300 U</td>
</tr>
<tr>
<td>CPT004 10-14'</td>
<td>9/17/2014</td>
<td>12:35</td>
<td>Water</td>
<td>500</td>
<td>80 U</td>
<td>34000</td>
<td>75 U</td>
<td>80 U</td>
<td>770</td>
<td>33000</td>
<td>120 U</td>
</tr>
<tr>
<td>CPT005 12-16'</td>
<td>9/17/2014</td>
<td>12:45</td>
<td>Water</td>
<td>500</td>
<td>1200</td>
<td>4100</td>
<td>75 U</td>
<td>80 U</td>
<td>14000</td>
<td>6000</td>
<td>120 U</td>
</tr>
<tr>
<td>CPT007 10-14'</td>
<td>9/17/2014</td>
<td>14:05</td>
<td>Water</td>
<td>200</td>
<td>46 J</td>
<td>15000</td>
<td>30 U</td>
<td>32 U</td>
<td>3900</td>
<td>13000</td>
<td>45 U</td>
</tr>
<tr>
<td>CPT006 12-16'</td>
<td>9/17/2014</td>
<td>14:10</td>
<td>Water</td>
<td>1000</td>
<td>160 U</td>
<td>72000</td>
<td>150 U</td>
<td>160 U</td>
<td>5300</td>
<td>69000</td>
<td>120 U</td>
</tr>
<tr>
<td>CPT008 10-14'</td>
<td>9/17/2014</td>
<td>14:10</td>
<td>Water</td>
<td>5000</td>
<td>800 U</td>
<td>130000</td>
<td>750 U</td>
<td>800 U</td>
<td>5000 J</td>
<td>760000</td>
<td>1200 U</td>
</tr>
<tr>
<td>CPT009 8-12'</td>
<td>9/17/2014</td>
<td>16:05</td>
<td>Water</td>
<td>20000</td>
<td>3200 U</td>
<td>750000</td>
<td>3000 U</td>
<td>3200 U</td>
<td>3200 U</td>
<td>3200 U</td>
<td>4000 U</td>
</tr>
<tr>
<td>Method Blank</td>
<td>9/18/2014</td>
<td>00:00</td>
<td>Water</td>
<td>1</td>
<td>0.16 U</td>
<td>1.0 U</td>
<td>0.15 U</td>
<td>0.16 U</td>
<td>0.16 U</td>
<td>0.17 U</td>
<td>0.23 U</td>
</tr>
<tr>
<td>CPT012 8-12'</td>
<td>9/18/2014</td>
<td>08:43</td>
<td>Water</td>
<td>2000</td>
<td>320 U</td>
<td>639000</td>
<td>300 U</td>
<td>320 U</td>
<td>3900</td>
<td>140000</td>
<td>460 U</td>
</tr>
<tr>
<td>CPT011 8-12'</td>
<td>9/18/2014</td>
<td>08:48</td>
<td>Water</td>
<td>5000</td>
<td>1000</td>
<td>80 U</td>
<td>2500</td>
<td>75 U</td>
<td>80 U</td>
<td>1700</td>
<td>59000</td>
</tr>
<tr>
<td>CPT010 8-12'</td>
<td>9/18/2014</td>
<td>08:52</td>
<td>Water</td>
<td>1000</td>
<td>160 U</td>
<td>26000</td>
<td>150 U</td>
<td>160 U</td>
<td>160 U</td>
<td>59000</td>
<td>120 U</td>
</tr>
<tr>
<td>CPT013 10-14'</td>
<td>9/18/2014</td>
<td>10:53</td>
<td>Water</td>
<td>10</td>
<td>1.6 U</td>
<td>120</td>
<td>1.5 U</td>
<td>1.6 U</td>
<td>35</td>
<td>280</td>
<td>2.3 U</td>
</tr>
<tr>
<td>CPT014 10-14'</td>
<td>9/18/2014</td>
<td>11:00</td>
<td>Water</td>
<td>50</td>
<td>8.0 U</td>
<td>520</td>
<td>7.5 U</td>
<td>7.0 U</td>
<td>7.0 U</td>
<td>1400</td>
<td>12 U</td>
</tr>
<tr>
<td>CPT015 10-14'</td>
<td>9/18/2014</td>
<td>11:05</td>
<td>Water</td>
<td>10</td>
<td>1.6 U</td>
<td>20</td>
<td>1.5 U</td>
<td>1.5 U</td>
<td>54</td>
<td>71</td>
<td>2.3 U</td>
</tr>
<tr>
<td>CPT017 12-16'</td>
<td>9/18/2014</td>
<td>12:44</td>
<td>Water</td>
<td>50</td>
<td>8.0 U</td>
<td>1000</td>
<td>7.5 U</td>
<td>8.0 U</td>
<td>1300</td>
<td>3300</td>
<td>12 U</td>
</tr>
<tr>
<td>CPT018 10-14'</td>
<td>9/18/2014</td>
<td>12:54</td>
<td>Water</td>
<td>1000</td>
<td>160 U</td>
<td>53000</td>
<td>150 U</td>
<td>160 U</td>
<td>160 U</td>
<td>39000</td>
<td>120 U</td>
</tr>
</tbody>
</table>
High Resolution Site Characterization

- Result is more accurate and useful Conceptual Site Models (CSMs), less data gaps

**Lithology and CVOC Visualization**

- Evaluation of CVOC impacts with lithology
- Identification of data gaps
- Useful in design of final monitoring well networks
Acknowledgements:

• Wade Olsen, ITB, Inc.
• Wendy Robinson, Jacobs Technology (SSC)
• Jenette Gordon, NASA (SSC)
• Mark Schoppet, NASA (HQ)
• Jun Xu, ORNL
• Lance Robinson, EN Rx, Inc.
• Kent Armstrong, BioStryke Remediation
• Jim Langenbach, Geosyntec Consultants