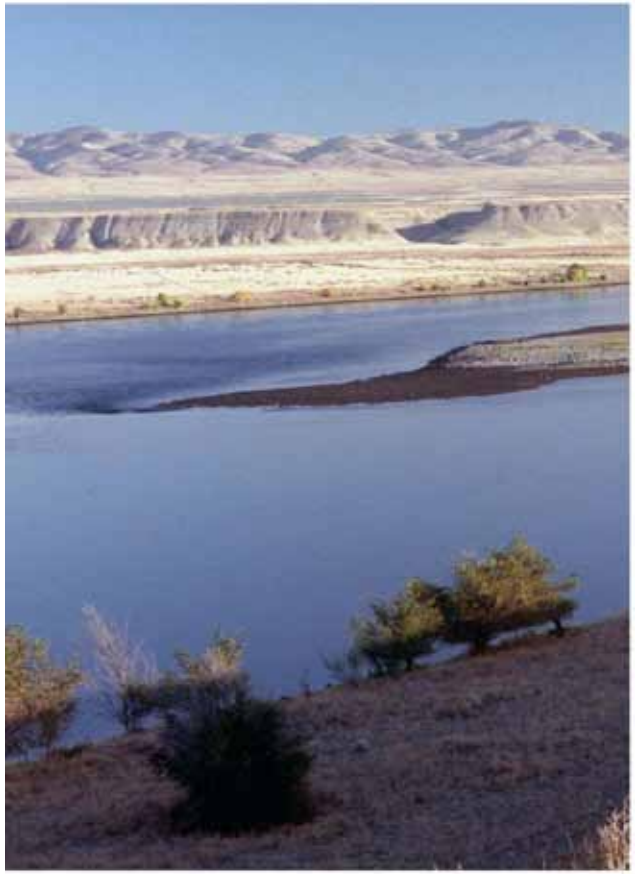
CH2MHILL
Plateau Remediation Company



General Response Action – In Situ Treatment

Presented by: T. J. Simpkin/M. J. Truex

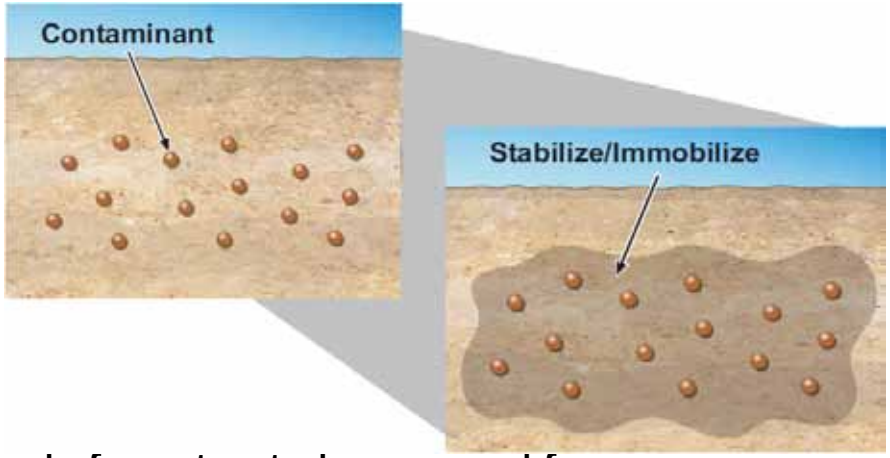
Location: Shilo Inn, Richland, Washington
Date: June 7, 2011

U.S. DEPARTMENT OF ENERGY

General Response Action – In Situ Treatment

General Description

- Apply a treatment to contaminants in the ground that degrades them or slows their movement sufficiently to meet groundwater remediation goals



State of Development

- In situ treatment has been applied as a remedy for saturated zones and for some vadose zone applications

Limitations/Development Needs

- Access to contaminated zones
- Implementation dependent on subsurface properties
- Effectiveness under unsaturated conditions
- Verification of treatment effectiveness

Contaminants of Potential Concern

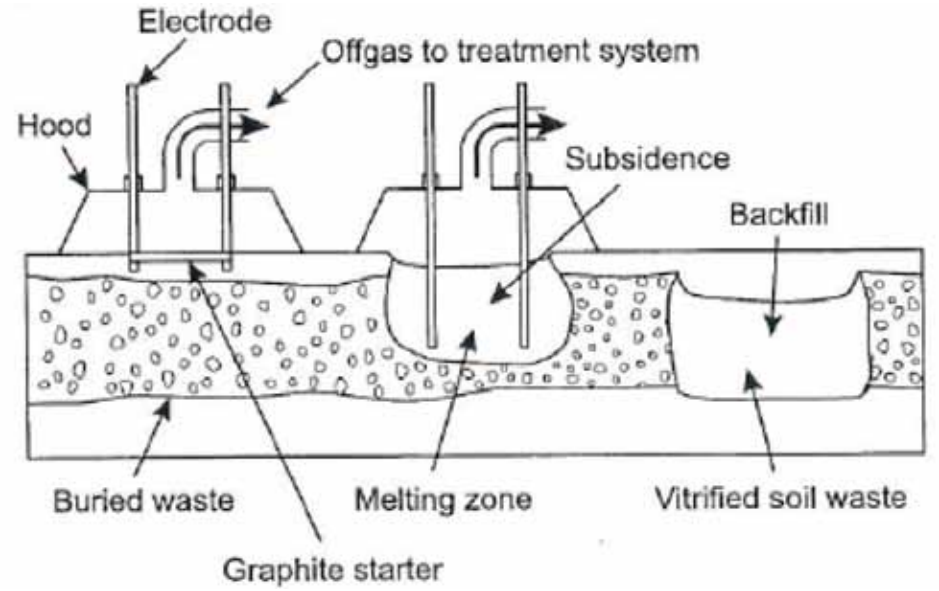
Contaminant of Potential Concern	Treatment Mechanism				
	Reduce	Degrade	Volatilize	Physical Sequester	Chemical Sequester
Uranium	X (Reduction of Uranium is potentially reversible)			X	X
Technicium-99	X (Reduction of Tc-99 is potentially reversible)			X	
Iodine-129				X	
Nitrate		X			
Hexavalent Chromium	X			X	X
Carbon Tetrachloride		X	X		

Technology – In Situ Vitrification

General Description

- Apply electrical energy to heat and then melt targeted zone of subsurface and encapsulate contaminants in glass
- Resulting product is typically 10 times stronger than concrete

Potential Contaminants:
- All



Schematic of In Situ Vitrification (RPP-ENV-34028, REV 0)

Technology – In Situ Vitrification

Example 1 Acre Site, 200 ft deep:
- With 5 ft ROI: need over 430 borings, each over 200 ft deep

State of Development

- Tests, demonstrations, and commercial operations of the technology have been conducted, but in generally shallow conditions

Limitations/Development Needs

- Energy intensive
- Tight spacing between heating elements is generally required, so very large number of borings would be required
- The technology has complex equipment requirements and challenging implementation

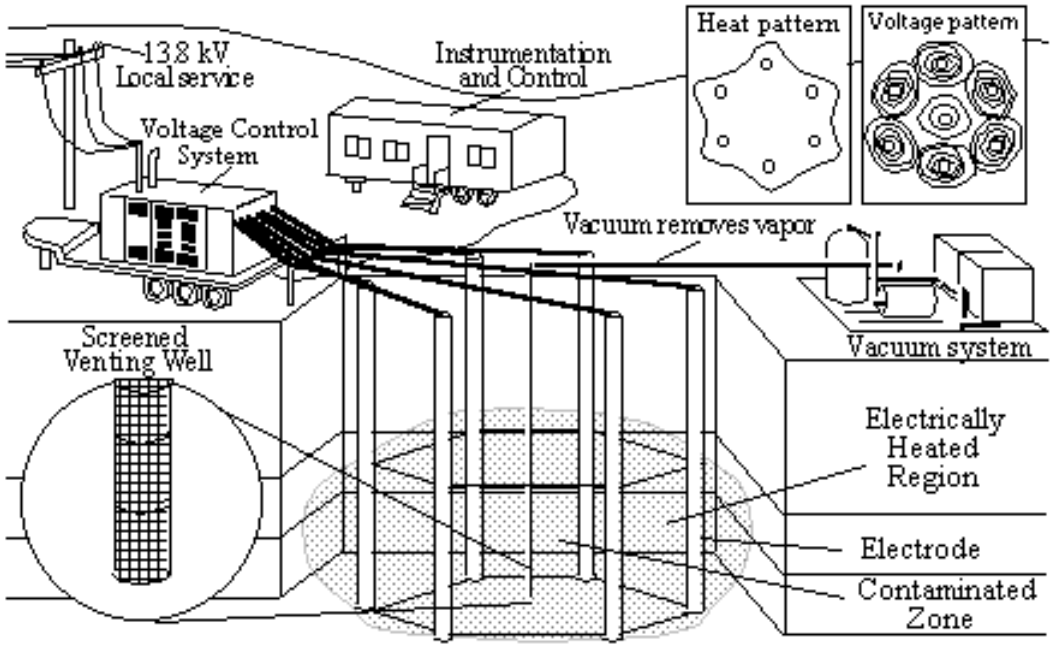
Lab Testing Only	Field Testing Only	**Limited Field Application**	Remediation Ready (limited application)	Remediation Ready

Technology – In Situ Thermal Desorption

General Description

- Direct application of heat to increase the temperature of soil and volatilize organic compounds
- Heating methods can include: electrical current to heat soil; electrical heater elements; injection of hot air, steam, or hot water; or radio frequency

Potential Contaminants:
• Volatile Organic Compounds



Typical Six-Phase Soil Heating System (http://www.frtr.gov/)

Technology – In Situ Thermal Desorption

State of Development

- Field demonstrations and full-scale applications have been completed for organic contaminants

Limitations/Development Needs

- Generally applied to shallower applications
- Energy intensive
- Tight spacing between heating elements is generally required, so very large number of borings would be required

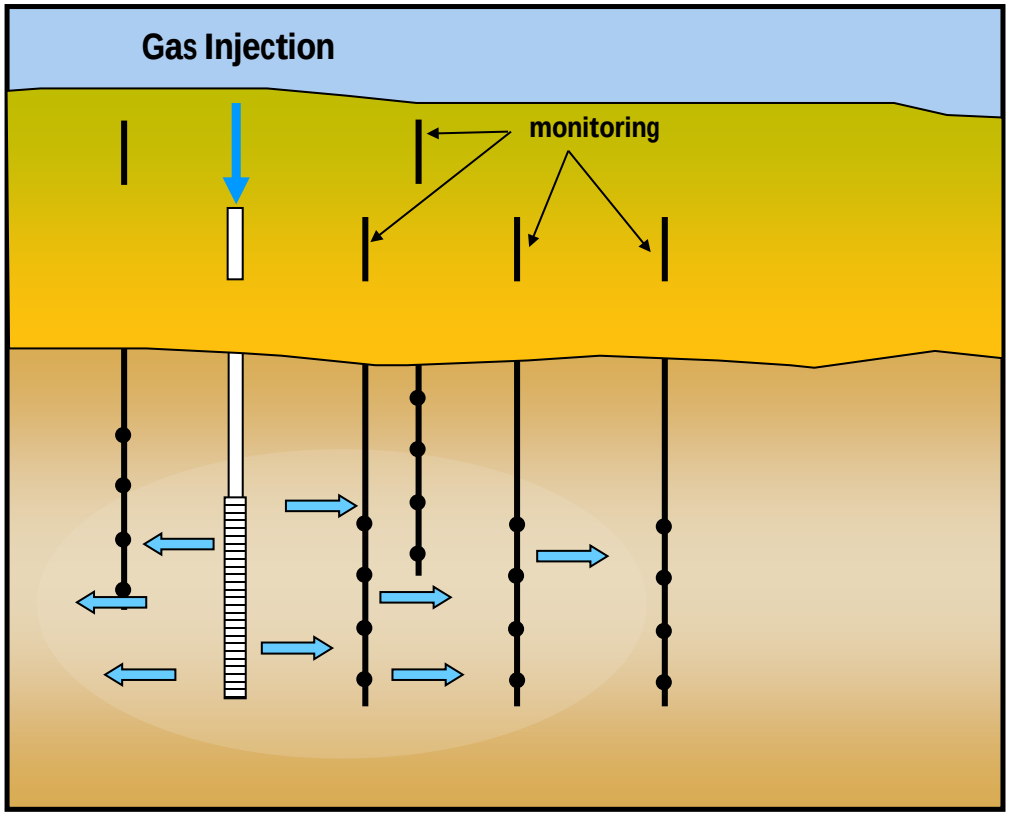
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Delivery Techniques

Technology – Gas Delivery

General Description

- Injection of gaseous reagent to the subsurface



Potential Contaminants:
- delivery method

Technology – Gas Delivery

State of Development

- Has been used in the field for some gases

Limitations/Development Needs

- Distribution is dependent on subsurface permeability and permeability contrasts (primary flow in high permeability regions)
- Delivery is dependent on the properties of the specific gaseous reagent

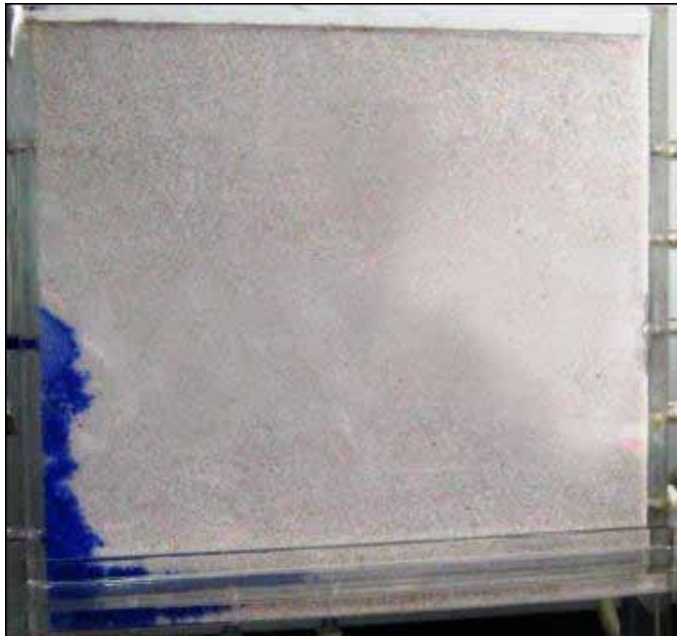
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Foam Delivery

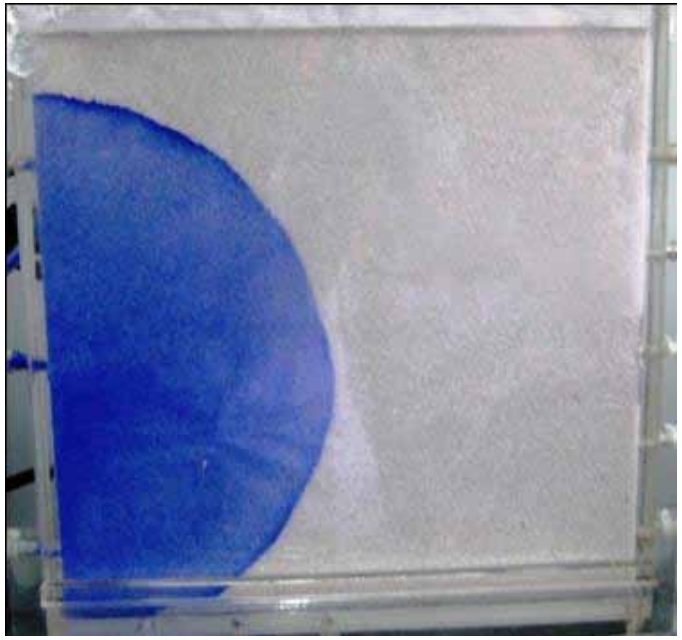
General Description

- A foam can be pushed through the vadose zone and carries amendments in the water that is part of the bubble

Potential Contaminants:
- delivery method



Aqueous injection to unsaturated sediments



Foam injection to unsaturated sediments

Technology – Foam Delivery

State of Development

- Foams have been used for subsurface applications, but not for amendment delivery in the vadose zone
- Laboratory testing of foams for amendment delivery in the vadose zone is underway

Limitations/Development Needs

- The effectiveness of foam formulations and delivery methods for the vadose zone need to be evaluated in the field

Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

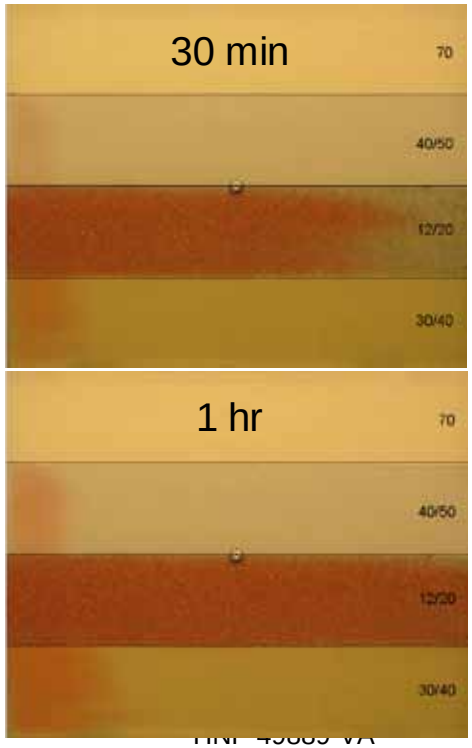
Technology – Shear-Thinning Fluid

General Description

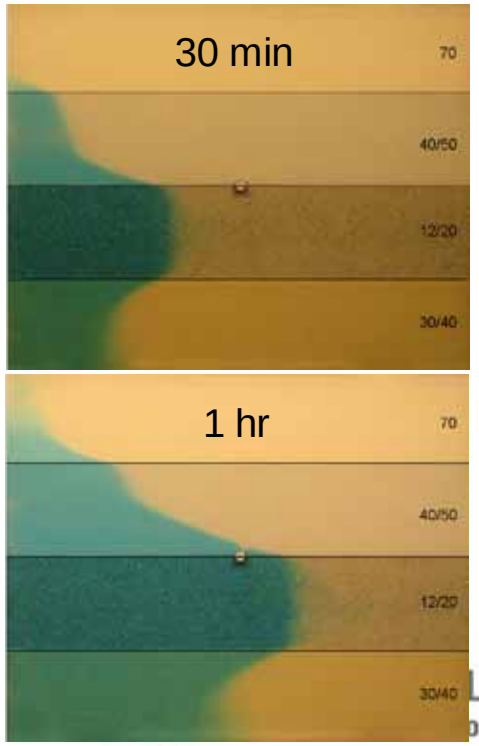
- Viscosity of some polymer solutions are a function of shear. Relatively more shear and lower viscosities in low-permeability units versus high-permeability units, so injection is more uniform

Potential Contaminants:
- delivery method

Water Injection



Shear-Thinning Fluid Injection



Technology – Shear-Thinning Fluid

State of Development

- Laboratory and field testing conducted for saturated zone and at water table

Limitations/Development Needs

- Applicable at the water table
- No testing or information for use in vadose zone except for hydraulic fracturing applications

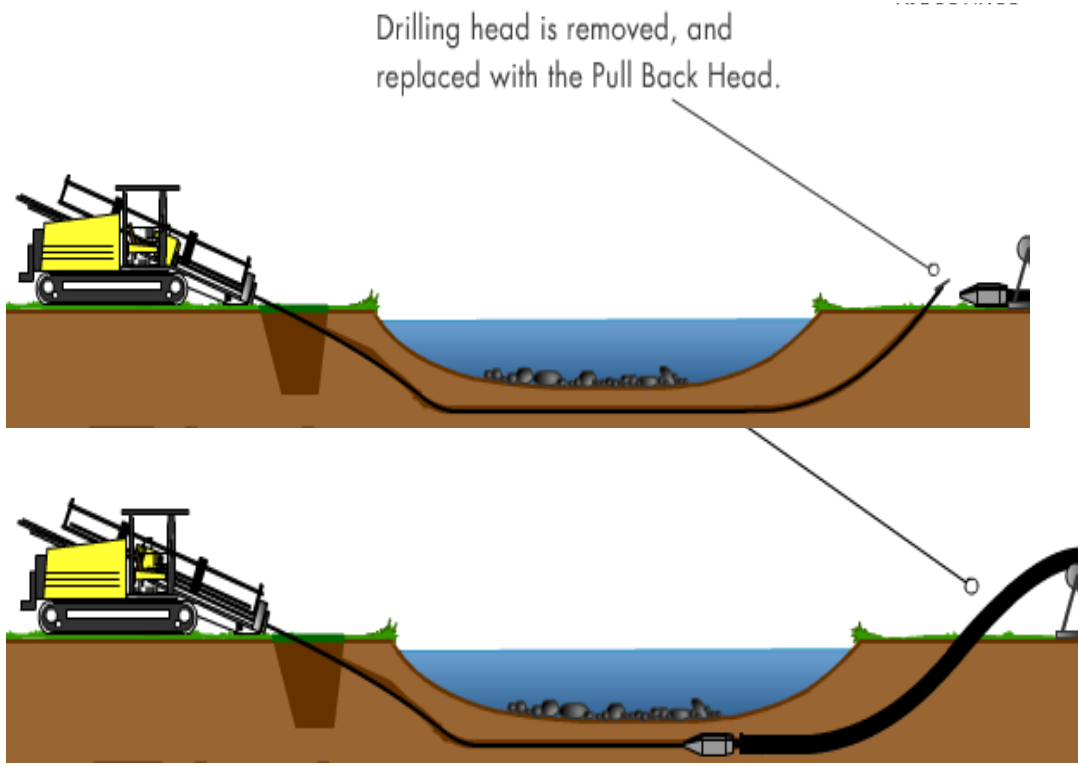
Lab Testing Only	**Field Testing Only**	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Injection/Extraction Wells (Horizontal)

General Description

- Delivery of amendments or extraction of soil vapor using horizontal wells
- Wells are installed using horizontal/directional drilling techniques

Potential Contaminants:
- Delivery Method



Source: www.isco-pipe.com/applications/directional_drilling_animation.htm

Technology – Injection/Extraction Wells (Horizontal)

State of Development

- Technology is well proven at shallow depths and certain geological conditions
- Pilot test conducted at 100-D at Hanford. Not successful due to cobbles

Limitations/Development Needs

- Effectiveness dependent upon subsurface conditions. Challenging in gravelly/cobbly lithologies
- Long pipe runs required to achieve deep depths

Lab Testing Only	Field Testing Only	Limited Field Application	**Remediation Ready (limited application)**	Remediation Ready

Technology – Injection/Extraction Wells (Vertical)

General Description

- Vertical wells can be used to inject reagents into groundwater, to treat contaminant plumes, extract groundwater, and monitor groundwater
- Typically implemented through temporary or permanent wells constructed with varying lengths of screen

Potential Contaminants:
- Delivery Method

Vertical Boring Equipment

Technology – Injection/Extraction Wells (Vertical)

State of Development

- Technology is well proven. Vertical wells are commonly used on environmental projects, including Hanford.

Limitations/Development Needs

- Little or no limitations or development needs to drill and install wells at Hanford

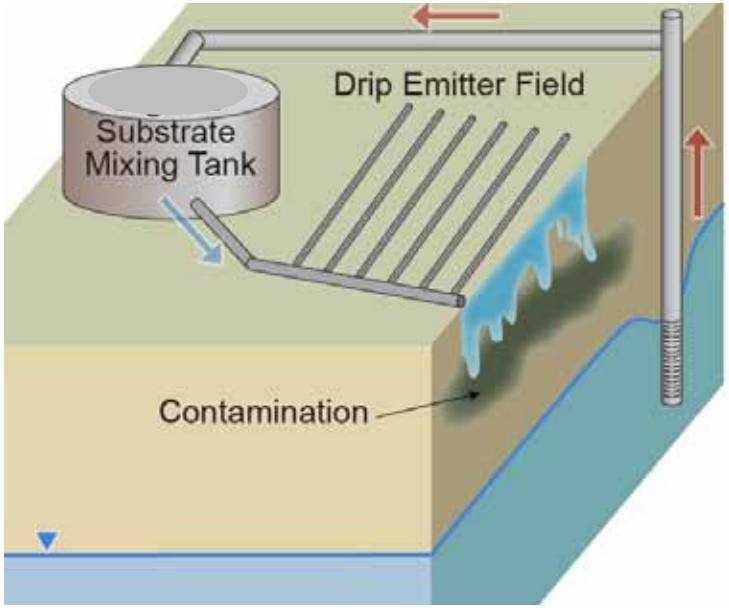
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

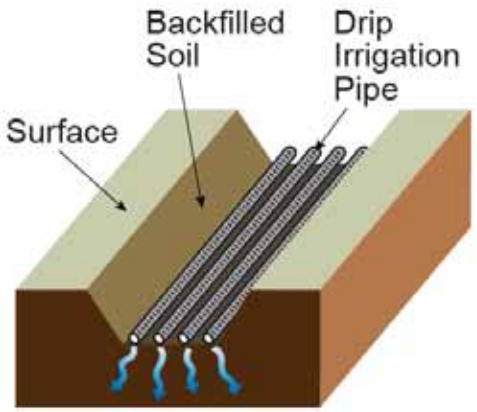
Technology – Surface Infiltration

General Description

- Reagent is applied to ground surface to treat contaminants within the vadose zone
- Surface infiltration can be done through drip irrigation, trenches, and shallow basin systems
- Can be applied to bottom of excavations to target deeper vadose zone

Potential Contaminants:
- Delivery Method





Cross Section of Drip Irrigation Lines

Technology – Surface Infiltration

State of Development

- Technology is well proven for a number of sites, but limited testing has been conducted at Hanford. Testing at 300-Area encountered challenges due to cemented soil layer.

Limitations/Development Needs

- Uniform delivery of amendments can be a challenge in the heterogeneous and deep vadose zone (liquids may not hit target zones)
- Recovery of potentially mobilized contamination into groundwater needs to be carefully designed
- Mobilization of non-target contaminants may occur

Lab Testing Only	Field Testing Only	Limited Field Application	**Remediation Ready (limited application)**	Remediation Ready

Technology – Deep Soil Mixing

General Description

- Large mixing augers (1.5 to 3 m [5 to 10 ft] in diameter) or horizontally rotating heads are used to blend and homogenize reactants with soil
- Provides uniform mixing in the soil column, and good contact and reaction between contaminants and amendments

Potential Contaminants:
- Delivery Method

Deep Soil Mixing Equipment

Technology – Deep Soil Mixing

State of Development

- The technology is proven effective in shallow applications and homogenous conditions
- May be effective in combination with other technologies (e.g., excavation)

Example 1 Acre Site, 200 ft deep:
- With 10 ft dia borings: need over 430 borings, each over 200 ft deep

Limitations/Development Needs

- Implementation may be challenging in gravelly and cobbly lithologies
- Soil mixing has been performed to depths of up to 50 meters (164 feet) below ground surface (bgs), but most applications have been limited to 15 meters (50 feet) bgs

Lab Testing Only	Field Testing Only	Limited Field Application	**Remediation Ready (limited application)**	Remediation Ready

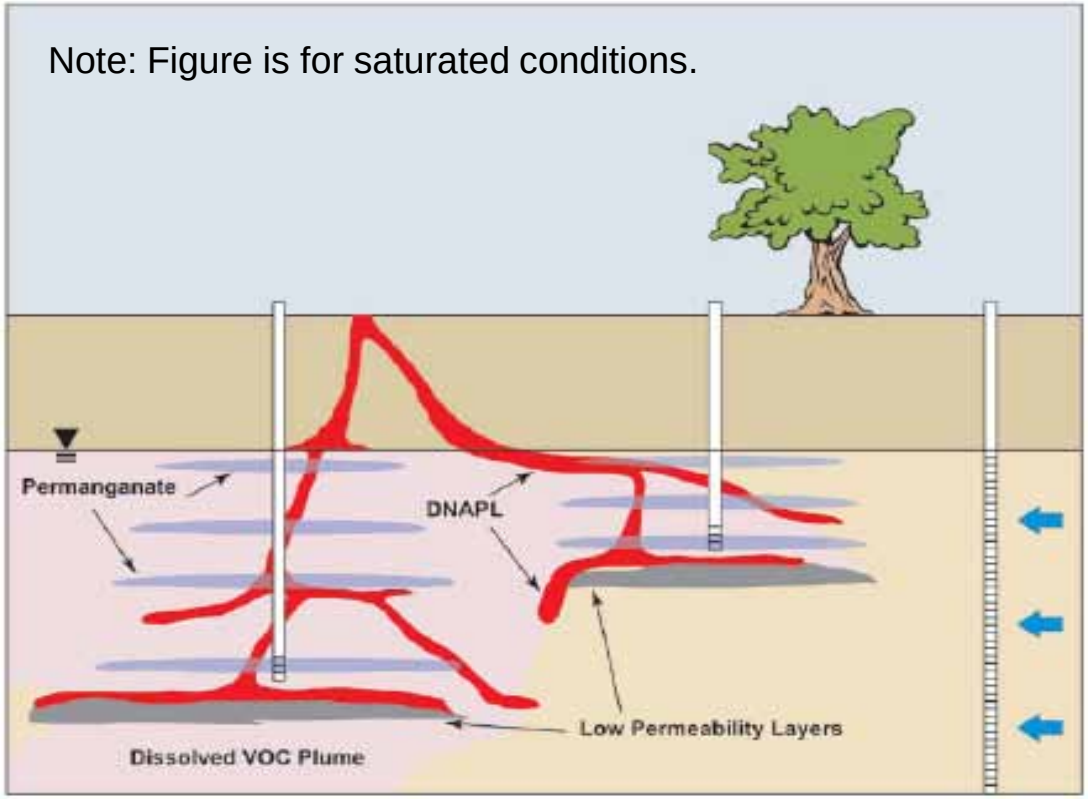
In Situ Treatment Technologies

Technology – Chemical Oxidation (ISCO)

General Description

- ISCO involves reduction/oxidation (redox) reactions that chemically degrade organic contaminants into nonhazardous or less toxic compounds
- Chemical oxidants include: hydrogen peroxide, ozone, permanganate, persulfate, percarbonate, etc

Potential Contaminants:
•Chlorinated organic compounds



In situ permanganate oxidation involving the emplacement method of oxidant delivery (USEPA ISCO Engineering Issue)

Technology – Chemical Oxidation

State of Development

- Technology commonly applied for some chlorinated organic contaminants in saturated conditions
- Not commonly applied for carbon tetrachloride or vadose zone conditions
- Chemical oxidants can be delivered using soil mixing, horizontal injections wells, or vertical injection wells

Limitations/Development Needs

- Additional research required to demonstrate applicability to carbon tetrachloride
- Effective delivery methods to deep vadose zone may be challenging
- Uniform delivery of amendments can be a challenge in the heterogeneous vadose zone

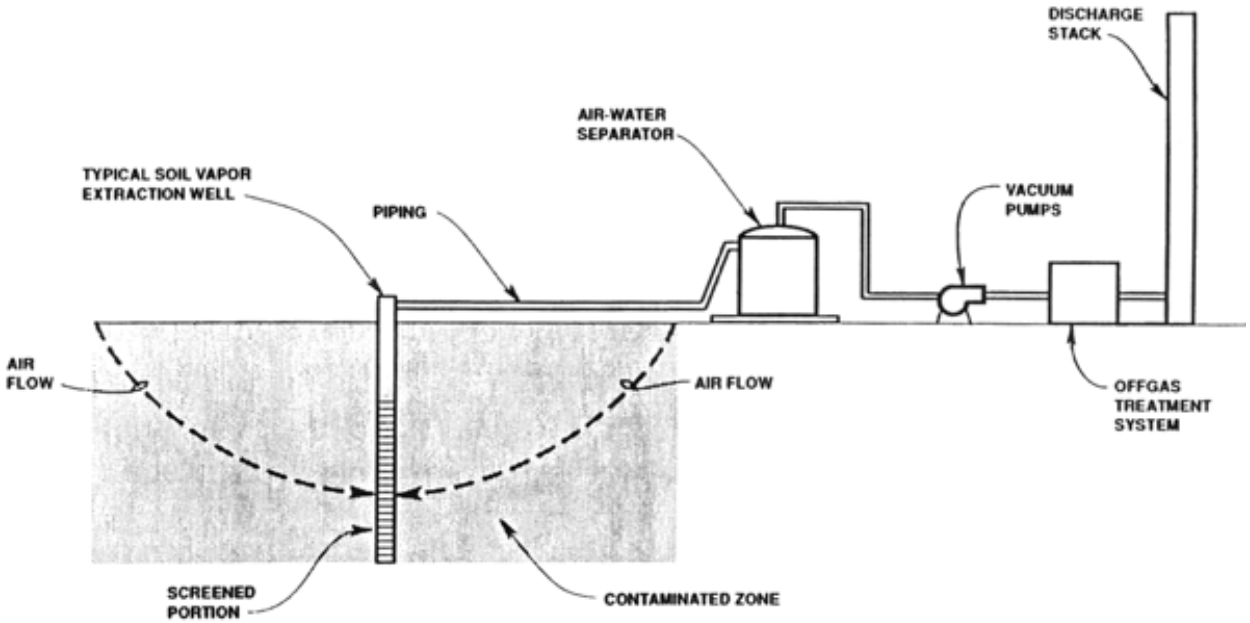
Lab Testing Only	Field Testing Only	Limited Field Application	**Remediation Ready (limited application)**	Remediation Ready

Technology – Soil Vapor Extraction (SVE)

Potential Contaminants:
- Volatile Organic Compounds

General Description

- Soil vapors are extracted through wells to induce contaminant mass transfer from soil to vapor
- Vapors are collected and treated separately or directly discharged to the atmosphere, if appropriate



Schematic of Soil Vapor Extraction System (http://www.clu-in.org/)

Technology – Soil Vapor Extraction

State of Development

- Technology is proven for remediating soils contaminated by volatile organic compounds
- Applied at Hanford in 200-PW-1 operable unit

Limitations/Development Needs

- Soil with high percentage of fines and a high degree of saturation require higher vacuums hindering operation
- Slow treatment for low-permeability portions of the vadose zone

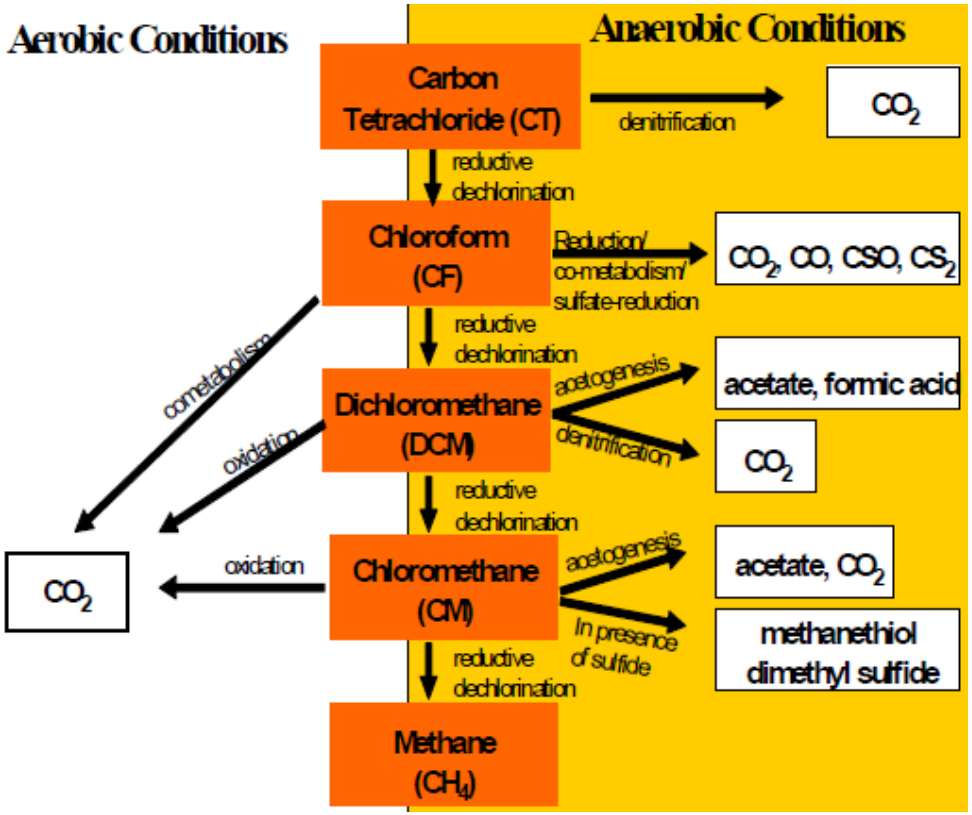
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Biological Reductive Dechlorination

General Description

- Biological remediation, via the addition of an organic substrate, will reductively de-chlorinate carbon tetrachloride. The substrate must be distributed to contact the carbon tetrachloride and allow reaction to occur.
- Microorganisms sequentially replace chlorine atoms with hydrogen forming more reduced de-chlorination products.

Potential Contaminants:
- Carbon Tetrachloride (CCl_4)



CT/CF/DCM/CM Degradation Pathways (ITRC, 2002)

Technology – Biological Reductive Dechlorination

State of Development

- Pilot-scale and laboratory bench-scale testing have been performed for reduction of carbon tetrachloride

Limitations/Development Needs

- Microorganisms that can reductively de-chlorinated carbon tetrachloride are not common in the environment, so that they may need to be added to the subsurface
- Requires additional research and development for implementation in the vadoze zone
- Effective delivery methods to deep vadose zone may be challenging

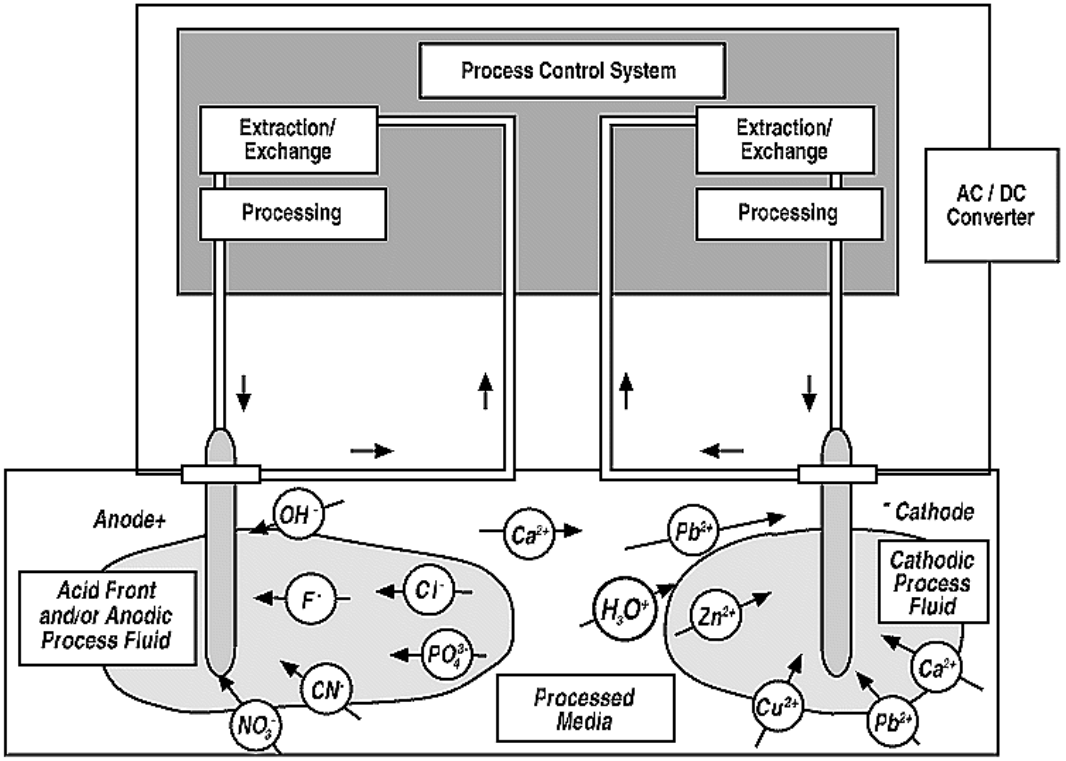
Lab Testing Only	**Field Testing Only**	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Electrokinetic Mobilization and Recovery

General Description

- Application of an electric field in the soil induces contaminant mobilization through electromigration, electroosmosis, or electrophoresis

Potential Contaminants:
- Uranium, Cr(VI), Tc-99, nitrate



http://www.frtr.gov/matrix2/section4/4-4.html

Technology – Electrokinetic Mobilization and Recovery

State of Development

- Very limited number of field applications; most applications have been for lower permeability soil in saturated conditions

Limitations/Development Needs

- Most applicable for moist, low permeability soil conditions
- Testing would be required to demonstrate the technology for vadose zone conditions
- Tight spacing between electrodes is generally required, so very large number of borings would be required

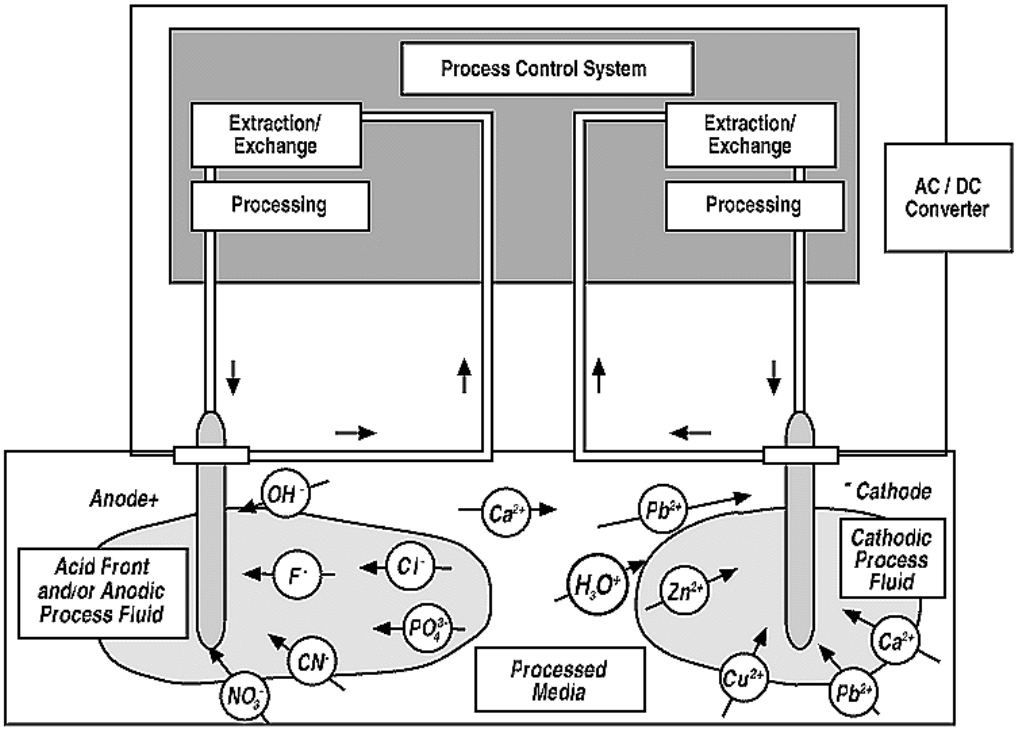
Lab Testing Only	**Field Testing Only**	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Hybrid Electrokinetic Delivery of Treatment Chemicals

General Description

- Mobilization of fluids to target areas by application of electric fields

Potential Contaminants:
- Depends on the type of treatment chemicals being applied



Technology – Hybrid Electrokinetic Delivery of Treatment Chemicals

State of Development

- Laboratory testing performed for reduction of chromate
- Control of subsurface chemical conditions is critical

Limitations/Development Needs

- Has not been applied for vadose zone conditions

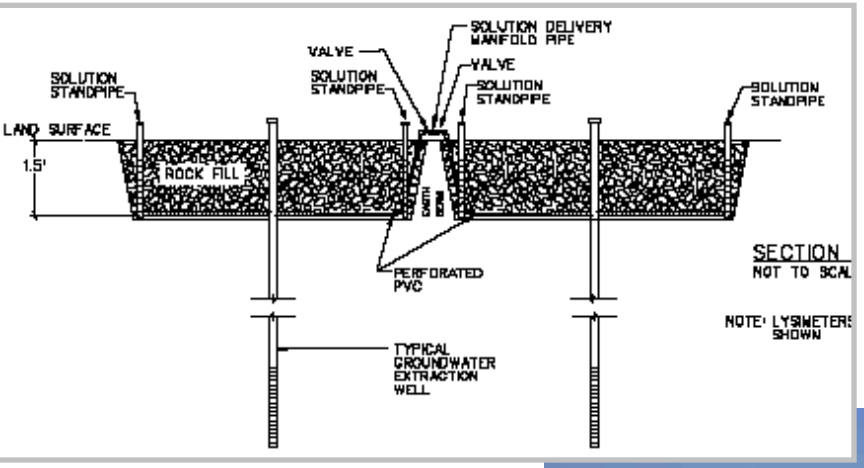
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

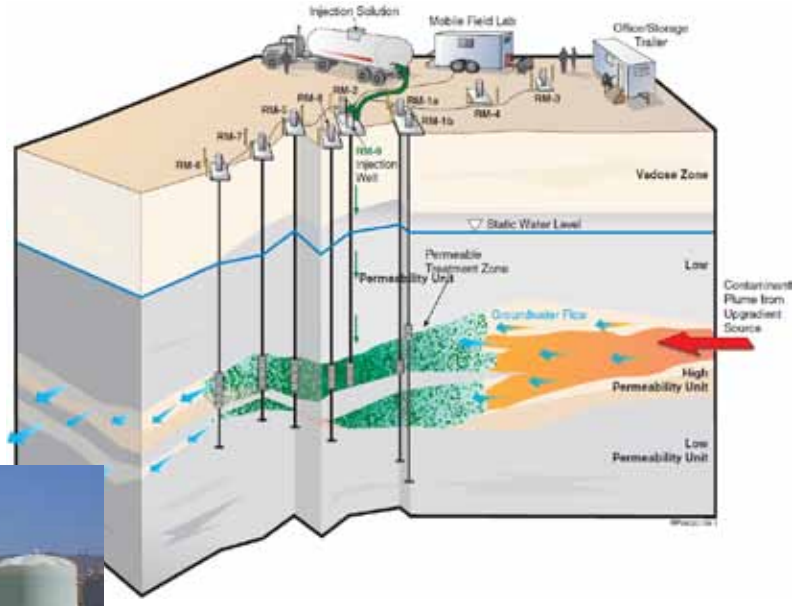
Technology – Aqueous Chemical Reductant

General Description

- Inject/infiltrate an aqueous chemical reductant such as sodium dithionite, calcium polysulfide, or ferrous iron to directly reduce target contaminants and to reduce sediment-associated iron that can act as a reactive zone to reduce target contaminants

Potential Contaminants:
- Cr(VI), U, Tc-99





Technology – Aqueous Chemical Reductant

State of Development

- Has been applied in saturated zone for chromium contamination
- Limited field and laboratory tests for vadose zone sediments and in conjunction with foam delivery
- Laboratory study of uranium and technetium reoxidation

Limitations/Development Needs

- Difficulty in delivery to the vadose zone
- Effectiveness under unsaturated conditions
- Uranium and technetium can reoxidize

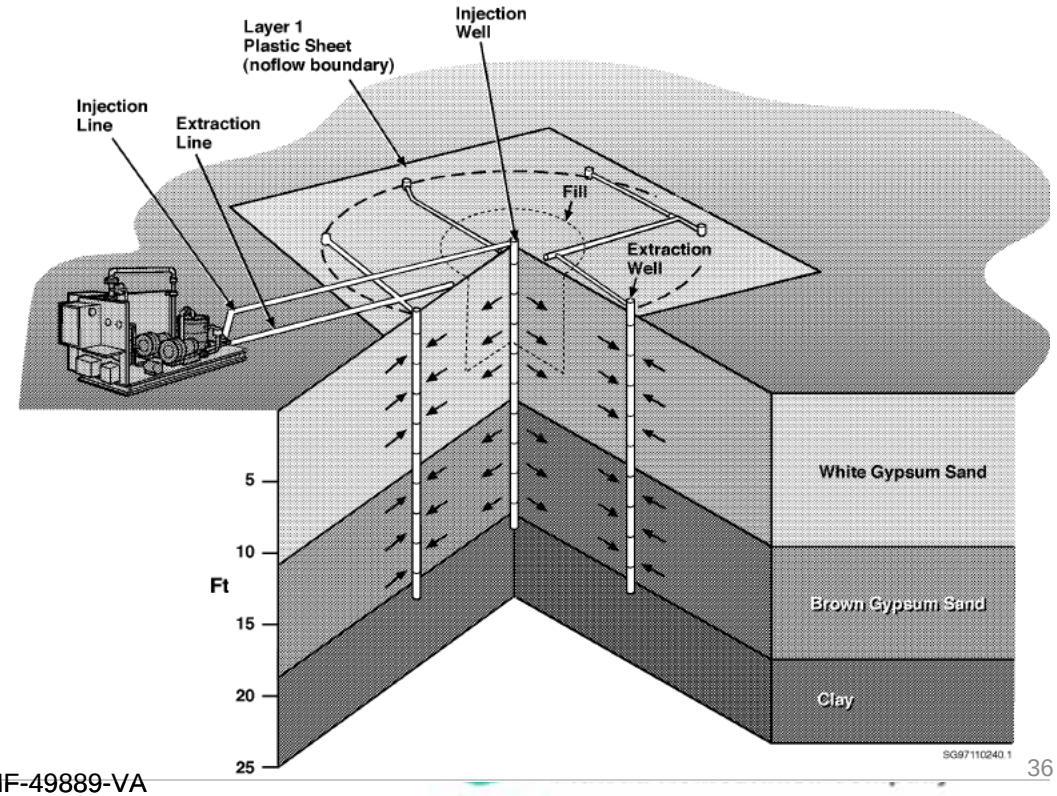
Lab Testing Only	**Field Testing Only**	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Gaseous Reductant

Potential Contaminants:
- Cr(VI), U, Tc-99

General Description

- Injection of gaseous reductant such as hydrogen sulfide gas to directly reduce target contaminants and to reduce sediment-associated iron that can act as a reactive zone to reduce target contaminants



Technology – Gaseous Reductant

State of Development

- Field tested for chromium
- Laboratory tested for uranium and technetium

Limitations/Development Needs

- Uranium and technetium can reoxidize
- Delivery of toxic gas

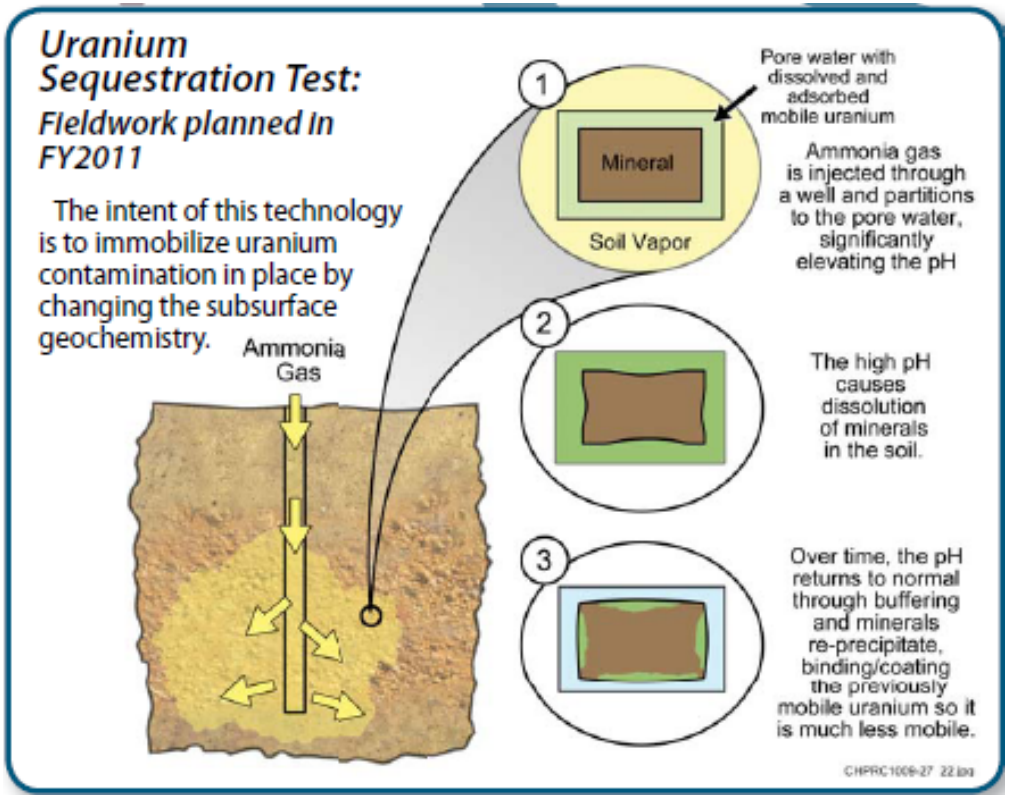
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Ammonia Treatment

Potential Contaminants:
- U

General Description

- Injection of gaseous ammonia increases pH, dissolves minerals, and with pH decline, precipitates form that coat/bind contaminants



Technology – Ammonia Treatment

State of Development

- Lab-scale investigations performed
- Field testing planned at Hanford

Limitations/Development Needs

- Needs evaluation of ammonia delivery and reaction under field conditions
- Treatment for technetium possible, but needs more development

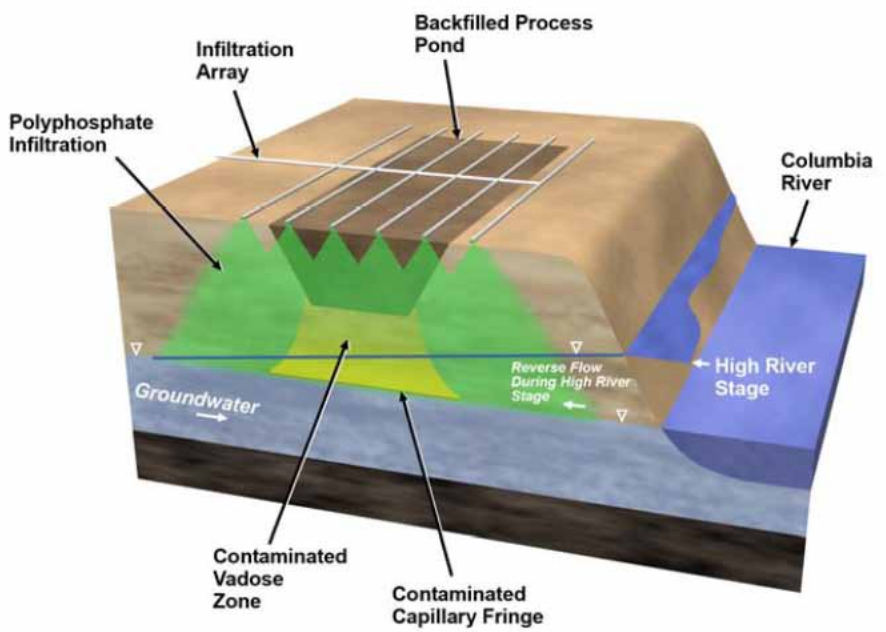
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Phosphate Sequestration

General Description

- Injection of aqueous-phase phosphate causes precipitation of phosphate compounds can incorporate contaminants and enhance sorption

Potential Contaminants:
- U



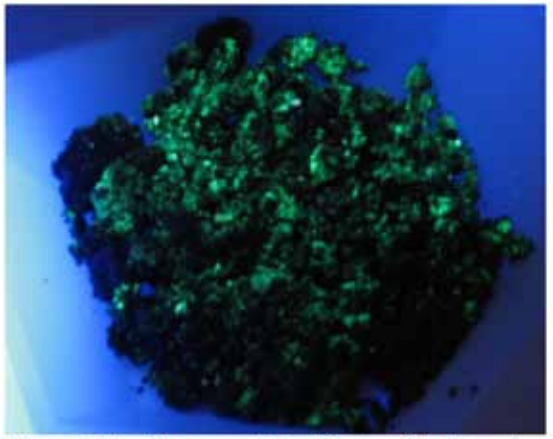


Figure 3.4. Representative Photo of Sediment Sectioned from the Effluent End of Column 1 Illustrating the Visual Identification of Uranium-Phosphate Under Short-Wave UV Radiation

Technology – Phosphate Sequestration

State of Development

- Some field testing and significant laboratory testing for saturated conditions
- Some laboratory testing for vadose zone sediments and in conjunction with foam delivery

Limitations/Development Needs

- Ability to distribute phosphate in vadose zone

Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Carbonate Sequestration

Potential Contaminants:
- U

General Description

- Geochemical manipulation to promote formation of uranium-carbonate compounds would make uranium less mobile than when just adsorbed

State of Development

- Uranium-carbonate compounds are already present in Hanford geochemistry.
- Use of carbon dioxide gas to manipulate pH and the carbonate system was evaluated in the laboratory

Limitations/Development Needs

- Not fully developed as a remedial process

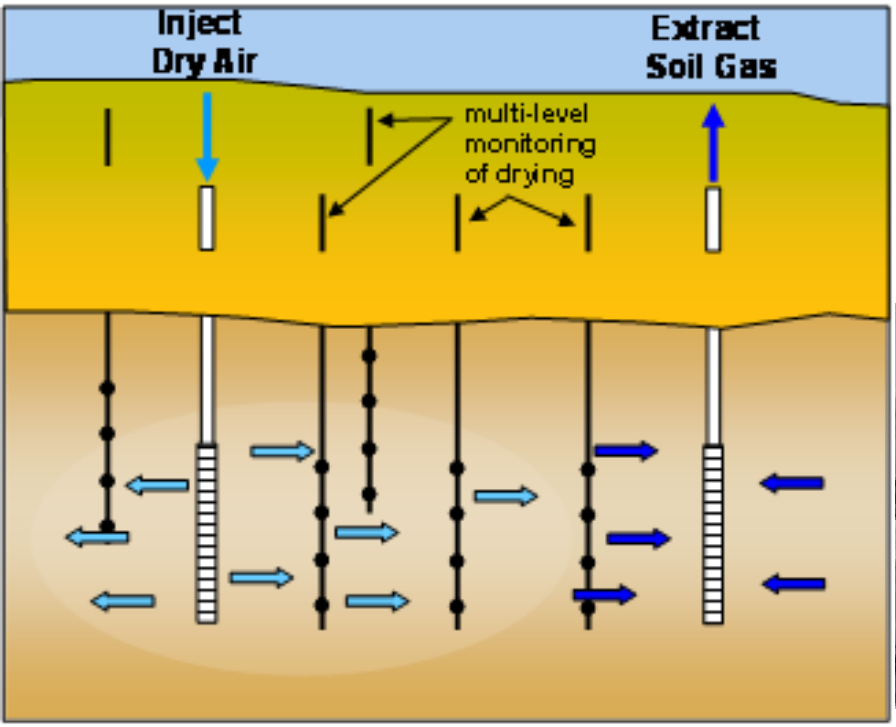
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology - Desiccation

General Description

- Injection low-humidity gas to create very dry conditions in the vadose zone that slows movement of contaminants

Potential Contaminants:
- All inorganic



Technology - Desiccation

State of Development

- Lab-scale investigations performed
- Field test at Hanford underway

Limitations/Development Needs

- Need to evaluate long-term effectiveness in slowing contaminant movement as rewetting occurs
- In most cases would be employed in conjunction with a surface barrier
- Distribution of drying affected by subsurface heterogeneity

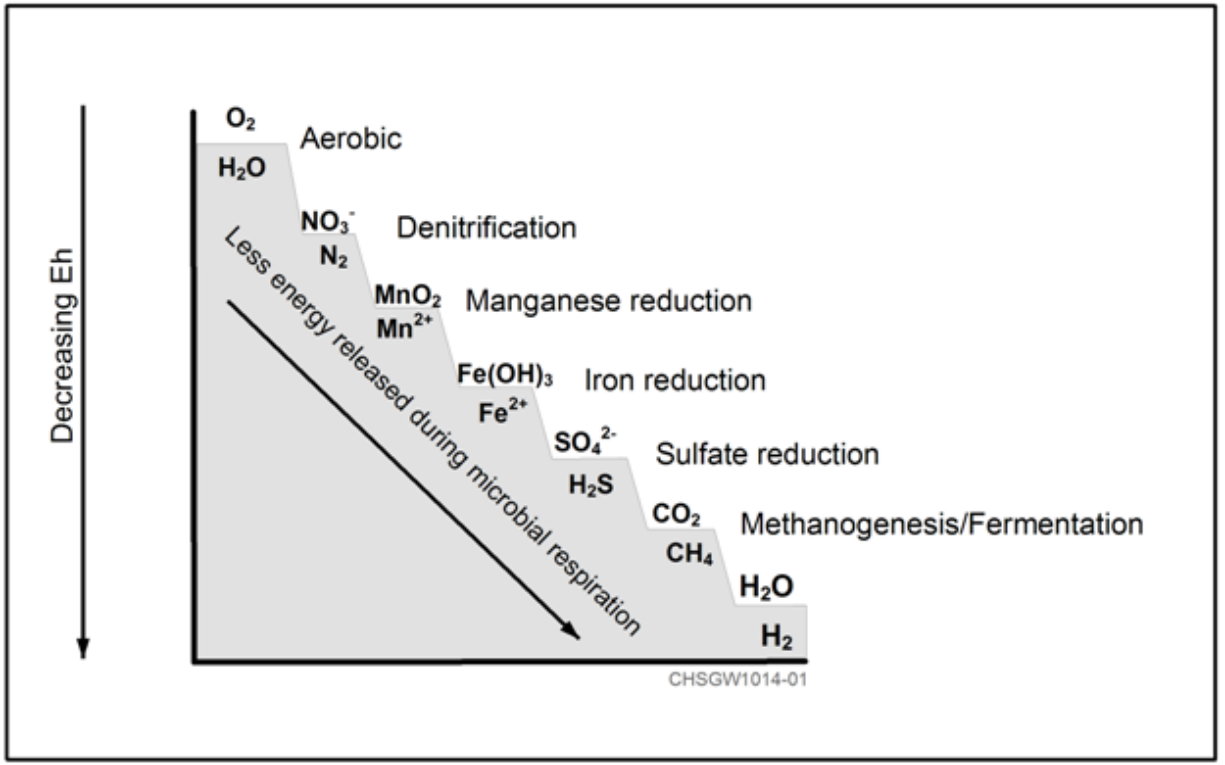
Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – In-Situ Biological Reduction

General Description

- Biologically generated reducing conditions created via the addition of an organic substrate
- Biological reduction of some contaminants may occur (nitrate and Cr(VI)) as part of metabolic processes.
- Microbially reduced species (e.g., ferrous iron and sulfide) may also chemically reduce contaminants (e.g. U, Tc-99, Cr(VI))

Potential Contaminants:
- U, Tc-99, Cr(VI), Nitrate



Relative Energetics of Common Microbial Redox Reactions

Technology – In Situ Biological Reduction

State of Development

- Proven in saturated conditions, but still requires testing to determine effectiveness in deep vadose zone settings
- DOE-SC supporting effort to study the long-term stability of uranium sequestration by sulfate-reducing bacteria

Limitations/Development Needs

- Effective delivery methods to deep vadose zone may be impact by oxidation of injected substrate
- Localized temporary generation of byproducts may occur
- Reduction of Uranium and Tc-99 are likely to be reversible

Lab Testing Only	**Field Testing Only**	Limited Field Application	Remediation Ready (limited application)	Remediation Ready

Technology – Monitored Natural Attenuation

General Description

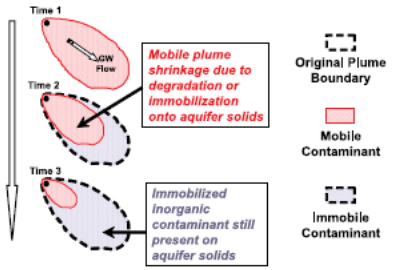
- Reliance on natural processes that degrade contaminants or limit their movement sufficiently to meet remediation goals

Potential Contaminants:
- All

EPA United States Environmental Protection Agency

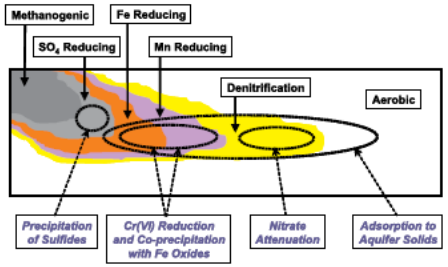
Monitored Natural Attenuation of Inorganic Contaminants in Ground Water
Volume 1
Technical Basis for Assessment

Evolution of Inorganic Contaminant Plume



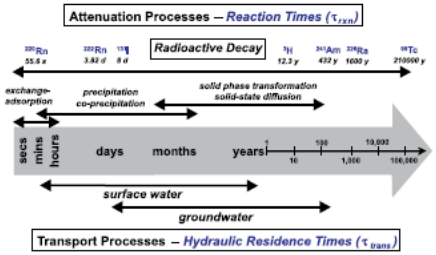
EPA United States Environmental Protection Agency

Monitored Natural Attenuation of Inorganic Contaminants in Ground Water
Volume 2
Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium



EPA United States Environmental Protection Agency

Monitored Natural Attenuation of Inorganic Contaminants in Ground Water
Volume 3
Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium



Technology – Monitored Natural Attenuation

State of Development

- Widely applied for multiple contaminants and environmental settings
- Technical protocols available

Limitations/Development Needs

- Needs site-specific analysis

Lab Testing Only	Field Testing Only	Limited Field Application	Remediation Ready (limited application)	Remediation Ready