Design Considerations for Enhanced Reductive Dechlorination

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Module 1: Purpose

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary drivers for the development of the ERD design submittal framework.
- **Evaluate** the scope of the framework to ensure consistency in Navy Environmental Restoration (ER) projects.

Executive Summary: Chlorinated solvents remain a critical groundwater issue at Navy sites, with Enhanced Reductive Dechlorination (ERD) frequently serving as the selected remedy. To address identified needs for improved design consistency and performance, this framework provides engineers with best practices, QA/QC measures, and standardized references to facilitate the development of high-quality design submittals within the Department of the Navy Environmental Restoration Program.

Design Framework Rationale

A recent survey of **Naval Facilities Engineering Command (NAVFAC)** Remedial Project Managers (RPMs) highlighted two critical findings:

- **Contaminant Persistence:** Chlorinated solvents continue to be a primary groundwater concern at impacted installations.
- **Remedy Selection: Enhanced Reductive Dechlorination (ERD)** is a preferred and frequently implemented remedy for these contaminants.
- **Performance Gaps:** There is a documented need for specialized **technology transfer tools** to optimize the design and field performance of ERD systems at Navy-specific sites.

Strategic Goals of the Framework

The **Alternative Restoration Technology Team (ARTT)** developed this guidance to unify the design process. The document serves the following core functions:

- **Standardization:** Establishes a consistent framework for ERD design submittals across the **Department of the Navy (DON)**.
- **Best Practices:** Integrates **lessons learned** from historical Navy sites regarding implementation and operational performance.
- **Technical Support:** Provides actionable tips for **Quality Assurance and Quality Control (QA/QC)** and lists applicable engineering standards.
- **Scalability:** The information is structured to be integrated into design formats that match the specific **scope of the project**.

Checkpoint Quiz

1. **According to the NAVFAC survey, why was this specific framework developed for ERD?**
    a) To transition all sites from passive to active remediation.
    b) Because chlorinated solvents are no longer a concern.
    c) To address the need for technology transfer tools to improve design and performance.
    d) To replace the need for Remedial Project Managers.

Answer: (c). The survey suggested technology transfer tools were needed to improve ERD design and performance at Navy sites.

2. **Which group was responsible for the development of this ERD framework?**
    a) The Environmental Protection Agency (EPA).
    b) The Alternative Restoration Technology Team (ARTT).
    c) The Federal Facilities Engineering Command.
    d) The Chlorinated Solvent Task Force.

Answer (b). The document was developed by the Alternative Restoration Technology Team (ARTT).

3. **What is the primary goal for design submittals within the DON Environmental Restoration Program?**
    a) To reduce the total number of design submittals.
    b) To ensure all ERD systems use the same amendment volumes.
    c) To facilitate improved and consistent design submittals using lessons learned.
    d) To eliminate the requirement for QA/QC measures.

Answer (c). The goal is to assist in the development of improved and consistent design submittals within the DON ER Program by incorporating lessons learned.

Module 2: Enhanced Reductive Dechlorination

Learning Objectives

By the end of this section, you will be able to:

- **Distinguish** between direct and cometabolic anaerobic biodegradation mechanisms for various chlorinated solvents.
- **Identify** the core components of Enhanced Reductive Dechlorination (ERD), including biostimulation and bioaugmentation strategies.
- **Evaluate** site-specific criteria, such as microbial population density, to determine the necessity of bioaugmentation.

Executive Summary: Enhanced Reductive Dechlorination (ERD) is a specialized in situ bioremediation technology that leverages anaerobic biological processes to degrade chlorinated solvents in the subsurface. By introducing amendments for biostimulation and, if necessary, specialized bacterial cultures for bioaugmentation, engineers can stimulate the transformation of contaminants of concern (COCs) into innocuous endproducts like ethene and carbon dioxide. Success depends on an accurate understanding of site-specific biodegradation mechanisms and the existing microbial landscape.

Biodegradation Mechanisms

Under anaerobic conditions, chlorinated solvents undergo biodegradation through two primary pathways:

- **Direct Dechlorination:** Also known as respiratory dechlorination, this occurs when certain bacteria, such as those from the genus **Dehalococcoides**, use chlorinated solvents (e.g., trichloroethylene [TCE]) as part of their respiratory process to grow.
- **Cometabolic Biodegradation:** This is a fortuitous reaction where a chlorinated solvent (**secondary substrate**) is biodegraded while bacteria are actively degrading another compound (**primary growth substrate**).

Core Components of ERD

ERD promotes subsurface dechlorination through two primary methods:

Biostimulation (Amendments)

The delivery of specific amendments to optimize the subsurface environment for indigenous or introduced bacteria. These typically include:

- **Electron Donors:** Fermentable organic compounds such as alcohols, sugars, fatty acids, or vegetable oils.
- **pH Buffers/Adjustments:** To maintain optimal acidity/alkalinity levels for microbial growth.

- **Nutrients:** Supplementing the subsurface to stimulate specific biodegradation reactions.

Bioaugmentation (Microbial Seeding)

The one-time injection of specialized dechlorinating bacterial cultures into the **Target Treatment Zone (TTZ)**.

- **Target Bacteria:** Common cultures include **Dehalococcoides**, **Dehalobacter**, and **Dehalogemonas**.
- **Implementation Criteria:** Bioaugmentation is site-specific and generally required when the population density of dechlorinating bacteria in groundwater is low (**< 10^3 cells/L**).

💡 **Design Tip:** Even at sites where dechlorinating bacteria are indigenous, bioaugmentation with exogenous cultures can significantly accelerate the rate of treatment.

Contaminant Susceptibility

The following table outlines the susceptibility of common chlorinated volatile organic compounds (CVOCs) to anaerobic degradation mechanisms.

Table 2-1. Typical Biodegradation Mechanisms for Selected CVOCs

Contaminant	Direct	Cometabolic
Chlorinated Ethenes		
tetrachloroethene	•	•
trichloroethene	•	•
cis-1,2-dichloroethene	•	•
trans-1,2-dichloroethene	•	•
1,1-dichloroethene	•	•
vinyl chloride	•	•
Chlorinated Ethanes		
1,1,1-trichloroethane	•	•
1,2-dichloroethane	•	•
1,1-dichloroethane	•	•
chloroethane	x	x
Chlorinated Methanes		
carbon tetrachloride	×	•
chloroform	•	•
methylene chloride	•	•
chloromethane	×	×

• Known to occur in natural and/or engineered systems; × Not known to occur; Modified from U.S. Environmental Protection Agency (U.S. EPA), 2000.

Legend: ● Known to occur in natural and/or engineered systems; x Not known to occur. Modified from U.S. Environmental Protection Agency (U.S. EPA), 2000.

Technical Resources for Design

Engineers should consult the following key resources for detailed design and implementation protocols:

- **SERDP/ESTCP:** Bioaugmentation for Groundwater Remediation (Stroo et al., 2013) and In Situ Remediation of Chlorinated Solvents (Stroo and Ward, 2010).
- U.S. EPA: Engineering approaches and introductory guides to in situ bioremediation (2000, 2006, 2013).
- **AFCEC:** Protocols for edible oil biostimulation (2007) and principles of enhanced anaerobic bioremediation (2004).
- **ITRC:** Guidance on enhanced attenuation and systematic approaches to bioremediation (2002, 2008a).

Checkpoint Quiz

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1. **What is the primary difference between direct and cometabolic dechlorination?**
   a) Direct dechlorination requires sunlight, whereas cometabolic does not.
   b) In direct dechlorination, bacteria grow by respiring the solvent; in cometabolic, the solvent is degraded fortuitously during the degradation of another compound.
   c) Direct dechlorination only occurs in soil, while cometabolic only occurs in groundwater.
   d) Cometabolic dechlorination is always faster than direct dechlorination.

Answer: (b). Direct dechlorination involves bacteria using the solvent for growth (respiration), whereas cometabolic dechlorination occurs fortuitously while bacteria degrade a primary growth substrate.

2. **At what bacterial population density threshold is bioaugmentation typically required to ensure complete dechlorination?**
   a) < 10^3 cells/L
   b) < 10^6 cells/L
   c) < 10^9 cells/L
   d) > 10^3 cells/L

Answer: (a). Bioaugmentation is typically required when the dechlorinating bacterial density is low, specifically less than 1,000 cells per liter.

3. **Which of the following is NOT a typical biostimulation amendment for ERD?**
   a) Vegetable oils
   b) pH buffers
   c) Heavy metals

Purchase this course to see the remainder of the technical materials.