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Supplemental Deployment Plan for Bioremediation and Natural Attenuation to Achieve In Situ Restoration of Chloroethene-Contaminated Groundwater at LLNL's Building 834 Operable Unit, Site 300, CA

Authors:

R. U. Halden
J. P. Ziagos

Contributors:

L. N. Peterson*
R. C. Starr*
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Proposal Submitted to the

U.S. Department of Energy
Oakland Operations Office
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November 1999

***Idaho National Engineering and Environmental Laboratory (INEEL)**

Environmental Protection Department
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Approved by:

Albert L Lamarre
Albert L. Lamarre
LLNL Project Manager

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Date

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Abstract

This supplemental deployment plan describes a project funded by the Accelerated Site Technology Deployment (ASTD) Program of the U.S. Department of Energy (DOE). The objective is to facilitate deployment of enhanced in situ bioremediation (ISB) and monitored natural attenuation (MNA) as a treatment strategy for chloroethene-contaminated groundwater at the Building 834 Operable Unit at Site 300, Lawrence Livermore National Laboratory (LLNL). The Building 834 Operable Unit is the second ASTD deployment location; enhanced ISB and MNA were first implemented at the Test Area North (TAN) of the Idaho National Engineering and Environmental Laboratory (INEEL). Enhanced ISB relies on the addition of nutrients to accelerate biotransformation of pollutants at the site. ISB of chloroethene-contaminated sites may occur under anaerobic conditions via microbial reductive dehalogenation reactions and/or under aerobic conditions via fortuitous co-oxidation reactions that are triggered by microbial growth on primary carbon sources. Monitored natural attenuation takes advantage of intrinsic ISB and additional abiotic processes that reduce pollutant concentrations over time.

Enhanced ISB and MNA will be implemented at the Building 834 Operable Unit to remediate several shallow, perched water-bearing zones (WBZs) that are impacted by chloroethene contamination. The site is ideal for technology evaluation because downward migration of pollutants is restricted by a thick clay layer of low permeability and lateral migration by "daylighting" of the contaminated formation downgradient of source areas (i.e. topographic truncation of contaminated strata). Trichloroethylene (TCE) spilled in the core area and leach field zone of the Building 834 Complex will be treated using a combination of aerobic and anaerobic intrinsic ISB. There is evidence that silicon oils, which occur as co-contaminants at the site, drive the degradation of chloroethenes under reducing and oxidizing conditions. This is important because local redox conditions may vary in space and time as a function of rainfall events. Injection of nutrients (e.g., lactate, ethylalcohol) will be attempted when the mass of silicon oils is insufficient for removing all dense nonaqueous phase liquid (DNAPL) sources. Dissolved TCE present in the downgradient plume may attenuate naturally by evapotranspiration of contaminated water at the hillside. If necessary, nutrient injection will be performed to achieve destruction of contaminants in this area. Specific deployment tasks include: (1) characterization of the microbial community at the site and correlation of community characteristics with chloroethene degradation ability, (2) installation of monitor and injection wells to facilitate implementation and evaluation of ISB and MNA, (3) monitoring of contaminants and biogeochemical indicators to better delineate ISB and MNA processes, (4) laboratory and field experiments to select the most effective nutrient supplements and to quantify the importance of chloroethene attenuation by evapotranspiration, and (5) generation of a final report for regulatory decision-making organizations.

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Acronyms and Abbreviations

ASTD	Accelerated Site Technology Deployment
B834	Building 834
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DCE	Dichloroethene
DGGE	Denaturing Gradient Gel Electrophoresis
DNA	Deoxyribonucleic acid
DNAPL	Dense Nonaqueous Phase Liquid
DOE	U.S. Department of Energy
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ESD	Explanation of Significant Differences
FLUTe	Flexible Liner Underground Technology
FY	Fiscal Year
INEEL	Idaho National Engineering and Environmental Laboratory
ISB	In Situ Bioremediation
ITRC	Interstate Technology Regulatory Cooperation
ISR	Intergenic Spacer Region
LLNL	Lawrence Livermore National Laboratory
LMITCO	Lockheed Martin Idaho Technologies Company
MNA	Monitored Natural Attenuation
OAK	Oakland (CA)
OU	Operable Unit
PCE	Tetrachloroethene
PCR	Polymerase Chain Reactions
PLFA	Phospholipid Fatty Acids
RD/RA	Remedial Design/Remedial Action
ROD	Record of Decision
ROI	Return On Investment
RTDF	Remedial Technologies Development Forum
TAN	Test Area North
TBOS	Tetrabutyl Ortho Silicate
TCE	Trichloroethene
TKEBS	Tetrakis(2-ethylbutoxy) Silane
TTP	Technical Task Plan
VOC	Volatile Organic Compound
WBZ	Water-bearing Zone

1. Introduction

This supplemental deployment plan was prepared for the Accelerated Site Technology Deployment (ASTD) program with the assistance of staff from Idaho National Engineering and Environmental Laboratory (INEEL). It is part of a larger ASTD proposal intended to promote deployment of in situ bioremediation (ISB) and monitored natural attenuation (MNA) at Department of Energy (DOE) sites across the country. The Building 834 Operable Unit at Lawrence Livermore National Laboratory (LLNL) Site 300 was selected by INEEL as the second of at least three deployment locations; in a previous document (DOE-INEEL 1999), it was referred to as "Deployment Site B."

1.1. Deployment Project Overview

The ISB/MNA project strategy has yielded excellent results at the INEEL Test Area North (TAN). Based on cost estimates prepared for INEEL, successful application of this technology will result in substantial cost savings relative to the current baseline. Technology implementation at TAN is being managed within the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) post-Record of Decision (ROD) framework which includes technology field evaluations; formal acceptance as a final remedial technology is pending. The next goal of the project is to transfer the technology to additional sites, the first being LLNL's Building 834 Operable Unit at Site 300, CA.

1.2. Deployment Objective: Remove Barriers to Technology Implementation

Common barriers to application of new technologies include the lack of field-scale performance and cost data essential to evaluate the feasibility of applying a technology at a particular site. The ISB/MNA project is intended to produce performance and cost data for field-scale application of both technologies. The second deployment location (Building 834, Site 300) offers an additional opportunity to evaluate the effectiveness of ISB/MNA to remove dense nonaqueous phase liquid (DNAPL) sources. The selected study site is ideal for this purpose because contaminant migration is aptially constrained both downward migration by a thick clay layer of low permeability and lateral by the limited extent of saturation as well as "daylighting" of contaminated strata on the western hillside. Successful implementation of ISB/MNA at LLNL will expand the applicability of ISB/MNA from a deep fractured-basalt aquifer with a dissolved chloroethene plume (INEEL, Deployment Site A) to relatively shallow water-bearing zones (WBZ) that contain DNAPL sources in addition to dissolved contaminants (LLNL, Deployment Site B). Successful testing of ISB/MNA at INEEL, LLNL and additional deployment locations may provide a sound technical basis for deploying these technologies at other sites across the country. Due to the relatively low implementation costs, the "return on investment" (ROI) for ISB/MNA is expected to be high.

Another well-known barrier to application of new technologies is the general lack of familiarity associated with the early full-scale implementations of any new technology. Therefore, personnel of federal and state regulatory agencies responsible for overseeing ER

activities at LLNL will be actively involved in the deployment process to promote acceptance of ISB/MNA as a valid treatment strategy. Presentation of laboratory and field data at technical symposia, in the peer-reviewed literature, and at workshops for decision makers will facilitate further acceptance of the technology by both technical experts and decision makers.

1.3. The Building 834 Operable Unit

1.3.1. History of the Building 834 Operable Unit

The Building 834 (B834) subproject includes the management of Environmental Restoration (ER) activities in the southeastern corner of Site 300 (DOE-LLNL 1994, 1995). The subproject area covers an estimated 0.51 square miles (326 acres) and includes three ridges and two intervening valleys. The Building 834 complex itself was constructed to conduct the Weapons Test Area activities. It is located on a hill top at an elevation of about 1,020 ft above sea level and consists of 4 core buildings (A,B,C,D) surrounded by a ring of 8 peripheral buildings (E, F, G, H, J, K, L, M). The latter are visually separated from the core buildings by 15-ft-high earthen berms. A temporary building, trailer T8340, was placed next to the four core buildings to house ER equipment and control systems. Access to the study area is restricted for security and safety purposes. Prior to the purchase of the Site 300 property for development as a DOE High Explosives test facility, the land was used for cattle ranching and livestock grazing. Three other subproject area locations border the Building 834 subproject area. They include the Building 832 Canyon to the south and west, the East and West Firing Areas to the northwest, and the General Services Area (GSA) to the east and southeast. Offsite land use to the north of Building 834 includes Primex, a private firm that operates its own explosive test facility.

1.3.2. Contaminants of Concern

The contaminants of concern in groundwater are primarily volatile organic compounds (VOCs), specifically trichloroethylene (TCE) and to a lesser degree cis-1,2-dichloroethylene (cis-1,2-DCE), and perchloroethylene (PCE). Additional groundwater contaminants of concern include nitrate and the silicon lubricants tetrakis(2-ethylbutoxy) silane (TKEBS) and tetrabutyl ortho silicate (TBOS).

1.3.3. History of Contaminant Releases

Since the late 1950's, the Building 834 facilities have been used for materials testing. TCE served as the primary heat transfer fluid; it was mixed with silicon oils (TKEBS, TBOS) to prevent degradation of pump seals and gaskets. DOE/LLNL estimates that approximately 550 gallons of the suspected human carcinogen TCE were spilled from leaking pipe systems either directly to the ground surface or to a nearby septic system (leach field) through connecting floor drains and pipes. The two resultant source areas (core area and leach field zone) presumably still contain DNAPL. The entire thermal testing system was dismantled between September 1993 and May 1994. The exact sources of nitrate contamination are still uncertain. Releases of raw sewage from the leach field may have contributed to elevated nitrate levels; however, they are unlikely to represent the sole source of nitrate contamination.

1.3.4. Hydrogeology

The Building 834 area is hydrogeologically complex. The primary source area (core area) is located on an isolated hilltop that is underlain by shallow (< 50 ft) perched groundwater. A second source area, a septic system leach field, is located about 150 ft to the southwest. The hydraulic connection between the perched WBZs of the two source areas is uncertain. Degree of contaminated perched groundwater occurs in semi-consolidated sands and gravel that are underlain by a bedrock sequence containing several low permeability layers (also referred to as aquitards). One of them, the $Tnsc_1$ aquitard, is located approximately 90 ft below the surface and consists of over 40 ft of low permeability siltstones and claystones. Soil vapor and groundwater monitoring data indicate that the $Tnsc_1$ aquitard acts as an effective barrier that prevents downward migration of contaminants through unsaturated sandstone layers to the regional aquifer 280 feet below. Lateral migration of dissolved contaminants is restricted by the limited extent of saturation and the topography. VOC concentrations in groundwater are typically in the parts-per-million (ppm) range whenever groundwater is encountered. Historical dissolved VOC concentrations in the core area have been as high as 800 part-per-million (ppm). However, the physical dimensions of the groundwater plume have not changed significantly over time despite the continuing presence of DNAPL sources. Today, as in 1982, the plume measures about 1,500 by 600 feet in length and width, respectively (Figure 4-1). Initial soil vapor surveying results indicate that volatilization of contaminants along the hill slopes southwest of the leachfield may be an important plume attenuation mechanism. In locations where contaminated formations are "daylighting," pollutants may volatilize and escape through the gas phase (soil vapor) into the atmosphere.

1.3.5. Remedial Activities

Groundwater and soil vapor extraction and treatment have been operative at the Building 834 core area in 1995 and are ongoing. In 1999, a combined total of 49 monitor and extraction wells were present at the site. Seventeen of the core area wells serve as combined groundwater and soil vapor extraction wells. Extracted water and vapors are transferred through copper pipes to the treatment facility, which is located on a concrete slab/asphalt area next to trailer T8340. Groundwater is treated by oil skimming, air sparging and carbon adsorption to remove silicon oils and VOCs. The resulting treated water is discharged into the air from misting towers to prevent recharge of the contaminated aquifer. Solvent-laden vapors are purified by carbon adsorption and released to the atmosphere.

Pump & treat cleanup at the site is hampered by (a) the complex hydrogeology, (b) limited groundwater yields (many wells produce less than 50 gallons per day) (c) the inability to remove nitrate from groundwater and (d) the presence of DNAPL sources that may require treatment for centuries if not longer. Due to these difficulties, the identification of alternative treatment technology is highly desirable.

1.3.6. Attenuation of Contaminants by Biological Processes

Biological processes may be more effective than pump & treat operations in removing nitrate and chloroethene contamination from the site. Vancheeswaran et al. (1999a) demonstrated in laboratory experiments that the hydrolysis of silicon oils (TKEBS, TBOS) releases alcohols (2-ethylbutanol and butanol) which exert a significant biological oxygen demand (BOD). Field data

suggest that microbial oxidation of hydrolysis products quickly leads to the successive depletion of available dissolved oxygen and nitrate (Halden et al. 1999). Once anaerobic conditions are established, fermentation of remaining alcohols produces dissolved hydrogen (Vancheeswaran et al. 1998). In the absence of oxygen, indigenous anaerobic groundwater microorganisms use the generated hydrogen to reductively dechlorinate PCE and TCE to *cis*-1,2-DCE (Vancheeswaran et al. 1998, 1999b). Groundwater and soil vapor monitoring data indicate that *cis*-1,2-DCE does not persist at the site. In anaerobic conditions, *cis*-1,2-DCE may undergo further reductive dechlorination to yield ethene/ethane; this hypothesis is supported by the detection of small quantities of vinyl chloride (VC) and larger quantities of ethene/ethane in site groundwater. In aerobic conditions, *cis*-1,2-DCE may also be co-oxidized to benign compounds (such as carbon dioxide, water, and salt) by microorganisms that use ethylbutanol and butanol as primary growth substrates (Vancheeswaran et al. 1999a).

In summary, the silicon oils play a central role in chloroethene biotransformation reactions by slowly releasing alcohols that serve as electron donors for microorganisms. Because TCE and silicon oils were spilled as a mixture, there is a high potential for in situ biotransformation/biodegradation of DNAPL sources at the site. Unfortunately, the rapid dechlorination of TCE observed in the laboratory and in the field is almost completely suppressed during pump & treat operations; influx of oxygen is the presumed inhibitory cause. A recent analysis of field data suggests that approximately 6 ± 3 kg of VOCs were destroyed in biotransformation reactions over a period of two months when the treatment facility was shut down; this number compares favorably to the 1.2 kg of VOCs that would have been recovered by groundwater extraction over the same period of time. Although these initial mass removal estimates are promising, they entail a large uncertainty that can be reduced only by improving the existing monitoring network at the site and conducting additional field experiments.

1.3.7. Attenuation of Contaminants by Abiotic Processes

Analytical data from a soil vapor survey conducted in July 1999 indicate that natural abiotic processes may play an important role in attenuating VOC concentrations in the area downgradient of the leachfield zone (downgradient plume). The mass of VOCs detected in soil vapor at the western hillside of the Building 834 Operable Unit exceeded those of other site locations by up to two orders of magnitude. These high VOC concentrations were detected in an area where the contaminated formation was predicted to daylight, suggesting that evapotranspiration of VOCs at the western hillside may be an important mass removal mechanism (i.e. volatilization of pollutants from soil and plant surfaces). However, additional passive and active soil vapor flux measurements are needed to confirm and quantify the relevance of evapotranspiration as a natural attenuation process.

1.3.8. Regulatory Framework

In 1995, an Interim Record of Decision (ROD) was signed for the Building 834 Operable Unit (DOE-LLNL 1995). This document will be replaced with a Final Interim Site-Wide ROD in December 2000. The Final Site-Wide Feasibility Study and the Interim Site-Wide ROD for Site 300 LLNL already contain contingencies to use ISB and MNA as cleanup strategies. However, the current Proposed Plan identifies pump & treat as the likely remedy for the Building 834 Operable Unit. Changing from conventional treatment to ISB/MNA may require an Explanation of Significant Differences (ESD).

2. Management Commitment

Technology implementation at LLNL is led by the U.S. Department of Energy Oakland Operations Office (DOE-OAK) Deputy Division Director of the Environmental Restoration Division, Mr. Hannibal Joma. Mr. Joma has the overall responsibility for and authority to commit the necessary facilities and resources to the project.

2.1. Implementing Site Commitment

The LLNL will function as the ASTD implementing site. The implementation location will be the Building 834 Operable Unit TCE groundwater plume at Site 300. This area is a designated CERCLA site, Operable Unit 2, and is currently in the Interim-ROD remedial design/remedial action cleanup phase of CERCLA remediation.

2.2. Points of Contact

DOE-OAK Deputy Division Director of the
Environmental Restoration Division
Hannibal Joma
DOE-OAK Operations Office
1301 Clay Street
Oakland, CA 94612-5208
Phone: (510) 637-1563
(925) 422-0830
E-mail: hannibal.joma@oak.doe.gov

EM-50 Program Manager
Kim Abbott
DOE-OAK Operations Office
1301 Clay Street
Oakland, CA 94612-5208
Phone: (510) 637-1501
E-mail: kim.abbott@oak.doe.gov

EM-40 Remedial Project Manager
Paul Ko/Hannibal Joma
Lawrence Livermore National Laboratory
P. O. Box 808, L-574
Livermore, CA 94551
Phone: (925) 422-1075/(925) 422-0830
E-mail: paul.ko@oak.doe.gov/
hannibal.joma@oak.doe.gov

Implementation Site Project Manager
John Ziagos
Lawrence Livermore National Laboratory
P. O. Box 808, L-544
Livermore, CA 94551
Phone: (925) 422-5479
E-mail: ziagos1@llnl.gov

Implementation Site Technical Lead
Rolf Halden
Lawrence Livermore National Laboratory
P. O. Box 808, L-542
Livermore, CA 94551
Phone: (925) 422-0655
E-mail: halden1@llnl.gov

3. Project Strategy

The scientific and technical merit of ISB and MNA has been discussed in previous documents (DOE-ID 1998a, 1998b, INEEL 1999). Deployment at LLNL will follow the general approach outlined in the above work plans as closely as possible. The three-step process will include qualification, implementation and deployment.

3.1. Qualification Strategy

Qualification is defined as the process of determining whether a particular site or Operable Unit is amenable to ISB, MNA or a combination of the two technologies. Qualification of the B834 Operable Unit for ISB/MNA will be conducted in a manner analogous to the process used at TAN/INEEL. It entails review of existing data, identification of data gaps, collection of additional required data and a final review.

3.2. Implementation Strategy

Implementation is defined as the process of conducting a well defined set of activities that provide data to validate that the field scale ISB/MNA process is working at the selected site. Implementation at LLNL's Building 834 Operable Unit will be conducted in close collaboration with staff from INEEL to capitalize on technical and managerial know-how gained during the initial implementation at INEEL's TAN site.

3.3. Deployment Strategy

Deployment is defined as the process of (a) evaluating the validation/optimization data collected during the implementation step, (b) completing the decision process for regulatory selection of ISB/MNA as the final remediation strategy, and (c) executing long-term field-scale restoration activities. This process begins with preparation of a field evaluation report for regulatory agency review. Subject to regulatory review and selection of enhanced ISB/MNA (singly or in combination with other remedies), an ESD will be filed to reflect the agencies' decision for the final plume restoration remedy. Funding of long-term field-scale restoration activities for LLNL's Building 834 Operable Unit groundwater plume will be provided entirely by EM-40 resources. LLNL has proposed that the cost savings realized by the implementation and deployment of enhanced ISB/MNA at LLNL would be reinvested in remedial actions at Building 850, Pits 3 and 5.

3.4. Measures of Success

Successful deployment of enhanced ISB/MNA can be monitored using incremental and overall performance measures. These measures are conveniently divided into three separate categories: (1) Technical Success, (2) Financial Success, and (3) Deployment Success. Specific measures appropriate to each category are presented below.

3.4.1. Technical Success

Technical success will be measured by tracking the abundance of chloroethene-degrading, microbial communities using various techniques including phospholipid fatty acid (PLFA) analysis, denaturing gradient gel electrophoresis (DGGE) and intergenic spacer region (ISR) analysis (Task 1), and, even more importantly, by comparing the measured rates of ISB/MNA to the (modeling-derived) minimal rates required for timely cleanup of the site (Tasks 2, 3 and 4).

The ASTD program can measure progress toward technical success by tracking and evaluating key components of the deployment process. As these components are implemented, specific technical performance measures can be evaluated. Table 3-1 identifies the key components of the deployment along with associated technical performance measures.

The project tables presented in Appendix A will be included in monthly reports and will document incremental progress and final attainment of technical performance measures.

3.4.2. Financial Success

Financial success will be measured during the deployment process by tracking project schedule and budget. Monthly reports will contain performance measures including schedule status, budgeted cost of work scheduled, budgeted cost of work performed, and actual cost of work performed. Maintaining a ±10% project variance will constitute financial success during the qualification and implementation stages of the project.

Once the deployment stage is reached, financial success will be monitored through the EM-40 project management process and will no longer be reported to the ASTD program office. A key element of the ASTD financial performance measure will be third party validation of proposed cost savings. The proposed cost savings will be estimated from process and field data collected during the implementation of ISB/MNA at the LLNL. As a result, cost saving performance measures will be addressed in the second year of the deployment process.

In summary, the main elements of performance measure for financial success are:

(a) Maintaining acceptable project schedule and project budget variance (±10%)

(b) Third party validation of proposed cost savings (with a target of 50% reduction in remediation costs relative to the baseline)

(c) Tracking of life cycle cost savings following deployment of technology (based on ROI)

(d) Reinvestment of cost savings to accelerate cleanup at Building 850, Pits 3 and 5.

3.4.3. Deployment Success

The clear and unambiguous measure of deployment success is regulatory acceptance of the technology by partially or completely replacing a previously selected remedy (pump & treat and soil vapor extraction operations) with ISB/MNA in the ROD. Issuance of an ESD will include regulatory agency review of performance data generated to support evaluation of technical and financial success and may be a component of the decision making process taking place within the EM-40 CERCLA cleanup process. The ASTD program must measure deployment success on the basis of technical and financial evaluation strategies presented above. Actual deployment

of ISB/MNA at LLNL may take place outside of the ASTD-funded portion of the deployment project. Deployment should meet the following global ASTD goals:

- Deployment technology selected in CERCLA ROD or amended ROD.
- Deployment site cleanup goals were achieved.
- Cleanup activity was completed ahead of the baseline schedule.
- Complex-wide technology utilization issues were resolved.
- Stakeholders were actively associated with deployment.

4. Project Control

Deployment of ISB/MNA at the Building 834 Operable Unit will be managed by the LLNL project team. Project staff will provide input for INEEL's monthly status reports. Additional reports itemized below will be generated for project documentation. The remainder of this section addresses the specific scope, schedule and budget baseline for deployment of ISB/MNA at LLNL.

4.1. Scope

The five tasks described below have been carefully integrated with the EM-40 funded CERCLA RD/RA groundwater restoration project currently underway at the Building 834 Operable Unit. The project life cycle scope includes independent ASTD activities and coordinated EM-50/EM-40 activities that support deployment at LLNL. The detailed life cycle scope for each of the ASTD funded tasks is described below.

4.1.1. Task 1: Microbial Community Characterization

Microbial characterization techniques will be used at the Building 834 Operable Unit to test the ability of three different screening techniques [phospholipid fatty acid (PLFA) analysis, denaturing gradient gel electrophoresis (DGGE), and intergenic spacer region (ISR) analysis], to identify microbial communities that can degrade chloroethenes. Specific objectives are (a) to observe the spatial and temporal differences in the microbial community due to changes in concentrations of contaminants and nutrient amendments, and (b) to identify microbial communities/species that have the ability to degrade chloroethenes. If PLFA, DGGE and/or ISR techniques can reliably discriminate communities that are capable of degrading chloroethenes from those incapable of doing so, they may replace conventional assessment tools that typically are more time-intensive and also necessitate cultivation of microorganisms in the laboratory. Methods having the requisite discriminatory ability will be recommended for use at other deployment sites.

A detailed discussion of the principles and benefits of PLFA- and deoxyribonucleotide-(DNA) based microbial characterization tools has been presented previously (INEEL 1999). The application of DGGE for characterization of microbial communities has been proposed only recently (Muyzer et al. 1993). Following extraction of microbial DNA from environmental samples, the polymerase chain reaction (PCR) serves to amplify 16S ribosomal DNA genes (16S rDNA). The reaction produces DNA strands of identical length that can be separated on a polyacrylamide gel based on their different melting behaviors. The resulting banding pattern and band intensities provide a measure of changes in the microbial community, as each band represents a different organism. Bands of interest can be excised, sequenced and their respective microbial representatives determined using the Ribosomal Database project (Maidak et al. 1999).

Other research data indicate that the intergenic spacer region (ISR) between 16S rDNA and 23S rDNA may be even better suited than 16S rDNA methods to differentiate microorganisms on a genus and species level (Grayson et al. 1999, Jensen et al. 1993, Leblond-Bourget et al. 1996, Christensen et al. 1999). In order to isolate the ISR region, genomic DNA is extracted

from environmental samples and subjected to PCR using primer pairs that flank the ISR region. Amplified DNA is then cloned into a plasmid vector, transformed into *E. coli*, isolated and sequenced. Sequence data is compared to entries in a suitable database (e.g., NIH BLAST) for identification of microorganisms. The time-consuming initial work of establishing a site-specific database has already been completed for the LLNL deployment site (Schindler and Lowe, 1999).

Microbial community characterization at LLNL will include the following tasks:

Task 1.1—Collection of Groundwater Samples at the Building 834 Core Area

Activity 1.1a: Sample 3 wells during February 2000

Activity 1.1b: Sample 3 wells during August 2000

Activity 1.1c: Sample 3 wells during February 2001

Activity 1.1d: Sample 3 wells during August 2001

Activity 1.1e: Sample 3 wells during February 2002

Activity 1.1f: Sample 3 wells during August 2002

Task 1.2—Collection of Groundwater Samples in the Building 834 Leachfield Zone

Activity 1.2a: Sample 3 wells during February 2000

Activity 1.2b: Sample 3 wells during August 2000

Activity 1.2c: Sample 3 wells during February 2001

Activity 1.2d: Sample 3 wells during August 2001

Activity 1.2e: Sample 3 wells during February 2002

Activity 1.2f: Sample 3 wells during August 2002

Task 1.3—Collection of Groundwater Samples During Push-Pull Tests

Activity 1.3a: Obtain 3 samples during each test in FY 2001

Activity 1.3b: Obtain 3 samples during each test in FY 2002

Task 1.4—Conduct PLFA, DGGE, and ISR Analyses

Activity 1.4a: FY 2000 Microbial Characterization Analyses

Activity 1.4b: FY 2001 Microbial Characterization Analyses

Activity 1.4c: FY 2002 Microbial Characterization Analyses

Task 1.5—Analyze Results and Prepare Report

Activity 1.5a: FY 2000 Microbial Characterization Report (December 2000)

Activity 1.5b: FY 2001 Microbial Characterization Report (December 2001).

Activity 1.5c: FY 2002 Microbial Characterization Report (December 2002).

4.1.2. Task 2: ISB/MNA Monitoring Network Optimization

Optimization of the monitoring network at the Building 834 Operable Unit will be completed in three phases. Required wellfield modifications include (a) drilling and completion of three monitoring wells with depth-discrete sampling capabilities for groundwater and soil vapor using the Flexible Liner Underground Technology (FLUTe), (b) drilling and completion of three conventional monitor wells to fill data gaps, (c) destruction of three well clusters (7 monitor wells total) that are improperly constructed, (d) drilling and completion of three conventional monitor wells to replace the destroyed wells, (e) conversion of two existing core-area-extraction wells to dedicated monitor wells, (f) drilling and completion of four monitor/injection wells to facilitate enhanced ISB studies. Existing and proposed well locations are shown in Figure 4-1. The majority of work relating to the monitoring network optimization will be carried out in FY 2000; expenses are primarily covered by EM-40 funds (Table 4-1).

Task 2.1—Installation of New Monitor Wells

Activity 2.1a: Drill and complete three FLUTe monitor wells (FY 2000)

Activity 2.1b: Drill and complete three conventional monitor wells (FY 2000)

Task 2.2—Destruction of Improperly Constructed Monitor Wells

Activity 2.2a: Destroy wells W-834-S2, -S2A, -S3, -T4, -T4A, -T4B, -T4C (FY 2000)

Task 2.3—Installation of Replacement Wells

Activity 2.3a: Drill and complete three replacement wells for S2-, S3- and T4-well clusters (FY 2000)

Task 2.4—Conversion of Extraction Wells

Activity 2.4a: Convert two existing extraction wells to dedicated core-area-monitor wells (FY 2000)

Task 2.5—Installation of New Injection Wells

Activity 2.5a: Drill and complete two injection wells (FY2001)

Activity 2.5b: Drill and complete one injection well (FY2002)

4.1.3. Task 3: Natural Attenuation and Bioremediation Monitoring

The scope for this task includes monitoring of groundwater and soil vapor in the core area, the leachfield zone, and the downgradient plume including the "daylighting" area on the western hillside. Depth-discrete sampling devices will be acquired for three monitoring wells during FY 2000; they will allow LLNL staff to determine the vertical distribution of contaminants and indicator parameters. Biogeochemical and other indicator compounds were selected based on recommendations by various agencies (Air Force Center for Environmental Excellence 1995, 1996). Monitoring of these parameters should provide the "Lines of Evidence" that are necessary to identify ISB and MNA as suitable remedies. Thus, groundwater samples will be collected for determination of volatile organic compounds (PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, VC), general minerals (cations and anions), water quality parameters (COD, DIC, DO, ORP, SC, pH, T) and dissolved gasses (methane, ethane, ethene, carbon dioxide, hydrogen). Monthly monitoring of the above parameters in additional wells will be conducted to study the influence of drought and rainfall events on microbial activity. The monthly monitoring plan will include wells located in the core area, leachfield zone, and downgradient plume area. Sampling locations and intervals will be modified and optimized as deemed necessary (e.g., higher sampling frequency during and immediately after storm events).

Task 3.1—Acquire Depth-discrete Sampling Device

Activity 3.1a: Design and procurement of the FLUTe devices.

Task 3.2—FY 2000 Vertical Profile Sampling of Three FLUTe Monitor Wells and Monthly Monitoring

Activity 3.2a: Collect depth-discrete and monthly samples for VOC and indicator analysis

Activity 3.2b: Analyze samples

Activity 3.2c: FY 2000 data analysis and reporting

Task 3.3—FY 2001 Vertical Profile Sampling of Three FLUTe Monitor Wells and Monthly Monitoring

Activity 3.3a: Collect depth-discrete and monthly samples for VOC and indicator analysis

Activity 3.3b: Analyze samples

Activity 3.3c: FY 2001 data analysis and reporting

Task 3.4—FY 2002 Vertical Profile Sampling of Three FLUTe Monitor Wells and Monthly Monitoring

Activity 3.4a: Collect depth-discrete and monthly samples for VOC and indicator analysis

Activity 3.4b: Analyze samples

Activity 3.4c: FY 2002 data analysis and reporting

4.1.4. Task 4: In Situ Bioremediation and Natural Attenuation Experiments and Data Analysis

Various laboratory and field experiments will be conducted to infer the rate and extent of pollutant biotransformation. Additional studies will focus on evapotranspirative processes as a means for natural attenuation at the site.

4.1.4.1. Microcosm Studies

A set of microcosm experiments is required to resolve discrepancies observed between previous laboratory and field investigations. Previous groundwater microcosm studies revealed that microorganisms indigenous to the Building 834 core area can use hydrogen generated during the hydrolysis and fermentation of silicon oils to reductively dechlorinate PCE and TCE (Vancheeswaran 1998, 1999b). These reactions occur readily, follow zero-order kinetics and produce stoichiometric quantities of cis-1,2-DCE, which accumulates as a dead-end product in the laboratory (Vancheeswaran 1999b). Field data also suggest that reductive dehalogenation reactions play an important role in the transformation of TCE at the B834 Site. However, detections of VC and ethene/ethane at ppb concentrations in groundwater field samples suggest that, in contrast to laboratory findings, cis-1,2-DCE is completely dechlorinated in situ. It is possible that the lack of sediment material in the groundwater microcosms prevented the enrichment of anaerobic microorganisms capable of dechlorinating cis-1,2-DCE and VC.

Other laboratory studies raised additional questions. Vancheeswaran et al. (1999a) demonstrated that an aerobic enrichment culture obtained from the Corvallis Wastewater Treatment Plant can utilize TKEBS and TBOS for growth while concurrently co-oxidizing TCE and cis-1,2-DCE at the same time. However, the research group was unable to find microorganisms with similar capabilities in enrichment cultures from Building 834 groundwater. The lack of organo-silicon-oxidizing microorganisms at the site is unexpected given the long potential period for adaptation. Again, the use of anaerobic groundwater rather than aerobic sediment material may have prevented enrichment and detection of the desired degradative function in laboratory studies.

In order to resolve the above discrepancies, additional microcosm studies will be conducted using fresh sediment material obtained from the core area and the leachfield zone during drilling activities. The objectives are to (a) determine whether cis-1,2-DCE can undergo complete reductive dechlorination under simulated field conditions (b) determine the rate and extent of reductive dechlorination reactions, (c) study the effect of fluctuating redox conditions on the fate of chloroethenes, (d) determine whether indigenous microorganisms can grow on organo-silicon compounds and, if applicable, (e) determine the rate and extent of cooxidation of TCE and cis-

1,2-DCE with silicon oils. Experimental design of microcosm experiments will follow previously developed protocols (Vancheeswaran et al. 1998, 1999a, 1999b) and recommendations put forward by the Air Force Center for Environmental Excellence (1996).

Task 4.1—Microcosm Studies

Activity 4.1a: Construct/sample anaerobic sediment microcosms (FY 2000)

Activity 4.1b: Construct/sample aerobic sediment microcosms (FY 2000)

Activity 4.1c: Send selected samples to LBNL for VOC isotope analysis (FY 2000)

Activity 4.1d: Construct/sample anaerobic sediment microcosms (FY 2001)

Activity 4.1e: Construct/sample aerobic sediment microcosms (FY 2001)

Activity 4.1f: Send selected samples to LBL for VOC isotope analysis (FY 2001)

Activity 4.1g: Construct/sample anaerobic sediment microcosms (FY 2002)

Activity 4.1h: Construct/sample aerobic sediment microcosms (FY 2002)

Activity 4.1j: Send selected samples to LBL for VOC isotope analysis (FY 2002)

4.1.4.2. VOC $^{13}C/^{12}C$ Isotope Studies

The determination of compound-specific stable isotope ratios is a rapidly emerging technology for assessing the relative importance of volatilization, oxidation, and reductive dechlorination of environmental pollutants at contaminated sites (Poulson and Drever 1999, Conrad et al. 1997, Hunkeler et al. 1999). This analytical tool will be used to determine the fate of TCE and its daughter compounds at the Building 834 Operable Unit. Highly specialized equipment required for this task is available through a research collaboration with the Lawrence Berkeley National Laboratory (LBNL), CA.

Task 4.2—VOC $^{13}C/^{12}C$ Isotope Studies

Activity 4.2a: Obtain and analyze field and laboratory groundwater samples (FY 2000)

Activity 4.2b: Obtain and analyze field and laboratory groundwater samples (FY 2001)

Activity 4.2c: Obtain and analyze field and laboratory groundwater samples (FY 2002)

4.1.4.3. Push-Pull Experiments

The effectiveness of various nutrient amendments and resulting rates of biotransformation will be determined using push-pull technology (Beller et al. 1995, Reinhard et al. 1997). Effective biotransformation of TCE in perched groundwater at the Building 834 Operable Unit

currently appears to be limited to release area locations containing relatively immobile TBOS and TKEBS as co-contaminants. As previously stated, silicon oils are sustaining a microbial community capable of reductively dechlorinating TCE to cis-1,2-DCE at high rates (Halden et al. 1999, Semprini et al. 1999); in addition, they may also support cometabolic oxidation of cis-DCE to carbon dioxide and chloride (Vancheeswaran et al. 1999a). The proposed push-pull tests will help to determine whether injection of a non-toxic carbon and energy source in the form of sodium lactate (CH_3-CHOH-COO^- Na^+) into the TCE plume can effect biotransformation activities similar to those elicited by silicon oils in the release area. Sodium lactate has been used successfully at TAN and by other research groups in the past (Gibson and Sewell, 1992; Fennell et al. 1997).

Each field experiment will consist of (a) a hydraulic test to determine hydraulic conductivity and maximum sustainable pumping rate, (b) a tracer study to characterize the local hydrogeology and (c) one or two biological push-pull experiments to determine the effectiveness and kinetics of enhanced in situ bioremediation. Target pollutants will include nitrate, PCE, TCE, and cis-DCE. During the hydraulic test, groundwater will be extracted from a target well to determine the highest sustainable flow rate achievable. Extracted groundwater will be treated in the B834 groundwater treatment system. During the tracer study, a volume of approximately 100 gallons of uncontaminated groundwater (extracted from a clean well or clean treatment effluent) will be amended with a conservative tracer X (e.g., bromide, granular fluorescent dyes or natural $^{18}0$-signature of water) and injected into the target well by gravity feeding. During the incubation period of 3 to 6 weeks, water samples will be taken periodically from the injection well and the nearest downgradient well and analyzed for the presence and concentrations of tracer compound. At the end of the incubation period, approximately 200 gallons of groundwater will be extracted to achieve 95+ % recovery of the tracer compound. This second test phase will yield information on the recovery of the injection slug as a function of incubation time.

During the final (biological) test phase, one hundred gallons of groundwater will be extracted from the target well and transferred into a closed vessel containing a conservative tracer Y and a lactate-spike solution (test slug). Next, 100 gallons of uncontaminated groundwater will be amended with a conservative tracer Z and injected into the target well to establish a TCE-free buffer zone resembling in chemical composition the local groundwater. Immediately thereafter, the previously extracted volume of groundwater (test slug) will be (re-)injected into the target well. During the incubation period of 3 to 6 weeks, water samples will be taken periodically from the injection well. At the end of the test, approximately 200 gallons of groundwater will be extracted and fractions thereof analyzed for the presence and concentrations of tracer compounds, lactate, TCE, nitrate, nitrite, dissolved oxygen, cis-1,2-DCE, VC, ethene, ethane, hydrogen as well as pH and redox values. In addition, the isotope fractionation in the residual VOCs will be determined. The creation of a buffer zone is expected to increase the mass balance accuracy for TCE and its degradation products, because limited mixing of the injection slug with buffer-zone water will not increase the total mass of extracted contaminants. Tests will be repeated if necessary to give the indigenous microorganisms sufficient time to adapt to both changing redox conditions and the new growth substrate. The Regional Water Quality Control Board has already approved the (re-)injection of small quantities of VOCs during the tests (approximately 20 g per test). Additional experiments may be carried out with ethylbutanol as the electron donor compound; in these tests, initial cooxidation of VOCs may be followed by

reductive transformation reactions. Isotope fractionation patterns in residual VOCs will yield information regarding the relevance of the two processes for mass removal.

Task 4.3—Push-Pull Experiments

Activity 4.3a: Conduct push-pull tests in leachfield zone (FY 2001)

Activity 4.3b: Conduct push-pull tests in downgradient area (FY 2001)

Activity 4.3c: Conduct push-pull tests in leachfield area (FY 2002)

Activity 4.3d: Conduct push-pull tests in downgradient area (FY 2002)

4.1.4.4. Soil Vapor Flux Studies

The importance of evapotranspiration as a mass removal process for VOCs will be determined by soil vapor flux measurements along the western hillside of the Building 834 Operable Unit. Passive soil vapor monitoring tools (Gore-Sorbers) will be used to delineate areas with significant vapor flux (qualitative assessment). Follow-up experiments will rely on active soil vapor flux monitoring tools (flux chambers etc.) to determine the VOC mass transferred from the subsurface into the atmosphere via evapotranspiration (quantitative assessment).

Task 4.4—Soil Vapor Flux Studies

Activity 4.4a: Conduct passive soil vapor screening survey (FY 2000)

Activity 4.4b: Conduct passive soil vapor survey to delineate “daylighting” area (FY 2001)

Activity 4.4c: Conduct active soil vapor survey in “daylighting” area (FY 2001)

Activity 4.4d: Conduct active soil vapor survey in “daylighting” area (FY 2002)

4.1.4.5. Modeling

Data obtained during monitoring will be processed and incorporated into suitable computer models to predict the effect of various (combinations of) remedies and the time required for cleanup. Modeling results and underlying assumptions will be presented in the Summary Field Report to assist regulatory agencies and ER personnel in the decision making process.

Task 4.5—Modeling of ISB/MNA Processes

Activity 4.5a: Select and optimize computer model (FY 2001)

Activity 4.5b: Run initial simulations with available data set (FY 2001)

Activity 4.5c: Calibrate model with FY 2002 field data (FY 2002)

Activity 4.5d: Use FY 2001/2002 field data and predict required cleanup time (FY 2002)

4.1.4.6. Risk Assessment

In addition to the above fate and transport modeling, an additional analysis of human exposure to VOCs will be conducted to identify health risks associated with the presence of contaminants in groundwater and soil vapor. This work will follow the approach outlined in previous documents (Section 2.6 of DOE-LLNL 1995).

Task 4.6—Risk Assessment Analyses

Activity 4.6a: Perform initial analysis based on available data (FY 2001)

Activity 4.6b: Perform final analysis (FY 2002)

4.1.5. Task 5: Preparation of Reports

The Supplemental Deployment Plan will serve as a comprehensive guide throughout the project. A Summary Field Report will be generated to provide detailed information on the relative success of each project task. The Summary Field Report will serve regulatory agencies and ER personnel in the decision-making process.

Task 5.1—Project Documentation and Reporting

Activity 5.1a: Prepare Final Supplemental Deployment Plan (FY 2000)

Activity 5.1b: Prepare Summary Field Report (FY 2002)

4.2 Schedule

The implementation schedule for the enhanced ISB/MNA project and a comparison to the CERCLA baseline schedule is shown in Figure 4.3. The basic elements of the ROD schedule and key milestones will not change during the time frame identified for technology deployment. The ASTD project implementation of ISB/MNA at the Building 834 Operable Unit will provide deployment data necessary to meet CERCLA milestones. Amendment of existing documents with an ESD currently appears to be the most likely path for deploying ISB/MNA at the Building 834 Operable Unit.

4.3. Budget

Life-cycle project planning costs associated with deployment of ISB/MNA at the Building 834 Operable Unit are shown in Table 4-1. The table is specifically designed to highlight the matching ratio of ASTD and EM-40 funds by fiscal year and deployment task. The total ASTD budget request is for $925 K over the three-year project duration. The LLNL EM-40 program is supplying $1.6 for each dollar provided by the ASTD program. Overall life cycle project costs are $2.4M with $1,475K stemming from EM-40 funds (61%).

4.4. Reporting, Deliverables, and Milestones

Monthly reports will be prepared following the "Project Table" format recommended by ASTD to facilitate project management and performance monitoring of the enhanced ISB/MNA deployment project. Appendix A contains the detailed project tables that will be used to monitor progress of each of the five tasks defined in Section 4.1. Significant deliverables and milestones for each task are summarized in Table 4-2.

5. Cost Benefit Analysis

Implementing enhanced ISB/MNA at LLNL's Building 834 Operable Unit will result in an estimated cost saving of $9.6M (See Appendix C of INEEL 1999 for Letter of Commitment stating original estimate). The ASTD contribution to the overall deployment cost is $925K over 3 years; thus, a return-on-investment factor of 10 results for implementation and deployment of ISB/MNA at LLNL.

6. Return on Investment

A primary objective of the ASTD program is to effect cost savings and/or schedule acceleration for the DOE cleanup effort. LLNL and other participating sites will calculate return on investment (ROI) and provide the calculation and supporting information for third party validation. The validated cost savings will be available for use at the participating sites. As stated previously, a ROI factor of 10 will result, if environmental management costs at LLNL can be reduced by an estimated $9.6M over the lifetime of the project.

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Table 3-1. Technical performance measures for deployment of ISB/MNA at LLNL.

Task	Deployment component	Performance measure	Description
1	Microbial community characterization.	PM 1	PLFA, DGGE, and ISR samples collected, analyzed, and interpreted.
		PM 2	Microbial biomass analyses indicate the presence and, where desired, enrichment of microbes that facilitate degradation of chlorinated solvents.
2	Installation of ISB/ MNA monitoring network at INEEL	PM 3	Proposed wellfield modifications are implemented at the Building 834 Operable Unit with EM-40 funding.
		PM 4	Proposed wellfield modifications are implemented at the Building 834 Operable Unit with ASTD funding.
3	Natural Attenuation & Bioremediation Monitoring	PM 5	Depth-discrete sampling system designed, fabricated, and delivered.
		PM 6	Depth-discrete samples and monthly samples are collected and analyzed.
		PM 7	Adequate contouring of core area, leachfield and downgradient plume area are facilitated.
		PM 8	Spatial and temporal trends in concentration can be evaluated.
		PM 9	Attenuation rates can be calculated, and indicate that remedial action objectives can be met.
4	ISB/ MNA Experiments and data analysis & representation	PM 10	$^{13}C/^{12}C$ Isotope ratio analysis yields information on fate of cis-1,2-DCE and other metabolites in the core area, leachfield zone, and downgradient area
		PM 11	Microcosm experiments yield qualitative and quantitative information on importance of anaerobic processes for VOCs destruction (reductive dechlorination)
		PM 12	Microcosm experiments yield qualitative and quantitative information on importance of aerobic processes for VOCs destruction (co-oxidation by methanotrophs and butanol-oxidizing bacteria
		PM 13	Nutrients amendments suitable for enhanced ISB are identified in push-pull tests
		PM 14	In situ reaction rates for VOC destruction are determined in push-pull tests
		PM 15	Passive soil vapor surveying allows contouring of locations where contaminated formations are "daylighting"
		PM 16	Active soil vapor flux measurements yield information on the magnitude of VOC evapotranspiration as a function of air temperature, solar radiation, wind speed etc.
		PM 17	Project plans and results presented to regulatory and stakeholder organizations
		PM 18	Geochemical conditions in the enhanced ISB zone are successfully manipulated
		PM 19	Nutrient amendment increases biological activity.
		PM 20	The flux of dissolved contaminants out of the leachfield zone is reduced
		PM 21	Modeling results yield estimates for required cleanup time for intrinsic/ enhanced ISB and MNA
		PM 22	Risk assessment determines human health risk associated with VOC volatilization at the western hillside
		PM 23	Qualification data gaps, if any, filled.
		PM 24	Qualification data presented to agencies for consideration of ISB/ MNA as a remedial approach.
5	Preparation of Reports	PM 25	Supplemental Deployment Plan and Summary Field Report are prepared

Table 4-1. Life-cycle cost estimate and generalized schedule for ASTD deployment of enhanced ISB/MNA at the B834 Operable Unit.

Deployment tasks	Activity descriptions	FY 2000		FY 2001		FY 2002	
		EM 40	EM 50	EM 40	EM 50	EM 40	EM 50
Task 1: Detailed Microbial Characterization supporting enhanced ISB/MNA evaluation	One sample set each from core area and leachfield zone semi-annually during FY 2000 and FY 2001; additional studies in FY 2001 and FY 2002 will accompany the push-pull tests. Estimated cost: $10K per sample set.		40		60		60
	ISB Field Evaluation						
Task 2: ISB/MNA Monitoring Network Optimization	Two dedicated monitor wells with depth-discrete sampling capabilities (FLUTe) installed during FY 2000 to fill data gaps in the core area		60				
	Conversion of two existing extraction wells to dedicated monitor wells to facilitate more accurate monitoring in the core area	5					
	One monitor well installed during FY 2000 to explore VOC hotspot identified in the core area by the 1999 soil vapor survey	25					
	Two dedicated monitor wells (1 FLUTe + 1 regular) installed during FY 2000 to fill data gaps in the leachfield zone	25	20				
	One dedicated monitor well installed during FY 2000 to fill data gaps in transition zone between core area and leachfield area	25					
	Destruction of three well clusters with a total of seven monitor wells in the downgradient plume area during FY 2000 to prevent migration of contaminants into deeper zones and to prevent the collection of data that may be compromised by poor well design	18					
	Three dedicated monitor wells installed during FY 2000 to replace the three well clusters in the downgradient plume area that are ear-marked for destruction	75					
	Three injection wells installed during FY 2001 and FY2002 to facilitate testing of enhanced in situ bioremediaton			25	25	25	
Task 3: Natural Attenuation & Bioremediation Monitoring	Acquire depth discrete sampling devices (3 total) for use in vertical profiling of contaminant distribution in distal zone.		15				
	Collect depth discrete samples from at least 3 wells two times per year.	15			30		30
	Laboratory analysis of depth discrete monitoring data annually for three years		15	30		30	
	Monthly monitoring of selected wells in the core area, leachfield and downgradient plume area to investigate the influence of draught and rain fall events on microbial activity	50		70	70	70	70
Task 4: Enhanced In Situ Bioremediation & Natural Attenuation Experiments and Data Analysis & Represenation	C13/C12 isotope ratio analysis of VOCs to determine the fate of cis-DCE in the core area, leachfield zone, and downgradient plume area	32			25		25
	Microcosm experiments to determine reductive dechlorination rates and kinetics of aerobic VOC co-oxidation in the presence of methane and/or ehtylbutanol	50		80		80	
	Push-pull test conducted in the leachfield area to determine reductive dehalogenation activity and in situ reaction rates			75			75
	Push-pull test conducted in the downgradient area to determine reductive dehalogenation following addition of alternative electron donors				75	75	
	Passive soil vapor surveying and active soil vapor flux measurements to determine the relevance of plume-"daylighting" at the western hillside as a natural attenuation mechanism for VOCs	10		95	80	80	80
	Modeling of bioremediation and natural attenuation processes			140		140	
	Risk assessment of human exposure risk resulting from VOC volatilization at the western hill side			65		65	
Task 5: Preparation of Reports	Supplemental deployment plan, FY 2000; Summary field report for decision making process, FY2002		30				40
	Annual Funding Contributions:	**330**	**180**	**580**	**365**	**565**	**380**

Life Cycle Distribution of Funds ($ K): **$2,400**	ASTD	LLNL
LLNL EM-40 Interim ROD Remedial Action	0	1,475
INEEL Technology Deployment Support, FY 2000	180	0
ISB/MNA Qualification Studies in FY 2001 and 2002	745	0
Total	925	1,475

Table 4-2. Deliverables and milestones.

Task	Deliverable		Milestone
Task 1: Microbial Community Characterization	FY 2000 Microbial sampling status report FY 2001 Microbial characterization report FY 2002 Microbial sampling status report	MS 1	Submit B834 Microbial Characterization Reports
Task 2: ISB/MNA Monitor Network Optimization	FY 2000 Installation of 3 FLUTe wells (ASTD funded) FY 2000 Destruction of 7 wells in 3 clusters (EM-40 funded) FY 2000 Installation of 3 replacement monitor wells (EM-40 funded) FY 2000 Conversion of 2 extraction wells to monitor wells (EM-40 funded) FY 2000 Installation of 3 monitor wells (EM-40 funded)	MS 2A	Complete Monitoring Network Optimization for FY 2000
	FY 2001 Installation of 2 injection wells (ASTD + EM-40 funded)	MS 2B	Complete Monitoring Network Optimization for FY 2001
	FY 2002 Installation of 1 injection well (EM-40 funded)	MS 2C	Complete Monitoring Network Optimization for FY 2002
Task 3: Natural Attenuation Monitoring and Bioremediation	FY 2000 Depth-discrete sampler FY 2000 Depth-discrete sampling status report FY 2000 Vertical Profile Report FY 2001 Depth-discrete sampling status report FY 2001 Vertical Profile Report FY 2002 Depth-discrete sampling status report	MS 3A	Depth-Discrete Sampler Delivered To LLNL
	FY 2002 Vertical Profile Report	MS 3B	Submit Vertical Profile Report
Task 4: Enhanced ISB/MNA Experiments and Data Analysis	Summary of microcosm studies	MS 4A	
	Summary of VOC $^{13}C/^{12}C$ isotope analyses	MS 4B	
	Summary of push-pull tests	MS 4C	
	Summary of soil vapor studies	MS 4D	
	Summary of modeling results	MS 4E	Execution, Analysis and Documentation of Laboratory and Field Experiments
	Summary of risk assessment results	MS 4F	
	Monthly technical performance reports	MS 4G	
	Presentation of plans and results to stakeholder groups at LLNL	MS 4H	
	Monthly business performance reports	MS 4J	
	Conference presentation	MS 4K	
	Collection and interpretation of ISB/MNA data from LLNL	MS 4L	
	LLNL ROI Report	MS 4M	
Task 5: Preparation of Reports	Prepare Final Supplemental Deployment Plan Prepare Summary Field Report	MS 5A MS 5B	Complete Documentation of Project for Decision Makers

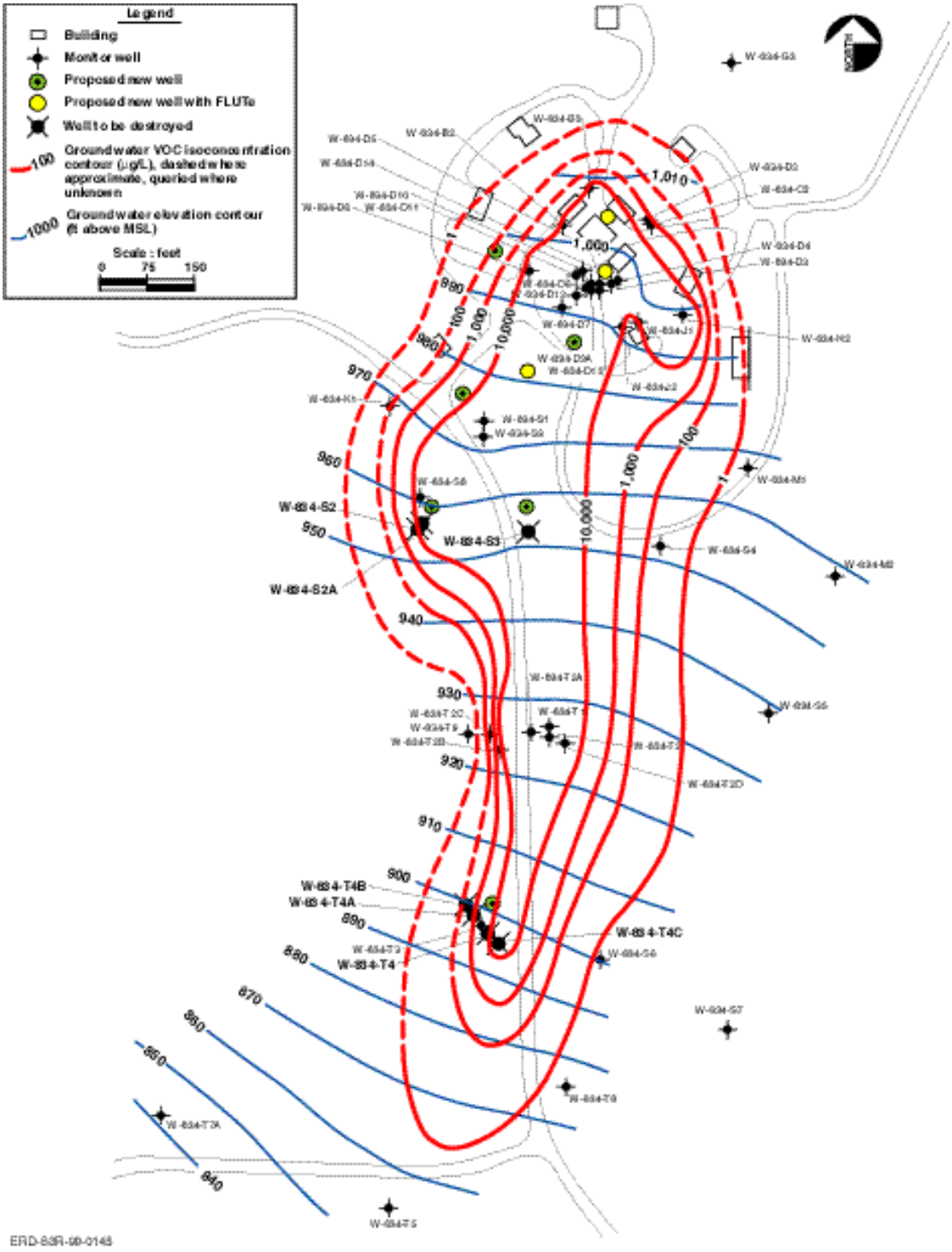

Figure 4-1. Existing monitor network and proposed new installations in the Building 834 Operable Unit; the locations of three additional injection wells have not been selected yet.

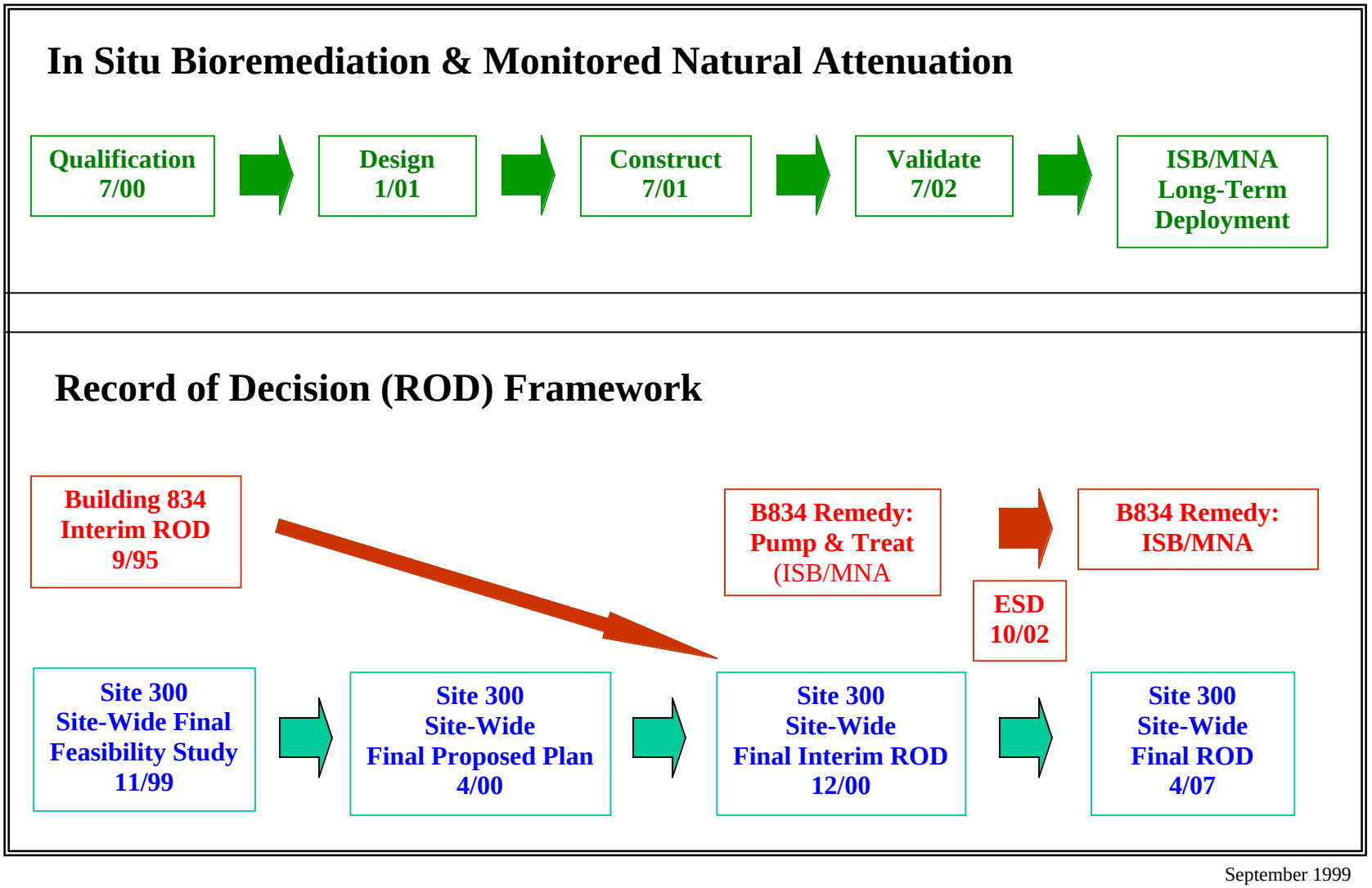

Figure 4-2. Implementation schedule for the enhanced ISB/MNA project and a comparison to the CERCLA baseline schedule.

Appendix A
Project Tables for the Building 834 Operable Unit, LLNL, CA

Table A-1. Task 1: Microbial community characterization.

Task and activity	Performance expected	Due date	Milestone/ deliverable	References and comments
Tasks 1.1, 1.2, 1.3 **Collection of samples**	**Sample 3 wells each in core area and leachfield zone in February and August; obtain samples during push-pull test; obtain monthly samples**	**9/30/00** **9/30/01** **9/30/02**	**Letter Report**	**Summarize sampling planned vs. performed.**
Task 1.4 **Conduct PLFA, DGGE, and ISR analysis**	**Analyze obtained samples**	**9/30/00** **9/30/01** **9/30/02**	**Data Summary**	**The data summary will be included in the Task 1.5 report as an Appendix.**
Task 1.5 **Prepare Microbial Characterization Report**	**Conduct data analysis, interpretation, and prepare report**	**9/30/00** **9/30/01** **9/30/02**	**Technical Report**	
Milestone MS-1 **Submit B834 Microbial Characterization Report**	**Submit Report to ASTD during 1st quarter FY 2001, FY 2002, FY 2003**	**9/30/00** **9/30/01** **9/30/02**	**MS-1A** **MS-1B** **MS-1C**	**Performing organization will complete report by the end of the FY, implementing site project team will review and submit to ASTD during 1st quarter of the following FY**

Table A-2. TASK 2: ISB/MNA monitoring network optimization.

Task and activity	Performance expected	Due date	Milestone/ deliverable	References and comments
Task 2.1a, 2.1b **Installation of new monitor wells**	**Drill and complete 3 monitor wells (FLUTe) with depth-discrete sampling capabilities; drill and complete 3 conventional monitor wells**	**9/30/00**	**Complete Wells**	**Three FLUTe monitor wells and three conventional wells ready for sampling**
Task 2.2a, 2.3a **Destruction of poorly designed wells and installation of replacement wells**	**Destroy wells W-834-S2, -S2A, -S3, -Ta, -T4A, -T4B, and –T4C** **Replace the three well clusters with three new monitor wells**	**9/30/00**	**Complete Wells**	**Poorly constructed wells have been destroyed. Three replacement wells ready for sampling**
Task 2.4a **Conversion of extraction wells**	**Convert two core area wells to dedicated monitor wells**	**9/30/00**	**Complete Wells**	**Two wells ready for sampling**
Task 2.5a **Installation of new injection wells**	**Drill and complete three new injection wells; two in FY 2001 and one in FY 2002**	**9/30/01** **9/30/02**	**Complete Wells**	**Three wells ready for sampling and injection**
Milestone MS-2 Complete Monitoring Network Optimization	**Drilling program is completed in three phases.**	**9/30/00** **9/30/01** **9/30/02**	**MS-2A** **MS-2B** **MS-2C**	**Monitoring network optimization competed**

Table A-3. TASK 3: Natural attenuation and bioremediation monitoring.

Task and activity	Performance expected	Due date	Milestone/ deliverable	References and comments
Task 3.1a **Acquire depth-discrete sampling device**	**Prepare specification, award contract, for new multi-level sampling device**	**9/30/00**	**Depth discrete sampler**	**Reusable, transportable, flexible liner depth-discrete sampling device, minimum of 5 sampling ports.**
Task 3.1a **Milestone MS-3A** **Depth-discrete sampler delivered to LLNL**	**Sampling device delivered to LLNL and staff trained.**	**9/30/00**	**MS-3A**	**FLUTe device is in place and personnel is ready for sampling**
Tasks 3.2, 3.3, 3.4 **Vertical Profile Sampling**	**Collect/analyze depth-discrete samples from FLUTe wells**	**9/30/00** **9/30/01** **9/30/02**	**Letter Report**	**Summarize sampling planned vs. performed.**
Milestone MS-3B **Submit Vertical Profile Report**	**Prepare technical report documenting results of vertical profile data analysis and interpretation.**	**9/30/00** **9/30/00** **9/30/00**	**MS-3B**	**Technical report summarizing results of depth-discrete sampling.**

Table A-4. TASK 4: ISB/MNA experiments and data analysis.

Task and activity	Performance expected	Due date	Milestone/ deliverable	References and comments
Task 4.1 **Milestone MS-4A** **Conduct Microcosm Experiments**	**Construct anaerobic and aerobic microcosms from sediment material obtained during drilling activities; sample vessels over time; analyze results; write report**	**9/30/00** **9/30/01** **9/30/02**	**MS-4A**	**Microcosm experiments yield information on potential biotransformation reactions and their respective kinetics**
Task 4.2 **Milestone MS-4B** **Conduct VOC $^{13}C/^{12}C$ Isotope Analysis**	**Groundwater samples from FLUTe wells, conventional monitor wells, microcosm experiments and push-pull tests collected and analyzed; write report**	**9/30/00** **9/30/01** **9/30/02**	**MS-4B**	**VOC $^{13}C/^{12}C$ Isotope Analysis yields information on the fate of various VOCs at the site**
Task 4.3 **Milestone MS-4C** **Push-Pull Experiments**	**Conduct push-pull experiments; analyze results; write report**	**9/30/00** **9/30/01** **9/30/02**	**MS-4C**	**Push-pull experiments yield information appropriate nutrient amendments, biotransformation reactions and their respective kinetics**
Task 4.4 **Milestone MS-4D** **Soil Vapor Flux Studies**	**Passive soil vapor surveying and active soil vapor flux studies performed; analyze results; write report**	**9/30/00** **9/30/01** **9/30/02**	**MS-4D**	**Soil vapor surveying and soil vapor flux studies indicate mass loss via evapotranspiration**
Task 4.5 **Milestone MS-4E** **Modeling**	**Data collected in microcosm experiments, push-pull tests and soil vapor surveys are analyzed to predict relevance of individual VOC removal mechanisms and required cleanup time**	**9/30/00** **9/30/01** **9/30/02**	**MS-4E**	**Modeling results allow selection of appropriate remedy/remedies**
Task 4.6 **Milestone MS-4F** **Risk Assessment**	**Risk assessment is performed to human health risks associated with contact/ingestion/inhalation of VOCs**	**9/30/00** **9/30/01** **9/30/02**	**MS-4F**	**Analysis will indicate whether MNA is a safe remedy**
Task 4.7 **Milestone MS-4G** **Monthly Reports**	**Monthly technical performance reports for progress reporting**	**Monthly**	**MS-4G**	**Monthly reporting helps to identify potential problems early on**
Milestone MS-4H **Stakeholder Updates**	**Presentation of plans and results to stakeholder groups at LLNL**	**Flexible**	**MS-4H**	**Milestone emphasizes importance of information exchange**
Milestone MS-4J **Monthly Business Reports**	**Monthly cost analysis report and project progress tracking**	**Monthly**	**MS-4J**	**Project cost analysis**
Milestone MS-4K **Conference Presentation**	**Report on project performance at national/international symposia**	**Flexible**	**MS-4K**	**Promotion of technology exchange**
Milestone MS-4L **Data Collection and Interpretation**	**Data management and analysis in preparation for final report**	**8/30/02**	**MS-4L**	
Milestone MS-4M **LLNL ROI Report**	**Use data to estimate long-term operations cost and ROI cost savings**	**FY03**	**MS-4M**	**Final budget report**

Table A-5. TASK 5: Preparation of reports.

Task and activity	Performance expected	Due date	Milestone/ deliverable	References and comments
Task 5.1 **Milestone MS-5A Prepare Final Supplemental Deployment Plan**	**Prepare a Final Supplemental Deployment Plan**	**4/30/00**	**MS-5A**	**Review draft document and make changes according to funding situation**
Task 5.2 **Milestone MS-5B Prepare Summary Field Report**	**Prepare Summary Field Report to facilitate decision making process and document project evolution**	**4/30/03**	**MS-5B**	**Draft report will be reviewed by INEEL prior to submission to ASTD**