Remedy Selection: Planning for Success & Lessons Learned

“The Universe of Technologies”

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Agenda

- ❑Remedial Options
- ❑Drivers for technology selection
  - ➢Throw in a few examples
- ❑Lessons learned
- ❑Sources of additional information

Assuming CSM has been developed and Risks have defined remedial goals

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Just a Sampling of Technologies to learn

- Activated Carbon-Based Technology for In Situ Remediation
- Air Sparging
- Bioreactor Landfills
- Bioremediation
- Capping
- Combining Remedies for More Effective Site Cleanup
- Electrokinetics: Electric Current Technologies
- Environmental Fracturing
- Excavation
- Evapotranspiration Covers
- Ground-Water Circulating Wells
- In Situ Chemical Reduction
- In Situ Flushing
- In Situ Oxidation
- Multi-Phase Extraction
- Natural Attenuation
- Nanotechnology: Applications for Environmental Remediation
- Optimizing Site Cleanups
- Permeable Reactive Barriers
- Phytotechnology's
- Soil Vapor Extraction
- Soil Washing
- Solidification
- Solvent Extraction
- Thermal Treatment: Ex Situ
- Thermal Treatment: In Situ

"See additional information at end of presentation"

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3

Magical Pixie Dust Does Not Exist

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4

What Typically Drives Technology Selection?

- ❑ Budget/Cost
- ❑ Client/Consultant Directive
- ❑ Regulatory Decision Document
- ❑ Timeframe

What *Should* Drive Technology Selection for Success?

- ❑ Geology / Media
- ❑ Contaminants
- ❑ Timeframe
- ❑ Remedial Goal
- ❑ Cost of course
  - ➢ Typically 50% of costs get you 90% there; it is that last 10%!!

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Geology

Soil Type - Key to determine detailed contaminant distribution with respect to Risks and remedial approach selection

- ❑ **Sand**: high permeability
  - ➢ Good for most remedial technologies
- ❑ **Silt**: low permeability
  - ➢ Can affect treatment timeframe and success
- ❑ **Bulk Clay**: very low permeability
  - ➢ Restricts use of many technologies
  - ➢ Incomplete treatment can lead to rebound
- ❑ **Heterogeneous:**
  - ➢ Where are the contaminants / Risk?
- ❑ **Bedrock**: Competent or weathered?
  - ➢ Well understood?

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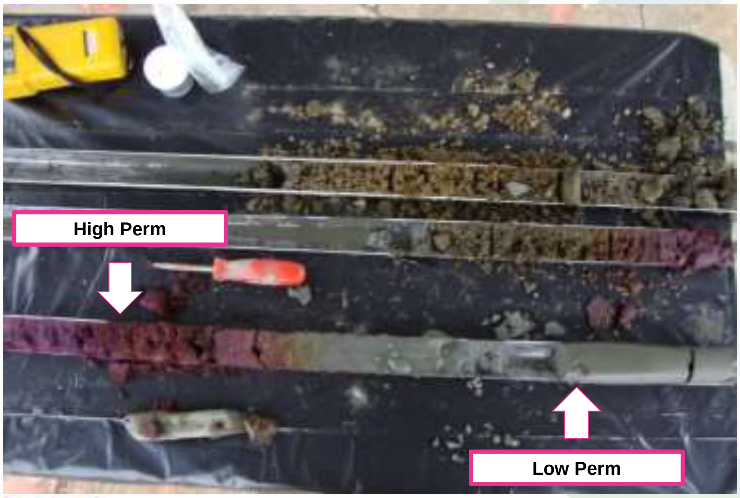
Geology



7

Geology

What if treating very low permeability clays or silts?

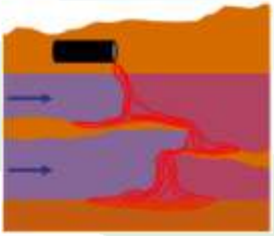
- ❑ Injection of sufficient fluids / reagents is unlikely. Drives options towards:
  - ➢ **Isolation:** Capping, institutional controls
  - ➢ **Containment**: Barrier systems, pump and treat
  - ➢ **Removal:** Excavation
  - ➢ **Soil Mixing**: ISCO or ISCR

8

Geology

Does your site look like this?

Or this?



Is geology stratified?

- ❑ Stratified geology with higher permeability lenses can mean pathways for contaminant migration, but ***also*** pathways for remediation
  - ➢ Air sparging may not work but pure oxygen biosparging may

9

What are the Contaminants?

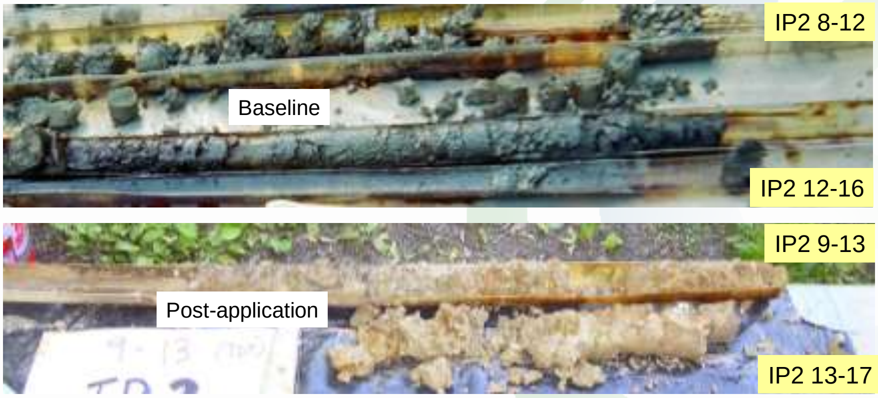
Volatiles

- ❑ Multiple treatment processes
  - ➢ Oxidation (ISCO, ISB) and Reduction (ISCR (e.g. ZVI)
  - ➢ Removal (pump and treat, SVE, sparging)
  - ➢ Isolation (Capping, stabilization)
  - ➢ Permeable reactive barriers (PRBs)
- ❑ NAPL
  - ➢ Treatment options vary from passive (e.g. skimmers for LNAPL or socks for DNAPL) to aggressive (e.g. ISCO, surfactant enhanced recovery)
  - ➢ Can preclude some technologies (e.g. ISB – timeframe, ISCO costs if significant NAPL)

Semi-volatiles

- ❑ Chemical oxidation/reduction
- ❑ Thermal, in-situ solidification, biodegradation
- ❑ Surfactant enhanced recovery

10



Coal tar impact addressed through ISCO

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Example: Mixed VOC / SVOC Site

- Manufacturing operations: approximately 1910 to 1997
- 2004: All operations cease, buildings razed
- VOC and SVOC impacts
- Detailed characterization show Risk associated with tight silts
- Aggressive remediation schedule < 18 months
- Client wanted to evaluate less aggressive thermal approach
- Treatability performed at varying temperatures to evaluate:
  - Enhanced SVE
  - Enhanced biodegradation

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Example: Thermal vs. Thermal Enhancement for VOCs and SVOCS?

- 8 Months of Operation: VOCs and SVOCs mass decreased by 58% and 73%, respectively
  - Approximately 86% of the mass reduction occurred via biodegradation (21,080 lb.)
  - Validated through oxygen utilization / COD measurements

	VOC (lb)	SVOC (lb)	Total (lb)
2007	39,500	2,100	41,600
2017	16,600	550	17,150
% Reduction	58%	73%	59%

- 12 Months of Operation: Site closure evaluated
  - 90% system shutdown approved by regulators
- 18 Months of Operation: Full system shutdown approved by regulators

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Cost-Effective "Sweet Spot" for Organics Remediation Technologies

Technology	Contamination on Soil						
	Free Flowing Product	Pore Filled Product	>10,000 mg/Kg	> 1,000 mg/Kg	>100 mg/Kg	>1 mg/Kg	< 1 mg/Kg
Excavation							
Extraction and Enhanced Extraction							
Soil Vapor Extraction (SVE)							
In Situ Chemical Oxidation (ISCO)							
In Situ Chemical Reduction (ISCR)							
In Situ Bioremediation (ISB)							
Air Sparging (AS)							
Natural Attenuation							
Thermal Enhancements							

Thermal enhancements could apply to several technologies including SVE and be applicable for higher concentrations of contamination.
Table is intended to represent the best use of a technology. Most technologies may have benefit in other conditions.

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14

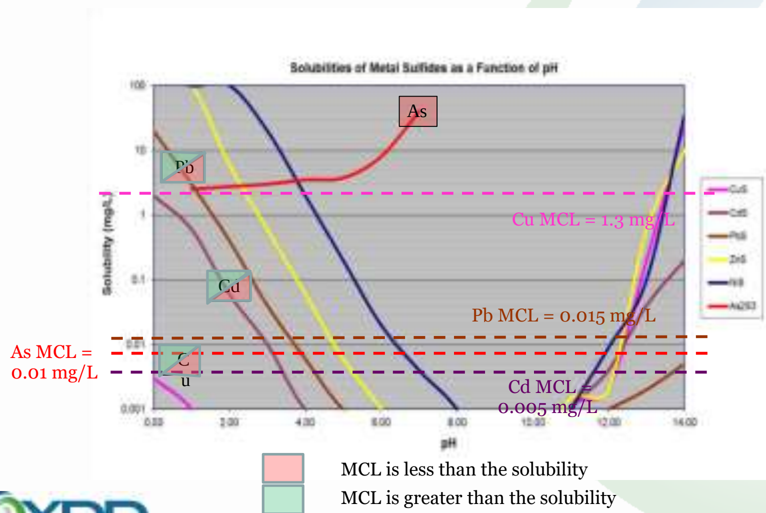
What are the Contaminants?

Metals

- Can't be physically destroyed
  - Isolation (capping)
  - Removal (excavation)
  - Chemical Stabilization
    - Dissolution / precipitation / coprecipitation
    - Adsorption / desorption
- Key Parameters for Stabilization
  - pH
  - ORP / Eh
  - Availability of stabilization compounds:
    - Sulfides
    - Carbonate
    - Iron minerals

15

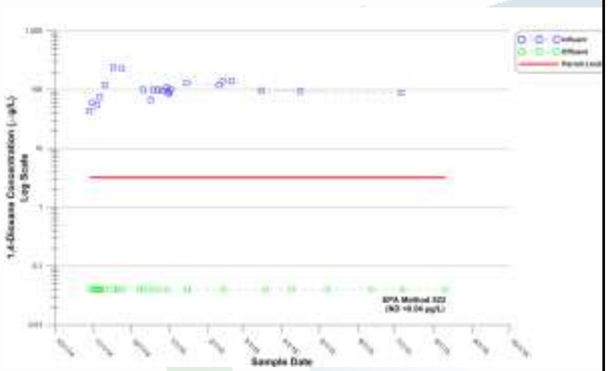
Precipitation as Sulfides:



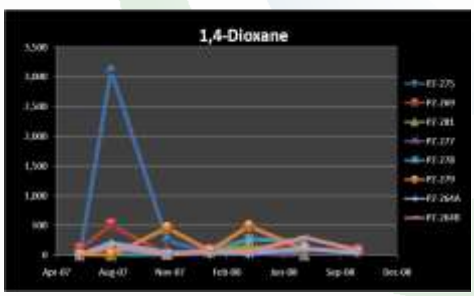
1,4, Dioxane

17

Sorption on resins

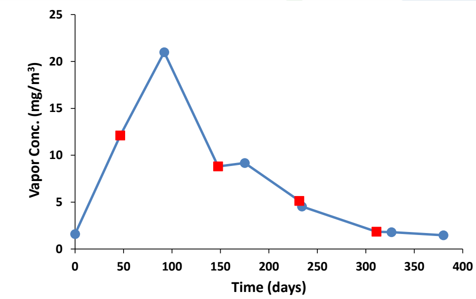


ISCO - Persulfate

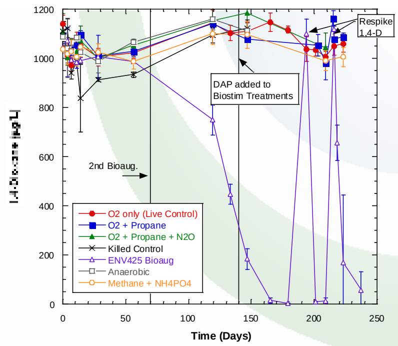


18

Thermally Enhanced SVE



Cometabolic Aerobic Biodegradation



19

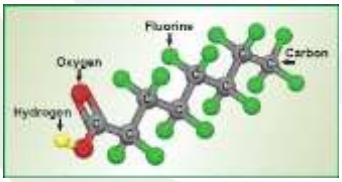
Per-, and Polyfluoroalkyl Substances (PFAS)

20

PFAS Physical-Chemical Properties

- Per- and polyfluoroalkyl substances
  - Backbone of Per's saturated C-F
  - Backbone Poly's unsaturated C-F
- C-F bonds are extremely strong

Perfluorooctanoic acid - PFOA



NIEHS – National Institutes of Health

PFAS REMOVAL OPTIONS: SUMMARY

- **Currently there are many unknowns with respect to PFAS quantification and toxicity**
- **Sorption and filtration options are the most common and reliable PFAS removal processes available**
  - **Removal effectiveness is variable and may be unknown for a number of PFAS**
  - **Treatment trains may be needed to meet stringent PFAS criteria**
- **Destructive processes require high energy and significant treatment time**
  - **Likely costly for high volume water or waste water treatment**
  - **Focus is use on treatment of concentrated PFAS waste streams**

Timeframe

Remedial timeframe can vary considerably depending on the technology

- ❑ Weeks to months
  - ➢ ISCO, Soil Mixing, Excavation, Thermal
- ❑ Months to years
  - ➢ ISB, AS/SVE
- ❑ Years to longer
  - ➢ Pump and Treat
  - ➢ PRBs
  - ➢ MNA

23

Lessons Learned

State of the Art vs. State of the Practice In Remedial Design

24

You Needed This:

But What You Got Was….

"State of the Practice" is often skipping key remedial design steps

SVE System Peer Review

- **SOP for SVE Design based on vacuum propagation**
- **SOA for SVE Design based on clean air pore volume exchanges**
- CA site SVE – 4 to 5 acres – SOP Design
  - Operating from 2002, silty sands and interbedded sands and clays
  - ~400 cfm system
  - High vacuum throughout well field and vapor / vacuum points
  - 10k's lbs. removed since 2002; only ~300 lbs. removed since 2014 – large mass remaining
- IL SVE Site ~2 acres – SOA Design
  - Operated 18 months; removed ~500k lbs.
  - EPA approved closure

26

Another Common State of the Practice

- Remedial design using dosing spreadsheets?
  - Usually a minimum dosing/application recommended
  - Good start…provides "Cost-Effective" starting point
- Must account for sensitive design parameters (not typically part of site characterization):
  - E.g., TOD, SOD
  - E.g., COD, BOD, abiotic reactions (interferences)
  - E.g., Interferences/scavengers, distribution
- Dosage is site-specific
  - Additional evaluation often recommended by the vendors
  - ….and often ignored….

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Bioremediation SOP vs. SOA

Superfund Site SC: Mixed source/plume with petroleum hydrocarbons

Aerobic Biodegradation: Comparison of oxygen release products for petroleum plume

- Evaluated oxygen release compounds on the market
- Provided vendors with site-specific data and requested recommended dosing of product (SOP) to achieve 90 percent reduction in contaminant mass
- Based on responses – tested all products at MAXIMUM dosage recommended by any of the vendors*

* some vendors recommended treatability to validate dosage

SOP = State of the practice

SOA = State of the art

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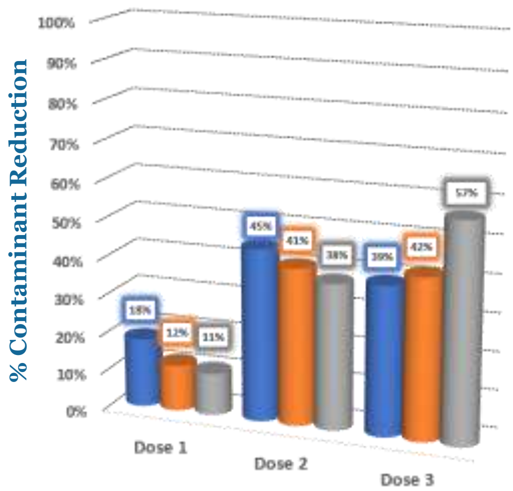
28

Oxygen Release Compound Performance



All Products Failed, Even After 3 Applications at the SOP Maximum Dose Recommendation

Treatability Study (SOA) Would Identify Dose Required for Certainty of Success

Treatability Study

Inappropriate Treatability Study Design and Interpretation

ISCO Peer Review - Diagnosis of Failure

- **Full-scale ISCO Injection was performed**
  - **Injected ~1,000's gallons CHP (catalyzed hydrogen peroxide)**
  - **Significant off-gassing / daylighting**
  - **Concentrations of CVOCs in source area did not decrease**
- State of Practice (not State of the Art) treatability design using CHP was flawed
  - Was considered a success as CVOCS were ND in test reactor
  - Treatability did not report the oxidant half-life
    - < 4hrs (from XDD data analysis of CHP concentration and gas generated)
    - < 4hrs half-life inadequate for oxidant distribution in the field
  - Expected result of field application?
    - Essentially gas generation in vicinity of well location and oxygenation of the aquifer
    - Limited to insignificant treatment of TCE
- What caused the treatability ND result?

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ISCO Peer Review - Diagnosis of Failure

- "Stripping" – possibly thermally enhanced.
  - Loss of TCE in treatability could be accounted for entirely by vapor concentration measured in off-gas, and
  - Theoretical gas volume generated from CHP decomposition (not measured)
- Pore volumes of reagent solution used in treatability testing: 21!
  - Common SOP issue
    - Misrepresents expectations for full scale, even if successful in the treatability
  - Not representative of field applications
  - 1 to 2 PVs in treatability studies is more appropriate
- Why did TCE concentrations increase in field application?
  - Hydraulic perturbations
  - Reduction in Foc

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32

Sources of Information

- **General Technology information**
  - https://clu-in.org/techfocus/
  - https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/erb/tech/rem.html
  - https://itrcweb.org/
  - https://frtr.gov/matrix2/section1/toc.html

- **Contaminant Specific**
  - https://clu-in.org/contaminantfocus/

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33

Thank You! Questions?

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34